Scanning Microscopy

Volume 2 | Number 2 Article 49

2-12-1988

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Mark F. Teaford
The Johns Hopkins University School of Medicine

Scanning Microscopy, Vol. 2, No. 2, 1988 (Pages 1167-1175) 0891-7035/88$3.00+.00
Scanning Microscopy International, Chicago (AMF O'Hare), IL 60666 USA

SCANNING ELECTRON MICROSCOPE DIAGNOSIS OF WEAR PATTERNS VERSUS ARTIFACTS ON FOSSIL TEETH

Mark F. Teaford
Department of Cell Biology & Anatomy
The Johns Hopkins University School of Medicine
725 N. Wolfe St.
Baltimore, MD, U.S.A. 21205
Phone No.: (301) 955-7034, 955-3173

(Received for publication July 12, 1987, and in revised form February 12, 1988)

Abstract

Recent work with modern mammalian teeth has shown that, during an animal's lifetime, microscopic wear patterns are generally laid down in a regular fashion at specific locations on the teeth. These regularities make it possible to distinguish real dental microwear (resulting from behaviors during life) from artifacts of preservation and preparation (postmortem wear) on fossil teeth. The size, shape, location, and orientation of microscopic wear features can all aid in making such distinctions.

Several types of postmortem wear are identifiable on fossil teeth. Since some of these effects are intimately tied to the taphonomic history of the fossil, some postmortem wear will vary significantly within and between paleontological sites. Moreover, certain forms of postmortem wear will undoubtedly pose problems for microwear interpretations involving fragments of teeth. Still, it is usually possible to distinguish postmortem wear from real dental microwear in complete specimens. If there is any doubt about such distinctions, it is best to discard the specimen from the analysis.

Key Words: Scanning Electron Microscopy, Teeth, Fossils, Abrasion

Introduction

Scanning electron microscope analyses of wear patterns on teeth have recently been used to yield insights into the diets of prehistoric species (e.g., Biknevicius 1986, Brace et al. 1981, Daegling and Grine 1987, Grine 1977a, b, 1981, 1984, 1985, 1986, Krause 1982, Peters 1982, Puech 1979, 1981, 1984, Puech and Albertini 1983, 1984, Puech et al. 1980, 1983, Rensberger 1982, 1986, Ryan 1979, Shkurkin et al. 1975, Teaford and Walker 1984, Walker 1980, 1981). Interpretations of the results of these studies are dependent on comparisons with modern animals for which dietary information is available (see Teaford, 1988, for a review of such studies). However, the most frequent question asked of investigators in this type of study is "How do you recognize "real" microwear (i.e., that caused during the animal's lifetime) on a fossil tooth?"

Over the past few years, a wide variety of mammalian teeth have been examined, ranging in age from roughly 50 million years B.P. through the present. Within those samples, certain patterns of wear have emerged that will prove useful in making the distinction between "real" microwear and artifacts of preservation and preparation.

Wear Patterns on Modern Teeth

The key point of contrast is that, during an animal's lifetime, microscopic wear patterns are laid down in a regular fashion at specific locations on the teeth, while after the animal has died, the entire tooth row and jaw will be subjected to various forms of postmortem wear.

Analyses of the teeth of modern mammals have shown that there are three critical areas that should be examined if one wishes to identify "real" microwear on teeth. First, there are distinct chewing and non-chewing surfaces on the teeth. The bulk of the microwear of interest to the investigator will be concentrated on the chewing (or occlusal) surfaces of the teeth, and close examination of the transition from chewing to non-chewing surfaces should reveal a drastic reduction in microwear in moving from the former to the latter (Figure 1). Second, teeth will only begin to show meaningful microwear as they come into occlusion. Thus, teeth that are not in occlusion will show little if any wear, and the degree of wear will vary with the stage of eruption of the tooth and the overall rate of wear of the dentition (Figures 2-3). Third, the wear that is present on certain chewing surfaces of the teeth will occur in fairly regular patterns since the jaw movements that ultimately caused the wear also follow regular patterns. For example, on shearing facets along the sides of teeth, the bulk of the wear features will be scratches running roughly parallel to each other (Figure 4). Features running in drastically different directions, especially those that change directions, should be viewed with a great deal of caution (Figure 5). On crushing facets bordering the central basins of teeth, however, wear features should be expected to show greater variation in size, shape, and orientation simply because they can be caused by a variety of movements (i.e., puncture-crushing and phases I & II of the power stroke of chewing) (Hylander, et al. 1987, Teaford 1985) (Figure 6).

This is not to imply, however, that the teeth of modern mammals are easier to study. They merely present their own set of problems. For instance, in longitudinal studies of modern animals, the biggest problem is cleaning and drying the teeth (Figure 7). If not careful, the investigator will end up with a beautiful cast of a saliva- or pellicle-coated surface.

