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Environmental indications provided by the Hadar formation (Afar, Ethiopia) fauna and correllation with geological evidence

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The Hadar Formation is a well exposed series of fossiliferous Plio–Pleistocene fluvio–lacustrine sediments located along both banks of the Awash River and certain of its tributaries in the Afar Depression of Ethiopia. Geochronological and palaeomagnetic evidence suggest an age of $<2.6-<3.3$ million years (m.y.) for the formation, with the fossiliferous portions of the sequence primarily confined to c. $>2.9-<3.3$ m.y. (Aronson *et al.* 1977; Aronson *et al.* this volume; Taieb *et al.* 1976). Biostratigraphic considerations generally confirm these results (Coppens & Gray this volume). Intensive palaeontological collection has been conducted in Hadar, in an area of only 45–50 km², since 1973, following a very brief visit in 1972. The relatively short timespan represented and the small size of the main collection area provide an ideal situation for palaeoenvironmental studies.

The taphonomic setting is unusual. Fine grain-sizes predominate for the fossiliferous portions of the sequence, although larger particles are present, precluding the possibility that only small material was available for fluid transport. Flow regimes responsible for such fine sediments seem to have

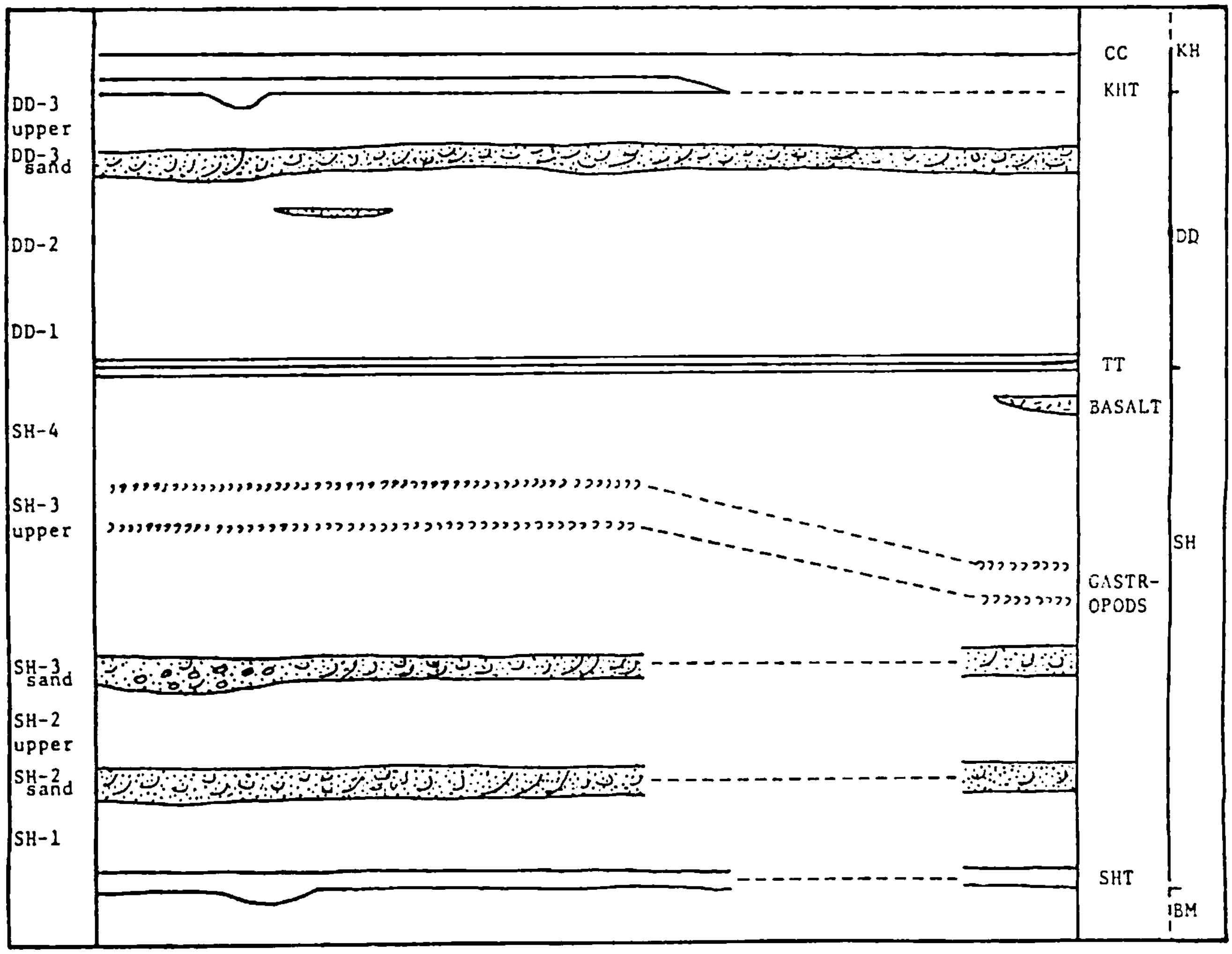

Fig. 1. Stratigraphic distribution of fossiliferous horizons.

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been of lower energy than the empirically determined threshold shear stresses of all but the smallest of bones (Behrensmeyer 1975; Dodson 1974; Voorhies 1969). The fossils themselves are often remarkably intact, generally displaying little if any sign of taphic abrasion, and partial and even complete skeletons are not uncommon. Most specimens show only slight evidence of weathering which suggests rapid burial of the bones. Thus it seems likely that the vast majority of the Hadar fauna derives from autochthonous assemblages.

The Hadar Formation is presently divided into four members (BM, SH, DD and KH, from bottom to top), the upper three defined by tuff horizons (SHT, TT and KHT, respectively) at their bases. Each member save the lowest is further divided into three or more submembers, numbered sequentially from bottom to top. Individual lithological units, easily recognizable in the field, may be defined within certain of the submembers, including most notably three extensive sand units (traceable across all of the main collection area), whose lower contacts define the bases of the SH-2, SH-3 and DD-3 submembers (Johanson *et al.