BUILDING MATERIALS AND TECHNIQUES IN THE EASTERN MEDITERRANEAN FROM THE HELLENISTIC PERIOD TO THE FOURTH CENTURY AD

by

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"When we build, let us think that we build for ever".

John Ruskin
(1819 - 1900)

TO

MY FAMILY

AND

TO THE MEMORY

OF

J. B. WARD-PERKINS
(1912 - 1981)

ABSTRACT

This thesis deals primarily with the materials and techniques found in the Eastern Empire up to the 4th century AD, putting them into their proper historical and developmental context.

The first chapter examines the development of architecture in general from the very earliest times until the beginning of the Roman Empire, with particular attention to the architecture in Roman Italy. This provides the background for the study of East Roman architecture in detail.

Chapter II is a short exposition of the basic engineering principles and terms upon which to base subsequent descriptions.

The third chapter is concerned with the main materials in use in the Eastern Mediterranean - mudbrick, timber, stone, mortar and mortar rubble, concrete and fired brick. Each one is discussed with regard to manufacture/quarrying, general physical properties and building uses. Chapter IV deals with marble and granite in a similar way but the main marble types are described individually and distribution maps are provided for each in Appendix I. The marble trade and the use of marble in Late Antiquity are also examined.

Chapter V is concerned with the different methods of wall construction and with the associated materials. There is an enquiry into the use of fired brick and a

comparative study of brick and mortar joint thicknesses in Rome with relation to those in the Eastern Mediterranean.

Chapter VI looks at all forms of timber construction including roofing with a discussion of the wooden roof truss.

Chapter VII discussed the origins of the arch and vault, relating pertinent early examples to Roman usage. It is concluded that the Greeks probably played a large role in the transmission of the idea of arcuated construction to the west. The development and use of pitched-brick vaulting is also traced.

In Chapter VIII the origins of domical construction are studied with examples from all over the Mediterranean. The origins of the pendentive are reviewed and a basic terminology is established in an attempt to end confusion.

Chapter IX deals with epigraphic and literary evidence for the financial costs of ancient building including labour, transport and material expenses. Architects and other skilled workmen are also discussed, and there is a study of the instance of re-use of materials in Late Antiquity and its implications.

Finally Chapter X complements Chapter I in discussing architecture up to the 7th century AD in both the East and the West, tracing distinctly Eastern Roman techniques into the Byzantine period.

PREFACE AND ACKNOWLEDGEMENTS

The study of Roman building materials and techniques in the Eastern Mediterranean is an enormous and complex subject. Inherent in this and the wide geographical area over which the field extends one also has to deal with a variety of languages with varying degrees of familiarity. This can cause confusion in the citation of place-names. Where possible a simple transliteration of Arabic names has has been made with the ancient name given if available. Every effort has been made to differentiate between the dotted and undotted 'i' of the Turkish language. The sources of all maps and diagrams are given where appropriate; elsewhere the illustrations are the author's. 'Pers Obs' in the catalogues indicates personal observations; 'Pers Com.' indicates information that has not been directly collected by the author. It will be noticed that figures 9 and 10, the sarcophagi distributions, do not have numbered locations as do the marble distribution maps in Appendix I compiled by the author. Unfortunately the most recent version of these (Ward-Perkins (1980)a) did not do so and it was felt best to reproduce them as given in the publication, with appropriate additions, without numbering the locations. Published sources of photographs are acknowledged in the appropriate place, but I should like to thank Mr Jon Coulston (Plates 17, 40, 122 and 127), Mr Rob Burns (Plates 18 and 37), Mr Alan Rushworth (Plates 16 and 34), Miss Jean Greenhalgh (Plate 136), Ms Karen Griffiths (Plate 14) and Mr and Mrs J. E. Dodge (Plates 9and 15) for the use of their photographs, as well as the Palestine Exploration Fund for providing the photograph taken by Corporal Philips

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Mediterranean marbles found during excavation at Colchester, and the staff of the Museum of London kindly provided me details of marble found in Roman London.

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Mr Jon Coulston travelled with me in the Middle East and in Italy, and his 'protection' made the trips much less harrassing and as a result much more successful! I should like to thank him for the hours of discussion he has afforded me, and the advice and criticism he gave on the text from its first stages to the final draft.

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VOLUME I

INTRODUCTION

The study of Roman architecture has been popular for over 100 years, and in the late 19th and early 20th century, there was a crop of travellers' and expeditionary publications describing the wonders of classical Greece and Rome in the Eastern Mediterranean [1]. Italy and Rome had been subjected to similar detailed studies from the early 19th century, but since the 16th century there had always been interest in the Roman antiquities. In the 15th century a traveller, Cyriac of Ancona, recorded Roman antiquities in Asia Minor, in particular the Temple of Hadrian at Cyzicus. Some of the earliest works, however, on the sites in the East were centred on Palmyra, by Dr W. Halifax in 1695, by J. Dawkins and R. Wood in 1753, and L-F. Cassas in 1799 [2]. These travellers stimulated interest in the Eastern antiquities, and such people as Lady Hester Stanhope at the beginning of the 19th century, and C-F. Volney, Irby and Mangles, and the Marquis de Vogüé followed in the footsteps of the earlier scholars [3]. These travels provided information and knowledge, in the form of writings and drawings as well as photographs in the later publications, that had only been guessed at previously, and they formed the basis for the study of Roman architecture on a broader scale. They also drew attention to the possibility of archaeological excavation at some of these ancient sites, especially at Ephesus, Epidaurus, Olympia and Pergamum.

Serious architectural studies have been carried out since Choisy's three volumes from 1873 to 1899 [4]. Scholars such as Durm, Cozzo, Blake, Lugli, Boethius and Ward-Perkins have gradually increased the knowledge of Roman architecture as well as given it a broader outlook [5]. However, despite the value of these studies, most have the same basic approach; they either concentrate on Rome to the exclusion of the provinces or if they do deal with any of the provinces, then usually the assumption is that all inspiration came from Rome. There is often an emphasis on plan and style of decoration. In this way many outside influences and their importance are either ignored or not given due credit; Ward-Perkins is an exception to this.

This is not to say that scholars were not interested in the East. There was an enormous fascination with the classical architecture of Greece, so much so that it had great influence on architectural design in Western Europe. There was much less interest in Roman as opposed to classical Greek. With sites further East, mainly due to the intrepid travelling scholars of the 18th, 19th and early 20th centuries, Roman monuments received more treatment, for example, in the work of Choisy, de Vogüé and Conder [6], and, at the turn of the century, the Princeton Expeditions under Butler.

In virtually all this work, the buildings are studied from the point of view of style and plan - what kind of capitals and columns, a Greek or Italian plan. With some exceptions, such as Choisy and Butler, there is little thought given to the actual materials used and the techniques associated with them. This type of work had been carried out for Rome in the earlier part of this century by van Deman, Cozzo and Durm [7], and by M. Blake in the 1940's. This approach was taken up by Lugli, MacDonald and Ward-Perkins so that finally the technical knowledge of the Romans began to be examined systematically and in detail [8]. The French took up this approach for Greek architecture [9] and for Roman architecture, mainly in the Western Empire. The study of Roman architecture, however, in the Eastern Mediterranean was left behind. The work of Ward-Perkins in 1958 helped to redress the balance [10] and recent Roman brick studies at Argos and other sites in Southern Greece have begun to put Roman Greece back on the map [11]. Thus a definite gap has existed in this kind of approach to Roman architecture.

Obviously, Rome had an enormous influence on the architecture of the Eastern Provinces, but hers was not the only influence and one finds a style of building which develops from many different traditions and in the context of local resources. Ward-Perkins has written on this a number of times [12], and his work is an invaluable source of information and ideas. These ideas can now be extended, modified and revised to bring them up-to-date and to use them as a basis for the study of Roman building technology in the East.

Four sources of information can be employed for this research i) excavation reports, both old and new; ii) other published works, the work of Blake, Lugli, Ward-Perkins etc; iii) travellers' accounts, drawings and photographs; iv) personal observation and photographs. It is while reading the published literature, especially some excavation reports, that one becomes aware of certain deficiencies. For example, it is very often the case that a building is described as being of brick, but nothing is said of how the bricks were used, their size or their colour. Similarly with marble and granite - 'white marble' and 'grey granite' are basically meaningless in the context of materials. The description of different types of materials is particularly important for the Eastern Mediterranean where there is much diversity, and it is the deficiencies in this which must be rectified.

Travellers' accounts are of particular importance, especially where there is a detailed photographic coverage, as with Gertrude Bell, Butler, Conder and Warren. Their photographs of now destroyed monuments, for example, those in Amman, are invaluable. Compare Plates 1 and 2 and this is very evident. To supplement their accounts and photographs a programme of detailed fieldwork has been carried out by the writer over the past four years (1980 - 84) in Greece, Turkey and the Middle East. Many of the sites, indeed, have not been published or have not been looked at for over 50 years. Thus, the research depends very much on personal observation and photography. There have, of course, been difficulties in this approach. The antiquity laws of each country must be observed if future work is to be at all possible.

This is particularly the case with Turkey where work was carried out without infringing those rules. No measurements were taken and only general observations were made with photographs. As far as the writer knows every site was published in some form. However, in order to conduct more research, a permit will be necessary to carry out detailed surveys and measurements. The countries of the Middle East, however, at present at least, do not have such regulations and some more detailed work was possible.

Obviously there are other limitations to such work. One would ideally wish to see every site and read every relevant publication. This is not possible, but the research carried out here is intended as a basis for further work in various directions; it does not propose to say the final word on Roman building materials and techniques.

Various problems regarding actual methods of research should be detailed. The fundamental factor is the difficulty of setting the materials apart from the techniques. To gain any insight into the technical knowledge available to and utilised by the Romans, whether in Rome, Italy or in the Eastern Provinces, the methods of manufacture and quarrying and the individual mechanical properties of the materials must be ascertained. This is not to say that these properties were understood in the Roman period, but only in this way can one begin to understand the expertise of the Romans as builders. Unfortunately their mistakes are unlikely to survive.

There were basic engineering concepts of which they were aware and, in their own way understood, but without examination of the buildings one cannot be sure how these all coalesced.

Various false impressions can be created by the evidence. The most important is the survival rate of monuments. This depends on so many factors: good foundations, durable materials, solid general construction. If one of these is defective the survival rate of the monument is lowered. Added to this is the ease with which its materials can be removed and re-used elsewhere. Re-use of bricks, marbles and stone blocks are all easily achieved; they have all been shaped and require little reworking. The main problem is to transport them to wherever they are to be used. Where this re-use cannot be recognised, false statements and conclusions can arise, and this should always be borne in mind.

The third factor which creates false impressions is the geographical spread of research. Unfortunately excavation and fieldwork is carried out more intensively in some areas than in others, as, for example, in Asia Minor compared with Jordan and Syria. Thus some distribution maps may show the distribution of work done rather than the distribution of whatever it claims to show. Thus, all distribution maps in this thesis do not claim to be complete, but invite the addition of new instances; they are merely a beginning.

The study of building materials and techniques in the Eastern Mediterranean is an enormous subject and as such certain limits have to be imposed. Geographically the area covered in detail is that of modern Turkey, Syria, Jordan, Lebanon and Israel. Greece and the Balkans which form subjects on their own, are drawn upon for comparative material. Egypt which also requires a great deal more work on its Roman monuments is likewise referred to for comparisons. The section on marble does include the Numidian quarries of giallo antico, strictly speaking in the Western Empire. This was one of the most important marbles in the Roman period and as it does occur in the East it seems appropriate to include it. The quarries of Greece and Egypt are also included because of their importance. As well as geographical limits, a chronological limit also had to be set to the research. Here lies a basic problem. Architecture cannot be divided into neat little compartments labelled 'Ancient Egyptian', 'Greek' or 'Hellenistic'. It is continually developing and although there are characteristic differences between the architecture of the different peoples there is no break in the development. Thus, in the East, where does Greek architecture end and Roman architecture begin? In Rome, where does Etruscan end and Roman begin? As a result of this problem the limits of the later Hellenistic (that is, 2nd century BC) to the 4th century AD have been set. In the 4th century emphasis in the Roman Empire changes from Rome to Constantinople; this seemed an appropriate event to use as an upper limit. In the 2nd century BC, Rome was beginning to develop a foothold in the East. However, despite the setting of these chronological limits, inevitably one has to reach back or look forward to view a particular aspect in its proper developmental context.

Thus, most sections deal with much earlier evidence as well as later. The Romans did not have a monopoly on building expertise. They were undoubtedly innovative architects, but many of their traditions and much of their expertise they gained from other civilisations, to whom time and space should also be given if there is to be any attempt to study the architecture of the Eastern Roman Provinces in the light of the materials and techniques and to assess its importance in the Empire as a whole.

CHAPTER I

THE DEVELOPMENT OF ARCHITECTURE AND THE ARCHITECTURE OF THE EASTERN PROVINCES

Architecture is the art and science of building construction. According to Vitruvius, architecture depends on Order, Arrangement, Eurythmy, Symmetry, Propriety and Economy [1]. Order is concerned with proportion and general planning so that each individual element fits in with and corresponds to the various other elements, with each member in its proper place. Basically this involves ground-plans and elevations. Eurythmy and symmetry are both concerned with correspondance between the various elements, for example the height of a column is suited to its breadth, and the columns are placed equidistant [2]. Propriety is about choosing the right order, decoration and style for a particular building, especially in the case of temples. The orientation of the building also comes under this heading. Vitruvius says, "There will be no propriety in the spectacle of an elegant interior, approached by a low, mean entrance" [3]. Basically, the outside should match the inside. Under economy comes the proper arrangement of materials and local resources. The architect should not demand things which would require great expertise, for example, marble and fir, and when building a house he should take into account for whom it is being built; a different type is appropriate to different classes.

Thus, architecture took many forms. Similarly, the architect, according to Vitruvius, must have a sound and wide education. Indeed, the Greek architekton regonises an architect's role as a designer who was needed to co-ordinate and direct. In Antiquity the distinction between architect (in modern terms) and engineer did not exist. Vitruvius mentions the various skills which an architect should have; he should be well-versed in history, drawing, geometry, philosophy, physics, music, medicine and law [4]. (See Chapter IX).

The basic structural requirements of any building have remained the same throughout the ages. The most important factor is for the structure to remain more or less immobile under whatever loads it is called upon to bear. The various forms that buildings have taken differ according to a number of factors. Firstly they have often been built according to various non-structural requirements, that is, according to the function of the building. This decides the plan and interior decoration as well as the roofing system in many cases.

In general, in ancient architecture, technical resources were more limited than in later periods and there was less understanding of the actions involved. Thus, simpler forms than in later times were constructed with a more restricted range of actions that were exploited. With the establishment of civilisation and relatively peaceful conditions, architecture developed technically with new ideas spreading with ease, but with a constraining factor of the available resources.

The materials used for building inevitably define its appearance and general construction. Materials react in different ways under varying conditions and have enormous influence on architecture in general.

Mudbrick and stone were the first materials in general use in Egypt, Mesopotamia and Anatolia. Timber was used only where it was locally available, which in Egypt very often meant not at all. Stone was expensive because it was hard and time-consuming to quarry and was only used for important temples and other structures, for example, the Pyramids. Timber was particularly good roofing material but was also costly if not a local resource, and therefore its uses could be limited. Where timber roofs could not be built because the material was unavailable, other materials had to be exploited and new techniques developed [5]. This led to the construction of vaults of mudbrick, pitched on end, which needed little or no centering to build (fig. 1). These vaults, at first small and in insignificant places, became a distinctive feature of the architecture of Egypt and Mesopotamia, which was taken up by the Parthians and Sassanids with large spans being achieved (see Chapter VII). This mudbrick architecture had a very significant impact on construction in the East with the translation of the technique into fired brick and its widespread use in the Byzantine period.

Small vaults and arches of stone were constructed in Egypt but most construction was according to the corbelling tradition which owed little to the true arcuated technique. There was reluctance indeed to experiment with stone vaulting before the Hellenistic period. Stone, of course, was used to the virtual exclusion of all other materials in the Greek world for construction, with timber for roofing. Neither fired brick nor mudbrick featured in the public and monumental architecture after the 7th to 6th century BC, and construction was based on the post and lintel technique. This technique depended very much on the use of columns.

The first columns were of wood, for example, in Minoan architecture, and of stone, for example, in various Egyptian temples. Their basic purpose was to help support the roof, reducing the spans to a manageable distance. They became prerequisites in Greek, Etruscan and Roman temple design which brought about the development of the various orders.

Whereas Egyptian and Mesopotamian architecture were both fairly innovative, Greek architecture was conservative in both materials and techniques. Walls were of stone, either laid dry or clamped together with metal clamps and dowels. Timber was the main roofing medium. Until the Hellenistic period most monumental buildings of any importance were of a religious nature, conforming to set plans and designs for their particular purpose. None fulfilled the technical promise reflected in the Mycenaean <u>tholos</u> tombs. The influence of the latter can be seen in the corbelled tombs of the Etruscans.

At this point it should be noted that it is in monumental and funerary architecture that innovation and invention inevitably took place. Where possible the more permanent materials were employed with a wider range of techniques. In private and domestic architecture, the dwellings and houses of ordinary people, one must assume that it was mudbrick that was usually used, even in Classical Greece where brick in general was unfavoured. In some areas of Anatolia and Syria, where supplies of rough stone were readily available, houses were of dry-stone walling with either stone roofs, as exemplified in Nabataean architecture, or with timber roofs if wood was available.

The Hellenistic period saw much progress and a diversification in architecture which set the scene for construction in the Roman East, but the development in the use of materials and techniques was due to many contrasting traditions. Asia Minor and Greece shared a rich classical heritage which dominated the native element in the Roman architecture of Greece, producing less inspired building than elsewhere in the Empire. In Asia Minor, however, this classical tradition developed under the tutelage of cultural centres such as Pergamum and Ephesus into an active and vibrant force in the Roman architecture of the East. As a creative force Greece was spent, but in Asia Minor the Hellenic tradition lived on, always innovative and developing under Roman influence.

"If within the Greek world the study of architecture of the Roman age is complicated by an essential duality of direction between the native Hellenic tradition and that which derived from Rome itself, when we turn to the eastern coastline of the Mediterranean world and to the lands beyond it the duet becomes a trio, if not indeed a chorus of mixed voices" [6]. This is in no way an exaggeration. The architecture of the Roman Levant owes as much to the Mesopotamian traditions of the Parthians and later on the Sassanids as to those from Rome. The traditional mudbrick becomes translated to a certain extent into fired brick, but under Roman impetus stone becomes an important construction material, despite its higher cost, transport difficulties and greater technical drawbacks.

This 'Roman influence and impetus', however, deserve a little space, in order to put the architecture of the Roman East into the context of East and West. The 'Roman influence' that is meant is essentially that of Rome. It is traditionally thought that it was the Etruscans to whom all things architectural were owed by the Romans. However, it becomes obvious that the Etruscans did not invent the arch, although they certainly seem to have known about it by the 3rd century BC. The arch may have come from the East via the Greeks to the Romans and Etruscans (see Chapter VII). Thus, neither did the Romans invent the arch and the vault. What one can credit them with is the exploitation of these forms on a grand scale, developing materials, in particular concrete, with which to build to such a massive degree. Before

Augustus, concrete was used in the great sanctuaries at Praeneste, Tivoli and Terracina [7] for solid foundations and vaulting, but it was not until the mid 1st century AD that concrete architecture and the architecture of Rome as a whole began to develop a character of its own.

This was essentially an architecture of the interior. Greek architecture had been logical and lucid, the niceties of which lay in the subtle use of familiar structural themes. It was also an architecture of the exterior, to be viewed and understood from without rather than experienced from within. The great Hellenistic assembly halls were a move away from this but there was still an uneasy balance between the Greek tradition and the new concept of interior space. The credit for the exploitation of interior space must be given to the inventiveness of Rome.

In this development the Golden House of Nero was a definite milestone, but there were still structural problems which are all too obvious in the awkwardness of the octagon roofing (Plate 3). However, the progress made in the quality of material and in the virtuosity of its handling is very evident in the Palatine Palace of Domitian built only 25 years later. Curved forms and impressive interiors were obviously becoming the characteristics of this new concrete architecture. The series of Imperial <u>Thermae</u> in Rome illustrate this with their huge and impressive groin-vaulted <u>frigidaria</u>. By Hadrian, the new architectural thinking had reached most of its goals. Hadrian's villa at Tivoli includes a number of extraordinary buildings graphically illustrating the Romans' technical mastery of the materials, brick-faced concrete, and the curvilinearity which had become common-place by now. Hadrian's Pantheon, however, more than any other single building, vividly epitomises the achievements of the sixty years since Nero's Golden House was planned. As Ward-Perkins says, "architectural thinking had been turned inside out" [8]. The columnar porch of the Pantheon was the architect's concession to Greek tradition but the rotunda was all Roman. Internally it was half the height of its own diameter (142 ft; 43.20 m in diameter) surmounted by a hemispherical dome exactly the same height above the pavement as the diameter of the building. The span was unsurpassed until modern times. (The dome of St. Peter's is 139 ft; 42.50 m in diameter). Its completion and survival is an outstanding example of structural engineering. The reasons for this achievement lay in the careful use of materials: the solid concrete foundation; the quality of the mortar; and the very careful grading of the <u>caementa</u>. The grading runs throught the building from the heavy <u>selce</u> used at the footings to the very light pumice used around the <u>oculus</u> of the dome [9]. The practice of using light materials for vaulting was a familiar building practice [10], but it was the grading of the aggregate which was innovative.

Thus the scene had been set for the rest of the Roman period. In general the concrete tradition remained unchanged, but there were several variations on the theme. Brick ribs in the concrete vaulting are found from as early as the later 1st century AD in the Colosseum (Plate 4), but it was later on that the practice found favour [11]. The technique appears in the Basilica of Maxentius, in the Minerva Medica, and in the Villa of the Gordians (Plate 5) and in the Baths of Diocletian. These were developed primarily to facilitate construction and they may have proved to have been a source of strength within the vaulting as a whole (see Chapter VII). Another addition to help lighten the loads at the base of the vaults was the inclusion of large earthenware jars (pignatte), for example, in the Villa of the Gordians (Plate 6), the Mausoleum of Helena, and the Circus of Maxentius.

It is with this background that one can turn back to the Roman East. Roman influence is everywhere, but the Roman techniques are adapted to the available materials so that they are used in a characteristically eastern way.

CHAPTER II

STRUCTURES

To appreciate building materials and techniques used at any one period their structural behaviour must be understood. Different materials react in different ways under certain conditions and these all affect their suitability as building media and for use with particular techniques.

When discussing structural problems in the ancient world modern terms have to be used to describe certain 'invisible' elements which must have been taken into account, however unwittingly by ancient architects. It would seem pertinent to summarise briefly and define the main elements which are important to a discussion of building materials and techniques associated with them.

Dead loads. These are the heavy elements such as columns, beams, floors, arches, domes (all found in Roman architecture) in a structure which must, first of all, support their own weight. The weight depends solely on the form of the structure and the materials of which it is made; it is unchanging.

Live loads. These are imposed on the structure by its users or its environment. Unlike dead loads, they do change with time, and in their effect, they differ from one another according to how quickly and how often they change. They also differ in the extent of their dependence on the form and materials of the structure; some are further dependent upon exactly how the structure is put together. These include loads imposed by furniture in a room, people or vehicles on a bridge, grain in a granary etc. Changes in temperature or humidity, and even the setting of cement can also produce similar loads if the expansions and contractions to which they tend to give rise are restrained.

Reactive loads. These are necessary to balance the total effects of all the other loads where the structure is supported. They also depend upon the exact method of construction. These may be the supporting loads where the foundations meet the natural earth. Reactive loads must equal active loads if a structure is to remain standing; they are therfore said to be in static equilibrium.

Tension, Compression, Shear. The purpose of a structure is to channel all the loads imposed by the various elements of the structure down to the ground. Elements of a structure can only push or pull, that is, they are either pulled by loads resulting in them being stretched (in tension), or pushed by them and they are shortened (in compression) (fig. 2). Shear is an action tending to cause the slipping of one part of an element on another, that is, lateral thrusts.

There are no perfectly rigid structural materials. There are tiny changes in length due to loads acting upon them. Loads are said to stress a structure which, as a result, strains under stress (fig. 3). Stress equals $\frac{\text{load}}{\text{area}}$ and expresses how hard, with how much force, the atoms at a point within the solid are being pulled apart or pushed together by a load. Strain is $\frac{\text{extension under load}}{\text{original length}}$ and expresses how far the atoms at a point within the solid are being dragged apart or pulled together. Structural materials must be strong in tension and/or compression. When the strength of a material is referred to, it usually means that stress which is needed to break it. The relationship between stress and strain indicates how stiff or how floppy a material is. This is expressed by Young's Modulus, $\frac{\text{stress}}{\text{strain}} = E$ (the elasticity of the solid). A material whose change in shape vanishes rapidly when loads on it disappear is said to behave <u>elastically</u>. This is the basis of the statement '<u>ut tensio sic vis</u>' the principle of which for the last three hundred years has been known as Hooke's Law [1].

If loads are kept within given limited values, all structural materials behave elastically, However, if these values are exceeded, the materials develop deformations which are larger and no longer proportional to the loads; these deformations, called <u>permanent</u> or <u>residual</u> deformations, do not disappear upon unloading. If this happens the material is said to behave <u>plastically</u> [2].

Materials which behave elastically under relatively small loads and plastically under higher loads do not reach breaking point suddenly. Once they stop behaving elastically, they keep stretching (or shortening) under increasing loads until they continue to do so even without an increase in loads; only then do they fail. Materials which do not _yield_ are described as being _brittle_, that is they behave elastically right up to breaking point and will fail without warning; they therefore cannot be used in structures, e. g. cast iron.

CHAPTER III

MATERIALS

The history of architecture is greatly affected by the character of the building materials, and the study of these as materials for construction is just as important as the study of the buildings in which they are used. Much work has been carried out on the materials used in the great building programmes of Imperial Rome [1], the concrete, tufas and travertines, as well as the marbles and granites. However, the situation prevailing in the provinces has rarely been discussed as a cohesive whole [2].

Materials used for building in the Eastern Roman Provinces can be divided into two main categories: the traditional materials, those in use in the region before the Roman period - mudbrick, timber and stone, and the 'new' materials introduced during the Roman period either directly or indirectly - mortared rubble, concrete and fired brick. These categories, however, are not mutually exclusive; the traditional materials were used in conjunction with the 'new' materials, and the decorative building stone, marble and granite, to all intents and purposes 'new', fall under the heading of stone. Marble was used before the Roman period but only in a very limited way by comparison [3]. The widespread use of granite is a definite Roman influence. However, to avoid unnecessary complications the physical and structural properties of marble and granite in general will be dealt with alongside those of other stones, but their quarries and uses will be treated in more detail in a separate section. Otherwise the strength and effectiveness of each material for construction will be discussed and assessed, with their weaknesses outlined as a basis for the discussion of how they were employed in the East.

MUDBRICK

Mudbrick is not a material usually associated with Roman monumental architecture, but its uses in some regions in the East during the imperial period are very important for the development of techniques in general.

Mudbrick has been used for millenia in the alluvial valleys of the Euphrates, the Tigris and the Nile, and on the Anatolian plateau, to construct simple structures. The mud, rammed hard and dried by the sun, was capable of resisting a compressive loading. When used in a mass like this, however, it is slow to dry and even with the addition of straw there is a tendency for it to crack as it dries and shrinks. Thus, bricks partially dried in the sun before use are more satisfactory. From the 4th millenium BC, high quality mudbricks, of regular size, were in use in Mesopotamia and Egypt, with, in the 3rd millenium BC, the introduction of the cigar-shaped 'plano-convex' bricks on a number of Mesopotamian sites [4].

The mudbricks were made by mixing mud with sand and chopped straw, pushed into a wooden mould. The brick was then turned out onto the ground to dry in the sun. This drying process took about a week. The bricks were set in mud mortar, often with reed mats incorporated at regular intervals in the horizontal joints [5].

Experiments with brickmaking in modern times have produced some useful results [6]. Pure Nile mud shrinks by over 30% in drying, but the sand and straw incorporated in the bricks prevent cracks forming. It has been found that the best mixture of constituents is one cubic metre of mud with a third of that amount of sand, plus 20 kg of straw. Bricks containing fine sand, and well-dried, can stand compressive stress of about 52 kg/cm^2 (roughly 23 lb per square inch), whereas bricks with the addition of straw are less strong [7].

Generally speaking, sun-dried mudbrick is a highly versatile medium. Massive walls could be built with them, as at Babylon and at Ur where ziggurats of considerable height were erected (up to about 55 feet high) [8]. It was also possible to construct small arches and vaults, for instance at Ur, Thebes in Egypt and Tel al Rimah [9].

The Greeks used mudbrick for the walls of some of their early temples, for example, the Heraion at Olympia (7th century BC), the Temple of Appollo Thermaios at Thermum (7th century BC) and the Temple of Artemis Orthia at Sparta (8th century (?)) [10]. In the classical period, however, mudbrick gave way, particularly for public building, to limestones and marbles. However, it remained a common material for the construction of civil and private buildings [11]. Placed on a foundation of stone and sometimes strengthened with a framework of wood, mudbrick was certainly the material used in the construction of houses in the classical period [12].

Mudbrick was widely used in Republican Rome and other parts of Italy before the development of the use of fired brick and concrete. Vitruvius gives a very useful account of the making of mudbricks [13]. The clay should be sandy or pebbly, but should be white and chalky or red. The reasons he gives are that they have much more durability and are easier to work with. Spring or Autumn are the best times for manufacture to ensure even drying; cracks do not then occur. Vitruvius advocates allowing the bricks to dry out thoroughly and not to use them for two years. He makes it quite clear that the Greeks used mudbrick on a wide scale for both public and private buildings [14].

The use of mudbrick in Rome and Italy gave way to concrete and fired brick in the mid 1st century AD, only a matter of decades after Vitruvius wrote his De Architectura. However, mudbrick continued to be used in the provinces and must have been the usual material for much of the ordinary domestic housing of the Eastern Provinces and North Africa. The small townships of Karanis and Soknopaiou Nesos in the Faiyum in Egypt are important because of the extraordinary survival and well-documented excavation of the mudbrick houses. These use hardly any stonework or timber, and afford one of the very few surviving examples of a building material and of building techniques which have all too rarely come down to us, but which must have been in widespread use in many parts of the Mediterranean in the Roman period [15]. Examples of mudbrick for construction in the Roman Empire also survive at Dura-Europos (Plate 7) and at il Anderin (Androna) in Northern Syria [16]. Owing to the poor survival rate of the material, other examples are scarce.

TIMBER

The study of the use of timber for construction is hampered by the material's poor survival rate and by the fact that most of the forest areas of antiquity which are in existence today are in a very sorry state in contrast to their past. The main regions of forest in the Eastern Mediterranean in Antiquity were Macedonia and Central and Southern Greece, the hills of the Southern Black Sea coast, the Taurus mountain range of Southern Turkey, the mountains of South-western Turkey and the great forests of Lebanon [17].

Trees can be divided into two groups, softwoods and hardwoods, which relate to certain peculiarities of growth and structure rather than to actual degrees of hardness [18]. A softwood tree is a conifer or evergreen that has needles or scale-like leaves and bears its seeds in cones; cedars, cypress and firs are all good examples. A hardwood is a deciduous tree with broad leaves that normally shed annually, and has heartwood that is very hard, for example, oaks [19].

Another useful characteristic of wood is its specific gravity. The specific gravity of each species of wood is the measure of the amount of cell wall material in the wood. It is thus a useful factor for determining the strength of wood. Generally speaking those with lower specific gravities are not desirable where load bearing is expected. A higher specific gravity means that there is relatively high content of wood cells and there must also be a large quantity of lignin which binds the cells together. These two properties give wood its strength and its elasticity qualities which are important in selecting construction properties [20].

The main differences between timbers lie in their density; spruce has about 30 per cubic foot (0.45) and oak 50 (0.7). With only minor additions and subtractions, the actual wood substance has in all cases the same chemical constituents and about the same density of 90 per cubic foot [21]. Roughly speaking, the mechanical properties of different timbers are proportionate to their densities; a timber twice as dense will be about twice as strong.

The main structure of wood consists of large numbers of tubular cells or fibres, squarish in cross-section and fitting very neatly together. Lateral tensile and compressive strengths, that is across these fibres or across the grain, are very low, only a few hundred pounds per square inch. The fibres separate or crush quite easily. The tensile strength along the grain, however, is around 15,000 per square inch. This is quite respectable and is much better than that of other engineering materials. Weight for weight, the tensile strength of wood is equivalent to that of a 300,000 per square inch steel, which is four or five times the strength of the steels in common use today [22].

The weakness of wood is in compression along the grain. Under a compressive load, the fibres buckle or corrugate. The slope of the grain can also weaken timber. It may have no appreciable effect or it may reduce the strength by as much as 15% [23].

As well as strength, timber also has the stiffness required to make engineering structures. The Young's Modulus of spruce is about 1.5 to 2.0 x 10^6 per square inch (12,000 MN/m^2), and other timbers are more or less stiff than this in relation to their densities [24].(figs. 4 and 5).

Thus, good stiffness combined with low density means that wood is very efficient in beams and columns and for strengthening. However, it also rots with age and has a tendency to 'creep', that is, if a stress is left on a load for a long time, the wood will gradually move away from it; compare the curve of old roof gable timbers under the weight of slates or tiles.

For the types of timber used in the Roman period one has to rely on the ancient sources. The areas of timber supply have been noted; Egypt and the desert areas of Mesopotamia are areas of great timber shortages and therefore one finds a careful use of the material, if at all. This brought about the extensive development of mudbrick techniques, especially in areas where suitable building stones were geologically absent.

Wood was used where it was available in the pre-Roman period. It was used as strengthening in walls in Anatolian houses in the Bronze Age and the Iron Age [25], for door posts and lintels and, of course, for the roofs of Greek temples.

In the Roman period in the East, timber remained an important building material and there were still plentiful supplies in Phoenicia and Asia Minor. The cedars of Lebanon were the providers of giant timbers, straight and long. Josephus records two instances of the use of the cedars in the Hellenistic period; a decree issued by Antiochus III of Syria to reward the city of Polemais for help given him during his war against Egypt, records that timbers from the Lebanon should be brought to complete their temple [26]; and when Agrippa II in the 1st century AD ordered timber from the Lebanon for the Temple at Jerusalem [27]. The cedars of Lebanon could also have provided timbers for the huge Temples of Jupiter Heliopolitanus and of Bacchus at Baalbek; the central span needed beams of about 60 ft [28]. Timber roofing is dealt with in detail in Chapter VI.

The cypress grew in Asia Minor and Greece, and according to Theophrastus it was abundant in Crete, Lycia, Rhodes, the Taurus Mountains and in the Lebanon coastal ranges [29]. The fir and pine were the two mountain species, along with the cedar, which were useful to the builder in the Eastern Mediterranean.

However, due to the poor survival rate of the material, timber construction is very difficult to study. While it may be possible to identify the use of timber in a building, for wall reinforcement or for roofing, it is, regrettably, virtually impossible to specify the type of timber used. One may only speculate, basing these speculations on the various ancient authors' writings about wood and trees, and on how we know today certain woods react under certain conditions. The use of timber for scaffolding, shuttering and centering will be dealt with elsewhere.

STONE

The traditional structural materials were probably stone, mud, reed and the lighter kinds of timber. As found stone is much the most durable of the four materials and therefore was preferred, wherever it was available, for those structures considered to be of greatest importance. It varies greatly in structure and hardness, and the ease with which it can be extracted from the mass and cut to shape.

Stones can be divided into three geological groups:

i) Primary or igneous rocks, formed by the solidification of molten magma, either well below the surface or close to it, due to volcanic action. These rocks are mostly crystalline and very hard, except for light volcanic deposits such as tufa. They lack any natural beds or cleavage planes and cannot therefore easily be split apart. Granites and basalts are examples of igneous rocks. Physically, igneous rocks have compressive strengths of 18,000 per square inch to 40,000 per square inch, and have a very low porosity and absorption rate. Granite is a very dense rock (180 lb per cubic foot) and has a very high conductivity of heat [30] (fig. 4); it is therefore good for columns.

ii) Secondary or sedimentary rocks are largely derived from primary stones by disintegration or decomposure followed by deposition, either on land or under water, and subsequent consolidation. The two main kinds of sedimentary stones are sandstones and limestones. Sandstones are largely composed of fragments of the mineral quartz cemented together. They are usually harder than limestones which are formed inorganically with calcium carbonate and organically with skeletons and shells of organisms. Limestone has a relatively low to good compressive strength (25,000 to 28,000 per square inch) and its porosity is many times greater than that of igneous rocks [31] (fig. 5). The fact that they have been formed in layers means that both sandstones and limestones can be split fairly easily from the bed-rock and then more readily cut into squared and shaped blocks.

iii) Metamorphic rocks are derived from primary and secondary rocks by the action of heat or pressure which changes their characteristics. Marble is the only metamorphic stone of much structural importance in the Roman period. The compressive strengths can vary from 12,000 to 21,000 per square inch, and its absorption rate is almost zero [32] (fig. 5). Sometimes the term marble is applied by architects and sculptors to a stone which is not a marble in the strict geological sense but which does show the paricular characteristics of hardness and ability to take a high polish. These stones are not metamorphic but have only gone through a moderated series of temperatures and pressures; the structure of the limestone is still preserved.

Generally speaking, the compressive strength of stone always greatly exceeds the tensile strength, usually by a factor of about ten. Obviously it varies considerably, but it is generally highest for granite and lowest for the poorer sedimentary stones [33] (fig. 5). As a result of the low tensile strength, the shear strength is also low, particularly along the cleavage planes of the sedimentary rocks. This restricts the use of stone for beams and lintels to short spans. Stones also vary greatly in their resistance to transverse loading, but they generally do not perform well [34]. In contrast, under direct compression in structures, a failure in stone is almost inconceivable [35].

Stone, at first, was used for the more important buildings in Egyptian and Mesopotamian architecture - palaces, tombs, temples etc. Some of the most remarkable monuments in stone are, of course, the Pyramids in Egypt, and due to the fine quality stones available in their domain, stone became the principal building material of the Greeks, for monumental architecture at least. They became masters in the handling of stone and fitted blocks together with extraordinary skill and precision. Before the development of long-distance trade in building and decorative stones, the geographical incidence of suitable stones was crucial for the development of architectural styles - limestone and marble in Egypt and Greece respectively.

The whole of the Eastern Mediterranean provided splendid building stone and the Romans exploited the resources to their fullest extent. In Asia Minor the limestones of the West and Southern coast mountain ranges provided ample supplies for general building; the white, very fine limestone of the Pisidian hills is particularly noteworthy [36]. This is very close in texture to marble. Another very similar stone is that used at Hierapolis in Phrygia, a form of travertine formed by the calcium oxide-bearing hot springs. Marble is particularly abundant in Western Asia Minor. The richest region of white marble is Caria, in an area defined by Phrygia and the valley of the Maeander. In the centre of this area the Baba Dağ mountain range was worked extensively in antiquity with the relatively large quarries of Aphrodisias and the smaller, more locally-based quarries of Denizli and Laodicea [37]. (See Chapter IV). The extensive volcanic activity can be seen in the granites of North-West Turkey, the volcanic stones of Cilicia and the andesite in extensive use at Pergamum.

Further East, good building stones still prevail but the situation was slightly different. Broadly speaking, two limestone varieties were available - a conglomerate which at its best resembled marble, and a darker, denser stone which was capable of equally fine work, but was not so freely used [38]. It was more difficult to work and less easily obtainable in large blocks. Thus it was really only used where nothing else was available. Around Jerusalem was a natural quarry-bed of good building stone. This ranged from a soft easily-worked limestone to one which was considerably harder and pinkish. The finest varieties of the softer ones weathered to deep yellow hues. This not only made for monumental ashlar construction but also contributed to the fineness of finish and the use of sharply drafted edges which distinguishes the very high quality of Herodian period masonry in Judaea (see Chapter V).

The quarries which supplied Baalbek were situated in a spur of the Anti-Lebanon to the north and west of the city. The western quarry was situated on the northern slope of Sheikh Abdallah Hill. This quarry, about 1 km long, was only half a kilometre from the sanctuary itself and, as it was higher that the complex as well, provided all the big blocks which were difficult to transport. This quarry is not worked now but still has one great reminder of those who used to work it - the largest cut stone in the world, the 'Stone of the Pregnant Woman'. This was originally destined for the massive podium of the Temple of Jupiter but was abandonned after a flaw was discovered. It was never fully separated off from its base. It is 21.72 m long with an average cross-section of 4.08 m square, which equals a volume of 500 m^3 and a weight of 1,200 tons, a truly gigantic monolith. The other stones of the Trilithon of the podium are all slightly smaller with an average weight of 1,000 tons per block. The other quarry is to the north of the town, about 2 km away, and presumably provided the smaller building blocks [39]. The natural colour of the Baalbek stone is an ivory white which weathers to a grey or deep yellow. It is dense and slightly crystalline in texture.

In the area of the Jordan valley, especially up near the Sea of Galilee, the local stone is a rather intractable volcanic basalt. This stretches east and north and covers the whole of the Hauran area of Southern Syria and Northern Jordan. The stone is very difficult to quarry, but the Nabataeans, who settled this area and that to the south for several centuries before the Roman period, became highly skilled in its handling and cutting. The Hauran was almost bereft of trees, so a different kind of architecture had to develop based on the use of stone for members usually made in wood - lintels, floors, balconies, even doors. Thus, the typical architecture of corbels supporting flat stone roofs, so well presented at Um el Jemal, emerged. As a result of the use of the grey-brown volcanic stone, cities such as Gadara (Umm Qais), Bostra (Bosra) and Philippopolis (Shahba) now have a very gloomy aspect.

There was no large scale transport of building stones (except marble and granite, see below pages 56 - 146) with cities having some kind of local supply. These supplies could be up to 12 miles away [40], and transport would have involved, presumably, ramps and rollers.

MORTAR

Mortar is the term loosely applied to a material used for bedding, jointing and rendering brickwork and stonework. It normally consists of a cementitious or other building material, with or without a suitable filler or fine aggregate. The term 'cement' is very often used synonymously with mortar but this should be avoided as it is a modern term referring to a compound obtained by exposing a mixture of limestone and clay to high temperatures and then reducing them to a powder. It also invites confusion with the latin caementa which refers to the aggregate alone or opus caementicium, the whole construction using mortar and aggregate.

The earliest, and simplest, mortars can be found in Ancient Egypt and Mesopotamia, where the mudbricks were jointed together with a mud mortar, sometimes with chopped straw added. The Babylonians and Assyrians used bitumen to cement together the burnt bricks and alabaster slabs [41].

The first instance of a mortar made on the same principles as Roman mortar is in the masonry constructions of Dynastic Egypt. These were not lime mortars but the cementing material was always obtained by burning gypsum [42]. This produced a mortar that was probably irregular in strength and troublesome to use successfully. Lucas [43] points out that the reason why gypsum was used instead of lime, when limestone was more abundant and accessible, could be due to the scarcity of fuel; lime requires a much higher temperature for calcination. Davey reports that to produce one ton of burnt lime requires the equivalent of the amount of wood in an oak trunk 18 inches in diameter and 30 ft long, or in two fir trunks of the same size [44].

Lime mortar was used at an early date in both Crete and mainland Greece, and of course later by the Romans. Lime does not occur naturally in a free state and is formed by burning limestone (calcium carbonate ($CaCO_3$)) at about 900 ^{o}C (1652 ^{o}F) to produce quicklime. For building purposes the lime is then slaked with water to produce hydrated lime; sand is added as required to produce a suitable mortar. There are basically two kinds of lime, non-hydraulic and hydraulic. Limestone rocks are found in varying degrees of purity. Many, for example, marble, some beds of carboniferous formation and white chalk, yield nearly pure lime after calcination. Such lime, slaked and used in mortar, hardens only by drying and reabsorption of carbon dioxide from the atmosphere. It thereby reverts very slowly to calcium carbonate. This type of mortar has very little strength and, because of its solubility in water, is unsuited for work either submerged in water or exposed to its influence; this is non-hydraulic lime. Hydraulic limes come from Lias limestone or chalk marl, limestone rocks containing clay impurities. These have the property of solidifying or hardening when immersed in water. During calcination, the silica combined with alumina present in the clay, separates in the soluble form. In this state, in the presence of moisture, the silica combines with the lime, forming silicates which are insoluble in water and harden both in air and water [45]. The quality depends on the relative proportions of calcium carbonate, silica and alumina present in the raw materials, the care in the preparation and mixing of the raw materials and the temperature at which they are calcined.

Vitruvius [45a] describes lime and its properties when mixed with sand and water. Obviously his account refers to the situation in Rome in the 1st century BC, but the basic methods would have been the same Empire-wide.

The Greeks were capable of producing some very hard lime mortars. This must have been partly due to the quality of the limestone used to make the quicklime. However, they were aware that certain volcanic deposits, if finely ground and mixed with lime and sand, produced a mortar which was not only of superior strength but was also capable of resisting water action, both fresh and salt [46]. The volcanic deposits particularly favoured were the volcanic tuffs from Thera (modern Santorini). These were usually used for such things as the linings of cisterns, as in the examples in the _temenos_ of the ruler cult at Pergamum dated to about 200 - 150 BC. These mortars were characteristically strong and their use continued in the Roman period with very similar strength and consistency.

The first knowledge of lime mortar presumably reached Rome from Greek Southern Italy [47], and it was certainly established in Roman use by the first half of the 3rd century BC. The town walls at Cosa, dated to 273 BC, were built in their lower parts of massive polygonal masonry, and in their upper parts of rubble-work of irregular limestone nodules laid in a generous mixture of lime mortar.

As has been seen, ordinary lime mortar depends for its strength on the chemical processess induced by successively dehydrating limestone through burning, mixing the quicklime with sand, and then rehydrating the mixture of quicklime and sand to create what is, in effect, an artificial limestone. The builders of Republican Latium and Campania discovered that by adding a volcanic dust, _pozzolana_, they could produce a mortar of exceptional strength, and effectively convert a non-hydraulic mortar to a hydraulic mortar.

Vitruvius and his contemporaries did not quite understand the processes that were at work, calling the pozzolona a sand, for example [48]. This volcanic deposit has a very high silica content, and when added to mortar, gives the mixture various qualities:-

1) the ability to set under water;

2) the need for less lime proportionally than ordinary sands making the resulting chemical fusion more complete;

3) the capability of bearing great weight and the possession of a high degree of tensile strength, not normal in mortars.

It was this kind of mortar that was used for Roman concrete, opus caementicium.

The addition of crushed brick and tile produced a mortar with very similar characteristics; ancient builders knew that the addition of pounded and sifted burnt brick to the sand, in a proportion of 1:3, strengthened the mixture because it absorbed some of the surplus water which might otherwise have weakened the mortar [49]. In most parts of the Roman East this was the only available hydraulic mortar. It is found at a number of sites, for example, at Ephesus and at sites in Cilicia [50]. However, it was never exploited to the extent of using it to produce a concrete.

MORTARED RUBBLE

Rubble walling is a common feature of ancient architecture, especially in the Hellenistic and Roman of the Eastern Mediterranean. Bound with mortar it became a standard building material, for both walls and vaults, in Roman Asia Minor and the Balkans. Superficially very similar to Roman concrete, it is, on closer examination, quite different and indeed can be viewed as an alternative to Roman concrete in the general absence of suitable materials. However, there were certain limitations to its use because of the amount of variation in strength that was achieved due to different kinds of stone available for use as aggregate, different amounts of mortar used and the quality of the mortar itself.[51] It was used extensively for wall construction in Asia Minor, and as a vaulting material it became much favoured. However, spans were limited to 8 to 10 m[52]; mortared rubble was effective as a vaulting medium for short spans but was increasingly unreliable for larger spans.

Mortared rubble was first used in the early 1st century AD, one of the earliest instances being in the aqueduct of C. Sextilius Pollio at Ephesus (AD 4 - 14)[53]. Despite its limitations it became one of the standard building materials in Asia Minor and the Balkans. Further East, mortared rubble does not seem to have been particularly favoured for building. There were already well-established stone traditions and mortared rubble probably did not present any vast improvement or advantage.

CONCRETE

The opus caementicium of Rome and Italy did not occur in the Eastern Roman Provinces. It has already been seen that the knowledge of the use of lime mortar and the benefits derived from adding some kind of pozzolanic materials spread from Greece to Rome. This knowledge brought about radical changes in construction methods in the Capital, the development of a new material, concrete, being the most important of all. This new material meant that more slender walls could be built and the use of arches and vaults exploited in a new and more flexible way. Concrete was greatly suited to these uses, being generally weaker in tension but strong in compression. Concrete was always faced in some way; the earliest type of facing was usually using stone similar to that forming the aggregate in the concrete. The standard facing material for Imperial Rome was burnt brick. In terms of construction, it was the quality of the core itself which represented a more significant advance. Normally the aggregate was laid in horizontal courses with a lavish admixture of mortar. The fusion of the mortar into a monolithic mass gave the concrete its strength. However, there was a problem in the lapse of time necessary between one stage of work and the next for the erection of scaffolding and shuttering. The situation was not satisfactorily resolved until the general adoption of brick as a facing material. Courses of larger tiles could be inserted to cap each successive stage; these bonding courses are visible in the imperial monuments of Rome and Ostia.

In the East, the use of concrete was rare. A unique Hellenistic use was at Corinth. The 2nd century BC fountain of the Upper Pirene was covered with a concrete barrel vault; the thickness of the vault was 0.21 m and it covered a chamber 2.30 m by 4.78 m. The concrete itself was a mixture of sea sand and pebbles in a mortar with a very high proportion of lime [54].

In the Roman period in the East, there are few areas which definitely employed a material that was similar in quality and function to the Roman concrete. This usually depended on a local source of pozzolana equivalent. In Asia Minor, Cilicia affords several examples, the so-called Reticulate Baths and the harbour mole at Elaeusa-Sebaste and the bath-buildings at Korykos [55]. Further East the main area is the Hauran, where the volcanic deposits were used to produce a brown/grey concrete which was much used for vaulting, for example, at Bostra and Philippopolis. However, no analyses of these materials have been carried out. In contrast, at Caesarea and Tiberias various mortared structures have been subjected to mechanical and microscopic examination. The materials were exposed to flowing spring water (Roman aqueduct, Caesarea), fresh lake water (Roman quay, Lake Tiberias) and mineral hot water (Hot spring baths, Tiberias). All were found to be built of concrete which was hydraulic and of good durability under aggressive conditions. All the materials used were local materials. The obviously high strength was put down to the use of suitable materials, correct mixture proportioning and good mixing and compacting. The lime used seems to have been ordinary lime but does seem to have had a very favourable chemical effect on certain aggregates, particularly basalt. Volcanic tuff was only found in the mortar of one building at Caesarea [56]. Thus it is obvious that the builders were very aware of what they were doing. However, it is worth noting that all instances of the use of a durable concrete occur in cities or areas which have been subjected to direct or relatively strong influence from Rome. Concrete features largely in the Herodian architecture of Palestine - the theatre at Caesarea and the Winter Palace at Jericho [57]. The Hauran became a focus for Roman administration in the East after Trajan's annexation of Arabia, and Cilicia was important under Augustus in a programme of colonisation.

The use of concrete in the East, therefore, very much depended on the right materials being available and the right impetus to adopt the material as a construction medium. In the absence of one or other of these, other alternative materials were sought. An exception to this would appear to be the semi-dome of volcanic _scoriae_ of the _nymphaeum_ at Jerash. The _scoriae_, lumps of light volcanic stone, were presumably brought from further north. Volcanic _scoriae_, because of their light nature, formed the basis of the Hauranite concrete for vaulting.

