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Managing paleoanthropology's nonrenewable resources: a view from Afar

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Abstract

Decades of research at major paleoanthropological sites in eastern Africa have shown that the archaeological and paleontological resources they contain are effectively non-renewable given geomorphological and geographical constraints. The landscapes of these fossil fields were produced by centuries of erosion. Once the antiquities are collected from the lag deposits armoring the sediments, active erosion is insufficient for timely replenishment. This means that only the first few collection bouts at any given locality will be rewarded with impressive yields of fossils. The occasional exposure of better-preserved specimens from the few available actively eroding slopes will follow as yields drop. The Middle Awash project is attempting to quantify these phenomena and thereby generate information to assist in long-term site management. A cast-recapture experiment has been designed to monitor collection efficiency, and collection cycles have been instituted to monitor the rate of fossil exposure. ***To cite this article: T.D. White, C. R. Palevol 3 (2004).***

Résumé

La gestion des ressources non renouvelables de la paléoanthropologie : perspectives de l'Afar. Les décennies de recherches conduites en Afrique orientale sur quelques-uns des principaux sites paléoanthropologiques indiquent que leurs contenus archéologique et paléontologique constituent des ressources non renouvelables, pour des raisons géomorphologiques et géologiques. Les paysages qui hébergent ces sites fossilifères ont été façonnés par des siècles d'érosion. Lorsque que les cuirasses sédimentaires à l'affleurement sont exploitées, l'érosion en cours ne permet pas le renouvellement de leur contenu fossilifère dans des délais raisonnables. Ceci implique que, pour chaque localité, les toutes premières phases de prospection obtiendront un rendement impressionnant en termes de fossiles collectés. Puis, lorsque les découvertes deviennent plus rares, les quelques pentes activement érodées fournissent occasionnellement des spécimens mieux préservés. Le *Middle Awash project* essaie de quantifier ces phénomènes, afin d'obtenir des données qui permettront une gestion à long terme des sites fossilifères. Une expérience en cours, impliquant la dissémination et la redécouverte de moulages sur le terrain, permettra de tester l'efficacité

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des récoltes de fossiles. Des récoltes cycliques ont été instituées pour contrôler le taux de mise au jour des fossiles par l'érosion.
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Keywords: Paleoanthropology; Middle Awash; Fossils; Aramis; Maka; Geomorphology; Ethiopia

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1. Background

During the 1800s, North America's First Great Dinosaur Rush pitted the field teams of Edward Drinker Cope against those of Othniel C. Marsh [7] in a race to extract dinosaur fossils from the badlands of the American West. In this competition, the dinosaur paleontologists understood that the first to discover a new site had the highest chance of recovering the best fossils. Once the surfaces of these outcrops had been exploited, the paleontologists quickly moved to the next site. Many of these Mesozoic fossil fields continue to produce new fossils and important contextual resources to modern paleontologists. Yet no scientist will ever again see these fossil sites in their pristine conditions. This is because the rate of surface collection almost always greatly exceeds the rate at which new dinosaur fossils are being exposed by active erosion.

Today another fossil 'rush' is underway – this time as the fossil fields of eastern Africa are being exploited by paleoanthropologically-motivated collection. The last three decades have brought dozens of new hominid discoveries from sites in eastern Africa. These discoveries have greatly illuminated hominid origins and evolution. The modern "rush" to obtain hominid remains has even led, among other things, to remarkably unethical behaviors [3,5]. Most observers, both public and professional, mistakenly perceive this burst of paleoanthropological discoveries as evidence that the eastern African hominid fossil record represents a still largely untapped resource base. Unfortunately, the experience of the last three decades indicates that this perception is false.

Research in the fossil fields of Tanzania, Kenya, and Ethiopia during the last thirty years has revealed that vertebrate fossils represent a non-renewable and rapidly dwindling resource [4]. Indeed, as Leakey perceptively noted in 1978, "It is unlikely that another locality of the size and richness of Koobi Fora will be found in Kenya" [8 (p. 12)]. Since then, the number of spatially extensive African fossil fields that remain to be discovered has further decreased due to successful inventory work in Ethiopia [1]. And on the surfaces of the known fossil fields, each season of collection has reduced the number of available fossils. Given these facts, it is obvious that there is an urgent need for scientists and government officials to collaborate in the development of effective programs to manage and protect paleoanthropological resources. These facts and their consequences remain little-appreciated among practicing paleoanthropologists [10].

