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ANATOMICAL INVESTIGATION OF 4,000-YEARS OLD *CEDRUS LIBANI* WOOD REMAINS FROM EGYPT

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The anatomical composition of the 4,000-years old *Cedrus libani* remains from an archaeological excavation is the same as the anatomical composition of xylem of recent *Cedrus libani*. The width of growth rings in the remains is narrow. The mean values are 0.82–1.78 mm. Within the growth ring, the early wood is wide and the late wood is fairly narrow. According to the growth ring width series, as nowadays, too, unfavourable years alternated with more favourable ones. Length of tracheids were formed in the wider growth rings, and longer ones in the narrower. Within the growth rings, the length of tracheids increases from growth ring boundary to growth ring boundary. Frequencies of the length of tracheids within a growth ring show the Gaussian distribution. The tracheid cells end in normal tip. The cell wall thickness is thin (3.1 µm) in the early wood, and thick (9.6 µm) in the late wood. The cell lumen is wide in the early wood (44.3 µm), and narrow in the late wood (23.8 µm).

Key words: ancient Egypt, 4,000-years old *Cedrus libani*, wood anatomy, growth ring width, length of tracheids, tracheid features

INTRODUCTION

During the excavations at the Sed festival palace of pharaoh Montuhotep Sankhkara (Middle Kingdom 2,010–1,998 BC) besides many other material, tree remains came up. The archaeological excavation of Sed festival palace (Thoth Hill, Thebes, Egypt) was carried out between 1995–1998 by the research group of Eötvös L. University under the directions of the egyptologist Győző Vörös.

The shape of the tree remains proved, that they were used as building material (post, rafter, lath) in the palace. According to the anatomical structure they belonged to *Cedrus libani* (gymnosperms) and *Ficus sycomorus, Acacia* sp., *Khaya* sp., *Mimusops* sp. (angiosperms). In this work we deal with the anatomical features, changing growth ring width and length of tracheids of the building material of *Cedrus libani*, probably imported from the Near East (Byblos) by Montuhotep Sankhkara.

MATERIALS AND METHODS

Altogether 18 tree remains were found during the excavations. Among these 5 samples proved to have been the remains of *Cedrus libani*. The fragments were in very good condition due to the extremely dry and warm climate characteristic of the Thoth Hill during the previous 4,000 years. On their surface we can observe the traces of wind erosion. As a result of this good condition the remains could be easily sawn and polished (see Fig. 8). Labels for the remains: b-2, c-1, f-3, g-4, h-5. On the previously properly prepared transversal surface of the finds we measured the width of growth rings with a special microscope. We also determine the width of the early and late wood within the tree rings. We counted the mean values and other characteristics as well. We separated the wide and narrow tree rings for the tracheid investigations. Tracheid maceration were prepared according to the Schulze-method (Sárkány and Szalai 1964). We made microscopic slider of the late as well as the early wood of wide growth rings. We measured 100–100 tracheids of the samples with the help of a microscope supplied with a video-setting. During measurements of lengths we observed the tips of the tracheids. We calculated the frequency values of tracheid length concerning the wide and narrow tree rings. We also counted some statistical features of tracheid lengths. Sectioning of samples were also carried out. After softening, the samples were sectioned by microtome in cross, longitudinal radial and tangential directions. Sections were counterstained in 2% of toluidine blue in 50% alcoholic solution, and after dehydrating permanent slides were made. On the cross sections the cell wall thickness and widths of tracheid lumens were measured both in early and late wood. Microphotographs were also taken.

RESULTS AND DISCUSSION

Wood anatomy

Anatomical investigations of the 4,000-years old tree remains showed anatomical features that *Cedrus libani*, similar to the present day living *Cedrus libani* (Fahn *et al.* 1986, Greguss 1955, Hollendonner 1913, Huber and Rouschal 1954, Schweingruber 1990). Within the growth ring the early wood is wide and the late wood is fairly narrow (Fig. 1). Axial resin ducts, typical to *Cedrus*, were found (Fig. 2). Radial resin ducts with different size are also present (Fig. 3). Rays in the early wood of growth rings are usually one and rarely two cells wide. Ray height can be small (2–5 cells), medium (7–15 cells) and high (18–32 cells) (Fig. 4). Rays of the late wood are always one cell wide (Fig. 5). Radial ray tracheids contain crystals (Fig. 6), a typical feature of *Cedrus*. On the walls of tracheid we can see the characteristic shaped biseriate bordered pits. Both the single and biseriate bordered pits have scalloped tori (Fig. 7). Longitudinal parenchyma was not found at the growth ring boundaries.

