2. A GEOLOGICAL APPROACH TO INTERPRETING THE KHMER CIVILIZATION

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Introduction

Geology is generally thought to be a study of the distant past. However, geology is actually concerned with the study of all sorts of natural phenomena which have occurred on the earth from the past to the present. One hundred and some tens of millions of years ago, when dinosaurs flourished, and one thousand years ago when the Khmer civilization was at its height of prosperity may each be considered to be simply ages which existed in the history of the earth. In other words, the natural environment of the period in which the monuments of Angkor were constructed and the natural disasters which occurred at that time can be elucidated by geological methods. Also, while the Angkor monuments are being subjected to detailed research by various disciplines such as architecture and archaeology, there is little work being done on the sandstone itself which has been used abundantly in the structures and it is believed that this too should be studied from a geological viewpoint.

With this as the objective of investigative research, a geological survey of Lake Tonle Sap was carried out firstly then secondly observations of the sandstone blocks were made. It was then discovered by studying the lake deposits the natural environment at the time the Khmer civilization flourished could be interpreted and that there was a certain artificial regularity in the laying of the sandstone blocks.

I. The Lake Tonle Sap Deposits (as a key to interpreting the palaeo environments)

Natural phenomena which have occurred on earth have affected

the deposits in the oceans and lakes in various ways and the biota which inhabit oceans and lakes, micro-organisms such as plankton in particular, are segregated according to various environments, their species compositions changing even extinction occurring as the environment changed. In other words, like magnetic tape, marine and lacustrine deposits record occurrences of natural phenomena such as earthquakes, tidal waves, typhoons, volcanic eruptions, floods, etc. and environmental changes which affect the ecological system. Records such as this often remain uninterrupted in deposits in deep seas and big lakes in particular, which are little affected by events in the outside world, and, by studying sea (and lake) bottom deposits and following them in sequence from the oldest, it is possible to observe the occurrence of environmental changes and natural phenomena from the distant past up to the present day. In order to understand global changes over a long period of several hundreds of thousands of years, geological research is mainly centered on the deep oceans. Lakes, however, which are generally closed bodies of water, often contain specific regional records in their deposits and they are closely associated with human society. Moreover, since the rate of deposition is faster in lakes than in the deep seas and it is possible to find events which occurred over the short period of several hundred years.

Tonle Sap (Fig. 1) is renowned as the "elastic lake" since its area trebles during the wet season It is the biggest lake in the Indochina Peninsula and has been closely associated with the history, life and culture of the Cambodian people from the time of the Khmer dynasty until the present. With this sort of background, an investigation of the Tonle Sap lake deposits makes it possible to reconstruct climatic changes and environmental changes from the time of the Khmer dynasty to the present. However, in order to do this, two conditions are necessary. One of these is that biological remains which reflect the

environment are contained in the Tonle Sap lake deposits and the other is that certain criteria which enable us to read the time, such as annual growth rings in tree trunks, are present in the lake deposits.

As a result of sampling the deposits during the wet season in August 1992, it became clear that there was a thin covering of light brown mud, about 1 cm thick, over dark greenish-grey mud at the bottom of the lake. The upper light brown mud was the same color as the mud which flows in and muddies the lake water in the wet season and it is clear that this sort of material settles out of suspension in the wet season. On the other hand, from its color, the underlying dark greenish-grey mud seems to be material deposited in the dry season when there is no depositional influx. In other words, materials having different characteristics are deposited alternately in the Tonle Sap lake in the wet season and in the dry season and these lake deposits can be used as annual units to measure time like the annual growth rings in tree trunks. Meanwhile, materials derived from the biota were recovered from the deposits as ostracoda, diatoms, sponge spicules and pollen. All of these would become indicators of the lake and its surrounding environment.

As mentioned above, in this survey the fact that the time from the Tonle Sap lake deposits could be read and that the deposits were the habitat of groups of micro-organisms which would be indicative of the environment were confirmed. This discovery shows that if the Tonle Sap deposits is drilled to a sufficient depth, environmental changes and the occurrence of natural phenomena from the time of the Khmer dynasty to the present as well as the relationship between climatic changes and the rise and fall of civilization in the Indochina Peninsula can be elucidated.

