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STONE AGE INSTITUTE PUBLICATION SERIES

NUMBER 2

Series Editors Kathy Schick and Nicholas Toth

BREATHING LIFE INTO FOSSILS:

Taphonomic Studies in Honor of C.K. (Bob) Brain

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Stone Age Institute Press · www.stoneageinstitute.org
1392 W. Dittemore Road · Gosport, IN 47433

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Front cover, clockwise from top left.

Top left:
Artist's reconstruction of the depositional context of Swartkrans Cave, South Africa, with a leopard consuming a hominid carcass in a tree outside the cave: bones would subsequently wash into the cave and be incorporated in the breccia deposits. © 1985 Jay H. Matternes.

Top right: The Swartkrans cave deposits in South Africa, where excavations have yielded many hominids and other animal fossils. ©1985 David L. Brill.

Bottom right: Reconstruction of a hominid being carried by a leopard. © 1985 Jay H. Matternes.

Bottom left: Photograph of a leopard mandible and the skull cap of a hominid from Swartkrans, with the leopard's canines juxtaposed with puncture marks likely produced by a leopard carrying its hominid prey. © 1985 David L. Brill.

Center: Photo of Bob Brain holding a cast of a spotted hyena skull signed by all of the taphonomy conference participants. © 2004 Kathy Schick, Stone Age Institute.

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Published by the Stone Age Institute.
ISBN-10: 0-9792-2761-5
ISBN-13: 978-0-9792-2761-5

CHAPTER 12

Taphonomy of Immature Hominid Skulls and the Taung, Mojokerto, and Herto Specimens

Gail E. Krovitz and Pat Shipman

Abstract

This study explored quantitative and qualitative methods for deducing the taphonomic history of immature hominid crania, in the hopes of developing models for use in diagnosing the timing and pattern of breakage in specimens of unknown history. First, two sets of cranial inventory data (of modern human archaeological samples) were used to develop a model of the taphonomic vulnerability of the different parts of the immature hominid cranium. We found that the nasal bones, vomer, basilar and lateral elements of the occipital, and zygomatic arches were highly vulnerable to breakage or loss, while the orbital rim of the frontal bone was rarely missing. In fact, the frontal bone plays an important role as a keystone that keeps crania articulated. Second, we reviewed the pertinent medical and forensic data on cranial damage, and discussed three temporal stages of cranial breakage: stage 1 (wet or fresh bone breakage), stage 2 (dry bone or postmortem breakage), and stage 3 (post-fossilization breakage). Patterns of breakage and disarticulation in 20 immature fossil hominid crania were also included in this discussion. Several new fracture types were observed in the fossil hominids, including temporal line, perpendicular, and metopic or para-metopic fractures, and a mosaic fracture pattern. Finally, the models discussed above were used to deduce the breakage histories of three immature fossil specimens that were exposed to different taphonomic influences: Taung 1 (*Australopithecus africanus*), Mojokerto (or Perning 1, *Homo erectus*), and Herto BOU-VP-16/5 (*Homo sapiens idaltu*).

Introduction

Although the tremendous importance of immature crania for documenting the growth, development, and evolution of various hominid species is widely recognized, their taphonomy has not been systematically addressed. That immature crania are rarer in the fossil record than adult crania is generally attributed to their greater vulnerability to damage because immature sutures are unfused and immature bones are thinner than adult ones (see discussion in Saunders, 2000). Here, we report a first step toward deducing the taphonomic history of immature hominid crania, which may prove useful in determining the timing, causes, and implications of damage to such specimens.

The primary aim of our project was to establish the expected pattern of breakage and destruction to immature hominid crania that have been subjected to minimal taphonomic disturbance. To this end, we carried out both quantitative and qualitative studies. We relied upon two sets of cranial inventory data. One of us (G.K.) conducted an inventory of the immature cranial remains of 272 recent humans in six cemetery populations from four broad geographic regions. Here, we refer to these crania as the Krovitz sample. For each cranium, she recorded the presence or absence of anatomical landmarks as an indicator of the loss or breakage of cranial elements. From these inventory data we developed a model of the taphonomic vulnerability of the different parts of the immature hominid cranium. We also analyzed bone inventory data on a sample of 81 modern human crania from a cemetery population in England that was excavated and studied by the Sedgeford Historical and Archaeological Project (SHARP); unpublished data were kindly provided to us by Patricia Reid of SHARP. The SHARP sample had been scored by the original researchers for the presence or absence of eight major cranial bones; age at death and sex had also been assigned. Only three of 82 individuals in the SHARP sample were immature, so this sample must be taken as representative of the cranial taphonomy of adults. Description and comparison of the results of the inventory studies constitute Part I of this paper.

