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Did earthquakes fell Aksum obelisks?

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Abstract
Most of the obelisks at Aksum (Tigray, Ethiopia) are lying in pieces on the ground, as the Aksumite obelisk now in Rome had been before its removal to Italy. Preliminary inspection of the alignment of the various fallen members makes it possible to identify a prevailing orientation. The historical tradition is very vague as regards the toppling of the obelisks (or stelae). Reference is made to Yodit or Gudit, a Jewish queen of the South, who supposedly had the *pagan* stelae knocked down in the 10th century A.D.; to Imam Ahmed ibn Ibrahim al Ghazi *al grañ*, Amir of Harar, who supposedly ordered them to be felled by cannon fire; and to earthquakes. Analysis carried out on a number of highly significant cases makes it possible to assert that some of the great obelisks at Aksum collapsed as a result of earthquakes. At the same time, inadequate systems of anchorage and the mediocre mechanical qualities of the soil were certainly conducive to collapse through both natural causes (earthquakes and erosion of foundations) and deliberate demolition.

Key words *Ethiopia – Aksum – stelae – obelisks – earthquakes*

1. Historical outline

While it is clearly impossible to sum up a civilization such as the Aksumite in a single phrase, an excellent starting-point is furnished by the British archaeologist Munro-Hay (1991) with his definition of Aksum as *an African Civilization of Late Antiquity*. The high point of this civilization was in fact reached during the first centuries of the Christian era, between the Roman and the Persian Empires, when Aksum came to control the whole of the Red Sea. The strength of a nation is also measured by the money it issues and the gold and silver coins bearing inscriptions in Greek together with the sun and crescent moon until these were replaced by the Christian cross on the conversion of King Ezana (the Constantine of Aksum) demonstrate that the Aksumite empire was an economic power.

The Aksumite civilization developed on the Ethiopian plateau at an average altitude of 2000 m. The plateau is delimited on the eastern side by a steep slope descending in the space of 50 km from Asmara at an altitude of 2300 m to the Red Sea port of Massaua. To the west, the plateau slopes down gently towards the Nile valley. There are no sharply delimiting features to the north or south. A wealth of raw materials was provided by gold mines, by an agricultural system which, while primitive, was sufficient to feed the population, by forests (supplying timber and ivory) and by the trade in slaves from the Nile region. Raw materials were thus obtained from the west while trade links were maintained in the east, reaching as far as Ceylon, and with the Byzantine empire in the north.

The rise of the Aksumite civilization was, however, not due solely to these factors but also to the influence still exercised by the waning Egyptian empire in the north. It is no coincidence that the first stone buildings erected in Africa were Aksumite. To the south of Ethiopia the next stone monuments and dwellings were built by the partially coeval civilization of Zimbabwe in Southern Africa. Even today stone houses are built only in the Tigray region. There are no detailed Aksumite chronicles, despite the fact that writing was known and that the southern Arabic script was used for monumental inscriptions.

There is also an imperialistic phase in Aksumite history. In an attempt to extend his influence on the far shore of the Red Sea, King Kaleb or Ella Atsbeha invaded modern-day Yemen on the pretext of protecting the local Christian population against persecution by a Jewish king.

While the Aksumite empire was certainly more powerful than the southern Arabian kingdoms, it was not strong enough to withstand the explosion of Islam, which marked the downfall of all the potentates in the region. While Aksum was not Islamized, unlike Persia and the south Arabian kingdoms, Islam established itself in the south and west along the shores of the Red Sea and in the province of Harar. Christianity has, however, survived until the present day in a monophysitic and virtually autocephalous form (Ullendorff, 1960). The Red Sea became a *Mare Arabicum* and the Aksumite fleet was forced to pay tribute. The agricultural yield also decreased as the overexploited soil became barren or was simply eroded as a result of excessive deforestation (Butzer, 1981).

Aksumite monumental architecture took on peculiar forms again giving rise to conflicting opinions. While some describe it as wholly autochthonous, others detect southern Arabian or Egyptian-Meroitic influence. Regardless of its origins, Aksumite temple architecture never attained the monumental character of its Egyptian or southern Arabian counterparts. A feature of Aksumite architecture was that of erecting stelae or obelisks.

2. Obelisks

The Greek term 'οβελί σκος denoted a tall, tapering, steeple-like stone monument with a square cross-section and flat sides crowned with a pyramidal point. The classical obelisks were those of Egypt, which the Greeks saw and for which they coined the term.

Stelae are slab-shaped monuments of rectangular cross section embedded in the ground and bearing inscriptions. The Aksumite obelisks were stelae, at least initially. We shall, however, follow customary practice and use the two terms as synonymous.

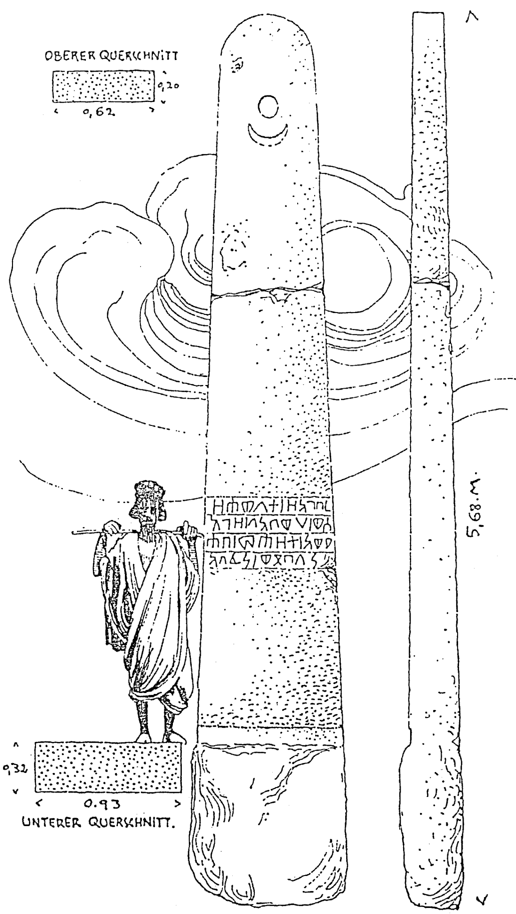


Fig. 1. The slab-shaped stele of Matara in Eritrea (from Kobishchanov, 1981).

While both stelae and obelisks have an unquestionably commemorative function, the latter are generally taller and stand on a stone base rather than being embedded in the ground.

As pointed out above, the slender Aksumite monuments were initially stelae, as exemplified by the monument at Matara (Eritrea) with a rectangular cross section and inscriptions in Ge'ez (Krencker, 1913; van Beek, 1967; Kobishchanov, 1981) (fig. 1). It is easy to see, however, that this specimen cannot be taken as the starting point. Fattovich (1987) sees the development of the Aksumite stelae/obelisks as a continuation of the African tradition of erecting oblong monuments. The origins of Aksum's monumental architecture are as uncertain as its early history.

At a certain point we have the sudden appearance of stelae which have only their elongated shape in common with their predecessors. These new stelae, all made by local syenite, have a rectangular cross-section, a terminal apex in the form of a crescent moon, deep recesses on the front and rear sides (on all four sides of the largest specimen) and horizontal fluting. Moreover, their stone surfaces are carved to display all the timber features of a residential building, including windows with grilles and doors with knockers and locks. In other words, they represent multi-storey houses (up to 13 storeys). The first known example of an obelisk with external projections representing timber ceiling beams is DAE 34 (fig. 2). This fairly crude monument, which was still standing at the time of the Deutsche Aksum-Expedition but collapsed a few decades ago, may constitute a point of transition from the earlier unadorned stelae to the multi-storey obelisks.

Fig. 2. Stele DAE 34: perhaps the first example of multi-storey obelisk, recently fallen (from Krencker, 1913).