Growth ring width

In general, the growth ring widths of the samples are narrow, in *Cedrus* sometimes the growth rings are narrow, and sometimes wide (Fig. 8). We counted the mean values of widths of the tree rings and late and early wood. We also counted the mean values of late and early wood concerning the tree ring widths. On the basis of these results we can determine the rate of early and late wood, as a characteristic feature (Table 1). From the data we can conclude that the average width of the tree rings is small (829–1784 μm), and that the maximum and minimum values are between 290 and 2690 μm. The five samples originate presumably from different tree specimens and they represent mature tree rings according to the widths of growth rings. It is known that the young trees (ages 0–15 years) growth rings are usually wide. This feature of trees is both genetically and environmentally determined, because to the strong growth in width strong growth in height is connected. Later the width of growth rings is more liable to the changes in growth conditions. Thus showing decreasing or increasing values. Mean values of early and late wood, and the rate of early and late wood proved the characteristics of *Cedrus libani*: the early wood is wide the late wood is narrow.

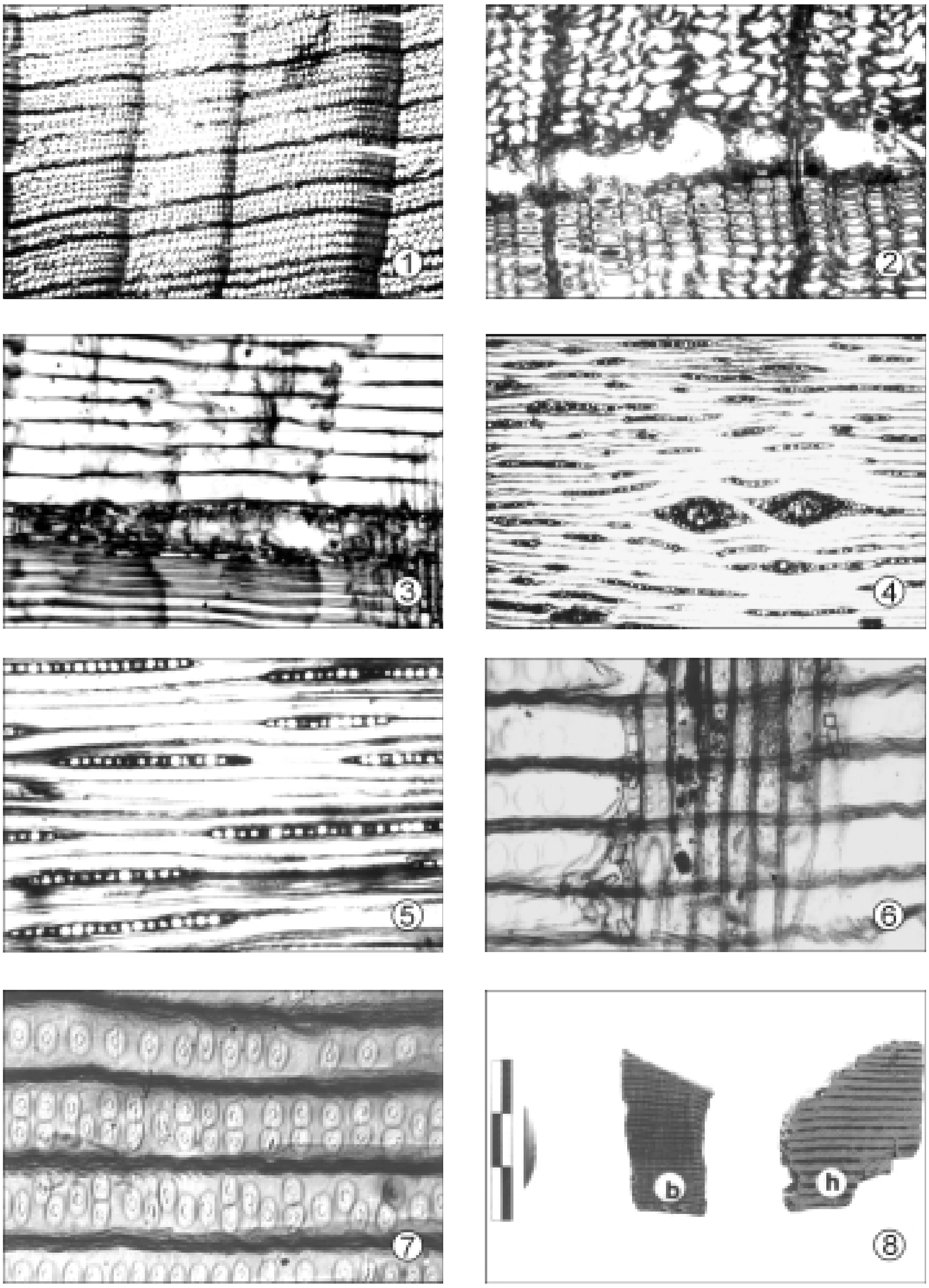
Series diagrams (Figs 9–10) of widths of growth rings measured per samples show clearly, that values of samples 3 and 5 change, but high and different from that of the other three samples. Curves of samples 2 and 4 decrease steadily along 20 years. The curve of sample 2 in the last 8 years fluctuates, but in character increases greatly. Values of widths of growth rings of sample 1 – which contained the most tree rings – change in 15 growth rings, but decreasing, and in the 16th year show a very low value (290 μm). In the subsequent 19 rings their widths change but increase.