Diagnoses of Wear on Fossil Teeth

For the purposes of this paper, the key point is that fossil teeth generally show the same distributions of microwear features as those on the teeth of living animals. Thus, distinct chewing, and non-chewing, surfaces are readily identifiable (Figure 8). Teeth that are just coming into occlusion will show different patterns or distributions of wear as compared with teeth already in occlusion (Figures 9 & 10). The wear that is present will occur in fairly regular patterns (Figures 11 & 12). A particularly useful pattern can even be found between the teeth of many animals since adjacent teeth are often worn against each other creating wear facets between the teeth. In contrast to facets on the occlusal surface, these "interstitial" or "interproximal" facets are formed primarily by tooth-on-tooth wear. Thus, they have a frosted appearance at low magnifications with very few features visible at higher magnifications (Figures 13-14). Interstitial facets are often ignored (or inaccessible) in analyses of modern animals where complete tooth rows are readily available. However, for analyses of fossil material, where isolated teeth are often of critical importance, interstitial facets can be extremely useful. Essentially, interstitial facets with microwear-like features should immediately leave one suspicious of postmortem damage. For that matter, fossil teeth showing differences from any of the above patterns should be treated very cautiously, if not discarded from the sample, as there are a number of

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Figure 1. LM^2 of Cebus apella (NMNH 338958). Note decrease in microwear in moving from facet 3 (right half of micrograph) to buccal surface of tooth (left half of micrograph).

Figure 2. LM_3 of laboratory vervet monkey (CWRU#1, impression date February 6, 1987). LM_3 is just coming into occlusion. Gingival tissue (G) separates protoconid (P) and metaconid (M) in left half of figure. Note extensive chipping of protoconid tip in right half of micrograph.

Figure 3. Development of wear on metaconid of LM_2 of laboratory vervet monkey (CWRU#3).

a = May 28, 1985 (tooth just into occlusion) - Note extensive chipping of transverse crest but lack of microwear on either side of it.

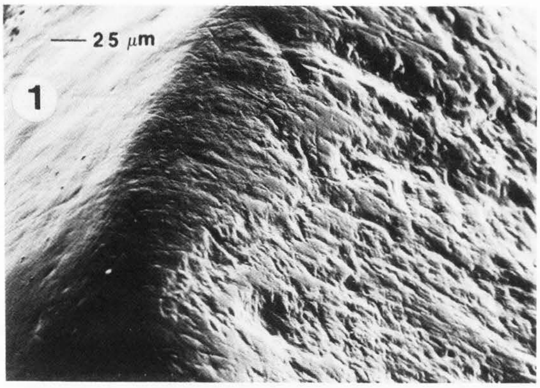
b = February 6, 1987 - Note dentin exposure on tip of metaconid, lack of chipping on transverse crest, and extensive microwear on either side of crest.

Figure 4. Shearing facet (facet 1) on RM^2 of Cebus nigrivittatus (NMNH 443216).

Figure 5. Shearing facet (facet 3) on LM_2 of laboratory vervet monkey (CWRU#6)(impression date: February 6, 1987). "Scratches" which change direction in right half of micrograph (labeled S) are toothbrush strokes in organic film on tooth.

Figure 6. Grinding (or Phase II) facet (facet 9) on LM_1 of laboratory vervet monkey (CWRU#3)(impression date: July 12, 1985). Note variety of microwear features and feature orientations.