FIRED BRICK

Fired or burnt brick is a material that did not really come into its own until the Roman period, and it was in the Eastern part of the Empire where the future of this phenomenon lay.

The best materials for brickmaking are clays which contain a natural admixture of sand or silt. The presence of sand in particular reduces the shrinkage that occurs when plastic clays - the products of the natural decay and disintegration of igneous rock and shale - are burnt. If sand is not present then a little sand is nearly always added to improve the clay for brickmaking. However, if there is too much sand, the whole mixture becomes friable as the clay shrinks from the grains [58].

The basic procedure for making bricks was to sift the sand and clay for pebbles etc. Then water was added, a process called puddling, and then the mixture was transferred to wooden frames for shaping and preliminary drying. The bricks were then fired. This process was used right through antiquity, the quality of the bricks depending on the clay used and on the methods of firing.

When bricks are burned there is a chemical change resulting from the expulsion of the water chemically bound in the clay; this causes shrinkage in the volume. Physical changes also occur. One of these is the melting of individual constituents of the mass without complete softening. This causes the eventual contraction of the mass and hence provides greater strength [59]. The fireproof quality of the brick depends on the amount of alumina and silica present which are not fusible. The majority of clays for brickmaking burn to a red colour when fired at about 1,000 °C in an oxidising atmosphere. They then turn a darker red or purple, and then brown or grey at about 1,200 °C. Underfired bricks are characterised by a pale pink colour and poor durability. In a reducing atmosphere, in general, the bricks fire to a purple/brown or bluish colour [60]. The presence of iron also has an effect on the colour of the brick. Even the smallest fraction of 1% of iron oxide in the mixture is sufficient to produce a buff colour [61]. Generally speaking, a high iron content in the clay produces ferric oxide in an oxidising atmosphere and the brick fires to a bright salmon pink at 900 °C and to a reddish brown at 1,100 °C. Ferrous oxide is produced in a reducing atmosphere and a bluish coloured brick is produced. If lime and magnesium are present in addition to iron, these combine at high termperatures to produce yellow bricks. These contain a large amount of calcium carbonate and are less expensive to burn because they vitrify more quickly. However, they do not stand up to weathering as well as bricks of red-burning clay. These are low in calcium carbonate and stand up well to exposure to the elements, hence their use for roof tiles [62].

The individual compressive strengths of the bricks are very dependent on the quality of the clay used and the firing process, and they are never equal to those of better stones. The process of manufacture makes it impossible to achieve a uniform surface, shape and size to permit their use without relatively wide mortar joints. This makes it impracticable to attain a compressive strength of the brickwork as a whole more than about one-third of that of the individual bricks. Thus the compressive strength may be a greater limitation on design than stone masonry. The tensile strength, however, is generally negligible, making it easier to construct curved forms, such as arches and vaults; the curvature is taken up by a slight tapering in the mortar joints. For such forms the compressive strength is not critical and the lower density, in comparison with stone, is an advantage [63].

Fired brick has been used for building since the 3rd millenium BC, for instance in the Sumerian cities of Ur, Lagash and Eridu [64]. However, despite its better durability, fired brick never overtook mudbrick as a major construction material. One reason was that a good supply of fuel - rushwood, reeds etc - was necessary to fire in large quantities. Thus, in Egypt, where timber was scarce, bricks until the Roman period were generally sun-dried [65]. From the 6th century BC fired brick is found in use at Babylon. It is not until the mid 4th century BC that burnt brick was used in Greece. An early, and rare, instance was in a house at Olynthos [66]. In 4th century BC Thrace fired brick was definitely known and in use, especially in the painted tombs of the area [67]. However, in Asia Minor, Greece and the East, it is not until the Roman period that burnt bricks become more common. In Rome itself burnt brick does not become common until Julius Caesar.

In the imperial period fired brick becomes the standard facing material in Rome for concrete, the first major project being the Tiberian castra praetoria [67a], and it was also used for bonding courses within the concrete. For the construction of arches, bricks were still just a veneer to the concrete core. It was never used as a building material in its own right in the West, but in the East, and especially in Asia Minor and the Balkans, it was.

The development of this tradition in the Eastern Mediterranean is interesting and is, of course, particularly significant for the history of later Roman and Early Byzantine architectural traditions. Fired brick made its first appearance in Greece in the 4th century BC and in Asia Minor in the early 1st century AD (see Chapter V); in the Balkans there seems to have been a small, but well-established tradition of brick construction since the 4th century BC. From what and where these early uses developed from is difficult to ascertain, but presumably it was in Mesopotamia [68].

That the introduction of fired brick into Asia Minor was a western one is very probable [69], but exactly how this introduction took place is far from clear. The most likely mode of assimilation was through the administrative network present in each province and major city. Fired brick was used in most cases for buildings of typically Roman plan and function - bath-buildings, basilicae, some temples - and those cities where there was particular use of fired brick were, generally speaking, important Roman centres.

There are a number of practical considerations which also may have influenced the widespread adoption of the material. For one thing construction in brick would almost certainly have been faster than in stone or mortared rubble, which both have drawbacks during construction [70]. Despite the fact that brick was probably more expensive than mortared rubble, it was both stronger and more durable in most cases; and it would have been cheaper than stone [71]. The adoption of brick, therefore, in Greece and the East was a definite Roman influence, but the adaption and subsequent development was very much an Eastern Mediterranean one.

From the start it was used as a building material in its own right, for walling and vaulting. In the case of the latter, brick was used alongside stone and mortared rubble but it did not take over from them. However, it was also used in the very distinctive form of 'pitched-brick' vaulting for which all precedents are in the mudbrick architecture of the Near East. Certainly there is much evidence to support the view that the architectural traditions of the East played a significant role in shaping the use and development of brick vaulting in Asia Minor. The best examples of this technique in mudbrick, unique because they are the only surviving instances within the Roman Empire, are at Karanis in the Egyptian Faiyum. The instance of pitched-brick, however, in fired brick at Dura-Europos on the Eastern frontier is a particularly graphic illustration of the western material and the eastern technique used together, as well as a good indication of the origins of the technique (see Chapter VII).

Apart from the use at Dura-Europos fired brick is not common in Syria and Arabia as a construction medium in the Roman period. It is found regularly, however, in those parts of bath-buildings particularly exposed to heat and fire. This can be seen at Philippopolis, in the Baths of Diocletian at Palmyra and, of course, in the Roman baths at Dura-Europos [72]. Fired brick is also found at Apamea and at Antioch-on-the-Orontes [73].

A phenomenon which emphasises the Roman nature of the material is emphasised by the fact that the buildings in which it was used were either of typically Roman type or were buildings directly funded or sponsored by the Emperor or Roman officials for instance, the Temple of Asclepius Soter at Pergamum, the basilica at Smyrna, the Gymnasium complex at Sardis and possibly the Serapaeum (Kızıl Avlu) at Pergamum.

The use of brick is also closely related to the architectural 'Marmorstil' and the development of city architecture in general in Asia Minor. With the introduction of new types of structures and of new techniques, in particular vaulting, it was felt necessary, in Asia Minor at least, to develop alternative materials to stone which did not lend itself very well to wide-span vaulting. Ward-Perkins says that the limiting factor for the use of both stone and mortared rubble is the fact that they are not versatile for vaulting of a Roman kind, and thus the use of brick developed [74]. This rather overstates the case perhaps, and it should be noted that brick was not the answer to all architectural problems and that it was used alongside stone and rubble and did not replace them.

There is no doubt that other instances of the use of brick must have existed but they no longer survive because of the ease with which brick can be looted and re-used. The use of brick could represent a certain amount of emulation of Roman Italian practice, if only skin-deep. Perhaps the reason for its more limited use further East in Syria is that Roman influence was not as strong and building was not on such a large scale; vaulting in particular could be carried out in stone as long as spans were not too great. Moreover there were materials available with which to manufacture a good strong concrete and these were exploited to the full by the Romans.

What can be said with certainty is that the use of fired brick in the Eastern Mediterranean was ultimately taken up into early Byzantine practice. As well as vaulting and general construction, bands of brick were also used in conjunction with bands of mortared rubble. This type of construction can be seen particularly clearly in the walls of Nicaea and was repeated in the Theodosian walls of Constantinople and of Antioch-on-the-Orontes (see Appendix II).

No kiln-sites have been found in the Roman East and the bricks were not stamped as they were in Italy. Presumably each city had local kilns using the local clays. The siting of modern brick kilns in Turkey may give an indication of where ancient ones were sited, for instance along the northern shore of Lake Iznik and along the main Izmir-Selçuk highway. It can be definitely stated that there was no organised brick industry as existed in Roman Italy, until the Byznatine period.

METAL

In ancient architecture metal was used for reinforcement or for clamping. In the Greek and Roman period iron was most usually used, but bronze was used for the trusses of the Pantheon portico [75], and copper was not uncommon [76].

Iron, of course, does not survive well but there are good reasons to believe that the Greeks made frequent use of iron bars inserted in masonry as reinforcement. Stone lintels and architraves were the vulnerable parts of a Greek structure and it was here that iron bars were sometimes inserted [77]. Perhaps the best example is the 5th century BC Temple of Olympian Zeus at Acragas. On the lower surface of the outer architrave blocks is a groove, 10 cm wide and 21 cm high. These cuttings did not continue for the whole length of the stone and were presumably to accommodate iron reinforcing bars [78].

Other examples of this type of reinforcement are in Athens, in the Erechtheum and in the Propylaea. In the West porch of the central part of the Propylaea two rows of Ionic columns support the marble ceiling. The arrangement of the ceiling beams was such that one comes over each column and over mid-span of each Ionic architrave. Each beam plus its share of ceiling weighed over 10 tons [79] and Mnesicles obviously felt it necessary to reinforce and strengthen the architraves with iron bars set into their top face. These bars did not run the full length of the architraves but stopped short of each end so that the load would be transferred to points just in from the supporting columns. The cutting for the iron bar was 0.25 m deeper over most of its length than at the two ends where the bar rested. This space allowed the bar to deflect slightly as it took up its load and not to rest on the marble architrave it was supposed to relieve. The iron bar was clearly seen as a simple beam, like the marble architrave, but of superior material. What is interesting is that there has been no attempt to exploit the high tensile strength of iron. To do this the bar should have been set with its end firmly anchored and in the under side of the architrave where the greatest tension has to be resisted.

Dinsmoor [80] says that "the Greeks were timid with regard to stone construction and erred on the side of safety". Certainly it seems so when it is considered that the maximum stress occurring in the outermost particles at the bottom of the architrave in question above would only be 103 lb per square inch, well within the amount of stress the marble beam could have coped with. With the insertion of the beam the stress was reduced to 57 lb per square inch in the marble. The stress in the iron beam, however, was 17,500 lb per square inch; in modern practice the maximum recommended is 12,000 per square inch. "In [illegible] therefore, it would appear that Mnesicles was far from timid ...." [81].

Such uses of iron reinforcement do not appear to have been favoured by the Romans, except perhaps in the Baths of Caracalla [82] and they certainly do not appear in the East until the 6th century with SS Sergius and Bacchus, where tie-rods were used in the upper gallery, and St. Sophia, where metal beams and tie-rods were used [83].

Metal was also used for clamps and dowels to fasten blocks of stone together. These are very common in Greek architecture and various forms existed - the dove-tailed clamp (found in wood in Egypt), the double-T clamp and latest of all the simple bar clamp with both ends bent down to form the Hellenistic and Roman hook clamp [84]. These were usually iron and were set in lead as protection against corrosion. However, metal and stone like this is a bad combination. Metal clamps probably served their purpose adequately well when the tensile stresses were small but otherwise they were far from satisfactory. The tensile strength of the clamps was well below that of the blocks that they joined and the lead used to anchor them in the blocks was unequal even to that strength [85].

In the East the stone vaults beneath the _cella_ of the Temple of Hadrian at Cyzicus incorporated metal clamps [86] (see p.236), and they were presumably used at Palmyra in the Temple of Bel. However, most stone construction in the Roman period appears to have been laid dry without metal or other methods of cementing. Obviously it is difficult, though, to prove one way or the other that metal clamps were used unless the building is in ruins, is dismantled, or is standing but has had its metal robbed by holes being cut into the joints.

Metal brackets, nails and fixtures, however, are very common for the attachment of marble veneer to walls. Very often the only evidence for these is the holes in which they were inserted, but occasionally they are found in excavation. At Petra, in the theatre, a total of 17 copper fixtures, single and double-pronged, were recovered near the _scaenae frons_, as well as nails and iron brackets. These can be paralleled in Rome in the Domus Aurea, the Pantheon and the Hadrianic Temple of Venus and Rome [87].

CHAPTER IV

DECORATIVE BUILDING STONES

THE STUDY OF ROMAN MARBLE

In recent years there has been a marked increase in the study of marble and the marble trade in the Roman period, and there has been a refreshingly different approach to this study. No longer are marble objects, whether sarcophagi, sculptures or architectural elements, regarded by all scholars as mere works of art in many spheres, but also as objects of commerce which can reveal an enormous amount about the use of marble in the Roman period [1]. The mere fact that these objects are 'of marble' is no longer of importance; indeed this kind of statement is virtually meaningless. Now the study involves marble quarries, marble analyses, identifications and distributions to gain a picture of the movement of marbles and granites within the Roman Empire. Ward-Perkins encapsulates this: "The other principal aspect of the marble trade to have attracted attention has been its impact upon classical, and particularly upon Roman architecture and sculpture. Here it has to be admitted that we have come up against a good deal of resistance from the forces of conservative art-historical scholarship. The notion that a sarcophagus, for example, can usefully be studied as an object of commerce, or indeed that its evaluation as a work of art may be affected by the type of marble from which it was made, these are notions that are positively repugnant to many of the traditionalists, who prefer to deal with matters of iconography and style"[2]. Despite this move to a more fundamental approach to the subject there are still a number of obstacles.

A basic problem has been the identification of the ancient quarries and the matching back to their respective quarries of artifacts found around the Empire. Nevertheless, the work of scholars such as N. Asgari, M. H. Ballance, P. Pensabene, Th. Kraus and J. Röder, and, perhaps most of all, that of J. B. Ward-Perkins, has made such studies easier.

Hand in hand with this goes the problem of the modern nomenclature of marbles. Some marbles go by the name given to them by Renaissance sculptors, for example, <u>africano</u>, <u>pavonazzetto</u>, and <u>giallo antico</u>. Others go by the name derived from their quarry site, as do most of the white marbles - Proconnesian, Pentelic, Thasian - and the granites. In the ancient sources many of these are given other names - <u>marmor synnadicum</u>, <u>marmor numidicum</u> and so on. When a description is given as well in the ancient literature, it is often very easy to match up names, but sometimes the sources are not as clear as they could be. The problem of <u>africano</u> and <u>marmor Luculleum</u> is a case in point (see below).

There can be no doubt that the impact of marble on Roman sculpture and architecture was very great. Sculpture and marble have been the subject of various individual studies by G. Ferrari, J. B. Ward-Perkins and N. Asgari in particular. However, the study of the architectural uses of marble and granite has been limited to Rome and Ostia, and Pompeii and Herculaneum; Lepcis Magna is the only provincial centre to be studied in detail in this respect. The trade in architectural marble within the Roman Empire, and especially in the East, where the majority of the decorative stones originated, has been less well-treated.

A number of aspects are important. Different marbles and granites invariably had different uses, whether primarily for columns, veneer or capitals. The reasons for this have to be sought in their physical properties as well as in their colour or general markings. How different stones are used together is particularly important for the trade and movement of marble. The absence or presence of a particular stone can be full of implications in this context, and it is important to look at the distributions of marbles and granites around the Roman Empire. However, the 'distribution' maps in Appendix I can only show certain factors. Those maps with no chronological division show the presence of a marble at any time during the Roman period up to the 6th century. Some later re-use is indicated (for example, at Damascus), but re-use within the Roman period is an important and influential element in the whole question of marble distributions. Furthermore, these maps do not show any trends which may have occurred at a particular site at one time, for example, the preference for a certain marble in one building programme. Thus, maps with some chronological division are necessary but then those incidences of use which cannot be dated, such as chance finds, have to be omitted. Re-use again probably distorts the distributions, especially in the context of the removal from one site to another of marbles for re-use. The best illustration of this is the possible removal by Justinian of eight porphyry columns from Aurelian's Temple of the Sun in Rome, to Constantinople for re-use in his Church of St. Sophia. This is a case of which we are aware, but there must be many of which we are totally ignorant. This does not invalidate the evidence of the distribution maps nor does it make the whole exercise pointless. The evidence from the quarries has to be brought in - when they stopped being worked; epigraphic evidence which might actually record the re-use of materials; and the evidence of the objects themselves, differences in size, style, length, must be considered (see below). The maps, though called 'distribution' maps, obviously do not show full distributions and do not claim to do so. They represent all instances attested and identified in excavation reports, research articles and by personal observations. However, one of the fundamental reasons for carrying out an investigation into the instances of marble in the Empire is to rectify the fact that marble and granite, up until recently at least, have rarely been identified beyond an often vague or misleading description.

ANCIENT SOURCES

Ancient writers and their works are sometimes condemned out of hand for their unreliability with little thought to the uses that they can and do have. They are of particular value in the study of the decorative building stones in the Roman period. They are the only contemporary comment on the employment of marbles and granites, so that not only is the information on the social views set down but also general information about the location of quarries and how the marbles were actually referred to. This being said, there are drawbacks in the employment of the ancient sources and without care they can be misused.

One of their most important uses is the identification of quarry-site and corresponding marble, with sometimes not only a description of the stone but also the ancient name applied to it. Strabo [3] locates the quarries at Docimium but says that the marble is called Synnadic after Synnada the administrative centre and collection point for the marble. Others refer to it as Phrygian marble [4]. Its purplish markings are mentioned by Sidonius Apollinaris [5]. Strabo also gives the locations of the quarries of the Carystian marble [6] and it is described by Dio Chrysostom as being variegated [7]. The quarries of Lacedaemonian marble are located in detail by Pausanias [8], and he describes the fact that the stone apparently could not be quarried as continual pieces of rock, but only as pebbles. The Romans called it marmor Lacedaemonium [9]. One Greek term for Lacedaemonian was Λακαινα λιθος[10], but Pliny [11] implies that the smaller pieces could be called Λακαιναι σμαραγδη when he mentions smaragdi that are dug on Mount Taygetus.

Theophrastus also mentions Laconian smaragdi [12].

Thus some marbles go by various names, even in Antiquity. Pliny [13] says that purple porphyry is also known as leptopsephos and Sidonius Apollinaris [14] calls it Aethiops, the Ethiopian stone. Egyptian red granite was also sometimes referred to as the Ethiopian stone [15], as well as Thebaicus lapis and Syenite [16]. Pliny also says that in earlier times it was known as pyrrhopoecilos, that is, mottled red.

Quarrying methods and the general use of different types of marble feature quite regularly in the ancient sources, particularly in Pliny's Natural History. Parian marble was apparently called lychnites because it was extracted in tunnels [17]. He also describes how marble is cut with iron and sand, a primitive saw of which traces have been found.[18]. He says it is really the sand that is important and that the Ethiopian variety is by far the best because it cuts without leaving any roughness. For polishing the marble, Indian sand is recommended as well as the sand from the Thebaid and pumice.

Pliny reports that Chian marble was the first of the 'favourite marbles' to appear in Rome [19]; this is presumably portasanta. Carystian and Luna marble columns also appear early in the 1st century BC [20]. Numidian marble, according to Pliny [21], first appeared in Rome in 78 BC in the house of Marcus Lepidus. He says that this is the first indication he can find of the importation of Numidian marble, which apparently is not imported as columns but as rough blocks. Hymettian marble also appears to have been used early [22]. Evidence from the quarries supports their early use.

Marbles were slow in gaining entrance into Roman architecture and before Augustus' time the Romans rarely used costly materials in public buildings. In 146 BC Q. Caeclius Metullus, the victor over the Macedonians, built the first temple of marble in Rome, that of Jupiter Stator [23]. This was pointed out as the first instance of 'magnificence or luxury in marble' among Roman public buildings [24].

By the 1st century BC marble was becoming common in the houses and villas of the rich; morals, apparently, had lost the battle against hellenistic luxury [25]. Pliny condemns this use saying that many men live quite happily without them and that the rich do such things for no other reason than 'ut inter maculas lapidum iaceant'. His comment that these marbles could not be seen when it was dark, which constituted half a man's life, clearly demonstrates the contempt that he feels for the use [26].

Later on Pliny brings in the question of morality, which is a common theme with other writers. He thinks that the whole affair is becoming a threat to the security of the morals of Roman society [27], especially as marble is used in private houses but terracotta is still used for temple decoration. Seneca [28] in a similar way deplores the use of Thasos marble for swimming pools in private houses when it is a very rare sight in temples. In another passage he says that every stone is quarried 'ad delicias dementis luxuriae' [29]. The marble used for columns in temples in the Greek period according to Pliny, was not as an embellishment; such lowly thoughts had not occurred to the Greeks. Marble was used because there was no other way of erecting stronger columns. Pliny, indeed, seems to have nothing against the use of white marble in the Greek period; it is the use of marble with markings that he finds so deplorable. Even Menander, he says, rarely alludes to them [30].

From these writers it is obvious that the use of marble in the late 1st century BC is one of luxury. Martial [31] describes Phrygian marble as precious and mentions Carystian, Numidian and marble from the Eurotas (presumably Lacedaemonian). Juvenal says that the millionaire protects his columns of Phrygian marble from fire by having ready day and night special squads of servants with fire buckets. He also pokes fun at the man who is rich enough to have Lacedaemonian on his floor but is so deficient in manners that he spits wine onto it [32].

What becomes evident is that the ancient writers do not really approve of the use of decorative stones. Pliny sums up the disdain and horror which is felt at these first uses of marble, 'Sed quisquis primus invenit secare luxuriamque dividere, inportuni ingenii fuit' [33], and then later on he states that marble grows in the quarries and therefore there would be marble a-plenty to satisfy the demands of luxury [34].

Pliny's writings on marble are a veritable sermon and deserve attention. A house which was regarded as luxurious in 78 BC, after 35 years no longer ranked among the first one hundred in Rome. Pliny implies [35] that Late Republican luxury, in architecture and otherwise, surpassed that of the imperial, or at least introduced it [36].

Augustus' boast that he found a city of brick and left it a city of marble [37] is borne out by the abundance of marble found in Rome. From the mid 1st century AD the use of marble was something expected in both public and rich private buildings. This can be seen in the attitudes expressed by ancient writers. The use of marble was largely condemned by those writing in the 1st century BC and the 1st century AD, for instance, Pliny, Martial, Juvenal, but gradually these attitudes changed so that marble, though still a symbol of luxury, is also an object of beauty to be admired for the colour. Even the Emperor sometimes disapproved as did Claudius when one of the procurators brought back some purple porphyry statues from Egypt [38].

While appreciating the usefulness of the ancient sources, one must also be aware of their limitations and pitfalls. One of the fundamental factors is that all the ancient writers were members of the upper classes and thus the views expressed are those of the aristocracy. Presumably these are a fair reflection, but only of Rome; the ancient sources do not refer to the provinces, unless to describe a quarry or marble.

Thus the ancient literature is only useful on an Empire-wide basis in this sense, to identify marble types and their quarries. A more general limitation is that in some cases there is no way of ascertaining the accuracy of what the writers say. We do know sometimes when they get things wrong. Pliny, for instance, states that the columns of the Basilica Aemilia are of Phrygian marble (pavonazzetto) [39], whereas they are of africano, and there is no trace of pavonazzetto columns. Of course, he may be referring to an earlier phase of which we have no knowledge, but this does seem unlikely. Pliny also is central to the controversy surrounding africano, marmor Luculleum and Chios [40]. Here because of textual difficulties and an unclear ancient description, africano was identified with marmor Luculleum until fifteen years ago and the work of Michael Ballance (see pages 98 - 99).

MARBLES, PORPHYRIES AND GRANITES: DEFINITIONS AND PROPERTIES

MARBLE For geologists marbles are calcarous rocks which, under the action of temperature and pressure, (metamorphism) recrystallise. Marbles derived from pure limestones consist simply of recrystallised calcite, but impurities in the form of dolomite (magnesium carbonate), silica, iron compounds, clay minerals etc., may give rise to other minerals which give certain marbles their characteristic appearance.

Stonemasons apply the term marble to almost any rock which shows the particular characteristics of hardness and the ability to take a high polish. As well as marbles, these are especially hard limestones which have not been metamorphosed.

PORPHYRY The name usually applied to intrusive igneous rocks which have recrystallised under conditions intermediate between plutonic and volcanic, and containing phenocrysts, relatively large crystals set in the finer-grained groundmass. Porphyries are hard.

GRANITE A coarse-grained igneous rock consisting essentially of quartz (20 to 40%) and feldspar with various other minerals depending on their exact formation. Granites characteristically contain a high proportion of silica, often more than 70%, and relatively high soda and potash. The rate of cooling of the molten material during the formation of granite has a large effect on the texture of the stone but it is always crystalline and very hard and very heavy.

In general marble, as well as granites or porphyries, is hard and reacts very well under compression (fig. 5), hence the use of some kinds, for instance, cipollino and giallo antico, for monolithic columns. As with other stones they are all weak in tension. Generally speaking, marble is a good thermal insulator but on direct exposure to intense heat most marbles are reduced to a friable condition. The profusion in Rome of lime-kilns, fed on marble from the Medieval period onwards is testimony to this fact. Granites and porphyries, on the other hand, have a very high conductivity of heat and crack when exposed to fire, but they do not become friable [41]. This helps to explain the better survival rate of ancient granite over marble. In recent years that marble which has survived the lime-kilns has had to contend with attack from acid and sulphur in the atmosphere. With more than a 90% calcium carbonate content, it is just eaten away.

GREEK AND ROMAN MARBLE AND GRANITE TO THE 2ND CENTURY AD

The extraction and use of marble for decorative purposes had a very long history before the Roman period. The dark red marble from Cape Taenarium, rosso antico, was used by the Minoans at Knossos [42] and the Mycenaeans also used it for carved decoration for the Treasury of Atreus at Mycenae [43]. No other evidence survives about the use of other marbles at this early date.

The Greeks had a huge variety of materials to hand. There were plentiful supplies of timber, rich geological deposits of different limestones, and there was an abundance of the necessary materials for the manufacture of tiles, mudbricks and terracotta decoration. It was not until the 7th century BC that in the marble-rich regions of the Greek world the geological deposits began to be tapped. This happened almost exclusively at first in the Cyclades and Asia Minor. The white marbles of Paros, Naxos, Tenos, Delos, Thasos, Ephesus and Sardis began to be used architecturally after their qualities had been tested in sculpture and general techniques had been perfected [44]. The architectural use of the marbles display considerable familiarity with the material. The first columns of marble were of Naxian marble, the votive column of the Naxians at Delphi and the one at Delos. At the beginning of the 6th century BC, small buildings in marble were constructed, the Naxian buildings on Delos and the temple on Paros. The first large building in marble, however, was in Asia Minor, the Temple of Artemis at Ephesus [45]. Quarries were opened specifically to furnish the building programme. It is not until the 5th century BC that the exploitation of marble occured in Mainland Greece, with the opening up of quarries at Mt. Pentelikon. However, with exceptions like the 5th century Athenian Acropolis buildings, in most other Greek building marble and limestone were used together, with the marble used for more decorative purposes. Herodotus reports that the 6th century Temple of Apollo at Delphi was the subject of political propoganda when an exiled Athenian family, the Alcmaeonids, set an important precedent in 513 BC by covering the whole of the façade with Paros marble. The walls were of tuff and the back columns were left of limestone [46]. The Temple of Artemis Knakneatis near Tegea was built entirely of marble, probably because of the proximity of the quarries of Doliana. It is obvious from the working techniques that the Greeks had great difficulty handling the material [47].

In the Peloponnese, marble was less abundant than limestone so its uses were limited to smaller decorative features. The late 4th century BC tholos at Epidaurus is essentially built of grey limestone with tuff columns, capitals and entablature, but the cella walls were of Pentelic and a black limestone from Argos; the interior Corinthian columns and the door were also of Pentelic, and the floor was of Pentelic with black limestone.[48].

This usage of dark stone in association with white marble is not unusual. The most noteworthy example is probably the Erechtheum on the Athenian Acropolis. The whole building was constructed of Pentelic marble with black Eleusian limestone for the frieze, and figures in white marble were attached to this with clamps [49]. The earliest known instance of the use of such contrasting materials is in the altar erected by the Chians for Apollo at Delphi in the late 6th century BC. This was a high pedestal faced with black limestone in pseudo-isodomic masonry crowned by a white marble cap [50].

Thus the idea of using different coloured stones together was a common one. However, coloured marbles were apparently not generally favoured until the Hellenistic period when there is a marked increase in the use of both white and coloured marble and the beginnings of the movement of marble overseas. Quarries were being opened up to supply whole cities with building stone, for houses as well as temples, for instance at Priene [51].

The use of coloured marble for decoration in Ptolemaic Egypt is attested in Lucan's description of Cleopatra's Palace [52]. Excavations in Alexandria apparently confirm his description of onyx and purple porphyry [53]. By the 2nd century BC, it is known that a number of quarries had been opened up, whether directly by the Romans or by the local population at the instigation of the Romans is unsure. Surely the Romans must have had a hand in these first exploitations. Numidian marble, giallo antico, was reaching Rome by this time [54], one of the first to be introduced. By the 1st century BC Hymettian, cipollino, pavonazzetto, portasanta and africano were reaching Rome [55], and in the late 1st century BC the Luna marble quarries were in production. In the 1st century AD Lacedaemonian, rosso antico, fior di pesco, breccia di settebasi and breccia corallina were all used in Rome in varying degrees. The Egyptian granite and porphyry quarries also went into production in the first half of the 1st century AD. According to the ancient sources marble was at first only used in private houses. There were exceptions, the Temple of Jupiter Stator built in 146 BC, which was the first temple of marble in Rome [56]. Nevertheless, by the late 1st century BC marble was in common use for public building, for example, the Temple of Apollo Palatinus (Luna marble, 28 BC), the so-called Temple of Vesta in the Forum Boarium (Pentelic, early 1st century BC), and Sulla brought marble columns from the unfinished Olympieion in Athens to the Capitoline Temple after the fire of 83 BC [57]. Under Augustus, marble, both coloured and white, was used not only for revetment and <u>opus sectile</u> but also for columns and whole buildings on a scale hitherto unknown.

This flood of marble from different parts of the Empire demanded co-ordination and organisation. The structure of the Greek quarry system was very simple and direct. For fine sculpture and for exceptional buildings the Greeks were prepared to ship marble considerable distances. Ordinary practice, however, especially for architecture, was to obtain supplies from the nearest possible source, or if there was no such marble source, to make do with some other material. Various building accounts survive, for example, the Parthenon and the Erectheum [58], and from these it is clear that it was common to order and pay for building stone quite literally block by block and as funds became available.

Construction in marble was an expensive business with the transport costs sometimes many times more than the quarrying costs. This was the case for the transportation of four blocks from the quarry to Delphi in the 4th century BC; the cost was ten times that of quarrying them [59]. The relative costs must have been very similar in some cases in the Roman period. Various building accounts survive for the Hellenistic Temple of Apollo at Didyma [60]. According to these, for one column the following prices apply;

extraction and working		13,151 dr
transport by sea	4,043	
transport by land	8,895	12,938
erection		2,426
final dressing and sculpture *in situ*		10,272
		38,787 dr

It can be inferred that marble was definitely a luxury.

Despite the increased interest in marble and the more varied supplies available in the Hellenistic period, there were few changes in this quarry system. Wealthy patrons did have the capital to order large quantities from distant quarries [61], and in the later Hellenistic period large monoliths were beginning to be quarried and shipped, for example, of *cipollino* and *giallo antico*. Nevertheless, there were no fundamental alterations to the system. The quarries were still in private hands, and long-distance transport was not common and could indeed be expensive.

The evidence for the import of coloured marbles into Rome before the mid 1st century AD shows that what had been, under the late Republic, a rare and exciting novelty, was becoming increasingly common under Augustus and his immediate successors. However, this must be put into perspective. Coloured marbles like this had not been seen before on such a scale, and they captured the imaginations of contemporary poets and moralists. Quite small quantities, cut into thin panels for paving and veneer, could make an impressive show.

Ward-Perkins states that the marble needed for a single cornice-block, measuring 5 ft by 4 ft by 3 ft, would serve to pave an area of about 80 square feet [62]. Even so it was expensive and remained so into the late 1st century AD. Thus the Forum Augustum, for which most of the marble of that period was destined, must not be viewed as the norm for Augustan monumental architecture. Columns of coloured marble were available for a few outstanding buildings apart from the Forum, for example, the Numidian columns of the portico beside the Temple of Apollo Palatinus [63]. The large mass of marble required, however, for the buildings of Augustan and Julio-Claudian Rome was white and was supplied by the quarries of Luna [64]. It was presumably this Augustus had in mind for his well-known boast [65]. It was not until marble began to be used extensively for bulky architectural elements that the quantities required became much greater. There appears to be little evidence of this before the Flavian period, but this itself may depend on other factors.

Suetonius reports that Tiberius annexed many of the major sources of supply in AD 17 [66] (fig. 6). Ward-Perkins believes that the annexation of Egypt with its abundance of fine stones had a direct influence on the decision [67]. Rome was now a world power and was a market capable of absorbing vast quantities of these decorated stones that it no longer made economic sense for quarries to produce only what was needed as it was needed. Thus an entirely new system of production and supply began to be evolved in the earlier part of the 1st century AD. This reorganisation involved six important factors as outlined by Ward-Perkins [68], each of which will be discussed in full later.

i) imperial ownership of the principal sources of supply;

ii) rationalisation of quarrying methods to increase quantity and efficiency of output;

iii) new customer-quarry relationship based on bulk-production and stock-piling at both the quarries and the marble-yards of the importing centres from which all normal orders could be met;

iv) standardisation and prefabrication;

v) availability at the quarries or the agencies of the quarries of specialised workmen skilled in the handling of the particular marble;

vi) establishment of overseas agencies to facilitate ordering and distribution.

Not all these innovations came into effect at once but some developed logically from the others (see p. 121).

The main market for these quarries was Rome with subsidiary markets on the Bay of Naples. Indeed, the study of the marbles found at Pompeii and Herculaneum has been very useful. All those found there must have been in use before AD 79 and their quarries were therefore being worked at this time. The very way in which they were employed at Pompeii and Herculaneum, _opus sectile_, beading, all requiring small pieces, reveal the novelty value that the material still had as compared with the large slabs and columns used only decades later in Rome and Ostia.

By the beginning of the 2nd century AD the marble-yards of the capital had built up enormous stocks of the more common marbles. Shipments to Rome did not cease, but there was a shift in emphasis from sheer bulk to quality. New markets were developed. "This was the golden age of the provincial municipalities, in which public munificence was one of the accepted responsibilities of the wealtny citizen" [69]. This large consumer market lowered prices yet more, and marble flooded the provincial markets as it had the Rome markets a century before.

DECORATIVE STONES IN USE IN THE EASTERN ROMAN PROVINCES

LUNA

Luna, modern Carrara

Generally pure white or with a bluish tinge. However, this can have many different variations.

The quarries, situated in the Apuan Alps around Mt. Altissimo, have been worked almost continuously from early Roman times. Today they are intensively quarried and it is certain that the Romans did not fully exploit the marble deposits. Julius Caesar may have first opened workings at the quarries but it was probably through Augustus that large-scale working occurred, and under Tiberius they probably became imperial property [70].

Until the end of the 1st century BC Greek marble met the demands for white marble in Rome. However, with the opening of the Luna quarries, Greek white marble was never used on a large scale architecturally in Rome or Italy. In the same way, Luna marble did not reach the East which had abundant supplies of good quality marble of its own. However, the marble was extensively used in Southern Gaul and Germany.

HYMETTIAN

Mt. Hymettus

Fine-grained marble of bluish-white colour and often marked with bands of various shades. When split off from the parent rock there is a bituminous odour [71].

The quarries are situated 8 km south-east of Athens on both sides of the mountain. They were extensively worked in Antiquity. Lepsius reports that in his day, the late 19th century, very little of the ancient quarries on the slopes of Mt. Hymettus facing the city actually survived, but a great many survived on the other side of the mountain [72]. The quarries on the city-facing slopes were swallowed up by modern ones [73]. In the 19th century, column shafts were noted lying in the quarries [74].

The quarries were worked by the Greeks from an early period [75], and the marble was extensively employed in the Roman period. It was used principally for architecture. The first use is recorded by Pliny when, in 91 BC, L. Licinius Crassus used six columns of Hymettian marble for the atrium of his house [76]. However, with the opening of the Luna quarries it ceased to be of great importance in Rome. It was presumably much employed in the Eastern Mediterranean, especially in Athens, though whether it had a very wide distribution is unknown [77].

PENTELIC (Appendix I, P; Map 1)

Mt. Pentelikon

A generally pure white, fine-grained, absolutely translucent marble, with streaks of green mica. The iron content makes the marble take on a rich golden colour on exposure for a long time to the atmosphere.

The quarries are situated 14 km north-east of Athens and were worked as early as the 5th century BC. The marble is difficult to quarry in fault-free blocks, unlike, for example, Proconnesian; there must thus, have been a considerable amount of waste.

The quarries supplied Athens with marble for the massive building programmes in the classical period. In the Hellenistic and Roman periods it was still in production but it seems to have been less economical to quarry [78]. The quarries still supplied Athens for architectural purposes and also Rome until the Luna marble quarries came into production, but examples of architectural use are not particularly numerous. Pausanias says that when Herodes Atticus built the stadium in Athens he used up most of the Pentelic quarry in the construction [79]. Ward-Perkins thinks this is a reason why the quarries may never have become imperial property [80]. The only quarry inscription on Pentelic marble recorded by Bruzza mentions the name of Herodes Atticus [81].

However, Pentelic marble was at the centre of a flourishing trade in sarcophagi and was still, in the Roman period, used for statuary.

THASIAN

Thasos

Two quite distinct types quarried in Antiquity. The marble from the north of the island has fine to fairly large crystals and is white or greyish white. The crystals are less numerous than in the marbles of the south part of the island. These are grouped around modern Aliki. They are fairly large-grained with clusters of finer-grained crystals in places. The colour can vary from white to light grey and sometimes there are bluish bands reminiscent of Proconnesian. A petrological analysis of the two different kinds of marble showed that those in the north of the island are dolomitic while those in the south are calcitic [82].

There are two deposits of marble on Thasos, the Kastri deposit and the Prophitis Ilias. It is the latter that was worked in Antiquity. It stretched from

Thasos town in the north to Aliki in the south and was extensively worked in the Greek and Roman periods. Many of the quarries are now submerged.

The marble from the north, slightly inferior in quality, was mainly for local use on the island and on the facing Macedonian coast, especially at Philippi. The marble from the Aliki region was very extensively used because of its glittering aspect caused by the large and irregularly-sized crystals. The marble, especially the banded variety, was used for columns; a number are left abandonned in the quarry. It was also used for veneers for pools and fountains and for general veneer and for sarcophagi. It was reaching Rome by the 1st century AD [83], but the exploitation of the quarries began in the Greek classical period [84].

The large crystals of Thasos marble means it is very difficult to handle and carve in detail [85]. It was not good for flooring because it wore unevenly. It appears on the Edict of Diocletian at 50 denarii per cubic foot, just a little more expensive than Proconnesian. Presumably the quarries flourished into the Early Byzantine period.

PROCONNESIAN (Appendix I, R; Maps 2 - 4)

Proconnesus

The most extensively extracted variety is white with parallel bands of dark blue and light grey. Also a light grey marble and a clear light blue marble.

All are fine quality, medium-grained, highly micaceous and not very translucent. There is also a very white translucent variety with fine grains. A characteristic of Proconnesian marble is a tar-like smell on fracturing [86].

Seven ancient quarries have been located around Saraylar on the north coast of the island of Marmara (ancient Proconnesus). The marble is very compact and had very few flaws; as a result it could be worked with a minimum of waste, unlike Pentelic, for example. This along with the fact that the quarries were right by the sea, made the Proconnesian quarries very famous and the marble low in price.

Vitruvius [87] reports that marble from Proconnesus was one of the stones used for Croesus' Artemision at Ephesus which points to early workings on the island. The quarries were already famous by the 4th century BC, as Proconnesian marble was exported to Halicarnassos for the architectural details of Mausolus' Palace there [88]. It was also used for the Temple of Hercules on the acropolis at Heracleia Pontica [89].

In ancient literature Proconnesus marble is referred to as Cyzican marble (<u>Cyzicenum marmor</u>) [90]. This was after the nearby city of Cyzicus in Mysia in whose administrative area the quarries lay. Not surprisingly Proconnesian marble is used extensively at Cyzicus in both the classical and Roman periods.

In the course of the 1st century AD the quarries on Proconnesus became imperial property. The success of the quarries was due, apart from the good quality of the marble itself, to their proximity to the sea. The stone could be transported by a series of ramps and sledges the short distance to the jetties built in the harbour for onward shipment. Recent excavations carried out by Dr. Nuşin Asgari have shown that much of the marble was worked on the island before shipment [91].

In general, Proconnesian was not a sculptor's marble. However, one of the main products of the quarries was sarcophagi. The distribution of these covers many parts of the Eastern and Central Mediterranean and also the Western part of the Black Sea (fig. 10). They were shipped out in roughed out form and were finished at their port of destination. The situation is the same for architectural pieces in Proconnesian marble. Blocks were exported which could be used for lintels, mouldings and perhaps also for capitals, though these were usually roughed out to a certain stage before export. The architectural use of Proconnesian par excellence was for columns. It was possible to quarry large fault-free pieces and the purple banding on white made it very attractive for this use.

Proconnesian marble did not have a great importance at Rome and in the West. Hadrian's Temple of Venus and Rome was the first major public building in the capital to have extensively used Proconnesian marble. The Hadrianeum built very soon after, was built entirely out of Proconnesian marble. These reflected the preference of the Emperor Hadrian for the marbles of

Greece; apart from the use of Proconnesian for the Temple of Venus and Rome, Pentelic marble was used for the porch of the Pantheon. From the early 2nd century Proconnesian is found more often in Rome but at no time did it ever rival Luna marble.

In the Eastern Mediterranean, because of its versatility, Proconnesian marble became the standard white marble and was used for all kinds of architectural elements, as well as a building stone in its own right. Indeed in Southern Asia Minor and the Levant, Proconnesus seems to have established a virtual monopoly in the export of white marble for building, just as it seems to have done in Alexandria for sarcophagi. It was frequently used in conjunction with coloured marbles and granites, the most ubiquitous combination being Proconnesian capitals and bases to Troad granite columns (see p. 107).

APHRODISIAS

Aphrodisias, Caria

Several varieties. Fairly large to large-grained white; medium to large-grained white with blue-grey markings; generally blue-grey with an overall dark aspect, medium-grained and sometimes marked with white lines. Other kinds can have red or greenish veins [92].

The quarries are situated 2 km from the city of Aphrodisias at modern Palamutcuk. Caria is one of the richest areas of white marble in Asia Minor. At the centre of Caria is the huge mountain range of Baba Dağ. On the opposite slope are two large complexes of quarries, both of which were worked in antiquity, the Laodicea quarries and those of Aphrodisias. In the Aphrodisias quarries there is much residual material but the quarries appear to have been very heavily worked to the point of exhaustion.

Aphrodisian marble was extracted from certainly the late Hellenistic period to Byzantine times [93]. It is not certain exactly when exploitation started but the quarries were in production by the 1st century BC when marble was needed for the Temple of Aphrodite. The quarries were an important reason for the prosperity of the city of Aphrodisias in imperial times, and they flourished in the Roman period due to the privileges granted to the city because of its sanctuary.

The marble was exported all over the Mediterranean, and especially to Rome, but it was rarely used architecturally outside the immediate locality of the city [94]. The use of Aphrodisian marble acquired a greater importance with the formation of a local school of sculptors. This school was active not only in the city and surrounding area but also in Italy and elsewhere [95]. Sarcophagi and statues formed the bulk of exports but the marble was also exported in small blocks and semi-completed goods [96], but there is always a problem of identification where no place of origin is given.

DOCIMIUM (Appendix I, F)

Docimium (modern Iscehisar, near Afyon), Phrygia

There are three main white marbles produced by the Docimium quarries as well as the coloured marbles (see p. 102).

Beyaz white, medium-grained crystals and very translucent. It is usually pure white.

Afyon Şeker white with medium-sized grains with golden-yellow/orange veins. This type is often characterised by a 'barley-sugar' look.

Sari Damarli generally white to yellowish with short very yellow veins [97].

These white types were quarried alongside the coloured marbles in the same quarries. (The quarries are described in detail in the pavonazzetto section, p. 102).

The Şeker type and the Sari Damarli types were generally local use and are very common in the sites around the quarries. However, they did also reach other parts of Asia Minor, in particular Pamphylia, for use in architecture (Plate 25). The very white Beyaz type was the only white marble from Docimium that reached foreign markets. It is best known as the material of the Asiatic sarcophagi. A number of studies have been carried out on the different types produced and their distributions (fig.7). The most important type is the Sidamara type of columnar sarcophagus. Their distribution is of great value as regards the general trade in marble products in Asia Minor [98]. It was also much used for architectural sculpture alongside the other two white Docimium marbles in Asia Minor.

EPHESIAN

Belevi region

A number of different varieties extracted in different regions. It is easier to deal with area and type together. The marble is generally white to grey.

The quarry of Ephesus is 12 km north-east of the city in a large area about 8 by 6 km, immediately to the east and south of Lake Belevi, and to the west of Tire, the ancient city of Thyrra. To the west and north of the area is the Küçük Menderes, the ancient Kaystros river; this passes in the vicinity of Lake Belevi and was probably the river by which the marble was transported to Ephesus and the sea. The places of extraction are rather numerous and quarrying methods and types of stone vary considerably.

South of Lake Belevi blocks were extracted in tunnels [99]. This can probably be dated to the end of the Hellenistic period. The marble was white with medium crystals and occasionally tending to grey.

The greater part of the quarry, however, was open [100], and different varieties of marble were extracted: i) white with medium and large crystals; ii) white tending to grey with medium and large crystals; iii) white with grey-brown veins and large crystals; iv) light-dark grey with darker lines and large crystals. Sometimes the marble has a tar-like smell on extraction, like Proconnesian.

There are also quarries 16 to 17 km to the north of Ephesus and Selçuk but there has been little study of these with most work having been carried out in the Belevi region.

The earliest area to be worked is the nearest to the lake and is presumably the quarry opened for the Artemision [101]. This continued to provide marble for the construction of the temple for the 120 years tradition says it took to build [102]. A study of the quarries of the Belevi region has revealed marks matching those left by the extraction of columns and blocks [103].

These quarries were worked in the imperial period and new workings had to be opened in the 2nd century [104]. Ephesus marble was only used locally for architecture. It was used in all public and private buildings in Ephesus, for example, the Library of Celsus, the Harbour Baths and the theatre. However, it is not always possible to distinguish it from Proconnesian which was also in use on the site.

As with Aphrodisias, the nearby presence of a source of good quality marble brought about the formation of specialist groups of craftsmen, and Ephesian marble was exported in the form of sarcophagi.

GREEK ISLAND MARBLE

Cyclades, Samos, Lesbos

CYCLADES

Naxos white with coarse granular crystals, often banded with grey or blue. The quarries were worked very early [105] and the marble was greatly used for both architecture and sculpture. The marble is not very pure with many accessory minerals present [106], and it is not very translucent. The quarries were worked in the Roman period especially for sculpture.

Paros Pure crystalline calcite marble with fine to very fine grains. It is translucent through a thickness of 35 mm. Pliny says that Parian marble was called 'lychnites' because it was tunnelled for by lamplight [107]. Most of the marble quarried on the island of Paros was obtained in the valley of present day Aghias Minas. The lychnites marble was mined in a bed only 3 m thick and dips quite sharply to the East [108].

The marble was well-used for statuary in the Greek and Roman periods as well as for some architectural decoration and was particularly popular for its durability, quality and reliability.

Other Parian marble was quarried on the west side of the same valley as well as elsewhere and is very like Naxian marble.

According to Bruzza, there were two kinds of marble from Paros, greco duro which was the underground kind, and grechetto duro, the open air variety [109].

Delos Very like Naxian marble in appearance and texture. It was quarried near Kabeirion and on the northern slopes of Theatre Hill [110].

Others Other islands in the Cyclades, for example Tenos, also had marble quarries working in the Roman period, but these were all for local use [111].

Lesbos A bluish marble, coarsely crystalline, often with conspicuous white veins [112]. It is the prevailing marble in the buildings at Mytilene but it is difficult to distinguish it elsewhere. It must have gone further afield as it appears on the Edict of Diocletian at 40 or 50 denarii. A black marble from Lesbos is mentioned by Philostratos [113].

GIALLO ANTICO: MARMOR NUMIDICUM (Appendix I, H; Maps 5 - 7)

Chemtou (Simitthus), Numidia

A very fine compact stone of high quality. Geologically it is not a true marble, but is one which takes a very high polish and has beautiful markings. Colour range is great, from ivory white to golden yellow. Generally it is veined with purple, brown, or a darker yellow. It can have a brecciated appearance.

The quarries were located at Simitthus in Numidia (modern western Tunisia). They were worked before the Roman period; an officina regia which occurs in several 2nd century AD inscriptions presumably refers to a quarry worked under the Numidian kingdom [114]. After the suppression of the kingdom in 46 BC, it is reasonable to assume that the quarries passed into public ownership. The marble reached Rome in the 2nd century BC, one of the earliest to do so, and operations continued in the Roman period on a large scale, despite transport problems. Although the sea was only about 20 miles to the north of the quarry the mountain ridges between formed a great obstacle to direct access. Instead, the marble had to be floated down the Medjerda river to Utica, a journey of 100 miles [115]. From Utica, the marble was then shipped overseas.

The first indication in the ancient sources of the importation of Numidian marble into Rome is in Pliny [116], when he reports that Marcus Lepidus had the door sills of his house made from it. He thinks it is rather sordid. There are freqent references to giallo antico in other contemporary writers, but the tone is still that of Pliny, and even towards the end of the 1st century AD Numidian marble was still a symbol of wealth and luxury. Giallo antico was imported in the form of blocks at first for veneer and paving and apart from the Forum of Augustus, there is no instance of its large-scale structural use before the latter part of the 1st century AD. The columns were quarried in a similar way to those at Carystos.

The trade in Numidian marble greatly increased at the beginning of the 2nd century AD when new markets were developing around the Empire. A number of inscriptions attest Hadrian's like for the stone [117] and he is recorded to have given 20 columns to Smyrna for the gymnasium [118]. A number of _giallo_ columns can be seen on the agora site at Smyrna, spirally fluted (Plate 27). It is not known whether these came from the hitherto unlocated site of the gymnasium. However, it is interesting to note that four similar columns were used in the first storey colonnade of the great Marble Court at Sardis. All the columns of the first storey were of _giallo_, but the four columns of the central pediment group are all spirally fluted and of a similar size to those at Smyrna. One wonders whether these were all part of the same consignment (Appendix I, H, 1).

The quarry-marks found in the Marmorata at Rome reflect this 2nd century expansion. Bruzza gives the earliest as AD 64 [119], but Ward-Perkins is sceptical about the dating [120]. Discounting this example, the earliest recorded quarry-mark from either the quarries or Rome, is dated AD 107. Thirty-seven quarry-marks are known from the whole of the 2nd century with a number recording the opening of new workings, known as _officina nova Aureliana_ in the mid 2nd century AD [121]. This series end in AD 199, but the quarries continue to be worked for a considerable time after this; the Gordians used 50 columns in their villa on the Via Praenestina and Tacitus gave 100 columns to Ostia [122].