To sum up, diagrams of the growth ring widths values showed that 4,000 years ago at the habitat of *Cedrus libani*, in the Near East (around

Table 1
Growth ring widths [μm] of tree remains of *Cedrus libani* from pharaoh Montuhotep Sankhkara's Sed festival palace (Thebes, Thoth Hill). Measurements in μm

Samples n = number of measured tree rings	Width of growth rings	
	average minimum maximum	average width of early wood average width of late wood rate of early and late wood
Sample c-1, n = 35	867	689
	290	178
	1370	3.86
Sample b-2, n = 28	118	777
	570	332
	2400	2.34
Sample h-3, n = 17	1784	1371
	1096	413
	2410	3.31
Sample f-4, n = 20	829	645
	550	183
	1250	3.52
Sample g-5, n = 12	1780	1241
	1260	540
	2690	2.29

Figs 1–8. Cedrus libani sections: 1 = cross section, ×48. Sample f-3. Characteristic growth ring of cedar. Wide early and narrow late wood containing just few cell rows. Uniseriate rays. Fractures in radial direction and waviness of rays can be seen on the section are results of aging of the wood. During the last 4,000 years elasticity of cellulose cell wall has been decreased. 2 = cross section, ×120. Sample b-2. Characteristic feature of cedar, the tangential toushing resin ducts, which follows the tree ring boundary and is formed at the beginning of the early wood. The cell wall disruptions are also aging of the wood. There is no cell wall degradation caused by fungal attack. 3 = longitudinal radial section, ×120. Sample g-4. On the radial section of the resin ducts we can easily observe that it is covered with thick walled parenchymatous cells. These cells produce the resin-drops. These cells are dissolved at some parts of the resin canal. 4 = longitudinal tangential section, ×48. Sample h-5. One- or two-cells wide rays in the early wood of the growth ring, tracheids can also be observable. Tangential resin ducts with different size and shape. Rays are wider (3–7 cells) at the traumatic resin ducts. 5 = longitudinal tangential section, ×120. Sample f-3. Uniseriate heterogeneous rays in the late wood. Rays are small and medium high. Dark resin material can be found in the individual parenchymatous cells. 6 = longitudinal radial section, ×300. Sample b-2. Heterogeneous ray, characteristic of cedars. Column crystals in the marginal ray cells. Piceoid pits on the walls of parenchymatous cells. Uniseriate bordered pits on the walls of tracheids. Late wood of tree ring. 7 = longitudinal radial section, ×300. Sample c-1. Biseriate bordered pits on the tracheid walls, early wood. 8 = Series of narrow (b) and wide (h) growth ring widths on transversal sections of tree remains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Byblos) the growth conditions bad for a long time. As a result, the widths of growth rings decrease steadily, for example from the 1st to the 16th tree rings of sample 2 or from the 12th to the 16th tree rings of sample 1. Thus it can be confirmed that, as nowadays, 4,000 years ago bad and good periods alternated.