In Part II, we first review the pertinent medical and forensic data on cranial damage and then describe and discuss the results of qualitative and quantitative observations conducted on photographs, casts, and occasionally upon originals of 20 immature fossil crania of *Homo erectus*, *Australopithecus africanus*, Neandertals, and anatomically modern *Homo sapiens* (including *H. sapiens idaltu*). Following forensic practice, we recognize three temporal stages of cranial or bone breakage: *stage 1, wet or fresh bone breakage*, which incorporates the stages forensic scientists recognize as antemortem breakage, which shows signs of healing on the broken edges, and perimortem breakage, which does not; *stage 2, dry bone or postmortem breakage*; and *stage 3, post-fossilization (fossilized bone) damage*. These three stages grade into one another along a temporal continuum and the placement of a specimen along this continuum has a marked impact on its response to potentially damaging agents. From our observations of modern and fossil crania, we summarize the types, frequency, and morphology of breaks seen in crania in each of these stages for potential use in diagnosing the timing of breakage in specimens of unknown history.

Finally, in Part III, we use the quantitative and qualitative results from the previous two sections to deduce the breakage histories of three immature fossil specimens that were exposed to different taphonomic influences. These are: Taung 1, *Australopithecus africanus*, which was dropped into a cave, probably by a leopard, while it was both fresh and fleshed (McKee, 2001; McKee, 2004, personal communication to P.S.); Mojokerto, *Homo erectus*, which was deposited in fluvial sediments (Huffman, 2001; Huffman and Zaim, 2003) and subjected to breakage and plastic deformation (Anton, 2003, personal communication to P.S.) at an unknown time; and Herto BOU-VP-16/5, *Homo sapiens idaltu*, which was modified and curated by hominids after the death of the individual (Clark et al., 2003; White et al., 2003) and underwent primarily post-fossilization damage (White, 2004, personal communication to P.S.). We use the taphonomic vulnerability model developed from the inventory data and the patterns of breakage and taphonomic destruction observed on casts and high resolution photographs of these specimens to deduce the specific taphonomic history of each of these specimens.

Quantitative Studies

Materials and methods

To determine how immature crania were preserved and damaged in specimens that were exposed to relatively few taphonomic forces, we used two sources of information.

The Krovitz sample consists of a landmark inventory of 272 immature crania of recent humans from archaeological samples conducted by one of us (Krovitz, 2000). Although the inventory was not designed for a taphonomic study, the results are useful here. The samples represent cemetery populations from England (Christ Church Spitalfields, 18th and 19th centuries; Adams and Reeve, 1987; Molleson and Cox, 1993), Medieval Denmark (A.D.1000-1500), Nubia (A.D. 0-1500; Vagn Nielsen, 1970), Edo Period Japan (A. D.1603-1867; Mizoguchi, 1997), St. Lawrence Island Yupik Eskimo (A.D. 1800; Collins, 1937; Utermohle, 1984; Heathcote, 1986), and Indian Knoll (2500-2000 B.C.; Snow, 1948). For each cranium, G.K. recorded the presence or absence of a set of 39 anatomical landmarks (Figure 1, Table 1). This provides fine-grained data on the location of breakage or complete loss of cranial elements.

Specimens were only included if they were undistorted, non-pathological, and had at least one anatomical region (face or neurocranium) that was largely articulated. Since disarticulated cranial bones, no matter how complete, were not included in the Krovitz sample, this inventory provides a conservative estimate of breakage for these samples. Recent human samples where completeness of the crania was a primary criterion for collection were excluded from the inventory.

Individuals in the Krovitz sample were divided into four developmental age groups based on tooth formation and eruption sequences: 0 – 3.0 years (Age Group 1), 3.1 – 6.0 years (Age Group 2), 6.1 – 9.0 years (Age Group 3), and 9.1 – 13.5 years (Age Group 4). Tooth formation was the primary method for dental age estimation (using data from Thoma and Goldman, 1960; Moorrees et al., 1963; Smith, 1991), although tooth eruption was also used when necessary (see discussion in Krovitz, 2000). These developmental age groups roughly coincide with the following developmental criteria (after Minugh-Purvis, 1988): 1) infancy (birth to completion of deciduous tooth eruption and development), 2) early childhood (period between deciduous tooth development and permanent tooth eruption), 3) mid-childhood (eruption of the first permanent teeth), and 4) late childhood (completion of permanent tooth eruption and development, except for the third molar).