Giallo antico is found from Arles and Orange in Gaul to Palmyra in Syria, but its distribution is a very patchy one. It does not generally penetrate into a province further than the main centres; an exception to this appears to be Palmyra where certain amounts of giallo are found for veneer and paving (Appendix I, H, 3 and 5).

The quarrying of Numidian marble certainly continued into the 4th century AD. It appears in the Edict of Diocletian of AD 301 costing 200 denarii per cubic foot, and as late as the end of the 4th century AD there are inscriptions from the quarries recording the opening of new workings [123]. When the quarries actually stopped one cannot say; there were enormous quantities already in circulation and available for re-use which would explain references to its use by Justinian in Santa Sophia [124].

CIPOLLINO: MARMOR CARYSTIUM (Appendix I, E; Maps 8 - 10)

Carystos, Euboea

A fine compact marble striated with mica. The parallel contour-like bands, darker green on lighter green or white, give the appearance of a cut-open onion, hence the term applied in the 16th century.

The quarries were located at the southern end of the island of Euboea. Strabo mentions Euboea as the source of marble from which columns are made [125]. The quarry at Myli, just above Carystos, was the main point of extraction. Many of the other quarry-sites in the area produced marble of an inferior quality. A number of unfinished and finished columns lie abandonned in the quarry at Myli [126], and give much information on quarrying techniques. In particular is a column still attached to the parent rock, thus demonstrating quite clearly that columns were quarried as curved pieces from the start rather than as large blocks and shaped after separation from the quarry face (Plate 79).

The Greeks made little, if any, use of <u>cipollino</u> but it was extensively exploited by the Romans. It was first introduced into Rome probably in the 1st century BC [127]. Indeed, its distribution shows that it reached both the eastern and western fringes of the Empire (Appendix I, Maps 8 - 10). Its most common use was for columns, but it was also employed for <u>opus sectile</u>, veneer and paving. A number of ancient authors attest the considerable use of <u>cipollino</u> by the Romans and their high regard for it [128].

The Carystian quarries appear to have become imperial property at an early date. A great deal of evidence comes from the Marmorata area of Rome [129], where shiploads of marble were unloaded and stored. Out of all the different marbles that Bruzza found and recorded in the emporium <u>cipollino</u> was the marble of which the greatest number of blocks were found. The earliest date was AD 17 and the latest AD 135 [130]. Dubois points out that the numbers following the dispatch numbers were very high; the highest he found was 2,400 [131].

<u>Cipollino</u> was used throughout the Empire; new quarries were opened under Hadrian to help meet the increased demand caused by the opening up of new markets [132]. It is most commonly found as columns and

was used at many major coastal sites in the Eastern Mediterranean in this capacity (Appendix I, H, 2). Its occurrence at Palmyra is a graphic illustration of the determination of the Romans to move large pieces of marble around the Empire and points to a central organisation and a large financial source. Cipollino was extensively employed in Rome and Campania. It does seem to have been a marble particularly favoured for public and official building. The quarries were certainly still worked at the beginning of the 4th century AD as it appears in the Edict of Diocletian as costing 100 *denarii* per cubic foot.

BRECCIA DI SETTEBASI (Appendix I, D; Map 11)

Scyros

Brecciated, dark purple stone with white, red and yellow inclusions [133]. There are a number of different varieties but they are all generally fine-grained with oblong pieces of breccia. One particular variety called *breccia di settebasi gatteggiante* [134] is dark purple with irregular large pieces of white with blood-red patches, a much patchier appearance than the ordinary kind.

Breccia di settebasi was exported from Augustus onwards and was known at Herculaneum and Pompeii as well as at Rome [135]. Its name derives from its use in the villa of Septimius Bassus on the Via Latina. The marble is mentioned by several ancient writers as being of particular beauty and merit [136]. It is called ποικιλης λιθου by Strabo [137]. Generally *breccia di settebasi* was not used for imperial buildings and this leads Gnoli to conclude that the quarries were not imperial property. Bruzza, however, thought that they were [138]. He recorded two quarry inscriptions on *breccia di settebasi* in the Marmorata [139], one of which he dates to AD 69. He therefore concludes that the Scyros quarries were under imperial control by Nero [140]. Ballance suggests that it was used as a cheap substitute for *pavonazzetto* [141]. In contrast, the *gatteggiante* variety was rare at Rome and in Italy in general, except in the later period when it was used in the villa at Piazza Armerina [142]. However, columns are found at Lepcis Magna and at Side. This type would appear to have been used later than the ordinary kind, from possibly the Severan period [143]. The use of *breccia di settebasi* (presumably not the *gatteggiante* variety) at Fishbourne is interesting and noteworthy.

In the Edict of Diocletian Scyros marble cost 40 *denarii*; thus it was still in production in the 4th century AD. This presumably refers to the *breccia di settebasi* rather than the white marble which was also quarried on the island.

FIOR DI PESCO (Appendix I, G; Map 12)

Chalcis

A fine-grained, compact marble with white, red and purple inclusions of various shapes; on occasions it could be taken for *pavonazzetto*.

The quarries are 3 km north of Eretria, just south of Chalcis [144]. Blake, however, says that the quarries were in Epirus [145]. The first examples occur at Herculaneum and Pompeii, but these are all small pieces. It was used in Rome for veneering and columns, in villas and private houses from the Flavian period [146]. It is noticeably absent from public buildings in Rome. However, its distribution in the Empire is widespread, especially in Italy, Greece and North Africa. It is rare in Asia Minor. It is most prolific under the Severans, especially at Lepcis Magna, but appears to decline after this period [147].

PORTASANTA: MARMOR CHIUM (?) (Appendix I, Q; Maps 13 - 15)

Chios

A breccia marble of delicate pastel shades, pink, lilac, soft grey, and is generally opaque rather than translucent. It takes a high polish.

Until recently there has been a certain amount of confusion as regards the origins of portasanta. In the 19th century Bruzza and Corsi stated the problem but did not venture to ascribe the marble to a particular place of extraction [148]. Barbier de Montault stated that it was quarried at Iasos in Caria and called it marmor Iassense [149]. The matter was further confused by applying the term marmor chium to africano. Ward-Perkins thought that portasanta was quarried somewhere in Caria [150]. The quarries have now been identified on Chios [151].

Portasanta is rarely mentioned by ancient authors. Pliny gives the first reference to the quarries on Chios but does not indicate the nature of the stone extracted [152]. Statius also mentions 'chian stone' but he too omits a description of its appearance [153].

The quarries were imperial property and we have a number of inscriptions from the Marmorata. The earliest date recorded by Bruzza is AD 167, the latest AD 179. A large amount of this marble was exported to Rome and the number 1095 occurs on one of the blocks recorded by Bruzza [154].

Portasanta was introduced into Rome not long after the first examples of *giallo antico*, *africano*, *cipollino* and *pavonazzetto* were reaching the capital. It was first used in *opus sectile* (Appendix I, Q, 2), but it became very popular for columns in both Rome and Ostia (Appendix I, Q, 1). In the 2nd century AD the quarries continued to flourish. Though the marble was not widely used outside Rome and its immediate vicinity, it was used at Ephesus, Pergamum, Sardis and Smyrna (Appendix I, Maps 13 - 15) on the west coast of Asia Minor. Its limited use in Asia Minor is comparable with that of *africano*.

ROSSO ANTICO (Appendix I, T; Maps 16 - 18)

Cape Taenarium

Very fine-grained marble ranging from a blood-red colour to purple, sometimes with white breccia or white veins.

Rosso antico was used very early by the Minoans and Mycenaeans[155]. There is no evidence for its exploitation by the Greeks but it was in use in Rome by the end of the Republic [156]. It was used particularly for architectural ornament, cornices, little columns and in opus sectile; it is found at Pompeii and Herculaneum in this capacity [157]. In the Hadrianic period it was used for statuary, probably because of its strong similarity to purple porphyry which was much more expensive. Outside Rome, apart from Pompeii and Herculaneum, it is quite rare with little use in Asia Minor or Greece (Appendix I, Maps 16 - 18). In the later Empire it was used in the Baths of Diocletian at Palmyra and at Ostia, but these are rare examples (Appendix I, Map 18). By this time, it would seem that the quarries were no longer in production.

VERDE ANTICO: LAPIS ATRACIUS (Appendix I, U; Maps 19 - 21)

near Larissa, Thessaly

A large-grained ophicalcite, a variety of marble in which forsterite (a rock-forming silicate) formed by thermal metamorphism has been altered to serpentine. It has the characteristic green mottled markings and is very compact. It is called a serpentine-breccia by Lepsius [158].

Three main quarries were worked, Chasambali, Kastri and Tissaion [159] in Thessaly, but Grimm thought that *verde antico* came from the island of Tenos [160]. The quarries did not go into production until Trajan at the earliest [161]. *Verde antico* was definitely reaching Rome under Hadrian and it remained a favourite until Justinian when quarrying presumably ceased. It was abundant at most late Roman and early Byzantine centres, for example, Ravenna, Tyre and Constantinople (Appendix I, Map 21), and was much re-used in later periods, for example in the façade of San Marco, Venice. In the Early Byzantine period it was also used for sarcophagi. The distribution of *verde antico* is mainly Eastern Mediterranean with no evidence for its use in North Africa. The use of *verde antico* from Thessaly for the orchestra paving of the Italica theatre has been called into question by A. Canto [162].

Verde antico appears in the Edict of Diocletian as θεσσαλου and costs 150 *denarii* per cubic foot (fig. 11).

AFRICANO (Appendix 1, A; Maps 22 - 24)

Teos

A very distinctive stone and one of the most variable of the ornamental stones used by the Romans. A breccia containing lumps of white, grey or pink marble, the crystals of which vary from minute to very large. These lumps are embedded in a black, dark green or greyish matrix; this is usually harder than the marble itself. It is very difficult to work and often contains very hard veins of quartz.

The quarries have been located by Ballance at Teos [163]. Previously the source of africano was listed as unknown or uncertain. Bruzza identified africano as the ancient marmor chium and both Caryophilus and Corsi identified it with the marmor Luculleum described by Pliny [164]. Isidore of Seville ascribes it to Chios [165]. Thus, confusion has arisen between, africano, portasanta and Chios. Bruzza's identification of marmor Luculleum is based on a misunderstanding of Pliny.

The grey marble quarries on Teos have been recognised since the 19th century. Hamilton and Chandler both gave descriptions of what they saw [166]. They only mentioned, however, the grey stone. These grey quarries, though small, were imperial property [167].

The only literary reference to Teian marble is in Dio Chysostom [168] where Teos appears in a list of cities benefitting by the possession of a supply of finely-coloured or variegated stones.

The earliest quarry-mark recorded by Bruzza on africano is AD 64; the latest is AD 135. The period of principal use therefore appears to be Augustan to Antonine with a great deal of africano being used under Trajan and Hadrian in Rome and at Ostia. Its main use was for veneer and columns and it had a fairly wide distribution in Italy and North Africa (Appendix I, Maps 22 - 24). Ballance says that it is rare in Asia Minor [169], but a certain amount does turn up as columns at Ephesus and Pergamum, and also at Side. It reaches Palmyra for <u>opus sectile</u> and veneer.

Ballance dates the abandonning of the quarries to the later 2nd century AD [170]. The evidence of the distribution maps would appear to substantiate this.

BRECCIA CORALLINA (Appendix I, C; Map 25)

Verzirken, Bithynia [171]

Fragments of red, pink, white or yellow in a coral-coloured matrix. There are two varieties, one being more brecciated in appearance.

The quarries themselves have not been identified but their general area has been located in the Verzirken region of north-west Turkey. <u>Breccia corallina</u> was in particular demand in the Roman period for columns because of its colour. It does not appear in the range of marbles at Pompeii and Herculaneum, and Gnoli concludes that it was probably introduced after AD 79 [172], although Blake states that it was used for the interior columns of the Temple of Mars Ultor in Rome at the end of the 1st century BC [173]. However, as already pointed out, the Forum Augustum was an exceptional building programme at that time and thus these columns may have been brought especially, assuming that the identification is correct.

The distribution of <u>breccia corallina</u> shows that there was a considerable demand for the stone as columns (Appendix I, Map 25). As well as Rome it was also used at Lepcis Magna and in Diocletian's Palace at Split. Generally speaking, however, its distribution is an Eastern Mediterranean one.

Ward-Perkins considers it likely that <u>breccia corallina</u>, along with other Bithynian stones, was handled by Nicomedia, a possible centre for Proconnesian, Docimium and Troad granite[174]. A comparison of the distributions of these stones is interesting (see page 131).

<u>IASOS: CARIAN MARBLE, CIPOLLINO ROSSO</u> (Appendix I, L; Map 26)

Iasos, Caria

Red variegated stone with white and grey banding, often slightly undulating and thus resembling <u>cipollino</u>. The term <u>cipollino rosso</u>, however, should be avoided as this is only one variety. Iasos marble can also be marked with white patches as opposed to bands.

Generally speaking, Iasos marble did not come onto the export market until the 3rd century AD. Gnoli thinks that the quarries were not actually worked until this time[175], but Pensabene implies that some was reaching the West as early as the late Flavian period[176]. Presumably it was in small quantities and the marble was not used widely abroad until the 3rd century AD. It has been found at Ostia, Rome, Lepcis Magna and Zadar (Appendix I, Map 26), but on the whole Iasos marble has an Eastern Mediterranean distribution.

It was much used in the early Byzantine period, especially in Constantinople[177] and at Ephesus in the

Basilica of St. John and other Christian churches of Asia Minor. Production presumably ceased in the 6th century AD.

Interestingly it does not appear on the Edict of Diocletian. Bruzza and Middleton [178] identified it with portasanta.

PAVONAZZETTO (Appendix I, O; Maps 27 - 29)

Docimium (modern Iscehisar, near Afyon), Phrygia

The main coloured marbles produced by the Roman Docimium quarries are:-

Pavonazzetto a white fine-grained stone, sometimes tending to yellow with yellow veins running through, with purple blotches which can look very red. It sometimes has a very brecciated aspect; it is not, however, a breccia.

Afyon kaplan postu dark grey with much mottled light grey pattern, with medium grains.

Gri light grey with a tinge of dark grey, which sometimes gives it an overall blue look.

The main varieties of white marble from Docimium are dealt with on page 84.

The Docimium quarries are located 23 km to the north-east of Afyon and about 15 km south-east of Iscehisar. The face of the marble runs south-east for 9.5 km and is roughly 2.5 km wide. Röder made an intensive survey of the ancient quarries and defined two principal areas, both very heavily worked, according to the period at which they were exploited [179].

The first area is the so-called 'Latin quarries' because of the large number of Latin inscriptions found on blocks and at the quarry-face. These were the Roman quarries. The most notable region of these quarries was the huge single quarry of Bacakale. The second area, the Greek quarry, so-called because of the Greek inscriptions and Christian symbols, was worked in the Byzantine period.

The three different types listed above plus the white marble on page 84 were all quarried commercially. All were quarried in both the Greek and Latin quarries, but in the Greek quarries pavonazzetto was only found towards the west and was often much more red and breccia-like [180].

In the Roman period the marble from Docimium went by several different names: Synnadic marble, after Synnada (modern Şuhut), the administrative centre for the quarries [181], and Phrygian marble, because of the quarries' location.

According to Strabo [182], marble from Docimium was a very good commercial stone and was quarried very intensively; this is presumably the pavonazzetto which was undoubtedly the biggest export from Docimium. The quarries were certainly imperial property by the time of Augustus. Pliny mentions the use of pavonazzetto in the Forum of Augustus and in the Basilica Iulia [183]. The quarries possibly came into imperial hands by inheritance from M. Vipsanius Agrippa. His name appears on a column of <u>pavonazzetto</u> found in Rome.[184]

As already seen the <u>beyaz</u> type of white marble was the only white marble that was exported to foreign markets (see page 84). The distributions and uses of the two main exports, the white, and the <u>pavonazzetto</u>, vary considerably. <u>Pavonazzetto</u> was one of the most popular marbles at Rome and was one of the earliest to reach the capital. Thereafter, it was used throughout the Roman period. It was exported both in block-form for veneer and as columns and it was also occasionally used for sculpture.

How Docimium marble and products were transported from Synnada to their various destinations has been a subject for discussion for some years. The distribution of Docimium sarcophagi within Anatolia shows that the producers were prepared to transport it by land whenever there was no alternative (fig. 7). Indeed, with all the products of the quarries, blocks, columns, sarcophagi, the first part of the journey would have to be by road to Synnada; this added to the overall cost of the product. The two natural water outlets were south-westwards down the Maeander or northwards down the Sangarios (Sarkarya). Neither river today is particularly well-suited for this transport; the Sarkarya is little more than a stream as far north as Gordion. Further north, however, it can be a fairly fast flowing and wide water-way depending on the season. It is well-known how much the Büyük Menderes, the ancient

Maeander, has changed its course and general character since antiquity.

It is also not known exactly from which ports the Docimium marble products were shipped. If the marble came down the Maeander one would imagine it would be Miletus or a port in that general area. The northern water route is a little more problematic. The Sarkarya flows into the Black Sea, not particularly expedient for the transport of marble to the cities of the Mediterranean. Ward-Perkins believes that Nicomedia could possibly have been a principal outlet for Docimium marble [185]. Pliny's famous letter to Trajan about the cutting of a canal to link Nicomedia with the nearby lake Sophon (now Sapanca Göl) mentions marmora amongst the various products which could then be transported more cheaply [186]. Ward-Perkins postulates that this may be the Docimium marble. It does not seem unreasonable that by AD 110, despite all inconveniences of frequent loading and unloading, the short land trip from the Sangarios to the Propontis was a viable alternative to shipment down to the coast and then on by way of the Black Sea and the Hellespont.

From the Augustan period the demand for pavonazzetto increased greatly. There is a large series of inscriptions on blocks and columns at the quarries themselves, at Rome and in Tripolitania [187]. These inscriptions record the serial number, when a block was quarried, in which sector of the quarry, and sometimes who was in charge.

These inscriptions covering the period from the Julio-Claudians to the Severi testify to the continued use and large distribution of pavonazzetto. The greatest expansion occurs in the 2nd century AD. Röder calculated that between 400,000 and 500,000 m^3 of marble was removed from the Bacakale quarry, which was about a quarter or a fifth of the production of the whole quarry [188]. This was enough for the massive building programmes of the 2nd century in the capital and throughout the Empire, reaching the major cities of Asia Minor and as far east as Palmyra and to North Africa (Appendix I, Maps 27 - 29), as well as penetrating west.

The quarry-marks stop at the beginning of the 3rd century; this is comparable to events elsewhere. However, quarrying continues in the following period, although it may have been at a reduced level. Docimium marble, presumably pavonazzetto, appears on the Edict of Diocletian, costing 200 denarii (fig. 11). This must partly reflect the high transport costs involved. The foundation of Constantinople meant renewed workings and the opening of the new places of extraction, specifically the 'Greek quarries'. The Greek inscriptions and symbols show working continued to at least the end of the 8th century AD [189]. In a Law of AD 414 announcing the remission of taxes throughout the Empire, Docimium is named with Proconnesus and the Troad quarries as being exceptions to the law. The quarries could obviously well-afford to pay their tax dues in full. These quarries appear to have been worked through into at least the 10th century [190], though probably on a much reduced scale.

<u>LACEDAEMONIAN: MARMOR LACEDAEMONIUM</u> (Appendix I, M; Maps 30 - 32)

Croceae, near Gythion, 20 km south of Sparta

Dark green porphyry with lighter green inclusions of labrodite, the size and shape of which varies. This has been erroneously called a serpentine, which is the medieval and modern name applied to it [191]. Lacedaemonian has also been referred to as <u>porfido verde antico</u> which should also be avoided because of confusion with the <u>verde antico</u> from Thessaly.

This stone could only be quarried in small irregular lumps. This was the result of the hardness of the rock and also because it did not occur in continuous veins [192]. The quarries were worked as early as Helladic times and a quantity of rough blocks were discovered in the Palace of Knossos [193]. As a result of the quarrying difficulties the stone was only used for <u>opus sectile</u> and small columns.

Lacedaemonian was reaching Rome by the mid 1st century AD, and was much used in conjunction with purple porphyry, <u>pavonazzetto</u> and <u>giallo antico</u> in <u>opus sectile</u>. In the Early Empire, its use was concentrated on Rome with an interesting outlying use in the Palace at Fishbourne. By the later Empire Lacedaemonian was reaching cities in the Eastern Mediterranean (Appendix I, Map 32). The date of the abandonment of the quarries is not known.

Many ancient authors comment on the beauty of Lacedaemonian stone, and Pausanias says it is particularly beautiful when used in baths and for water sources [194].

PURPLE PORPHYRY (Appendix I, S; Maps 33 - 35)

Mons Porphyrites (modern Gebel Dokhan)

Purple matrix with white inclusions, phenocrysts. Medium-grained and very hard.

The quarries were situated at Gebel Dokhan, Mountain of the Smoke. In Antiquity it was called Mons Porphyrites or Mons Igneus [195]. It lies 1661 m above sea-level, about 50 km from the ancient port of Myos Hormos, modern Abu Shaar, on the Red Sea, and about 150 km from Koptos on the Nile, both considerable distances to haul large quantities of stone overland.

It is usual to date the beginning of the large-scale quarrying of purple porphyry by the Romans to Claudius because Pliny reports that Vitrasius Pollio brought to Rome from Egypt statues of a mottled variety (leptosephos) of porphyry [196]. However, Pliny elsewhere confused purple porphyry with red granite, and Vitrasius Pollio was Prefect under Caligula and in the very first years of Claudius' reign [197]. Porphyry statues were reaching Rome at the beginning of Claudius' reign which means that the quarries must have been worked at least as early as Caligula if not Tiberius or Augustus. From Lucan's description of Cleopatra's Palace purple porphyry was apparently worked in Ptolemaic Egypt [198]. Delbrueck considered that work began in the Augustan period [199]. Purple porphyry was certainly in use under Caligula because of its use in the Nemi pavements, and Nero had a sarcophagus of purple porphyry [200]. The stone quickly came to symbolise imperial power and dignity, and from Flavian times purple porphyry was very important and widely used in Rome, with ever larger blocks being exported [201].

The stone was much used for sculpture, especially under Hadrian and the Tetrarchy, but it had many architectural uses. Early on it was used mainly for small columns and in <u>opus sectile</u>, but as the size of blocks that could be quarried increased so purple porphyry was used for large columns, especially in the later period. It was in the 3rd to 5th/6th centuries that purple porphyry was used on a more Empire-wide basis, though it was used at London and Colchester in possibly early contexts [202]. Its concentration however, at all periods is in imperial centres (Appendix I, Maps 33 - 35).

Diocletian made great use of porphyry for his palace at Split and Constantine apparently shipped enormous amounts, at the expense of Rome, to the new capital [203]. The honorific column that he erected in the centre of his forum at Constantinople was perhaps one of the grandest expressions of the taste for purple porphyry [204]. It was made up of seven cylindrical drums of the stone and had a square pedestal; the height of the column is now 34.8 m and is the tallest monument in purple porphyry in existence.

The date of the abandonment of the quarries is uncertain, but because of the relative hardness and the very high esteem in which purple porphyry was held, monuments in the stone had a longer life than works in other materials. Often purple porphyry pieces were removed to churches and therefore have survived [205]. The date of the abandonment of the quarries is discussed on pages 138 - 139.

EGYPTIAN GREY GRANITE: GRANITO DEL FORO (Appendix I, I; Map 36)

Mons Claudianus (modern Gebel Fatireh), Egypt

A granodiorite containing white quartz with very small inclusions of grey feldspar and an abundance of black mica.

The quarries are situated in the mountains close to the west coast of the Red Sea, about 55 km south of the ancient port of Myos Hormos. Thus, the same transport problems occurred as for purple porphyry. The quarries were extensive. Judging by the columns still lying at the quarry faces and the loading ramps, huge loads were put on each wagon. For example, one column was 65 ft long and 8 ft 6 ins in diameter and weighed 210 tons [206]. A normal load would probably have been less than this.

Egyptian grey granite arrived in Rome in the Flavian period and there was a massive influx under Trajan and Hadrian, which continued until the beginning of the

4th century with the Baths of Diocletian and the Basilica of Maxentius. In contrast to Egyptian red granite the Mons Claudianus granite is rare outside Italy, but it does occur at Pergamum, Ephesus and Split (Appendix I, Map 36). It is not unduly surprising to find the granite at these centres [207]; at Pergamum it was used in conjunction with Egyptian red in the Kızıl Avlu, which was probably a Serapaeum.

The problems of transport may have been a limit on its distribution, but both purple porphyry and Aswan granite had these difficulties and yet had wider distributions [208]. In the Edict of Diocletian, Mons Claudianus grey granite costs 100 denarii, a price that certainly does not reflect high transport costs. However, it also had to contend with other grey granites, in particular with that from the Troad, which were much nearer the sea and therefore must have been cheaper all round.

EGYPTIAN RED GRANITE (Appendix I, J; Maps 37 - 39)

Syene (modern Aswan), Egypt

This is an alkali-granite made up of proportions of alkali and calcium-sodium feldspars. The red inclusions average 3 cm across.

The quarries, situated at Aswan, ancient Syene, were supremely located for cheap water transport down the Nile. They were worked in Dynastic times when the Egyptians made great use of red granite for obelisks.[209] Sometime in the early part of the 1st century AD the Romans began exploiting the quarries and Aswan red granite began to reach Rome in large quantities from the mid 1st century AD. It was used almost exclusively for columns and was extensively employed in the Eastern Mediterranean (Appendix I, Maps 37 - 39). Indeed the general distribution of Egyptian red granite is an eastern one with Rome being one of the most western sites [210]. In the East, however, it was much used in imperial centres, for example, Antioch, Nicaea, Caesarea, as well as at less important sites.

The position of the quarries right on the Nile must have kept the price of the granite down. In the Edict of Diocletian the cost is 100 denarii. Yet the Romans were prepared to haul huge columns of almost 100 tons each uphill to sites such as Baalbek, Palmyra, Damascus and Jerash. The production of the granite must, therefore, have been very large to permit the low price to remain at a reasonable level to support the other transport costs of large columns.

The abandonment of the quarries, as in so many other cases, is controversial but may have been in the 5th century AD (see page 140).

TROAD GRANITE: MARMOR TROADENSIS: GRANITO VIOLETTO

(Appendix I, K; Maps 40 - 42)

Çanakkale, Kocali, Kestambol, Assos

Generally grey granite with large white and violet particles of quartz and feldspar and some small black inclusions. This gives an overall pinky appearance.

The quarries of Troad granite have still to be systematically explored [211]. Cook describes the quarries at Kocali and at Kestambol, and reports columns in the quarries at Kocali, some still not split off from the parent rock. Schliemann also visited the site and a number of blocks and columns have apprently disappeared from the site since his visit [212]. Other quarries almost certainly await identification; the nature of the stone was such that it involved quarrying over a wide area rather than the exploitation of a single large quarry.

The quarries do not seem to have been opened until the beginning of the 2nd century but it quickly became a very good commercial stone. It was used almost exclusively for columns with large quantities being exported over much of the Eastern Mediterranean reaching Baalbek, Pergamum and Pamphylia by the end of the century (Appendix I, Maps 40 - 42). In the later Empire, Troad granite reached Rome and Lepcis Magna [213]. It is recorded in the Theodosian Code [214] as being one of the three big quarries (with Proconnesian and Docimium) not exempt from taxation. Thus it must have flourished into the 5th century.

ALABASTRO ANTICO: MARMOR ALABASTRUM

Mainly Egypt, Syria, Asia Minor

The ancients apparently used the words 'onyx' and 'alabastres' for both the stone and the gem [215] and, unfortunately, the term alabaster in modern times is applied to a sulphate of lime, which is different from ancient alabaster. Oriental alabaster is the equivalent of alabastro antico which is a carbonate of lime and a real marble. It is formed by the deposition of calcite in calcareous water. The colour combinations are due to other substances held in solution and deposited with the lime. This creates varied markings.

Egypt Alabaster occurs at various locations in Egypt in the Nile valley. Important quarries were at Wadi Asiut, El Amarna, Hatnub and Wadi Gerrawi [216]. Pliny says that alabaster was also found near Thebes [217]. Theophrastus also says this [218], though there are no beds of alabaster in that area. The nearest quarries are 100 miles away from Thebes, though the city may have been a distribution point for this stone [219].

Pliny describes alabaster as being honey-coloured and those varieties that are marked with spirals and are opaque are most appreciated [220]. In the Ptolemaic period alabaster was much favoured for small objects [221]. According to Pliny [222] it was introduced into Rome in 57 BC. Egyptian alabaster was used in the Temple of Mars Ultor for the veneer of the rise of the steps [223].

Syria Damascus was also an important source of alabaster [224], and a bright and brilliant variety came from the Syrian desert around ancient Sergiopolis, modern Resafe [225].

Asia Minor Several varieties are found in Asia Minor. In Cappadocia an alabaster is mentioned by both Pliny and Strabo [226]. This is worked even today near modern

Kirşehir. Pliny mentions a stone, marmor phengites, which he says comes from Cappadocia and was used by Nero to rebuild the Temple of Fortune [227].

The marble of Hierapolis in Phrygia formed by the deposition of calcite is a proper onyx marble or alabaster (Plate 80). This was not used at Rome but must have been extensively used locally.

Other ancient alabasters came from India, Tunisia and Algeria. These were used in Rome but have not been identified in the East [228].

Generally speaking, alabaster was especially effective for wall linings and floor coverings. Occasionally it was used for larger objects, for example columns [229].

LOCAL MARBLE IN ASIA MINOR

Asia Minor was very rich in white marbles and coloured stones, marbles, granites and limestone breccias (fig. 8). Many of these were for local use, whether in the immediate locality of the quarry or in Asia Minor more generally. Some of these quarries have been located and studied, while for others evidence is lacking [230].

WHITE MARBLE

Heracleia by Latmos and Miletus These quarries are situated in the Lake Bafa region and have been the subject of a recent study by Anneliese Peschlow-Bindoket [231].

The main area of the marble quarries of Miletus are in the hills between Bafa and Mersinet. Building inscriptions at Didyma refer to quarries near Ionapolis, the site of which was found at Mersinet Iskelesi south-east of Lake Bafa. Unfinished column drums of Didyma size were found still lying in the quarries. This enabled the Germans to identify the Miletus quarries with the quarries of Ionapolis mentioned in the inscriptions at Didyma. The marble is white with bluish tinges.

The marble of Heracleia can be white or grey and is sometimes banded. The quarries were extensively worked disproportionately to the needs of Heracleia [232]. The conclusion of the survey team was that the marble must have been exported in antiquity. It does appear on the Edict of Diocletian at 75 denarii. Further large quarries were recorded east of the Temple of Zeus at Euromos and on the next ridge to the south. These must have supplied the stone for the temple.

Tests were carried out at Didyma, Miletus and Heracleia to determine the provenance of the marble in use at the three sites. The results show that both the Miletus and Heracleia quarries supplied material for the Didyma temple, with no specific use for either marble. At Heracleia all the marble was from the quarries south of Bucak, and at Miletus the Bouleuterion makes extensive use of Miletus marble. The marble of the Temple of Athena at Priene was also analysed. The results were interesting in that it could possibly be Miletus marble not the local Priene marble. This, however, is uncertain [233].

Priene This marble is often called Mycale marble, Mycale being the name of the range of hills which project westwards, modern Samsun Dağ [234]. The marble quality varies considerably from a good quality white to a large-grained grey/blue. The general area also produces crystalline limestones, a black variety and a white variety as well as a white/bluish-grey type [235].

The extraction of this marble was exclusively for the buildings and sculptures of Priene from the 4th century BC.

Mylasa Greyish varieties of marble ranging from a fine-grained grey/white to a grey/black marble [236].

The quarries are situated 2 km south of Milas above the road to Bodrum, where the ancient workings can still be seen. The use of the marble was probably limited to the city of Mylasa and the many temples in the vicinity of the quarries [237].

Sardis White or lightish blue marble with large crystals and a white marble with a few grey or bluish bands with large crystals.

The quarries are situated at Mağara Deresi. They were exploited purely for local use. They were worked possibly from the 6th century BC and they provided the marble for the Temple of Artemis in the 4th to 3rd centuries BC. In the Roman and Byzantine periods abundant use was made of the marble, in particular for the sumptuous baths/gymnasium complex. Based on the quarries was a workshop of sculptors [238].

Denizli and Aphrodisias Region The mountainous massif between Denizli and Aphrodisias forms one of the most important deposits of white marble in the Aegean area [239]. A total of 32 quarries have been identified in the region. The Laodicea quarries produced a white crystalline limestone as well as a white medium-grained marble with grey veins. They are situated 20 km south of Hierapolis. The marble was used at Laodicea-ad-Lykos and at Hierapolis [240].

White marble was also quarried at Heracleia-Salbake to the south of Denizli and a good white limestone to the north [241] (fig. 9). To the south of Aphrodisias white marble was quarried at Hançam. The quarries, though located, have not been systematically studied.

Uşak - Eldeniz Area This also appears to have been a rich area of white marble with quarries at Kirtaş near the village of Selvioğlu [242] and at Eldeniz. Here a whole series of quarries have been identified.

Altintaş Area Recent work by Dr. Marc Waelkens in the Altintaş area of Phrygia has revealed a series of quarries producing similar marble to that of Docimium. In the Altintaş valley a white marble, a white marble with grey and yellow veins and pavonazzetto were all quarried. In the Burgas Dağı valley and in the Istiklalbaği valley white marble was produced and at Yeşilkoy a white and grey veined marble was quarried [243].

A group of sculptors were apparently based on these quarries at Altintaş. They produced marble for a school of itinerant sculptors who were acitive in the whole valley. Burgas Daği provided marble for the ateliers at Akmonia and Sebaste, and the Istiklalbaği quarries supplied the ateliers of Pessinonte and Eudoxias.

Other white marble quarries in Asia Minor which have been identified but not studied are at Nicaea, Gölmarmara and Stratonikeia [244].

COLOURED MARBLE

Many ancient quarries producing coloured marble have been identified (fig.8), but there are problems in matching the quarries up with the stones that are found in use in the Empire. It has, however, been possible to do this with some.

Ezine (Neandria) breccia Pavonazza di Ezine This is a pinky violet breccia and has been identified in use in the Asclepieion at Pergamum for the paving of the theatre orchestra [245].

Bilecik Area occhio Pavone Rosso lithos Sangarios [246] A dark red fossiliferous marble. Gnoli identifies this with the *Potamogallenos* of the Edict of Diocletian recorded as being 50 *denarii*.

Others include Nicaea, Gebze, Hereke, Tasikigi, Gemlik and Peperene, for which there is very little evidence (fig. 8). Gnoli mentions various stones giving provenance only as Asia Minor: <u>breccia giallo</u>, a dark yellow stone with lighter yellow markings, used in the Vedius Gymnasium at Ephesus [247]; and <u>bianco e nero tigrato</u> used for veneer in the Asclepieion at Pergamum [248].

BLACK MARBLE

Black marble was generally rare in the Roman world. It seems to have been quarried in a number of places, but generally speaking black marble remains an enigma. A black, or very dark, marble, <u>marmor Luculleum</u>, was introduced into Rome in the 1st century BC [249] and was named after the man who introduced it. Its source, however, is very uncertain. It was possibly quarried on Chios [250], but wherever it came from it was still being quarried at the beginning of the 4th century AD because it appears in the Edict of Diocletian at the high price of 150 <u>denarii</u>.

The quarries of Taenarium described by Pliny have been considered the source of <u>nero antico</u> [251], and there are various literary allusions to the columns of Taenarian marble in use in the Augustan period [252]. Gnoli, however, considers the source of <u>nero antico</u> to be in Tunisia near Chemtou [253]. This may be based on Pliny's citation of Varro [254]. Generally the black marble is jet black and compact with faint streaks of white.

Several districts in Gaul produced black marble, which was usually marked with white. The most famous is the marmor celticum which was quarried in the Pyrenees. A very similar kind was used in St. Sophia and in St. Poleuktos, but this may be the stone which is quarried today near Adapazarı. No ancient workings have been found at this site.

THE ROMAN MARBLE TRADE

The evidence for the marble trade in the Roman Empire is of three kinds, literary, epigraphic and archaeological. Each has its own limitations. The literary evidence, in particular, is fragmentary and can therefore be unreliable. Epigraphy throws important light on the working and administration of the quarries. It can take several forms - quarry-marks; inscriptions of merchants dealing in marble; and inscriptions of craftsmen handling it. Several groups survive from Rome and from the quarries themselves, but there are still many unanswered questions. The largest single body of evidence is provided by the buildings themselves, but here there are problems of identification and re-use.

The second half of the 1st century AD saw the beginnings of an organised movement of marble from the quarries to Rome and Italy. The 2nd century AD saw this organisation encompassing much of the Roman Empire. As stated above (page 74) six components of this organisation can be identified.

i) Imperial ownership Suetonius records that Tiberius took under imperial control many of the principal sources of supply throughout the Empire [255]. Many of these quarries can be named because of the system of accounting and control used for a time involving the cutting or painting of crude inscriptions on the blocks at the quarries or during transit. Lead seals were also used. These quarry-marks are an invaluable source of information about the operation of the imperial quarries. Those incised or painted at the quarries or at the administrative centre of the quarries relate to the extraction of the marble and to the supervision and control of the quarrying operations. The quarries at Docimium provide a number of inscriptions where there is much detail given. For those blocks to be exported the consular date is given with the number of the place of extraction, the *locus* [256]. There are various *officinae*, areas of supervision, which are sometimes mentioned [257]. The *officina Papi* is recorded in an inscription found by Bruzza in the Marmorata [258]. The *bracchium* is sometimes also given. This must mean the particular area under the *officina*. With this goes the name of the man responsible for the technical operation of the cutting of the marble blocks from the quarry-face, *caesura*, and for the supervision of the workers. Domitius was responsible for the *caesura* of the *officina Asiatici* in *bracchio quarto* [259]. Claudianus was concerned, between AD 161 and AD 163, with the *caesura* of the *officina Pelagi* [260]. Some blocks have no names but have certain abbreviations, for example, *repr(obatum)* [261], which probably means the blocks have passed the approval of the *probator*. The marble then apparently went to Synnada, the administrative centre of the quarries, where the procurators put their names on the blocks for export plus the phrase *sub cura* and a consignment number preceeded by *n(umero)* to distinguish it from the extraction number [262]. This is not done apparently directly at the quarry. On the underside of a column of *pavonazzetto* found by Bruzza [263] is:

> L. AELIO/CAESARE N II ET BAL/BINO COS RATIONIS/ URBICAE SUB CUR IRENAEI/AUG LIB PROC CAESURA TULLI/SATURNIN LEG XXII PRIM.

Thus the column was quarried in AD 137 (consuls Hadrian and Balbinus) for the building of Rome (*rationis urbicae*) at a time when the quarries were under the administration of the procurator Irenaeus. The man responsible for its actual quarrying was Tullius Saturninus, a centurion in the *legio* XXII *Primigenia*. Also on this column were two other inscriptions: LOCUS NII CIA/LOC XVI B and OFF PA/NLXXXVI. Thus Tullius Saturninus was working in the *officina Papi* and the consignment number was 86. Another very similar inscription recorded by Bruzza [264] has the same *officina* and other details, but the consignment number is 94 and the *locus* is XX. On one of these columns Bruzza [265] records that a lead seal was also found with the name of the Emperor Hadrian. Lead seals were usually used as an alternative to painting or incising inscriptions. These would have the same information on them and were presumably set into the marble. Bruzza says they were easier to use [266], but there does not seem to be any quarry which used these as opposed to any other method. Lead seals have been recorded for africano, pavonazzetto, giallo antico, cipollino and the grey Teian marble [267]. Two drums of imported onyx marble were recovered at Ostia still with the small circular impressed seals of lead attached to them [268].

The form of the quarry-marks taken by the Docimium quarries are fairly representative and are probably those known in most detail. The abbreviation ex rat, meaning for the building of the city, that is, Rome, is found on cipollino, africano and portasanta in the Marmorata [269], but generally there is little variation.

At the marble yards of the importing centres, official stock-takings also apparently took place. The oft-cited example of the two Numidian marble blocks found at Ostia serve as illustration. They were quarried and registered in the time of Domitian under the charge of the imperial slave Felix. Another text on the same blocks gives a consular date of AD 132 which is probably the record of a stock-take in the marble yards of Rome undertaken in that year. These were not used until AD 394 [270].

The evidence supplied by the quarry inscriptions, however, is partial and limited. The chances of survival are heavily loaded against those quarries which painted them or used lead seals. Further, the system of accounting which the incised inscriptions represent was only in use for a mere 150 years, from Nero to Septimius Severus. The latest recorded by Bruzza is on a block of Parian marble dated to AD 206 [271].

The fundamental way in which the evidence of the quarry inscriptions is limited is the fact that not all the major quarries followed this system. Those that did, that is those from which we have quarry inscriptions, are the quarries of Luna, Paros, Docimium (both white and pavonazzetto), Carystos, Teos (the africano), Chios (portasanta), Scyros (breccia di settebasi), Chemtou (giallo antico) and the Egyptian granite and porphyry quarries. Those that apparently did not follow this system are Pentelic, Thasian, Proconnesian, verde antico, rosso antico, Lacedaemonian and Troad granite.

All the local quarries of Asia Minor were presumably privately owned, but it is a notable fact that the quarries of Ephesus did export although they appear to have never been under imperial control. If they had been, it is inconceivable that there should be no trace of this situation in the abundant record. Another notable exception is the Pentelic quarries. By the Roman period these quarries had already been very heavily worked, and Ward-Perkins suggests that it would have made more economic sense to have left them in private hands [272]. All the rest, however, were heavily exploited in the Roman period and presumably must have used another system [273].

ii) rationalisation in quarrying methods and increase in production This was the prime object of the imperial takeover. Increased production can be seen in the opening of new quarries, for example, at Carystos under Hadrian [274], and at Chemtou under Antoninus Pius and Marcus Aurelius [275]. The quarry-marks were a result of increased production, and are a sign of this rationalisation, but they do not mark the beginning of production.

iii) bulk production and stock-piling The evidence for stock-piling is obvious in the Marmorata and Ostia finds already mentioned, most of which are blocks and columns. This created a new customer/quarry relationship where most needs were met from the marble yards of the imperial centres. This involved the setting up of agencies dealing with this side of the business.

iv) standardisation and prefabrication This was a natural development of the situation that was convenient in a number of ways. A good illustration is the production of columns in standard lengths. An inscription from Ephesus records a donation of twenty 5½ ft columns of Docimium marble [276], and Bruzza records a porphyry column found in Rome near the Church of SS. Apostoli inscribed on the underside ΠΟΔ'Θ (9 ft) [277]. The well-known inscription on the underside of the red granite column of Antoninus Pius records that it was one of a pair of 50 ft columns [278]. The granite columns of the Pantheon porch are exactly 40 Roman feet high, and columns of 16, 20 and 24 Roman feet are a standard feature of the Severan buildings at Lepcis Magna.

In the shipwreck off Punta Scifo near Crotone, eight columns of pavonazzetto were recovered, all 12 or 20 Roman feet long [279]. These columns had a projecting collar, a standard feature to facilitate handling and allowed for a measure of adjustment in the finished length. It would also prevent any minor damage to the column ends from being prohibitive to their use. A column 38 Roman feet long was recorded in the Troad granite quarries [280]. This dimension occurs in Pliny's description of the columns of the Theatre of Scaurus [281]. A group of unfinished columns of cipollino were all intended to be 40 Roman feet and can still be seen in the quarries [282]. This standardisation made it easier and cheaper to work to a restricted number of standard lengths and sizes for which there was an assured market.

Columns were usually exported in a nearly finished state (apart from the extra collar pieces), for example, the columns from the Punta Scifo wreck [283]. Other articles were exported from the quarries either in the form of roughed out blocks, for veneer, or with the design already outlined, for example, capitals and entablatures, or almost finished as with columns. Sarcophagi were generally roughed out at the quarries to be finished at their destination (see page 134). They were not exported as blocks to be hollowed out on arrival. This was always done before despatch as it cut down on weight and bulk.

v) and vi) <u>skilled workmen at the quarries and agencies overseas</u> Evidence for groups of skilled workmen and craftsmen centred on certain quarries has been established at Docimium, Aphrodisias, Proconnesus, Ephesus and the quarries in the Altintaş area. Most of the evidence is epigraphic. For Docimium there are at least 12 inscriptions dating to the 2nd and 3rd centuries from the region which testify to a school of Docimium artists [284]. Much work has been carried out recently to establish the presence of a school of Bithynian sculptors at Nicomedia, based on the Proconnesian quarries [285], and there is much evidence for the Aphrodisias school at the city [286]. However, their great importance to the marble trade is that workshops of these craftsmen were set up in places other than at the sources of supply. Thus there is Asclepiades, the marmorarius Nicomedia at Lepcis Magna [287]. At Nicopolis-ad-Istrum were working a group of Nicomedian sculptors in the 2nd century AD. They dedicated an altar with an inscription on it on behalf of the craft association of the Nicomedian sculptors [288]. Thus in the same way, Aphrodisian sculptors are attested in Sicily, Greece and Crete as well as at Rome [289]. These craftsmen worked in other stones as well as their own marble, and thus had great influence on the architecture and sculpture of the area.

DISTRIBUTIONS, SHIPWRECKS AND SARCOPHAGI

The distribution maps (Appendix I, Maps 1 - 42) show, as far as possible, certain trends for the different kinds of marble. These are all architectural uses. Few marbles at any time, go west of Rome. Troad granite, Parian, *cipollino*, purple porphyry, *verde antico*, *pavonazzetto*, Lacedaemonian and Pentelic all reach sites west of Rome (Appendix I, Maps 1, 19, 27, 30 and 33). Usually these are only in small quantities. Generally speaking, most marbles have an Eastern Mediterranean bias after the initial flood to Rome. There are exceptions to this. *Africano* is mostly a western distribution and is especially concentrated in Italy, in Rome and Campania (Map 22). Palmyra is the easternmost site that it reaches. Here it is in small fragments and may not represent the transport of large blocks. *Portasanta* also has a mainly western distribution with its being found only in the East in the locality of the quarries in Asia Minor. None has been recorded in Syria (Map 13).

It is clear from the maps that some marbles were heavily used in the first two centuries AD, but there is little evidence of their use in the later period, for example, *rosso antico*, *portasanta* and *africano* (Maps 15, 18 and 24). There are some, however, whose distribution widens in the later period (from Septimius Severus) - Troad granite is found further west at Rome; Lacedaemonian is found in the Eastern Mediterranean, for example, at Palmyra [290], as is purple porphyry; and the distribution of *verde antico* generally widens (Map 21). This latter case, though, may be explained in that the quarries only came into production under Hadrian.

Generally speaking, in the later period there is a shift to the distributions being centred on the Eastern part of the Empire, for example, pavonazzetto (Map 29). Some, however, are not found in Syria or Asia Minor or only in very small quantities. For example, there is very little pavonazzetto or giallo antico in the Levant and giallo is rare in Asia Minor. Verde antico is also uncommon outside Rome and Constantinople; it is noticeably absent at Lepcis Magna.

The granites show interesting distributions. Egyptian grey grantie almost exclusively goes to Rome and Ostia; this has been acknowledged for some time [291]. However, it is found at Pergamum in the Kızıl Avlu, the Serapaeum sanctuary along with red Egyptian granite and Troad. The Egyptian association of the sanctuary itself must explain this. The columns and piers were presumably special imports (Map 36). One of the most interesting factors about the distribution of Egyptian grey granite is that it is not found at Lepcis Magna; Troad granite is found under Severus but the Mons Claudianus quarries may have been run down at this time or it was simply too expensive. Troad granite seems to have had the monopoly for the grey granite market. None is found in Greece [292], but its distribution is huge in Asia Minor and the Levant. It reaches Rome in the late period but it is not used at Ostia.

Egyptian red granite has a huge Eastern Mediterranean distribution with Rome and Lepcis Magna being the only two western sites that it reaches, apart from the red granite base discovered in London (map 37). It has not been recorded at Ostia. As with Troad, the Romans appear to have been quite prepared to haul huge columns uphill for hundreds of miles to Baalbek, Samaria-Sebaste and Palmyra (Maps 37 - 39). An interesting point with red granite is that it is often used with local stone for capitals and bases, etc., for example, at Palmyra, Jerash and Baalbek. Yet, certainly in the case of Palmyra, Proconnesian capitals were transported to the city. One wonders with what stone these were used.

The white marbles also produce some valuable information. Pentelic is not found in the Eastern Mediterranean apart from Greece. Luna is not used in the East but is the white marble in use in Northern Italy, Southern Gaul and Germany. Proconnesian is very common in the Levant and in Asia Minor it is found at most sites, even where there is also a local source, for example, at Ephesus. It is also used at Rome and Ostia, enjoying the favour of Hadrian, Severus Alexander and Maxentius.

In the light of Ward-Perkin's work, the distributions of Proconnesian, breccia corallina, pavonazzetto and Troad granite can be profitably compared (Maps 2-4, 25, 27-29, 40-42). Ward-Perkins has discussed the possibility that one centre, Nicomedia, handled the export of breccia corallina and Troad and much of the Proconnesian and pavonazzetto output [293]. The distributions are very similar in the East, though pavonazzetto has not been recorded on the Levantine coast; breccia corallina has. All four are found in Pamphylia and on the West

Coast of Asia Minor and all are used in the later period at Rome and Lepcis Magna. The distributions of Troad and Proconnesian are particularly similar. It is most usual for Troad columns to have Proconnesian capitals and bases. A particularly graphic example of this is at Umm Qais, ancient Gadara, where there were two Troad columns with four capitals of Proconnesian to go with them.

It has been suggested that the instance of marble in Britain cannot have been part of this organisation. This, however, seems to be ignoring the evidence. Marble has not been found in the quantities more usual in the Mediterranean but it was certainly used to a large extent for veneer in imperial buildings in London and Colchester [294]. The use of Lacedaemonian and <u>pavonazzetto</u> at Fishbourne illustrates a Roman influence on a native ruler. A similar occurrence takes place under Herod in Palestine. At Masada in the Hanging Palace, walls are painted to represent marble. The marble being transported to Britain and also to Germany, would have been small quantities by Mediterranean standards but must have been part of the same organisation because of the wide variety. The monument at Richborough, with a definite propoganda purpose, was cased in marble, Pentelic and Luna being two of them [295]. These would have been quite large blocks and would have required the same organised movement as anywhere else in the Empire.

A recent article on the exploitation of marble in

Roman Spain [296] has made claims which illustrates the necessity to make careful analyses of marble. Alicia M$^{\underline{a}}$ Canto says that a marble exactly like cipollino was quarried at Anasol [297]. She goes on to say that it was the Spanish cipollino that was used at Lepcis [298]. The basis of her argument is that cipollino, along with Egyptian red granite, was apparently inexhaustible and the fact that it not only came from Carystos but also from Elba and Spain might help to explain the huge quantities. However, a study of the Carystos quarries shows them to be very extensive and perfectly capable of providing the huge quantities of stone to the Roman Empire. This is the quarry site always mentioned in ancient sources; no mention is given of the other two. This is not to say that they were not exploited in Antiquity, but that it was only on a local scale. The problem can really only be solved by petrological analysis. However, until such tests find that Spain did export the marble from Anasol one must assume that all the cipollino is Carystian except for the local market in Spain. Further, if pavonazzetto, portasanta, giallo antico and africano were all imported [299] there is no reason why cipollino should not have been also. Canto also claims that the verde antico used in the orchestra of the theatre at Italica is of Spanish origin [300]. It must be, she says, since the theatre is Tiberian and the verde antico quarries were not opened until a century later; she seems to forget that refurbishment can take place without an epigraphic record.