Similarly, growth rings of *Cedrus libani* beams from the Al-Aqsa Mosque (Jerusalem), 14C dated 1670±50 AD, also showed narrow and wide groups (Lev-Yadun 1992).

Length of tracheids

Results and statistical features of measurements on lengths of tracheids in wide and narrow tree rings are contained in Table 2. We present length frequencies in Figs 11 and 12.

According to Table 2, the mean length of tracheids in early wood of wide tree rings is smaller (3.18 µm), than in late wood of the tree rings (3.49

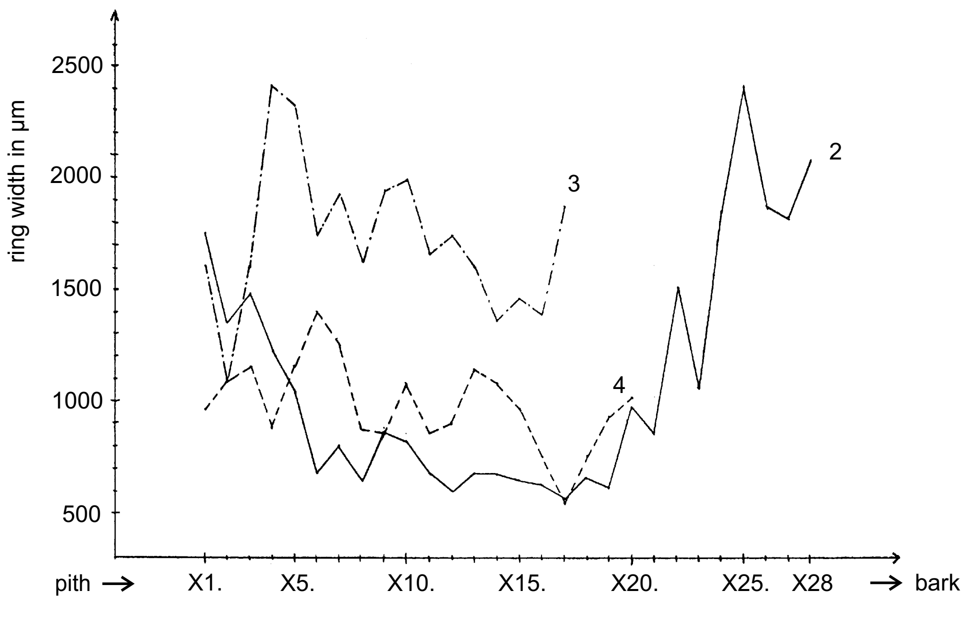

Fig. 9. Diagrams of growth ring width of *Cedrus libani* samples. On this diagram we drew the width series of samples b-2, f-3 and g-4. The numbers from the x1, x5 and x28 marks on the horizontal axis mean the number of measured tree rings. X means the real age of the tree ring, which must be before 2,010 BC. We show the first year of the different growth rings series at the same calendar year just for simplicity, of course the different growth ring width have been formed during different ages of the different samples