II. Regularity of Distribution of Sandstone Blocks seen in the Angkor Monuments

Since sandstone is sand which has been deposited in various places on the surface of the earth and consolidated with the passage of geological time, it bears many and various structures internally and on its upper and lower surfaces which reflect the deposition site at the time. These structures, called sedimentary structures, are important geologically not only because they show the environment at the time the sandstone was formed but they are also used to determine geologically upper and lower strata (younger and older strata). The development of many such sedimentary structures have been observed in the sandstone which was used as the principal building material for the Angkor monuments and from their form, and the presence of fossil shells, it can be assumed that at the time the place where these sandstones were formed was a shallow sea near the mouth of a large river.

In this survey, at three Bayon type temples, (Bayon, Banteay Kdei and Prah Khan), the positions and sedimentary structures in each sandstone building were recorded and then investigated which parts of the buildings sandstones with which sedimentary structures were used. In particular, attention was paid to whether the blocks had been placed horizontally or vertically with respect to the sedimentary structure (Fig. 2) and, for the blocks whose geological top and bottom could be determined, whether the placement was geologically correct, As a result, the facts discussed below became clear.

1. In all places which were surveyed, the vertically placed blocks were smaller than the horizontally placed blocks and far less of them were used. On viewing the Bayon first gallery, whereas the horizontally placed blocks were rectangular or square, many of the vertically placed blocks were inverse trapezia. Also, many vertically placed blocks

were used in the Bayon upper terrace in places where the placement of the blocks was complicated, such as around the small shrines. This probably means that the vertically placed blocks were used to fill gaps created by the placement of the blocks.

2. The Bayon upper terrace can be roughly divided into four sections and the numbers of blocks used in each section differ widely. In each section there are also major differences in the numbers of vertically placed blocks, which account for about 2.6% of the total number of blocks (Fig. 3). It can be suggested that the causes of differences such as these may be that the sections were constructed at different times or by different teams of workers.

3. Many vertically placed blocks were used in the second, third and fourth rows of the walls of the Bayon first gallery (Fig. 4). Supposing that in constructing a wall, the blocks were laid one row at a time and that the row was started from either the left end or the right end, or perhaps from both ends, no more than one vertically placed stone should be required to close the gap. The fact that few vertically placed blocks were used in the first row, which became the foundation for the wall construction, means that the work was probably done in this way. The use of a comparatively larger number of vertically placed blocks in the second, third and fourth rows indicates that these rows were started by laying blocks in several places along the wall. Considering that the second to fourth rows in the wall are at a height of 30 cm to 1 m where a man is able to work comfortably while standing and that the average weight of the blocks was such that they could be handled by one man, it would seem that at that time walls were constructed by first placing the first row of blocks precisely then several workers at several places would lay the second, third and fourth rows by hand. From the fifth row up, when hand work became difficult, the blocks were probably lifted

up one by one using a tool such as a scaffold and laid horizontally from a certain place in the wall.

4. Many of the sandstone blocks with advanced oblique bedding in the Bayon first gallery show no signs of chipping at the top or bottom, that is to say they appear to be completely natural at the top and bottom, and their thicknesses are well matched at about 25 cm. This suggests they were simply quarried from a single stratum (with well defined erosion or deposition surfaces at top and bottom) and used as they were and the thickness of the stratum may have been used as the standard measure of thickness.

5. The blocks at Banteay Kdei and Prah Khan have sedimentary structures which are not seen in the blocks at Bayon. This shows that the quarry for the former two temples is different from that for the Bayon blocks.

6. The horizontally placed stones of the Bayon first gallery have generally been placed without regard for the geological top and bottom. Conversely, nearly all the stones at Banteay Kdei and Prah Khan have been placed correctly. It can be assumed that the correct placement of most of the stones in the latter cases was due to some artificial or natural causes. A possible artificial cause is that consideration was given to placing the blocks with a view to making them look natural. On the other hand, a possible natural cause is that the blocks were kept horizontal throughout the processes of quarrying, transportation and construction. The random placement of the blocks at Bayon probably means that no such consideration was given or that the method of transportation was different.

7. In some cases, consideration has been given to placing continuously aligned horizontally placed blocks in the Bayon first wall so that the sedimentary structure in the block on the left or right is continued. It is believed that this

has been done for appearance. This may mean that part of the Bayon first wall was unpainted.