Shipwrecks and sarcophagi also add to the general picture of the Roman marble trade. A number of ancient shipwrecks carrying marble have been located but it has not been possible to identify the marble on board all of them. With some, however, it has. The Punta Scifo wreck near Crotone had a large cargo of pavonazzetto columns and blocks and also Proconnesian blocks and one block of Docimium white [301]. The blocks were all roughed out and the columns were in a finished state with the extra collars left. What is interesting is that these two marbles are being transported together. This seems to support Ward-Perkins' suggestion that Proconnesian and pavonazzetto were handled at the same centre.

The San Pietro wreck in the Gulf of Tarento carried a cargo of rough-cut marble sarcophagi from Aphrodisias of a type only found in Rome [302]. Here is a glimpse of the practice of manufacture for certain markets and with sarcophagi this can be clearly seen.

The ground has been covered in detail [303], but a general summary is appropriate. The shipment of sarcophagi entails a certain amount of prefabrication. The sarcophagi were regularly hollowed out and roughly shaped before shipment; this is obvious from the evidence of shipwrecks. In some cases the element of prefabrication was carried much further. In the case of the Attic sarcophagi much of the carving was carried out in Athens [304] before export. The details of the high-relief carving must have been done after shipment but the remarkable stylistic and iconographic uniformity of the whole series of Attic sarcophagi suggests that the earlier stages were centralised. There must have been agencies in the provinces which could provide craftsmen capable of undertaking or completing the carving in the required manner; Aquileia was apparently one of these [305]. Other major quarries which exported finished products, though this was not by any means true of all their exports, are Docimium, especially the Sidemara type sarcophagus, and some Ephesian. Most others are exported half-finished [306].

This prefabrication in certain cases extended to the features of decoration in which the quarries took a good account of the requirements of the individual markets involved. A case in point is that of the Aphrodisian sarcophagi in the San Pietro wreck. In the Proconnesian sarcophagi several different models can be distinguished, each one produced for different overseas markets. The Proconnesian garland sarcophagi, produced predominantly for the Eastern Mediterranean market, were designed for completion with a design of three garlands supported by putti or animals' heads along each of the two long sides with a single garland on the two ends. At the quarries this was roughed out with the intention that it should be finished after receipt. Provided there was a competent workshop this is what happened. Two such workshops have been distinguished, one at Alexandria and another on the Syrian coast, perhaps at Berytus [307]. Often, however, the sarcophagi were used with simply the quarry design tidied up (Plate 81).

In western Asia Minor, the Proconnesian garland sarcophagus was only one of a number of available types of marble sarcophagus, some imported, others made locally in a variety of local Asiatic marbles, for example, Ephesian and Aphrodisian. These include several similar but distinctive forms of the garland motif [308]. These were produced for a local market where the type could hold its own, but they lacked the prestige and commercial mechanisms for a wider diffusion (fig. 7).

The Attic sarcophagi had a virtual monopoly in Mainland Greece, and in Asia Minor shared the market with Docimium, Proconnesian and these local types (fig. 9). Attic marble (Pentelic) is not used in Asia Minor for architecture. Attic sarcophagi had a very high reputation which was reflected in their high price. They shared the market in Syria with Proconnesian; again Pentelic marble is not found in Syria for architectural use. In Egypt Attic sarcophagi are almost absent, but in Cyrenaica they had a virtual monopoly. In the West the main markets were Rome with a large agency based at Aquileia[309]. Proconnesian, however, is found in large numbers in Asia Minor and Syria, but it is not recorded in Greece (fig. 10). A couple have been found in Cyrenaica, but Proconnesian sarcophagi are found to the near exclusion of other types in Alexandria and the Black Sea area. This reflects the distribution of Proconnesian for architectural use. Proconnesian, however, is used for architecture in Rome under Hadrian, but sarcophagi are not recorded in number there until late Antiquity [310], though large numbers are recorded at Ravenna, thought to be the main agency [311]

Thus, it becomes clear that the distribution of a marble for architectural use differs from that of the same marble used for sarcophagi. Some Ephesian and Aphrodisian marble sarcophagi reached Rome but they enjoyed a much wider distribution in Asia Minor than either marble did for architectural use. One must assume that this was principally influenced by the workshops of craftsmen set up at these quarries.

MARBLE AND LATE ANTIQUITY

The quarry system employed by some quarries apparently ceases under Septimius Severus, but it is known from the Edict of Diocletian (AD 301) in which twenty marbles are listed, that many of the quarries worked into Late Antiquity. There is no doubt that due to the unrest in the 3rd century imports to Rome itself fell off greatly, but they did not cease [312]. There were still periods of considerable building activity. Presumably Septimius Severus and Caracalla imported stone as they did for Lepcis Magna. Not all demands could have been met by the re-use of earlier materials or from the marble yards. Under the Tetrarchy there was another great demand that occurred not only in Rome with the Baths of Diocletian and the Basilica of Maxentius, but elsewhere in imperial centres, and some of the marble could not possibly have been re-used from earlier buildings. The fact remain, however, that the quarry-mark accounting system finished at the end of the 2nd century AD. It may be that the lead seals took the place of the inscribed marks in the 3rd century. However, of the dated seals known only a small number are after 200 [313].

In the 4th, 5th and 6th centuries the Eastern Provinces flourished with much building activity, but materials were beginning to be re-used. The whole question of re-use is tied in with the end of quarrying and with information given by Diocletian's Edict.

The information in the Edict is the best place to start. Putting together all the fragments found [314] the names of 19 marbles have been identified (fig 11). The Edict was basically a list of various goods available at the beginning of the 4th century, from wages to animals and cloth. The list of stones represents those available commercially under Diocletian, and therefore presumably still being quarried.

Porfyritici is obviously the purple porphyry of Egypt. The quarries were certainly neglected after the Arab conquest but it is uncertain how long before that they had lain unworked. As already seen porphyry was transported to Constantinople from Rome by the Emperors, hence its name 'Roman' or 'Egyptian' marble by the Byzantine writers [315]. The early Byzantine emperors of the 4th and 5th centuries were buried in porphyry sarcophagi [316], the last being Marcian who died in AD 457. This is more than 150 years before the Arab invasion. Some slacking of exploitation of the porphyry quarries in the Egyptian desert may be noticed in the mid

4th century AD [317]. It is certain that there was no complete break in supplying Rome or Constantinople with porphyry works, but there was a delay and decrease in the size and number [318]. During the earlier, intensive period of exploitation some huge pieces of porphyry - columns and blocks - were delivered to Rome. Justinian used purple porphyry to adorn St. Sophia; this is known from the description of Paulus Silentiarius [319]. Obviously as far as Paulus was concerned the quarries were no longer in production and Vasiliev concludes that the purple porphyry needed for the decoration of St. Sophia was delivered to Constantinople from Rome, where it had been in the marble yards [320]. There is a tradition that the eight purple porphyry columns used in St. Sophia were ones taken by Justinian from Aurelian's Temple of the Sun in Rome [321]. An anonymous treatise, <u>On the Building of St. Sophia</u>, says that a certain widow Marcia, sent by boat from Rome eight Roman columns which she had received as a gift or dowry [322], "Roman column" meaning porphyry column. It is possible that after 457, the last imperial sarcophagus of purple porphyry, the quarries were so neglected and exhausted that it was beyond their capacity to manufacture such colossal pieces for sarcophagi; architecturally, however, there was enough of the material around to meet the needs of early Byzantine Constantinople. Thus a date of sometime in the 5th century for the ceasing of operations at the quarries would seem appropriate.

<u>Lacedaemonii</u> This stone, like purple porphyry because

of its hardness, was re-used many times in opus sectile. The Cosmati Brothers (late 12th to early 13th century AD) developed a distinctive form of flooring based on Lacedaemonian and purple porphyry. Lacedaemonian is used in St. Sophia, but it is likely to be re-used or transported from Rome. The quarries had probably ceased by the 4th/5th century AD.

Numidici (?) (assuming the reading is correct) The price of 100 denarii would seem reasonable. Inscriptions at the quarries continue into the 4th century [323]. The latest dated use, that is, not re-use, is in the Baths of Diocletian at Palmyra. Giallo was used in St. Sophia for veneer and paving, but this could have been supplied from Rome. On the epigraphic evidence a date in the late 4th century for the cessation of quarrying is indicated.

Luculleі As has been seen, very little is known about this marble. Its high price of 150 denarii presumably reflects the high regard afforded it (as well as high transport costs?). The quarries on Chios have not been investigated.

Pyrrhopoicili Pliny shows that this is the red granite from Aswan [324]. The latest uses are recorded under Diocletian at Palmyra, Rome and Split; the size surely precludes re-use. Red granite is found re-used in Constantinople, Damascus and Jerusalem. As with porphyries, granite was re-used rather than burnt fown for lime as were marbles. The quarries were probably no longer in production by the 5th century.

Claudiani The Mons Claudianus grey granite. The bulk of this material went to Rome and Ostia. The latest use of it is under Diocletian. The use at Split in the Mausoleum of Diocletian could be re-use as a number of different marbles and granites are used in the same colonnade. Thus, perhaps an earlier date of the mid 4th century for the end of quarrying would be appropriate [325].

Alabastreni This marble only appears in the Aezani text of the Edict [326] but to which alabaster it refers is not known.

Docimeni There is no doubt about this marble, but presumably it refers to the pavonazzetto variety. It is known from both the Theodosian Code and from the evidence at the quarries that the white and coloured marble flourished into the Byzantine period [327]. They were worked intermittently until modern times when intensive exploitation started up again.

Anacasteni and Euthydemiani Nothing is known of these two stones, but they are both relatively low in price and therefore presumably quarried near the sea. They both possibly came from Asia Minor [328].

Tripontici Nothing is known of this stone.

Thessalici verde antico The quarries, very important in the 5th and 6th centuries, provided marble for imperial sarcophagi once purple porphyry was no longer available, as well as for columns for St. John Studion and St. Sophia. Presumably the quarries stopped working soon after this.

Carusti The Carystian quarries of cipollino continued to be worked into the Byzantine period though on a much lesser scale [329]. It would appear that the Byzantines preferred the verde antico of Thessaly.

Scyriani breccia di settebasi Its use at Piazza Armerina probably means that the quarries continued into the 4th century, and probably stopped being worked by the end of the century.

Heracleotici Presumably the white marble from the Heracleia quarries in Asia Minor. As already stated, these quarries were extensively worked in Antiquity and may have continued to furnish local cities with marble well into the 6th century.

Lesbi The quarries have not been studied on Lesbos and the problem of identification precludes any estimate of its use outside the immediate area of Lesbos.

Thassi The Thasos quarries were still in production in the 6th century and were providing marble to Philippi. A number of coastal quarries were flooded about the 7th century which may have finally put an end to marble exploitation [330].

Proconnesi Extensive studies at the quarries show that the Proconnesian marble was quarried well into the Byzantine period [331]. It became the marble used for church decoration in Asia Minor and was, of course, especially used in Constantinople.

Potamogalleni Gnoli identifies this with the λιθος Σαγγαριος of the Byzantine sources [332]. The stone was widely used in Byzantine times, in particular for imperial sarcophagi in the 8th to 10th centuries, but it is rare before late Antiquity [333].

There are some notable ommissions - africano, Iasos, Luna, Paros, Pentelic, portasanta, rosso antico and Troad granite. The africano quarries had probably ceased production by the mid 3rd century [334], and presumably the portasanta and rosso quarries stopped being worked before Diocletian. Pentelic has been an exception all the way along. Paros marble may also have ceased by the 4th century. Iasos is used from the 3rd century onwards and is extensively used in the Byzantine period, but it may not have reached a high degree of prominence by AD 301. The ommission of Troad granite, however, is difficult to explain. This granite was exported in enormous quantities in the Eastern Mediterranean and was obviously flourishing in the early 5th century because of the edict in the Theodosian code [335]. Obviously it may be one of the unidentified names in the Edict, but there are epigraphic references to columnae Troadensis [336] which have been archaeologically verified. The only point therefore that appears to be certain is that Troad was omitted; the reasons why are elusive.

As can be seen a central factor to the discussion of quarries and their working in Late Antiquity is that of re-use. The re-use of marble within the Roman period is not necessarily a sign of a decline in building standards, nor is it a sign that a particular marble quarry has ceased production, but it shows an intelligent use of the available resources. One particular example is at Ephesus where a certain wealthy lady called Scholastikia, in c. AD 400, demolished several buildings including the Prytaneion, in order to acquire stone and marble for the construction of the Scholastikia Baths. Also at Ephesus, the colonnaded streets, reconstructed at several periods in the Roman period, were made up in their later phases of re-used columns.

As quarries ceased to provide marble and granite, re-use became a necessity if marble was required. Though at the same time, columns may have been used in later periods simply because they were conveniently to hand, as for example, in Damascus. The fate of a lot of marble was the lime kilns. Lanciani gives an account of the activities in Rome of the calcarii, the lime-burners [337]. Presumably this also happened in the East, but a large amount, as in Rome, were re-used in religious buildings, churches, mosques, and it is because of this that they survive.

The organisation of the Roman marble trade was almost entirely dependent on the stable conditions created by the Pax Romana, and with the collapse of central authority it too was bound to collapse. Obviously, as already seen, this did not happen overnight. However, it is doubtful that the principal quarries were still in imperial control after the 3rd century, Some perhaps were but there appears to have been a general drift back to the original customer-quarry relationship. Admittedly most of the major quarries lay within the ambit of Constantinople, which continued to afford reasonably peaceful conditions and an assured market. The Theodosian Code gives valuable information on this.

Under Constantine in 320 an edict was issued which granted the right to quarry marble to any person who wished [338]. In 363 another edict states that the desire for marble had put the price up and that anyone who applies for a license to quarry marble will be granted one. Thus in the 4th century the quarrying of marble is being encouraged and the quarries are to be the object of private enterprise [339]. By 393 private persons are not allowed to operate marble quarries [340]. Presumably this is the state minimising competition for workers and the market from private owners.

Having mentioned reports of material being taken from Rome to Constantinople, in 357 an edict was issued stating that materials should not be taken from one city to embellish another [341].

This gradual move back to the previous system must have caused a number of quarries to close. There was a decreased demand anyway, and many needs could be met from the quantities of material in the marble yards at Rome. In Late Antiquity, there was a smaller range of stones in use, presumably partly due to Byzantine taste [342]. The closing of quarries cannot be blamed on the invasions of the Arabs. Most of them were in decline already and the important ones, such as Proconnesus and Docimium appeared to survive these events which were so disastrous elsewhere.

CHAPTER V

FOUNDATIONS, WALLS AND GENERAL CONSTRUCTION

FOUNDATIONS

The fact that the ancient architects were aware of the importance of good, solid foundations is obvious from an inspection of the surviving monuments. The ideal foundation is bedrock which requires little additional work except for some trimming and levelling. It is this that has ensured the survival of most of the earlier structures that are still standing from the pyramids onwards.

The role of foundations is to keep the structure above ground and to support it without undue movement. As a result, clay, silt and loose sand are much less suited for foundations because of their inability to support directly large concentrated loads. Like any other structural form, a foundation will be deformed to some extent as it takes up the load put upon it. This is usually a slight vertical sinking, and it is generally important that this should be uniform and not vary from place to place. Differential sinking, as exemplified by the Leaning Tower of Pisa, can be much more serious than a sinking of the structure as a whole. It can cause tilting, as with the Tower of Pisa, or total collapse as with one of the columns of the Temple of Olympian Zeus in Athens. Tacitus [1] reports the collapse of a wooden amphitheatre at Fidena, built by a certain Atilius. The collapse occurred because the foundations were not on solid ground and the whole structure was not properly braced. Under the weight of people, the amphitheatre broke inward and sagged outward. Unstable foundations can cause fundamental problems with structures of mortared rubble. The material itself was less compact and less monolithic than the solid concrete of Italy. The concrete was certainly prone to cracking as the building settled, but this did not badly effect the general stability of the structure. With the much looser nature of the mortared rubble, this cracking could have had very serious repercussions.

The typically Greek form of substructure for temples was either bedrock or a stone platform or a combination of the two. The Temple of Apollo at Delphi was built on a cellular stone platform which itself was built on a fairly steeply sloping natural rock. The stone blocks were accurately cut and were of uniform size clamped together and also interlocked at their intersections in order to maximise the resistance to any relative lateral displacement. The Partheneon was constructed on an artificial platform terraced out from the summit of the Acropolis to form a level.

The Romans took similar care with the foundations of their monuments. The important Roman innovation was the massive concrete footing, for example the solid ring of concrete, 4.5 m deep, of the Pantheon in Rome. This, of course, was most important for the underwater foundations of jetties and harbour moles, for example at Ostia, and in the Eastern Mediterranean, at Tiberias [2].

Concrete was used for the foundations of the Roman circus at Antioch-on-the-Orontes [3]. The forms for the concrete varied in height from 0.60 m - 0.7 m. The concrete was made up of lime and coarse river sand with an aggregate of fieldstones laid in regular courses. There was an average of five courses to one cast and between each cast there was a thin levelling bed of lime.

However, generally in the Eastern Provinces, either bedrock or a solid platform of masonry on bedrock was constructed. The nature of the foundations cannot always be ascertained. The podium of the Temple of Artemis at Jerash was constructed on bedrock, but some massive masonry foundations were also built. These comprised a series of parallel barrel vaults which formed a terrace out from the hillside for the temple <u>temenos</u>. One of the most impressive examples is that of the Temple of Bacchus at Baalbek. In places the foundations extend down to bedrock by as much as 17 m (56 ft) below ground level [4]. With a number of buildings the construction of an artificial platform or terrace was involved. At Pergamum the Temple of Trajan on the acropolis was built on a terrace measuring 69 by 58 m, which levelled off the highest part of the acropolis by means of an arched and vaulted substructure [5]. It basically comprised three parallel series of barrel vaults; the first supported the temple itself, the second carried the flight of steps approaching the temple from the west, and the third created the <u>temenos</u> around the building. This latter system was made up of eleven vaults. These were 19.30 m long, about 3.80 m wide and were carried on walls

2.20 m thick [6]. The Temple of Hadrian at Cyzicus is supported in a similar way by seven parallel vaults (see Chapter VII) and the basilica at Aspendos has substructures made up of a vault of pitched-brick (see Chapter VII).

The Sanctuary of Bel at Palmyra illustrates another method of forming a level area upon which to build. The Temple itself was constructed on an artificial hill. The extension of the <u>temenos</u> towards the end of the 1st century AD involved the extension of the central hill out to the surrounding colonnades. This was a massive filling operation and the <u>podium</u> of the <u>temenos</u> walls was not only to give a more impressive appearance, but was also to retain the higher level within [7].

<u>WALLS AND SUPPORTS</u>

<u>Mudbrick</u>

Mudbrick was a material much used for monumental architecture in Mesopotamia and Dynastic Egypt, for instance, at Ur and at Thebes (see Chapter VII). However, apart from some archaic temples, mudbrick was only used for domestic housing by the Greeks. As far as they were concerned, it could play no part in the development of monumental architecture. This remained the situation, for the most part, in the Eastern Roman Provinces. However, there were some notable exceptions, though in some areas these may not have been unusual in the Roman period.

Karanis and Soknopaiou Nesos in the Faiyum in Egypt have already been noted for the extraordinary survival of the use of mudbrick and of various associated vaulting techniques (see page 50). All construction was carried out in mudbrick. In Area G at Karanis in the later period (late 4th and early 5th centuries) [8], the walls were bricks laid in irregular courses of headers and stretchers. The bricks were held together with mud mortar that was mixed with a large amount of straw and was unevenly applied. In the walls belonging to the earlier period (2nd to 4th century) the bricks were laid with much greater care in regular courses and bonded with a fine mud mortar, about 0.01 m thick, evenly applied.

The city of Androna (il Anderin) in Northern Syria, which flourished into the 6th century AD, was almost entirely built out of mudbrick. Only the city walls, and the churches, were of neatly cut and fitted stone [9]. At Dura the northern section of the East city wall was built in mudbrick [10], and apart from some use of gypsum and fired brick, the major part of construction was in mudbrick.

STONE

Stone was used for monumental construction in the Eastern Mediterranean alongside mudbrick down to the end of the second millenium BC, when, in such areas as Greece and Asia Minor, it becomes the material most often used for this type of building.

In Egypt, the earliest stone buildings of blocks with close joints date to the 4th millenium BC, for example, in a First Dynasty tomb at Saqqara [11]. The use of stone, however, was almost entirely confined to palaces, temples etc. The most famous of Ancient Egyptian monuments of stone are, of course, the pyramids.

Mycenaean architecture is characterised by the type of walling known as Cyclopaean (Plate 82). This was made up of very large and irregular pieces of stone, roughly trimmed and piled up together, with smaller pieces of stone wedged in between to hold the whole together. Such masonry can be seen at Tiryns and Mycenae as well as on contemporary sites in Asia Minor [12]. The earliest wall at Tiryns dates to about 1400 BC and consists of enormous blocks, each weighing several tons. Hardly any trimming of the stone has been carried out, and the blocks were fitted together with the insertion of smaller pieces and clay packing; the wall averages 20 ft in thickness and was at least as high [13]. A similar arrangement existed at Mycenae. This type of masonry gave way to polygonal masonry, for example, the terrace of the Temple of Apollo at Delphi (Plate 83), and the retaining wall of the tomb of Lysimachides of Acharres in the Kerameikos Cemetery in Athens, dated to the mid 5th century. Both Cyclopaean and polygonal masonry were also used in Italy; good examples are at Ameria, Norba, Signia, Praenestae, Pyrgi, Cosa and Terracina [14].

By the 5th century BC ashlar masonry had developed and there were several different methods of building ashlar walls. Vitruvius mentions three [15]:

i) isodomic which used ashlar cut to standard sizes and laid in uniform courses;

ii) pseudo-isodomic where the blocks are laid in courses of uneven height and often thin blocks pass throughout the whole thickness of the wall, thereby reinforcing it;

iii) ἐμπλεκτον which consists of a solid core of unbroken stones, that is, not rubble, laid in courses. Vitruvius says that they were set in mortar [16], but Tomlinson [17] suggests that the use of mortar in this way was a late one and that earlier walls built in this way were dry-stone. The core of the walls was bonded to two faces of worked stone by means of headers and through stones. As a result of the use of headers and stretchers, the surface pattern of the faces resembles that of woven cloth, hence the name emplekton.

Mortar did not play a part in ashlar wall construction until the Hellenistic period [18]. The classical Greeks built their walls of blocks fitted perfectly together. With the use of finer stones, especially marble, the joints could be ground together very finely. This eliminated the instability caused by uneven stressing of the blocks which was so characteristic of earlier walls [19]. As a result walls could be constructed with a much reduced thickness without loss of strength.

If a bonding material was required in the Greek classical period, iron was used, dowels to fasten the blocks to those below them, and clamps of a double-T or dove-tail shape to connect blocks in the same course; all were seated in molten lead. The use of metal ties was to prevent lateral movement, especially as earthquakes were frequent. However, their use was expensive and was therefore restricted to the most esteemed buildings.

These three methods of ashlar masonry, isodomic, pseudo-isodomic and emplekton, as well as polygonal masonry, all survived in use through the Hellenistic period into the Roman period, especially in Asia Minor and the Levant. There were very few differences in technique; whereas clay or mud was used as a binder for the core (that is, if a binder was actually used) in the classical period, lime mortar began to be used in the later Hellenistic period. There was also a much wider variation in the use of metal clamps. Some cities used no binder at all to hold the stone blocks together [20].

Many cities in Asia Minor remained true to the Hellenistic traditions of stone masonry in some form or another; some more than others. Cities such as Ephesus, Pergamum, Sardis, Smyrna and Antioch-on-the-Orontes, adopted the new materials and techniques at a much faster rate, probably due to a much more direct Roman political, cultural or economic influence at an earlier time, because of their administrative or geographical importance. Cities such as Hieropolis, Arykanda, Myra, Cremna, Perge, Side and Aspendos all either adopted the new materials and techniques at a much later date or, as in the case of Hierapolis and Arykanda in particular, adopted just the techniques, constructing in stone as in the Hellenistic period. In the Levant, stone building continued to a much greater extent in all cities, even Bostra and Philippopolis, which display a great Roman influence in the use of concrete.

Despite its antiquity, polygonal masonry still remained in use at Arykanda in the theatre (2nd century BC). The back-wall of the stage-building was built of polygonal masonry. The walls and retaining walls of the agora below the theatre terrace were also of polygonal masonry, in this case of Cyclopaean proportions (Plate 84). Parts of the baths also used this type of masonry. Polygonal masonry was also used at Andriake in the Hadrianic granary (Plate 85). This is a particularly interesting example. Viewed from the front the building is constructed of quite superb drafted masonry, marred only by the lifting bosses still left on some of the blocks (Plate 86). However, the back-wall is constructed of much less well-finished stone, very closely resembling polygonal masonry. The dividing walls within the structure also show this type of construction.

At Arykanda, apart from the polygonal masonry, all other work was pseudo-isodomic. The masonry at Termessos, in the mountains to the west of Antalya, was both isodomic and pseudo-isodomic, with the main differences being in the finishing of the stone blocks; for instance, the <u>parodoi</u> of the theatre are only roughly dressed whereas the Gymnasium walls and those of the *bouleuterion* are beautifully drafted (Plate 87).

Isodomic masonry occurs at Cremna in the Library and at Myra in the theatre, both instances with well-finished blocks (Plate 88). Stone walls also occur on other sites, for example at Hierapolis in the two sets of baths. Here the coursing and the sizes of the blocks are not as regular but they are still finely dressed.

Much of the stone walling of Asia Minor, however, is difficult to put into any particular category. The workmanship varied from one region to another and depended very much on the available stone. Other cities which extensively used stone for walls in Asia Minor are Perge, Side, Assos, Alexandria Troas and Alinda.

Further East, stone is the principal building material and at almost all Roman sites it was used extensively for solid wall construction. Two influences were at work in the Levant in the immediate pre-Roman period. One was that of the Nabataeans, the nomad people who settled from Damascus in the north to Aqaba in the south by about 4th century BC, with their capital at Petra. By the 1st century BC they had become highly skilled in the handling of the soft sandstones of Petra itself and, more important perhaps, they had developed exceptional skills in the cutting and carving of the hard and intractable basalt rocks in the area of the Hauran. The second influence is found in the building programme of Herod in Jerusalem. Herod's building activities in the city were very much circumscribed by the hostility of the population [21]. However, two buildings which changed the whole aspect of the city were the Temple and Herod's palace on the western ridge. One factor becomes clear when one looks at Herodian architecture in general: in both planning and in the approach to the problems of construction the buildings seem to have leaned heavily on contemporary Roman experience, freely interpreted in terms of local materials, building skills and traditions.

The Palace and Temple were linked by two viaducts across the central valley; Wilson's Arch and Robinson's Arch were once part of these. All construction was in stone, Robinson's Arch (Plate 89) being 28 m above its base or about 20 m above the pavement which ran beneath it [22], displaying a great deal of familiarity with the materials and the techniques in employ.

The most noteworthy aspect of the Herodian masonry, apart from its size, is its visual aspect (Plate 90). Nothing of this kind had been seen in Jerusalem; the surviving masonry of the Maccabaean period was of very poor quality. Presumably masons were brought from Syria [23]. Architects from Rome must have been at work in the Wadi Qelt so it would not be unreasonable to assume that they were present in Jerusalem as well. There are no known parallels for Herodian masonry, however. The characteristic of the stonework of the heavy walls is stones of very large size with narrow flat margins and very slight bosses with a beautiful flat finish. (Plate 91).

At Roman sites most of the work is headers and stretchers, sometimes with a core of rougher stones. Examples of the various arrangements can be seen at Jerash. In walls of moderate thickness, no core was needed and walls were built up of headers and stretchers which bound the wall together, for example in the south wall of the Temple of Zeus, the back wall of the stage-building of the South Theatre, and in the cella walls of the Temple of Artemis (Plate 92). Obviously this binds the whole together. Even with a core of rougher stones binders were still included, for instance, in the Temple of Zeus at Jerash, forming a type of emplekton masonry (Plate 93). A particularly interesting instance is in the podium of the Temple of Artemis at Jerash, as it ties in with what Vitruvius says about emplekton masonry . He says "At intervals they lay single stones which run through the entire thickness of the wall. These stones, which show at each end, are called diatonos, and by their bonding powers they add greatly to the solidity of the walls" [24]. The masonry of the podium is of regular courses with headers and stretchers (Plate 94). On the headers are inscribed ΔΙΗ which must correspond to the diatonos of Vitruvius (Plate 95). Another example of emplekton-type masonry is in the Qasr el-Bint at Petra (Plate 96). In contrast, in the Triumphal Arch at Jerash, there is no special attempt to bond the well-cut and trimmed facing blocks to the core. As a result the walls eventually buckled [25].

The dressing and finishing of the blocks depended on the nature of the stone used and where it was used in a particular building. The outer walls that were not supposed to be seen, for instance, the outer wall of a theatre or odeum stage-building, were constructed of blocks which had drafted margins but the rest of the surface was left slightly rusticated. This can be seen very well in the outer wall of the odeum stage-building and the back of the nymphaeum in Amman (Plate 2) and the back wall of the stage-building of the South Theatre at Jerash (Plate 97).

As well as masonry walls, stone was ideal for the construction of load-bearing piers and columns. Obviously stone columns have a long history. Columns of superimposed stone drums were used in Ancient Egypt, for example, in the hypostyle hall of the 13th century BC Ramesseum at Thebes [26]. In the Greek period, the development of the masonry column was concerned with refining the basic form, making them appear, in reality or by means of optical refinements, to be less massive while still allowing them a full role as supports. In the later Hellenistic and Roman period, the form developed as far as it would go, with the use of monolithic shafts such as at Baalbek and Ephesus (see Chapter VII). Columns made up of drums, however, were still frequently used, for example, at Pergamum, Palmyra (Plate 98) and Jerash. With the development of the use of marble and granite the use of monolithic columns became very common.

Despite the introduction of new materials for vaulting, dressed stone was instinctively and invariably used for load-bearing piers. This occurs as late as the 6th century in St. Sophia at Constantinople and in the Basilica of St. John at Ephesus (Plate 99). Stone was admirably suited for the construction of load-bearing piers because of its high performance in compression, and is often found as a support for vaults of other materials. This is a particularly characteristic feature of construction in Asia Minor. Stone piers are used in conjunction with mortared rubble and brick in the Baths/Gymnasium complex at Sardis (Plate 100) and at Ephesus in the Harbour Baths, in conjunction with brick vaulting (Plate 101). In the Asclepieion at Pergamum the substructures of the rotunda at the south-east corner consist of a mortared rubble annular vault supported on piers of large ashlar masonry with much smaller blocks of stone less accurately cut and fitted (Plate 102).

CONCRETE

The use of concrete in the Eastern Mediterranean was a localised one (fig. 13), but did occur where there was a direct Roman influence on building in conjunction with the availability of the right materials. It is important to stress the problem created by the use of the word 'concrete' which has often been applied to rubble mortared together, as was commonly used in Asia Minor, but this causes confusion because the physical properties of this method are not the same. 'Concrete' must be used to refer to the material which was very similar in appearance, properties and use to the Roman <u>opus caementicium</u>.

The main areas of concrete construction were the Hauran, Antioch-on-the-Orontes and Cilicia. Bostra and Philippopolis were extensively constructed from a concrete utilising the local volcanic stones. Brown and grey lumps, about 3 cm in diameter, were set in courses in an abundance of brownish mortar, the strength of which was gained from the use of crushed volcanic stones in its make-up. The concrete appears to have been built up as one with the stone ashlar facing. This type of construction and material was not used for all wall construction but was used for the walls of the Philippeion and the Kalybe at Philippopolis [27], and at Bostra for the walls of the South Baths (Plate 103) and the North-West Baths [28].

River boulders and fieldstones were the main aggregate for the concrete used at Antioch and in Cilicia. At Antioch in Bath B, all the walls are faced with brick with a core of rounded stones set in a hard mortar of lime and sand with the addition of a little ash. In Bath C (2nd century) the upper walls of the hypocausts have a core comprising a mixture of rounded pebbles of widely differing sizes. At irregular intervals single courses of bricks were carried through into the core, sometimes extending through the whole thickness of the wall. Pieces of brick and roof tiles were also embedded with the pebbles in a very hard mortar of lime, crushed stone, a quantity of ordinary pebbles and bits of brick.

The report states that this was the hardest material which the excavators had to deal with [29]. The seating supports of the Roman circus, which are all that survive of the structure, were also of concrete (Plate 104). The aggregate was large river boulders set in courses in a white/grey mortar; exactly the same kind of construction was used for the so-called Temple complex to the east of the circus [30].

The main sites in Cilicia at which the use of concrete has been identified are Elaeusa-Sebaste, Korykos and Augusta Ciliciae. At Elaeusa-Sebaste (modern Ayaş), in the Reticulate Baths, the core of the walls was made up of a concrete resembling Roman <u>opus caementicium</u> in texture, with splinters of white limestone for the aggregate. Each course had fused into a unified whole. The walls were faced with <u>opus reticulatum</u>, hence the name of the Baths. At Korykos the concrete used in the two bath-buildings was of a similar kind to that used at Elaeusa [31]. At Korykos, however, the core is brought to a face with a variety of <u>opus incertum</u>. At Augusta Ciliciae, concrete was used for most of the Roman buildings which Gough identified [32]. It was made of a lime mortar, again very like Roman <u>opus caementicium</u>, with an aggregate of large water-worn stones. As far as could be ascertained, all the buildings were faced with bricks (Appendix II A, 9, 10, 11).

Two sites where concrete was used but which do not fall into any of the above areas are Caesarea and the Herodian Winter Palace in the Wadi Qelt near Jericho.

A study of Herod's building programmes reveals a strong Italian influence in both materials and techniques [33], and the Winter Palace is no exception. The whole complex is a mixture of native and Roman traditions, with mudbrick, stone and timber used alongside a type of concrete and opus reticulatum (Plate 105). The report states that the 'concrete' is 'not a true Roman concrete after the pattern of the Italian cement made with pozzolana' [34], but is simply a good grade mortar. However, it goes on '... the method of handling the stones in the mortar here at Jericho is a characteristic concrete technique. Roman architects and Roman builders were definitely in charge of this work'. At Caesarea, however, concrete was definitely used for the main structure of the theatre, with stone seating [35].

The use of concrete at Corinth continued in the Roman period (see Chapter III). However, it was only a very grudging appearance, in contexts which were apparently derived almost directly from early Imperial Italian use. It was used for the cores of the temple podia, in the substructures of the theatre and odeum (rebuilt mid 2nd century), for the vaulting of the North-West shops built under the Flavians and in the Baths of Eurykles (2nd century) [36].

MORTARED RUBBLE

Mortared rubble was extensively used for wall construction in Asia Minor and the Balkans, often in conjunction with brick or stone, and faced in a number of different ways. It was also employed in Syria, but to a lesser extent (fig. 12).

The mortared rubble of the Eastern Provinces consisted essentially of a core of irregular lumps of whatever stone was available laid in horizontal courses in mortar and faced (see page 46). The core was laid in precisely the same courses as the facing. The core and facing were obviously built in a single operation. The proportion of stone to mortar was higher than in any but the poorest Italian concrete [37]. It had a much thicker consistency than concrete and its construction was far looser. As a result of this, air pockets were left in the fabric of the wall and because the mortar dried so quickly there was no chance for the horizontal layers to fuse into a single compact mass.

The quality of the mortared rubble varied from one region to another and depended on the quality and size of the aggregate used, as much as on the quality of the mortar; in some areas it came very close in consistency and strength to the opus caementicium of Rome. Its use continued into the Byzantine period when it was most often used in conjunction with bands of brickwork (see Appendix II B).

The earliest instance of mortared rubble employed for wall construction is in the aqueduct of Pollio at Ephesus (AD 4 - 14), and by the end of the 1st century AD its use was firmly established in the cities of Western Asia Minor, for example, Baths of Capito at Miletus (Claudian), the Humeitepe Baths at Miletus, the extensions to the theatre at Ephesus, the nymphaeum and aqueduct at Miletus (Plate 106) (all late 1st century AD). Early 2nd century examples include the Hadrianic Baths (Plate 107) and the rotunda substructures in the Asclepieion at Pergamum, the Hadrianic Baths at Aphrodisias, and the Vedius Gymnasium at Ephesus.

In Syria the use of mortared rubble was much less favoured. It was used at Bostra and Philippolpolis for the city walls in the 2nd and 3rd centuries respectively. The walls were built up of two faces of roughly quadrated blocks with a core of large lumps of basalt mortared together. Obviously without analysis it is often impossible to tell the difference between concrete and mortared rubble, but generally speaking these instances of mortared rubble in the Hauran are of a much less compact nature than the concrete used for the vaulting. This looser type of construction was also used for the walls of the Hexastyle Temple at Philippopolis [38].

By the end of the 2nd century the use of mortared rubble begins to appear in the architecture of the Balkans, especially in association with other materials. At Doclea in South-eastern Yugoslavia, the characteristic masonry of the 2nd century buildings, and indeed of the whole region, was alternating dressed stone with coursed mortared rubblework brought to a face with small squared blocks of stone [39]. Ward-Perkins views this as a local equivalent of the Roman concrete and opus reticulatum and brick facings and sees this type of construction spreading from Northern Italy. Mortared rubble was, by this time, firmly established in both Greece and Asia Minor for wall construction. The use of mortared rubble with brick bands was in very early use in Greece (Appendix II B, 2 - 6, 10, 11), and it does not seem improbable that it spread north to Thrace and thence to Asia Minor. There does appear to be a definite chronological progression from Greece northwards and eastwards. It was well-established by the early 3rd century AD in Asia Minor and it was ultimately to be taken over by the architects of Constantinople (see Appendix II B). However, although it was well-established in the city by Constantine, by the 6th century AD it was obsolete [40].

BRICK

The study of the use of fired brick for wall construction stimulates much argument and debate because of the varied techniques with which it is associated in the Roman Empire. However, it is possible, on present evidence, to make some general observations. As will be seen, though, the evidence is not always reliable nor the ways in which it has been interpreted.

Fired brick was exploited to the full in the Eastern Provinces and was used as a construction material in its own right. In the West one does not find wall construction of solid brick until the Tetrarchic period, the most prominent examples being at Trier (Plate 108), in the Basilica and the Kaiserthermen (Plate 109).

Brick made its first appearance in Greece and Asia

Minor in the early 1st century AD, for example at Argos and Elaeusa-Sebaste (see Appendix II, A and B). In the Balkans, however, tombs incorporating brick have been found dating to the 4th century BC [41]. By the beginning of the 2nd century AD brick was firmly established as a major building material thoughout the area.

The walls were made up of coursed bricks, whole and broken, set in mortar and brought to a face with bricks, the size and type depending on a number of factors. Such a construction did in fact appear in Rome in the early imperial period and was referred to by Vitruvius as <u>structura testacea</u> [42]. In this form roof tiles were laid in irregular rows in an abundance of strong Roman mortar and faced with roof tiles. This method had disappeared by the mid 1st century AD as other materials were used in conjunction with the tiles in the mortar - tufa, <u>selce</u> and broken bricks. There is no evidence to suggest that this <u>structura testacea</u> was a precursor to the brickwork of the East. However, there was considerable Roman activity in Southern Asia Minor with Augustus' colonisation programme and it would not be impossible for a similar type of material and construction to be used for the monumental architecture.

Solid brick walls are found, for example, at Argos, Olympia, Epidaurus, Tralles, Ephesus (Plate 110), Palmyra (Plate 111), Aspendos and Apamea (see Appendix II A). Brick was also used in conjunction with mortared rubble (page 164) in Greece, the Balkans and Asia Minor, (see Appendix II B). The brick bands, usually four to eight courses, gave stability and strength to the loosely compacted mortared rubble as they went right through the thickness of the wall [43]. This type of construction appears in the West in the Late Empire in the Kaiserthermen at Trier and in the aqueduct of Los Milagro, at Mérida [44]. It is not found in Syria until its appearance in the 6th century AD at Qasr ibn Warden.

Roman bricks varied in size and shape [45], but in the Eastern Mediterranean the bricks in normal use were roughly square or rectangular (for example, Eleusis, 0.40 - 0.42 by 0.30 m - 0.34 m; Augusta Ciliciae, 0.42 m by 0.28 m) and in Asia Minor bricks averaged 0.30 m to 0.35 m square. These would have been equivalent to the <u>pedales</u> of western Roman use; this size of brick was rare in Rome [46]. <u>Bipedales</u> (average 0.60 m square) were regularly used for bonding courses in Rome from Domitian [47], and bricks of very similar size were used in Greece and the East from the early 1st century AD. Brickwork containing bonders like this in the Theatre Baths at Argos is dated by Ginouvès to the late 1st century on this account [48].

The methods of dating Roman brickwork has attracted much attention from scholars [49]. It has been generally accepted that the fact that mortar joints apparently become thicker with time is an important dating criterion for the brickwork of the capital. R. Cagnat and V. Chapot give the following figures [50]:

Claudius - Domitian	2 joints	thickness of 1 brick (Plate 112)
Hadrian	3 joints	thickness of 2 bricks
Septimius Severus	4 joints	thickness of 3 bricks
Maxentius	1 joint	thickness of 1 brick (Plate 113)

Broadly speaking van Deman and Lugli agree with these figures (Appendix II C, Table 1), but it must be appreciated that there was variation and irregularity. When Lugli's figures are plotted on a graph (Appendix II D, Graph 1) it is possible to note an increase in mortar joint along with a decrease in brick thickness, with the mortar joints increasing to a greater degree. In the Hadrianic period there is very little variation in the thickness of the mortar joints, but in the 3rd and 4th centuries enormous variations occur in the thickness of mortar joints and the thickness of bricks. Under Constantine and up to Theodoric the maximum thickness of mortar is greater than the maximum thickness of bricks. The whole scheme generally shows that the mortar joints increase in thickness in time and the bricks decrease in thickness, but it is not a continuous progression. The average thickness of the bricks which diminished under Claudius to Titus, increased with a certain regularity but only by a small amount to Hadrian, after which it decreased until Elagabalus/Probus. A new increase then showed under Diocletian to Constantine followed by a final sloping off.

There are buildings which do not fall into this scheme. In the tomb of Annia Regilla, the wife of

Herodes Atticus, for example, which is dated to AD 150 to 160, the brick thickness is 2.5 cm - 3 cm, while the mortar joints are 0.5 - 0.7 cm [51]. The figures given by Lugli for the period are 3.2 - 3.6 cm for the bricks and 1.5 - 1.8 cm for mortar joints [52]. This demonstrates clearly that one must be mindful of adhering too closely to the general scheme. Ginouvès is perhaps at fault in this respect. His aim is to show that the brickwork sequence at Argos follows that at Rome, but there are a number of buildings at the site which have no dating evidence. Ginouvès dates these by comparing their brickwork with that of dated buildings in Rome; he therefore makes the assumption that the brickwork in Argos does follow the Roman pattern. There are however, some important and fundamental differences (see below). However, his work is of great value for the study of brickwork in the Eastern Mediterrranean. All the figures used here for Asia Minor are either those collected by the writer or those of Ward-Perkins or Deichmann [53].

The figures show that in Rome as brick thicknesses decrease, so mortar joints increase. However, from Severus to Diocletian the bricks appear thicker, probably due to the fact that broken <u>bipedales</u>, thicker than normal bricks, are now being used for the facing. The bricks used under Diocletian are not <u>bipedales</u> and thus they do appear thinner in comparison with those used in the preceding period. The mortar joints therefore appear correspondingly thicker.

In Greece the diminution in thickness of the bricks and the increase of the mortar joints is particularly marked so that by the 4th century the mortar joints are almost twice the thickness of the bricks (Appendix II D, Graph 2). In Asia Minor and Syria the brick thicknesses remain remarkably consistent and are on the whole thicker than those used in Rome [54]. In the 2nd century on average they become a little thinner but rise again in the 3rd century. The mortar joints display a considerable amount of irregularity and variation which may, of course, be due to the scarcity of the available statistics. However, there does seem to have been a general increase to the 6th century when the proportion of brick to mortar joint is approximately 1:1 (Appendix II D, Graph 3).

If one looks at the available figures for the height of certain brick and mortar joint modules one can draw several useful conclusions (Appendix II C, Table 5). In Rome a module of 5 courses of bricks (and 5 of mortar) varies from 23 to 30 cm from Augustus to Theodoric, only a few centimetres in almost 500 years. In the East there is an altogether different situation. Generally, speaking, everything is thicker in the East, even in the early Empire. The Greek figures appear to be nearer those for Rome than do the figures for Asia Minor and Syria. At the end of the 1st century and the beginning of the 2nd the Roman and Greek are the closest, 5 courses in Rome = 26 - 28 cm, 10 courses in Greece = 0.50-0.60 m. From the mid to late 2nd century, however, in Greece and Asia Minor and Syria the height of the courses greatly increases.

Unfortunately until more work can be carried out in the East the only figures we have are those set out in Appendix II, and because of the smallness of the sample, only general observations can be made. More measurements need to be taken in order to verify or modify these observations.

FACINGS

Mortared rubble and concrete walls were faced in various ways in the Eastern Mediterranean.

Facings for mortared rubble were as far as possible small squared stones similar to the *petit appareil* of Gaul. This is especially characteristic of Ephesus and Pergamum, for example, the Baths of Vedius and the Hadrianic Baths. This can also be seen at Aphrodisias in the Hadrianic Baths and in the 3rd century baths at Perge. A particularly well-preserved example is that of the walls of Nicaea in Bithynia (AD 258 - 269) which are built of alternating bands of brickwork and mortared rubble. The latter is faced with small stones rather like Roman *opus incertum* and the resemblance to Gallic *petit appareil* is particularly clear. In areas where the local stone was more intractable by nature there was a dependence of fieldstones or riverstones. This is characteristic of Miletus, for example in the Baths of Capito, the Humeitepe Baths and the Baths of Faustina as well as the *nymphaeum*. It is also found at Sardis in the Baths-Gymnasium complex, in the Gymnasium at Alexandria Troas and at Anemurium.

As well as being used as a material in its own right, fired brick was also used on a few occasions as a facing material. Presumably this does reflect a direct western influence. This becomes more obvious when one looks at the sites where this occurs: Antioch-on-the-Orontes in Bath C [55], Myra in a building published as a bath building [56], and at Augusta Cilicae where the concrete buildings were faced with brick. Both Antioch and Augusta Cilicae had direct links with Rome. Myra is perhaps more difficult to explain, but the building is late, possibly of 4th century date and may reflect some contact with Constantinople (Plate 114).

In Augustan Rome the typical facing technique was <u>opus reticulatum</u>, square-based pyramidal blocks set point inwards, diamond fashion. This is found in Cilicia at the same time in the Reticualte Baths at Elaeusa-Sebaste [57]. Several other examples of this type of facing occur in the Eastern Mediterranean contemporaneously and after. At Jericho in the Wadi Qelt Herod built a Winter Palace complex which reveals the Italian influences at work under Herod. On the south bank of the Wadi was a sunken garden contained by an imposing façade with decorative niches and a terraced hemicycle in the centre all carried out in <u>opus reticulatum</u>. The residential wing on the north bank also extensively incorporated the technique (Plate 105). Another Herodian example is at Paneion [58]. At Jerusalem a circular building was recently discovered to the north-west of the Damascus Gate. This was also faced with opus reticulatum and has been dated to the time of Herod. The same technique was also used at Olympia in the 'House of Nero' [60], and an early mausoleum at Corinth on the Kenchreai road incorporates reticulate masonry [61]. Two later examples occur in Syria. The early 2nd century aqueduct on the plain of Daphne near Antioch was faced throughout with opus reticulatum formed of fairly carefully dressed small stones of uniform size [62]. At Homs Butler reported remains of a Roman mausoleum which he dated to the 2nd century. This was faced completely with reticulate masonry [63]. These examples must represent Italian influence as do those using brick as a facing material. Opus reticulatum may have been copied in the East as a particularly prestigious form of facing that would immediately have had some cultural meaning to whoever saw it (fig. 12).

CHAPTER VI

TIMBER CONSTRUCTION

Until the 18th century and the advent of massive iron and steel production timber was the only structural material which had tensile strengths to match its compressive ones, and which was available in quantity and in suitable sizes for the construction of roofs, floors, etc. Since prehistoric times timber supplies have been exploited wherever they grew, leading to excessive depletion of the better supplies and to marked variations from one time to another in what was available even in a single locality.

WALLS AND REINFORCEMENT

Solid walls of timber were generally too extravagent with the material and it is more usual to find timber combined with other materials for wall construction. Timber-framed houses are well-known from Helladic and Hittite cultures.[1]. Mudbrick, reeds and stone were used in conjunction with the timber [2]. This method of building up a framework of timbers set horizontally and vertically to form quadrangular panels was used at Mycenae even in the construction of palaces and in parts of buildings where ashlar masonry was employed [3].

The general practice of building mudbrick walls on stone foundations and reinforcing both with timber was widespread in the Bronze Age in Syria and the Aegean as well as all parts of Anatolia [4]. The technique is also found at Ur, Babylon and el-Amarna [5]. Thus there is fairly clear evidence for the structural use of timber in the ancient Near East from Neolithic times down to the Iron Age [6].

The purpose of the timbers must have been to add structural strength. The practice occurs widely, even in areas where timber was scarce, as at Babylon, and the fact that in a number of cases the timber was actually set into walling and sometimes plastered precludes any aesthetic considerations. The timber framework would have added stability to walls, especially in the event of earthquakes; the long timbers would have cushioned the shock to some extent and held the bonding together. The transverse timbers, though shorter, tended to prevent the walls from falling outward or inward [7]. The use spread south from Anatolia and Northern Syria to Tyre and the surrounding regions, whence carpenters and materials were sent by King Hiram to David and Solomon for the construction of their houses [8].

The Greeks made considerable use of wood for construction as well as for decoration [9]. Timber was used for reinforcement as in the earlier periods, for example at Samothrace and Olynthus [10]. Vitruvius advises the placing of horizontal ties in walls, perpendicular to the two faces [11]. An inscription relating to repairs to the walls of Athens in 307/306 BC allows a very precise reconstruction of beams used in all parts of the mudbrick work; the timbers formed a framework right through the wall [12]. This can be paralleled at Eleusis and Delos [13]. This technique is also found in Dacia and Martin sees this as an Hellenic influence [14].

The Qasr el-Bint at Petra, variously dated from 1st century BC to the 2nd century AD [15], illustrates this technique particularly well. Timber was extensively incorporated into the fabric of the temple walls to afford as much tensile strength as possible. The main wood string courses ran the length of the walls and around the vulnerable angles. These were constructed with two or three parallel balks of square section and placed side by side. The gaps were packed up with rubble and mortar to form a regular course. Transverse ties of flat section were incorporated at intervals across these courses. In addition to these the bed-joints were in places packed with deals and sprigs of timber driven into the damp mortar; some of these have been preserved [16]. The general preservation of the structure is very much due to the incorporation of these beams. There are several cracks which would have lead to collapse but which are still held together by the wood courses (Plate 124). However, there have also been the effects of the rotting of the timbers in places. This has resulted in a considerable amount of local displacement and collapse.

Vitruvius [17] describes the houses constructed by the Colchians in Pontus which are built entirely of sticks of timber laid on top of one another and packed with mud. The roof is also of timber (see Chapter VII).

The use of timber in monumental wall construction in the Roman period was generally precluded by the development of much stronger and more stable materials, such as brick and concrete. However, it would not have been unlikely that the use of timber as a reinforcement and framework for ordinary domestic housing continued [18].

Timber reinforcement was greatly employed in Santa Sophia in Constantinople. Timber ties were built into the walls across the window openings of the dome and semi-domes. These were wrapped in lead for protection. Wooden ties and struts were also put in over some of the minor arches of the aisles and galleries [19].

