

THE MAKAPANGS GAT LIMeworks GREY BRECCIA: HOMINIDS, HYAENAS, HYSTRICIDS OR HILLWASH?

by

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ABSTRACT

The question of the origin of the Makapansgat Limeworks grey breccia is here considered from two viewpoints:

- (a) the accumulation of bones within a catchment area; and
- (b) the possible concentration of the bones in their final resting place.

The potential role of hyaenas and porcupines as bone-accumulating agents is investigated. Nine categories of hyaena damage to bone surfaces could be distinguished on collections of bone taken from a series of recent hyaena breeding dens. All nine categories can be demonstrated in identical form on fossil bones from the grey breccia. It is concluded that carnivores have played a more substantial role as accumulators of the bones in this breccia than has previously been acknowledged.

Porcupines are excluded as major contributors to the grey breccia bone assemblage on the basis of the low percentage of porcupine-gnawed bones present compared with recent porcupine accumulations. Furthermore, the pattern of damage observed on porcupine-collected skeletal elements does not resemble that documented for the grey breccia.

A 3-dimensional computer plot of the topography of the Limeworks travertine floor shows the presence of two larger and two smaller basins separated from each other by floor "highs". A floor "high" around the grey breccia is demonstrated and may have been a significant factor in bone concentration. Sedimentation within separate basins need not necessarily have been synchronous or equivalent, and the practice of equating Members from one part of the cavern to another is questioned.

Stereographic projections of the dip and strike orientations of the long axes of a number of *in situ* grey breccia bones in two separate areas indicate orientation patterns and imbrication. The results of the projections suggest that a combination of water current action and gravity may have been responsible for the present configuration of the bones.

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INTRODUCTION

The mode of accumulation of the extremely bone-rich Makapansgat Limeworks Grey Breccia (or Member 3 of Partridge 1975, 1979) has been a controversial issue ever since Dart described the deposit as a midden of the carnivorous, predaceous, bone-collecting and tool-making hominid *Australopithecus prometheus* (now known as *A. africanus*) (Dart 1925, 1947, 1949 a, b, 1956, 1957, 1958 and elsewhere). This interpretation has been

vigorously challenged by numerous authors (e.g. von Koenigswald 1953, 1964, Oakley 1954a, b, Washburn 1957, Brain 1967, 1969a, Clarke 1966, Klein 1975, Hill 1976, 1978, Shipman and Phillips-Conroy 1976, 1977) and remains an unsolved question.

A number of observations have prompted the authors to consider the question of the origin of the grey breccia bones from two viewpoints: (a) the accumulation of bones in a catchment area; and

(b) the further concentration of these bones in their final resting place. The suspicion that the bones may have been somewhat concentrated is based on the following observations:

- (1) the unprecedented richness of the grey breccia (fig. 1); dense packing of bone on this scale remains, to our knowledge, unmatched in any recent or fossil bone accumulation from a cavern situation, the grey breccia being still richer in bone than the spectacular accumulation in the Arad striped hyaena den in Israel reported by Skinner (n.d.) and Skinner *et al.* (1980) and visited by one of us (J.M.M.) in August 1979 (fig. 2);
- (2) the grey breccia is a lenticular deposit which has accumulated mainly in low restricted recesses at the periphery of the cavern where the roof approaches the floor;
- (3) the fact that in some places the grey breccia bones are in direct contact with the cavern roof over an extensive area (fig. 3, 4);
- (4) the way in which the fossil bones are tightly packed around and amongst roof stalactites (fig. 4);
- (5) the very small amounts of matrix associated with the bones (non-carbonate detritus is very limited) (fig. 1);
- (6) the marrow cavities of the fossil limb-bones in the grey breccia are frequently filled with well-developed calcite crystals; they are often of the rhombohedron and scalenohedron habit, and Wells (1971) has pointed out that the presence of supersaturated waters is a prerequisite for this type of crystal development;
- (7) the original presence of a floor "high" in the travertine surrounding the *in situ* remnant of grey breccia (fig. 23) down which debris could gravitate or wash;
- (8) the nature and degree of weathering observed on some specimens of fossil bone, which suggests the presence of water.

Brain (1975: 115) succinctly sums up the situation with the statement that "The bones were clearly preserved in a deep subterranean cavern which must surely have been inaccessible to both the hominids and most of the animals whose remains are found there. Future research must be directed towards an understanding of the processes which resulted in the collection and concentration of these bones".



Figure 1. Partially developed block of bone-rich Member 3 breccia from Makapansgat Limeworks. Note the almost intact *Hyaena hyaena makapani* skull lying centrally in the block which contains relatively few flakes and an unusually high proportion of intact bovid limb bones. Note also the absence of stone fragments from the matrix, which is almost pure calcium carbonate. Scale in inches.

It is envisaged that the area in which bones may have accumulated was the surface of the original travertine floor above and some metres eastwards of the present *in situ* exposure of grey breccia (Member 3) on the west side of the Main Quarry (i.e. the "floor high" shown on the NW of the computer plot, fig. 23) and the contiguous, probably somewhat lower surface of the basal red mud (Member 2) which had accumulated in and partially filled the adjacent basins (seen to the NW and SW on fig. 23). An approximately NNE-SSW fracture line corresponding to the long axis of the floor high in this part of the cavern passes through the Limeworks at this point; in fact the presence of the fracture line probably controlled the extensive deposition of travertine immediately below it (Partridge 1975), giving rise to the floor high.

Large-scale destruction of the cavern and its contents by limeworkers has precluded the reconstruction of the original form of the cave. It is thus not certain at this stage whether it was possible for the bones to be carried into the cave by the bone accumulating agents themselves or whether they dropped down shafts or fissures. In a recent paper Maier (1973) has provided a reconstruction in which the bones of the grey breccia levels accumulated as heaps below narrow vertical shafts, situated on the fracture line, which linked the cavern

with above-ground occupation sites. However, this interpretation seems unlikely in view of the virtual absence of stone and other hillside detritus in the grey breccia. On the other hand, the presence of isolated nodules of hyaena coprolites in the grey breccia not only indicates the presence of hyaenas at that time but suggests that parts of the cavern may well have been accessible to the larger mammals at that stage of its development.

Whatever the case it can be seen that the envisaged area where bones might have accumulated and their final site of concentration along the western wall of the Main Quarry where the grey breccia is currently exposed (which Partridge (1975, 1979) rightly terms "distal recesses" of the ancient cavern) were at no great distance from one another, so that transport distances would have been small.

Several bone-concentrating mechanisms are possible, such as water action, gravitational slumping, leaching of the intervening sediment between bones and concentration of the bones by the biological bone-accumulating agents themselves. Observations (2) (3) and (4) listed above would seem to make the biological agents the least likely as final bone-concentrators although this possibility can not be excluded.



Figure 2. Extensive bone accumulation inside striped hyaena den, Arad, Israel. The large bones are mainly limb bones of camels, horses and donkeys, the smaller bones and flakes having gravitated downwards. The hyaenas appear to have concentrated the bones somewhat, leaving a relatively bone-free walkway (left background).

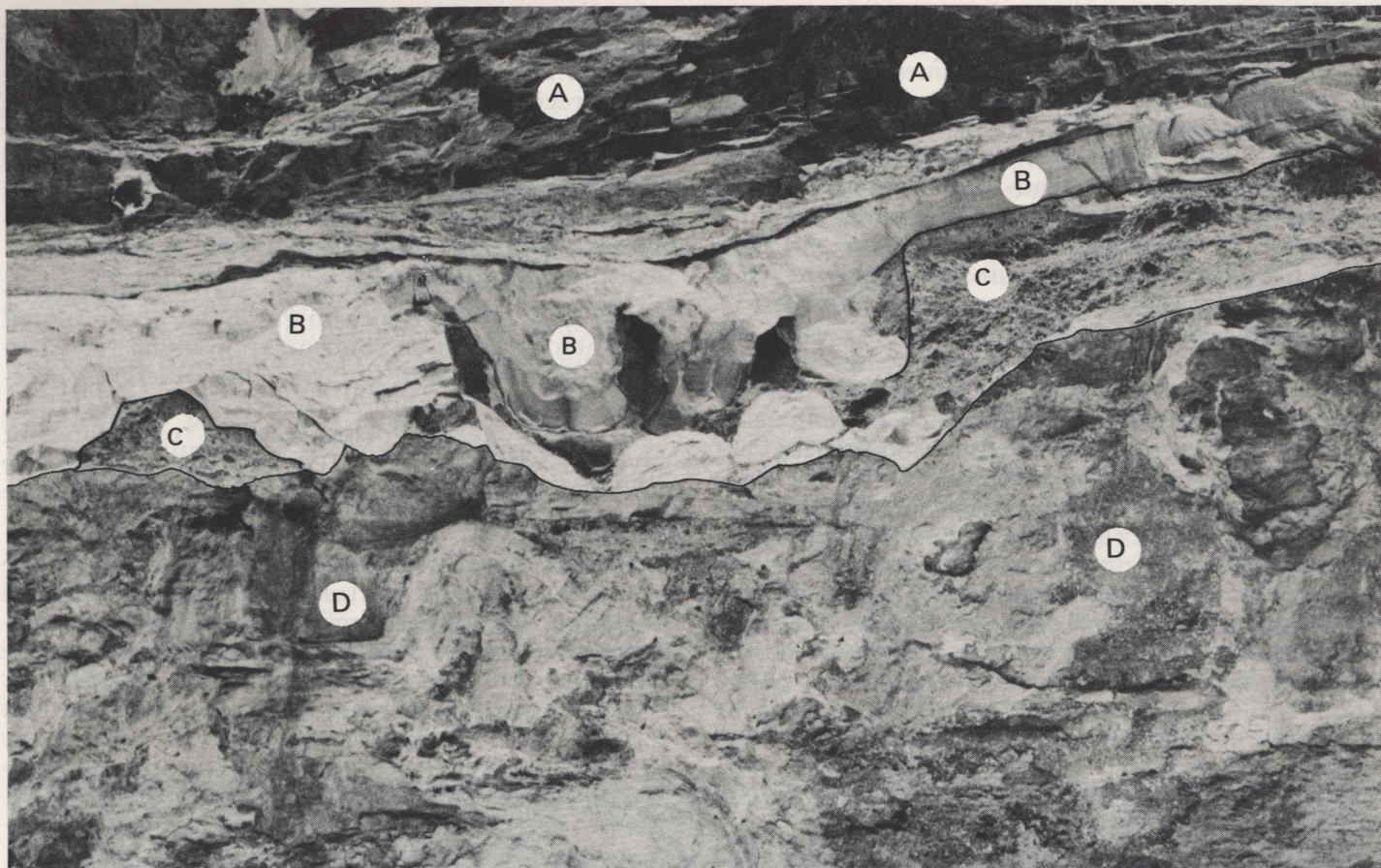


Figure 3. Lateral view of unmined remnant of roof travertine, Makapansgat Limeworks, as seen from the western side of the cone, looking west.

- A: dolomite roof, from which travertine has been blasted by limeworkers.
 B: roof travertine, with a central group of fractured stalactites.
 C: remnants of grey breccia in direct contact with roof travertine.
 D: western wall of Limeworks cavern.

VIEWPOINT A: THE ACCUMULATION OF BONES IN A CATCHMENT AREA

Investigations during the last two decades (see Brain 1980, in press) have revealed that there are nine possible significant means by which bones may have accumulated within ancient dolomitic caves or their immediate catchment areas. These are:

- (1) "hillwash", or periodic sheetflooding (Wells 1974, Partridge 1975, 1979);
- (2) caves acting as natural death traps (Gow 1980, this volume);
- (3) voluntary entry to caves by animals for refuge or to obtain water and failure to emerge (Gow 1973, Wells 1973);
- (4) birds: owls which may use caverns as roosts and eagles and vultures which may use krantzies in the vicinity of cave entrances as nesting sites (Brain 1980, in press);
- (5) leopards (Brain 1968, 1969b, 1970, 1975, 1976);
- (6) hyaenas: striped, brown, spotted and possibly the extinct hunting hyaenas (Ilani 1975, Skinner n.d., Skinner *et al.*, 1980, Mills and Mills 1977, Bearder 1977; Sutcliffe 1970, Brain 1980, in press);
- (7) sabre-toothed cats (Brain 1980, in press);
- (8) porcupines (Hughes 1958, Hendey and Singer 1965, Maguire 1976, 1978);
- (9) Early Man (Brain 1969c, 1974).