Figure 7. LM_3 of laboratory vervet monkey (CWRU#4)(impression date: October 22, 1986)(P = protoconid tip). Apparent scratches visible at low magnification (left half of micrograph) are really toothbrush strokes in organic film on tooth (as visible at higher magnification in right half of micrograph).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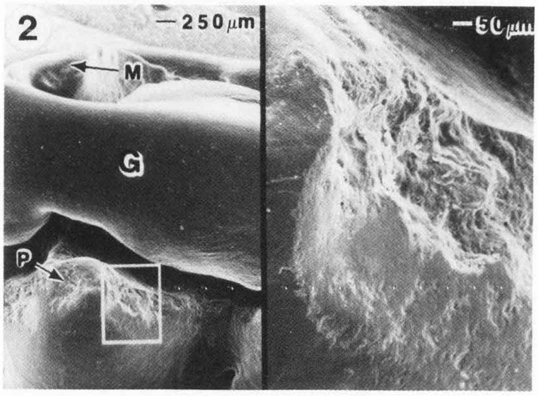
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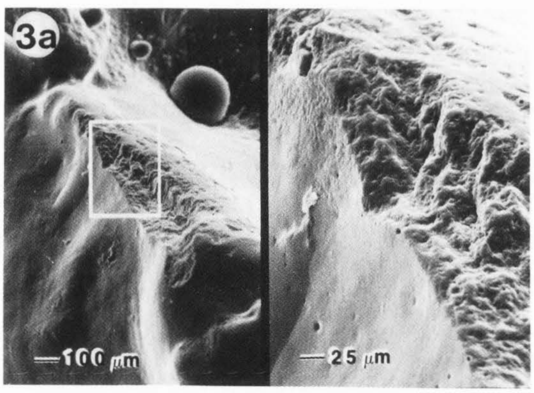
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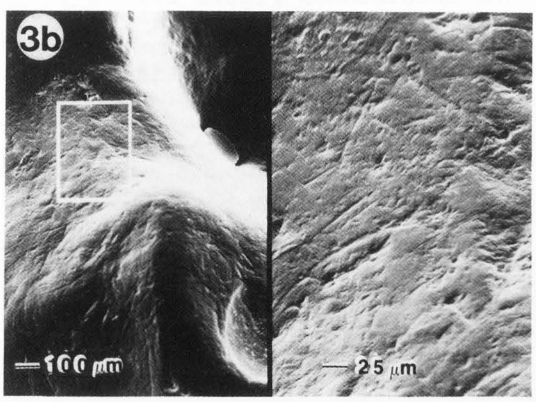
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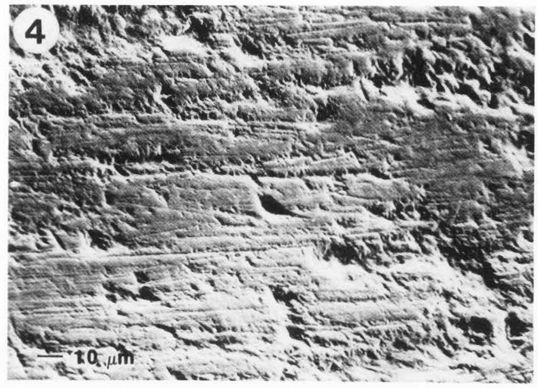
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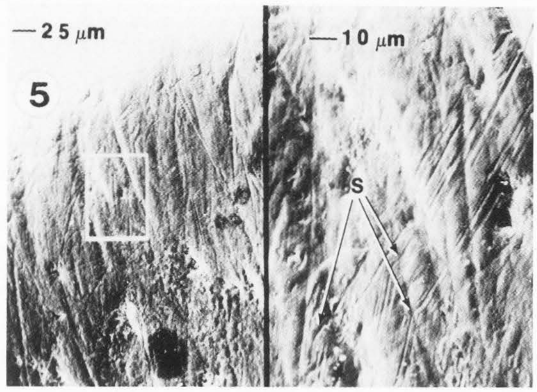
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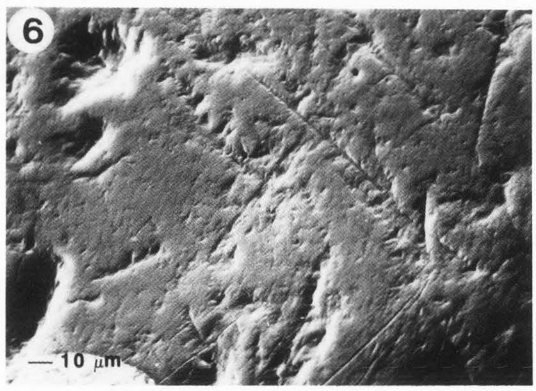
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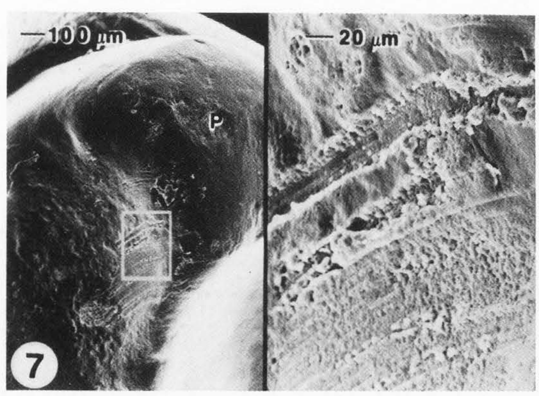
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P

postmortem factors which can alter microscopic wear patterns on teeth.

