A New Method for Examining Hominin Dietary Strategy:

Occlusal Microwear Vector Analysis of the Sangiran 7 *Homo erectus* Molars

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Summary

Many hominin species are best physically represented and understood by the sum of their dental morphologies. Generally, taxonomic affinities and evolutionary trends in development (ontogeny) and morphology (phylogeny) can be deduced from dental analyses. More specifically, the study of dental remains can yield a wealth of information on many facets of hominin evolution, life history, physiology and ecological adaptation; in short, the organisms paleobiomics. Functionally, teeth present information about dietary preferences, that is, the dietary niche in ecological context and, in turn, masticatory function.

As the amount and types of information that can be gleaned from 2-dimensional tooth measurement exhaust themselves, 3-dimensional microscopic modeling and analysis presents a largely fertile ground for reexamination and reinterpretation of dental characteristics (Bromage et al., 2005). As such, a novel, non-destructive approach has been developed which combines the work of two established technologies (confocal microscopy and 3D modeling) adapted specifically for the purpose of mineralized tissue imaging. Through this method, 3D functional masticatory and therefore occlusal molar microwear is able to be visualized, quantified and comparatively analyzed to assess dietary preference in Javanese *Homo erectus*. This method differs from other microwear investigative techniques (defining 'pits'- vs- 'scratches', microtexture analysis etc.) in that it defines a molars masticatory microwear functional interactions in 3-dimensions as its baseline dataset for further interpretations and analyses.

Due to poor specimen collection techniques employed during the first half of the 20th century, the very complex geologic nature of the Sangiran Dome and

disagreements over its chronostratigraphy, only very few scientific works have addressed the Sangiran 7 (S7) *Homo erectus* molar collection (n=25) (e.g. Grine and Franzen, 1994; Kaifu, 2006). Grine and Franzen's (1994) work was a predominantly qualitative initial assessment of the specimens and identified five specimens that might better be ascribed to a fossil pongid rather than *H. erectus.* They also noted several molars to which tooth position (M1 or M2) was unable to be ascribed (Grine and Franzen, 1994). Kaifu (2006) comparatively examined crown sizes in several S7 molars.

The Sangiran 7 collection originates from two distinct geologic horizons: ten from the older Sangiran Formation (S7a, ~1.7 to 1.0mya) and fifteen from the younger, overlying Bapang Formation (S7b, ~1.0 to .7mya). During this million year period, Java was connected to the mainland during various glacio-eustatic low-stands in sea level. These mainland connections varied in size, extent, climatic condition and therefore in faunal and floral composition. As the S7 sample may be representative of the earliest *Homo erectus* migrants into Java and spans long durations of occupation, its investigation yields potential to understand the various influences climatic and ecogeographic fluctuations had on these populations. Since the sample consists only of teeth, an ecodietary approach has been deemed the most logical and appropriate investigative approach. Questions regarding the intra- and inter- S7 sample relationships will also be addressed.

By comparing various aspects of the *H. erectus* dentition against that of hunter/ gatherer's (H/G) whose diet is known, functional dietary similarity can be directly correlated. Thus a comparative molar sample consisting of the below historic hunter/ gather's (n=63) has been included in order to assess *H. erectus's* diet in ecological context: Inuit (n=9), Pacific Northwest Tribes (n=11), Fuegians (n=11), Australian Aborigines (n=12) and Bushman (n=20).

Methodologically, this approach produces a 3D facet microwear vector (fmv) signature for each molar which can then be compared for statistical similarity. Microwear (and, as such, the fmv signatures) was defined by the regular, parallel striations found on specific cusp facets known to arise from patterned, directional masticatory movements. This differs significantly from post-mortem or taphonomic microwear which produces striations at irregular angles on multiple, non-masticatory surfaces (Peuch et al.1985, Teaford, 1988). A 'match value' is produced to determine the similarity of two molars fmv's. The 'match values' are ranked (high to low) and these rankings are used to statistically analyze and infer dietary preference: between Sangiran 7 (as an entire sample) compared against that of the historic hunter/ gatherer *H. sapiens* whose diet and ecogeography is known; within S7a and S7b and then among the S7 sample (eg. S7a-vs-S7b); whether the purported Pongo molars actually affiliate well with *H. erectus,* the hunter-gatherer's or if they demonstrate distinctly different fmv signatures altogether; whether fmv signatures are useful in distinguishing molars whose tooth position is in doubt (eg. M1 or M2).

When compared against individual H/G molars, the results show that Sangiran 7 *H. erectus* most closely correlates with Bushmen across all areas of fmv signature analysis. However, within broader dietary categories (yearly reliant on proteinaceous foods; seasonally reliant on proteinaceous foods; not reliant on proteinaceous foods), it was found that *H. erectus* most closely allied with the two hunter/ gatherer sub-populations associated with the 'Seasonally reliant on proteinaceous foods' (Australian

Aboriginals and Pacific Northwest Tribes). There was also evidence for dietary change or specialization over time. As the environment changed during occupation by the earlier Sangiran to the later Bapang individuals, the dietary preference shifted from a focus on vegetative foods to a diet much more inclusive of proteinaceous resources. These results are considered logical within the larger ecogeographic and chronostratigraphic context of the Sangiran Dome during the Pleistocene. However, a larger sample would be needed to confirm this. Although general dietary preferences can be drawn from this method, it is not possible at present to define specific foods consumed on a daily basis (eg. tubers or tortoise meat).

Out of the five specimens possibly allied with Pongo, S7-14 matched at the 'high' designation with a hunter/ gatherer, S7-62 matched 'moderately', S7-20 matched 'low' while the remaining two were not able to be matched with any other teeth for various reasons. Although designation to Pongo cannot be ruled on at this time using this method, it does demonstrate that at least two of the teeth correlate well with various hunter/ gatherer's who do not share dietary similarity with Pongo. This suggests their designation as Pongo should be more closely reevaluated. As for the four specimens whose tooth position was unsure, S7-14 matched 'highly' with 1st molars, S7-62 and S7-78 matched 'moderately' with 2nd and 1st molars respectively while S7-20 only matched at the 'low' designation. Although this approach is still exploratory, it adds another analytical tool for use in defining tooth position.

In sum, this method has demonstrated its usefulness in defining and functionally analyzing a novel 3D molar microwear dataset to interpret dietary preference. Future work would include a pan- *H. erectus* molar sample in order to illuminate broader populational, taxonomic and dietary correlations within and amoung all *H. erectus* specimens. A larger, more heterogenous historic H/G sample would also be included in order to provide a wider dietary comparative population. This method can be further extended to include and compare any and all hominins as well as any organism which produces micro wear upon it molars. Also, the data obtained and resultant fmv signature diagrams have the potential to be incorporated into 3D VR reconstructions of mandibular movement thus recreating mastication in extinct organisms and leading to more robust anatomical and physiological investigations especially when viewed in the context of larger environmental conditions or changes.

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Zusammenfassung

Viele Hominiden-Arten sind überwiegend durch fossile Zahnreste bekannt und durch deren Morphologie definiert. Systematische Zugehörigkeit und evolutionäre Trends in der Individualentwicklung (Ontogenese) und in der Konstruktion (Phylogenese) können durch Zahnanalysen abgeleitet werden. Daher liefert die Untersuchung von fossilen Zähnen eine Fülle von Informationen über die Evolution früher Hominiden, wie z.B. zur Lebensgeschichte sowie zur physiologischen und ökologischen Adaptation an den Lebensraum (Human Paleobiomics). Funktionelle Interpretationen der Zähne lassen Rückschlüsse auf Nahrungspräferenzen, das ökologische Umfeld, und die Kaufunktion zu.

Die traditionellen Methoden zweidimensionaler Vermessungen von Zähnen wurden seit einigen Jahren von dreidimensionalen Methoden und Analysen abgelöst, die innovative Ansätze für die Interpretation dentaler Eigenschaften ermöglichen (Bromage et al., 2005). Für die vorliegende Untersuchung von Hartgeweben wurde eine zerstörungsfreie Methode entwickelt, die zwei sich schnell weiterentwickelnde Technologien koppelt, die konfokale Mikroskopie und das 3D-Modeling. Hiermit können sowohl funktionelle 3D Kaubewegung als auch okklusale Abnutzungsspuren bei Molaren („Microwear") dargestellt, quantifiziert und vergleichend analysiert werden, um Nahrungspräferenzen von *Homo erectus* aus Java zu analysieren. Die hier angewendete Methode unterscheidet sich von den üblichen „Microwear"-Techniken (z.B. Bewertung von „Gruben" und „Kratzern", Mikrotexturanalyse, etc.), da die funktionelle Molaren-„Microwear" Interaktion des Kauvorganges räumlich dargestellt als Datengrundlage für die Interpretation definiert wird.

Die Grundlage für die vorliegende Arbeit ist die Sammlung G.H.R. v. Koenigswald aus Sangiran, Java, die im Senckenberg Forschungsinstitut Frankfurt am Main kuratiert wird. Aufgrund ungenauer Angaben zu Alter und Chronostratigraphie der Hominidenfunde aus Sangiran, die auf unzureichende Sammlungsstrategien während der ersten Hälfte des 20sten Jahrhunderts und die sehr komplexen Geologie des

Sangiran Doms zurückgehen, wurden bislang nur wenige Arbeiten zur *H. erectus* Molarensammlung Sangiran 7 (S7) (n=25) veröffentlicht (z.B. Grine und Franzen, 1994; Kaifu, 2006).
Grine und Franzen (1994) erreichten mit ihrer Arbeit eine erste qualitative Einschätzung der Stücke und identifizierten fünf der vermeintlichen *H. erectus* Zähne als einem fossilen Pongiden zugehörig. Bei einigen Stücken ist es nicht eindeutig, ob es sich hierbei um einen ersten oder zweiten Molaren handelt (Grine und Franzen, 1994). Kaifu (2006) untersuchte vergleichend die Kronengröße bei einigen S7 Molaren.

Die Sangiran 7 Sammlung stammt aus zwei verschiedenen geologischen Horizonten: Zehn Exemplare stammen aus der älteren Sangiran Formation (S7a, ca. 1,7 bis 1,0 Mio. Jahre) und fünfzehn Zähne aus der jüngeren, darüber liegenden Bapang Formation (S7b, ca. 1 bis 0,7 Mio. Jahre). Während dieser Periode war Java mit dem südostasiatischen Festland verbunden, da aufgrund langanhaltender Vereisungen der Meeresspiegel deutlich niedriger stand als heute. Diese Verbindungen zum Festland variierten in Größe und Ausdehnung je nach klimatischen Bedingungen und bedingten somit unterschiedliche Floren- und Faunenzusammensetzungen in Java.

Die S7 Sammlung repräsentiert, zumindest teilweise, die ersten *H. erectus* Immigranten in Java und insgesamt, den langen Zeitraum den diese Frühmenschen auf Java siedelten. Die Untersuchung der fossilen Reste erlaubt daher Hinweise zu den verschiedenen klimatischen Einflüssen und ökogeografischen Schwankungen auf diese frühmenschliche Population. Da die S7 Sammlung nur aus Zahnmaterial besteht, bietet sich eine nahrungsspezifische Untersuchung mit ökologischem Aspekt an.

Fragen zur inner- und zwischenartlichen Beziehung in der S7 Sammlung werden ebenfalls untersucht. Beim Vergleich der *H. erectus* Zähne mit denen von Jäger und Sammlerpopulationen (H/G) mit bekanntem Nahrungsspektrum kann eine funktions-nahrungsspezifische Beziehung überprüft werden. Daher wurde eine vergleichende Auswahl an Molaren von Jäger/Sammler Populationen (n=63) hinzugezogen, um die Nahrung von *H. erectus* im ökologischen Kontext zu beurteilen: Inuit (n=9), „Pacific

Northwest Tribes“ (n=11), Feuerländer (n=11), australische Aborigines (n=12) und Buschmänner (n=20).

Untersucht wurde die sogenannte „Microwear“, parallele Striationen, die auf bestimmten Zahnfacetten durch die gerichteten Kaubewegungen entstanden sind. Von jedem Molaren wurden die Vektoren der Hauptstriationen bestimmt (3D facet-microwear-vector – fmv) und statistisch verglichen. Durch die Kaubewegungen entstandene Striationen unterscheiden sich deutlich von postmortal auf taphonomischem Weg entstandenen „Microwear“-Muster. Diese erkennt man durch eine hohe Variabilität von unregelmäßigen Richtungen auf den Kauflächen der Zahnoberfläche (Peuch et al.1985, Teaford, 1988). Ein Übereinstimmungswert „match-value“ wurde definiert, um Übereinstimmungen des 3D fmv zweier Molaren zu bestimmen. Die “match-value”-Werte sind von hoch bis niedrig kategorisiert. Die Rangordnung wurde zur statistischen Analyse herangezogen und erlaubt Rückschlüsse zu den Nahrungspräferenzen der Gruppen.

Folgende Vergleichsuntersuchungen wurden durchgeführt:
Sangiran 7 (die komplette Sammlung a und b) wurde verglichen mit historischen Jäger/Sammler Proben von *H. sapiens*, deren Nahrungszusammensetzung und Ökogeografie bekannt ist. Sangiran S7a wurde gegen S7b getestet.
Die vermeintlichen Pongo-Molaren in der Sammlung wurden jeweils mit S7a und S7b und mit der kompletten Sangiran 7 Sammlung verglichen, um festzustellen, ob die fmv Signaturen mit *H. erectus* und/oder den Jäger/Sammler Zähnen übereinstimmen, oder sich grundsätzlich unterscheiden. Bei der Untersuchung der Molaren wurde auch bestimmt, ob die fmv Signatur hilfreich sein kann, um die Zahnposition von isolierten M1 oder M2 Proben zu identifizieren.

Beim Vergleich mit den Einzelgruppen der Jäger/Sammler Molaren fiel auf, dass die S7 *H. erectus* bei allen fmv Analysen eng mit den Buschmann Molaren korrelieren. Buschleute zählen zu den Generalisten, die alle zur Verfügung stehende Nahrung konsumieren, aber sie bevorzugen pflanzliche vor proteinreicher Kost.

Werden jedoch breitere Nahrungskategorien zum Vergleich herangezogen (ganzjährige- oder saisonale Abhängigkeit von proteinhaltiger Nahrung, oder unabhängig von Proteinnahrung), fällt eine hohe Ähnlichkeit von *H. erectus* mit Jäger/Sammlern auf, die saisonal von Proteinnahrung abhängig sind (Aborigines und die „Pacific Northwest Tribes“). Obwohl diese Populationen eine ausreichende Menge pflanzlicher Kost zu sich nehmen, setzt sich deren Nahrung zum größten Teil aus proteinhaltigen Quellen zusammen. Sie neigen dazu, ihre Nahrung anders aufzubereiten als die Buschleute (z.B. Fische trocknen oder kochen in Erdgruben).

Es gibt auch Anzeichen für eine zeitliche Änderung und/oder eine Spezialisierung in der Nahrungszusammensetzung. Während der Besiedelung Javas durch die frühen Sangiran Populationen bis zu den späteren Bapang-Frühmenschen, veränderten sich die jeweiligen Lebensräume, was sich auch auf die Nahrungszusammensetzung der Frühmenschen auswirkte. Eine ursprünglich mehr vegetarische Kost wurde im jüngeren Zeitabschnitt durch stärker proteinreiche Nahrung abgelöst. Die Ergebnisse erscheinen schlüssig, wenn man den ökogeografischen und chronostratigrafischen Kontext des Sangiran Doms während des Pleistozäns berücksichtigt, der von einem feuchten, sumpfigen Seengebiet zu einem trockeneren Lebensraum mit offener Waldfläche überging. Allerdings wäre eine höhere Anzahl an Zahnfunden nötig, um dies statistisch zu bestätigen. Obwohl sich mit dieser Methode generelle Nahrungspräferenzen erkennen lassen, ist es nicht möglich spezifische Bestandteile der täglichen Nahrung genauer einzugrenzen, wie etwa der Verzehr von Knollen oder Schildkrötenfleisch.

Von den fünf Exemplaren, die als möglicherweise *Pongo* klassifiziert wurden, passt S7-14 in der Rangstufe „hoch“ zu einem Jäger/Sammler, S7-62 „mittel“, S7-20 „niedrig“, während die übrigen zwei sich keiner Kategorie zuordnen lassen.
Wenn also eine morphologische Zuordnung zu Pongo nicht ganz ausgeschlossen werden kann, zeigt sich zumindest, dass wenigstens zwei Zähne gut mit den

Jägern/Sammlern korrelieren, die keine Nahrungspräferenz mit Pongo teilen. Diese zwei Molaren sollten daher *H. erectus* zugeordnet werden.
Von den Zähnen, deren Position in der Zahnreihe unsicher war, passt S7-14 „hoch“ zu einem M1, S7-62 und S7-78 passen „mittelmäßig“ zu einem M2 und M1, während S7-20 nur mit „niedrig“ zugeordnet werden kann.

Obwohl diese Untersuchungsmethode noch ganz am Anfang steht, bietet sie ein zusätzliches Werkzeug, um die Zahnposition von isolierten Molaren zu bestimmen. Zusammenfassend bieten die neuen Methoden mit der Analyse neuer „Microwear“-Parameter, innovative Grundlagen für die Interpretation von Nahrungspräferenzen.

Weiterführende Arbeiten sollten sämtliche verfügbaren *H. erectus* Molaren einschließen, um Erkenntnisse zur Variabilität von Populationen und die taxonomischen und nahrungsspezifischen Korrelationen innerhalb verschiedener *H. erectus* Gruppen zu erhalten. Zusätzlich sollte eine größere und heterogenere Stichprobe der modernen Jäger/Sammler Vergleichspopulation hinzugezogen werden, um die Stichprobe zu vergrößern.

Die neu entwickelte Methode ist generell auf Säugetiermolaren mit erhaltener „Microwear“ anwendbar und daher von grundlegender Bedeutung für die paläobiologische Analyse fossiler Säugetiere. Die resultierenden fmv Signaturdiagramme bieten zusätzlich die Möglichkeit zur virtuellen 3D-Rekonstruktion von okklusalen Unterkieferbewegungen und somit zur Rekonstruktion und Visualisierung von Kaubewegungen ausgestorbener Säugetiere. Dies lässt Rückschlüsse auf anatomische und physiologische evolutive Neuerwerbungen zu, die durch Umweltbedingungen und –veränderungen verursacht wurden.

Chapter 1

Sangiran Stratigraphy and Dating

1.1 Introduction

The overall chronostratigraphy of the Sangiran Dome has been the subject of much contention virtually since the region was discovered as a fossiliferous site. The lack of scientific consensus stems from the areas very active and complex geology where uplift, subsequent doming and faulting, periodic volcanism producing lahars and ashfalls etc. confounded by fluviatile reworking have all conspired to create one of the most interpretively difficult fossil sites (Duyfjes, 1936; Bilsborough, 2000; Larick et al., 2000). Recently, two differing dating schemes have emerged; one which posits very early depositional dates (an 'old chronology') and another which suggests later dates (a 'young chronology'). As either chronology has yet to be definitively and/ or universally eliminated or supported, both will be briefly presented and considered.

The central Javan sediments themselves, although relatively complex lithostratigraphically are well known and will be described in some detail and correlated with each chronology. This in order to assess and interpret fluctuations in climate and thus environment as finely as possible. Although there is largely geologic continuity within each sedimentary layer across central Java, the formation names differ depending on the geographic local in which they are found. As such, at Sangiran, the lower stratigraphic layer is termed 'Sangiran' while at Trinil and other central Javan sites, it is called 'Pucangan'. The upper layer is termed 'Bapang' at Sangiran and

'Kabuh' at other sites (Itihara et al., 1985). Since the sample studied in this thesis originates from Sangiran itself and in an attempt to reduce confusion, the terms Sangiran and Bapang will be used here and described from oldest to youngest.

1.2 Stratigraphy

At the Sangiran Dome, the oldest beds belong to the upper Kalibeng Formation and were uplifted and exposed only through a small area at the center of the dome. The lowest layer consists of blue-gray marine marls and clay and contain many gastropods, pelecypods (bivalves) and crabs (Fig.1.1) (Koenigswald, 1934; 1935; 1940). Prevalent ostracods indicate a brackish environment. As the Kalibeng Fm. gets younger (moving vertically through the formation), they also get sandier with oysters predominating. The uppermost layers consist of limestone almost entirely composed of barnacles indicating tidal deposition. This facies succession indicates a marine regression culminating with the deposition of fresh water pelecypod beds (Hertler & Rizal, 2005).

The lower lahar unit (LLU) uncomformably overlies the pelecypod beds such that the lahar forms an irregular ring around the exposed Kalibeng sediments (Fig.1.1). The lahar is overlain by black clays which are characteristic of the Sangiran Formation (vanBemmelen, 1949). This facie contains freshwater gastropods for about 25m but grades suddenly to sandy layers. These sands contain marine mollusks and represent a sudden marine ingression. The area remained brackish for some time as indicated by the presence of 15m thick diatomaceous beds. A period of volcanism (lava flows, ash falls etc.) sealed off the area from marine intrusion forming a giant lake. Normal limnic sedimentation resumed during this period resulting in the deposition of more black clays with layers of mollusks forming white bands (Koenigswald, 1934; 1935; 1940). Larick et al. (2004) posit that the Sangiran Fm. environment began as a low wetland which gradually transitioned into a lush landscape pockmarked by shallow lakes as uplift of the Sangiran Dome proceeded. At its deepest, the Sangiran Fm. is 200m thick and corresponds to the Satir fauna in its lowest layers and the Ci Saat fauna in the upper.

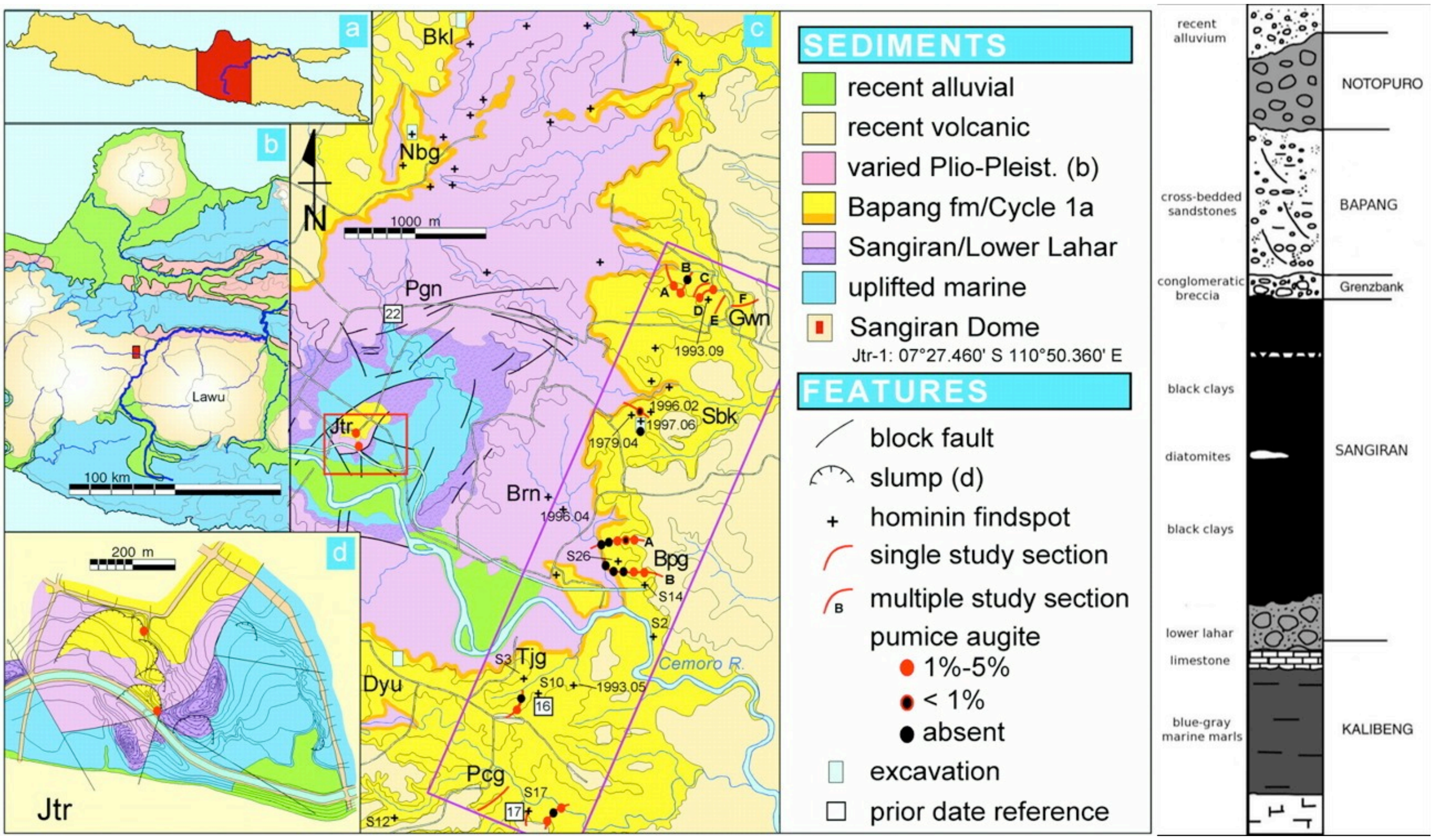


Figure 1.1. Sangiran Dome formations and lithostratigraphy.
(Adapted from Larick et al., 2001 and Bouteaux, 2007)

At the uppermost limit of the Sangiran Fm., the deposits transition into a sandy-conglomeratic layer ~1m thick which, at many points is interrupted by deposits of calcareous breccia (Fig. 1.1). This facie is termed the Grenzbank unconformity and contains vertebrate fauna comparable to those at Trinil. It has also yielded several hominin mandibles attributed to the relatively robust *Homo erectus 'Meganthropus'*. The

Grenzbank marks the base of the Bapang Formation which is typified by cross-bedded fluviatile sandstones that reach a total vertical depth of ~100m (Koenigswald, 1934; 1935; 1940). These facies are divided into sedimentary cycles by three volcanic tuffs: the lower, middle and upper tuffs (Fig. 1.2). The majority of hominin remains come from just below and above the middle tuff. The Trinil fauna correlates with the sedimentary cycle bounded by the Grenzbank unconformity and the lower tuff. The Kedung Brubus fauna corresponds to the sedimentary cycles superior to the lower tuff to just above the upper tuff.

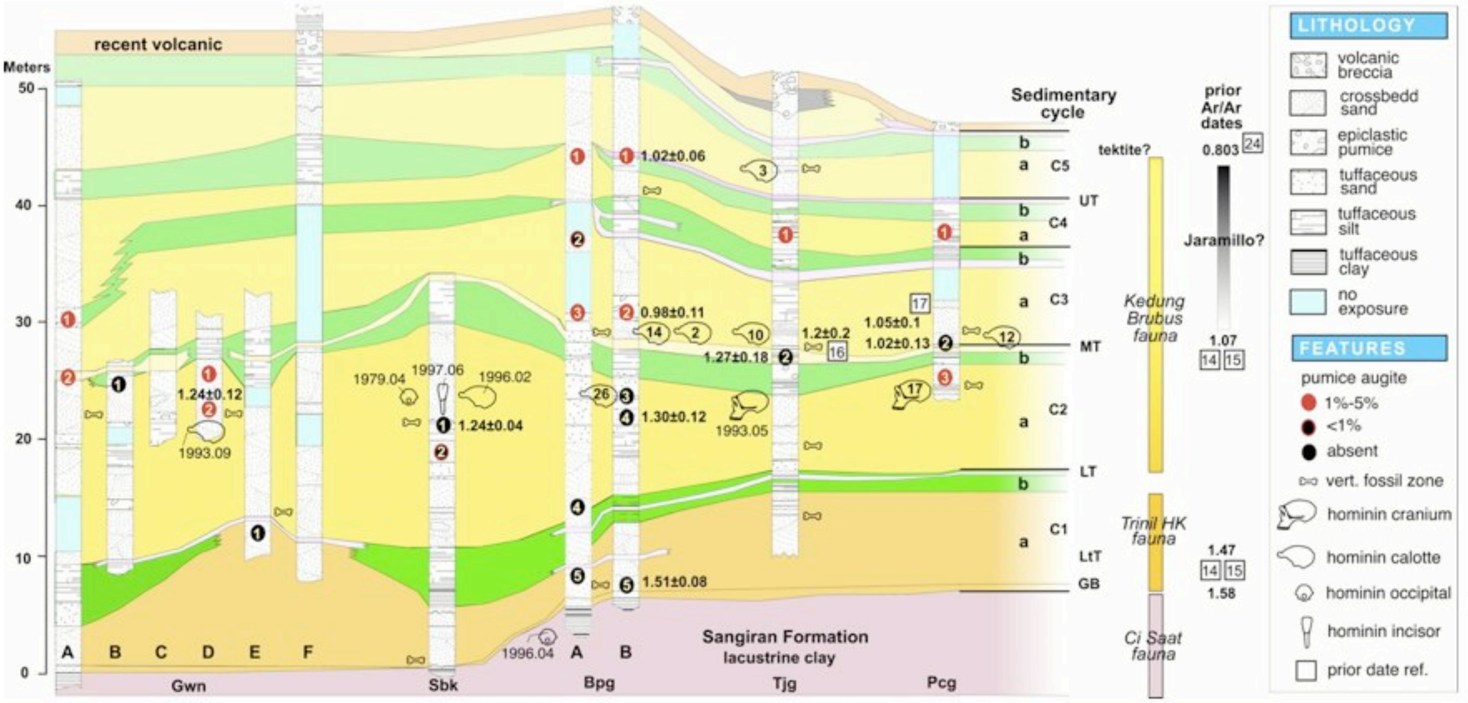
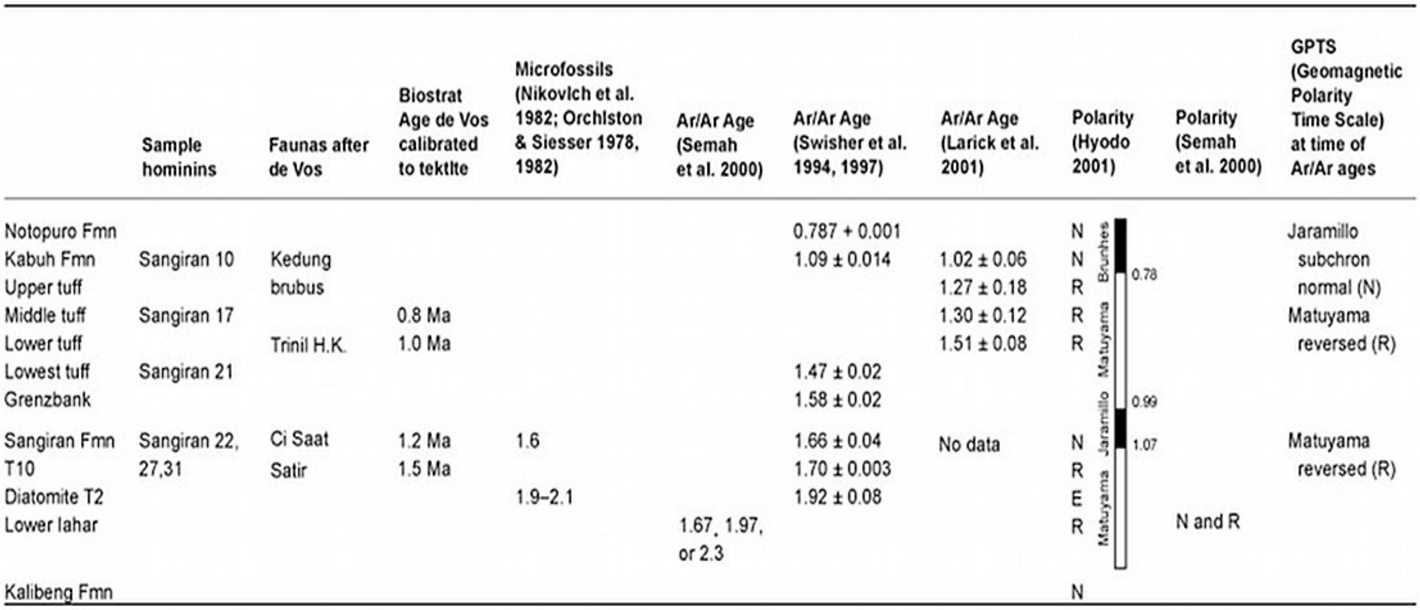


Figure 1.2. Bapang Formation lithostratigraphy.
(Adapted from Larick et al., 2001)

1.3 Dating

As introduced above, there is much disagreement regarding the dating of the Central Javan sediments (Fig 1.3). The arguments for early deposition rely on $^{40}Ar/^{39}Ar$ dating of pumice deposits. Work by Bettis et al. (2004) suggests that the LLU was deposited as early as 1.90+/-0.02 Ma. Swisher et al. (1994) and Huffman (2001) dated the volcanic layer from which the Mojokerto cranium originated to 1.81 +/- 0.04 Ma while the earliest Sangiran hominids (S27 and S31) are said to date to ~1.62 +/- 0.04 Ma (Indriati & Anton, 2008). Larick et al. (2001) obtained dates of 1.51 +/-0.08 Ma for the Sangiran/ Bapang Formation boundary which lies 10m above the earliest hominid remains (Brn 1996.04). They also found a date of 1.02 +/-0.06 Ma at the superior border of the Bapang hominid fossil-bearing sequence. These sediments have yielded ~80 *H. erectus* specimens most of which have known provenance (Dennel, 2003).



	Sample hominins	Faunas after de Vos	Biostrat Age de Vos calibrated to tektite	Microfossils (Nikovich et al. 1982; Orchiston & Siesser 1978, 1982)	Ar/Ar Age (Semah et al. 2000)	Ar/Ar Age (Swisher et al. 1994, 1997)	Ar/Ar Age (Larick et al. 2001)	Polarity (Hyodo 2001)	Polarity (Semah et al. 2000)	GPTS (Geomagnetic Polarity Time Scale) at time of Ar/Ar ages
Notopuro Fmn						0.787 + 0.001		N		Jaramillo
Kabuh Fmn	Sangiran 10	Kedung				1.09 ± 0.014	1.02 ± 0.06	N		subchron
Upper tuff		brubus					1.27 ± 0.18	R		normal (N)
Middle tuff	Sangiran 17		0.8 Ma				1.30 ± 0.12	R		Matuyama
Lower tuff		Trinil H.K.	1.0 Ma				1.51 ± 0.08	R		reversed (R)
Lowest tuff	Sangiran 21					1.47 ± 0.02				
Grenzbank						1.58 ± 0.02				
Sangiran Fmn	Sangiran 22,	Ci Saat	1.2 Ma	1.6		1.66 ± 0.04	No data	N		Matuyama
T10	27,31	Satir	1.5 Ma			1.70 ± 0.003		R		reversed (R)
Diatomite T2				1.9–2.1		1.92 ± 0.08		E		
Lower lahar					1.67, 1.97, or 2.3			R	N and R	
Kalibeng Fmn								N		

Figure 1.3. Various conflicting dating schemes for Sangiran sediments.
(Adapted from Anton and Swisher, 2004 & Kaifu et al. 2005)

These findings are, however, inconsistent with palaeomagnetic, biostratigraphic and lithological studies which attest to more recent hominin arrival dates in Java (Semah, 2001; Matsu'ura et al., 2006). Semah et al. (2000), combining ^{40}Ar/^{39}Ar and palaeomagnetic data, suggest that the LLU dates to 1.67 Ma which corresponds to the

Olduvai/ Matuyama transition (Fig 1.3). As such, hominins couldn't have arrived prior to this as the LLU marks the first appearance of dry land in Java. Interestingly, Anton & Swisher (2004) adopt a date of ~1.78Ma (Berggren et al., 1995) for the Olduvai/ Matuyama boundary but place the base of the LLU at ~1.9Ma as consistent with Bettis (2004). Fission track analysis of the Sangiran Fm. by Itihara (1985) applied dates of 1.51+/- 0.25mya to Tuff 5, 1.49+/-0.32 to Tuff 6 and 1.16+/-0.24 mya to Tuff 11 (Fig. 4). Tuff 5 and 6 lay ~45m and ~75m respectively superior to the base of Sangiran Fm. (Morwood et al. 2003) while Tuff 11 lies slightly below the Grenzbank (Hyodo, 2001). Tuff 11 closely correlates with the beginning of the Jaramillo subchron at 1.07Ma (Hyodo et al., 1993, 2004) which places the Sangiran/ Bapang transition at ~.99Ma (Fig.1.4)(Hyodo et al., 2002). Faunal analyses by Leinders et al. (1985), Sondaar (1984) and van den Bergh et al. (2001) all place the earliest hominins in the Ci Saat fauna (1.2-1.0 Ma). Recently, Morwood et al. (2003) have reported a much more recent $^{40}Ar/^{39}Ar$ age of 1.49 +/-0.13Ma for the Mojokerto skull.

Essentially, what has occurred is that proponents of the older chronology assert that deposition of the Sangiran Formation began between 500 to 300ky earlier than proponents of the younger chronology. de Vos and Sondaar (1994), Langbroek and Roebroeks (2000) and Hyodo et al. (2002) claim that the dates obtained by Swisher et al. (1994) and Larick et al. (2001) are confounded by sedimentary reworking. They also cite Australasian tektites dated to 790ka recovered from the middle Bapang as evidence of a younger chronology. Larick et al. (2010), Anton (2002), Anton and Swisher (2004) of the older chronology reject their criticisms saying that the tektites are of uncertain provenance, the palaeomagnetic techniques employed are outdated and that other methods used are flawed. Interestingly, Anton & Swisher (2004) state: "Paleomagnetics, $^{40}Ar/^{39}Ar$, and fission-track dating, as well as faunal correlations, currently provide the best critical means of assessing age.". However, many of these techniques are the very ones which they reject in making their case for an older chronology. Also, they fail to address an important question which needs to be rectified: Why did hominins reach Indonesia ~500ky years before the first evidence of occupation in China (Dennel, 2003)?

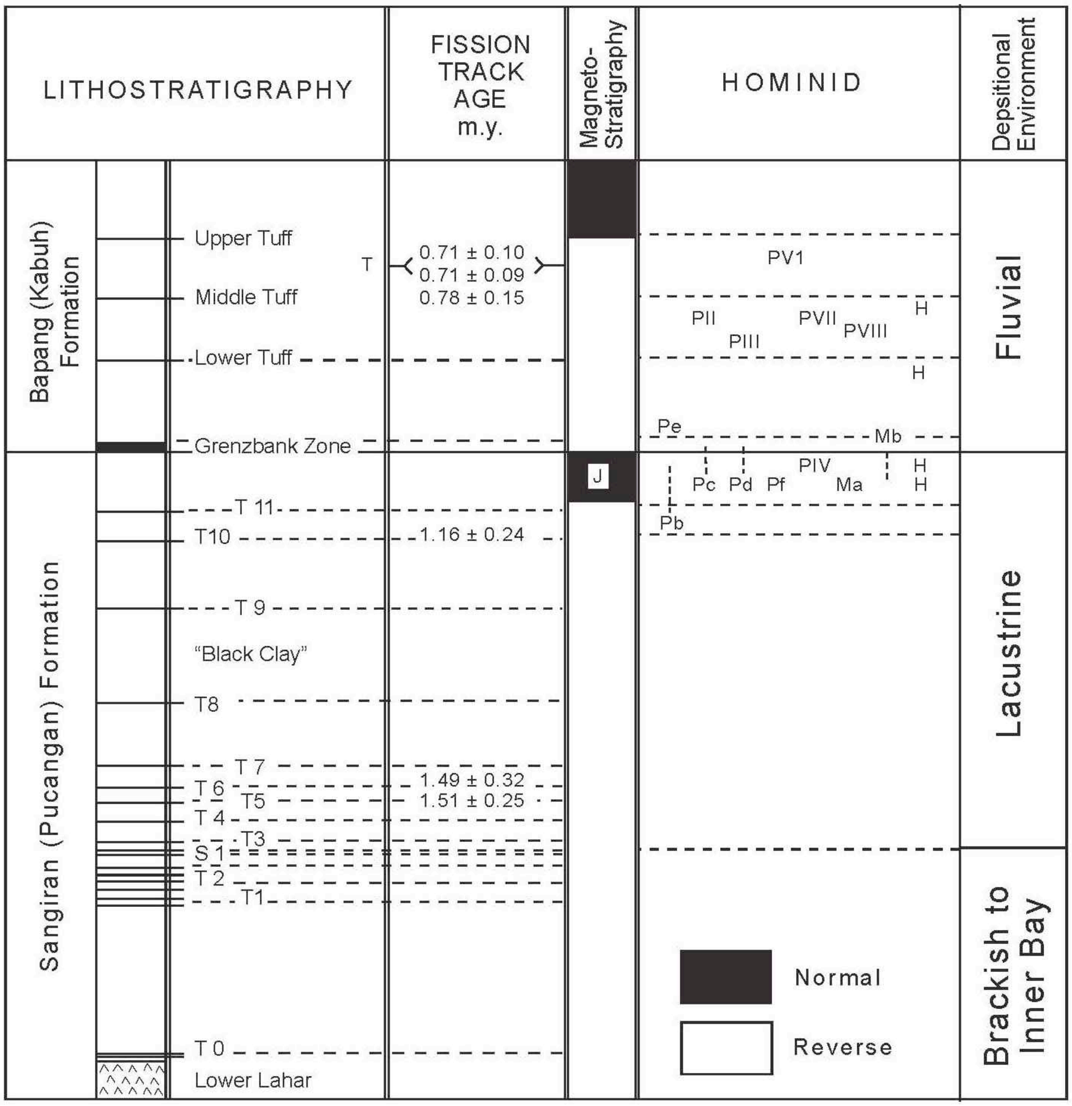


Figure 1.4. Sangiran Fm. correlated chronology.
(Adapted from Itihara, 1994)

Chapter 2

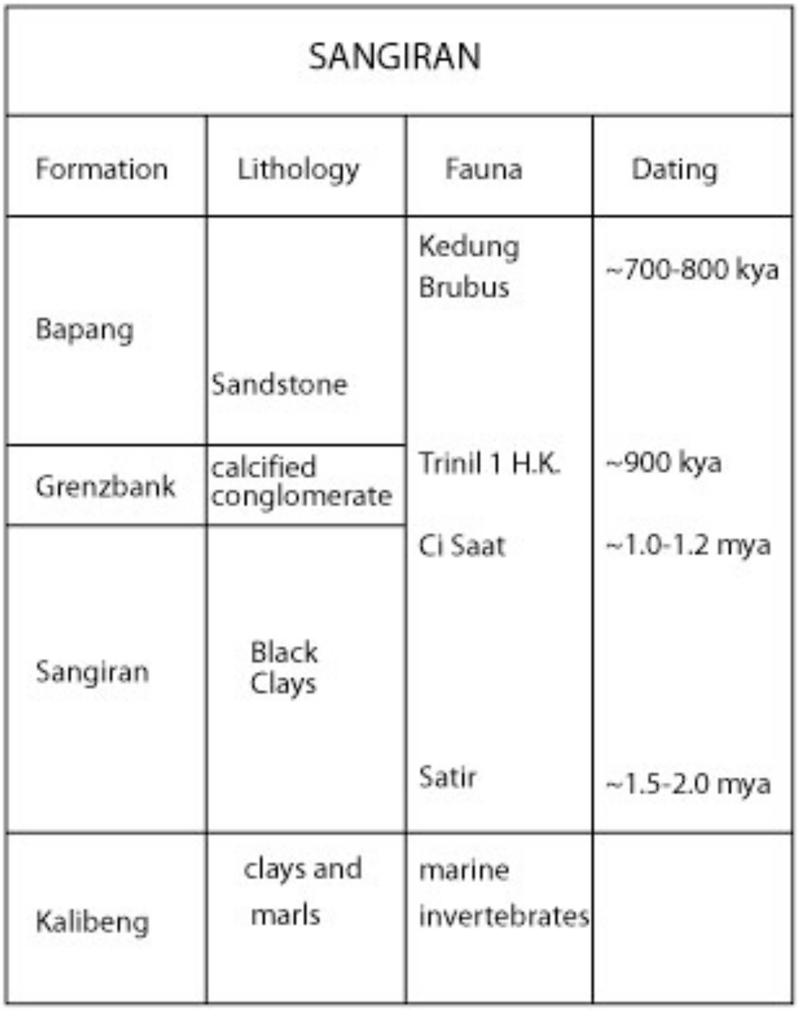
Sangiran Paleoecology

2.1 Introduction

The faunal types at Sangiran are indicative of the varying environments in which the Sangiran 7 *Homo erectus* individuals existed. The transition of species through time also reflects regional and global climatic shifts as sea levels rose and fell and Java was connected to, isolated from and reconnected to the mainland. The movement and or/ isolation of faunas to and from the mainland would directly reflect the possible migratory routes of *H. erectus* during these periods. The species composition of the faunal groups also demonstrate well what *H. erectus* would or could have been hunting, scavenging and gathering during the different periods of its tenure there. This will, in turn, influence the type of enamel microwear wear observed and concordant masticatory cycle which produced it. Therefore, a complete and accurate accounting of Javan organisms existing alongside *H. erectus* gives us direct insight into the actual world in which they would have lived, trod, fed and died.

2.2 Biogeography

Dubois (1892) was one of the earliest researchers to describe the Pleistocene palaeoenvironments of Java. However, von Koenigswald (1933, 1934, 1935 a, b, c, d) was the first to standardize the Javan Quaternary biostratigraphic succession. Later, inconsistencies were recognized in his sequences which necessitated a reorganization of their timing and makeup (de Vos et al., 1982; Braches and Shutler, 1984; Theunissen et al., 1990). de Vos (1983, 1985), de Vos et al. (1982) and Sondaar (1984) then proposed a new biostratigraphic scheme for the Javan Pleistocene (Fig. 2.1). The Sangiran 7 hominins date approximately from the middle Sangiran Formation (~1.3mya) which corresponds to the transition between the Satir and Ci Saat faunas through the middle Bapang Formation (~700kya) which correlates to the Trinil HK and Kedung Brubus faunas (Duyfjes, 1936; Pope and Cronin, 1984; Watanabe and Kadar, 1985; Pope, 1988; de Vos et al., 1994).



SANGIRAN			
Formation	Lithology	Fauna	Dating
Bapang	Sandstone	Kedung Brubus	~700-800 kya
Grenzbank	calcified conglomerate	Trinil 1 H.K.	~900 kya
Sangiran	Black Clays	Ci Saat Satir	~1.0-1.2 mya ~1.5-2.0 mya
Kalibeng	clays and marls	marine invertebrates	

Figure 2.1. Sangiran correlated biostratigraphy
(Adapted after Sondaar 1984, Leinders et al., 1985; Theunissen et al., 1990; de Vos et al., 1994; de Vos and Long, 2001; van den Bergh et al., 2001).

2.2.1 Satir

The Satir and Ci Saat faunal stages are not well represented either from poor fossilization or a simple lack of species due to Java being largely isolated from the mainland during these periods (Van den Bergh, 2001). The Satir fauna consists of *Sinomastodon bumiajuensis*, *Hexaprotodon simplex* (a dwarf hippo), a few unidentified cervids, *Chiropodomys gliroides* (common pencil-tailed tree-mouse), several species of *Mus* and *Rattus* and the giant tortoise *Geochelone* (Van der Meulen and Musser, 1999; Van den Bergh, 2001) while carnivores are notable absent (Table 2.1 at end of chapter). Correspondingly, and in conjunction with palynological evidence, the environment is largely considered to be swampy or mangrove in nature (Sémah, 1984; deVos and Long, 2001). Although *Homo erectus* has been very contentiously dated to this period (de Vos and Sondaar, 1994; Van den Bergh, 1999; Dennel, 2003), swamps and mangroves are notoriously difficult terrain to colonize (much less traverse and hunt in) and the relative dearth of species and individuals of any one species would have represented a sparse food resource base. Also, if Java was in fact an island at this time, it is not widely believed that populations of *H. erectus* had the ability to cross large areas of open water (Fig. 2.2). On these bases, it is considered highly unlikely that *H. erectus* could have existed or persisted on Java at this time.

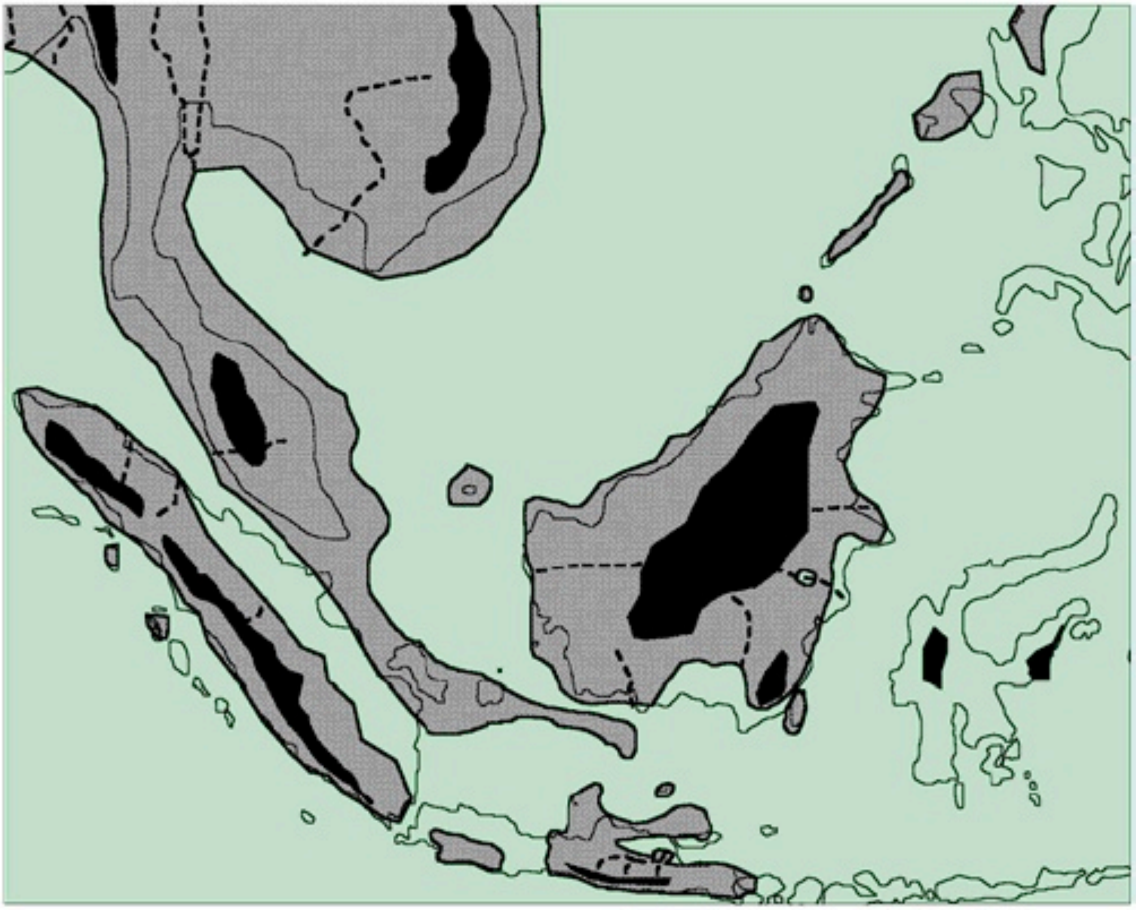


Figure 2.2. Malay Archipelago: early Pleistocene during occupation of Sangiran by the Satir fauna
(Adapted from Meijaard 2004)

2.2.2 Ci Saat

The Ci Saat fauna is represented by *Stegodon trigonocephalus, Hexaproton sivalensis, Muntiacus muntjak*, several unknown cervids and bovids, *Axis lydekkeri*, an endemic pig (possibly *Sus stremmi*) as well as a possible panthera species (Aziz and Van den Bergh, 1995; Van den Bergh, 2001). Meijaard (2004) would add *Chiropodomys gliroides*, a *Rattus* sp., *Antilope saatensis, Cervus palaeojavanicus, Cervus hippelaphus* to the list of species present (Table 2.1). As can be seen when comparing represented species from the Satir to Ci Saat, a faunal turnover occurs here and is likely due to climate shifts and/ or intermittent contact with the mainland (Sémah,1984). deVos and Long (2001) and Bouteaux (2007) consider this evidence of a drier, more open, grassy environment. However, Van den Bergh (2001) does not necessarily see this as indicative of any specific habitat. Overall, it is more feasible for *H. erectus* to have existed in this environment as there was likely a small, periodic overland migration route (via the Malay Peninsula, the islands of Pulau Bangka and Billiton but not contiguous with Sumatra or Borneo) in an opening habitat with more game to be had (Fig. 2.3).

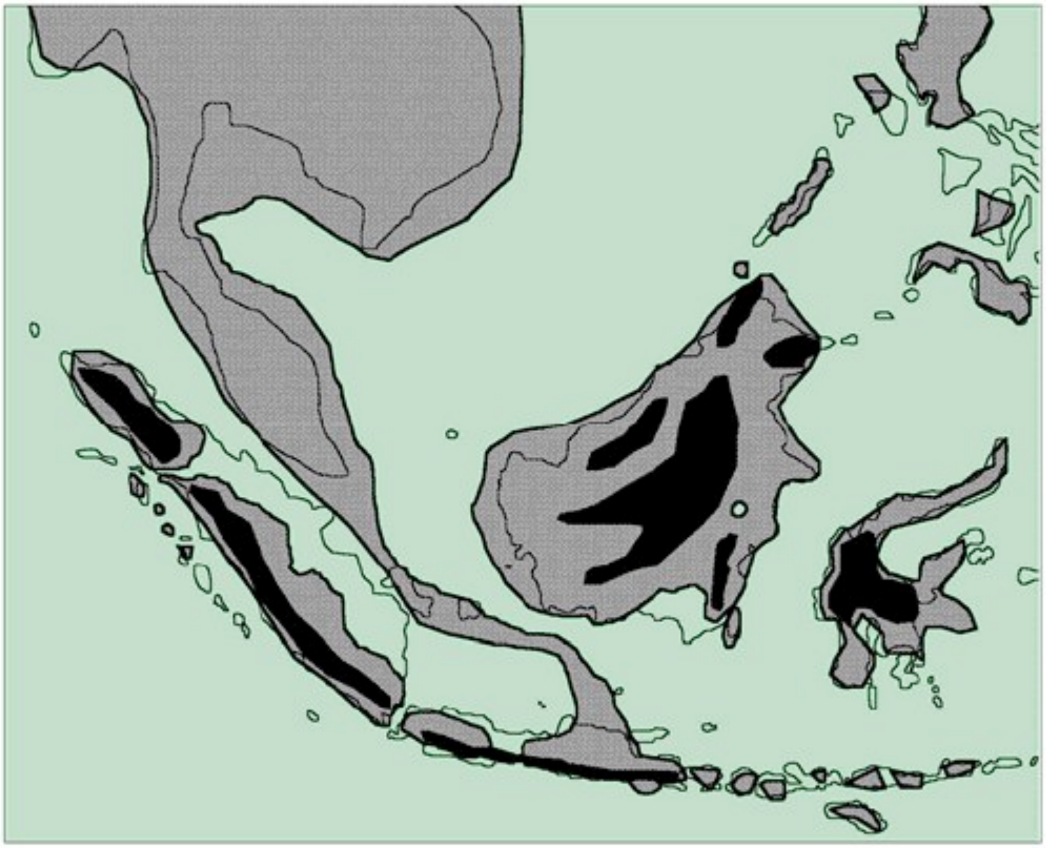


Figure 2.3. Malay Archipelago: early-middle Pleistocene during occupation of Sangiran by the Ci Saat fauna
(Adapted from Meijaard 2004)

2.2.3 Trinil HK

A marked increase in species number and types occurs with the transition to the Trinil HK fauna (the HK suffix is added to distinguish this fauna from von Koenigswalds earlier biostratigraphic system (1933, 1934, 1935 a, b, c, d). This new fauna is largely a continental addition to the Ci Saat species with only three types (the endemic pig, a few of the unidentified cervids and *Hexaproton sivalensis*) not persisting into the Trinil HK

(Heaney, 1991). Added to the Ci Saat to create the Trinil HK are *Hystrix brachyura*, *Rattus trinilensis*, *Bubalus palaeokerabau*, *Bibos palaesondaicus,* the antelope like bovid *Duboisia santeng*, *Rhinoceros sondaicus*, *Stegodon trigonocephalus,* two primates *Trachypithecus cristatus* and *Macaca fascicularis*, a dog species *Meceyon trinilensis,* a small cat *Prionailurus bengalensis* and *Panthera tigris trinilensis* (Van den Bergh, 2001). Meijaard (2004) would further include *Rattus* aff*. tiomanicus* and 3 more unidentified *Rattus sp., Homotherium zwierzyckii, Sus brachygnathus, Cervus problematicus, Bos palaesondaicus, Panthera pardus* and *Catopuma* (Table 2.1). Kaifu et al. (2001) make a good case for the first appearance of *Pongo pygmaeus* and *Symphalangus syndactylus* on Java at this time. The Trinil fauna also contains many bird species such as *Leptoptilos* cf. *dubius* (an Adjutant Stork), *Ephippiorhynchus* cf. *asiaticus* (Black-necked Stork), *Pavo muticus* (Green Peafowl), *Branta* cf. *ruficollis* (a western Siberia goose), *Tadorna tadornoides* (Australian Shelduck) and *Grus grus* (Common Crane) (Weesie, 1982; Meijaard, 2004). Bouteax (2007) reports the presence of turtle and crocodile remains. *Homo erectus,* regardless of which Sangiran stratigraphic chronology (long or short) is used, is definitively present on Java at this time.

The presence of many, large continental mammals and associated carnivores indicates the Trinil HK fauna were adapted to a mosaic environment composed of open woodlands with grassy habitats interspersed by rivers (Van der Meulen and Musser, 1999; Bouteaux, 2007). These environments would have been predicated by relatively cool, dry climatic conditions conducive to a global low stand in sea level that occurred during this period. These lower sea levels would have created a larger migration corridor than during the period of the Ci Saat Fauna. This corridor would have been contiguous with Sumatra and Borneo via the Malay Peninsula but had not yet expanded to include the Indochinese Peninsula thus creating the more direct connection to mainland Asia referred to as Sundaland (Meijaard, 2004) (Fig. 2.4). The existence of *Pongo pygmaeus* and *Symphalangus syndactylus*, both of which are poor dispersers and swimmers, bolsters the notion of a land-bridge connection. However, they also indicate that the environment was not homogeneous as the orangutan and siamang are strictly tropical rain forest species. This is reinforced by the presence of a diverse avian fauna adapted to mangroves, swamps or colder climates that may have prevailed in refugia or at altitude respectively (Wessie, 1982; Simpson & Day 1996).

Hence, *H. erectus* would have found itself in a very favorable faunal and climatic environment during the period of the Trinil HK. Dispersal from Asia would have been relatively straightforward in the following of game and also would not have required extended water crossings. The abundance of game and proximity to riverine environments would have provided for many hunting/ scavenging options and opportunities. In essence, the conditions present would have fostered the establishment and persistence of *H. erectus* populations over extended periods of time.

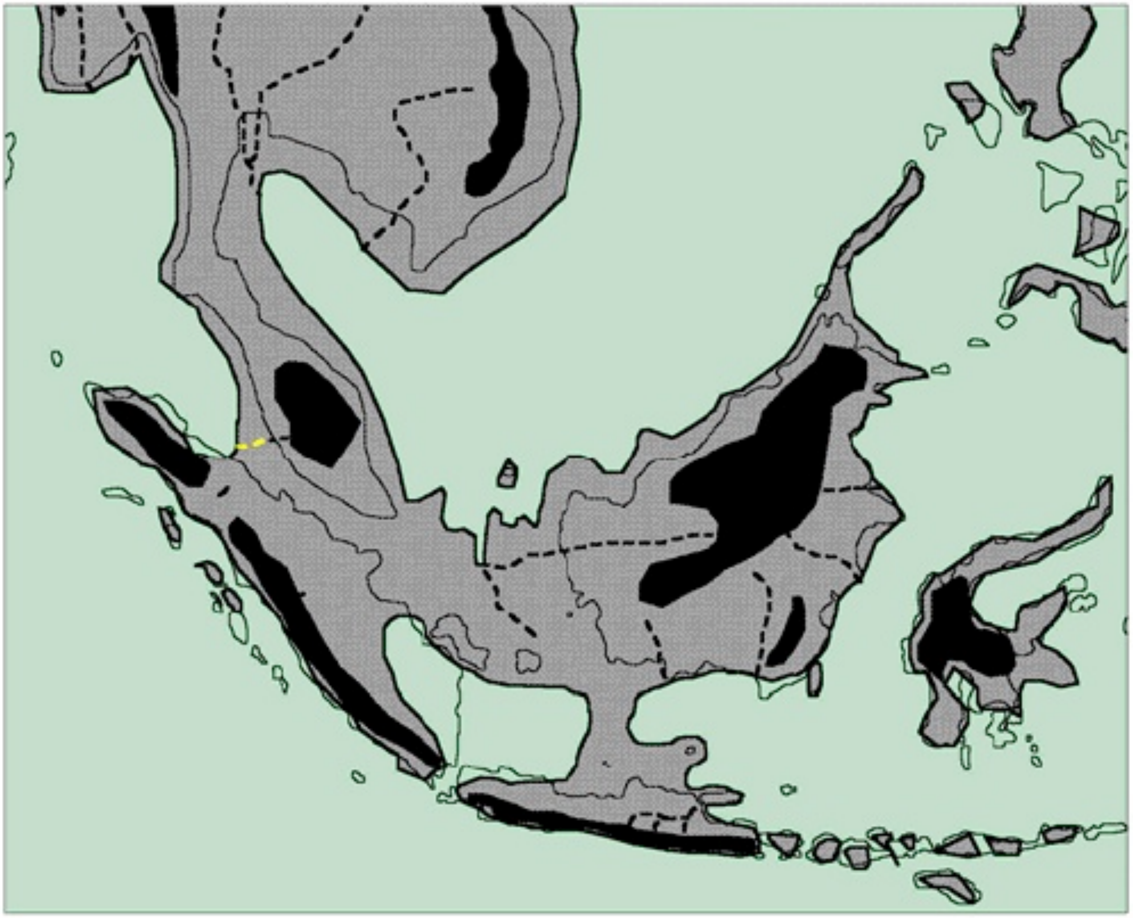


Figure 2.4. Malay Archipelago: middle Pleistocene during occupation of Sangiran by the Trinil HK fauna
(Adapted from Meijaard 2004)

2.2.4 Kedung Brubus

Around 700kya, the Kedung Brubus fauna can be distinguished on Java. A faunal turnover occurs with an influx of several medium to large Asiatic mammals (*Rhinoceros unicornis*, *Hexaprotodon sivalensis, Elephas hysudrindicus, Epileptobos groeneveldtii, Tapirus indicus*, unidentified cervids*, Rusa sp., Manis palaeojavanica*, *Hyaena brevirostris*, *Lutrogale palaeoleptonix*) and the disappearance of all *Rattus sp., Maxomys sp., Mececyon trinilensis, Homotherium zwierzyckii, Sus brachygnathus, Cervus problematicus, Cervus hippelaphus, Cervus palaeojavanicus, Antilope saatensis* (Van den Bergh et al., 1992; Van den Bergh, 2001; Meijaard, 2004). All other species from the Trinil HK series not specifically listed above survive this turnover and persist on Java (Table 2.1).

The movement of larger mammals into Java was encouraged by an exposed Sunda Shelf intersected by a 'savanna corridor' probably during a glacial maximum (Musser, 1982; Van den Bergh et al., 1996; Brandon-Jones, 1998) (Fig. 2.5). Vrba et al. (1989), through isotopic ratios of foraminifera tests, suggest that sea levels may have been as low as 100m below present day. A fauna similar to the Kedung Brubus was found in Citarum, West Java suggesting a land connection (and lowered sea levels) between Central and West Java during this period (Batchelor, 1979; Aziz & de Vos 1999). Lowered sea levels indicate cool, dry climatic conditions and, coupled with species present in the Kedung Brubus fauna, dry, open woodland habitats (forests with grasslands as represented by the presence of *Poaceae sp., Asteraceae sp., Fabaceae sp.* and *Mimosaceae sp.*) with any tropical forest remaining restricted to refugia (Heaney, 1986; Semah, 1984, 1993, 1998; Bilsborough, 2000; Semah, F. 2001; Semah and Semah 2001; Storm, 2001; Lee et al., 2004; Louys, 2007). Bouteax' (2007) evidence of fluviatile transport at Tanjung near Sangiran suggests that rivers were a feature of the area. These results correlate with palynological (Semah, 1998) and sedimentological data (Semah, 1984, Watanabe & Kadar, 1985). Bird (2005) believes that during interglacial periods, tropical forests may have expanded across much of Sundalands lower elevations. The Kedung Brubus species became isolated on Java when higher sea levels eroded the Karimun Jawa Ridge and its connection to Bangka and Belitung. Java then became reconnected in the late Middle Pleistocene as evidenced by the arrival of the Punung Fauna (Heaney, 1986).

The maintenance of contact with mainland Asia would have continued to favor the establishment of *Homo erectus* on Java. Gene flow would tend to keep unfavorable mutations from building up as might occur on a small, isolated island (Brody, 1970). The persistence of large mammal populations along with the close proximity to riverine and coastal environments would have afforded *H. erectus* many opportunities to hunt, gather and thrive. However, periodic glacio-eustatic rises in sea level which may have cut off *H. erectus* from the mainland or larger source populations (e.g. Sumatra or Borneo) could have been detrimental. Gross prey animal numbers would have fallen, mal-adaptive mutations would have the opportunity to become endemic and any communicable pathogens would have the potential to quickly lower *H. erectus* and/ or prey population numbers.

Although *Homo sapiens* have successfully colonized tropical rain forests, they have only done so using considerable amounts of relatively sophisticated hunting (bows, blowpipes, nets) and basic farming technology (Gamble, 1993). These environments would have presented much more of a challenge to *Homo erectus* as they are not known to have possessed advanced hunting tools (and only a relatively ancestral tool kit) nor cultivate staple crops; a much later development (Foley, 1987). *H. erectus* was undoubtably quite adaptable (as demonstrated by its epic and rapid migration from Africa to Java), however, there is currently no evidence that they existed in sub-tropical or tropical forests (Ciochon, 2009). Storm (2005) states: "This theoretical stance can be evaluated using the large number of Javanese fossils to make some inferences about the paleoecology of *H. erectus* in Java. The faunal units Trinil H.K., Kedung Brubus, and Ngandong contain what is clearly *H. erectus*; these faunas suggest an open woodland habitat (de Vos, 1995; Storm, 2001).".

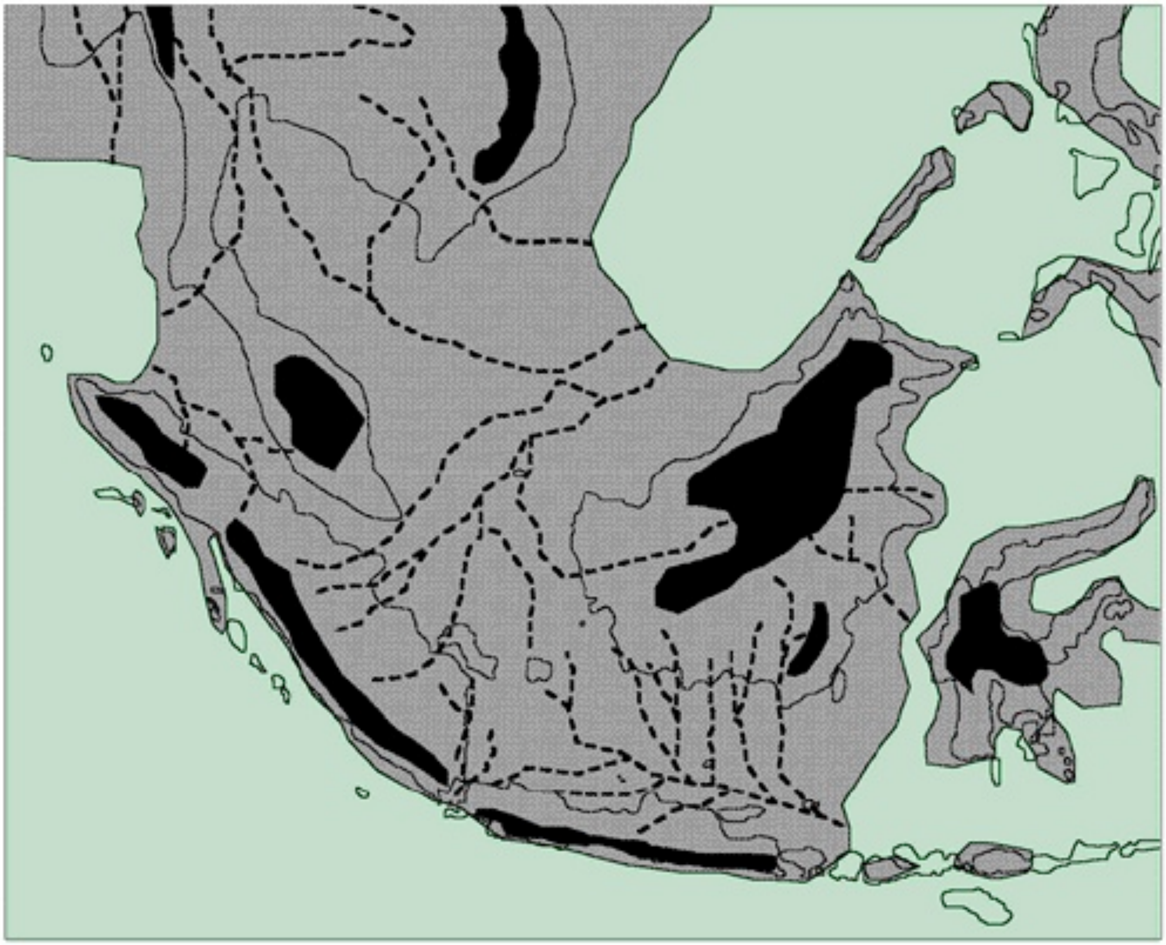
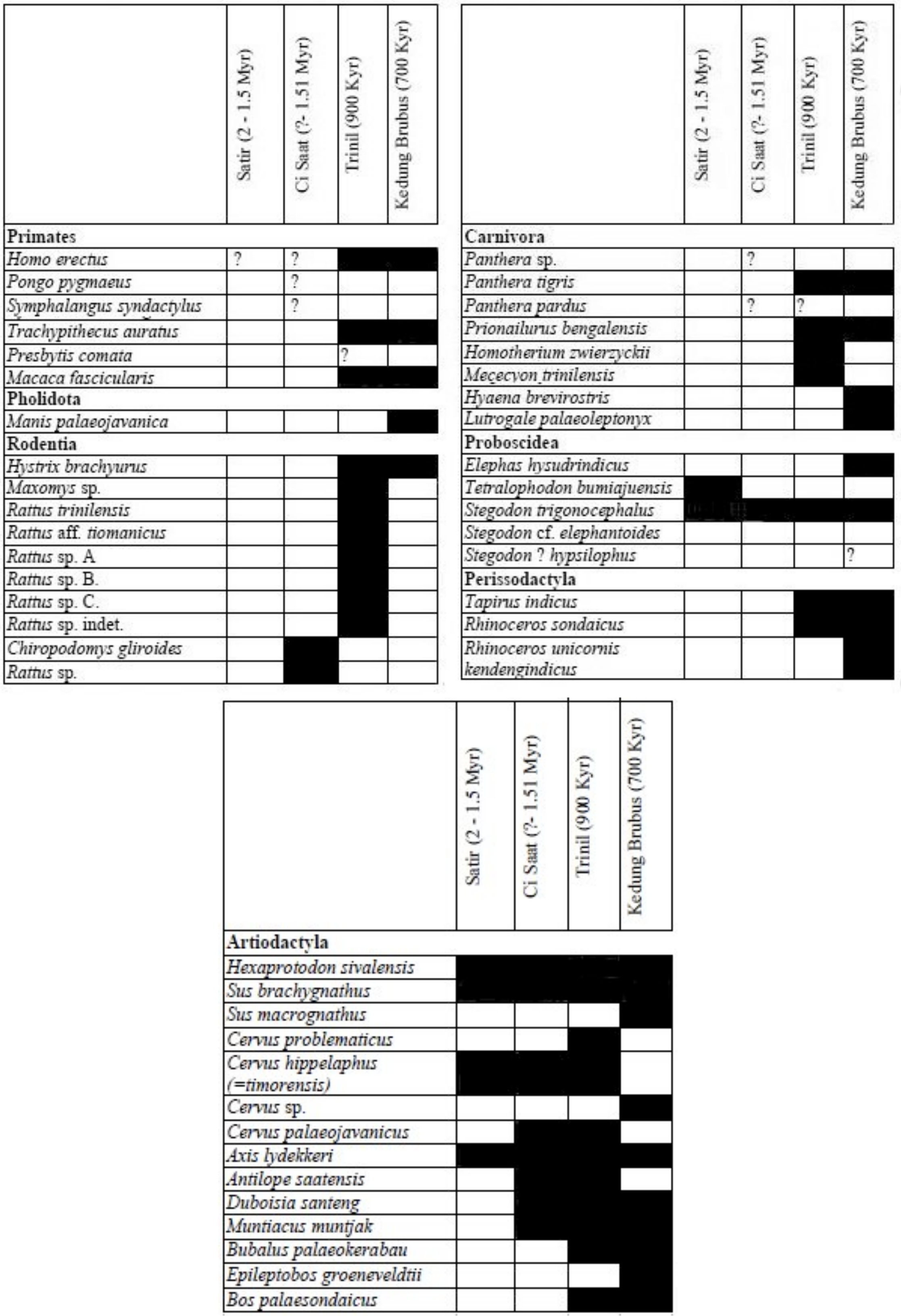


Figure 2.5. Malay Archipelago: late Pleistocene occupation of Sangiran by the Kedung Brubus fauna
(Adapted from Meijaard 2004)



	Satir (2 - 1.5 Myr)	Ci Saat (?- 1.51 Myr)	Trinil (900 Kyr)	Kedung Brubus (700 Kyr)
Primates				
Homo erectus	?	?	■	■
Pongo pygmaeus		?		
Symphalangus syndactylus		?		
Trachypithecus auratus			■	■
Presbytis comata			?	
Macaca fascicularis			■	■
Pholidota				
Manis palaeojavanica				■
Rodentia				
Hystrix brachyurus			■	■
Maxomys sp.			■	
Rattus trinilensis			■	
Rattus aff. *tiomanicus*			■	
Rattus sp. A			■	
Rattus sp. B.			■	
Rattus sp. C.			■	
Rattus sp. indet.			■	
Chiropodomys gliroides		■		
Rattus sp.		■		

	Satir (2 - 1.5 Myr)	Ci Saat (?- 1.51 Myr)	Trinil (900 Kyr)	Kedung Brubus (700 Kyr)
Carnivora				
Panthera sp.		?		
Panthera tigris			■	■
Panthera pardus		?	?	
Prionailurus bengalensis			■	■
Homotherium zwierzyckii			■	
Meçecyon trinilensis			■	
Hyaena brevirostris				■
Lutrogale palaeoleptonyx				■
Proboscidea				
Elephas hysudrindicus				■
Tetralophodon bumiajuensis	■			
Stegodon trigonocephalus	■	■	■	■
Stegodon cf. *elephantoides*				
Stegodon ? hypsilophus				?
Perissodactyla				
Tapirus indicus			■	■
Rhinoceros sondaicus			■	■
Rhinoceros unicornis kendengindicus				■

	Satir (2 - 1.5 Myr)	Ci Saat (?- 1.51 Myr)	Trinil (900 Kyr)	Kedung Brubus (700 Kyr)
Artiodactyla				
Hexaprotodon sivalensis	■	■	■	■
Sus brachygnathus	■	■	■	■
Sus macrognathus				■
Cervus problematicus			■	
Cervus hippelaphus (=timorensis)	■	■	■	
Cervus sp.				■
Cervus palaeojavanicus		■	■	
Axis lydekkeri	■	■	■	■
Antilope saatensis		■	■	
Duboisia santeng		■	■	■
Muntiacus muntjak		■	■	■
Bubalus palaeokerabau			■	■
Epileptobos groeneveldtii				■
Bos palaesondaicus			■	■

Table 2.1. Represented mammals of Sangiran faunal stages
(Adapted from Meijaard, 2004)

Chapter 3

Inferences on the Dietary Habits of *Homo erectus*

3.1 Introduction

Gross masticatory apparatus (face, mandible and muscles) and overall size and shape of teeth are a good predictor of what an organism is adapted to ingest and digest. However, other foods can and are eaten which the animal may not naturally be mechanically or physiologically adapted to consume (think of a horse eating a carrot…). As is demonstrated in *Homo sapiens*, the use of technology to obtain (e.g. projectiles, traps, nets) and process (e.g. cutting, crushing, grinding, cooking) food has significantly influenced our masticatory apparatus, dental occlusion and physiology by reducing or altering the respective stresses applied to these systems (Sheiham, 1984; Popkin & Doak, 1998; Wrangham & Conklin-Brittain, 2003). The understanding of food acquisition (hunting, scavenging and gathering) and preparation techniques in *Homo erectus* is, therefore acutely important as these behaviors significantly influenced what and when foods could be consumed (Isaac, 1978). This, in turn, would likely affect larger biological, behavioral and social patterns (Wrangham & Conklin-Brittain, 2003).

3.2 *Homo erectus'* Diet

Differing food acquisition (a predominance of hunting, scavenging or gathering) and preparation techniques (or lack of) alter a foods material properties and can introduce exogenous materials (e.g. grit, sand or ash) into it. Therefore, foods that are processed or not (whether they be from plant or animal) will differentially affect tooth occlusion. Macro- and microwear signatures on those teeth will thus be dictated by that foods properties. These signatures can then be used to 'reverse engineer' that diet in fossil organisms if there are correlates to compare them against. Therefore, the central questions regarding *Homo erectus'* diet become:

1) "To what extent did *H. erectus* hunt and/ or scavenge?" This because hunting would produce choice meats as opposed to remnant portions of lesser quality and quantity. Although scavenging may have been focused on the acquisition of marrow, hunting would also have yielded this high energy resource. Access to meat in quantity should be discernable through microwear while scavenging would presumably yield a less definitive signature as the components consumed would either be very soft (marrow, brains) or too varied to produce a consistent signature on teeth.

2) "To what extent were any meats processed (i.e. cooked) and in what manner (baked on rocks, seared on a stick etc.)?" It is likely impossible to know the later but cooking does significantly change the properties of meat and so this behavior may be able to be deduced from microwear.

3) "To what extent did *H. erectus* gather plant foods?" It is undoubtable that *H. erectus* gathered at least a portion (but likely much more) of its total diet (Lee, 1973; Lee and DeVore, 1976). As most edible plant parts are usually only seasonally available, a concentration on specific foods during any one time of the year could yield different microwear signatures. For instance, consuming large quantities of nut meat (relatively soft and non-fibrous) versus roots or tubers (relatively hard and fibrous) would entail different masticatory strategies. Again, consuming leafy or herbaceous vegetation (with

high contents of cellulose and silica) versus fruits or berries (soft and aqueous) would produce different dietary wear signals. A predominance of seeds would also produce a distinct signature.

4) "To what extent were any plant foods processed?" Cooking, grinding, drying etc. greatly alter a plants consistency and ability to be efficiently used metabolically. Although there is no archeological evidence for the processing of plant foods in *Homo erectus*, processing should yield a different dietary signal than from those that are consumed raw.

3.2.1 Meat consumption

Based on archeological evidence, meat eating factored significantly in *H. erectus* diets. Large concentrations of stone tools and modified bones are found at many African sites after 1.9 mya (Leakey, 1971) although they are not seen in Southeast Asia until much later (Tong, 2001). This, combined with thinner enamel and a higher incidence of small enamel pits suggests, improved abilities to slice and shear soft, tough foods such as meat (Shipman and Walker, 1989; Teaford & Runestad 1992). Ungar (2004) states: " Increased consumption of animal products may have played a role in the dental adaptations of the earliest members of our genus." Anton and Swisher (2004) calculated that the brain of *H. erectus* would consume about 17% of total resting energy (~ 260 Kcal) while only 11% would be used in *Australopithecus (sensu lato)*. In order to fuel this requirement, Walker et al. (1982), Shipman &Walker (1989) and Schoeninger et al. (2001) believe that *H. erectus* must have relied more heavily on animal fat and protein. Sporadic meat consumption by some extant primates (Stanford 2001) and earlier hominins (de Heinzelin, 1999) develops an evolutionary provenance for this activity. Hoberg et al. (2001) lend further support to an increase in meat consumption associated with *Homo erectus*. By investigating tapeworm evolutionary divergence times in the two most closely related human-specific species (*Taenia saginata* and *T. asiatica*), they found divergence times between 1.7 mya and 780 kya. which suggests that a human host (*H. erectus*) was infected during this time period.

Current consensus appears to favor aggressive scavenging, with some predation, as the most likely method of meat procurement by *H. erectus* (Lewin, 1984; Dominguez-Rodrigo, 2002; Dennell, 2003). Evidence for any sustained big-game hunting culture during the early to middle Pleistocene is lacking, however (Clark, 1968; Zihlman, 1978; Klein, 1999) and only gained prominence with the development of spears and hafted weapons around 500kya (Bower, 1997). These types of technology and/ or cultures are completely absent from the east Asian archaeological record and are only inferred from rhino bone accumulations found at various Chinese sites beginning ~500kya (Tong, 2001 & 2002). Recently and intriguingly, phytolith analyses have associated Acheulean hand axes at Peninj, Tanzania (1.5 to 1.4mya) with wood-working (M. Dominguez- Rodrigo, 2001). What types of tools were being produced is not know but, it is highly likely that such an advanced (and presumably adaptive) skill would have persisted and dispersed with migratory populations.

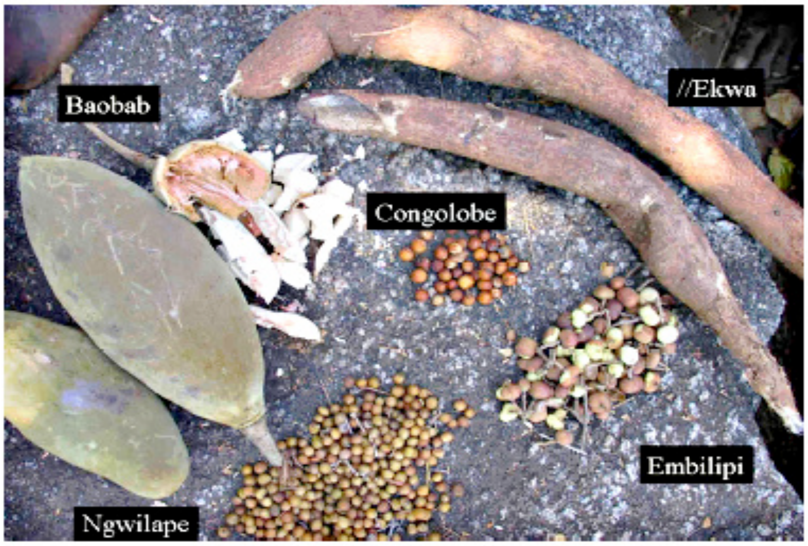
Homo erectus would, through active confrontational scavenging and or limited hunting, likely have had access to intermittent amounts of 'choice' meats (limb-bone muscle etc.), organs and marrow. However, remnant carcass products such as marrow, brains and lower value meats (vertebral, rib etc.) would have been a much more common (and safer) component of the diet. Any tooth wear signature thus associated with the consumption of meat products would likely not come from the sustained use of 'high value' meats. Notably, Peuch (1979) and Zihlman (1978) caution that, due to the relative durability of bone as opposed to plant material, the archaeological record likely exaggerates the amount of meat in early hominid diets.

3.2.2 Vegetative consumption

Ungar (2004) states: "We cannot know the full complement of foods available in the past, let alone infer their material properties.". Although one could easily agree with the former part of this statement, the later should be open to scientific interpretation. Palynological studies demonstrate evidence of fossil flora which still exist or have modern correlates. As the association between diet and wear are highly correlated (Teaford, 1991) wear produced on teeth by these modern analogues would produce very similar wear on fossil hominin teeth. Cranio-dental adaptations and an advanced material culture likely expanded *H. erectus'* dietary versatility and allowed them to exploit a broader spectrum of foods than earlier hominins (Ungar, 2006). Thus, an investigation of edible vegetable foods common in *Homo erectus'* environment offer a means of understanding this larger dietary breadth and strategy which would then directly influence microwear signatures.

It has long been acknowledged that plant foods formed a very important component of hominin diets (Bartholomew & Birdsell, 1953; Washburn & Avis, 1958; Zihlman, 1978). World-wide, studies of modern hunter gatherers reveal that, except for specialized arctic hunters, more calories are obtained from gathered foods (presumably predominantly vegetative in manner) than from meat obtained by hunting (Lee & deVore, 1974). Sebastion et al. (2002) calculated that upper Paleolithic preagricultural *H. sapiens* diets consisted of 35% lean meats (wild game) and 65% plant foods. Stable isotope studies of *H. erectus* dentition suggest a diet which contains a mix of C3 and C4-based foods comparable to that of earlier hominins and extant primates whose diets contain relatively small amounts of meat (Lee-Thorp et al. 2000, van der Merwe et al. 2003). Wrangham et al. (1999), Wrangham and Conklin-Brittain (2003) and Wrangham (2006 & 2009) have proposed that underground storage organs (USO's: roots, tubers, corms, rhizomes) contributed significantly to *Homo erectus'* diet and were at least partially responsible for large increases in brain size at that time. Elevated Sr/Ca levels found in *H. erectus* teeth seemed to confirm this as USO's are high in strontium (Sillen et al., 1995). Walker and Shipman (1997) and Ungar et al. (2006), from studies of microwear pits in East African *H. erectus,* concluded that food items with intermediate fracture properties were consumed. They deduce that these foods were likely "…harder USO's or tough animal tissues…" though they also stipulate that these foods were likely only consumed when other foods were unavailable and that a variable diet was also indicated. However, in order to fully exploit their nutritive value, USO's need to be cooked (Brain & Sillen, 1988). As there is little evidence for the controlled use of fire at this time (see below), USO's may not have had the profound impact envisioned by Wrangham.