Various of these researchers, notably Brain (1980, in press), have attempted to establish criteria whereby the accumulations of some of these bone-accumulating agents may be recognized. The grey breccia bones are currently being reassessed in the light of these findings and recent observations of our own. The present preliminary report is focused on hyaenas and porcupines as possible bone-accumulating agents, and water action is considered as a possible bone-concentrating mechanism.

Two species of hyaena are represented as fossils in the brey breccia: *Hyaena hyaena makapani*, a striped hyaena only sub-specifically different from the extant striped hyaena of North Africa, Middle East and Indian peninsula, and *H. cf. brevirostris*, an extinct hyaena larger than either the extant spotted hyaena, *Crocuta crocuta*, or brown hyaena, *Hyaena brunnea*, which presently inhabit the African subcontinent (Toerien 1952, Randall 1973).

Three species of porcupine — *Xenohystrix crassidens*, an extinct giant porcupine, *Hystrix makapanensis*, a large extinct porcupine, and *H. africaeustra-*

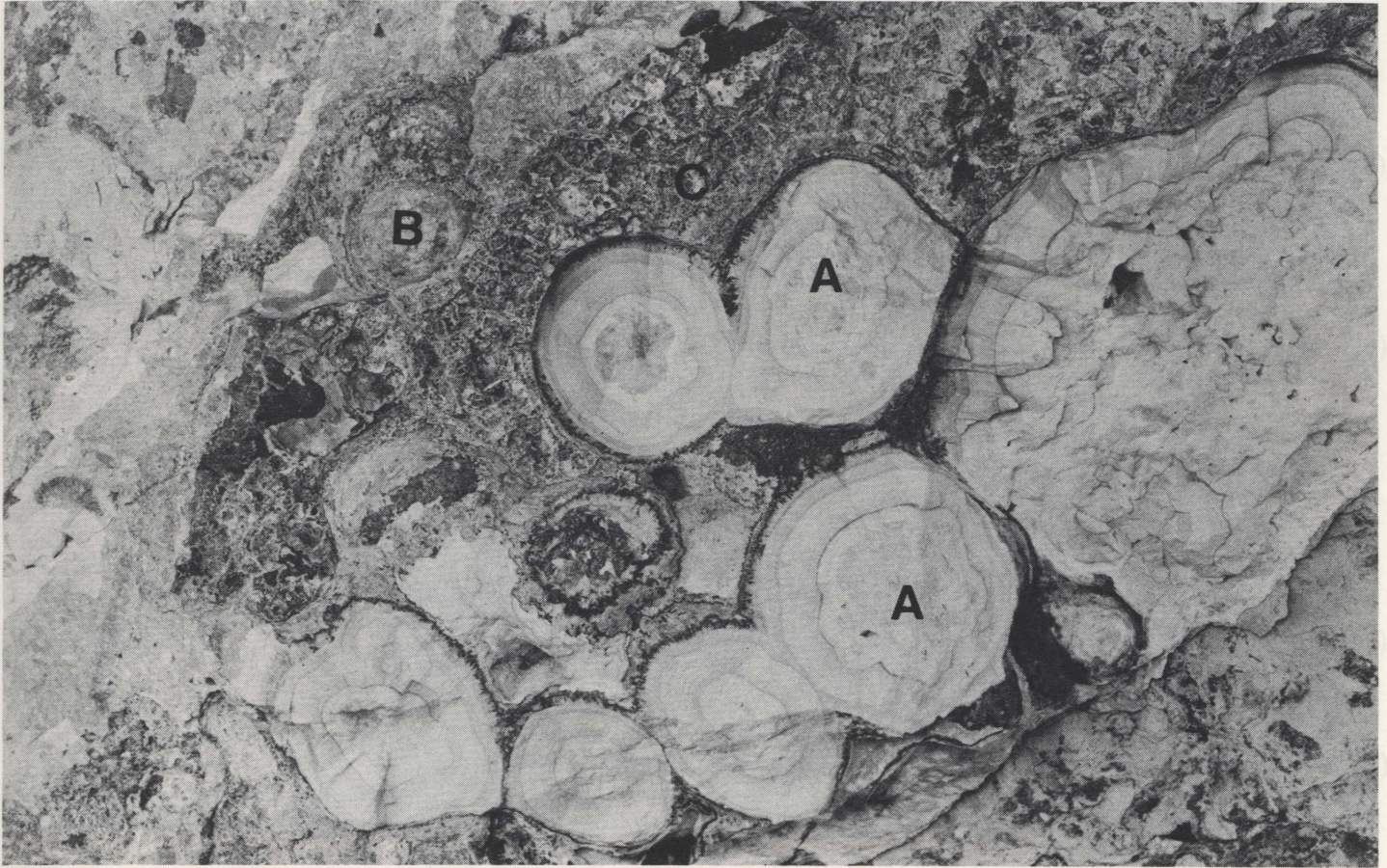


Figure 4. Damaged roof travertine and stalactites shown in Figure 3, viewed from below:

- A: transversely fractured roof stalactites, showing concentric growth.
 B: rounded tip of unfractured roof stalactite.
 C: grey breccia in contact with and completely surrounding stalactites.

lis, a porcupine indistinguishable from the recent species — are present in the grey breccia (Greenwood 1955, 1958, Collings *et al.*, 1976, Maguire 1978).

Hyaenas as Bone-Accumulating and Bone-Damaging Agents

It is now widely recognized that all three extant species of hyaena utilize rocky recesses, low caves and narrow tunnels leading off these as breeding dens, particularly where the disused burrows of aardvarks and porcupines are not available and where the substrate is not suitable for excavation. It has recently been clearly demonstrated that substantial accumulations of bone can build up in and around some of these breeding dens (Sutcliffe 1970, Ilani 1975, Mills and Mills 1977, Bearder 1977, Skinner n.d., 1980, Brain 1980, in press).

A sample of 335 bones collected by Mills and Mills (1977) from in and around brown and spotted hyaena breeding dens in the Kalahari Gemsbok National Park, bones from a variety of brown and spotted hyaena dens in the Transvaal collected by Brain (all housed in the Transvaal Museum) and over 300 bones from a striped hyaena den in Israel were analysed for evidence of surface damage and patterns of fracture of the various skeletal elements.

Nine distinct types of surface damage were found, all nine categories being represented in spotted, brown and striped hyaena breeding den collections in differing proportions. These categories have been designated as follows:

- (1) *ragged-edged chewing* (fig. 5a, b). On robust, thick-walled bones this would correspond to Brain's (1980, in press fig. 4 : 12d) incisor-canine gnawing of uncrackable bones, but the present authors have used the term more broadly to include carnivore-produced ragged edges on more delicate bones such as scapulae and pelves;
- (2) *shallow pitting which is often localized* (fig. 6). It is not at present clear whether or not this type of damage is produced exclusively by the teeth of juvenile animals;
- (3) *punctate depressions or perforations* (fig. 7a, b). Probably caused by the robust, conical, bone-crushing premolars (P^3 and P_3 and P_4) of adult hyaenas. It was interesting to note that in the collections of hyaena-damaged bone examined punctate depressions and perforations were frequently present on one surface of the bone only;
- (4) *lunate or crescent-shaped fracture scars* (fig. 8a). Half of a punctate bite mark when the strength of the bite has been sufficient to split the bone

so that the fracture line passes through the punctate perforation. Lunate fracture scars are often associated with a "back flake", which detaches from the concave surface of the bone at the point of tooth impact (fig. 8b);

- (5) *striations or gouge marks* (fig. 9a, b). Usually short and straight and roughly perpendicular to the long axis of the bone, as illustrated and described by Sutcliffe (1970 fig. 4, left) who suggests that striations are the work of juvenile animals;
- (6) *contiguous or close, irregular and randomly-orientated grooves* (fig. 10). Often encountered at the ends of long limb bones, as illustrated by Sutcliffe (1970, fig. 4, right). These appear to be the result of more persistent gnawing than is the case in striations, which are shorter, more widely-spaced and incidental and do not cover such large areas of bone. For these reasons, it was decided to consider grooves as a separate category of bone damage;
- (7) *scooping or hollowing out* (fig. 11) of cancellous bone by incisors and canines as described by Sutcliffe (1970) and Brain (1980, in press: Chap. 4);
- (8) *acid-etching and erosion of bone* by hyaena stomach acids (fig. 12). This type of damage (Sutcliffe 1970: fig. 5) is encountered only on regurgitated fragments;

- (9) *splintering or shatter-cracking* ("comminuted fractures") (fig. 13). Such fractures are usually encountered as extremely jagged transverse breaks across the shafts of limb bones. This category does not correspond to the splintering of bones by adult spotted hyaena described by Sutcliffe (1970) where the term is used to describe fracture scars in general.

An average of 68 per cent of the bones accumulated by brown hyaenas and 80 per cent of bones collected by spotted hyaenas bore traces of one or more of these forms of damage, and 47 per cent of the bones from the striped hyaena den were affected.

An analysis of these hyaena-damaged bones showed that striations and ragged-edged chewing were the most frequently encountered type of damage, followed by lunate fracture scars, pitting, punctate marks, irregular grooves, splintering, scooping of cancellous bone, and acid-etching (fig. 14a-d). The frequency with which each type of damage occurs is to some extent controlled by the skeletal elements represented in the sample. For example: scooping of cancellous bone is confined to the epiphyses of limb bones and other bones possessing cancellous portions; striations are most commonly encountered on the shafts of the long limb bones; and acid etching is only encountered on small regurgitated bone flakes, fragments and isolated teeth.



Figure 5a. Four humeral shaft pieces from a recent striped hyaena lair, showing coarse ragged-edged gnawing typically seen on thick bone.