The SHARP data, which were made available to us but were not collected by us, consist of bone inventories of 82 individuals represented by articulated remains from the Anglo Saxon cemetery at Sedgeford buried between 662 and 881 A.D. (Stillwell, 2002; Sedgeford Historical and Archaeological Research Project or SHARP,

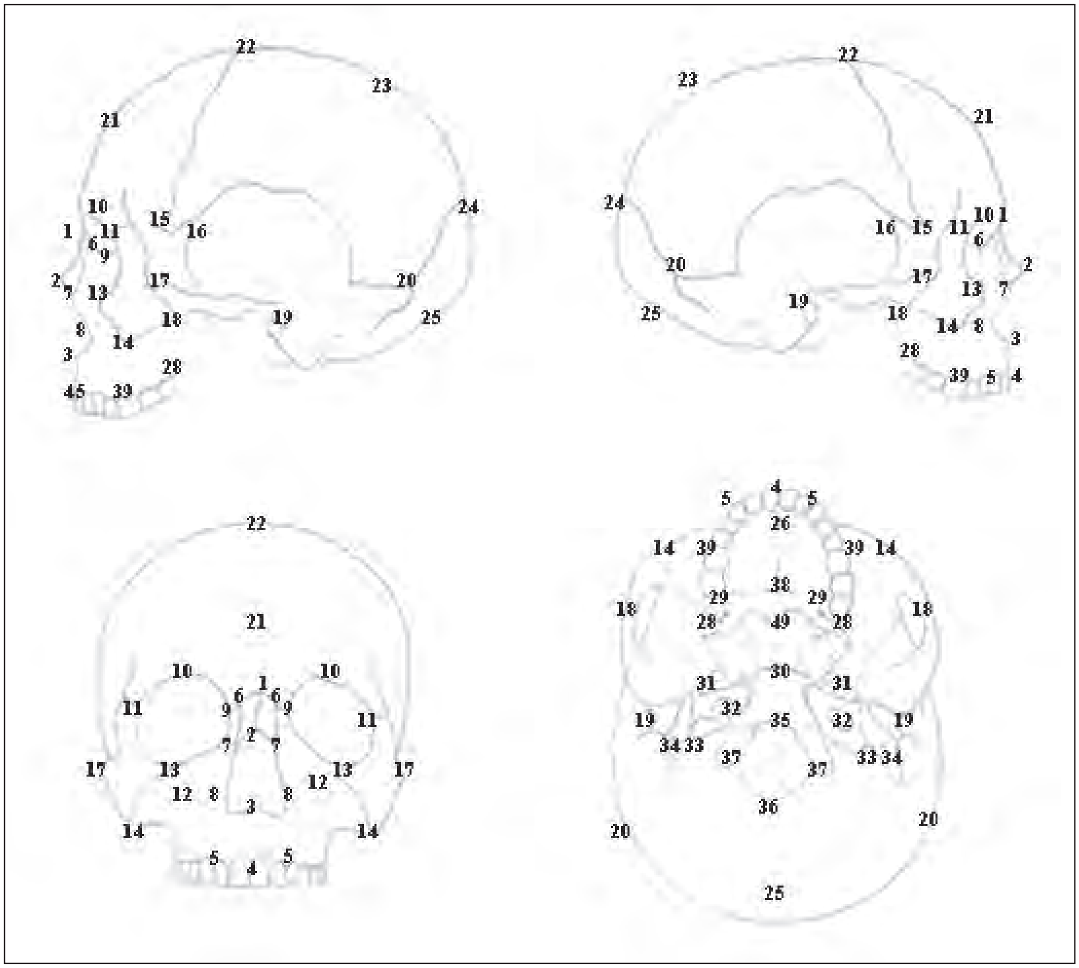

Figure 1. Landmarks used in this study. See Table 1 for landmark descriptions.

Table 1. Description of landmarks used in this analysis; see Figure 1 for location of landmarks. All landmarks described with L/R were collected from either the right or left side, depending on which side was better preserved in that individual.