Despite the recovery of the many hominid fossils now comprising eastern Africas's six-million-year record of human evolution, one axiom still holds firmly: paleoanthropologists will need to find many more fossils in order to understand the phenomena they investigate. Regrettably, hominid fossils are rare and difficult to find – even in the *most* productive hominid-bearing localities. These localities are *themselves* rare. Unlike the extensive spatial exposures of Mesozoic sediments in North America, the Late Neogene hominid-bearing fossil fields of Malawi, Tanzania, Uganda, Kenya, and Ethiopia are overwhelmingly confined to a small fraction of the area within geographically restricted, narrow rift valleys. Even smaller are the fossil-bearing breccia pockets of South Africa. Most of the rest of Africa has been eroding rather than depositing during the Neogene, or is now mantled by vegetation. For many African countries, it is a geological fact that no amount of intensive exploration will yield significant paleoanthropological resources.

The spatially limited, tectonically bound fossiliferous sedimentary packages of Late Neogene age are few and far between in Africa. Outcrops of these sediments are ultimately only available through the action of tectonics. Initial tectonics created the paleo-basins in which sediments accumulated. And subsequent tectonics have brought these deposits to the earth's surface where they are exposed to water erosion. It is usually this erosion that literally brings these antiquities to light, and to the attention of collectors. The impact of these geologically constrained phenomena on paleoanthropology can be best understood from the historical perspective. After reviewing the history of how these phenomena came to be appreciated, I will consider how geomorphological forces impact paleoanthropological resources, and then consider how these forces are influencing ongoing research in the Middle Awash study area of Ethiopia.

2. History

The first truly large hominid-bearing fossil field to be exploited in eastern Africa was the Omo Shungura Formation, in southern Ethiopia. There, vertebrate fossils were initially found in the earliest years of the 20th century (1902). A major expedition led by C. Arambourg collected additional vertebrate fossils in 1933. In retrospect, this early work illustrates the rarity of hominid fossils, even on these once-richly fossiliferous outcrops. Not a single recognized hominid specimen was found in the Omo by any of its first paleontological explorers – or by the first scientific projects that followed. This significant fact held until 1967, when work by the Omo Research Expedition led to the discovery of the first Omo hominids. Today, the Omo vertebrate specimen catalog registers approximately 50,000 catalogued specimens. Of these, about 220 are hominid, and the vast majority of these are isolated teeth. Because of the intensive collection techniques employed by the Omo team, this percentage abundance (or, more accurately, percentage rarity) in the Omo is our best approximation of the real ratio of hominids to other vertebrates in a large African Pliocene fossil field.

In the Omo, defined fossil localities were relatively small outcrops sampling a certain stratigraphic interval. An effort was made to collect all identifiable fossils from each of the hundreds of numbered localities. Relative abundance data from other fossil fields is not comparable because the emphasis of collection at most of these other sites was on hominid, carnivore, and cercopithecid fossils. This was certainly the case for the next truly large fossil field to be worked – a fossil field in the same modern basin, where contemporary sediments are exposed east of Lake Rudolf (now Lake Turkana), in northern Kenya. Here, as outlined by Leakey [8], a radically different collection strategy was employed. Much larger collection localities ("Areas") were defined, initially at Ileret. For logistical reasons, no effort was made to collect all identifiable vertebrate specimens from these outcrops. Rather, specialized teams (the 'Hominid Gang') crisscrossed the large, richly fossiliferous areas, mostly in a focused search for hominid fossils, but sometimes collecting well-preserved fossils of other vertebrate taxa.

Leakey's collection philosophy for the enormous badland terrain of East Rudolf involved removing any spatial and/or stratigraphic constraints from members of the collection team, giving them the option to roam freely in search of the best fossils. The strategy paid off. The hominid fossils found by the East Rudolf Research Project were among the most spectacular in paleoanthropology. The second field season (1969) saw the recovery of five hominid specimens, including two crania. The next year saw the recovery of 16 hominid specimens, including the first postcrania. Large numbers of vertebrates were collected, but only in 1971 did it become routine to place the collected fossils on aerial photographs. As the collection team learned how to identify hominid postcrania, the numbers of collected hominids went to what Leakey describes as 'a spectacular yield' [8]. Today, hominids continue to be found at Koobi Fora, but never at the recovery rates of the early and mid 1970s.

A similar pattern of fossil recovery across the first decade of collection was experienced by the team collecting the Hadar site in Ethiopia. The first years located the richest localities, and the fossil yields of these early seasons were spectacular in both abundance and preservation [6]. Today, the site continues to produce important new fossils. This pattern – initial abundance followed by lesser yields in later seasons – also characterized the work at Laetoli in Tanzania. There, the smaller outcrops were rapidly depleted of hominid fossils. The major hominid fossils in the main Garusi River valley (L.H. 2, 4, 5) were collected in a matter of weeks from relatively small patches of exposed sediment (initially, by collection team members from the East Rudolf project). Once the more complete hominid specimens had been collected, mostly isolated hominid teeth were found in subsequent years (with the exception of L.H. 21, found in an adjacent valley to the south of the Garusi).