* 1978; Taieb *et al.* 1976; Taieb & Tiercelin this volume). These are recognized as distinct from the primarily finer-grained (largely argillaceous) sediments which they underlie (Fig. 1). These sand units are interpreted as representing distributary networks, while the finer-grained deposits variously reflect lacustrine, marshy lake edge and floodplain conditions (Johanson *et al.* 1978; Taieb & Tiercelin this volume).

Much of the collected fauna may be assigned to one of the 10 lithological horizons within the SH and DD Members. (The BM and KH Members are not included here, as the bulk of these portions of the sequence are essentially nonfossiliferous). The use of so many stratigraphic subdivisions does raise difficulties in a few cases due to the resultant small sample sizes for certain of the horizons. With one exception, though, the commonly represented taxa are known in most horizons, suggesting close proximity of distinct habitats in a mosaic of environments such as is typical of many rift valley settings in eastern Africa today. On the other hand, interesting quantitative variatoins may be seen between the faunal assemblages from different horizons which are thought to reflect primarily the prevailing environmental conditions. Due to the relatively small collection area, it is also felt that only one ecological zone has been sampled by each horizon, with little overlap with adjacent zones.

In order to avoid difficulties in assigning some postcranial specimens to taxa below the familial level, only cranial and dental remains of the mammalian fauna will be discussed here. Further, to reduce taphonomic bias (Behrensmeyer 1975 and this Congress (not submitted for publication); Dodson 1974; Voorhies 1969), the medium-sized forms (e.g. bovids, suids and equids) will be emphasized. Application of the specialized techniques required for recovering microfaunal remains has been very unequal through the stratigraphic sequence. Larger mammals will be mentioned, but these comprise fewer taxa, and are generally less well represented. One exception would be the Elephantidae, which are significant for their remarkable abundance at Hadar. Indeed, elephants are a major part of the fauna in all horizons, and in fact are the dominant element in many. While Behrensmeyer's recent studies (1977) show that this may be due in part to simple taphonomic bias according to size, it is felt that this factor alone is insufficient to explain totally the abundance of elephantids. We are unfortunately at present unable to offer an explanation for this phenomenon.