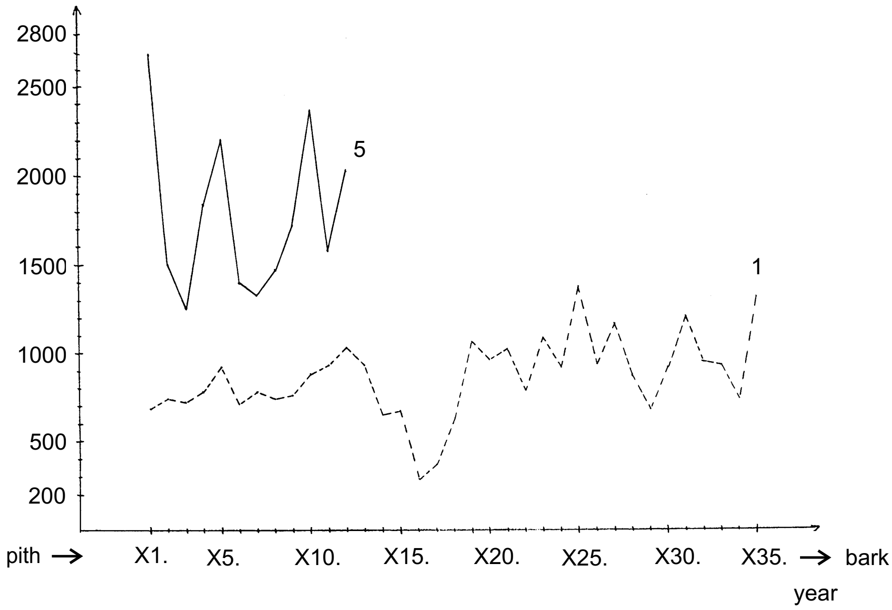

Fig. 10. Diagrams of width rings of *Cedrus libani* samples c-1 and g-5. Legend is the same as above (Fig. 9)

Table 2
Length of tracheids of tree remains of *Cedrus libani* from pharaoh Montuhotep II Sankhkara's Sed festival palace (Thebes, Thoth Hill)

Sample	Mean minimum maximum	SD	$S\bar{x}$	CV	Fahn *et al.* (1986)
Sample g-5, 2340 µm wide early wood of wide growth ring, n = 100	3.18	975.6	353.5	12.0	1.600
	1.98				940
	4.50				2.23
Sample g-5, 350 µm wide late wood of wide growth ring, n = 100	3.49	585.0	353.5	10.1	
	2.52				
	4.68				
Sample g-5, 2690 µm wide growth ring, n = 200	3.46	672.3	381.8	11.0	
	1.98				
	4.68				
Sample b-2, narrow growth ring, 570 µm, n = 100	3.62	427.9	447.2	12.3	
	2.16				
	5.04				

Measurements in µm. SD = Standard deviation; $S\bar{x}$ = Standard error of the mean; CV = Coefficient of variation

Note. According to the only citation the values of tracheid length of cedar are smaller. Neither the age and width of the annual rings that can be found in the samples, nor the number of measurements are given μm). The smaller mean values of early wood is well proved by the smaller extreme values (1.98–4.50 μm), too. The bigger mean values of the late wood also well coincide with the bigger extreme values of it (2.52–4.68 μm). It can be concluded that the length of tracheids within the growth rings increases from one growth ring boundary to the next in *Cedrus libani,* as in other gymnosperms. That correspond to the results of anatomical researches of other colleagues and mine, who dealt with the variability of length of fibre tracheids in tree rings of angiosperms (Babos 1970, Liese and Ammer 1957, Süss 1967). Averagely shorter tracheids (3.46 μm) were

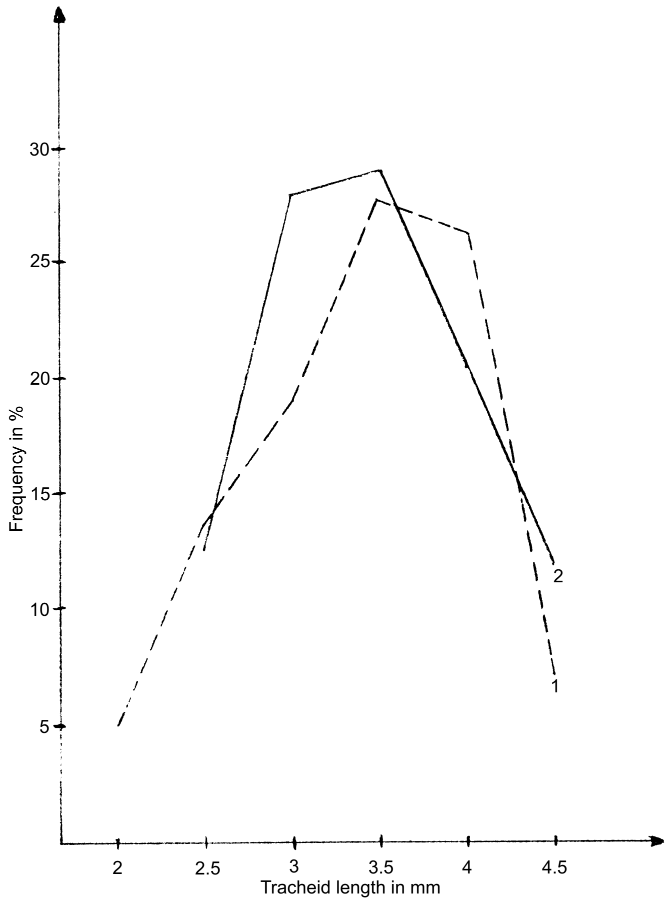

Fig. 11. Diagrams of tracheid length frequency in the early (1) and late wood (2) of a wide tree ring of *Cedrus libani* sample g. Marks on the horizontal axis of the diagram are round figures in mm. We arranged the measured fraction values of tracheid lengths, made them round up or down. We counted the frequency on the basis of the occurrence of marks