The Hadza of Tanzania inhabit a mosaic of savanna/ woodlands interspersed with water sources such as would have been encountered by *H. erectus*. The Hadza have lived in this region for approximately 35,000 years (Tishkoff, 2009) and so a knowledge of their gathered subsistence foods will offer a glimpse into what may have been available to *H. erectus* also existing in such a habitat (Schoeninger, 2007; Berbesque & Marlowe, 2009). Most Hadza foods are available only seasonally: during the dry season they collect tubers, berries, honey and baobab fruit and seeds; during the wet season they forage for tubers, many types of fruit, baobab seeds and honey with larva (Fig. 3.1)(Skinner, 1991). It's not unreasonable to believe that *H. erectus* could have developed the same rudimentary processing methods (grinding/ crushing of seeds, winnowing, scraping of fruit pulp) which the Hadza use today (Schoeninger, 2007). Although it may be speculative to make direct correlations between *H. erectus* and current *H. sapiens* dietary habits, similar environments support similar types of species and diversity (Baum et al., 1998; Thulin et al., 2004; Danforth et al., 2006; Stollhofen et al., 2008).



	Fat	Protein	Carbs (starch)	Sugars	Kcal
Honey	<8.0	<4.0	Trace	**96.0**	403-439
Meat	1.3-9.0	**57.3-68.2**	Trace	Trace	216 -609
Tuber	0.6 -3.4	2.3 -10.4	**19.4 -61.3**	6.2 -48.3	73-85 , 146-298 , 177-279
Berries	<2.0	7.1 -15.2	Trace	61.1-72.7	108-145 ,318-342
Baobab*	**15.0**	19.4	5.5	23.4	328.5

Figure 3.1. Hadza staple foods and their nutritive composition
(Adapted from Berbesque & Marlowe, 2009)

3.2.3. Other dietary considerations

Homo erectus was likely quite opportunistic and broadly indiscriminate in foraging and would have included any small game, reptiles and insects it came across (Shipman and Walker, 1989). Choi and Driwantoro (2007) have found evidence of clamshells being used for butchery at Sangiran. If the clams were collected live (as opposed to the shells being gathered from a beach), it stands to reason that the clam meat itself would have been consumed and not wasted. Long-tailed macaques and baboons have been observed using stones to access the meat of mollusks and crustaceans (Malaivijitnond, 2007) demonstrating that aquatic foods are regularly exploited by primates. Verhaegen & Puech (2000) even postulate that: "A dietary supplement of shellfish eating, perhaps only seasonal, could also help to explain the dramatic increase in brain size in *Homo.* It would have abundantly provided the elements essential for brain-growth." As it is quite likely that *H. erectus* existed very near aquatic environments (saline and/or fresh), many different types of aquatic food items would have been readily available for gathering.

Other evidence for a broad and sophisticated diet come from more indirect lines of evidence. Milton (1999) states: "It is clear that dietary change would have been required to support the increased body mass of *Homo erectus*…and that this change most probably involved exploitation of both underground storage organs (e.g., tubers) and animal resources." Changes in thorax shape suggest that gut reduction had occurred in *H. erectus* and, coupled with enlarged body size, offers support for increased diet quality or at least enhanced nutrition, since both are correlated with larger size (Cole, 2000). Hawkes et al. (1997 & 1998), O'Connell et al. (1999), Kaplan et al. (2000) and Aiello & Key (2002) see shorter interbirth intervals (as afforded by a more energetically efficient diet) resulting in a male/ female division of labor in order to support the energetic demands of a gestating female or her lactating infant and a dependent weanling. As female chimps leverage sexual access to induce meat sharing by males, Mitani and Watts (2001) and Schoeninger (2007) hypothesize that *H. erectus* females, being adapted for more complex decision making than chimps, may have collected and used surplus plant foods to encourage meat sharing thus reinforcing or initiating any labor division. Finally, Ungar (2006) proposes 'sufficient dietary versatility' as influencing *H. erectus'* ability to migrate from Africa.

3.3 Fire

The control of fire may be the most important event in hominins dietary evolution. Fire softens vegetable matter and stiffens meats for easier processing by bunodont teeth. "The cooking of food produces much more complex changes than just reduction in toughness, involving changes in the shape of the stress-strain relationship." (Lucas, 2004). Wrangham (1999, 2003) believes that cooking was initiated by *Homo erectus* as early as 1.9 mya. He contends that the release of essential nutrients by the cooking of USO's fueled the large brain size increase and subsequent diminution in overall masticatory apparatus seen in *H. erectus* at that time (Wrangham, 2006 & 2009). Ungar et al. (2006) see cooking as essential for *H. erectus's* ability to effectively exploit USO's "…some morphological evidence may suggest that these hominins would have been less able to process hard, abrasive roots and tubers within the mouth. These hominins simply do not show clear morphological adaptations suggesting specialization on such resources."

Others generally share this view of an early date for controlled use of fire but place the advent, based on fossil evidence (fire pits enclosing ash etc.), a bit later. Gibbons (2007) discusses claims for dates of 1.5 mya at Olduvai Gorge, Tanzania and Koobi Fora, Kenya based on the presence of burned clay and stone tools. Others offer similar dates of 1.5 mya at Swartkrans, South Africa and 1.4 at Baringo, Kenya based, respectively, on animal bones and clay burnt at high temperatures (Gowlett et al. 1981, Brain 1988, Bellomo 1994).

However, there is a considerable amount of disagreement regarding what exactly constitutes definitive evidence of controlled fire use (Goren-Inbar, 2004). Some would contend that irrefutable evidence of habitual cooking requires stone hearths. Solid evidence for hearths with stones encircling ash have been found no earlier than 250 kya at several southern Europe sites. Charred bones, stones, ash, and charcoal 300 to 500kya at sites in Hungary, Germany and France are also believed to indicate hearths (Klein, 1999). Recently, burned flints, seeds and wood found in a hearthlike pattern have been uncovered in Israel and dated to 790kya (Goren-Inbar, 2004).

Lucas et al. (2006) see the evidence for cooking as being more indirect. A mutation in jaw muscle myosin which greatly reduces human bite force potential has been dated to just over two million years (Stedman et al., 2004). Also, the fossil record shows that by ~1.5 mya, there had been a considerable reduction in the size of chewing teeth (premolars and molars) (Wood, 1992). "Both trends are plausibly linked to the effects of cooking on food, which generally eases mechanical particle size reduction."

(Lucas, 2004). Bellomo (1994) believes from evidence at FxJj 20 Main, Koobi Fora (~2.0mya), that controlled fire was used primarily as a source of light, heat and protection from predators. It is not beyond reason to envision that, once fire is controlled, cooking of food would soon be developed accidentally or intentionally by *Homo erectus*.

3.4 Tool Use

Cutting implements would greatly increase the ability of *Homo erectus* to procure and further process any food items before cooking or eating. Stone, bone or other tools used for processing can alter a foods mechanical properties and thus change the demands placed on the masticatory apparatus. "Tools, therefore, become a confounding variable in assessing form-function relationships between teeth and jaws, on the one hand, and food properties, on the other." (Ungar et al., 2006). Keeley & Toth (1981) believe that tools were used to process animal and plant tissues during the Pleistocene. Evidence of stone tools used to process meat is first seen in East Asia ~1.66 mya at Majuangou, North China (Zhu et al., 2004). Early stone tool assemblages are somewhat rare in Indonesia, however, and hominins have yet to be found in direct association with stone tools (Corvinus, 2004).

Excavations have produced tools from the Grenzbank conglomerate (the boundary between the Sangiran and Bapang Formations of the Sangiran Dome), the Bapang Formation (Semah et al. 1992, Simanjuntak 2001), the Trinil Beds (von Koenigswald and Ghosh, 1972) and Upper Pleistocene deposits at Sambungmacan (Jacob et al., 1978). These tools typically consist of flakes, flaked cores, scrapers and borers with retouched flakes representing a very small percentage. This assemblage would be analogous to an Oldowan-like tool kit (Anton & Swisher, 2004). Widianto et al. (2001) place this flake industry at 800 kya during the transition from the Early to Middle Pleistocene. More recent research at Sangiran has uncovered tools dated to 1.2 mya but possibly as old as 1.6 mya (Stone, 2006)

Non-lithic tool use has been documented in the black clay deposits of the Pucangan Formation, Sangiran by Choi and Driwantoro (2007). Cut marks on bovid bones indicate butchery using clamshells and document the oldest evidence of shell tool use (Figure 3.2). Via experiments with capuchin monkeys, Westergaard and Suomi (1995) have postulated the development and use of a bamboo tool technology in East Asian *H. erectus* populations. Organic tools such as bamboo are much more versatile than stone but, although bamboo has been known to petrify (Brea and Zucol, 2007), no fossil bamboo tools have ever been recovered in Asia or elsewhere. Many Southeast Asian scholars champion the idea of *H. erectus'* non-lithic tool use as exemplified in the Bamboo-Karst Model which emphasizes the replacement of Acheulean bifaces with bamboo and/ or wooden tools (Boriskovskii, 1968; Hutterer, 1977; Wolpoff, 1985; Schick, 1994; Ungar et al., 2006).

Chimpanzees have long been documented as tool makers and users (Goodall, 1968). Through observations conducted in the Tai Forest, Ivory Coast, chimpanzees are known to use 5 different types of tools (wooden and stone clubs, twigs, branches and leaves) in eighteen distinct activities including the use of a hammer (wood or stone) against a specifically selected anvil stone (Boesch & Boesch, 1999). Recently, this hammer and anvil technology was observed being used to reduce larger food items into smaller portions which constitutes direct evidence for food processing (as opposed to accessing) in chimpanzees (Koops et al. 2010). Savanna chimps have even been documented fashioning and using spears to 'gig' galagos at the Fongoli research site, Senegal (Pruetz, 2007). Even capuchin monkeys have been observed to select and use stone tools to process nuts (Fragaszy et al. 2004). In these primates, tool use is taught to offspring and is now recognized as forming distinctive local cultural traditions (Boesch, 1993 & 1996). Therefore, it is not unreasonable to believe that *H. erectus* would also have developed similar tools, passed that knowledge to offspring and established quite advanced food processing traditions.

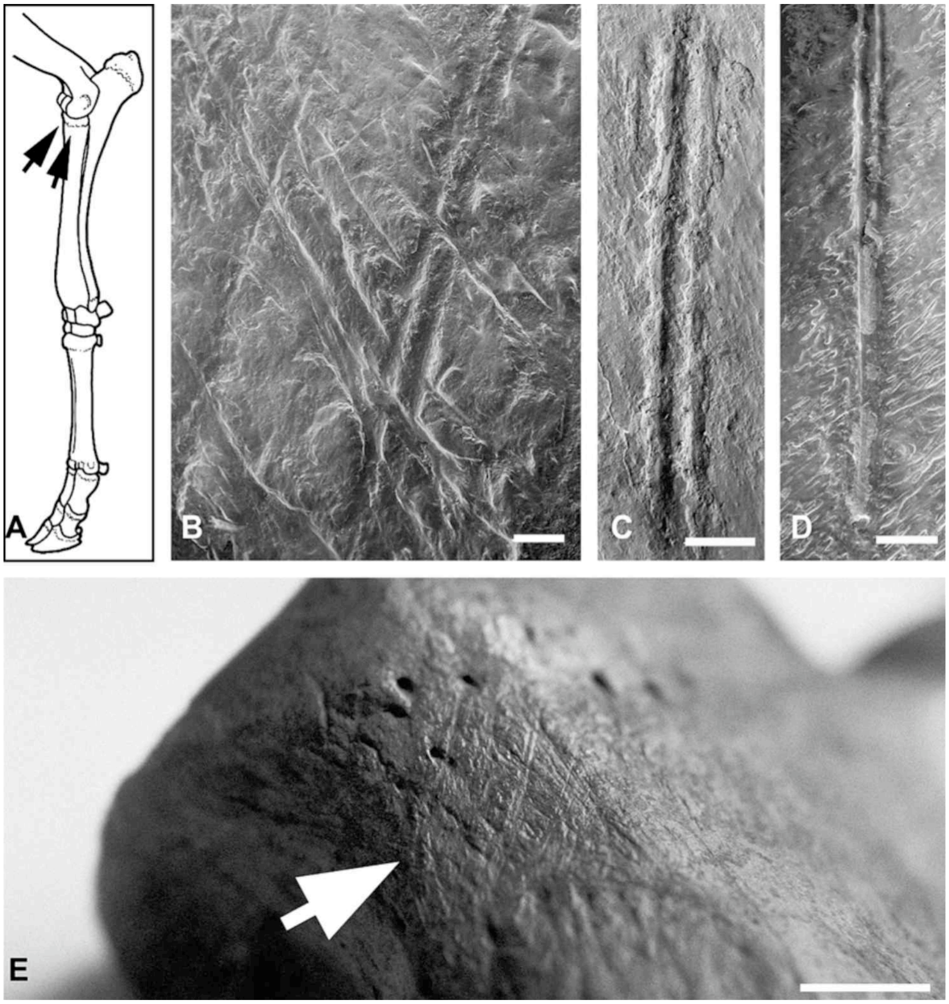


Figure 3.2. Clamshell cutmarks on bovid proximal radius from Sangiran
(Choi and Driwantoro, 2007)

Chapter 4

Historic Hunter/ Gatherer Diets

4.1 Introduction

The challenges historic hunter/gatherers faced in finding, accessing and ultimately consuming foods in diverse environments offer a window into the types of dietary strategies *Homo erectus* may have used it its quest for sustenance. Although *H. erectus* likely existed in environments similar to those of historic hunter/gatherer's, it is unwise to *a priori* assume that *H. erectus* would have consumed the same foods as these populations. However, *H. erectus* is not known or believed to have been a specialized 'niche' feeder and its migratory prowess indicates it was quite likely a highly adaptive dietary generalist. Therefore, it is not unreasonable to believe that they would have exploited any and every food resource available in their environment such as historic hunter/gatherer's did.

A detailed accounting of selected hunter/gatherer dietary economies follows wherein the total dietary strategy and breadth will be examined. Such a detailed analysis is necessary so that any potential seasonal food preferences are able to be discerned. These dietary strategies should then reveal themselves as distinct enamel microwear patterns. Those patterns can then be used as proxies for correlating *H. erectus* enamel microwear to similar environments and/or dietary strategy.

4.2 Inuit

4.2.1 Diet

North American Inuit exist from Alaska to Greenland inhabiting cold, coastal maritime or near coastal tundra environments. Largely, the growth and retreat of seasonal sea ice dictates when and which environment and its concomitant organisms are most easily exploited. Geographic location of all populations near the Arctic Circle precludes the use of many plants foods as vegetation simply does not thrive in sufficient abundance to contribute significantly to any populations dietary economy. The Inuit are, therefore, considered to be almost exclusively hunters consuming almost no vegetable material (De Poncins, 1941; Vanstone, 1962; Draper, 1978) which may lead to notions that they are homogenous in their dietary strategies. This, however, is not necessarily the case as El-Zaatari (2008) found differences in microwear between two Alaskan Inuit populations living in close proximity to each other.

Bang et al. (1980) calculated that the traditional Greenland Inuit diet provided daily about 377 g of protein (63%), 162 g of fat (27%) and 59 g of carbohydrate (10%). They go on to say that '…without Western contact the Eskimos were totally carnivorous and their food was almost free of carbohydrate, except for a few berries, roots, and leaves in summer.' (Bang et al., 1980). Draper (1977) states that the diet is comprised "…mainly of land and sea mammals and fish…" while Campbell (1905) observed the 'Esquimauxs' subsistence being 'chiefly derived from cetacea such as seals, walrus and whale.' He and others also note that bear, reindeer, musk ox, fox, hare, fish, fowl (ducks and geese) and fowl eggs will also be taken when abundant or as permitted (Campbell, 1905; Heinbecker, 1928; Sinclair, 1952; Gotfredsen, 1997). Johansen et al. (2004) are more specific for Greenland populations listing seal muscle, liver, kidney and blubber, whale, beluga and narwhal blubber and kidneys, halibut, snow crab, king eider and kittiwake. Seasonal vegetable foods such as cranberry, bilberry, dandelion, sorrel, angelicas, Iceland moss, a few flowers, buds, roots and shoots may be consumed. Seaweed makes up the only year-round source of vegetable foods. The contents of musk ox and reindeer stomachs are also eaten (Campbell, 1905; El-Zaatari, 2008).

4.2.2 Food Processing

Most mammal meat (aquatic and terrestrial) is eaten raw or frozen (freezing being the primary method of preservation) (Fig.4.1). The skin of porpoise, seal and whale are consumed raw and often chewed for long periods of time (Balikci, 1970). Cetaceans are sometimes roasted or stone boiled. (Campbell, 1905) while fish is eaten raw or dried (de Poncins, 1941). On occasion, certain portions of an animal (commonly seal heads) are fermented into a delicacy called mikiak (Campbell, 1905).

Figure 4.1. An Inuit consuming raw narwhal blubber.
(Adapted from National Geographic, by Paul Nicklen)

4.3 Pacific Northwest Tribes (PNWT)

4.3.1 Diet

Salmon and other marine vertebrates have been proposed to be the most important food resource for these maritime peoples (Suttles, 1968; Lazenby and McCormack, 1985; Deur, 1999). At one archeological site, carbon isotope data indicate they obtained 90% of protein intake from marine resources (Chisholm et al., 1983). Among the Salish of central Vancouver Island, annual per capita salmon intake ranged between 600-700 pounds (1.65-1.90 pounds per day) (Bennett, 1975; Boxberger, 1989). They heavily utilized all salmon species when seasonally abundant while herring and herring roe (specifically during the March spawn), cod, red snapper, rockfish, halibut, seals, sea lions, and 'beach foods' (basket cockles, horse clams and butter clams etc.) supplemented salmon consumption from February through the summer months. In all, 27 species of finfish, 16 species of shellfish and 10 species of 'other' marine non-vegetable foods were exploited. They also relied to a lesser degree on non-marine resources such as deer, elk, wild goat and birds (~31 species) (Fediuk, 2003).

Early estimations of dietary reliance on vegetable material suggests that no more than 10% of the PNWT diet was derived from this type of resource (Suttles, 1968). However, more recent research indicates that vegetable material formed a much more important component of the daily diet. Turner (1982) states"…early ethnographic accounts and recollections of contemporary Northwest Coast native people indicate that plant foods, including 'roots', also played a significant role in the diet…Over 100 plant food species including over 25 with edible roots were traditionally used by British Columbia coastal populations." More specifically 4 mushroom, 3 marine plant, 22 berry, several ferns and 16 tree species such as hazelnut and acorns are known to have been consumed (Turner, 1982; Ames & Maschner, 1999). More recent research confirms this and challenges the traditional notion that PNWT subsisted almost exclusively on salmon throughout the year (Lepofsky, 2004; Deur & Turner, 2005). Campbell and Butler (2010) also caution: "Only recently, with help from analyzed faunal records…., have archaeologists begun to realize they have been suffering from 'salmonopia', a kind of tunnel vision focused on salmon alone that has biased and limited interpretation. Characterization of Native American cultures as “salmon based” is an oversimplification…"

Any food item was subject to various factors affecting availability: 1) local variation due to irregular shore lines, broken topography, differences between salt and fresh water and differences in temperature and precipitation; 2) seasonal variation, especially in vegetable foods and in anadromous fishes; 3) yearly fluctuations, partially due to regular cycles of different fish populations but also to less predictable changes in weather (Suttles, 1960). As such, in speaking of Oregon coastal tribes, Smith (1983) states: "…historical records show that famine occurred periodically during early spring immediately before the first salmon of the season were caught."

4.3.2 Food Processing

Preparation of foods for immediate use and especially for future preservation were important aspects of tribal life (Stern, 1934; Suttles, 1974; Ham, 1982). Fish and shellfish were dried and smoked while mammal flesh was generally boiled (Fig. 4.2)(Ames & Maschner, 1999). Candlefish oil was used to preserve salmon eggs, berries and mammal flesh (Oswalt, 1988) while roots and corms were pounded into flour.

Figure 4.2. Vancouver Islander smoking salmon
(Adapted from University of Washington Libraries)

4.4 Fuegians

4.4.1 Diet

The Fuegians were primarily dependent on hunting and fishing (Gusinde, 1939; Orquera et al., 1977; Chapman, 1986). Darwin (1859) reported their diet to have consisted of shellfish, sea-eggs (sea urchins), fish, seal, whale carrion, sea otters, dogs, humans, berries of the dwarf arbutus tree and fungi both being consumed uncooked. Campbell (1905) noted that inland tribes hunt guanacos while coastal tribes subsist on birds, bird eggs and porpoises. He also adds that animal foods were often eaten raw (freshly caught fish) or sometimes roasted over a fire (Bridges, 1948). Stable isotope analysis of Yamana skeletons (a sub-tribe of the larger Fuegian culture) indicates that their diet was based primarily on marine proteinaceous resources, but that terrestrial animal foods formed a part of their diet as well (Yesner et al., 2003).

4.4.2 Food Processing

Other than occasional roasting of meat, no other forms of food processing or preservation are known in the Fuegians.

4.5 Australian Aborigines

4.5.1 Diet

There are many ecozones and thus different historical tribal economies associated with the aborigines of Australia. Although they have never been pastoralists nor agriculturalists there were some regional semi-agricultural practices which took the form of wild stock preservation and promotion (O'Dea, 1991). Charles Darwin (1859) even observed their lack of interest in sedentism saying: "They will not, however, cultivate the ground…or even take the trouble of tending a flock of sheep when given to them." As such, O'Dea (1991) observes: "Aborigines from all over Australia were omnivorous, deriving their diet from a wide range of uncultivated plant foods and wild animals. The composition and diversity of the food supply, and the relative proportions of plant and animal foods, were greatly influenced by both the season of the year and the geographic location."

In light of the above statement, there seems to be some disagreement regarding the relative dietary contribution of plants and animals to the historic Aboriginal diet. Lee (1996) states: "For many years it was believed that the Australian Aboriginal (AA) diet was predominantly vegetarian, particularly in the desert areas, but this view is no longer accepted. There is now strong evidence to show that AA diets in many areas were meat-oriented and there was a preference for meat, fat, honey and freshly harvested food." Brand-Miller & Holt (1998) also observed: "Of the plant foods…, most appear to have been eaten infrequently, with only a few staples contributing significantly to the diet. In desert areas some plant species were important staples, but this desert existence may have been unnatural, the result of forced exile from their traditional lands." The animal staples they refer to included terrestrial mammals, birds, bird and reptile eggs, reptiles, insects (the bogong moth during summer in south-eastern alpine regions (Flood, 1980), witchetty grubs, honey and honey ants through the year, marine mammals, fish (fresh and salt water), crustaceans (notably crayfish along the Murray River (Sahlins 1972) and shellfish (see Fig. 4.3 for a partial regional listing). In general, everything edible on an animal was consumed including fat deposits, organ meats, bone marrow, some stomach contents, peritoneal fluid and blood. Left over bones were often consumed by women (Molnar, 1971). As Campbell (1939) observed "...the women enjoy the bones... [and] are very fond of breaking them into bits and chewing them."

However, there is much evidence that plant foods contributed significantly at least seasonally to the aboriginal diet. O'Dea (1991) states: "A wide variety of uncultivated plant foods was eaten in the traditional diet: roots, starchy tubers, seeds, fruits and nuts. The plant foods were generally high in fibre….". Brand-Miller & Holt (1998) documented over *800* Aboriginal plant foods (emphasis theirs) and calculated that plants provided between 20 to 40 % of dietary energy (Fig.4.4). The types of plant resources exploited included tubers (notably, the long yam (*Dioscorea transversa*) used in northern Australia as a dry-season staple (Allen 1974), nuts and seeds (from the Bunya pine in S. Queensland (Sahlins 1972), native millet during summer in the Darling

Northwest Kimberley
  Mammals
    Antelope kangaroo *(Macropus antilopinus)* [most common in this region]
    Dugong *(Dugong australis)*
  Birds and reptiles
    Pacific black duck *(Anas superciliosa)*
    Freshwater crocodile *(Crocodylus johnstoni)*
    Northern snake-necked turtle *(Chelodina rugosa)* [small fresh water turtle]
    Flatback turtle *(Chelonia depresa)* [large sea turtle]
    Gould's goanna *(Varanus gouldii)* [0.25–0.4 m long]
  Fish and crustaceans
    Mangrove ray *(Himantura granulata* [stingray]
    Black bream *(Hephaestus fuliginosus)*
    Bluebone *(Choerodon albigena)*
    Freshwater barramundi *(Lateo calcarifer)*
    Yabbie *(Cherax sp.)* [freshwater king prawn]

Southeast Kimberley
  Birds and reptiles
    Australian bustard *(Ardeotis australis)* ["wild turkey"]
    Gould's goanna *(Varanus gouldii)*

Central Australia
  Mammals
    Black-footed rock wallaby *(Petrogale lateralis)*
    Antelope kangaroo *(Macropus antilopinus)* [young]
  Birds and reptiles
    Emu *(Dromaius novaehollandiae)*
    Gould's goanna *(Varanus gouldii)*
    Perente *(Varanus giganteus)* [large goanna, 1–1.5 m long]
  Insects
    Witchetty grub *(Xyleutes sp.)*

Northeast Arnhemland
  Molluscs
    Land snail *(Xanthomelon durillii)*

Southeast Australia
  Mammals
    Eastern grey kangaroo^a *(Macropus giganteus)*
    Eastern wallaroo^a *(Macropus robustus)*
    Red kangaroo^a *(Megaleia rufa)*
    Black-tailed wallaby^a *(Wallabia bicolor)*
    Long-nosed potoroo^a *(Potorous tridactylus)*
    Common wombat *(Vombatus ursinus)*
    Koala *(Phascolarctos cinereus)*
    Brushtail possum *(Trichosurus vulpecula)*
    Ringtail possum *(Pseudocheirus peregrinus)*
    Platypus *(Ornithorhynchus anatinus)*
  Reptiles
    Red-bellied black snake *(Pseudechis porphyriacus)*
  Crustaceans and molluscs
    Yabbie *(Cherax sp.)* [freshwater king prawn]
    Mussel *(Mytilus sp.)*

Figure 4.3. A regional list of animal foods consumed by Australian Aborigines
(Adapted from Naughton et al. 1986)

River basin of W. New South Wales (Allen, 1974), some cereal grain use (e.g. *Panicum* spp.) (via archaeological evidence dating back 15ky) in grassland areas (Brand-Miller & Holt, 1998), beans, fruits, berries, gums and nectar (O'Dea,1991). Although vegetable matter was obviously widely exploited (even if only seasonally), Lee (1996) contends that "Plants played an important supplementary role in the animal dominated diet of these nomadic peoples…"

The aborigines also divided food procurement along gender lines (Tonkinson 1978; Kirk 1981; White 1985). Generally, women were the 'subsistence' gatherers of plant foods, honey, eggs, small mammals, reptiles, fish, shellfish, crustaceans and insects. Although men sometimes participated in gathering, they were primarily hunters of larger game such as kangaroo, emu, goanna (monitor lizards gen. *Varanus*) and large fish. (O'Dea,1991). As food was often eaten while being procured, this division of labor may contribute to sexual differentiation among tooth wear (Campbell 1939; Molnar, 1971; Molnar, 1983)

4.5.2 Food Processing

Muscle and organ meats were often cooked over hot coals and/or partially eaten before being transported back to camp ('bush' cooking). Shellfish and fish were also often cooked and eaten on the spot or sometimes eaten raw (Jones 1980). More formal cooking was often accomplished using pit stoves wherein meats or whole animals were placed in a hole in the ground, covered with boiled stones, hot sand and ashes (pit cooking) (Campbell, 1925, 1938; Campbell & Moore, 1930; Naughton, et al. 1986). This 'bush' and pit cooking may have introduced significant amounts of grit into the diet.

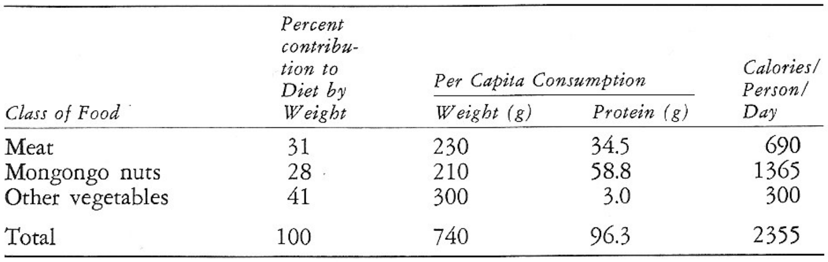
Processing of plant foods likely varied by region and season. Beck (1985) estimates that approximately half of plant foods consumed in northern Australia were processed in some manner before being eaten. For example, starchy tubers were baked in coals or pits and seeds were often roasted then ground (Kirk 1981; Flood 1983; Hiatt & Jones 1988; Beck et al. 1988). Grass seeds are known to have been wet-milled and tree seeds (e.g. Acacia sp.) dry-milled between flat stones and then baked into cakes in grassland areas (Campbell, 1925, 1938; Campbell and Moore, 1930; Kirk, 1983). In some instances, foods were also dried for storing (O'Dea et al. 1990). However, the aborigines had no cooking pots and so no boiling of either plant or animal material is known (Brand-Miller & Holt, 1998). Although the aborigines processed many foods, others were simply eaten fresh or raw as foods were not processed unnecessarily but only to make more palatable, digestible or edible.

4.6 'Bushmen'

4.6.1 Diet

Many different Bushmen tribes inhabit the Kalahari Desert which is more/ less uniform in habitat and therefore food stuffs available. Foods are generally distributed relatively uniformly within the family group although adults and hunters tend to receive more prized portions than children. Most foods are considered to be seasonally and locally abundant. Clement et al.(1956) states "The Bushman's diet consists of whatever he can find to eat, and he practices no form of agriculture…." Larger prey animals are hunted whenever encountered and include gemsbok, springbok, steinbok, wildebeest, eland, kudu and wild pig. The entire animal is consumed except for rumen contents, skin (although giraffe hide is roasted and eaten) and other parts used as tools (Thomas, 1958). Smaller animals also contribute to the diet and include hares, duiker, aardvark, porcupine, guinea fowl, lizard, mice and long-eared foxes (Lee, 1984). However, Lee (1984) calculates that meat only constitutes ~30% of daily caloric intake. Insects such as beetles, caterpillars and grubs are also consumed (Thomas, 1958).

Lee and DeVore (1976) found that up to 70% by weight of dietary intake consisted of vegetable materials (Fig. 4.4). Lee (1984) cataloged over 100 edible plants comprising 14 fruits and nuts, 15 berries, 18 species of edible gum, 41 edible roots and bulbs, 17 leafy greens and beans and melons. Of these, the Tsama melon, spiny cucumber and baobab, mongongo, marula and Tsi nuts are some of the most important staples. Some seasonally abundant and/ or preferred foods include spring season vegetables, the 'bi' or Xua (a fibrous, watery root) and edible gums during the summer hot season and other specific roots found only in winter (Thomas, 1958).



Class of Food	Percent contribution to Diet by Weight	Per Capita Consumption		Calories/ Person/ Day
		Weight (g)	Protein (g)	
Meat	31	230	34.5	690
Mongongo nuts	28	210	58.8	1365
Other vegetables	41	300	3.0	300
Total	100	740	96.3	2355

Figure 4.4. Daily contribution of several food items to Bushman's diet
(Adapted from Lee, 1984)

4.6.2 Food Processing

Bushman cook a fair amount of their foods. Larger and smaller game may be roasted directly on the coals or stewed in dried Tsama melon bowls. Tortoises will be baked in their own shells while ants will be eaten raw. Nuts, seeds, roots, melons and tubers may be eaten either raw or roasted on hot stones depending on species (Lee, 1984) (Fig. 5). Clement et al. (1956) note that much of the Bushman's food is "…contaminated with the fine, hard, desert sand which probably explains the marked degree of tooth abrasion characteristic of all primitive Bushmen.".

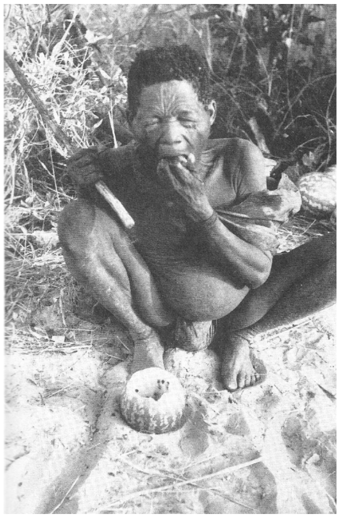


Figure 4.5. Bushman consuming raw Tsama melon amid the Kalahari sands.
(Adapted from Thomas, 1958)

Chapter 5

Diet and Molar Wear

5.1 Introduction

It has long been recognized that diet is the single most important predicator of behavioral and ecological differences among organisms (Robinson, 1963; Ungar, 1998; Fleagle, 1999). As diet directly affects occlusal micro- and macro-morphology, these surfaces and the wear produced upon them represent encapsulations of the organism's behavioral and ecological adaptations themselves. However, specific microwear signatures do not necessarily correlate to macrowear (Grine, 1986; Dennis et al. 2004). For extant organisms, the morphology of worn surfaces can be described in direct reference to the observed experimental or natural diets which produced them. However, by the very nature of a [paleo] organism *being* extinct, its diet can never be observed and, as such, only scientifically explicated assertions of what caused dental wear can be made. These attributions then can only be based on correlations drawn from studies of extant organisms diet, ecology and biology which impact tooth wear.

For many decades, wear studies have been conducted on extinct and extant non-primate mammals (Butler, 1952; Baker et al., 1959; Rensberger, 1978; Walker et al., 1978; Covert & Kay, 1981; Krause, 1982; Gordon & Walker, 1983; Kay & Covert, 1983; Young & Marty, 1986; Young et al., 1987a & b; Solounias et al., 1988; Teaford, 1988a; Robson & Young, 1990; Van Valkenburgh et al., 1990; Hayek et al., 1991; O’Leary & Teaford, 1992; Solounias & Moelleken, 1992b, 1993, & 1994; Solounias &

Hayek, 1993; Strait, 1993; Hunter & Fortelius, 1994; Anyonge, 1996; Gutierrez et al., 1998; Mainland, 1998, 2000, 2003, & 2006; Ward & Mainland, 1999; Lewis et al., 2000; Capozza, 2001; Filippi et al., 2001; Oliveira, 2001; Silcox & Teaford, 2002; Rivals & Deniaux, 2003; Franz-Odendaal & Solounias, 2004; Merceron et al., 2004a, 2004b & 2005b; Semprebon et al., 2004a; Green et al., 2005; Merceron & Ungar, 2005; Nelson et al., 2005; Palombo et al., 2005; Hopley et al., 2006; Merceron & Madelaine, 2006; Rivals & Semprebon, 2006; Schubert et al., 2007), extinct and extant non-hominin primates (Mills, 1955; Walker, 1976; Ryan, 1979 & 1981; Covert & Kay, 1981; Gordon, 1982; Teaford, 1983a; 1983b, 1985, 1986, & 1993; Kay & Covert, 1984; Teaford & Walker, 1984; Biknevicius, 1986; Kay, 1987; Teaford & Robinson, 1989; Kelley, 1990; Ungar, 1990, 1992, 1994, 1996, & 1998; Strait, 1991; Teaford & Glander, 1991 & 1996; Teaford & Leakey, 1992; Burnell et al., 1994; Lucas & Teaford, 1994; Walker et al., 1994; Ungar et al., 1995 & 2004; Teaford et al., 1996; Ungar & Teaford, 1996; Crompton et al., 1998; Daegling & Grine, 1999; King, 2001; Rafferty et al., 2002; Merceron, 2003a & b; Godfrey et al., 2004, 2005a & b; Lambert et al., 2004; Nystrom et al., 2004; Galbany et al., 2005; Merceron et al., 2005a & 2006; Scott et al., 2005; El-Zaatari et al., 2006; Teaford & Ungar, 2006) and extinct (Grine, 1977, 1981, 1986; Puech, 1979; Puech & Prone, 1979; Ryan, 1980a & b; Puech et al., 1981 & 1983a; Walker; 1981; Gordon, 1984; Puech & Albertini, 1984; Grine, & Kay, 1987; Teaford, 1988b; Ryan & Johanson, 1989; Ungar & Grine, 1991; Daegling & Grine, 1994; King et al., 1999a; P´erez-P´erez et al., 1999 & 2003; Gugel et al., 2001; Semprebon et al., 2004; Ungar et al., 2005 & 2006; Grine et al., 2006; Teaford et al., 2007) and extant hominins (Dahlberg & Kinzey, 1962; Puech, 1979; Fine & Craig, 1981; Puech et al., 1981 & 1983b; Walker, 1981; Peters, 1982; Kay & Covert, 1983; Walker et al., 1987; Gordon, 1988; Harmon & Rose, 1988; Lukacs & Pastor, 1988; Borgognini et al., 1989; Hojo, 1989; Walker & Teaford, 1989; Boyde & Fortelius, 1991; Bullington, 1991; Maas, 1991; Ungar et al., 1991; Pastor & Johnson, 1992; Molleson et al., 1993; Pastor, 1993; P´erez-P´erez et al., 1994; Walker & Hagen, 1994; Gambarotta, 1995; Ungar, 1995; Teaford & Lytle, 1996; Muendel, 1997; Strait, 1997; Danielson & Reinhard, 1998; Rose & Ungar, 1998; King et al., 1999b; Ungar & Spencer, 1999; Schmidt, 2001; Teaford et al., 2001; Grine et al., 2002; Ungar et al., 2003; Reinhard & Danielson, 2005; Mahoney, 2006a, b & c; Organ et al., 2006a & b; Scott et al., 2006; Teaford, 2006 & 2007). More recently, tooth microwear studies have been extended to non-mammalian clades (Fiorillo, 1991& 1998; Purnell, 1995; Goswami et al., 2005; Schubert & Ungar, 2005; Barrett, 2006; Purnell et al., 2006; Rybczynski & Vickaryous, 2006, Williams et al., 2009).

Generally, early studies (pre-1980's) were restricted to qualitative, two-dimensional (2D) descriptions of wear (e.g. Crompton and Hiiemae, 1970) until more quantitative work began to surface during the 1980's (e.g. Grine & Kay, 1988). This work was, however, impeded by the inability to adequately describe three-dimensional (3D) surfaces from 2D images. As 3D technologies began to develop and become more accessible in the later 1990's, 3D renderings (e.g. Zucotti et al., 1998) began to more accurately describe and quantify the complexity of occlusal surfaces. The 2000's have seen more complex, quantitative 3D research employing emergent technologies (Ungar & Williamson, 2000; Kullmer et al, 2002; Ulhaas et al., 2004 & 2007; Scott et al. 2005; Kullmer et al. 2009; Fiorenza et al., 2010).

5.2 Sources of Enamel Wear

Tooth enamel is the hardest substance (hardness: 2.5- 6.0 Giga Pascals (GPa) in any organism (bone ~0.37 GPa). There are two potential sources for tooth macro- and microwear: tooth-tooth attrition and tooth-food abrasion. However, during mastication tooth-tooth contact is considered minimal because food particles are interspersed between occluding features. Therefore, the main cause of enamel wear should be dietary however, food-stuffs are softer than enamel (otherwise teeth would not be very effective in processing the foods…). Animal tissue is obviously softer than enamel (as established above) as are most vegetable foods (excepting possibly some seed coats) (Peters, 1982; Puech et al., 1986).

Two likely causes of wear then present themselves. The first is silica (7.0 to 7.78 GPa) (Baker et al., 1959) in exogenous grit from dust, soil or ash adhering to foods (Puech et al., 1981 & 1985; Kay and Covert, 1983; Ungar et al., 1995; Lalueza et al., 1996; Ungar and Spencer, 1999; Nystrom et al. 2004; Ungar et al., 2006) (Fig. 5.1). Certain cooking procedures (directly in coals, ash or on heated rocks), methods of cleaning (directly on the ground) or preparation (grinding, pounding) all have the potential to introduce exogenous grit into foods (Lalueza et al., 1996; Teaford & Lytle, 1996; Ungar & Spencer, 1999; Schmidt, 2001). Also, freshly dug, raw, unwashed tubers will not have an insignificant amount of grit adhering to them.

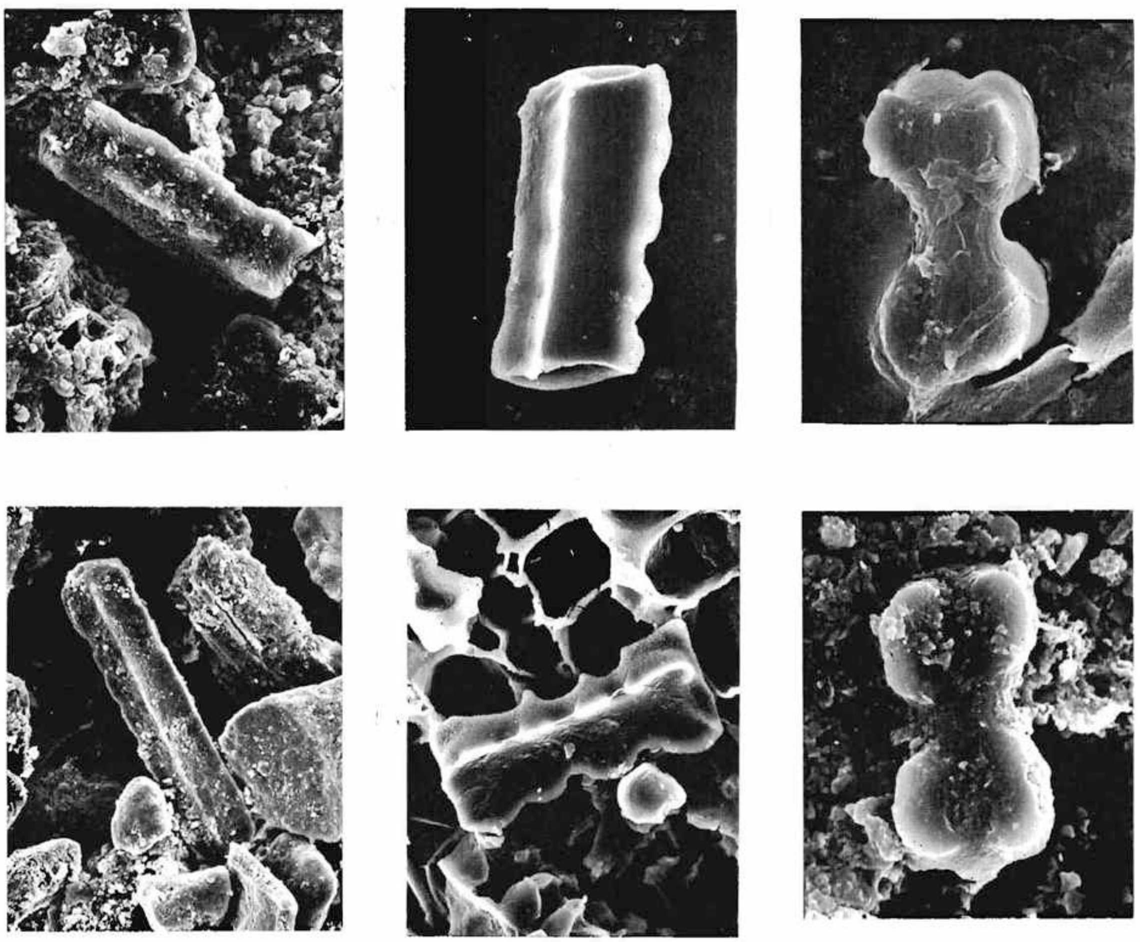


Figure 5.1. Soil phytoliths from areas dominated by tall and short grasses.
(Adapted after Black, 1986)

The next source of wear potentially comes from opal phytoliths (5.8 to 6.0 GPa) (Baker et al., 1959) (Fig. 5.2) formed from monosilicic acid absorbed thru groundwater and deposited in the cell walls of consumed vegetable material (Baker et al., 1959; Peters, 1982; Lucas and Teaford, 1995; Ungar et al., 1995; Danielson and Reinhard, 1998; Pearsall, 2000; Gugel et al., 2001; Lucas, 2004; Ungar et al. 2006). Comparative studies demonstrate that herbivory produces more wear than omnivory and this more than carnivory when under controlled environmental conditions (Lalueza et al., 1996). However, 'soft' foods may still produce wear (e.g. earthworms coated in dirt, lions consuming prey in the Namib desert) (Silcox and Teaford, 2002) although this wear is much more likely to be 'overwhelmed' by other more abrasive foods if consumed (Teaford, 2007). Recently, Sanson et al. (2007) questioned whether opal phytoliths were even capable of producing wear on teeth. They found that the hardness of opal phytoliths from selected grasses (0.5 to 2.1 GPA) was *below* that of sheep tooth enamel (2.5 to 3.9 GPa) and so suggested that opal phytoliths as a source of tooth wear should be reevaluated.

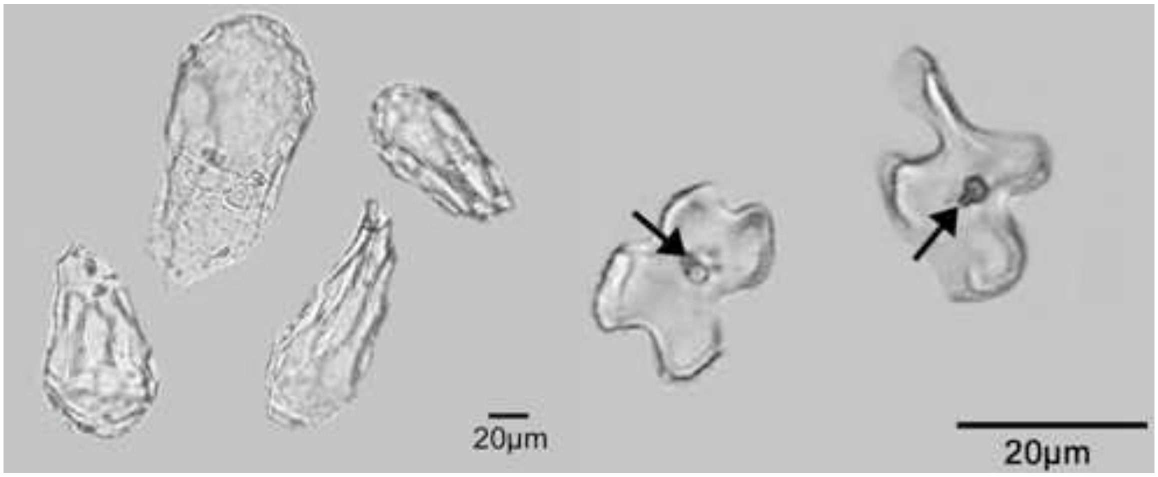


Figure 5.2. Opal phytoliths from a species of domesticated squash (left image) and maize leaves (right image).
(Adapted after Piperno, 2006)

Experimental evidence has shown that the size and shape of abrasive foods, the magnitude of occlusal forces and possible differences in underlying enamel structure factor into the morphology of wear produced (Gordon and Walker, 1983; Maas, 1991). Correlations have been found between microwear patterns (defined as frequency and size of pits and scratches) and some abrasive diets (e.g. Walker et al., 1978; Teaford and Walker, 1984). However, at present, it is not possible to tell exactly which type of substance (exogenous grit or phytoliths) caused wear as no differentiation has been observed in striation pattern, width or orientation between the two (Kay & Covert, 1981; Ungar, 1992; 1994a & b; Lalueza, 1996). To illustrate the difficulty in assessing the origin of wear, Lalueza et al. (1996) proposed that microwear striations on Inuit enamel came from "…grit, dust, ash, bone powder or ancient phytoliths from the soil, present in the food.". However, they failed to directly acknowledge in their explanation that (although they categorize the Inuit as 'carnivorous') there is very little vegetable material in their diet, the Inuit don’t typically do much cooking of food and that they prepare much of their foods on snow or ice for much of the year and so the source of the microwear is quite ambiguous.

5.3 Macrowear

Molar occlusal surface topography evolves and is adapted to most efficiently mechanically process a species preferred diet (Kay, 1975; Sheine & Kay, 1977; Sussman, 1978; Lucas, 1979; Maier, 1984; Sussman, 1987; Fleagle, 1999; Ungar & Williamson, 2000; Ungar & M'Kirera, 2003). This diet will present different challenges to the occlusal surface based on the foods physical properties (Spears & Crompton, 1996). Therefore, depending upon the organism's gross dietary adaptation (simply considered as carnivory, omnivory or herbivory), wear facets on specific cusps will reflect the attrition and abrasion incurred on them by the diet (Peuch, 1979). This complex interaction between cusps and food occurs through rhythmic mandibular movement (Simpson, 1933) over finite durations defined as an organism's masticatory sequence. This activity involves a complex set of temporal interactions among the masticatory muscles, tongue, gross bony masticatory apparatus and tooth size, shape and occlusal topography and the ingested food.

An analysis of macrowear in *Homo erectus* as compared to that of historic hunter-gatherers is confounded by each species relative omnivory. This strategy, by definition, includes a wide range of food-stuffs and necessitates finely defining the physical properties of meat and vegetable materials. General terms used to describe foods such as 'abrasive', 'tough', 'hard' and/ or 'brittle' belie the actual complexity inherent to an omnivorous (or even herbivorous) diet and the masticatory plasticity required to process it. For example, 'raw meat' is described as a tough, fibrous foodstuff with low abrasiveness. However, this only applies to muscle meat and does not reflect the properties of organ meats (liver, kidneys) nor lipid-rich animal products (fat deposits, marrow). Again, the texture of plant materials varies widely across species and within different anatomical plant parts. Leaves, stems and other vascular parts tend to contain silica phytoliths which render them highly abrasive while buds, flowers and shoots are usually softer and less abrasive. Fruits demonstrate a wide variety of physical forms (although they are generally softer and somewhat acidic), seeds themselves may not be 'tough' yet the seed coat may present a considerable barrier and underground storage organs (tubers, corms, roots) are normally 'tough' though not abrasive unless consumed with adherent grit. The properties of foods (and their determination of inclusion in a diet) are also greatly altered through cooking and/ or processing. However, Mahoney (2006) states that food processing does not necessarily produce a less resistant diet.

This argument is bourne out in looking at the relationship between diet and masticatory morphology in *Papio;* an extant species with a known diet. Their large incisors and bunodont molars indicate a frugivorous diet (Fleagle, 1999; Ungar, 1998), yet many baboon populations consume high proportions of grasses (Harding, 1976; Strum, 1987). "*Papio* is highly successful and widely distributed although dependent on a food source for which it is ill equipped. Dental morphology undoubtedly reflects an organism's dietary adaptations and phylogenetic history, but this is not necessarily concordant with *actual* behaviour. The problem is magnified in animals that are generalists." (Lee-Thorp, 2003; Ungar et al., 2006).

5.4 Microwear

Teaford (2007) states that dental microwear is *direct evidence* (emphasis mine) of past behavior where "…seasonal, geographic, and annual differences impact microwear." As such, the study and interpretation of microwear yields one of the few avenues of research which actually have the ability to document the daily subsistence demands imposed upon organismal biology and metabolism. However, Teaford (2007) does go on to say that: "…interpretations are dependent on current correlations between diet and microwear and, possibly more importantly, that these interpretations will always be limited by our inability to account for all seasonal, habitat-specific and/ or individual dietary variation.".

Gordon (1982 & 1984) identified molar position, facet type and inclination and tooth age as some of the major variables affecting inter- and intra-specific interpretations of microwear. She states: "Gradients in the amounts of shear and compression generated at different points in the molar series relative to the condyle probably account for pattern variations associated with molar position, while differences in facet inclination may affect the vectors of compression and shear, resulting in facet differences." (Gordon 1984). Others have also commented upon this mesio-distal biomechanical loading gradient and its potentially confounding effects in creation of microwear (Mckee & Molnar, 1988; Mahoney, 2006; Ungar et al., 2008). However, El Zaatari (2008), studying several historic hunter-gatherer populations found no consistent inter-individual differences in microwear along the tooth row.

Another confounding factor in interpreting microwear has been termed 'The Last Supper' phenomenon (Grine, 1986). This is based on the possible high degree of microwear turnover with the introduction of different foods and, therefore, that microwear only demonstrates diet over very short durations before death (days to weeks) (Walker et al., 1978; Covert and Kay, 1981; Teaford and Oyen, 1989; Teaford & Tylenda, 1991, Teaford, 2007). As Ungar et al. (2006) state: "Primate diets [and thus microwear] can be affected by idiosyncratic food preferences and differences in microhabitat, study site, observation technique, season, and even year of observation (Teaford & Glander, 1996; Olupot, 1998; Chapman et al., 2002; Doran et al., 2002)." However, if specific foods were available seasonally in great quantities (such as mongongo nuts eaten by the Kalahari San (Lee, 1973 & 1984), their continued consumption and concomitant tooth microwear signal would persist as long as that food was in sufficient supply. Demonstrating this possibility, Sponheimer et al. (2006) used carbon-isotope ratios to document seasonal dietary pattern variation in *Paranthropus* teeth. Also, due to potentially high turnover in microwear, if an organism has a preferred food or staple in its diet that is available somewhat continuously (65% of the year per say), that food (if it is abrasive) would routinely be 'over-writing' any other foods that it may be consuming the remaining 35% of the time. Thus, in this scenario, 65% of observed microwear would be indicative of that organism's most common dietary component. For these reasons, the environmental context an organism existed in and seemingly fine distinctions in what was included in a dietary regime and how it was or was not processed become increasingly important.

5.4.1 Occlusal Microwear

Comparative microwear studies have been used to distinguish between grazing and browsing in two sympatric species of hyrax (Walker et al. 1978), grazing and browsing in ungulates (e.g. Solounias & Moelleken, 1992; Merceron *et al*., 2005b), identify gramnivory, folivory, frugivory and specifically hard object feeding in primates (e.g. Semprebon et al., 2004), show high correlations between extinct and extant diets in lemurs and ungulates (respectively) (Godfrey et al., 2004), predict diets of 'unknown' extant primates against a sample with known diets (Semprebon et al. 2004), infer diets in hominoids (e.g. Teaford & Walker, 1984; Daegling & Grine, 1994; Ungar, 1996) and early hominins (e.g. Grine, 1986; Teaford, 1988; Ryan & Johanson, 1989; Ungar, 1998). Studies have also shown that microwear striation patterns in primates can change: under differing vegetable diets seasonally and by ecosystem (Teaford and Runestead, 1992), between subspecies (e.g. *Gorilla gorilla berengei vs. G. g. gorilla*; (King et al., 1999)), between gross primate populations (e.g. Teaford, 1985; Teaford and Glander, 1991) and populations within the same species per ecozone and season (e.g. Teaford and Robinson, 1989; Merceron et al. 2004). Others have found no significant intra-specific differences between habitats saying that "…intra-specific microwear differences related to habitat are generally not of sufficient magnitude to swamp inter-specific differences." (Dennis et al., 2004). Teaford (1988) and Teaford & Oyen (1986) found that wear patterns were indistinguishable between laboratory monkeys fed 'hard-' and 'soft-' food as there was a comparable amount of abrasives in each diet. Finally, Gordon (1984) cautions: "…intra-specific and intra-individual differences in microwear may be extreme.".

Surprisingly, little microwear research has been conducted on fossil *Homo*. As Ungar & Scott (2009) state: "Only one comprehensive study of dental microwear in early *Homo* has been published to date." Peuch (1979) noted an increasing number of horizontal and a decreasing number of vertical grooves on molars from *H. erectus* to H. *sapiens* which he correlated to a "…decreasing degree of effort produced by the teeth…" Waddle (1988) and Walker & Shipman (1997) noted that molars of east African *H. erectus* demonstrated heavy pitting. Perez-Perez et al. (2003) observed distinct differences in microwear pattern between 'strictly carnivorous' Inuit and Fuegian and Neanderthals although they both presumably relied heavily on hunting. They thus inferred that modern microwear might not correlate to that of fossil populations. However, El-Zaatari (2007, Ph. D. Dissertation) was able to correlate by ecozone Neanderthal and 'pre-Neanderthal' microwear to that of more modern groups of known diet. Fiorenza et al. (2010) demonstrated that dietary preferences shifted in Neanderthal early *Homo sapiens* according to habitat. Ungar et al. (2006) examined 'all available' Plio-Pleistocene African *Homo* molars and noted several characteristics: early *Homo* tend to group with extant primates [Pan & Gorilla] that do not regularly eat very fracture-resistant foods, East African *H. erectus* had high yet moderate pit percentages similar to those of Aleuts, *H. erectus* had more small pits than did *H. habilis* suggesting that *H. erectus* may have consumed more brittle or tough items than did *H. habilis* and a lack of evidence for dietary specialization in east African *H. erectus*. They summarize their findings saying that "…both the occlusal topography and microwear texture data vitiate notions that the origin and early evolution of the genus *Homo* were marked by major shifts towards specialization for mechanically challenging preferred foods. On the other hand, both the microwear and occlusal morphology evidence are more consistent with dietary versatility than with specialization."

Various research conducted on *Homo sapiens* is also instructive of what can be deduced from molar occlusal microwear. Peuch (1979) found that microwear differed in two subjects with different diets (vegetarian and meat). Smith (1984) determined that wear is similar within subsistence strategies whether "…agriculture is based on wheat or corn, and whether meat comes from sea mammals or marsupials." Studying historic hunter-gatherers from arid environments (Australian Aborigines & Bushmen), Perez-Perez et al. (2003) found a less abrasive microwear pattern than that of Upper Paleolithic peoples although no significant differences in diet were expected. Mahoney (2006), using a Bronze-age population, suggests that microwear analyses are capable of detecting subtle dietary differences in a geographically localized area. Finally, El-Zaatari (2010) demonstrated that the microwear signatures of Pacific-Northwest tribal peoples and Fuegians indicate a diet low in abrasives which reflects their reliance on dietary marine meat. She also saw that the mixed diet of the Bushman was correlated to more abrasive molar wear when compared against the above mentioned populations.

5.4.2 Buccal Microwear

Studies of hominin molar mesowear have also yielded dietary signals. Lalueza et al. (1996) were able to compare striations from historic hunter/ gatherer populations with known diets (e.g. Inuit and Fuegians) to those of Neanderthals to make predictions about Neanderthal diets. Studying the Sima de los Huesos *Homo heidelbergensis* population, Perez-Perez et al. (1999) found distinct patterns of intra-population variability and significant differences between *in situ* and isolated dentition (possibly caused by postmortem processes). Lee at al. (2004), investigating molar scratch density in several Javan individuals, correlated buccal microwear to environment. They found that Sangiran 27 from the Sangiran Fm (a marshy, humid environment) had the least scratch density which they correlated to a largely carnivorous diet. Ardjuna 9 recovered from the Grenzbank and thought to be from an open, herbaceous environment, had an intermediate scratch density which they corresponded to a diet intermediate between omnivorous and vegetarian. Two isolated teeth from Bapang (an open, herbaceous yet dry environment) had the highest scratch density which they interpreted as demonstrative of a largely omnivorous diet. The Song Terus Holocene *Homo sapiens* (also included in their sample) wear correlated to that of Sangiran 27. The mandibular cheek teeth of Song Terus also exhibited an unusual macro-wear pattern that might indicate the consumption of dried fish (Puech & Puech, 1993) or the use of teeth in the construction of fishing nets (Ubelaker et al., 1969). Such 'craft functions' produce wear but different from that produced by masticatory behavior (Molnar, 1972).

5.4.3 Microwear, Occlusal Mechanics and Food Properties

Many researchers have documented that molar microwear direction correlates to mandibular masticatory movement (Butler, 1952; Mills, 1955; Dalhberg and Kinzey, 1962; Murphy, 1964; Ryan, 1979; Baron et al., 1972; Greaves, 1973; Butler, 1983;

Teaford and Walker, 1983; Gordon, 1984; Walker, 1984; Rajaona et al., 1987; Young & Robson, 1987; Teaford and Byrd, 1989; Young, et al. 1990; Young, 1998). Therefore, microwear orientation is a direct record of the diet which produced it and masticatory behavior can be reconstructed from it (Reisz, 2006). Grine (1981) stated that microwear feature linearity should "…reflect the angle of approach of opposing facets, and that the angle of approach should reflect the mechanical properties of foods to be fractured." Several other recent researchers have echoed this but also caution that the unknown nature of a fossil organisms masticatory biomechanics limit predictions of their diets (Ungar, 2007; Chen, 2009).

A foods mechanical properties (commonly referred to as their textural properties) and initial bolus size and shape are the major factors influencing masticatory muscle activation and thus the mechanics and duration of the masticatory cycle (Luschei & Goldberg, 1981; Lesh et al., 1986; Horio & Kawamura, 1989; Hiiemae et al. 1996; Peyron et al. 1996; Agrawal, 1998; Mioche et al., 1999; Shiga et al., 2001; Lucas et al. 2002; Bhatka et al., 2004; Williams et al. 2005; Piancino, 2008; Goldmann, 2007; Takahashi et al. 2009). Foods demonstrate many different textural properties defined as; Hard: high resistance to deformation by applied force, Tough: high and persistent resistance to breakdown on mastication, Soft: low resistance to deformation by applied force, Tender: low resistance to breakdown on mastication, Brittle: tendency to crack, fracture or shatter without substantial prior deformation on the application of force, Gritty: presence of small, hard particles, Coarse: presence of large, constituent particles, Fibrous: presence predominantly of readily-separated filamentous structural elements (Jowitt, 1974). There can be multiple interactions or combinations of these various textural properties within any one food type or category (fruit, vegetable, meat). This, when added to the potential dietary variety which an animal can ingest (especially in omnivores) may confound attempts to generalize masticatory processes within a species. When comparing the masticatory behavior between two species, variation in each organism's masticatory anatomy only adds to the difficulty. To wit, Byrd et al. (1978) found large differences in masticatory behavior between *H. sapiens* and M. *fascicularis* when fed the same type of food.

Specific food texture types have yielded some generalizations regarding masticatory movement in humans. Comminuting hard, brittle foods (low $(R/E)^{0.5}$) require larger lateral excursions of the mandible than softer, tougher foods (high $(R/E)^{0.5}$) (Fig. 5.3) (Agrawal et al. 2000). R/E is defined as: R= toughness (measure of a materials resistance to crack propagation)/ Youngs elastic modulus (measure of a materials stiffness or rigidity) (Takada et al. 1994; Anderson et al., 2002; Lucas, 2004; Foster et al. 2006). Lateral movements are more highly correlated to $(R/E)^{0.5}$ than vertical and anterior-posterior movements though both are modulated by food texture (Agrawal et al. 2000). There are many possible combinations of textural properties in a food with concomitant gradations in R/E which will produce various masticatory themes on the above generalities (See Fig. 5.4 for the $(R/E)^{0.5}$ of foods mentioned in recent literature).

It is known that the masticatory sequence is not identical between individuals even when chewing the same type of food (Gerstner, 2005) and chewing cycles are non-identical within the same individual (Goldmann et al., 2007). The statistical differences within these categories does not, however appear to be significant (Morel, 1991). Also, there is more variability among Phase II movements as opposed to Phase I

(Hayasaki et al. 2003). As such, there can never be *exact* correspondence of inter- and intra-individual wear patterns.

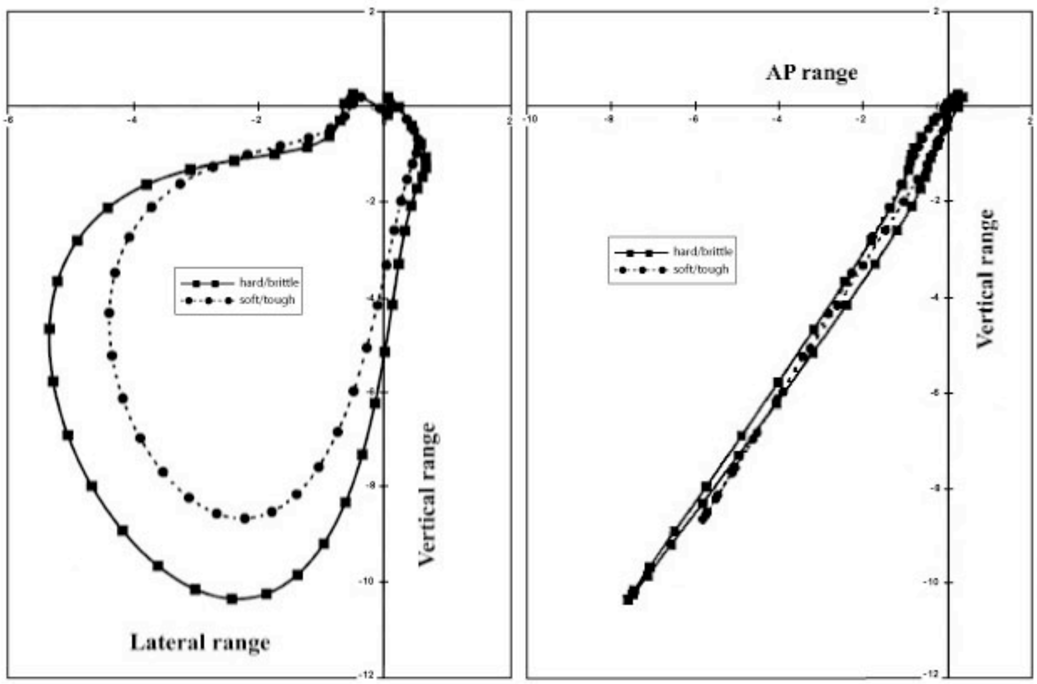


Figure 5.3. Lateral, vertical and anterior-posterior mandibular movements associated with hard/ brittle (solid lines) and soft/ tough foods (dotted lines). (Adapted after Anderson et al., 2002)

However, there are some 'constants' with regard to wear which result from human facial biomechanics. In humans, the working side condyle is the center of rotation for mandibular transverse movements during closing (Hiiemae, 1978). As the distance from the condyle increases (mesially along the tooth row), the arc through which each molar travels also increases. Therefore, transverse movement is longest at M1 and shortest at M3 and compression/ bite force also varies inversely along the tooth row. This also entails that microwear vectors will have longer more curved arcs on M1 and decreasing in length and arc curvature towards M3 (Gordon, 1984). Also, relative wear of molars is characterized by greater lingual wear on the maxillary molars and greater buccal wear on the mandibular molars (Molnar et al., 1983). This occurs because the maxilla is wider than the mandible and as the mandible swings up into centric occlusion, the mandibular buccal cusps consistently contact the maxillary lingual cusps.

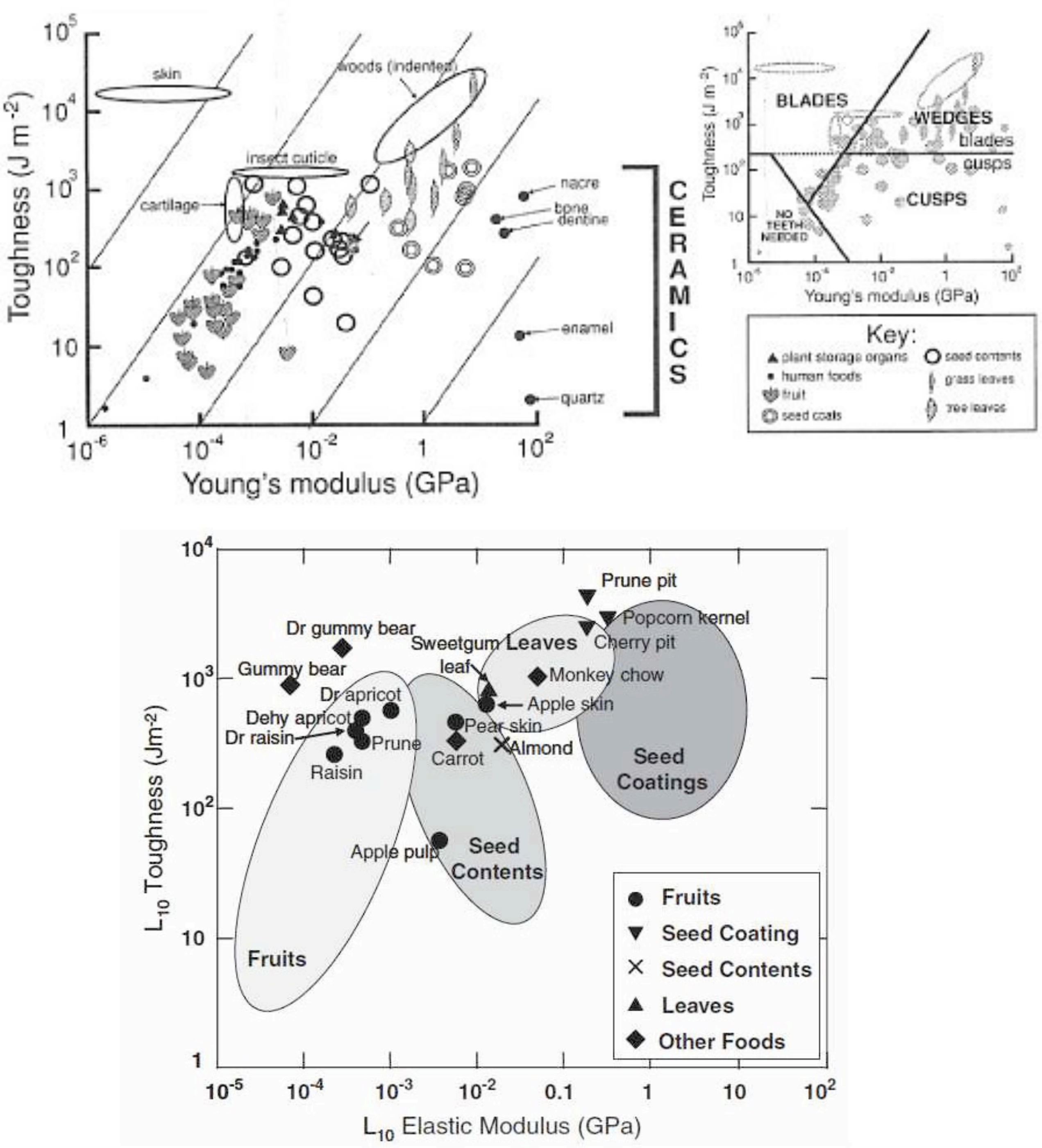


Figure 5.4. The R/E of selected foods.
(Top adapted after Lucas 2004; bottom after Williams et al. 2005)

5.5 Some Issues Regarding Tooth Wear

5.5.1 Taphonomic and/or Diagenetic Processes

Fossilizing specimens (by some definitions at least 10ky old) are subjected to considerable amounts of time in the earth (~1.7 my for the present sample) during which they can be subjected to innumerable taphonomic and/or diagenetic forces. These postmortem processes have the potential to damage, alter, deteriorate and/ or destroy features of interest. Factors such as the length of time a specimen has been exposed to the elements, the presence of destructive acids or other minerals in the post-depositional environment and whether or not the specimen was excavated or collected on the surface all impact its disposition upon examination (Teaford, 2007). Depositional damage to fossils by biological organisms (worms, insects etc.) is, however, not known (Sognnaes, 1963). Due to the durability of enamel, teeth themselves prove quite robust over time.

It has been shown that post-depositional taphonomic erosive processes, both physical (by sediment transportation) and chemical (acid erosion) (Fig. 5.5) are distinctive and recognizable and tend to erase ante-mortem microwear features rather than to increase them (Gordon, 1984; Ungar and Teaford, 1996; Perez-Perez et al., 1999; Martinez & Perez-Perez, 2004)." It has also been found that, over time, a buried tooth is subjected to wear at innumerable, unusual locations and angles (Puech et al., 1985) and this diagenetic wear will be represented on all tooth surfaces and not only the occlusal surface (Grine, 1986; Teaford, 1988; King et al., 1999). In contrast, wear patterns caused during mastication are laid down in regular patterns at specific locations (Teaford, 2007).

The 'problem' with postmortem wear then becomes that it *is* recognizable and, as such, specimens often have to be discarded from an analysis due to excessive alteration. The proportion of fossil specimens useful for microwear studies may, therefore, vary dramatically from site to site depending upon its historically specific taphonomic and/ or diagenetic processes. For example, less than 25% of Koobi Fora teeth are useful while ~60% of Olduvai can be analyzed (Teaford, 2007). Ungar et al. (2006) were only able to use 18 out of 83 (~23%) early Homo teeth from East and South Africa which is a percentage similar to that found for Plio-Pleistocene monkeys at some of the same sites (Leakey et al., 2003; El Zaatari et al., 2005). Samples sizes of undamaged molars are reportedly too small for meaningful comparative microwear research on *H. habilis*, *H. rudolfensis*, and *H. erectus* (Ungar et, al 2006).

Figure 5.5. Acid erosion on S7-64. Note the heavy pitting and mottling of the enamel surface.

5.5.2 Measurement Error

Ungar et al. (2008) discuss methodological sources of error in wear studies. Inter-observer error leading to low repeatability and limited accuracy would be the initial issue encountered by a researcher. Grine et al. (2002) and Semprebon et al. (2004) found inter-observer error rates of ~9% within a single technique while the use or collation of data from different quantification processes yield error rates of ~17%. These error rates are for 'standard' 2D microwear studies where pits and scratches are counted or measured in some manner and so these rates may or may not be applicable to 3D studies using much different quantification techniques. Semi-automated processes were also used within and across different imaging platforms to decrease error rates. Also, data suggests that these error rates will not significantly affect gross determinations of diet (Ungar et al., 2008). The second most commonly encountered source of error is in trying to characterize 3D surfaces using 2D methods (Janis, 1990). The relatively high topographic relief of macro- and micro-features dictate that light emanating or striking a specimen from different angles can produce shadow and/or aberration. Therefore, the geometry of the system dictates the quality of features visible (Gordon, 1988; Pastor, 1993; Solounias & Semprebon, 2002). This issue was controlled for in this study by standardizing the system configuration, specimen mounting process and spatial quantification of the specimen at the time of imaging. Repeatability of image accuracy was checked by returning the specimen to its 3D coordinates at least one day later to determine whether an exact image could be again acquired.

5.5.3 Sex and Wear

Findings of differences in molar wear by sex have been ambiguous. Lovejoy (1985) observed no macro-wear differences in a hunter-gatherer Woodland period population from Ohio. M'Kirera & Ungar (2003) found no sexually correlated occlusal relief differences in chimps and gorillas. However, McKee & Molnar (1988) saw a range of intra-populational variation among Australian Aborigines even though both sexes were judged to have the same diet. Perez-Perez et al. (1999) also found a 'highly significant sex-related difference' in microwear among the Sima de los Huesos *Homo heidelbergensis* population. Molnar (1971) found sex to be a major factor impacting tooth wear among a tribe of California indigenous peoples. A higher degree of attrition was found among females with the maxillary teeth worn more heavily than mandibular and the left mandibular molars more heavily worn than right. He explains this variation (but not morphology) through a sexual division of labor saying that as women gather tough, fibrous plant foods, they are also eating them and so expose their molars to more abrasion than men. Nystrom et al. (2004), studying wild baboons, observed no significant differences between sexes, age groups, or different troops. Whereas, Molnar et al. (1983), researching a different population of Australian Aborigines than the 1988 study, were able to correlate wear by sex and age. Gordon (1984) posited that age-related differences could be the result of surface and subsurface variations in enamel hardness.

Chapter 6

Materials

6.1 Introduction

The sample is composed of 88 maxillary and mandibular molars whereof 25 are *Homo erectus* and 63 are historic hunter-gatherers (HG). Three-dimensional imaging was performed using high resolution dental casts produced from moulds of the original specimens. Casts were used as tooth enamel has a high reflective index and, using the techniques described in the 'Methods' section, produce images which are too diffuse for accurate reassembly by alignment software. The molding and casting procedure follows Fiorenza (2009). *Homo erectus* microwear striae were imaged using the original teeth but the HG striae were imaged from dental casts again following Fiorenza (2009). All molars regardless of wear stage are considered here with the degree of wear being determined by evaluating the amount of cusp removal and dentin exposure per Smith (1984) (Fig. 6.1). Grine (1986) found no relationship between wear stage and standard microwear measurements in early hominins. Since right molars were more numerous in both samples, left molars were digitally mirrored in order to increase sampling ability and correspondence.

The Sangiran 7 von Koenigswald *Homo erectus* molars were selected based on several factors. Each molar was collected as an isolated surface find and, due to the less sophisticated collection techniques employed during the collection period, the exact position of the molars was not recorded. Indeed, Huffman et al. (2005) report that: "von

Koenigswald was often careless or unconcerned about exact field circumstances from which fossils came.". As such, their exact taxonomic and temporal inter- and intra-stratigraphic relationship is open to interpretation. Since they were discovered over seventy years ago, only 5 papers have dealt specifically with the sample. Three of the teeth were described by Grine (1984) then Grine and Franzen (1994) described the collection qualitatively with some very preliminary quantitative data being acquired. This quantitative data has never been applied to any sort of larger statistical analysis. They also identified five molars which they suspected of being more closely affiliated with *Pongo* than *H. erectus.* Dean (2001) used specimen S7-37 in an analysis of enamel growth increments while Kaifu (2006) used seven of the molars in a comparative study of crown areas. Finally, Indriati (2004) simply included them in a catalogue of Indonesian fossil hominins. Based on the relative paucity of research conducted on this sample, the uncertain nature of their provenance and various lingering taxonomic and chronostratigraphic questions, the sample presents itself as ripe for systematic quantitative interpretation and inclusion into and comparison with the larger body of hominin dental remains.

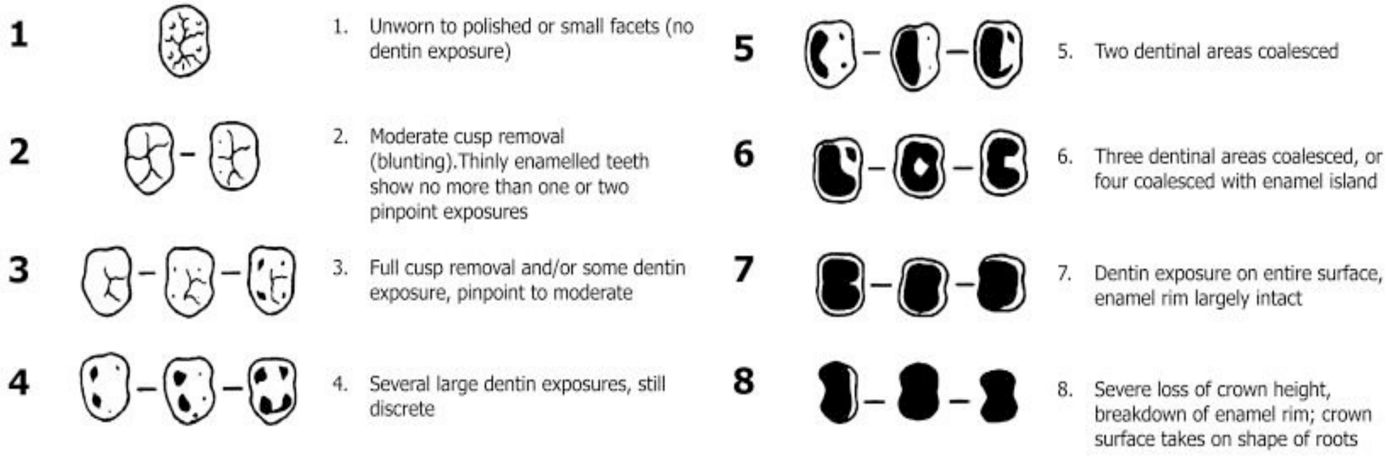


Figure 6.1. Enamel wear scoring
(after Smith, 1984)

The historic hunter-gatherer sample was selected based on the range of total dietary strategies demonstrated. Although each population is known to subsist on and/ or specialize in the consumption of various foods (e.g. the Inuit consume large amounts of meat), this was not an *a priori* consideration as it could introduce bias into the analysis. The possible presence of considerable seasonal and/ or individual variation must also be taken into account so assigning specific dietary classifications to each population is avoided. Also, these populations all tend to demonstrate relatively large molars within *Homo sapiens* variation and, as Sangiran *H. erectus* crown size tends to fall around the upper limit of human variation, represent good functional correlates for comparison (Huffman et al. 2005; Kaifu, 2006).

6.2 Sangiran 7 (S7) *Homo erectus* sample

From 1937 to 1941 G.H.R. vonKoenigswald oversaw the collection of the Sangiran (S7) *Homo erectus* remains from the Sangiran Dome, Java. The sample consists of 25 molars all currently housed at the Senckenberg Research Institute, Frankfurt, Germany. The sample is further broken down into two sub-sets based on the Sangiran Dome stratigraphic horizons from which they originated (Table 6.1). The horizons are separated provisionally by the Grenzbank conglomerate. Grine and Franzen (1994) state that the molars "…most probably came from a section between the middle Pucangan [Sangiran] and the middle Kabuh [Bapang], which would place these specimens between 1.3 and 0.7 million years." Ten molars, designated Sangiran 7b, are of the younger Bapang Formation. Three of these (S7-14, -17 & -20) are thought to be affiliated with *Pongo* and not *H. erectus* by F. Grine (Grine and Franzen, 1994). Kaifu et al. (2007), however, disagree that S7-17 should be assigned to *Pongo* citing its flat occlusal wear and basic similarity to other *H. erectus* specimens. Ciochon et al. (1996) also encountered problems in distinguishing *Pongo* from other hominid genera finding that large *Pongo* teeth have been confused with *Gigantopithecus* while small, worn *Pongo* teeth have been termed *Homo*. They then offer some resolution on the issue saying that peripheral placement of molar cusps is diagnostic of *H. erectus* even in highly worn specimens. Weidenreich (1937) weighs in on the topic saying that as *Pongo* molars wear, they lose their characteristic occlusal 'wrinkles' making them difficult to diagnose. He also cautions that even slightly worn upper Pongo molars occasionally exhibit "a pattern of the chewing surface surprisingly similar to that of Sinanthropus.". However, he also states that *Pongo* upper molars exhibit a unique, double crista transversa (mesial trigon crest uniting the paracone and protocone) which is normally evident even with extreme wear (Weidenreich, 1937).

The remaining fifteen molars, designated Sangiran 7a, are of the older Sangiran Formation. Two of these molars (S7-63 & -65) are thought to be affiliated with *Pongo* and not *H. erectus* by F. Grine (Grine and Franzen, 1994). Kaifu (2006) reviewed vonKoenigswald's allocation of thirteen specimens (molars and pre-molars) to the Bapang Formation and agreed with their placement excepting S7-8. He doesn't give a reason for this nor suggest an alternate allocation for S7-8 but states that the crown size does not differ significantly from other Sangiran area molars. Kaifu et al. (2005) also state that 'some' of the S7 molars resemble remains from the Grenzbank conglomerate based on their state of fossilization though they do not state exactly which teeth they are referring to. All molars are from adults or sub-adults, specific age and sex cannot be determined and only three of the molars (S7-3b, -3c & -3d) can be associated with one individual. Kaifu (2006) found no significant difference between molar crown size in purported male and female Sangiran specimens. Dean et al. (2001), based on daily incremental enamel growth, estimated an M1 gingival emergence time of ~4.4 years and M2 at ~7.6 years for S7-37 and M1 emergence time for KNM-WT15000 at ~4.0 years. Therefore, any first (e.g. S7-20) and second molars (e.g. S7-62) demonstrating little occlusal wear could possibly be used as base-lines to approximate ages sample-wide (Kaifu et al., 2005).

The physical condition of each molar varies with some being almost completely unworn to others being worn quite flat. The crowns are all complete except for S7-14 whose distal enamel edge is missing. The enamel surfaces range from almost pristine to [likely] acid etched to the degree that microwear is barely discernable (S7-64). Peuch et al. (1985), Teaford (1994) and King (1999) found that when exposed to acid, almost all microwear features were removed revealing the underlying enamel prism network. Again, due to poor collection techniques, post-mortem diagenetic and/ or taphonomic factors responsible for any damage cannot be positively assessed. However, it is important to note that from examination of facet microwear, distinct, individual patterns were discernable which indicate that none of the molars (except the above mentioned) were affected by environmental factors to such a degree as to damage or alter the macro- or microanatomy of the occlusal surfaces.

The S7 sample constitutes part of a larger sample from the Sangiran Dome of which *Pongo* teeth and gnathic fragments were also recovered. As stated in Grine and Franzen (1994), "It is commonly difficult to distinguish isolated, worn, eroded and/or acid etched molar crowns of fossil *Pongo* from those of fossil *Homo* because of similarity in

Table 6.1. Sangiran (S7) descriptive data

Specimen (n=25)	Species	Formation	Age	Tooth^	Wear Stage*
3b	*H. erectus*	Bapang	~.7 to 1.0ma	URM1	3
3c	*H. erectus*			URM2	3
3d	*H. erectus*			URM3	2
6	*H. erectus*			ULM3	2
8	*H. erectus*			ULM1	5
9	*H. erectus*			URM1	3
10	*H. erectus*			URM1	3
14	*Pongo?*			URM1/2	4
17	*Pongo?*			URM3	4
20	*Pongo?*			LLM1/2	2
		Grenzbank			
37	*H. erectus*	Sangiran	~1.0 to 1.5ma	URM1	3
38	*H. erectus*			ULM1	4
40	*H. erectus*			URM1	4
42	*H. erectus*			LRM1	3
43	*H. erectus*			LLM1	3
53	*H. erectus*			ULM2	3
61	*H. erectus*			LRM1	3
62	*Pongo?*			LRM1/2	2
64	*H. erectus*			LRM2	2
65	*Pongo?*			LRM2	2
73	*H. erectus*			ULM3	2
76	*H. erectus*			LRM1	2
78	*H. erectus*			LLM1/2	4
84	*H. erectus*			LRM2	3
89	*H. erectus*			URM2	3

^1/2 means possible M1 or 2 *Smith 1984

size, overall morphology and enamel thickness.". Due to significant dietary and overall ecological differences, it is expected that, even though *Pongo* has not been included in the comparative sample, molars that are affiliated with *Pongo* will not group statistically with either *H. erectus* or *H. sapiens* and thus reveal themselves secondarily. Also, Kaifu et al. (2005) disagreed with Grine and Franzen's (1994) allocation of several S7 incisors to *Pongo* (he concluded that they were hominin) and so it may be possible that they were also wrong in assigning the above mentioned molars to *Pongo*.