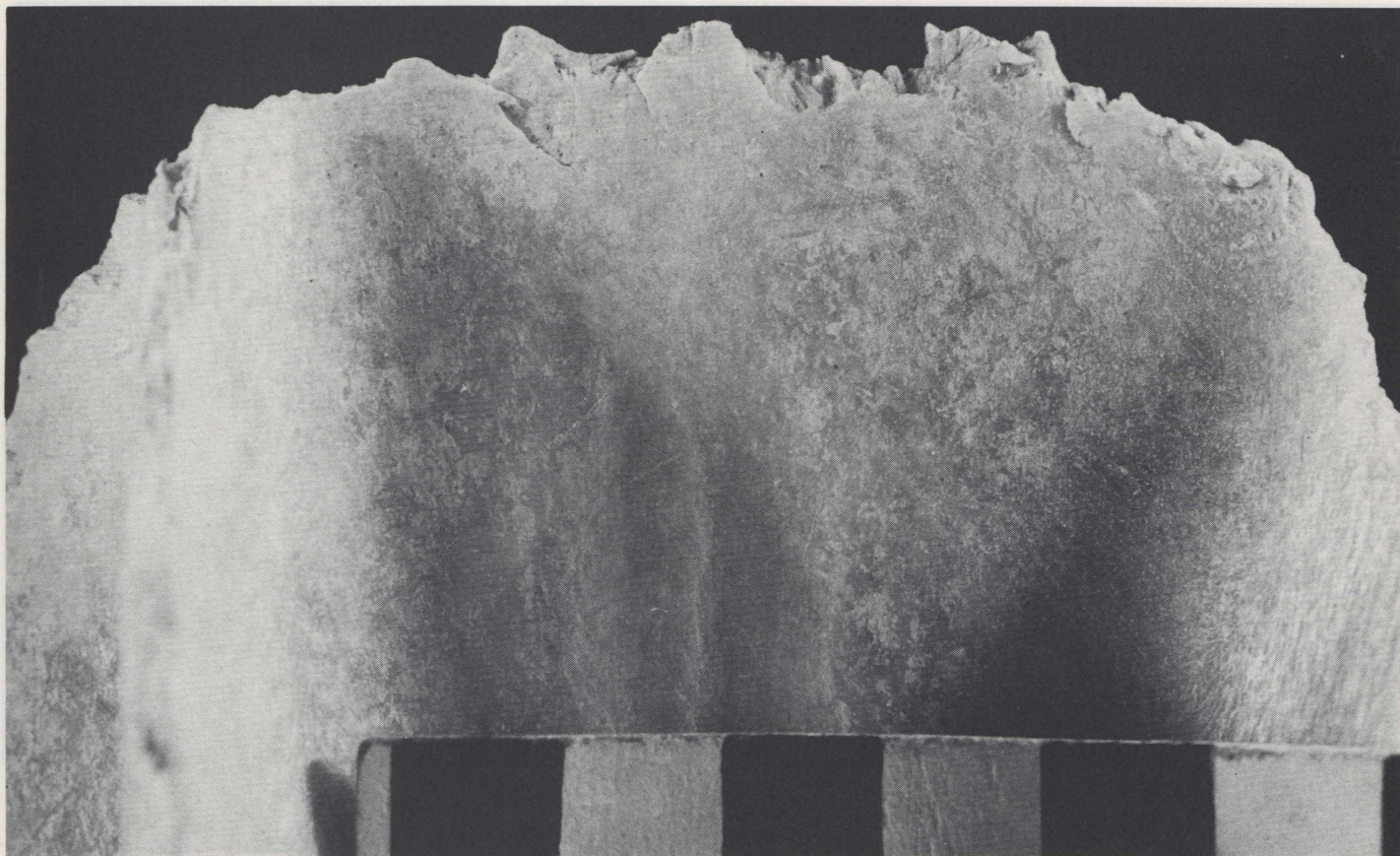


Figure 5b. Distal margin of bovid scapula blade from recent brown hyaena den showing fine ragged-edged gnawing typically seen on relatively fragile skeletal elements.



Figure 6. Distal end of bovid humerus from recent brown hyaena den showing localized pitting damage, probably caused by premolars of immature hyaenas.

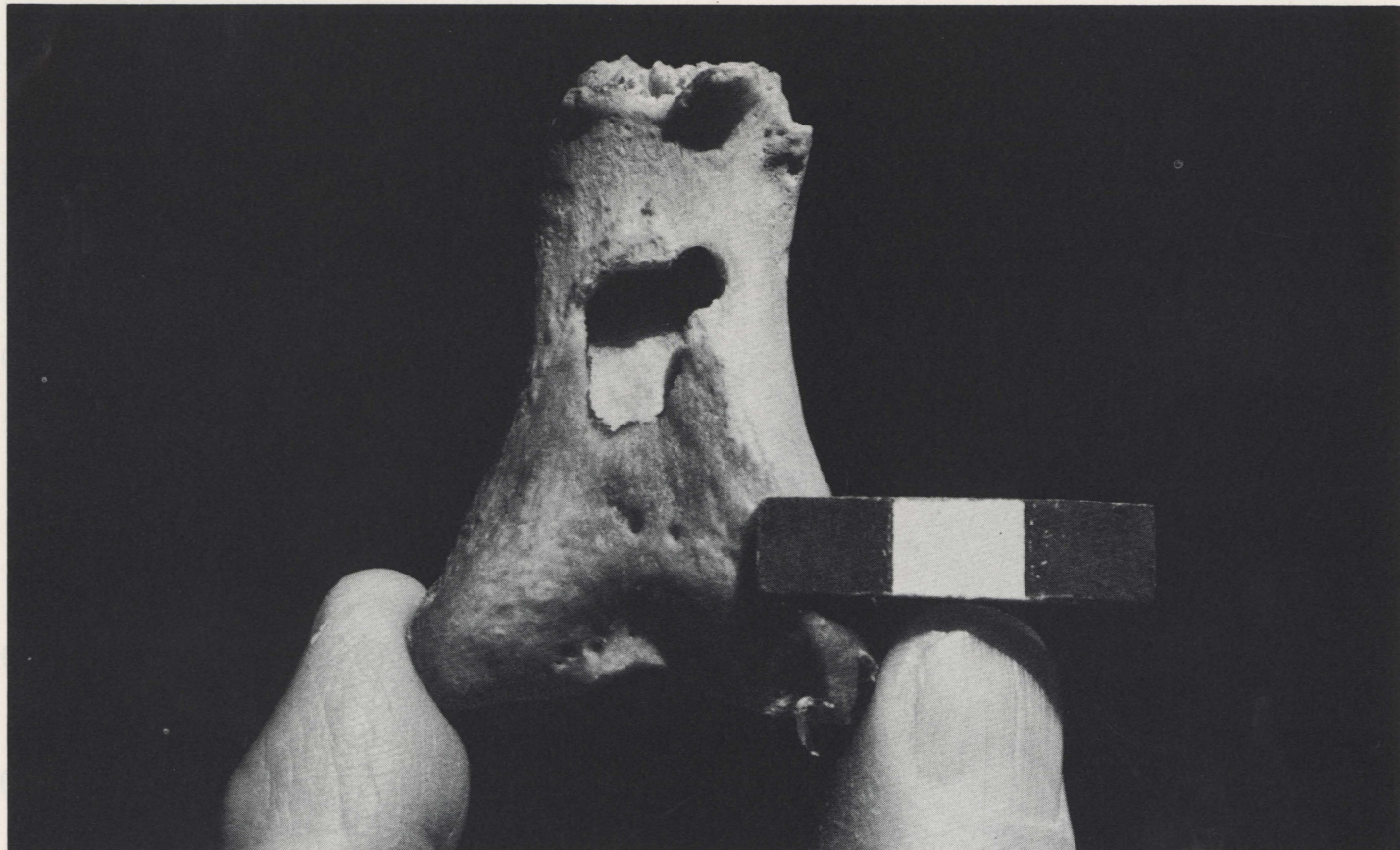


Figure 7a. Bovid phalange from recent striped hyaena den showing large punctate depression made by the robust bone-crushing premolars of an adult hyaena.



Figure 7b. Fossilized bovid scapula from the grey breccia showing several deep inwardly depressed punctate marks made by a carnivore.

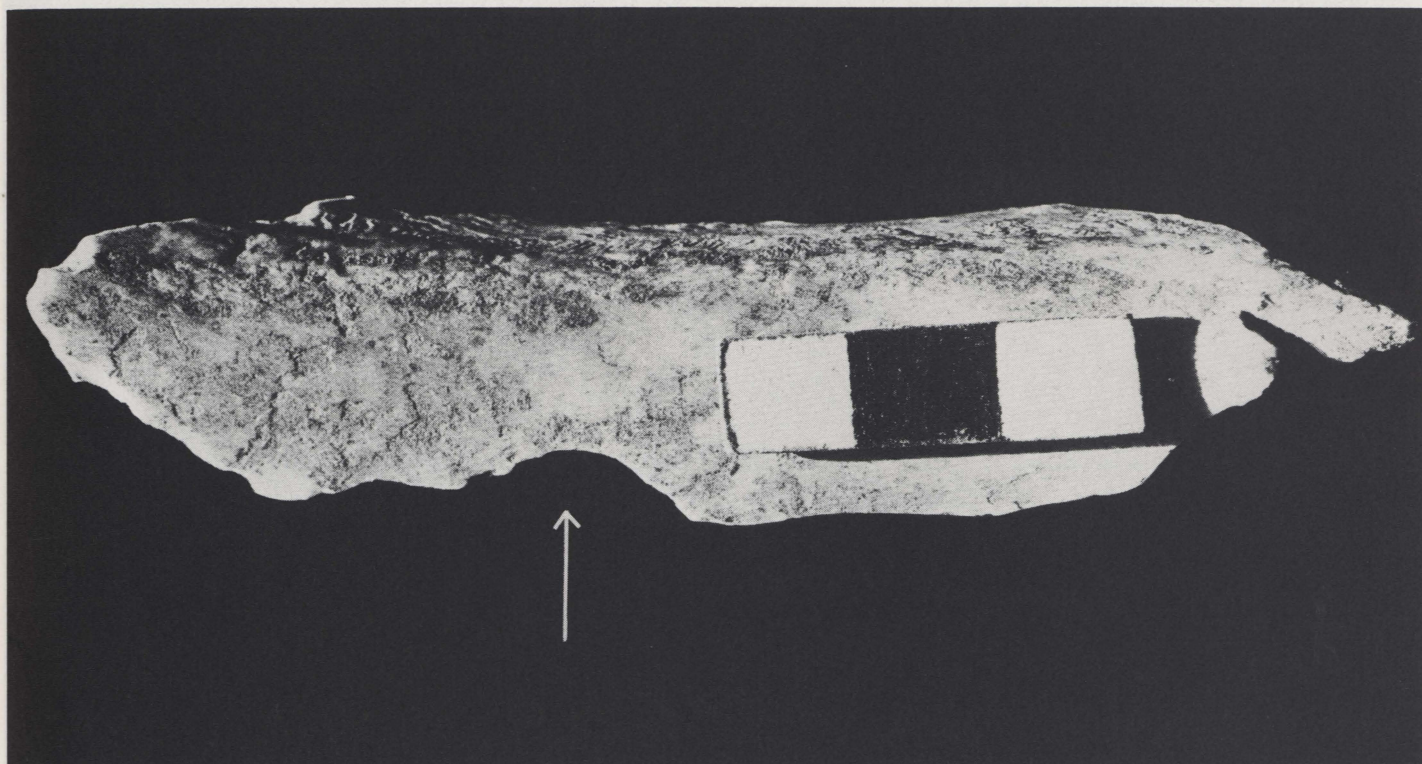


Figure 8a. Bone flake from recent spotted hyaena den showing crescent-shaped lunate fracture scar. The fracturing bite has been sufficiently powerful to split the bone so that the fracture line passed through a punctate perforation. The corresponding shaft fragment would bear a counterpart lunate fracture scar.