The architectonic elements displayed in the multi-storey obelisks are those of an Aksumite palace (Krencker, 1913), with four corner towers creating deep central recesses on all sides. It is, however, important to stress the sudden appearance of these monuments, possibly at the beginning of the Christian era. Given the absolute lack of inscriptions, no dating is possible. The presence of holes laid out in a cross-shaped pattern for attachment purposes show that the crowning elements of the large obelisks must have been decorated with a bronze (or gold?) frieze. In our view, there are no real grounds for concluding that the monuments were erected upon the introduction of Christianity into Ethiopia (van Beek, 1967). They may well have been crowned with the sun and crescent moon (Krencker, 1913), but this motif is found in identical form on the opposite shore of the Red Sea. In this case, an earlier date of carving would have to be assigned to at least some of the obelisks.

At the beginning of this century, the Deutsche Aksum-Expedition (DAE) led by Erno Littmann undertook a global campaign of studies, the results of which are still the best available in many respects. Among other things, the DAE meticulously surveyed and catalogued all the Aksumite monuments, including the obelisks.

Most of the obelisks are now lying in pieces on the ground. Brief examination of the Munro-Hay map (1989) (figs. 3.1, 3.2, 3.3 and 3.4) is sufficient to identify a prevailing NW-SE alignment of the fallen monuments. Given Ethiopia's history of seismic activity (Palazzo, 1915), it is reasonable to regard earthquakes as a possible cause of the collapse of the obelisks.

3. Historical evidence on the collapse of the obelisks at Aksum

Legend has it that the Jewish queen Yodit or Gudit (monster) of South Ethiopia conquered and sacked Aksum in the first half of the 10th century of the Christian era and ordered the demolition of the stelae as symbols of a foreign religion (Christianity). On conquering Christian Aksum in 1526, Ahmed ibn Ibrahim al Ghazi *al grañ* (the left-handed), the Turkish-backed Muslim conqueror from Harar, is said to have turned his cannon on the obelisks. The Portuguese Jesuit Francisco Alvares would have been the last to see Aksum before the arrival of the *Turks* but supplies no evidence to establish which obelisks were still standing (Conti-Rossini, 1928). Father Alfonso Mendes writes that in 1630 (Gregorian or Julian calendar?) a violent earthquake caused serious damage to the Aksumite monuments (Monneret de Villard, 1938). Strangely enough, however, the chronological history of Ethiopian earthquakes (Palazzo, 1915) makes no mention of this event. This may be because even violent earthquakes have little importance in a country lacking not only great monuments but even stone houses, which are damaged most by such phenomena (Palazzo, 1915). While this remark may appear to contradict the previous reference to the large size of the Aksumite monuments, it may be that little was left of them by 1630 after the destruction caused by man and nature.

Of the three possible explanations for the collapse of the Aksumite obelisks, the use of canon can be ruled out or restricted to a few rare cases. The second largest obelisk of Aksum (DAE 2 or *Die zweitgrößte Stele*) has stood in Rome since its unlawful appropriation by the fascist regime in 1937. The first phase of the battle of Porta San Paolo of September 8th, 1943 took place at Piazza di Porta Capena, where this obelisk stands. It was hit by two 88 mm German shells slightly above the door of the side facing towards the Circus Maximus but the damage was confined to circular indentations of about 20 cm in diameter and 8-10 cm in depth (fig. 4). A 16th century cannon fired stone projectiles of 200 mm and could have done little damage, if any, to the large obelisks. We are thus left with the hypotheses of deliberate demolition and natural causes (earthquake and erosion of foundations).

4. The role of natural forces in toppling the obelisks at Aksum

Whatever natural forces may have affected the stability of the stelae at Aksum, one definitively established factor is the heterogeneous nature of the ground in which they were embedded (Butzer, 1981). The bedrock consists of effusive rock with varying degrees of alteration and columnar jointing in some cases. Above this are alternating eluvial and colluvial layers with clear signs of anthropization. The detrital layer is so thick (over 4 m) as to have completely buried some upright stelae (fig. 5). Excavations in the Stelae Park (Munro-Hay, 1989) have also shown that the ground below the obelisks was reinforced with stones and in some cases with stone slabs. Taken together these elements form a heterogeneous context also with respect to the transmission and amplification of seismic waves. In other words, two obelisks of the same geometry and the same material could have reacted differently to a seismic event depending on the foundation ground (Funiciello *et al.*, 1995).

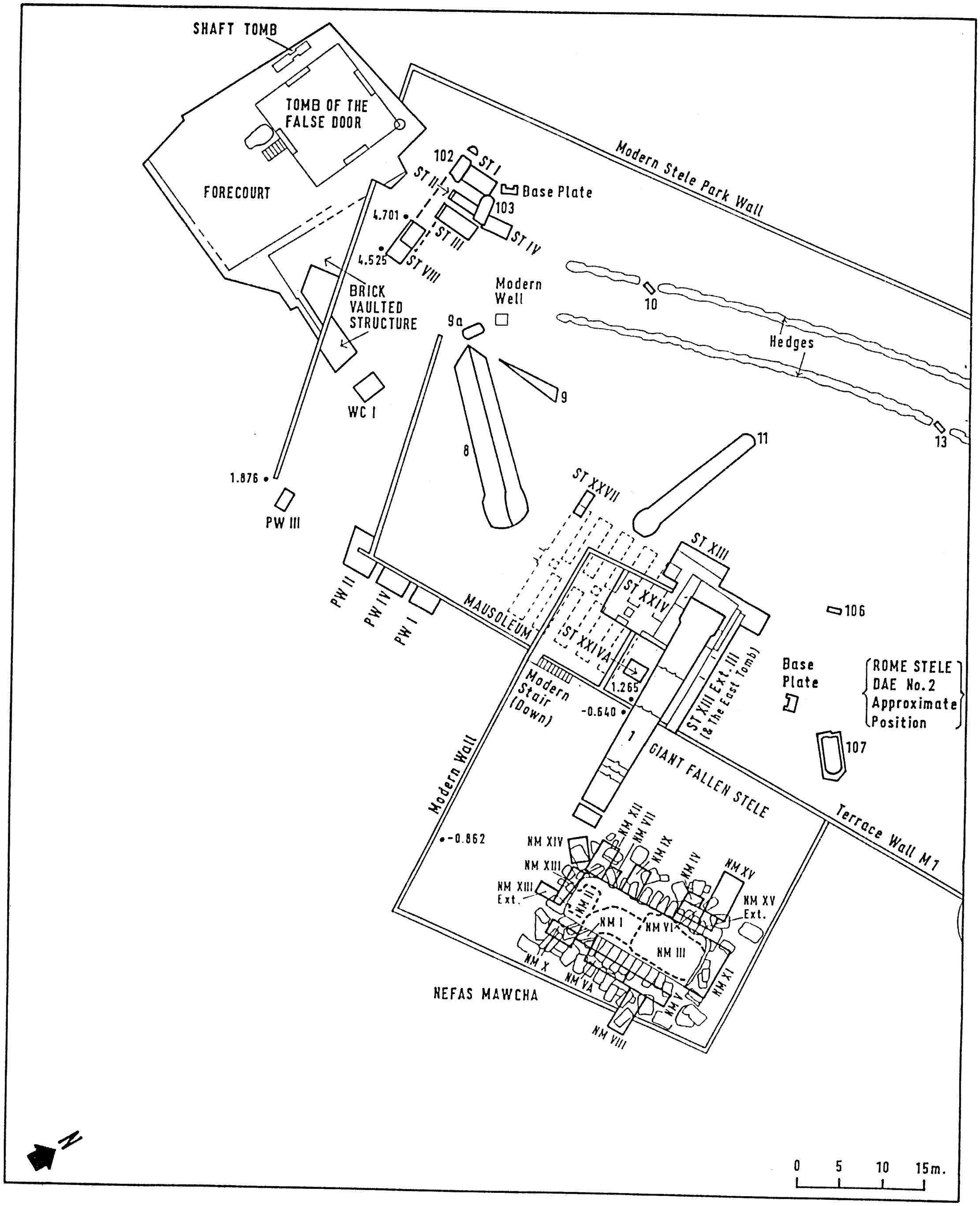


Fig. 3.1. Plan of the Stelae Park (west) (from Munro-Hay, 1989).