6.3 Historic Hunter/Gatherers

The historic hunter/gatherer sample consists of 63 specimens: 9 Inuit, 11 Vancouver Islanders, 11 Fuegians, 12 Australian aborigines and 20 Bushmen (Table 6.2). As many of these samples were collected in the early part of the twentieth century during a time in which strict collection protocols were not observed, detailed provenances do not exist for many of these specimens. All of the crowns are complete and show no post-mortem damage or alteration. Although many of the peoples considered here still exist as distinct cultures, their lives and economies have been radically altered from their 'historic' condition by contact with European 'white' populations. As these samples are believed to have been collected from periods shortly after initial contact and before subsequent destruction (in most cases) of traditional ways, these samples are representative of individuals conducting themselves as their cultures had done for, likely, millennia.

6.3.1 Inuit

This sample is composed of nine molars (14.3% of total HG sample) from specimen FC 833-3 currently curated in the Natural History Museum of London, England. This specimen was collected from an unknown island approximately five miles off the south-west Greenland coast and is believed to have originated from an individual existing between 1400 and 1700AD. The sex of the individual is not known but fully adult dentition is indicated. Tomenchuk & Mayhall (1979), in a sample of Igloolik Inuit, demonstrated that male maxillary molars were worn ~30% more rapidly than in females which may indicate a sexual division of labor. The maxillary left and right M^1 to M^2, mandibular left M_1 thru M_3 and mandibular right M_1 to M_2 were collected and are analyzed here.

6.3.2 Pacific Northwest Tribes

This sample is composed of eleven molars (17.5% of total HG sample) from specimen FC 848 currently housed at the Natural History Museum of London, England. This specimen was collected from 'Coffin Island' which is perhaps synonymous to the current Coffin Rock which lies off the Oregon coast at the mouth of the Columbia River. No date of collection is indicated but the specimen is known to be of an adult male. The maxillary left and right M^1 thru M^3, mandibular left M_1 to M_2 and mandibular right M_2 to M_3 were collected and are analyzed here.

6.3.3 Fuegians

The sample consists of eleven molars (17.5% of total HG sample) from specimen NHMW 6035 currently curated in the Natural History Museum of Vienna, Austria. This specimen may have originated from 'Philip Bay' located on the northern coast of Isla Grande de Tierra del Fuego. This may indicate affiliation with the Ona (Selk'nam) tribe who were known to specialize in guanaco hunting in the interior of the island. However, the coastal collection site likely indicates a more maritime dietary economy. The sex of the individual is not known and no date of collection is given but fully adult dentition is indicated. The maxillary left and right M^1 thru M^3, mandibular left M_2 to M_3 and mandibular right M_1 thru M_3 were collected and are analyzed here

6.3.4 Australian Aborigines

The sample consists of six molars each from specimens NHMW 8687 and NHMW 811 (19.1% of total HG sample) currently housed in the Natural History Museum of Vienna, Austria. No specific collection locale is given for either specimen. The sex of the individuals is not known and no date of collection is given but fully adult dentitions are indicated. Molnar et al., (1983 a&b) found that aboriginal males subsisted on 'bush tucker' (i.e. 'wild' plants and animals) while on extended hunting trips and that the abrasiveness and toughness of this diet produced more rapid tooth wear than in females. For both specimens, the maxillary left and right M^1 thru M^3 were collected and are analyzed here.

6.3.5 Bushmen

The sample consists of twenty molars (31.7% of total HG sample) from specimens S5, S9 and S16 currently curated in the Department of Anthropology, University of Vienna, Austria. The specimens were collected by Rudolph Pöch between 1907 and 1909 (Pacher, 1961). Specimen S16 is listed as 'Bushmen' while specimens S5 and S9 appear to originate from south of the Orange River. The Orange River marks the southern boundary of the Kalahari basin and, as such, these specimens are nominally assigned to the Korana tribe. The Korana were semi-nomadic hunter/

gatherers who owned livestock. Their dietary economy was very similar to that of 'Bushmen' proper with the addition of milk and blood from their livestock (Barnard, 1992). El Zaatari (2008) found no significant difference in microwear pattern between Bushmen populations from different regions and so this is not considered problematic. Specimen S5 is an adult male, while S9 is an adult of unknown sex and S16 is a 'sub-adult' female. For specimen S5, the entire maxillary and mandibular molar set is used while specimen S9 consists of the maxillary right M^1 to M^2. Specimen S16 is represented by maxillary right M^1 to M^2 and mandibular right and left M_1 to M_2.

Table 6.2. Historic hunter-gatherer descriptive data

Specimen	Group	Location	Sex	Age	Tooth	Wear Stage*
FC848	PNWT	Columbia River mouth	M	Adult	URM1	4
n=11					URM2	3
					URM3	2
					ULM1	4
					ULM2	3
					ULM3	2
					LRM1	3
					LRM2	2
					LRM3	2
					LLM1	3
					LLM2	2
FC833-3	Inuit	SW Greenland	Unk.	Adult	URM1	4
n=9					URM2	3
					ULM1	4
					ULM2	3
					LRM1	4
					LRM2	3
					LLM1	4
					LLM2	3
					LLM3	3
NHMW6035	Fuegians	North Coast Isla Grande	Unk.	Adult	URM1	4
n=11					URM2	4
					URM3	3
					ULM1	4
					ULM2	4
					ULM3	3
					LRM1	4
					LRM2	4
					LRM3	3
					LLM2	3

					LLM3	3
NHMW8687	Aust. Abor.	Australia	Unk.	Adult	URM1	4
n=6					URM2	3
					URM3	2
					ULM1	4
					ULM2	3
					ULM3	3
NHMW811			Unk.	Adult	URM1	4
n=6					URM2	3
					URM3	3
					ULM1	4
					ULM2	3
					ULM3	3
S5	Bushmen/ Korana	South of Orange River	Male	Adult	URM1	4
n=12					URM2	3
					URM3	3
					ULM1	4
					ULM2	3
					ULM3	3
					LRM1	3
					LRM2	2
					LRM3	2
					LLM1	4
					LLM2	3
					LLM3	3
S9			Unk.	Adult	URM1	4
n=2					URM2	3
S16		Kalahari Basin	Female	'Sub'-adult	URM1	3
n=6					URM2	2
					LRM1	3
					LRM2	2
					LLM1	3
					LLM2	2

Total: n=63

* Smith 1984

Chapter 7

Methods

7.1 Introduction

This project presented a unique set of problems and challenges for several reasons. The initial objective of visualizing for analysis both macro- and micro- 3-dimensional (3D) information simultaneously entailed the use of several somewhat disparate imaging technologies. These technologies each extract different levels/ types of information, use different imaging platforms/ methods for such and have never been employed together. As such, the merging of these various technologies required novel thought about and application of the various platforms.

Foremost of the difficulties was that, although microwear images contain 3D information, the images themselves were, by nature 2-dimensional (2D) representations of that 3D information. The problem then was how can 2D information be converted to or mated with 3D representations of where that 2D information was extracted?

The problem is compounded when the ultimate objective is added to the above. This final objective entails, via the images synthesized from the above technologies, reproducing the functional direction of mandibular movement for individual molars. This then, in effect, could be considered a 4-dimensional problem. Visualizing, extracting and statistically analyzing this novel (4D?) data also required innovative methods not previously employed. Only one similar study is known whereby 2D microwear images were mated to a 3D tooth surface (Williams et al., 2009). However, this study was conducted on hadrosaurid dinosaurs (with relatively simple mandibular movements), microwear images were captured with an SEM, visualized using stereographic projection techniques and was not comparative.

7.2 Microwear Image Acquisition

7.2.1 Imaging System and Specimen Alignment

A K2S Bio portable confocal microscope (Technical Instrument Co. Sunnyvale, CA; Bromage US Pat. App. No.: 10/960,325, OIL Id. No.: BRO03-01PRO.) was chosen due to its unique imaging capabilities as previously demonstrated for use in examinations of hominin dentition by Bromage and Perez-Ochoa (2003) and Bromage et al. (2005 & 2007). However, due to technical considerations inherent to this project, some methodological modifications were necessary. The first and most important modification is that the imaging system and stage need to leveled, aligned and squared in exact XYZ planes per a right-handed Cartesian Coordinate System with '+X' towards the viewer, '+Y' to the right and '+Z' straight up (Fig. 7.1). Although there are different configurations of the coordinate system across various disciplines (mathematics, computer graphics etc.), this configuration was chosen because 'Z' is normally used as the distance between the specimen and objective lens in microscopy and for correspondence across the analysis platforms used here.

Leveling etc. were accomplished through the use of a spirit level and two laser levels. The spirit level is placed atop the confocal module which is then adjusted to horizontal (in the XY plane). As there is some play in attachment of the objective lens, the laser levels are placed at right angles (at a distance sufficient enough to allow the beams to trace the vertical length of the objective tube) focusing their beams vertically on the center of the objective tube to ensure that it is vertical (XZ & XY planes). The camera mount does not seat the camera itself in any specific direction and so the camera itself must be squared to the coordinate system. This also can be accomplished using the laser levels at right angles to each other. The camera also must be mounted so that the image is *in situ* and not rotated 180º.

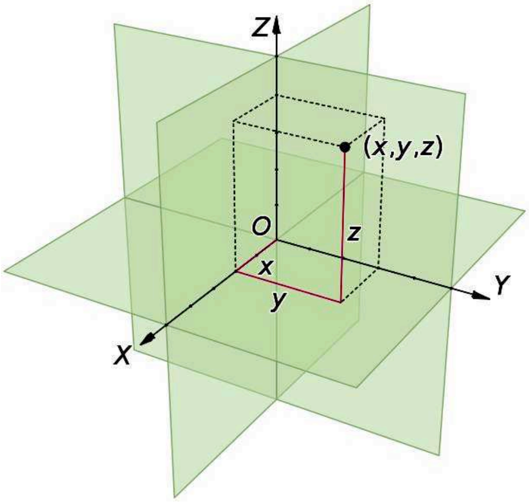


Figure 7.1. Right-handed Cartesian Coordinate System.

A manual goniometer stage is then affixed to a modified XY stage (Fig. 7.2). A goniometer is added here so that the exact position of the specimen (here a tooth) in space can be recorded as it is rotated into optimum position for viewing of individual facet microwear. Any method of affixing the goniometer onto the XY stage may be used but modeling clay was available and found to be quite adequate and functional. Clay is firm yet malleable which allows the goniometer to be delicately manipulated while centering and squaring it with the XY stage. This centering and squaring is again accomplished using the level lasers at right angles to each other. This entire apparatus is then squared beneath the objective lens (and with the confocal module itself) using the laser levels.

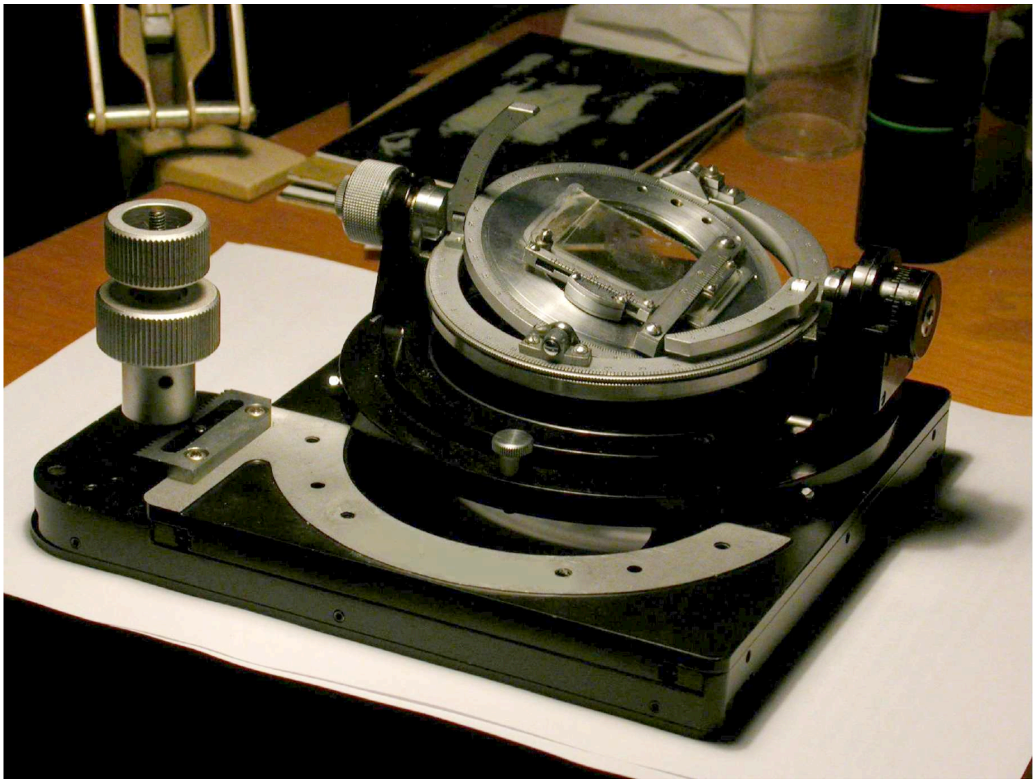


Figure 7.2. Goniometer atop modified XY stage.

The specimen tooth must then be oriented in a standardized manner. As Gordon (1998) states, "Variation in specimen orientation can affect the definition of microwear features." and so the orientation process was developed with this in mind. A small glass platform/ stage was customized from microscope slides such that one side lies directly in the XZ plane, another directly in the YZ plane and the base in the XY plane. The YZ side lies only in the -Y axis while the XZ side lies only on the -X axis so that a 90º corner is formed. This corner defines a space occurring from the origin (0,0,0) into (-X, -Y, Z) (Fig. 7.3). Glass microscope slides were used so that laser light could penetrate and illuminate the tooth in preparation for a future alignment step. Before the tooth can be affixed to the platform it must be measured to determine its morphological center in XY (½ bucco-lingual by ½ mesio-distal dimension). A small dot is placed on the tooth at this point using a non-permanent, fine point marker.

Figure 7.3. Customized specimen platform with tooth fixed in viewing position.

The tooth is then placed on a small piece of clay (to hold and stabilize the tooth) affixed in the corner of the glass platform with its mesial border flush with the XZ side of the platform and its buccal or lingual border (depending on if the tooth is sinistral or dextral) flush with the YZ side. The tooth is then leveled in XY using its cervical margin as the reference. The two level lasers are configured to project beams at the same height in the XY plane from opposite sides of the tooth. This ensures that a solid line is cast around the entire tooth in the XY plane. Tooth position is then adjusted so that the cervical margin lies in the XY plane. If the cervical margin is unclear or damaged, then a 'best-fit' margin is determined and used. Each successive tooth can now be squared and leveled in the same manner regardless of its root size or height. The height of the tooth in Z is then taken using calipers. This measurement is defined as the distance of the central occlusal fossa from the center of rotation upon the goniometer and is essential for being able to reposition the digitized tooth in later steps. The tooth is now cleaned using a small, soft bristle paint brush (cotton swab fibres tend to snag in small cracks and fissures in the tooth surface) using an 80/20 water/ alcohol or water/ acetone solution. Cleaning is done at the end of the alignment process as much handling and manipulation of the tooth is required which introduces not insignificant amounts of skin oils etc. onto the enamel surface.

Finally, the glass stage with aligned tooth is affixed to the goniometer platform (again using clay) so that the morphological XY axis of the tooth is lined up at the center of goniometer platform. This 'center' is easily recognized as the illuminating light emanating from the objective lens passes directly thru here (assuming all alignment has been done properly) (Fig. 7.4). The height (or Z) of each tooth is measured from the top of the goniometer specimen base to the morphological axis so the tooth's center of rotation can be factored back into 3D model alignment. Dennis et al. (2004) employed similar specimen orientation techniques of which Ungar et al. (2002) had previously deemed to be repeatedly precise to within 1%.

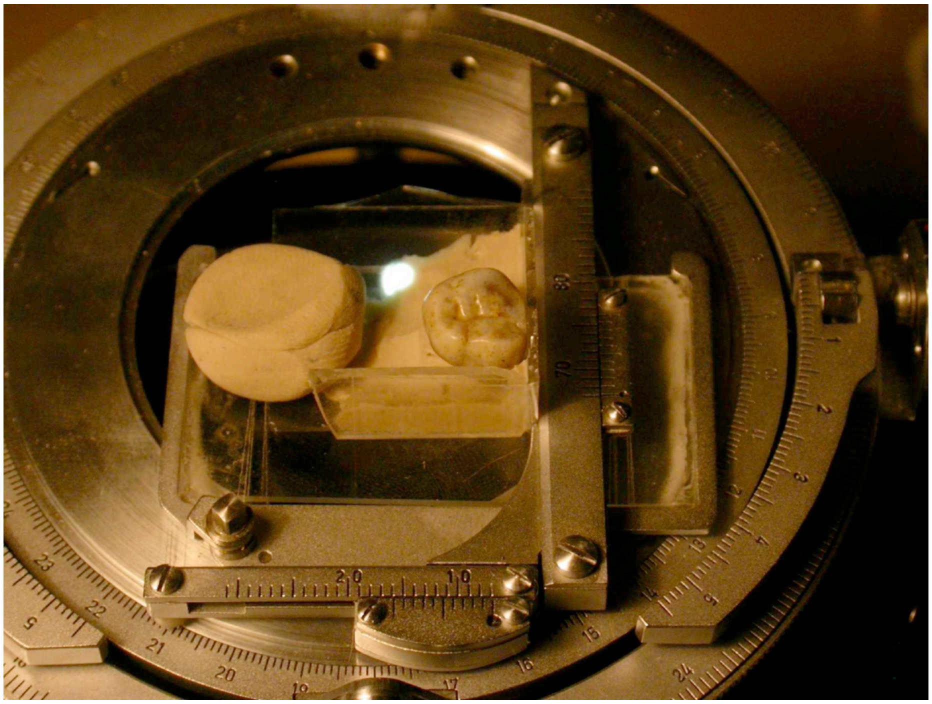


Figure 7.4. Specimen platform and tooth affixed to goniometer. The tooth has not yet been brought to center which is seen as the bright dot just to the tooth's upper left.

7.2.2 Microwear Imaging

After the system and specimen have been squared, imaging can commence. Three wear facets per tooth were chosen for imaging of microwear. These facets are representative of buccal and lingual Phase I & Phase II masticatory movements. For maxillary and mandibular molars, facets 3 & 4 correspond to buccal Phase I shearing while facets 5 & 6 correspond to lingual Phase I shearing. Facet 9 is representative of Phase II crushing and grinding movements in both upper and lower molars (Fig. 7.5) (Hiiemae & Kay, 1973; Kay & Hiiemae, 1974; Maier & Schneck, 1981; Janis, 1990). In the event that a facets microwear was not discernable due to diagenetic and/ or taphonomic etc. reasons (which occurred more frequently in the *H. erectus* sample but much less in the historic HG sample), another facet representing the same occlusal phase was chosen. For example, if maxillary facet 9 demonstrated no wear, then facet 12 was substituted.

Using the underlying XY stage, the goniometer with affixed tooth is slid beneath the objective lens so that the facet under investigation is directly under the illuminating beam. The goniometer is then manipulated so that the specimen is tilted in such a manner that the facet under investigation is as near horizontal (into the XY plane) as visually possible. Achieving maximum horizontality allows a larger area of the facet to be continuously imaged without having to make major adjustments in focus. Any blurring or distortion caused by out of focus planes is also minimized. The entire facet is initially scanned with a 5X objective to determine whether the facets microwear is present and if it truly represents microwear and not taphonomic and/or diagenetic artifact. Microwear is evident as multiple parallel striae running in a consistent direction

(Fig. 7.6) (Appendix A & B). There can be more than one area per facet with differently manner that the facet under investigation is as near horizontal (into the XY plane) as visually possible. Achieving maximum horizontality allows a larger area of the facet to be continuously imaged without having to make major adjustments in focus. Any

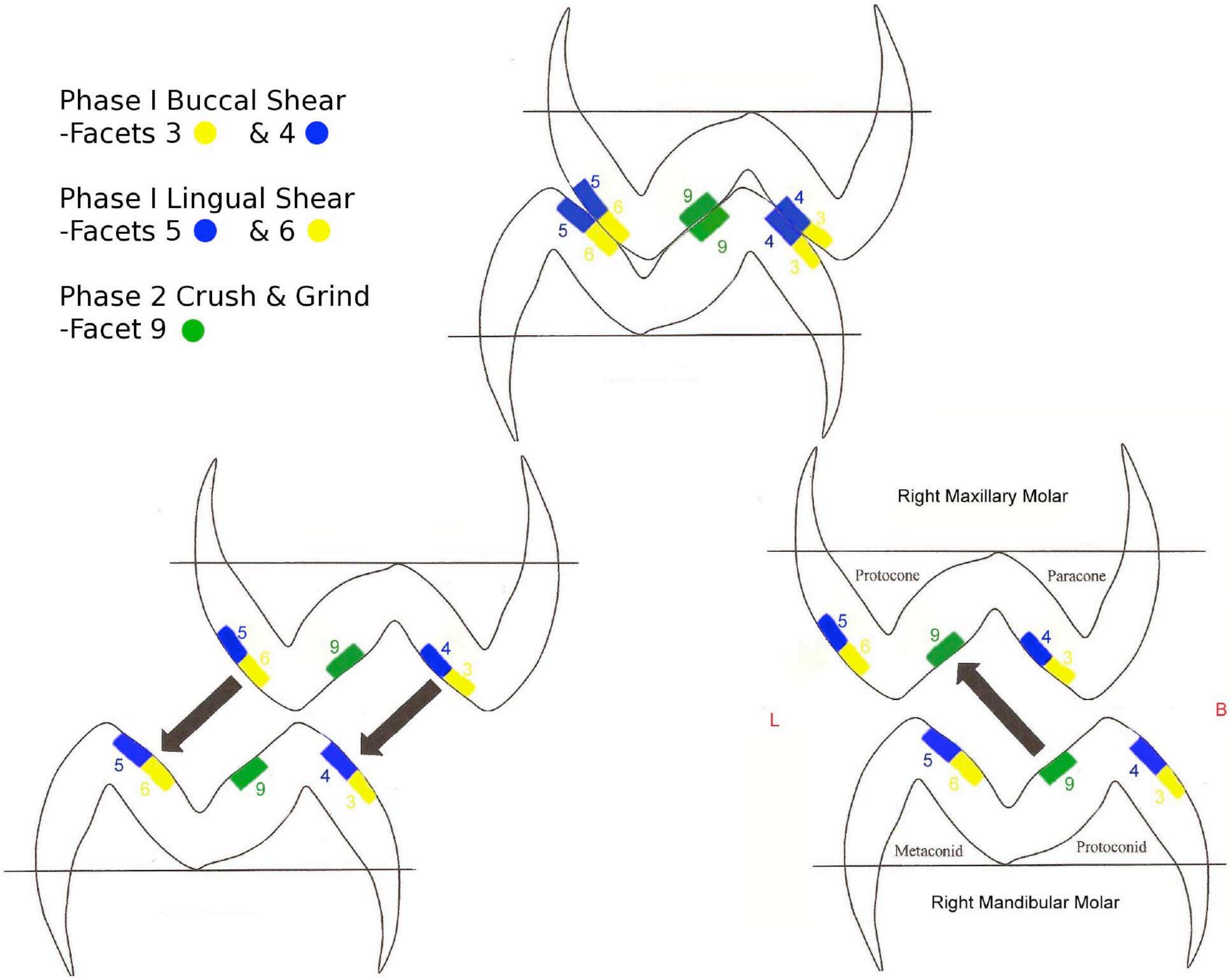


Figure 7.5. Schematic illustration of masticatory movements and the wear facets related to this study. Numerical system after Maier and Schneck (1981) and color coding after Kullmer et al (2009). Masticatory movements begin in the lower right diagram with the mandible starting its incursive movement from the latero-inferior of the maxilla and driving superio-medially. As this occurs, complementary Phase I buccal (4&3) and lingual (5&6) facets shear past each other. Phase I shearing ends as centric occlusion is reached (upper central diagram) with the mating of complimentary facets 9. Crushing occurs between these facets at the transition from Phase I to Phase II movements. Phase II continues with a grinding action between facets 9 in an inferio-medial direction. There is a seamless transition from Phase I to II. This is an idealized and somewhat simplistic representation of what is actually occurring during mastication as it implies simple up/down right/left movement when in actuality the incursive and excursive movements can begin and end through a large range of horizontal and vertical movements depending upon wear stage and diet.

blurring or distortion caused by out of focus planes is also minimized. The entire facet is initially scanned with a 5X objective to determine whether the facets microwear is present and if it truly represents microwear and not taphonomic and/or diagenetic artifact. Microwear is evident as multiple parallel striae running in a consistent direction (Fig. 7.6) (Appendix A & B). There can be more than one area per facet with differently angled concentrations of striae. These concentrations can overlap others. Multiple concentrations of striae angled differentially indicate that the facet was used in more than one direction. On any tooth, no more than five of these concentrations were identified and this occurred only on a very small percentage of facets with approximately 2.5 concentration areas per facet being the average. Striae that were singular, very deeply cutting into the facet surface, irregularly wide or moving in an inconsistent direction were deemed to be artifact and not imaged.

If microwear was evident using the 5X objective then an image was acquired. When possible, the entire facet surface was imaged but if striae were concentrated in specific regions, only these were imaged. Several images were normally required to adequately document striae concentrations. These image sequences were saved as .jpeg files, numbered consecutively and manually montaged at a later stage. Once an image is captured, the goniometer is read for +/- tilt of the XY plane about the X or Y axis. Positive X values are read on the right scale (right side up) and negative on the left (left side up) while positive Y values are read on the front scale (front side up) and negative on the rear (back side up) (Appendix C & D). For example, the configuration shown in Figure 7.2 above would correspond to the values (-1.5, 0, 0) as the left side of

Figure 7.6. Three different microwear directions on facet 5 of Sangiran 7-3c. Imaged using the 5X objective lens.

the goniometer is up, there is no XY tilt around Y and Z is zero as no specimen is affixed. In order to reduce the amount of reorientation necessary in later steps, rotation around the Z axis was done very rarely and only when a facets striae could not be adequately imaged otherwise. Magnification was also recorded to facilitate reproducibility. If microwear was not readily imageable with the 5X objective then the 10X objective was employed. Rarely was it necessary to employ a higher power objective. This was also undesirable as the field of view becomes increasingly small and, as such, the ability to judge whether the striae being imaged were relevant (i.e. actually identifying true directions of movement across the facet surface as opposed to random artifact) decreases. Gordon (1988) showed that magnification could materially affect the 'perceived wear fabric' while Semprebon et al. (2004) showed that low magnification microscopy (as opposed to high magnification electron microscopy which is often used in microwear studies) had low inter- and intra-observer measurement error. Also, the portability of the confocal system engenders certain design restrictions which contribute to image 'bounce' or vibration at higher magnifications in many situations. First, the system must be lightweight and so a heavy or vibration resistant base can not be included. Second, the system must be easily and readily assembled and disassembled which sacrifices some solidity of the systems components. Most modern buildings (as found in developed nations) contain large ventilation systems which introduce a considerable amount of vibration into a building itself which becomes an issue at high magnifications. Several vibration dampening measures are included in the system but none have been completely successful in eliminating all 'bounce' or vibration. Many buildings in developing nations do not contain these ventilation systems and so, interestingly, this issue is less of a problem in 'remote' locations.

7.3 Mating of 2D and 3D Molar Images

Using 3D optical topometric methods established by Kullmer et al. (2002) and employed elsewhere by Ulhaas et al. (2004 & 2007), Fiorenza (2009 & 2010) and Kullmer et al. (2009), the hunter-gatherer and *H. erectus* molars were scanned to a surface resolution of ~50 μm and digitized to create 3D virtual reality (VR) models. Fiorenza (2009, Doctoral dissertation) contains a detailed discussion of the methods employed in model generation and post-processing. The 2D microwear striae acquired above are then mated to these 3D VR models employing several different image manipulation programs and processes.

7.3.1 Tooth Model Alignment and Facet Delimiting

The 3D VR molars are imported into the IMEdit module of PolyWorks® 10.1 (InnovMetric Software Inc.) where they are oriented to exactly match the coordinate position of the original tooth. They first must be leveled in the horizontal (XY plane) by digitally defining a best-fit line around the cervical margin and then translating the cervical line and associated tooth to the XY plane (Fiorenza, 2009). The tooth is then digitally rotated so that the mesial border is flush with the XZ plane. The morphological axis is marked digitally using the same measurements as above. This point was used to measure the height of the crown above the goniometers axis of rotation (recorded during image acquisition) and so the tooth needs to be translated vertically to match this height.

The facets from which the striae were acquired are then defined by manually inserting a polyline around the facets anatomical border. The original tooth or cast was always at hand to visually confirm this border. A best-fit plane is created which defines the surface bounded by the polyline (Fiorenza, 2009).

7.3.2 Mating of 3D Facet and Microwear Striae

First, the entire VR tooth is returned to the coordinate position in which a facets microwear striae were imaged. Using the rotational measurements recorded from the goniometer, an automated rotational feature in IMEdit ensures that the tooth's (and thus facets) 3D position during microwear striae imaging is exactly reproduced (Fig. 7.7). The plane representing the facets occlusal surface in 3D space is then saved as a separate .bitmap file.

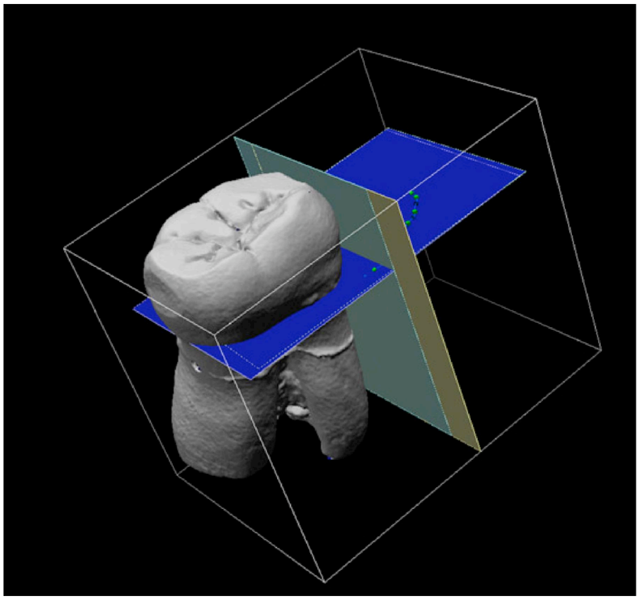


Figure 7.7. *H. erectus* specimen Sangiran 7-20 fully aligned and rotated into a position in which microwear striae were imaged.

The facet planes .bitmap file is then imported into Rhinoceros® 4.0 NURBS modeling software (McNeel). For unknown reasons, Rhinoceros flips the facet planes vertically resulting in the need to flip the original microwear images vertically as well (this is not a 180° rotation but a vertical flip!). The microwear images are then imported into Rhinoceros as well and aligned beneath the facet plane. The microwear striae are now visible beneath their 3-dimensionally oriented facet as they originally appeared on the tooth (Fig. 7.8). The microwear images can be aligned anywhere beneath the facet image as it's the microwears gross direction that is of importance and not its exact position on the facet.

A line drawing tool is then used to trace one striae from each microwear concentration onto the facet plane (yellow line Fig. 7.8). Only one striae from each concentration needs to be reproduced as a facets totality of microwear yields no further information here. If multiple microwear striae concentrations were present on a facet, a line from each concentration can be drawn in sequence. The facet planes .bitmap image with inserted microwear striae are then saved as a single image. The inserted lines now exactly reproduce that facets microwear striae in 3 dimensions.

The facet and striae .bitmap images are then imported back into IMEdit. As long as the VR tooth was not moved from the position it was oriented in to extract the facet surface for export into Rhinoceros, the facet is automatically mated back to its original position on the occlusal surface. The exact 3-dimensional orientation of the microwear striae are now fused to and visible upon their appropriate facets of the VR tooth. Working backwards from the goniometer readings for that facet, the tooth is then returned to its original squared position in preparation for repeating the process for each facet.

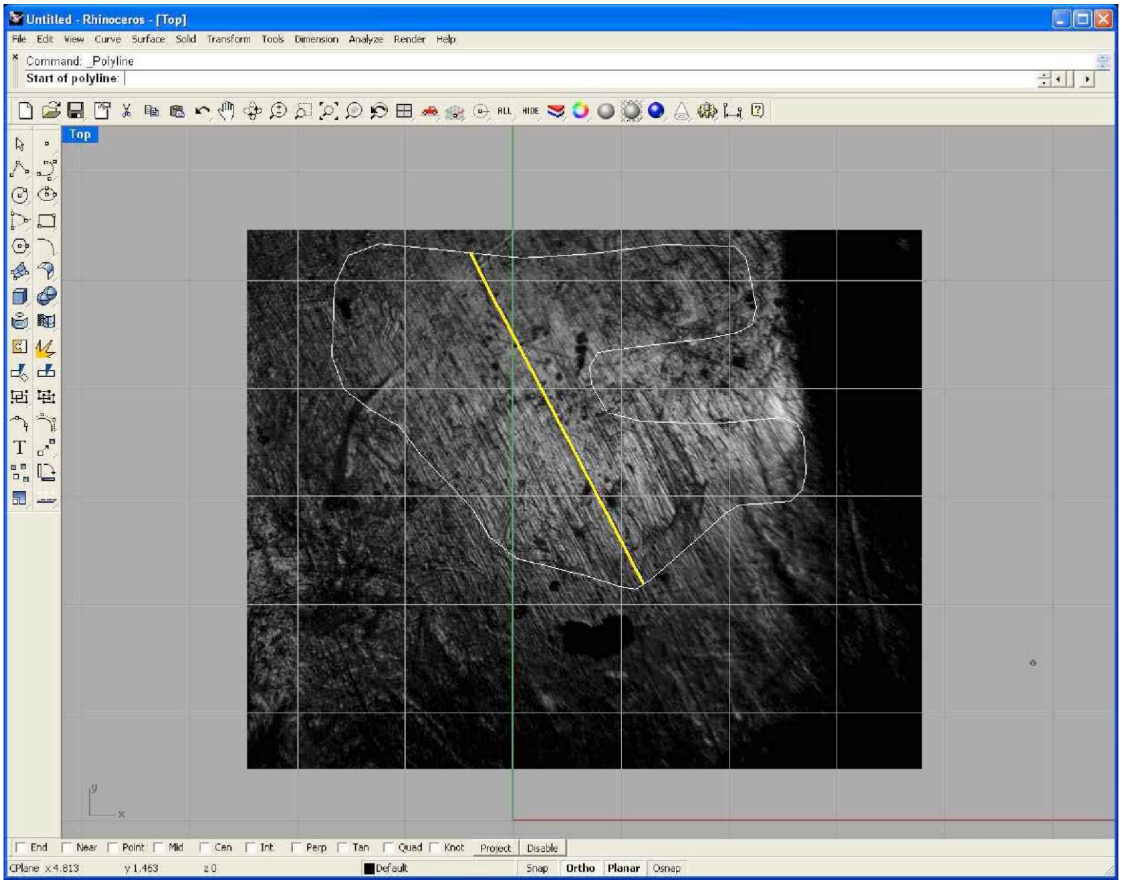


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Figure 7.8. Cusp facet on top of microwear image in Rhinoceros. The yellow line drawn across the surface exactly duplicates the microwear on that facet.

7.4 Creation of Facet Microwear Vector Signature Diagrams

The composite directionality of all facet microwear vectors (fmv's) can not be readily interpreted from simply viewing the 3-D tooth with the vectors in place on the facets. They must therefore be subjected to several modifications and re-visualized in a form which produces easily compared representations of their directionality in 3-D space. Thus, facet microwear vector signature diagrams were developed to facilitate this.

The initial length of the fmv's were all variable as they were drawn according to the breadth of the facet surface. Therefore, any facet could have multiple vectors of differing lengths crossing its surface requiring that they need be standardized for length. This was done using an algorithm specifically written for use on this project (described in detail below). The algorithm first mirrored all left teeth to the right in order to increase sample size. It then extracted the fmv 3-D positionality data from the appropriate Polyworks files, standardized the length of each fmv to 1 (an arbitrary unit useful for visualizing the vectors), translated one endpoint of the fmv's to the coordinate systems central axis (0,0,0) and exported the fmv's into a new Polyworks IMEdit file such that each fmv is now represented by an x, y, z coordinate in space (Appendix E & F). The fmv's were translated to (0,0,0) in order to meaningfully visualize the fmv's as movement into/ out of maximum intercuspation (see Fig. 7.5). The fmv's in this new file were then color coded according to which facet they originated from following Kullmer et al. (2009).

In order to give directional reference to the fmv's, a red circle with radius 5 was created in the XY plane (Fig. 7.9). Each circle's superior direction ($0/360^{o}$) corresponds to mesial position in the mouth (capital M in red) and 'right' (90^o) corresponds to buccal direction. Here Z is coming straight out of the page at the viewer and represents an occlusal view of the tooth intended to relatively match the position of the tooth as it would naturally sit in the mandible. Placing the fmv's within a circle delimited the dip direction of each fmv while also yielding a rough idea of the fmv's dip angle. As such, if the fmv is touching the bounding circle it means that the dip angle is zero or very near that. As the dip angle increases, the end of the fmv moves farther from the bounding circle as it is pointing more inferiorly or superiorly from zero inclination (Kullmer, 2009). All the fmv's on the right side of the bounding circle (blue and yellow vectors located from 0^o to 180^o) represent incursive Phase I buccal and/or lingual mandibular movements which necessarily end at centric occlusion (central axis (0,0,0). A small red sphere was placed at this location to highlight the termination of incursive movements and the beginning of excursive movements. All the fmv's on the left side of the bounding circle (green and sometimes orange vectors located from 180^o to 360^o) therefore represent excursive Phase II mandibular movements. The right diagram is simply the left diagram tilted mesially 90^o into the ZX plane so that now -Y is coming straight out of the page directly at the viewer. A red circle of radius 2.5 was created in the ZX plane to aid in demonstrating dip angle. The arrow at the tip of each fmv is an artifact of the vector creation process and should not be construed as indicative of movement or directionality.

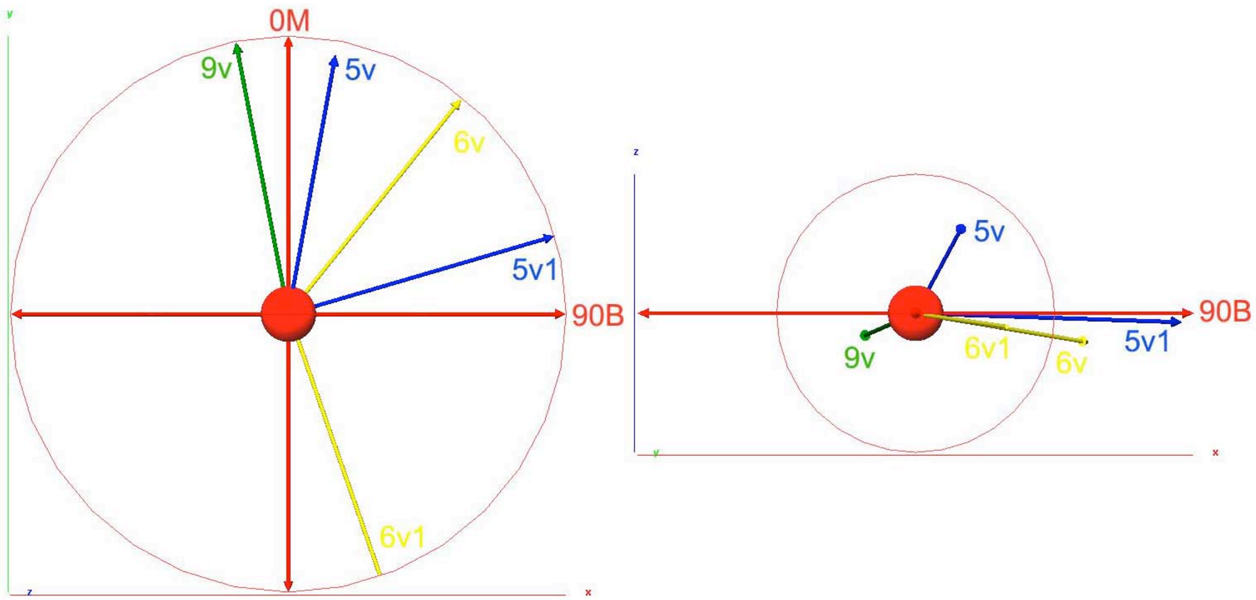


Figure 7.9. Facet microwear vector signature diagram of S7b-43: llm1 (Sangiran)

7.5 Facet Microwear Vector Analysis Algorithm

In order to quickly and efficiently compare directionality of fmv's, an algorithm was written in C++ programming language (Appendix G) which automates the processes described below. The facet microwear vectors are represented in IMInspect with two-point polylines (straight lines with 2 end points) which contain data on the fmv's dip and dip direction (Kullmer et al., 2009). Essentially, the algorithm extracts this data and compares each tooth's individual fmv's dip and dip direction to all other teeth with the same row number (1st, 2nd or 3rd molar) and wear stage (stages 1 through 5) to establish overall similarity of facet microwear direction between each tooth's homologous facets (Gordon, 1982, 1984,1988; Bullington, 1991; Bunn & Ungar, 2009). Left teeth are reflected to the right in order to increase sampling ability. A weighted number is then assigned to each 'match' and these numbers can be statistically compared.

7.5.1 Description of fmv Analysis Algorithm

To illustrate the analysis algorithm, a pair of hypothetical teeth (T1 and T2) will be used. Initially, all of a tooth's microwear polylines are extracted and exported into the algorithm as text files resulting in:

T1:
Facet 6 V(1)
-9.138148, 0.255849, 5.800442
-8.204950, 1.766495, 5.454597
Facet 3 V(1)
8.985074, 1.850269, 5.998956
8.154467, 1.760739, 5.458500

T2:
Facet 4 V(1)
-9.392605, 4.705084, 3.513849
-8.384149, 4.431296, 3.176092
Facet 3 V(1)
-8.912851, 1.593785, 4.153487
-10.055149, 1.855509, 4.692036
Facet 3 V(2)
-7.342283, 1.24433, 5.251234
-9.223142, 1.25534, 5.779374
Facet 3 V(2)
-6.57745, .988673, 4.99234
-8.85532, 1.16718, 5.84563

This shows that tooth T1 has two facets (6 and 3) each with one microwear vector per facet. Tooth T2 has two facets where facet 4 has one microwear vector and facet 3 has three microwear vectors. Each vector is defined by the X, Y, Z coordinates of its two polyline endpoints. Because the algorithm examines only a microwear vectors directionality and not spatial location, the data is simplified by translating the polylines to the central axis of the coordinate system so that one endpoint of each polyline resides at (0,0,0) and the other endpoint at $(X_1 - X_2, Y_1 - Y_2, Z_1 - Z_2)$ where the subscripts 1 and 2 represent the upper and lower data points for each facet vectors polyline. For example, T1 Facet 6 V(1) would yield:

$$V = (X_1 - X_2, Y_1 - Y_2, Z_1 - Z_2)$$
$$V = (-9.138148 - (-8.204950), 0.255849 - 1.766495, 5.800442 - 5.454597)$$
$$V = (-.933198, -1.510646, .345845)$$

The data points are additionally homogenized via normalization so that all vector lengths are fixed at 1. Using the same tooth and facet as above:

$$|V| = \sqrt{.933198^2 + 1.510646^2 + .345845^2}$$
$$|V| = 1.809$$
$$v/|v| = (-.516, -.835, .191)$$

Thus, for our pair of hypothetical teeth, we have the following:

T1:
Facet 6 V(1)
(-.516, -.835, .191)
Facet 3 V(1)
(.880, .093, .519)

T2:
Facet 4 V(1)
(-.837, .220, .276)
Facet 3 V(1)
(.673, -.175, -.315)
Facet 3 V(2)
(.962, -.006, -.270)
Facet 3 V(3)
(.753, .016, .601)

A comparison of two teeth begins with the identification of appropriate comparison pairs based on the criteria previously noted (tooth row and wear stage). For our hypothetical pair, T1 is a *Homo sapiens* upper left 2nd molar at wear stage 3 while T2 is a *Homo erectus* upper right 2nd molar at wear stage 3 as well. The next step is to identify common facets between teeth. T1 and T2 only have a single facet in common (Facet 3) therefore only a single facet comparison can occur. Non-matching facets and thus their microwear vectors are excluded from further analysis. The comparison of two facets essentially is a comparison of every fmv from the first tooth's facet with every fmv on the second tooth's facet. Here, three fmv comparisons can occur:

T1-Facet 3 V(1) with T2-Facet 3 V(1)
T1-Facet 3 V(1) with T2-Facet 3 V(2)
T1-Facet 3 V(1) with T2-Facet 3 V(3)

An fmv comparison generates two values. The first is the angular separation between the two directions represented by the fmv's. Because fmv's represent linear motion with no information regarding positive or negative direction, the fmv's are treated as intersecting lines and the smallest of the resulting angles is recorded. In order to obtain the smallest of the angles between the two 'intersecting' vectors, it is observed that the four angles made by any two intersecting lines add up to 360°. Furthermore, the angles form two pairs of equal angles. Therefore, if a single angle 'A' is calculated, the formula for the other angle 'B' is given by:

$$B= 180- A$$

The equation for the angle between two vectors is derived from the dot product:

$$A \circ B= A_X B_X + A_Y B_Y + A_Z B_Z$$
$$A \circ B=|A|\,|B|\cos(\theta)$$

Because in our case all vectors are normalized, $|A|\,|B|=1$. Thus:

$$\theta= \cos^{-1}(A_X B_X + A_Y B_Y + A_Z B_Z)$$

Yielding the first angle between T1-Facet 3 V(1) and T2-Facet 3 V(1)

$$\theta= \cos^{-1}(.880(.673) + .093(-.175) +.519(-.315)$$
$$\theta= \cos^{-1}(.592 -.016 -.163)$$
$$\theta= \cos^{-1}(.413)$$
$$\theta=65.64^{\circ}$$

Using the formula above,

$$B= 180- 65.64$$
$$B=114.36$$

65.64° is therefore recorded as the angle of separation between the two vectors (A) as it is the smaller of the two angles.

The second quantity returned by a vector comparison is the weight (described below) given by the function:

$$\begin{array}{cc} 1 & \text{if angle} \leq 10.0^{\circ} \\ -5.73(R) + 2.0 & \text{if angle is between } 10^{\circ} \text{ \& } 20.0^{\circ} \\ 0.00001 & \text{if angle} \geq 20.0^{\circ} \end{array}$$

Where R is the smaller angular separation ('A' calculated above) converted to radians (A x .0175). So, for the three vector comparisons, we obtain the following weighted values:

T1-Facet 3 V(1) with T2-Facet 3 V(2): $(9.16^{\circ})(1)= 9.16$
T1-Facet 3 V(1) with T2-Facet 3 V(3): $-5.73\ (13.11^{\circ}\text{x}.0175)+2.0= .685$
T1-Facet 3 V(1) with T2-Facet 3 V(1): $(65.64^{\circ})(.00001)= .00066$

The sum of the weighted values are then added and divided by the sum of the weights themselves $(1+(13.11^{o}x.0175)+.00001=1.23)$ to obtain the similarity value for the facet.

So: $$9.16+.685+.00066= 9.846$$

$$9.833/ 1.23= 8.005$$

Where multiple facets for comparison exist this process would be repeated for each facet comparison. The similarity values for each facet are then added and divided by the total number of facets compared to obtain the overall match average termed the 'Match Value'. As the Match Value increases, similarity between teeth decreases.

7.5.2 Weighing Function

To accurately characterize fmv similarity between two facets (and therefore between teeth), categories must be established to define what constitutes correspondence of angular separation. When visually comparing the fmv signatures between two teeth, it is possible to identify which teeth appear similar and, as such, dissimilar. The weighting function attempts to mathematically quantify this admittedly subjective appraisal. So, from an extensive visual appraisal of the fmv signatures, it was determined that if a pair of vectors was separated by 10.0^{o} or less, they matched very well in dip and dip direction and would be assigned a weight of 1. Angular separation between 10^{o} and 20.0^{o} receives a weight which falls off linearly as the separation increases. This linear correcting was necessary as differences in the 3-dimensional angular separation of dip and dip direction begin to become more pronounced as the angle approaches 20.0^{o}. Any vector comparisons with an angular separation larger than 20.0^{o} are considered poor matches and receive a low weight.

7.6 Statistical Analysis

As this is a completely new method for understanding the complexity of molar microwear/ diet interactions, the novel data could have been statistically considered in many ways. At this early stage of inquiry, it was deemed more logical to begin with the simplest forms of analysis in order to gain a basic understanding of the data initially being generated and the most meaningful ways of interpreting that data. This as opposed to looking at the various types of data that *could* be extracted with any number of concomitant methods for interpreting that data when the methodology itself was just beginning to be understood. As such, explanations of the somewhat basic analytical methods are described within the results section as it was more expedient to the descriptive flow and interpretive exercise.

As stated above, it is believed that this method will eventually yield more robust interpretations of masticatory movement/ microwear with regards to diet which will necessitate more complex forms of statistical analysis. The small sample size of the *H. erectus* specimens precluded more in depth, multivariate analysis of inter- and intra-sample variation. Boot-strapping may provide a 'fix' to this issue but increasing the hominin sample size would yield results that are more conducive to multivariate analyses such as ANOVA/ MANOVA. Statistical analyses of inter- and intraspecific fmv *directional* movement (incursive 3D angle -vs- excursive 3D angle) as seen in and based upon the fmv diagrams should be possible. Also, several researchers (Teaford & Walker, 1984; Semprebon et al., 2004) have used homologous facet microwear from both upper and lower molars (but the same molar in the tooth row) to increase sampling ability as the mandibular tooth produces wear in the same direction on the maxillary as it does upon itself. Using the new method described here, the correct angular transformations respective of the topographic 'male/female' mating of occlusal facets could be undertaken thus increasing sample size. This may also lead to the feasibility of using a singular molar to predict the microwear upon a corresponding absent molar.

Chapter 8

Results

8.1 Introduction

The results of the facet microwear vector matches as obtained from the vector analysis algorithm are presented (Table 8.1). Generally, four different categories of comparisons were made using this data. The first comparison presented is that between the Sangiran 7 (S7) *Homo erectus* subpopulation and the several different historic hunter/ gatherer *Homo sapiens* samples. This was done to investigate the amount of similarity between the two samples fmv signatures and, as such, their diets. This initial comparisons are then broken down by S7 sub-sample (Bapang and Sangiran) and again compared to the *H. sapiens* specimens. This in order to exam whether the two *H. erectus* sub-sets individually differ in fmv similarity to the *H. sapiens*. Any differences between samples might indicate changing dietary preference based on environmental shifts or population turnover due to altered migratory patterns. Several of the *H. erectus* specimens did not match with any other specimens (either *H. erectus* or H. *sapiens)* and reasons are given as to why.

The second set of match comparisons were made intra- *H. erectus* to establish any similarity of fmv within or between the S7 subsets. The third set is derived from the uncertain designation of several of the *H. erectus* specimens to Pongo by Grine in Grine and Franzen (1994). The S7 purported Pongo to *H. sapiens* match values were used to determine if and how similar any of the 'Pongo' were to the *H. sapiens*. The fourth fmv match comparison is derived from the uncertainty as to whether some of the S7 specimens are first or second molars which was also noted by Grine and Franzen (1994). The teeth in question were compared initially to all other (*H. erectus* and *H. sapiens*) first molars and then to all other second molars. The lowest resultant match then indicated whether the tooth was more likely a first or second molar.

8.2 *Homo erectus* to *Homo sapiens* Matches

The results of the *H. erectus* to *H. sapiens* fmv matches are presented in Table 8.1. These match values are mated with select fmv signature diagrams in Plates 1 through 28. These plates visually demonstrate most but not all of the significant matches as it was felt that select examples were sufficient to demonstrate the method and fmv similarities. The top fmv signature diagram is always the *H. erectus* specimen and it is identified as either coming from the Bapang Formation (S7b) or the Sangiran Formation (S7a). The lower diagram is always the *H. sapiens* specimen and its population affinity is given. For both, after the specimen number the tooth disposition is given (eg. llm1= lower left 1st molar). The match value and wear stage for the tooth pair are displayed. Below the diagram set an explanation of the visual fmv similarity is given.

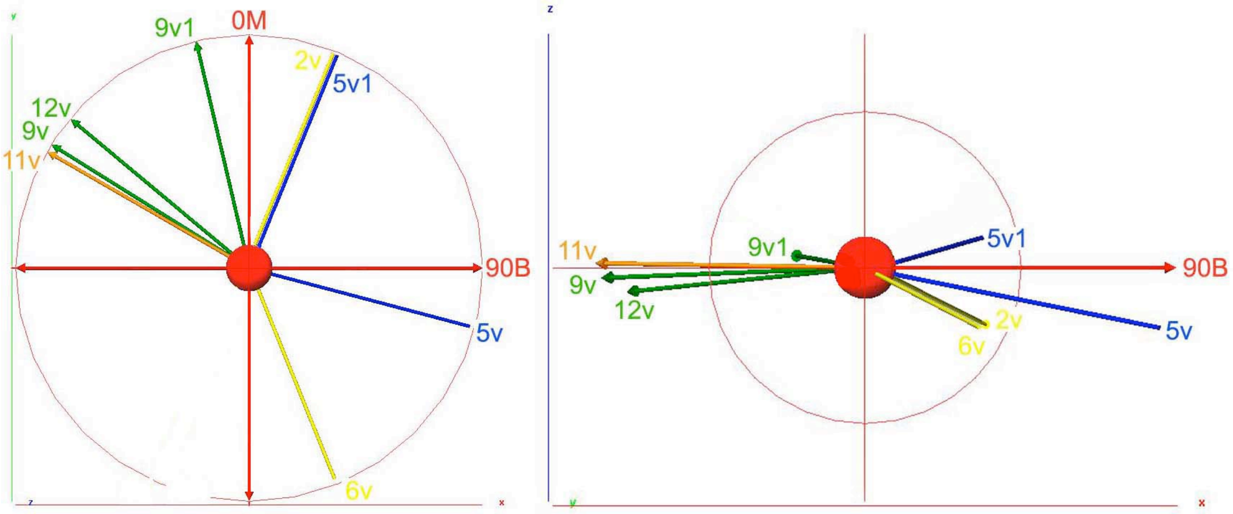
Table 8.1. All Facet Microwear Vector Match Values

Specimens	Value
3b and NHMW6035-urm1	5.4
3b and NHMW8687-urm1	9.63
3b and S5-ulm1	10.97
3b and NHMW811-ulm1	13.1
3b and FC848-urm1	13.59
3b and S5-urm1	13.9
3b and NHMW6035-ulm1	16.91
3b and FC848-ulm1	17.9
3b and 40	20.35
3b and S9-urm1	23.48
3b and FC833-3-urm1	24.1
3b and 38	47.33
3b and FC833-3-ulm1	55.84
3b and 14	67.2
3b and NHMW811-urm1	67.96
3c and 89	8.71
3c and FC848-ulm2	13.83
3c and S9-urm2	14.05
3c and NHMW8687-ulm2	14.38
3c and NHMW811-ulm2	21.29
3c and FC833-3-urm2	24
3c and S5-ulm2	27.76
3c and NHMW811-urm2	29.08
3c and FC848-urm2	31.01
3c and NHMW8687-urm2	34.71
3c and S5-urm2	62.26
3d and NHMW8687-urm3	14.68
3d and FC848-urm3	24.99
3d and FC848-ulm3	35.88
6 and S5-urm3	16.36
6 and NHMW811-urm3	41.88
6 and S5-ulm3	56.43
6 and NHMW811-ulm3	56.85
6 and NHMW6035-ulm3	57.93
6 and NHMW6035-urm3	62.9
6 and NHMW8687-ulm3	66.29
10 and S16-urm1	17.87
10 and 37	34.55
14 and NHMW6035-urm1	9.18
14 and S5-urm1	30.02
14 and FC833-3-ulm1	39.78
14 and FC848-ulm1	41.96
14 and FC848-urm1	42.9
14 and NHMW811-urm1	44.09
14 and NHMW6035-ulm2	45.89
14 and 38	46.72
14 and NHMW8687-ulm1	47.55
14 and NHMW6035-ulm1	48.84
14 and NHMW811-ulm1	52.13
14 and NHMW6035-urm2	53.2
14 and NHMW8687-urm1	54.61
14 and S9-urm1	54.68
14 and 40	55.14
14 and FC833-3-urm1	57.98
14 and S5-ulm1	64.8
20 and 62	23.38
20 and S16-lrm2	25.38
20 and FC848-lrm2	27.32
20 and FC848-llm2	29.46
20 and S5-lrm2	31.99
20 and 76	38.29
20 and S16-llm2	64.17
37 and S16-urm1	9.78
38 and FC848-urm1	12.12
38 and FC848-ulm1	12.93
38 and FC833-3-urm1	15.85
38 and NHMW6035-ulm1	17.94
38 and S5-ulm1	29.32
38 and 40	29.91
38 and NHMW6035-urm1	30.04
38 and NHMW811-urm1	30.94
38 and FC833-3-ulm1	31.33
38 and NHMW811-ulm1	33.93
38 and NHMW8687-ulm1	39.53
38 and NHMW8687-urm1	42.1
38 and S5-urm1	43.05
38 and S9-urm1	46.19
40 and FC848-urm1	6.91
40 and NHMW6035-urm1	7.76
40 and S5-urm1	9.82
40 and S5-ulm1	11.33
40 and FC833-3-urm1	15.12
40 and NHMW8687-ulm1	15.43
40 and FC833-3-ulm1	16.92
40 and FC848-ulm1	20.91
40 and NHMW8687-urm1	22.24
40 and NHMW811-ulm1	24.96
40 and NHMW6035-ulm1	25.42
40 and NHMW811-urm1	28.76
40 and S9-urm1	28.91
42 and S16-llm1	14.65
42 and FC848-llm1	32.85
42 and S16-lrm1	36.13
42 and FC848-lrm1	40.92
42 and S5-lrm1	50.14
43 and S5-lrm1	4.93
43 and FC848-lrm1	13.97
43 and S16-lrm1	20.16
43 and S16-llm1	25.13
43 and 61	36.96
43 and FC848-llm1	37.39
43 and 42	38.32
53 and S16-urm2	54.43
61 and FC848-lrm1	24.15
61 and S5-lrm1	25.66
61 and S16-lrm1	29.73
61 and FC848-llm1	39.39
61 and S16-llm1	47.98
61 and 42	55
62 and FC848-llm2	16.55
62 and FC848-lrm2	18.71
62 and S16-lrm2	23.55
62 and S5-lrm2	32.04
62 and 76	36.21
62 and S16-llm2	69.93
78 and FC833-3-llm1	13.92
78 and S5-llm1	15.78
78 and 84	17.7
78 and NHMW6035-lrm2	26.39
78 and FC833-3-lrm1	32.73
78 and NHMW6035-lrm1	47.18
84 and NHMW6035-lrm2	22.02
89 and S9-urm2	8.87
89 and NHMW8687-urm2	10.65
89 and FC848-ulm2	12.24
89 and NHMW8687-ulm2	14.15
89 and FC833-3-urm2	14.67
89 and NHMW811-ulm2	15.38
89 and S5-urm2	15.82
89 and NHMW811-urm2	27.06
89 and S5-ulm2	28.98
89 and FC848-urm2	33.66

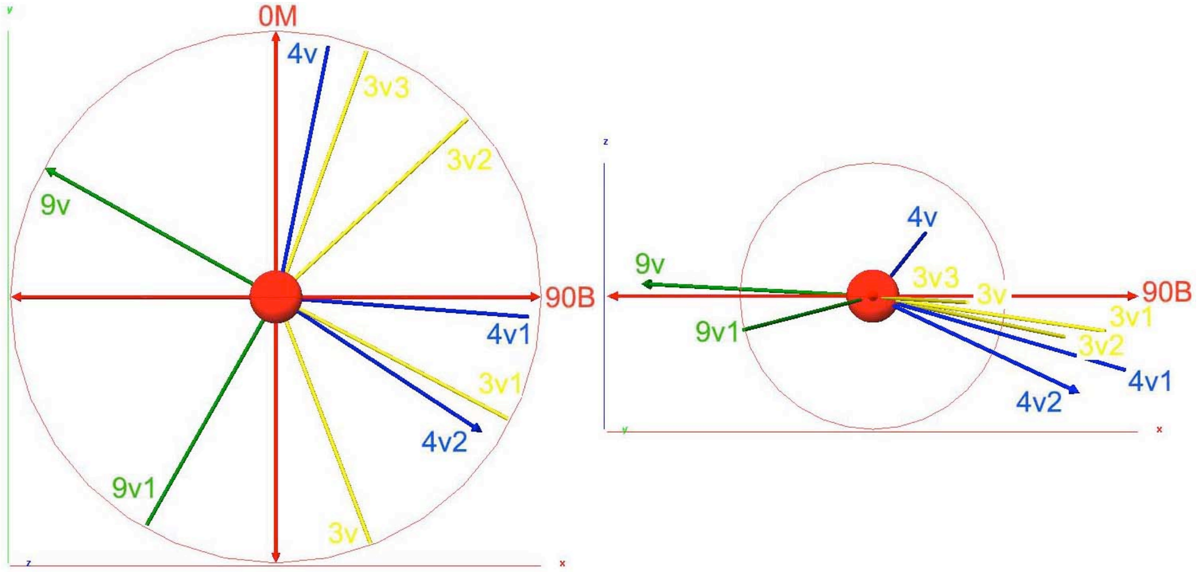
Note*- yellow highlights indicate matches at the 2nd molar where tooth position uncertainty existed

- *H. erectus* specimen numbers are left, *H. sapiens* are right in the 'Specimen' column

Plate 1



S7b-3b: urm1 (Bapang)

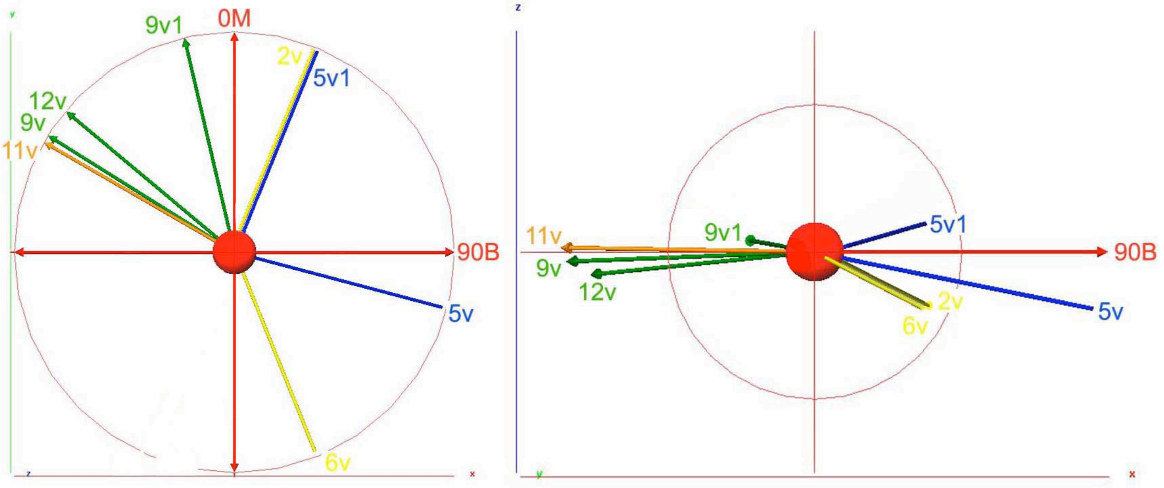


NHMW6035: urm1 (Fuegian)

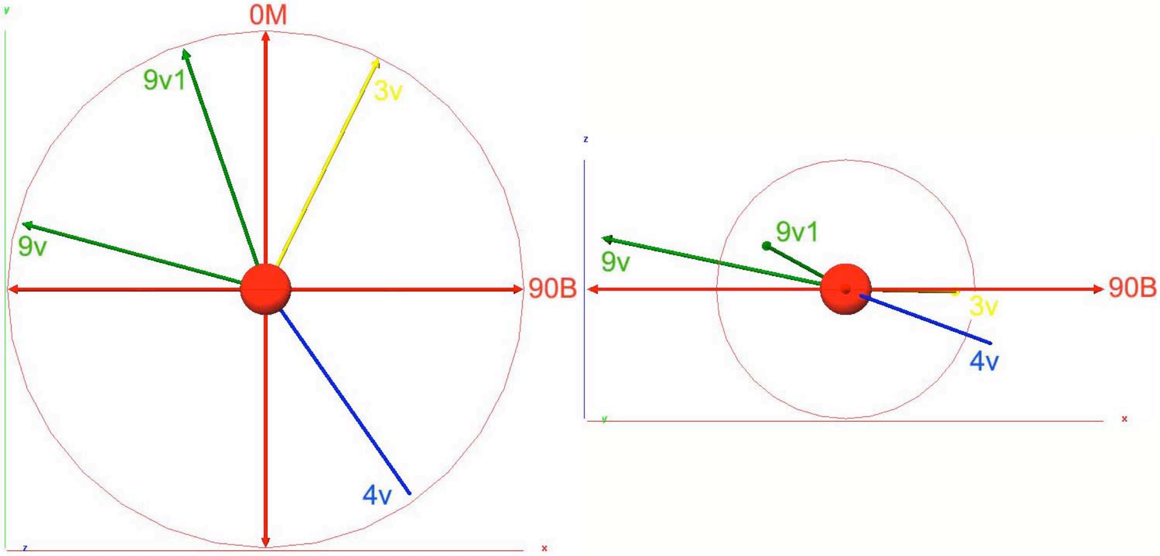
Match Value= 5.40; Wear Stage= 4

High correlation is seen between specimens for fmv 9v. Facets 3 and 4 yielded no vectors in specimen 3b and so vectors from facets 2, 5 & 6 were substituted. This does not influence the match value but is instructive of overall mandibular movement as seen in the similarity of dip and dip direction between 3b fmv's 6v & 5v and FC848 3v and 4v1 respectively.

Plate 2



S7b-3b: urm1 (Bapang)

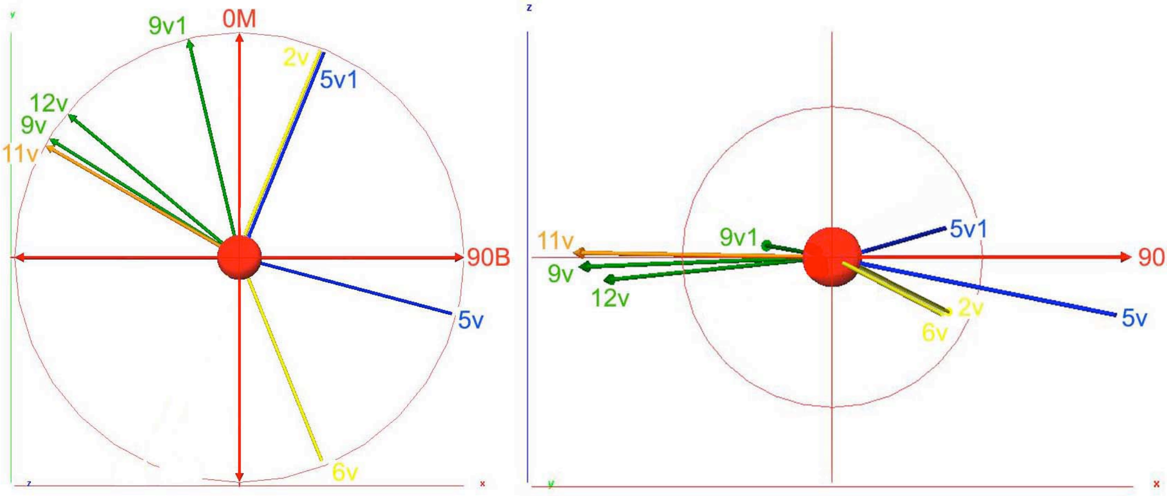


NHMW8687: urm1 (Aust. Abor.)

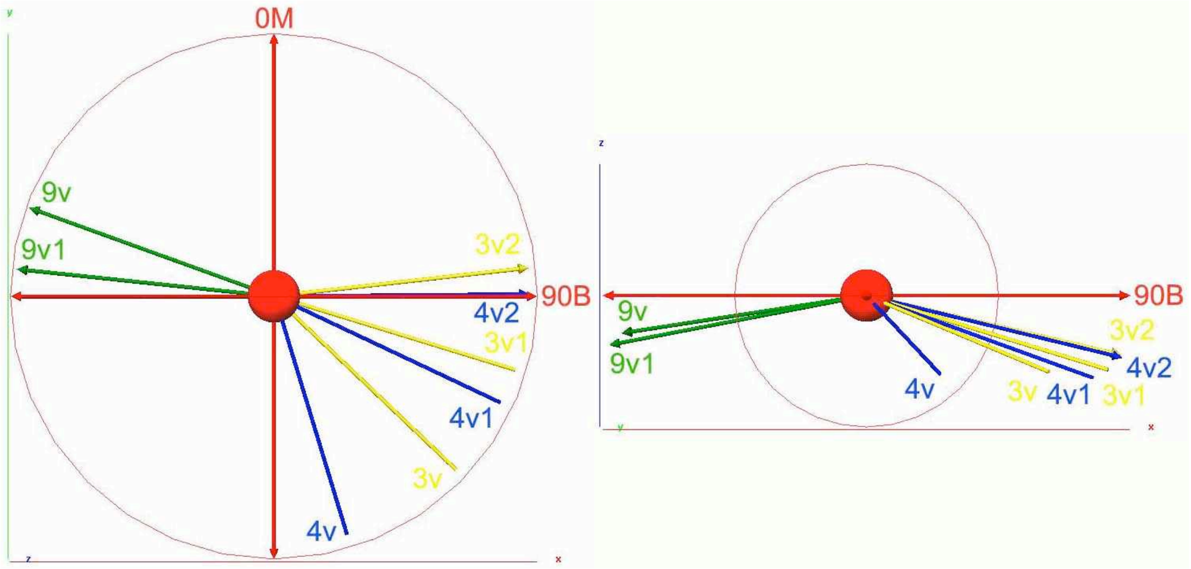
Match Value= 9.63; Wear Stage= 4

High correlation is seen between specimens for fmv's 9v & 9v1. Facets 3 and 4 yielded no vectors in specimen 3b and so vectors from facets 2, 5 & 6 were substituted. This does not influence the match value but is instructive of overall mandibular movement as seen in the similarity of dip and dip direction between 3b fmv's 2v & 6v and FC848 3v & 4v respectively.

Plate 3



S7b-3b: urm1 (Bapang)

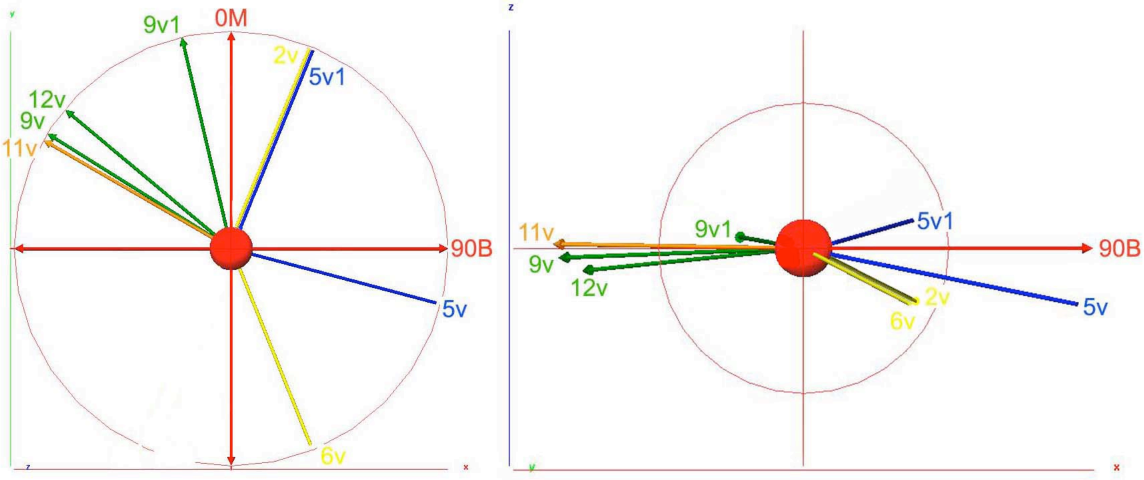


FC848: urm1 (PNWT)

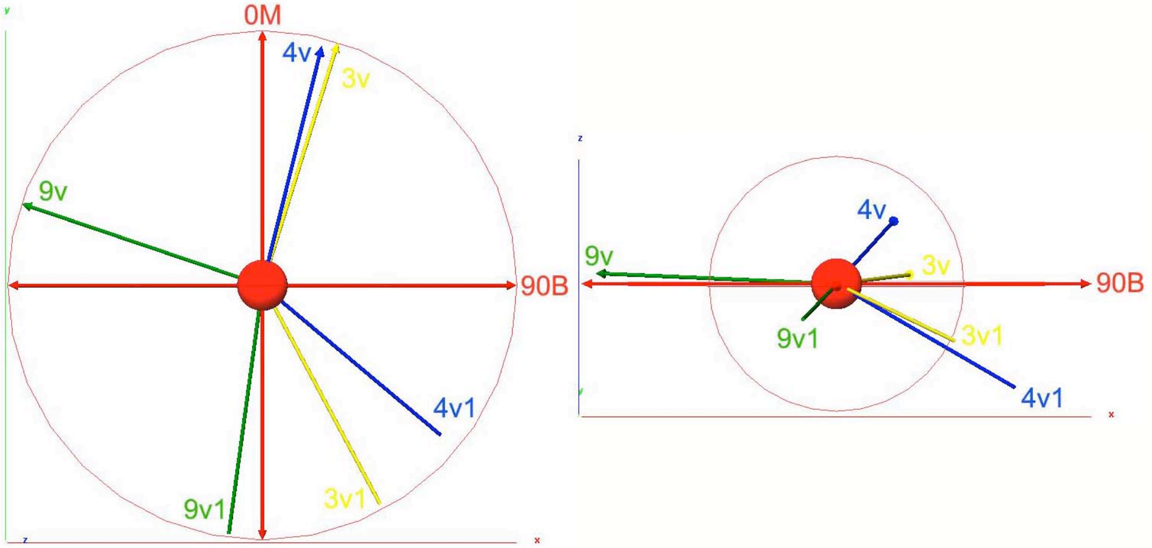
Match Value= 13.59; Wear Stage= 4

Moderate correlation is seen between specimens for fmv 9v. Facets 3 and 4 yielded no vectors in specimen 3b and so vectors from facets 2, 5 & 6 were substituted. This does not influence the match value but is still instructive of mandibular movement as seen in the similarity of dip and dip direction between 3b fmv's 5v & 6v and FC848 4v1 and 4v respectively.

Plate 4



S7b-3b: urm1 (Bapang)

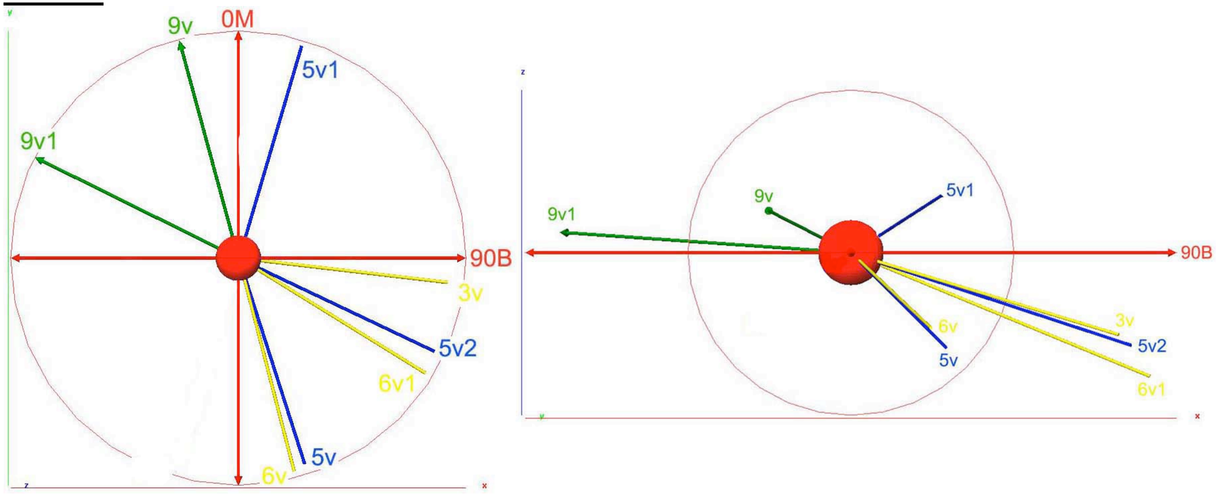


S5: urm1 (Bushmen)

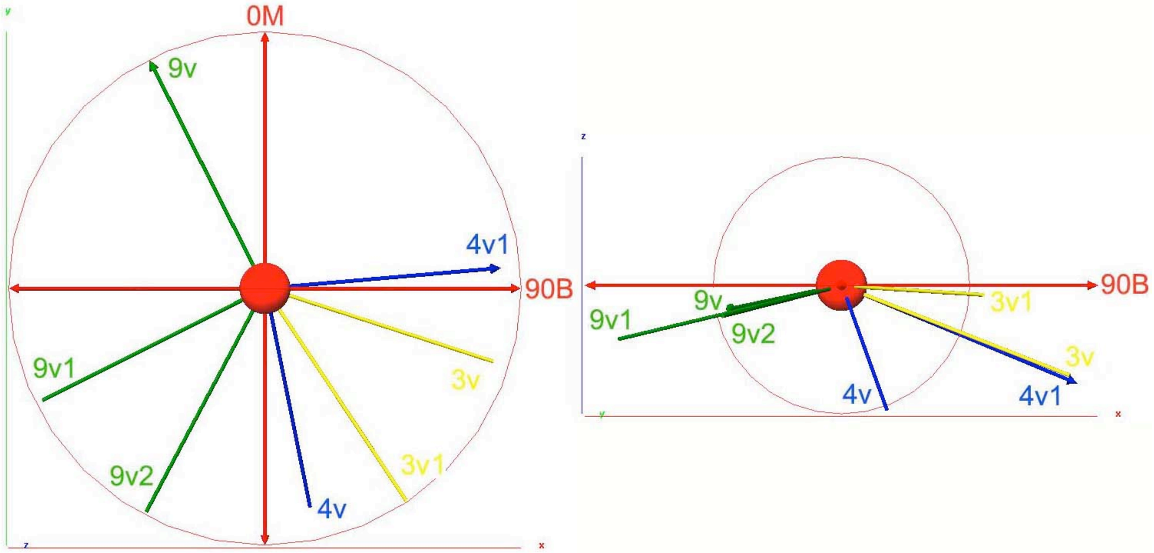
Match Value= 13.90; Wear Stage= 4

Moderate correlation is seen between specimens for fmv 9v. Facets 3 and 4 yielded no vectors in specimen 3b and so vectors from facets 2, 5 & 6 were substituted. This does not influence the match value but is still instructive of mandibular movement as seen in the similarity of dip and dip direction between 3b 5v1, 5v & 6v and S5 4v, 4v1 & 3v1 respectively.

Plate 5



S7b-3c: urm2 (Bapang)

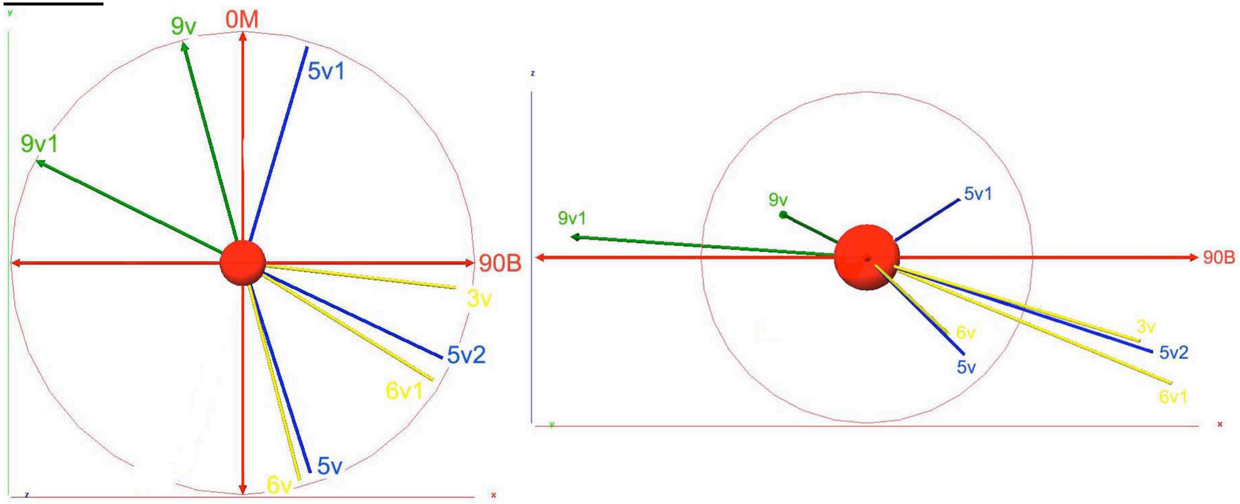


S9: urm2 (Bushmen)

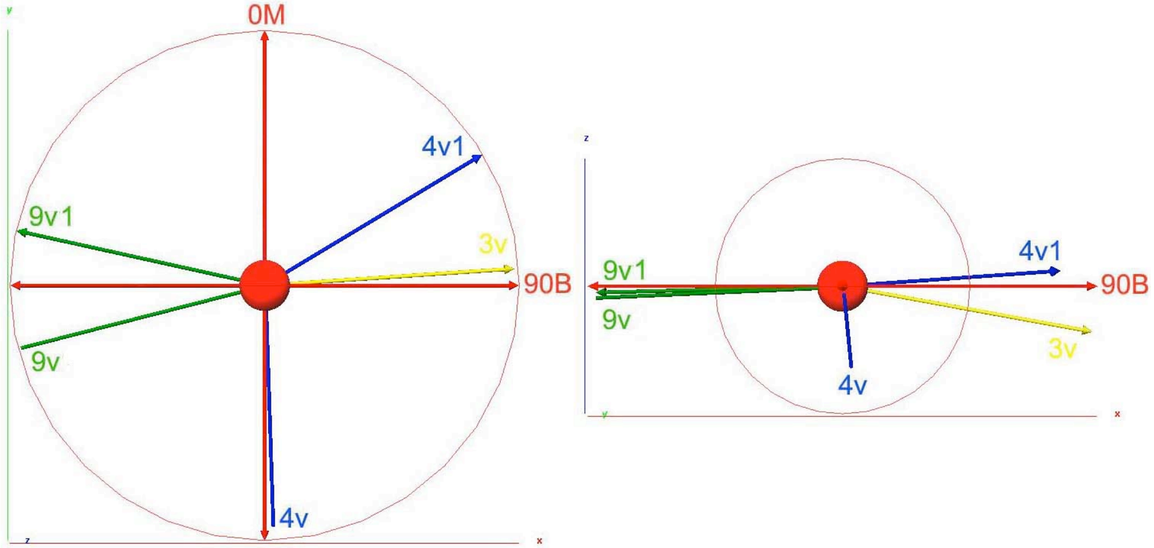
Match value= 14.05; Wear Stage= 3

Moderate correlation is seen between specimens for fmv 3v. Facet 4 yielded no vectors in specimen 3b and so vectors from facets 5 & 6 were substituted. This does not affect the match value but is still instructive of mandibular movement as is seen in the high similarity of dip and dip direction between 3c fmv 5v and S9 4v and also for most of the remaining Phase I fmv's.

Plate 6



S7b-3c: urm2 (Bapang)

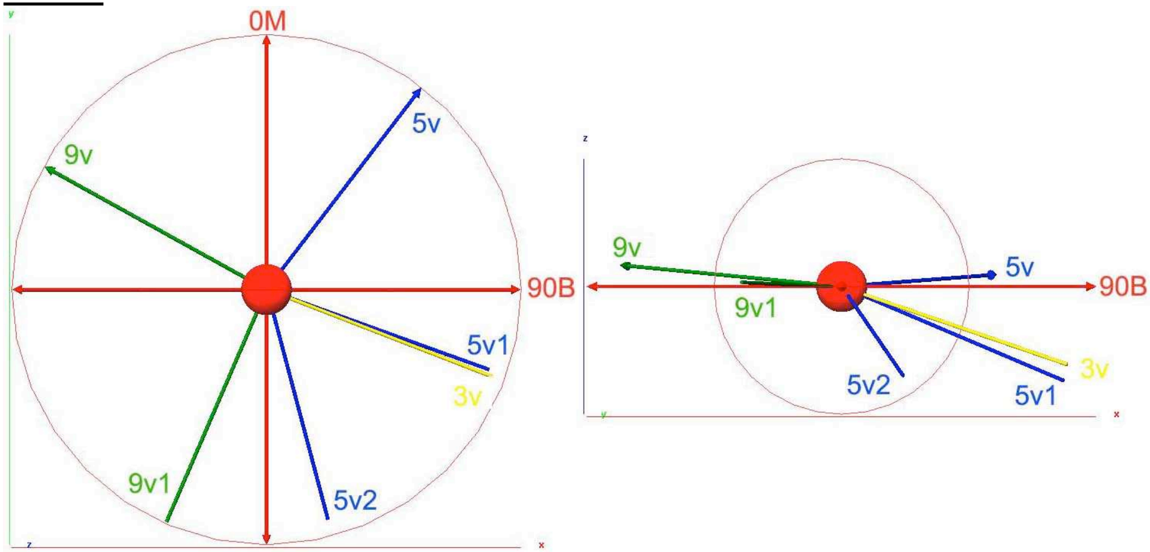


NHMW8687: ulm2 (Aust. Abor.)