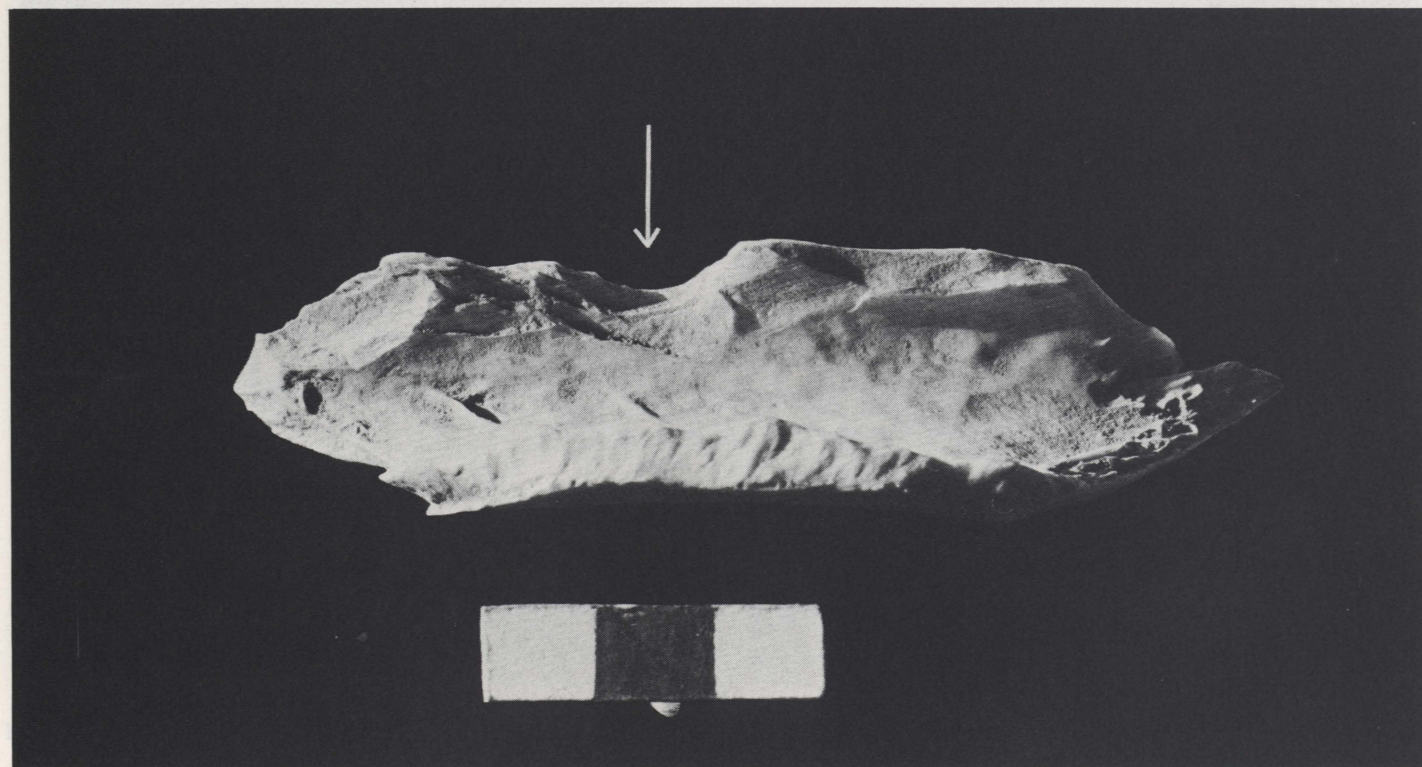


Figure 8b. Inner surface of the same specimen, showing "backflaking" which is commonly associated with lunate fracture scars.



Figure 9a. Bone flake from recent brown hyaena den showing several fairly widely spaced striations orientated at right angles to the long axis of the bone.



Figure 9b. Shaft of fossil bovid metapodial from the grey breccia showing striations similar to those made by recent hyaenas (fig. 9a).



Figure 10. Bovid mandible from recent brown hyaena den showing closely placed grooves, some of which run contrary to the long axis of the bone.

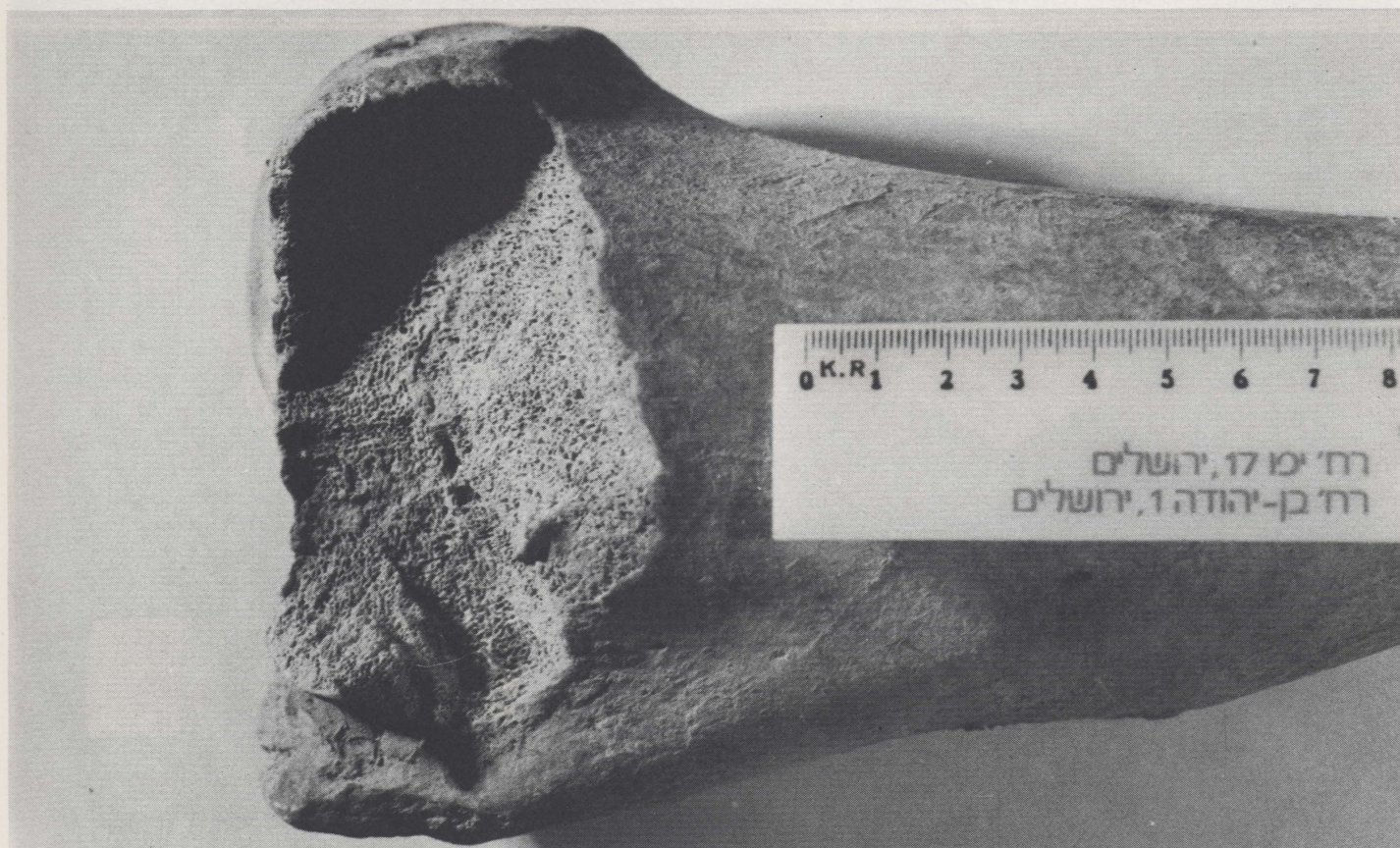


Figure 11. Proximal end of humerus recovered from recent striped hyaena den showing scooping out of cancellous bone by hyaena incisors. Note scrape marks made by incisors on the spongy tissue and the fact that the margin of the scooped out area is free of any other forms of hyaena damage.



Figure 12a. Bone flakes showing fine fissuring and etching of the surface caused by stomach acids of recent spotted hyaenas.

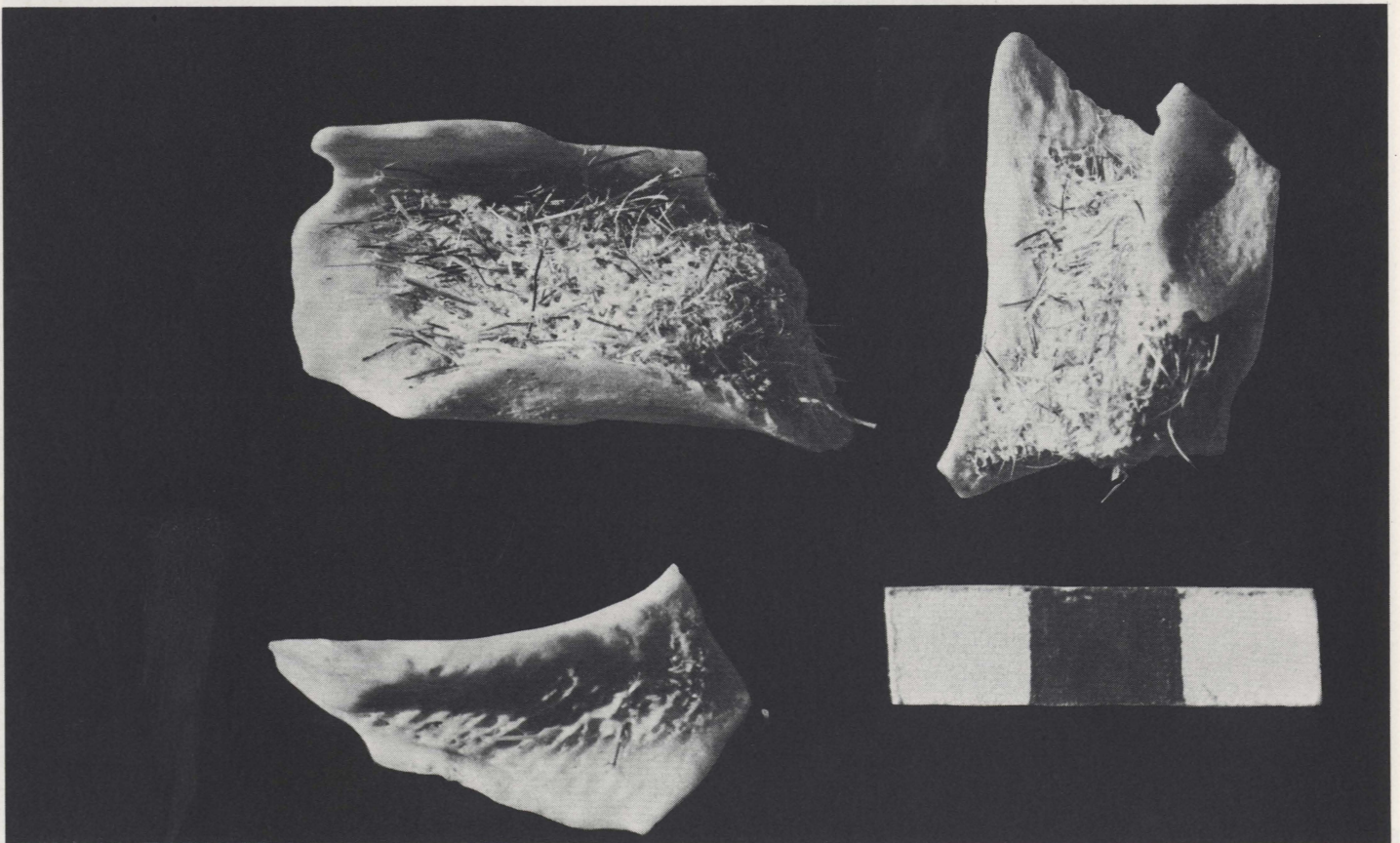


Figure 12b. Bone flakes showing how fracture margins have become smoothed and eroded by stomach acids of recent spotted hyaenas. Note how hair has become trapped in the remaining spongy bone tissue.