In the Hata Member of the Bouri Formation in Ethiopia's Middle Awash study area, a total of c. 400 vertebrate fossils, including the *A. garhi* holotype and several other hominids were collected between 1995 and 1997 [2,4]. Subsequent visits to the same outcrops on an annual basis have yielded only a few additional collectable specimens, and no additional hominids. Collectors now refer to these outcrops as 'dead'. Although actively eroding windows into these landscapes occasionally yield a well-preserved fossil, such discoveries are rare, and the overall fossil yields have never rebounded to initial discovery levels.

To understand the pattern described above – a pattern that invariably features dramatically diminishing rates of survey return for continued surface collection of fossiliferous outcrops – it is necessary to understand how the fossil collection teams work in the field. It is also necessary to comprehend how the typical modern geomorphology of these fossil fields actively conditions what these teams are able to find and recover.

3. Geomorphology and fossil yields

At this moment in the history of paleoanthropology, it is evident that large samples of hominid fossils are still required to solve most outstanding research problems. However, as outlined above, the outcrops available to produce the needed samples are limited in spatial and stratigraphic extent. Today, the rate of discovery of large uncollected fossil sites is dropping rapidly toward zero in eastern Africa. And geomorphological principles constrain the rate of fossil recovery from those outcrops that have *already* been discovered.

Most of the important hominid fossils recovered from eastern African localities during the last 30 years were discovered as a result of field paleontologists walking sedimentary outcrops and finding the specimens exposed on the surface. In contrast, only small fractions of useful fossils have been produced as a result of excavations into undisturbed sediment. Vertebrate fossils, particularly hominid fossils, are at such a low density in most sedimentary packages that it is completely unrealistic to hope to recover them as a result of excavation (except in rare hominid-bearing bone beds). Consequently, erosion is the natural excavation tool that is used by paleontologists to reveal fossils in these fields.

Many paleontologists spend each rainy season imagining the fresh bumper crop of new fossils that will be exposed at the localities that they have already visited and collected. Yet despite sometimes-torrential rains and major erosion, most paleontologists are repeatedly disappointed to find that their locality never again produces a yield approaching that of their initial collections. This disappointment is the direct product of geomorphological circumstances.

Vertebrate fossils are embedded in sediments of variable induration. When saturated by water, these sediments often soften and expand (particularly the silty and bentonitic sediments). Upon dessication, the sediments contract. The dessication cracks thus formed often shatter the fragile, still-embedded fossils before they reach the surface. When a fossil is finally exposed to the surface (and is therefore visible to the collector), the first fragments often tumble downslope and scatter, followed by other pieces of the same specimen that become exposed and dislodged during subsequent rainstorms. Depending on the quality of fossilization, these fragments will survive on the surface for months to centuries, moved inexorably downslope by water and gravity, and eventually finding their way into gullies and lag deposits (Fig. 1).

Most eastern African fossil fields are badlands characterized by steep slopes and subhorizontal outwash surfaces (pediments, lag surfaces, alluvial fans). The latter first two, often together termed "desert pavements," are sometimes the spatially dominant landform in these terrains. These mantle lag surfaces take centuries, if not millennia, to form. During the first few years of fossil collecting at any site, these lag surfaces often yield abundant durable fossils that have survived exposure and transport. Well-fossilized specimens are relatively easily spotted and extracted from such residual, secondary lag contexts. However, once these fossils have been collected from these stabilized subhorizontal lag surfaces, no new ones will appear. Rather, these surfaces provide an effective armor for the softer sediments below, protecting them – and the fossils they contain – from exposure by erosion. Once stripped of fossils, the lag surfaces yield nothing new. Year after year, decade after decade, these lag surfaces barely change – and they do not rejuvenate until headward erosion resulting from a lower base level cuts into them.

In contrast, the actively eroding, un-armored sediments across these fossil fields usually amount to only