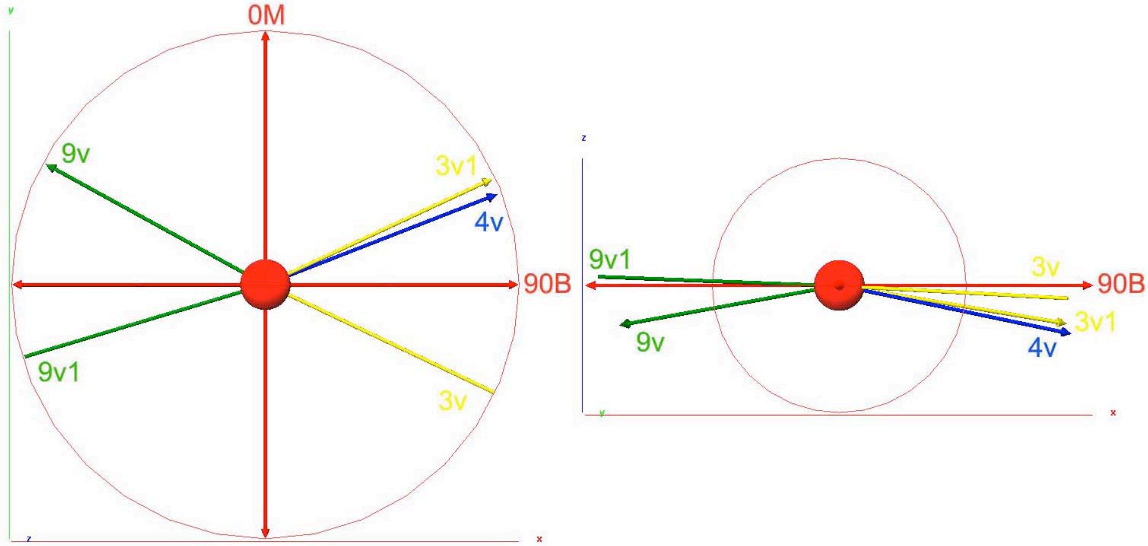
Match Value= 14.38; Wear Stage= 3

Moderate correlation is seen between specimens for fmv's 9v1 & 3v. Facet 4 yielded no vectors in specimen 3c and so vectors from facets 5 & 6 were substituted. This does not affect the match value but is still instructive of mandibular movement as seen in the similarity of dip and dip direction between 3c fmv 5v and NHMW8687 4v.

Plate 7



S7b-3d: urm3 (Bapang)

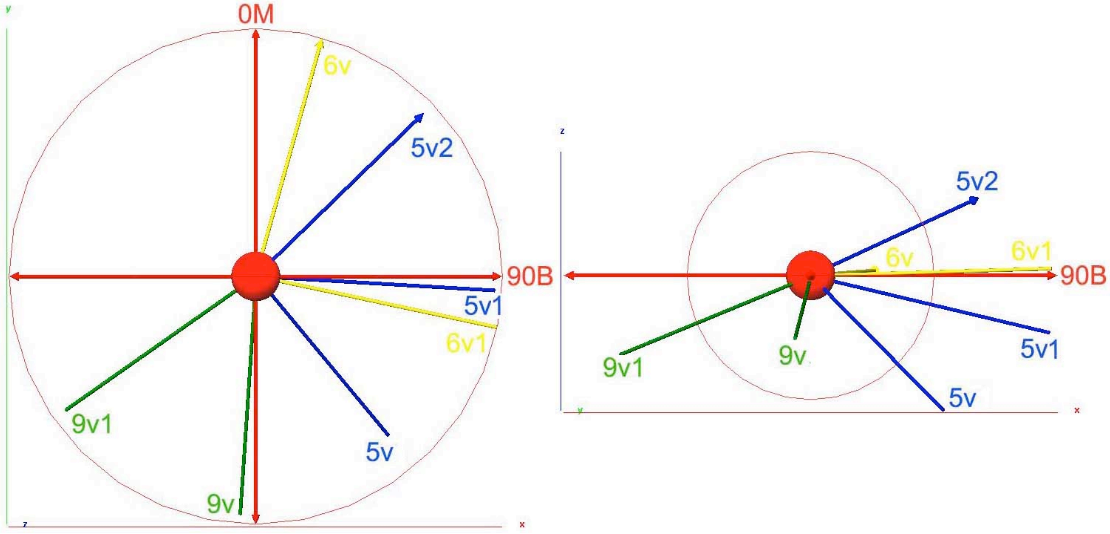


NHMW8687: urm3 (Aust. Abor.)

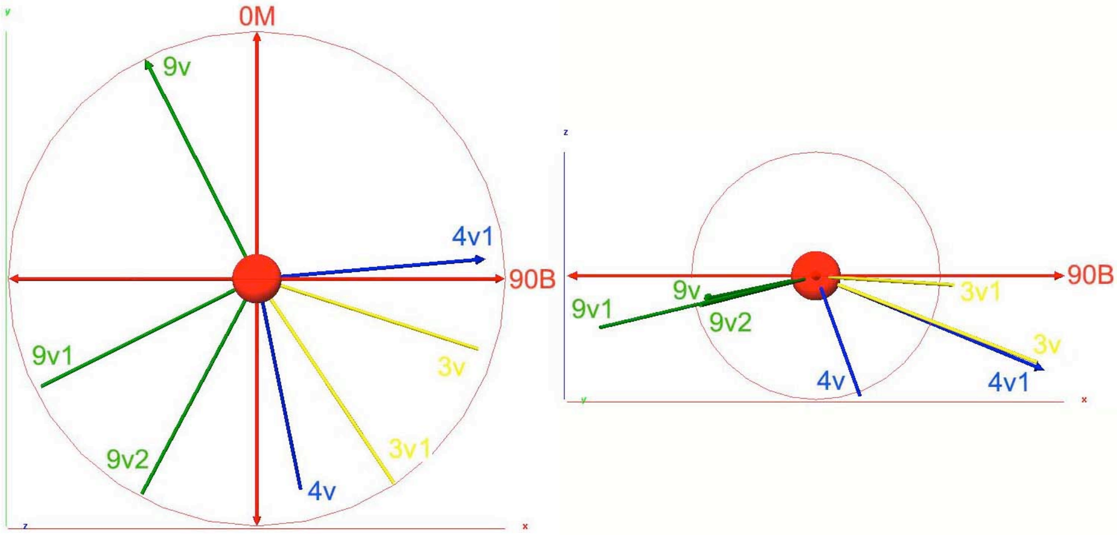
Match Value= 14.68; Wear Stage= 2

Moderate correlation is seen between specimens for fmv's 9v and 3v. Facet 4 yielded no vectors in specimen 3d and so vectors from facet 5 were substituted. This does not affect the match value but is still instructive of mandibular movement.

Plate 8



S7b-6: ulm3 (Bapang)

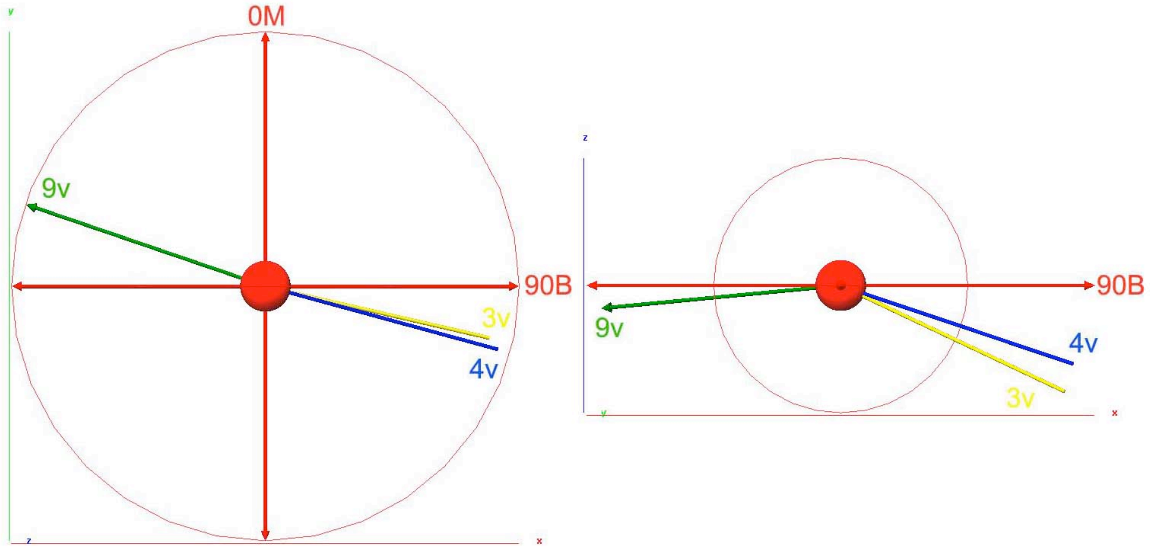


S5: urm3 (Bushmen)

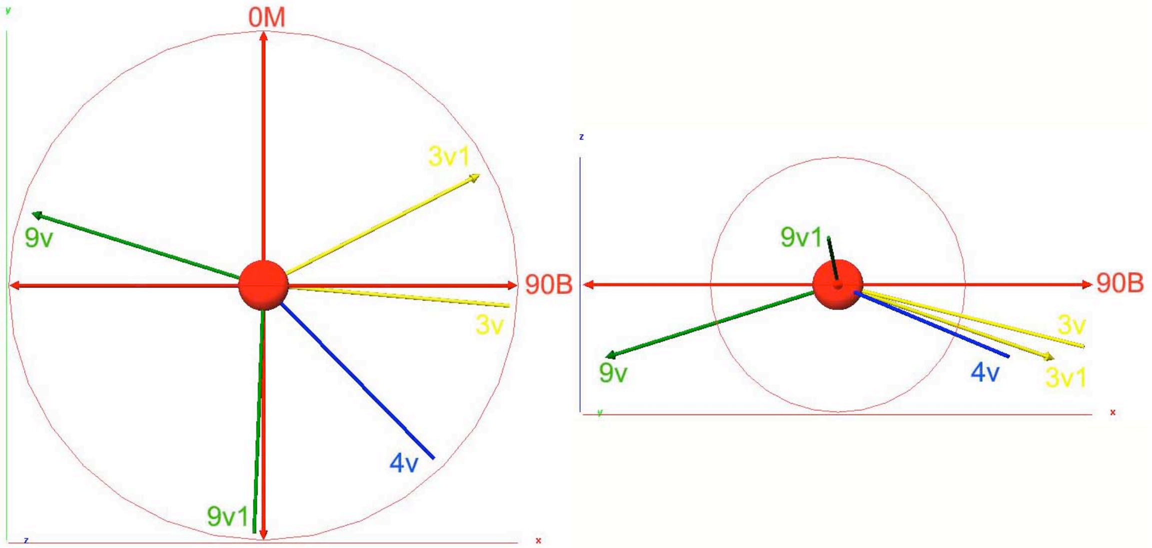
Match Value= 16.36; Wear Stage= 3

Moderate correlation is seen between specimens for fmv 9v1. Facets 3 and 4 yielded no vectors in specimen 3b and so vectors from facets 5 & 6 were substituted. This does not affect the match value but is still instructive of mandibular movement as seen in the similarity of dip and dip direction between 3b fmv's 6v1, 5v & 5v1 and S5 3v, 4v & 4v1 respectively.

Plate 9



S7b-10: urm1 (Bapang)

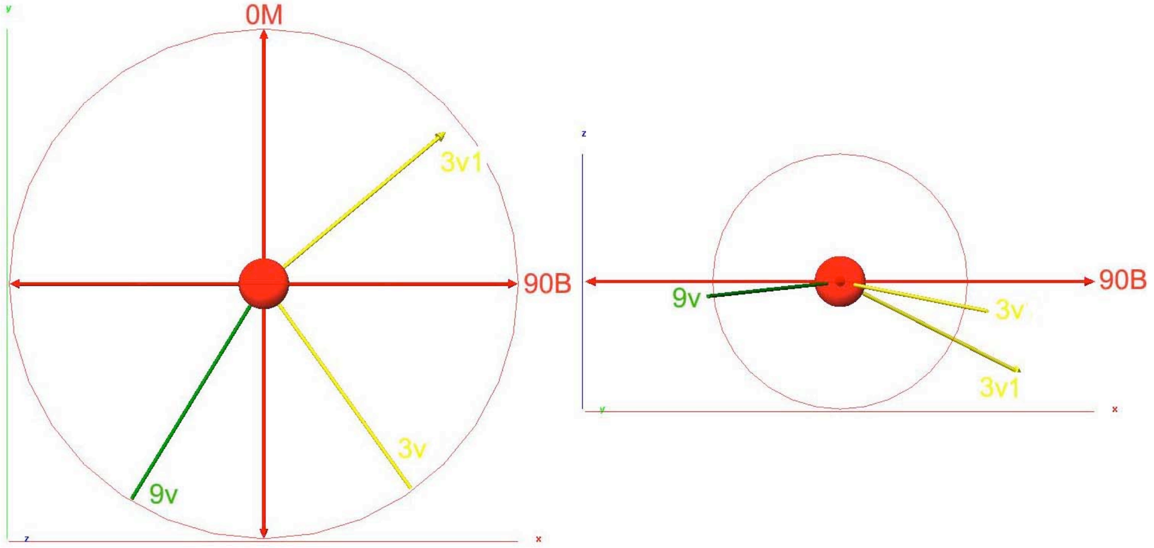


S16: urm1 (Bushmen)

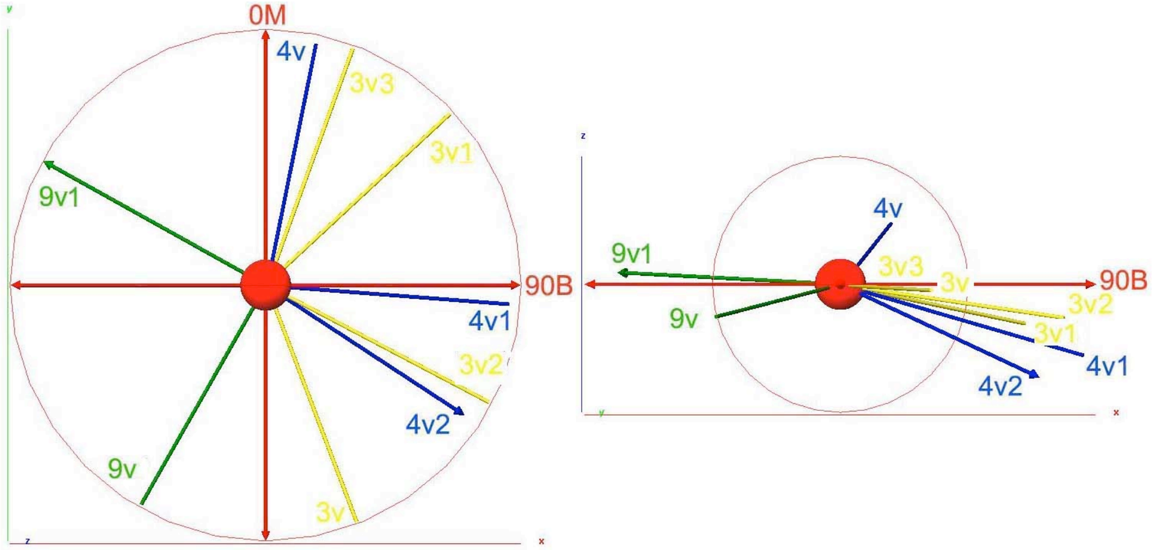
Match Value= 17.87; Wear Stage= 3

Moderate correlation is seen between specimens for fmv's 9v and 3v. There is also some similarity of dip and dip direction between both at fmv 4v.

Plate 10



S7b-14: urm1 (Bapang)

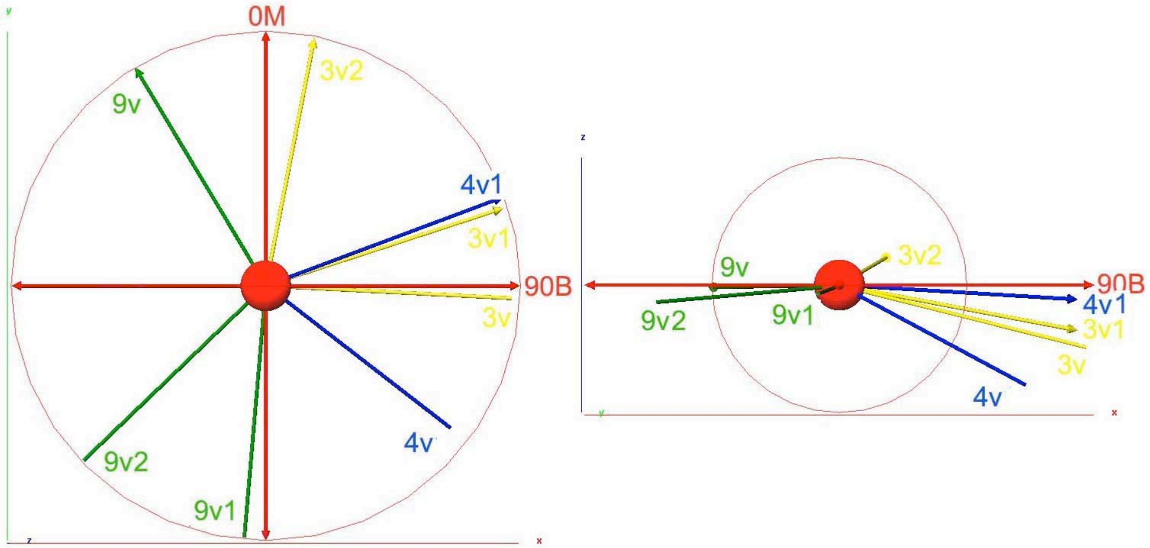


NHMW6035: urm1 (Fuegian)

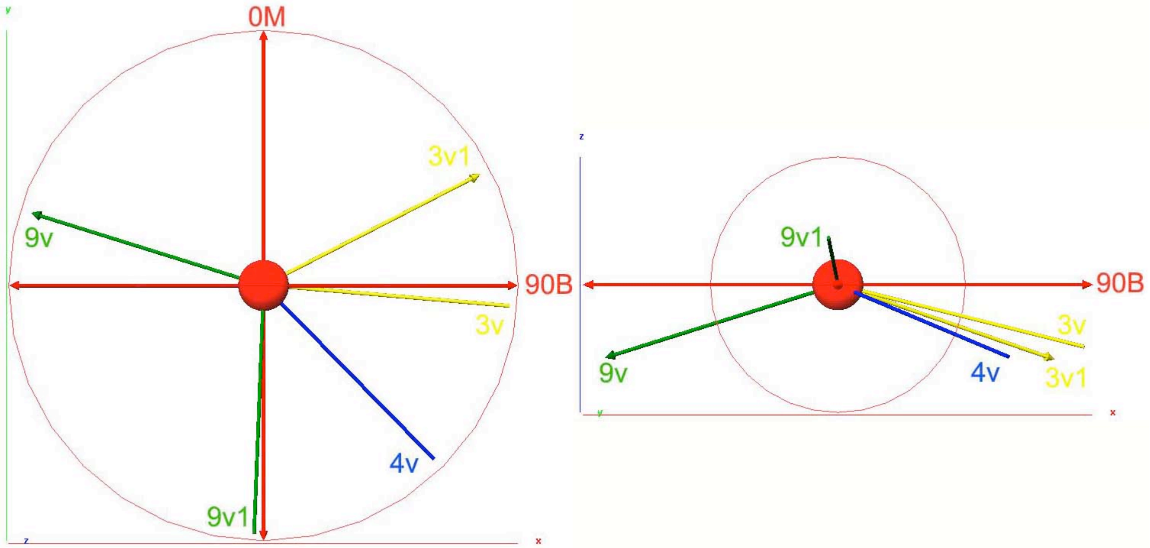
Match Value= 9.18; Wear Stage= 4

High correlation is seen between specimens at fmv's 9v, 3v and 3v1.

Plate 11



S7a-37: urm1 (Sangiran)

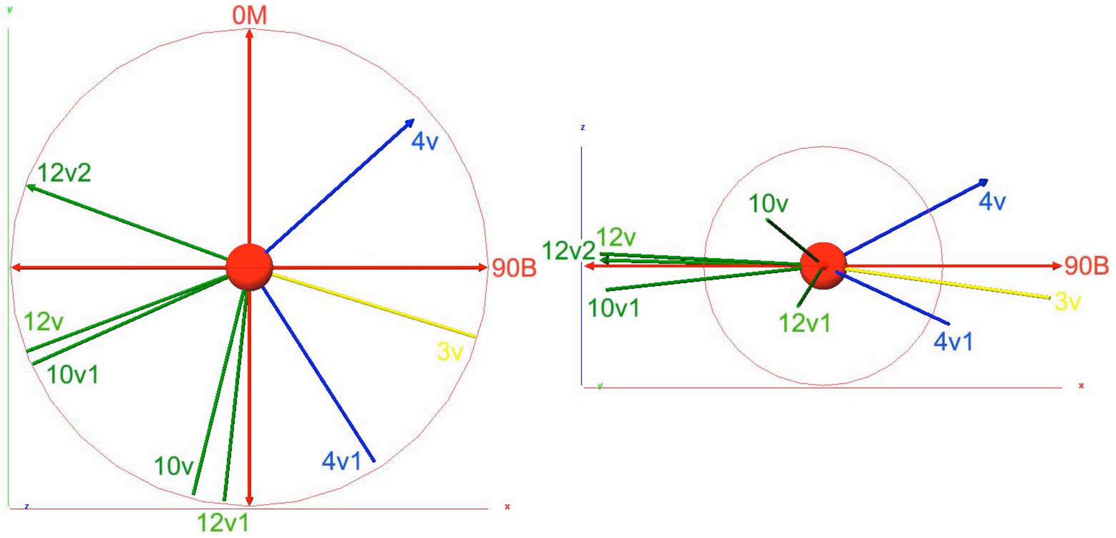


S16: urm1 (Bushmen)

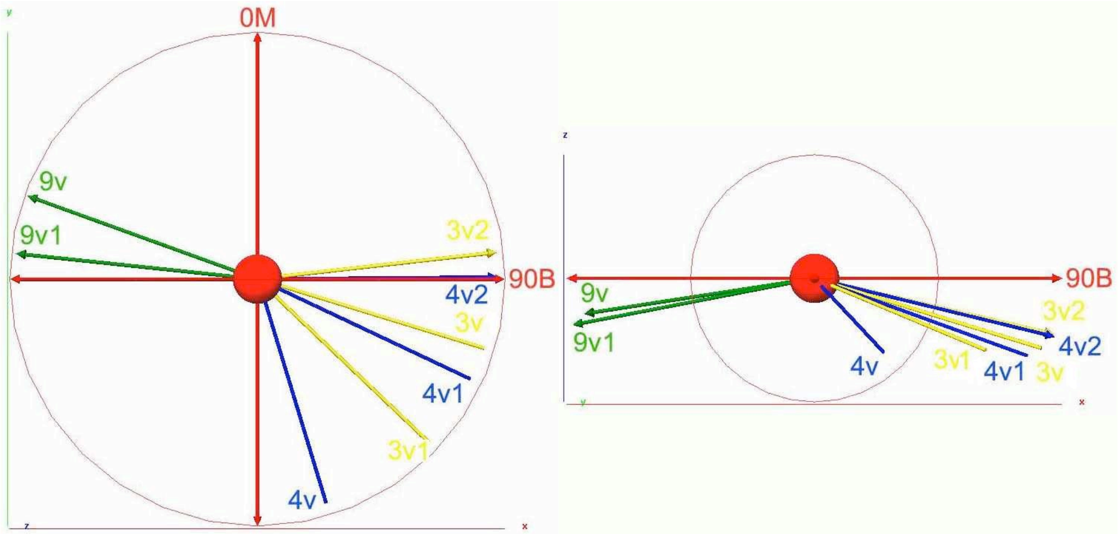
Match Value= 9.78; Wear Stage= 3

High correlation is seen between specimens at fmv's 3v, 3v1 and 4v. There is also some similarity of dip and dip direction at fmv 9v1.

Plate 12



S7a-38: ulm1 (Sangiran)

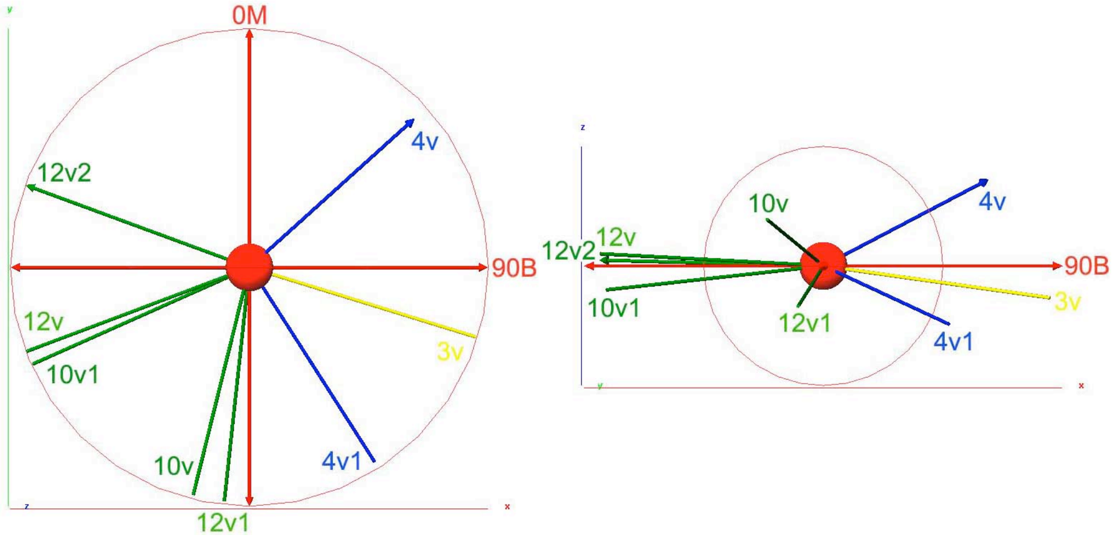


FC848: urm1 (PNWT)

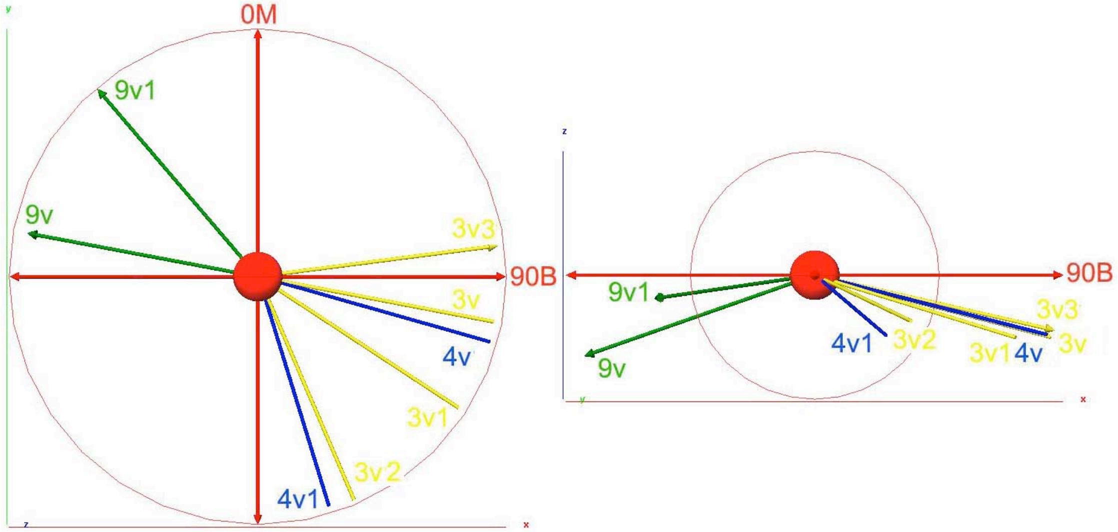
Match Value= 12.12; Wear Stage= 4

Moderate correlation is seen between specimens for fmv 3v. Facet 9 yielded no vectors in specimen 38 and so vectors from facets 10 & 12 were substituted. This does not affect matching capability but is still instructive of mandibular movement as seen in the similarity of dip and dip direction between 38 fmv's 12v2 & 4v1 and FC848 9v/ 9v1 & 4v/ 4v1 respectively.

Plate 13



S7a-38: ulm1 (Sangiran)

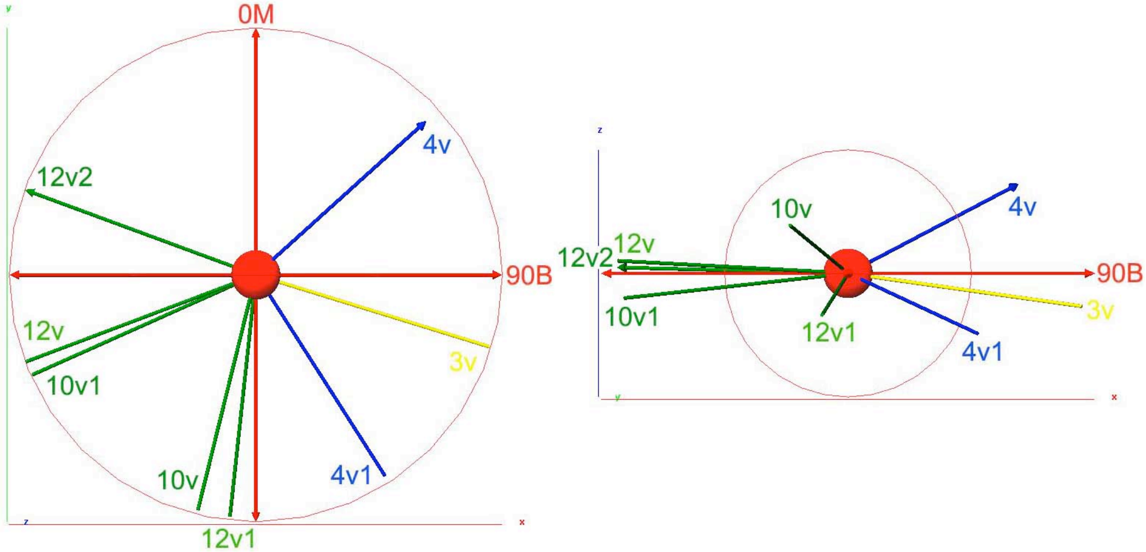


FC848: ulm1 (PNWT)

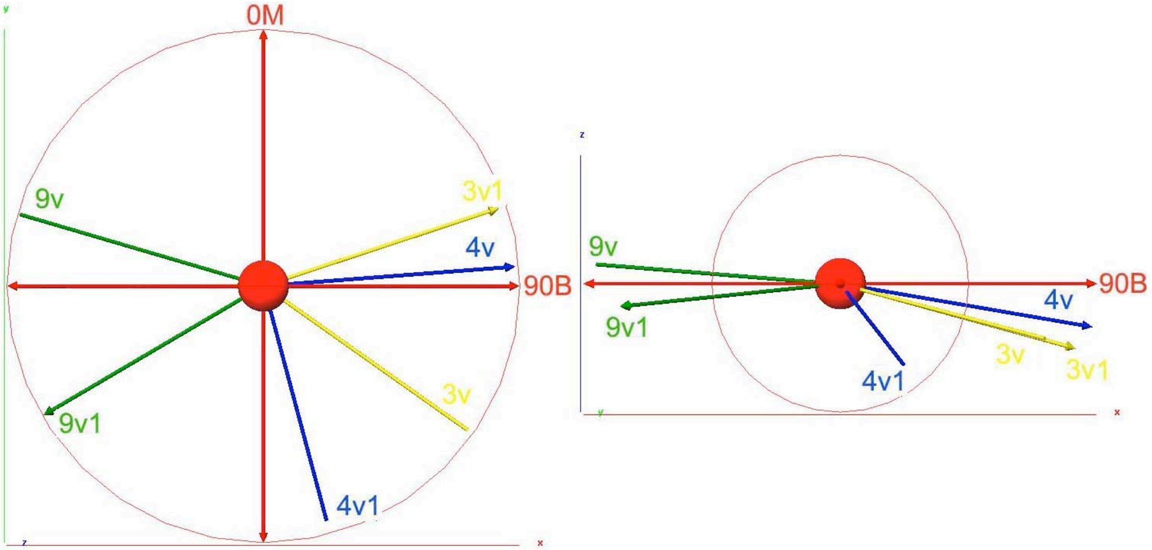
Match Value= 12.93; Wear Stage= 4

Moderate correlation is seen between specimens for fmv 3v & 4v1. Facet 9 yielded no vectors in specimen 38 and so vectors from facets 10 & 12 were substituted. This does not affect the match value but is still instructive of mandibular movement as seen in the similarity of dip and dip direction between 38 fmv 12v2 and FC848 9v.

Plate 14



S7a-38: ulm1 (Sangiran)

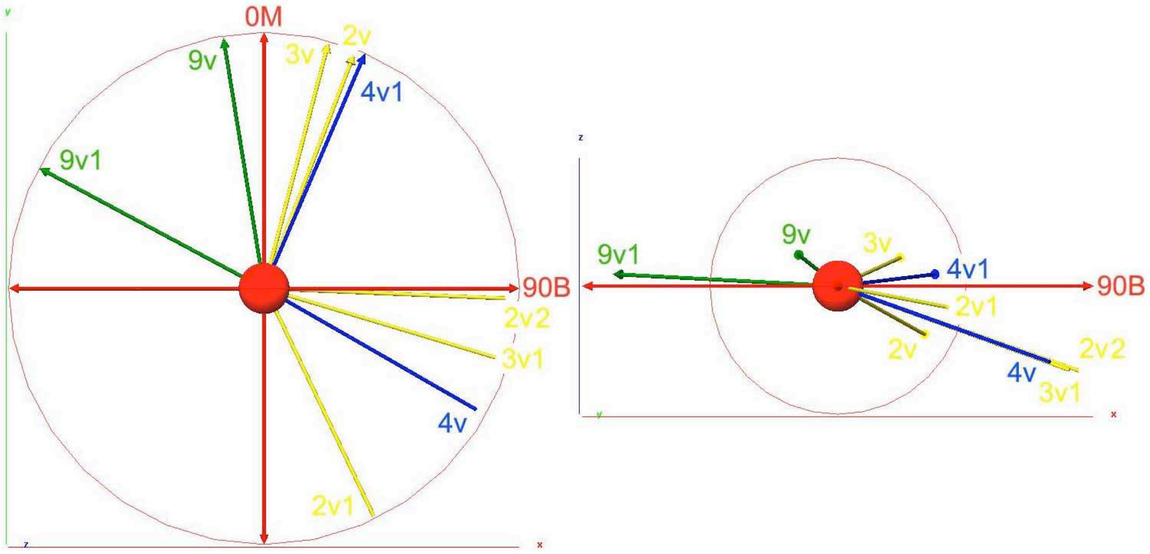


NHMW6035: ulm1 (Fuegian)

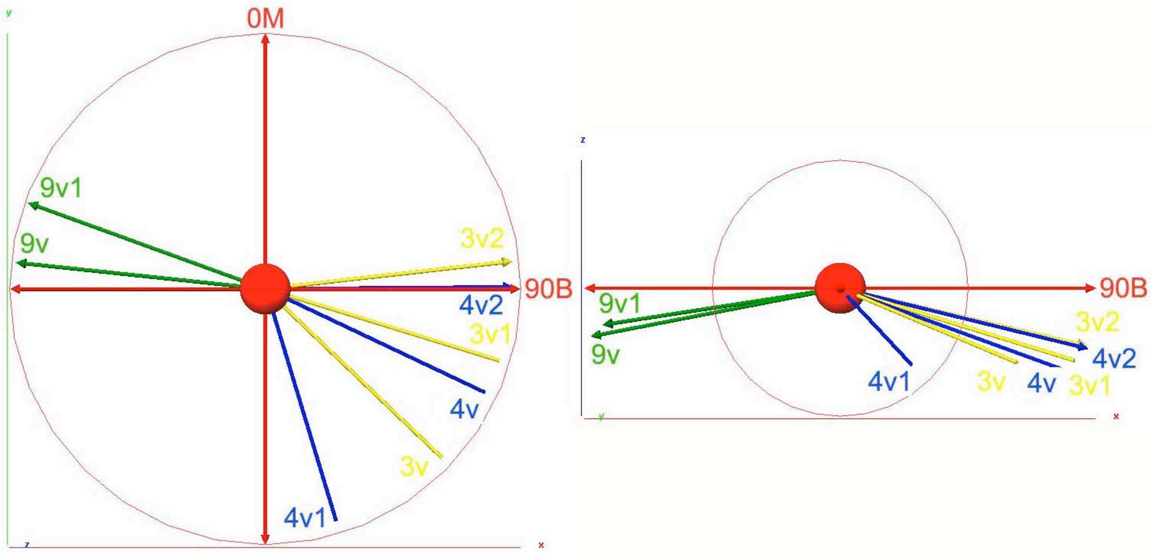
Match Value= 17.94; Wear Stage= 4

Moderate correlation is seen between specimens for fmv's 3v & 4v1. Facet 9 yielded no vectors in specimen 38 and so vectors from facets 10 & 12 were substituted. This does not affect the match value but is still instructive of mandibular movement as seen in the similarity of dip and dip direction between 38 fmv's 12v2 & 12v/10v1 and NHMW6035 9v and 9v1 respectively.

Plate 15



S7a-40: urm1 (Sangiran)

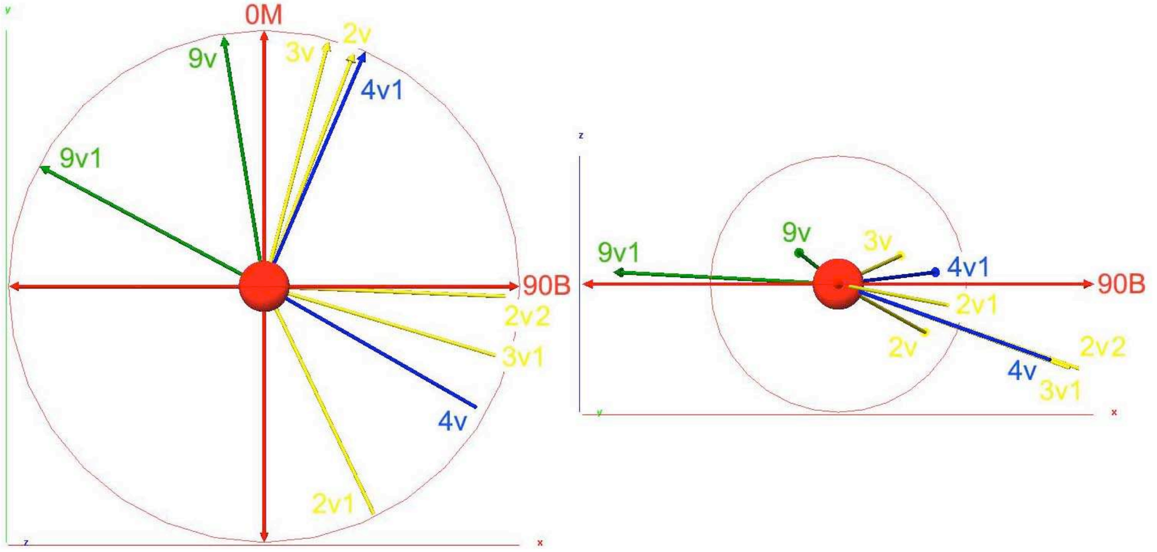


FC848: urm1 (PNWT)

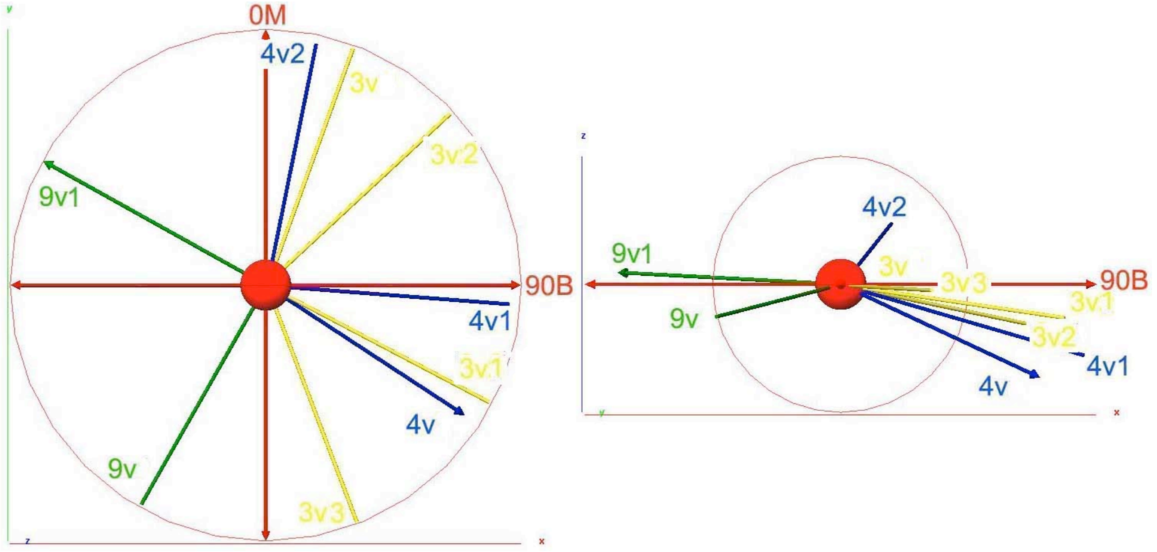
Match Value= 6.91; Wear Stage= 4

High correlation is seen between specimens for fmv 3v1, 4v & 9v1. There is also good similarity of dip and dip direction between 40 fmv 2v2 and FC848 3v2/ 4v2 which is instructive of mandibular Phase I movements.

Plate 16



S7a-40: urm1 (Sangiran)

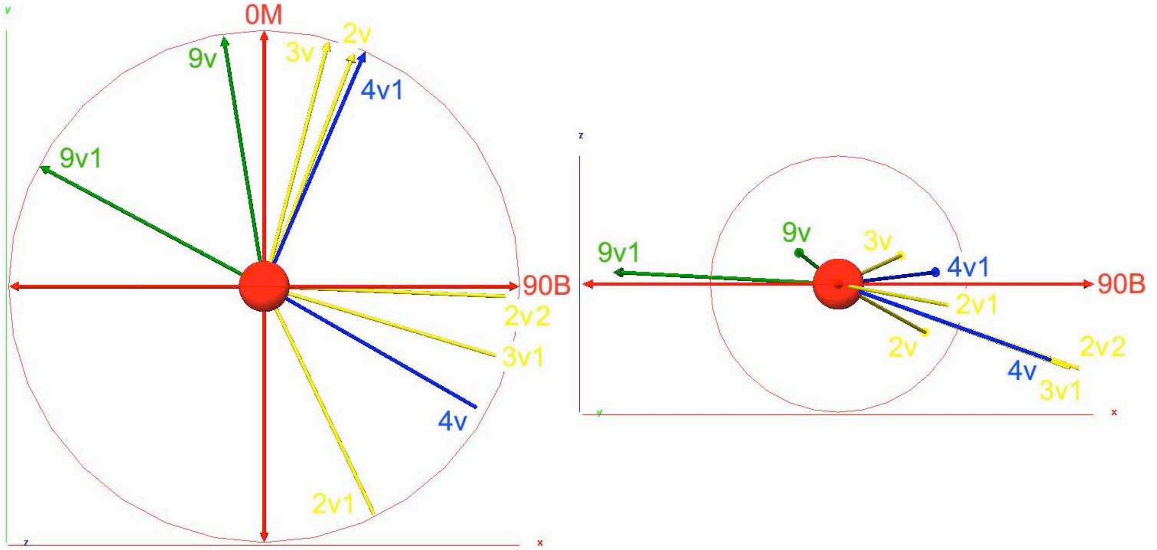


NHMW6035: urm1 (Fuegian)

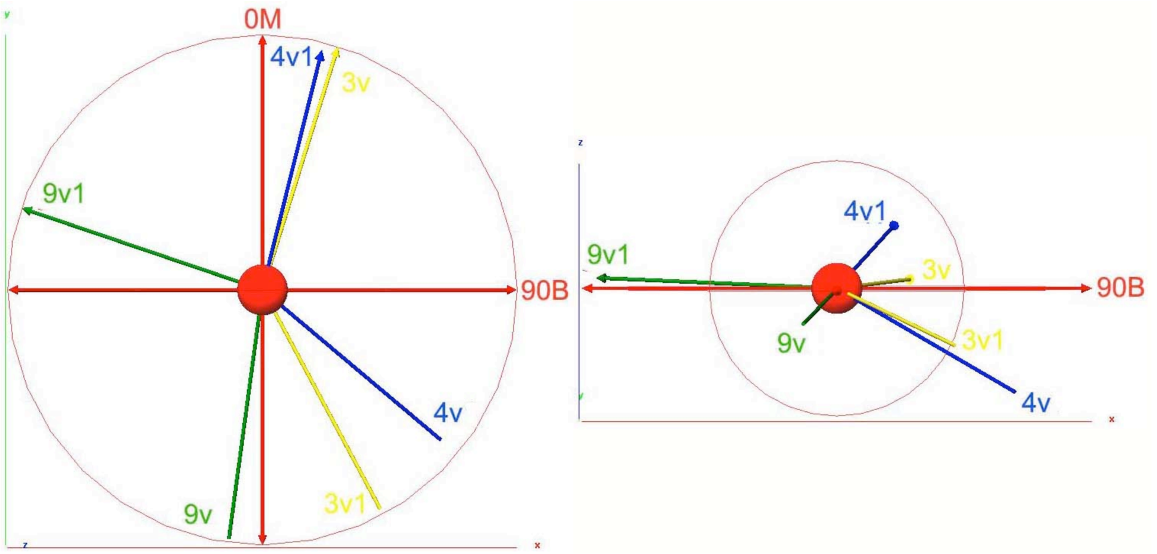
Match Value= 7.76; Wear Stage= 4

High correlation is seen between specimens for fmv 3v, 3v1, 4v & 9v1. There is also high similarity of dip and dip direction between specimen 40 fmv's 2v2 & 2v1 and NHMW6035 4v1 & 3v3 respectively which is instructive of mandibular Phase I movements.

<u>Plate 17</u>



S7a-40: urm1 (Sangiran)

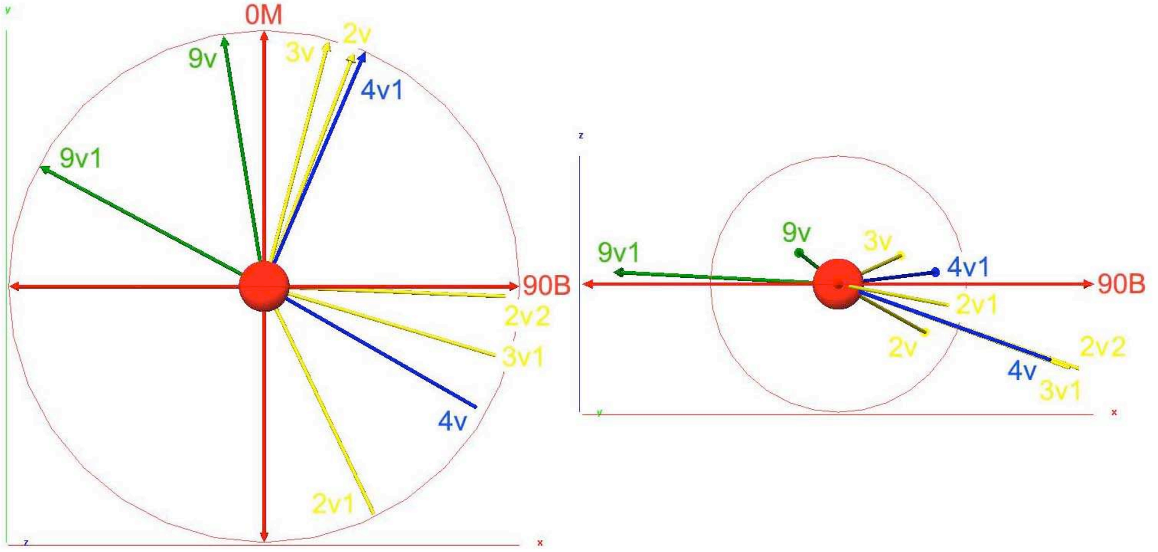


S5: urm1 (Bushmen)

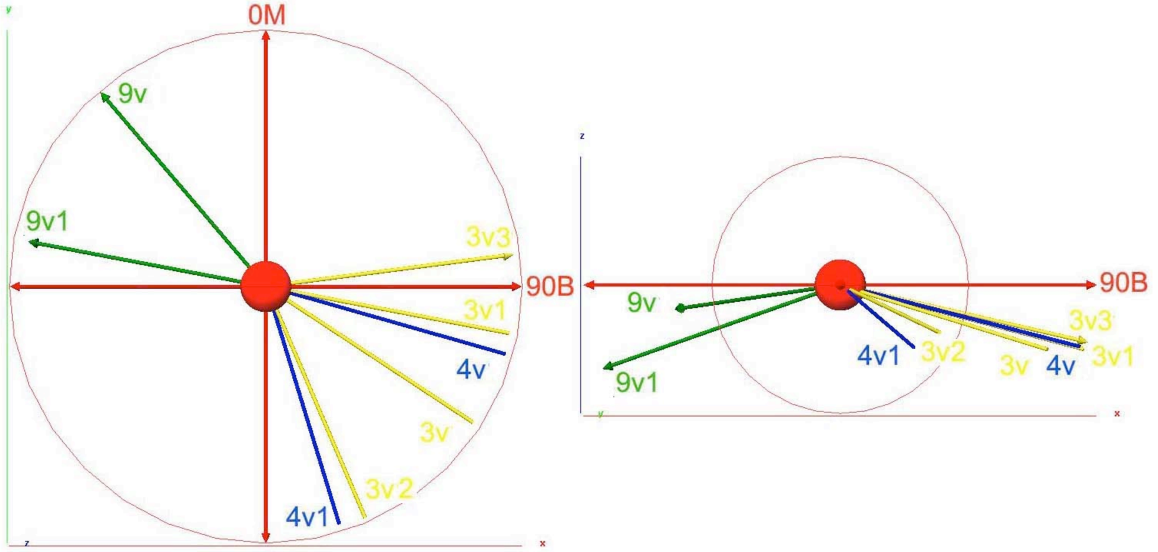
Match Value= 9.82; Wear Stage= 4

High correlation is seen between specimens for fmv 3v, 4v & 9v1. There is also good similarity of dip and dip direction between 40 fmv 2v1 and S5 3v1 which is instructive of mandibular Phase I movements.

Plate 18



S7a-40: urm1 (Sangiran)

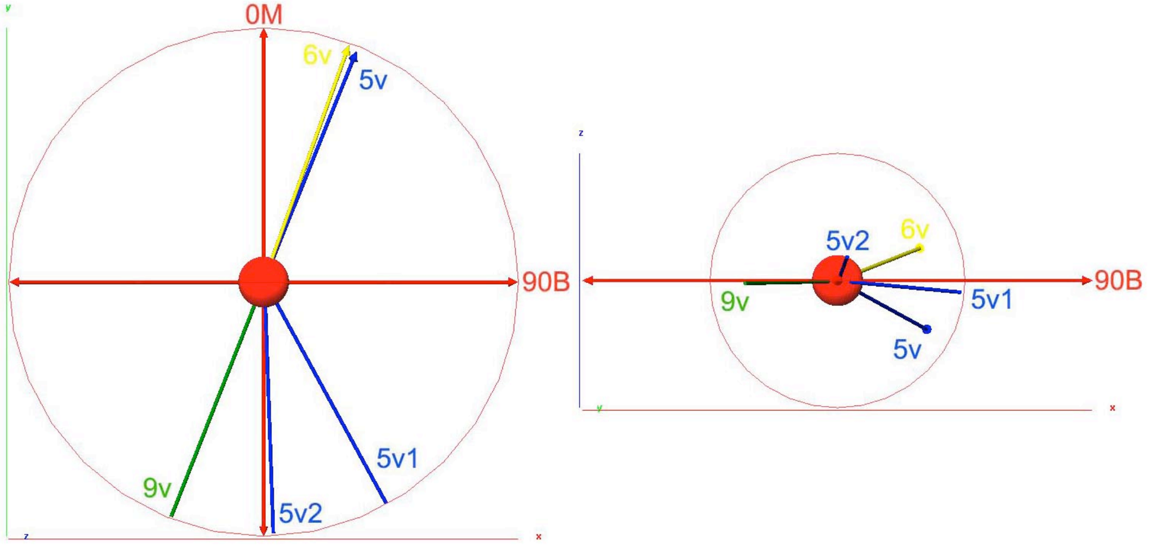


FC848: ulm1 (PNWT)

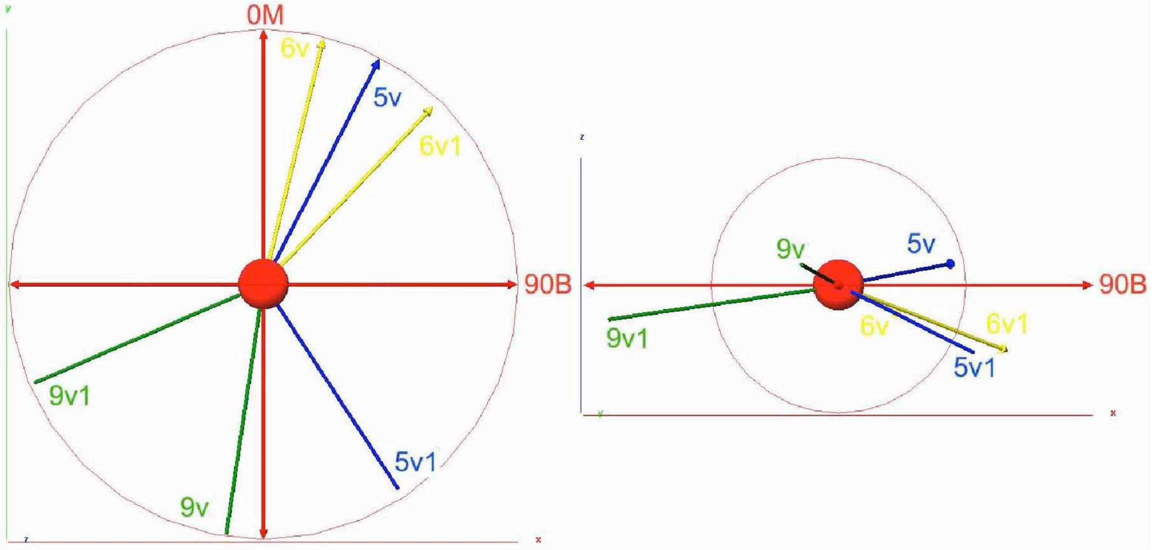
Match Value= 20.91; Wear Stage= 4

Low correlation is seen between specimens for fmv's 3v1 & 4v. There is also good similarity of dip and dip direction between 40 fmv's 2v1 & 2v2 and FC848 3v2 & 3v3 which is instructive of mandibular Phase I movements. Similarity of mandibular movement is also indicated by 40 fmv 9v1 and FC848 9v/ 9v1.

Plate 19



S7a-42: lrm1 (Sangiran)

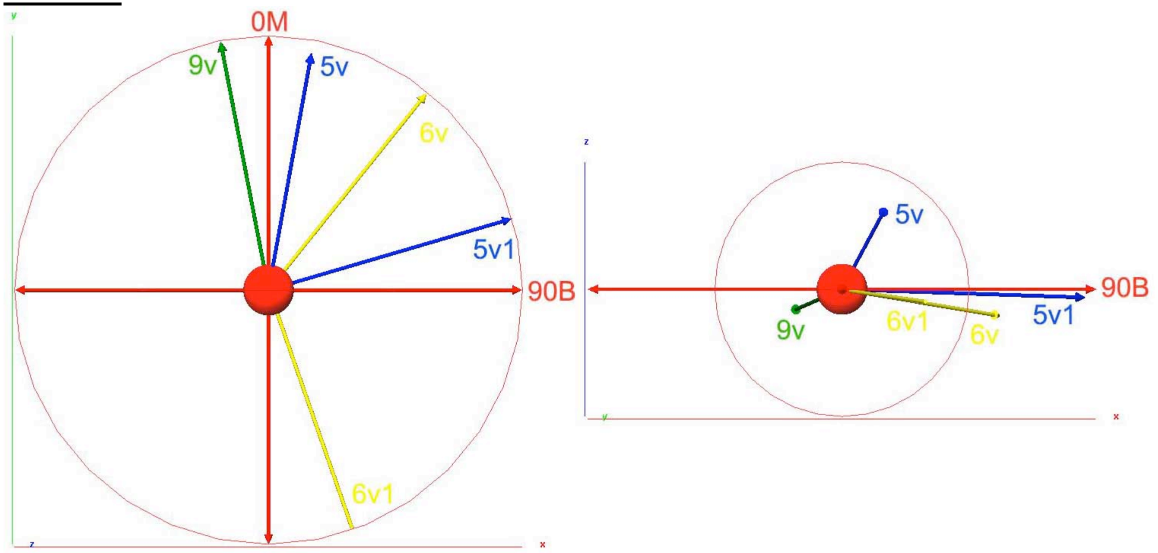


S16: llm1 (Bushmen)

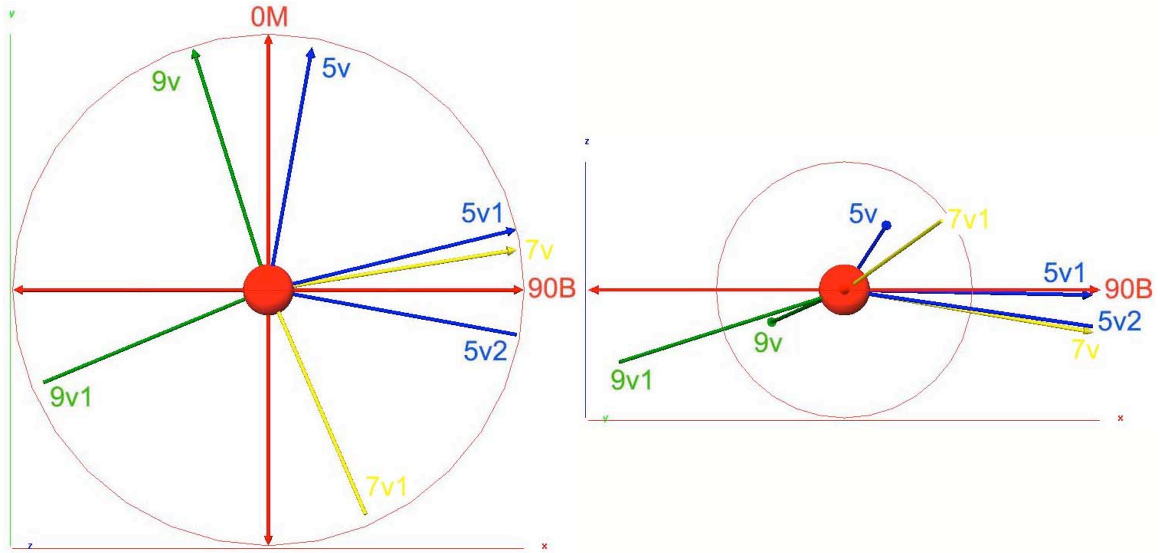
Match Value= 14.65; Wear Stage= 3

Moderate correlation is seen between specimens for fmv's 9v and 5v1. There are some other lesser similarities between specimens in the dip and dip direction for fmv's 6v & 5v which is instructive of mandibular Phase I movements.

Plate 20



S7a-43: llm1 (Sangiran)

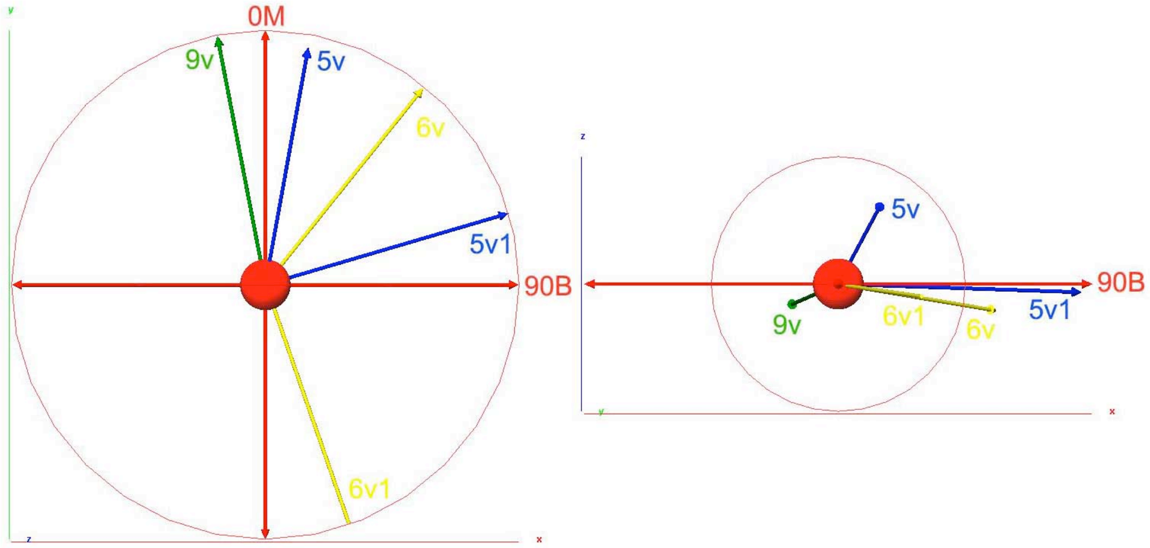


S5: lrm1 (Bushmen)

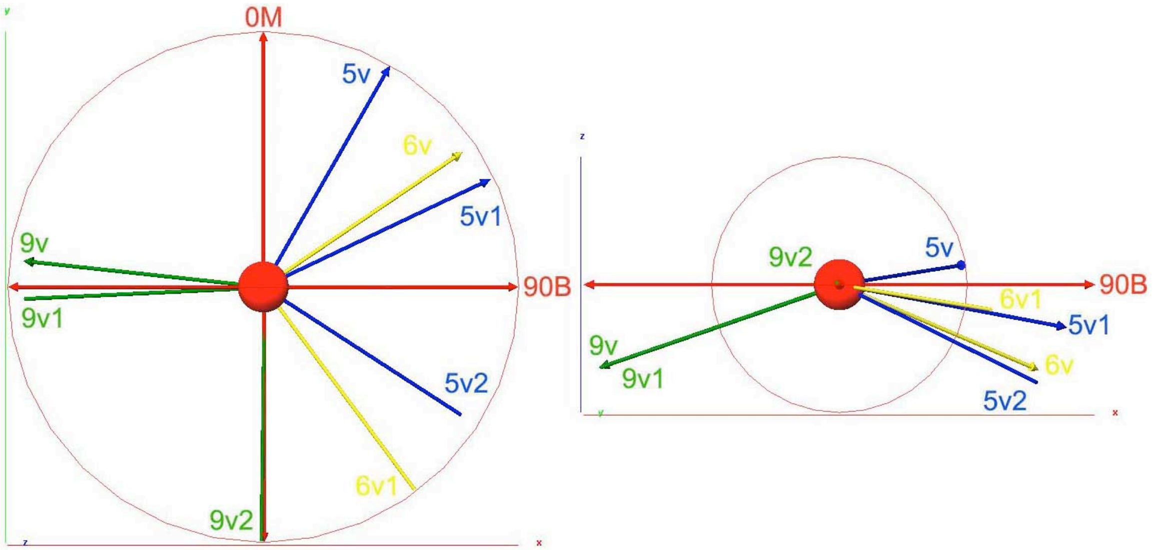
Match Value= 4.93; Wear Stage= 3

HIgh correlation is seen between specimens for fmv's 9v, 5v and 5v1 but no others.

Plate 21



S7a-43: IIm1 (Sangiran)

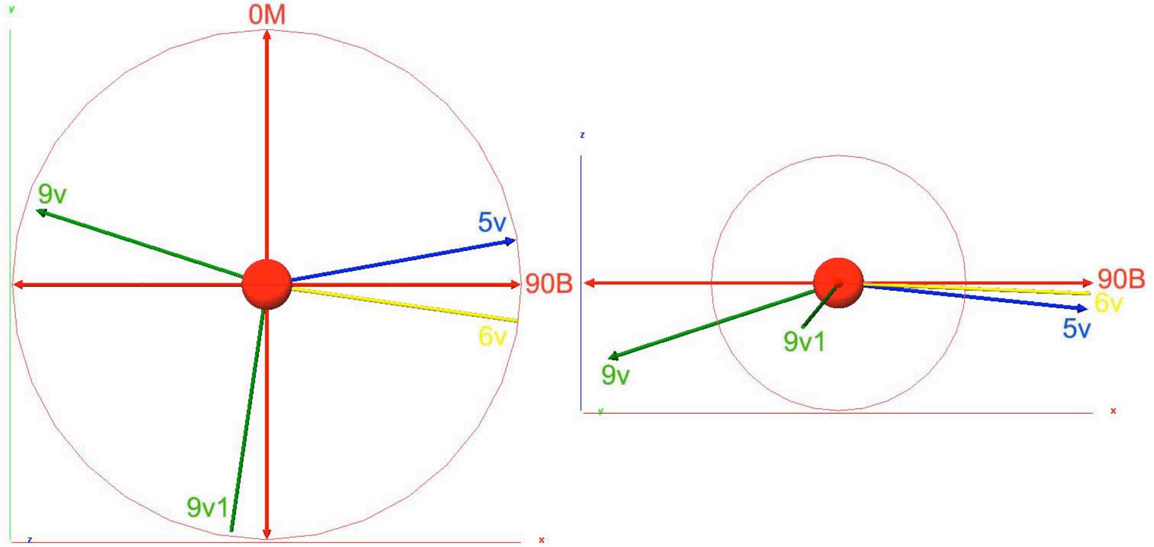


FC848: Irm1 (PNWT)

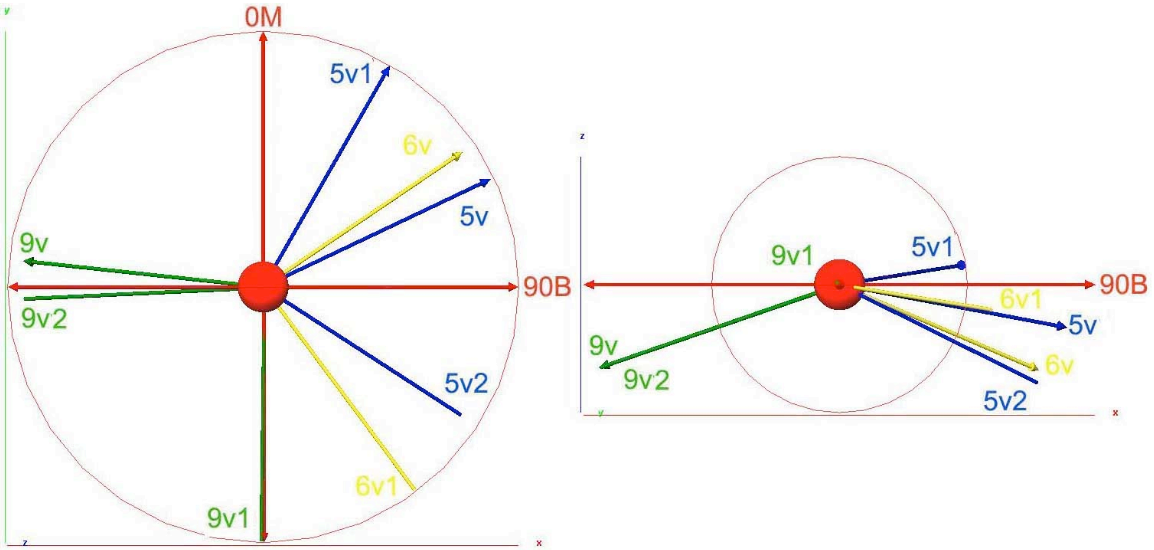
Match Value= 13.97; Wear Stage= 3

Moderate correlation is seen between specimens for fmv's 6v, 6v1 and 5v1 though there is no correlation in the Phase II fmv's.

Plate 22



S7a-61: lrm1 (Sangiran)

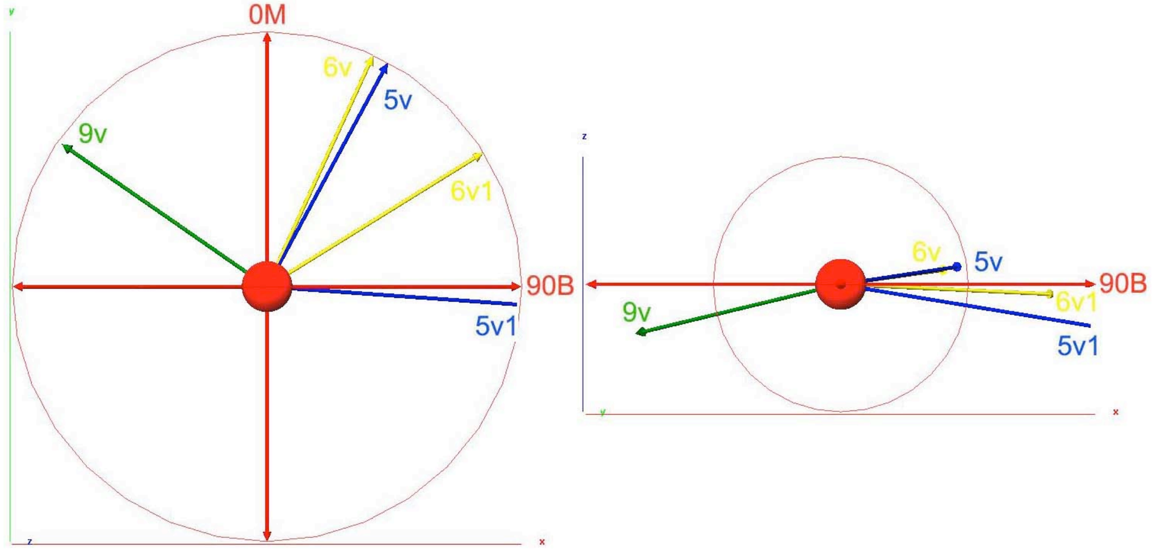


FC848: lrm1 (PNWT)

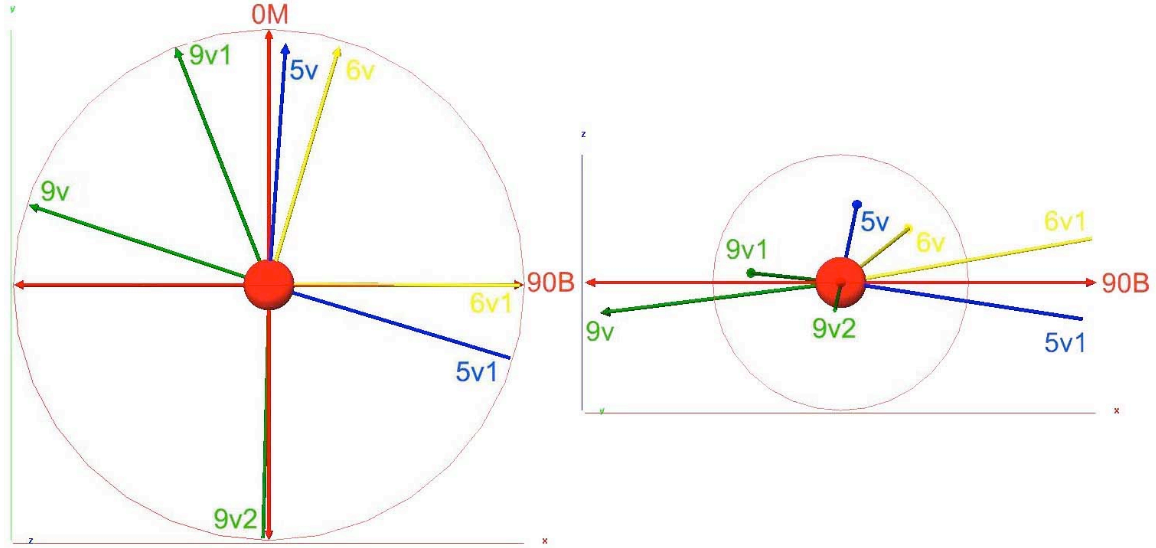
Match Value= 24.15; Wear Stage= 3

Low correlation is seen between specimens for fmv's 9v and 5v while 9v1 also demonstrates some similarity in orientation.

Plate 23



S7a-78: llm1 (Sangiran)

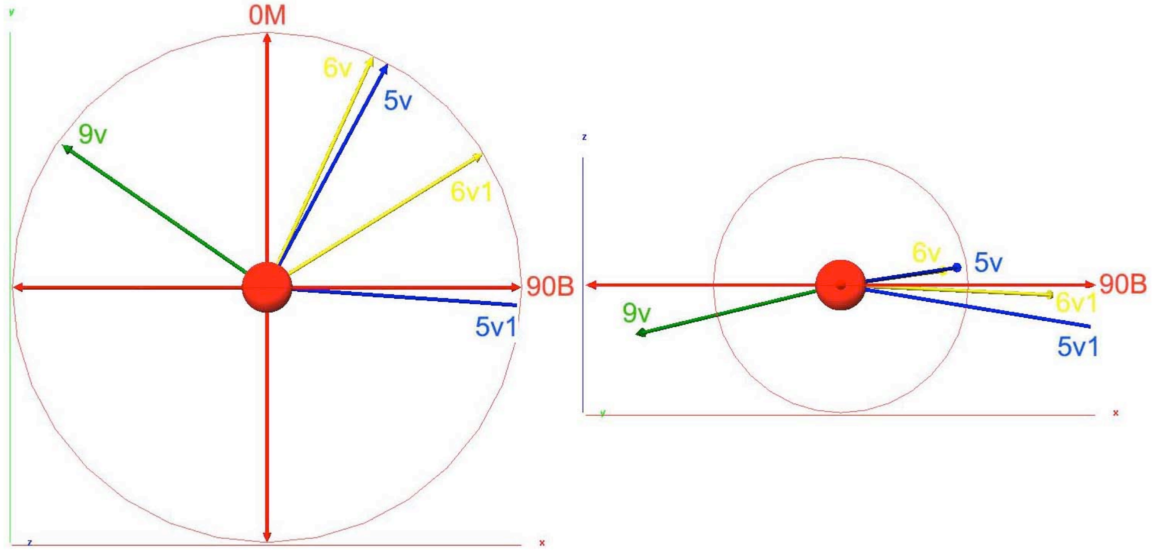


FC833-3: llm1 (Inuit)

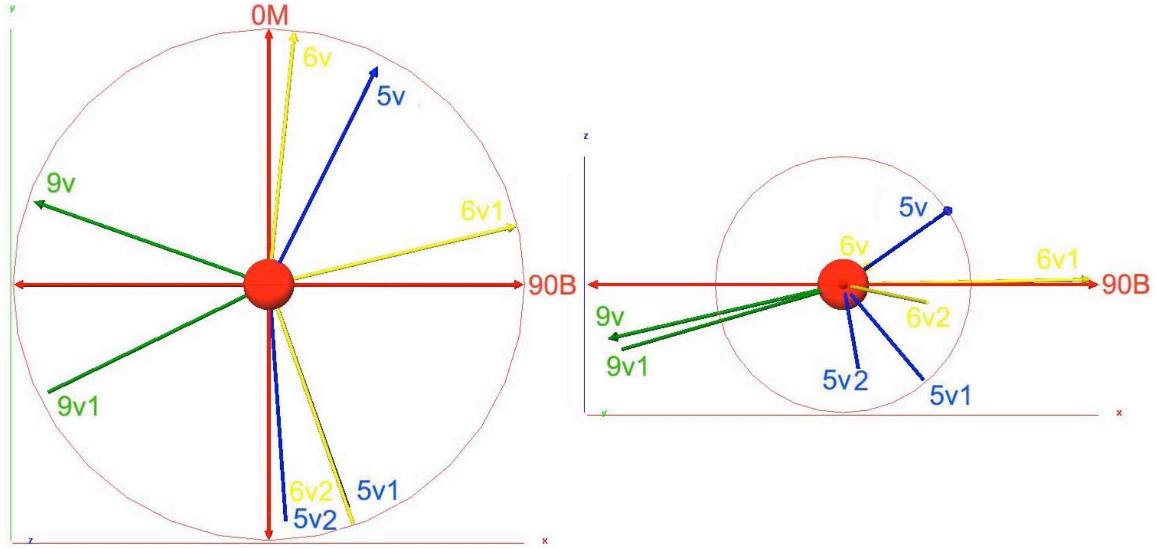
Match Value= 13.92; Wear Stage= 4

Moderate correlation is seen between specimens for fmv 5v1, 6v & 9v.

Plate 24



S7a-78: IIm1 (Sangiran)

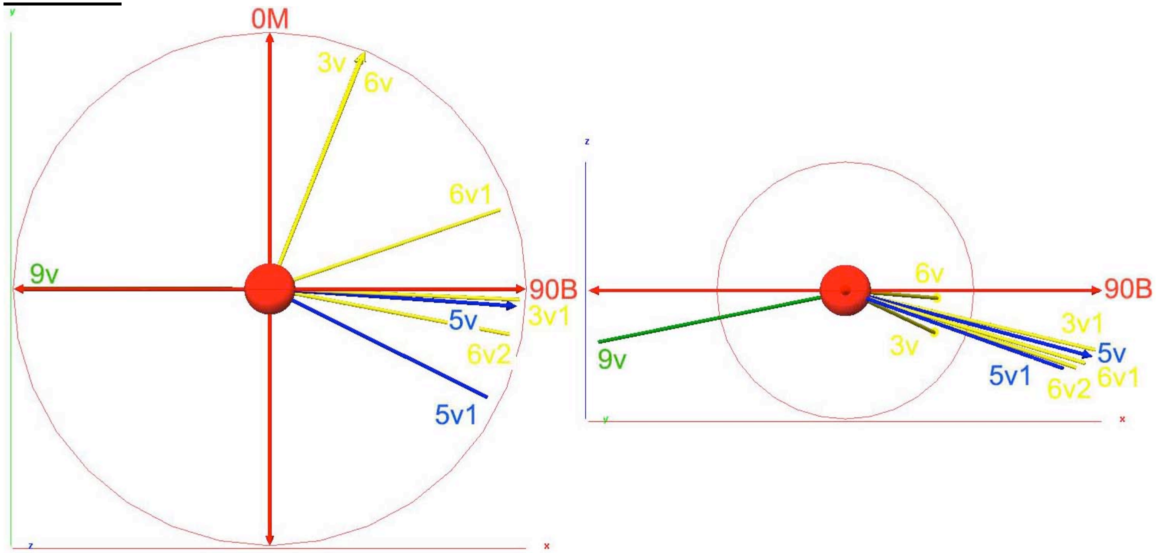


S5: IIm1 (Bushmen)

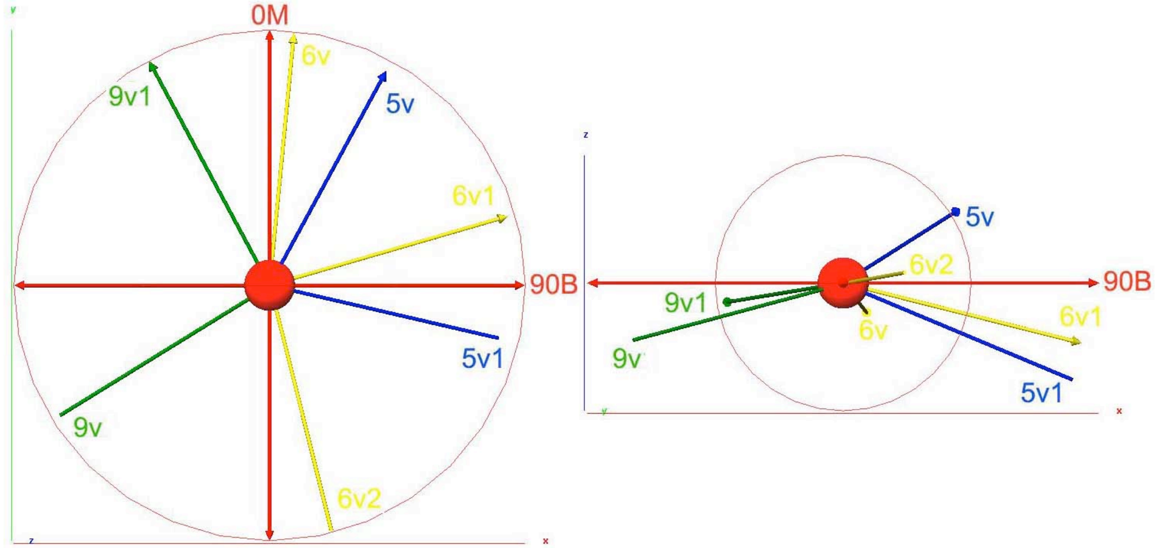
Match Value= 15.78; Wear Stage= 4

Moderate correlation is seen between specimens for fmv's 5v, 6v1 & 9v.

Plate 25



S7a-84: lrm2 (Sangiran)

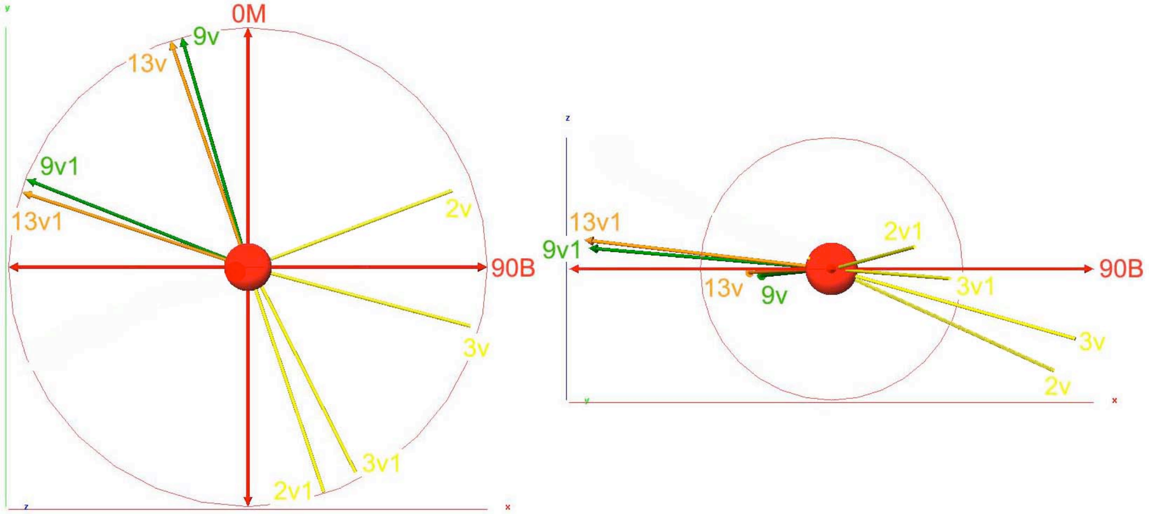


NHMW6035: lrm2 (Fuegian)

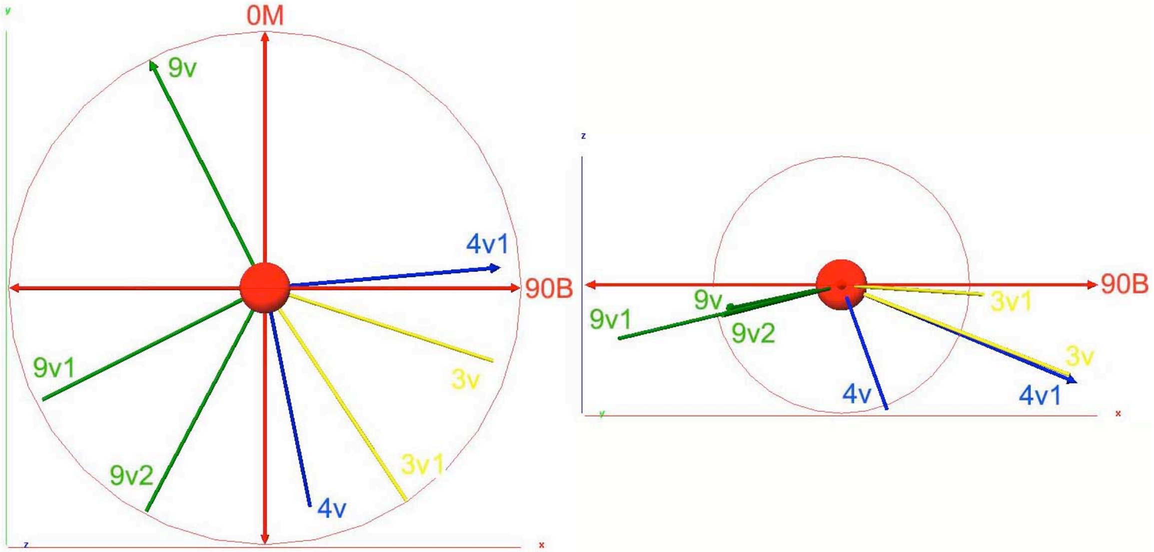
Match Value= 22.02; Wear Stage= 4

Low correlation is seen between specimens at fmv's 5v1 and 6v1. There is also some limited similarity at fmv 9v which is instructive of mandibular Phase II movements.