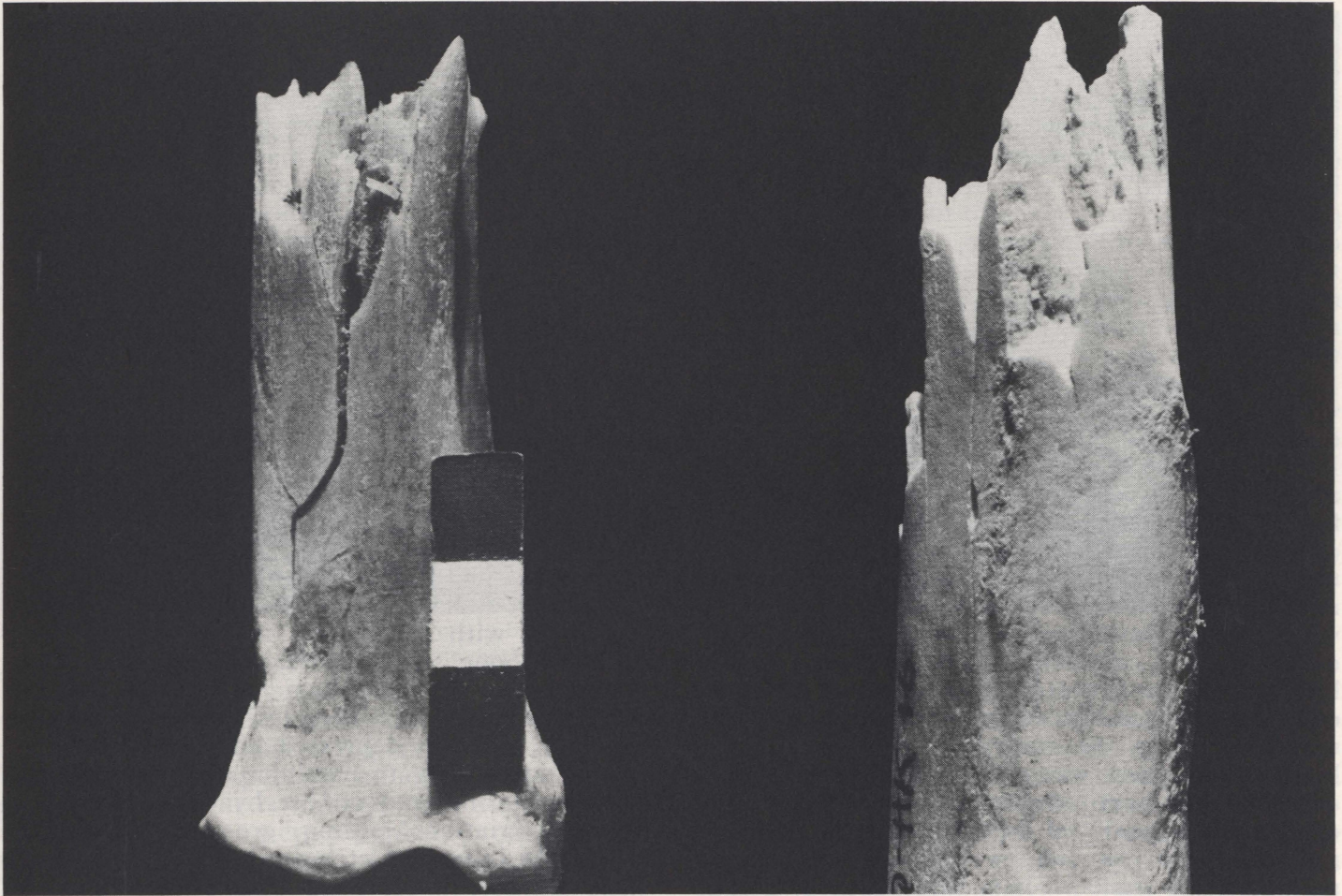


Figure 13. Splintering or comminuted fractures:
(left) radial shaft splintered by Topnaar Hottentots to obtain marrow;
(right) tibial shaft splintered by recent spotted hyaenas.

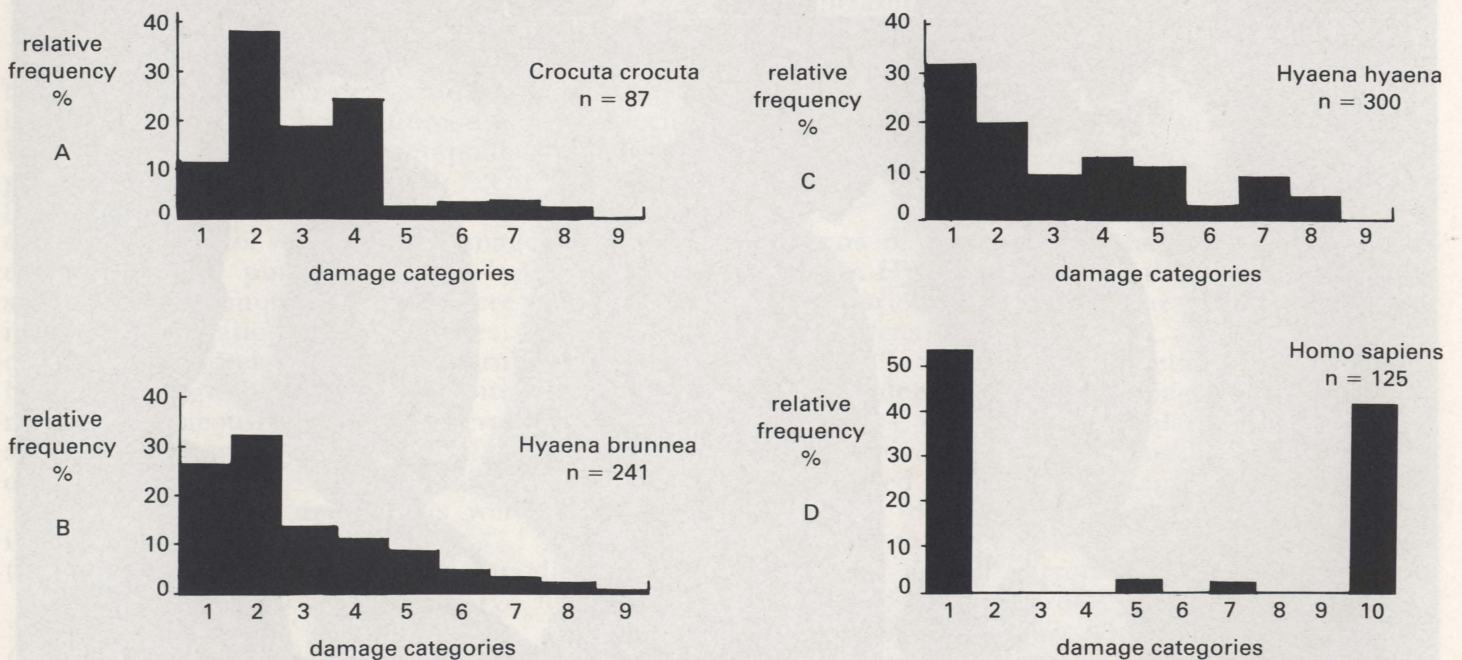


Figure 14. Results of an analysis of hyena-damaged and Hotentot-damaged bone assemblages. Damage category 1 = ragged-edged gnawing; 2 = striations; 3 = lunate fracture scars; 4 = pitting; 5 = punctate perforations; 6 = irregular groves; 7 = splintering; 8 = scooping out of cancellous bone; 9 = acid etching and erosion; 10 = cut and chop marks made by knives and choppers.

Humans as Bone-Damaging Agents

A control sample of bovid bones damaged by the teeth of a group of Topnaar Hottentots was analysed for evidence of "hominid damage" to establish if any categories of bone damage are produced in common by carnivores and humans. The bones examined were derived from a young male goat which had been given to the Hottentot villagers to eat in traditional style, the bones being retrieved before village dogs could superimpose carnivore damage (Brain 1976, 1980 in press). The results of a more detailed analysis (by J.M.M.) of the damage is shown in Figure 14d.

It was surprising to note that the Hottentots were capable of inflicting a considerable amount of damage on the goat bones with their teeth. Ragged-edged chewing, practically indistinguishable from that produced by hyaenas on the more frail skeletal elements, was observed in particular on the scapulae and pelvic bones (fig. 5b, 15). For this reason, ragged-edged chewing, if unaccompanied by one or more additional categories of carnivore damage on the same specimen, was not included in the calculation of average number of bones from the breeding dens showing carnivore damage, nor was it counted as evidence of carnivore damage in the analysis of the grey breccia bones. Splintering was also common to both the carnivore and hominid samples (fig. 13). The only other human-produced damage which in any way resembles that caused by hyaenas was impact marks on the shafts of long limb bones produced

by percussion. Sometimes such marks superficially resemble the carnivore punctate category (fig. 3, 16), but the punctates can usually be distinguished by the conical depression. When percussional impact has been sufficient to split a bone, the two halves of the impact point may resemble carnivore lunate fracture scars, particularly those on bone flakes. However, it is extremely seldom that carnivore punctates and lunates occur on their own without additional supporting evidence of carnivore damage: only three out of 451 in the case of punctates and six instances in the case of lunates. Nevertheless, comminuted fractures and punctate and lunate fracture scars were not counted as evidence of carnivore damage in the analysis of the grey breccia bones unless supported by additional evidence.

Two types of damage not encountered on the bones from the hyaena dens were found on bones from the Hottentot sample: crushing by human teeth and knife-produced cut marks. The former category of damage can be reproduced by repeated crunching with the molars and premolars on a fairly soft bone, such as a chicken limb bone or immature goat or sheep bone, after the articular epiphyses have been removed so as to leave a splintery, inwardly depressed margin to the shaft.

It is interesting to note that five categories of damage encountered on the hyaena-accumulated bones — striations, pitting, grooves, scooping of cancellous bone and etching by stomach acids — were not observed on the Hottentot sample. Al-



Figure 15. Goat pelvic bones showing fine ragged-edged damage produced by the teeth of Hottentots. Compare with Figure 5b.

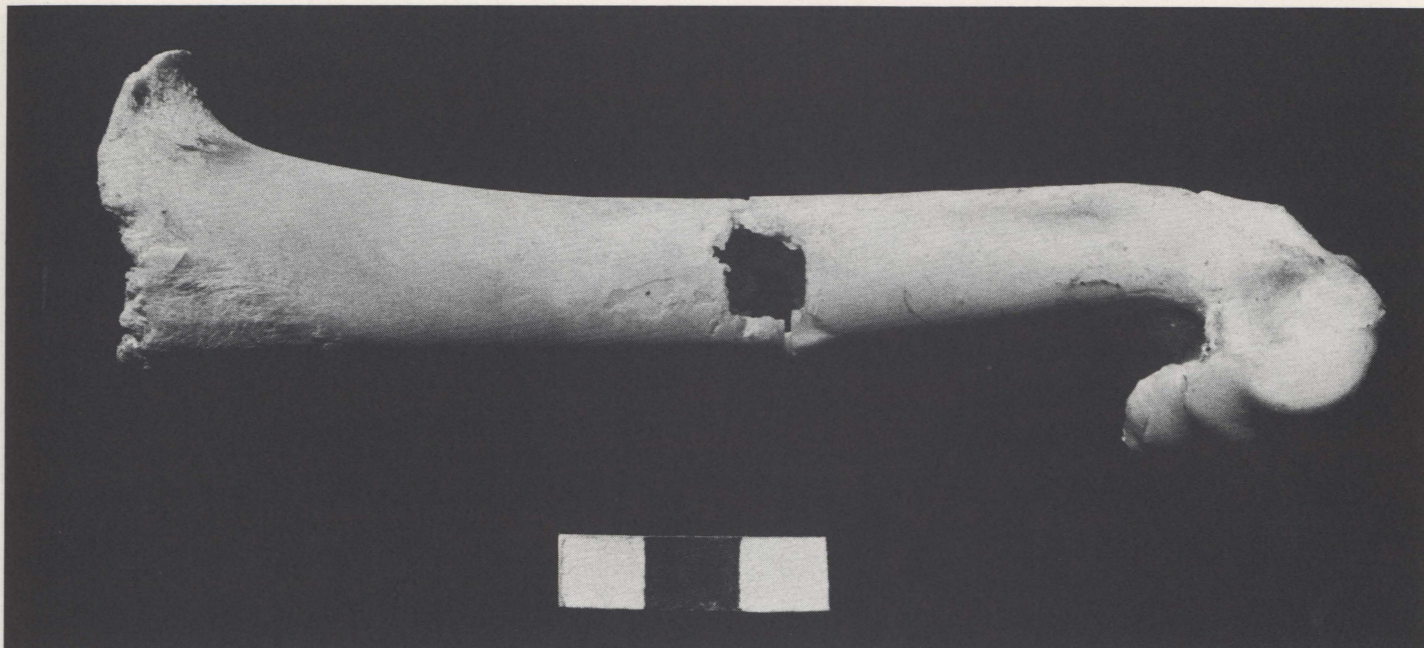


Figure 16. Goat humerus fractured transversely by a sharp blow from an unmodified stone on a stone anvil. The resultant fracture resembles carnivore punctate marks (fig. 7A).

though the teeth of *A. africanus* were larger and more robust than those living Hottentots and were thus potentially capable of inflicting a greater degree of damage, it is unlikely that the bunodont teeth of this species were capable of producing pitting, striations, grooves or scooping damage. There is certainly no basis for attributing such damage to the teeth of hominids when it can be demonstrated conclusively that carnivores can and do produce such damage.