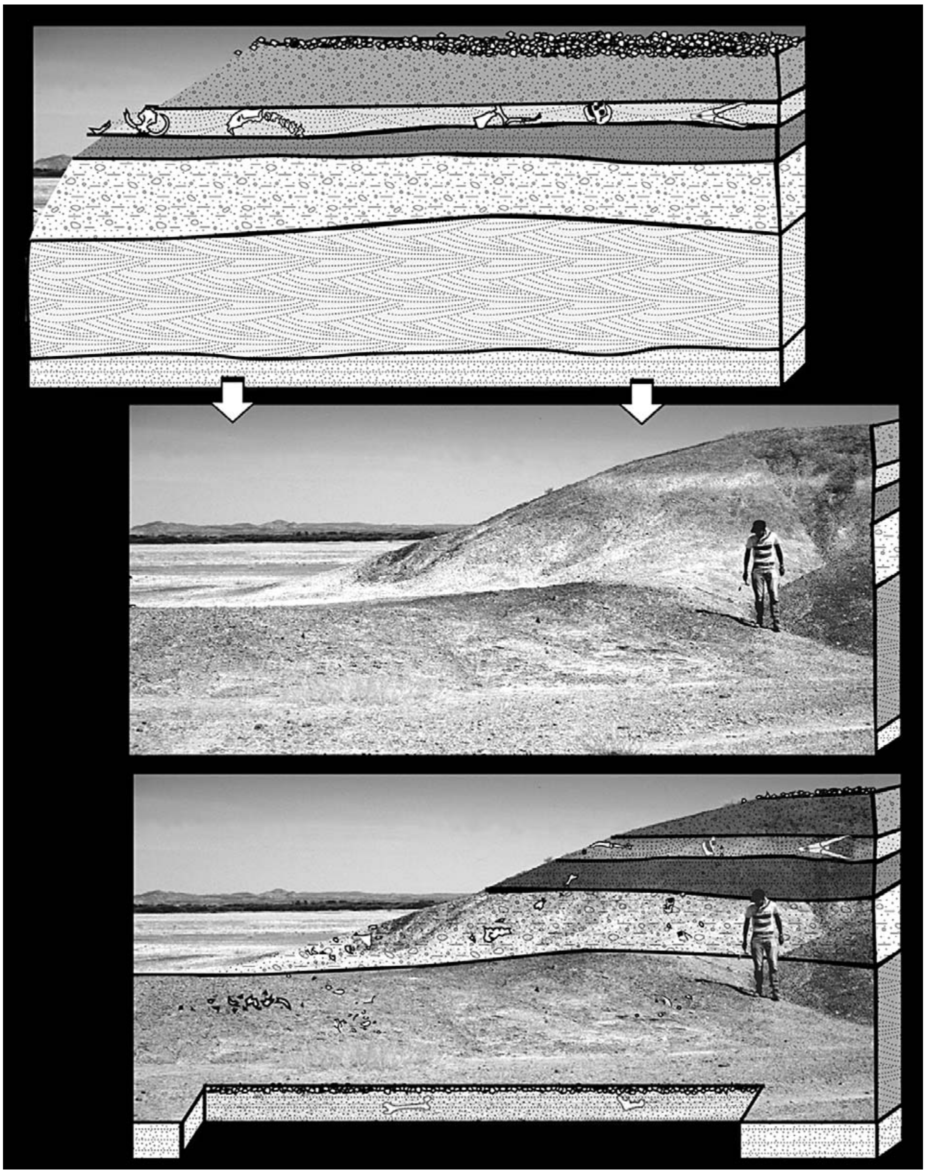

Fig. 1. Geomorphology of the hominid-bearing BOU-VP-12 fossil locality, Hata Member, Bouri Formation, Middle Awash study area, Afar depression, Ethiopia. Fossils embedded in the softer sands and silts are revealed to paleontological collectors as the erosion surface carves into the sediment. The fossils and other harder concretions move downslope due to gravity and water, and concentrate in pebble and gravel lags sometimes called 'desert pavements', in which many fossils are found. Once a locality has been intensively surface-collected, these armoring pavements do not yield additional fossils, and the only new fossils available to the collector come from active erosional windows. This geomorphological situation has profound consequences for paleoanthropological field research.

Fig. 1.Géomorphologie de la localité fossilifère BOU-VP-12, contenant des restes d'Hominidés, Membre Harta, Formation Bouri, zone d'étude de Middle Awash, dépression de l'Afar, Éthiopie. Les fossiles contenus dans les silts et sables meubles se révèlent aux collectionneurs paléontologues sous la forme de moulages sur la surface d'érosion, dans le sédiment. Les fossiles et autres concrétions plus dures se déplacent vers le bas de la pente, en raison de la gravité et des circulations d'eau et se concentrent sous forme de dépôts graveleux et caillouteux, appelés « pavements désertiques », dans lesquels on trouve de nombreux fossiles. Une fois qu'un endroit a été intensément échantillonné en surface, les pavements qui le cuirassent ne livrent pas de fossiles supplémentaires, et les seuls fossiles disponibles pour le collectionneur proviennent de fenêtres d'érosion actives. Cette situation géomorphologique a de profondes conséquences sur la recherche paléo-anthropologique de terrain.

a relatively small proportion of the total land surface in most fossil fields (see Fig. 1). These are the only active erosional windows into the sediments, and it is only on these limited outcrops that newly exposed fossils can appear. Some localities consist of little-moved lag in proximity to the active erosional slopes. Such a lag is often associated with well-preserved fossils, prior to their more extensive fragmentation and dispersal. These geomorphological facts explain why the Hadar museum collection in Addis Ababa is so spectacular, with drawers and shelves of abundant, exquisitely preserved fossils. In contrast, only scraps of unidentifiable bone remain at many of the very localities that yielded such fine fossils during the 1970s collections. Once collected, many localities will take centuries or even millennia to accumulate the same number of fossils that were once present upon initial discovery.