Sources of postmortem wear on teeth can be roughly divided into two groups: (1) those occurring after the death of the animal but before the fossilized remains are collected, and (2) those occurring during collection and preparation of the specimen. At first glance, the first group might seem to be the most insidious, because there are many destructive forces that can have a variety of effects on bone and teeth (Shipman 1981). However, once an animal dies, postmortem destructive forces go to work on the entire skeleton, not just the chewing surfaces of teeth. Thus, while certain types of abrasive weathering can easily lead to the obliteration of microwear patterns caused during life (Gordon 1984, Puech et al. 1985), the new patterns of abrasive wear will occur wherever the tooth was exposed to the abrasives (Figure 15). The same is true for forms of chemical weathering (Figure 16). As a result, the chances of new wear patterns occurring solely on the chewing surfaces of those teeth that are in occlusion are very slim indeed. Even if this happens, the new microscopic wear features will probably be of unusual sizes, shapes, and/or orientations (Gordon 1984, Puech et al. 1985).

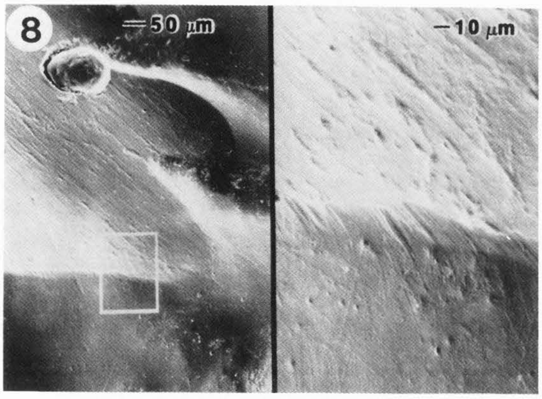
Damage occurring during the collection and preparation of specimens may have even more potential to confuse investigators, if only because human collectors and preparators can restrict their activities to tooth surfaces which they feel are important. Since variations in tooth crown morphology are of critical importance to many functional and taxonomic interpretations, teeth frequently receive more than their fair share of cleaning and preservatives. Still, most of these effects are readily recognizable. Two of the most common artifacts are those caused by dental picks and by the application of preservatives to the tooth surface. Unusually large gouges will be the most common result of the overzealous use of a dental pick (Figure 17). A perfectly smooth surface, with no wear features and no enamel prism relief, is a reliable indicator that a preservative has been left on the tooth surface (Figure 18). Often, if the tooth has been cleaned after the application of the preservative, additional tell-tale signs will be visible - e.g., brush-marks overlying the real tooth surface (Figure 19) or an abrupt end to the smooth surface, with microscopic wear features disappearing under the preservative (Figure 20). Of course, any matrix left on the tooth can also be detected through similar clues (Figure 21).

To date, no postmortem factors have been shown to precisely mimic the effects of "normal" wear, and those postmortem events which <u>do</u> affect teeth are usually identifiable in complete specimens. However, some factors may pose problems for the interpretation of dental microwear on fragments of teeth. The best advice for such situations is "when in doubt, throw it out!" Obviously, since the preservation of fossils varies from site to site, there may be some collections that will prove very useful for dental microwear analyses and some that will prove almost useless. As a general guideline, when working with various fossil collections, one should plan on eliminating 30%-40% of the specimens from the sample for various reasons. That way, one may be pleasantly surprised by the information that <u>can</u> be derived from dental microwear analyses.

Acknowledgments

I wish to thank the following people for allowing access to specimens in their care: Ken Rose and Tom Bown (USGS specimens), Richard Leakey (National Museums of Kenya), Richard Thorington (Smithsonian Institution). I also wish to thank Alan Walker for discussions during the preparation of the manuscript and for access to dental replicas in his