Conclusion

To speak of preservation and restoration of the monuments is likely to mean complete restoration of the whole structure. On this point, looking at the applicable areas of geology it seems that geology is unlikely to be able to make a major contribution to the actual restoration of the Angkor monuments. However, a geological elucidation of the natural environment which prevailed and the natural disasters which occurred at the time the various monuments were constructed will provide important information for understanding the social life of the people at that time and will certainly become a reference for the long term preservation of the monuments. Firstly, with this survey, we have been able to grasp a key for interpreting ancient environments. In addition, by looking at the sandstone blocks of the monuments from a geological viewpoint, we have been able to gain several new ideas regarding the way the blocks were used. In many case, the research not yet gone beyond the stage of pre-supposition but it is believed that its expansion can be look forwarded to with the advance of future surveys.

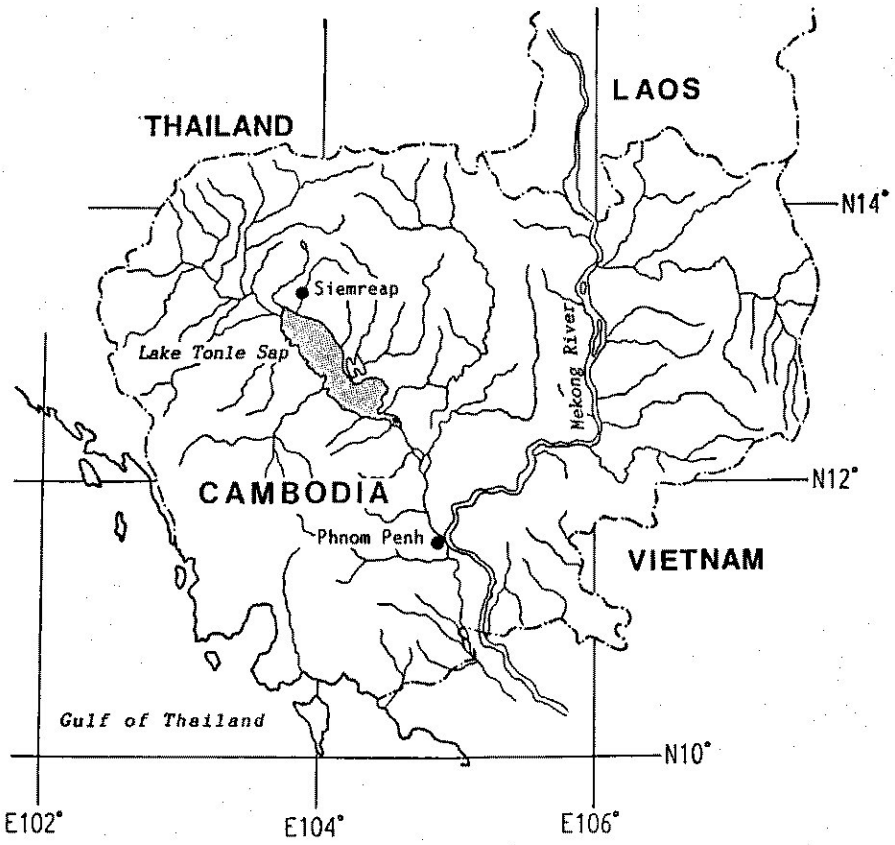

Fig. 1 Position of Tonle Sap Lake and Angkor monuments

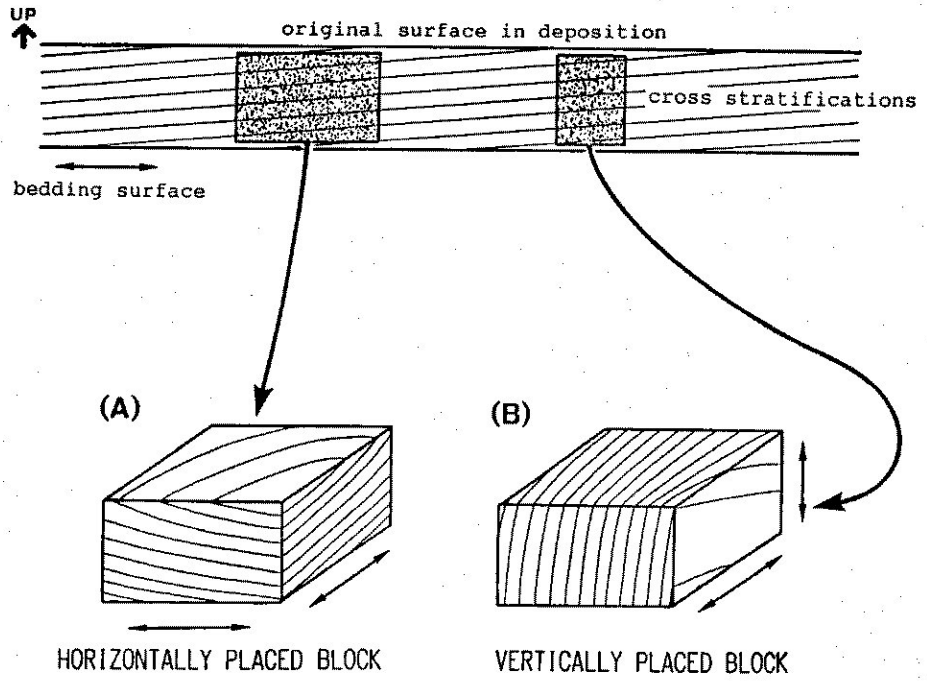

Fig. 2 Horizontal placement (left) and vertical placement (right) of sandstone blocks

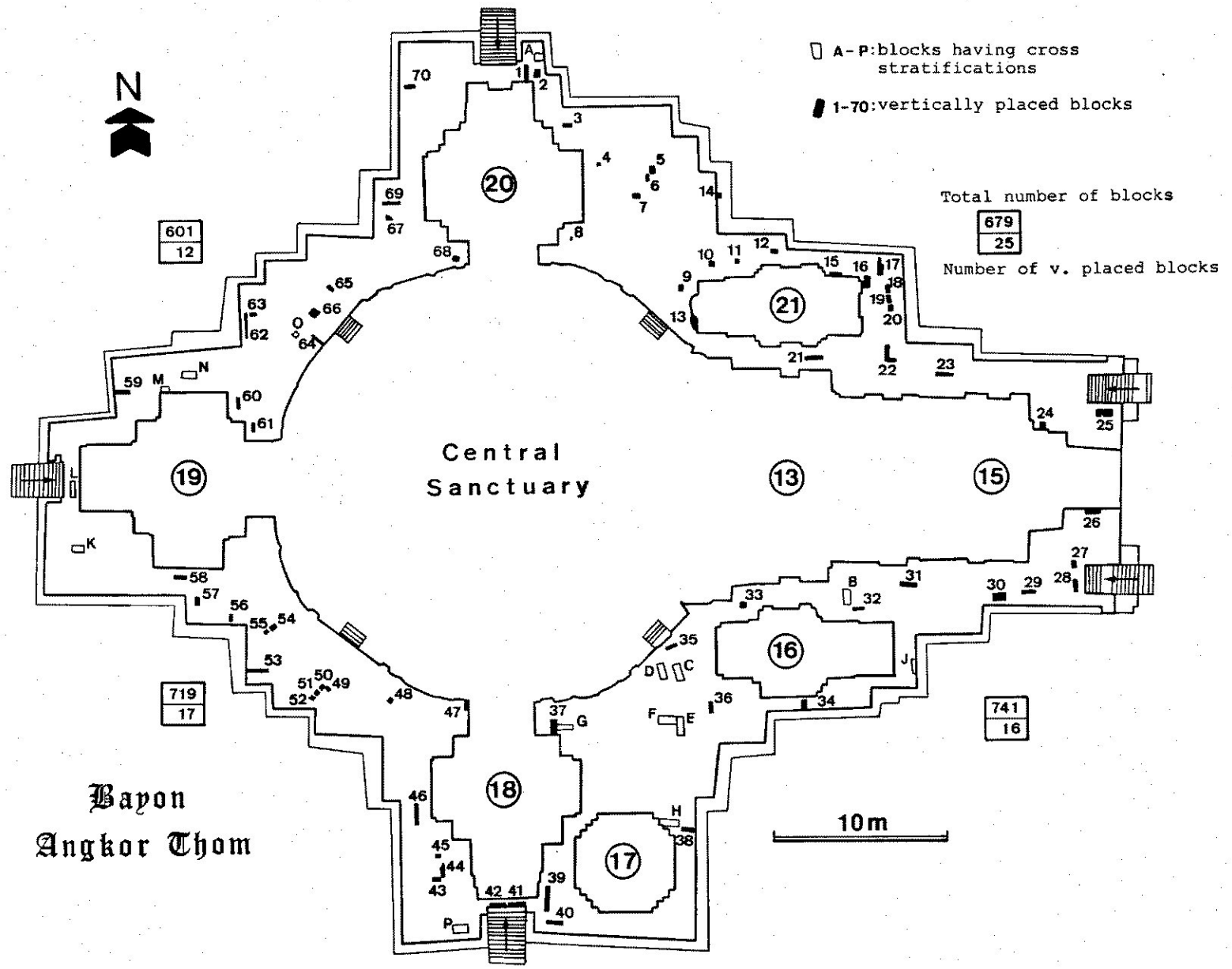

Fig. 3 Positions of vertically placed blocks in Bayon upper terrace (after Dumarcay, amended)