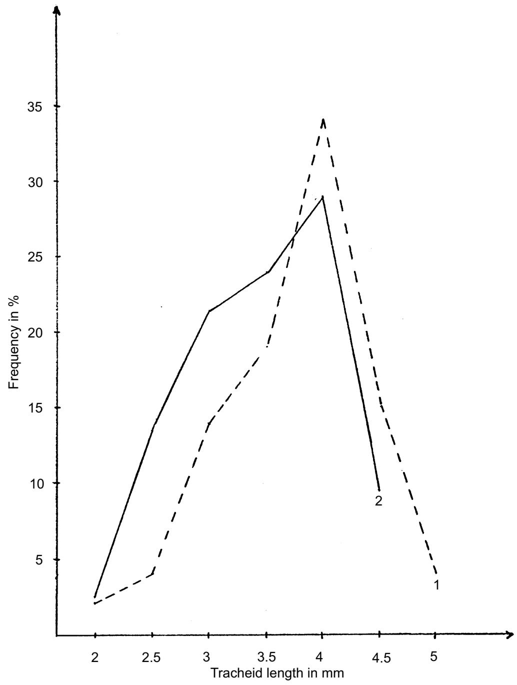

Fig. 12. Diagram of frequency of tracheid length of narrow (b-1) and wide (g-2) tree rings of *Cedrus libani* samples. Legend is the same as above (Fig. 9)

formed in the wider growth rings, than in narrower ones (3.62 µm). Lower extreme values (1.98–4,68 µm) are connected to lower mean values of tracheid length of the wide tree rings. Higher tracheid lengths of narrower tree rings are connected with higher extreme values (2.10–5.04 µm). As we can see in Figs 11 and 12, both the frequency values of tracheid length of early and late wood of the wide tree rings and wide and narrow rings show Gaussian distribution. Other measured features of tracheids are shown in

Table 3
Other feature of the remains of *Cedrus libani* from pharaoh Montuhotep II Sankhkara's Sed festival palace (Thebes, Thoth Hill)

Place of measurement	Wall thickness		Lumen diameter		Tracheid end
	early wood	late wood	early wood	late wood	
Growth rings of samples b-2 and g-5, n = 100	2.3–3.1–4.6	4.6–9.6–13.8	34.5–44.3–50.6	11.5–23.8–36.8	Ending in a smooth peak

Measurements in µm

Table 3. According to the data, cell wall width of tracheids in the late wood (9.6 µm) is three times of that of early wood (3.1 µm). Concerning the lumen, we face that the situation is the twice as much of that of the late wood (23.8 µm). Ending of tracheids in both cases is a smooth peak.

APPENDIX

"It is four thousand years since pharaoh Montuhotep Sankhkara (rule 2,010–1,998 BC) raised a temple on the peak of horizon on the west bank Thebes, on a hill rising to the north of the Valley of the Kings (Fig. 13). This abandoned desert shrine remained unknown until the beginning of the twentieth century, when it was discovered by the German explorer Georg Schweinfurth and the British scholar Flinders Petrie.

The Thoth Hill is surrounded by desert ravines, and the ancient path leading up to the temple is impassable for pack-animals like camels or donkeys. The temple lies 5 km from the nearest desert road accessible to vehicles, and 400 m above it. This difficult terrain discouraged archaeologists, until the Hungarian expedition, from attempting a methodical excavation of the pharaonic sites on the summit of the hill that closes off the Valley of the Kings from the north.