Figure 8. Shearing facet (facet 7) on LM^2 of 50 million year old fossil primate (<u>Cantius</u>) (USGS #4672). In right half of micrograph, note decrease in microwear in moving from wear facet (top half) to lingual side of tooth (bottom half).
Figure 9. Start of wear on LM^3 of 50 million year old fossil primate (<u>Cantius</u>) (USGS #6153). Note chipping of crest in middle of micrograph (P = tip of paracone).
Figure 10. Start of facet 3 on LM^3 of 50 million year old fossil primate (<u>Cantius</u>) (USGS #411).
Figure 11. Shearing facet on LM^2 of 50 million year old fossil primate (same facet and specimen as Figure 8).
Figure 12. Grinding (or Phase II) facet (facet 9) on RM^2 of 50 million year old fossil primate (<u>Cantius</u>) (USGS #473).
Figure 13. Interproximal facet (I) and shearing facet (f.5) on LM^1 of 20 million year old fossil primate (<u>Proconsul major</u>) (KNM-SO 934). Note scratches on shearing facet and lack of scratches on interproximal facet.
Figure 14. a = Grinding facet (#10n) on RM_2 of 2 million year old fossil primate (<u>Australopithecus</u>) (KNM-ER 1814). Note scratches and gouges.
b = Adjacent interproximal facet from same tooth. Note nearly total lack of microwear features.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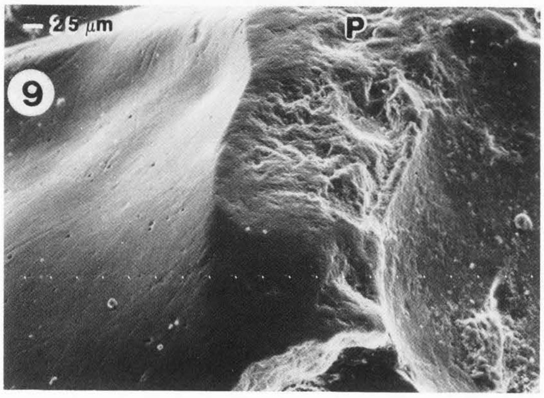
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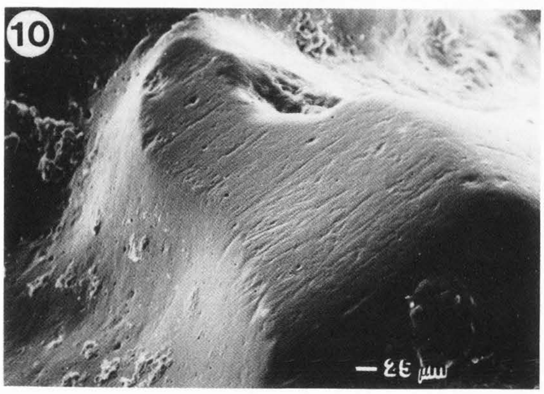
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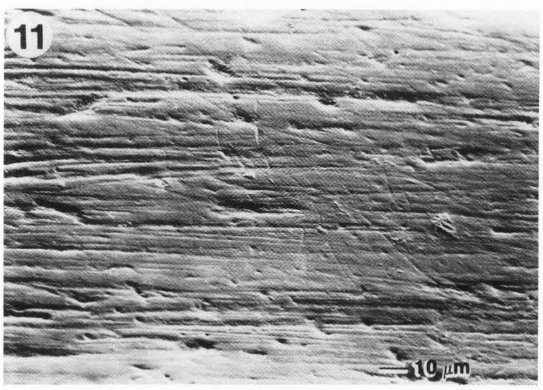
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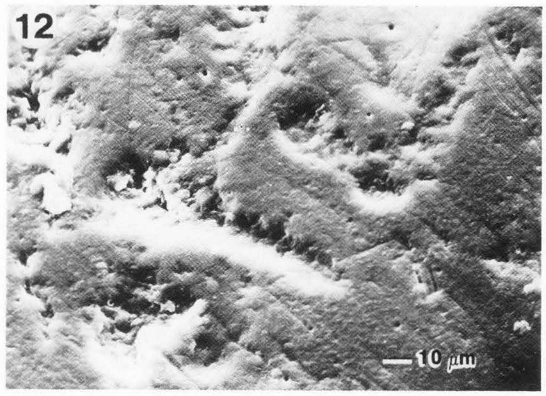
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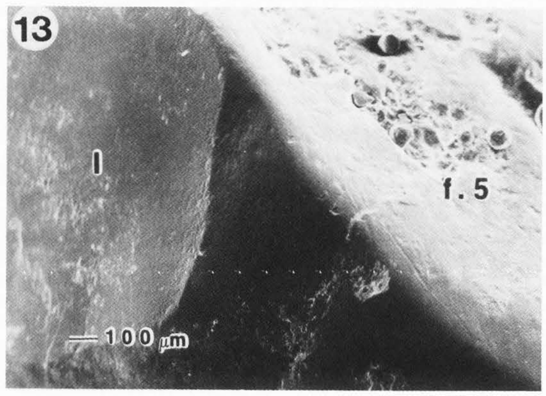
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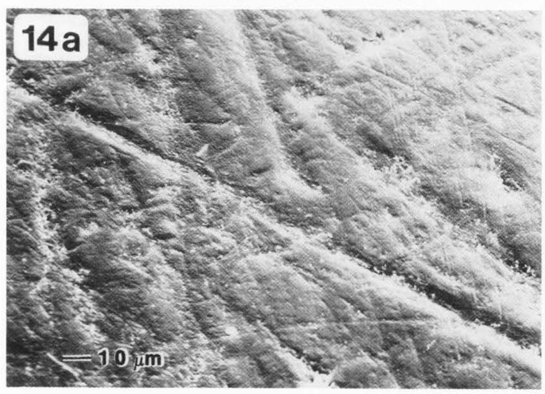
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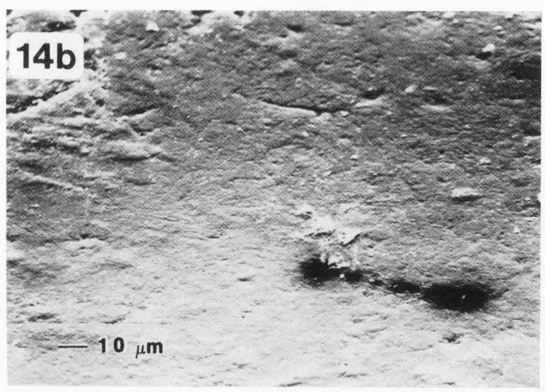
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care. Kathleen Gordon, Pierre-Francois Puech, and John Rensberger provided useful comments on the manuscript. The laboratory studies of vervet monkeys at Case Western Reserve University are being conducted in conjunction with Dean Oyen and with the support of NIH grant # R23 DE07182.