Plate 26



S7a-89: urm2 (Sangiran)

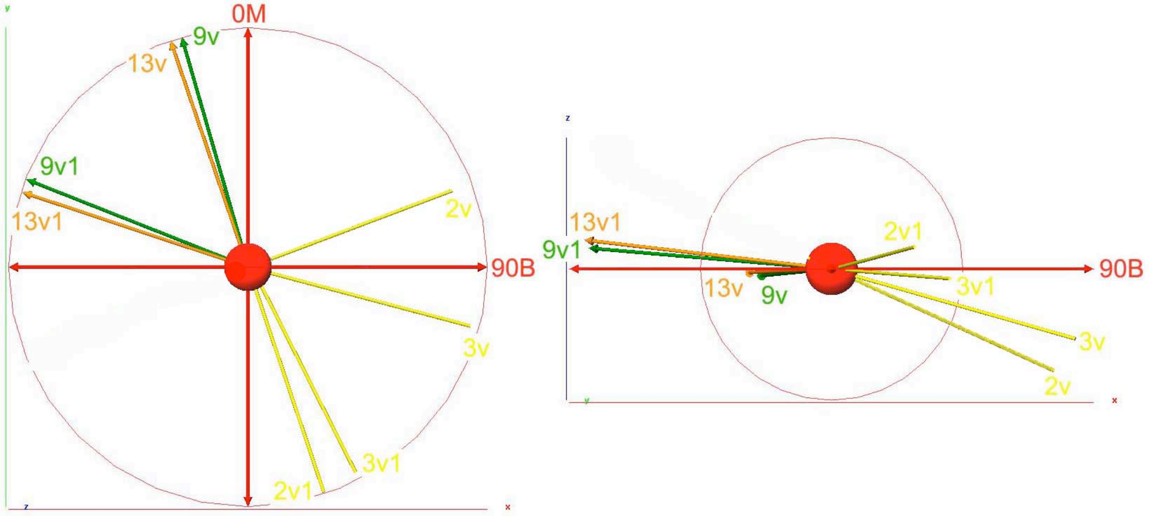


S9: urm2 (Bushmen)

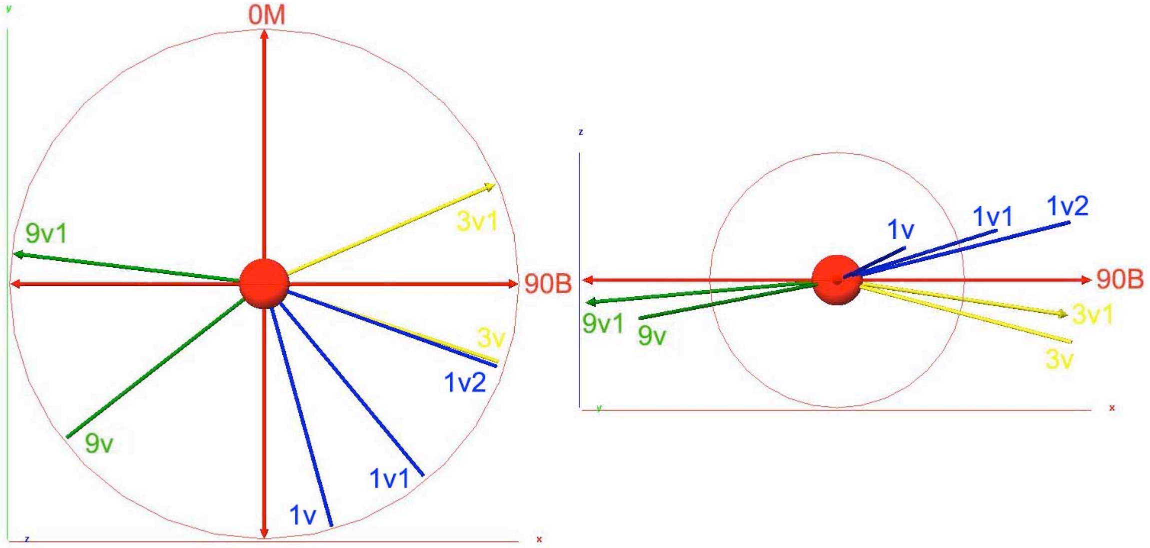
Match Value= 8.87; Wear Stage= 3

High correlation is seen between specimens for fmv's 3v, 3v1 and 9v. Facet 4 yielded no vectors in specimen 89 and no others of the same phase number could be found as substitutes.

Plate 27



S7a-89: urm2 (Sangiran)

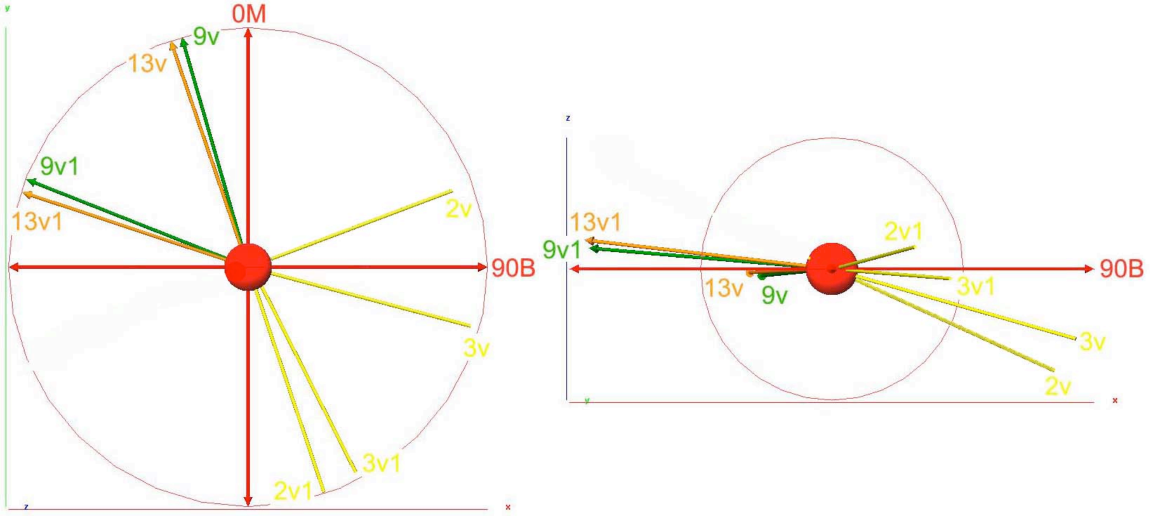


NHMW8687: urm2 (Aust. Abor.)

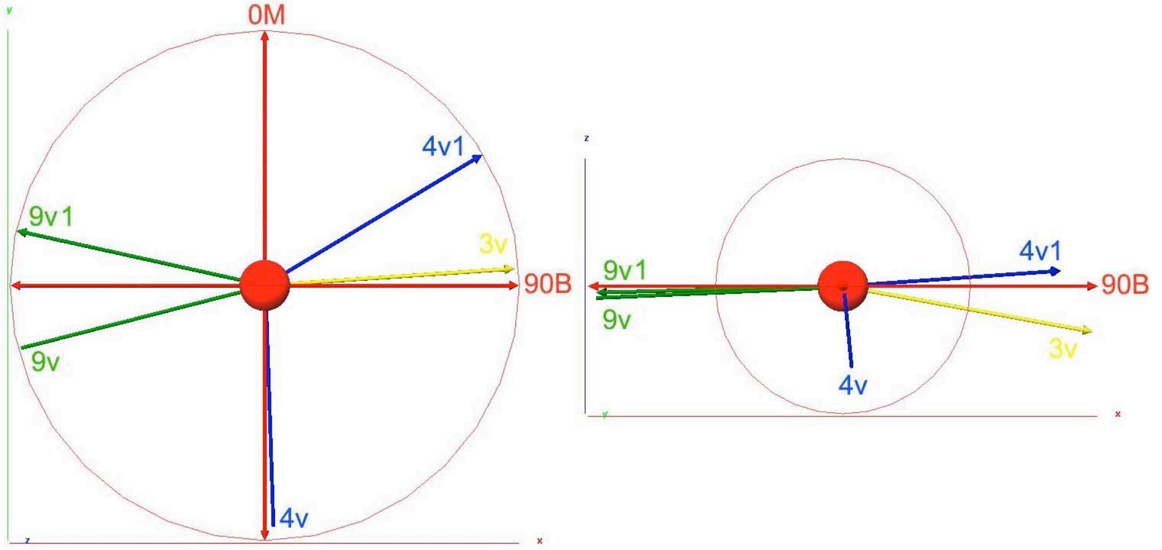
Match Value= 10.65; Wear Stage= 3

Moderate correlation is seen between specimens for fmv's 3v and 9v1. There is some similarity in fmv's for 89 2v & 2v1 with NHMW867 3v1 & 1v respectively which is instructive of mandibular Phase I movements. Facet 4 yielded no vectors in specimen 89 and no others of the same phase number could be found as substitutes.

Plate 28



S7a-89: urm2 (Sangiran)



NHMW8687: ulm2 (Aust. Abor.)

Match Value= 10.65; Wear Stage= 3

Moderate correlation is seen between specimens for fmv 9v1 with a more limited similarity of orientation in 3v. Facet 4 yielded no vectors in specimen 89 and no others of the same phase number could be found as substitutes.

8.2.1 H. erectus to H. sapiens fmv Match Value Summary and Analysis

The complete list of significant match values between *H. erectus* and *H. sapiens* is presented below (Table 8.2). They are ordered from lowest match value to highest. The lower the match value, the higher the correlation between specimens which is also indicated here. An analysis of these match values follows the table.

Table 8.2. *Homo erectus* to *Homo sapiens* Match Value Summary

Plate #	Specimen #	Affiliation	Match Value	Correlation
20	S7-43	Sangiran	4.93	High
	S5	Bushmen		
1	S7-3b	Bapang	5.4	High
	NHMW6035	Fuegian		
15	S7-40	Sangiran	6.91	High
	FC848	PNWT		
16	S7-40	Sangiran	7.76	High
	NHMW6035	Fuegian		
26	S7-89	Sangiran	8.87	High
	S9	Bushmen		
10	S7-14	Bapang	9.18	High
	NHMW6035	Fuegian		
2	S7-3b	Bapang	9.63	High
	NHMW8687	Aust. Abor.		
11	S7-37	Sangiran	9.78	High
	S16	Bushmen		
17	S7-40	Sangiran	9.82	High
	S5	Bushmen		
27	S7-89	Sangiran	10.65	Moderate
	NHMW8687	Aust. Abor.		
Not Demonstrated	S7-3b	Bapang	10.97	Moderate
	S5	Bushmen		
Not Demonstrated	S7-40	Sangiran	11.33	Moderate
	S5	Bushmen		
12	S7-38	Sangiran	12.12	Moderate
	FC848	PNWT		
Not Demonstrated	S7-89	Sangiran	12.24	Moderate
	FC848	PNWT		
13	S7-38	Sangiran	12.93	Moderate
	FC848	PNWT		
Not Demonstrated	S7-3b	Bapang	13.1	Moderate
	NHMW811	Aust. Abor.		
Not Demonstrated	S7-3b	Bapang	13.59	Moderate
	FC848	PNWT		

3	S7-3c	Bapang	13.83	Moderate
	FC848	PNWT		
4	S7-3b	Bapang	13.9	Moderate
	S5	Bushmen		
23	S7-78	Sangiran	13.92	Moderate
	FC833-3	Inuit		
21	S7-43	Sangiran	13.97	Moderate
	FC848	PNWT		
5	S7-3c	Bapang	14.05	Moderate
	S9	Bushmen		
28	S7-89	Sangiran	14.15	Moderate
	NHMW8687	Aust. Abor.		
6	S7-3c	Bapang	14.38	Moderate
	NHMW8687	Aust. Abor.		
19	S7-42	Sangiran	14.65	Moderate
	S16	Bushmen		
Not Demonstrated	S7-89	Sangiran	14.67	Moderate
	FC833-3	Inuit		
7	S7-3d	Bapang	14.68	Moderate
	NHMW8687	Aust. Abor.		
Not Demonstrated	S7-40	Sangiran	15.12	Moderate
	FC833-3	Inuit		
Not Demonstrated	S7-89	Sangiran	15.38	Moderate
	NHMW811	Aust. Abor.		
Not Demonstrated	S7-40	Sangiran	15.43	Moderate
	NHMW8687	Aust. Abor.		
24	S7-78	Sangiran	15.78	Moderate
	S5	Bushmen		
Not Demonstrated	S7-89	Sangiran	15.82	Moderate
	S5	Bushmen		
Not Demonstrated	S7-38	Sangiran	15.83	Moderate
	FC833-3	Inuit		
8	S7-6	Bapang	16.36	Moderate
	S5	Bushmen		
Not Demonstrated	S7-62	Sangiran	16.55	Moderate
	FC848	PNWT		
Not Demonstrated	S7-3b	Bapang	16.91	Moderate
	NHMW6035	Fuegian		
Not Demonstrated	S7-40	Sangiran	16.92	Moderate
	FC833-3	Inuit		
9	S7-10	Bapang	17.87	Moderate
	S16	Bushmen		
Not Demonstrated	S7-3b	Bapang	17.9	Moderate
	FC848	PNWT		
14	S7-38	Sangiran	17.94	Moderate
	NHMW6035	Fuegian		

Not Demonstrated	S7-62	Sangiran	18.71	Moderate
	FC848	PNWT		
Not Demonstrated	S7-43	Sangiran	20.16	Low
	S16	Bushmen		
18	S7-40	Sangiran	20.91	Low
	FC848	PNWT		
Not Demonstrated	S7-3c	Bapang	21.29	Low
	NHMW811	Aust. Abor.		
25	S7-84	Sangiran	22.02	Low
	NHMW6035	Fuegian		
Not Demonstrated	S7-40	Sangiran	22.24	Low
	NHMW8687	Aust. Abor.		
Not Demonstrated	S7-3b	Bapang	23.48	Low
	S9	Bushmen		
Not Demonstrated	S7-62	Sangiran	23.55	Low
	S16	Bushmen		
Not Demonstrated	S7-3c	Bapang	24	Low
	FC833-3	Inuit		
Not Demonstrated	S7-3b	Bapang	24.1	Low
	FC833-3	Inuit		
22	S7-61	Sangiran	24.15	Low
	FC848	PNWT		
Not Demonstrated	S7-40	Sangiran	24.96	Low
	NHMW811	Aust. Abor.		
Not Demonstrated	S7-3d	Bapang	24.99	Low
	FC848	PNWT		
Not Demonstrated	S7-43	Sangiran	25.13	Low
	S16	Bushmen		
Not Demonstrated	S7-20	Bapang	25.38	Low
	S16	Bushmen		
Not Demonstrated	S7-40	Sangiran	25.42	Low
	NHMW6035	Fuegian		
Not Demonstrated	S7-43	Sangiran	25.66	Low
	S16	Bushmen		
Not Demonstrated	S7-78	Sangiran	26.39	Low
	NHMW6035	Fuegian		
Not Demonstrated	S7-89	Sangiran	27.06	Low
	NHMW811	Aust. Abor.		
Not Demonstrated	S7-20	Bapang	27.32	Low
	FC848	PNWT		
Not Demonstrated	S7-3c	Bapang	27.76	Low
	S5	Bushmen		
Not Demonstrated	S7-40	Sangiran	28.76	Low
	NHMW811	Aust. Abor.		
Not Demonstrated	S7-40	Sangiran	28.91	Low
	S9	Bushmen		

Not Demonstrated	S7-89	Sangiran	28.98	Low
	S5	Bushmen		
Not Demonstrated	S7-3c	Bapang	29.08	Low
	NHMW811	Aust. Abor.		
Not Demonstrated	S7-38	Sangiran	29.32	Low
	S5	Bushmen		
Not Demonstrated	S7-20	Bapang	29.46	Low
	FC848	PNWT		
Not Demonstrated	S7-61	Sangiran	29.73	Low
	S16	Bushmen		

Table 8.3 below shows the relationship between each *H. sapiens* subpopulations sample size, possible matches, significant matches and percent significant matches with *H. erectus*. What can be seen is that the sample sizes of the *H. sapiens* subpopulations does not predict the total number of 'All Possible Matches'. This indicates that sample size has no influence on matching capability. Although the 'Total Significant Matches' seem to track somewhat closely with 'Sample Size', the 'Percentage Significant Matches-vs-Possible' does not vary severely demonstrating that there is no skewing or bias in the ability of each *H. sapiens* subpopulation to match at reasonably high levels regardless of its sample size. For example, there are 11 Fuegian and 11 PNWT specimens (each 17.5% of the total sample) which both have a quite high 'Percentage Significant Matches-vs-Possible' (66.7% & 62.5% respectively) though we see that the PNWT actually number almost double in their number of 'Total Significant Matches'. This is due then to the fact that there are more possible and significant matches simply due to the phenology of the *H. erectus* sample.

Table 8.3. Overall Analysis of Match Significance Values

H. sapiens	Sample Size	All Possible Matches	Total Significant Matches	Percentage Significant Matches-vs-Possible
Inuit	9	14	7	50.0%
Fuegian	11	12	8	66.7%
PNWT	11	24	15	62.5%
Aust. Abor.	12	28	14	50.0%
Bushmen	20	38	24	63.2%
Totals	63	116	68	58.6%

Further analysis of match values (Table 8.4) totals by correlation category the number of significant matches made (from 1 to 30° per the matching algorithm) by any *H. erectus* specimen to each of the *H. sapiens* samples (Inuit, Fuegian, PNWT, Aust. Abor. and Bushmen). Then, for each of the *H. sapiens* samples, the number of significant matches by correlation category are added and divided by the number of all significant matches thus yielding a percentage affinity. For example, the first line (Inuit) of Table 8.4 shows that the Inuit matched zero *H. erectus* specimens with a 'high' correlation, five matches were made at the 'moderate' level and only two correlations in the 'low' category for a total of seven out of sixty-eight yielding a percentage of 10.3% of total significant matches. These percentages are then summed based on broader dietary categories demonstrating *H. erectus's* affinity to each category. For example, 'Yearly reliant on proteinaceous foods (Inuit, Fuegian)' shows that 22.1% of all *H. erectus* fell within this dietary category. The remaining analyses in this section and those in the following section are conducted in the same manner.

Table 8.4: *H. erectus* to *H. sapiens* total number of significant matches (n=68)
Inuit- 0 High, 5 Moderate, 2 Low= 7/ 68= 10.3%
Fuegian- 3 High, 2 Moderate, 3 Low= 8/ 68= 11.8%
PNWT- 1 High, 9 Moderate, 5 Low= 15/ 68= 22.1%
Aust. Abor. - 1 High, 7 Moderate, 6 Low= 14/ 68= 20.6%
Bushmen- 4 High, 9 Moderate, 11 Low= 24/ 68= 35.3%

Yearly reliant on proteinaceous foods (Inuit, Fuegians): 7+8=15/68= 22.1% sig.
Seasonally reliant on proteinaceous foods (Abor. & PNWT): 14+15/68= 42.6%
Not reliant on proteinaceous foods (Bushmen): 24/68= 35.3%

From the above analysis we see that *H. erectus* has a higher total number of significant matches by dietary category with groups 'Seasonally reliant on proteinaceous foods' by a factor 1.21 over the next highest dietary category.

The second analysis (Table 8.5) seeks to further clarify these dietary relationships by assigning a weight to each correlation category. Therefore, a 'high' correlation was assigned a weight of 3, 'moderate' correlation was assigned a weight of 2 and 'low' correlation was a weight of 1. These weights were then multiplied by the number of matches each *H. sapiens* sample made with any *H. erectus* within each correlation category. The value of weighted correlations were added together within each *H. sapiens* sample and then divided by the total of all weighted correlations to yield a percentage at which the *H. erectus* affined to each *H. sapiens* subpopulation. For example, the first line (Inuit) under 'Weighted matches' shows that *H. erectus* matches zero times at the 'high' correlation and therefore yields a weighted match at that correlation value of zero. *H. erectus* matches five times at the 'moderate' correlation rank and yields a weighted value of 10 while also matching two times at the 'low' correlation value and yielding a weighted correlation value of 2. When these values are added together, they sum as 12 which is 10.2% of the total weighted correlation values.

Although the weighted correlation values may not in some cases differ significantly from the unweighted correlation values, it is felt that the weighted value better represents the overall similarity of teeth and corrects for any sample size issues which may exist. The remaining weighted analyses in this section and those in the following section are conducted in the same manner.

Table 8.5: *H. erectus* to *H. sapiens* weighted matches (n=118)
Inuit- 0(3)+ 5(2)+2(1)= 12/118= 10.2%
Fuegian- 3(3)+ 2(2)+ 3(1)= 16/118= 13.6%
PNWT- 1(3)+ 9(2)+ 5(1)= 26/118= 22.0%
Aust. Abor. - 1(3)+ 7(2)+ 6(1)= 23/118= 19.5%
Bushmen- 4(3)+ 9(2)+ 11(1)= 41/118= 34.7%

Yearly reliant on proteinaceous foods (Inuit, Fuegians): 12+16= 28/118= 23.7%
Seasonally reliant on proteinaceous foods (Abor. & PNWT): 26+23/118= 41.5%
Not reliant on proteinaceous foods (Bushmen): 41/118= 34.7%

From the above analysis we see that *H. erectus* has a higher total number of weighted correlations by dietary category with groups 'Seasonally reliant on proteinaceous foods' by a factor of 1.20 over the next highest dietary category.

8.2.2 Sangiran to H. sapiens fmv Match Value Summary and Analysis

The complete list of significant match values between the Sangiran *H. erectus* subpopulation and *H. sapiens* is presented below. They are ordered from lowest match value to highest. The lower the match value, the higher the correlation between specimens which is also indicated here. An analysis of these match values follows the table.

Table 8.6. Sangiran to *H. sapiens* Match Value Summary

Plate	Specimen #	Affiliation	Match Value	Correlation
20	S7-43	Sangiran	4.93	High
	S5	Bushmen		
15	S7-40	Sangiran	6.91	High
	FC848	PNWT		
16	S7-40	Sangiran	7.76	High
	NHMW6035	Fuegian		
26	S7-89	Sangiran	8.87	High
	S9	Bushmen		
11	S7-37	Sangiran	9.78	High
	S16	Bushmen		
17	S7-40	Sangiran	9.82	High
	S5	Bushmen		
27	S7-89	Sangiran	10.65	Moderate
	NHMW8687	Aust. Abor.		
Not Demonstrated	S7-40	Sangiran	11.33	Moderate
	S5	Bushmen		
12	S7-38	Sangiran	12.12	Moderate
	FC848	PNWT		
Not Demonstrated	S7-89	Sangiran	12.24	Moderate
	FC848	PNWT		
13	S7-38	Sangiran	12.93	Moderate
	FC848	PNWT		
23	S7-78	Sangiran	13.92	Moderate
	FC833-3	Inuit		
21	S7-43	Sangiran	13.97	Moderate
	FC848	PNWT		
28	S7-89	Sangiran	14.15	Moderate
	NHMW8687	Aust. Abor.		
19	S7-42	Sangiran	14.65	Moderate
	S16	Bushmen		
Not Demonstrated	S7-89	Sangiran	14.67	Moderate
	FC833-3	Inuit		
Not Demonstrated	S7-40	Sangiran	15.12	Moderate
	FC833-3	Inuit		
Not Demonstrated	S7-89	Sangiran	15.38	Moderate
	NHMW811	Aust. Abor.		
Not Demonstrated	S7-40	Sangiran	15.43	Moderate
	NHMW8687	Aust. Abor.		
24	S7-78	Sangiran	15.78	Moderate
	S5	Bushmen		
Not Demonstrated	S7-89	Sangiran	15.82	Moderate
	S5	Bushmen		
Not Demonstrated	S7-38	Sangiran	15.83	Moderate
	FC833-3	Inuit		

Not Demonstrated	S7-62	Sangiran	16.55	Moderate
	FC848	PNWT		
Not Demonstrated	S7-40	Sangiran	16.92	Moderate
	FC833-3	Inuit		
14	S7-38	Sangiran	17.94	Moderate
	NHMW6035	Fuegian		
Not Demonstrated	S7-62	Sangiran	18.71	Moderate
	FC848	PNWT		
Not Demonstrated	S7-43	Sangiran	20.16	Low
	S16	Bushmen		
18	S7-40	Sangiran	20.91	Low
	FC848	PNWT		
25	S7-84	Sangiran	22.02	Low
	NHMW6035	Fuegian		
Not Demonstrated	S7-40	Sangiran	22.24	Low
	NHMW8687	Aust. Abor.		
Not Demonstrated	S7-62	Sangiran	23.55	Low
	S16	Bushmen		
22	S7-61	Sangiran	24.15	Low
	FC848	PNWT		
Not Demonstrated	S7-40	Sangiran	24.96	Low
	NHMW811	Aust. Abor.		
Not Demonstrated	S7-43	Sangiran	25.13	Low
	S16	Bushmen		
Not Demonstrated	S7-40	Sangiran	25.42	Low
	NHMW6035	Fuegian		
Not Demonstrated	S7-43	Sangiran	25.66	Low
	S16	Bushmen		
Not Demonstrated	S7-78	Sangiran	26.39	Low
	NHMW6035	Fuegian		
Not Demonstrated	S7-89	Sangiran	27.06	Low
	NHMW811	Aust. Abor.		
Not Demonstrated	S7-40	Sangiran	28.76	Low
	NHMW811	Aust. Abor.		
Not Demonstrated	S7-40	Sangiran	28.91	Low
	S9	Bushmen		
Not Demonstrated	S7-89	Sangiran	28.98	Low
	S5	Bushmen		
Not Demonstrated	S7-38	Sangiran	29.32	Low
	S5	Bushmen		
Not Demonstrated	S7-61	Sangiran	29.73	Low
	S16	Bushmen		

Table 8.7. Sangiran Fm. *H. erectus* to *H. sapiens* total number of significant matches (n=43)
Inuit- 0 High, 5 Moderate, 0 Low= 5/ 43= 11.6%
Fuegian- 1 High, 1 Moderate, 3 Low= 5/ 43= 11.6%
PNWT- 1 High, 6 Moderate, 2 Low= 9/ 43= 20.9%
Aust. Abor. - 0 High, 4 Moderate, 4 Low= 8/ 43= 18.6%
Bushmen- 4 High, 4 Moderate, 8 Low= 16/ 43= 37.2%

Yearly reliant on proteinaceous foods (Inuit, Fuegians): 5+5=10/43= 23.3%
Seasonally reliant on proteinaceous foods (Abor. & PNWT): 9+8=17/43= 39.5%
Not reliant on proteinaceous foods (Bushmen): 16/43= 37.2%

From the above analysis we see that the Sangiran *H. erectus* have a higher total number of significant matches by dietary category with groups 'Seasonally reliant on proteinaceous foods' by a factor of 1.06 over the next highest dietary category.

Table 8.8. Sangiran Fm. *H. erectus* to *H. sapiens* weighted matches (n=75)
Inuit- 0(3)+ 5(2)+0(1)= 10/75= 13.3%
Fuegian- 1(3)+ 1(2)+ 3(1)= 8/75= 10.7%
PNWT- 1(3)+ 6(2)+ 2(1)= 17/75= 22.7%
Aust. Abor. - 0(3)+ 4(2)+ 4(1)= 12/75= 16.0%
Bushmen- 4(3)+ 4(2)+ 8(1)= 28/75= 37.3%

Yearly reliant on proteinaceous foods (Inuit, Fuegians): 10+8= 18/75=24.0%
Seasonally reliant on proteinaceous foods (Abor. & PNWT): 17+12/75= 38.7%
Not reliant on proteinaceous foods (Abor. & Bushmen): 28/75= 37.3%

From the above analysis we see that the Sangiran *H. erectus* have a higher total number of weighted correlations by dietary category with groups 'Seasonally reliant on proteinaceous foods' by a factor of 1.04 over the next highest dietary level.

8.2.3 Bapang *to H. sapiens fmv Match Value Summary and Analysis*

The complete list of significant match values between the Bapang *H. erectus* sub-set and *H. sapiens* is presented below. They are ordered from lowest match value to highest. The lower the match value, the higher the correlation between specimens which is also indicated here. An analysis of these match values follows the table.

Table 8.9. Bapang to *H. erectus* Match Value Summary

Plate	Specimen #	Affiliation	Match Value	Correlation
1	S7-3b	Bapang	5.4	High
	NHMW6035	Fuegian		
10	S7-14	Bapang	9.18	High
	NHMW6035	Fuegian		
2	S7-3b	Bapang	9.63	High
	NHMW8687	Aust. Abor.		
Not Demonstrated	S7-3b	Bapang	10.97	Moderate
	S5	Bushmen		
Not Demonstrated	S7-3b	Bapang	13.1	Moderate
	NHMW811	Aust. Abor.		
Not Demonstrated	S7-3b	Bapang	13.59	Moderate
	FC848	PNWT		
3	S7-3c	Bapang	13.83	Moderate
	FC848	PNWT		
4	S7-3b	Bapang	13.9	Moderate
	S5	Bushmen		
5	S7-3c	Bapang	14.05	Moderate
	S9	Bushmen		
6	S7-3c	Bapang	14.38	Moderate
	NHMW8687	Aust. Abor.		
7	S7-3d	Bapang	14.68	Moderate
	NHMW8687	Aust. Abor.		
8	S7-6	Bapang	16.36	Moderate
	S5	Bushmen		
Not Demonstrated	S7-3b	Bapang	16.91	Moderate
	NHMW6035	Fuegian		
9	S7-10	Bapang	17.87	Moderate
	S16	Bushmen		
Not Demonstrated	S7-3b	Bapang	17.9	Moderate
	FC848	PNWT		
Not Demonstrated	S7-3c	Bapang	21.29	Low
	NHMW811	Aust. Abor.		
Not Demonstrated	S7-3b	Bapang	23.48	Low
	S9	Bushmen		
Not Demonstrated	S7-3c	Bapang	24	Low
	FC833-3	Inuit		
Not Demonstrated	S7-3b	Bapang	24.1	Low
	FC833-3	Inuit		
Not Demonstrated	S7-3d	Bapang	24.99	Low
	FC848	PNWT		
Not Demonstrated	S7-20	Bapang	25.38	Low
	S16	Bushmen		
Not Demonstrated	S7-20	Bapang	27.32	Low
	FC848	PNWT		
Not Demonstrated	S7-3c	Bapang	27.76	Low
	S5	Bushmen		
Not	S7-3c	Bapang		

Demonstrated	NHMW811	Aust. Abor.	29.08	Low
Not Demonstrated	S7-20	Bapang	29.46	Low
	FC848	PNWT		

Table 8.10. Bapang Fm. H. *erectus* to *H. sapiens* total number of significant matches (n=25)
Inuit- 0 High, 0 Moderate, 2 Low= 2/ 25= 8%
Fuegian- 2 High, 1 Moderate, 0 Low= 3/25= 12.0%
PNWT- 0 High, 3 Moderate, 3 Low= 6/ 25= 24.0%
Aust. Abor. - 1 High, 3 Moderate, 2 Low= 6/ 25= 24.0%
Bushmen- 0 High, 5 Moderate, 3 Low= 8/ 25= 32.0%

Yearly reliant on proteinaceous foods (Inuit, Fuegians): 2+3=5/25= 20.0%
Seasonally reliant on proteinaceous foods (Abor. & PNWT): 6+6=12/25=48.0%
Not reliant on proteinaceous foods (Bushmen): 8/25= 32%

From the above analysis we see that the Bapang *H. erectus* have a higher total number of significant matches by dietary category with groups 'Seasonally reliant on proteinaceous foods' by a factor of 1.5 over the next highest dietary category.

Table 8.11. Bapang Fm. *H. erectus* to *H. sapiens* weighted matches (n=43)
Inuit- 0(3)+ 0(2)+2(1)= 2/43= 4.7%
Fuegian- 2(3)+ 1(2)+ 0(1)= 8/43= 18.6%
PNWT- 0(3)+ 3(2)+ 3(1)= 9/43= 20.9%
Aust. Abor. - 1(3)+ 3(2)+ 2(1)= 11/43= 25.6%
Bushmen- 0(3)+ 5(2)+ 3(1)= 13/43= 30.2%

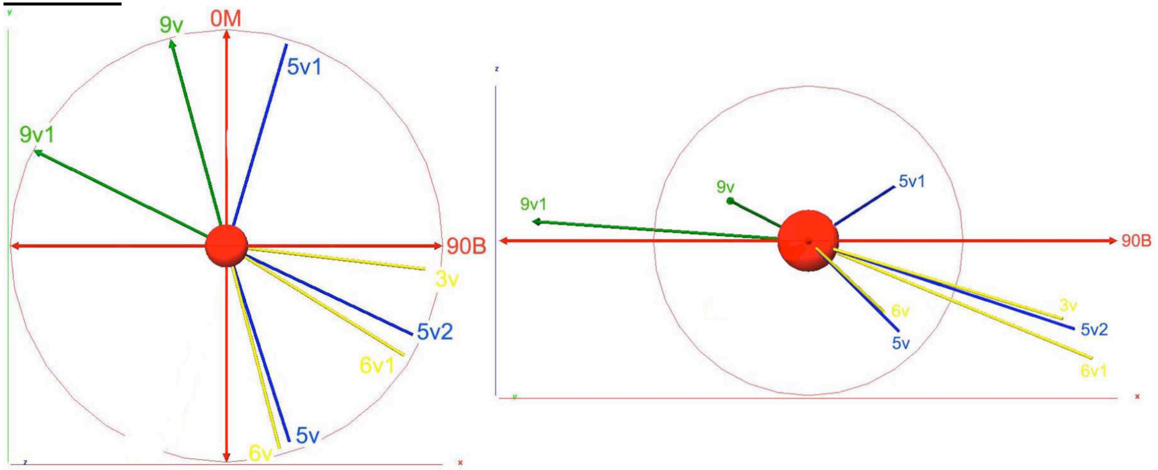
Yearly reliant on proteinaceous foods (Inuit, Fuegians): 2+8= 10/43= 23.3%
Seasonally reliant on proteinaceous foods (Abor. & PNWT): 9+11/43= 46.5%
Not reliant on proteinaceous foods (Abor. & Bushmen): 13/43= 30.2%

From the above analysis we see that the Sangiran *H. erectus* have a higher total number of weighted correlations by dietary category with groups 'Seasonally reliant on proteinaceous foods' by a factor of 1.54 over the next highest dietary category.

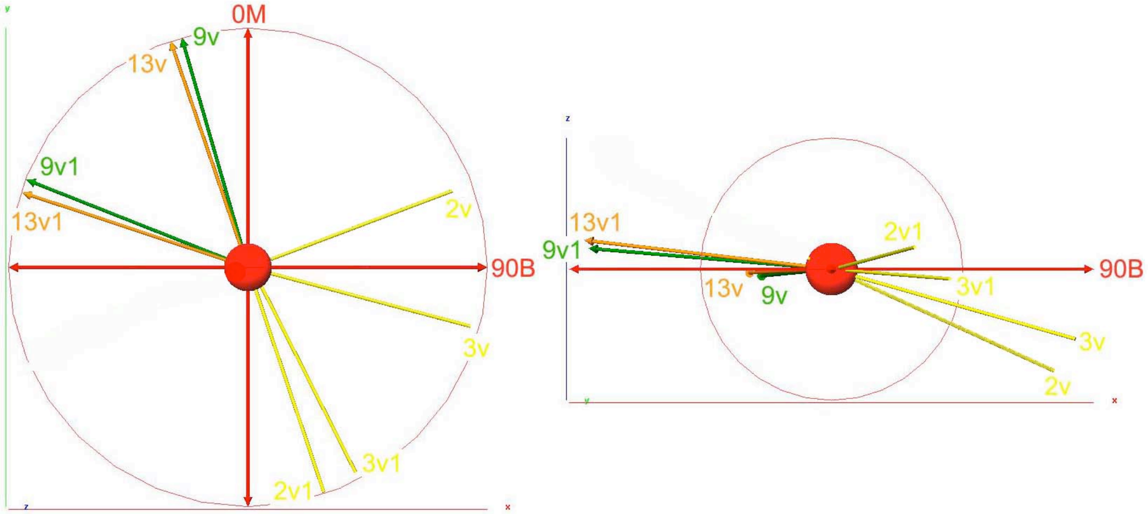
8.3 *H. erectus* to *H. erectus* Facet Microwear Vector Matches

The most significant results of the *H. erectus* to *H. erectus* fmv matches are visually demonstrated via fmv signature diagrams in Plates 29 through 34.

Plate 29



a) S7b-3c: urm2 (Bapang)

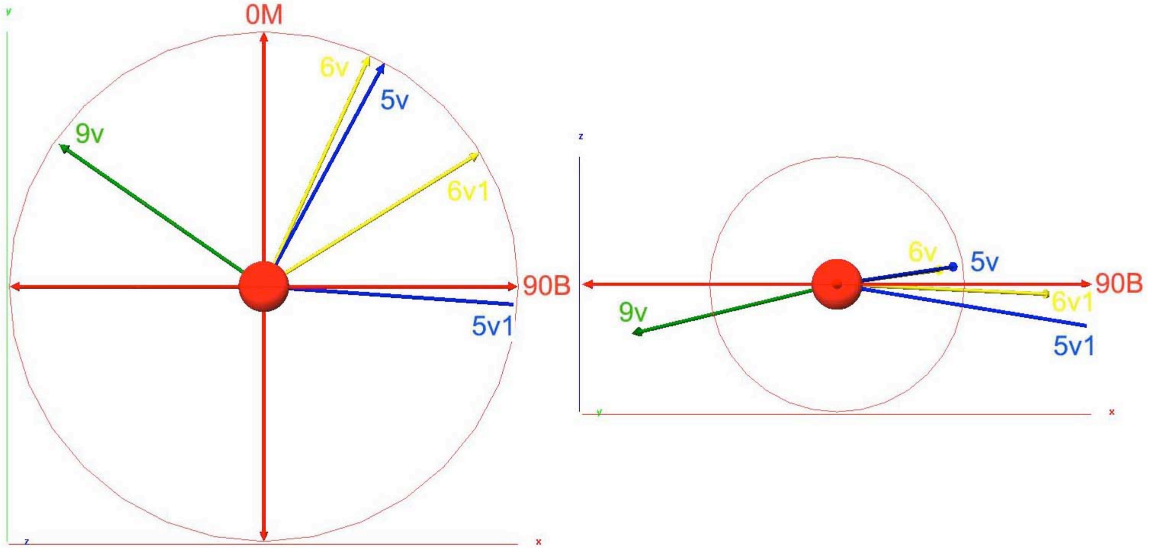


S7a-89: urm2 (Sangiran)

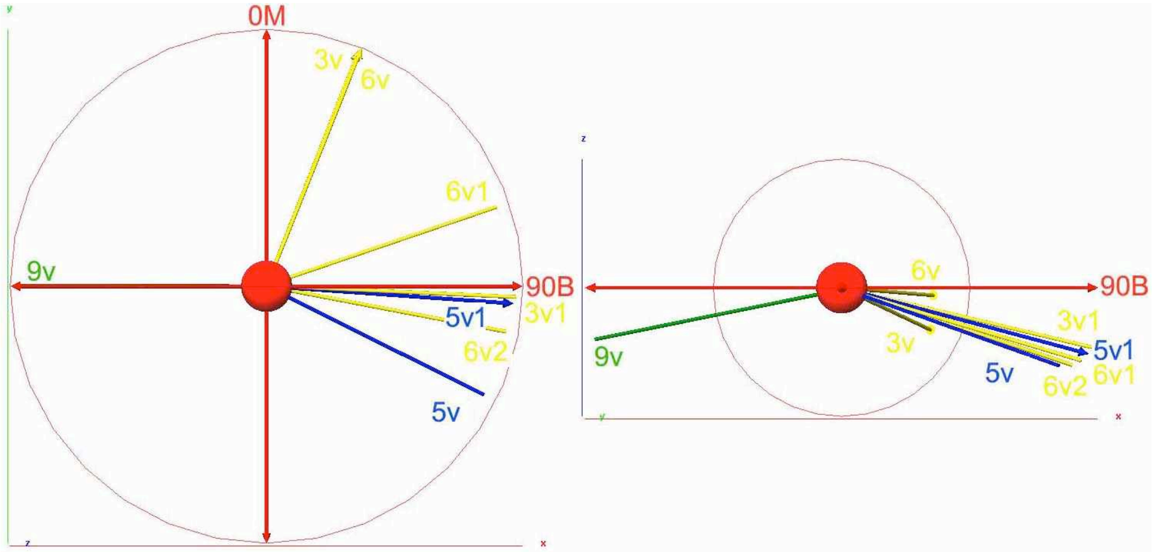
Match Value= 8.71; Wear Stage= 3

High correlation is seen between specimens at fmv's 9v, 9v1 and 3v. Facet 5 demonstrated no vectors in specimen 89 and no substitutes could be found.

Plate 30



S7a-78: llm1 (Sangiran)

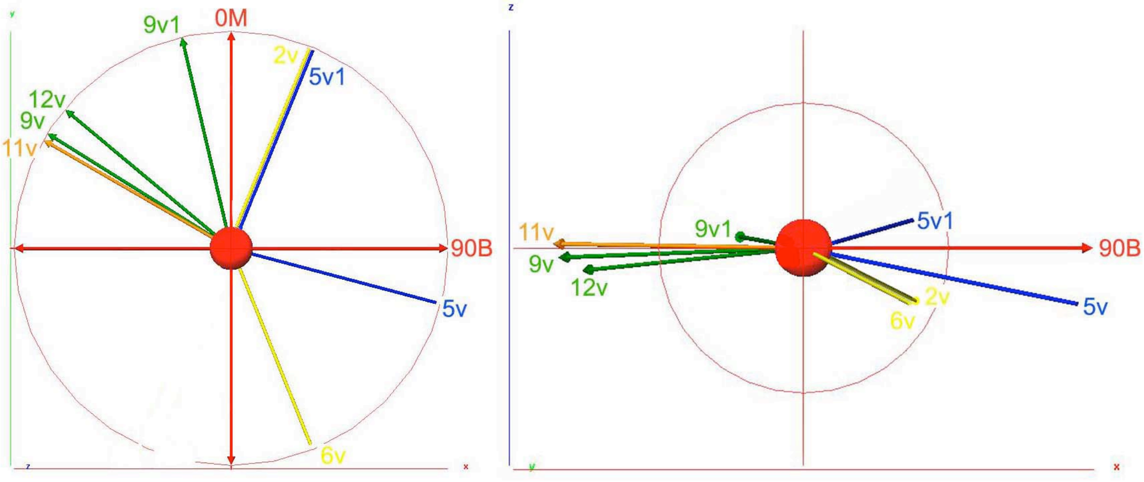


S7a-84: lrm2 (Sangiran)

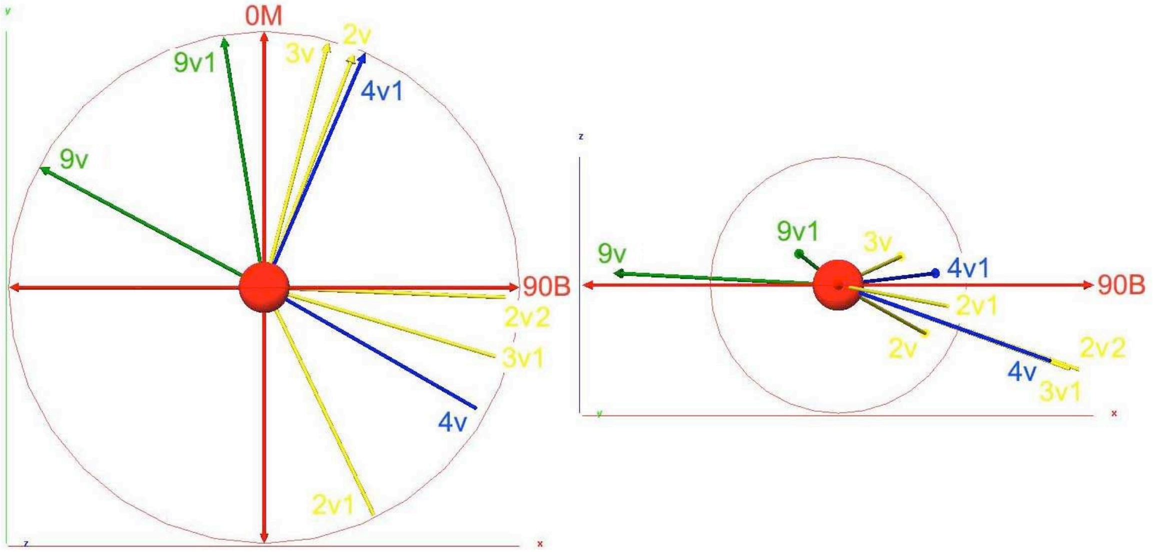
Match Value= 17.70; Wear Stage= 4

Moderate correlation is seen between both specimens at fmv's 6v, 6v1 and 5v1.

Plate 31



S7b-3b: urm1 (Bapang)

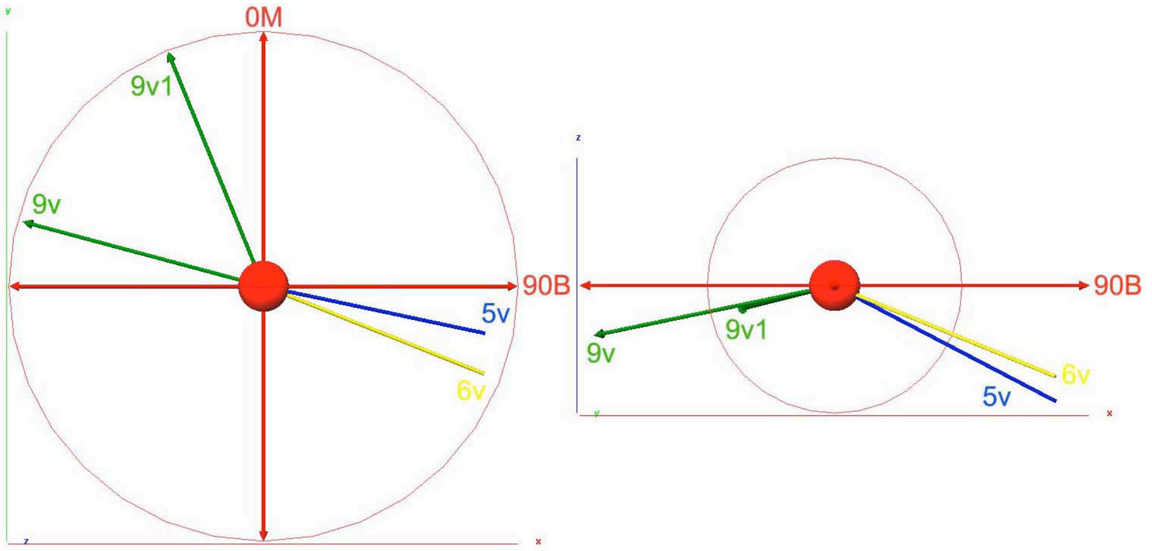


S7a-40: urm1 (Sangiran)

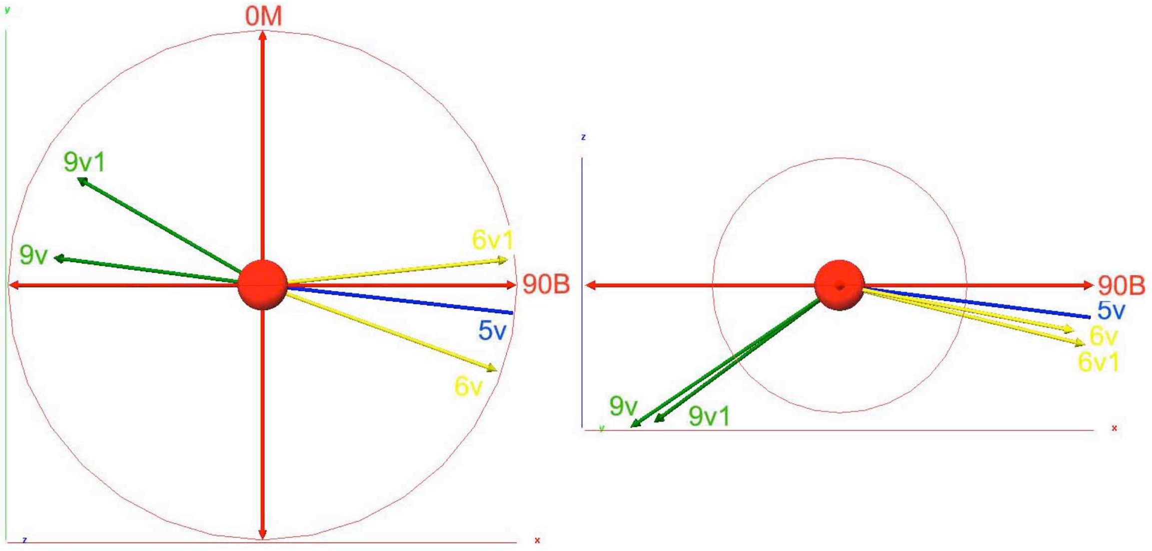
Match Value= 20.35; Wear Stage= 4

Low correlation is seen between specimens at fmv's 2v, 9v & 9v1. There is also good similarity in 3b fmv's 5v, 5v1 & 6v with 40 3v1, 4v1 & 2v1 respectively which is instructive of mandibular Phase I movements.

Plate 32



S7b-20: llm2 (Bapang)

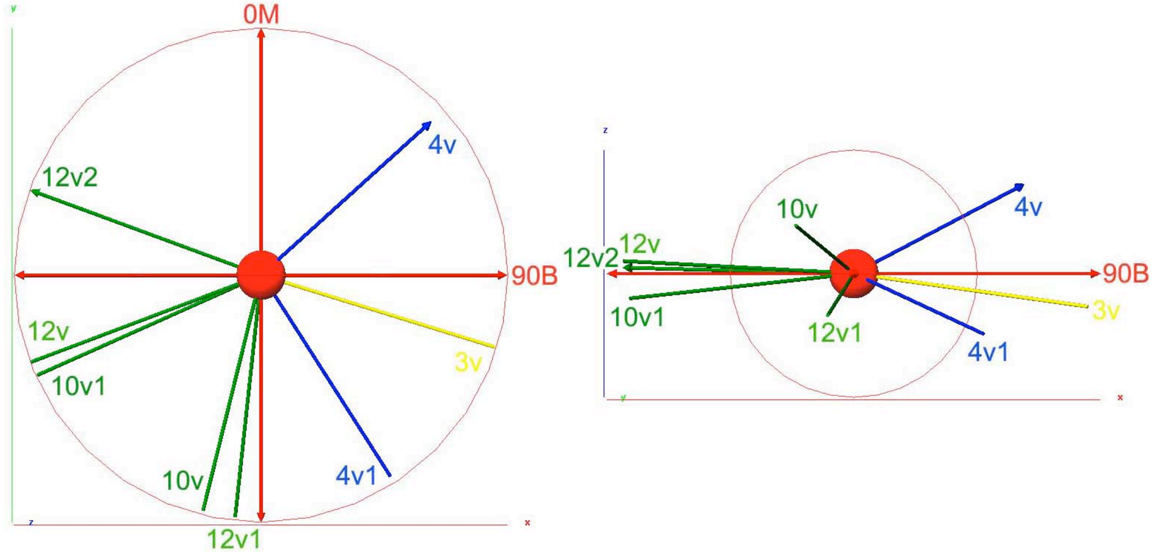


S7a-62: lrm2 (Sangiran)

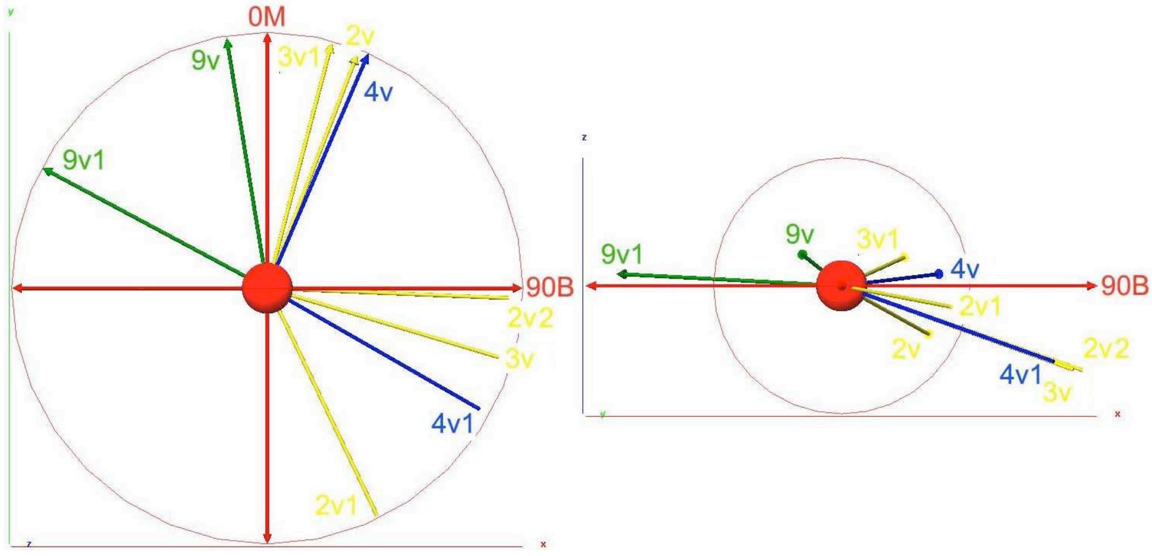
Match value= 23.38; Wear Stage= 2

Low correlation is seen between both specimens at fmv's 9v, 9v1, 5v and 6v. However, overall directionality demonstrates good similarity for the fmv's shared by both specimens.

Plate 33



S7a-38: ulm1 (Sangiran)

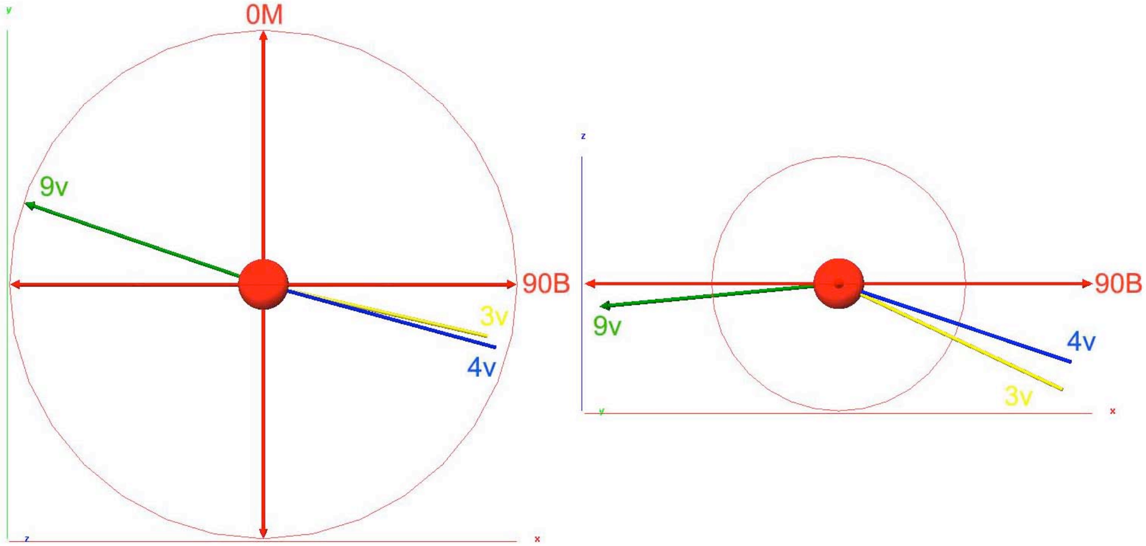


S7a-40: urm1 (Sangiran)

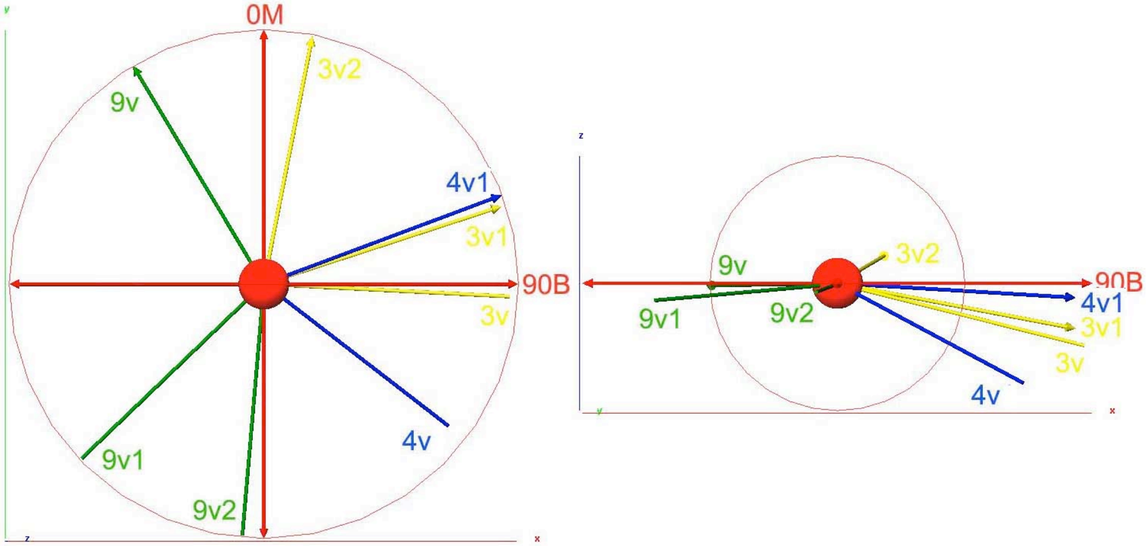
Match Value= 29.91; Wear Stage= 4

Low correlation is seen between both specimens at fmv 3v. There is good correlation between 38 fmv 12v2 and 40 9v1 which is instructive of mandibular Phase II movements. There is also some lesser similarity at fmv's 4v & 4v1 which is instructive of mandibular Phase I movements.

Plate 34



S7b-10: urm1 (Bapang)



S7a-37: urm1 (Sangiran)

Match Value= 34.55; Wear Stage= 3

Very low correlation is seen between both specimens at fmv's 3v and 4v. Although the match value is quite low, absolute 3D directionality of the fmv's 3v and 4v do show some moderate correlations.

8.3.1 Homo erectus to Homo erectus fmv Match Value Summary and Analysis

The complete list of match values between *H. erectus* sub-sets are presented below. *H. erectus* specimens which did not match with any other sample specimens are listed at the bottom of the table.

Table 8.12. *Homo erectus* to *Homo erectus* Match Value Summary

Plate	Specimen #	Affiliation	Match Value	Correlation
29	S7-3c	Bapang	8.71	High
	S7-89	Sangiran		
30	S7-78	Sangiran	17.70	Moderate
	S7-84	Sangiran		
31	S7-3b	Bapang	20.35	Low
	S7-40	Sangiran		
32	S7-20	Bapang	23.38	Low
	S7-62	Sangiran		
33	S7-38	Sangiran	29.91	Low
	S7-40	Sangiran		
34	S7-10	Bapang	34.55	Very Low
	S7-37	Sangiran		
Not Demonstrated	S7-43	Sangiran	36.96	Very Low
	S7-61	Sangiran		
Not Demonstrated	S7-20	Bapang	38.29	Very Low
	S7-76	Sangiran		
Not Demonstrated	S7-42	Sangiran	38.32	Very Low
	S7-43	Sangiran		
Not Demonstrated	S7-14	Bapang	46.72	Very Low
	S7-38	Sangiran		
Not Demonstrated	S7-3b	Bapang	47.33	Very Low
	S7-38	Sangiran		
Not Demonstrated	S7-42	Sangiran	55.00	Very Low
	S7-61	Sangiran		
Not Demonstrated	S7-14	Bapang	55.14	Very Low
	S7-40	Sangiran		
Not Demonstrated	S7-3b	Bapang	67.20	Very Low
	S7-14	Bapang		
	S7-3d	Bapang	matches only with *H. sapiens*	
	S7-6	Bapang	matches only with *H. sapiens*	
	S7-8	Bapang	no other tooth at same wear stage	
	S7-9	Bapang	no other tooth with same facets	
	S7-17	Bapang	no other tooth at same wear stage	
	S7-53	Sangiran	matches only with *H. sapiens*	
	S7-64	Sangiran	bad surface	
	S7-65	Sangiran	no other tooth at same wear stage	
	S7-73	Sangiran	no other tooth at same wear stage	
	S7-76	Sangiran	no other tooth at same wear stage	

From the above table it is readily evident that there are no discernable intra- (Bapang to Bapang or Sangiran to Sangiran) or inter- (Bapang to Sangiran) sub-sample fmv relationships from the possible matches.

8.4 Purported *H. erectus* as Pongo Summary and Analysis

Table 8.13 H*. erectus* as Pongo

S7 *Homo erectus* Purported Pongo	Facet Microwear Vector (fmv) Match Values
14	NHMW6035-M1= 9.18
17	No Matches
20	S7-62-M1= 23.38
	S16-M2= 25.38
	FC848-M2= 27.32
	FC848-M2= 29.46
62	FC848-M2= 16.55
	FC848-M2=18.71
	S16-M2=23.55
65	No Matches

*Match values in red indicate correlation with *H. sapiens*

The Sangiran 7 specimens listed in Table 8.13 have been identified by Grine (Grine & Franzen, 1994) as possibly being more closely allied with Pongo than Homo (no specific reasons are given). From the facet microwear fmv match values in Table 8.13, it can be seen that S7-14 demonstrates high correlation with the Fuegian NHMW6035. As such, S7-14 can be closely allied with Homo calling into question its designation as Pongo. For S7-17, no historic hunter/ gatherer upper 3rd molars at wear stage 4 were present and so no comparisons could be made to obtain match values nor rule on its inclusion/ exclusion as Pongo. S7-20 had 3 low correlation matches with historic hunter/ gatherers (one with Bushmen and two with PNWT) and one with another *H. erectus*. These matches are at the low end of significance indicating that more research needs to be conducted before possibly ascribing this specimen to Pongo. Specimen S7-62 demonstrated 2 moderate (PNWT) and 1 low (Bushmen) correlation with *H. sapiens.* This affiliation may be viewed as indicating an association with hominins possibly calling into question its designation as Pongo. For S7-65, no historic hunter/ gatherer upper 2rd molars at wear stage 1 were present and so no comparisons could be made to obtain match values nor rule on its inclusion/ exclusion as Pongo. For all the above it is understood that including Pongo molars in the sample set would create more relevant correlations and therefore determinations of taxonomic affinity. However, it is highly likely that Pongo and *Homo erectus* had quite different dietary niches and therefore facet microwear vector patterns and so the above determinations can be seen as having some relevance to the stated question.

8.5 Uncertainty of Tooth Position Summary and Analysis

Table 8.14. Uncertainty of tooth position

S7 possible 1st or 2nd Molar	Highest Matches at 1st Molar	Highest Matches at 2nd Molar
14 (ur)	NHMW6035 (ur)=9.18	NHMW6035 (ul)=45.89
	S5 (ur)=30.02	NHMW6035 (ur)=53.20
20 (ll)	S7-76 (lr)=38.29	S16 (lr)=25.38
		FC848 (lr)=27.32
62 (lr)	S7-76 (lr)=36.21	FC848 (ll)=16.55
		FC848 (lr)=18.71
78 (ll)	FC833-3 (ll)=13.92	S7-84 (lr)=17.70
	S5 (ll)=15.78	NHMW6035 (lr)=26.39

*Match values in red indicate correlation with *H. sapiens*
*'u'=upper, 'l'=lower; 'r'=right, 'l'=left

Table 8.14 lists Sangiran 7 molars whose status as 1st or 2nd molars is unclear (Grine and Franzen, 1994). Each of the molars fmv match values were compared as 1st and 2nd molars to determine whether any could be more accurately identified to tooth row position. For S7-14, high correlation is seen with an historic hunter/ gatherer 1st molar but no correlation at the 2nd molar position. Therefore it is highly likely that S7-14 is a 1st molar and not a 2nd. S7-20 shows two low correlations at the 2nd molar position and no correlation at the 1st position and so from this analysis may be provisionally considered a 2nd. Kaifu (2006) also believes that S7-20 is a 2nd molar (although no reason is given) and so lends credence to the determination found here. For S7-62, no correlation is seen at the 1st molar position while two moderate correlations are seen at the 2nd molar position. S7-62 could thus be considered a 1st molar pending further resolution. S7-78 shows two moderate match values at the 1st molar position each of which is lower than the lowest value at the 2nd molar position. However, the moderate value at the 2nd molar position makes this determination difficult and so more definitive proof will have to be sought before making a positive determination.

Chapter 9

Discussion

9.1 *H. erectus* to *H. sapiens* fmv Match Values

9.1.1 Unweighted Match Values with H. sapiens Subpopulations

The match values discussed in this first section represent broad generalizations of *H. erectus* over long spans of geologic time (~1.3my) through dynamic and diverse ecogeographic environments. The following analyses should be understood in that light. More specific analyses of *H. erectus'* occupation within each sedimentological period are investigated in the next section.

From the upper half of Table 8.4, it can be see that *H. erectus* demonstrates the highest percentage of significant matches with Bushmen (35.3%). This indicates that the Sangiran 7 *H. erectus* subpopulation generally exhibited dietary characteristics most similar to Bushmen. This can be understood as showing the sum of dietary strategies theoretically employed by Sangiran 7 *H. erectus* would have been that of an opportunistic omnivorous generalist as others have postulated (Shipman and Walker, 1989; Ungar, 2006). The Bushmen diet is comprised primarily of vegetable material (70% by weight) (Lee and DeVore, 1976) and only 30% meat (per caloric intake) (Lee, 1984). Bushmen have several staple vegetable foods which are largely available throughout the year (mongongo, baobab and marula nuts) (Thomas, 1958; Lee and DeVore, 1976; Lee, 1984) but also rely on various other seasonally abundant foods (eg. Tsama melons, 'bi' roots) (Thomas, 1958; Lee and DeVore, 1976; Lee, 1984). As diet and tooth wear are highly correlated (Teaford & Walker, 1984; Grine, 1986; Teaford, 1988; Ryan & Johanson, 1989; Teaford, 1991; Daegling & Grine, 1994; Ungar, 1996; Ungar, 1998; Semprebon et al. 2004), it might therefore be inferred that Sangiran 7 *H. erectus'* diet consisted primarily of vegetable foods which follows earlier predictions of hominin diets (Bartholomew & Birdsell, 1953; Washburn & Avis, 1958; Zihlman, 1978; Wrangham et al.,1999; Lee-Thorp et al., 2000; Sebastion et al., 2002; van der Merwe et al., 2003; Wrangham and Conklin-Brittain, 2003; Wrangham, 2006 & 2009).

However, the next highest significant percentages correlate almost equally to both the Australian Aborigines (20.6%) and PNWT (22.1%). As the Australian Aborigines inhabited environments roughly similar to Bushmen (and thus Sangiran *H. erectus*), this can be readily understood (Smith, 1984; Baum et al., 1998; Lee at al., 2004; Thulin et al., 2004; Danforth et al., 2006; Mahoney, 2006; El-Zaatari, 2007; Stollhofen et al., 2008) (although the Aborigines probably consumed more protein overall than *H. erectus* due to the use of hunting/ trapping technologies likely not available to *H. erectus* (Clark, 1968; Zihlman, 1978; Lewin, 1984; Bower, 1997; Klein, 1999; Tong, 2001; Dominguez-Rodrigo, 2002; Tong, 2002; Dennell, 2003; Anton & Swisher, 2004) but the relatively high percentage of matches with PNWT are harder to interpret. Lithostratigraphy of the Sangiran Formation demonstrates three distinct depositional periods. The lowest and therefore oldest layers contain large deposits (25 meters deep) of freshwater gastropods that suddenly turn brackish for a considerable time. This is evidenced by the presence of layers of marine mollusks 15 meters thick indicating a seawater ingression. This period ends with the sealing off of the marine intrusion by volcanic deposition forming a very large inland lake which then reverted to normal limnic sedimentation. The

Sangiran Fm. correlates to the relatively sparse Satir Fauna at its lowest, youngest layers and transitions to the more diverse Ci Saat Fauna at its highest layers. The Sangiran Fm. ends at the Grenzbank conglomerate which also marks the base of the Bapang Fm. Here, the sediments lack such large deposits or thick concentrations of organisms indicative of non-fluviatile aqueous environments. There is however periodic deposition of cross-bedded fluviatile sands which would indicate the presence of rivers or streams. The Bapang Fm. is characterized by the diverse and speciose Trinil HK Fauna (indicative of open lacustrine or fluviatile woodland) at its lowest layers and transitions to the Kedung Brubus Fauna which indicates a dryer, more open woodland/ savanna environment.

These series demonstrate the continued presence of substantial aqueous environments at Sangiran (except at the end of the Bapang Fm. correlated to the Kedung Brubus fauna) (Koenigswald, 1934, 1935, 1940; Larick et al., 2004; Hertler & Rizal, 2005) and, as such, the opportunity for *H. erectus* to exploit any aquatic resources including fish and shellfish (Verhaegen & Puech, 2000; Choi and Driwantoro, 2007) that would certainly have been abundant especially so during the Sangiran Fm. sequence. This may account for the relatively high percentage of significant match values obtained for *H. erectus* with the PNWT whose diet contained quite high components of fish and/ or proteinaceous resources (Suttles, 1968; Bennett, 1975; Chisholm et al*.,* 1983; Lazenby and McCormack, 1985; Boxberger, 1989; Deur, 1999).

It also must be noted that *H. erectus* does not correlate very highly with either the Inuit or Fuegian subpopulations. This may be anticipated as these populations exist in quite extreme, colder environments different from *H. erectus* and where vegetable foods are rarely consumed due to their scarcity or suitability in the environment (Darwin, 1859; Campbell, 1905; Gusinde, 1939; De Poncins, 1941; Vanstone, 1962; Draper, 1977, 1978; Orquera et al., 1977; Bang et al., 1980; Chapman, 1986; Yesner et al., 2003).

9.1.2 Broader Dietary Unweighted Correlations with H. sapiens

The lower portion of Table 8.4, groups the significant match values according to broader dietary categories. This demonstrates that *H. erectus* matches with *H. sapiens* by a factor of 1.21 times more often at the 'Seasonally reliant on proteinaceous foods' (PNWT and Australian Aborigines) than any other dietary category. This result is consistent with the two main sources used to establish ecodietary potential. The lithostratigraphic and faunal records both indicate that the environment of the Sangiran Dome would have contained ample mammalian, avian and aquatic sources of protein but also substantial vegetative resources when/ if proteinaceous resources were not available (Koenigswald, 1934, 1935, 1940; Weesie, 1982; Semah, 1984, 1993, 1998; Heaney, 1986; Van den Bergh et al., 1992; Aziz and Van den Bergh, 1995; de Vos, 1995; Simpson & Day 1996; Van der Meulen and Musser, 1999; Bilsborough, 2000; Verhaegen & Puech, 2000; Semah, 2001; Semah and Semah 2001; Storm, 2001; Van den Bergh, 2001; Larick et al., 2004; Lee et al., 2004; Meijaard, 2004; Hertler & Rizal, 2005; Bouteaux, 2007; Choi and Driwantoro, 2007; Louys, 2007).

The next highest match values are with Bushmen whose dietary economy and environment would also have been similar to those encountered or used by *H. erectus* at least at certain times of the year or through the span of *H. erectus'* occupation at Sangiran (see paragraph 2, section 9.1.1). Again, there is a relatively low correlation of

H. erectus with either the Inuit of Fuegian subpopulations likely for the reasons given in the last paragraph of section 9.1.1.

9.1.3 Weighted Match Values with H. sapiens Subpopulations

From the upper half of Table 8.5, the percentage correlations of *H. erectus* to individual *H. sapiens* samples as seen in Table 8.4 remain relatively constant. As such, all of the explanatory text regarding the correlations of Table 8.4 can also be applied here for Table 8.5. This weighted value may be seen as confirming that the unweighted percentages are not biased but, for the sake of accuracy and consistency, the unweighted and weighted values will be given for all further comparisons.

9.1.4 Broader Dietary Weighted Correlations with H. sapiens

The lower portion of Table 8.5, groups the significant match values according to broader dietary categories. This demonstrates that *H. erectus* matches with *H. sapiens* by a factor of 1.20 times more often at the 'Seasonally reliant on proteinaceous foods' (PNWT and Australian Aborigines) than any other dietary category. This value is statistically the same as seen for that obtained in Table 8.4 and so all the explanatory text regarding the correlations of Table 8.4 can also be applied here for Table 8.5.

9.2 Sangiran Fm. *H. erectus* fmv Match Values with *H. sapiens*

9.2.1 Unweighted Match Values with H. sapiens Subpopulations

From Table 8.7, it can be seen that the chronologically older Sangiran *H. erectus* sub-set (~1.3 to 1.0ma) matches most strongly with the Bushmen (37.2%). This correlation is significantly higher than the next highest match values of 20.9% and 18.6% for PNWT and Australian Aborigines respectively. This is an interesting result as the Sangiran Fm. lithostratigraphy along with the correlation with the Satir and Ci Saat Faunas indicate the widespread presence of non-fluviatile aquatic features in the environment. Bushmen are known to inhabit more dry, open country with less stable water sources and so this result needs to be further investigated with respect to the larger dietary categories (see below).

9.2.2 Broader Dietary Unweighted Correlations with H. sapiens

The lower portion of Table 8.7, groups the significant match values according to broader dietary categories. This demonstrates that *H. erectus* matches with *H. sapiens* by a factor of 1.06 times more often at the 'Seasonally reliant on proteinaceous foods' (PNWT and Australian Aborigines) (39.5%) than any other dietary category. This result does not significantly differ from the next best represented category 'Not seasonally reliant on proteinaceous foods (Bushmen)' which correlates at 37.2%. As such, these results indicate *H. erectus* was not following any one specific dietary strategy at this time (predominantly relying on protein over vegetation). *H. erectus* would likely have been moving between resources exploiting local food concentrations depending upon seasonal, migrational (as in the following of game) and/ or climatic shifts. The lithostratigraphic and faunal records both indicate that the environment of the Sangiran Fm. would have been relatively abundant in mammalian, avian and aquatic sources of protein but also substantially lush vegetative resources when/ if proteinaceous foods were not available (Koenigswald, 1934, 1935, 1940; Weesie, 1982; Heaney, 1991; Van der Meulen and Musser, 1999; Van den Bergh, 2001; Larick et al., 2004; Meijaard, 2004; Bouteax, 2007; Choi and Driwantoro; 2007). It thus seems that *H. erectus* was following an opportunistic omnivorous strategy. But it is quite interesting that erectus was probably able to include so much protein in its diet with out the benefit of an archeologically demonstrated hunting culture (Clark, 1968; Zihlman, 1978; Lewin, 1984; Bower, 1997; Klein, 1999; Tong, 2001; Dominguez-Rodrigo, 2002; Tong, 2002; Dennell, 2003; Anton & Swisher, 2004).

9.2.3 Weighted Match Values with H. sapiens Subpopulations

The results obtained from the entirety of Table 8.8, are essentially the same as the percentages and correlations obtained from the unweighted analysis of this data as seen in Table 8.7. As such, the explanatory text regarding Table 8.7 also applies for Table 8.8.

9.3 Bapang Fm. *H. erectus* fmv Match Values with *H. sapiens*

9.3.1 Unweighted Match Values with H. sapiens Subpopulations

From the upper portion of Table 8.10, it can be seen that the chronologically younger Bapang *H. erectus* sub-set (~.7 to 1.0ma) most closely matches the Bushmen over the next highest *H. sapiens* subpopulation by a considerable degree (32.0% to 24.0%). The Bapang individuals would have existed initially in a mosaic environment composed of open woodlands with grassy habitats interspersed by rivers (correlated to the Trinil HK Fauna) (Van der Meulen and Musser, 1999; Bouteaux, 2007) which transition to more dry, open savanna type habitats (although still with some rivers present and correlated to the Kedung Brubus Fauna) (Heaney, 1986; Semah, 1984, 1993, 1998; Watanabe & Kadar, 1985; Bilsborough, 2000; Semah, 2001; Semah and Semah 2001; Storm, 2001; Lee et al., 2004; Bouteax', 2007; Louys, 2007). These habitats are quite similar to those in which the Bushmen exist and so this correlation is logical and also remains consistent with what is seen in the Sangiran Fm. *H. erectus*.

9.3.2 Broader Dietary Unweighted Correlations with H. sapiens

The lower portion of Table 8.10, groups the significant match values according to broader dietary categories. This demonstrates that *H. erectus* matches with *H. sapiens* by a factor of 1.5 times more often at the 'Seasonally reliant on proteinaceous foods (Aust. Abor. & PNWT)' (48%) than the next highest category 'Not reliant on proteinaceous foods (Bushmen)' (32%). As compared to the results obtained for the Sangiran Fm. *H. erectus* using the same analysis (Table 8.7) where there is virtually no difference between the two broader dietary categories, this result might indicate a shift away from simple 'gathering' to a more 'hunting' dietary economy. This would not necessarily be unexpected as the Trinil HK Fauna of the early Bapang Fm. and the Kedung Brubus Fauna of the later Bapang Fm. (along with lithostratigraphy) indicate the presence of many large, open range mammals, ample avian species and the persistence of fluviatile aquatic habitats where fish, shell fish, tortoises etc. would be readily procurable (Heaney, 1991; Weesie, 1982; Van den Bergh et al., 1992; Van den Bergh, 2001; Meijaard, 2004; Bouteax, 2007). During this period, species numbers would have increased to approximately 40 over the ~17 present during the Sangiran Fm. era.

9.3.3 Weighted Match Values with H. sapiens Subpopulations

From the upper portion of Table 8.11, the percentage correlations continue to indicate that *H. erectus* most closely associates with Bushmen (30.2%) presumably for the reasons discussed in several sections above. However, unlike the previous analyses of weighted match values which show much more sharp distinctions between *H. erectus* correlations with individual *H. sapiens* samples, there seems to be a subtle gradation in correlation percentage from the Bushmen to Australian Aboriginal to PNWT and into Fuegian (which for the first time significantly approaches the correlation percentages seen in the three above mentioned *H. sapiens* samples). It is possible that this shows that *H. erectus* is moving distinctly toward more reliance upon proteinaceous food resources. This outcome would logically follow per the paleoecological shift which was occurring at the time (see section 9.3.2).

9.3.4 Broader Dietary Weighted Correlations with H. sapiens

The lower portion of Table 8.11, demonstrates that *H. erectus* matches with *H. sapiens* by a factor of 1.54 times more often at the 'Seasonally reliant on proteinaceous foods' (PNWT and Australian Aborigines) than any other dietary category. This value is statistically the same as seen for that obtained in Table 8.10 and so all the explanatory text regarding the correlations of Table 8.10 can also be applied here for Table 8.11.

9.4 Summary of *H. erectus* to *H. sapiens* Match Value Analysis

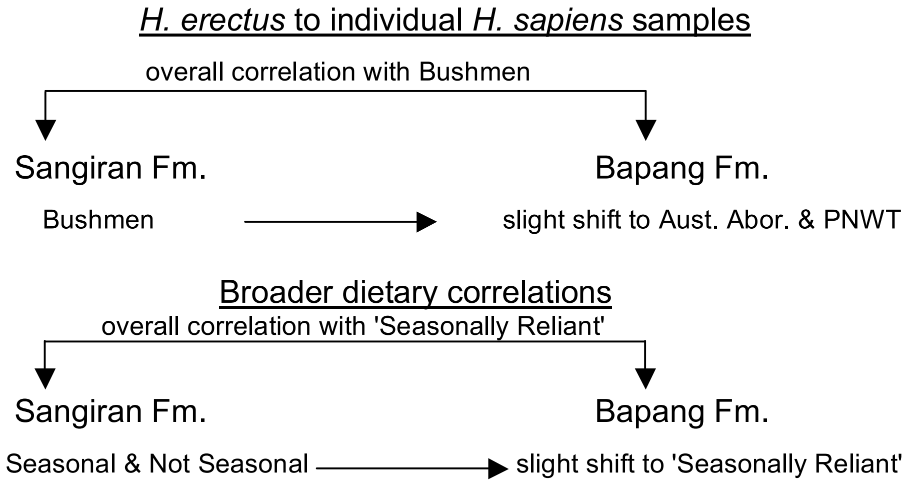
From the above analyses of 'Total Significant/Unweighted Matches' and

'Weighted Matches', it can be readily seen that *H. erectus* consistently correlates most often with Bushmen. The next most highly correlated sample is PNWT followed closely by Australian Aborigines. *H. erectus* does not correlate very well with the Fuegians and even less so with Inuit. The correlations are consistently high in the first two analyses ('All' and 'Sangiran Fm.' *H. erectus* to *H. sapiens*). The correlation however drops off a bit with regards to the Bapang Fm. sub-set (Sangiran 7b) such that the percentage point match difference between Bushmen and Australian Aborigines (and to a slightly lesser extent PNWT) evens out.

From the analysis of 'Broader Dietary Unweighted & Weighted Correlations', it is evident that *H. erectus* consistently correlates most often with 'Seasonally Reliant on Proteinaceous Foods (PNWT & Australian Aborigines)'. The next most highly correlated category is 'Not Seasonally Reliant on Proteinaceous Foods (Bushmen)' and least often with 'Yearly Reliant on Proteinaceous Foods (Fuegians and Inuit)'. These correlations are consistently high in the analyses 'All' and 'Bapang Fm.' but are statistically equal between 'Seasonally Reliant' & 'Not Seasonally Reliant' when looking at the 'Sangiran Fm.' analysis.

The two above dietary summations may, at first, be seen as inconsistent, however, as Figure 9.1 shows, both data sets point to an *H. erectus* that is becoming more dietarily specialized through chronostratigraphic time. Although the overall correlation of *H. erectus* with individual *H. sapiens* samples is with Bushmen, a distinct signal arises through its occupation on Java which indicates that it begins to expand its diet by the time of the Bapang Fm. The larger correlation in the 'Broader' category is that of 'Seasonally Reliant' but does not shift significantly so until the Bapang Fm.

Figure 9.1: *H. erectus* Chronostratigraphic Dietary Trend



During the transition from the Sangiran Fm. to the Bapang Fm., Southeast Asia experienced an environmental shift that lowered sea levels to such an extent that Java was now connected to the mainland by the large landmass Sundaland (Batchelor, 1979; Musser, 1982; Vrba et al., 1989; Van den Bergh et al., 1996; Brandon-Jones, 1998; Aziz & de Vos 1999; Meijaard, 2004). The flora and fauna shifted from a wetter more swampy, lacustrine biome to a drier, open-woodland/ savanna environment interspersed with rivers and streams. This transition fostered the migration of larger mainland game animals to Java as well as providing ample habitat for avian and aquatic (fish, turtles, shellfish etc.) proteinaceous foods. In short, an environment which was much more rich, diverse and speciose than that which existed during the Sangiran Fm. It therefore appears that *H. erectus* was taking advantage of this relative bounty as demonstrated by the results obtained. These results differ from a relatively small sample of Sangiran teeth investigated by Lee at al. (2004) (section 5.4.2.).

9.4.1. H. erectus' diet in context to H/G's

From this analysis it is impossible to ascertain specifically what *H. erectus* was consuming and whether those foods were being processed in any manner. However, through the correlations shown and the apparently greater dietary sophistication through time, more robust inferences can be drawn regarding *H. erectus'* diet.

It is known that *H. erectus'* cranial capacity had increased significantly over earlier hominins. The exact reasons for such are the subject of much debate but most involve or include a dietary component (Milton; 1999). As shown here, *H. erectus'* diet shifted from a more generalized Bushmen model to that of an organism beginning to specialize in proteinaceous foods. How much hunting/ gathering (shellfish etc.)/ scavenging of these foods occurred cannot be known but the simple inclusion of more game (as defined by animals that must be hunted and processed in some manner) would yield the opportunity to consume more fats from organ meats or marrow. The use of stone tools at Sangiran (von Koenigswald and Ghosh, 1972; Jacob et al., 1978; Semah et al. 1992; Simanjuntak, 2001; Widianto et al., 2001; Stone, 2006) show that *H. erectus* had the capability to hunt and process game while the presence of only three large carnivores (as opposed to approximately 9 in Africa at this time) would have offered a niche within which *H. erectus* could successfully compete for these proteinaceous resources.

Per the apparent shift towards and/ or specialization in acquiring proteinaceous foods, their consumption by *H. erectus* would have been greatly facilitated through the use of fire. Although definitive proof of use of fire at Sangiran has not been found, some contentious proof has been found in East Africa (Bellomo, 1994). If fire was controlled in

Africa then, its continued use in Java (through cultural migration) would seem likely. Several researchers have proposed the controlled use of fire as having originated in East African *H. erectus* in order to facilitate the consumption of USO's (Wrangham, 1999, 2003). It is thought that cooking would make the USO's more metabolically useful thus aiding in the ability to nourish the larger brain seen in *H. erectus* (Wrangham, 2006 & 2009).

The inclusion of vegetative foods in Sangiran 7 *H. erectus'* diet has been only mentioned as a correlate to protein comsumption. The analyses, however, speak indirectly to this topic. The high correlations seen with Bushmen may indicate a comparable breadth of vegetative foods consumed by *H. erectus* (Schoeninger, 2007; Berbesque & Marlowe, 2009). This is not unreasonable as the Hadza of Tanzania (maybe a more accurate ecogeographical correlate than Bushmen) subsist on a wide range of wild vegetative foods (Skinner, 1991). The analytical categories and, as such, fmv signatures could potentially then be seen as being reflective not only of protein consumption but as a balance between and instructive of vegetative *and* protein intake. The comparative H/G samples composition and the desire for simplicity of argument precluded finer dietary distinctions, however.