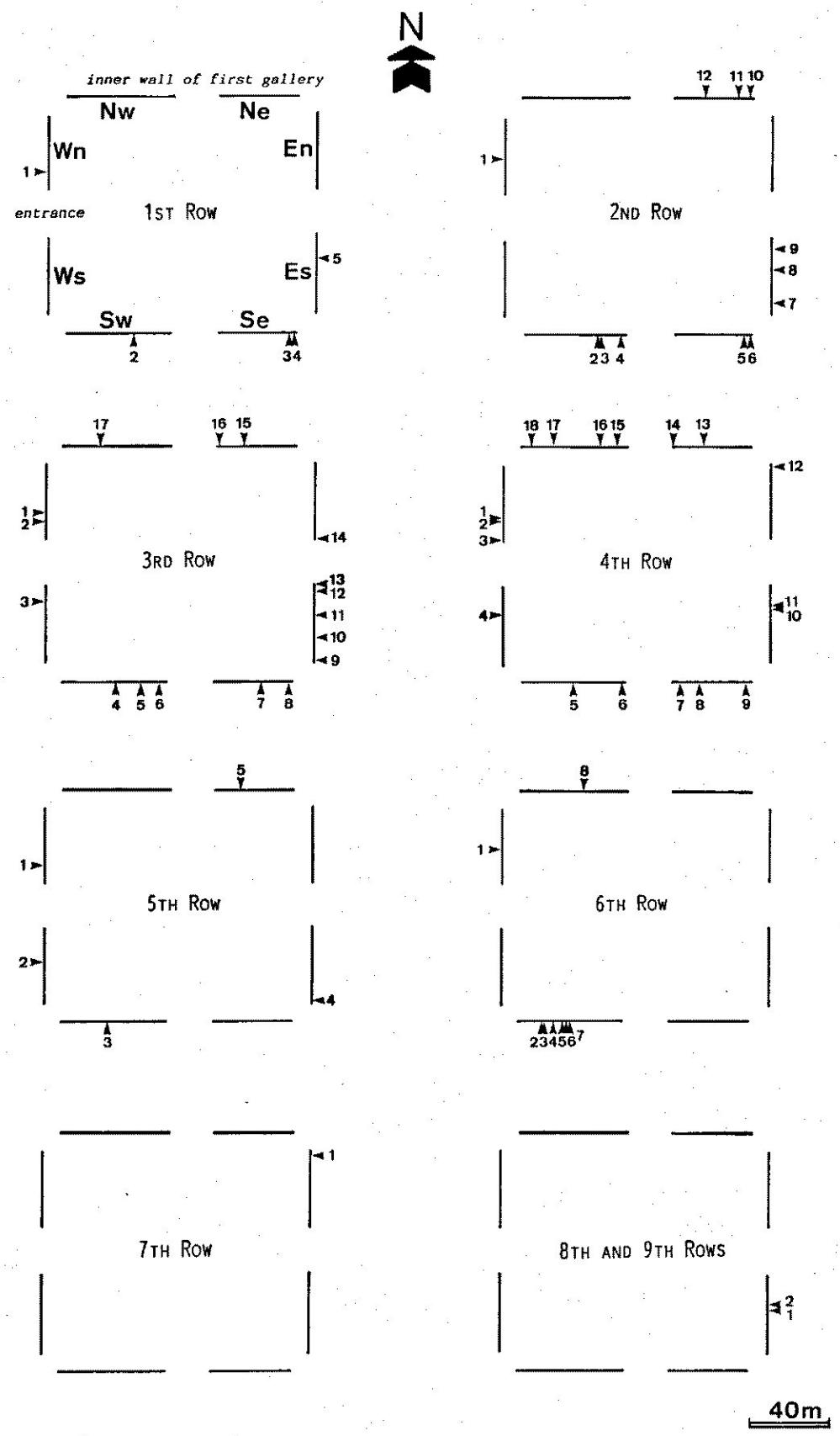

Fig. 4 Positions of vertically placed blocks in the wall of Bayon first gallery