The Thoth Hill Expedition from Eötvös L. University (ELTE) in Budapest spent 15 months at Thebes, excavating and restoring in the field. The

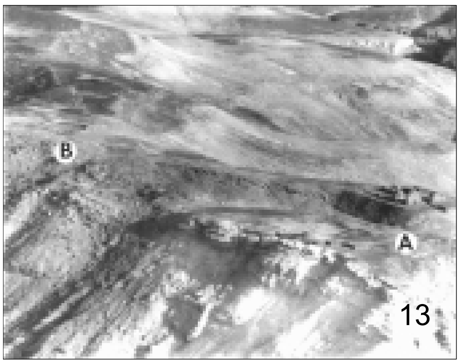

Fig. 13. Hot-air balloon photograph of the Thoth Hill temple (A) with the Sed festival palace (B) 124 metres due west (on the left)

Fig. 14. Aerial photograph of the Sed festival palace of pharaoh Montuhotep Sankhkara after the excavation on the Thoth Hill

expedition lasted four digging seasons, and brought to light the whole ancient history of the Thoth Hill. The ruins of Montuhotep Sankhkara's temple yielded all the architectural features and archaeological finds needed to assess the site from an Egyptological perspective." (Vörös 1998).

"The second task for the 1996–97 season was to uncover the Sed festival palace of pharaoh Montuhotep Sankhkara (Fig. 14). This was built 124 metres due west of his Thoth Hill temple, as a rectangular building aligned from north to south (Fig. 15). The well-preserved timber remains from the palace were examined. These must have been brought thousands of kilometres to Egypt via the Red Sea in the time of Montuhotep Sankhkara by the royal expedition to Punt (northern Somalia), rock inscriptions describing which were found at the end of the nineteenth century by Egyptologists in a valley in the eastern desert.

The rulers of Egypt held Sed festivals as early at the Old Kingdom to celebrate the thirtieth jubilees for their reigns. This rite of rebirth, involing the king's recoronation, was in later times held earlier and sometimes re-

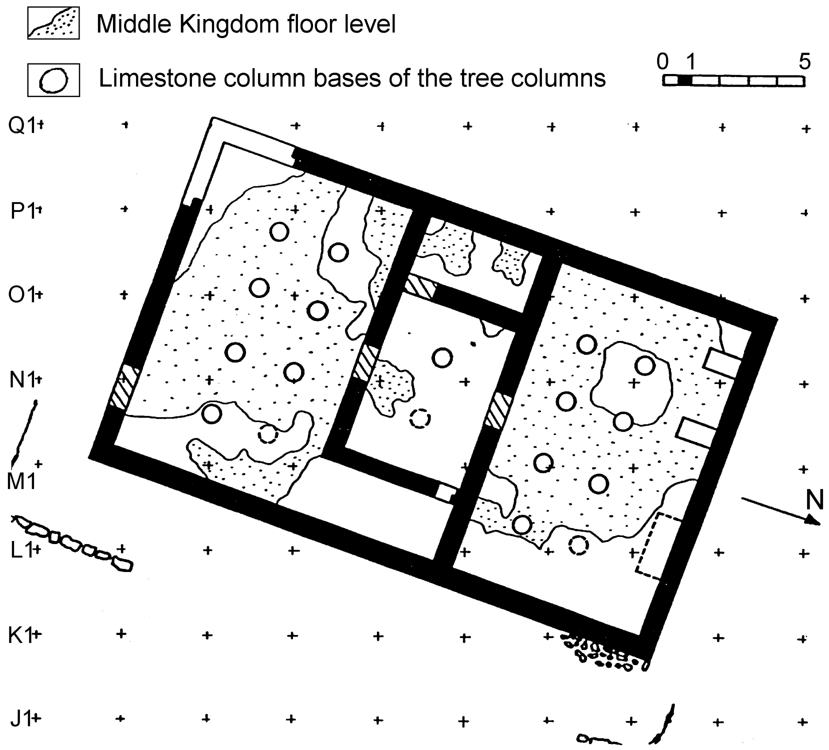

Fig. 15. Ground plan of the Sed festival palace of pharaoh Montuhotep Sankhkara

peated. The ceremony took place in separate palaces or temple forecourts, which were always aligned on a north–south axis. They contained two large halls to symbolise the Nile valley and the Delta, as if depicting Upper and Lower Egypt. The kings, as the legendary Menes once did, proceeded from the hall symbolising Upper Egypt into the hall of Lower Egypt, symbolically reuniting the Two Lands.

The highest point at Thebes, on the pinnacle of the horizon on the Nile west bank, was ideal for this ritual: the people of the capital could see the heights to which their virile ruler had to climb" (Vörös 1998).

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