Confounding the analyses and above arguments are two inorganic factors common to microwear studies. The first is the inclusion of exogenous grit and/ or soil phytoliths in the diet (Baker et al., 1959; Puech et al., 1981 & 1985; Peters, 1982; Kay and Covert, 1983; Lucas and Teaford, 1995; Ungar et al., 1995; Lalueza et al., 1996; Danielson and Reinhard, 1998; Ungar and Spencer, 1999; Pearsall, 2000; Gugel et al., 2001; Lucas, 2004Nystrom et al. 2004; Ungar et al., 2006). No studies have systematically investigated the effect this grit can have on mastication generally and microwear specifically *in vivo*. As such, the effect exogenous grit has had upon the fmv signatures (*H. erectus* and *H. sapiens* alike) and thus this analysis is difficult to establish. However, the diets of at least Bushmen and Australian Aborigines likely contain significant amounts of grit due to the drier environments within which they exist and the processing of food on the ground and/ or cooking in ashes or on stones (Lalueza et al., 1996; Teaford & Lytle, 1996; Ungar & Spencer, 1999; Schmidt, 2001).

The second factor is that of the so called 'Last Supper Phenomenon' (Grine, 1986). Some research suggests that microwear patterns can be overwritten rather quickly and easily by dietary changes making it likely that any microwear signal is only indicative of foods consumed shortly (days to weeks) before death (Walker et al., 1978; Covert and Kay, 1981; Teaford and Oyen, 1989; Teaford & Tylenda, 1991, Teaford, 2007). In both samples (*H. erectus* and *H. sapiens*), the exact season and/ or ecological context (eg. whether the individual was near or far from a water source which would hypothetically influence what they would be eating) of death are unknown. Consequently, this analysis has sought to portray the sum of each samples fmv signatures as dietary generalizations and not as definitive statements regarding their full dietary breadth or strategy. However, it is also possible that seasonally abundant (eg. mongongo nuts in Bushmen and salmon in PNWT) or stable, reliable resources (eg. shellfish in *H. erectus*) were being consumed prior to death (at least in some of the sampled individuals) and so it not unreasonable to believe that some of the fmv signatures do represent longer dietary trends and not simply an individuals last meal.

9.5 *Homo erectus to Homo erectus fmv Match Value Analysis*

From Table 8.12 it can be seen that there are no intra- or inter-sub-set relationships discernable from the match values. This is likely a factor of sample size especially since 10 of the specimens either matched only with *H. sapiens* or did not match any other tooth per the reasons stated in Table 8.12. It is believed that by increasing the sample size to include all Javan, Chinese and African *H. erectus*, larger taxonomic/ dietary patterns will emerge.

9.6 Purported *H. erectus* as Pongo Analysis

Although inclusion of Pongo in the comparative sample would have been much more illustrative, Table 8.13 demonstrates that this method has some potential to discern genera. Three of the specimens whose generic affinity was in question matched 'high' (S7-14), 'moderate' (S7-62) and 'low' (S7-20) with Fuegians, PNWT & Bushmen and Bushmen & PNWT respectively.

9.7 Uncertainty of Tooth Position Analysis

Table 8.14, shows that this method has some ability to discern tooth position. Of the four specimens in question, S7-14 matched 'high' with Fuegians, S7-20 matched 'low' with Bushmen & PNWT, S7-62 matched 'moderate' with PNWT and S7-78 matched 'moderate' with Inuit and Bushmen.

9.8 A Note On Facet Microwear Vector Signature Diagrams

The facet microwear vector signature diagrams were initially created to visualize and quantify data suitable for statistical analysis. As the fmv diagrams document a tooth crowns 3D functional masticatory movements, they also facilitate an understanding of the complex and highly variable nature of masticatory processes per dietary preference. As such, in future work, it will be possible to recreate exact 3D VR mandibular movement for any one tooth or individual if the entire tooth set is used. This will allow larger, more succinct dietary, metabolic and possibly taxonomic and migrational issues to be explored.

9.9 Future Work

The work contained herein can be applied to ANY organism that demonstrates microwear on its teeth. Apart from the obvious use in further paleoanthropological and archaeological research, this method may be of much value to the Mesozoic reptilian (dinosaurs et al.) paleontologist as there is much public interest and contention in this field regarding metabolic strategy (homeotherm-vs-heterotherm). This method may also find useful applications in the fields of dentistry and orthodontics.

It is planned that this method will be used on any and all *H. erectus* dentition that can be obtained in order to establish broader populational, taxonomic and dietary inferences when compared against a larger, more heterogenous historic HG sample. A comparison of the larger Java *H. erectus* with *Homo floresiensis* might prove particularly interesting as Javan *H. erectus* is theorized as having been the parent population to this new species. As stated above, further analysis of the facet microwear vector signature diagrams may lead to a database of mandibular movement which would be open and available to any researcher which might find it useful. Also, this method adds another layer of data to the occlusal compass concept and furthers its usefulness and robusticity in determining the occlusal fingerprint of any one individual.

Beyond answering the above questions, potentially the most important aspect of this work is the development of techniques through which 3-dimensional masticatory movement can be recreated via virtual reality computer generated simulations as the true functional behavior of an extinct organism. When seen against and within the totality of environmental factors, this behavior will yield definitive insight into the actual physiology and metabolism of *Homo erectus*; the direct ancestor to *Homo sapiens.* An important step will thus be taken in illuminating that evolutionary relationship from a wholly organismal perspective with the repercussions to understanding the factors which led to our own humanity being implicit and manifest.

Conclusions

The enclosed thesis demonstrates that 3D occlusal facet microwear vector (fmv) signatures can be derived from and useful in defining an extinct hominin species dietary preference in an ecogeographic context. Through the use of historic *H. sapiens* correlates it was found that the Sangiran 7 *H. erectus'* diet most closely resembled that of Bushmen when looking at individual teeth. However, it was also demonstrated that, when looking at larger dietary and sample-wide signals, that *H. erectus* correlated most closely with historic groups which are 'seasonally reliant on proteinaceous foods'. Both of these results are consistent with the larger Pleistocene ecogeographic context in which the Sangiran 7 *H. erectus* existed.

This thesis also demonstrates that this novel method has some usefulness in distinguishing molars by tooth row position (M1 or M2) while possibly having some ability to discern molars at the generic level.

The method has further uses in visualizing and defining the overall 3D directionality of microwear movement upon molar facets. As such, mandibular movement and overall masticatory function can be extrapolated for individual teeth and especially for entire molar dental sets. This may lead to more precise conceptions of diet, physiology, life history and evolutionary adaptive strategy in extinct hominins.

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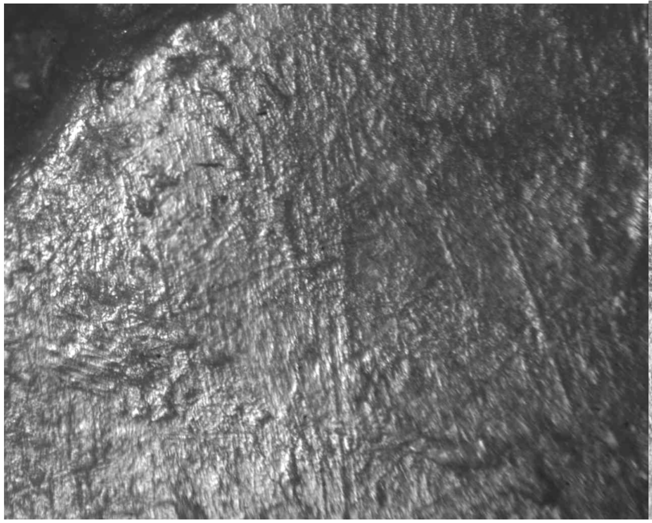
Appendix A. Facet Microwear: Sangiran 7 *Homo erectus*

3b



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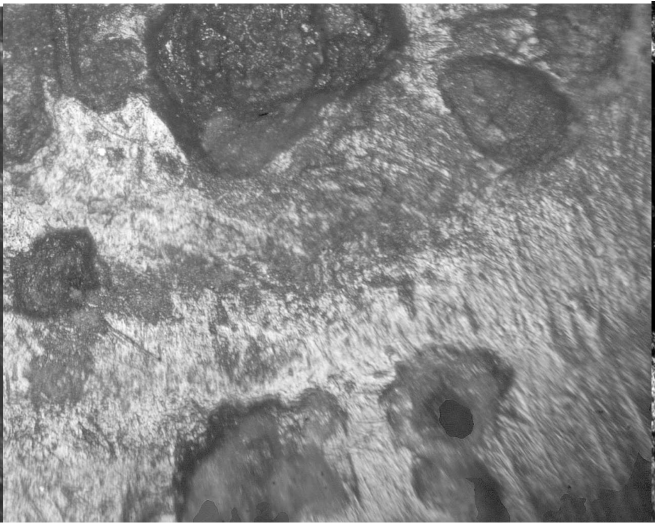

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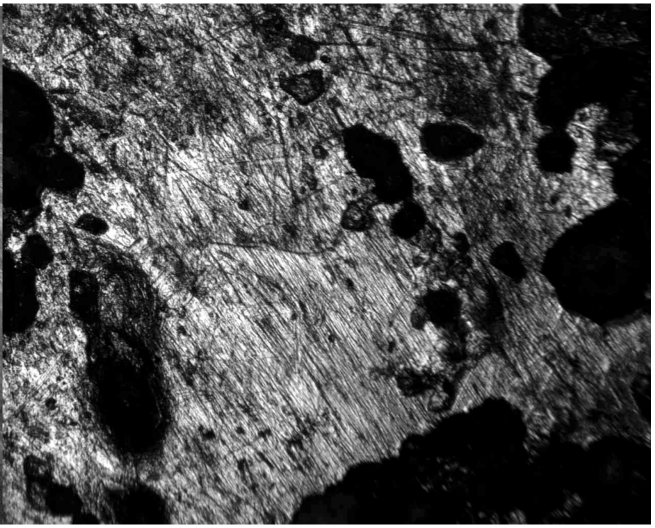

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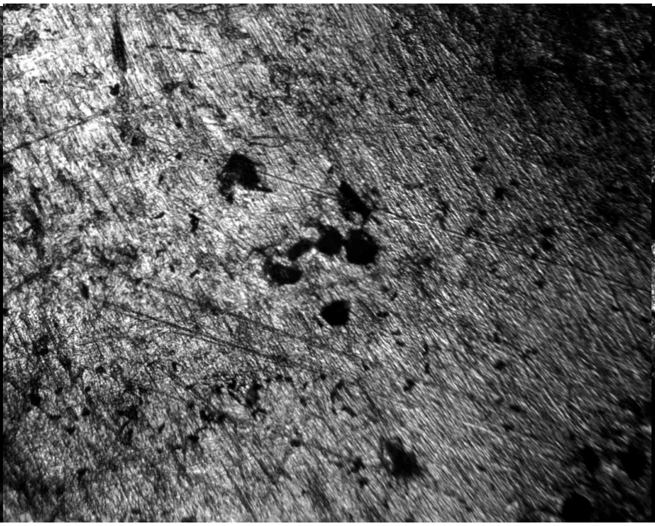

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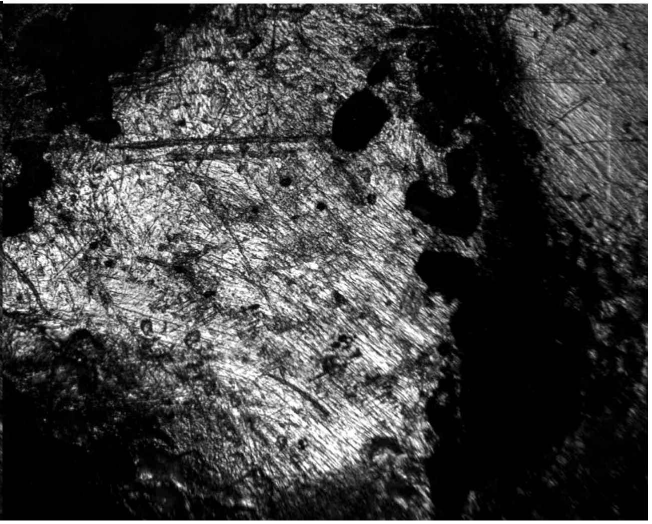

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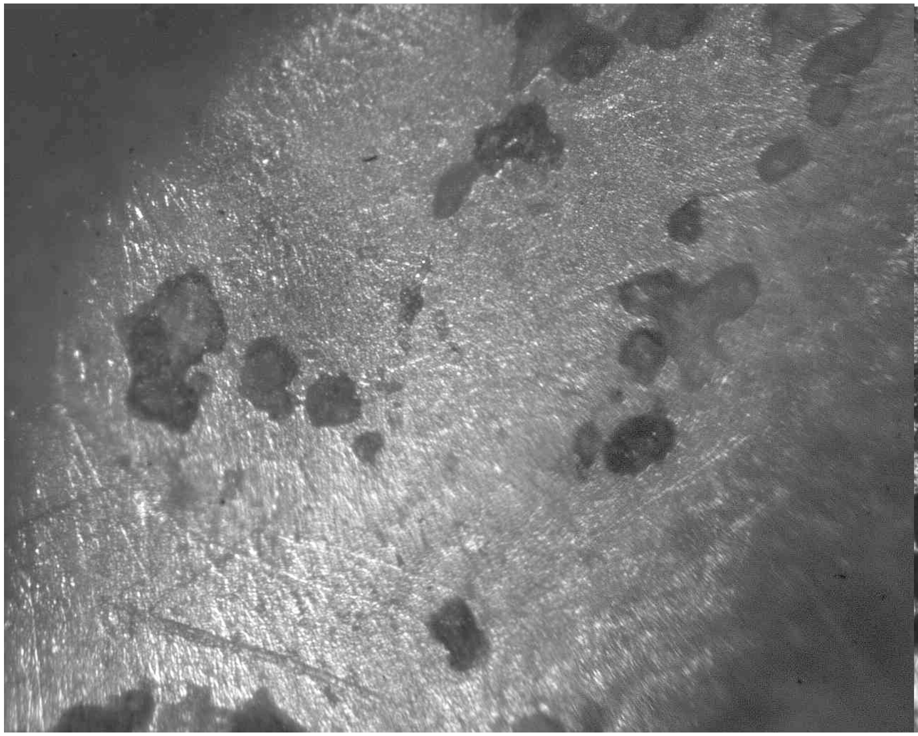

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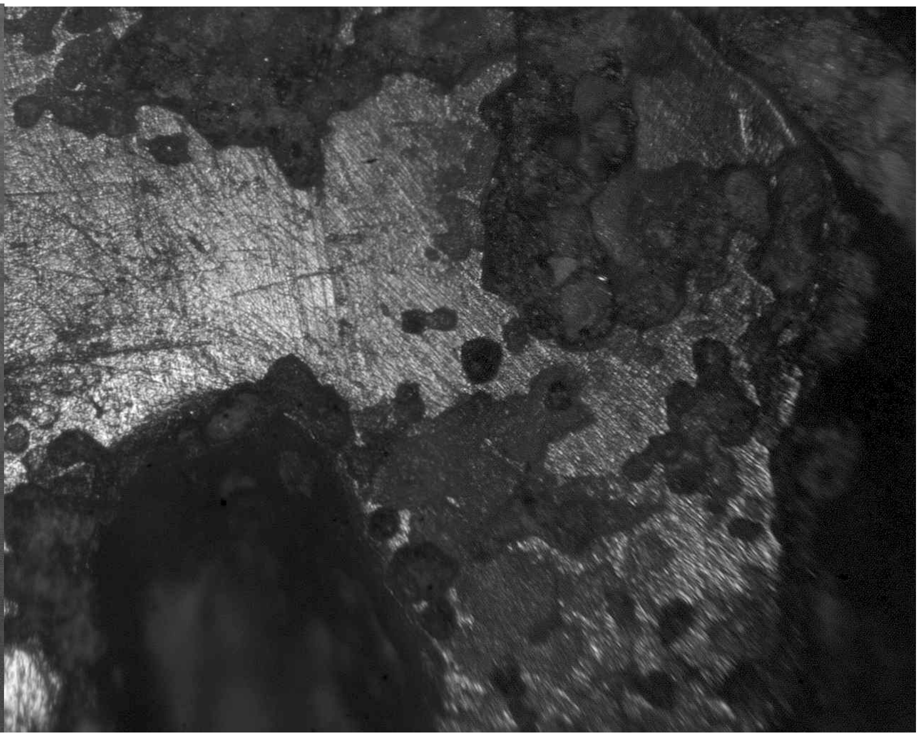

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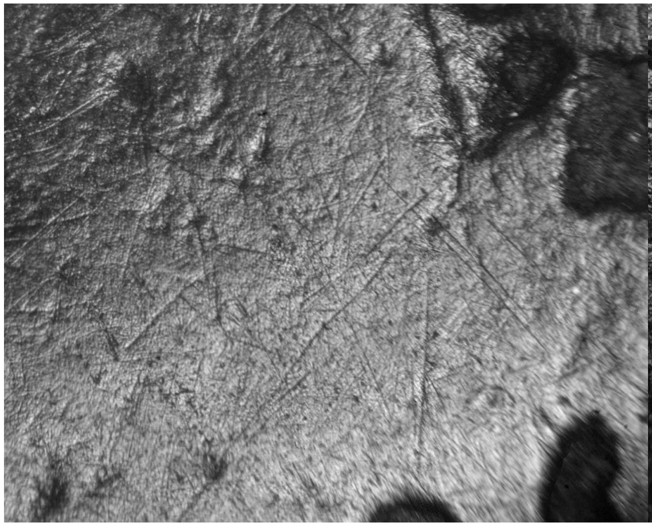

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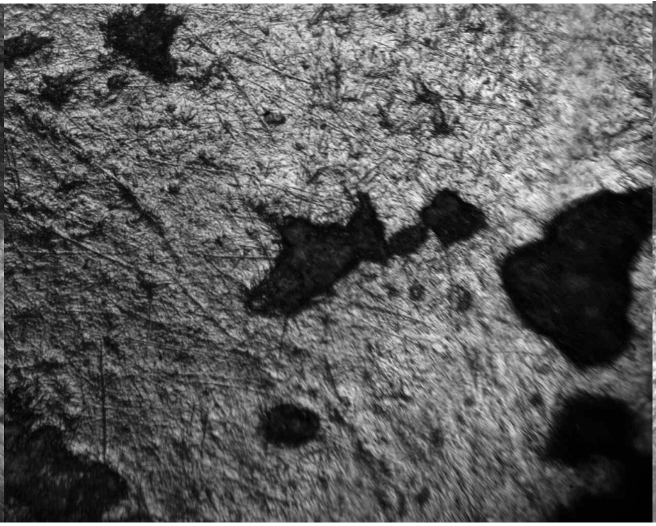

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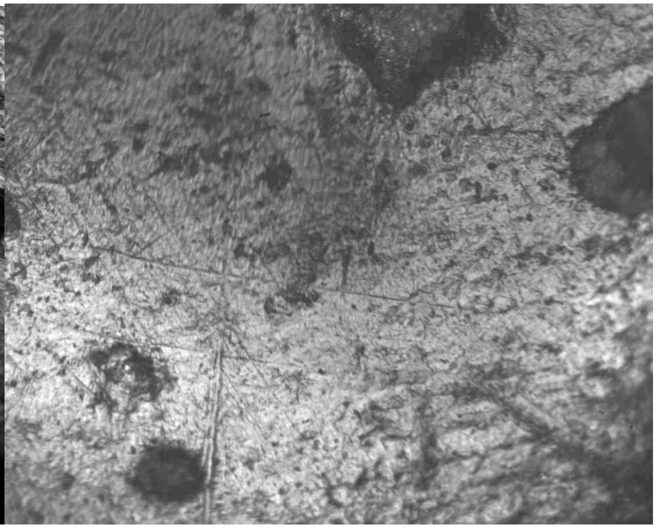

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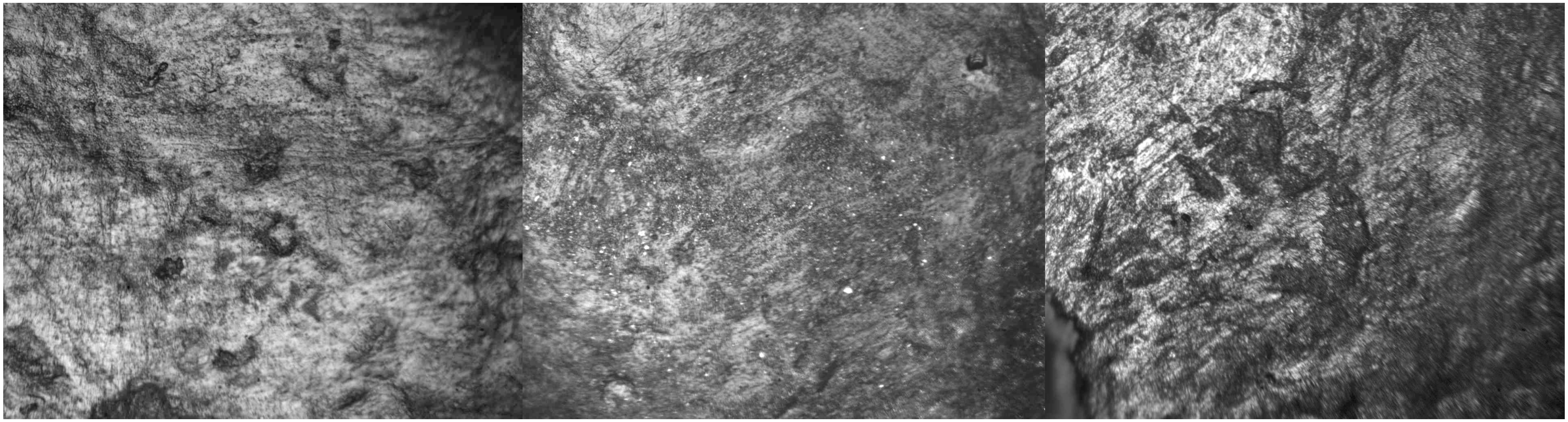

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F3 F4 F9

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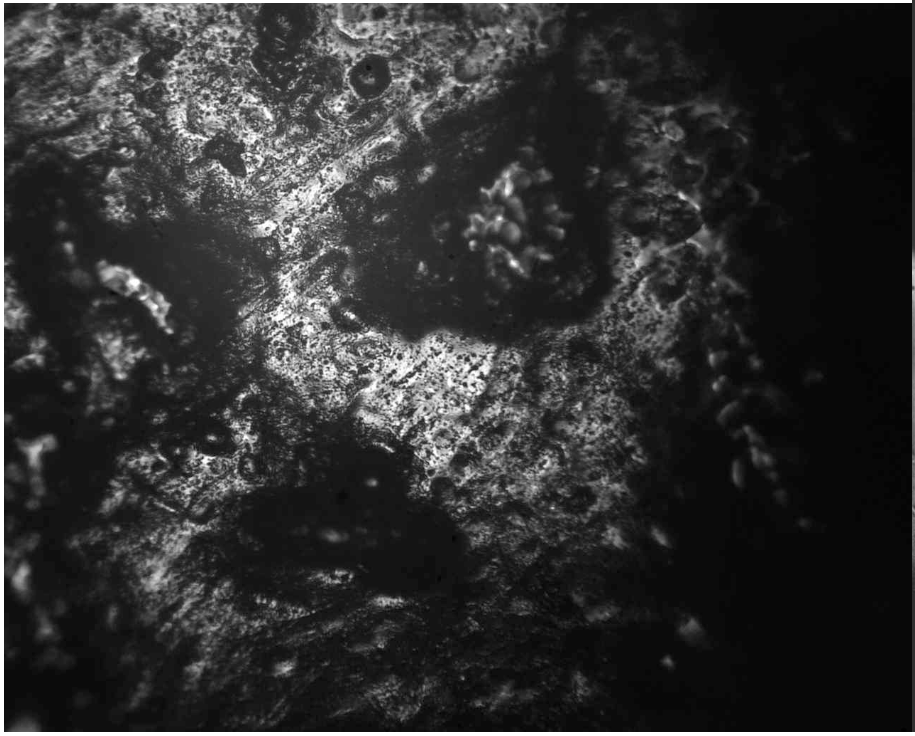
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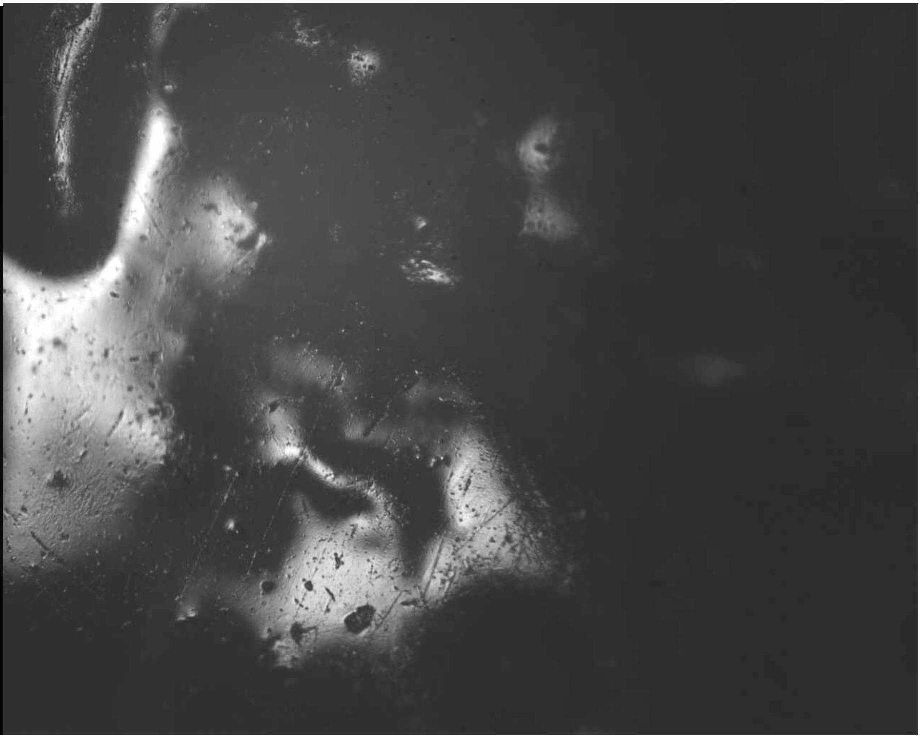
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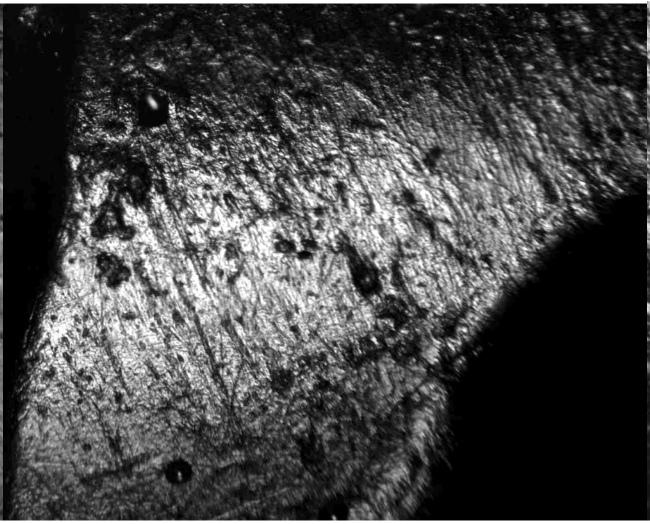
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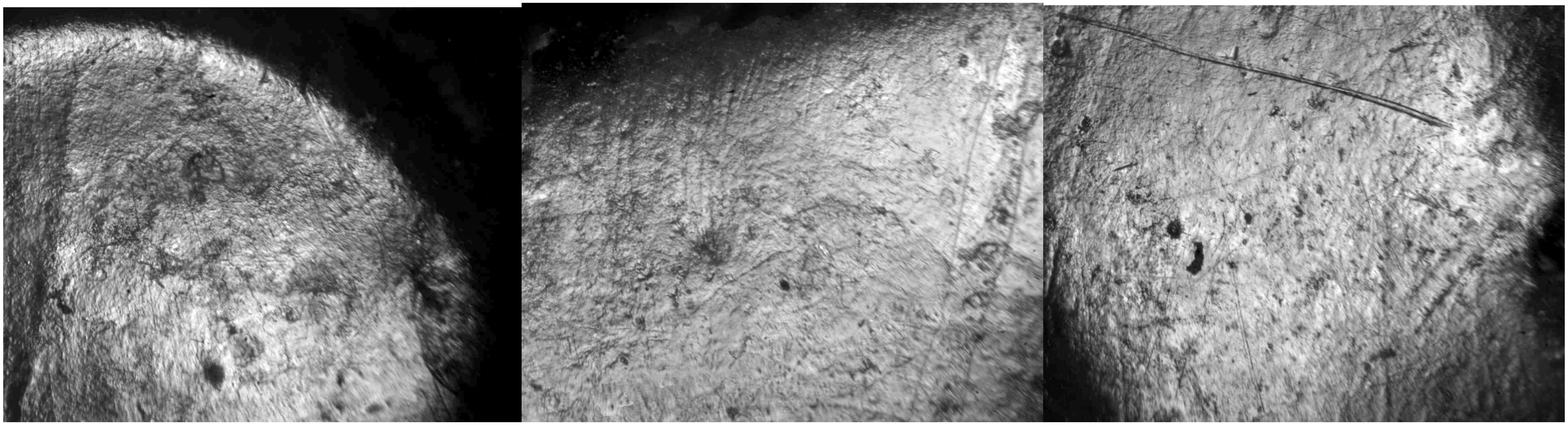

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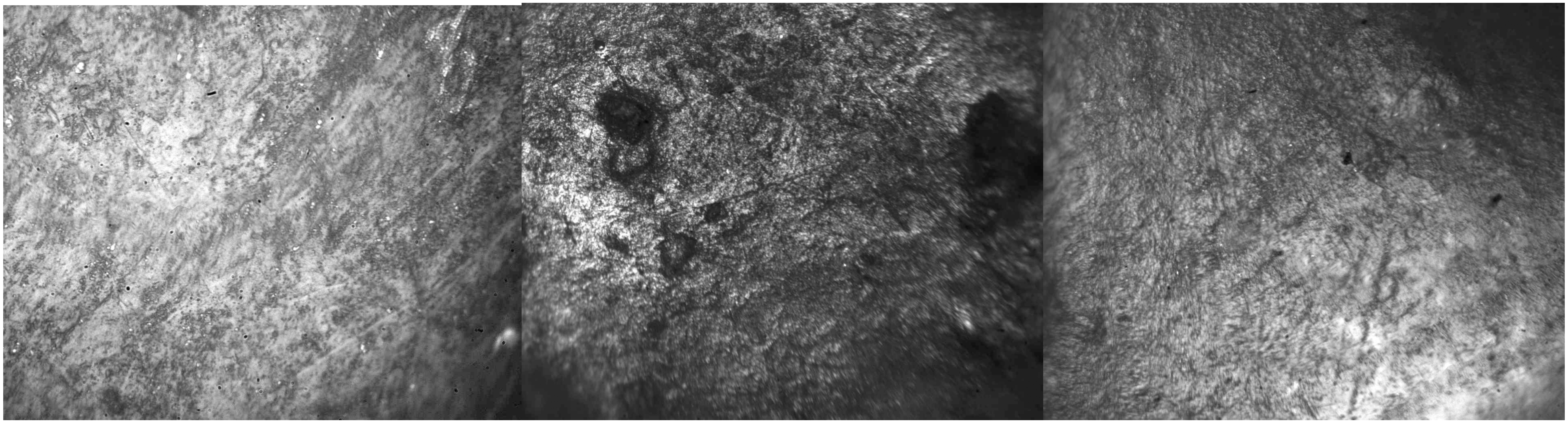
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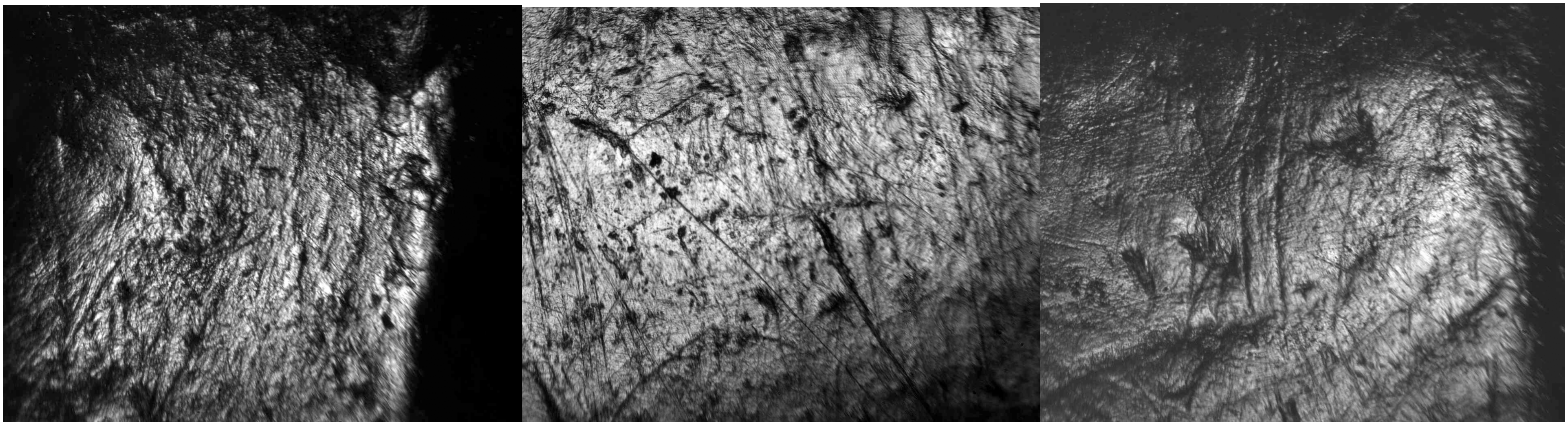
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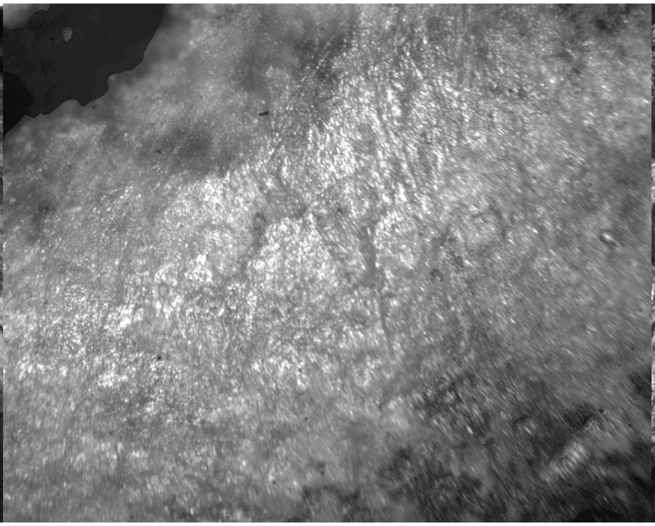
F6


F9

Appendix B. Facet Microwear: Historic Hunter/ Gatherer *Homo sapiens*

Australian Aborigines

NHMW- 811

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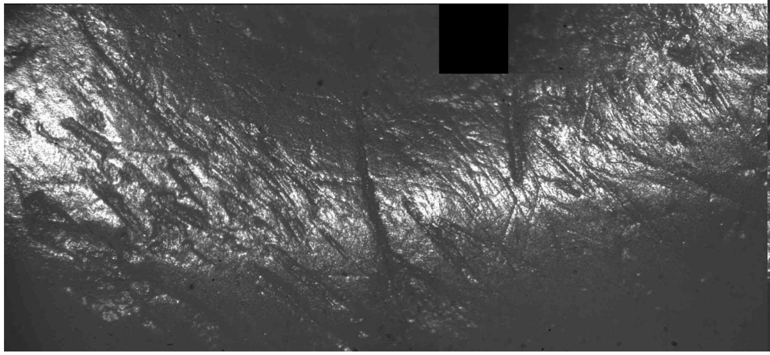

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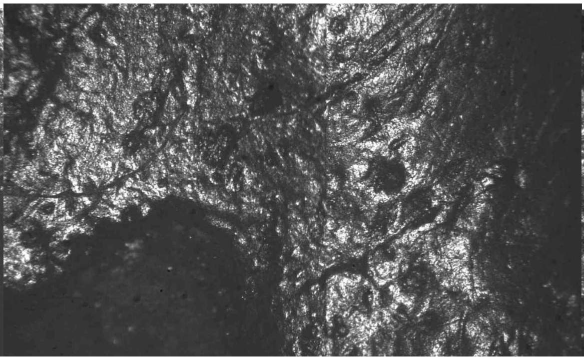

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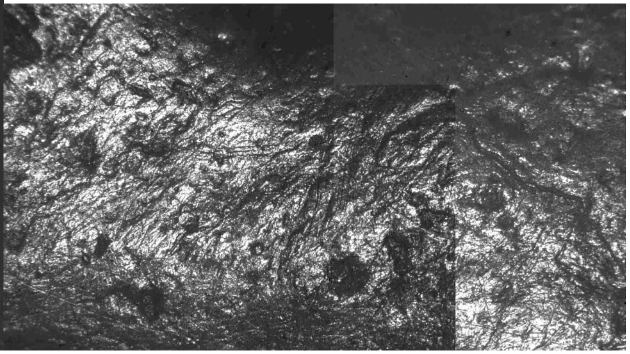

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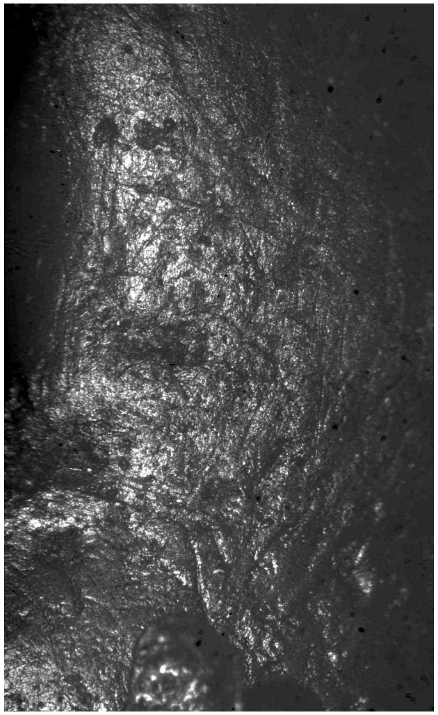

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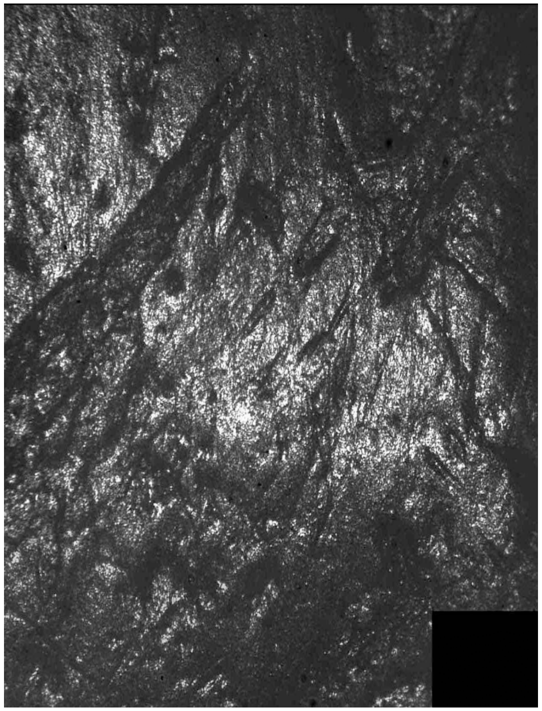

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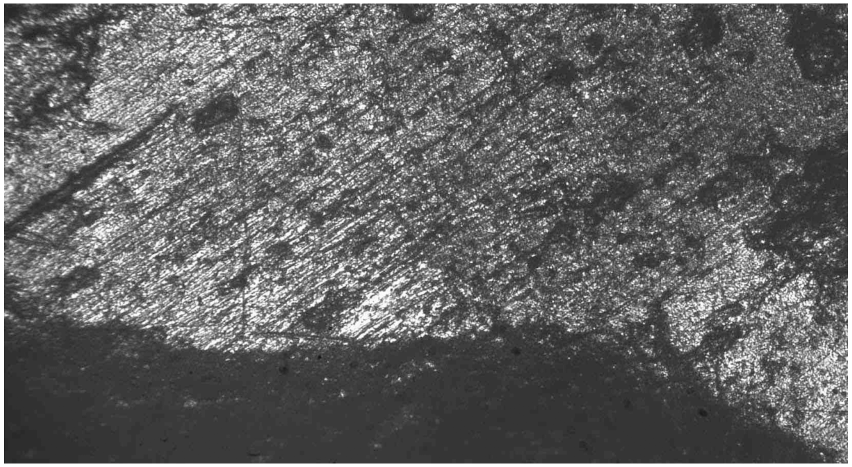

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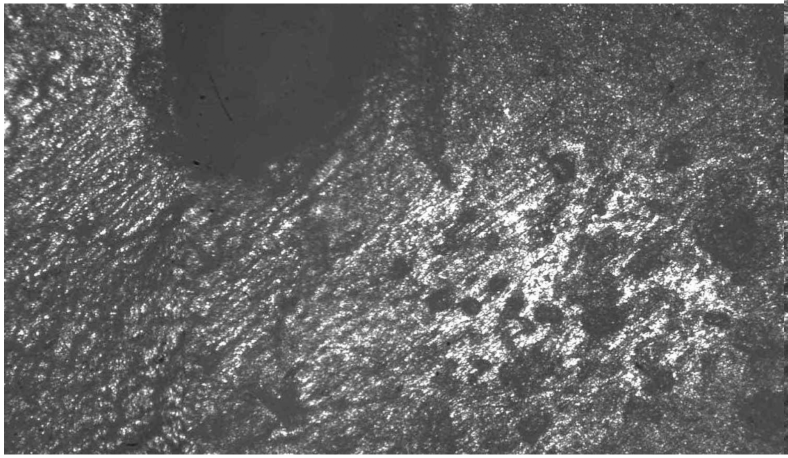
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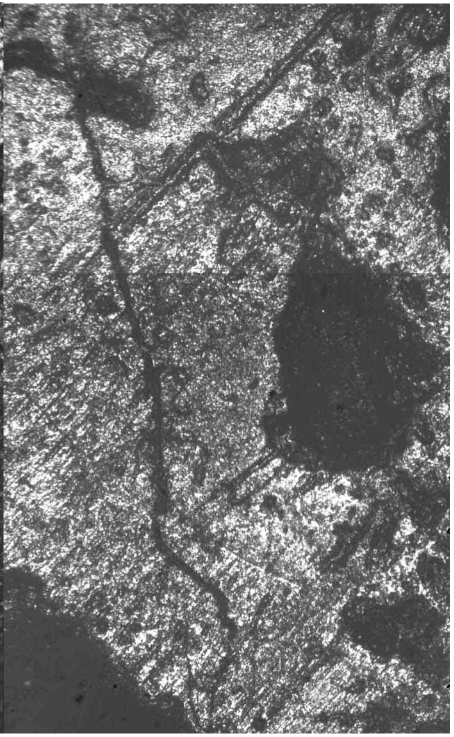
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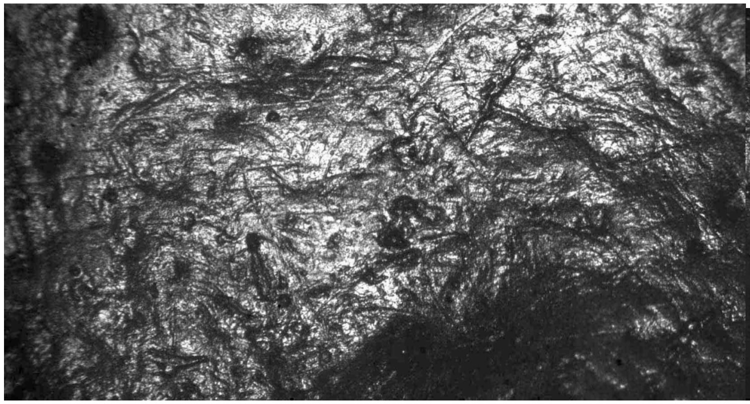
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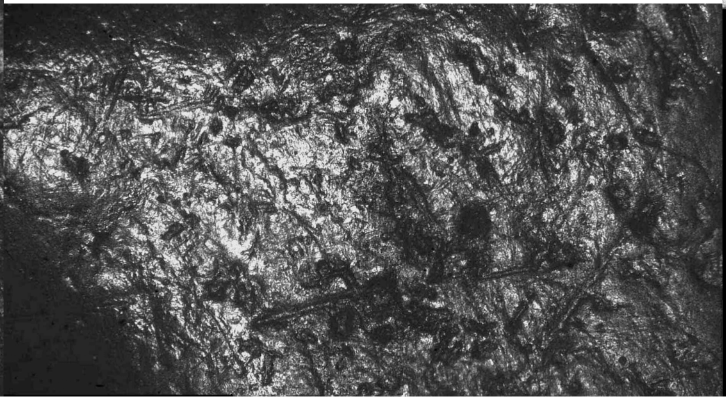
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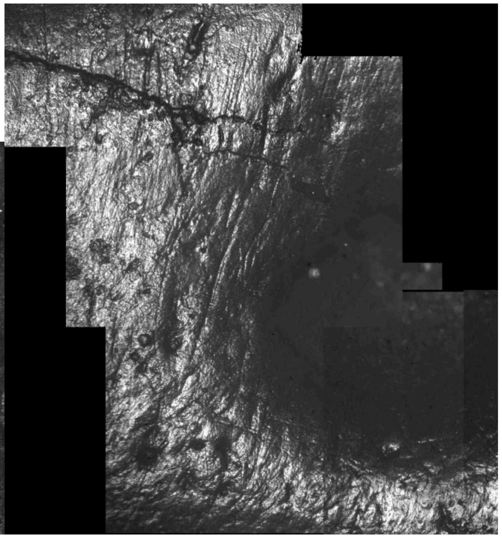
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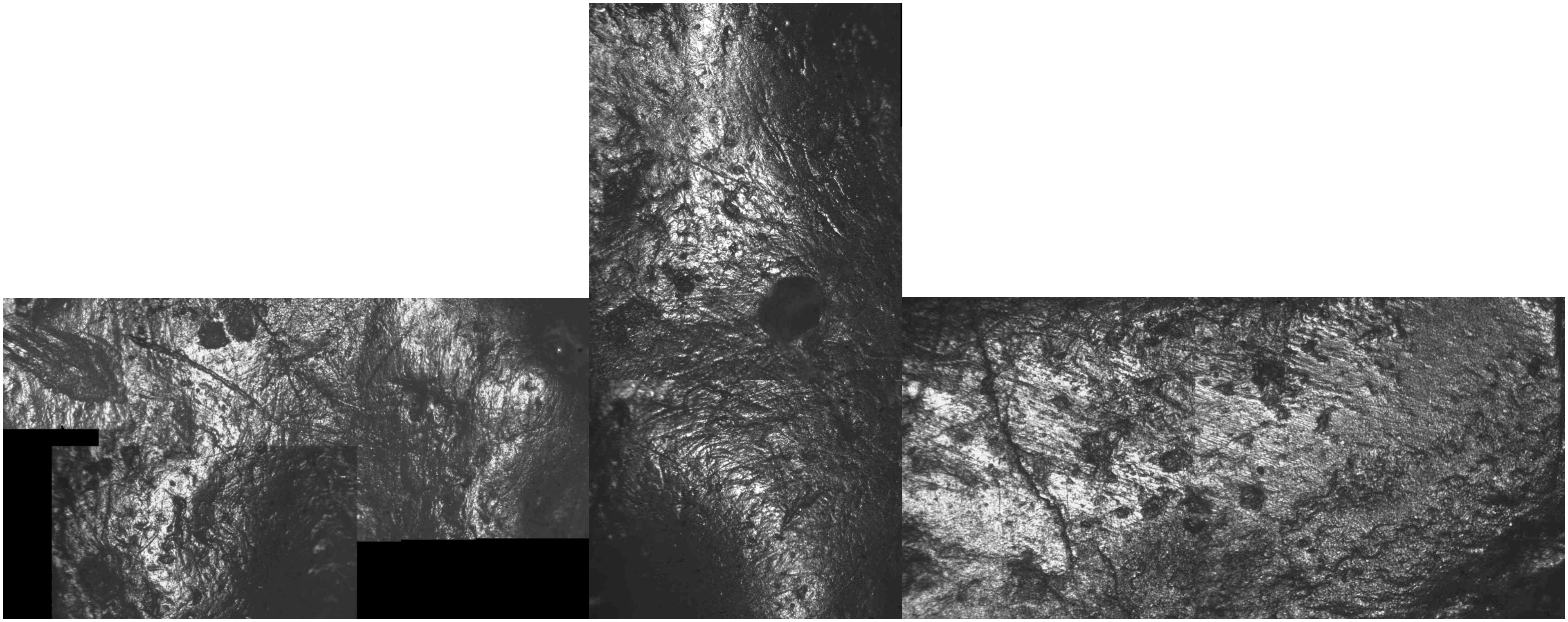

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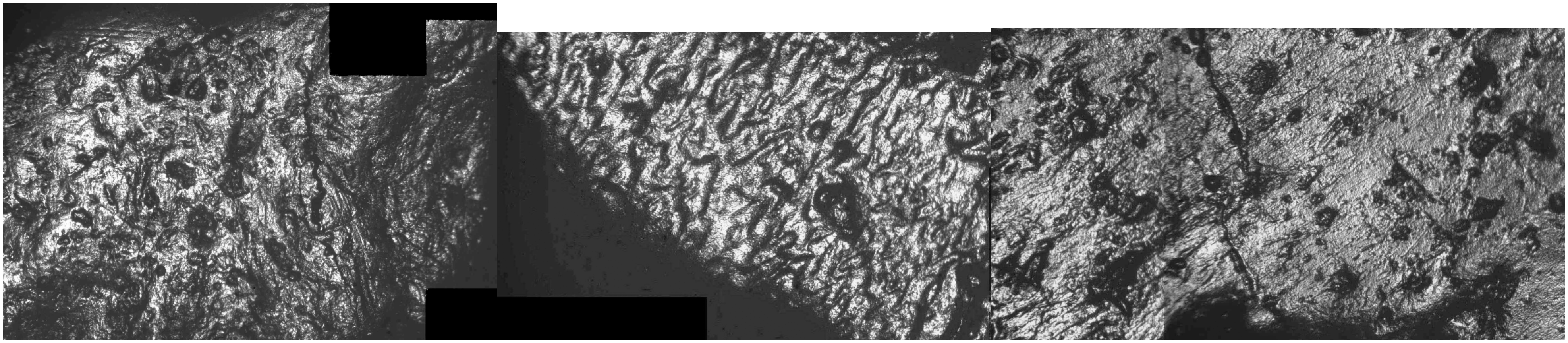

NHMW-8687
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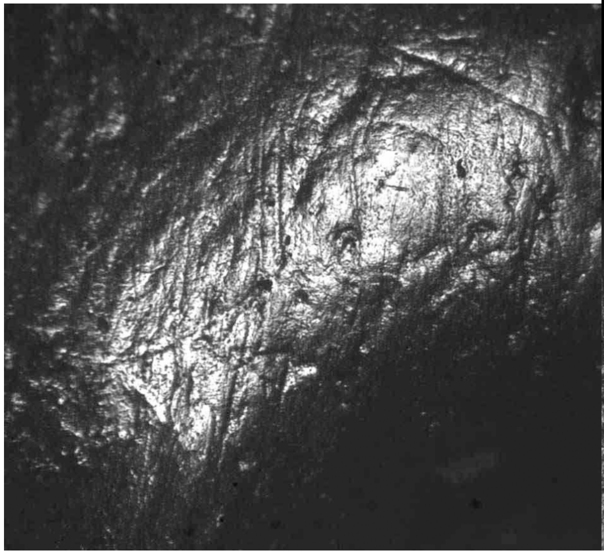
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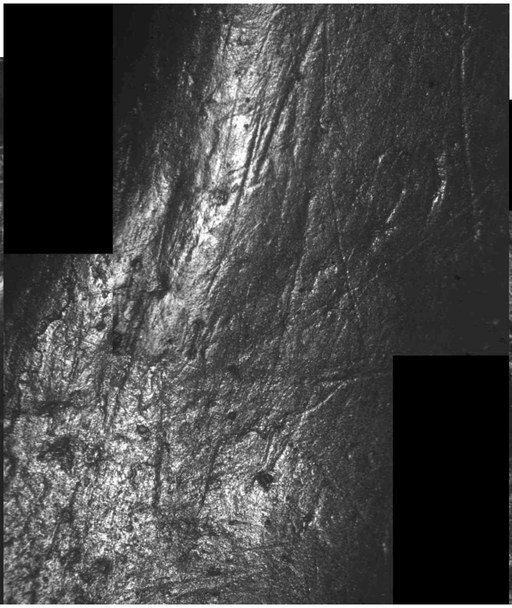
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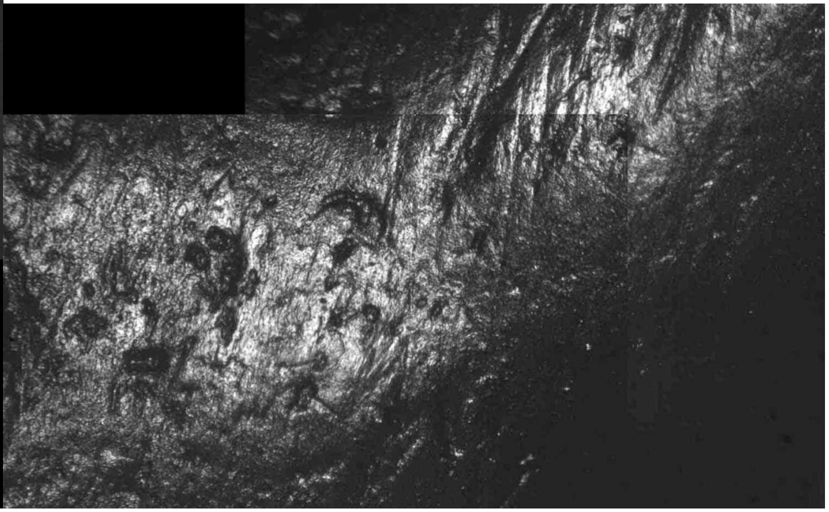
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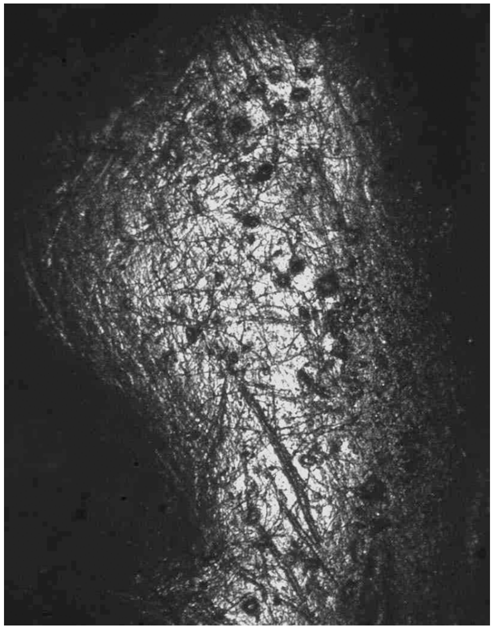
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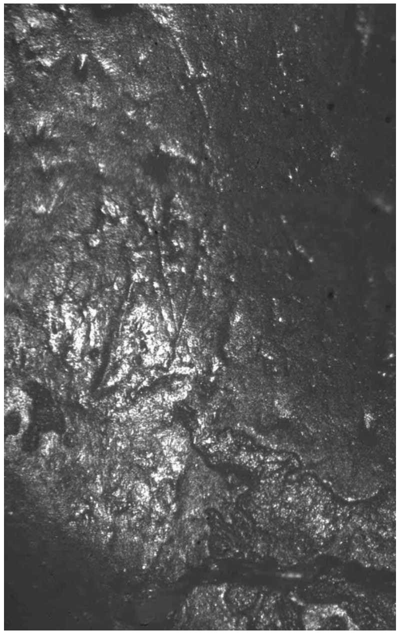
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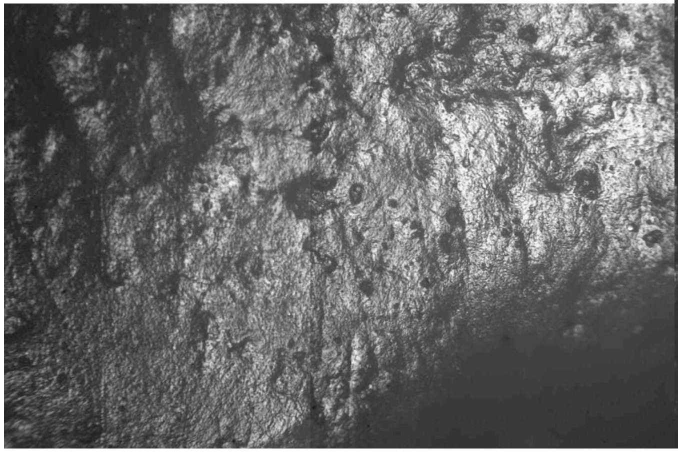
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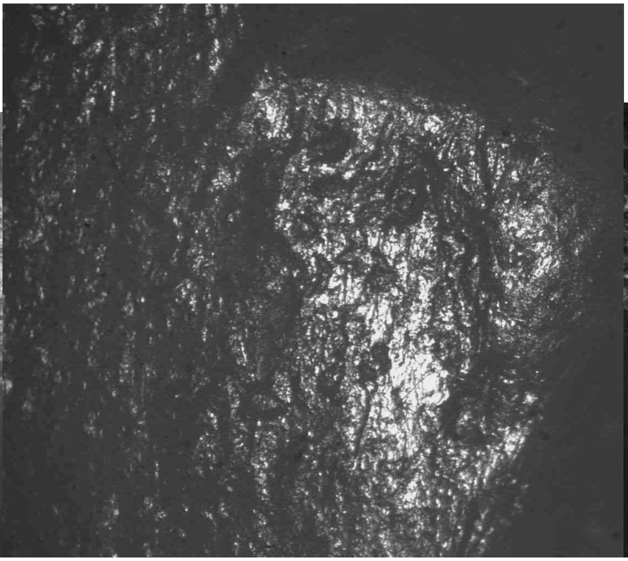
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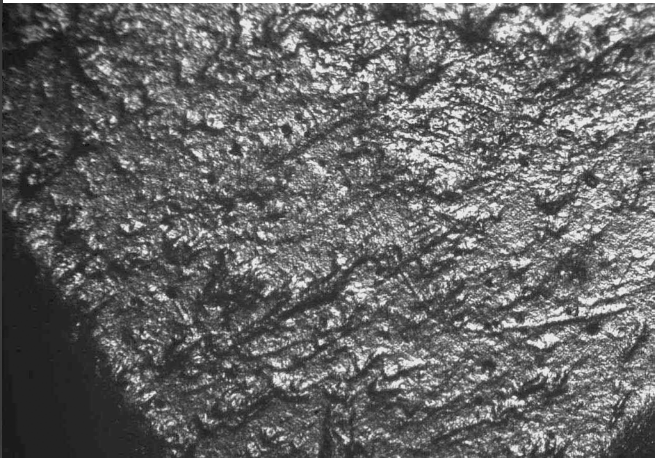
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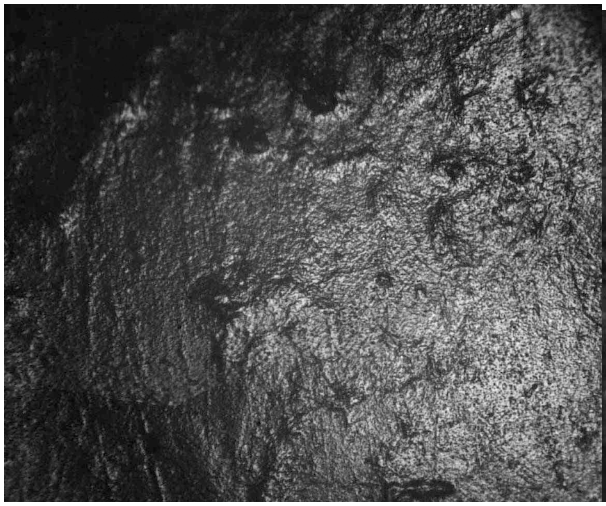
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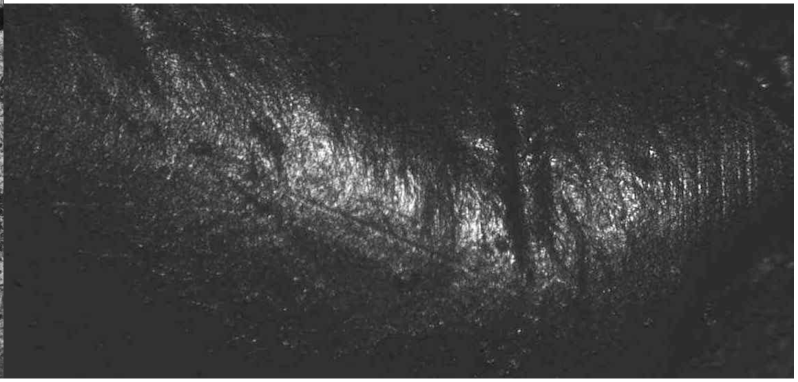
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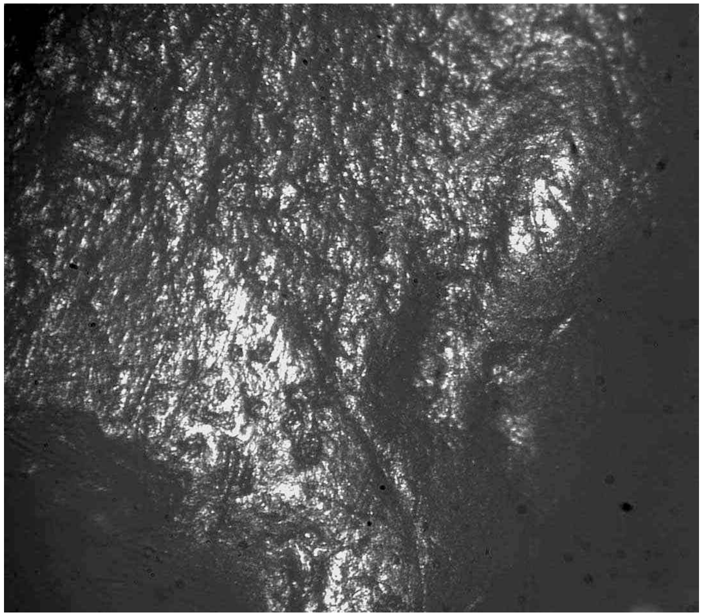
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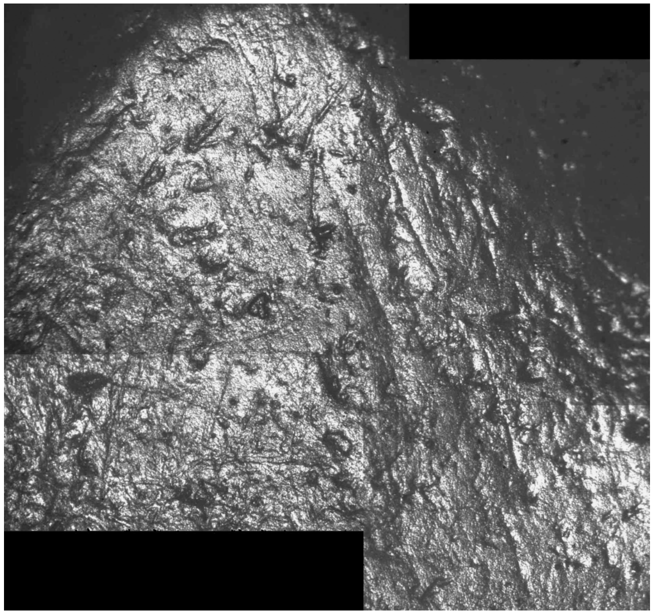
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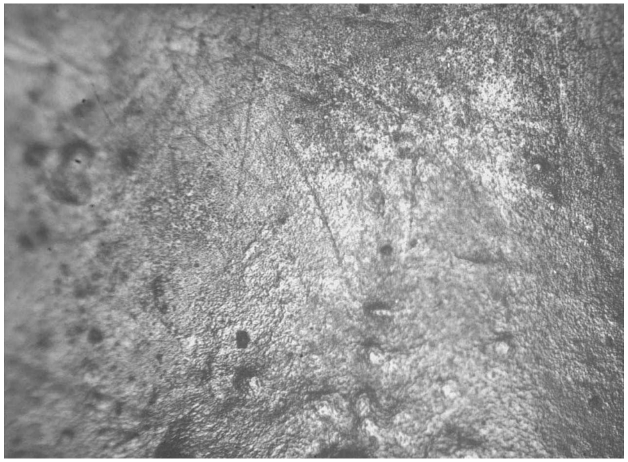

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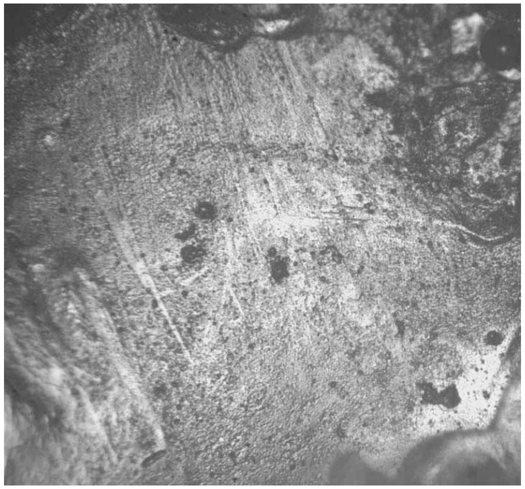

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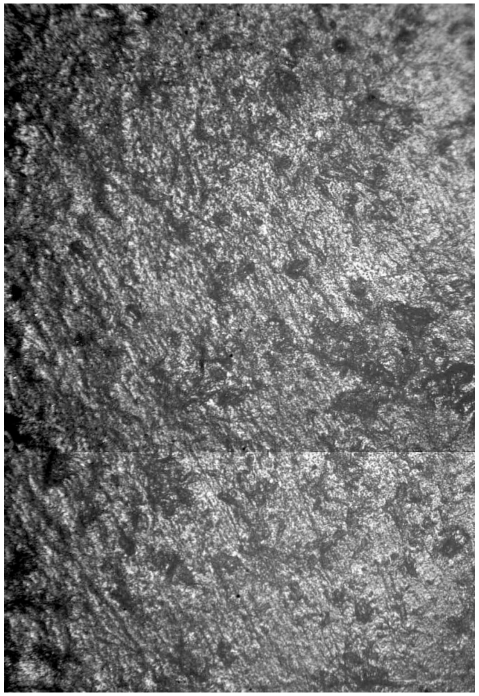

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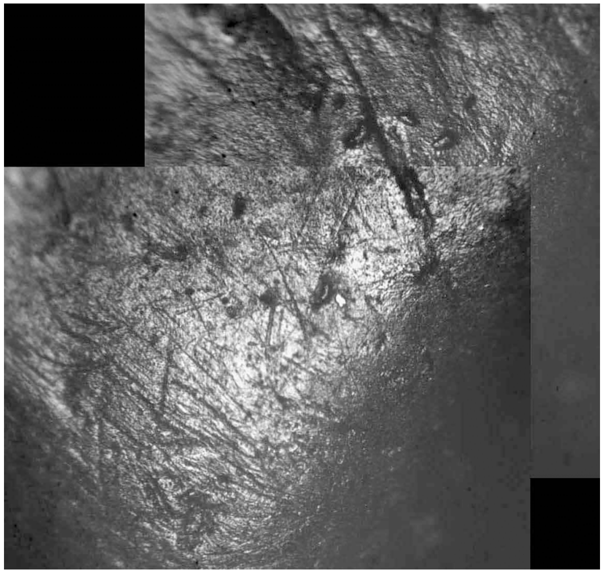

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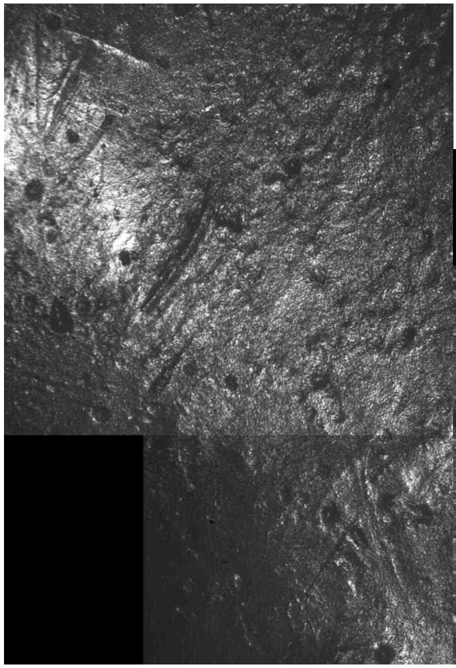

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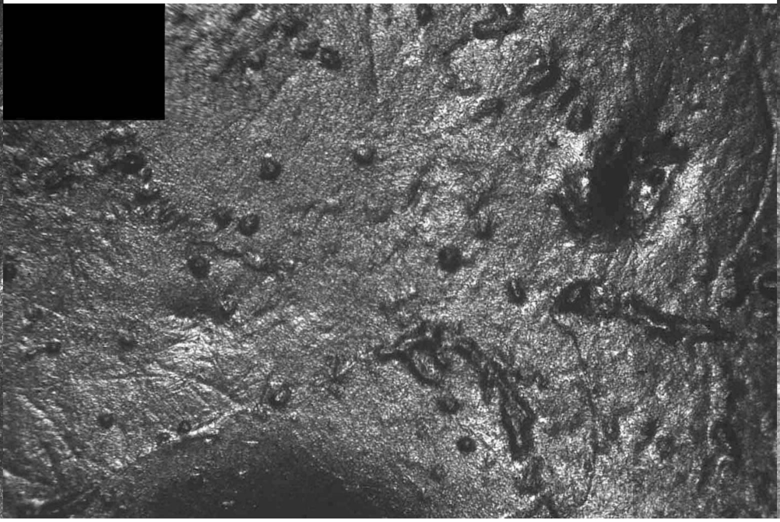

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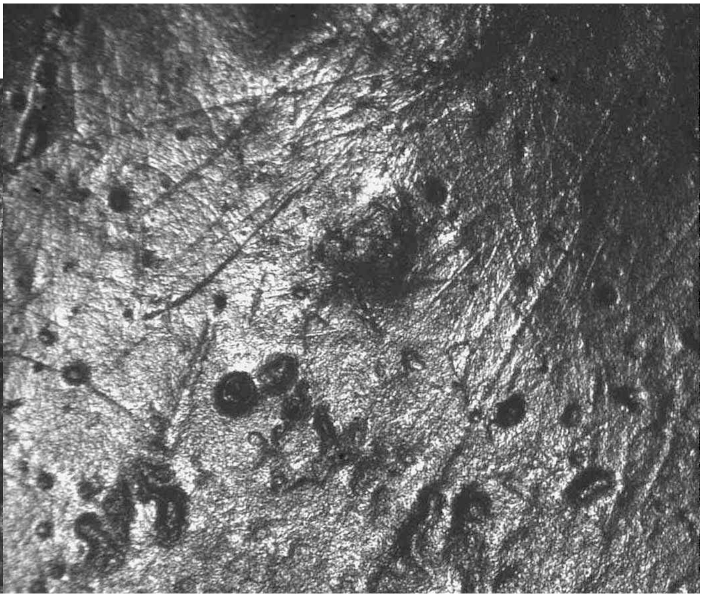

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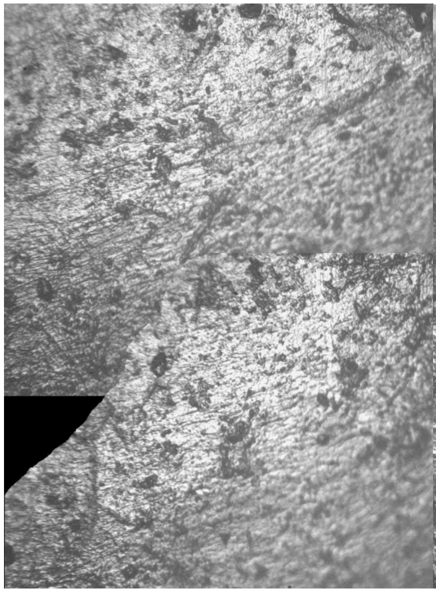

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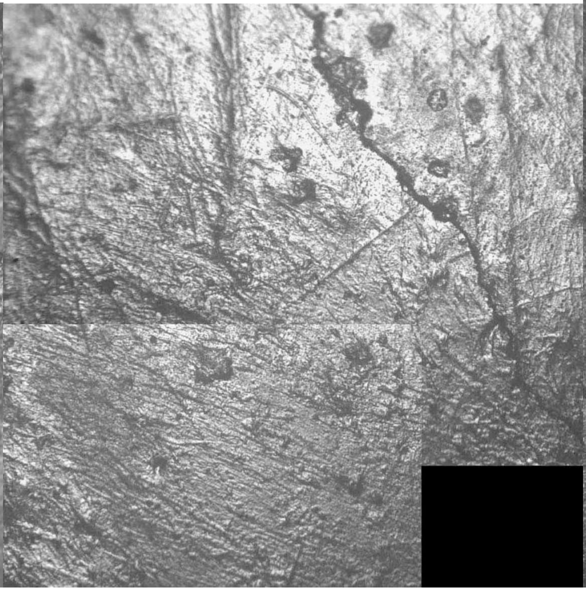

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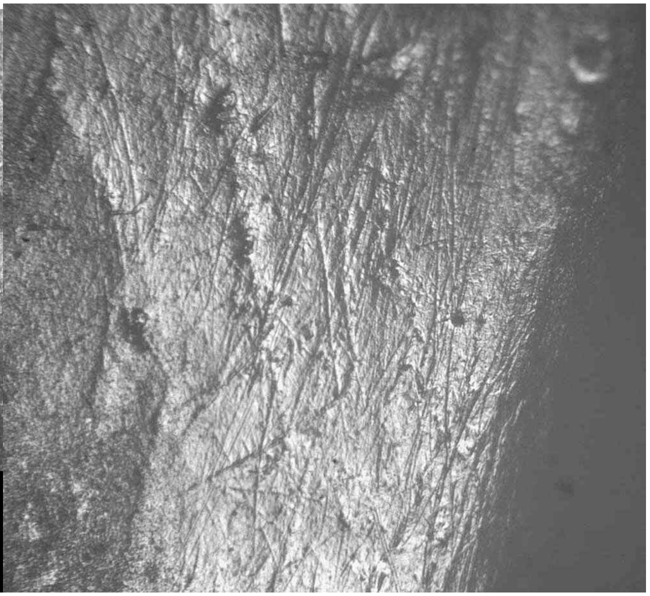

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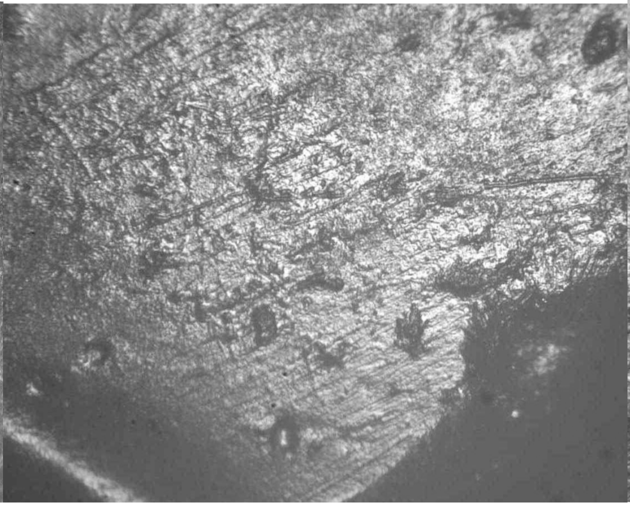
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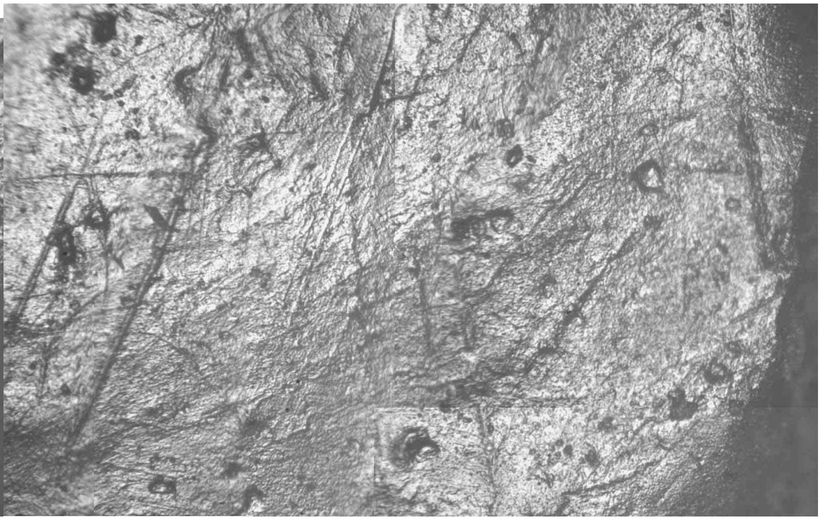
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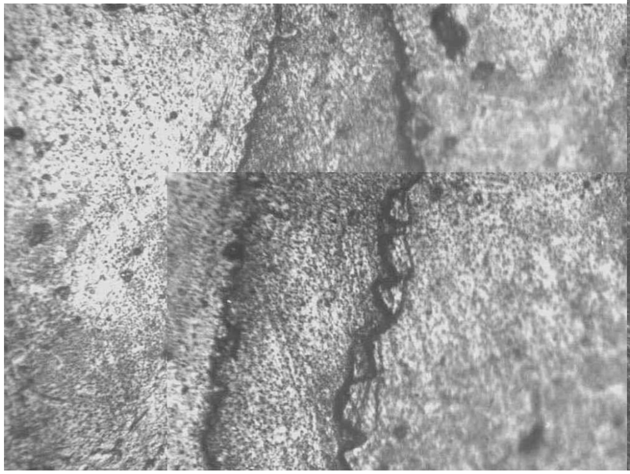
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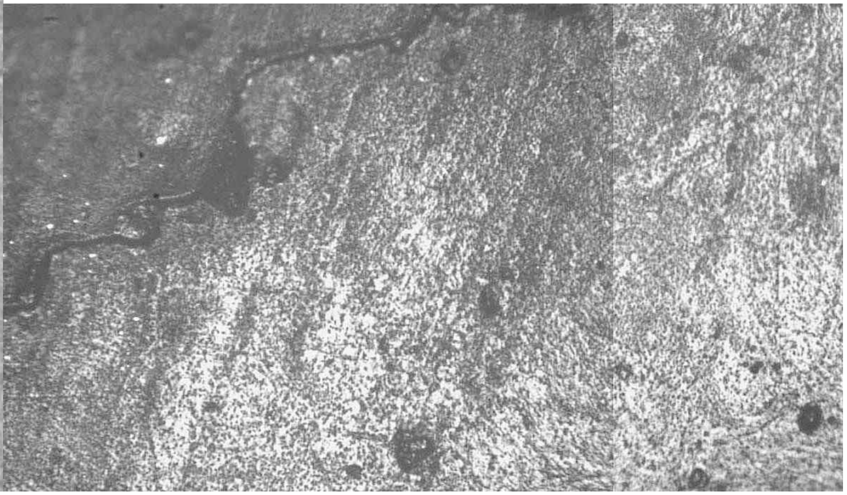
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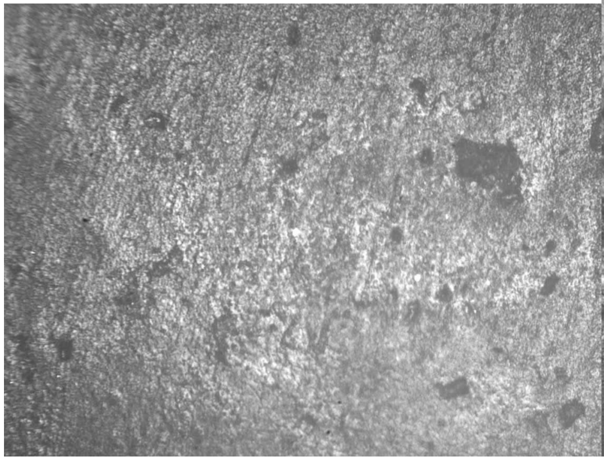
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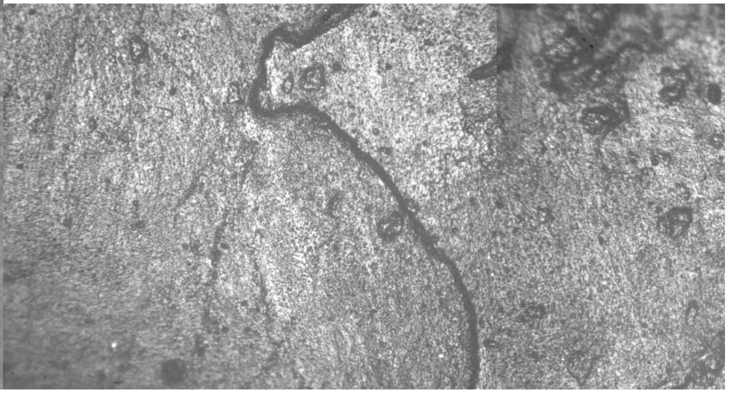
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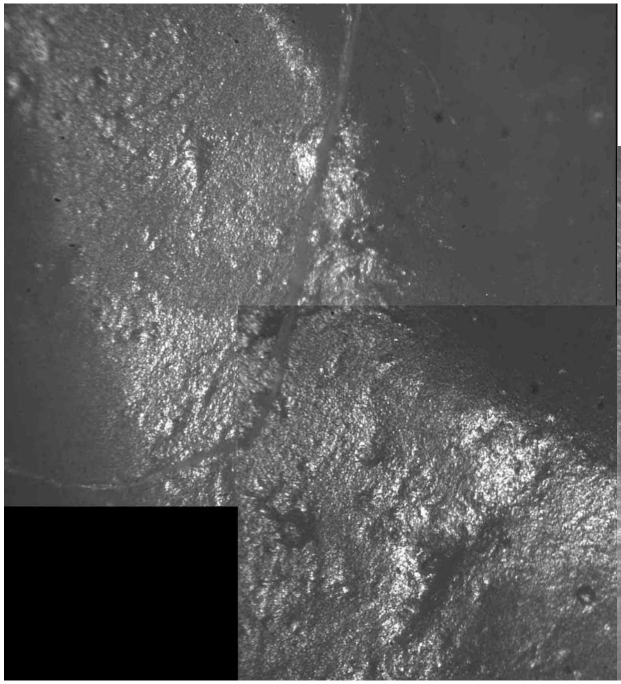
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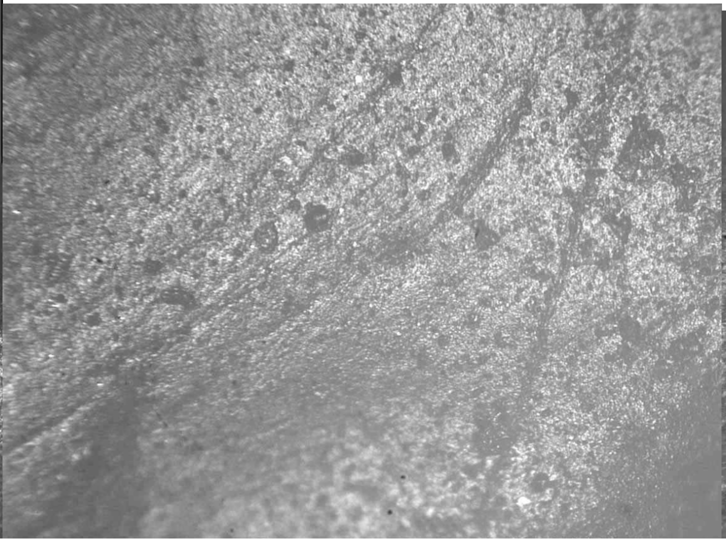
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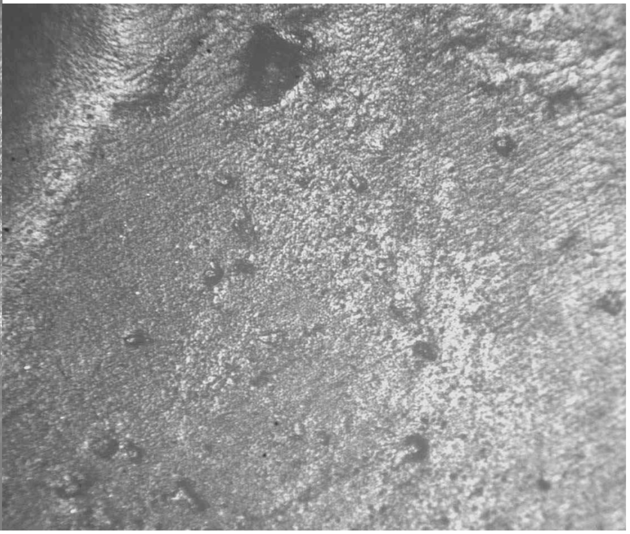
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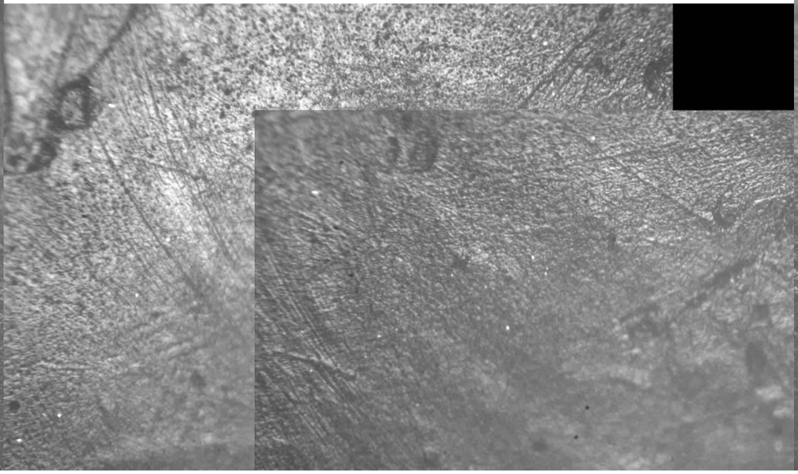
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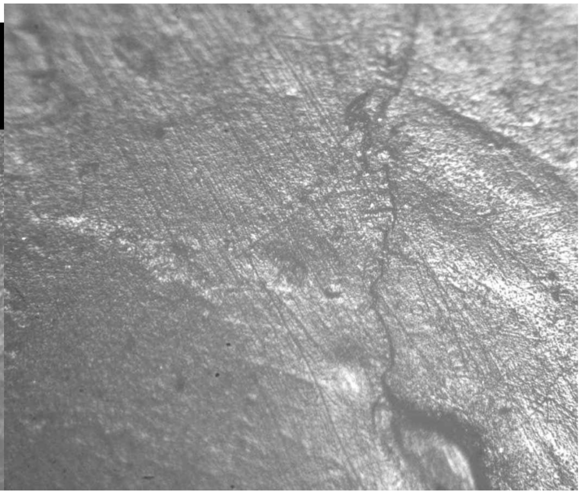
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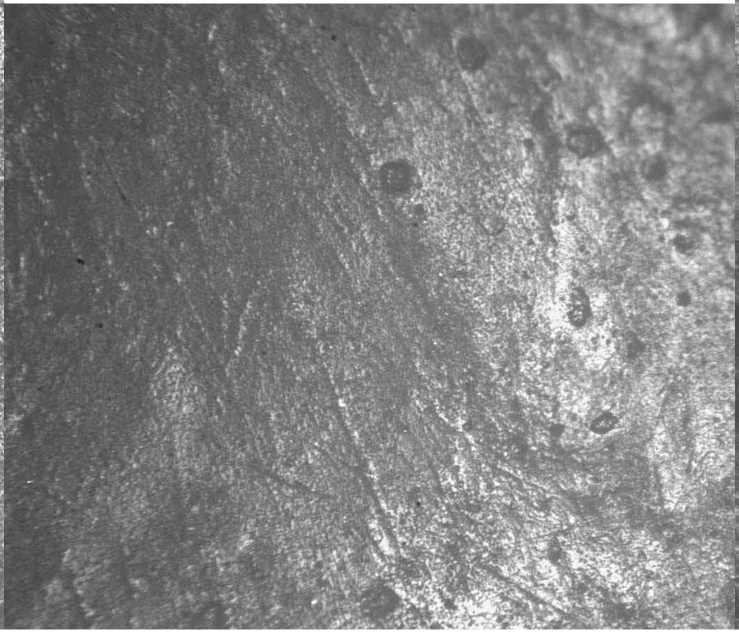
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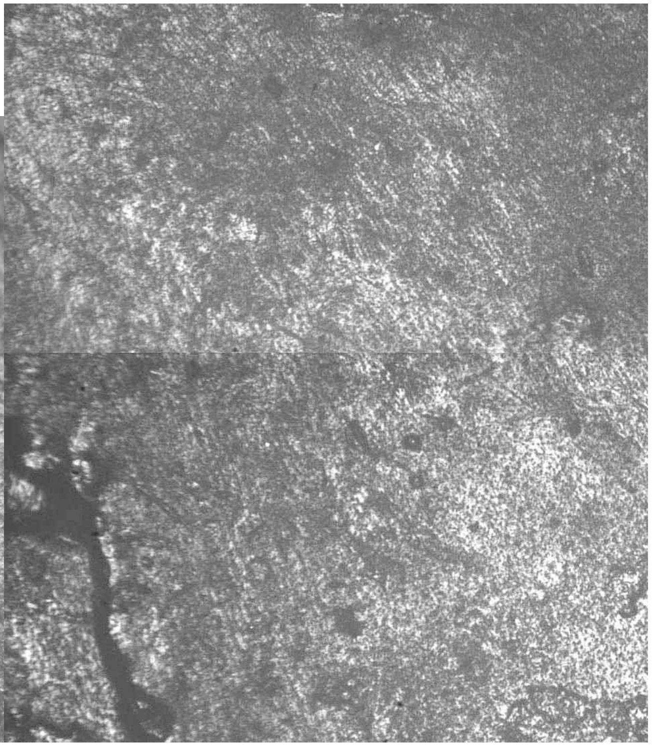
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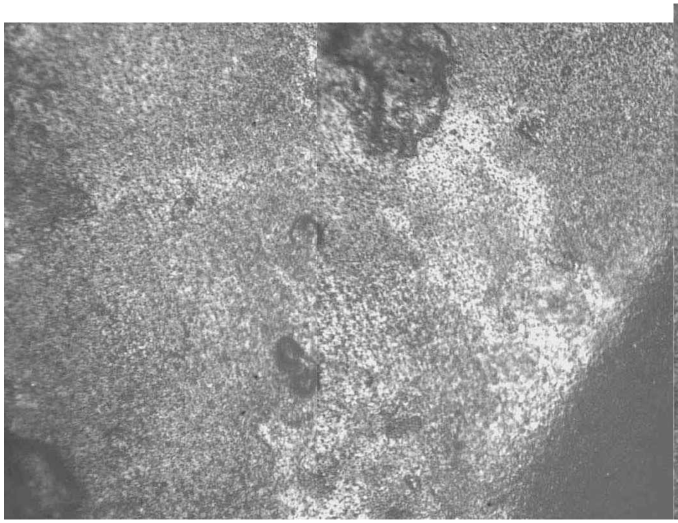