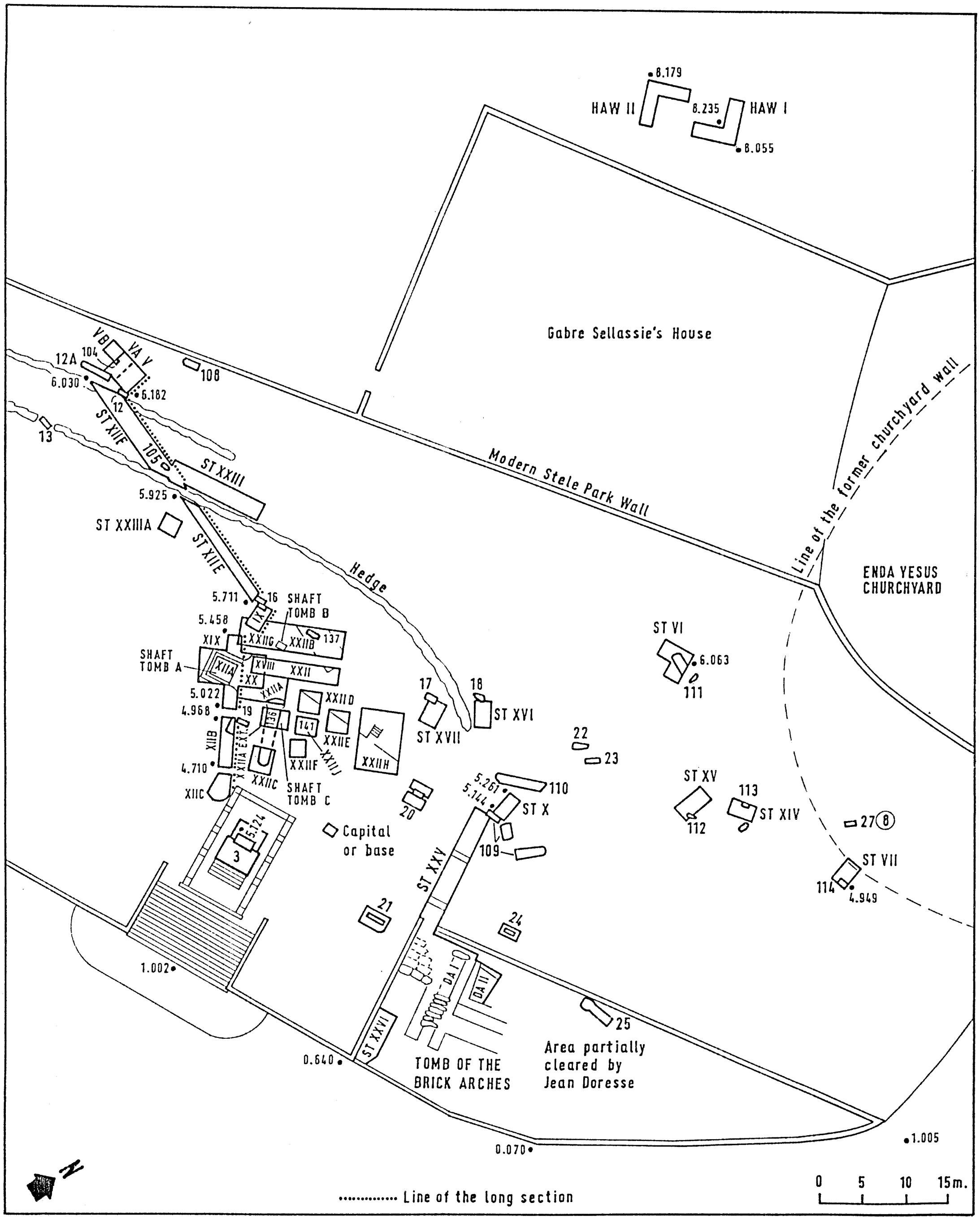


Fig. 3.2. Plan of the Stelae Park (east) (from Munro-Hay, 1989).

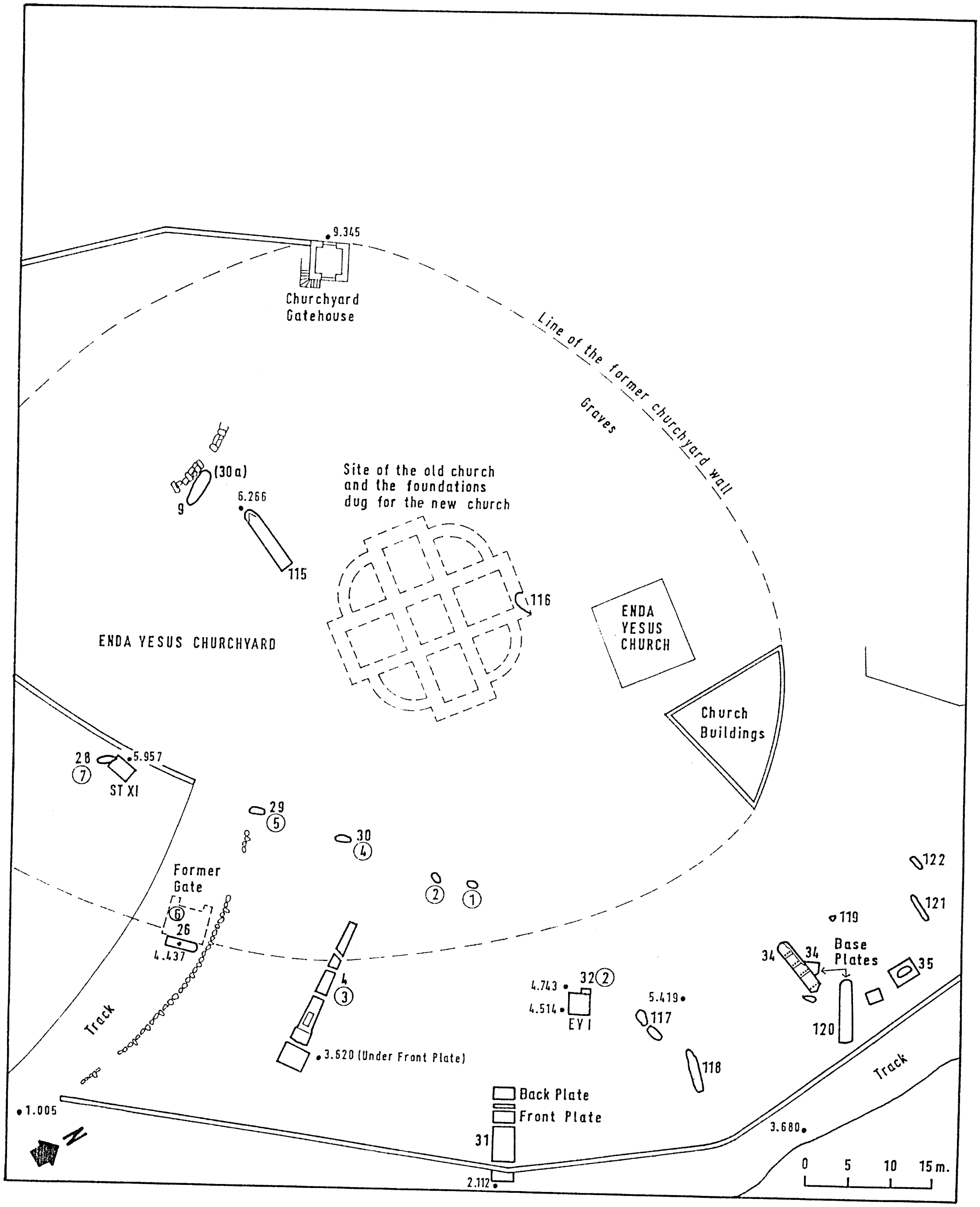


Fig. 3.3. Plan of the Northern Stelae Field, western limit (from Munro-Hay, 1989).