The Yerebatan Seray and the cistern of Studios both had tie-beam reinforcement and in the Binbirdirek, some of the columns were joined together by triple tie-beams in some places [20].

Timber was used in various other ways in construction in the East. Doors, balconies, floors and window frames would all have been of wood unless, as in the Hauran, it became cheaper and easier to use stone [21]. The use of timber in this way must have been particularly common in domestic architecture.

ROOFING CONSTRUCTION AND RELATED ELEMENTS

> 'Solomon [22].... built the House of the Forest of Lebanon; its length was 100 cubits, and its breadth 50 cubits, and its height 30 cubits, and it was built upon three rows of cedar pillars. And it was covered with cedar above the chambers that were upon the 45 pillars, 15 in each row.'

Wooden columns and roofs are a common feature of ancient architecture. The mechanics involved take full advantage of the nature and structural properties of timber. The main drawback of a study of these particular uses is that the material itself does not survive and therefore there is much reliance on archaeological interpretation and on the ancient literary sources.

The earliest columns were almost certainly saplings, tree branches or bundles of reeds simply thrust into the ground. The Minoans made lavish use of the abundant timber supplies in Bronze Age Crete and broad wooden columns supporting wooden ceilings and roof beams are characteristic of their architecture. The roofs, from all indications, appear to have been more or less flat [23].

Wooden columns and pillars in early Greek architecture and in particular in domestic construction, are frequently attested in the archaeological record as well as in representations - votive models, vase painting etc [24]. The early temples frequently had wooden columns on a stone base. A well-documented example is the Temple of Hera at Olympia (7th century BC). Pausanias [25] in the 2nd century AD found that one of the two columns in the opisthodomos was of oak, and indeed the surviving stone columns are an extraordinary mixture of styles from archaic Greek to Hellenistic and Roman forms [26].

Wooden pillars were used for several archaic stoas, in particular the South Stoa at Samos. The stoa of the Asclepieion at Cos still had wooden pillars in the 3rd century BC [27]. The houses at Olynthus had peristyles surrounded, more often than not, by wooden posts rather than stone pillars [28].

The use of timber for roofing in general is one which, most of all, has greatly influenced the development of architecture and architectural techniques. It is clear that the basic features of the Greek orders are ossified timber elements - the triglyphs represent the ends of the cross beams and the guttae are the pegs used to fix the various timber elements together [29]. These were translated into stone by the 6th century BC. When one looks at a building it is particularly illuminating to bear in mind that the way in which the architect has chosen to solve his roofing problem has affected not only the design of the roof but also of the whole character of the building [30].

In building it is generally the roof that causes the greatest construction problems. Not only does a large area have to be spanned with as few supports as possible, it also has to be waterproof. The woodwork of Greek buildings has of course perished, but a lot can be learned about the arrangement of timbers from the provision of supports and cuttings for beams in the surviving stonework.

The normal principle involved was a simply supported beam (fig. 14). Long poles or joists spanning a space can transmit the weight of the roof from their ends, vertically downwards into the masonry of the walls, without any need to push sideways and outwards. This is what must be guarded against when constructing vaulted or domed roofs, where the sideways thrust on the tops of the walls is too great, the line of thrust in the masonry will be displayed to a critical extent and the walls will collapse. With a simple wooden roof there is no such disturbance to the thrust line and so the walls can be made quite thin (compare vaults etc, Chapter VII) and will not need buttressing.

The Greeks certainly knew various complex joints to make a wooden frame but their structural timbers seem normally to have been laid one above the other without elaborate jointing. The side porticoes of a temple were comparatively narrow and the space between the colonnade and the _cella_ was easily covered without intermediate support, by fairly small closely spaced rafters. Over the _cella_, or main part of the building, was placed a low-pitched ridge roof which had a ridge-beam supporting the inner ends of the rafters. The ridge-beam was carried on an axial colonnade, as, for example, in stoas, such as the Stoa Basileios in Athens (6th century BC) and the South Stoa of the Argive Heraion (mid 5th century BC). In temples, however, there was rarely such a colonnade in the _cella_, though there was one in the 6th century BC 'Basilica' at Paestum. Thus the ridge-beams could only be given indirect support by props from a set of cross-beams running between the inner colonnades or the _cella_ walls. Thus, in buildings with ridge-roofs but no axial colonnade, there had to be three distinct sets of beams:

i) crossbeams supporting

ii) ridge-beam supporting

iii) rafters.

This was quite complex and by the end of the 5th century BC was avoided where possible [31]. Beams, called purlins, running parallel to the axis of the building, that is parallel to the ridge-beam might be used to help support the rafters in the middle of the long span, but they were only used where they could be directly supported from the stonework [32]. Thus purlins were usually only used in temples as the cella walls, and inner colonnades if present, could give them direct support, for example in the Parthenon [33] (fig, 15). In the early stoas there was no such support.

In a typical 5th century stoa the heavy beam carried by the inner colonnade acted as the ridge-beam. On this rested the rafters. These were fairly thick timbers because they had to cover a span of up to 6 m (fig. 16). In a Hellenistic stoa with a pitched roof, the arrangement could vary, but generally the beam carried by the inner colonnade did not directly support the rafters. On this beam rested the ends of the heavier sloping crossbeams above which came purlins and a small ridge-beam. The rafters rested on these. The whole system apparently relied purely on its solidity, the weight being entirely dead load [34] (fig 17).

Generally the Greeks tended to use very heavy timbers, main beams being about 0.50 m by 0.90 m. However, the spans had to be restricted because the beams were usually under bending strain and therefore could not be built of several pieces. Greek buildings usually provided support for the roof at intervals of 5 to 7 m [35].

An interesting late classical timber-roofed building and which can be accurately restored is the arsenal of Philon at Piraeus (about 340 BC) (fig. 18). We are fortunate to have the general specifications surviving and there is much detail given to the roof-system [36]. There were 35 columns on each side; these carried huge beams (81 cm x 73.5 cm) longitudinally as architraves which also served as purlins for the roof. The columns also carried transverse beams across the central passage. On the centre of each of these transverse beams rested a block of timber which supported the ridge-beam (57 cm x 45 cm). The rafters rested on the flank walls, the longitudinal architraves and on the ridge-beam.

During the Hellenistic period new types of monumental buildings became popular, especially large meeting halls where unobstructed interiors were preferred; roof spans became correspondingly greater. In the <u>bouleuterion</u> at Miletus (<u>c</u>. 170 BC) the clear spans reached about 16 m, far short of Roman roof spans a century later [37], but it does raise the possibility that a more sophisticated roof structure was known.

This brings us to the question of whether the tie-beam truss was used, as opposed to the prop and lintel type of roof (fig. 14). The truss is a triangular frame of timbers, so jointed to one another that the horizontal beam acts in tension tying together the feet of the two rafters. The horizontal beam need not be as thick as in the bearer beam (prop and lintel) system normally used by the Greeks as it is easier for a beam to resist tension than bending [38]. In addition a tie-beam can be made up of two pieces provided that they are jointed properly. A much larger span is thus possible without any increase in the size of timber used. This must have been the system that produced the vastly increased spans under the Romans, but did the Greek architects know about the roof truss? As already observed, spans of about 15 m did occur in some Hellenistic buildings, the bouleuterion at Miletus (see above) and the ekklesiaterion at Priene (14.60 m), and Coulton speculates on their being roofed on the truss principle [39]. The problem lies, however, in when it was first known and how widely it was used.

In stoas, even in the Hellenistic period, there is a marked tendency to restrict roof spans to 6 m or 7m, and evidence suggests that the roof truss was never widely used and probably never fully understood. If the principle of the truss were generally understood, one would expect one-aisled stoas with spans of 12 - 14 m to be at least as common as the two-aisled stoas with sloping roofs on bearer beams which are found so often.

However, there are other factors. Hodge notices that in western Greek colonies in Sicily temples were built with no internal colonnade breaking up the spans; on the mainland it was felt preferable to make spans smaller by the use of internal colonnades [40]. He concludes, not unreasonably, that something must have made it easier for the Sicilian Greeks to roof rather wider spans; either there were better materials available or there was a better method - the truss [41]. Hodge believes that the truss roof was known very early on in Sicily by the Greeks and he suggests that it may have been learned from the Carthaginians.

A similar situation exists at Samothrace where the excavators argue against Hodge, pointing to the notable series of wide spans in the architecture of Samothrace, and suggesting that the truss was in fact known in the North Eastern Aegean from a fairly early date [42]. However, bearing in mind that in Greek architecture in general and even in the Hellenistic period, long spans were avoided in most parts of Greece, it becomes clear that with Sicily and Samothrace it is a question of local groupings of unusually large spans. It is well-known that Thrace and Macedonia were famous for their timber [43] and it is highly likely that it was the influence of better materials that brought about the wide spans. At Samothrace most of the spans were 10 to 11 m which the bearer beam system was quite capable of dealing with [44].

The availability of better materials would also seem a likely explanation for the general superiority of western Greek roofing in the 6th century BC. The area of Southern Italy and Sicily was full of wood suitable for building and for ship construction [45].

Hodge argues that if this was the explanation for the wide spans in Sicilian temples, then the mainland Greeks would have imported the Sicilian timber if it had been better. Although it is known that timbers were transported over considerable distances in the classical Greek world [46], one cannot immediately assume that timber was generally available on a commercial scale [47]. It seems reasonable, therefore, that it was due to the availability of better timber than to knowledge of the truss that these wider spans occur in some areas of the Greek world.

The first description of what appears to be a roof of couple rafters connected by a horizontal tie is in Vitruvius: 'the main beams are those which are laid upon columns, pilasters and antae; tie-beams and rafters are found in the framing. Under the roof, if the span is quite large, are the crossbeams and struts; if it is of moderate extent, only the ridge-pole, with the principle rafters extending to the outer edge of the eaves. Over the principal rafters are the purlins, and then above these and under the roof-tiles come the common rafters, extending so far that the walls are covered by their projection' [48]. The oldest surviving roof of this kind is that of the 6th century church of the monastery of St Catherine on Mt Sinai and it is basically a triangular truss form with the foot of the rafters tenoned into each end of each tie-beam. In addition there is a secondary system of a central post with inclined struts notched and tenoned into it and into lengths of timber bearing up against the underside of the rafters. These central posts did not rest on the horizontal ties and themselves act as ties supporting the feet of the inclined struts, thereby providing support against any tendency of the rafters to sag. Having the lengths of timber bearing up against the rafters obviated the need to weaken the rafters by cutting into them to joint the struts to them [49] (fig. 19).

Although nothing actually survives of the roof of the Temple of Bacchus at Baalbek, the rest of the structure is so well preserved that a very detailed picture of its roof structure can be obtained (fig. 20). Huge stone slabs span the 2.50 m distance between the architrave of the peristyle and the cella wall. These slabs are each about 5 m long and 1.20 m thick and average 45 tons each in weight. Their underside is elaborately decorated with figurative motifs [50]. The roof extended over both this ceiling and the inner ceiling.

The roof was made of timber trusses 8 m high in the middle and which spanned 19 m across the cella. Purlins were placed on top of the trusses and parallel to the ridge; these carried a sheathing of boards and a lead cover. The main timber beams spanning the cella from interior column to interior column were dove-tailed into the cella walls and formed the bottom chords of the roof trusses above; they therefore served as lateral ties for the whole building. The rafters reached out to the cornice blocks. The wooden ceiling of the cella was carried on the crossbeams [51].

Though we have very little other evidence for Roman timber roofs, it can be reasonably assumed that this was the form taken in most cases. The temples at Baalbek were constructed with a great deal of imperial involvement and there is no reason to doubt that the methods of timber roofing should not have been those widely used in imperial Rome, for example in the Basilica Ulpia and the Basilica Aemilia. Certainly spans of 24 m and 30 m seem not to have been unusual. Agrippa's Odeion in Athens had a clear span of 24.38 m (80 ft) without any internal support. When the roof collapsed a century later the span was considerably reduced [52]. The Diribitorium which Agrippa started in Rome and was completed in 7 BC was reputed to have the widest span of any timber roof ever built, and Pliny says that within living memory a beam 100 ft (30.48 m) long and 1½ ft thick was left over from the Diribitorium and exhibited in the Saepta because of its incredible size [53]. The precedents can possibly be sought in Campania, for example the covered theatre at Pompeii, built soon after 80 BC, with a span of 90 ft (27.60 m) [54].

As well as pitched roofs of this kind over temples and basilicas etc, the street colonnades must also have been roofed in wood. Lean-to or shed-type roofs would have been most appropriate. This type of roof was most advantageous when built against a wall. Colonnades are generally shorter in span and would therefore require only one set of timbers, sloping rafters running across the building directly carrying the roof covering.

The transport of wood suitable for roofing is a subject whose study is dogged by difficulties. The fundamental problem is that the basic evidence no longer survives. One has to rely on the series of holes left behind in the structure's walls, but these only survive if the building is in a near perfect state. For a city such as Palmyra the use of timber must have been substantial, and this is of special interest considering the distance over which it was necessary to bring it. Presumably most of the roofing timbers were brought from either the Lebanon mountain range or from north Syria.

The truss type of roofing system was used for the roofing of the early Christian basilicas, for example the Basilica of St Peter's [55]. It is interesting that wooden roofs were often chosen in preference to vaults and domes for these early religious buildings. It did mean the whole construction programme was simpler in that the structure did not require the elaborate buttressing that went hand-in-hand with vaulted construction. This is a phenonmenon much more noticeable away from the main religious centres. With the exception of such vaulted and domed churches as at Ravenna, Constantinople, Qasr ibn Warden, Bostra and Ephesus, which were all part of the metropolitan architectural traditions, churches were basilical in plan with timber roofs (see Chapter X).

SCAFFOLDING, SHUTTERING, CENTERING

Timber played an important part during the course of the construction of buildings. One of the most obvious is for scaffolding which allowed access and a platform from which masons and builders could work and for the ramp and ladder systems which would have formed an integral part of the wooden framework. Very little evidence survives of how the Romans built their scaffolding; some putlog holes survive and a certain amount can be gained from them (see below). The Trebius Junius wall-painting of brick masons at work is important in this respect (Plate 125). It depicts a building in the course of construction, surrounded by a timber scaffolding of a relatively flimsy nature, with a wooden ladder for access to the higher levels [56]. Indeed the scaffolding found in use in modern building in the Middle East cannot be far removed from the Roman arrangement.

Basically the scaffolding would rise at the same time as the building. It does not act as a support as shuttering or centering. A simple form would be like that depicted on a Gallo-Roman relief now in the Museum at Sens [57]. In the scene workers stand on scaffolding made up of trestles and planks; they are obviously painting or applying stucco to a wall. This type of scaffolding would have been particularly useful for such interior decorations.

For general construction in stone or bricks, the scaffolding rose independently of the walls and columns. The main vertical supports would have been set firmly in the ground, perhaps in mortar, and horizontal beams, or putlogs, were attached between the vertical supports. On these horizontal beams rested the planking from which the work was carried out. To brace the whole structure and to prevent it from instability, beams were placed diagonally from one vertical support to another. The importance of these increased as the scaffolding rose higher. In some cases the putlogs were actually anchored within the fabric of the wall, sometimes going right through, for instance, in Gaul in the 'Temple of Janus' at Autun [58] (Plate 126). Putlog holes are particularly in evidence at the springing line of vaults.

The use of timber for shuttering comes into play when materials such as mortared rubble and concrete are used unfaced and therefore require support until they set sufficiently to support their own weight. This is particularly found for foundations which were rarely faced. The shuttering usually consisted of a system of planks held in place by short squared, vertical timbers, which were themselves braced by similar cross-pieces. The negative forms of the posts and the boards, which were often left in place, sometimes survive so clearly that the grain of the wood can be seen, for example, in the Domus Aurea in Rome (Plate 127) and the Great Palace in Constantinople [59]. Once set the shuttering could be moved for the next piece of work. Again analogies can be found in modern day usage. Faced walls have a ready-made and permanent shuttering system and a wooden system would have been unnecessary and indeed unlikely [60], though the facing could not have been built up too far before pouring in the concrete core.

Centering for arches and vaults is an important use of timber in Roman architecture. Its use is probably the simplest expedient for constructing an individual arch or vault of any size. However, it does create problems of its own. The most important one is that it introduces an indeterminacy into the structural action of the whole as long as it remains in place because it helps to support the dead weight of the arch or vault being constructed as well as carrying itself. This will be even more crucial when large amounts of mortar are used, especially concrete which is cast <u>in situ</u> and initially has no stiffness or strength and shrinks as it sets and gains both [61].

From this viewpoint the ideal way is to build the whole form out of closely fitting, pre-cut units so that the centering serves as a temporary prop. This is what would be used for stone and brick and the centering would have been held in place either by small projections at the springing line, like the Pont du Gard, or by inserting the timbers into the fabric of the wall, making putlog holes. These are in evidence in many Roman buildings in the East, for example, in the East Gymnasium at Ephesus (Plate 129). The one difficulty is then to be mindful to cut the centering so that it had the desired shape even after being deformed under the weights of all but the last voussoir.

Any centering or formwork, no matter how economically designed, tends to be expensive in both materials and labour in relation to the costs of the building being constructed [63]; it contributes nothing to the finished structure. This must have been the case also in the Roman period, especially when particularly large timbers were needed (see below). Timber centering (and also ordinary scaffolding) was therefore designed to be re-used a number of times with the minumum of trouble. A long barrelvault can be constructed in sections on much narrower centering or formwork which could be periodically slid along, assuming the profile remains the same throughout. This is very obvious in the Pont du Gard where each arch consists of several independent parallel arch-rings, only one of which would have needed support at any one time.

Thus the construction of a formwork can cause as many problems as that of the structure itself. The Pantheon is a case in point. Although no large timbers were required in its construction the concrete dome was entirely dependent on the formwork. (This was particularly complex because the coffering had to be reproduced in wood also [64]). This formwork had to span the whole building, 43.20 m, a colossal distance in wood, and must have been made up of a series of trusses.

In the architecture of Rome, it is possible to note a move to reduce the amount of centering required. Later domes and vaults were increasingly being constructed of lighter materials and incorporated brick ribs and hollow vessels, thereby obviating the heavy framework of the earlier buildings. However, in the East the centering required must have continued to need to be strong and heavy simply by virtue of the materials in use. However, vaults can be built without centering.

Construction without centering depends on a firm base provided by what has already been built. Each successive block or brick must be set in place in such a way that it will be held there, until construction advances or is finished, by

i) friction, as between mudbricks in pitched-brick vaulting

ii) a mechanical key, as with clamps and dowels

iii) the bonding action of a rapidly setting mortar for example, in pitched-fired brick vaulting

iv) the arching action of a few blocks set in place together.

Friction can only be relied upon when the bedding angle is fairly small [65], and centerless construction in stone is not very practical because a bond is more effective when there is a large surface area in relation to the weight of the unit. In this respect brick and tile are particularly suited to centerless construction, and the development of pitched-brick vaulting in the East and its adoption into the architecture of the Eastern Roman provinces is an important one (see Chapter VII).

CHAPTER VII

ARCUATED CONSTRUCTION

THE ARCH - THE STRUCTURE

The earliest attempts at a kind of arch construction were really no more than simple adaptations of naturally occurring forms, for example, a boulder lodged between two rocks forming a rudimentary arch. One might then have two long blocks of stone inclined inwards to meet as an inverted 'V' as in the north entrance of the Pyramid of Cheops at Giza.

'False' and Corbelled Arch - This was an early form of construction which was widely used in Mesopotamia, Dynastic Egypt and in Greece and Italy down to the 4th century BC. These sometimes had stepped soffits and sometimes soffits dressed back to a smooth inverted 'V' or a smooth curve. They are distinguished by the fact that the blocks or bricks are bedded more or less horizontally on one another. At each course they project slightly beyond those of the course below, until the two sides eventually meet at the centre or the gap can be spanned by a single block; a corbelled arch is thus formed. This form does not need any temporary support during building, being merely an overhanging extension of the walling of which it was part. The two halves are independently stable of each other. In this type of construction, two factors are important; firstly, no block can project more than half its length beyond the one below without tipping over or falling, and secondly, the total weight of masonry bearing down behind the edge of the opening must always exceed the total weight projecting in front of it. Therefore, each projecting half acts as a cantilever and as a result the masonry must be capable of developing tension as well as the compression that is normally developed in wall action. Thus, the effectiveness of corbelled construction very much depends upon the materials from which it is built. Figure 21a shows what would happen if each half was completely monolithic. No tensile re-inforcement is used so the necessary tension could be developed in the most effective way by using large blocks of stone, in such a way that each block projects back behind the edge of the opening at the base at least as far as it projects in front (fig. 21b). If shorter blocks or bricks were used (fig. 21c) the potential tensile resistance of the individual units could only be developed by frictional forces at the horizontal bed-joints. It would be totally ineffective at the vertical joints and could only be about as half as effective at the most as in the long continuous blocks of figure 21b. Thus lack of tensile strengths in the individual blocks and inadequate friction at the horizontal joints would lead to cracking and tipping over (fig. 21 b and c). This collapse could be forestalled by a thrust from the other side and the introduction of a kind of true arch action (fig. 21c).

The chief merit of these early forms was that very little or no centering or temporary support was needed to construct them besides what might be necessary to make easier the handling of the larger blocks. However, they could only be used for very limited spans and they created such enormous thrusts that they needed massive abutment for them to remain standing.

True Arch - The false and corbelled arch is rather a crude affair and the evidence would appear to show the East, Mesopotamia and Egypt, as the original homelands of the true arch [1]. Mud-brick was probably one of the first materials used for this type of construction, the first few ring of bricks being set on edge 'voussoir' fashion. The true arch constructed with wedge-shaped voussoirs is a development from this.

The arch is compressed all over and its strength depends upon the compressive strength of the material from which it is made. As has already been discussed, stone is very strong in compression but weak in tension. Thus a horizontal lintel which puts stone into tension cannot span wide gaps whereas an arch which puts stone into compression is capable of spanning much wider distances. The wedge-shape of the voussoirs prevents them from falling down under the action of gravity. The structural function of the arch is to support the downward loads acting upon it; the greater the load the stronger the arch. It turns the loads into a lateral thrust which runs round the ring of the arch and pushes the voussoirs against each other, transmitting the thrust one to the other. The voussoirs in turn push against the abutment or springings of the arch (fig. 22).

The ideal form for an arch to take is that of an inverted catenary, that is, the curve assumed by a chain or cable uniformly loaded along its length and freely suspended from two horizontally-separated points. Figure 23a illustrates the different thrust lines that might arise in a single arch. Instability will occur if the thrust line comes close to the inside or outside of the arch at four or more points.(fig. 23b). If this happens at only three points then a 'hinge' develops and the arch is still perfectly safe (fig. 23 c and d). All this basically means that the arch is very stable indeed and is not unduly sensitive to the movements of its foundations; some sort of distortion is, in fact, quite common.

The shape of a Roman arch was always a semi-circle and needed a wooden centering or scaffolding in order to construct it. If the shape of an arch is flattened, that is, the rise in proportion to the span is reduced, the compressive thrust between the voussoirs of the arch is increased considerably. However, the compressive stresses are still generally well below the crushing strength of the masonry. The deflections which occur when the arch settles after the centering is removed may be quite large, especially when there is considerable use of mortar or concrete. The use of joggled voussoirs is an obvious expedient to reduce the likelihood of slipping, for example, in the theatre at Orange, in the north gateway in Diocletian's Palace at Split (Plate 130) and in the Mausoleum of Theodoric at Ravenna. Joggling not only reduces the risk of slipping after construction is finished but also facilitates building when the centering is not completely rigid.

Arches in the Roman period were constructed in all materials - stone, brick, concrete, mortared rubble - depending on their availability and the local building traditions. However, well into the 1st century AD in Rome itself, stone and brick were preferred for the construction of arches, even in buildings otherwise constructed in concrete. The Roman engineers already knew the strength of these materials and that, though lacking the strength of *opus caementicium*, an arch constructed from them would be ready sooner than one of concrete to carry further loads.

ORIGINS AND DEVELOPMENT: THE BEGINNINGS OF ARCUATED CONSTRUCTION

The principal problem in the study of the arch and the vault, as indeed in the study of any architectural form, is one of survival. Given that only a proportion of arches survive, how far is it possible to draw conclusions about the use of arcuated construction. A number of factors are involved:

1 intensive excavation and survey work in some areas creating false impressions when compared to survival rates of monuments in areas less well-covered;

2 the burial of monuments, either intentionally as with tombs, or over time through disuse;

3 the use of superior technical skills;

4 the use of more or less durable materials;

5 continuous use or refurbishing of monuments.

EGYPT

The Ancient Egyptians had a very sophisticated civilisation and their technical knowledge in a number of fields was not surpassed until Medieval times. The pyramids demonstrate a high level of mathematical and technological competence [2] and familiarity with the use of stone. The use of this material, however, was reserved for extraordinary monuments as the pyramids and the temples of the gods [3]. This is not to say that Egypt did not have good supplies of stone. Generally speaking limestone extends from Cairo up the Nile as far as Esna, where it gives way to sandstone, which, with occasional outcrops of granite and diorite, extends throughout Nubia [4].

However, the natural and most convenient building material in Egypt was brick. Usually this was sun-dried but kiln-baked brick was also used. It was this material which was employed almost exclusively for the arch and vault.

The earliest certain examples of the use of brick vaults in Ancient Egypt are at Saqqara [5]. These are in burials surrounding a large tomb (no. 3500) which is dated to about the First Dynasty (3100 BC - 2890 BC). Usually a wooden roof is given to the brick-lined pit which forms the grave, but in these examples both brick lining and wooden roof are missing. Over these subsidiary graves are the best preserved brick superstructures of any graves of their type so far discovered. They are roofed by inclined vaults of rings of mud-brick built against the enclosure wall of tomb 3500; the bricks are laid across the axis of the vault [6]. Other slightly later examples are known in tombs R1 and R40 Reqaqneh [7]. It is clear that the inclined vault was known by the late First Dynasty (c. 3000 BC) and used in Lower Egypt to cover short spans. Spencer deduces from this that the vault was probably introduced into Upper Egypt at a much later date; Second Dynasty tombs (2890 BC - 2686 BC) in Upper Egypt had corbelled roofs and corbelling in brick was apparently restricted to Upper Egypt at this period. Most of the examples come from Naga ed-Der and El-Amra [8].

Corbelling continued to be used quite widely even after the technique of true vaulting was introduced. The most frequent use was for tombs, but corbelled vaults are also found elsewhere. The granaries attached to tomb 3038 at Saqqara are closed in at the top by corbelled brickwork; the same technique is found in granaries in the Graeco-Roman town of Edfu [9]. The technique of corbelling varies little with date or location. The corbels were nearly always laid as headers. In this way each brick could project further without there being any risk of them falling. To give rigidity to a structure of corbelled brickwork, a great quantity of mud was usually plastered over the top.

True arches apparently came into use later than the inclined vault. The earliest certain examples are in the Third Dynasty (2686 BC - 2613 BC) tombs at Beit Khallaf (Tomb K1), Reqaqneh (Tombs R1 and R40) and at Saqqara.

The use of arches and vaults increased greatly and was widespread in the tombs of the Old Kingdom (2680 - 2258 BC) [10].

Clarke and Englebach defined two kinds of brick arch used in Ancient Egyptian architecture:

1) those constructed with ordinary building bricks; and 2) those where the form of the bricks was specially designed [11].

The first kind never had a span of more than a few feet, though it apparently dates from early times [12]. The passageway of the great mastaba of the Third Dynasty at Beit Khallaf is roofed by an arch of this kind. The bricks were laid edgeways side to side and pebbles and mud-mortar were packed above them [13]. This type of arch and vault with the bricks laid lengthways (that is, radially) along the axis of the arch was used in all periods.

The second kind of arch was used to cover much wider spans and could support greater weights. The bricks used were thinner than ordinary bricks [14] and were often heavily scored on one side or the other to help adhesion during construction. The arches and vaults were then constructed by laying bricks on the longest edge in concentric rings, each ring slightly inclined against the previous ring. This is exactly the construction of the inclined vaults of Saqqara and Reqaqneh [15]. However, the best known examples are in the Ramesseum complex at Thebes. These are of much later date (Nineteenth Dynasty, 1314 - 1197 BC), but display the same techniques of construction. At the back of the temple are long store-rooms covered by brick vaults which are inclined or 'pitched' (Plate 131).

In some great archways, rings of special bricks were used as a centering for rings of ordinary bricks laid as stretchers along the axis of the vault. The advantage of the inclined vault, and small arches and vaults of ordinary bricks, was that they could be constructed without the need for centering, a very important consideration in a relatively treeless country. With free-standing archways some form of light centering was necessary to provide temporary support for the first rings of bricks set on edge. Subsequently these acted as support for the successive rings of bricks set with their longer dimensions running radially and at right-angles to the face of the arch, eg. the brick archway of the Tomb of Mentuenhet at El-'Asasif at Thebes which has a span of about 4 metres. There were originally at least ten rings of bricks of which only six are still in place [16]. In these composite arches, the spring of each successive ring is slightly higher than the one below, a feature which gives the structure great strength.

At Giza in the Tomb of Sabef, the coffering has a vault of special interlocking bricks laid across the axis of the vault which acted very much as the joggled arch of later periods. Later examples, however, are in stone not brick.

It is not until the New Kingdom (1567 - 1085 BC) that there is evidence of brick vaulting in other than funerary contexts, for example administrative buildings, palaces and storehouses (as in the Ramesseum storehouses,

Plate 131). Vaulted roofing was common in domestic architecture from the late Dynastic period into the Roman period in Egypt.

The stone arch, as distinct from the brick arch, is not found until the Middle Kingdom (c. 2130 - 1570 BC). However, it is not the kind of stone arch that the Romans might construct where the voussoirs are held in place and support one another by friction: this form hardly exists in Ancient Egyptian architecture.

False arches and vaults in stone can take two forms in Ancient Egypt:

1) 2 slabs leaning against one another, eg. in the King's chamber in the Great Pyramid, the under surface sometimes shaped to a curve to give the effect of an arch, eg in the chamber of the Ninth Dynasty (2160 - 2130 BC) temple of El-Deir el-Bahari (c. 2500 BC) and in the Pyramid of El-Lahus [17];

2) corbelled. The earliest stone corbel vaults in Egyptian architecture are over the burial chamber of the Pyramid of Snefferu at Meydum [18] (c. 2680 BC) and in the Grand Gallery of the Great Pyramid at Giza [19]. In the Middle Kingdom corbelling was frequently used for roofing mastabas as in a Twelfth Dynasty (1991 - 1786 BC) example at Dashur [20]. Corbelling was extensively used for the construction of false arches in the New Kingdom. The number of corbelled courses, however, is significantly less than in earlier examples. The false arch in the sanctuary of the temple of Seti I at Abydos has effectively two courses of corbelling and the arch at El-Deir el-Bahari in the central sanctuary of the

Eighteenth Dynasty (1567 - 1320 BC) temple had five. The undersides of the two blocks, forming the top of the corbelled arch, were cut away on the underside to give the appearance of an arch.

The true arch in stone constructed with a keystone does not appear in the record until Saite times (c. 7th century BC). However, the technique is still very much dependent on corbelling. Arches of Twenty-Fifth Dynasty shrines at Medinet Habu show this very well (747 - 656 BC); the first three or four courses were corbelled with the uppermost joints being sufficiently flat for the next course to remain in position until the keystone could be inserted [21].

The joggled arch has already been mentioned in connection with brickwork but the joggled arch in stone is not known before Ptolemaic times, for example, in tombs at Kom Abu Billo in the Delta. The joggled arch is where each voussoir except the keystone hangs on the adjacent ones by means of the peculiar shaping of the bedding joints. These particular examples in the Delta have approximately a 2 m span and the arches tend to be slightly ovoid rather than semicircular [22].

MESOPOTAMIA

Mesopotamia has, by many scholars, been hailed as the original homeland of the technique of arcuated construction [23]. Surviving examples date back at least as far as the earliest of the Egyptian examples, if indeed they are not earlier.

The earliest known example of the radial brick vault spans a rectangular hall at Tepe Gawra [24] of the 4th millenium BC. At the same time some of the earliest of the Royal Tombs at Ur were constructed c. 3200 BC and these show a wide variety in construction techniques. Three are stone-built throughout, PG/777, PG/779, PG/1236; and both PG/777 and PG/1236 are roofed by a corbel vault with the stones laid flat, each one overlapping the one below. However, the excavators considered PG/779 to be a distinct structural advance on the other two [25]. Although the successive courses overlap, the stones themselves are not laid flat but on a slope which gets progressively steeper as the sides of the roof get higher; in some places the effect is practically that of a voussoir-arch [26].

PG/789 is covered by a vault of burnt bricks laid voussoir-fashion with the central portion constructed of contiguous rings of true arching and the aspidal ends of corbelled work [27]. PG/789 and PG/1236 have arched doorways of burnt brick to the tomb chamber [28]. Swift [29] discounts these examples as showing any real technical achievement in arcuated construction because plano-convex bricks were used [30]. However, Woolley states that the bricks were flat, not plano-convex. He uses this fact to date the tombs to before the 1st Dynasty of Ur when the plano-convex brick was introduced [31].

In the 3rd and 2nd millenium BC three techniques of vaulting were in simultaneous use: radial, corbelling and pitched-brick [32]. At Ur, the Mausoleum of Ur-Nammu is covered by a corbel vault (c. 2100 BC) [33]. Also at Ur, an arch was discovered collapsed on the threshold of room 5 of No. 3 New Street, dated by the excavators to 2100 BC [34]. Beneath some of the houses, small chambers or 'chapels' were found which were covered by brick vaults, both corbelled and barrel-vaults [35]. At Tell al Rimah, in present day Northern Iraq, the excavations on the south side of the mound have produced examples of mudbrick arches dating from c. 2200 BC [36], and in the Phase 2 building in the same area arches dating to c. 2000 BC have been revealed. However, it is from the early 2nd millenium BC and later phases at Tell al Rimah and Ur that we have well-preserved examples of the use of different techniques of vaulting in both mudbrick and burnt brick [37], and it is very relevant to look at some examples in detail.

Tell al Rimah is situated on the Northern Iraq Plain about 60 km from Nineveh and the Tigris to the East and about 100 km from Assur to the south-east. The construction of the Great Temple employed widespread vaulting. The stair leading up to the Temple from the city was carried on three vaults of progressively increasing height [38], and many of the ground floor rooms were roofed by vaults. All the vaults, both for the original temple complex (c. 1800 BC) and for the major reconstruction about a century later, were constructed with mudbricks laid radially like voussoirs. One unusual feature, however, is their high-pitched profile. The first few courses above the spring were corbelled out and then the voussoirs were turned at an angle so that each one was supported by the one before. Only the crown of the vault would have required some kind of scaffolding support [39]. Generally, the temple-builders demonstrate a familiarity with their materials and techniques which seems to point to a long tradition. Oates does describe a particularly indicative example of this, where an internal doorway, surviving to full height, is not spanned by a lintel of timber, as perhaps one might expect but by a flat arch of mudbrick [40].

The sounding on the south side of the mound (Area AS) uncovered a honeycomb of small vaulted chambers in the substructures. The vaults of Phase 2 (c. 2100 BC) are of pitched-brick [41] with a construction similar to that of the storehouses behind the Ramesseum at Thebes in Egypt [42]. The individual bricks are laid with their faces across the long axis of the vault in rings slightly inclined back against the previous ring. To cover a long space, this kind of vault construction proceeds from both ends with the first ring at each end leaning against the end wall of the chamber. On occasion the rings are set at a considerable slant and the first ring may be supported by incurving triangular fans of brickwork which rest on the side walls [43]. These are formed of bricks laid as truncated-ring segments of progressively increasing length. Oates erroneously refers to them as 'pendentives'.

This method of vaulting is particularly suited to mudbrick and is intended to economise in the use of timber. If a quick-drying mortar and relatively light bricks are used, then the pitched-brick vault can be built without centering. The bricks used in the pitched-brick vaults at Tell al Rimah were smaller and thinner than those employed for the walls [44]. In the Phase 2 building they measured about 24 cm square and about 4 cm thick; some have parallel finger impressions on the two broad faces as a key for the mortar. The average brick size in the contemporary walls and radial arches were 34 - 35 cm square and 8 - 9 cm thick [45].

However, Oates states that though these techniques were apparently intended to cut down the use of timber [46], their use can hardly be inspired by the conditions in Northern Mesopotamia where even today timber is plentiful for roofing and scaffolding in parts of the Tigris valley and the foothills to the north-east. He considers it more likely that the technique developed in the south and was introduced into Assyria at Tell al Rimah and perhaps other sites for use in load-bearing capacities [47]. However, here again the problem of survival is important to bear in mind.

Thus the evidence for pitched-brick vaulting at Tell al Rimah takes us back to c. 2100 BC and down to c. 1350 BC [48]. These are not isolated examples of this kind of construction in Mesopotamia. At a slightly later date pitched-brick vaulted tombs were built at Assur; the excavations found several tombs most of them dating to c. 800 BC, but one was dated to c. 1200 - 1000 BC [49]. It is interesting to note that when the site was re-occupied in the Parthian period this sort of vaulting was used for larger spans (see below).

At Ur burnt brick was freely used for construction from c. 2000 BC. Arches are employed over house doorways, probably the earliest known examples of arches employed as architectural elements in the facade of a building (c. 1900 BC) [50]. The majority of the Kassite graves (c. 1550 - 1150 BC) dug by Woolley [51] were covered by brick corbel vaults, though one (KG17) was roofed by a barrel vault.

The E-Dublal-Mah at Ur was rebuilt c. 1400 BC. This temple is very well-preserved, partly because of the durability of the burnt brick. Two features are important here. The two doors of the outer chamber were arched, employing proper voussoirs; indeed the arches were so deep that they could almost be termed vaults [52]. Of the arch over the south-west doorway only a few voussoirs remained but the north-east arch survives intact. Its height was 0.3 m and its span 0.80 m.

Evidence for the later use of vaulting in the area can be found down to Parthian times. Radial vaulting was used to a great extent at Babylon, by this time in burnt brick . The 6th century BC 'Vaulted Building' in the north-east corner of the South Citadel was made up of parallel vaulted chambers on either side of a central passageway [53]. All the chambers were vaulted with semi-circular arches consisting of ring courses separated from each other by level courses [54]. Before this, all examples of vaulting were in tombs or other subterranean substructures where the surrounding earth gave the necessary abutment. In this example, however, the vaulting was carried from one free-standing wall to another, probably one of the earliest attempts at this kind of construction.

The arched doorway in the South Citadel is constructed in a series of ring courses, one above the other, each of them covered by a flat course. The bricks are ordinary, not wedge-shaped. The lower ring alone was an actual arch. The two upper rings begin some courses higher than the last and follow only part of a semi-circle, forming a segment. They begin with the brick laid horizontally not sloping. Koldeway comments on this arch: "It is obvious that the planning of this arch construction is very faulty and inconsistent in comparison with Roman stone vaulting" [55].

Pitched-brick vaulting was used in a 15th century repair of a small room at Tell al Rimah and the technique apparently becomes simplified, with the abandonment of the fan-shaped features, in favour of the simple vault resting against the end walls. This kind of vault does not seem to occur in Late Assyrian or Neo-Babylonian periods; one of the latest uses appears to be at Khorsabad in vaults of the drainage system of the Palace platform [56]. However, it does clearly survive to be employed in both domestic and monumental architecture in the Roman and Byzantine periods (see below).

THE ETRUSCANS

The work of Boethius, Blake and Lugli on Etruscan and early Roman architecture has demonstrated beyond doubt that the Etruscans did not invent the arch [57]. It was usually to them, in the past, that the credit had been given for passing on the arch and the vault to the Romans [58].

Corbelled vaulting was widely used for tombs; indeed this is where most of the early evidence comes from. The Regolini Galassi tomb in the Sorbo necropolis west of Cerveteri is an impressive example of c, 650 BC [59]. It has two rectangular chambers, the main one being corbelled. The passageway leading to it was later provided with a corbelled roof with a single stone slab covering the gap between the two walls. The tombs at Orvieto show a slightly different feature in that the main chambers have very steeply pitched corbelled ceilings with the top of each chamfered to project beyond the course below [60]. Tombs near Cortona also have corbelled roofs.

The corbelled arch continues to be used in the late 4th and 3rd centuries BC. The corbelled arch of the Porta dell'Arco (late 4th century BC) at Arpino [61] has a span of over 4m and rises to over 4 m in height (Plate 132). The substructures of the Via Appia (312 BC) are covered by corbelled vaults [62] and the lower chamber of the so-called Tullianum, dated to the 3rd century BC, also had a corbelled roof [63].

The most spectacular use of the technique of the true voussoir arch, and possibly also the earliest surviving examples in Etruria, occurs in barrel-vaulted tombs in the Chiusi and Perugia area. All these can now be dated to no earlier than the 4th century BC and Blake puts the majority in the 3rd. These include the 'Tempio di San Manno' near Perugia [64] and the Tomba del Granduca at Chiusi [65], both dated to the 3rd century at the earliest.

From the late 3rd century BC, towns in Latium and Etruria began to acquire arched city gateways which have a typical form. The elegant gateway at S. Maria di Falleri (c. 241 - 100 BC) has long narrow voussoirs with a cap-moulding in grey peperino; the springers are on a moulded impost [66]. The same arrangement appears in the Porta del'Arco at Volterra (c. 300 BC). The late 2nd century BC Porta Furia at Sutri indicates a slight development of this arrangement. The ring of voussoirs in outlined by a row of shorter blocks which are also wedge-shaped [67], and the Arco d'Augusta has two rings of voussoirs [68].

The 3rd century also saw more bridges and aqueducts constructed which employed the principle of the true arch. The 2nd century BC Ponte San Lorenzo near Eulicame was an arch constructed of 7 wedge-shaped blocks of travertine with joints that were not radial [69]. The Etruscans themselves, however, never built bridges employing the arch. All the evidence indicates that the Etruscan bridge was nothing more that a flat timber affair supported by masonry piers, and that the arched bridge did not appear in Etruria until the Romans' huge expansion and road building programmes in the 3rd century BC.

From the mid 2nd century BC examples become too numerous to mention. It is at this time that the advent of the new material, concrete, was making an impact on Rome and Latium and a different architectural tradition was coming into being, which was to revolutionise the use of arcuated construction. It is clear from the evidence that the Etruscans did not invent the arch; the Egyptian and Mesopotamian examples clearly demonstrate this. However, if the dating of the monuments is correct, there is almost no evidence to suggest that the arch and vault were in use by the Etruscans before Roman influence began to spread northwards into traditionally Etruscan territory. This then seems to suggest that the Romans passed on the idea to the Etruscans. This is certainly a novel theory, and is, perhaps the result of an oversimplification. However, one other factor has not been mentioned: the presence of the Greeks in Southern Italy since the 8th century BC. Did they have the knowledge to pass onto the Romans or was it passed onto both the Romans and the Etruscans at about the same time? An examination of the Greek evidence produces some very interesting results.

THE GREEKS

In complete contrast to the Etruscans, the Greeks' claim to an early use of the arch and vault was not fully realised until about 25 to 30 years ago [70]. That they did employ the true arch and vault has now been established. The important points to ascertain are how early did the Greeks use arcuated construction; in what way did they use arches and vaults in relation to both function and material; and did the Greeks develop the techniques of their own accord or were they using knowledge and experience acquired by another civilisation.

There is no evidence before the 6th century BC for the use of the true voussoir arch and vault in the Greek world [71]. Before this all vaults were corbelled. One of the earliest examples that has survived is the so-called 'Royal Tomb' at Isopata on Crete [72], dated to about 1450 BC. This was sunk deep in the ground and consisted of a sloping passage leading down to an anteroom and a rectangular chamber. The main chamber was roughly 8 metres by 6 metres and was covered by a corbelled vault in limestone; the soffit was cut into a curve. The magazines in the fortified walls (c. 1250 BC) at Tiryns are covered by enormous roughly trimmed blocks each one projecting beyond the one beneath [73]. Several tholos tombs at Mycenae have corbelled relieving arches over the flat door lintels in much the same arrangement as the Lion Gate of the Citadel. In Sicily, two corbelled examples of the 6th century BC survive: a bridge at Agrigento and at Selinunte a corbelled arch was placed over a trench [74].

From the 6th century BC onwards, in addition to the corbelled arch, the true arch begins to be used in the Greek World. A 6th century BC tomb at Pyla on Cyprus is vaulted with only two specially shaped blocks forming the vault itself without a keystone [75]. In Southern Italy, an arched city gate with voussoirs, has recently been discovered at Velia which has been dated to the 5th century BC [76]. If it is correctly dated, this is the earliest example that we have of the use of the true voussoir arch by the Greeks.

No examples are yet known on the Greek Mainland dating to before the late 4th century BC. The earliest ones include the first of a long series of barrel-vaulted tombs in Macedonia at Vergina. Orlandos and Boyd have published much valuable work on the use of the arch in Greek architecture and though reiteration is not required, certain examples are worth further comment [77]. All Greek arches were constructed in stone and they did not always take the same form. A large number were semi-circular in shape with the voussoirs arranged symmetrically around a centre of curvature, for example some of the gates of the walls of Heracleia by Latmos (late 3rd century BC). However, there were also a number of variants, some of which can be classified.

i) the skewed arch is where the radial joints are not perpendicularly aligned to the faces of the arch. This was used for an early arch (c. 300 BC) in the Long Wall connecting Corinth with her port Lecheion;

ii) the stilted arch is quite common. This is where the lower joint faces of the springers are set lower in elevation than the centre of curvature of the arch (fig. 24ii), for instance, in the vaulted passageway at Epidaurus leading from the <u>tholos</u> area to the west side of the stadium [78]. On the southern side of the theatre at Sikyon beneath the cavea the vault is constructed in the same technique;

iii) the segmental arch is not a full semi-circle but has the lower radial joint face of each springer located higher in elevation than the centre of curvature of the arch (fig. 24i). At Sikyon in a vault on the northern side of the theatre the voussoirs form an arc of 162 degrees, although it appears to be a full semi-circle. This arises because the curvature of the intrados of the vault continues below the springer courses and is carried into the impost courses [79]. Other examples of segmental arches are in the theatre at Eretria where the vault describes an arch of approximately 177 degrees. These examples all seem to be early 3rd century in date. The market gate at Priene is a later example, about 150 BC, and is important because it is the only known free-standing arch in Greek architecture [80];

iv) the flat arch is structurally the least desirable form found in Greek architecture [81] (fig. 24iii). Dura-Europos affords a simple late 4th century BC example of two springer courses and a keystone course [82]. An interesting example survives at Sillyon, in one of the towers. This dates to about 250 BC and consists of nine voussoirs. Of particular interest is that the flat arch is on the outward side of the tower; on the city side is a round arch [83]. Boyd concludes that because of the presence of the more conventional round arch the flat arch here was an experiment.

The arcuated technique, once established, was not only used for arches, gates, passageways, bridges and tombs in the Hellenistic period. By the 2nd century BC, the Greeks employed rows of arches for plain yet monumental facades, for example at Lindos and at the Asclepieion on Cos where the retaining wall of the middle terrace is in fact buttressed by an arcuated facade [84]. A similar arrangement occurs in the Stoa of Eumenes in Athens. The retaining wall behind the stoa is in fact arcaded to buttress it although this is concealed by an ashlar wall [85].

Barrel vaulting clearly developed with the use of the arch; the former is a horizontal extension of the latter so it is difficult to say exactly when an arch becomes a vault. The vaults of the theatre at Sikyon and the vaulted passageway at Epidaurus have already been mentioned. Others which should be noted are the 3rd century BC vaulted passageway into the stadium at Olympia (Plate 133), the Middle Gymnasium staircase at Pergamum (c. 180 BC) and the Temple of Apollo at Didyma (early 3rd century BC) (Plate 134). Access to this last complex was by two descending passages covered by sloping barrel vaults made up of three large, five-sided blocks, the middle one acting as the keystone.

The staircase forming the entrance to both the Middle and Upper Gymnasia is one of the most important constructions in the city of Pergamum [86]. This structure is very well preserved. The five flights comprising the winding stairway are covered by a series of intersecting barrel vaults at varying heights. The skill and craftsmanship involved shows a great familiarity with the materials and the technique.

The barrel vault was used by the Greeks as a covering as well as a support, but this was not the only method used. From the 3rd century a system of arches carrying stone slabs became quite common, for instance, in the theatre cistern of Delos [87] (Plate 135). The floor of the central room of the Nekyomanteion at Ephyra was supported by a series of arches connected by stone slabs [88]. The lower level of the temple of Apollo at Klaros comprised two rooms which were connected by a maze of passages. Originally these rooms were covered by slabs of blue marble, forming the floor of the temple above. Square pillars supported the slabs. After a fire in the early 1st century BC the scheme was remodelled and a series of arches were constructed instead to carry the floor slabs of the <u>cella</u> above [89].

The credit for the earliest groin vault, later so popular with the architects of Rome, must go to Hellenistic builders [90]. The earliest example of certain date is at Delphi where one is incorporated into a complex dedicated by Attalos I of Pergamum [91] (Plate 136). Beneath the terrace in front of the Stoa is an exedra which supports the statue base. The exedra itself is in the form of a 'pi' and has groins where the three vaulted legs of the exedra actually intersect. A long centrally located pier supports one side of the three vaults with specially cut blocks for the salient angles of the groins set on the north end. On the opposite side were either L-shaped or mitre-cut blocks. The whole structure suggests a familiarity with the technique of groin vaulting.

Another example of this technique occurs in a tomb at Pergamum, the date of which is uncertain, but is probably attributable to c. 2nd century BC [92]. Here two barrel vaults intersect at the same level to form a cross or groin vault. The blocks at the junction are cut to fit both vaults, and as Dinsmoor points out, this is too perfect a piece of engineering and craftsmanship to be the first attempt [93].

As already stated, all Greek vaulting was carried out in stone, usually without any kind of mortar or binding material. However, in some instances, the use of dowels and clamps does occur. Why they are used for some and not for other examples is not clear. Of the two passageways of the theatre at Sikyon the north vault is constructed with the use of metal dowels while the south one is not. The barrel-vaulted tunnel into the stadium at Olympia incorporates both clamps and dowels as does the groin vault at Delphi. It may have been felt that some strengthening was necessary perhaps against earthquakes. However, it does show unfamiliarity with the techniques and a reluctance to rely on the compressive actions of the arch and vault for their strength which probably stemmed from incomprehension.

It is thus abundantly clear that the Greeks did know of the arch and that it was used from the late 4th century BC. There are earlier examples but they are noticeably fewer in number. The question as to who passed on the technique to them will be discussed below.

THE ARCH AND THE VAULT IN THE EASTERN ROMAN PROVINCES

The use of the arch and vault in Mesopotamia, Egypt and Greece before the Roman period depended to a great extent upon locally available materials. As a result brick (mudbrick and burnt brick) is the predominant material for arcuated construction in Dynastic Egypt and in Mesopotamia. In the classical period the Greeks rarely used mudbrick and never used burnt brick before the Roman period for their monumental architecture; their building tradition was based on the use of stone for construction, and the post and lintel technique was the predominant practice. As has been seen the Greeks did adopt the arch and vault into their repertory but only in stone, In complete contrast, the Romans in the East were not constrained by an architectural tradition dependent upon the availability of a particular kind of material. A tradition that could be, and was, adaptable to local practices developed so that a distinctive form of architecture was evolved, based on materials of differing structural behaviour and properties, to create a unique combination of materials and techniques which was to prove to be the basis of the architecture of the Byzantine Empire [94].