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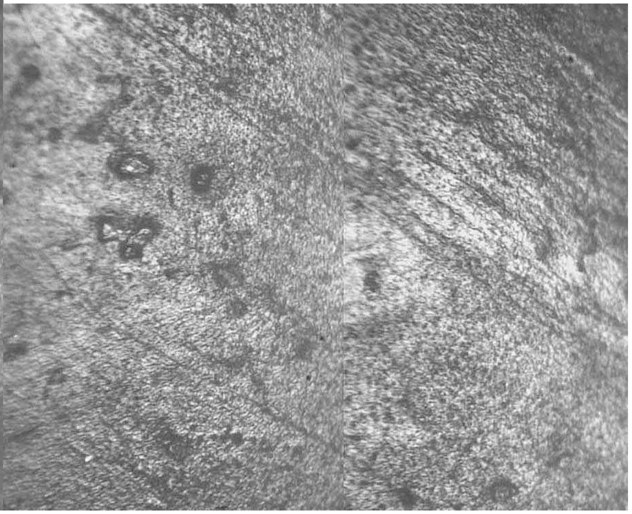

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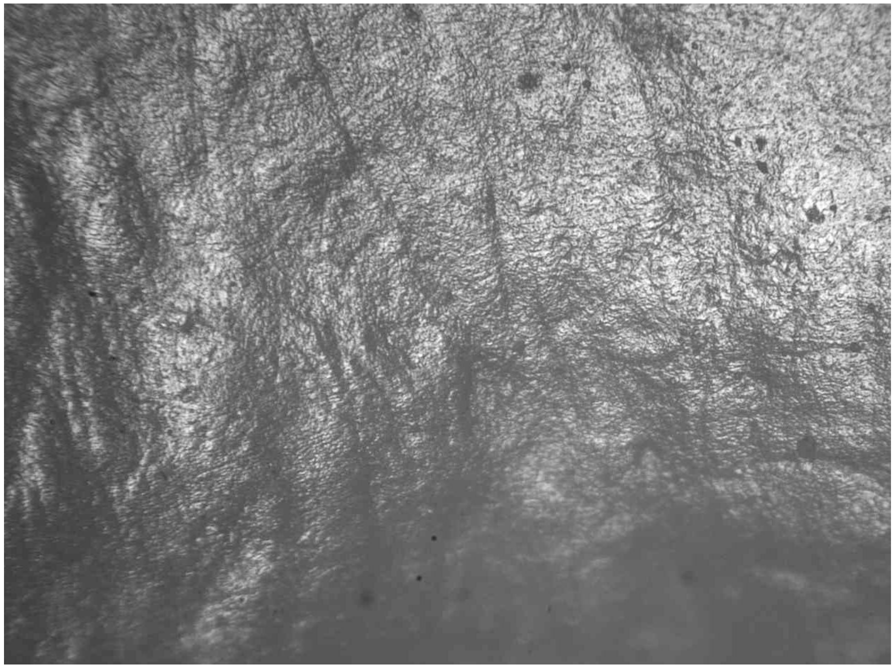

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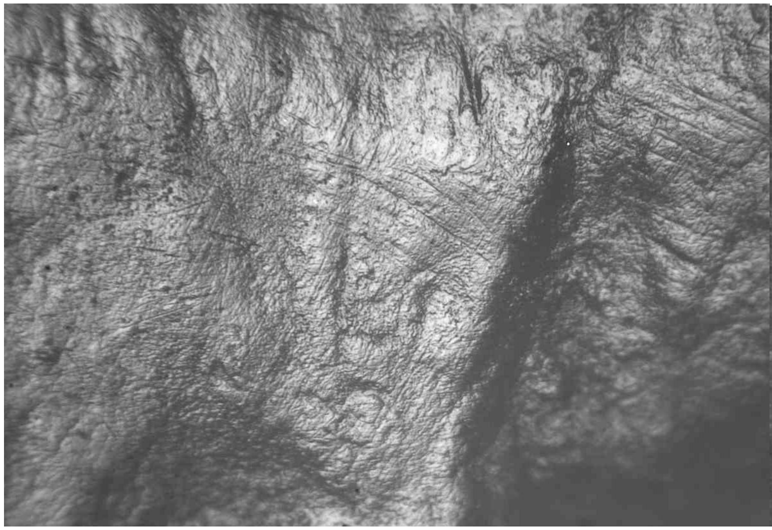
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F9

LRM2


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F9

ULM1


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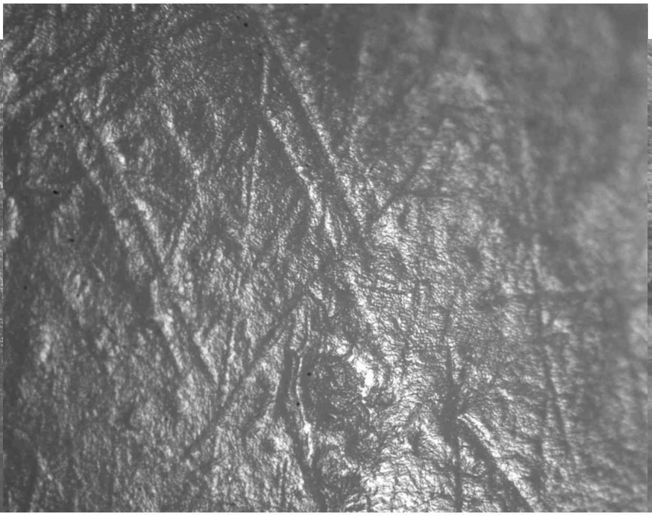
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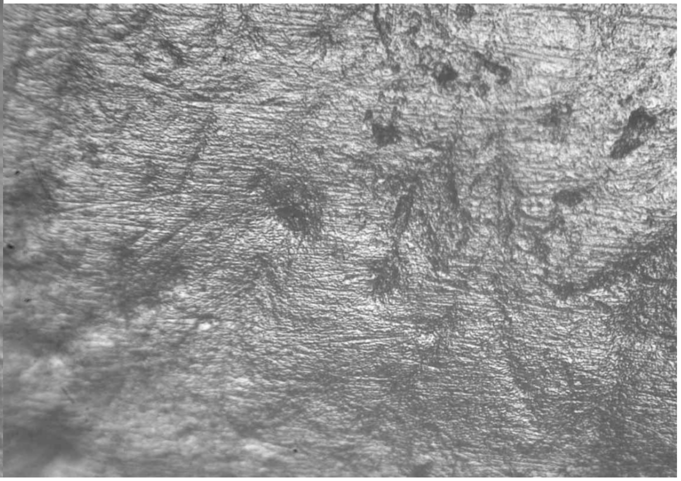
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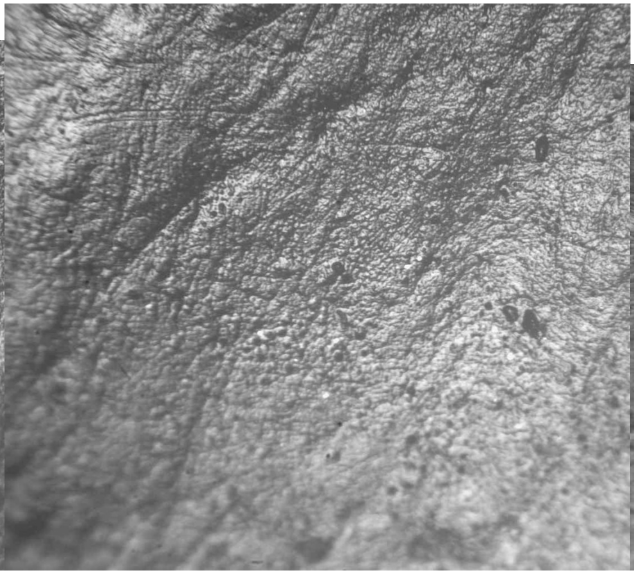
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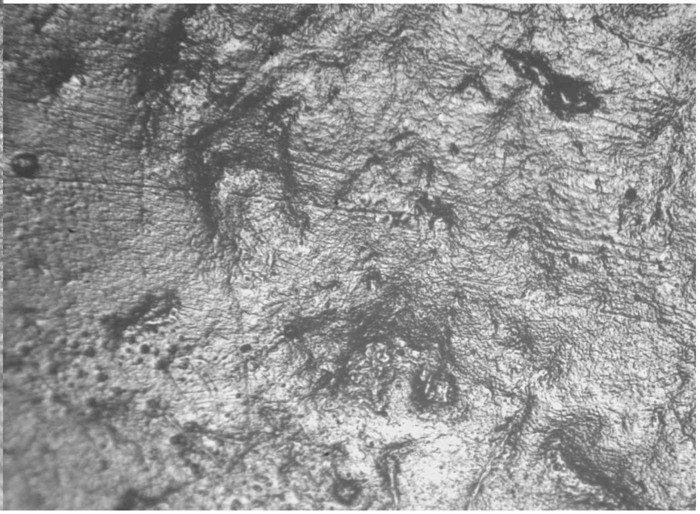
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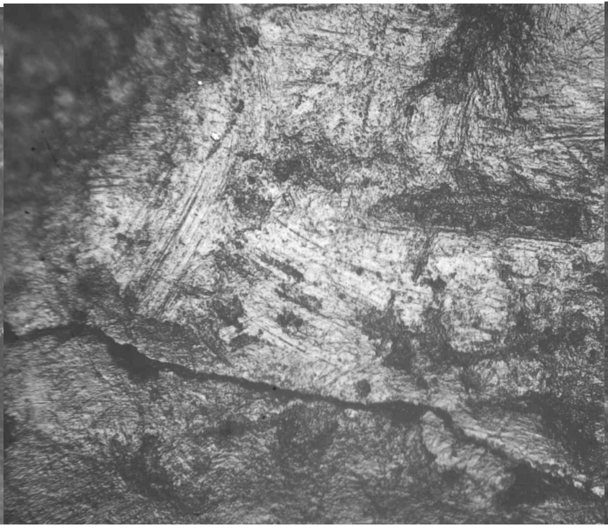
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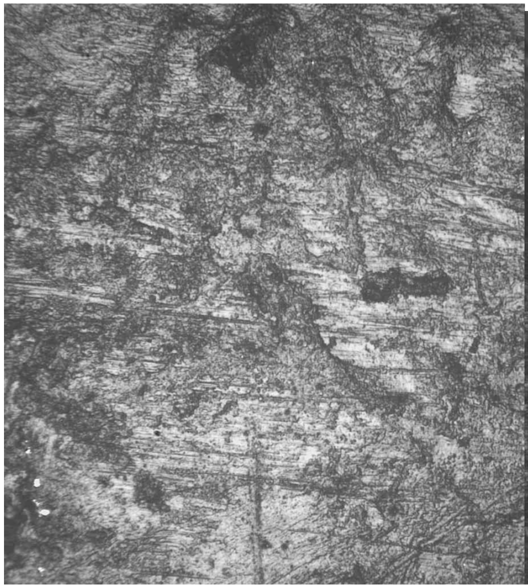
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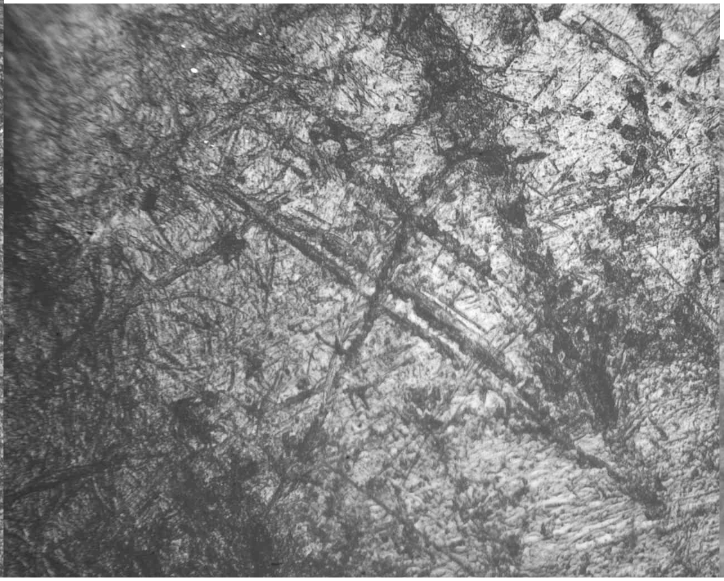
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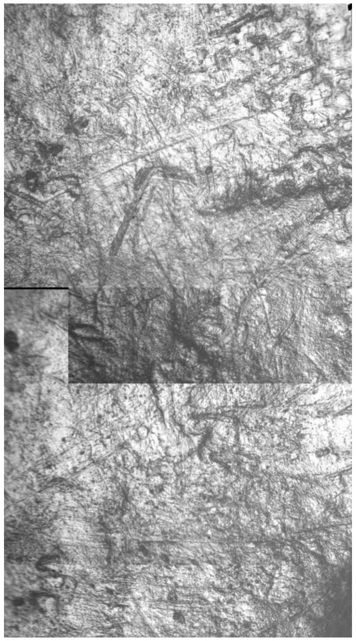
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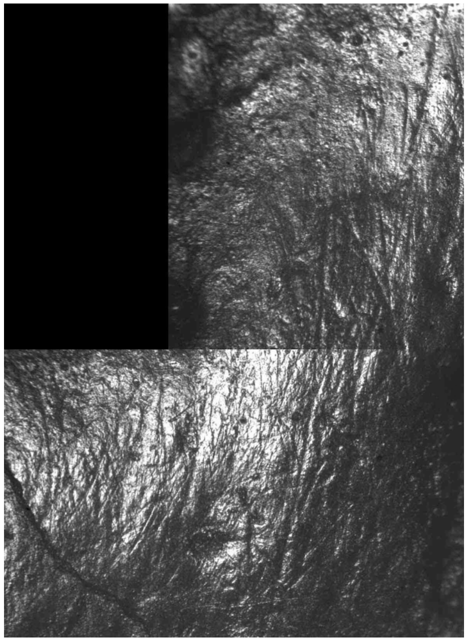
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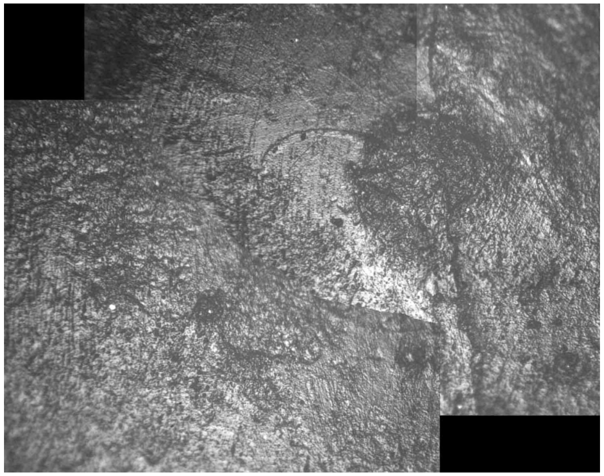
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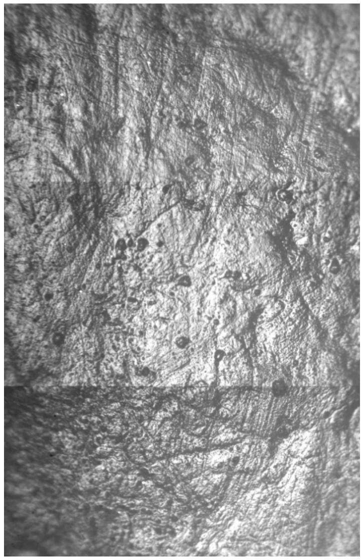
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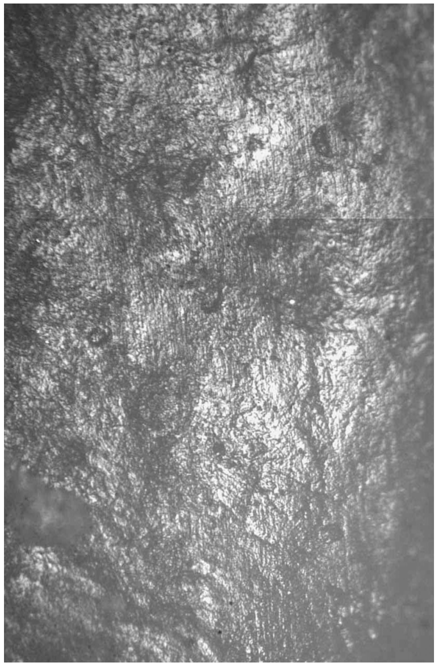
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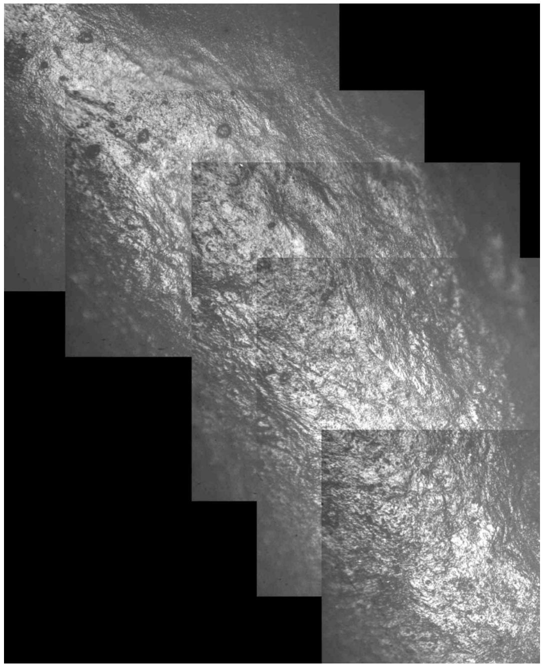
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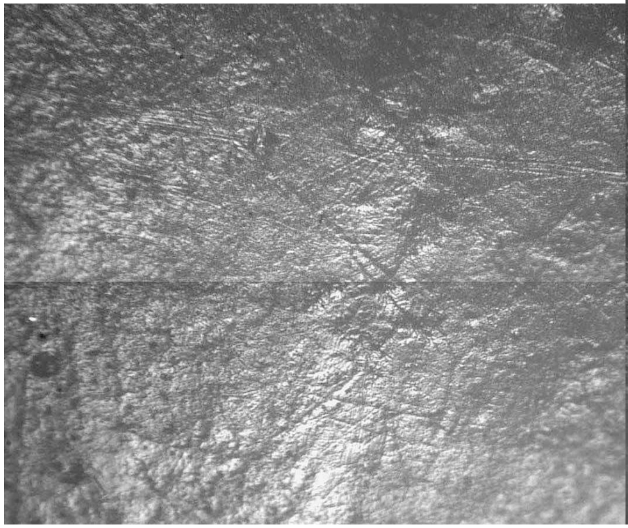
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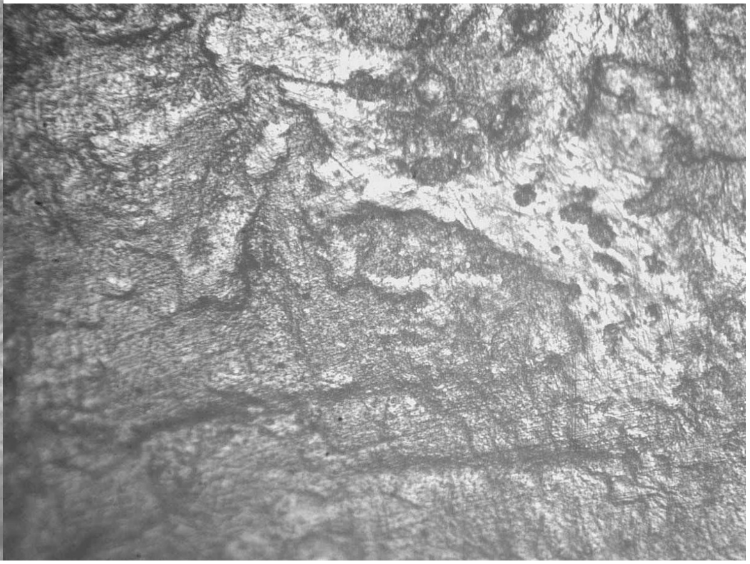
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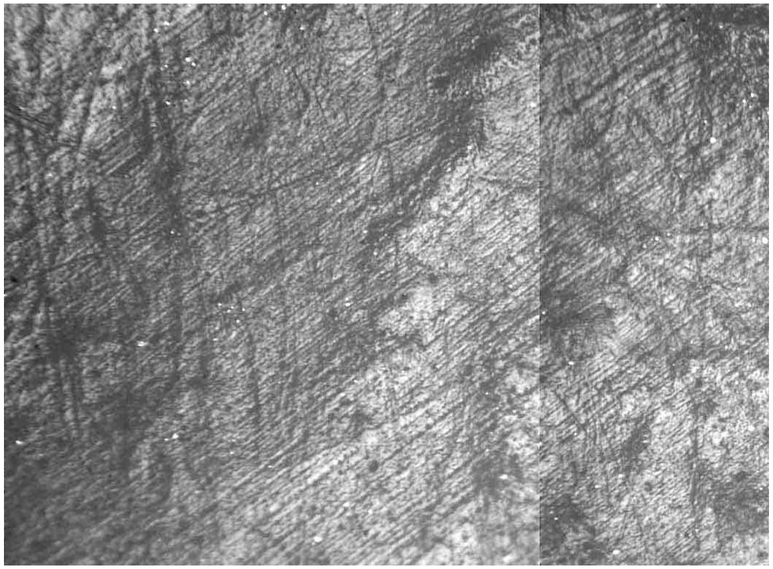

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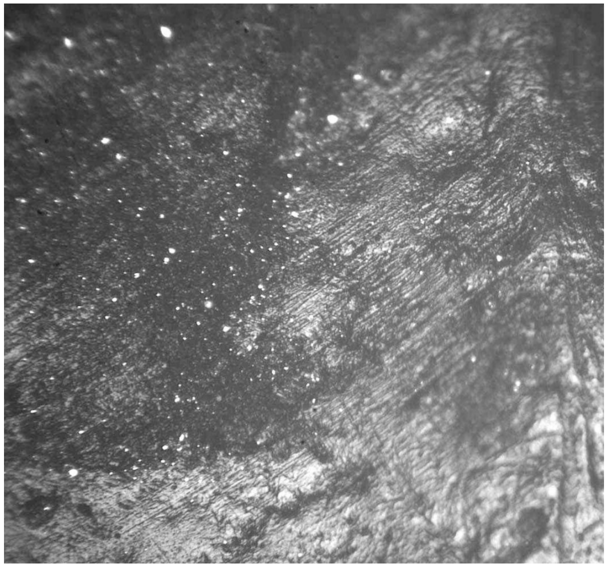

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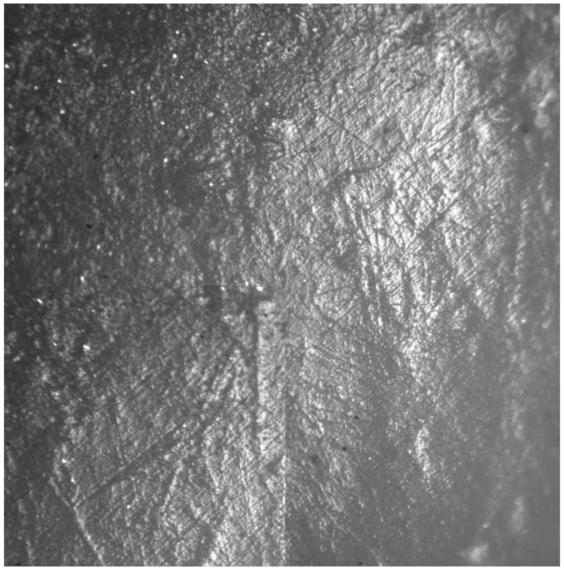

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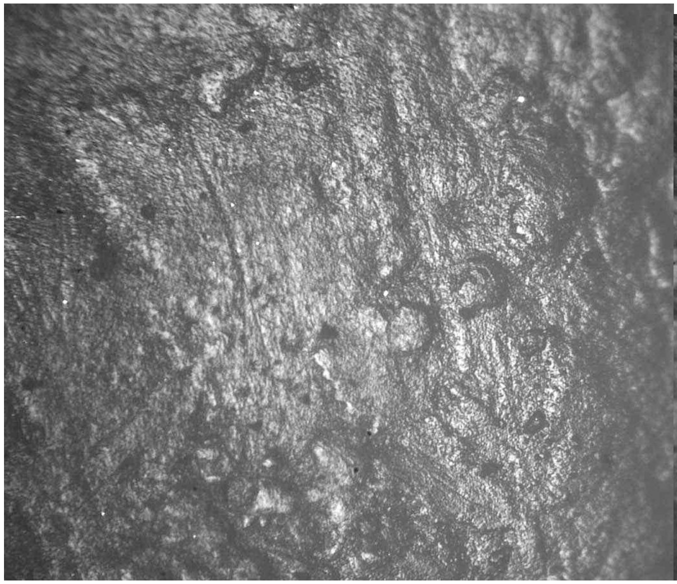

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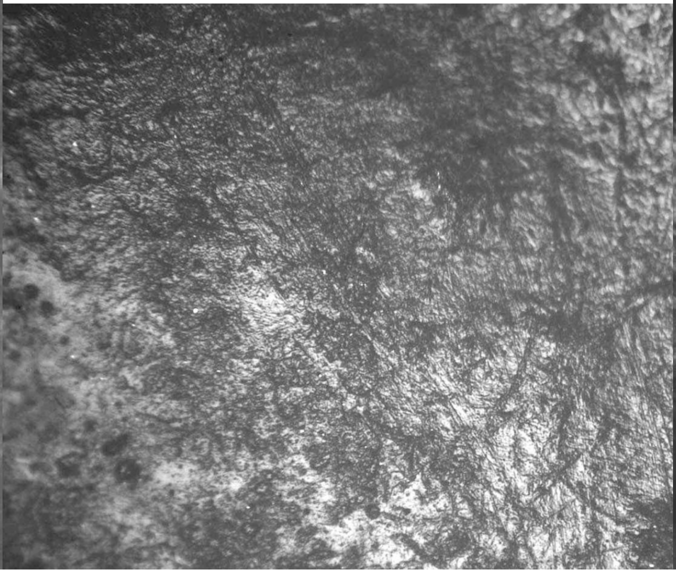

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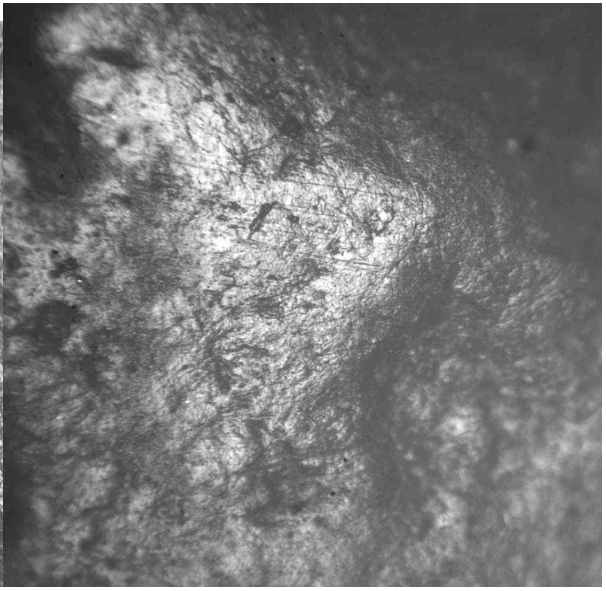

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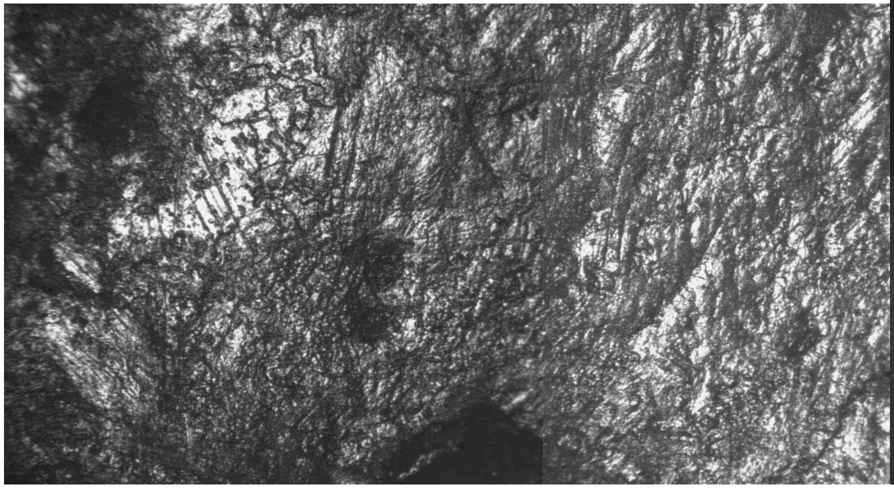
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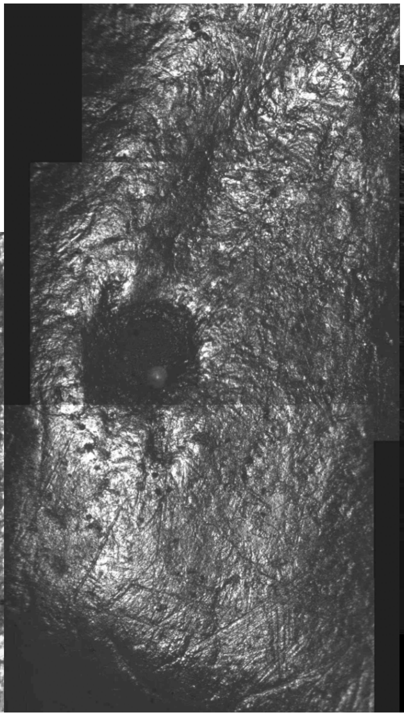
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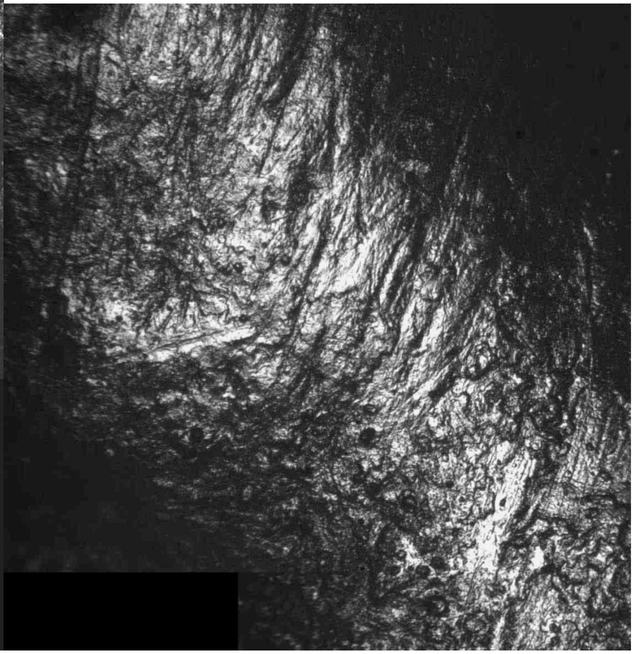
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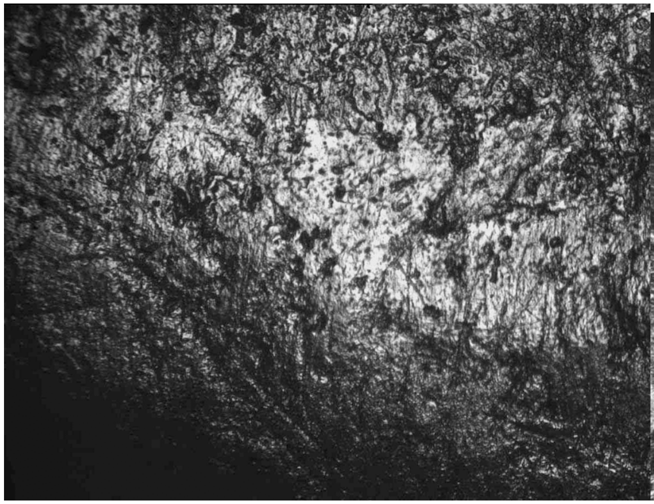
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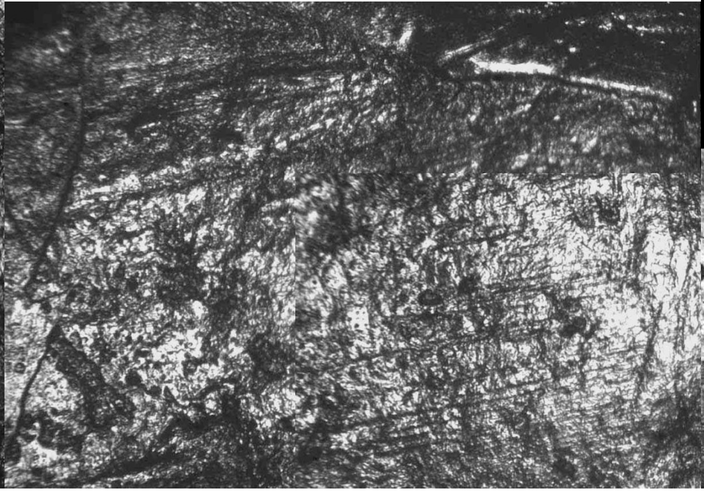
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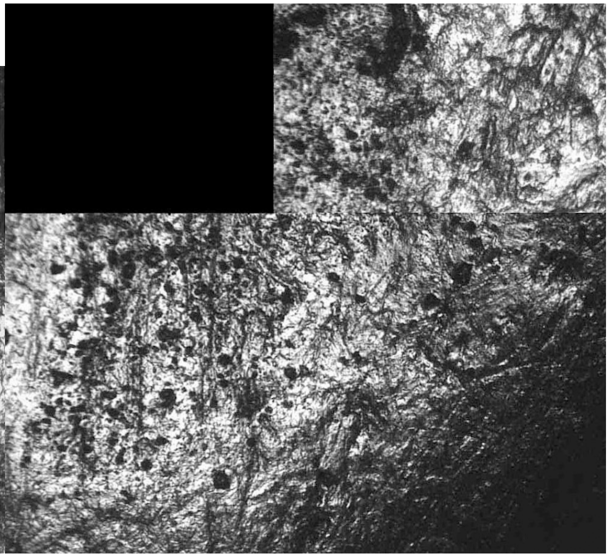
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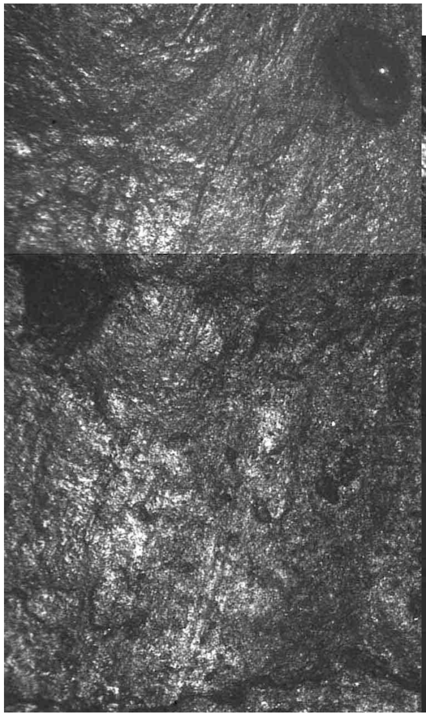
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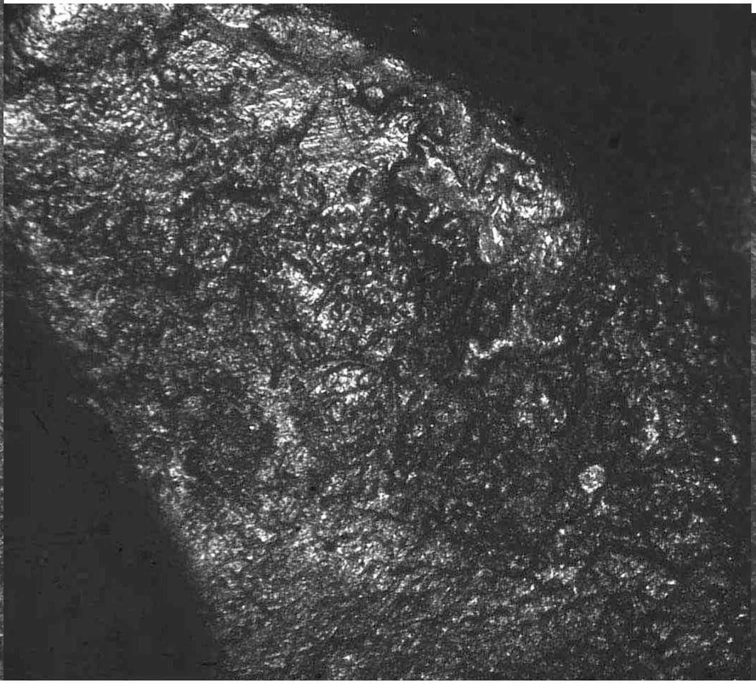
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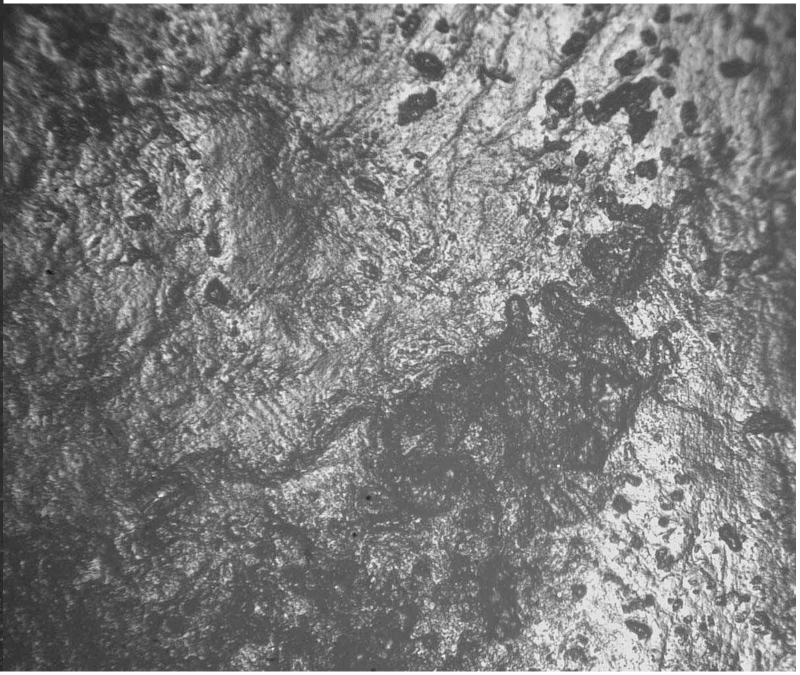
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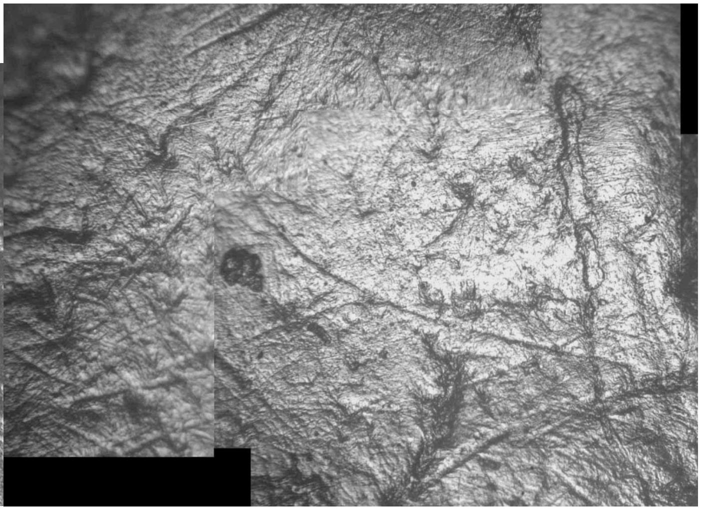
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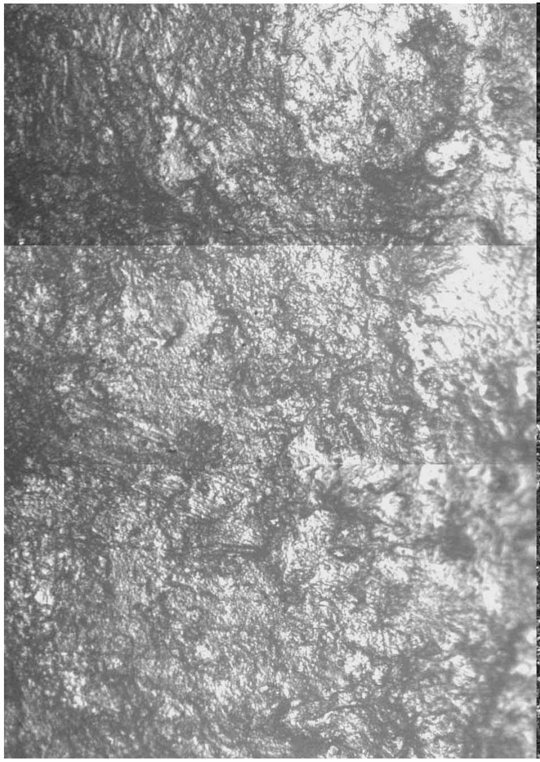
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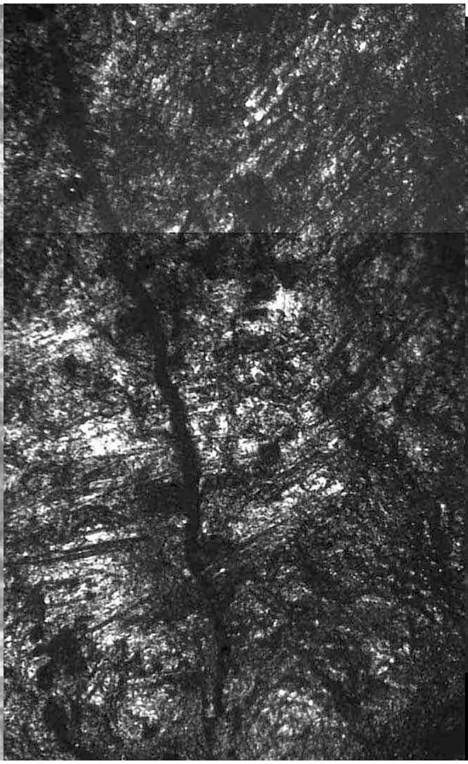
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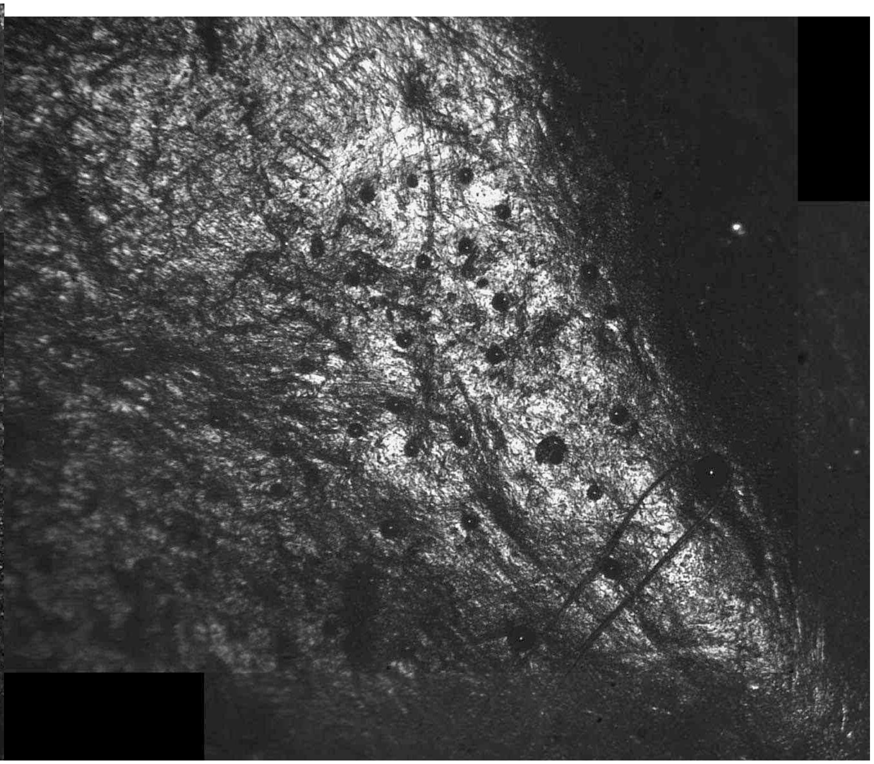
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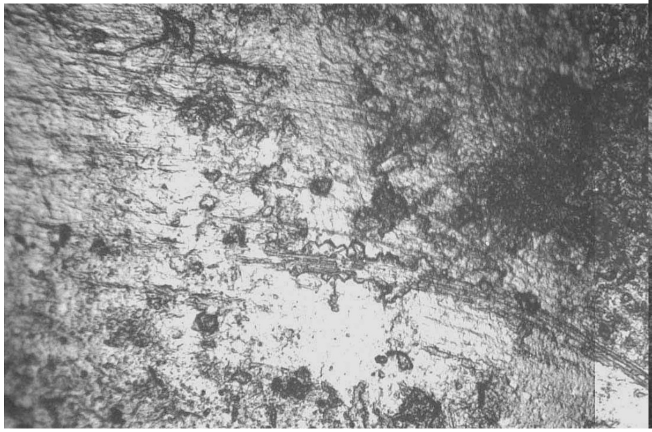
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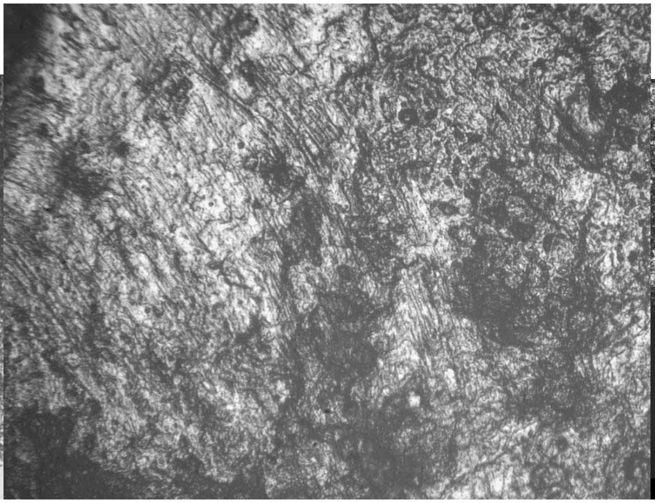
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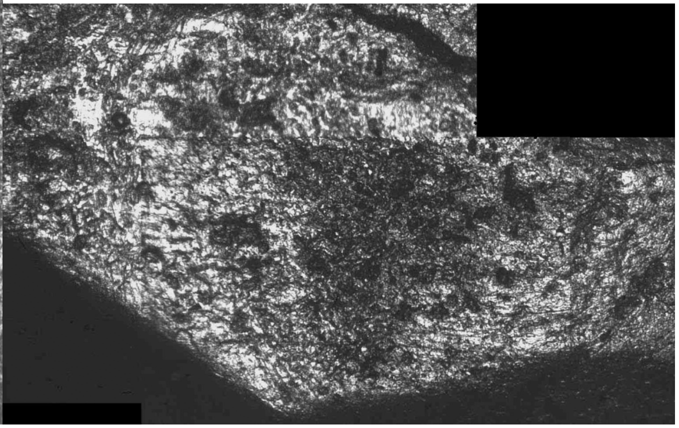
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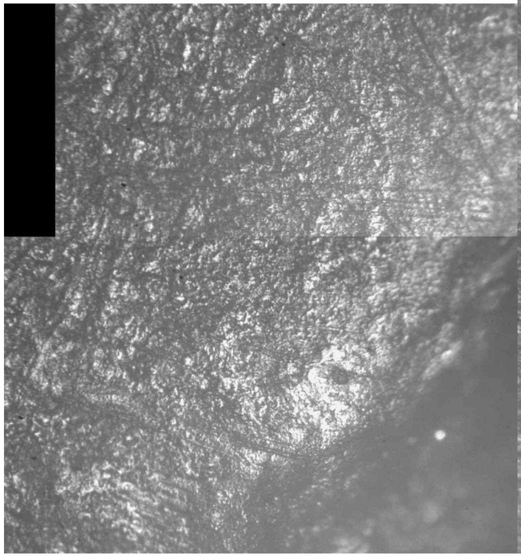
S9

URM1



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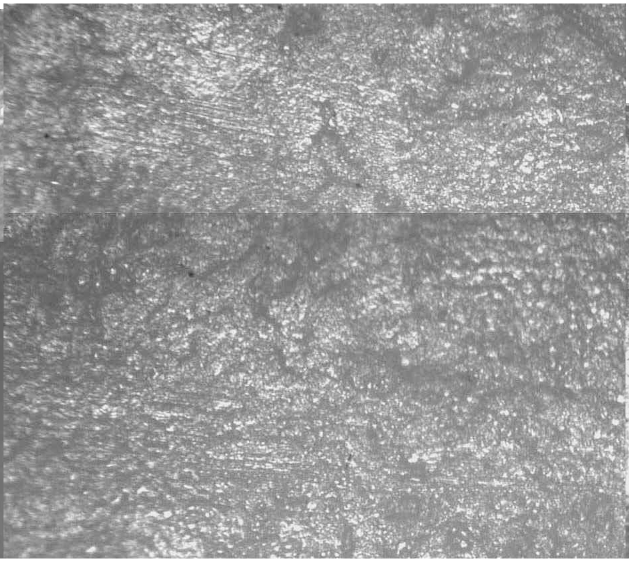

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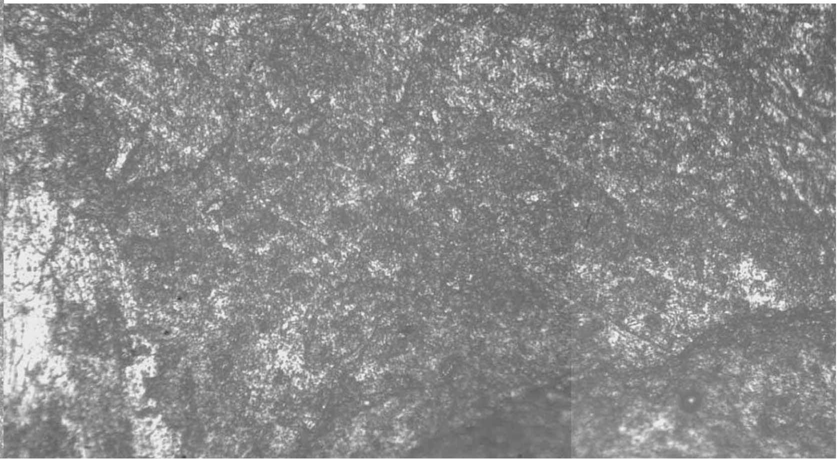

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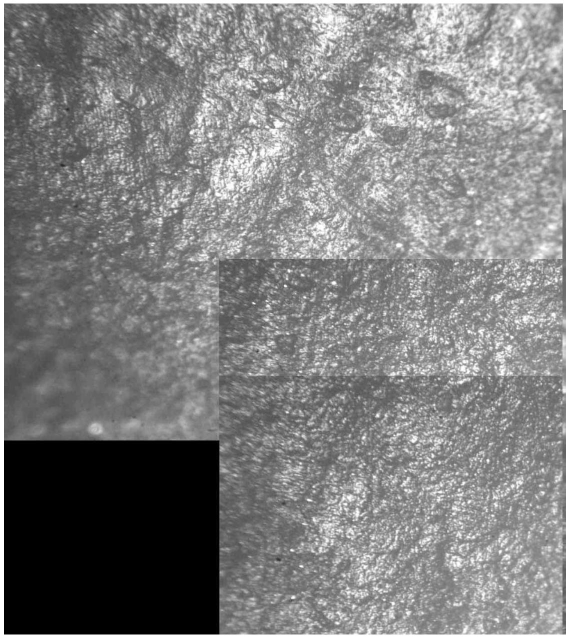

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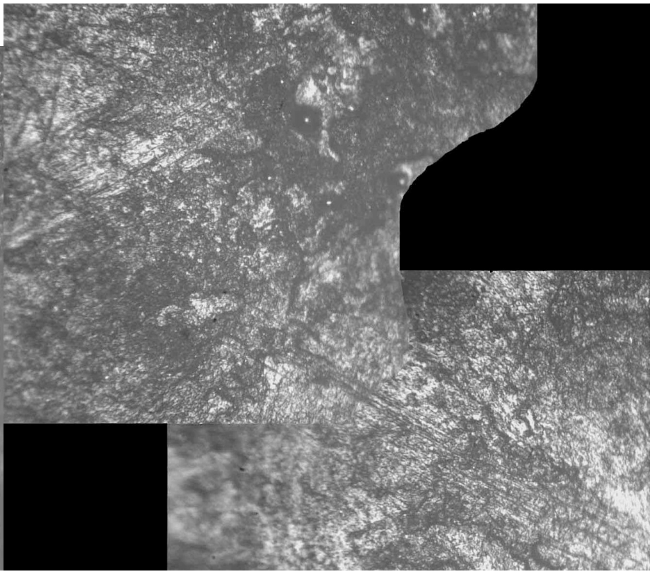

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S16

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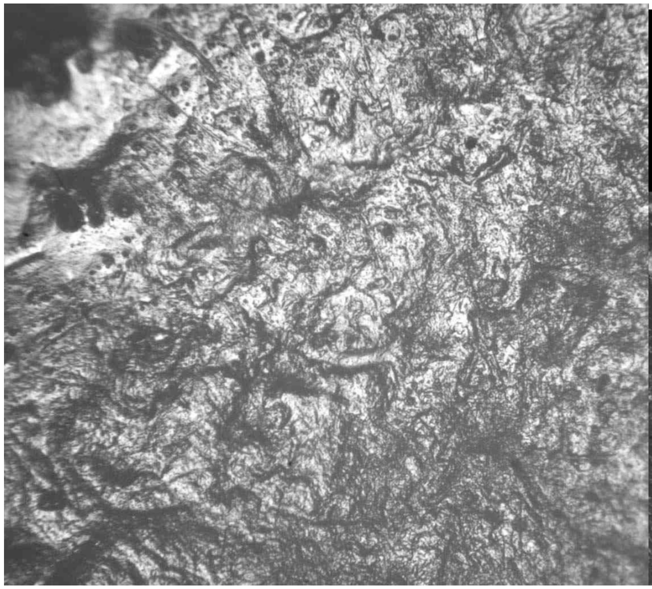
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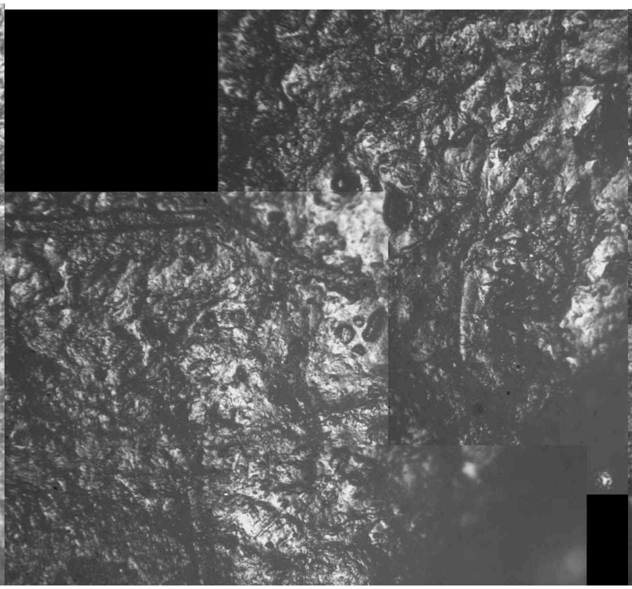
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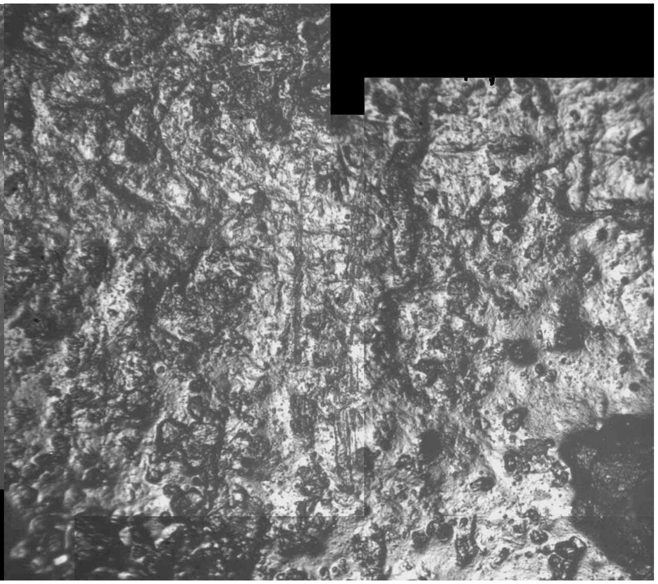
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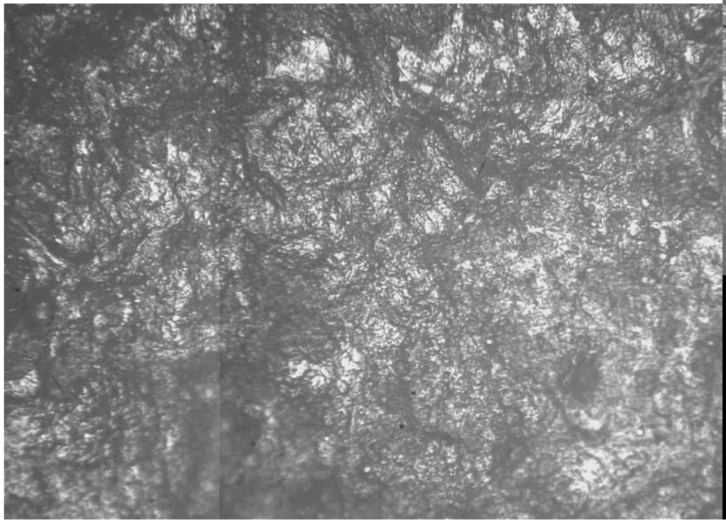
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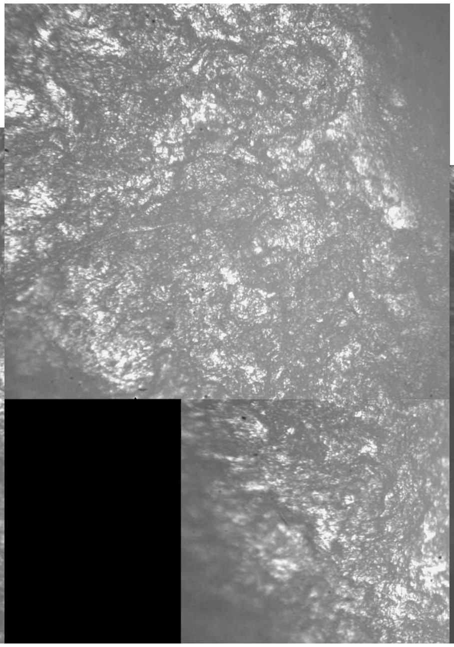
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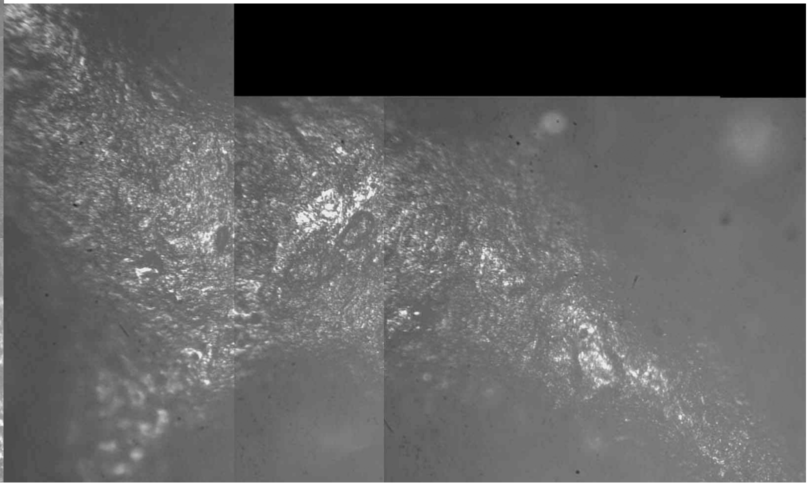
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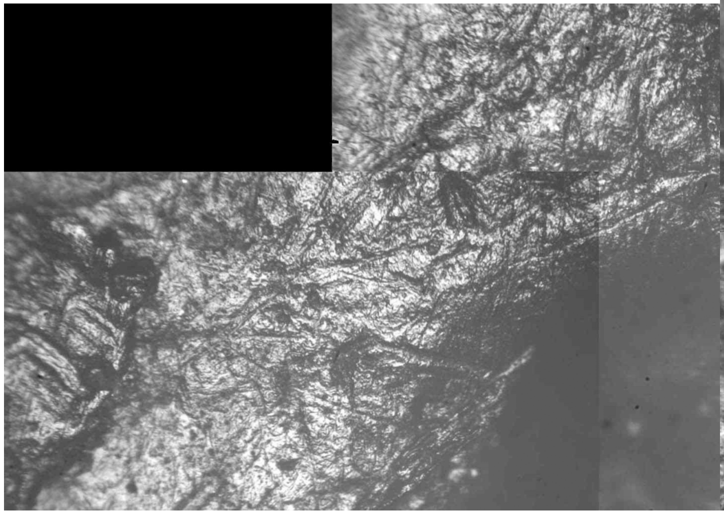
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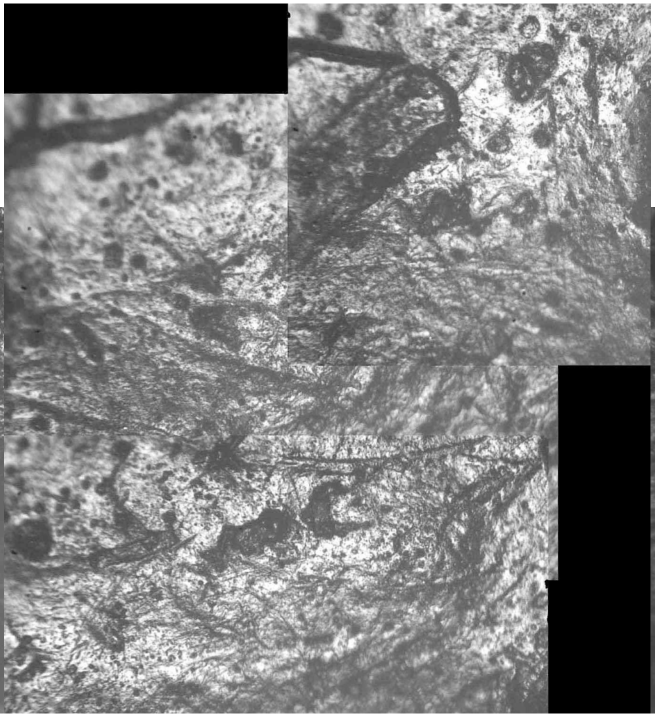
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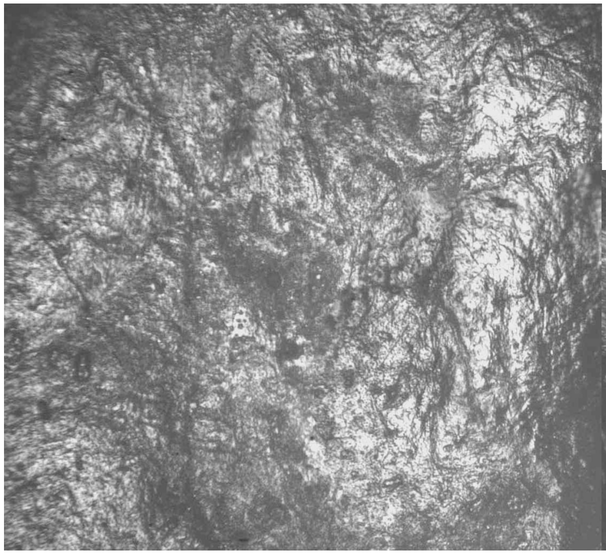
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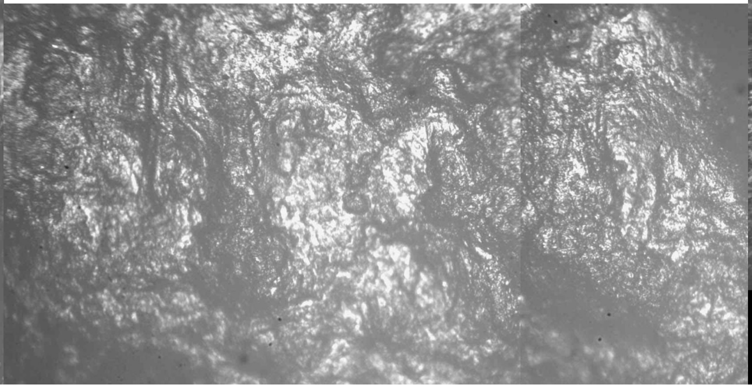
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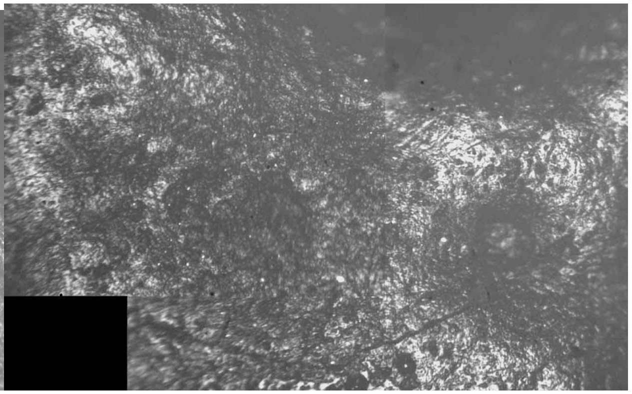
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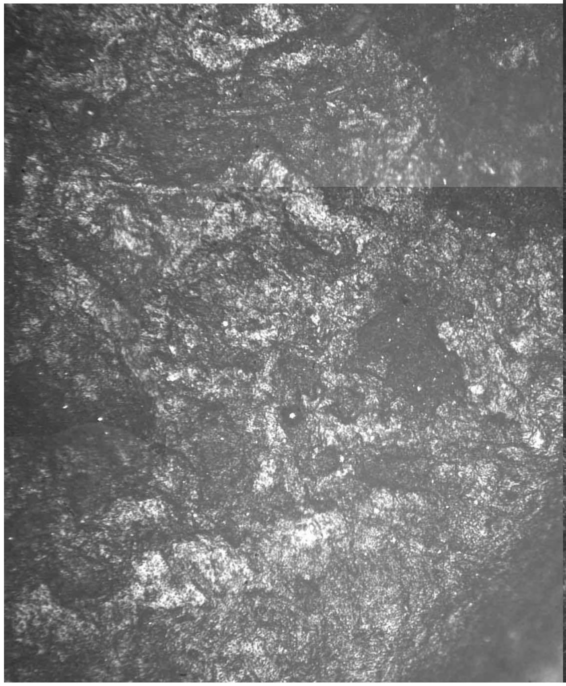
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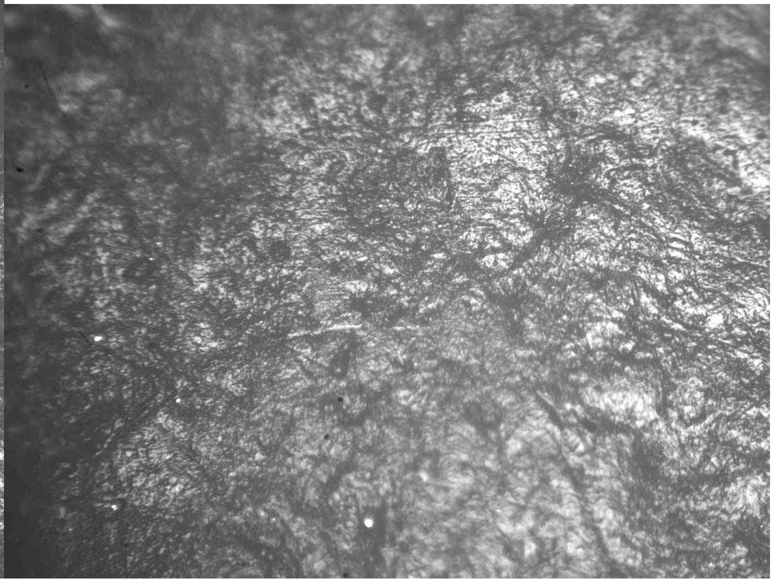
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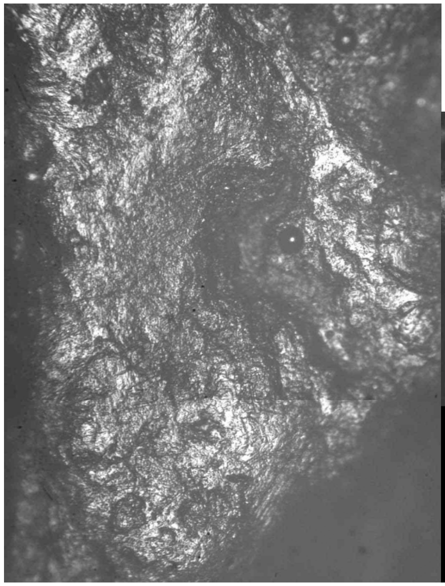
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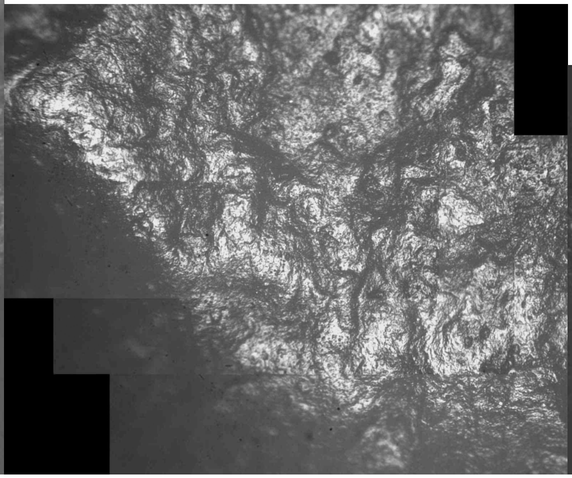
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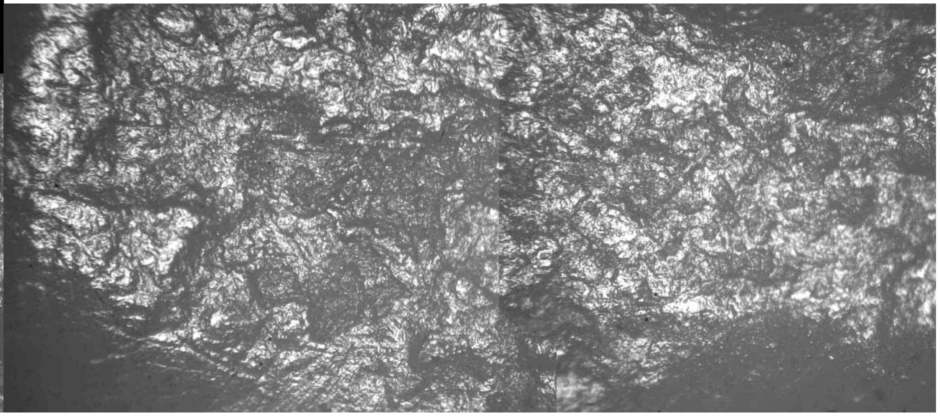
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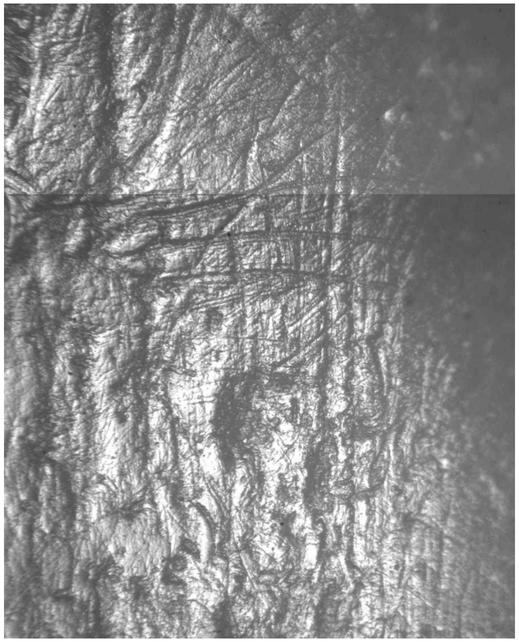
Vancouver Island Tribe