Whether found in situ or in a lag concentrate, a variety of techniques can and should be used to identify the source of any particular fossil, and to recover all of its fragments. White [11] recounts some of these procedures in his description of the recovery of the MAK-VP-12/1 mandible of an adult *Australopithecus afarensis* mandible found in the Middle Awash in 1990 [12].

4. The Middle Awash Project

Early in our team's research in the Middle Awash study area of Ethiopia's Afar depression, we realized that we were forever altering the surfaces of the fossil fields there, particularly by reducing the abundance of surface fossils. Furthermore, we recognized that with the variety of paleoanthropological resources in the study area, flexibility in the application of various field methods would yield the best results. A variety of techniques have been employed in paleontological collection of the Middle Awash paleontological localities since 1981. General survey has been done in most areas, with small (n = c. 10) teams of people walking the surface of outcrops and collecting fossils. This is the typical collection mode used at most of the fossil fields in eastern Africa. Yield is a function of outcrop size and content, collector skills, fossil visibility, and time on the outcrop.

In any paleontological program, constraints of time and money influence the time allotted to collect fossils from any set of localities or outcrops. As the yield from any given locality approaches zero, decisions about when to move on – and when to return – must be reached. These decisions are made difficult by the lack of information on replenishment rate for most sites in eastern Africa. As a consequence, most decisions about optimal re-collection intervals are based on anecdotal accounts. To our knowledge, there have never been controlled attempts to establish either the efficiency of collection by field crews, or the rate of exposure of new fossils at these kinds of sites. We are therefore currently engaged in attempts to quantify these variables in the Middle Awash. If successful, these efforts might provide some guidance to paleontologists and governmental officials responsible for regulating ongoing research.

Three broad phases of fieldwork characterize conventional modern paleoanthropology in eastern African fossil fields. All three are currently part of ongoing research in the Middle Awash study area. First, 'reconnaissance survey' is required to identify exposures with good potential for producing paleontological and archaeological evidence relevant to the research questions. In this first phase, field teams conduct vehicle and foot survey of outcrops identified and targeted as potentially fossiliferous by the use of satellite and aerial remote sensing. Current Middle Awash examples are the northerly regions of the Middle Awash study area (Messalou and Borkana) that have not been adequately explored.

When successful, reconnaissance survey is followed by an intensive phase of multidisciplinary work, or 'focused research'. This phase concentrates on extracting mostly surface fossils and artifacts, with particular attention being paid to firmly establishing the stratigraphic and spatial placement of each specimen. This phase usually seriously depletes the surface assemblages, particularly where the fossils are in a secondary lag deposit or "armor" that protects underlying softer sediments from erosion. This phase of research is represented by current Middle Awash project fieldwork at Bouri, and on the Western Margin upper Miocene sites.

The third fieldwork phase involves long-term, periodic revisitation or 'maintenance collection' of fossiliferous localities. This site management activity is rare in eastern Africa. In the past it has often been practiced only as a result of a new research team opening a site years after abandonment by a previous team. Because of the constraints discussed above, it is clear that maintenance collection will, of necessity, ultimately dominate future paleoanthropological research in the African rift system. A main goal of the maintenance research phase is the recovery of fossils just as they emerge to the surfaces of the active erosion slopes. The maintenance revisitation interval will depend on the nature of the eroding sediments and their contents, steepness of slope, and degree of "armor." The Middle Awash sites of Aramis and Maka provide good examples of areas that require regular maintenance survey.

Below we describe two active Middle Awash project experiments designed to generate knowledge crucial for establishing management programs for fossil fields throughout eastern Africa, and beyond.

5. Aramis: measuring the rate of exposure

The Aramis localities began to produce fossil hominids in 1992. They continue to yield fossils a decade later. We have undertaken a program of systematic, controlled crawling across all available outcrops of a 1–4-m stratigraphic interval that lies sandwiched between the DABT and GATC volcanic horizons, dated to 4.4 Myr. We collect all paleontological material encountered – vertebrate, invertebrate, and botanical – no matter how fragmentary. Thus far, hundreds of thousands of fossils have been collected from this interval, either as bulk samples of unidentifiable fragments (now numbering in the hundreds of thousands), or as the nearly 6,000 catalogued specimens from localities sandwiched between the dated horizons. Because this limited stratigraphic interval comprises silts and carbonates which dissolve and crumble upon exposure, there are many fresh and steep erosional slopes in the Aramis catchment.