Evidence of Carnivore Damage on Bones from the Grey Breccia

All nine categories of damage observed on the bones from the hyaena dens can be demonstrated in identical form on bones from the grey breccia. In a sample of 2 000 fossil metapodials and metapodial flakes, between 25 per cent (including flakes) and 30 per cent (excluding flakes) bore clear evidence of carnivore damage. (Ragged-edged gnawing, punctate marks, lunate fracture scars and comminuted fractures were not included in these calculations). Bone flakes characteristically show a lower incidence of carnivore damage because a single bone-fracturing bite by a hyaena may simultaneously produce several bone flakes, some of which will bear no trace of carnivore tooth damage at all.

Metacarpals and metatarsals were chosen for initial investigation because:

- (a) the cylindrical shafts of the metapodials are robust and well preserved in large numbers in the grey breccia;
- (b) striations are commonly found on the shafts of long limb bones, including the metapodials;
- (c) striations are amongst the commonest form of hyaena damage, and they are considered to be reliable evidence of carnivore damage.

Microscopic examination showed that it is easy to distinguish between striations caused by carnivore teeth and those caused by slips of the punches used in preparing the fossils. Real striations frequently contain particles of breccia or minute amounts of calcite crystals, but the scratches caused in preparation have a fresh clean appearance.

The severity of weathering which a high percentage of the fossil bones appear to have suffered may have substantially reduced the percentage of recognizable carnivore-damaged bones, certain categories of damage being more prone to obliteration than others. Because weathering frequently takes the form of exfoliation of the outer layers of bone, striations are amongst the more vulnerable forms of damage.

Patterns of Fracture of the Skeletal Elements from Hyaena Dens and the Grey Breccia

The various skeletal element categories from the hyaena dens showed distinct and recurrent patterns of fracture, each skeletal element having hyaena-vulnerable and hyaena-resistant portions. Horn picks, cranial bowls, palatal scrapers, mandibular knives, spirally fractured humeri, polished and pointed flakes, etc., such as Dart (1957 and elsewhere) described from the grey breccia and attributed to manufacture and/or use by australopithecines, are all mirrored in similar form in the collections of bone from the hyaena lairs (figs. 17–19). The frequency with which each type of skeletal element fracture pattern occurs has yet to be calculated for both recent carnivore and hominid bone accumulations.

It is important to note that not all of the forms of bone damage and fracture documented by Dart



Figure 17. Bovid cranial fragments from recent spotted hyaena dens which closely resemble the "cranial bowls" described by Dart (1962).

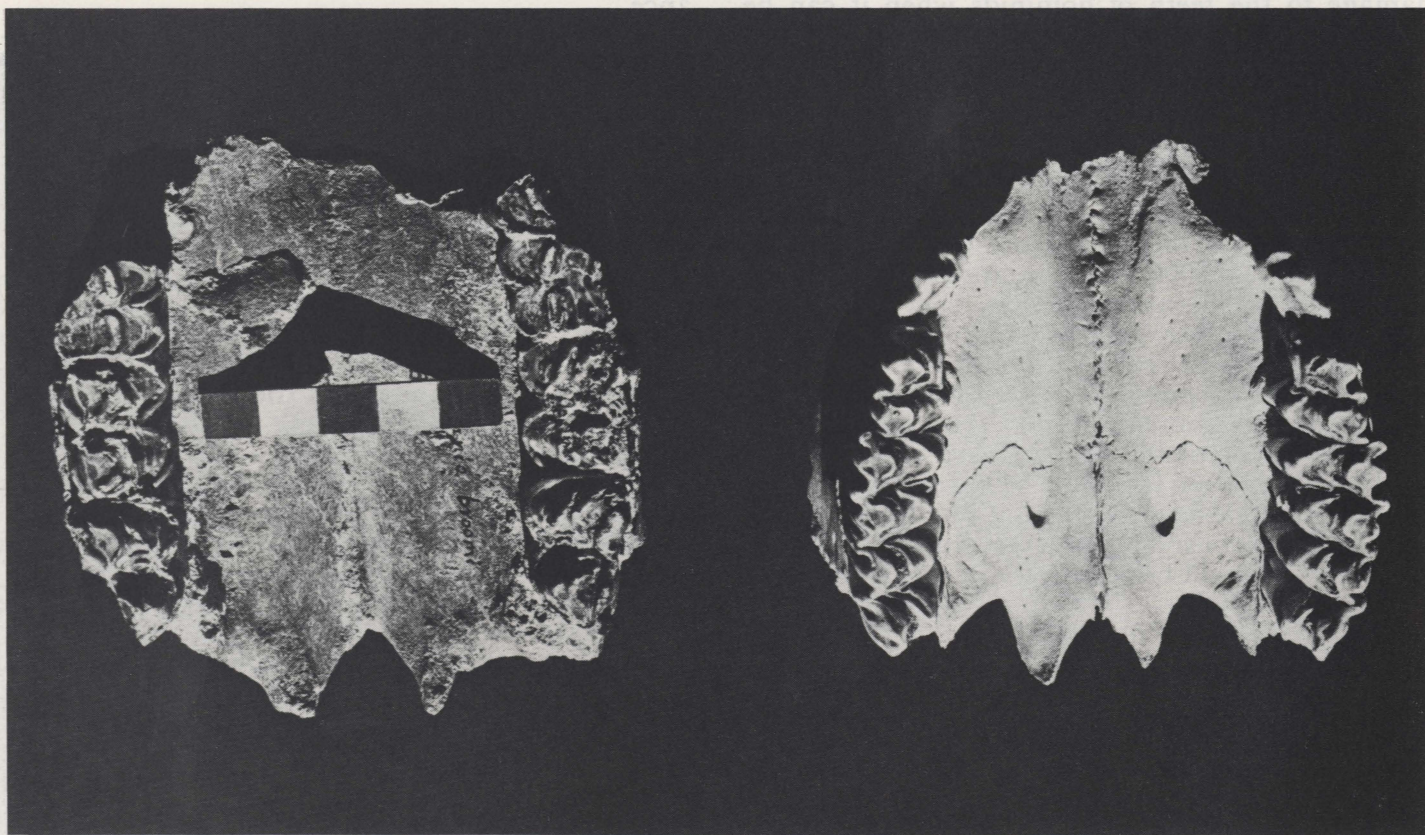


Figure 18. Maxillary fragments resembling the "palatal scrapers" described by Dart (1957):
 (left) palate of the fossil bovid *Makapania broomi* from the grey breccia;
 (right) bovid palate from a recent spotted hyaena den.

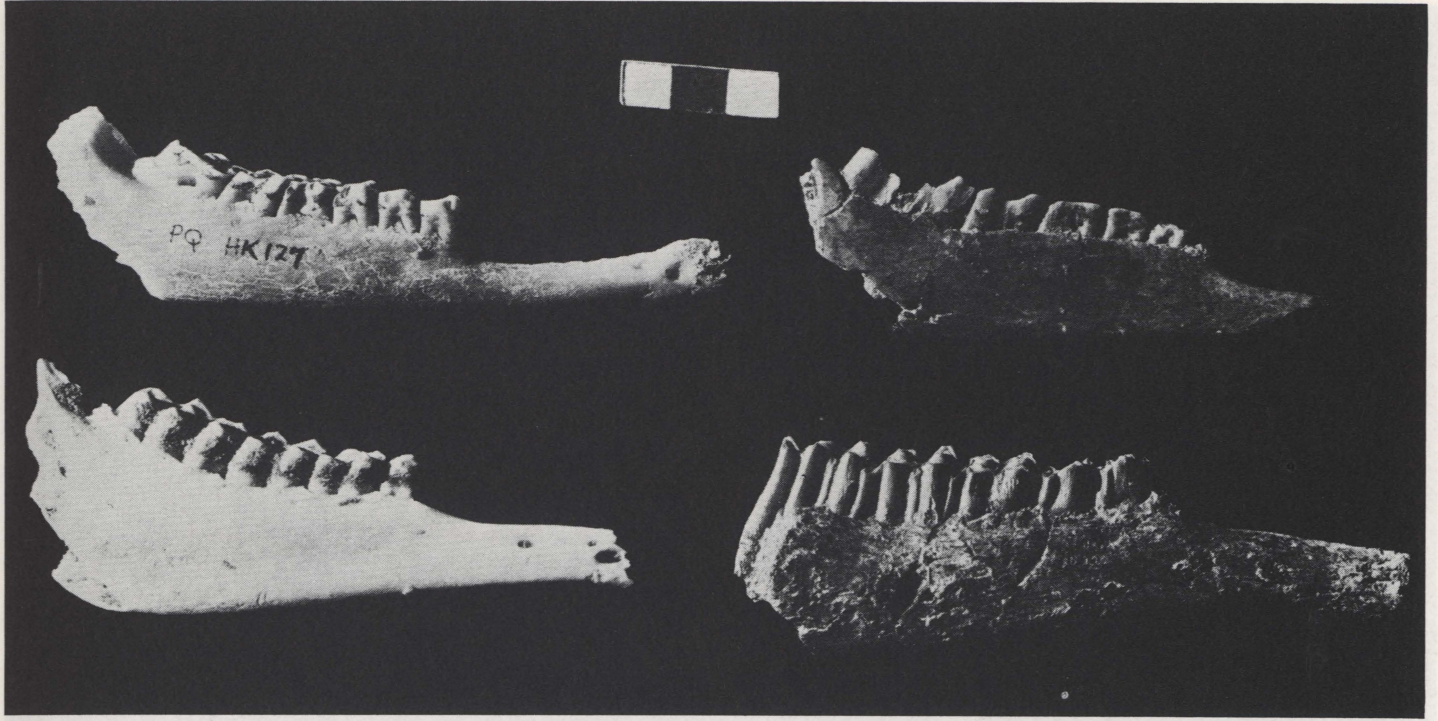


Figure 19. Fragmentary bovid mandibles removed from recent hyaena dens (left) which closely resemble fossil "mandibular knives" (right) described by Dart (1957).

were encountered in the hyaena-accumulated bone sample. For example, neither bone-in-bone fragments such as those described by Dart (1965a, 1965b) and Tobias (1968, 1971), nor locally-tapered "thong stretchers" (Kitching pers. comm.) were found, nor were any fragments found showing evidence of localized pounding, such as those reported from the grey breccia (Dart 1965c). The demonstration of localized pounding damage may well prove to be a useful way of demonstrating the presence of hominid activity, since this type of damage appears to be absent from both carnivore and porcupine bone accumulations. One possible explanation for the absence of bone-in-bone fragments from hyaena dens is that no bone-concentrating mechanism has yet been active at the lairs investigated. The question of localized wear on both the recent and fossil fragments requires further study.

Porcupines as Bone Accumulators and Bone Damaging Agents

Most of the published data on the characteristics of porcupine-collected bones have been taken from contaminated collections, that is, agents other than porcupines have also been operative (Hughes 1958, Hendey and Singer 1965, and Brain 1980, in press). The Hartebeesthoek porcupine lair (Maguire 1976), on the other hand, has offered an opportunity to isolate the effect of porcupine damage from that of any other bone-damaging agents, particularly large carnivores. Systematic collections have been made at the lair annually for nine years. The rate of accumulation is about 55 bones per year, but this is likely to

have been limited by the availability of bone. Only two types of damage are present:

- (1) gnawing by the broad, chisel-shaped upper and lower incisors, which takes the form of broad, contiguous shallow scrape marks (fig. 20);
- (2) scooping or hollowing out of cancellous bone; this is usually accompanied by type (1) damage around the margin of the scooping and elsewhere on the bone (fig. 21). Superficially it resembles carnivore scooping of cancellous bone (fig. 11), but type (1) damage is invariably also present.