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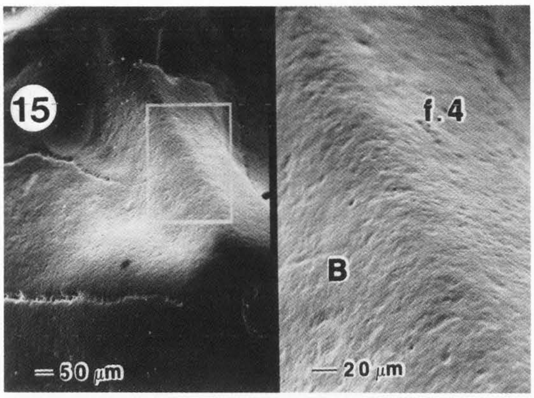

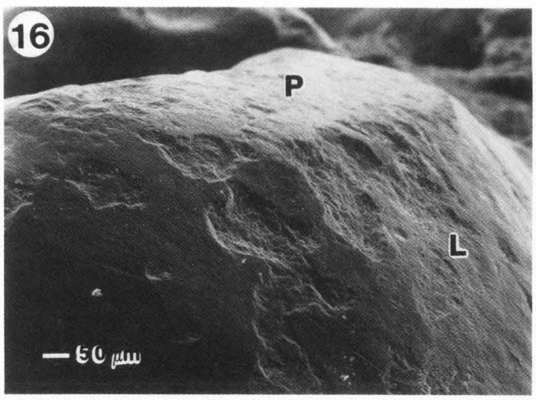

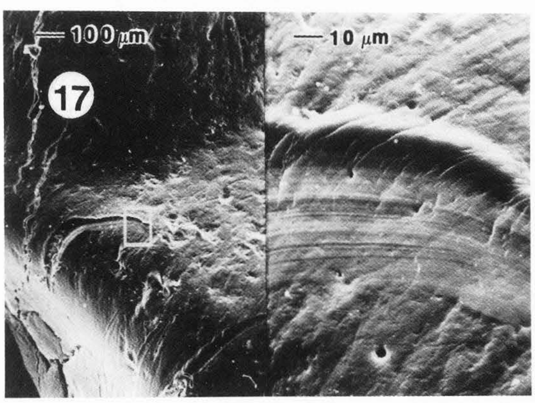

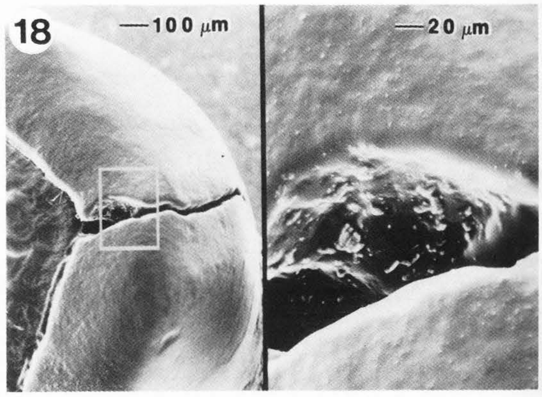

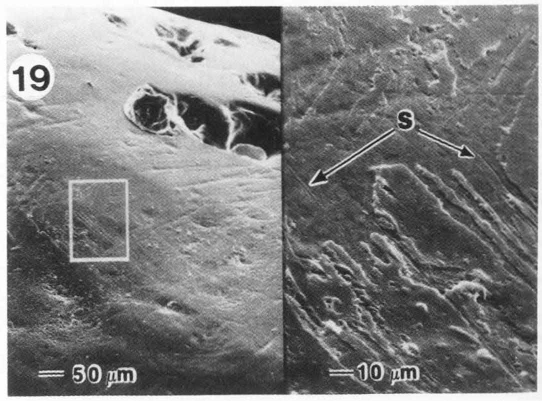

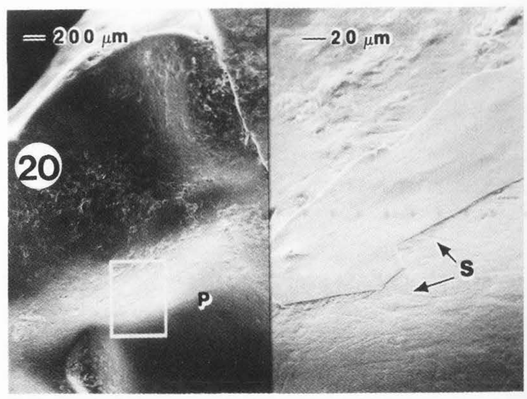

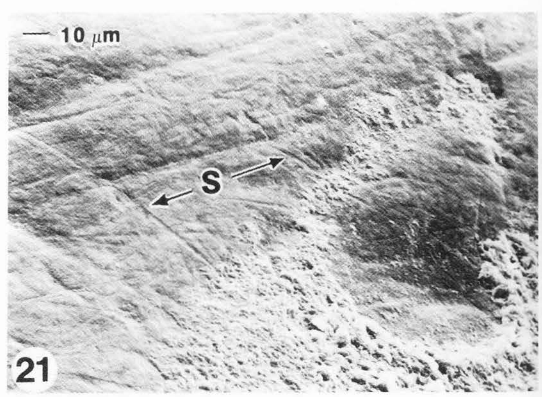

Figure 15. Postmortem abrasive wear on RM^1 of 50 million year old fossil primate (Cantius)(USGS #441). Note similar microwear patterns on facet 4 (f.4) and buccal side of tooth (B).
Figure 16. Postmortem chemical weathering on LM^1 of Early Miocene fossil primate (Proconsul indet.)(KNM-ME 11). Note erosive pitting on protocone tip facet (P) and lingual side of tooth (L).
Figure 17. Gouge caused by dental pick on cast of LM^2 of museum specimen of Cebus nigrivittatus (NMNH 388192). Deformation of microwear features (in right half of micrograph) shows that epoxy cast is damaged, not the original specimen.
Figure 18. RM_2 of museum specimen of Presbytis rubicunda (MCZ 35653). Preservative has been left on the surface of the tooth. Note lack of prism detail in crack in enamel (right half of micrograph).