In normal reconnaisance survey and focused research, the number of fossils available for surface recollection in any given area will equal the sum of all specimens missed during previous survey plus all newly-exposed fossils. In sites where the survey technique consists of collector wandering across the surface of outcrops, the number of fossils available for collection during re-survey depends on the quality of the previous collection. The number of newly exposed fossils depends upon the geomorphological variables mentioned above, combined with the amount of erosion in the interval between re-collection (usually proportional to overall rainfall, which can vary greatly in these semiarid regions).

Beginning in 1992 at Aramis we developed a 'crawling' system to control against the survey team overlooking exposed fossils during its collecting activities. This system places collectors shoulder to shoulder, crawling across each outcrop, and collecting 100% of all fossils (Fig. 2). In this manner, the target outcrops are stripped of all fossils. Consequently, any new specimens collected during subsequent seasons represent newly exposed fossils. It is likely that this mode of collection will eventually come to characterize all of the major fossil fields of eastern Africa, although this may be difficult with spatially extensive exposures. After a decade of intensive work on the Aramis exposures, we are now in a position to measure the rates of new fossil exposure. These rates are high enough to merit biannual collection of vertebrate fossils. For the foreseeable future, logistical constraints will make the application of this collection mode impossible for all but a few special localities such as Aramis.

In the Middle Awash, we have found it necessary to carefully consider different sets of localities independently when estimating the rate of new fossil exposure. For example, the sandy silts of the Hata and Aramis Members of the Middle Awash are roughly the same sedimentary hardness and composition. However, the Hata beds contain ferruginous carbonate rootcasts that are concentrated on the surface by erosion and winnowing, forming an interlocking armor, even on steep slopes. This renders these localities poorly productive on an annual basis. In contrast, the Aramis slopes lack this armor, and weather more quickly. The Aramis localities are among the most productive in the Middle Awash, and we have found that anything longer than a biannual round of intensive collection risks the loss or damage of substantial numbers of new fossils.

6. Maka: measuring the efficiency of collection

The Middle Awash team discovered the Maka vertebrate paleontology site in 1981 as part of a broadscale survey directed by the late J. Desmond Clark. On

Fig. 2. The crawling technique being employed at the Aramis ARA-VP-1 locality, Sagantole Formation, Aramis Member, Middle Awash study area, Afar depression, Ethiopia. The team is collecting every fossil within a demarcated 30-m strip as it crawls slowly, shoulder-to-shoulder, across the surface of sediments sandwiched between the overlying 4.4 Myr Dam-Aatu Basaltic Tuff (DABT; dark horizon above collectors) and an underlying vitric tuff of the same radiometric age. Once stripped of fossils, subsequent revisits can establish the rate at which new fossils appear. This rate will depend on the degree of surface lag, the contents of the sediment, and the amount of year-to-year erosion.

Fig. 2.Technique de rampement utilisée à la localité Aramis ARA-VP-1, formation Sagantole, membre Aramis, zone d'étude de Middle Awash, dépression de l'Afar, Éthiopie. L'équipe récolte chaque fossile à l'intérieur d'une bande de 30 m en rampant épaule contre épaule à travers la surface des sédiments pris en sandwich entre le tuf basaltique Dam-Aatu de 4,4 Ma, susjacent (DABT ; horizon sombre au-dessus des personnes qui récoltent) et un tuf vitreux sous-jacent, de même âge radiométrique. Une fois les fossiles ôtés, des visites ultérieures peuvent établir la vitesse à laquelle de nouveaux fossiles apparaissent. La vitesse dépendra du degré du dépôt de surface, du contenu du sédiment et du taux d'érosion année par année.

the afternoon of November 26, 1981, T. White found the first fossil hominid at Maka, a proximal femur fragment on the surface (MAK-VP-1/1). This had eroded from the encasing sediment as a single piece and has been described elsewhere [9].

The Maka locality is typical of eastern African Plio-Pleistocene sites. Here, the modern topography is erosional, with uplifted Pliocene sediments weathering into a badlands topography characterized by steep erosional slopes, deep erosional gullies, and subhorizontal outwash fans and lag surfaces. The sediments are exposed over several square kilometers of semi-desert landscape sparsely covered by a very thin scatter of modern vegetation (Fig. 3).