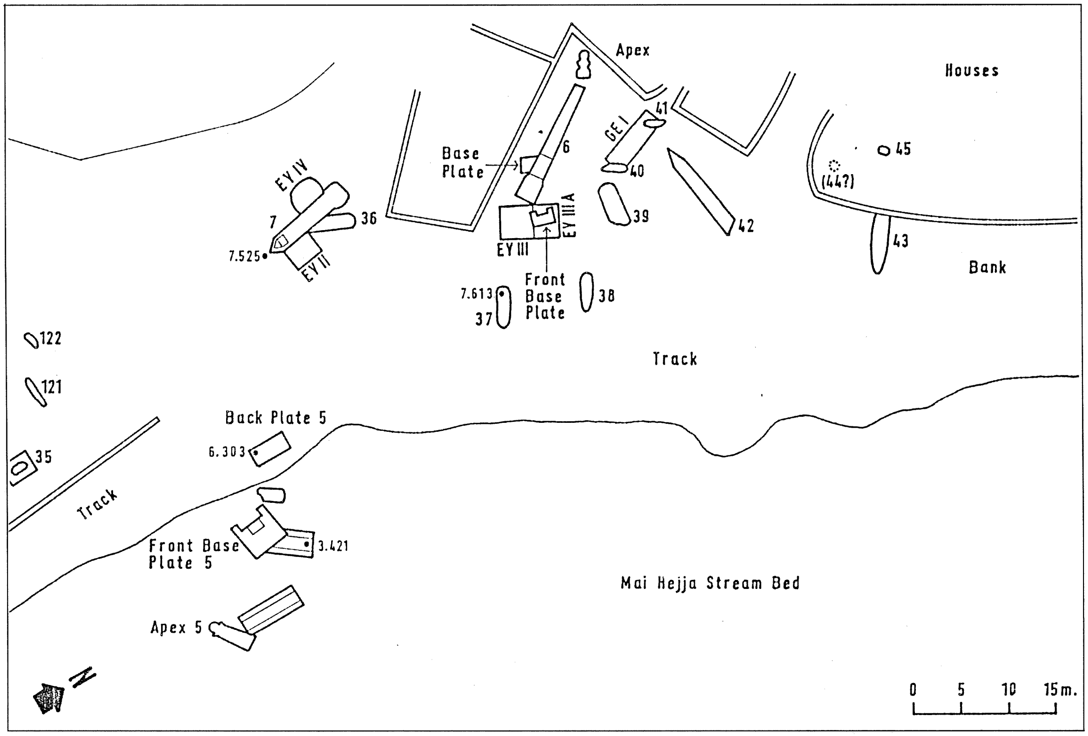


Fig. 3.4. Plan of the Northern Stelae Field, continued (from Munro-Hay, 1989).

It is a striking fact that the stelae and obelisks mainly fell in the same direction, *i.e.* from the second to the fourth quadrant, parallel to the shorter side of the cross section. It appears reasonable to suggest that the stelae were uprooted by a seismic event with a significant component of the acceleration in the NW-SE direction. Given the considerable height of the stelae with respect to the embedded portion, collapse could be caused by a very modest seismic shock (in the region of a few hundredths of gravitational acceleration: see Appendix) that would certainly be compatible with the seismicity of the region.

It is also necessary to explain how some stelae were broken at the base (fig. 6) and often in various places along the shaft. Palazzo (1913) claims that an earthquake can even break obelisks like the Egyptian ones in Rome. But we tend to dismiss any suggestion that the stele-foundation system acted as a cantilever firmly held at the base, as the external force required to break a syenite shaft of such size would have been very great indeed. As pointed out above, far less force would suffice to dislodge a stele from its foundations – even assuming excellent mechanical properties of the soil – given the very small amount embedded in proportion to total height.

A mechanism capable of accounting for the breaking of the originally monolithic stelae into pieces is as follows (fig. 7). Under the impulse of an external force (earthquake) the stele is wholly dislodged from its emplacement with a combination of translational and rotational motion in which the instantaneous centre is a point in the lower part, well below the centre of gravity. On falling, the upper part of the stele strikes the ground first, bounces up, falls back and breaks at the base on impact with the

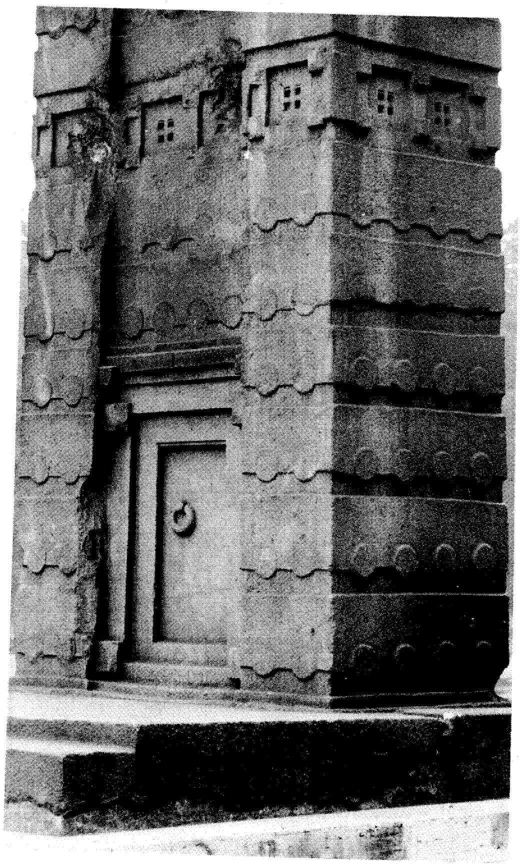


Fig. 4. The Aksumite Stele (DAE 2) of Rome. Two circular impact-holes, due to WW II 88-mm German shells, can be seen in the middle of the first windows row.

slab of the semi-base remaining *in situ*. The lower part of the stele returns towards its foundation emplacement re-entering only in part, while the still moving upper part can break into pieces on impact with any hard features of the ground.

5. The obelisks examined

Examination focused on five obelisks whose collapse raises various questions:

– stele DAE 1 (or *Die Riesenstele*);
– stele DAE 4 (or *Die Stele vor 'Enda Jesus*);
– stele DAE 5 (or *Die Stele am Bache*);
– stele DAE 6 (or *Die nordlichste Stockwerk-Stele*);
– stele DAE 31 (nameless).

A brief description of all the stelae at Aksum is provided by Munro-Hay (1989).

– *The Great Stele (DAE 1)* (figs. 8, 9, 10 and 11) – DAE 1, once the largest monolith in the world, was carved to represent a 13-storey building with front and rear doors. It simulates an Aksumite palace with its four slightly projecting corner towers creating four longitudinal central recesses running from top to bottom. Another characteristic peculiar to this monument is the perfect symmetry between the front and rear and between the left and right sides. The total height is 33.4 m, only 2.6 of which were embedded in the ground. This already constitutes a source of instability in that the embedded part is only 1/12 of the total height. There is no trace of the two collar-type semibases that usually served as an altar with steps and, above all, to help keep the obelisk in an upright position. The absence of these semibases can, unfortunately, be interpreted in two different ways with different consequences.

– The semi-bases never existed. This would support the views of those (Phillipson) who maintain that the Great Obelisk fell during erection. We find it odd, however, that the obelisk should have been carved on all sides while on the ground, which would entail a rotation of 90° to carve the rear side.

– They were removed after completion either to facilitate deliberate demolition or for reuse elsewhere.