Figure 19. RM_2 of 18 million year old fossil primate (Proconsul africanus)(KNM-RU 2088A). Preservative has only been partially removed from tooth surface. Apparent scratches visible at low magnification (left half of micrograph) are really minute strips of preservative left on tooth. In right half of micrograph, note "real" scratches (S) deep to preservative.
Figure 20. RM_2 of museum specimen of Cebus nigrivittatus (NMNH 443210) (P = tip of protocone). Smooth surface in middle of right half of micrograph is a patch of preservative left on the tooth surface. Note scratches (S) disappearing deep to preservative.
Figure 21. RM^1 (facet 3) of 20 million year old fossil primate (Proconsul major)(KNM-SO 418). Note scratches (S) disappearing under matrix remaining on tooth.

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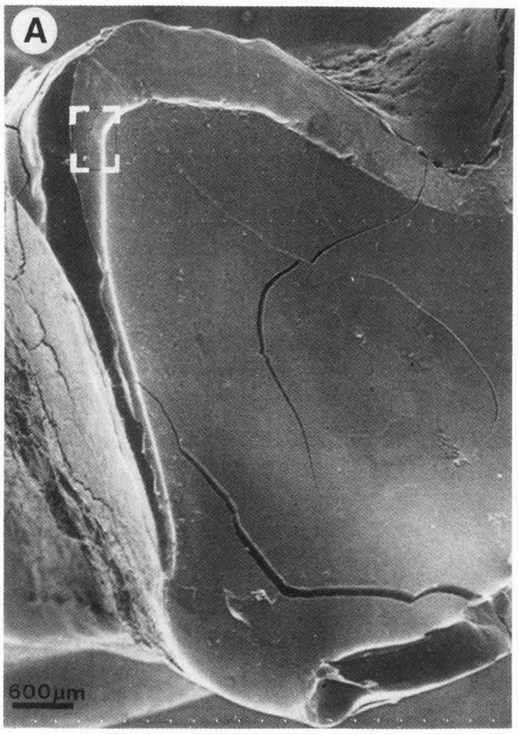
Discussion with Reviewers

K. Gordon: I think it is important to note that even eliminating all suspicious teeth from one's sample would not with any certainty eliminate all artifacts from a microwear sample. Some will clearly slip by. This fact emphasizes the need to regard microwear analysis as a statistical approach to reconstructing oral behavior, one which requires large sample sizes. Only with large samples (or as large as humanly possible) can we be fairly confident that unsuspected anomalies or artifacts will be "swamped" by real data.
Author: Thank you for this comment.