The main fossiliferous horizon at Maka is a sand and gravel unit referred to informally as the 'Maka sands' of the Matabaietu Formation. These faunally rich sand and gravel deposits represent pedialluvial aggradation in the paleobasin at c. 3.5 Myr. The Maka sands are mostly unconsolidated and therefore subject to rapid erosion. Each rainstorm has the potential to expose new fossils still in situ, and to scatter already exposed fossils down the steep slopes. The sands are paleontologically rich, and 180 vertebrates were collected from these Maka deposits during the 1981, 1990, and 2000 field seasons.

Vertebrate paleontology at Maka cannot effectively employ the crawling techniques developed for the Aramis deposits – there are too many fossils and the outcrops are too large. At Maka, collection strategy has followed the more conventional model for the collection of macromammals in eastern Africa. In this model, all identifiable elements belonging to primates, carnivores, and other rare taxa are collected by team members who crisscross the landscape on foot, looking for fossils. Postcranial remains of other vertebrates are

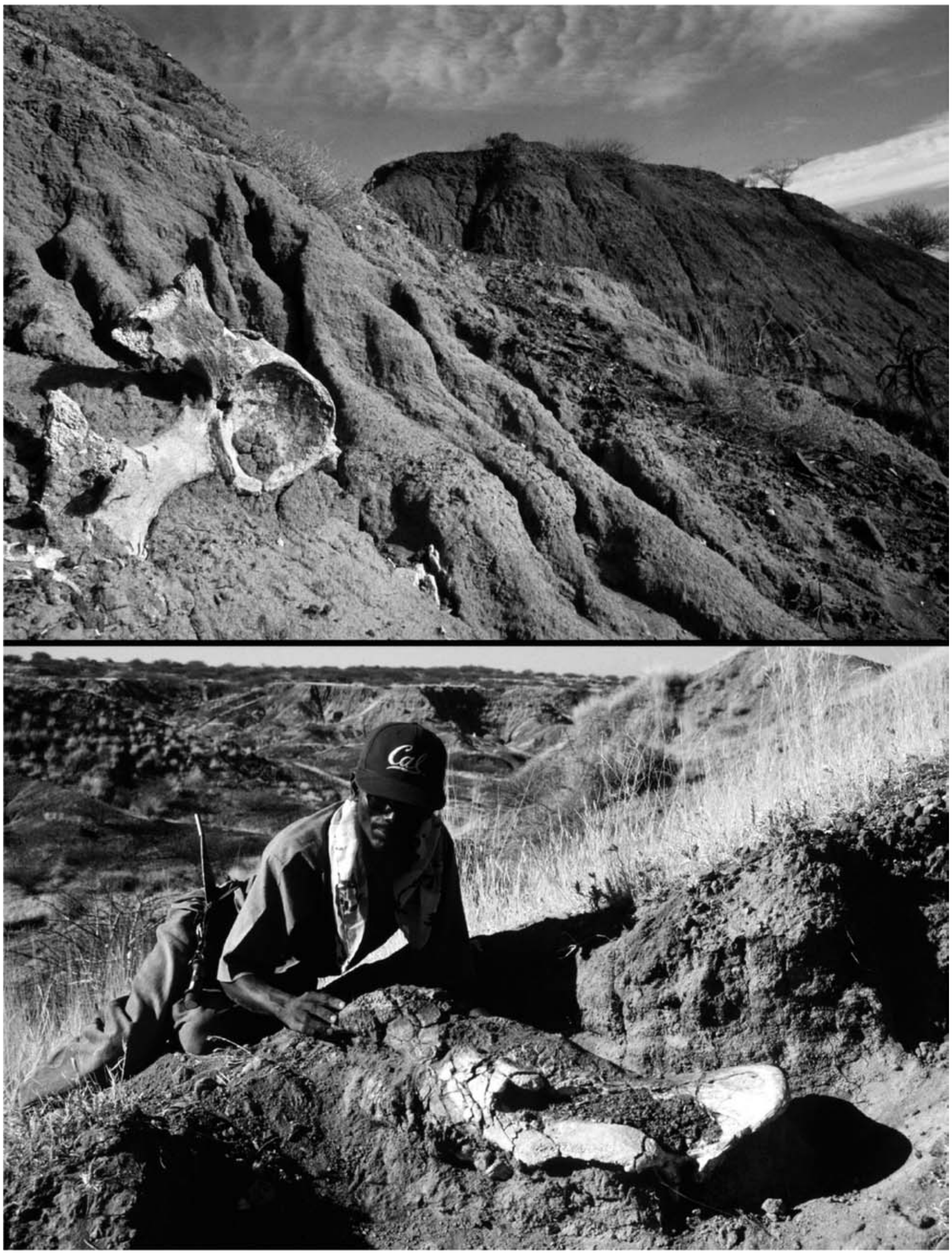

Fig. 3. Two views of the MAK-VP-1 fossil locality, Matabaietu Formation, Maka sands unit, Middle Awash study area, Afar depression, Ethiopia. Above: an ungulate pelvis embedded in the sands and gravels is shown after exposure to erosion. Below: a complete cranium of a *Ceratotherium* has been exposed on the surface and is being prepared for collection. The white portions of the bone were visible to collectors in 2000. None of this fossil was exposed two years earlier. After another rainstorm it would have shattered into hundreds of pieces and scattered downslope.