Examination of the arrangement of the pieces of the Great Obelisk on the ground (fig. 8) shows that it must have fallen without striking against the two semi-bases as this would have led to a fracture at the base similar to that seen in the cases of the obelisk of 'Enda Jesus (fig. 6). The fractures of DAE 1 are of one and the same type and were caused by impact with the ground. We are by no means convinced by Munro-Hay's (1991) claim that the

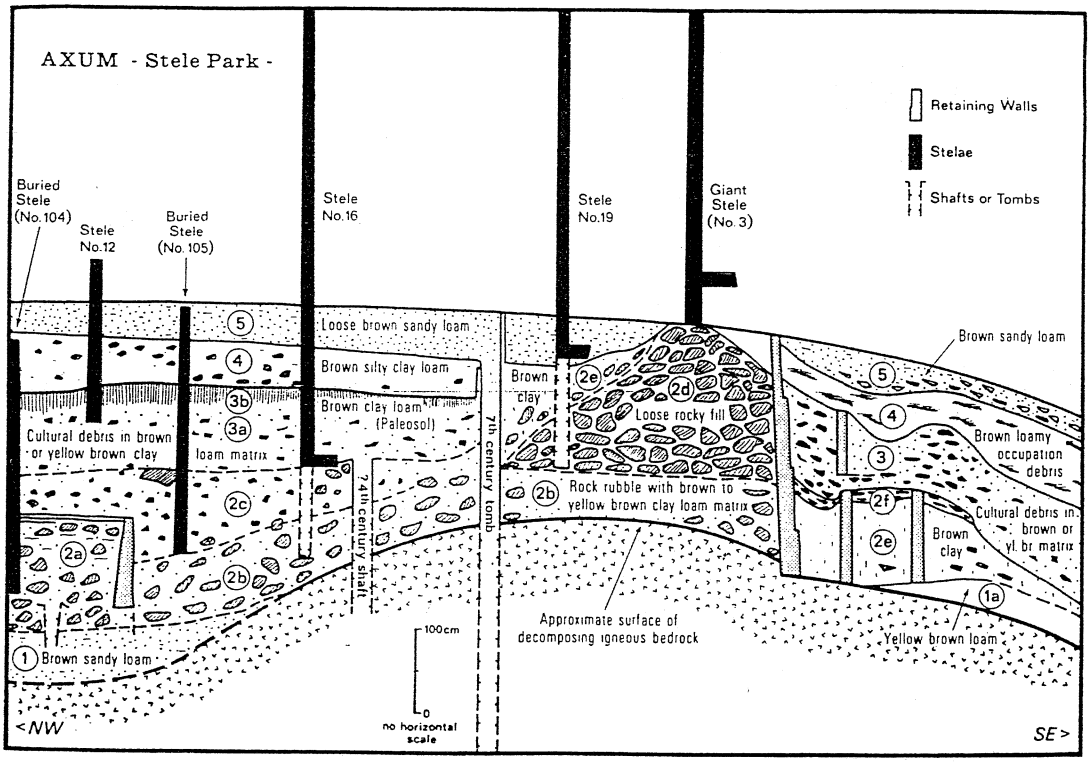


Fig. 5. Composite and simplified cross-section of archaeological sediments below Stelae Park (from Butzer, 1981).

apex of the Great Obelisk struck and damaged the tomb of Nefas Mawcha on falling. The obelisk was first broken slightly below its centre on impact with a sharp rise in the terrain (fig. 8). The upper part then broke up, thus losing still more energy. The apex would therefore have had too little force to dislocate the monolith of 500 tonnes forming the roof of the tomb of Nefas Mawcha.

In our view, the collapse of the Great Obelisk may be due either to natural causes (as lack of stability or an earthquake) or to deliberate demolition by uncovering its foundations. We further believe that no definitive answer can be given until archaeological excavations are carried out below the obelisk. Unfortunately, a great opportunity was missed in 1937 when Ugo Monneret De Villard removed the pieces of the Second Obelisk (DAE 2) (fig. 12) for transport to Rome. It was noted that the rear semi-base was missing but no record was made of what was lying beneath the obelisk or of its precise position.

– *The stele before 'Enda Jesus (DAE 4)* (fig. 6) – The present authors regard DAE 4 (*Die Stele vor 'Enda Jesus*) as constituting – together with the neighbouring stelae DAE 5 (*Die Stele am Bache*) and DAE 6 (*Die nordlichste Stockwerk-Stele*) (fig. 13d,b,c) – a more evolved stage with respect to the three largest obelisks DAE 1 (*Die Riesenstele*), DAE 2 (*Die zweitgrößte Stele*) and DAE 3 (*Die noch stehende Stockwerk-Stele*) (fig. 13a). While nothing can as yet be proved as regards the age of these stelae or their chronological

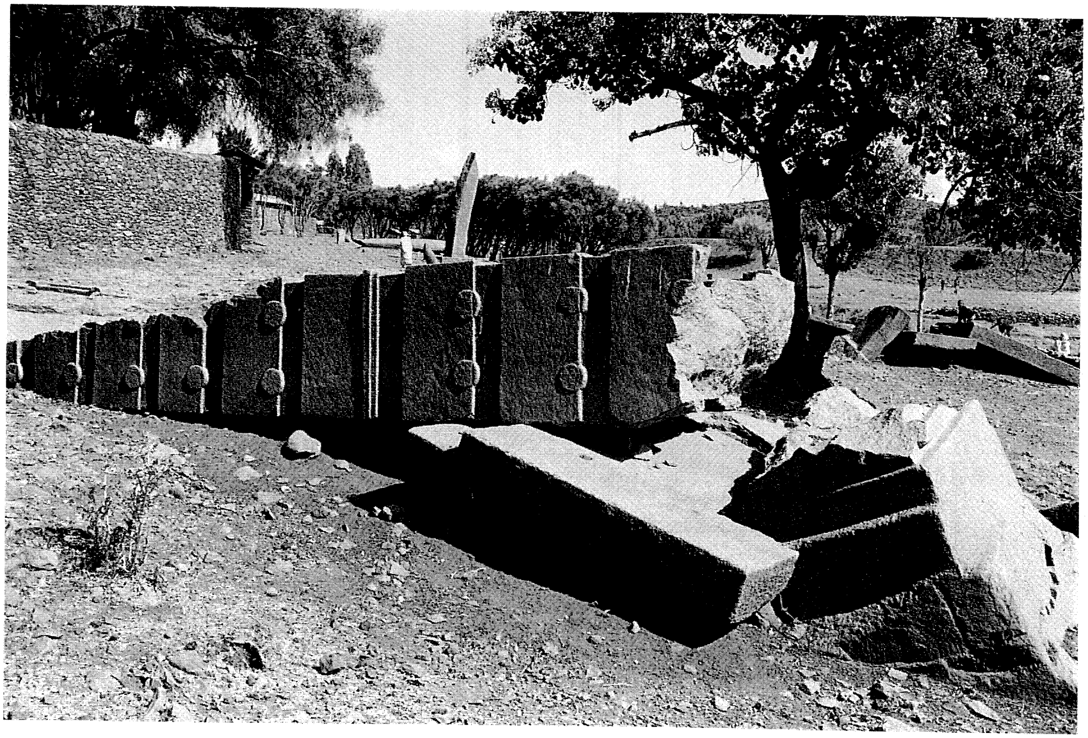


Fig. 6. The stele before 'Enda Jesus (DAE 4).