P-F. Puech: Dental occlusal contact areas (OCA) are frequently distinguished from contact free areas (CFA), don't you think that damages must be observed on both areas to determine the causes and mechanisms of degradation? Furthermore, if the goal is to determine food choice in extinct species, must the study be limited to microdefects like scratches, pits, and flakes?

I have established by analogy with Bushmen that hard food and abrasive particles have produced important dental wear in Australopithecus. However, in Homo habilis from Olduvai, rapid wear has apparently been caused by a combination of polishing, chemical erosion, and high stress action [Puech, P-F. (in press). Microwear studies of early African hominid teeth, in: Hominid Evolution, Behaviour and Dispersal. MH Day, R Foley and W Rukang (eds), Allen & Unwin, London]. One of the characteristic features seen on the teeth of H.habilis is a pattern of furrows formed by parallel, fabric-like grooves. Similar features are seen on the teeth of grazers such as sheep which frequently show significant degrees of wear on their teeth (Figure A). Furrows are present on the contact free areas (CFA) of the teeth of sheep (Figures B & C), and slight acid-etching of the teeth causes these furrows to disappear. The retention of similar furrows on the teeth of Homo habilis, together with localized areas of chemical erosion, suggests that the chemical erosion of enamel and dentin resulted from acidic food and was not of postmortem origin.
Author: Clearly, the safest way to make inferences about the dietary habits of prehistoric species is to use every available source of information, including microscopic and macroscopic analyses of dental morphology and wear. As I've indicated above, diagnoses of wear patterns on teeth are best made with complete specimens where we can examine the occlusal and non-occlusal surfaces of the teeth.

I've avoided the distinction between occlusal contact areas and contact free areas only because I feel that, at the microscopic level, it is a misleading oversimplification - especially in analyses of mammals other than modern humans. While it is true that tooth-tooth contacts cannot occur at certain points on the occlusal surface, tooth-food-tooth contacts can occur anywhere on the occlusal surface. Moreover, we still have a very poor understanding of the intricacies of tooth-food-tooth interactions in chewing. For instance, at the microscopic level, are there really significant tooth-tooth contacts in chewing, or is there always a thin film of food between the teeth? Do different areas on the tooth experience more tooth-tooth (or tooth-food-tooth) contacts during the mastication of different foods? How might contact patterns vary



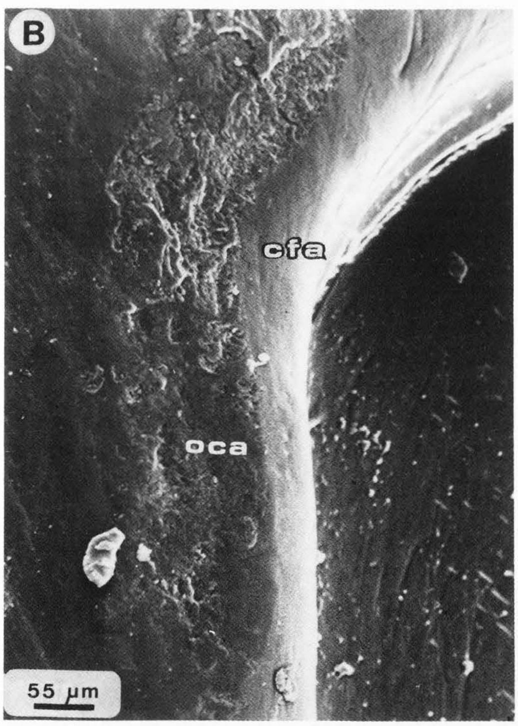


Figure A. Low magnification micrograph of sheep tooth.
Figure B. Higher magnification micrograph of same tooth. CFA = contact free area; OCA = occlusal contact area.
Figure C. Higher magnification micrograph of same tooth. Note furrows on contact free area in right half of micrograph.

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between animals with drastically different diets? Until we can answer these questions, distinctions between contact- and contact-free areas may do little more than give us the illusion of understanding what is in relity a very complicated situation.

As for the dietary inferences concerning Homo habilis, I still suspect that the erosion of the teeth of OH16 is of postmortem origin. Enamel is a surprisingly subtle indicator of exposure to dilute acids - i.e., short exposures to dilute acids will yield recognizable effects on tooth enamel and still not obliterate larger features such as the "furrows" built over the underlying dental microstructure. Thus, the presence of such furrows on fossil teeth does not necessarily rule out the possibility of postmortem chemical weathering.