Fig. 3.Deux vues de la localité fossilifère MAK-VP-1, formation Matabaietu, unité des sables de Maka, zone d'étude de Middle Awash, dépression de l'Afar, Éthiopie. En haut : un pelvis d'ongulé contenu dans les sables et graviers et présenté après exposition à l'érosion. En bas : un crâne complet de *Ceratotherium* a été mis au jour et est en cours de préparation pour la récolte. Les portions blanches de l'os étaient visibles pour les collectionneurs en 2000. Aucune partie de ce fossile n'étaient exposée deux ans plus tôt. Après une nouvelle averse, il aurait été fragmenté en centaines de morceaux et dispersé en bas de pente.

collected when association with collected cranial remains is demonstrable. Fossils from large but diagnostic mammals are sometimes photographed and measured, but left in the field due to logistical reasons.

With this kind of collection strategy, it is never known how many specimens are missed by the traversing collecting teams. Indeed, the knowledge that collection has not been complete has, in some cases, been used as an incentive for return to the site, and an incentive to 'look harder.' But how many times should one return to a site for re-collection? How many hominid fossils are left behind on outcrops by collection teams employing this nonrandom wandering technique? The Maka site provides an opportunity to begin to answer these questions.

After it had produced the first hominid fossil in 1981, the Maka outcrops were not revisited during a governmentally imposed eight-year research hiatus. When our collection teams returned in 1990, a ten-person team of experienced collectors conducted intensive, focused research. Among the 130 vertebrate fossils collected were important new hominid specimens, including the most complete mandible of *A. afarensis* (MAK-VP-1/12). After a ten year interval, the site was again revisited in 2000 and worked by a five-person collection crew. Approximately 50 new vertebrate fossils were collected. As expected, the total specimen count yield for this year was low, but the newly-exposed fossils were spectacular, and included the most complete *Ceratotherium* cranium found at the site (Fig. 3), and the most complete specimens of *Oryx howelli*. In contrast to the first years of survey at Maka, and in keeping with experiences at other hominid-bearing sites, no new hominid specimens were found at Maka during the 2000 collections.

In an effort to establish the efficiency of typical paleontological collection by workers walking the surface, we modified a mark-recapture technique widely used to census wild animals. At the end of our Maka collection in 2000, the author scattered more than 200 realistically colored plaster and plastic casts of fossil hominids across the Maka outcrops. Casts were dropped unobserved on erosional (not depositional) slopes of the fossiliferous Maka sands. They were never intentionally hidden, nor were they placed in vegetation, but always in a visible position. There was no attempt to hide these casts, and none were buried. Cast location was not registered in any manner, and only the distributor (the author) witnessed the planting. The casts were always emplaced in an area with actual fossils already visible on the surface.

The planted casts are those of hominid fossils, primarily from Hadar and Omo. The body part representation is approximately 20 specimens from each major segment of the body, from isolated teeth and phalanges on the small end of the size range, to large axial and limb fragments. Because all of these casts are registered by specimen number, it will be easy to monitor how many of them are found in future collection rounds on the Maka outcrops. The percentage of the original > 200 casts recovered will be a valuable indicator of how effective our collection methods are at recovering fossil hominids. In turn, this will assist in guiding the collection team in deciding how much time to allocate to a continued collection of the outcrops.

7. Paleoanthropological resource management

Effective long-term management strategies for paleoanthropological antiquities resources will be created only when techniques of paleoanthropological collection are incorporated in their design. The Middle Awash experiments described above represent the first tentative steps in this regard. These experiments are focused on collection methods and intervals, and their results will be of value to both scientists and antiquities managers. They show that even in the richest hominid-bearing sites, depletion of the record is a real phenomenon. Effective paleoanthropological management will require far more than careful assessment of fossil depletion by the activities of scientific teams. Paleotourism, as part of adventure tourism, is poised for dramatic growth in the decades ahead, a fact directly related to the demography of wealthy nations. As this industry grows in the years to come, paleoanthropological sites will undoubtedly become the targets of non-scientific trophy collection by amateurs and tourists. It will be important for scientists and government officials to work together with local inhabitants of the fossiliferous regions of Africa to create effective partnerships to protect, educate, and develop cultural and paleontological heritage.

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