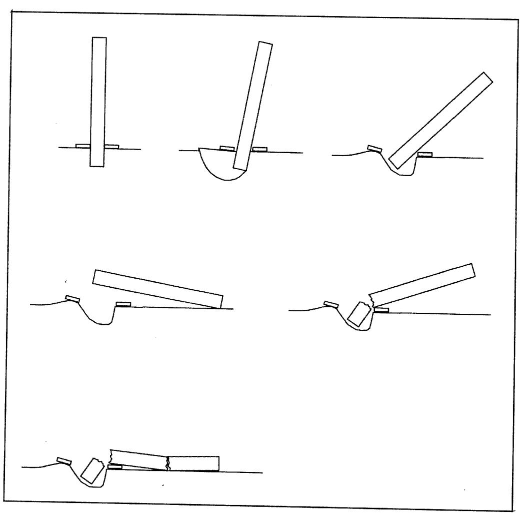


Fig. 7. A possible mechanism for toppling and breaking of obelisks.

order, it seems reasonable to regard the first three large stelae as representing an archaic phase in the evolution of the multi-storey obelisk with externally portrayed timber elements. Supporting evidence would be provided by the rigorous monotony and severity of their ornamentation.

The second group of stelae is instead characterized both by the fact of representing houses with higher (and hence fewer) storeys and by far more elaborate bilobate apexes. The ornamental details of the base also show more careful workmanship than the first group.

DAE 4 (fig. 13d) has a total height of 18.2 m and lies on the ground in 8 pieces. The bilobate apex is in two pieces, one of which lies in the so-called garden of Ezana and the other near the church of Mariam Tsion. The most significant feature of this stele is its position. The base plinth emerges partially from the foundation pit (fig. 6), which had been re-

Fig. 8. A view of the Main Stelae Field: on the left the fallen Great Stele (DAE 1), on the right the Standing (and leaning) Stele DAE 3. The Rome stele (DAE 2) was supposed to lay broken approximately in the position of the two wooden poles.

inforced with vertical stone slabs, and there is a break at the base exactly at the beginning of the ornamented part. The two semi-bases are present but out of position. A possible explanation of the mechanism of these fractures has been proposed in the previous section.

– *Stele DAE 31* (fig. 14) – This slab-shaped stele with no ornamentation has a total height of 12.45 m and a base section of 2.6 x 0.44 m. It lies on the ground in 3 pieces with the plinth dislodged but still embedded in the ground and the semi-bases no longer embedded. The mechanism of fracture may be the same as that of DAE 4 (fig. 6).

– *Stele DAE 5* (fig. 13b) – DAE 5 is a three-storey obelisk of 15.8 m in height and displays a less elaborate bilobate apex than those of DAE 4 and DAE 6. The stele stood on the bank of a seasonal stream called Maj Hejja, which has scattered the pieces. The presence of the semi-bases suggests that it may have collapsed in similar fashion to DAE 4 and DAE 31.

– *Stele DAE 6* (fig. 13c) – This three-storey obelisk has a total height of 15.2 m and is practically intact, the apex alone being broken. It lies in a perfectly horizontal position with the plinth wholly exposed and the semi-bases present but out of position. The evidence suggests that it fell without breaking at the base.

The fallen obelisks described above are all aligned NW-SE and NNW-SSE (Munro-Hay, 1989) (figs. 3.1, 3.2, 3.3 and 3.4).

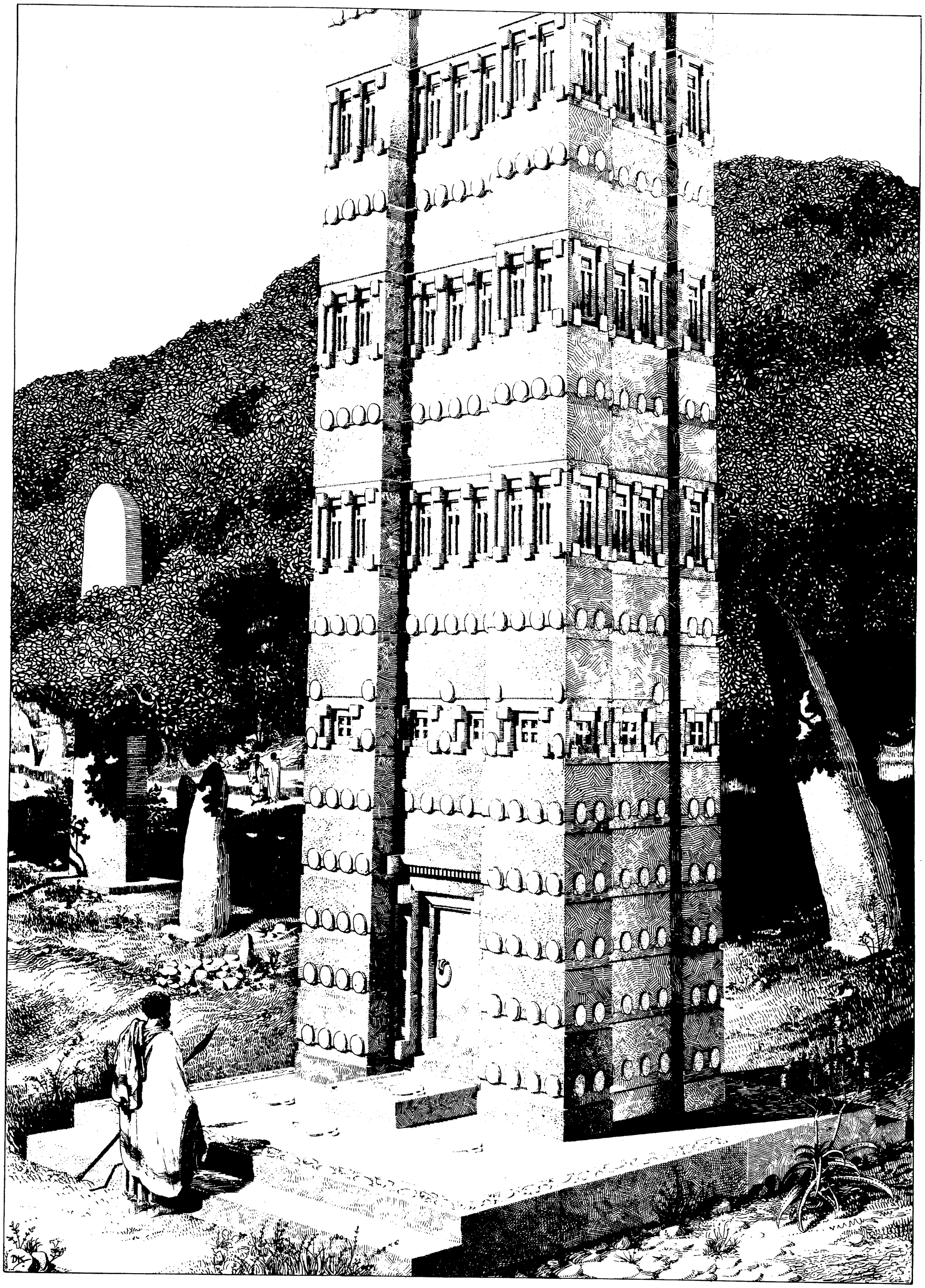


Fig. 9. Reconstruction of the Great Stele (from Krencker, 1913).