STONE

Stone was the building material that without exception, was used for Hellenistic monumental architecture. It was this tradition of ashlar masonry which the Romans met in Asia Minor and to a lesser extent in Syria, Arabia and Palestine. The Greeks employed the arch and the vault on a large scale from the late 4th century and early 3rd century BC and they always built of squared stone. This practice continues to a large extent unchanged, into and right through the Roman period at many sites in Asia Minor and the East [95]. There are too many examples to discuss all of them separately. However, some of the most important and most representative ones may be listed as follows:

Asia Minor

EPHESUS: Aqueduct of Sextilius Pollio. AD 4 - 14.
Forschungen in Ephesos, iii, 1923, p. 256 - 63.
Arches of fine squared stone with abutments and superstructure of mortared rubblework.

EPHESUS: Stadium. mid 1st century AD. (Plate 137)
Ward-Perkins (1958)b, p. 98. Pers Obs.
To support the seating on the north side a barrel vault runs its full length. This consists of two concentric rings of flat stones laid radially which supports a mass of rubble.

HIERAPOLIS: City Baths. Hadrianic. (Plate 138)
Ward-Perkins (1981), p. 296. Pers Obs.
This has the largest preserved span of ashlar. The North Frigidarium is covered by a vault 21 m long and 12.50 m wide and rises to a height of about 13 m. The caldarium vault was even larger with a span of about 16 m.

PERGAMUM: Hadrianic Baths, Upper Gymnasium. early 2nd century AD (Plate 139).
Pers Obs.
A number of main arches turned in well-cut stone.

PERGAMUM: Kızıl Avlu: vaults over river beneath sanctuary. early 2nd century AD (Plate 140)
Pers Obs.
Stone arches at both ends of vaults, presumably to give the barrel vaults of mortared rubble a decorative end.

EPHESUS: Baths/Gymnasium of Vedius, c. AD 150 (Plate 141)
Pers Obs.
Doorways in the frigidarium are covered by flat stone arches with a central keystone.

PERGE: Stadium. 2nd century AD (Plate 142)
Ward-Perkins (1980)a, p. 302;
Vann (1976), p. 116. Pers Obs.
The seating support is formed by sloping barrel vaults, 9.85 m long and 6.50 m high. Spectators entered through every third vault. On the east side walls of c. 4 m high support a horizontal barrel vault for a length of 4.30 m. At this point the vaults are pitched at an angle of 38 degrees, equal to the slope of the seating which they support. On the west side there were no horizontal vaults.

SIDE: Theatre. 2nd century AD (Plate 143)
Mansel (1963), p. 122 - 24. Pers Obs.
The seating above the diazoma is supported by a double tier of 23 sloping radiating barrel vaults, similar to the stadium at Perge.

ASPENDOS: Stadium. 2nd century AD (Plate 144)
Lanckoronski (1890)1, p. 91; Vann, p. 117.
Pers Obs.
The seating on the west side is placed directly on the hill. On the east side it is supported on pitched barrel vaults, as the Side theatre and stadium at Perge. The north end is carried on two concentric barrel vaults like the stadia at Selge and Sillyum.

HIERAPOLIS: Theatre. 2nd century AD (Plate 145)
Pers Obs.
The floor of the stage building is supported by transverse arches. A floor of stone slabs was laid over these.

PERGAMUM: Amphitheatre. 2nd century AD (Plate 146)
Pers Obs.
Lower vaults of the structure are of large blocks of stone backed with mortared rubble.

PERGAMUM: Roman theatre. 2nd century AD (Plate 147)
Pers Obs.
Some of the vaulting is carried out in fine cut stone, especially 'The Ruined Gate' which formed one end of the cavea, but, as it stands now, is a wedge-shaped. stone vault.

TERMESSOS: Gymnasium. 2nd century AD (Plate 148)
Vann (1976), p. 124. Pers Obs.
Beneath the floor is a cistern. The slab floor is supported by a series of parallel arches.

EPHESUS: Temple of Serapis. mid 2nd century AD.
Akurgal (1978), p. 163.
The cella was covered by a stone barrel vault, with a span of 29 m. The walls of the cella are very thick to support the weight of the vault.

ARYKANDA: Baths. 2nd century ? AD (Plate 149)
Unpublished. Pers Obs.
Main chambers were once covered by enormous barrel vaults constructed of very large stones laid without mortar. The springing line is very visible today.

PERGE: Theatre. 2nd century AD.
Vann (1976), p. 113. Pers Obs.
Four vaulted entrances, two in the rear and two in the parodoi. The former are sloping ramps covered by vaults of a similar pitch, 11 m long and 3 m wide. The parodos vaults are 13.50 m long and very steeply pitched, rising from a point about 3 m above the ground level to well over 10 m at the level of the first diazoma.

MILETUS: Theatre. 2nd century AD (Plate 150)
Pers Obs.
Quite extensive use of cut-stone for barrel vaults, particularly the barrel vault running around the diazoma.

IZMIR: Agora: rebuilding. late 2nd century AD (Plate 151 and 152)
Pers Obs.
West Basilica: Substructures formed of three parallel vaults consisting of arches supporting stone slabs. These slabs formed the floor of the basilica above. The angles of the arches are built up to form a flat wall at the height of the crown of the arch.
North Basilica: Substructures formed of three sets of parallel vaults, the foremost of which consists of stone arches supporting stone slabs similar to the West Basilica. One difference is that every alternate arch rests on a large stone pier on the north side; this may represent a later strengthening. At the west end of each of the front two parallel vaults is a square compartment covered by a stone vault made up of stone ribs crossing the

square and supporting stone slabs.

NICAEA: Theatre. 2nd century AD (Plate 153)
Pers Obs.
Rubble _cavea_ supported by radial stone barrel vaults. The lower ones are inclined, the upper ones are horizontal.

ANEMURIUM: _Odeum._ 2nd/3rd century AD.
Rosenbaum (1967), p. 3.
Beneath the _cavea_ over a square chamber is a groin vault of quarry stone.

ANEMURIUM: Baths III 2 B. 3rd century AD.
Rosenbaum (1967), p. 8.
A number of barrel vaults survive of quarrystone work of irregular limestone.

Syria, Arabia, Palestine

JERASH: South theatre. Late 1st century AD (Plate 154 and 155).
Kraeling (1938), p. 19. Pers Obs.
The upper seating is supported by stepped barrel vaults, each step being equal to the height of one seat. In the west wing of the stage building the square crossing point is covered by a groin vault.

JERASH: South Decumanus Bridge. Late 1st century AD (Plate 156)
Kraeling (1938), p. 17. Pers Obs.
This consists of a series of cut stone arches across a distance of 73 m. The arch over the stream itself has a span of 10 m and a height of 17 m.

PETRA: Theatre. 1st to early 2nd century AD (Plate 157)
Hammond (1965), p. 38 - 39. Pers Obs.
The stage floor is supported by arches in the same way as at Hierapolis.

JERASH: Temenos of Temple of Zeus. 1st/2nd century AD (Plate 158)
Kraeling (1938), p. 17 - 19. Pers Obs.
The monumental staircase was supported by a series of terraces up the hillside, each one being carried by a barrel vault. The bottom most one forms a _crytpoporticus_.

AMMAN: _Odeum_. 2nd century AD (Plate 159)
Hadidi (1974), p. 89. Pers Obs.
The side entrance is carried by a sloping barrel vault of very well cut-stone and the stage building is connected to the outer wall by a barrel-vaulted passage.

BOSTRA: Theatre. 2nd century AD.
Pers Obs.
Beneath the _cavea_, for access as well as to support the seating, are radiating and annular barrel vaults. The radiating vaults are stepped as at Jerash.

AMMAN: Over conduit in valley. 2nd century AD (Plate 1)
Conder (1889), p. 39; Butler, _S. Syria_, p. 59.
This no longer survives, but the whole length of the stream was covered over by a barrel vault of well cut stone. The span was probably 10 m if Conder's description is correct.

UMM QAIS: North theatre. 2nd/3rd century AD.
Schumacher (1890), p. 50 - 53. Pers Obs.
Barrel vaults beneath the _cavea_, some sloping. They were constructed of basalt with no mortar, showing excellent craftsmanship and close joints.

SHAQQA: Basilica. Late 2nd century AD. (fig. 25)
Butler, _Architecture_, p. 365.
Consists of 6 sets of transverse stone arches set closely together. Each set is made up of a broad central arch with two storeys of arches on either side. Longitudinal arches connected the transverse arches at crown level of the lower side arches and carried the floor slabs of the galleries.

JERASH: West Baths. 2nd/3rd century AD (Plate 160)
Kraeling (1938), p. 23. Pers Obs.
Extensive use of barrel vaults for main chambers. The large hall is divided into 3 nearly equal parts by great arches springing from heavy piers on the long sides of the room. The arches and end walls supported 4 sections of heavy barrel vaulting running east west.

JERASH: East Baths. 3rd century AD (Plate 161)
Pers Obs.
Walls of ashlar 5 m thick suggest heavy barrel vaulting. The springing of stone vaulting is still visible in the main hall especially.

JERASH: Triumphal Arch. Late 2nd/early 3rd century AD (Plate 162)
Kraeling (1938), p. 81 - 83. Pers Obs.
The pavilions on either side were vaulted in stone with the vaults tilted upwards and away from the arch.

BRAD: Private bath building. early 3rd century AD.
Butler, _N. Syria_, p. 299 - 302.
Cut stone barrel vaults survive intact, highly finished with the utmost precision in jointing and cutting.

PHILIPPOPOLIS: Theatre. 3rd century AD (Plate 163)
Butler Architecture, p. 391 - 2; Coupel and Frezouls (1956).
Pers Obs.
The cavea is on two storeys of concentric curved vaulted passages. Sometimes these are intersected by radiating passages. The vaults are of stone weighted with rubble. Groin vaults do occur.

UMM EL JEMAL: 1st - 6th century AD (Plate 164 and 165)
Butler, S. Syria, p. 156 - 9. Pers Obs.
Various techniques used, corbelled cantilevers, transverse arches supporting roofing slabs.

SHAQQA: Palace. 3rd century AD.
Butler, Architecture, p. 370 - 375.
Roughly L-shaped in plan, this is roofed with stone slabs supported on series of transverse arches. The longest arm contains 10 transverse arches. On the outside of the long wall are a series of buttresses to resist the thrust of the interior arches where the points of pressure are concentrated.

It is evident that the use of stone for this technique is widespread and common in the Roman period, above ground and in both prominent and concealed places. In theatres and stadia the use of stone arches is very common. Without exception Greek theatres were built against a hillside using the slope as support for the cavea. A frequent occurrence in the Roman period is the adaptation of a Greek style theatre into a more Roman layout; this entailed extending the seating out from the hillside on vaults, for instance, at Ephesus and Miletus [96]. Where a new theatre was built, if there was no hill-slope, the auditorium was built up on a system of barrel vaults, as at Side, Bostra and Philippopolis. These vaults often radiate from the orchestra and demonstrate expert stone cutting, dressing and laying. The stadium at Perge illustrates this particularly well. The vomitoria of the South Theatre at Jerash and the theatre at Bostra, as well as the hippodrome at Jerash, are covered by stepped barrel vaults made up of a series of arches instead of sloping barrel vaults. These arches equal the depth of each tier of seats; the bays of the hippodrome at Jerash were covered by arches, each one 0.41 m above its neighbour. This equals the height of each tier of seats. Since each arch was 0.60 m thick, each row of seats must have been 0.60 m wide [97].

A particular method of roofing, often used in the Hellenistic period (see above) is where a series of arches is constructed to support a flat roof or floor slabs, for instance the theatre cistern at Delos and the chamber beneath the Temple of Apollo at Claros (see above). There are several Roman examples from Asia Minor, but it is interesting that, for the most part, they are in cities which remained true to the Hellenistic ashlar tradition throughout the Roman period. At Hierapolis the stage-building floor is supported by a series of stone arches, though no paving survives. At Etenna in the foothills above modern Manavgat in Southern Turkey, a structure on the northern side of the site, presumably a cistern, is roofed in the same way [98]. The cistern beneath part of the gymnasium at Termessos is an interesting variant of this method. The floor above it is supported on parallel arcades, not just single transverse arches on solid walls. When there are single arches, all the lateral thrust is directed to the side walls and is absorbed by them; these walls are amply buttressed by the earth behind them. However, in the Termessos example, the system works slightly differently. Each arch of the arcades exerts a counter thrust to the lateral thrust of its neighbours. This force is then directed down onto the load bearing pier and also along the arcade to the solid walls of the chamber. One is reminded of the Vaulted Building at Babylon (see above). The substructures of the North and West Basilicas in the agora at Izmir (ancient Smyrna) show this technique of arches supporting stone slabs in connection with other materials.

In the provinces of Syria, Arabia and Palestine the same technique is observed but in rather different circumstances. The mountains of North Central Syria were once plentiful producers of timber. This was a great influence on the architecture of the area, both before and after the coming of the Romans. All monumental building as well as private houses were based upon wooden construction; timber was used for door and window frames, balconies, internal floors and roofs [99]. Butler [100] observed that some buildings would have required very large beams for roofing. It would have been too expensive if timbers had to be imported from a great distance and an alternative kind of architecture would have been developed, as was the case in the Hauran. One notable exception to this almost exclusive use of timber for roofing is the early 3rd century baths at Brad (ancient Barade) observed by Butler in the early 1900's [101] which employ well-cut stone for the barrel vaults and domes.

The Hauran (modern Southern Syria) was deforested long before the Roman period [102]. Butler sees this as the reason why the volcanic basalt of the region was used for almost all construction; as the basalt was difficult to quarry in large blocks, the arch was used more than further north [103]. The typical method of roofing a building in the Roman period was by placing long flat slabs of stone across a series of transverse arches. This was the method used by the Nabataeans from the 1st century BC. This nomad tribe learned to handle the intractable material with great skill and craftsmanship, and it is to them that the credit must go for this technique in this area. Butler was mistaken in attributing the development of the Hauranite arch to the architects of the Roman period and consequently overlooks the expertise of the Nabataean builders.

The town of Umm el Jemal, founded by the Nabataeans in the early 1st century BC, lies on the main caravan route from the South to Damascus to the North. Butler produced some very useful plans and sections illustrating the techniques prevailing in the area in the pre-Roman period [104]. The main hall of Building XVII was situated to the south of the courtyard. The hall was roofed over by three arches with slabs placed across these. In Building XVIII, three rooms, one to the west of the large court and the other two to the east, are roofed by single arches across the middle of the rooms. Long slabs of basalt were then placed across to the arches from the main walls. Only the wider halls, however, were covered over by arches [105]. The smaller rooms were roofed by long slabs of basalt resting on corbelled courses. In many cases these corbels are of first-rate workmanship.

These techniques continued to be used at this site after the annexation of the area by the Romans in the early 2nd century AD. The barracks, a two-storey building around a central court with a tower at the south-east corner, probably dates to the 3rd century AD. A chamber at the tower corner of the building is roofed by two arches, the spaces between being covered by slabs of stone laid on corbels resting on the arches. The Praetorium, probably contemporary with the Barracks, shows some interesting developments. Most of the rooms are roofed by the arch and slab system, the main hall having two arches as opposed to the single one of the other four rooms. However, the room at the south-east corner of the house is different. It is cruciform in shape with the central square defined by four broad arches. This area is roofed by a kind of dome.

These techniques are found elsewhere in the Hauran, for example, the three temples at Si' and in the late 2nd century basilica at Shaqqa, as well as at Petra, the Nabataean capital [106]. In the basilica at Shaqqa the thrust of the transverse arches is largely taken by the long engaged piers projecting from the south walls; these are, in effect, internal buttresses. The Palace at Shaqqa is also roofed by single transverse arches and stone slabs. On the outside of the long wall buttresses were constructed to resist the thrust of the interior arches at the points of pressure. In other examples with transverse arches the walls are sufficiently thick to support the arches and few examples had two or three at the most. In the Shaqqa basilica the side arches helped to resist the thrust of the main and highest arches across the central portion of the building. Thus the Palace is particularly important for the use of the external buttresses. Buttresses are used before this in Roman architecture, so the Palace does not incorporate a completely new development. Granaries, both military and civilian, were buttressed primarily to take the weight of the heavy stone roof, but also to allow for the lower windows necessary for ventilation and to a certain extent to resist the lateral thrust of the loads inside [107]. The vestibule to Domitian's Palace on the Palatine in Rome has immense spur buttresses, each one measuring 60 Roman feet square (about 19 m), along the shorter sides of the room. The vault curved across the long dimension [108], but probably the best known example of huge buttresses is the Basilica of Maxentius in Rome. These help to resist the load exerted by the central concrete vault by transferring the thrust to the exedra whose structural function was to buttress the central nave.

Groin vaults, though not common in the East, do occur in the Roman period. The example in the South Theatre at Jerash covers the crossing point of two barrel vaults in the West wing of the stage building. The level of workmanship is very high with the blocks cut so that a zig-zag line is formed by the joints along the groin. Roux records other examples at Hierapolis and Baalbek [109].

In complete contrast to Greek and Hellenistic practice, a large amount of Roman stone vaulting was constructed without the use of clamps or dowels and very little mortar was actually used. At the sites in Syria and Arabia very often stone blocks for arches and vaults are laid dry making the structures very dependent on the actual mechanics of the techniques involved. At Jerash, no evidence has been found of any form of metal cramp being used [110] and all work was laid dry. However, at Palmyra, one only has to look at the Temple of Bel to realise that originally metal clamps were used. The building is pock-marked with holes drilled into both column and block to extract the metal. In Asia Minor, it would not be unreasonable to expect or find mortar or clamps used, as this tradition prevailed in the few hundred years before. Clamps were used at Cyzicus in the stone vaults beneath the <u>cella</u> of the Temple of Hadrian [111]. It is difficult to say one way or the other, short of dismantling a building, whether metal clamps were used. Mortar was used at a number of sites in Cilicia for the vaults but this might be explained by the nature of the rough quarry-stone that was used, which required some kind of binding agent.

CONCRETE

In general the materials were not available in the East to make a concrete of the type used in Rome and Italy (see above). Other materials were found in which to carry out the vaulting techniques normally associated with the opus caementicium of the West. However, there are a few isolated areas in the East where geological conditions exist to enable the manufacture of a material very similar to Roman concrete. The two main areas are Cilicia in Southern Turkey and the Hauran in Southern Syria.

In Cilicia, the use of a type of concrete is centred on the Korykos area. At Korykos and Elaeusa-Sebaste a material resembling Roman concrete both in its structural qualities and in the way it was used, was employed, though it is only occasionally used for actual vaulting [112].

AUGUSTA CILICAE: West Building. 2nd/3rd century AD (?)
Gough (1956), p. 172.
No actual vaulting survives but there are signs of vaulting in the east part of the hall. Signs of buttressing and the thickness of the walls also indicate vaulting.

KORYKOS: 'Antike Bad'. Roman.
Ward-Perkins (1958)b, p. 98. Otherwise unpublished.
Three parallel barrel vaults. The monolithic qualities of the Cilician concrete is well demonstrated by the size of the fallen lumps. Use was made of a brown porous limestone to lighten the vaults.

In the Hauran in Southern Syria, vaults of light volcanic scoriae occur in the Roman period.

DURA-EUROPOS: Roman Baths, M7, E3, C3. Early 3rd century AD.
Dura 6, p. 84. Pers Obs.
Five room nucleus of each bath was once covered by a concrete vault. Little evidence can be seen now of these vaults.

PHILIPPOPOLIS: Baths. Mid 3rd century AD (Plate 166)
Ward-Perkins (1981), p. 343; Butler, Architecture, p. 384-389.
Pers Obs.
Five rooms covered by barrel vaults. The vaults are of small dark volcanic scoriae laid in a good cement. All the vaults are much lighter in construction than other parts of the building. The barrel vault of Room H is perfectly preserved and rests on massive walls, 1.20 m thick.

BOSTRA: South Baths. 3rd century AD ? (Plate 167)
Ward-Perkins (1981), p. 345 - 346;
Butler, S. Syria, p. 260 - 261. Pers Obs.
Two barrel vaults of light volcanic scoriae set in good mortar. Only the springing of vault S is intact. Vault O, which is now used as a house, is probably perfectly preserved.

MORTARED RUBBLE

Mortared rubble is one alternative found in the Roman East to Roman opus caementicium; indeed it occurs extensively in Asia Minor and is used only in a minor way in Syria. As with stone, the examples in Asia Minor are abundant and only an important selection is given below.

ELAEUSA-SEBASTE: Reticulate Baths. 1st century AD.
Ward-Perkins (1958)b, p. 96 - 97.
The main vaults have an intrados of rough stone laid radially with a backing of mortared rubble. The rubble is laid in distinct horizontal layers 20 - 35 cm apart. The vaults rest on concrete walls faced with brick.

MILETUS: Baths of Capito. Mid 1st century AD.
Ward-Perkins (1981), p. 274 - 5 and 295.
Pers Obs.
Barrel vaults of mortared rubble with the stones radially laid. The mortared rubble is rather coarse owing to the nature of the local stone.

PERGAMUM: East Baths of Upper Gymnasium. Hadrianic. (Plate 139)
Ward-Perkins (1981), p. 296. Pers Obs.
Main vaults of mortared rubble with the main arches turned in stone.

APHRODISIAS: Baths. Hadrianic (Plate 168)
Ward-Perkins (1981), p. 296. Pers Obs.
Mortared rubble vaults, used in conjunction with squared stone.

PERGAMUM: Odeum. on North side of Upper Gymnasium.
Early 2nd century AD (Plate 169). Pers Obs.
Annular vault of radially laid fieldstones in white mortar to support the seating. The stones vary in size.

CYZICUS: Temple of Hadrian. 2nd century AD.
Ward-Perkins (1958)b, p. 96.
Substructures of <u>cella</u> consist of 3 parallel tunnels covered by barrel vaults. Inner vaults are of rubble laid radially. Outer ones of ashlar.

PERGAMUM: <u>Cryptoporticus</u> of the Asclepieion.
2nd century AD (Plate 170)
Vann (1976), p. 88. Pers Obs.
Barrel vault of uncut fieldstones laid radially with large amounts of mortar. Stones varied in size.

MILETUS: <u>Nymphaeum.</u> 1st century AD (Plate 171 and 172)
Ward-Perkins (1958)b, p. 99. Pers Obs.
Internal vaults of radially laid rubblework in mortar. The aqueduct forms an integral part of the construction with a band of courses of specially selected long flat slabs along the crown.

PERGAMUM: Asclepieion, Rotunda substructures.
c. AD 130 - 140 (Plate 173)
Ward-Perkins (1981), p. 284 - 85. Pers Obs.
Annular vaults of radially laid mortared rubble on 17 piers and ashlar walls.

MILETUS: Baths of Faustina. Mid 2nd century AD (Plate 174 & 198)
Ward-Perkins (1981), p. 274. Pers Obs.
Two qualities of radially laid stone set in mortar.

EPHESUS: Baths of Vedius. c. AD 150 (Plate 175)
Ward-Perkins (1981), p. 292. Pers Obs.
Mortared rubble vaulting with cut stone used extensively for the main load-bearing walls.

MILETUS: Theatre. 2nd century AD (Plate 176)
Pers Obs.
As well as vaulting in stone, mortared rubble was also used, for example, for the barrel vault running around the top of the <u>cavea</u>. Radial barrel vaults of mortared rubble are visible at the very top of and behind the <u>cavea</u>.

PERGAMUM: Amphitheatre. 2nd century AD (Plate 146)
Pers Obs.
Upper vaults supporting <u>cavea</u> of rubble laid in abundant mortar.

PERGAMUM: Roman theatre. 2nd century AD.
Pers Obs.
Upper part of <u>cavea</u> supported by small mortared rubble radial barrel vaults.

PRIENE: Roman Gymnasium. 2nd century AD (Plate 177)
Pers Obs.
Rough mortared rubble vaulting.

IZMIR: Agora: North Basilica substructures. Late 2nd century AD (Plate 178)
Pers Obs.
The back barrel vault of the substructures is constructed of mortared rubble with stone arch ribs, presumably to act as a strengthening.

ALEXANDRIA TROAS: Baths/Gymnasium. 2nd century AD
A. Smith (1979), pl. IIb.
Some rubble vaulting on ashlar walls.

EPHESUS: Baths of Varius. 2nd/3rd century AD (Plate 179)
Pers Obs.
The main vaults are of mortared rubble with facing of small square stones. On the north side the baths are rock-cut.

SIDE: Agora latrine. 2nd/3rd century AD (Plate 180)
Vann (1976), p. 160; Mansel (1963), p.99.
Pers Obs.
Semi-circular vault of mortared rubble faced with small stones. Vault rested on walls 5.10 m high; the height from floor to ceiling is 7.40 m.

MYRA: Bath building? 4th/5th century AD (Plate 181)
Pers Obs.
Main vaults of mortared rubble on brick faced rubble walls.

The quality and character of the finish of the work might vary greatly depending on the importance of the building and still more on the sort of stone that was available. Mortared rubble is often used in association with the traditional ashlar masonry.

BRICK

"An immediate and architecturally very important result of this lack of suitable materials (that is, to make Roman concrete) was that the sort of concrete building which was being undertaken in Rome during the second half of the 1st century AD ...... could have no immediate and direct counterpart in Asia Minor, or indeed anywhere else in the Roman East. As unquestionably the most progressive architecture of its day, it was bound in the long run to make itself felt all over the Roman world; but its impact could not take the obvious form of direct imitation" [113]. It has already been seen that, as well as the 'traditional material of stone, mortared rubble was used for vaulting. From the 1st century AD, burnt brick begins to make an appearance in the Roman East, used as a building material in its own right for wall and vault construction. Mudbrick was used to varying degrees by the Greeks and the Romans and it must have been much used for domestic architecture. Its survival rate is very low and it is impossible to say how much, if at all, it was used in the same way as burnt brick in monumental architecture in the Roman period.

Asia Minor

SARDIS: Tomb 2 in Artemis Precinct, Early 1st century AD.
(Plate 182)
Hanfmann (1983), p. 59. Pers Obs.
Vault of 39 brick voussoirs with joints 4 - 5 cm filled with carefully smoothed lime plaster containing an abundance of crushed brick. Height of vault 85 cm. Bricks - 33 cm sq by 3.5 - 4.5 cm thick

MILETUS: Baths of Humeitepe. Late 1st century AD.
Ward-Perkins (1958)b, p. 99. Pers Obs.
Some traces of brick vaulting, but this is minimal.

EPHESUS: Harbour Baths. 1st/2nd century AD (Plate 183)
Ward-Perkins (1981), p. 274. Pers Obs.
Radial brick vaulting on marble superstructure. The 4th century arcades of the atrium are of concentric rings of brick. Bricks are a warm red colour, average size 34 cm sq x c. 5 cm.

EPHESUS: Theatre Baths. Early 2nd century AD ?/Severan? (Plate 184)
Pers Obs.
Vaulting of brick on brick upper walls and stone footings. Bricks also used for some vaulted substructures for example, a service corridor running along the south side of the main building, which is covered by a radial brick vault on stone. Bricks 24 cm sq x 5 cm.

PERGE: Baths to south-west of Hellenistic Gate. 2nd century AD.
Lanckeronski (1890), I, p. 45 - 6: Ward-Perkins (1958)b, p.101.
Pers Obs.
Vaults of main rooms are of brick springing from ledges set back in the two long walls. Brick size 27 - 28 cm sq x 4.5 cm.

MILETUS: Baths of Faustina. Mid 2nd century AD, restored late 3rd century (Plate 185)
Ward-Perkins.(1958)b, p. 99. Pers Obs.
Main vaults of brick with some rubble vaults.

EPHESUS: Baths of Varius. Mid 2nd century AD (Plate 186)
Ward-Perkins (1981), p. 292. Pers Obs.
Some main brick vaults especially prominent at the west end of the <u>caldarium</u>. Brick barrel-vaulted substructures also, mostly radially laid brick but one junction of two barrel-vaults is covered by a pitched square of brick.

EPHESUS: Baths of Vedius, <u>c</u>. AD 150 (Plate 187)
Pers Obs.
In the substructures some small vaults and arches are carried out in brick, for example, a radial vault over the seating for a hot boiler.

IZMIR: Agora: North Basilica substructures. Late 2nd century AD (Plate 188)
Pers Obs.
Middle of the three parallel vaults making up the substructures, composed on stone arches connected by shallow pitched-brick brick barrel vaults.

SARDIS: Gymnasium Complex. 2nd/3rd century AD (Plate 189)
Vann (1976), p. 145 - 151. Pers Obs.
All vaulting radially laid brick on mortared rubble walls. Room, BEA, 9.80 m by 14.10 covered by a brick vault. East - west walls c. 2.50 m thick. Room BEW, vault 46.50 m long by 12.50 m, springing 9.65 m above the paving level. Bricks average 38 cm sq by 4 cm. Bricks were laid radially on wooden forms. Rubble placed above haunches once mortar has set to provide buttressing effect against lateral thrusts.

SARDIS: Roman Basilica.
Foss (1979), p. 36. Pers Obs.
3 brick cross-vaults, radially laid, on 8 massive marble piers, span of 50 m x 13.50m.

PRIENE: Theatre stage-building. 2nd century AD (Plate 190)
Pers Obs.
Three rooms each covered by a brick radial vault backed with mortared rubble.

ALEXANDRIA TROAS: Baths/Gymnasium. 2nd century AD.
A. Smith (1979), p. 24.
Brick vaulting on ashlar walls.

ANAZARBUS: Baths. 2nd/3rd century AD.
Gough (1952), p. 85 - 150.
Possible brick vaulting.

RHODIAPOLIS: Baths? Cistern? 2nd/3rd century AD?
C. Bayburtuoğlu, Lycie, (n.d) pl. between p. 16 and 17.
Crown of vault of pitched brick on lower courses of radially laid brick.

ANKARA: Baths of Caracalla. Early 3rd century AD.
(Plate 191)
Ward-Perkins (1981), p. 230. Pers Obs.
Brick used only for vaulting small areas eg, drains, staircases and perhaps some smaller rooms.

ASPENDOS: Aqueduct.? 3rd century AD (Plate 120)
Ward-Perkins (1955), p. 120.
Arches turned in brick. The upper arches had a double ring of brick voussoirs.

ASPENDOS: Baths. 3rd century AD.
Ward-Perkins (19 ~~77~~), p. 167. Pers Obs.
Only the springing of the vaults survive; these are of radially laid brick. Perhaps had pitched brick vaulting forming the crown as the Basilica at Aspendos and the cistern (?) at Rhodiapolis.

EPHESUS: Houses to South of Embolos, the Hanghaüser.
Some originally built in 1st century BC/AD. Many altered c. AD 300 from which time vaults presumably date.
(Plate 192) Pers Obs.
Pitched and radial brick vaults.

PERGE: Baths to west of city. 3rd century AD.
Ward-Perkins (1958)b, p. 101. Pers Obs.
Vaults of main rooms of brick. Individual bricks measure 27 - 28 cm x 4.5 cm.

NICAEA: Towers of walls. 3rd century AD.
Ward-Perkins (1958)b, p. 87.
Narrow dog-legged corridor from inside city to the ground immediately in front of curtain-wall vaulted in brick.

EPHESUS: East Gymnasium. 3rd century AD (Plate 193)
Pers Obs.
Similar construction to the Harbour Baths of brick vaulting on a marble superstructure.

ASPENDOS: Basilica superstructures. 3rd century AD. (Plate 194)
Ward-Perkins (1958)b, p. 96.
At least three chambers with the end walls of ashlar masonry. The side walls are of mortared rubble with a projecting course of large stone blocks. From this spring brick barrel vaults. The first 18 - 22 courses are laid radially along either side with the crown of the vault consisting of bricks pitched across the line of the vaults. The joints are very close. Estimated size of bricks 34 cm square by 7.5 cm.

EPHESUS: Houses to west of Baths of Scholastikia. 4th century AD (Plate 195)
Pers Obs.
Several rooms covered by brick barrel vaults with radial shoulders and pitched crown.

EPHESUS: Palace or so-called 'Drunken Baths'. 4th century (Plate 196)
Pers Obs.
North end of complex behind the cistern a small room covered by a pitched-brick vault, rather like a sail vault (see Chapter VIII).

KORYKOS: 'Antike Gebaude'. Bath buildings. Date ?
Ward-Perkins (1958)b, p. 98.
Flat arch of brick with a relieving arch over it.

MYRA: Bath building. 4th/5th century AD ? (Plate 197)
Pers Obs.
Windows and small openings are vaulted over by sloping vaults of brick set in abundant mortar. Perhaps some vaults of the smaller rooms also were of brick.

ANEMURIUM: Baths III 2 B, room C and G. Mid 3rd century AD.
Rosenbaum (1967), p. 75.
Rows of marks are clear on the surface of the mortar of the vault. These are the 'negatives' of bricks from which the vault was originally constructed. The bricks were laid in vertical rows.

SIDE: Agora Baths, Room 1. 5th century AD.
Rosenbaum (1967), p. 76.
Pitched brick vaulting, some of which can be seen today. The bricks used were not regular in shape, the under surface being 2 cm shorter than the upper.

DURA-EUROPOS: Bath M7. Early 3rd century AD.
Dura 6, p. 86. Pers Obs.
Cellar beneath room 1 roofed by vault of pitched burnt brick. The praefurnium contained arches also of burnt brick laid as radiating voussoirs.

DURA-EUROPOS: Bath E3. Early 3rd century AD.
Dura 6, p. 93. Pers Obs.
Semicircular brick barrel vault, 2.10 m to the crown covered large flue in S. W. corner. Also the springing of a vault in brick survives in one of the larger rooms.

DURA-EUROPOS: House of Scribes (L7). 3rd century AD ?
Dura 6, p. 66.
Passageway vault of burnt brick. Bricks are half bricks 23 cm x 11 - 12 cm x 5 cm thick set edgewise, that is pitched, across the vault.

From the above it becomes clear that there are two techniques of building a brick vault that are used in the Roman East:

1) laying the bricks parallel to the axis of the arch or vault, which is the normal Roman method;

2) laying the bricks end to end across the vault along the line of the curvature (fig. 1).

This second method, 'pitched' brick vaulting, is of particular interest when one considers that this is the manner of most Byzantine vaulting. There is no precedent in the architecture of the Roman West or of Asia Minor for pitched-brick vaulting, though it has long been recognised that the structural principles involved in this technique were known and used in the Ancient East as early as the 2nd millenium BC. The use is a mudbrick technique going back to Dynastic Egypt and 2nd millenium BC

Mesopotamia, for instance in the Ramesseum at Thebes and at Tell al Rimah respectively.

Construction of this kind of vault in mudbrick normally proceeds from both ends of the room to be covered. The end walls are built up to the level of the crown of the vault. The first ring at each end leans against the end wall usually at a slant; the degree of slant varies considerably. Work continues until the rings meet in the middle. Depending on the angle of slant a gap may remain in the crown of the vault. This can be reduced by interlocking segments of diminishing length or by bricks laid radially. There are various advantages with this method. During construction each brick as it is laid rests partly on the previous brick laid in the same ring and partly on the sloping surface of the previous ring: only one ring is laid at one time unlike a radially laid brick vault where several courses are laid simultaneously. Thus the pitched brick mudbrick vault could be built without centering. If a quick-drying mortar and relatively light bricks are used, the pitched brick vault could be constructed with burnt bricks. It is this technique of vaulting which is translated into burnt brick in the Roman period.

The principal examples of this technique are as follows, demonstrating both the antiquity of the technique and how widespread its adaption became in the Roman and early Byzantine periods.

SAQQARA: Subsidiary graves of tomb 3500. c. 3000 BC?
Spencer (1979), p. 10 - 11.
Vaults of mudbrick of rings laid at a slight slant against the main wall of the tomb.

BEIT KHALLAF: Tomb K1. c. 2700 BC.
Spencer (1979), p. 23.
Inclined vault of similar kind. Bricks 28 cm x 12.5 cm x 9 cm.

TELL AL RIMAH: Great Temple, terrace substructures on the S. slope of mound. 1800 - 1350 BC.
Oates (1965 - 70), and Oates (1973).
Pitched mudbrick vaults used abundantly with a number of variations in construction. One method is using a fan-shaped feature (referred to as a 'pendentive' by Oates) to support the inclined vault. The bricks used are smaller and thinner than those employed for wall construction, presumably to reduce the weight of the vault. Brick size in vaults 24 cm sq x c. 4 cm as opposed to 34 - 35 cm sq x 8 - 9 cm thick. Some of the brick have parallel finger impressions diagonally across the face as a key for the mortar.

KARNAK: Temple of Amenhotep. c. 1400 BC.
Spencer (1979), p. 67.
At the rear of the temple is a transverse hall with a brick vault of 7.70 m, the largest brick vault so far known in Egyptian architecture.

THEBES: Storerooms behind the Ramesseum. 1250 BC.
Spencer (1979), p. 86;
Clarke and Engelbach (1930), p. 182 and fig. 215.
The vaults are constructed of at least four rings of mudbricks pitched on edge. As with Tell al Rimah the faces of the bricks are heavily scored with finger marks. Brick size c. 34 cm x 17 cm x 3 - 4 cm.

ASSUR: Tomb. c. 1200 - 1000 BC.
Andrae and Lenzen (1954), p. 27 - 29.
Pitched brick vault.

ASSUR: Tombs. c. 800 BC.
Andrae and Lenzen (1954), p. 27 - 29.
Pitched brick vaults.

SELEUCIA ON THE TIGRIS: Two tombs. 1st century AD.
Ward-Perkins (1958)b, p. 93 - 4.
One tomb covered by a pitched-brick vault. The other has a crown of pitched-brick laid on radially laid shoulders.

HATRA: Temples. 1st - 3rd century AD.
Ward-Perkins (1958)b, p. 98.
Temple VIII survives enough to show that they were covered by pitched-brick vaults, divided and strengthened by radially-laid brick ribs.

ATHENS: Vault beneath street over aqueduct to Nymphaeum in Agora. c. AD 40.
Walker (1979), p. 163.
Vault of three curved bricks set on end. Bricks 40 cm (inner edge), 60 cm (outer edge), 17 cm long x 5 cm thick.

ARGOS: Early phase of baths. 1st century AD.
Walker (1979), p. 179, n. 16.
Pitched-brick vault.

ELEUSIS: City Baths. c. 2nd century AD ?
Walker (1979), p. 179, n. 16.
Pitched-brick vault.

ELEUSIS: Aqueduct. 2nd century AD ?
Choisy (1873), p. 153, fig. 173.
Barrel-vault of 3 bricks set on edge.

IZMIR: Agora: North Basilica substructures. Late 2nd century AD (Plate 199)
See above - brick catalogue.

RHODIAPOLIS: Baths? Cistern? 2nd/3rd century AD.
See above - brick catalogue.

ASSUR: Palace, main hall. Early 3rd century AD.
Colledge (1977), 138; Andrae and Lenzen (1954), p. 36 - 37.
Roofed with pitched burnt brick barrel vault.

ASPENDOS: Basilica substructures. 3rd century AD.
See above - brick catalogue.

DURA-EUROPOS: Bath M7. Early 3rd century AD.
See above - brick catalogue.

DURA-EUROPOS: House of Scribes (L7). Early 3rd century AD.
See above - brick catalogue.

KARANIS: House B24, Room L. 2nd - 3rd century AD.
Boak (1931), p. 23 - 24.
Pitched mudbrick vault, one half leaning one way, the other in the opposite direction. A number of examples at Karanis, 1st - 4th century. Bricks are thinner and wider than those for wall construction.

SALONICA: Mausoleum of Galerius. c. 300 AD.
Ward-Perkins (1958)b, p. 90, and (1981), p. 453.
Upper parts of the vaults of the radiating bays are of pitched brick; the courses are radially laid.

ATHENS: Cistern on slope of Acropolis. Late Roman.
(Plate 200)
Cowan (1977), p. 65.
Pitched-brick vault on radial lower courses.

CONSTANTINOPLE: Theodosian Land Walls. Early 5th century AD.
Ward-Perkins (1958)b, p. 66 - 67.
Internal vaults of towers, both radial and pitched which spring either direct from the walls or from a system of internal piers.

ROME: Wall tower, near Porta San Sebastiano, Honorian?
Unpublished.
Pitched groin vault.

SIDE: Agora Baths, Room I. 5th century AD.
See above - brick catalogue.

CONSTANTINOPLE: Golden Gate interior. 5th century AD.
(Plate 201). Pers Obs.
Vaults of internal staircase.

CONSTANTINOPLE: Yerebatan cistern. 6th century AD.
Pers Obs.
Pitched-brick groin vaults.

CONSTANTINOPLE: Church of St Polyeuktos, Sarachane.
Early 6th century AD (Plate 202)
Harrison and Firatli (1965), p. 233 and pl. 4.
Building O. Long room with cross vault and barrel-vaulted for the rest of length. The cross vault is of brick, some pitched, and the barrel vault is of both radially laid and pitched-brick. The vault rests on walls which have lower courses of rough stone and upper courses of brick.

CONSTANTINOPLE: Santa Sophia. 6th century.
Ward-Perkins (1958)b, p. 72; Krautheimer (1979), p. 219.
Pitched brick vaults used in various positions, either on radially laid courses or on lower corbelled out courses.

CONSTANTINOPLE: Santa Eirene. 6th century AD.
Ward-Perkins (1958)b, p. 59. Pers Obs.
Groined vaults of present narthex. The north and south aisles are an adaption of the technique.

RESAFA: Cistern. 6th century AD.
Mango (1976), pl. 10.
Pitched-brick barrel vault.

ZENOBIA: Praetorium. 6th century AD.
Mango (1976), pl. 10.
Pitched groin vault.

CTESIPHON: 'Arch of Chosroes' - Iwan. 6th century AD.
Ward-Perkins (1958)b, p. 95.
Pitched burnt brick.

QASR IBN WARDAN: Palace. 6th century AD.
Butler, N. Syria, fig. 37.
Pitched-brick groin and barrel vaults.

CONSTANTINOPLE: Great Palace substructures. 6th century AD.
Ward-Perkins (1958)b, p. 59.
All the vaults but two are pitched on lower corbelled courses.

THESSALONIKA: Santa Sophia. Early 8th century AD.
Pers Obs.
Pitched-brick.

DISCUSSION

The old view that the Romans invented the arch is a fallacy. The arch and the vault were in use nearly 4,000 years before the Romans made their first attempts [114]. However, it is true to say that the Romans were probably the first builders to appreciate fully the advantages of the techniques. How much of their skill can be put down to a solid knowledge of structural engineering and mechanics and how much to sheer instinct and a feeling of balance is debatable.

It has been a recognised fact since the beginning of the century that it was probably in the East that the use of the true arch originated [115]. The use of arcuated construction in Egypt, however though still considered to be early, has always been dated a little later than in Mesopotamia. This notion can now be modified; the development appears to have been generally a parallel one in both regions. However, there are several similarities between the use of the arch and vault in the two areas which are very important. Some of the earliest examples date back to c. 3000 BC, for example, at Tepe Gawra, the Royal Tombs at Ur and at Saqqara. These are all constructed in the same material - mudbrick [116]. In both regions the corbel is also found and is probably earlier than the true arch [117].

However, mudbrick is not the only material used for vault construction. In Egypt stone is quite frequently used from the New Kingdom onwards for corbelling and from the 7th century BC for true arches. In Mesopotamia, the use of brick is dictated by the geological conditions even more than in Egypt. Not only mudbrick is used but also burnt brick and stone. Burnt brick is very rarely used in Egypt before the Roman period; it is used at Ur in the Royal Tombs PG/789 and PG/1236 [118] in the 4th millenium BC, but it is not freely used until c. 2000 BC. Stone is used in Mesopotamia from the 4th millenium BC also; both PG/777 and PG/779 in the Royal Cemetery at Ur have stone corbel vaults. The earliest stone vault in Egyptian architecture is in the Pyramid at Meydum (c. 2680 BC) [119].

There are also differences in how the arch and vault are employed. In Egypt they are used in subsidiary buildings and tombs; it is not until the Ramesseum that vaults are used freely above ground.[120] In Mesopotamia, however, arcuated construction was from earliest times used not only in tombs and religious architecture, but also as a constituent element of all architectural construction, for instance, the radial vault at Tepe Gawra [121] and numerous examples at Ur and Tell al Rimah [122]. Thus it is fair to say that it was the Mesopotamian architects who were the more adventurous and who first developed the use of the arch and the vault as a part of both monumental and domestic architecture.

Once it has been established who first used and developed the arch and vault, perhaps the question of the source from which the Romans learnt about arcuated construction can be examined. The Etruscans were generally thought to have developed the arch and vault in Central Italy and to have passed it on to the Romans [123]. However, the case for the Etruscans is not very strong. Corbelled construction appears to have been the technique favoured [124] and there is no example which can be definitely identified as a true arch or vault and which can be called Etruscan in workmanship, expertise and actual construction. From the late 4th and early 3rd century BC, arched city gates and tombs covered by barrel vaults are built in Etruria [125]. However, it is at this time that most of this area comes under Roman domination. This is a period of great Roman expansion north and south and there is no reason to disbelieve that these examples are built, if not by Romans, then by Etruscan workmen directed by Roman engineers, and that the ideas are Roman.

It is clear that the dating of these examples of true arches and vaults in Etruria is crucial. The majority of them can only be called Etruscan in a geographical sense; they happen to be in those areas which were taken over by the Romans from the 4th century BC when the Etruscans began to lose their supremacy over Central Italy, for example, the gates of Santa Maria di Falleri were constructed after the revolt and subsequent destruction of the town, in about 241 BC; the 2nd century BC Porta Sanguinaria at Ferentium was built well after the city had fallen into Roman hands [125]. There are obvious examples which do not fit into this pattern, such as the Porta dell 'Arco at Volterra, dated to c. 300 BC [126]. The city of Volterra did not come under Roman domination until Sulla. However, it is not impossible that it was copied from a Roman example or that the idea (and perhaps the craftsmen) was brought from areas under Roman rule. At about this time an alliance may have existed between Rome and Volterra [127]. Etruscan culture was certainly a strong influence on Early Roman art and architecture, as indeed Greek influences are evident in Etruscan art, and there is every reason for there to have been cross-cultural interchange in architectural traditions.

If the Romans were responsible for the building of these arches in Etruria, who passed the concept of arcuated construction on to the Romans? One possibility is the Greeks. A 5th century BC arched city gate has been found at Velia in Southern Italy [128] which proves that the Greeks in Magna Graecia were familiar with the technique. The ultimate origin of this must, presumably, be Mesopotamia and Egypt. The Greeks were great travellers and colonisers and through this medium, knowledge of the East and Egypt spread back to the Aegean and the Mediterranean. This must have been the channel through which architectural ideas, especially that of the arch and the vault, reached the Greek World.

Greek architecture was based on the post and lintel technique, and indeed their monumental buildings had developed into types which excluded the use of any kind of arch. Despite the fact that they had reached a very high level of masonry dressing and craftsmanship, structural progress was very slow in comparison [129].

Boyd in 1978 [130] put forward the theory that the principles of the arch and vault might have been brought back from Mesopotamia by Alexander and his Generals. This is not unreasonable; they must have had craftsmen, engineers and architects among the army, and it would be natural for them to take notice of a principle of construction totally different from their own - one which could span greater widths without the need for intermediate supports.

However, this does not explain the vaulted Macedonian tombs, including the so-called tomb of Philip II, at Vergina, which date to before Alexander's conquests in the East [131]. Nor does it explain the 5th century BC arch at Velia nor the vaulted tomb on Cyprus dated to about 600 BC. This does not vitiate Boyd's argument; it merely necessitates its adaption.

The Greeks knew of the arch and vault principle before Alexander. This must now be undisputed. They learned of it by the exchange of ideas and reports of vaulted buildings of impressive dimensions, the main carriers being traders, colonists and travellers. Arches were used before Alexander but only where they would not be seen, as in underground tombs and cisterns. These early arches were experiments and are obviously early examples in a long chain of development [132]. Until the 3rd to 2nd century BC, the flat-lintel remained the only reputable means of spanning a gap, even though the span could not be very great and iron bars might have to be inserted as a precaution against cracking (see Chapter III). The Greeks, to adapt arcuated construction, not only had to learn the skills involved in building arches, but they also had to translate those skills for use with stone [133]. All the examples of vaulting that the Greeks would have known, or have seen, in the East and Egypt were constructed of brick, either sun-dried or fired. The two materials are very different to work with and the architects in Mesopotamia had perfected their methods over several thousands of years. It is really no wonder that the Greeks were slow to incorporate it into their architectural repetoire. They had developed a monumental architecture which did not need vaults and arches to any large extent [134]. However, they were prepared to try out the new methods, but in the medium of stone with which the Greeks were very familiar.

Thus, to recapitulate, before Alexander the arch was definitely known and used. One result of Alexander's campaigns in both Mesopotamia and Egypt was the widespread adoption of arcuated construction. He provided the channels with the right expertise to be able to carry the ideas back to the Aegean and to be able to put them into practice with little need for experimenting and practice. The Etruscans did not introduce the technique of the arch and the vault to the Romans. They used the corbel, as did the Greeks and the Romans from an early period [135], but it was apparently through the Greeks that the technique travelled from Mesopotamia and Egypt where it was first used. The Romans did not therefore introduce these techniques into Asia Minor and Syria, but they did greatly influence the materials associated with them in these areas. Cut stone became the traditional material of the Greek and Hellenistic builders, and under the Romans, as has been seen, cut stone remained a principal building material. However, the Romans introduced materials previously unexploited as regards arcuated construction in the East.

Concrete was the construction medium par excellence in Rome and its environs (see above) but very few areas of the Eastern Provinces could actually provide appropriate materials with which to manufacture concrete of the Roman kind. The Hauran in Southern Syria and Cilicia in Southern Turkey are the two areas where this was possible. The Hauran in particular came under strong Roman influence. The Roman city of Bostra was constructed in the early 2nd century AD after Trajan's campaigns in the East. Laid out beside the irregular Semitic city [136], it was established as the capital of the new province of Arabia and was provided with the typical regular Roman street grid. Philippololis (modern Shahba) was a direct imperial foundation by Philip the Arab [137]. Both cities demonstrate the use of volcanic <u>scoriae</u> for vaulting which resembles Roman concrete very closely, both in composition and in use. The cities of Cilicia were also under early Roman influence; it was an area in which a number of Augustan colonies were founded. This can physically be seen in the <u>opus reticulatum</u> at Elaeusa-Sebaste and the volcanic sands of the coast were used to make a concrete of similar strength and properties to the Roman Italian material. Thus the type of concrete found utilizing volcanic material can be viewed as a direct Roman introduction.

Elsewhere in Asia Minor, in the absence of any volcanic material, mortared rubble was used for vaulting. This is found from the early 1st century AD and it is a practice patently derived from Italian <u>opus caementicium</u>.

However, the use of brick in the Roman East provides the most interesting examination. As already stated, mudbrick was the main building material in both Egypt and Mesopotamia; fired brick was not used in the former until Ptolemaic and Roman times, in the latter it was much earlier. Two methods of mudbrick vaulting were common, pitched and radial, their most significant difference being in their method of construction (see above).