Well over 90 per cent of the bones from this particular lair showed clear evidence of porcupine damage. Punctate marks, lunate scars, pitting, striations of the carnivore type, comminuted fractures and so forth were not observed.

The sample of 2 000 grey breccia bones examined showed that less than 2 per cent of the bones bore evidence of porcupine damage. Since porcupine gnawing cuts more deeply into the bone than do most categories of hyaena damage, it is not likely that much evidence of gnawing has been obliterated by weathering. In fact, where evidence of porcupine gnawing occurs on fossil bones, it is clear and unmistakable (fig. 22).

Sufficient bones have now been collected from Hartebeesthoek (between 400–500) to enable degradation sequences for each skeletal element to be studied. The patterns are totally different from those observed on corresponding skeletal elements from the Limeworks grey breccia. Of particular note is the failure of both the proximal and distal articular ends of limb bones to survive, so that



Figure 20. Series of humeri gnawed by recent porcupines. Note that both articular ends are prone to destruction by porcupine gnawing, and that there is no evidence of any fracturing. Note also the irregular shapes resulting from such gnawing damage and the groove-like scars produced by the incisor teeth. Tubular shaft-pieces are the typical end result of porcupine gnawing of limb bones.

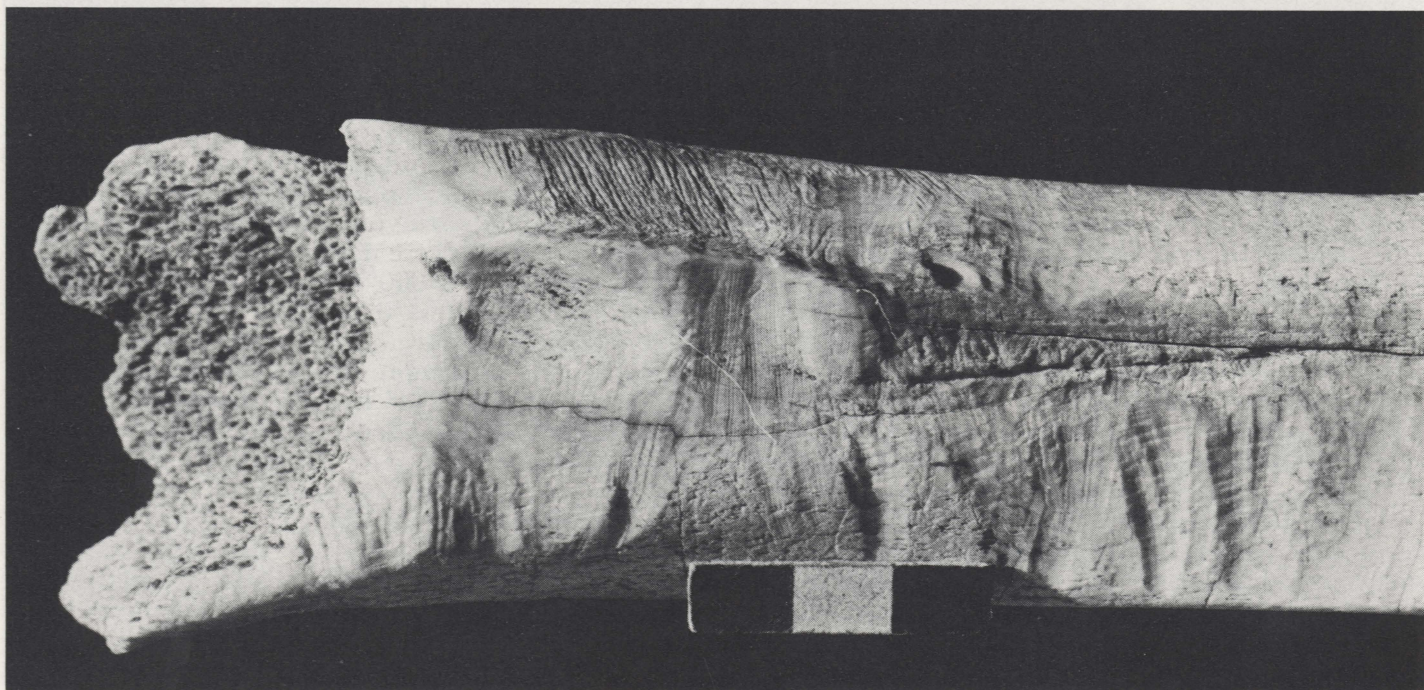


Figure 21. Radius from recent porcupine lair showing scooping out of cancellous bone by porcupines, which closely resembles that done by hyaenas (fig. 11). However, the margins of the scooped out area show extensive porcupine gnawing as does the rest of the radial shaft.



Figure 22. Fossilized bovid femur from the grey breccia showing gnawing by an extinct porcupine.

tubular shaft pieces are very common (fig. 20). Furthermore, it is clear that porcupines are incapable of splitting or cracking the shafts of limb bones, so that bone flakes are exceedingly rare in porcupine-collected bone accumulations.

VIEWPOINT B: BONE CONCENTRATION

Investigations on the possible mechanisms of concentration of the bones have not yet been completed. So far these have centred on three aspects: an investigation of the 3-dimensional topography of the travertine floor (Member 1), particularly in the vicinity of the remaining *in situ* remnant of grey breccia; stereographic analyses of the long axis dip and strike orientations of individual bones in the grey breccia; and breccia block dismantling to establish bone-matrix relationships, the sedimentological characteristics of the matrix and the degree of weathering exhibited by associated bones.

Structural Control and its Influence on Bone Concentration

The shape of the undulating travertine floor (Member 1) of the Limeworks as seen in sections drawn by Brain (1958) and Partridge (1975) indicates floor "highs" and "lows". In an attempt to reconstruct this floor topography a 3-dimensional computer plot was produced, using the SURFACE TWO GRAPHICS SYSTEM designed by the Kansas Geological Survey. One hundred and sixty-five x - y - z

data points obtained from Partridge's (1975) transects criss-crossing the Limeworks deposit were used as base data (fig. 23). Each grid node is calculated by a distance-weighted average of the sample points found by a nearest neighbour search around that grid intersection. The weighting function used is inverse distance ($1/D$). The highs and lows in this plot cannot be exaggerated because it is not possible for an average to lie outside the range of values from which it was calculated. The data were smoothed over three columns and three rows. The x axis represents a distance of 81,2 m, the y axis 71,8 m. The scale of x and y are equal and the z axis is scaled to 50 per cent of the maximum range of x and y . The viewing angle is 35° E of South, and the elevation above the horizon is 35° . The distance from the viewer to the centre of the object is 10 000 matrix units.

The floor highs form an amphitheatre around the area in which the grey breccia accumulated (marked by an arrow and a 'G' in fig. 23). This may have been a significant factor in bone concentration. It has been suggested by Brain (1958) that the seasonal fluctuation of the water table up and down this floor high may have assisted in concentrating the bone in its present position. The position of the high in relation to the grey breccia also suggests that gravity could have caused bone to slide down the slope to form a talus collection at the bottom. For this to happen bone would first have to accumulate on the lip of the high.

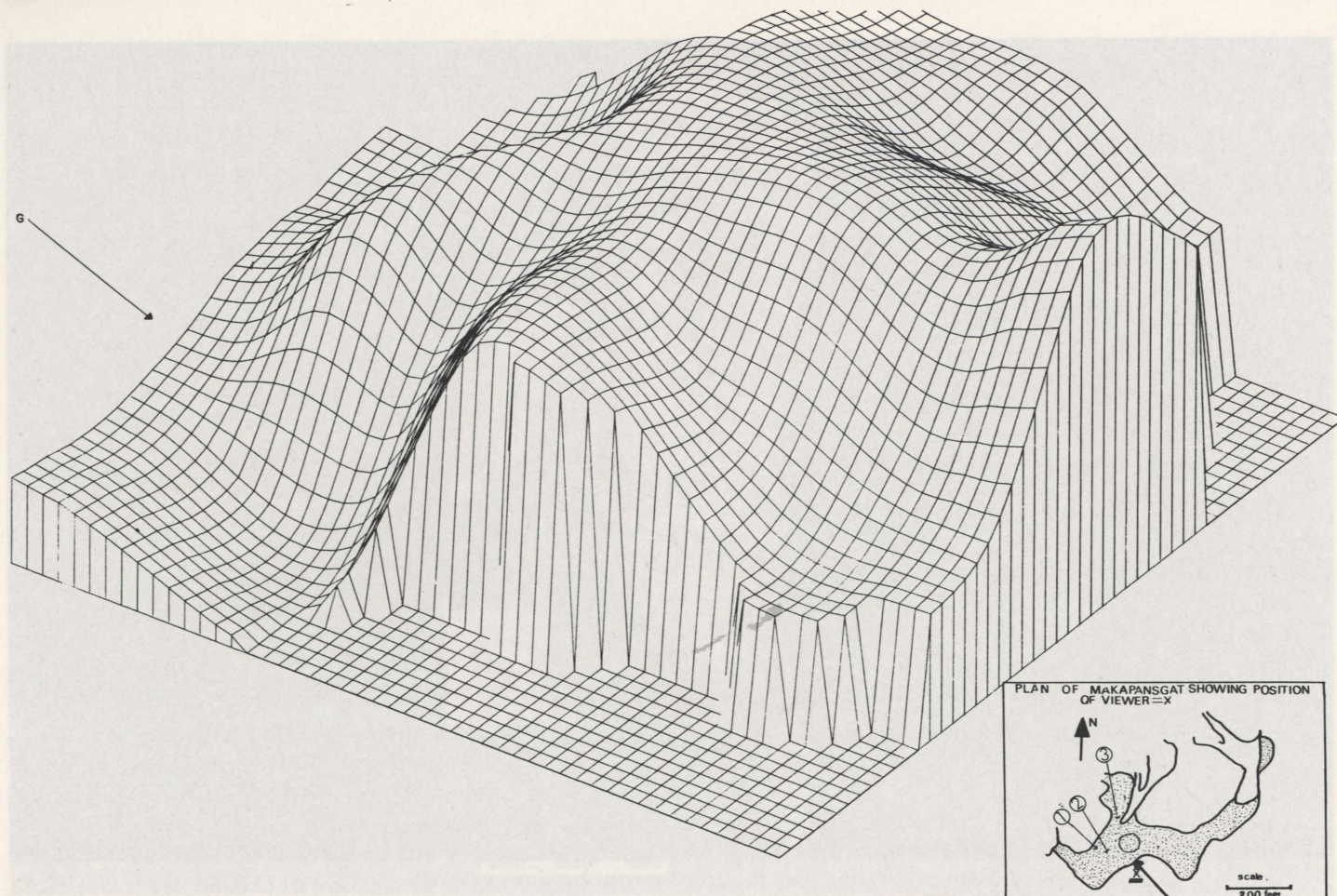


Figure 23. Three-dimensional computer plot illustrating the original configuration of the Makapansgat Limeworks travertine floor. Note the amphitheatre of floor high surrounding the area of deposition of the grey breccia (area G) and the four basins separated by floor highs.

It is important to note that Member 2 would have only partially filled the two basins in this area of the cave.

The 3-D plot has also revealed the presence of four separate basins separated by floor highs. The sedimentary histories of these basins need not have been synchronous or equivalent. Consequently, equating Members or Beds from one part of the cave to another is inadvisable.

Bone Orientation and Stereographic Projections

The orientation of fossils in a deposit is often graphically depicted by means of a rose diagram, but this approach is suitable only if the fossils all lie in the same plane (Toots 1965: 220). Three-dimensional data, such as the orientations of bones in the Makapansgat Limeworks grey breccia, are better presented by means of stereographic projections, a type of spherical projection which portrays the data in two dimensions. Figures 24–26 are stereographic projections on which the pole of the axis of each long bone on the lower hemisphere is shown by a dot. The term “long bone” refers to bones which have a length-to-width ratio of at least 3:1. Points around the circumference of the circle (the projection plane) represent bones that are horizontal, whereas points near the centre

represent bones that approach the vertical position.