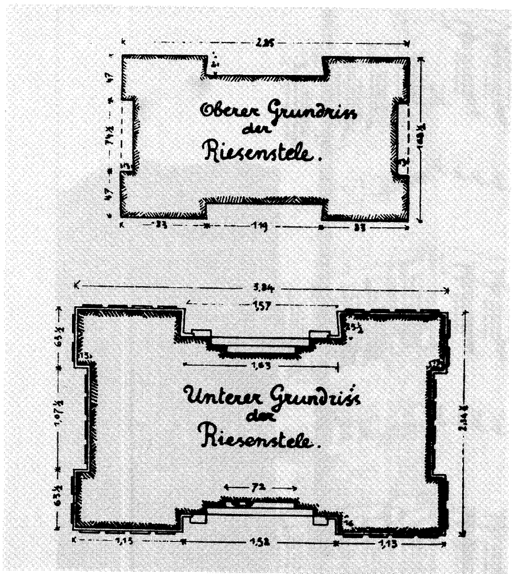
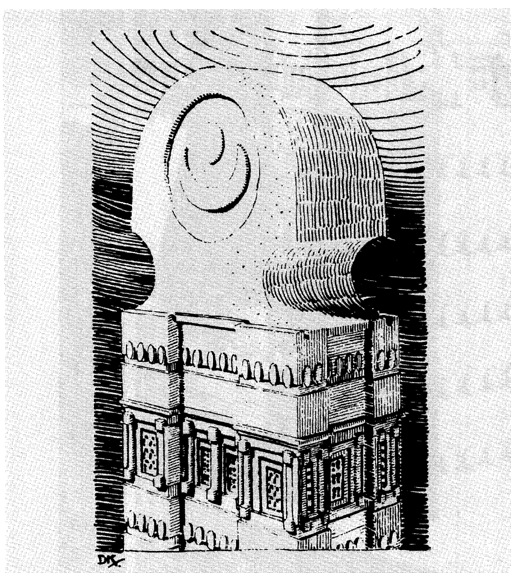


Fig. 10. Upper and lower sections of the Great Stele (from Krencker, 1913).



Rekonstruktion des Kopfes der »Riesenstele« in Aksum.

Fig. 11. Reconstruction of the head of the Great Stele: the Sun and the Moon, two Sabaean symbols, can be seen (from Krencker, 1913).

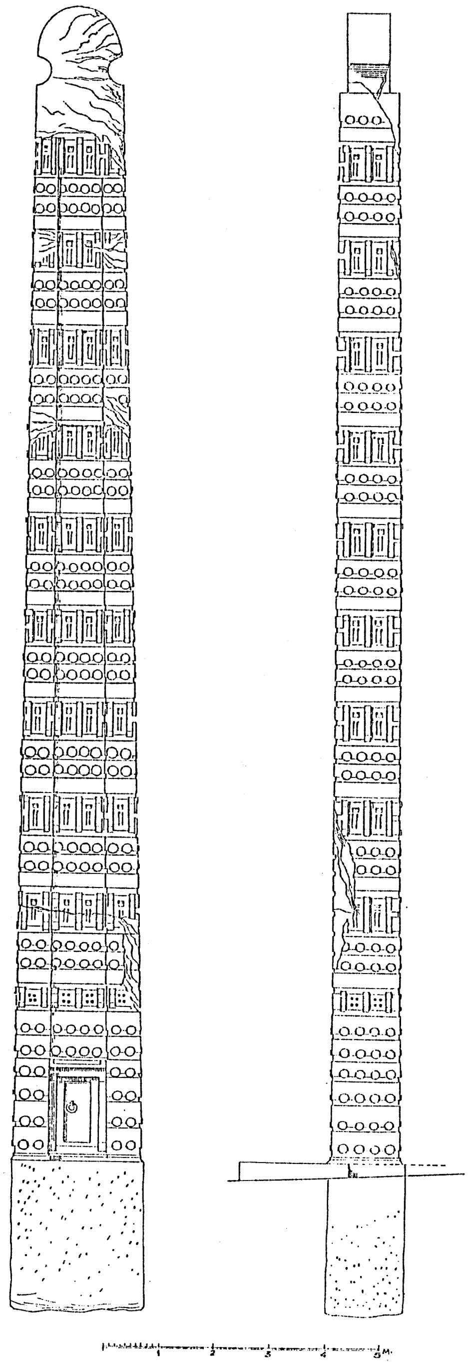


Fig. 12. The Aksumite Stele (DAE 2) now in Rome (from Krencker, 1913).

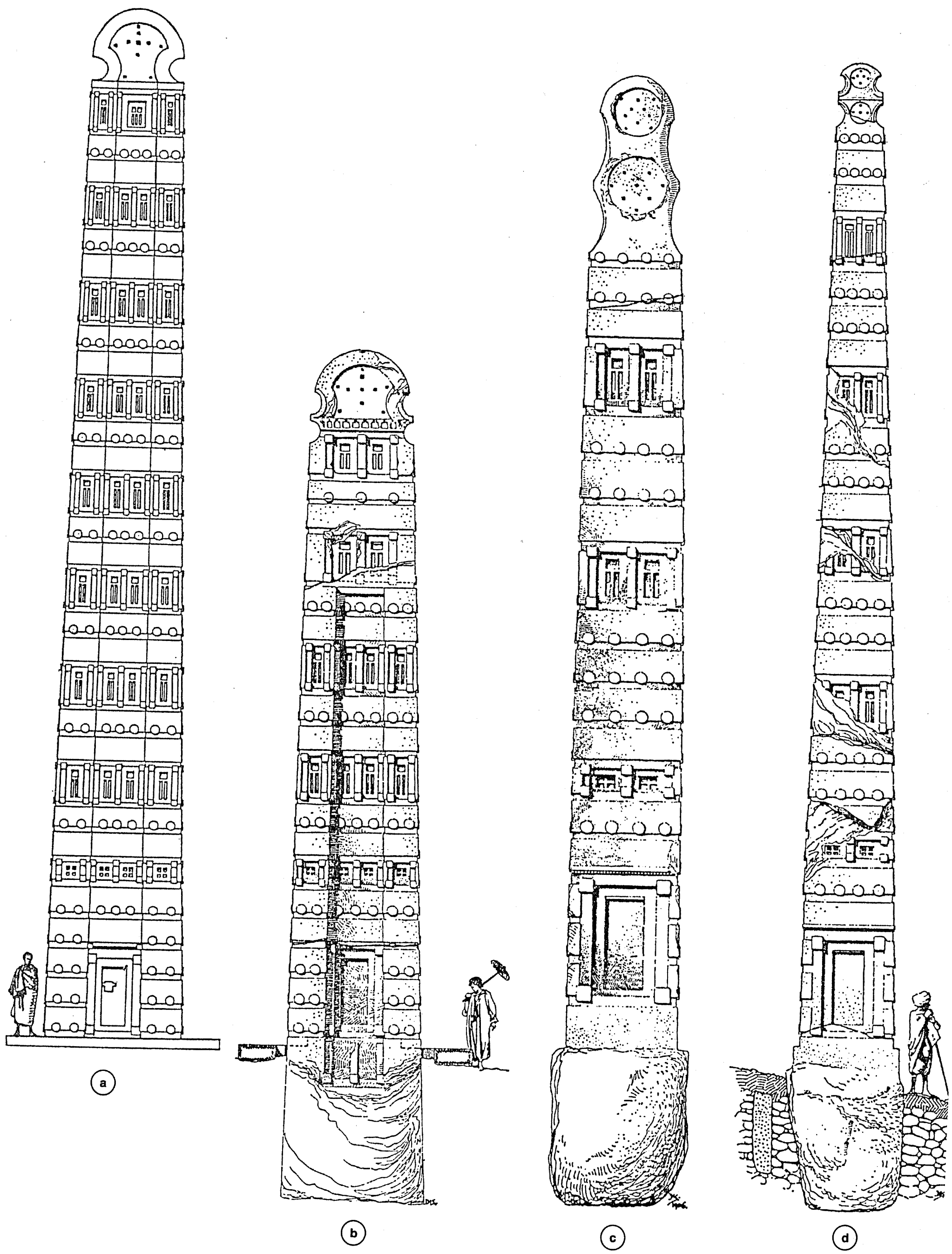


Fig. 13a-d. Reconstruction (not to a same scale) of four main Aksumite obelisks: a) *Die noch stehende Stockwerk-Stele* (DAE 3); b) *Die Stele am Bache* (DAE 5); c) *Die nordlichste Stockwerk-Stele* (DAE 6); d) *Die Stele vor 'Enda Jesus* (DAE 4) (from van Beek, 1967).