In Rome and the West, brick (that is, fired brick) was not a material employed for vaulting; indeed it was not used as a building material in its own right (see Chapter V). It is in the eastern part of the Empire, especially Asia Minor, that one finds the extensive use of fired brick for vaulting. Ward-Perkins puts forward two possible channels through which brick as a vaulting medium first passed into the architecture of Western Asia Minor in the late 1st and early 2nd centuries AD. Firstly, Thrace and the Balkans [138]. There are several examples, notably tombs, and the small covered theatre at Nicopolis ad Istrum, where the stone seats were carried on brick vaults [139]. These examples are of radially laid bricks and this is the normal technique in Asia Minor (see above). The second source is Syria [140], but evidence is lacking to support this. Fired brick was certainly used at Babylon in the 6th century BC but there is no evidence of fired brick in Syria immediately before and early on in the Roman period which could have in any way influenced the use of fired brick in Asia Minor in the late 1st and early 2nd centuries AD. However, from about the late 2nd and the early 3rd centuries AD brick vaults began to be built on the 'pitched' method in Asia Minor and earlier ones occur in Greece albeit on a small scale. For the pitched brick vault there is no precedent in the architecture of the Roman West, of Greece or of Asia Minor itself, but the structural principles behind this method had long been known and used with mudbrick in Egypt and Mesopotamia. The use of fired brick per se may be seen to be a western introduction into Asia Minor but its use for vaulting is an Eastern Mediterranean development and occurs from the 1st century AD. The use of fired brick vaulting at Assur and Ctesiphon may have been influenced by this. The earliest known examples of the technique appear to be in the 3rd millenium BC (see above) in mudbrick, but there could very well be examples just as early in Mesopotamia which have simply not survived given the extreme perishability of mudbrick.

There is quite explicit evidence that demonstrates that pitched-brick vaulting was used throughout the classical period in both Egypt and Mesopotamia. At both Assur and Seleucia such vaults were employed [141] and one could reasonably assume that these examples influenced the implementation of the technique at Dura-Europos [142]. In Egypt the two sites of Karanis and Soknopaiou Nesos afford the only surviving examples of pitched mudbrick vaulting within the Roman Empire [143]. It is obvious that this is a mudbrick technique and the examples in fired brick in the Roman East are a translation of this in to a more durable material. Ward-Perkins sees these as the immediate source of the use of pitched-brick vaults in the Byzantine period [144] and the evidence does suggest that even if it was not the principal method of constructing a brick vault it was certainly a leading one in the Roman period.

Although much of this discussion is necessarily speculative, some conclusions are possible. There are several possible hypotheses.

i) Greek travellers learned, before Alexander, of the technique in Egypt and Mesopotamia and some experiments were carried out in stone, mostly in places where they would not be seen. Under Alexander, there was widespread contact with the East and his architects provided the means for the adoption of arcuated construction on a large scale in the Greek world. The ideas spread from Greece to Magna Graecia in both the period before Alexander and after. It was from these Western Greeks that the Romans learned of the technique and they, in turn, through the programme of expansion and colonisation from the 4th century BC, spread the idea into Etruscan areas.

ii) The Greeks learned of arcuated construction as outlined above. They passed it on to the Etruscans; from early times there had been an interchange of art and ideas. As the Romans pushed north they in turn learned the technique.

iii) The Romans developed the arch and the vault independently of Greek influence, drawing directly upon the skills from the East. The Etruscans did not build either form until Roman expertise was available.

Hypothesis i) best fits the evidence, but depends very much on the dating of so-called Etruscan examples of arches in Central Italy, as well as of the Roman expansion into Etruscan areas. Most arches are dated to c 4th century BC or later. The Greeks in Southern Italy employed the arch as early as the 5th century BC and it would seem logical for the idea to spread north to Rome and thence, via the Romans, to Etruria.

Hypothesis ii) assumes that the Etruscans adopted the arch early on, but there are no true voussoir arches before the 4th century BC that can definitely be called Etruscan. They are built after the area came under Roman domination and, therefore, presumably were built with Roman expertise.

Hypothesis iii) seems unlikely on present evidence.

Voussoir arches obviously reached Italy as a more or less complete architectural achievement. The Greeks certainly brought arcuated construction westwards, but only built in stone, a phenomenon which continues in Italy until the development of <u>opus caementicium</u>, and in the Greek East until the development of brick and mortared rubble. The Romans, having learned of the technique, used it extensively in Etruria and the voussoir arch became an important part of the hellenized domestic architecture [145]. It was then left to the Romans to exploit the arch and the vault to the full. The Romans did not introduce it into the Eastern Provinces.

At the beginning of the chapter it was emphasised that survival plays a large part in architectural studies. A surprisingly large number of examples of arcuated construction survive in the Roman East, but one cannot say whether this is due to the way in which they were constructed or simply to chance. The factor of robbing for building materials plays a very large part in the survival of burnt brick buildings. Bricks can be carried away and re-used with ease, but concrete is virtually useless for re-use. The survival of the concrete buildings in Rome is very high in proportion to the brick survivals in Constantinople. There is also the question of how much theoretical knowledge of structural mechanics went into the structures and how much pure instinct and experience. That the Romans learned through experience initially must be assumed but beyond that one cannot say. It is unfortunate that the 'experiments' and the 'mistakes' do not survive, though of course one can glean a certain amount from the buildings themselves. The various Roman building manuals that have come down to us do not really help in the matter apart from Vitruvius' description of what an architect should know [146]. Those that do not survive and which we only know by name, for instance Heron's treatise 'On Vaulting' almost certainly contained little more than geometrical rules for setting out and some simple Archimedean statics [147].

Thus, in the Eastern Provinces, the Romans drew upon the knowledge embodied in the architectural traditions they found there. They had to experiment a lot more with materials if they were to build on a scale as grand as in Rome and they had to experiment with variations in the technique of arcuated construction. The result was an architecture that was developing all the time, one that was based on the arch and vault technique, as it was in Rome; but it was also one which, in many ways, was more varied than the architecture of the capital, in both materials and techniques. Arcuated construction demonstrates this in a way no other architectural feature can. The vaulting techniques of the Roman Eastern Provinces looked forward to and formed the basis for those of the Early Byzantine period.

CHAPTER VIII

DOME CONSTRUCTION

Structure

The earliest domical form was almost certainly that taken by very simple huts constructed of a framework of light saplings or reeds, covered with earth or mud. From this, over time, the form was transferred to mudbrick and stone. It is virtually impossible to put dates that have any meaning to the period of this development.

Early domes, whatever the material used, were conical or egg-shaped. This was due to the corbelling technique that was employed (fig. 26). Thus early domes were all false. Each block could project forward only a certain distance without the risk of falling. However, every complete course of blocks acted similarly to a true arch, each one being prevented from falling forward by the friction working between the blocks. As a result the stones did not have to project back behind the springing as far as they projected out over the internal space, but there was a resulting radial thrust which, if it did not act obliquely to the bed-joints, caused the blocks to slip on one another. Thus the blocks had to be thicker and heavier than if the joint were more or less radial in relation to the profile, as in a true arch.

Early brick domes (usually mudbrick) were built either entirely by corbelling or by arching the otherwise horizontal brickwork over the corners of the area to be covered and inclining them slightly. These form fans upon which the rest of the brickwork lies. This is often found in association with pitched-brick vaulting and was a construction that was used over circular and square bays, and was employed as late as the Late Roman and Early Byzantine periods. These fan-shape features have been called pendentives which has led to confusion and debate.

The true dome of cut-stone, with each block laid more or less at right angles to the profile of the inner surface, was a late development compared with the voussoir arch [1]. There were probably several reasons, one of the most important being the high degree of expertise required to cut the stone. Each block had to be slightly wedge-shaped in two directions and had to fit closely with its neighbour. During construction, individual blocks in the upper part of the dome would tend to slide forwards until the horizontal ring in which they were set was complete. Some kind of wooden framework or scaffolding was therefore essential.

There are two series of forces in a hemispherical dome (fig. 27). One set forms a number of vertical arches intersecting at the crown. These forces are compressive throughout. The other set forms a series of parallel hoops which increase in diameter from the crown to the springings. These horizontal stresses are compressive in the upper part of the dome but tensile in the lower part. The change occurs at a circle which forms an angle of $52^{\circ}\ 24'$ with the crown and $37^{\circ}\ 36'$ with the horizontal [2]. These tensile stresses can be reduced, as they were, for instance, in the Pantheon, where the thickness of the concrete is so great in the lower part of the dome that the hoop tensions are very low [3].

As seen above, semicircular arches and vaults produce horizontal thrusts which have to be resisted by an external force. In a hemispherical dome these horizontal reactions are absorbed by the hoop tension. Provided that the supports do not move, the thrusts can be made to act tangentially to the surface of the dome. If the shell is a true hemisphere, they will be purely vertical and can easily be transmitted down. For a shell less than a full hemisphere, there will inevitably be some horizontal thrust which must be absorbed by the supports. In a full hemisphere, tension inevitably develops in the lower part but a sufficiently shallow dome would be wholly in compression given adequate buttressing [4].

Domes occur in three different forms in Roman architecture;

i) the hemispherical dome (fig. 28a). With this form there is no advantage in making the structure any thicker than necessary so long as the material can resist tension. Added thickness means added load and the pressure per square foot due to its own weight would remain the same. Therefore the part of the dome which is in compression can be very thin and of very light materials.

ii) the dome with apex opening (fig. 28b). The <u>oculus</u> effectively lowers the joint of rupture, thereby increasing the area in tension.

iii) the segmental dome (fig. 28c). This form is less than half a circle, and the springing line is effectively lifted. The area in tension is therefore decreased and the radial thrust at the abutments increased. However, such forms (also called saucer domes) are strong if proper buttressing is provided.

Radial stress in a vault is best countered at as many points as possible along the circumference, and a dome thickened at the haunches reduces hoop tension. This is admirably illustrated by the Pantheon in Rome.

Despite the expertise which all Roman domes (in Rome and the Eastern Provinces) display, their construction also betrays the basic lack of confidence on the part of the Roman architects in the materials and the technique itself. The dome is strong because of its double curvature, and it was this fact and its resulting properties which were not fully exploited.[4] In the concrete domes of Rome, the thickness at the crown was usually one-tenth to one-fifteenth of the radius; lower down it was always much thicker. Provided that the conditions of support at the base were appropriate and that the hoop tensions in the lower part could be resisted without cracking, the possible thickness could be reduced to about one two-hundredth of the radius [5].

In the later Roman period, various methods of reducing the weight, and therefore the outward thrusts, of the dome were used in the Capital. Amphorae in the haunches of vaults and domes and systems of embedded ribs incoporated into the main concrete structure created a cellular-like construction which helped to stiffen and lighten the whole fabric. Terracotta pipes in vaulting were already a feature of the architecture of 1st century AD Dura-Europos (Plate 203) and 3rd century North Africa [6].

Once these methods and new forms had been developed in Rome, they were introduced to many parts of the Empire. This meant, wherever the natural ingredients for making Roman concrete were not available, constructing them in brick, cut-stone or rubble. One result of this was the constraint placed upon the methods of construction, as it was necessary to build the dome layer by layer if more than minimal thickness was required. The profile, therefore, had to be hemispherical or an equally simple geometric shape, such as more pointed or flatter. This fact also prohibits the geometrically rather indeterminate transitions from non-circular plans to domical forms, so characteristic of concrete domes.

The problem of transition can be dealt with in a number of ways. On a small scale, if the radius of the dome itself is made much greater than that of its circular springing-line, thus making it very shallow like a saucer or segmental dome, the dome can be carried down to the supports with the same radius. This forms a sail vault (fig. 29e) and examples of this in different materials are quite common in the Roman East. However, the increased radius increases the thrust and complicates the stability and construction of the structure. One alternative was to build the dome on pendentives with the dome springing from them with a reduced radius of curvature (fig. 29f). Another was to span the corners of the ground plan with secondary arches referred to as 'squinches'. Both methods were stable because of the complete circular ring at the base of the dome proper.

The actual construction of brick and stone domes, in general, posed no more problem than those of concrete. If greater thickness was required, centering was only necessary for the innermost layer. The support that even this required was further reduced by the fact that each ring, when complete, was initially under circumferential compression and potentially able to support itself. It would only need support while the mortar, if indeed any was used, hardened and could take the compression without undue deformation. Some brick domes required even less support due to the reduction in the length of the rings by setting the bricks in small radiating fans arranged around the circumference and superimposed on each other like the scales of a fish. This can be seen very well in the Mausoleum of Diocletian at Split [7].

TERMINOLOGY: WHAT IS MEANT BY 'DOME'?

Domes have been the subject of controversy for more than a century. The origins of dome construction and the ways in which it was applied have both been heatedly debated [8]. In the light of this, two questions arise. Have some scholars made too much of these matters, thereby creating unnecessary problems and a false controversy?

And was there really any 'problem' as regards the dome and the square bay?

The underlying issue, however, is that of terminology. Respected scholars have plunged into the debate, only to confuse the situation further by the omission of an adequate definition of terms [9]. Where definitions are given, they are either inconsistent through the text, or do not correspond to those in general use. This leads to confusion, misunderstanding and 'problems with domes'.

One thing that most scholars agree upon is that the dome is a kind of vault. R. J. Mainstone defines a dome as

> "A spanning space-enclosing structural element circular in plan and commonly hemispherical or nearly so in total form" [10].

R. Krautheimer defines it as "a hemispherical vault" [11], and the Penguin Dictionary of Architecture gives the following definition

> "A vault of even curvature erected on a circular base. The section can be segmental, semicircular, pointed or bulbous".

Thus it emerges that the term 'dome' is non-specific, a blanket-word to describe an hemispherical or similar spanning element. When such a vault is placed on a circular wall, as in the Pantheon in Rome, the 'Temple of Mercury' at Baia or the Tor de'Schiavi on the Via Praenestina, there is little disagreement or variation in the term applied to the roofing element; it is a dome. Problems start to occur in recent critical literature when such an element is placed over an octagonal, polygonal or square bay.

A domed structure was placed over an octagon during the Roman period in one of two ways. The first is exemplified by the octagonal atrium or fountain hall of the Domus Aurea in Rome (Plate 3), and the domed octagonal hall in the lower range of rooms on the north side of the Sunken Peristyle of the Domus Augustana is a good example of the second (Plate 201) [12].

The shape of the Domus Aurea vault is unusual, in that its diameter is more than the height of the building. Vitruvius advocates for such circular structures that "their height to the bottom of the curved dome should be equal to their width" [13]. As a result of its shape the interior surface of the vault bears little resemblance to a true hemisphere. Eight panels form the lower part rising from the straight sides of the octagon; they turn inward as they narrow in width. At a level about two-thirds up the height of the vault, the lines dividing these panels die out. The upper part of the vault forms a shallow curve, likened by MacDonald to part of an annular vault [14], which terminates in a great <u>oculus</u>.

A similar arrangement can be seen in the 'Temple of Minerva Medica' in the Licinian Gardens in Rome (Plate 205). The transition from the decagonally planned walls to the dome was accomplished by simply merging the angles of the decagon inwards to form a circle upon which the dome could rise [15]. Swift would have us believe that the resulting features when this merging takes place are "merging pendentives" [16]. Durm, however, shows that the structural theory behind these features is really corbelling [17].

The octagonal room on the lower level of the Sunken Peristyle of the Domus Augustana was one of two identical rooms flanking a square chamber. Only the vault on the north side of this chamber survives intact. Both rooms were roofed with panelled vaults, that is, a vault each made up of eight flat or slightly curved sections, curving up to meet at the apex of the vault. Another example can be seem in the South Baths at Bostra in the Syrian Hauran, where an octagonal room was covered by an octagonal dome made up of eight panels.

There is a clear difference between these two types of construction. Most scholars agree that the first example should be defined as a dome. It could be referred to as 'an octagonal or polygonal dome', but this does imply that it should be octagonal throughout its height, which of course, it is not. However, 'octagonal or polygonal dome' would not be a misleading term for the second category. Nevertheless, for this a more appropriate definition would be a 'domical vault'.

The <u>Penguin Dictionary of Architecture</u> gives the following definition of a 'domical vault':

> "A vault rising direct on a square or polygonal base, the curved surfaces separated by groins" [18].

In American and some British publications, this feature is called a 'cloister vault' and this has given rise to some of the terminological confusion. However, both Mainstone and Krautheimer, who both use the term 'cloister vault', do point out that it is also called a domical vault. Mainstone's definition is:

> "A vault approximating to the dome but polygonal rather than circular in plan" [19];

and Krautheimer's definition is:

> "A vault composed of four, eight or twelve curved surfaces, as would result from the interpenetration of two, four or six barrel-vaults of equal height and diameter; also four-sided, eight-sided, etc, dome" [20].

These two definitions exactly describe the Domus Augstana and Bostra examples. Rivoira'a definition of the Domus Aurea dome demonstrates how unnecessarily convoluted some terms get. He refers to it as a 'cloister vault dome'. He also calls the domical vault 'the ungroined cloister dome' [21]. The term domical vault can be applied to such a vault on a square base, that is, made up of four panels, as Krautheimer points out. It is with this particular kind of domical vault that even more acute problems of definition have arisen in the past.

Butler, in his description of the South Baths at Bostra, calls the octagonal dome, referred to above, an 'eight-sided dome' [22]. The two square rooms of the complex (R and T on Butler's plan) were also vaulted. That over room R is still intact and Butler refers to it as a 'cloistered vault' or a 'square dome'. The first term, as already demonstrated, is the American term for the domical vault, but by its qualification as a square dome has caused some scholars to make some rather misguided statements. Ward-Perkins refers to the structure as a domical vault [23]. Creswell refers to the 'square dome' of the Praetorium at Musmiye (ancient Phaena), at the same time giving the French and German terms, voute en arc de cloître and klosterküppel [24]. It is obvious from these that he means the domical or cloister vault. However, Swift calls this kind of vault "the so-called cloister dome on a square plan" [25]. By this definition it becomes obvious what kind of structure he is referring to, and he also gives Musmiye as an example.

Having mentioned the domical vault described by Rivoira as an ungroined cloister vault, one should, for the sake of clarity, briefly consider the term groin-vault. Krautheimer's definition can be taken as representative:

> "The vault formed over a square bay by the interpenetration of two barrel vaults of equal diameter and height, the lines of intersection (the groins) forming a diagonal cross; also known as a cross-vault" [26].

Thus it differs from a domical vault.

This leaves the question of the dome, that is, the hemispherical or segmental dome, on a square bay. The two basic devices for transforming a square into a circular base for a dome are the pendentive and the squinch. The latter can be defined as follows:

> "A structural element .... in which the angle between the two walls or arches is bridged by a smaller arch set diagonally to help provide a more nearly circular base for the support of a dome" [27].

However, we are concerned here more with the pendentive and how it was used to enable a dome to be constructed over a square bay. It is this feature that has given rise to most confusion and dispute. Three definitions, by Mainstone, Krautheimer and Ward-Perkins, demonstrate how this problem has come about and possibly how it can be resolved. It must be emphasised that definitions were not a problem which dominated the thoughts of ancient architects [28]. However, it is one which has been slowly growing in the minds of architectural historians, art historians, antiquarians and archaeologists since the last century at least [29]. With each paper written on the subject, more fuel has been added to the fire which is only kept alight by clouded statements and misguided notions. The problem as stated is a 'non-problem'.

What exactly is meant by a 'pendentive'? Mainstone defines it as

> "A transitional structural element between two walls or arches meeting at an angle and part of the circular base or springing line of a dome carried, in part, by them. Its inner surface is, or approximates to a triangular portion of the large hemisphere whose base would just circumscribe the feet of all the arches or the meeting points of all

the walls and whose diameter at the level from which the dome springs is equal to or slightly less than that of the dome itself. When the dome is not a distinct element, but merely an upward continuation of the larger hemisphere to which the pendentives belong, the latter are known as 'merging pendentives' " [30].

Krautheimer gives this definition:

"Architecturally, a triangular segment of a sphere, bordered by arches and resulting from the interpenetration of a cubic space (bay or room, square in plan) and a hemisphere, the latter constructed from the circle circumscribed over the square plan. If the top of the hemisphere is cut off horizontally, spherical sections are left between the bordering arches. These triangular sections - or pendentives - terminate in the circle inscribed in the square of the plan. They thus form a base on which the dome can be placed, either directly or raised on a drum (dome on pendentives). If, on the other hand, the hemisphere constructed over the circumscribed circle is continued from the pendentives to its apex, the result is a pendentive dome (also termed a sail vault)" [31].

Ward-Perkins' definition adopts a slightly different standpoint:

"Concave triangle of spherical section, constituting the transition from a square or polygonal building to a dome of circular plan " [32].

Thus two different arrangements occur:

1) where the dome is of a different curve from that of the pendentives;
and 2) where the dome and the pendentives are of the same curve.
Herein lies the 'problem' which has been so much debated.

Taking the second of these arrangements, Ward-Perkins has pointed out that this is not really a dome at all but "a vault of which the uniformly curved surface reaches down without a break into the angles" [33]. However, he then calls it a 'domical vault', but gives the Italian and German terms, volta a vela and Hangeküppel, both of which translate as 'sail vault'. The Penguin Dictionary of Architecture defines a sail vault as follows:

> "Another method of developing a dome out of a square is to take the diagonal of the square as the diameter of the dome. In this case the dome starts as if pendentives, but their curvature is then continued without a break. Such domes are called sail vaults, because they resemble a sail with the four corners fixed and the wind blowing it" [34].

This describes the dome with pendentives of the same curve and it becomes clear that these are not pendentives at all. They may be triangular and they do curve in two planes, but they are of the same curve as the dome, and they do not provide a definite seating for a dome of a different curve. Many terms have been applied to this kind of structure and behind most of them, is the idea that the triangular features are pendentives. Mango, like Ward-Perkins, refers to it as a 'domical vault' [35]; Swift calls it a 'dome on merging pendentives' [36]; Krautheimer describes it as a 'sail vault' or 'pendentive dome' [37]; the latter term is also used by Rivoira [38]. Traquair uses no less than four terms to describe this particular structure: 'dome on pendentives', 'dome on continuous pendentives', 'intersecting dome vault' and 'saucer dome' [39]. None of these adequately defines the structure and the use of the term 'pendentive' here can only lead to confusion and misunderstanding.

As one looks at the 'problem' in more detail, the need to be precise about terminology becomes increasingly apparent. Creswell states that the difference between the 'sail vault' and the dome on pendentives is only in the dome: "there is no difference in the pendentives, (the radius of which, being half the diagonal of the square remains unchanged) ...." [40]. Mango also uses this point to distinguish them [41]. Creswell goes on to say, "a question of terminology is involved". He berates Gertrude Bell, Rivoira and Sisson for distinguishing between the two 'pendentives', the one being continuous with the dome, the other being of different curve [42]; and his disparaging remarks about Ebersolt's statement that the two types are different and the continuous variety "ne peuvent s'etablir l'un sans l'autre" [43], clearly reveal Creswell's standpoint. In his view the pendentive is identical in each case. If the Turkish Government took down the present dome of Santa Sophia, he asks, leaving the pendentives, and replaced it by a shallow dome, "would the present 'true pendentives' cease to be true pendentives?" [44]. This epitomizes the problem.

If one calls those parts of a sail vault which extend down into the angle between the defining arches 'pendentives', then this term must be used for every such form and the word becomes meaningless by its over-application. This argues for discipline in its use and a restriction to 'true pendentives'. The answer to Creswell's question is, yes, they would cease to be true pendentives. The whole basis of his argument is mistaken because it is the change in curve between the pendentive and dome that is structurally vital for the spanning of such a large area as the nave of Santa Sophia [45]. In segmental domes the tensional area is decreased and the radial thrusts at the abutments increase. There is thus the tendency for the dome to push out the supporting walls and for the whole structure to collapse if it is not properly buttressed and if the area it spans is too great. With a dome on pendentives which have a different curve, it makes it possible to put a dome with a smaller diameter over a square whose diagonal is greater. Even if this dome is still segmental and not hemispherical as is the case with Santa Sophia (the original dome was also segmental), the fact that the dome has a smaller diameter, and therefore greater height, makes it more structurally sound for covering large spans. If the dome is segmental it requires a great deal of abutment because of the lateral thrusts. The north and south walls of Santa Sophia now lean outwards as a result of the weight of the dome. A hemispherical dome theoretically exerts no horizontal thrust at the springing, as long as a material capable of resisting tension is used. Therefore, in such a situation, the amount of buttressing required would be much less [46].

One can say, therefore, that the question of terminology has caused this 'problem' with domes and related forms. It is not a real but an academic question and one which has, unfortunately, been allowed to dominate discussions of the dome, the pendentive and the square bay.

With the foregoing definitions and discussion in mind, the terms used by the writer are as follows:

PENDENTIVE — A triangular, spherical structural element, between two arches or walls meeting at a right angle. It terminates in a circle inscribed in the square of the plan, forming a base on which a dome can be set. The dome has a different curve from that of the pendentives. The pendentive is structurally independent of the dome (fig 29f) and is not a corbelled element.

SAIL VAULT — In this kind of vault, the diagonal of the square bay may be taken as the diagonal of the dome. The dome starts as if pendentives are to be formed, but continues without a change in curve. The vault is one unbroken form as opposed to the dome on pendentives which is two distinct forms. The low curvature of the vault limits both the height to which it can rise and the space which it can span (fig. 29e).

DOMICAL VAULT	A dome rising directly from a square or polygonal base, with its curved surfaces separated by groins, forming a four-sided, eight-sided, etc, dome (fig. 29d).
DOME	A vault of usually even curvature erected on a circular base whose elements are set radially rather than corbelled. The profile can vary. The term can be applied in a general way to other domical forms (such as the domical and sail vault) (fig. 29b and fig. 28a - c).
CORBELLED DOME	A false dome constructed like a corbelled arch by bedding each course more or less horizontally but projecting a little inward from the one below. The profile is always fairly sharply-pointed (fig. 26).

PRE-ROMAN DOMES

Evidence for the use of domical construction before the Roman period is scarce. As a result some rather wild claims about the origins of domes and their use have been made.

EGYPT

Domes are not common in Egyptian architecture until Coptic times (5th and 6th centuries AD) [47]. However, the Ancient Egyptians did construct small domes, probably without centering, in brick from the Old Kingdom onwards. At Giza the mastabas of Seneb and Neferi [48] had chambers with domed roofing, though this was more dependent on the corbelling method than anything else. The courses of the dome consisted of stretchers tilted inwards by placing chips of stone under the outer edge of the bricks. The tomb of Merra at Dendera [49] and the Fifth dynasty tomb at Abydos [50] had domes placed over square chambers and their form as a result shows considerable distortion. Spencer [51] puts this down to the fact that pendentives were not used, but it is more likely to be a result of unfamiliarity with the technique generally.

However, the use of pendentives has been claimed for a tomb dated to the New Kingdom (c. 1500 BC) at Dira abu'n-Naga, Thebes [52]. The tomb is built of mud-brick and consists of two chambers. Over one chamber was a dome of mudbricks, each one scored with grooves on the upper and lower surfaces. It was built of rings of brickwork of decreasing diameter. In shape it did not form a true hemisphere but was really composed of an arc around each corner. It does not form a true circle and therefore the shape of the dome is distorted. The angles of the chamber are filled in by what Pieron calls 'pendentifs disposés en corbellement' [53]. These pendentives are composed of nine oversailing courses of brick; the lowest one consists of a single brick set across the angle. The upper courses form a series of arcs, each slightly larger than the one below it. One cannot, however, call these 'pendentives' because their construction depends on the corbelling technique. Spencer says that the dome is of a different curve [54], but Pieron quite definitely states that it must have been the same: "la coupole ... devait ... avoir son rayon commun avec celui des pendentifs" [55]. The second chamber was covered by a vault which rests at one end on a fan-shaped feature over the doorway. Each course of bricks leans inwards, but Pieron's description and drawing of the vault are not very clear. Indeed, his style of language only obscures his claims that this feature may have been the prototype for the "pendentifs embryonnaires" in the other chamber which cannot thus be seriously assessed.

The fortified camp at Deffeneh provides a few examples of domes in the later period (c. 650 BC) but these are apparently put over a square bay by way of bricks placed across the angles [56].

Domes appear more frequently in the Roman and Coptic periods in Egypt. Spencer puts it down to "ignorance of the pendentive" [57] that domes were rarely used in the Dynastic period because of the problems inherent in placing a dome over a square bay. However, it must also be remembered that they made good use of pitched-brick vaulting over square or rectangular rooms which did not raise such problems.

MESOPOTAMIA

Evidence for domes in Mesopotamia is centred upon two sites, Ur and Tell al Rimah. However, as with the arch and vault, the question of survival must always be borne in mind.

The Royal Cemetery at Ur is important here because of the building techniques used in the tombs [58]. The three parallel chambers of tomb PG/779 were each covered by a stone corbelled vault which had an apsidal end. The square corners of the chamber were resolved into a half-circle by the use of fan-shaped features which are very characteristic of pitched-brick vaulting. Woolley refers to these as 'regular pendentives' [59]. PG/789 and PG/800 were of fired brick and show a similar method of construction; the central portion of the vault was composed of contiguous rings of 'true arching' [60], while the apsidal ends were of corbelled work. Here Woolley claims a step towards true domical construction, as the bricks, though each projects beyond the course below, were not laid flat but with a downward and inward slope to give a radial joint. PG/1054 had a domed chamber intact with the main body of the dome of ring courses carefully laid. Again Woolley claims the use of pendentives [61].

The nature of these so-called pendentives becomes clearer when one turns to the site of Tell al Rimah, whose importance for the use of pitched-brick vaulting has already been discussed. Very often the vaults were used in conjunction with fan-shaped elements, very similar to those described by Woolley at Ur [62]. These can be seen very clearly. In the Phase 2 building the vaults date back to c. 2000 BC. In AS1a and AS8b the end and side walls were erected to the same height and then fans of brickwork were constructed beginning from each corner of the chamber and extending diagonally upwards and outwards. Oates claims a very close resemblance to true pendentives [63]. The resulting vaults had a very flat profile, and, seen from above, the use of these fan features reduced the outline of the original rectangle to a somewhat irregular octagon [64]. This technique is used 2000 years later at Karanis in Egypt to produce exactly the same effect [65].

There are few other indications of domed construction in Mesopotamia. There are, however, the tholoi or circular buildings at Arpachinyah near Nineveh [66]. These had stone foundations and a superstructure of pisé. Although they were apparently domed this was presumably again by the corbelling technique.

The famous Kuyuryik relief found at the Palace of Sennacherib by Layard shows high-profiled and hemispherical domes [67] but we have very little structural evidence in Mesopotamia to confirm this depiction.

THE ETRUSCANS

For the early use of any kind of vaulted construction by the Etruscans one has to look at their tombs. Monumental, round or rectangular tomb halls of ashlar masonry with corbelled roofs belong to the 7th and 6th centuries BC. Archaic rectangular corbelled chambers were apparently used mainly in the southern city-states of Etruria. To the north corbelled domes are used instead. These beehive tombs, <u>tholoi</u>, are probably structurally descended from those built by the Mycenaeans in Greece from the 15th to 12th century BC. Nevertheless the corbelled dome is a monumental type which appears fully developed in Italy. There are several important examples. In the Tomba di Casale Marittimo near Volterra, dated to <u>c</u>. 600 BC, the corbelled dome was made up of eleven annular stepped courses [68]. Across the angles of the square chamber were flat stones which served to help convert the square to a more circular shape. A column was erected in the centre to support the top stone as well as the weight of the soil above it. The contemporary Montaguola <u>tholos</u> tomb at Quinto Fiorentino is made up of a <u>dromos</u>, about 13.5 m long, and a corbelled rectangular chamber with lateral side rooms. Behind this arrangement lies the <u>tholos</u> [69]. This has a diameter of about 5.30 m and a construction similar to that of the Tomba di Casal Marittimo with a corbelled dome and a central massive support.

At Vetulonia and Populonia there occur square chambers which have corbelled domes set over them [70].

The transition from square to circle is achieved by features in the angles referred to by Boethius as "primitive pendentives" [71]. This can be seen in the Tomba della Pietrera at Vetulonia.

Apart from these examples, a number of cisterns in Central Italy were roofed with conical domes. One on the acropolis at Circeo [72] starts with a circle 4.75 m in diameter which diminishes to an opening of 58 cm at the top. It probably dates to the very beginning of the 4th century BC. Other examples which are probably contemporary are at Norba and near Peperino [73].

As with arcuated construction, the Etruscans depended on the corbelling technique for domical architecture, and it is not until the 2nd or early 1st century BC that true domes based on the voussoir principle begin to occur, for instance, in the Stabian Baths at Pompeii.

THE GREEKS

The most impressive domical remains of prehistoric Greece are the circular Mycenaean beehive or tholos tombs. These were built between the 15th and 12th centuries BC, and the latest group includes the 'Treasury of Atreus' at Mycenae. In all the examples the bulk of the tomb was excavated into the hillside, and in the latest group very large blocks were used. The 'domes' were built throughout of overlapping horizontal courses with their faces cut to the proper curve. The beehive tradition tends, owing to the corbelling principle, to favour flat courses at the springing of the dome and pointed dome shapes.

The diameter of the 'Treasury of Atreus' is 14.5 m and "marks the culmination of vaulted construction in pre-Roman times" [74]. Such corbelled domes require a considerable amount of buttressing to resist the outward thrusts which despite the horizontal coursing of the blocks, would cause the lower courses to slip on one another and thereby, allow the upper ones to tip inwards and fall. In the 'Treasury of Atreus', to avoid this, the stone blocks themselves were very deep in the direction of the bed joints, and great masses of earth were heaped up against the outside as external buttressing. This was presumably done during construction.

The problems of stone-cutting probably prevented the classical Greeks from attempting true dome construction; they would have known about its potential just as they were aware of true arching and vaulting [75]. However, as has already been seen, with the Hellenistic period there came a change of attitude towards arches and vaults by the Greeks. This change in attitude also embraced the dome. Early attempts probably resembled the arrangement found in the Horologion of Andronichos of Cyrrhus, the 'Tower of the Winds'. This is an octagonal building of Pentelic marble [76] built in the second half of the 1st century BC. It has an inner diameter of about 7 m and is 12.80 m high. The roof is of 24 self-supporting marble slabs which converged on a central keystone, creating an external conical shape [77].

The slabs are rounded inside although they follow externally the octagonal line of the walls [78]. A cistern with a central column at Pergamum was probably roofed with slabs in a similar way (Plate 207).

At Pergamum there also survive several Hellenistic examples of the semi-dome. One which is set into the south retaining wall of the Athens Polias Sanctuary just below the western extremity of the stoa along the south side of the precinct, is dated to the reign of Attalus II (159 - 138 BC) [79]. Its diameter was 4.20 m and it extended 2.13 m into the wall. Only the lowest course of the half-dome is in place.

Another Pergamene example is beneath the Altar of Zeus (c. 175 BC) where a partially preserved apsidal building was found [80]. This had a semicircular apse at the east end. The exterior curve of the semi-dome was concealed by the two slanting walls meeting at an angle of 157°.

Apart from these very few examples, there is very little surviving evidence for the use of true domes by the Greeks.

However, the Greeks did build timber roofs over circular buildings. Wooden roofs in general were a very common feature of Greek architecture and thus it is not an unusual occurrence. Wooden domes are very light and could safely be raised over large spans. The natural way to roof a circular building with timber is with a 'wig-wam cone' of rafters, the outer ends resting on the wall or colonnade, and the inner ends meeting at the centre [81]. The Arsinoeion at Samothrace, dated to c. 285 BC, was evidently roofed in such a way. This building has the largest clear span known in Greek architecture, 16.80 m compared with 16 m for the bouleuterion at Miletos and over 25 m in later Roman architecture [82]. One reason for this is that in a building roofed in this way the longest timbers required are the rafters, which are rather more than half the total span. The outward thrust of such a roof could be reduced by increasing the slope of the rafters.

DOMES IN THE ROMAN EAST

The importance of the rate of survival of certain kinds of architectural feature has already been pointed out in connection with arches and vaults. Domes are even more vulnerable to the ravages of time, and their survival very much depends on the materials used and the techniques employed during construction. Although domes are not as common in the East as arches and vaults, this is not, however, due simply to the accidents of survival. Domical structures were not as favoured as perhaps they were in the West. In the Balkans there is very little evidence for dome construction.

TIMBER

Timber is a material which has a bearing on the origins of the dome, as can be seen in the writings of

Vitruvius. He describes the method used by the Colchians in Pontus to build their houses of timber. These are square in plan with the roofs formed by "beams across the angles, drawing them together in steps. Thus from four sides they rear the cones in the middle, and covering these with both leaves and mud, make the roofs of the towers in a barbarian fashion tortoise-shaped" [83]. It is interesting to note that such an arrangement of beams and angle slabs occurs in the tomb called Gümüş Kesen at Mylasa in Caria, in stone; this is dated to about the 2nd century AD and may represent the translation of a wooden technique into the more durable stone (Plate 208). The rotunda in the south-east corner of the Asclepieion at Pergamum which had rubble vaulted substructures also presumably had a timber roof with a central oculus [84].

STONE

Stone was not very much favoured for dome construction in Asia Minor but further East a number of examples survive.

Asia Minor

MYLASA: Roman tomb, Gümüş Kesen. 2nd century AD (Plate 208)
Pers Obs.
Square colonnade with 12 Corinthian columns with stepped pyramidal roof formed by slabs placed across angles.

KARABEL: Monastery Church. c. AD 530 - 540. (Plate 209)
Harrison (1963), p. 131 - 135. Pers Obs.
The roofing of the central square bay was by a stone dome. Harrison postulates pendentives supporting a dome with a different curve. The south chapel, perhaps little later than the central bay, was also roofed by a stone

dome resting on triangular features which have no clear division between them and the walls they are between.

ALACAHISAR: Church partly rock-cut. Mid 6th century AD.
Harrison (1963), p. 136.
The square bay was apparently covered by a light masonry dome. This rests on 'fully developed pendentives' cut out of rock.

Syria

HERODIUM: Bath suite. Late 1st century BC. (Plate 210)
Pers Obs.
Small circular room, c. 4 m in diameter covered by a shallow stone voussoir dome.

JERUSALEM: Double Gate. Herodian.
Creswell (1932), p. 463 - 4. Pers Obs.
Square compartment covered by a sail vault. The decoration gives the impression of a change of curve. This may have prompted Creswell to call the triangular features pendentives.

EMMAUS: Baths. 1st century AD (?)
Gichon (1979), p. 101 - 111.
Room 4, identified as a frigidarium, 12.80 m x 5.10 m. A central domical vault spanned the room, 6.50 m above the floor. The vault was constructed of 4 equal tapering segments, each terminating beneath its apex to form a square aperture, 1 m along each side.

PETRA: Baths. 1st century AD.
Tell (1969), p. 29 - 37, pl 13 and 14.
Sail vault with central oculus. Claimed by Tell as a dome on pendentives.

MUSMIYE: 'Praetorium'. 2nd century AD.
Creswell (1932), p. 454; Hill (1975), p. 347 - 9.
The square internal area is covered by a domical vault.

AMMAN: Taba Bur, tomb. 2nd century AD ?
Horsfield (1924), p. 73 - 74.
Although the tomb is in a very ruinous state it would seem to have had a sail vault over the square central bay. The diameter was at the most 5 metres.

AMMAN: Tomb near Mosque. 2nd century AD ?
Creswell (1932), p. 454; Conder (1889), p. 43 - 5.
Square chamber (internal 5.48 m). Roofed with cut stone dome which was set on the square regardless of the difference at angles. There was no specific provision for support except for a very small corbel in each corner.

AMMAN: Qasr Nueijis, tomb. Late 2nd century AD. (Plate 211)
Pers Obs.
Cruciform plan similar to that of Taba Bur. Roofed by a sail vault. Usually put forward as an early 'dome on pendentives'.

JERASH: West Baths, chamber to north of caldarium.
Late 2nd - early 3rd century (Plate 212)
Kraeling (1938), p. 23. Pers Obs.
Closely resembles Qasr Nueijis in plan and size. Also put forward as a 'dome on pendentives'. Kraeling mistakenly describes the dome as being supported on squinches. It is, however, a sail vault.

SAMARIA: Pagan tomb. Late 2nd century ? (Plate 213)
Hamilton (1938), p. 64 - 71. Pers Obs.
Similar in plan to Qasr Nueijis and the Jerash West Baths example. Approximately square compartment, 3.47 m - 3.50 m by 3.27 m defined by arched recesses in the walls and covered by a sail vault, 3.27 m in diameter and 71 cm high. The tomb has been dismantled since excavation.

BAALBEK: 'Temple of Venus'. Early 3rd century.
Ward-Perkins (1981), p. 320.
The circular <u>cella</u> is covered by a shallow stone dome (diameter 8.83 m). The entablature is designed in a series of concave loops, the central parts of which rest on the <u>cella</u> wall above the niches. This in fact forms a series of horizontal arches so placed as to transfer the thrust of the dome on the weakest part of the walls to the heavy masses of masonry which rest on the columns.

BRAD: Baths. 3rd century AD.
Butler, <u>N. Syria</u>, p. 299 - 302; Creswell (1932), p. 463.
Small room 3 metres square covered by a sail vault. According to Creswell the room is covered by a dome on spherical triangle pendentives which are monolithic.

SHAQQA: Kalybe. 3rd century AD.
Butler, <u>Architecture</u>, p. 396 - 7.
Area 8.15 m square with a broad arched opening. Square chamber covered by a masonry dome supported on stone slabs set across the angles.

UMM EZ ZEITUN: Kalybe. AD 282.
Creswell (1932), p. 454; De Vogüé (1865 - 77), p. 43 - 44.
Area 5.80 m square. A slab was put across each angle to produce an irregular octagon. On this seating a course of dressed stone was placed with one set aside each of the eight angles. Two more courses were placed like this producing a polygon of 32 unequal sides upon which a dome was set.

LATAKIEH: Tetrapylon. 3rd century AD ?
Creswell (1932), p. 455. Pers Obs.
The arches vary in width; one pair is 7.80 m wide, the other is 4.48 m, making the base an oblong. In each corner is a triangular feature, not curved, of three courses of cut stone. These incline inwards. This forms a regular octagon. A cornice is set on this, and then a low dome, 9.70 m in diameter, is placed on this seating.

JERUSALEM: Golden Gate. c. 5th to 7th century AD (date contraversial) (Plate 214).
Creswell (1932), p. 463. Pers Obs.
Sail vaults and domes on pendentives.

CONCRETE

There is no evidence for the use of concrete, as defined in Chapter III, for domical construction in Roman Asia Minor. However, there are several examples from the Hauran in S. Syria.

Syria

JERASH: Nymphaeum. Late 2nd century AD (Plate 215)
Kraeling (1938), p. 21. Pers Obs.
Semi-dome of volcanic scoriae, springing from a line just above the broken pediments.

BOSTRA: Caldarium, South Baths. 3rd century AD (Plate 216)
E. Smith (1956), p. 45; Butler, S. Syria, p. 260 - 63.
Pers Obs.
A very flat dome of eight gores over an elongated octagon, 15 m by 12.75 m, constructed of volcanic scoriae set on walls 2.3 m - 3 m thick.

BOSTRA: One of small square rooms, South Baths.
3rd century AD (Plate 217)
Butler, S. Syria, p. 260; Ward-Perkins (1981), p. 443.
Pers Obs.
Domical vault of light volcanic scoriae set in good mortar, about 9 m square and with a central oculus. Butler calls it a 'cloistered vault'.

PHILIPPOPOLIS: Baths. Mid 3rd century AD.
Butler, Architecture, p. 384; Smith (1956), p. 45.
Pers Obs.
Two domes of volcanic scoriae 9 m diameter on circular walls 1.20 m thick.

MORTARED RUBBLE

Mortared rubble was used very little for dome construction, and there is no evidence for its use in Syria and the East.

Asia Minor

MILETUS: Caldarium, Baths of Capito. Mid 1st century AD (Plate 218)
Ward-Perkins (1958)b, p. 99. Pers Obs.
Dome on circular base of fieldstones set radially in abundant mortar.

PERGAMUM: Rotundas of Serapaeum. 2nd century AD.
Ward-Perkins (1958)b, p. 85. Pers Obs.
Mortared rubble domes set on rubble walls faced with small squarish stones.

BRICK

As with mortared rubble domical construction in brick seems to be confined to Asia Minor, and even here these are few in number. An important example in Greece is the fountain building in the Agora at Athens which has a small brick dome. It is presumably late 1st or early 2nd century [85].

Asia Minor

PERGAMUM: Temple of Asclepius. 2nd century AD.
Vann (1976), p. 167. Pers Obs.
The excavators found the collapsed dome of radially laid brick. The dome had an outer diameter of 30.15 m and an inner diameter of 23.00 m.

EPHESUS: Theatre Baths. 2nd century AD. Repairs in late Antiquity.
Alzinger, R. E. Suppl XII, 1611 - 1613.
The presence of pendentives have been reported but not verified.

SARDIS: Gymnasium Complex. 3rd century AD (Plate 219)
Vann (1976), p. 166. Pers Obs.
Room BCH measures 11.60 m by 18.10 m and covered by either a single oval dome or by a pair of half-domes with an intermediate barrel vault. In the north-east and south-east corners of the room triangular features survive (called 'pendentives' by Vann). The north-east example has a maximum height of 2.55 m and a width of 0.60 m. Vann describes this as 'a definite parabolic curvature of the vertical surface ...' and '.... concavity noticeable at the top'. While this is true there is really too little of the whole element in each case surviving to make a definite statement one way or the other.

AUGUSTA CILICAE: Baths. Roman.
Gough (1956), p. 173 - 75.
N. W. room, 9.30 m square. Triangular features survive in three corners. However, from the published photographs too little survives to verify a pendentive claim. These could just as easily be part of a sail vault.

CONSTANTINOPLE: St. Polyeuktos. Early 6th century AD.
Harrison (1967), p. 276. Pers Obs.
A domed basilica. From the foundations, which are substantial, a plan anticipating that of St. Sophia has been suggested, with a dome 20 m in diameter.

CONSTANTINOPLE: St Irene. Begun AD 532.
Krautheimer (1979), p. 263 - 4. Pers Obs.
Much of the upper superstructure was rebuilt after the earthquake in AD 740, but it is generally accepted as a domed basilica.

CONSTANTINOPLE: St. Sophia. AD 532 - 7, dome rebuilt 558. (Plate 220).
Krautheimer (1979), p. 215 - 230; Mango (1976), p. 109 - 123.
Domed basilica. The first dome, 100 ft in diameter, was a very shallow dome on pendentives. In 558 it collapsed and was replaced by a steeper ribbed dome, some 20 ft higher, also on pendentives.

MAGNESIA ON THE MAEANDER: Vault beneath Roman walls. 2nd - 3rd century ?
Choisy (1873), p. 102.
Very low sail vault built on the pitched-brick technique.

SIDE: Mausoleum. 4th century.
Mansel (1959), p. 369.
Basically a rectangular area with apses on each side. The main area was covered by an oval dome. The so-called pendentives are constructed of brick laid fan-like and belong to the same spherical surface as the dome; it is therefore a sail vault.

EPHESUS: Governor's Palace Reception Hall. 4th century AD.
See Pitched-Brick Catalogue in Chapter VII.

CONSTANTINOPLE: Yerebatan Saray. 6th century AD.
Krautheimer (1979), p. 251. Pers Obs.
Small pitched-brick sail vaults.

CONSTANTINOPLE: Binbirdirek Cistern. 5th century AD.
Krautheimer (1979), p. 251.
Small pitched-brick groin-vaults and sail vaults.

Syria

APAMEA: Baths, caldarium. 2nd/3rd century AD.
Balty (1981), p. 53 and pl. 49. Pers Obs.
Brick semi-dome.

QASR IBN WARDEN: Church AD 564.
Krautheimer (1979), p. 260 - 1; Mango (1976), p. 151.
A domed basilica. The central bay is a rectangle 15 m by 18.5 m defined by four structural arches. A drum, octagonal on the outside, is placed on the arches and the pendentives, which reduce the square to a circle, spring within the drum, not below it.

THE DOME AND THE PENDENTIVE

One particular question about domes which has been the subject of heated discussion for many decades is that of pendentives and how to roof a square bay. It has already been seen that many of the arguments in this debate are based on very vague definitions of dome and pendentive. Many of the examples that have been cited in the past are clearly not pendentives at all. The following structures have been described as domes on pendentives, and no apology is given for reproducing them here, re-defined in consistent terminology; some new examples are added.

DIRA 'ABU'N-NAGA: Tomb. 15th century BC.
Pieron (1908), p.173 - 7; Spencer (1979), p. 47 - 48; Creswell (1932), p. 452. Above p. 278.
The triangular features employed to support the dome are corbelled and of the same curve as the dome; they cannot therefore be called pendentives.

KERCH: Royal Tumulus. 5th century BC.
Creswell (1932), p. 453.
Domed chamber 4.50 m square. Very similar construction to Dira 'Abu'n-Naga. The dome is cone-shaped and the transition is effected by a gradual rounding of the courses at the corners and by setting forward each curved piece step-fashion beyond the course below. This then is clearly another instance of corbelling.

VETULONIA: Tomba della Pietrera. 7th century BC ?
Boethius (1978), p. 98; Creswell (1932), p. 453.
Rectangular chamber covered by a dome. In the angles are 'primitive pendentives' to convert the rectangle into a circular shape. The technique, however, is exactly that found at Kerch and Dira 'Abu'n-Naga, that of corbelling.

MINORI: Villa Romana. c. 1st century AD.
Schiavo (1939), p. 131 - 2.
A 'volta a vel', that is, a sail vault over a rectangular room. The vault is constructed of concentric courses of travertine.

PETRA: Baths.
See above p. 288.
This is a sail vault.

ROME: Domus Augustana. Late 1st century AD (Plate 221)
MacDonald (1982), p. 66; Swift (1951), p. 118.
Pers Obs.
Triangular features remain in the angles of the rectangular room on one side of the Sunken Peristyle. These are probably all that remains of a groin or possibly a sail vault.

VIA NOMENTANA: Sedia del Diavolo. c. AD 137.
Rivoira (1925), p. 152 - 5.
Lower floor is a square chamber 5.20 m square covered by a flat sail vault. There was a similar arrangement in the upper chamber. Only the triangular angle features survive and have therefore been called 'pendentives'. Various other tombs are similarly cited by Rivoira as having true pendentives, the most interesting is the tomb near the 'Casale del Pazzi' on the Via Nomentina, Rome. These also were probably covered by sail vaults, or possibly groin-vaults.

JERASH: West Baths.
See above p. 289.
This is in fact a sail vault

QASR NUEIJIS: Tomb.
See above, p. 289.
Like Jerash this is a sail vault.

SAMARIA-SEBASTE: Tomb.
See above p. 289.
Like the preceding two examples this is a sail vault.

LATAKIEH: Tetrapylon.
See above, p.290.
The inclined flat triangular sections have been called pendentives, but by definition a pendentive has to curve in two directions. This example does not do so.

BRAD: Baths.
See above, p. 289.
This is a sail vault.

EPHESUS: Theatre Baths.
See above, p. 291.

SARDIS: Gymnasium Complex.
See above, p. 292.
Published as pendentives but too little survives to be certain. They could just as easily form part of a sail vault.

MAGNESIA ON THE MAEANDER: Large building. Constantine?
Choisy (1873), p. 159, fig. 175.
Possibly four small circular rooms covered by stone (?) sail vaults, described by Choisy as 'coupoles sur pendentifs'. There does not appear to be a change in curve.

SIDE: Mausoleum in Eastern Necropolis.
See above, p. 292.
This is a sail vault.

ABU MINA: Shrine of St Menas - Substructures of Period IV Church. c. 400 (Plate 222)
Ward-Perkins (1949), p. 56 - 58.
Brick dome springs from fully developed spherical triangular pendentives.

CONSTANTINOPLE: Santa Sophia.
See above p. 292.
The first dome was definitely a dome on pendentives, but it was a very shallow segmental dome; this was a large contributory factor to its collapse in 558. The rebuilt dome was 20 ft higher but still segmental.

KARABEL: Monastery Church.
See above, p. 287.
The central bay may possibly have been covered by a dome on a pendentive-like feature, but there is very little evidence to indicate definitely. The south chapel was covered by a dome with a curve that was different to the triangular features. These are curious because they appear to be a combination of corbelling and a generally rounding of the corners. They act in the same way as pendentives.