Much of the SH Member corresponds to Phase I of Taieb & Tiercelin (this volume) and represents the initial infilling of the sedimentary basin in and around Hadar. Distributary networks and marshy lake edge deposits are represented (SH-1 through SH-3 sand). *Aepyceros* and *Tragelaphus* are common, perhaps indicative of woodland conditions. Suid evidence suggests that generally the sand units reflect more open conditions than the finer-grained horizons, based primarily on the relative frequencies of *Notochoerus* and *Potamochoerus*. It may also be noted that hippopotamids and *Ceratotherium* are significantly better represented in the SH-2 sand unit than elsewhere (the sample size for the SH-3 sand is very small). *Ugandax* and alcelaphines are consistently represented, although never in great numbers. Carnivores and cercopithecoids are also relatively more common in this portion of the succession than elsewhere.

Immediately above the SH-3 sand a rather marked shift occurs in the fauna. More open settings are suggested by the dominance of alcelaphines (apparently only one species) among the bovids. The relative increase in numbers of *Kobus* specimens may indicate the presence of streams (? represented by sand lenses) bordered by woodland. *Notochoerus* is common, and *Hipparion* is also well represented. The occurrence of dense concentrations of gastropods in discrete horizons may reflect rapidly fluctuating lake levels.

By SH-4 times more fully lacustrine conditions had been established in Hadar (Phase II of Taieb & Tiercelin this volume), although the abundance of fauna (including the least transportable body parts) may indicate periodic emergence of the land surface. There is no sound reason to separate the SH-4 and DD-1 submembers on the basis of geological environments, and due to the nature of the outcrops it is more convenient to consider their contained faunas together. The occurrence of *Kobus* increases somewhat, although *Aepyceros* and *Tragelaphus* are also common, as are *Notochoerus* and *Hipparion*. *Kobus* continues its rise in frequency into the DD-2 submember, where it attains a completely dominant status. Indeed, it accounts for 40–45% of the medium-sized fauna, and this figure is probably not fully representative as most of the collected specimens represent male individuals. *Notochoerus* and *Hipparion* are the only other taxa which are at all well represented. This agrees well with the geological interpretation of a floodplain (? intermittently inundated by the lake) with small meandering streams flowing across it (Johanson *et al.* 1978; Taieb & Tiercelin ,this volume).

Immediatly above lies the third of the extensive sand units, at the base of the DD-3. Geologically this unit strongly resembles that of the SH-2, and in many respects the two faunal assemblages are also quite similar. However, certain differences are also seen. In particular, the relative frequencies of *Ceratotherium* and hippopotamids are notably lower in the DD-3, while *Kobus* and *Hipparion* are much more common. Fish remains are also better represented in the DD-3 sand unit.

The upper part of the DD-3 submember appears to be quite similar to the upper part of the SH-3. Alcelaphines are again the most common dorm, with *Kobus*, *Notochoerus* and *Hipparion* also being important elements. The similarity between these two units is quite interesting, given that both seem to represent transitional phases toward fully lacustrine conditions; a short distance above the DD-3, lacustrine conditions are indicated by features such as the CC marker unit (Johanson *et al.* 1978; Taieb *et al.* 1975; Taieb & Tiercelin this volume).

In summary, then, fluctuating conditions , from closed to open woodland, seem to characterize most of the Hadar sequence, with occasional periods of more open conditions. The latter seem to precede immediately fully lacustrine settings.

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