Dip and strike orientations of long bones from two separate areas of *in situ* grey breccia (Member 3) were determined using a Brunton compass. The first area was close to the western wall of the Limeworks cavern, the second between this wall and the stalactite fringe where *in situ* grey breccia adheres to the original dolomite roof (fig. 23, localities 1 and 2). Approximately 45 readings were taken at each locality. Orientation data were also recorded for an exposure of manganese-blackened bones in Member 2 on the western face of the Main Quarry (fig. 23, locality 3). There appears to be incontrovertible evidence (Brain 1958, Partridge 1975, 1979) that Member 2 has been water laid; it was thus of interest to determine the orientation pattern of bones preserved in it.

Figure 24 shows the orientation data for bones situated against the western wall of the Limeworks cavern; the scattered occurrence of points indicates a random orientation. This is most probably due to current eddies and lag alongside the irregular surfaces of the wall in this part of the cavern.

In Figure 25, however, there is an apparent concentration of points in the south-west and north-east quadrants, with few points in the north-west and south-east. The lack of points at the centre in-

dicates that there are no vertical bones, the lack of points at the circumference indicating that few bones are horizontal. The remaining points indicate that the greatest number of bones dip between 10° and 30° . Potter and Pettijohn (1963) have demonstrated that stereographic patterns similar to the one illustrated (fig. 24) are the result of the combined action of gravitational and water forces. Unless future research demonstrates that similar orientation patterns can be fortuitously produced in bone accumulations made by the biological bone-accumulating agents, it would appear that gravitational and water forces in combination were responsible for the orientation of the grey breccia bones in this part of the deposit.

It has frequently been pointed out (Seilacher 1960, Toots 1965) that the long axes of bones may be orientated either parallel to the current direction or at right angles to it. Long limb bones with one end markedly heavier than the other usually take on the former type of orientation, and those bones that tend to move by rolling usually become orientated transverse to the current. The concentration of points in a stereographic projection of bone deposits which have this dual orientation usually takes the form of a cross (e.g. Voorhies 1969: fig. 9). However, Figure 25 shows only one set of orientation data. The problem is to determine whether the pattern represents bones which lie parallel to the current or transverse to it. The former seems more likely. If the latter were true, it would mean that the current would have had the dolomite wall of the cavern as an obstacle; furthermore, a visual appraisal of the bones them-

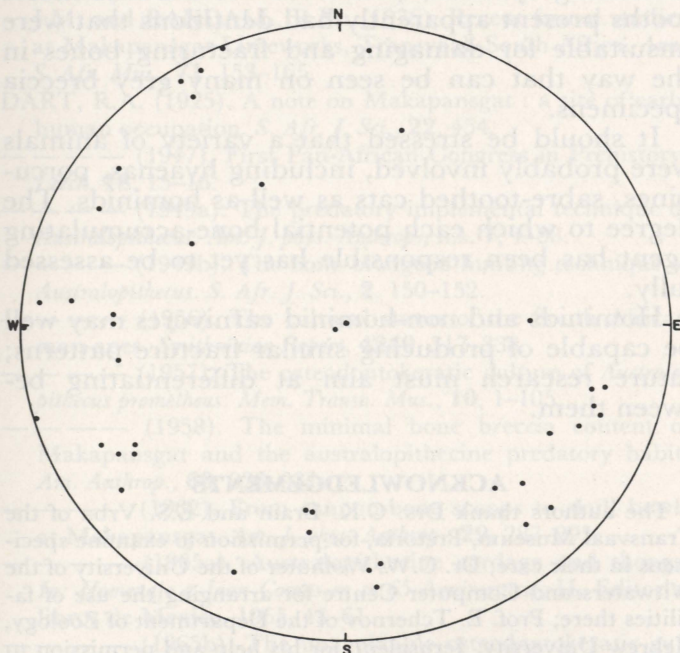


Figure 24. Stereographic projection of bone orientations in the grey breccia in contact with the western wall of the Limeworks cavern. The scattered pattern of points indicates a random orientation of the long axes of bones, which is probably due to current eddies and lag alongside the irregular surface of the cavern wall in this area.

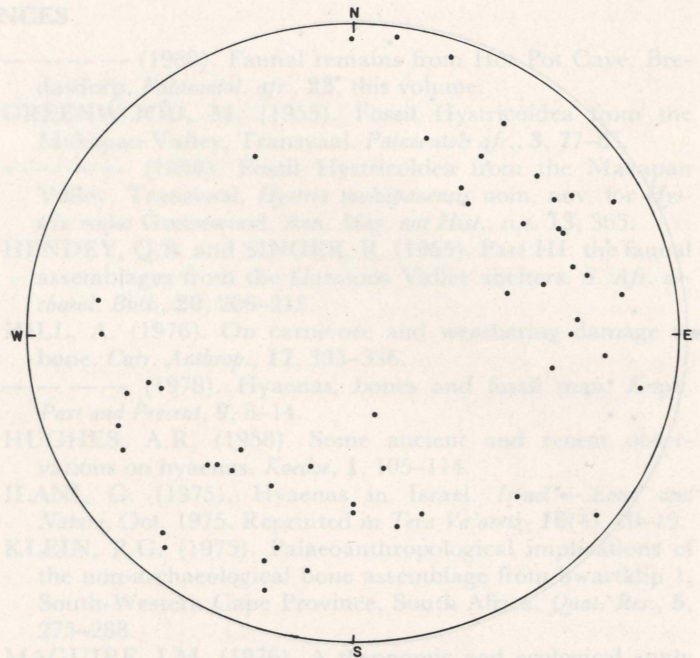


Figure 25. Stereographic projection of orientation for *in situ* grey breccia bones between the western wall of the Limeworks cavern and the fractured stalactite fringe (fig. 3, 4). The concentration of points in the south-west and north-west quadrants suggests that the combined action of gravitational and water forces may have been responsible for the observed orientation pattern.

selves showed them to be predominantly long limb bones, which characteristically orientate parallel to the current (Voorhies 1969). As yet, it cannot be said with certainty whether this current flowed south-west or north-east, but the former current direction appears to us more likely.

Figure 26 is a stereographic projection of the orientation of blackened bones in Member 2 exposed on the western face of the Main Quarry (fig. 23, locality 3). There is a marked concentration of points in the north-west sector, indicating that the great majority of bones were orientated in this direction, dipping at an angle of 15° – 20° in approximate conformity with the slope of the travertine floor in this part of the cave. The explanation for this uni-directional orientation probably lies in the fact that the bones lay on or close to the sloping travertine floor. The force of gravity, possibly in conjunction with a stronger water current because of the slope, influenced their orientation more strongly than was the case in locality 2 where the bones are at a greater distance from the travertine slope. The different current direction, from the south-east to north-west, is expected in terms of the floor topography in this part of the cave.

It is suggested that bone concentration by flowing water took place intermittently, quieter periods alternating with fairly vigorous flows which could have carried the bones of dismembered carcasses off the floor high and adjacent areas towards the back of the cave.

The presence of coprolites and insect pupae as components of the grey breccia admittedly appears

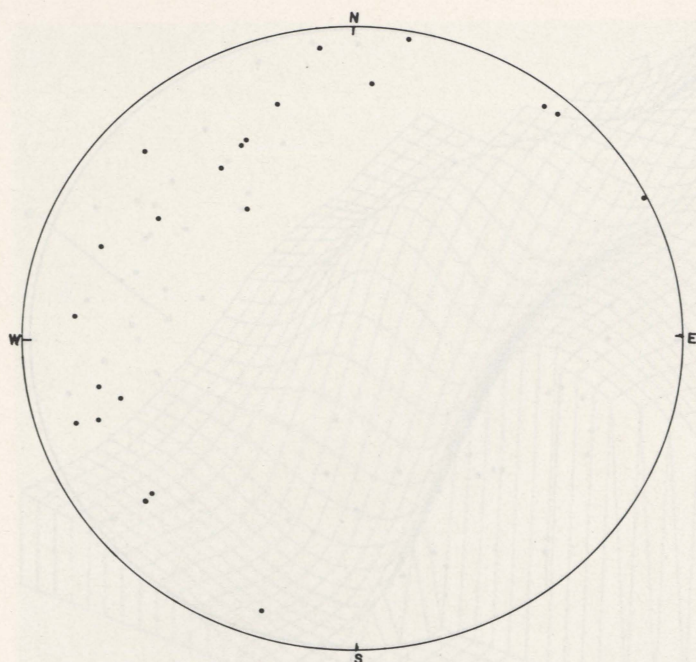


Figure 26. Stereographic projection indicating orientation of the blackened bones exposed in Member 2 on the western face of the main quarry. The marked concentration of points in the north-west sector indicates that most bones had their long axes orientated in this direction, dipping at an angle of between 15° and 20° .

to contradict the presence of water. However, their geological context has been destroyed; the grey breccia-derived specimens came from blocks of breccia discarded on the hillside as miners' waste. Furthermore, some of the "grey" breccia blocks in which insect pupae have been found are noticeably different from typical grey breccia seen in the *in situ* exposures. Partridge (1979) suggests that, "Between sheetfloods decomposing carcasses attracted carrion flies. The restricted roof height and distance from the cave opening argue against any lengthy occupation of this area by predators or scavengers; such creatures probably concentrated their activities near the cave mouth. Their coprolites could have been incorporated in the deposit during episodes of quieter flow".

DISCUSSION

The question of the origin of the grey breccia has been considered from two viewpoints: bone-accumulating agents and bone-concentrating agents. Water current action has been considered as a possible bone concentrating mechanism. Amongst the nine possible significant bone-accumulating agents attention has focused on hyaenas and porcupines.

In view of the presence of no fewer than three species of fossil porcupines, the extremely low percentage of gnawed fossil bones is surprising. Since the patterns of damage in well-documented porcupine lairs are not matched by skeletal elements from the grey breccia, it is concluded that porcupines had little to do with accumulating the grey breccia bones.

Nine categories of surface bone damage were noted on collections of bone retrieved from dens of extant striped, brown and spotted hyaenas. There appear to be no differences in the ways in which the three extant species of hyaena damage the surfaces of the bones they collect. All nine categories of carnivore damage could be demonstrated in the sample from the grey breccia. Between 25 per cent and 30 per cent of the sample was clearly damaged by carnivores. A substantial amount of carnivore damage may have been obliterated from the fossil bones by weathering.

The patterns of fracture of the various skeletal elements collected by the three species are likewise similar.

The patterns observed in collections from extant hyaena dens are, in many cases, mirrored in skeletal elements from the grey breccia.

It is concluded that fossil carnivores have played a more substantial role in the accumulation of the Limeworks grey breccia than has previously been acknowledged. However, by no means all the damage on the grey breccia bones can be explained in terms of carnivore damage. Bone-in-bone fragments, pounding damage, and tapered and polished bones may have been manufactured by hominids. Nevertheless, there no longer appear to be valid grounds for apportioning the major part of the responsibility for accumulating and fracturing the grey breccia bones to *Australopithecus*.

Amongst the carnivores the giant hyaena, *Hyaena cf. brevirostris*, or the fossil striped hyaena, *H.h. makapani*, were the most likely bone-accumulators. Leopards are as yet unknown in fossil form from the grey breccia, and the false and true sabretooths present apparently had dentitions that were unsuitable for damaging and fracturing bones in the way that can be seen on many grey breccia specimens.

It should be stressed that a variety of animals were probably involved, including hyaenas, porcupines, sabre-toothed cats as well as hominids. The degree to which each potential bone-accumulating agent has been responsible has yet to be assessed fully.

Hominids and non-hominid carnivores may well be capable of producing similar fracture patterns; future research must aim at differentiating between them.

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