ALACAHISAR: Rock-cut church.
See above, p. 288.
The church up to the height of the springing of the dome has obviously been carved from the rock in imitation of another building with a true dome on pendentives. However, because they are cut from the rock they do not and cannot act as true pendentives; they are not subject to the same stresses and strains. They are representatives in rock of true pendentives.

JERUSALEM: Golden Gate.
See above, p. 290.

DISCUSSION

The roofing of internal spaces has posed problems and questions for engineers and architects throughout the ages. For two hundred years, since the Roman period when dome construction became a regular feature in architecture, the record for the widest interior span has been held by the dome [86]. The use of any form of domical structure is rare before the later Hellenistic period, and, when it is employed, the principles used are based on corbelling rather than on true dome construction.

The earliest attempts at this form of roofing for other than domestic structures were made in Egypt and Mesopotamia in mudbrick. The most adaptable materials for domical construction are those of a homogeneous nature, that is, materials in which joint and structural unit are equally strong. Mudbrick is one such material as the mud joints combine with the bricks. In Egypt, though never common in the Dynastic period, small corbelled domes were constructed mainly over tombs, for instance at Giza and Abydos [87]. Such structures were placed over square and circular rooms and when used over the former much distortion has occurred. The lack of pendentives has been given as the cause [88], but the technique was not one with which the Egyptian builders appeared familiar. Indeed, to cover square chambers one more often finds domes constructed on principles more akin to pitched-brick, for instance the tomb at Dira 'Abu'n-Naga, Thebes, and at Tell al Rimah in Mesopotamia [89].

Corbelled domes were also a common feature in Mycenaean and Etruscan tombs. Indeed, these are the most impressive structures of these two peoples, and show great technical skill in the more developed examples, for instance, the Treasury of Atreus at Mycenae and the Tomba di Casal Marittimo at Volterra. However, despite the fact that stone was the main building material, and its use was developed to a high degree, true domical construction was never attempted.

Indeed, it is not until the latter part of the Hellenistic period that we find examples of the true dome.

Structurally the dome is remarkably efficient, and it is the hoop tensions that present the major structural problem in the design of masonry domes. However, these also tie the vertical arches together, so that theoretically a hemispherical dome exerts no horizontal thrust. It only needs a vertical support and therefore makes elaborate buttressing unnecessary. In a segmental dome the springing line is effectively lifted, decreasing the tensional area and increasing the radial thrust at the abutments. If such a dome is thickened at the haunches, this reduces the hoop tensions, and, if proper abutments are provided segmental domes are strong forms, for example, the sail vault in the West Baths at Jerash. Of course the most famous segmental dome is that of Santa Sophia.

As has been said, the earliest examples of true dome construction in the Eastern Mediterranean did not appear until c. 175 BC. These were small in span and were constructed in stone. The earliest dome in Italy was over the frigidarium in the Stabian Baths at Pompeii (2nd century BC) [90]. The dome was not as common as the vault in the Roman East, and, as the behaviour of a dome is different from that of the arch and vault, so the materials in which domical construction was carried out are different.

Stone, for example, though much used for arcuated construction in both Asia Minor and Syria, was only used for domical construction in the latter until the later period [91]. This may have been due to the very high standard of Nabataean stoneworking in the area, both before and during the Roman period. The cutting and fitting of the individual stone blocks was crucial to the structure as a whole. Another important factor was the very nature of the stone, its lack of tensile strength which is so important in the lower part of a dome. In Asia Minor, the use of another material had developed for vaulting - fired brick [92]. As has already been seen the tensile strength of brick is usually negligible, and it is only practicable to achieve a compressive strength of brickwork as a whole that is a third or less of that of the individual brick. This, taken in conjunction with the effect of the quality of the clay on the individual compressive strengths of bricks, means that compressive strength may be a greater limit on design than it need be in stone masonry. However, it is much easier to construct curved forms in brick than it is in cut stone [93]. This is very evident in the use of brick for arches and vaults in Roman Asia Minor, and it was only natural that this material should have been adopted for domical construction. In the Hauran in Southern Syria, it was possible to make concrete and this was the material for dome building. Mortared rubble, Asia Minor's alternative to concrete, facilitated dome construction in much the same way, although span then became a problem [94].

It is evident that the true masonry dome did not enter the classical architectural repertoire until the later Hellenistic period, at about the time that concrete domes first appeared in Italy. Thus it would be incorrect to say that the dome was a Roman invention [95]. The Hellenistic and Roman builders unquestionably developed the scientific aspects of arcuated and domical construction, but the geometric forms of arches, vaults and domes were already known. The dome was certainly known in Egypt from early times, but its potential was not exploited to any extent [96]. It has been claimed, as for arcuated construction, that the dome originated in the brick architecture of Mesopotamia [97]. The evidence usually put forward to support this theory is the hemisperical form depicted on the reliefs of Ashurnasirpal's palace at Nimrud [98]. This undoubtedly shows that the Assyrians knew the domical form but it does not prove that the dome first appeared in Mesopotamia. The dome in the relief is a protective covering on the tower of a battering ram, its very use therefore precluding masonry construction; it must have been built of wood. Thus the relief does support the assumption that domical forms took shape in pliable materials, that is reeds and clay, and were translated first into wood and then brick and masonry.

The wooden dome is very significant in the early evolution of domical styles, but has been disregarded simply because of its poor survival record. A dome of timber (as for instance, the 5th century <u>tholos</u> in the Athenian Agora, the Arsinoeion on Samothrace) was light, relatively easy to construct and could be of wide span on relatively thin walls [99]. Once constructed its rigid framework exerted comparatively little thrust. Many architectural historians have minimized the possibilities of domical construction in wood because they think areas such as Syria, Palestine etc, as barren and timberless; Syria certainly was not [100]. The existence of forests and the use of timber as late as the 6th century AD are clearly verified by Procopius [101]. However, one cannot recognize with certainty an instance of a wooden dome before the Hellenistic period. During the Roman period wooden domes gave way to ones of masonry construction. There were problems of deforestation and transport to contend with, along with the conviction that masonry construction itself was more enduring and represented greatness and superiority [102]. The Roman engineers perfected the mechanics of vault and dome construction, and the dome became a mark of divine and royal power. There is no doubt that the dome became symbolic of the celestial heights in Christian architecture, for example, the various martyria in Asia Minor and Constantinople, and in Syria the dome was characteristic of church architecture, in various materials. Domes were widely used by the Arabs, in varied materials [103].

Many inaccurate claims have been made about dome origins using the construction materials as a basis. Strzygowski tried to prove that all elements of Christian architecture, including the dome, derived from the brick architecture of Mesopotamia and Iran [104]. His hypothesis centred upon Antioch as the point from which a brick architectural tradition could have spread, and upon Qasr ibn Warden, believing that its construction techniques were of Mesopotamian rather than Byzantine (and ultimately Roman) derivation. However, as has been seen, vaulting in fired brick was characteristic of Roman Asia Minor, and this passed into normal Byzantine practice. Domes were also constructed in this material (Santa Sophia, Constantinople, St John, Ephesus). The brick domes of Syrian churches merely indicate a prevalence of the Byzantine tradition, plus the availability of the correct materials for brick making.

No dome constructed in the East achieved a diameter greater than that of the brick dome of the Temple of Asklepius Sotor at Pergamum (outer diameter 30.15 m and inner diameter 23 m); several stone domes are only three to four meters in diameter (Qasr Nueijis and the West Baths at Jerash) [105]. The flat elongated octagonal dome over the caldarium of the South Baths at Bostra is at its widest 15 metres. This may be compared with the Pantheon which has a diameter of 43.20 m, and the 'Temple of Mercury' at Baia (21.55 m) [106]. That larger domes were not constructed presumably was due partly to a lack of confidence in both materials and technique in the East. Why this should have been so is difficult to explain. Barrel vaults of at least 10 m in different materials were not uncommon in the Eastern Provinces; the frigidarium of the large baths at Hierapolis (stone 12.50 m wide) [107]; room BEW in the Baths/Gymnasium complex at Sardis (brick, 12.50 m wide) [108]; cella of the Temple of Serapis at Ephesus (stone, 29 m wide) [109]; Hadrianic Baths of the Upper Gymnasium at Pergamum (mortared rubble, 10 - 15 m wide). Thus large spans were not rare. Vann gives the following maximum spans for different materials - mortared rubble 8 - 9 m, cut stone 14 - 16 m, fired brick 18 - 20 m [110]. However, a comparison of domical use in the Roman West with that of the East shows that, in general, domes in the West were of concrete and built over circular or roughly circular bases. In the East, the situation was different. The only concrete domes are those of volcanic scoriae in the Hauran [111]; these are mostly over circular rooms, except for two examples at Bostra in the South Baths which are domical vaults over square rooms (9 m square) [112]. Thus concrete is not a material used to any extent for domical construction in the East. However, in other materials one finds the dome over square and circular bays, but never with large spans. The small diameters could be due to some uncertainty about both materials and technique. Large domes could obviously be constructed in concrete, but materials such as stone and bricks were apparently not handled with the same assurance.

Lack of confidence certainly played a part in this situation, but as well as the facts that it was not possible to make concrete except in a few isolated areas and that the Eastern builders were not accustomed to domical construction with the associated materials, there is a third, more important point to bear in mind. Outside "imperial" contexts, such as Bostra, Philippopolis, Pergamum and Ephesus, generally there is no call for the large scale buildings that one finds in Rome and Italy; and, as a result, therefore, one does not find large domes. Indeed, large vaults on the lines of the

Palatine and the Baths of Caracalla were not necessary in the East until perhaps 324; the whole scale of things was much smaller generally in the Provinces. There are exceptions, such as the enormous 2nd century AD Thermae at Odessus, which were built on a scale more characteristic of Rome than the provinces. Thus, the fact that large domes were not constructed in the Eastern provinces must not be considered a problem; larger domes were not needed in the architectural tradition.

However, as far as the dome over the square bay is concerned, one can be more positive. This, as has been seen, involves the question of the pendentive. The examples outlined above have been judged according to what they have been claimed to be and according to what they in fact are; a consistent terminology is applied to each. It becomes obvious that the vast majority of those claimed to be domes on pendentives are in fact sail vaults. Those which do not fall into this category, such as the arch at Latakieh, have domes supported on flat triangular features which have no curvature at all; curvature in both the horizontal and the vertical plane is one prerequisite of the pendentive. Indeed the strength of the pendentive lies in the fact that it curves in these two planes and it is supported by being wedged between the four arches or walls of the square. The debate centres on whether the dome on pendentives has eastern or western origins. It is evident that the concrete dome as a covering for a circular or polygonal space, had a widespread use from the 1st century AD, in the West. However, in response to Strzygowski's claims for Armenia as the medium for the transmission of these ideas to the west, a number of wild counter-claims have been made [113]. The two most notable standpoints were taken, on the one hand, by Rivoira and Swift, who assigned the origins to Italy [114], and on the other by Creswell who favoured the Hellenistic world and especially Syria [115]. The earliest example cited by Rivoira for pendentives in Italy is the Domus Augustana. The room in question was covered by a low domical or perhaps a sail vault [116]. Other Italian examples prove to be similar [117]. Pendentives have been claimed for structures such as the 'Temple of Minerva Medica' in Rome, but both Durm and Rivoira have shown that these are 'merely a matter of corbelling ....' [118]. Indeed the Romans in the West did not need to develop the pendentive for large rectangular buildings; one simply has to look at the soaring heights of the groin vaults of the imperial thermae. These performed the same function as a dome, that of providing large and high areas of internal space, and indeed as regards structural action were easier to construct. The thrusts of a groin vault are localised at the four angles and it is here that the abutments are required; the radial stress of a dome, is best countered at as many points as possible along the circumference, thus requiring, as far as the Romans were concerned, massive haunches capable of resisting these thrusts at all points.

"A knowledge of dome-building is not of much use unless it is accompanied by a knowledge of some device whereby a dome can be set over a square bay" [119].

This statement typifies the extremes reached in the domes and pendentives debate. The Romans in the West certainly knew about dome-building and made good use of it. The Pantheon and the caldarium of the Baths of Caracalla illustrate their obvious skills admirably. However, it should be pointed out that domes were only used where they had to be, or where they seemed most appropriate, over circular or polygonal areas; the groin vault took care of the square base. There is nothing to suggest that they were incapable of setting a dome over a square bay; it was simply not required and therefore they were not interested in it [120]. Thus, Creswell in his attempts to pin the origins of the pendentive in Syria, took this standpoint completely ignoring the essence of the monumental concrete imperial architecture of the Capital.

The sail vaults which have been claimed as domes on pendentives do indeed incorporate triangular features closely resembling pendentives. There is no reason why these should not be in some way connected with the development of the dome on pendentives. In a sail vault, the curved domical element is inevitably a segmental dome. Such domes exert a greater thrust than those which are in fact full hemispheres. As soon as the segmental dome begins to exceed a certain limited size the thrust at the centres of the sides (that is, on the crowns of the arches) becomes too great. The vault would be too flat and it would not be possible to contain the hoop tension. A change of shape is therefore implied. To illustrate this point, Bagenal uses Santa Sophia [121].

The church's first dome was segmental and very flat, though there was certainly a change in curve between the pendentives and the dome [122]. The second dome was still segmental, but with a much more marked change of curve above the pendentives. "The pendentive does not take its full character until this distinction of curves has fully come about" [123]. To take this one stage further, one must not apply the term pendentive unless this statement fully applies to the structural element. To do so would be to cause the confusion which led Creswell to make his extreme statement.

Turning to the actual structures, one must see the development of the pendentive in an eastern context. The earliest certain, surviving dome on pendentives is that at Abu Mena [124]. The triangular features are of a different curve from that of the brick dome [125]. It may be small (only 3 to 4 m across), but its use is of no little significance. Ward-Perkins believes that the technical background for such vaulting lies in the indigenous craftsmanship of Roman Egypt [126]. There are certainly a number of examples of sail vaults at Karanis and in the cemetery of el-Bagawat [127]. If this is the case and sail vaults are the technical predecessors to the dome on true pendentives, then the form could have developed anywhere in the Eastern Mediterranean. The sail vault was in use throughout the Mediterranean world long before the earliest appearance of the true pendentive (see above) [128].

In looking for a dome on pendentives before the 6th century, scholars have, in fact, been searching for a building which could have been the supplier of technical ideas needed for the construction of Santa Sophia. The basic assumption of this is that as Santa Sophia is so large there must have been an earlier smaller attempt, but larger than the Abu Mena example. Would Justinian have experimented so daringly if one had not existed? This, however, does not do justice to the engineering skills of the day nor does it sufficiently take into account Roman usage of materials and techniques. Santa Sophia is large, but so was the Bailica of Maxentius in Rome. The vaulting of the Basilica was obviously carried out in concrete which had a long tradition in Roman Italy. The brick vaulting of Santa Sophia had a long and established tradition in Roman Asia Minor. The covering of the central nave of the Basilica of Maxentius was formed by three great groin vaults, again the usual practice. The square nave of Santa Sophia is covered by a dome, constructed of brick, a typical Eastern Mediterranean vaulting material. The dome is unusual because of its size but not because it is over a square bay. Putting a dome over a square bay required the right materials in conjunction with the right technique. Groin vaults would not have been possible in the available materials, but dome construction was known and quite frequently used [129]. It is possible that some intermediate examples have been lost, but this does not alter the fact that Santa Sophia is technically a Roman building, the culmination of Roman architecture, employing the materials and the techniques of Roman Asia Minor and the East and the engineering skills first learned in Rome itself. St. Polyeuktos in Constantinople, if Harrison's suggestion is correct, may have been a predecessor to Santa Sophia, on a similar scale and with similar materials. Away from Constantinople possible candidates for contemporary domes on pendentives are at Karabel and Alacahisar [130]. The latter is rock-cut in the form of a square bay with pendentives and is an imitation either of a local example or of a church further away, perhaps Constantinople. Karabel may represent a local example, but the features which actually survive in the south chapel are not at all like those cut at Alacahisar. The evidence for pendentives in the main part of the church is too inconclusive. Certainly the area of south-west Anatolia had a lively local architectural tradition in which pendentives could have evolved. In addition Anthemius and Isidorus, the architects of St. Sophia, came from this region, but the ideas may not necessarily have done. The development of the pendentive was almost inevitable if height and width were required while still keeping the domical form over a square bay. If the dating of these monuments is correct, it would seem that the pendentive developed in Lycia and South Turkey independently of and contemporary with St. Sophia.

"The architects of Imperial Rome had been the first to exploit architecturally the space-enclosing potentialities of the dome" [131]. The important word here is 'exploit'; the Romans did not invent the dome.

However, the technical potential of dome construction was more nearly achieved than ever before. The dome was already known in the East before the Romans established the Eastern Provinces. However, by introducing new materials (particularly brick and the use of mortared rubble) the constraints of stone construction could be avoided and domes could be built of more manageable materials. In the East, however, the barrel vault was preferred to the dome and when a dome was used it was only of small span. This was not because the skill was not available to construct large domes but because everything was on a smaller scale than Western practice. Thus, the domical vault and the sail vault were sufficient for roofing square chambers. It was only with the move of the centre of the Empire, first away from Rome under the Tetrarchy and then to Constantinople under Constantine, that 'big building' became necessary in the East and methods of spanning greater distances were required. The development that led finally to the dome on pendentives of St. Sophia, had its roots in the domical traditions of the Roman East. The need was for a device to support a dome over large spans without enormous lateral thrusts. Whether the technique was developed and exploited in Constantinople first and then used elsewhere or whether it was developed elsewhere, perhaps in Anatolia and early examples do not survive, is difficult to say on present evidence. The dating of some examples is not certain and it is dangerous to use such instances without reservations. However, the technique passed on into general Byzantine practice with the 6th and 7th century churches of Constantinople and Syria, but its origins and materials were Roman, introduced and developed in the Hellenistic world of the Eastern Mediterranean.

CHAPTER IX

THE COST OF BUILDING

There are a number of difficulties as regards construction costs in Antiquity. The fundamental problem is that one cannot work in absolute costs but only in relative costs. This is still a valid proposition and can be very valuable.

Basically, the cost of building is made up of the cost of quarrying or manufacture of the materials; the cost of the transport of the materials; the cost of the actual erection of the building; and the cost of labour. The evidence is mainly epigraphic but the amount which survives varies from one area of a province to another. The use of particular materials will, of course, have depended in part on their availability and cost, and on the funds available. Another problem is that often prices given cover several of the above categories, for instance, the marble prices in the Edict of Diocletian cover, presumably, the cost of quarrying and of transport to wherever it was required and whatever wages would be due. Reference has already been made to the figures for one column for the Temple of Didyma in the 4th to 3rd century BC, and it is worth quoting them again [1]:

Extraction and cutting			13,151 dr
Transport	land	8,895	
	sea	4,043	12,938
Erection			2,426
Dressing and final sculpting			10,275
			38,787 dr

This is an example where all the costs are split up as with the various accounts of the Parthenon and Erechtheum in Athens, and at Epidaurus. However, from the Roman period, there are no such records surviving. We have the Edict of Diolcetian, but this was an attempt to enforce price-restraint and to halt price-speculation by profiteers asking vastly inflated prices in comparison to what were fair. The prices in the Edict are not an indication of the market rates prevailing in AD 301 but they do represent a deliberate attempt by the government to lower and fix prices and keep them below a certain limit.

The question of who actually financed building is of particular interest. There were three main sources: municipal funds, imperial funds and private donations from wealthy individuals. The evidence is mainly epigraphic, but there is also a certain amount of literary evidence. There are, however, ambiguities. If an inscription records that a building was constructed from civic funds, the meaning is clear. It might also give an amount of money spent, but it is often not specified whether the money covered all costs from material manufacture/quarrying to the final details of building, or whether it only covered part of them. Presumably it is all the costs, but when imperial and private donations are involved it is never clear. In addition, an imperial dedication does not necessarily mean an imperial donation.

Where costs are known of buildings whose size is known from existing remains, there is considerable scope for investigations of actual building costs in different towns. However, comparisons between different provinces show that prices could vary considerably, but these can still be useful [2].

One other factor which can greatly influence prices is the re-use of materials within the Roman period. This is not necessarily an economic pointer to the unavailability of the materials, but is an element which must not be ignored.

Manufacture and quarrying of materials The prices of materials in a particular area depend on their local availability, or on the local availability of the right materials for their manufacture. The more expensive materials were stone, including marble, and wood which, even if local resources, would have to be transported to where they were required. Transport, especially over land, greatly influenced their prices. Timber and stone also required more working and preparation before they could be generally used for construction - cutting, dressing and shaping required skilled craftsmen. In contrast, fired bricks, once a kiln had been set up, could be made locally with little difficulty and in large quantities. The quality of the bricks obviously depended on the kind of clay available. The kilns could be established in close proximity to where they were needed in order to minimise transport costs. Pliny recommends in connection with the rebuilding of the aqueduct at Nicomedia, which had already proved very expensive and was still unfinished, the use of brick for some of the arches; this would be cheaper and easier than stone [3]. Brick was a much more versatile material than stone and though perhaps less durable, it became very important in the Roman East. Pitched-brick vaulting obviated the need for complex, and therefore expensive, scaffolding which was always a necessity for true arch construction in stone. Unless timber was readily available brick could provide a cheaper form of roofing. In the Byzantine period brick became a very important material, a fact which owed much to its inexpensiveness. Even here though to economise on the use of bricks an increasing amount of mortar was used between the bricks which correspondingly became thinner (see Chapter V). Mortared rubble was obviously cheap because any stones could be used, field-stones, river-worn pebbles, so long as they were all roughly the same size. However, the quality of the material depended on the quality of the mortar which could be on site as and when it was required.

<u>Transport</u> Very little evidence survives for transport costs in the Roman period. The Edict of Diocletian is virtually our only source of information for freight charges by sea, and almost the only source for land freight charges. In contrast, evidence for the Greek period survives in an embarrassing quantity. The building accounts of Athens, Epidaurus, Delphi and Eleusis, already referred to, not only give labour rates but also how much the transport of materials cost. The accounts of Eleusis,

Epidaurus, and Delphi (the rebuilding of the Temple of Apollo) all date to the later part of the 4th century BC [4]. In figure 30 various amounts are shown for material transport for these sites. Several interesting points emerge. There is no correlation between the cost for limestone transport at Epidaurus and Delphi, but the high cost at the latter is probably due to the steepness of the road making transport very hazardous. The similar prices at Eleusis and Epidaurus for Pentelic may suggest a more regulated price for the transport of finer stones.

Cato gives land transport costs for Republican Italy [5]. The transportation of a heavy article by ox-team was 17% of the cost of the article for a distance of 25 miles. For 75 miles it cost nearly 75% of the original purchase price. Land transport was not only more expensive but also slower than water transport [6]. Pliny at the beginning of the 2nd century AD requests permission to build a canal from Lake Sophon (now Lake Sabanja) near Nicomedia to the sea to cut out the costly and difficult journey by cart [7]. Transhipment from land to water transport and vice versa also added to the cost.

The Edict of Diolcetian gives freight charges for sea transport with a series of sums payable per kastrensis modius for carriage between specified destinations [8]. For example, from Libya to Gaul it cost 4 denarii, and 6 denarii from Libya to Sicily. The inscriptions, however, are fragmentary. The prices for land transport are very much higher. The freight charge for a 1,200 pound wagon was 20 denarii per Roman mile [9]. It is the cost of land transport which increases the price of building materials. The prices of different kinds of marble in the Edict reflect this (fig. 11). Docimium marble, far inland in Anatolia, is five times as expensive as Proconnesian where the quarries are by the sea. Thus local resources were always exploited where possible and marble, unless there was a local source, was only in great use in the richer cities [10]. Even then the more expensive marbles were still only for the more wealthy.

If timber was unavailable locally for roofing and the cost of transport could not be raised, other methods had to be found; brick vaulting has already been mentioned. In the Hauran, in the almost complete absence of timber, stone was used for roofing (Plates 164 and 165). Thus the cost of the transport of materials greatly influenced their use and helped to evolve various architectural styles.

Costruction costs on site These were probably made up to a large degree by labour costs. There are virtually no figures surviving apart from the cost of erecting a column at Didyma. However, presumably the more expertise and technological knowledge that was required, the higher the costs.

Labour costs The whole process of building involved vast numbers of workmen, for example, the Erechtheum accounts of 408 - 7 BC which list over 100 men engaged on the final stages of decoration and finishing - 44 masons, 9 sculptors, 7 woodcarvers, 22 carpenters, sawyers and joiners, a lathe worker, 3 painters, a gilder, 9 labourers and other unspecified workers [11]. Temple building elsewhere in the Greek period shows a heavy dependence on imported labour, for example, the Temple of Asclepios accounts at Epidaurus, c. 370 BC, in which workmen from Argos, Corinth, Athens, Paros, and Arkadia are listed. In the African provinces and in Asia Minor, itinerant workmen must have played a large part [12]. Salaries are also given by various Temple accounts [13]. Salaries given in the Edict of Diocletian are per day -

Stone mason	50 denarii
Lime burner	50 denarii
Marble worker	60 denarii
Mosaicist	50 denarii
Carpenter	50 denarii
Ironworker	50 denarii

In the Roman period slaves worked in the quarries as well as freedmen. Quarrying was a highly skilled job. In general there was a shortage of skilled labour and the movement of craftsmen in the Roman period is very evident. Livy reports that when the marble roof of the Temple of Juno at Lavinia was stripped by one of the censors in 173 BC, it could not be replaced because there were no workmen capable of doing the job [14]. Sculptors from Aphrodisias and other parts of the Greek world moved West where there was enormous demand for their expertise and work [15].

The same is true for architects. Trajan tells Pliny that he cannot send out skilled architects to supervise repairs as every province has men trained in these skills; these men usually came from Greece anyway [16]. Trajan's chief architect, Apollodorus of Damascus, was, of course, Greek.

The role of the architect in the Roman period is interesting. The original meaning of the word, was manifold - chief artificer, master-builder, director of works, engineer, architect. There was no distinction between architect and engineer in the ancient world; Vitruvius is an extreme example. The role of the architect was as a designer who was needed to direct and co-ordinate. They had to be experienced in the ways of many different materials and diverse crafts. Vitruvius gives a detailed account of what he believes an architect should be well-versed in (see Chapter I). One cannot imagine that all architects could claim to be so; presumably Vitruvius has in mind the 'gentlemen architects' as opposed to the ordinary, and doubtless more numerous, architects. There is evidence that Roman architects drew plans of buildings on parchment [17], and plans survive on stone, for example, the plan on marble from Perugia (Plate 223) [18], and in mosaic (Plate 224). According to Cicero models were also frequently used [19].

Architects were in the employ of the government or of the municipalities. There were also military architects of which we have much epigraphic evidence from all over the Empire. These form a separate group, however.

Architects, at lease the 'gentlemen architects', were not paid a wage because they did not render personal service under contract; instead they received an honorarium. This, however, cannot always have been the case. City architects, presumably, were paid out of municipal funds. These were common in the cities of Asia Minor. Though the body of evidence is small, it is greater here than elsewhere in the East. Zeno was the architect at Aspendos, who was not only in charge of building the theatre, but also of other public works as well. Aurelius Antonius held a similar position from AD 220 to 240 at Tanais on the Bosphorus where he rebuilt walls, gates and the forum amongst other public buildings [20].

However, it is difficult to ascertain the various processes of building from start to finish. They were obviously complex, but in comparison to Africa and the West there is very little evidence in the East. However, such evidence as there is suggests that the situation in the West was different from that prevailing in the Eastern Provinces. The practice of allotting building contracts by competitve tender was normal in Rome in the Late Republic [21]. Presumably this was the case elsewhere in Italy. There is no reason why the imperial building programmes of Rome should not also have followed this method, the difference being that an architect was already on hand; it was the builders and craftsmen who had to be employed.

The same process was apparently used in Nicaea where

Pliny talks about a rival architect's opinions on the rebuilding of a gymnasium [22]. However, in inscriptions of Stratonikeia in Caria, Miletus and Pergamum, the system is different though whether this is typical of the other cities cannot be stated with certainty [23]. An inscription relating to the building of the theatre at Miletus [24] tells of a dispute over the contract of a group of workmen under the foreman Epigonos. They contemplated striking or looking for alternative employment in the locality, but decided to consult the oracle of Apollo at Didyma. Also named are Ulpianus Heros, the public overseer, and Menophilus, the architect. Thus four levels can be identified: the workmen, their representative, the public overseer and the public architect. A fragmentary inscription from Pergamum [25] about a strike by builders clearly shows that workmen were contracted individually or as a group by the public overseer who also had to deal separately for the materials.

By far the largest resource which the emperor could make available to the municipalities was the army. In its ranks were surveyors and engineers/architects. Soldiers with the title _architectus_ were common in the oversight of quarries [26]. Two recorded instances of building by the army in the East are at Bostra in Arabia and at Dura in Syria. In the 2nd century AD at Bostra the walls were built by _legio_ III _Cyrenaica_ [27], and at Dura under Marcus Aurelius, the amphitheatre was built by vexhillations of the _legio_ III _Cyrenaica_ and _legio_ IV _Scythica_ [28]. Army work inevitably is most common on the frontiers. The army were often involved in projects of specific Roman building type, demanding special expertise and labour, for example, roads, aqueducts, walls, amphitheatres and baths. It was thus a possible medium of Roman architectural influence in the East.

Various depictions of workmen on building sites survive.

i) From Terracina (Plate 225). Sculptural relief depicting the emperor as the architect. An ashlar wall is being constructed and a crane is in use with pincers for lifting blocks. One man is dressing blocks. Two men appear to be foremen.

ii) Tomb of Trebius Iustus (Plate 125). A wall painting showing a building, wholly or partly of brick, in the course of construction. Scaffolding has been erected and two men work on this at the wall. A ladder gives access to the scaffolding and bricks are being carried up to the bricklayers in large containers supported on the man's shoulder. A man is apparently mixing mortar in the righthand corner. The man on the ladder may be carrying mortar.

iii) 4th century Manuscript of Virgil has a depiction of an architect and masons at work. The architect is apparently directing the work of one of the masons dressing a block [29].

iv) Mosaic, Bardo Museum, Tunisia (Plate 226). This depicts an architect and his assistants. A column is being carted to the site (bottom right). Mortar is being mixed by two men in the middle right of the mosaic. In the top righthand corner a sculptor is shaping, or perhaps fluting, a colonnette. The architect appears at the top of the panel holding a 5 ft measuring stick [30] while gesturing with the other hand to a wreathed inscription now lost. Beside him are a capital, a set square, a plumb-bob with cord, and a stake for fixing setting out lines in position.

v) Painting from Villa of San Marco, Stabiae. A detailed depiction of transport, lifting and working of materials [30a].

The Sources of Finance

Three sources were able to pay for the erection of public buildings: municipal funds, imperial funds and private donations. The various cities had various expenses of which, one of the most important was the provision of public buildings. Funds raised from various revenues were apparently put aside for this. There were misappropriations and wastages as recorded by Pliny where sums as much as 10 million sesterces were involved [31]. Not all building was carried at the expense of the cities themselves. The Emperor played a part in the provision of public buildings in the provinces, often supplementing costs as imperial gifts. Hadrian was the most prolific builder, especially in the Eastern Mediterranean. His biographer says that he built some building in almost every city [32]. One of the best known examples is when he gave 1,500,000 drachmae to Smyrna for the construction of a grain market, temple and gymnasium [33]. In Athens he built a whole new quarter to the city having completed the Temple of

Olympian Zeus and constructed a Library and gymnasium [34]. Sometimes financial help was necessary because of some natural disaster, as for instance, when Marcus Aurelius helped Smyrna rebuild many public buildings after an earthquake [35].

The third source of finance was that of the wealthy citizens of the city. These were displays of wealth and munificence and ensured a certain amount of honour and dignity for one's family. Many are recorded in inscriptions often with the amount of money donated, but it is very difficult to know whether this covered all costs incurred or only part, the rest to be made up by other means. The following examples may be taken as representative.

Pergamum Under Hadrian there was an extensive building activity, largely at the expense of wealthy citizens [36].

Smyrna 1,500,000 dr and various marbles were given by Hadrian to the gymnasium as well as private donations of 4,500 to 70,000 dr for various purposes [37].

Ephesus Theatre stage-building completed with a bequest of Flavius Montanus, Trajanic. From the same source 75,000 dr for buildings on the harbour [38]. Under Antoninus Pius the Vedius Gymnasium was constructed by P. Vedius Antoninus [39].

Miletus Elaborate *nymphaeum* terminating in a long aqueduct by M. Ulpius Traianus, Trajan's father in AD 79 - 80 [40]. Restoration and repairs in the south market, with imperial help for the south portico after an earthquake [41]. Baths of Faustina under Marcus Aurelius, probably at imperial expense [42].

Trebanna in Lycia An assembly hall by the family of M. Aurelius Solon, using public timber [43].

Aspendos 2,000,000 denarii given by Tiberius Claudius Erymneus to bring in the aqueduct [44].

Sagalassos Temple to Antoninus Pius and the gods of the city by the city, but portions were donated by private individuals [45]. 13,000 d. by P. Ael. Aquila for a macellum under Commodus [46].

Adada 3,500 d. by Aur. Antiochianus for the Severan gymnasium erected by the city [47].

Sidamaria Bath building to Hadrian by the council and assembly [48].

Iotape 1,025 d. to public bath and 15,000 d. for a gymnasium by Kendeus.[49].

Jerash Zabdion, son of Artomachos, and a priest of Tiberius Caesar, gave gifts for the building of the Temple of Zeus, AD 22 [50]. Titus Flavius, a veteran decurio paid for a block of seats in the South Theatre [51].

Two millionaires of the 2nd century AD who provided enormous sums for public building are particularly important. Herodes Atticus was a native of Marathon and with his enormous wealth became a cultivated patron of the arts and a generous benefactor to Athens and other Greek cities. He built the Odeion on the slopes of the Acropolis and the Stadium in Athens [52]; he added the stone terraces to the stadium at Delphi [53]. He also built a swimming bath at Thermopylai [54], and a nymphaeum at Olympia. His beneficence was not confined to Mainland Greece. Philostratos reports that the aqueduct of Herodes Atticus at Alexandria Troas cost 7,000,000 dr of which the emperor contributed 3,000,000 and Herodes Atticus the rest [55].

The second millionaire is Opramoas, a citizen of Rhodiapolis at the time of Antoninus Pius. He made exceptionally generous gifts to almost every city in Lycia [56]. For a bath building at Oenoanda, 10,000 d. were given; 30,000 to Xanthus for the restoration of the theatre; more than 20,000 to Limyra for the construction of a theatre; and over 100,000 d. were given to Myra for building construction. Thus the building activities of the private individuals benefitted the cities as well as those giving the money.

Re-use

The re-use of building materials is not necessarily an indication of a decline in building standards nor of a lack of inspiration or craftsmanship, but often represents an intelligent use of available resources. The cost of building was on the increase throughout the imperial period and as buildings either fell into ruin or were knocked down, so their materials were used elsewhere. This is particularly true of marble and granites whose production and transport was particularly susceptible to the vagaries of historical and economic factors. The example of the Baths of Scholastikia has already been mentioned but in the later Empire re-use of marble and granites became commonplace. Often it is easy to identify this - columns are different lengths or capitals are different designs - but with other materials it can be sometimes very difficult. Both brick and stone were easy to re-use but with brick it is much more difficult to recognise the practice. Bricks can be re-used in wall-cores and unless they can be measured there is no way of determining this (Chapter V). Stone, however, especially if there is some kind of carving, is easier to identify. Much re-used stone has been located in defensive town walls in the West [57], and at Vaison-la-Romaine column drums were re-used in the footings of the cathedral. In the Eastern Provinces, conditions remained stable enough for stone quarrying to continue and there does not appear to be as much re-use of stone. At Palmyra, the Sanctuary of Bel was completely taken over and fortified by the Arabs with the east wall being rebuilt from the various pieces to hand (Plate 227). The Propylaea and west wall was heavily fortified with column drums used as binders in the walls (Plate 228). Monolithic granite columns were used as binders in the battering of the citadel at Aleppo (Plate 43), and in the walls of the Crusader sea castle at Sidon, as well as in a number of Crusader constructions at Tyre and Caesarea. As already seen the re-use of marbles and granites was common in both Rome and Constantinople. The re-use of materials from ancient sites in the Eastern Mediterranean, of course, continues to the present day with unprotected sites often providing fine building stones for modern villages.

Thus it is virtually impossible to come to a figure which actually represents the cost of building. The poor survival of material is the main reason. The inscriptions that do survive may not be a representative sample of the real situation. For Italy and Africa, Duncan-Jones has carried out extensive studies into building costs, but it becomes evident that with prices expressed in denarii in some, and drachmae in others, there are immediate difficulties [58].

However, some comparisons can be made. The theatre at Nicaea was costing 10 million sesterces according to Pliny; the theatre at Madauros in Africa was 375,000 [59]. The discrepancy between these can be explained. The theatre at Nicaea is free-standing while that at Madauros is not, plus there seems to have been a considerable amount of wastage at Nicaea. The price of the macellum at Cuicul [60] in c. 138 - 61 was over 30,000 sesterces; the one built at Sagalassos by P. Ael. Aquila cost 13,000 d., a figure not too dissimilar. Little more than these basic comparisons can be made.

CHAPTER X

AFTER THE 4TH CENTURY

After the military crisis of the 3rd century AD the position of Rome within the Empire was drastically changed. The situation no longer allowed the city to be the unchallenged centre of the Roman world. Under the Tetrarchs new capitals were established away from Rome at Antioch, Nicomedia, Thessalonika, Sirmium, Milan and Trier. The architecture of these cities drew largely upon local building traditions but one can begin to see a breaking down of regional boundaries. The needs were the same whether in Antioch or Trier.

The overriding influence on the architecture of these cities is one derived from the East and Asia Minor. At Trier the first instance of all-brick construction in the West is the early 4th century basilica. The Kaisarthermen in many respects resembled the gymnasium/bath-buildings of Asia Minor, and their combination of materials for construction, brick bands alternating with small squared blocks, is another feature typical of the Eastern Empire. This type of wall construction is also typical of Thessalonika and Antioch, where solid brick construction was also common.

The use of brick for walls spread slowly west under Tetrarchic influence. It was a well-established technique in Asia Minor and parts of Syria and found favour in the Later Empire as a good alternative to brick-faced concrete. Brick became a common material for walling in the churches of the west [1].

In Rome, building still carried on in the familiar brick-faced concrete; the culmination of this tradition can be seen, for example, in the Basilica of Maxentius and the Baths of Diocletian. New techniques in vaulting were already reaching the West. The use of hollow jars has already been mentioned (page 17). Vaulting in brick, though it did not reach Rome, was extensively used at Split in the Palace of Diocletian, and played an important part in the early Christian architecture of Central and Northern Italy [2]. The use of interlocking tubular tiles in vaulting is a technique similar to the use of hollow amphorae, which is often considered to be the first tentative steps toward the systematic solution found at Ravenna. However, the already perfected technique is found in the 1st century at Dura (Plate 203) and in the 3rd century in Africa. It is difficult not to conclude that the technique was transmitted from East to West via North Africa [3].

At Ravenna the technique is found from the early 5th century. The Mausoleum of Galla Placidia (c. 425) had a dome of brick with a filling of amphorae set in lime. On this rested the roof tiles [4]. The apse vault of S. Apollinare Nuovo (c. 490) was constructed of hollow tubes fitted together and the dome over the Baptistery of Neon also employed this technique (11.30 m in diameter). The most important example, however, is the dome of S. Vitale (c. 546 - 8). This is of conical form, made of a double coil of terracotta tubes interlocking and bedded in lime. Rivoira gives the measurements of 16 cm long and 5 cm thick for the tubes, and he considers the technique to be Roman in origin. He gives the example of one of the three chapels added in the mid 5th century to the Lateran Baptistery in Rome. The central groin vault was apparently of tubes [5].

With Constantine's removal of the capital to Constantinople there was a shift in emphasis and the focus of events was very much in the Eastern Mediterranean. In the early part of this century there was much debate as to the 'Western' or 'Eastern' nature of the Early Byzantine architecture (as it may be conveniently referred to). The question of whether it was a derivative of the architectural traditions of Rome and Italy, or of the Eastern part of the Empire, where new forces and ideas had been at work, was hotly debated. Central to this question was the 'origins' of the dome on pendentives discussed above (Chapter VIII).

The architecture of the provinces had always had a vigorous life of its own, in particular the provinces of the Eastern Mediterranean. These areas had come under the influence of a number of different and strong architectural traditions which had converged to produce the typical Eastern Roman traditions. This was the region which Constantinople naturally drew upon for materials and ideas, but one can also identify traditions derived from Rome and other major imperial centres.

The materials and techniques of Constantinople were most definitely those established in Roman Asia Minor. The faced rubblework alternating with brick bands exemplified in the walls of Nicaea and which was common in the Balkans in the 2nd and 3rd century became a typical Early Byzantine technique of walling, for example the Theodosian Land Walls. From the 2nd century onwards brick was used for walls and vaults, and this was taken over by the architects of Constantinople. Dressed stone was always favoured for the important load bearing points and continued to be so, for example, the piers of St. Sophia.

The destruction of pre-Justinianic Constantinople has made it difficult to assess the influence of Rome, but there was a deliberate appeal back to the old capital, to its regional organisation, its plan and its major public buildings. Constantinople was, after all, the 'New Rome'. However, even in the 6th century Constantinople there is much which one can almost call Roman in tradition. This is not surprising, the architecture of the Roman East was very often an interpretation in local materials and techniques of the monuments of Rome.

To these two differing traditions, that from Rome and that from the Roman East, the architectural experience of the Tetrarchic centres was added. As has been seen, these were already drawing upon local materials and traditions, but they were still essentially Roman in character. Their major contribution was to develop an architecture of a more cosmopolitan nature which began to break down the old distinctions between one province and another. It was this tradition that Constantinople was destined to receive and which for several hundred years held sway.

In general, Byzantine construction can basically be divided into two categories: ashlar masonry which was characteristic of Syria-Palestine, areas of Asia Minor and Armenia and the Georgian borders; and brick and rubble, either both together or brick alone, which was typical of Constantinople, the west coast of Asia Minor, the Balkans and Italy.

Cut-stone construction was limited in Constantinople because of its expense [6] and was far more widely used with other materials, but in the Levant and parts of Asia Minor where good building stone was readily available, ashlar construction was the norm, as it was in the Roman period. This can be illustrated by the churches at Jerash, the cathedral at Bostra, and Qa'lat Si'man in Northern Syria. In Asia Minor, the cut-stone tradition continued into the Early Byzantine period, for example Meryemlik, Alahan, Karabel and the churches of Hierapolis. Generally, roofing was of timber, which was in good supply, but in some cases vaults and domes were carried out in stone as well.

The brick and rubble construction and solid brick construction, as already seen, were already in general use in Severan Constantinople, in Asia Minor and the Balkans, and was thus the natural technique for the architects of Constantinople to adopt. The bricks were generally larger than Roman bricks and from the 4th to the 6th century were apparently subject to some kind of control [7]. All the vaulting was generally of brick. Rubble and brick construction continued throughout the Byzantine period until the 14th century, but the particular type of mortared rubblework in the walls of Theodosius was obsolescent by the 6th century [8]. Byzantine mortar of lime and sand and an admixture of crushed brick or pebbles was applied very liberally. In brickwork there is a tendency for the proportion of mortar to bricks to increase, resulting in the use of an increasingly wide horizontal joint (see Chapter V and Appendix II). The excessive use of mortar has caused problems for some buildings as they have settled and as the mortar has dried out. This has been particularly serious in the case of St. Sophia. Away from Constantinople the rubble is generally replaced by small squared blocks; these alternate with bands of solid brick, for example, Qasr ibn Warden, and Philippi. The vaulting of these buildings was almost exclusively carried out in brick. The use of this material for vaulting had been perfected in the Roman architecture of Asia Minor and presumably owed much to Mesopotamian practice. This is more evident in the pitched-brick technique which became typical Byzantine technique, for example in Qasr ibn Warden.

After the 6th century there was a sharp decline in innovative architecture and there was certainly nothing displaying the inventiveness and liveliness of the traditions inherent in St. Sophia. Certain churches do stand out, for example, the church of St. Sophia in Thessalonika and the church at Dereağzi, but all display the features of St. Sophia, the centralised dome over a square bay, with vaulting very often in brick.

Byzantine architecture has been described as the culmination of Roman inventiveness, styles and traditions. In many ways this is true, but its Roman nature is tempered by many other convergent traditions, all of which were at work in the Eastern Mediterranean in the Roman period. The architecture found in the Byzantine period is merely a development and progression from this, and to try and find a distinctive dividing line would be grossly misleading.

CONCLUSION

Building materials and techniques form only one aspect of Roman architecture. However, it is fundamental to the study of the subject of Roman architecture as a whole. The assessment of Roman technical knowledge depends on the study of the monuments. Their survival, therefore, has dictated where such research should take place, and work has tended to concentrate on Rome. This is Roman architecture in its strictest sense, but how 'Roman' is the architecture, and therefore the materials and techniques, of the provinces, in particular, the Eastern Provinces. How meaningful is the term 'Roman' in this context? And is it possible to treat the architecture of the Roman East as a unit, and contrast it with that of Rome?

This is a perplexing problem because the question has to be, what do we mean by Rome? Generally speaking, the architecture of Rome covers that of the imperial capital and most of Italy, with some variations. In the provinces, this Roman architecture becomes diluted by local traditions. The important point is that it is the 'diversity within unity' which characterises Roman achievement in so many fields [1]. Currents flowed from Rome to the provinces, for example, the introduction of distinctly Roman buildings, and sometimes the process was reversed. Nevertheless, Rome did not have to be at the centre of these currents, which were, on occasions, inter-provincial. For example, the huge Severan building programme at Lepcis Magna, both architecture and sculpture was the work of craftsmen from the Aegean and Asia Minor working to Eastern models that had little to do with contemporary Rome: 'an East Roman architecture transported, under direct imperial patronage which nevertheless by-passes the imperial capital' [2].

There were also currents flowing from the West, notably from Rome itself, to the East, but within the geographical boundaries of the Eastern Mediterranean architecture varied from one centre to another, sometimes considerably. To treat the architecture of the Empire as the product of two contrasting elements - 'East and West', 'Rome and the Orient' - is to simplify a complex story to the point of distortion.

Roman architecture, in general, was a mixture of different traditions. As has been seen, the Romans' mastery of arcuated construction was a product of their own technical expertise and the basic groundwork begun 2000 years before by the Egyptians and Mesopotamians, The architectural development of the latter was limited to a certain extent by their materials, though they cannot be described as having been hampered by them. Conversely, the Greeks were hampered by them, with their reluctance to build in anything but stone. To architecture, however, they contributed Greek science. This did not facilitate construction, but did provide an absolute foundation for the theory of design, by relating architecture to the scientist's concept of an ordered world. Architectural theory was based on science as understood in the Greek period. The Romans used this theory and developed according to their knowledge and understanding of the principles of construction.

As a result of the Greeks' conservatism, there was little technical experimentation and innovation. There was experimentation with the orders and refinements but these represented the finer points of architecture. Stone and timber were the only materials employed and the strict and rigid architectural tradition did not allow the use of arcuated construction, except in very insignificant situations. It was not until the wide-spread expansion of the Greek world under Alexander the Great that the arch became common currency in the Aegean area, by which time the classical Greek architectural tradition was waning.

The complexity of the subject is evident. In the architecture of the Eastern Roman Provinces, many prevailing and strong traditions can be identified but these vary from one area to another, and sometimes from one city to another. The Eastern Mediterranean had been under Greek influence from the 4th century BC in Syria, and at least the 8th century BC in Asia Minor. However, Persian, Parthian and later Sassanid influences made themselves felt to greater and lesser extents. Thus, when the Romans began to absorb the East into their Empire there was no one unifying tradition. There was little choice but to adapt their traditions, originating in Rome, to those they encountered.

The Eastern Mediterranean was the area on which Rome drew most heavily for architects and technical skills, though unfortunately there is very little evidence for these architects apart from the standing buildings. However, it is clear that the architecture was lively and innovative in a number of ways which derived from a number of different traditions. Building in the Eastern Provinces was dependent on the local resources; if some materials were unavailable they adapted what was available to suit their purposes. The most significant example is that of concrete, the building material par excellence of Rome and Italy. This could only be made in certain areas of the east. Thus, the use of other materials was developed, for example, fired brick and mortared rubble, and construction in stone was perfected. This latter owed much to the Greek and Nabataean techniques of fine cut-stonework. Mortared rubble was Asia Minor's alternative to concrete, though it never achieved the structural properties of concrete. However, it was the use of fired brick as a building material in its own right that was particularly innovative. In the Balkans, Asia Minor and Syria the material was not subordinate to opus caementicium, and it was used for vaulting as well as wall construction. The technique employed with the materials were basically Roman, that is, derived from Rome, but they were interpreted and carried out according to local traditions. Pitched-brick vaulting was derived from Mesopotamian and Egyptian use and became an important technique in the Early Byzantine period. Domical construction was probably derived from Western use but the use of domical forms over square bays is a purely Eastern development.

There were some obviously direct Roman introductions into the Eastern Mediterranean. Certain building types, for example, the basilica, the amphitheatre and the bath-building were among these, and in the case of bath-buildings helped to develop the use of vaulting on a large scale in different materials. Many Greek theatres in Asia Minor were remodelled and reorganised to conform with Roman practice. The use of concrete in Cilicia and the Hauran was introduced directly from Rome under Roman instigation, and the use of *opus reticulatum* at Elaeusa-Sebaste is part of this process. Other examples of the technique should be viewed as imitations of the Roman technique or of the involvement of someone well-versed in the Roman techniques of the West.

The use of marble in the Roman period in the Eastern Mediterranean was a direct result of the wide-spread exploitation of the quarries by the state. Many of the cities near the quarries became administrative centres, gaining increased prestige and wealth. The use of marble for architecture had a fundamental effect on building. The development of the 'marble-style', based on the quarry production of Asia Minor and Greece, spread rapidly over large parts of the Mediterranean coastlands during the first half of the 2nd century AD. The influence of this style of architecture was felt all over the Eastern Mediterranean, in Tripolitania and also in Rome where craftsmen whose training was purely Asiatic were at work. This large reservoir of skilled craftsmen, sculptors and architects was continually being drawn upon by Rome and the Western Provinces. Guilds and workshops were set up in Rome, Lepcis Magna and Nicopolis-ad-Istrum, and architects from Greece and Asia Minor were continuously in demand [3].

The most important characteristic of East Mediterranean architecture as a whole was that, no matter what the differences may have been from one area to another, it was always developing and changing; it was never static. In contrast, architecture in Rome made no great developments after the 2nd century AD, though it continued to demonstrate a high degree of technical expertise.

Into general Byzantine practice passed such Eastern features as brick vaulting, including pitched-brick, brick and faced rubble wall construction, and cut-stone for load-bearing piers and walls. The move of the capital from Rome to Constantinople provided new stimulation for building in the Eastern Provinces. In contrast, in Rome there was very little new building. Some major marble quarries were given a new lease of life as the new market of Constantinople was established; others faltered, either because of their distance from the capital or simply because of Byzantine taste. The re-use of materials, including marble, was a characteristic of late Roman and early Byzantine architecture, and old materials were transported from Rome and other centres to Constantinople. Buildings were stripped of all transportable materials for re-use elsewhere, especially bricks and decorative stones. In Rome, this did not mean the total destruction of monuments; it was impossible and impractical to haul away the concrete. However, the bricks of Constantinople were used and re-used in later periods so that very little of Roman and early Byzantine Constantinople survives in comparison to Rome.

The architecture of Rome and Constantinople, in relation to provincial developments, reflect to a great extent the social, economic and political trends in the positions of the two capitals within the Empire.