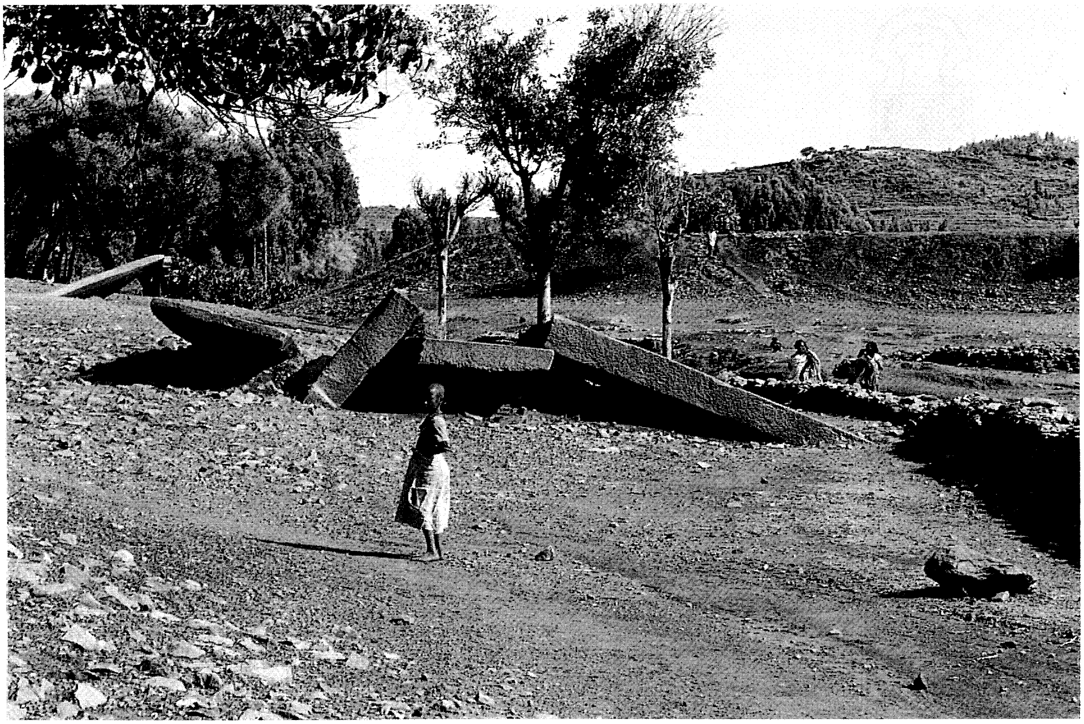


Fig. 14. The slab-shaped stele DAE 31.

6. Conclusions

Of the three historical causes given for the collapse of the obelisks at Aksum, Turkish cannon fire can unquestionably be assigned a marginal role, at least in the case of the larger monuments.

Deliberate demolition is a possible explanation in some cases if we admit preliminary disruption of the foundations.

However, we are inclined to consider earthquakes as the prevailing cause of collapse, especially in the case of DAE 4 (*Die Stele vor 'Enda Jesus*), DAE 5 (*Die Stele am Bache*), DAE 6 (*Die nordlichste Stockwerk-Stele*) and DAE 31.

It is more difficult to identify the causes responsible for the collapse of the Great Stele (DAE 1 or *Die Riesenstele*) and the obelisk now in Rome (DAE 2 or *Die zweitgrößte Stele*): a possible mechanism implying soil failure under earthquake excitation is described in Appendix.

Appendix

In this Appendix a mechanical model for the collapse of an obelisk is proposed, which implies failure of the underlying soil, but not of the obelisk-soil connection. It will be shown that even under these limit assumptions moderate horizontal actions are sufficient to topple an obelisk of the dimensions of the Great Stele (DAE 1). The effect of natural erosion or of excavations around the base would make the obelisk even more vulnerable, so that it is not surprising that so few have stood up to our day.

For the sake of simplicity, the obelisk will be considered prismatic, with dimensions b, s,

h (fig. 15a,b); N and F denote respectively the weight and a horizontal force, supposed as acting to the middle of the height; e is the eccentricity of the resulting force $N + F$ with respect to the shorter side s of the base; it results

$$e = (Fh) / (2N) . \qquad (1)$$

We look for the maximum value of F compatible with the bearing capacity of the soil, considering a superficial foundation at a depth D from ground level. As usual in Geotechnics, we refer to a reduced base, as suggested by Meyerhof,

$$A_{red} = s' b, \quad \text{with} \quad s' = s - 2e .$$

Denoting by γ the weight of the obelisk per unit volume, the maximum pressure σ on the foundation is

$$\sigma = s b h \gamma / A_{red} = \gamma h / (1 - 2e/s) . \qquad (2)$$

In order to have equilibrium, this value must be smaller than the limit one q_l, given by the Terzaghi relation

$$q_l = \zeta_q N_q \gamma_t D + \zeta_\gamma N_\gamma \gamma_t s'/2 + \zeta_c N_c c$$

where:

γ_t: weight of the soil per unit volume;
ϕ: angle of friction of the soil;
c: coesion of the soil;
N_q, N_γ, N_c: coefficients depending on ϕ;
ζ_q, ζ_γ, ζ_c: shape coefficients, depending on ϕ, s', b:

$$\zeta_q = 1 + (s'/b) \text{ tg } \phi; \quad \zeta_\gamma = 1 - 0.4 (s'/b);$$
$$\zeta_c = 1 + (s'/b)(N_q/N_c) .$$

From (1) and (2) the limit condition

$$\sigma = q_l$$

becomes

$$e = s (q_l - \gamma h) / (2 q_l); \qquad (3)$$

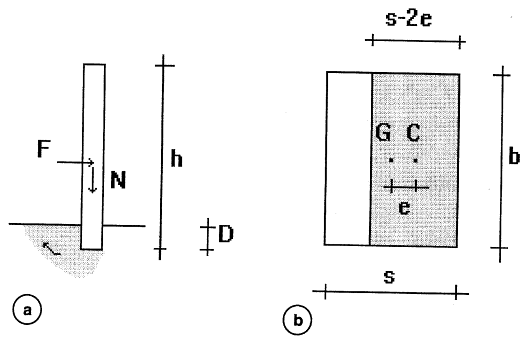


Fig. 15a,b. Sketch of an obelisk (a) and its base (b).

$$F = 2\, e\, s\, b\, \gamma . \qquad (4)$$

The horizontal *seismic acceleration* that can induce such a force F will be denoted as $k g$, with g the gravity acceleration; so

$$F = k N = k \gamma s b h \qquad (5)$$

and from (4)

$$k = 2\, e/h . \qquad (6)$$

Such a force F could also be supposed as due to *wind*, acting on the stele with a dynamic pressure p; we have in this case

$$p = F/(b(h - D)) = 2\, e\, s\, \gamma/(h - D) . \qquad (7)$$

As an example, consider the Great Stele (DAE 1), with

$$h = 33.4 \text{ m}, \quad s = 2.35 \text{ m}, \quad b = 3.84 \text{ m},$$
$$D = 2.6 \text{ m}, \quad \gamma = 2.8 \text{ t/m}^3$$

and assume also

$$\phi = 30°, \quad c = 2 \text{ t/m}^2, \quad \gamma_t = 1.7 \text{ t/m}^3;$$

it results

$$N_q = 18.40, \quad N_\gamma = 22.40, \quad N_c = 30.14$$

and in the limit condition

$$\zeta_q = 1.2;\ \zeta_\gamma = 0.9;\ \zeta_c = 1.2 \quad (\text{with } s'/b = 0.3)$$

$$q_l = 190 \text{ t/m}^2$$

and from (3)-(6)

$$e = 0.25 \quad s = 0.6 \text{ m};$$

$$F = 30 \text{ t};$$

$$k = 0.04;$$

such a peak acceleration of 0.04 g would be certainly compatible with the seismicity of the region af Aksum.

In the case of wind we have from (7)

$$p = 0.26 \text{ t/m}^2$$

and we cannot exclude that this value of dynamic pressure, still taking into account the shape effect, could be reached in a strong wind storm.

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