FC848

LLM1


F5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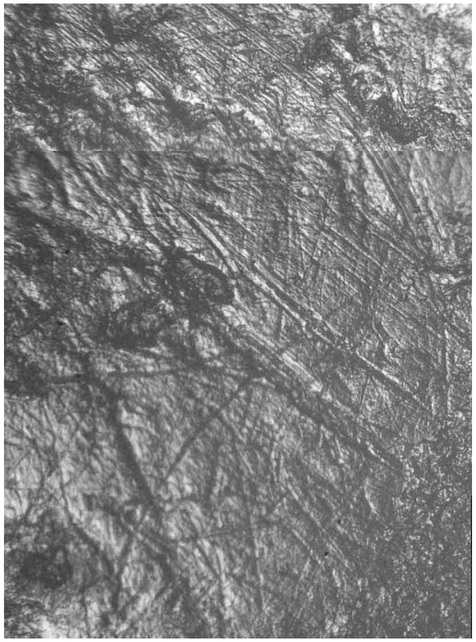
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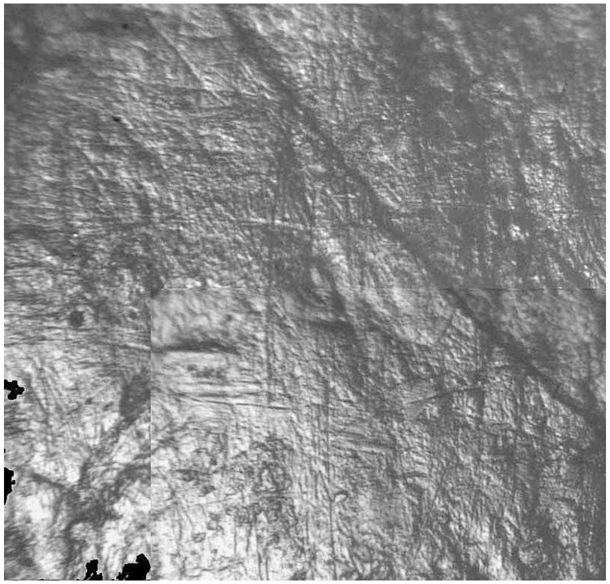
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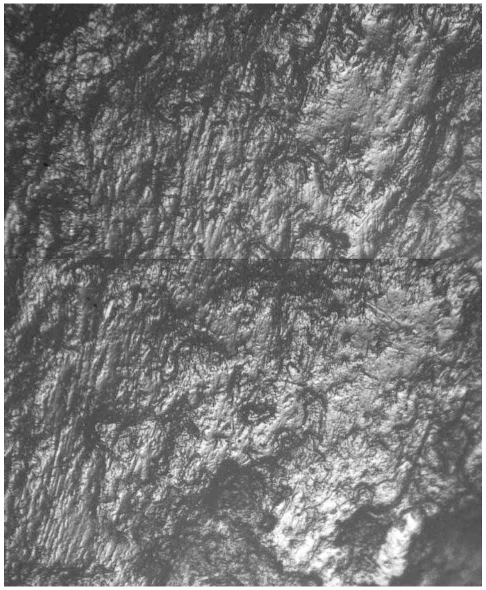
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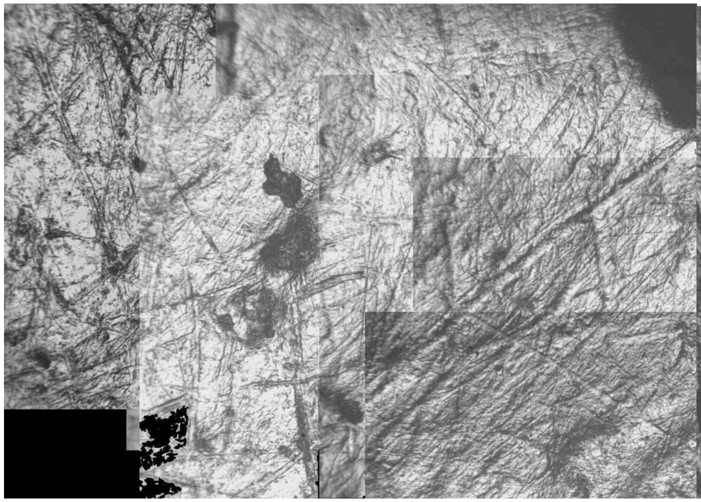
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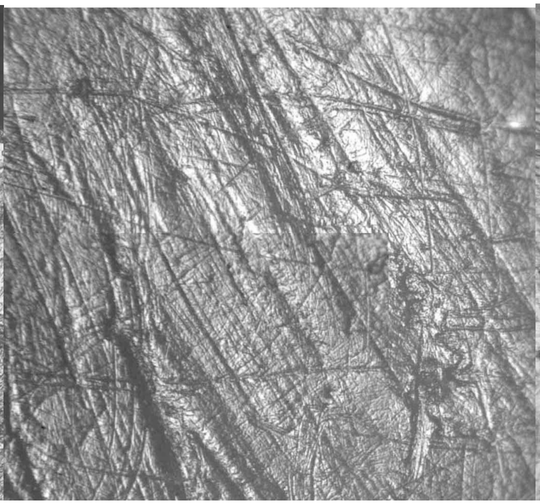
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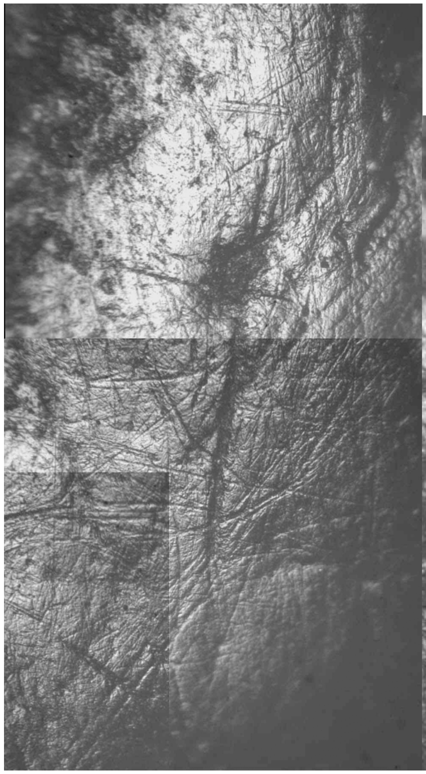
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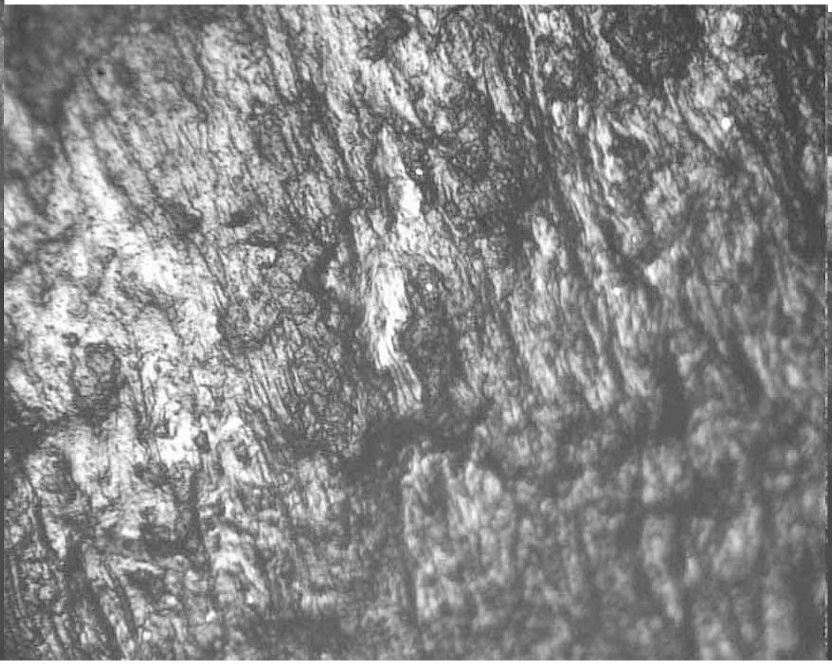
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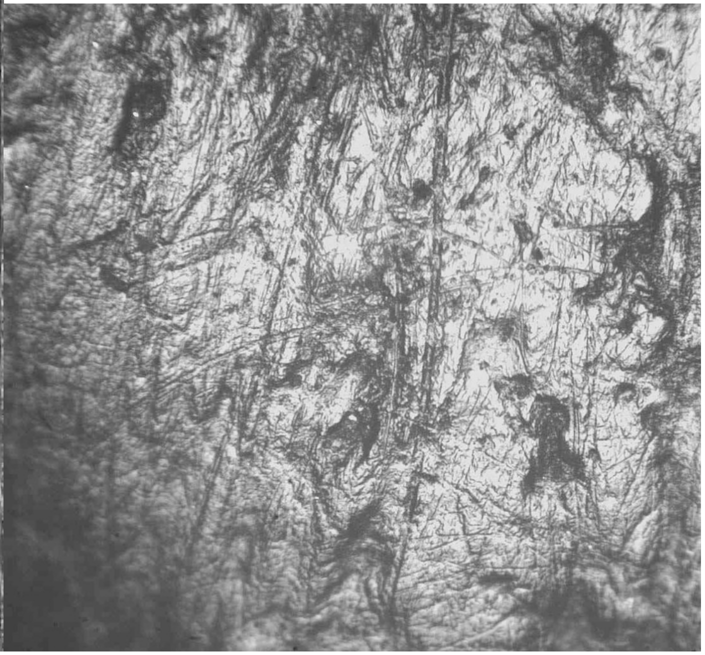
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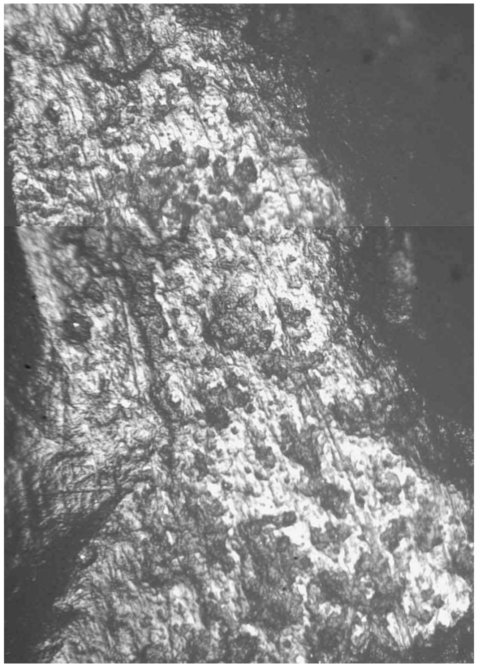
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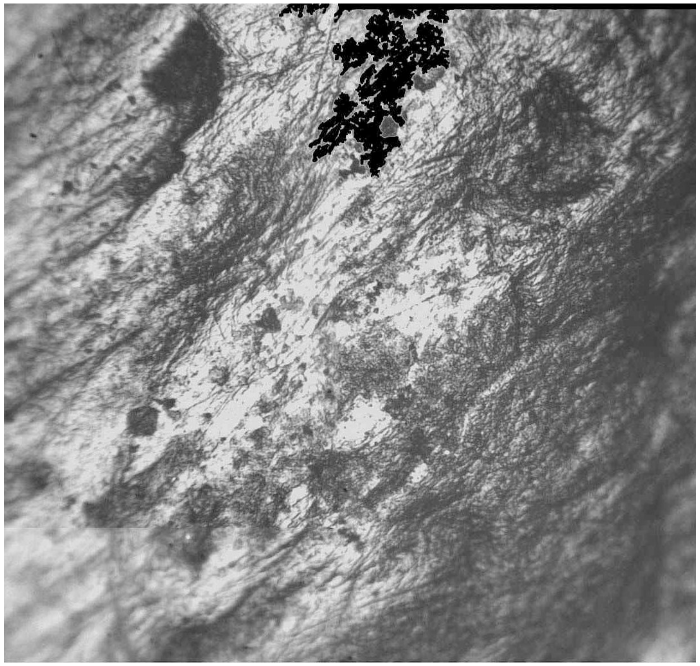
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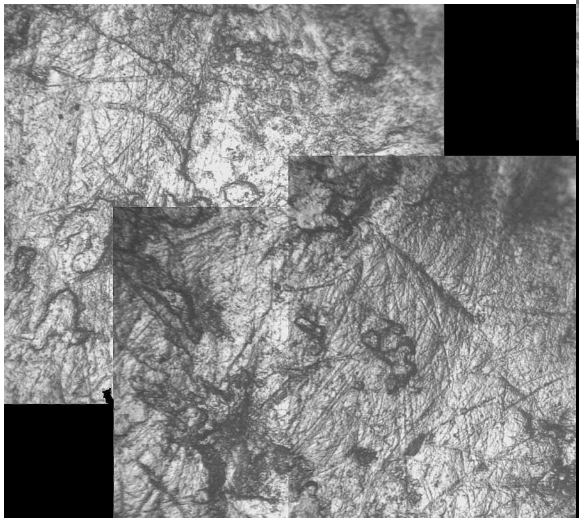
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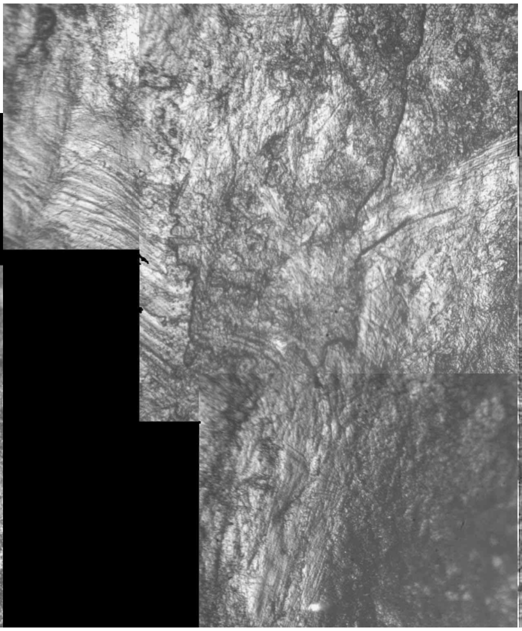
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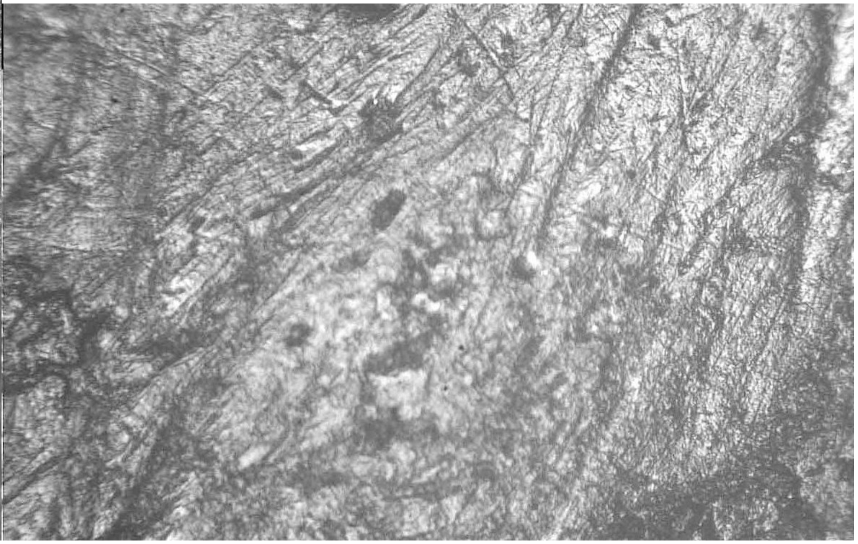
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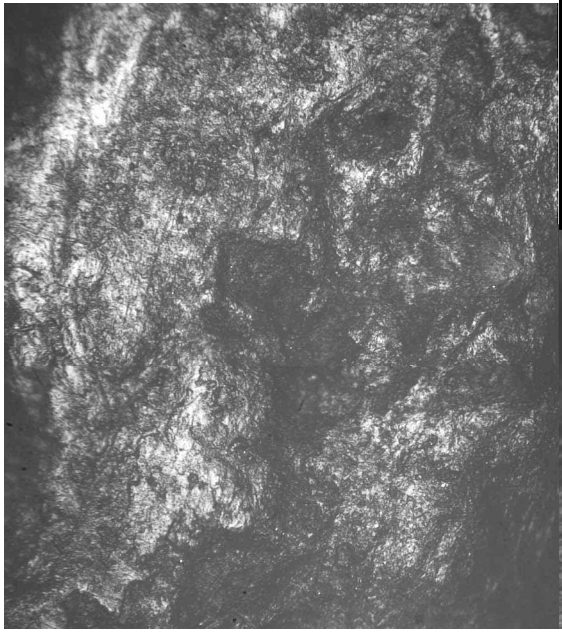
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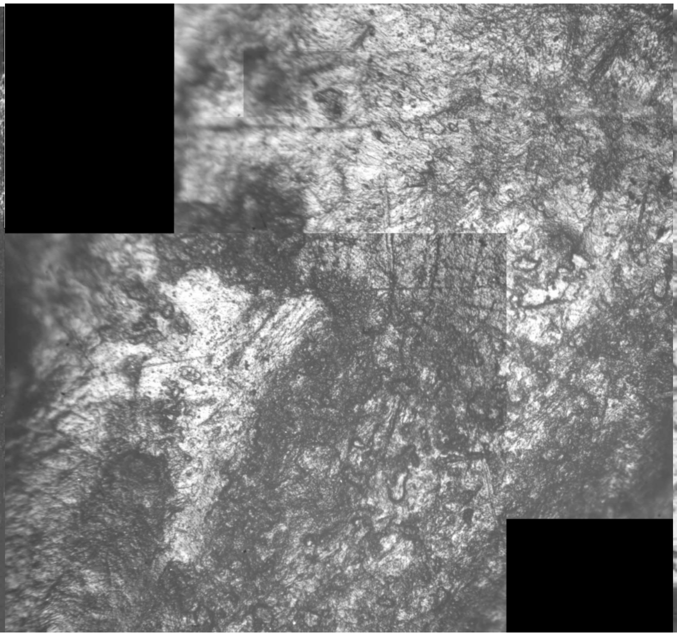
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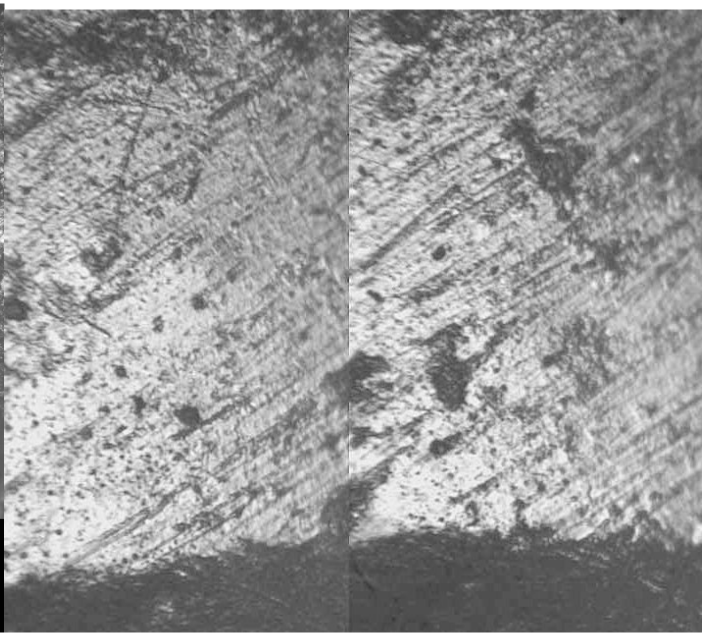
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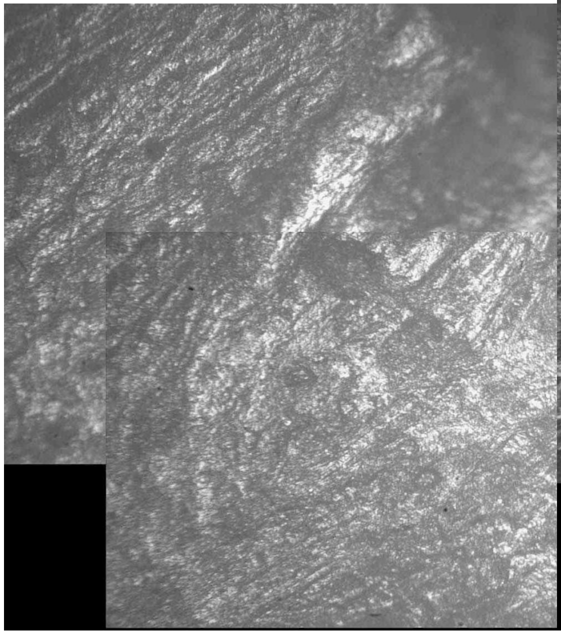
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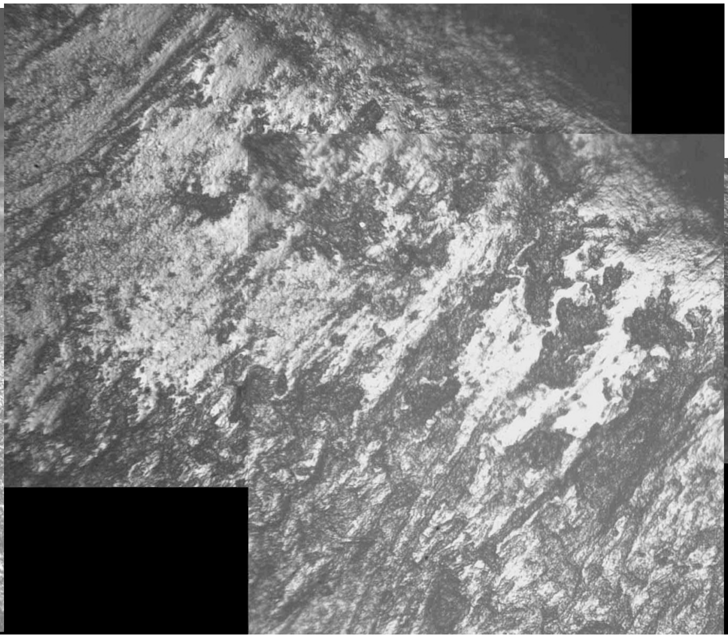
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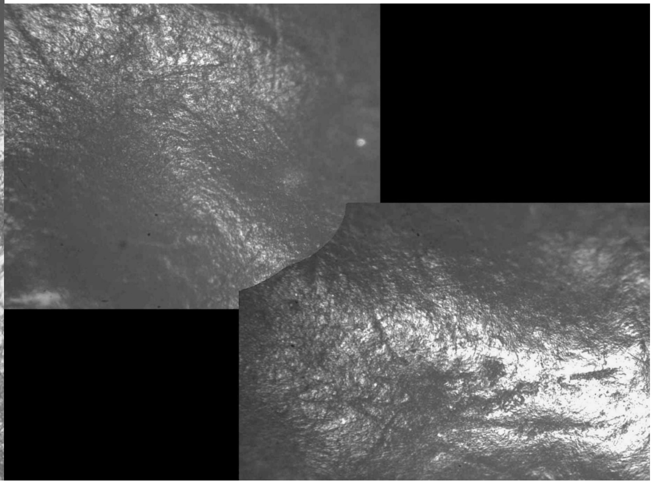
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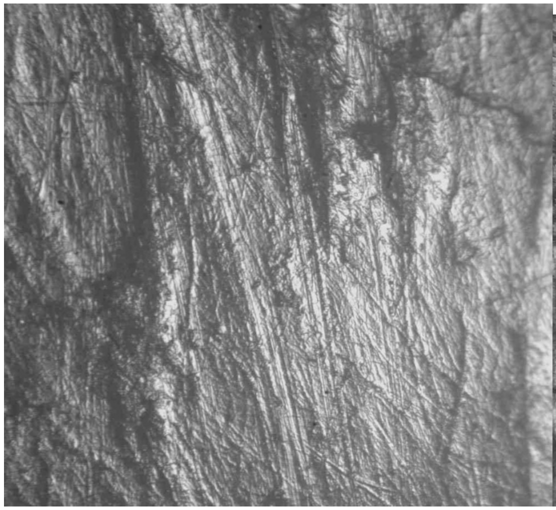

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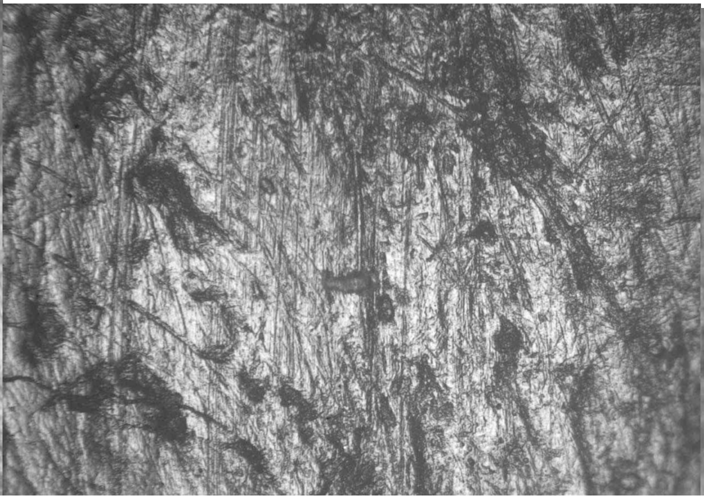

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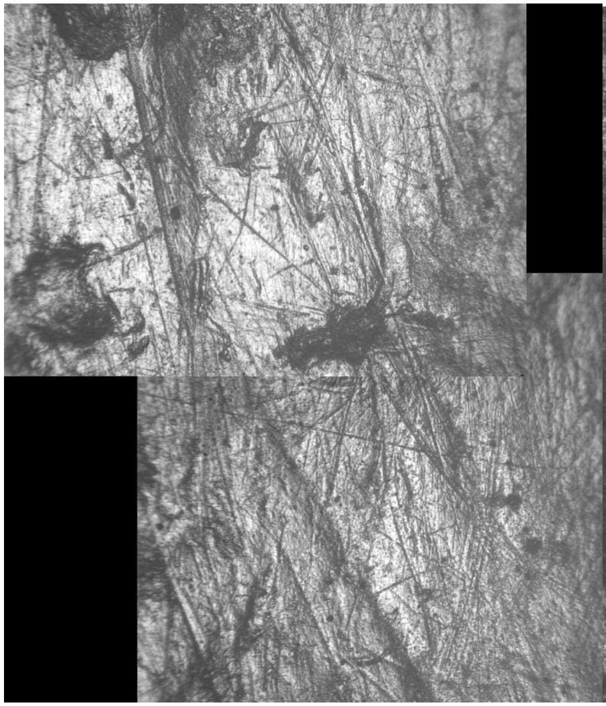

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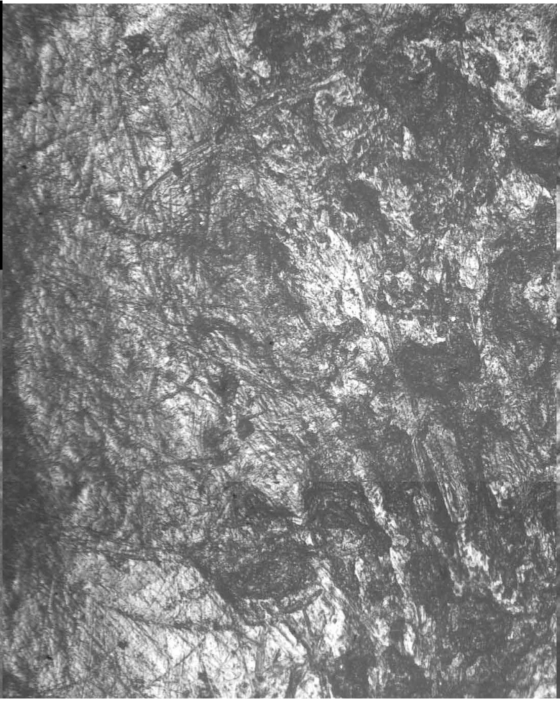

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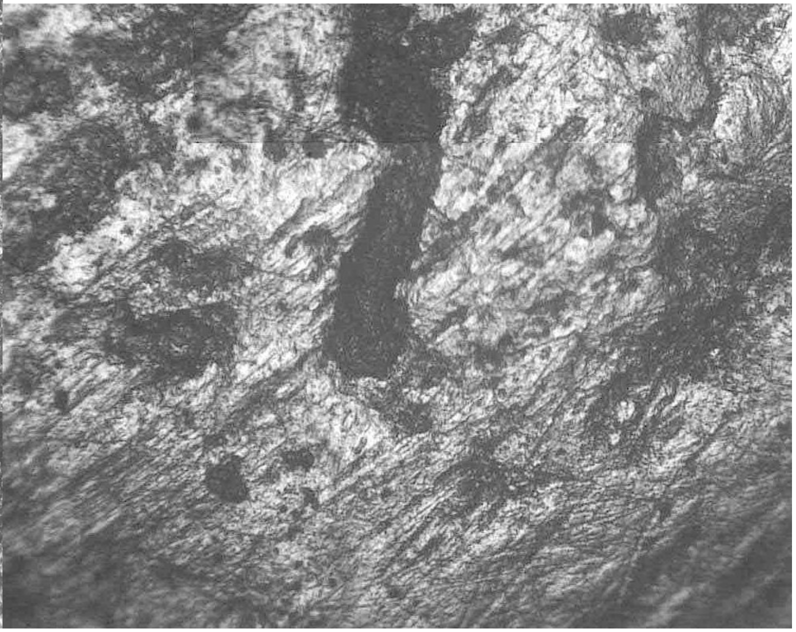

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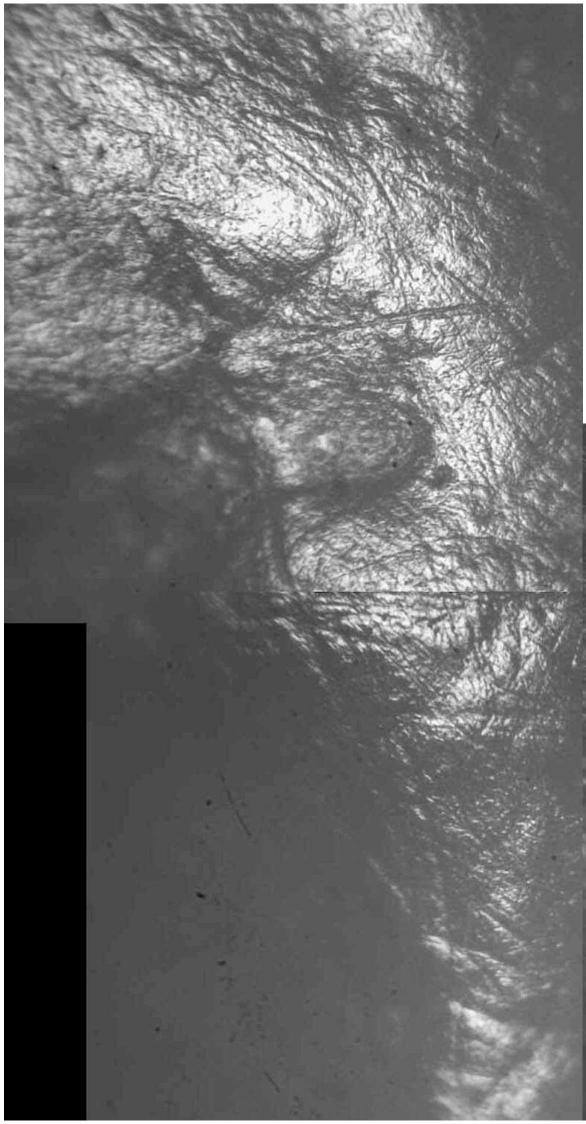

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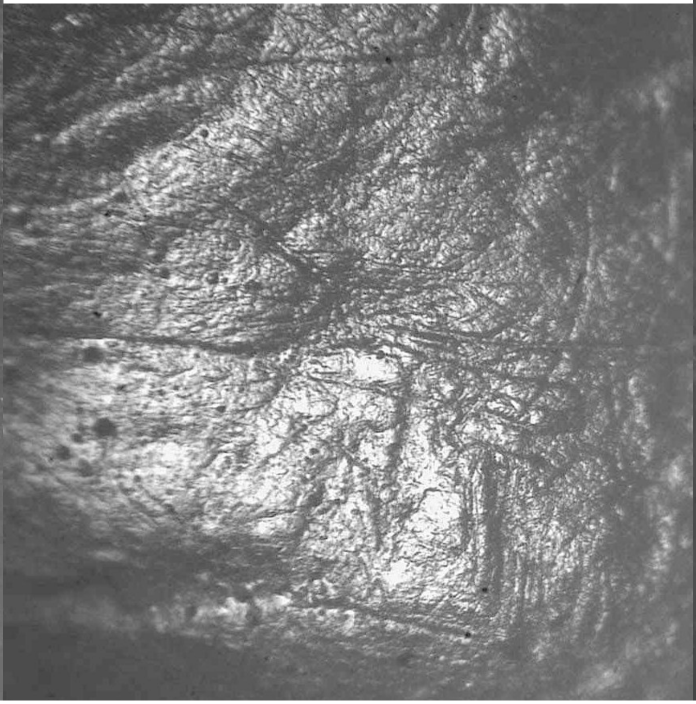

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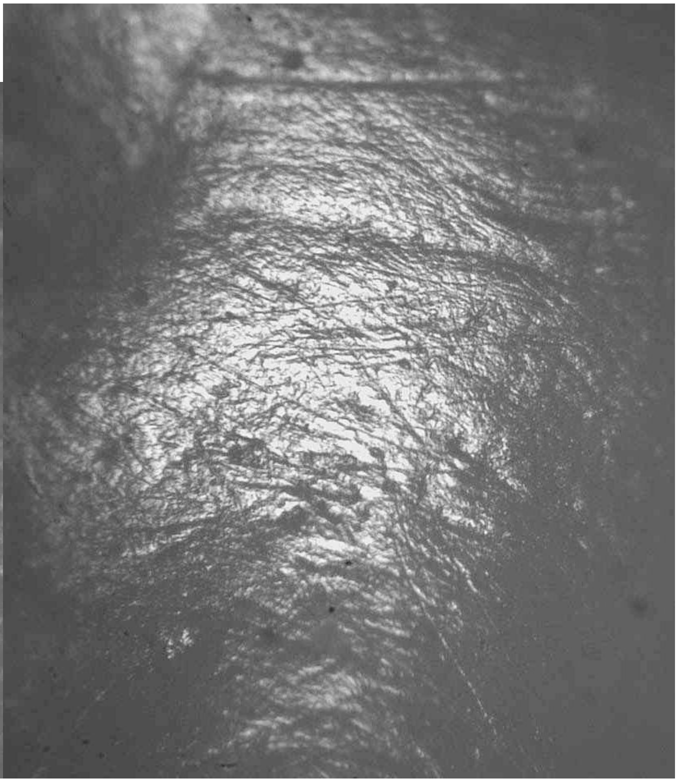

F9

Appendix C. Raw Goniometer Data: Sangiran 7 *Homo erectus*

Upper Left

Specimen	Facet	X	Y	Z	Z^1	Objective Lens
S7-6	9	-0.5	-14	0	12	20x
	5	-5	1.1	2	12	20x
	6	-5.2	0.9	0	12	20x
S7-8	3	-4	21.2	0	12.81	20x
	4	2.4	23.17	0	12.81	20x
	9	-0.3	10.8	0	12.81	10x
S7-38	10	-12.5	2	0	13.03	10x
	12	-2	4.5	0	13.03	20x
	3	6	9	0	13.03	10x
	4	5	13.5	0	13.03	20x
S7-53	9	7	-9	0	12.65	5x
	12/10	1	-14.5	0	12.65	5x
	3	1.5	19.4	0	12.65	5x
	4	-1	25	3	12.65	5x
S7-73	9	-14	-6	0	12.17	10x
	3	0.5	19	0	12.17	10x
	4	-7	15	0	12.17	10x

Upper Right

Specimen	Facet	X	Y	Z	Z^1	Objective Lens
S7-3b	11	-2.5	2.5	0	12.33	5x
	2	-10.5	-5	0	12.33	5x
	12	-2	-8	0	12.33	10x
	9	2.5	7.5	0	12.33	5x
	5	8	-9.5	0	12.33	10x
	6	8	-9.5	0	12.33	10x
S7-3c	9	-1.5	14.8	0	12.69	5x
	6	1.3	6	0	12.69	5x
	5	1.3	6	0	12.69	5x
	3	1	-10	0	12.69	5x
S7-3d	9	-1	-4.5	0	11.8	5x
	11	-2	6	0	11.8	5x
	1	6	4.1	0	11.8	5x
	3	9.5	-10	0	11.8	5x
	5	14	-17.8	0	11.8	5x
S7-9	6	6	-33	0	12.55	5x
	8	0	-9.5	0	12.55	5x
S7-10	9	-1	11	0	12.01	5x

	4	8	-10	0	12.01	5x
	3	5	-20	0	12.01	5x
S7-14	9	2	10	0	12.68	10x
	3	-10	-16.5	0	12.68	10x
S7-17	9	-3	1	0	20.24	5x
	3	-3	-4.75	0	20.24	5x
	4	1	-2	-20	20.24	10x
S7-37	9	-1	15	22	20.51	5x
	12	4	10	12	20.51	10x
	4	16	14	12	20.51	10x
	3	-3	-12	12	20.51	10x
S7-40	9	1	5	0	12.7	10x
	4	11.5	-9.5	0	12.7	10x
	3	2	-15	0	12.7	10x
S7-89	9	0	2	0	12.67	5x
	13	0	2	0	12.67	5x
	3	-4	-9.5	0	12.67	10x
	2	-4	-14	0	12.67	10x

Lower left **Specimen**	**Facet**	**X**	**Y**	**Z**	**Z^1**	**Objective Lens**
S7-20	9	2.5	-15.4	0	18.96	10x
	6	-4.5	-4.5	0	18.96	10x
	5	-15	26.3	0	18.96	10x
S7-78	9	6	-16.3	0	12.09	10x
	6	-5	9.75	0	12.09	10x
	5	-5	13	0	12.09	10x
S7-43	5	-23	13	0	11.7	10x
	9	6	-21.5	0	11.7	20x
	6	5	15.3	0	11.7	10x

Lower Right **Specimen**	**Facet**	**X**	**Y**	**Z**	**Z^1**	**Objective Lens**
S7-42	9	1.5	28	0	11.46	10x
	6	-7	-14.7	0	11.46	20x
	5	4	-12	0	11.46	20x
S7-61	9	-6	20	0	12.54	10x
	6	-0.3	1.4	0	12.54	10x
	5	-14.5	-5.15	0	12.54	5x
S7-62	9	-2.9	14.1	0	11.69	10x
	6	11	-22.3	0	11.69	10x
	5	-20.5	-14.5	0	11.69	10x

S7-64	9	acid-etched		0	12.25	10x
S7-65	5	-14	-12	0	11.65	10x
	6	4.5	-2.5	0	11.65	10x
	9	1.7	-33	0	11.65	20x
S7-76	9	1	33	0	25.47	10x
	6	15.5	-23.2	0	25.47	10x
	5	-20	-18.6	0	25.47	10x
S7-84	9	1.5	13.5	0	11.25	10x
	3	-7	-8.5	0	11.25	5x
	6	-3.5	-8	1.5	11.25	10x
	5	-13.5	-15	0	11.25	10x

Notes: I X, Y, Z data in degrees
is tooth crown height in mm above rotational axis

Appendix D. Raw Goniometer Data: Historic hunter/ gatherer *Homo sapiens*

Specimen	Tooth	Facet	X	Y	Z	Z^1	Objective lens
NHMW-8687 Aust. Abor. n=6	RM^1	1	-1	3	0	13	10x
		3	-0.75	0.75	0	13	10x
		4	-1	-10	0	13	10x
		9	3.5	-24	0	13	5x
		13	-3	-3	0	13	5x
		12/10	0	-5.25	0	13	5x
	RM^2	1	-37	-16.5	0	12	10x
		3	0	-5.5	0	12	10x
		9	-3	9	0	12	5x
	RM^3	3	13	-2	0	11	5x
		4	3	-9	0	11	5x
		9	21	7	0	11	5x
	LM^1	3	-4.5	-2	0	11	5x
		12/10	3	-4	0	11	5x
		4	3	7	0	11	5x
	LM^2	3	-2	1	0	10	5x
		1	0	5	0	8	5x
		9	4	-7	0	8	5x
	LM^3	9	7	-21	0	8	5x
		4	-5	-7	0	8	5x
		3	9	-4.5	0	8	10x
NHMW-811 Aust. Abor. n=6	LM^1	3	-2	1	0	11	5x
		9	-1.5	-17.5	0	11	5x
		4	-8	6	0	11	5x
	LM^2	4	-9	17	0	11	5x
		9	-2.5	-16	0	11	5x
		6	6	2	0	11	5x
	LM^3	4	-13	-4.5	0	11	5x
		9	-7	-20	0	11	5x
		6	-1	-1	0	11	5x
	RM^1	3	-2.5	-11	0	12	5x
		4	-2.5	-11	0	12	5x
		9	1	-2	0	12	5x
	RM^2	9	6	19	0	12	5x
		3	-15	-12	0	12	5x
		1	-20.5	-16.5	0	12	5x
		4	0	-19.5	0	12	5x
	RM^3	9	11	17.5	0	12	5x
		3	11	-16	0	12	5x
		6	15	-2	0	12	5x
		1	8	16	0	12	5x
S5 Bushmen n=12	LM^1	3	3	3.5	0	12	5x
		4	0.5	7.5	0	11	5x
		9	-4	-2	0	11	5x

	LM^2	4	4	-1	0	9	10x
		9	-3	14	0	9	10x
		3	-9	-1	0	11	5x
	LM^3	3	5	10	0	10	5x
		9	7	1	0	10	5x
		1	-8	-11	0	10	5x
	RM^1	3	-2	-7.5	0	11	10x
		4	-12	-15	0	11	10x
		9	0	3	0	11	10x
	RM^2	4	-3	-5	0	10	5x
		9	1	11	0	10	5x
		3	8.5	-7	0	10	10x
	RM^3	6	6	-17	0	12	10x
		9	8	9	0	12	5x
		5	-2	19	0	12	10x
	LM_1	9	3	-4	0	8.5	5x
		6	-3	3	0	8.5	10x
		5	7.5	7	0	8.5	10x
	LM_2	5	19	16	0	8	10x
		6	-1	6	0	8	10x
		9	4.5	-17.5	0	8	10x
	LM_3	5	23.5	13	0	6	10x
		7	-11	-2	0	6	10x
		9	-5	-24.5	0	6	10x
	RM_1	5	13	-5	0	10.5	10x
		7	-12	-8	0	10.5	10x
		9	-2	13	0	10.5	10x
	RM_2	5	20	-15	0	10	10x
		3	-5	2	0	10	10x
		9	20	-27	0	10	10x
	RM_3	5	17	-15	0	10	10x
		3	-8	-4	0	10	10x
		9	10	20	0	10	10x
S16 Bushmen n=6	RM^1	4	-7	-17	0	10	10x
		9	11	7	0	10	10x
		3	-7	-11.5	0	10	10x
	RM^2	3	-23	-21.5	0	8	10x
		5	1	-24	0	8	10x
		6	14	-10.5	0	8	10x
	RM_1	5	3	-6	0	8	10x
		9	-6	13	0	8	10x
		6	-12.5	-22	0	8	10x
	RM_2	6	-2	-31	0	9	10x
		9	-8	-25	0	9	10x
		5	8	-20	0	9	10x
		1	15	-14	0	9	10x
	LM_1	9	2	-8	0	9	10x

		6	-7	16	0	9	10x
		5	2	16	0	9	10x
	LM_2	1	-8	0	0	9	10x
		9	-13	-25	0	9	10x
		2	-15.5	4	0	9	10x
S9 Bushmen n=2	RM^1	4	-11	-4	0	9	10x
		3	-4	-12	0	9	10x
		9	-3	14	0	9	10x
	RM^2	4	-21.5	-16	0	10	10x
		3	21	-10.5	0	10	10x
		9	-2	28	0	10	10x
NHMW6035 Fuegians n=11	RM_1	6	-3	9	0	9	5x
		5	17	9	0	9	5x
		9	4	17.5	0	9	5x
	RM_2	9	-30	12	0	10	10x
		5	-2	-3	0	10	10x
		6	-2	-3	0	10	10x
	RM_3	5	24	5	0	8	10x
		6	-7	-1	0	8	10x
		10	-7	15	0	8	10x
	LM_2	5	26	13.5	0	10	10x
		6	7	4	0	10	10x
		9	23	-24	0	10	10x
	LM^3	5	30	13	0	10	5x
		6	-4	6	0	10	5x
		9	3	-33	0	10	5x
	RM^1	3	-1	-7	0	8	5x
		4	-9	3	0	8	5x
		9	-6	-1	0	8	5x
	RM^2	3	1	-13	0	8	5x
		4	-25.5	-7.5	0	8	5x
		9	-2	-18	0	8	5x
	RM^3	3	5	2	0	9	5x
		4	-29.5	14	0	9	5x
		9	-4	-11.5	0	9	5x
	LM^1	3	-2	4	0	8	5x
		4	-10.5	9	0	8	5x
		9	-6	-11	0	8	5x
	LM^2	3	-3	20	0	9	5x
		4	-29.5	9.5	0	9	5x
		9	-2.5	-20	0	9	5x
	LM^3	3	-1.5	10.5	0	8	5x
		9	16	-13	0	8	10x
		4	-20	-12.5	0	8	5x
FC848 Pacific NW Tribal People	LM^1	3	-1.5	20	0	10	5x
		4	-8	14.5	0	10	5x
		9	-5	-22.5	0	10	5x

n=11	LM^2	3	3	25	0	10	5x
		4	-30	15	0	10	5x
		9	-7	-25	0	10	5x
	LM^3	5	-15	-17	0	9	5x
		1	-3	-5.5	0	9	5x
		9	4	24	0	9	5x
	RM^1	3	0.5	-7	0	8	5x
		4	-9	-1	0	8	5x
		9	-9.5	26	0	8	5x
	RM^2	3	17	8	0	8	5x
		4	24	10	0	8	5x
		9	3	-32	0	8	5x
	RM^3	5	19	-28	0	8	5x
		3	-13	4	0	8	5x
		4	14	10.5	0	8	5x
		9	-8.5	-40	0	8	5x
	LM_1	6	10	-25	0	8	5x
		5	-10	-15	0	8	5x
		9	1	23	0	8	5x
	LM_2	6	9	-31	0	7	5x
		5	-28	-34	0	7	5x
		9	-6	25	0	7	5x
	RM_1	5	-16	9	0	9	5x
		6	4	12.5	0	9	5x
		9	7	-31	0	9	5x
	RM_2	6	19	15	0	9	5x
		5	-36	12	0	9	5x
		9	-13	-29	0	9	5x
	RM_3	5	-21	8.5	0	10	5x
		6	16	13	0	10	5x
		9	5	-33	0	10	5x
FC 833-3 Inuit n=9	LM^1	3	0	4	0	8	5x
		4	-4	-4	0	8	5x
		9	4	3.5	0	8	10x
	LM^2	3	-6	5.5	0	9	5x
		4	-22	-9.5	0	9	5x
		9	3	16	0	9	5x
	RM^1	3	-4	4	0	8	5x
		4	5	4	0	8	5x
		9	5	2	0	8	5x
	RM_1	5	3	6	0	8	5x
		3	-3	5.5	0	8	5x
		9	0	1	0	8	5x
	RM_2	6	-4.5	6.5	0	8	5x
		9	-2.5	-15	0	8	5x
		5	-17.5	8	0	8	5x
	RM^2	3	-1	7	0	7	5x

		9	4.5	-17	0	7	5x
		5	15	9	0	7	5x
	LM$_1$	5	-20	-7	0	8	5x
		6	0.5	5	0	8	5x
		9	-5	10	0	8	5x
	LM$_2$	9	-4	17	0	7	5x
		6	-4	-3	0	7	5x
		5	-28	-6.5	0	7	5x
	LM$_3$	9	2.5	20	0	7	5x
		6	3	-10.5	0	7	5x
		1	11	-2	0	7	5x

Notes: All X, Y, Z data in degrees

Z^1 is tooth crown height in mm above rotational axis

Appendix E. Microwear Vector Raw Data: Sangiran 7 *Homo erectus*

Upper Left

Specimen	**Facet**	**X**	**Y**	**Z**
6	5	0.971	0.057	0.230
		0.537	0.645	0.544
		-0.682	0.660	0.314
	6	0.978	0.207	-0.029
		-0.269	0.963	0.021
	9	-0.777	0.543	0.319
		-0.065	0.965	0.252
8	3	0.883	0.274	0.382
		0.552	0.812	0.190
		-0.725	0.578	-0.375
	4	0.478	0.832	0.283
	9	0.642	0.764	0.064
38	3	0.947	0.291	0.133
	4	-0.692	0.624	0.363
		0.523	0.817	0.243
	10	-0.235	0.953	-0.193
		-0.935	0.352	-0.050
	12	-0.909	0.405	0.100
		-0.106	0.980	0.168
		0.938	0.345	0.024
53	3	-0.212	0.977	-0.034
		0.402	0.834	0.377
		0.775	0.272	0.570
	9	0.934	0.310	-0.176
		0.214	0.924	0.318
	10	-0.437	0.893	0.105
		0.687	0.725	-0.047
		0.372	0.928	0.004
		-0.024	0.998	0.059
73	3	0.179	0.982	0.055
	4	0.224	0.950	-0.217
	5	0.487	0.873	-0.016
		-0.846	0.460	-0.269
	9	-0.941	0.329	0.082
		0.241	0.935	-0.260

Upper Right

Specimen	**Facet**	**X**	**Y**	**Z**
3b	2	0.372	0.909	-0.189
	5	0.376	0.920	0.108
		-0.949	0.251	0.191
	6	-0.367	0.911	0.190

	9	-0.228	0.973	0.040
		-0.848	0.530	-0.033
	11	-0.866	0.499	0.014
	12	-0.765	0.639	-0.078
3c	3	-0.919	0.107	0.380
	5	-0.866	0.412	0.285
		-0.291	0.912	0.290
		0.277	0.944	0.179
	6	-0.823	0.510	0.250
		-0.243	0.942	0.230
	9	-0.259	0.957	0.132
		-0.894	0.443	0.063
3d	1	0.993	0.106	0.043
		-0.847	0.532	-0.009
	3	-0.888	0.343	0.305
	5	0.609	0.792	0.047
		-0.240	0.906	0.349
		-0.874	0.314	0.370
	9	0.397	0.918	-0.018
		-0.872	0.482	0.084
	11	-0.400	0.915	-0.049
9	6	0.516	0.835	-0.191
		-0.835	0.090	0.543
	8	-0.443	0.873	0.206
		-0.248	0.968	0.045
10	3	-0.886	0.203	0.418
	4	-0.918	0.249	0.308
	9	-0.943	0.321	-0.090
14	3	0.715	0.597	-0.363
		-0.579	0.807	0.115
	9	0.523	0.851	0.057
17	3	0.377	0.918	-0.125
	4	-0.991	0.090	-0.104
		0.696	0.713	0.088
		-0.507	0.861	-0.037
	9	0.881	0.462	0.099
		0.462	0.887	0.021
37	3	0.936	0.305	-0.178
		0.190	0.975	0.112
		-0.969	0.049	0.244
	4	-0.730	0.561	0.391
		0.935	0.349	-0.057
	9	0.720	0.691	0.065
		-0.513	0.858	-0.009
		0.085	0.996	0.033
	12	-0.542	0.814	-0.210
		0.640	0.756	0.133

		0.898	0.373	0.233
40	2	0.352	0.915	-0.196
		-0.429	0.900	0.081
		-0.943	0.039	0.330
	3	-0.906	0.271	0.326
		0.252	0.961	0.115
	4	0.395	0.917	0.048
		-0.829	0.474	0.296
	9	-0.881	0.470	0.047
		-0.159	0.979	0.127
	11	0.927	0.373	-0.043
		0.307	0.947	0.089
		0.995	0.012	-0.095
89	2	-0.318	0.944	-0.086
		0.860	0.324	-0.394
	3	-0.932	0.247	0.265
		-0.451	0.892	0.036
	9	-0.927	0.367	0.079
		-0.277	0.961	-0.027
	13	-0.324	0.946	-0.015
		-0.943	0.313	0.110

Lower Left

Specimen	Facet	X	Y	Z
20	5	0.871	0.185	0.454
	6	0.868	0.346	0.355
	9	0.376	0.922	-0.094
		0.947	0.254	-0.196
78	5	0.984	0.070	0.162
		-0.474	0.878	0.071
	6	-0.850	0.526	-0.040
		-0.417	0.907	0.058
	9	0.806	0.559	-0.194
43	5	-0.170	0.934	0.315
		-0.959	0.281	-0.033
	6	0.329	0.943	0.047
		-0.623	0.775	-0.105
	9	0.189	0.978	-0.083

Lower Right

Specimen	Facet	X	Y	Z
42	5	-0.479	0.876	0.045
		0.365	0.909	-0.200
		-0.035	0.995	-0.095
	6	0.335	0.933	0.132
	9	0.366	0.931	0.008
61	5	0.979	0.175	-0.103

	6	-0.989	0.140	0.042
	9	-0.909	0.293	-0.297
		0.142	0.975	0.172
62	5	-0.986	0.111	0.125
	6	0.967	0.101	-0.234
		-0.924	0.337	0.179
	9	-0.823	0.108	-0.558
		-0.730	0.421	-0.539
64	No data	Acid etched		
65	5	0.033	0.979	0.201
	6	-0.816	0.351	-0.459
	9	0.974	0.088	-0.207
76	5	0.950	0.307	-0.051
		0.089	0.935	0.342
		-0.838	0.443	0.319
	6	0.920	0.224	-0.321
	9	0.682	0.625	0.379
84	3	0.371	0.928	-0.030
		-0.972	0.043	0.230
	5	-0.964	0.068	0.258
		-0.853	0.425	0.304
	6	0.360	0.917	-0.170
		-0.943	0.179	0.281
		0.903	0.307	-0.300
	9	-0.980	0.001	-0.197

Note: All X, Y, Z coordinates are derived from absolute positionality of the vectors in 3D space

Appendix F. Microwear Vector Raw Data: Historic H/G *Homo sapiens*

Specimen	Facet	X	Y	Z
FC848-ulm1	3	-0.967	0.125	-0.223
		0.386	0.904	0.185
		0.951	0.182	0.250
		0.809	0.532	0.250
	4	0.934	0.265	0.240
		0.284	0.928	0.242
	9	0.929	0.176	-0.327
		0.645	0.758	-0.094
FC848-ulm2	3	0.870	0.242	0.429
		-0.219	0.957	-0.188
	4	0.909	0.144	0.392
		-0.497	0.774	0.392
	9	0.504	0.861	-0.066
FC848-ulm3	5	-0.690	0.556	-0.463
	6	-0.318	0.844	-0.431
		-0.960	0.232	-0.159
	9	0.757	0.641	-0.124
FC848-urm1	3	-0.692	0.661	0.290
		-0.917	0.282	0.282
		0.968	0.109	-0.227
	4	-0.859	0.406	0.312
		-0.276	0.914	0.295
		0.972	0.008	-0.237
	9	-0.930	0.337	-0.144
		-0.977	0.103	-0.189
FC848-urm2	3	0.917	0.327	-0.228
		-0.221	0.904	0.367
		-0.906	0.177	0.384
	4	-0.391	0.733	0.556
		-0.860	0.229	0.456
	9	0.181	0.980	0.081
		0.610	0.748	0.260
FC848-urm3	3	-0.817	0.514	0.262
		0.081	0.997	-0.020
	4	-0.208	0.898	0.387
	5	0.259	0.883	0.392
		-0.859	0.466	-0.210
	9	-0.282	0.878	-0.387
		0.193	0.978	-0.075
FC848-llm1	5	0.369	0.863	0.345
		-0.810	0.586	-0.010
		0.008	0.957	0.290
		0.813	0.479	0.332

	6	-0.964	0.044	-0.262
		-0.212	0.964	-0.160
	9	-0.937	0.118	0.328
		0.614	0.771	-0.170
FC848-llm2	5	-0.007	0.808	0.590
		-0.947	0.089	-0.309
	6	-0.911	0.353	-0.214
	9	0.661	0.672	-0.335
FC848-lrm1	5	0.891	0.422	-0.168
		0.495	0.865	0.079
		-0.775	0.502	0.384
	6	-0.594	0.798	0.097
		0.780	0.528	-0.335
	9	0.012	1.000	-0.010
		0.945	0.045	0.325
		-0.940	0.102	-0.325
FC848-lrm2	5	0.979	0.137	-0.148
		-0.556	0.637	0.533
		0.254	0.845	0.470
		-0.747	0.467	0.472
	6	0.870	0.429	-0.245
	9	-0.080	0.983	-0.165
		-0.806	0.372	-0.460
FC848-lrm3	5	0.951	0.063	-0.301
	6	0.861	0.386	-0.332
	9	-0.639	0.625	-0.448
		-0.400	0.849	-0.344
FC833-3-ulm1	3	0.847	0.509	0.156
		-0.018	0.999	0.041
	4	-0.089	0.986	0.139
		-0.896	0.421	-0.142
	9	-0.964	0.265	-0.012
		-0.130	0.978	0.164
FC833-3-ulm2	3	-0.489	0.871	0.041
		0.309	0.918	0.250
		-0.891	0.431	-0.142
	4	0.606	0.549	0.575
		-0.921	0.290	-0.261
	9	-0.224	0.959	0.175
		-0.510	0.844	0.165
		-0.914	0.394	0.100
FC833-3-urm1	3	-0.979	0.042	0.198
		0.547	0.837	-0.004
		-0.860	0.458	0.225
	4	0.890	0.443	-0.111
		-0.246	0.957	0.156
		-0.895	0.395	0.209

		0.352	0.935	0.044
	9	-0.607	0.780	0.154
FC833-3-urm2	3	-0.866	0.427	0.261
		-0.181	0.968	0.173
	5	-0.888	0.305	0.344
		-0.458	0.778	0.430
		-0.114	0.910	0.398
		0.730	0.677	0.094
	9	0.197	0.945	0.260
		-0.896	0.388	-0.218
FC833-3-lrm1	3	-0.978	0.206	0.020
		-0.188	0.969	0.161
		0.997	0.068	0.026
	5	0.335	0.931	0.147
		-0.880	0.453	0.141
	9	0.791	0.603	0.102
		0.019	0.988	0.150
		0.239	0.959	0.149
		-0.949	0.312	0.035
FC833-3-lrm2	5	-0.284	0.825	0.488
		-0.784	0.486	0.385
	6	0.523	0.852	0.004
		-0.944	0.270	0.188
		-0.491	0.853	0.176
	9	0.411	0.882	0.231
		-0.583	0.810	-0.064
FC833-3-llm1	5	-0.066	0.946	0.317
		0.947	0.285	0.146
	6	0.985	0.005	-0.173
		-0.276	0.936	0.219
	9	0.943	0.312	-0.119
		-0.024	0.994	0.108
		0.365	0.930	0.039
FC833-3-llm2	5	-0.991	0.108	-0.083
		0.728	0.524	0.442
		-0.292	0.828	0.478
		0.120	0.831	0.543
		-0.948	0.314	0.053
	6	0.561	0.801	0.209
	9	0.934	0.296	-0.201
		-0.109	0.975	0.191
FC833-3-llm3	1	-0.303	0.953	-0.007
		-0.685	0.728	-0.001
	6	-0.380	0.921	0.091
		0.721	0.673	0.167
	9	-0.411	0.894	0.177
		0.568	0.822	-0.031

		-0.117	0.985	0.126
NHMW6035-urm1	3	0.339	0.936	-0.097
		-0.355	0.934	0.021
		0.725	0.672	-0.151
		-0.878	0.461	0.129
	4	-0.958	0.074	0.278
		-0.779	0.510	0.365
		0.192	0.951	0.242
	9	-0.873	0.486	0.046
		0.492	0.861	0.126
NHMW6035-urm2	3	-0.909	0.063	0.412
	4	-0.864	0.167	0.475
	9	-0.655	0.755	-0.037
		0.024	0.994	0.111
		-0.928	0.349	-0.129
NHMW6035-urm3	3	-0.841	0.542	0.012
	4	0.996	0.056	0.074
		-0.835	0.529	0.153
	9	0.997	0.063	-0.035
		-0.562	0.826	-0.041
NHMW6035-ulm1	3	-0.919	0.303	-0.253
		0.798	0.564	0.212
	4	0.245	0.918	0.313
		-0.983	0.076	-0.169
	9	-0.859	0.504	0.089
		0.957	0.280	0.078
NHMW6035-ulm2	3	0.965	0.083	0.249
	4	0.353	0.706	0.615
		0.858	0.122	0.499
	9	-0.962	0.219	0.162
NHMW6035-ulm3	3	0.791	0.611	0.032
	4	0.822	0.552	0.140
		0.322	0.886	0.334
	9	-0.969	0.143	0.201
		0.383	0.863	-0.331
NHMW6035-lrm1	5	-0.832	0.501	0.238
	6	-0.333	0.940	0.079
		-0.860	0.503	0.082
	9	-0.919	0.392	0.042
		-0.049	0.984	0.173
		0.870	0.481	0.111
NHMW6035-lrm2	5	-0.902	0.209	0.378
		0.457	0.841	0.290
	6	0.095	0.988	-0.121
		-0.242	0.969	-0.043
		0.933	0.271	-0.236
	9	-0.471	0.878	-0.078

		0.830	0.512	0.222
NHMW6035-lrm3	5	0.085	0.901	0.426
		-0.470	0.804	0.365
	6	-0.501	0.864	-0.052
	10	-0.392	0.917	-0.072
		0.974	0.183	0.137
		-0.934	0.329	-0.140
NHMW6035-llm2	5	-0.942	0.146	-0.302
		0.859	0.196	0.472
		-0.686	0.713	0.141
		-0.270	0.872	0.407
	6	0.893	0.361	0.268
	9	0.909	0.416	0.037
NHMW6035-llm3	5	0.429	0.703	0.566
		-0.243	0.822	0.514
		0.949	0.137	0.282
	6	0.849	0.525	0.055
	9	0.818	0.444	-0.366
		0.572	0.797	-0.193
		-0.027	0.990	0.141
NHMW8687-ulm1	3	0.961	0.267	0.070
	4	0.948	0.291	0.130
	10	0.959	0.281	-0.042
NHMW8687-ulm2	3	-0.982	0.066	-0.179
	4	0.031	0.949	0.314
		-0.856	0.514	0.061
	9	0.969	0.247	-0.025
		-0.976	0.215	0.043
NHMW8687-ulm3	3	0.242	0.964	-0.107
		0.991	0.130	0.024
		-0.996	0.080	-0.049
	4	0.960	0.164	0.226
	9	0.583	0.789	-0.193
NHMW8687-urm1	3	0.440	0.898	-0.010
	4	-0.562	0.801	0.207
	9	-0.319	0.932	0.174
		-0.946	0.255	0.199
NHMW8687-urm2	1	-0.263	0.956	-0.128
		-0.626	0.755	-0.196
		-0.916	0.328	-0.231
	3	0.909	0.393	-0.138
		-0.921	0.306	0.242
	9	0.780	0.608	0.149
		-0.989	0.119	-0.089
NHMW8687-urm3	3	0.896	0.417	-0.151
		-0.902	0.429	0.049
	4	0.915	0.356	-0.191

	9	0.957	0.287	-0.037
		-0.866	0.475	-0.157
NHMW811-ulm1	3	-0.684	0.718	-0.128
	4	0.507	0.846	0.162
		0.912	0.353	0.208
	9	0.824	0.504	-0.259
NHMW811-ulm2	4	-0.321	0.937	0.138
		0.825	0.358	0.437
		0.229	0.907	0.353
	6	-0.151	0.984	-0.090
		0.766	0.641	0.040
	9	0.504	0.855	-0.122
NHMW811-ulm3	4	0.596	0.801	0.047
	6	0.525	0.839	-0.143
	9	0.637	0.733	-0.237
NHMW811-urm1	3	-0.885	0.450	0.120
		0.060	0.998	0.025
	4	-0.859	0.488	0.155
	9	0.918	0.287	0.275
NHMW811-urm2	3	0.907	0.401	-0.131
		-0.395	0.840	0.372
	4	0.368	0.907	0.204
		-0.808	0.390	0.442
	9	-0.313	0.942	-0.122
NHMW811-urm3	1	0.027	0.987	-0.158
		-0.812	0.548	-0.198
	3	0.289	0.898	-0.332
		-0.832	0.376	0.407
	6	0.838	0.393	0.379
		0.504	0.791	0.347
	9	0.500	0.850	-0.166
S5-ulm1	3	-0.885	0.461	-0.063
		-0.967	-0.214	-0.140
	4	-0.943	0.321	-0.085
		-0.950	-0.246	-0.192
	9	-0.927	-0.373	-0.042
S5-ulm2	3	0.744	0.593	0.309
		-0.925	0.315	-0.212
		-0.509	0.861	-0.005
	4	0.927	0.293	0.234
		0.058	0.971	0.233
		0.600	0.750	0.280
	9	0.408	0.911	-0.057
		-0.890	0.452	0.059
S5-ulm3	1	0.933	0.352	-0.079
	3	0.228	0.968	0.106
		-0.930	0.327	-0.165

	9	0.619	0.784	0.051
		-0.766	0.637	-0.082
		0.994	0.043	0.096
S5-urm1	3	0.297	0.955	0.027
		-0.462	0.861	0.214
	4	0.234	0.941	0.247
		-0.701	0.589	0.401
	9	-0.946	0.321	0.038
		0.133	0.983	0.128
S5-urm2	3	0.229	0.968	-0.102
		-0.184	0.983	0.020
	4	-0.374	0.887	0.272
		0.660	0.751	0.005
	9	-0.503	0.855	-0.122
		0.742	0.668	0.056
S5-urm3	5	-0.908	0.201	0.368
		0.072	0.908	0.413
		-0.151	0.873	0.463
	6	-0.092	0.996	-0.007
		-0.916	0.299	0.267
	9	-0.861	0.481	-0.167
		0.047	0.996	-0.073
S5-llm1	5	0.065	0.927	0.368
		0.312	0.876	0.369
		-0.425	0.854	0.299
	6	-0.100	0.992	0.073
		-0.973	0.230	0.019
		0.331	0.941	0.068
	9	-0.870	0.424	0.252
		0.921	0.325	-0.212
S5-llm2	5	0.929	0.233	0.287
		-0.283	0.921	0.267
		-0.960	0.254	-0.120
	6	-0.487	0.870	-0.082
		0.997	0.074	-0.002
	9	0.843	0.375	-0.386
		-0.898	0.081	0.432
		0.430	0.887	-0.166
S5-llm3	5	0.911	0.231	0.343
		-0.592	0.790	0.157
	7	0.997	0.073	-0.004
	9	0.556	0.807	-0.198
S5-lrm1	5	0.171	0.950	0.263
		0.971	0.236	-0.020
		-0.974	0.176	0.142
	7	0.974	0.157	-0.166
		-0.380	0.883	-0.274

	9	-0.295	0.946	-0.131
		0.887	0.367	0.281
S5-lrm2	3	-0.993	0.007	0.121
		-0.435	0.900	0.031
	5	0.752	0.649	0.119
		-0.378	0.732	0.567
	9	0.863	0.059	0.502
		-0.552	0.831	-0.065
S5-lrm3	3	0.922	0.265	0.284
	5	0.842	0.537	-0.047
		0.232	0.934	0.271
		-0.961	0.006	0.277
	9	0.911	0.164	0.378
		-0.590	0.795	-0.140
S16-urm1	3	-0.967	0.082	0.243
		0.851	0.436	-0.293
	4	-0.672	0.685	0.281
	9	-0.915	0.285	-0.286
		0.039	0.981	-0.190
S16-urm2	3	0.130	0.887	-0.443
		-0.950	0.151	0.273
	5	-0.896	0.332	0.295
		0.408	0.857	-0.315
	6	0.231	0.891	-0.390
		-0.087	0.936	-0.340
S16-lrm1	5	-0.818	0.547	0.177
		0.981	0.153	-0.117
		0.514	0.857	0.030
	6	-0.263	0.964	0.028
		-0.008	0.999	-0.047
	9	-0.968	0.071	-0.241
		-0.513	0.843	-0.164
S16-lrm2	5	-0.737	0.491	0.464
		0.851	0.523	-0.058
	6	-0.371	0.924	0.092
		0.836	0.296	-0.462
	9	0.914	0.104	0.392
		-0.436	0.842	-0.318
S16-llm1	5	0.530	0.806	0.263
		-0.457	0.886	0.086
	6	-0.236	0.965	-0.116
		-0.667	0.698	-0.260
	9	-0.911	0.390	0.133
		-0.147	0.986	-0.080
S16-llm2	1	-0.313	0.950	0.007
		0.856	0.505	-0.110
	2	-0.213	0.972	-0.099

	9	-0.331	0.927	-0.176
		-0.764	0.628	0.147
S9-urm1	3	0.938	0.255	-0.236
		-0.001	1.000	-0.009
	4	-0.150	0.975	0.166
	9	-0.519	0.848	-0.109
S9-urm2	3	-0.553	0.832	0.035
		-0.891	0.288	0.350
	4	0.921	0.080	-0.382
		-0.174	0.858	0.483
	9	0.466	0.877	0.119
		0.874	0.439	0.208
		-0.450	0.888	-0.094

Note: All X, Y, Z coordinates are derived from absolute positionality of the vectors in 3D space

Appendix G. Facet Microwear Vector Analysis Source Code

```
HalfVec translate ( HalfVec vec )
{
if ( vec.y < 0 )
{
}
return vec;
}
HalfVec polarToCartesian ( double r, double phi, double theta )
{
double x;
double y;
double z;
double pi(3.141592654);
theta = theta * pi / 180;
phi = phi * pi / 180;
x = r * cos(phi) * sin(theta);
y = r * sin(phi) * sin(theta);
z = r * cos(theta);
HalfVec theVec( "asdf", "asdf", x, y, z );
theVec.x = x;
theVec.y = y;
theVec.z = z;
return theVec;
}
HalfVec normalize ( double x, double y, double z, double x1, double y1, double
z1 )
{
double length(0);
HalfVec tempHalfVec("fasdf","fasdf", 3, 3, 3, 4);
length = sqrt( pow((x-x1),2) + pow((y-y1), 2) + pow((z-z1), 2));
tempHalfVec.x = (x1 - x)/length;
tempHalfVec.y = (y1 - y)/length;
tempHalfVec.z = (z1 - z)/length;
return tempHalfVec;
}
double GreaterThan (ComparisonResult<string, string> num1,
ComparisonResult<string, string> num2)
{
return (num1.result<num2.result);
}
#ifndef TEST_CPP
#define TEST_CPP
#include <iostream>
#include <string>
```

```
#include <fstream>
#include <vector>
#include <cmath>
#include <map>
#include <algorithm>
using namespace std;
#include "declarations.h"
#include "classes.h"
int main()
{
string fileName;
string directory("");
string currentFile;
string currentLine("fail");
string tempLine("You should not see this.");
string tempLine1;
string tempLine2;
string toothName;
string outputName;
string population("");
string wearStage("");
int opened(0);
int failed(0);
double pi(3.141592654);
char inputLine[99999];
vector<Tooth> allTeeth;
vector<SomeItem> allItems;
HalfVec tempHalfVec( "dsasd", "asdfa", 4, 5, 6);
vector<string> fileNames;
ifstream inputFile;
ofstream outputFile;
vector<ComparisonResult<string, string>> toothResults;
outputFile.open("C:\\Documents and Settings\\ME\\Desktop\\vectors.txt");
{
cout << "Please enter the filename of the tooth list (type d for default):" << endl;
cin.getline(inputLine, 99999);
fileName = inputLine;
if (fileName == "d")
fileName = "C:\\Documents and Settings\\ME\\Desktop\\easyword.txt";
if (openFile( inputFile, fileName ))
{
break;
}
else
cout << endl << "Could not find or open file." << endl << endl;
}
```

```
cout << "Please enter the directory containing tooth information files to be
processed:" << endl;
cin.getline(inputLine, 99999);
directory = inputLine;
if (directory == "d")
directory = "C:\\Documents and Settings\\ME\\Desktop\\work stuff\\teeth\\";
getFileList( inputFile, &fileNames );
unsigned counter(0);
while (counter < fileNames.size())
{
cout << fileNames[counter] << endl;
counter++;
}
counter = 0;
system ("cls");
allTeeth = readItems( allItems, directory, fileNames );
inputFile.close();
inputFile.clear();
inputFile.open("C:\\Documents and Settings\\ME\\Desktop\\lower.txt");
inputFile >> tempLine1;
while (!inputFile.fail())
{
while (counter < allTeeth.size())
{
if (allTeeth[counter].toothID == tempLine1)
{
allTeeth[counter].vertical = "lower";
break;
}
counter++;
}
counter = 0;
inputFile >> tempLine1;
}
counter = 0;
inputFile.clear();
inputFile.close();
inputFile.open("C:\\Documents and Settings\\ME\\Desktop\\upper.txt");
inputFile >> tempLine1;
while (!inputFile.fail())
{
while (counter < allTeeth.size())
{
if (allTeeth[counter].toothID == tempLine1)
{
allTeeth[counter].vertical = "upper";
```

```
break;
}
counter++;
}
counter = 0;
inputFile >> tempLine1;
}
counter = 0;
inputFile.clear();
inputFile.close();
inputFile.open("C:\\Documents and Settings\\ME\\Desktop\\work stuff\\teeth
groupings\\grouplist.txt");
fileNames.clear();
while (!inputFile.fail())
{
inputFile >> fileName;
fileNames.push_back(fileName);
}
inputFile.clear();
inputFile.close();
unsigned counter1(0);
unsigned counter2(0);
while (counter < fileNames.size())
{
fileName = "C:\\Documents and Settings\\ME\\Desktop\\work stuff\\teeth
groupings\\" + fileNames[counter] + ".txt.";
inputFile.open(fileName.c_str());
inputFile >> tempLine;
while(!inputFile.fail())
{
counter1 = 0;
while ( counter1 < allTeeth.size() )
{
if (allTeeth[counter1].toothID == (tempLine + "-1") )
{
groupAndWear(fileNames[counter], population, wearStage);
allTeeth[counter1].wearStage = wearStage;
allTeeth[counter1].population = population;
break;
}
counter1++;
}
inputFile >> tempLine;
}
inputFile.close();
inputFile.clear();
```

```
counter++;
}
counter = 0;
inputFile.close();
inputFile.clear();
inputFile.open("C:\\Documents and Settings\\ME\\Desktop\\pos1.txt");
inputFile >> tempLine1;
while (!inputFile.fail())
{
while (counter < allTeeth.size())
{
if (allTeeth[counter].toothID == tempLine1)
{
allTeeth[counter].horizontal = "1";
break;
}
counter++;
}
counter = 0;
inputFile >> tempLine1;
}
counter = 0;
inputFile.close();
inputFile.clear();
inputFile.open("C:\\Documents and Settings\\ME\\Desktop\\pos2.txt");
inputFile >> tempLine1;
while (!inputFile.fail())
{
while (counter < allTeeth.size())
{
if (allTeeth[counter].toothID == tempLine1)
{
allTeeth[counter].horizontal = "2";
break;
}
counter++;
}
counter = 0;
inputFile >> tempLine1;
}
counter = 0;
inputFile.close();
inputFile.clear();
inputFile.open("C:\\Documents and Settings\\ME\\Desktop\\pos3.txt");
inputFile >> tempLine1;
while (!inputFile.fail())
```

```
{
while (counter < allTeeth.size())
{
if (allTeeth[counter].toothID == tempLine1)
{
allTeeth[counter].horizontal = "3";
break;
}
counter++;
}
counter = 0;
inputFile >> tempLine1;
}
counter = 0;
inputFile.close();
inputFile.clear();
inputFile.open("C:\\Documents and Settings\\ME\\Desktop\\left.txt");
inputFile >> tempLine1;
while (!inputFile.fail())
{
while (counter < allTeeth.size())
{
if (allTeeth[counter].toothID == tempLine1)
{
allTeeth[counter].leftRight = "left";
break;
}
counter++;
}
counter = 0;
inputFile >> tempLine1;
}
counter = 0;
inputFile.close();
inputFile.clear();
inputFile.open("C:\\Documents and Settings\\ME\\Desktop\\right.txt");
inputFile >> tempLine1;
while (!inputFile.fail())
{
while (counter < allTeeth.size())
{
if (allTeeth[counter].toothID == tempLine1)
{
allTeeth[counter].leftRight = "right";
break;
}
```

```
counter++;
}
counter = 0;
inputFile >> tempLine1;
}
outputFile.close();
outputFile.clear();
outputFile.open("C:\\Documents and Settings\\ME\\Desktop\\vectors.txt");
allTeeth[0].output(outputFile);
compareGroups( "Bapang", "Sangiran", allTeeth, outputFile, toothResults);
vector<Tooth> special;
counter = 0;
while (counter < allTeeth.size())
{
if (allTeeth[counter].population == "Bapang")
cout << allTeeth[counter].wearStage << " " << allTeeth[counter].horizontal << " "
<< allTeeth[counter].vertical << endl;
counter++;
}
counter = 0;
while(counter < allTeeth.size())
{
if (allTeeth[counter].population == "Bapang" || allTeeth[counter].population ==
"Sangiran")
{
special.push_back(allTeeth[counter]);
special[special.size()-1].population = "Erectus";
}
else
{
special.push_back(allTeeth[counter]);
special[special.size()-1].population = "Sapien";
}
counter++;
}
cout << special.size()<< endl;
compareGroups( "Erectus", "Sapien", special, outputFile, toothResults);
counter = 0;
Tooth* t1;
Tooth* t2;
t1 = &allTeeth[0];
t2 = &allTeeth[3];
findAndCompare("FC848-urm1-1","FC848-ulm1-1", allTeeth);
outputFile.close();
outputFile.clear();
outputFile.open("stuff.txt");
```

```
string group1, group2;
outputFile << "Tooth comparisons below. A match value of -1 indicates" << endl
<< "either no common facets between the teeth or no vectors compared." << endl
<< endl;
sort(toothResults.begin(), toothResults.end());
while (counter < toothResults.size())
{
outputFile << toothResults[counter].obj1 << " and " << toothResults[counter].obj2
<< ": " <<  toothResults[counter].result * 180 / 3.141593 << endl << endl;
counter++;
}
counter = 0;
}
#endif
#include "classes.h"
#include "declarations.h"
double compareFacets ( Facet &facet1, Facet &facet2 )
{
unsigned counter1(0);
unsigned counter2(0);
unsigned last(0);
double totalAngle(0);
double totalWeight(0);
HalfVec tempHalfVec("asdf","asdf", 2, 2, 2, 2);
while (counter1 < facet1.vectors.size())
{
while (counter2 < facet2.vectors.size())
{
tempHalfVec = compareVectors(facet1.vectors[counter1],
facet2.vectors[counter2]);
totalAngle = totalAngle + ( tempHalfVec.x * tempHalfVec.y );
totalWeight = totalWeight + tempHalfVec.y;
counter2++;
}
counter2 = 0;
counter1++;
}
facet1.comparedTo.push_back(facet2);
last = facet1.comparedTo.size() - 1;
facet1.comparedTo[last].matchValue = totalAngle/totalWeight;
facet2.comparedTo.push_back(facet1);
last = facet2.comparedTo.size() - 1;
facet2.comparedTo[last].matchValue = totalAngle/totalWeight;
return totalAngle/totalWeight;
}
#include "declarations.h"
```

```
#include "classes.h"
HalfVec compareGroups( string group1, string group2, vector<Tooth> &allTeeth,
ofstream &outputFile, vector<ComparisonResult<string, string>> &toothResults  )
{
cout << "Comparing " << group1 << " to " << group2 << endl;
vector<Tooth*> teeth1;
vector<Tooth*> teeth2;
Tooth *currentTooth1;
Tooth *currentTooth2;
double matchValue;
double totalMatchValue(0);
double numCompared(0);
double groupMatchValue(0);
double numTeethCompared(0);
HalfVec tempHalfVec("asdf", "asdf", 1, 2, 3, 3);
unsigned counter(0);
unsigned counter1(0);
if (group1 == group2)
{
while (counter < allTeeth.size())
{
if ( allTeeth[counter].population == group1 )
{
teeth1.push_back(&allTeeth[counter]);
teeth2.push_back(&allTeeth[counter]);
}
counter++;
}
}
else
{
while (counter < allTeeth.size())
{
if ( allTeeth[counter].population == group1 )
teeth1.push_back(&allTeeth[counter]);
else if (allTeeth[counter].population == group2)
teeth2.push_back(&allTeeth[counter]);
counter++;
}
}
counter = 0;
while (counter < teeth1.size())
{
currentTooth1 = teeth1[counter];
while (counter1 < teeth2.size())
{
```

```
currentTooth2 = teeth2[counter1];
if (currentTooth1->wearStage == currentTooth2->wearStage)
if (currentTooth1->vertical == currentTooth2->vertical)
if (currentTooth1->horizontal == currentTooth2->horizontal)
{
matchValue = compareTeeth(teeth1[counter], teeth2[counter1], toothResults);
cout << ".";
if ( matchValue == -1 )
;
else
{
totalMatchValue = totalMatchValue + matchValue;
numCompared++;
}
}
counter1++;
}
counter1 = 0;
counter++;
}
tempHalfVec.y = numCompared;
if (numCompared > 0)
{
groupMatchValue = totalMatchValue/numCompared;
tempHalfVec.x = groupMatchValue;
outputFile << "For " << group1 << " and " << group2 << endl << "     Match Value:
" << groupMatchValue << " Number Compared: " << numCompared << endl <<
endl;
cout << endl << "Done. " << group1 << " and " << group2 << ": " <<
groupMatchValue << endl << endl;
return tempHalfVec;
}
else
{
tempHalfVec.x = -1;
outputFile << "For " << group1 << " and " << group2 << endl << "     No teeth
compared." << endl << endl;
cout << endl << "Done." << endl;
return tempHalfVec;
}
}
#include "classes.h"
#include "declarations.h"
double compareTeeth ( Tooth *tooth1, Tooth *tooth2,
vector<ComparisonResult<string, string>> &toothResults )
{
```

```
tooth1->wasCompared = true;
tooth2->wasCompared = true;
bool t1flipped(false);
bool t2flipped(false);
ComparisonResult<string, string> tempResult;
Tooth tempTooth;
unsigned counter1(0);
unsigned counter2(0);
double numCompared(0);
double totalMatchValue(0);
if (tooth1->leftRight == "left")
{
tooth1->flip();
t1flipped = true;
}
if (tooth2->leftRight == "left")
{
tooth2->flip();
t2flipped = true;
}
while (counter1 < tooth1->facets.size())
{
while (counter2 < tooth2->facets.size())
{
if (tooth1->facets[counter1].facetNumber == tooth2-
>facets[counter2].facetNumber && tooth1->facets[counter1].facetNumber != -1)
{
totalMatchValue = totalMatchValue + compareFacets(tooth1->facets[counter1],
tooth2->facets[counter2]);
numCompared++;
}
counter2++;
}
counter2 = 0;
counter1++;
}
tooth2->matchValue = totalMatchValue/numCompared;
tooth1->matchValue = totalMatchValue/numCompared;
tooth1->comparedTo.push_back(tooth2);
tooth2->comparedTo.push_back(tooth1);
tempResult.obj1 = tooth1->toothID;
tempResult.obj2 = tooth2->toothID;
if (numCompared > 0)
tempResult.result = totalMatchValue/numCompared;
else
tempResult.result = -1;
```

```
toothResults.push_back(tempResult);
if (t1flipped == true)
tooth1->flip();
if (t2flipped == true)
tooth2->flip();
if (numCompared > 0)
{
return totalMatchValue/numCompared;
}
else
{
return -1;
}
}
#include "declarations.h"
#include "classes.h"
HalfVec compareVectors ( HalfVec vector1, HalfVec vector2 )
{
HalfVec tempHalfVec("asdfa", "asdfa", 2, 2, 2, 2);
double weight(0);
double angle(0);
double angle1(0);
double angle2(0);
tempHalfVec.x = -vector1.x;
tempHalfVec.y = -vector1.y;
tempHalfVec.z = -vector1.z;
angle1 = calcAngle(tempHalfVec, vector2);
angle2 = calcAngle(vector1, vector2);
if (angle1 < angle2)
angle = angle1;
else
angle = angle2;
if (angle <= .1745)
weight = 1;
else if (angle <= .3490)
weight = -5.73 * angle + 2.0;
else
weight = 0.00001;
tempHalfVec.x = angle;
tempHalfVec.y = weight;
return tempHalfVec;
}
#include "classes.h"
#include "declarations.h"
void findAndCompare( string tooth1, string tooth2, vector<Tooth>& allTeeth )
{
```

```
int counter(0);
Tooth t1;
Tooth t2;
double results(0);
while (counter < allTeeth.size())
{
if ( allTeeth[counter].toothID == tooth1)
{
t1 = allTeeth[counter];
break;
}
else if ( counter == allTeeth.size() - 1 )
cout << "Tooth1 could not be found." << endl;
counter++;
}
counter = 0;
while (counter < allTeeth.size())
{
if ( allTeeth[counter].toothID == tooth2)
{
t2 = allTeeth[counter];
break;
}
else if ( counter == allTeeth.size() - 1 )
cout << "Tooth2 could not be found." << endl;
counter++;
}
results = compareTeeth( &t1, &t2);
cout << tooth1 << " and " << tooth2 << ": " << results << endl;
}
#ifndef CLASSES_H
#define CLASSES_H
#include "declarations.h"
struct HalfVec
{
HalfVec (string tooth, string vecID, double x, double y, double z, double
averageAngle = 0) {tooth = tooth, vecID = vecID, x = x, y = y, z = z, averageAngle
= averageAngle; totalWeight = 0;}
string tooth;
string vecID;
double x;
double y;
double z;
double averageAngle;
double totalWeight;
void output(ofstream &outputFile, string toothID)
```

```
{
string tempID;
tempID = "";
unsigned counter(2);
while (counter < vecID.size())
{
tempID = tempID + vecID[counter];
counter++;
}
tempID = toothID + "-" + tempID;
//outputFile << vecID << " (" << x << ", " << y << ", " << z << ") ";
outputFile << "0 0 0 " << x << " " << y << " " << z << " 10 " << tempID;
}
};
struct SomeItem
{
string toothName;
string nameOfItem;
double length;
vector<HalfVec> halfVectors;
void setLength()
{
double lengthx;
double lengthy;
double lengthz;
lengthx = halfVectors[0].x - halfVectors[1].x;
lengthy = halfVectors[0].y - halfVectors[1].y;
lengthz = halfVectors[0].z - halfVectors[1].z;
this->length = sqrt( pow(lengthx, 2) + pow(lengthy, 2) + pow(lengthz, 2) );
}
};
struct Facet
{
string facetID;
int facetNumber;
double matchValue;
vector<Facet> comparedTo;
vector<HalfVec> vectors;
void flip()
{
unsigned counter(0);
while (counter < vectors.size())
{
vectors[counter].x = -vectors[counter].x;
counter++;
}
```

```
}
void output( ofstream &outputFile, string toothID )
{
unsigned counter(0);
string tempToothID("");
outputFile << "     #Facet " << facetNumber << endl;
while (counter < toothID.size() - 2 )
{
tempToothID += toothID[counter];
counter++;
}
counter = 0;
while (counter < vectors.size())
{
outputFile << "           ";
vectors[counter].output(outputFile, tempToothID);
outputFile << endl;
counter++;
}
}
};
struct Tooth
{
string toothID;
string vertical;
string horizontal;
string wearStage;
string population;
bool wasCompared;
vector<Facet> facets;
bool isFlipped;
vector<Tooth*> comparedTo;
double matchValue;
string leftRight;
void flip()
{
unsigned counter(0);
while (counter < facets.size())
{
facets[counter].flip();
counter++;
}
}
void output( ofstream &outputFile )
{
unsigned counter(0);
```

```
outputFile << endl << "# " << toothID << endl;
while (counter < facets.size())
{
if (facets[counter].facetNumber != -1)
facets[counter].output(outputFile, toothID);
counter++;
}
}
};
struct ToothGroup
{
string groupName;
vector<Tooth> teeth;
};
template<typename obj1, typename obj2>
struct ComparisonResult
{
double result;
string obj1;
string obj2;
bool operator<(ComparisonResult<string, string> thing2)
{
return this->result<thing2.result;
}
};
#endif
#ifndef TEST_FUNC
#define TEST_FUNC
#include <iostream>
#include <string>
#include <fstream>
#include <vector>
#include <cmath>
#include <map>
using namespace std;
struct HalfVec;
struct Tooth;
struct Facet;
struct SomeItem;
template<typename obj1, typename obj2>
struct ComparisonResult;
HalfVec translate ( HalfVec vec );
HalfVec polarToCartesian ( double r, double theta, double phi );
double calcAngle( HalfVec vec1, HalfVec vec2 );
HalfVec normalize ( double x, double y, double z, double x1, double y1, double
z1 );
```

```
void groupAndWear (string &name, string &population, string &wearStage);
HalfVec compareGroups( string group1, string group2, vector<Tooth> &allTeeth,
ofstream &outputFile, vector<ComparisonResult<string, string>> &toothResults
);
HalfVec compareVectors ( HalfVec vector1, HalfVec vector2 );
double compareTeeth ( Tooth *tooth1, Tooth *tooth2,
vector<ComparisonResult<string, string>> &toothResults );
double compareFacets ( Facet &facet1, Facet &facet2 );
void sortResults( vector<ComparisonResult<string, string>> &sortThis );
bool greaterThan( ComparisonResult<string, string> num1,
ComparisonResult<string, string> num2);
void findAndCompare( string tooth1, string tooth2, vector<Tooth>& allTeeth );
#endif
```

Curriculum Vitae

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Present- 2005	Goethe Graduate Academy (GRADE). Institut for Ecology, Evolution & Diversity (IEED) Universitat Frankfurt. Frankfurt-am-Main, Germany.
2004- 2002	New York Consortium in Evolutionary Primatology (NYCEP) CUNY Graduate Center. NYC, NY.
2002- 1999	Biological Anthropology MA program Hunter College, CUNY. NYC, NY.
1994- 1989	B.A. Anthropology, Minor: Biology University of Cincinnati. Cincinnati, OH.

Professional Experience

Present- 2008	Adjunct Lecturer in Biology BMCC, CUNY. NYC, NY.
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2007-2005	Adjunct Lecturer in Biology Bronx Community College, CUNY. NYC, NY.
Present- 2001	Adjunct Lecturer in Biology and Ecology Baruch College, CUNY. NYC, NY.
2004- 2001	Adjunct Lecturer in Anthropology Hunter College, CUNY. NYC, NY.

Research Experience

Present- 2006	Senckenberg Forschungsinstitut und Naturmuseum Frankfurt, Sektion Paläoanthropologie. Frankfurt, Germany. -Imaging, quantification and analysis of hominin molars
Present- 2002	HCRP (Hominid Corridor Research Project). Malawi, Africa. -Survey of fossil bearing sediments
Present- 2000	Hard Tissue Research Unit (HTRU). New York University College of Dentistry & Hunter College, CUNY. NYC, NY. -Preparation of mineralized tissue histological sections

Publications

Fiorenza, L., Benazzi, S., Tausch, J., Kullmer, O., Bromage, T. and Schrenk, F. 2010. 'Molar macrowear reveals Neanderthal eco-geographical dietary variation'. PLoS ONE. v. 6(3): e14769. Doi:10.1371/journal.pone.0014769

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Tausch, J. and Bromage, T., 2002. ‘The muscle-bone interface of the marmoset (*Callithrix jacchus*) femur’. Scanning- The Journal of Scanning Microscopies, v. 23 (2). pg.77.

GRANTS and AWARDS

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CUNY Professional Development Grant	AAPA (American Association of Physical Anthropologists) annual meeting. Columbus, Ohio. 04- 2008
CUNY Professional Development Grant	Senckenberg Forschungsinstitut und Naturmuseum. Frankfurt am Main, Germany. 07- 2007 to 08- 2007.
DAAD (German Academic Exchange Service) Ph. D. Research Grant	Senckenberg Forschungsinstitut und Naturmuseum. Frankfurt am Main, Germany. 01- 2006 to 07- 2006.
International Meeting of Scanning Electron Microscopy Honorable Mention	Oral Presentation of 'The Muscle-Bone Interface in the Common Marmoset Femur' NYC, NY. 05- 2002

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