LANDMARK DESCRIPTION			
1. NAS (Nasion)	11. L/R FZJ (Frontal-zygomatic junction at orbital rim)	21. N-B (1/2 way between nasion and bregma in midline)	31. L/R FOV (Foramen ovale, posterolateral point)
2. NAL (Nasale)	12. L/R IF (Infraorbital foramen, marked inferolaterally, most superior if many)	22. BRG (Bregma, coronal-sagittal suture intersection in midline)	32. L/R CAR (Carotid canal, posterolateral point)
3. ANS (Anterior nasal spine)	13. L/R ZYS (Top zygomatic-maxillary suture, at orbital rim)	23. B-L (1/2 way between bregma and lambda in midline)	33. L/R JUG (Jugular process, anterior point)
4. IDS (Intradentale superior, between central incisors)	14. L/R ZYI (Bottom zygomatic-maxillary suture)	24. LAM (Lambda, sagittal-lambdoid suture intersection, in midline)	34. L/R STY (Stylomastoid foramen)
5. L/R PMM (Premaxilla-maxilla junction at alveolar border, between I2 and C)	15. L/R PTN (Pterion, intersection of frontal-parietal and sphenoid)	25. L-O (1/2 way between lambda and opisthion, in midline)	35. BAS (Basion)
6. L/R NMT (Top nasal-maxillary suture at frontal bone)	16. L/R SPH (Squamous temporal-parietal-greater wing of sphenoid)	26. ICF (Incisive foramen, marked posteriorly)	36. OPI (Opisthion)
7. L/R NMB (Bottom nasal-maxillary suture at nasal aperture)	17. L/R SZA (Superior temporal-zygomatic junction on the arch)	27. PNS (Posterior nasal spine)	37. L/R CFM (Posterior border of the occipital condyle with foramen magnum)
8. L/R ALA (Alare)	18. L/R IZA (Inferior temporal-zygomatic junction on the arch)	28. L/R MXT (Maxillary tuberosity = junction maxilla and palatine bones on alveolus)	38. MXP (Junction palatine/maxilla in midline)
9. L/R FMO (Frontal-maxillary suture at orbital rim)	19. L/R EAM (External auditory meatus, uppermost lateral point)	29. L/R PAL (Junction on palatine suture with edges/curve of palate)	39. L/R DPM (Behind DM2/P4 on exterior alveolus)
10. L/R ORB (Top of orbit, 1/2 way between NAS-FZJ)	20. L/R AST (Asterion = parietal-temporal-occipital)	30. VSJ (Vomer sphenoid junction, taken on vomer)	

unpublished data; Reid, 2004, personal communication to P.S.). For each individual, the presence or absence of the frontal, maxilla, palatine, zygomatic, sphenoid, parietal, temporal, and occipital was scored separately for the right and left sides; the values for both sides were averaged for our purposes. If present, each bone was scored in completeness categories consisting of: < 25% complete; 25-50% complete; 51-74% complete; and 75-100% complete.

Unlike the Krovitz sample (which consisted entirely of immature individuals), 79 out of 82 (95%) individuals in the SHARP sample were adult. Cranial fragments and isolated bones that could not be associated with a particular burial were excluded from the database provided to us; however, the SHARP sample did include disarticulated cranial bones that could be associated with a burial (for example, one individual's cranial remains consist solely of an occipital bone). This is an important difference from the Krovitz sample that only considered relatively articulated crania and no disarticulated bones. Although healed lesions were observed on five individuals in the SHARP sample (Stillwell, 2002), no crania were grossly pathological. The SHARP bone inventory provided coarser-grained data on the preservation of various cranial elements in a predominantly adult sample of buried modern humans.

We selected deliberately buried specimens because this greatly simplified the potential range of taphonomic histories exhibited by the samples. Further, most modern humans are buried in some fashion, so most sizeable samples of modern human crania are derived from cemetery populations. Since interment occurred shortly after death, the possibility of lengthy surface weathering, significant waterborne transport, or substantial carnivore damage was eliminated. What we observed on these specimens represents a generalized or baseline pattern of destruction, damage, and preservation of immature crania undergoing deposition rapidly after death. Therefore, the condition of crania in our samples reflects the taphonomic vulnerability of various parts of the cranium based primarily on their mechanical resistance to breakage and on the structural integrity of various sutures between bones. The ways in which specimens of unknown taphonomic history, such as the fossil crania considered in Part III, deviate from this baseline pattern should provide clues to their exposure to other destructive agents.

Results and discussion

From the landmark inventory, we calculated the percentage of specimens in which each landmark was absent in each age group, and in all age groups averaged. The presence or absence of many landmarks was highly correlated with that of other nearby landmarks, with three obvious clusters of covarying landmarks (face, neurocranium, and basicranium). These groupings were undoubtedly caused by the close spatial relationships of the landmarks within each anatomical region and the general similarity in terms of robustness and/or geometry of bones within each region.

We could not derive a single predicted sequence of disarticulation and damage from these landmark inventory data because the variability among specimens was too great. Instead, we identified clusters of landmarks that exhibited high taphonomic vulnerability, intermediate taphonomic vulnerability, and low taphonomic vulnerability (Figures 2 and 3; Table 2). The high and low vulnerability clusters together comprise 16 of the 39 landmarks (41%). The remaining 23 landmarks (59%) are of intermediate vulnerability.

We argue that: (1) the primary factor determining the taphonomic vulnerability of a landmark is its structural resistance to breakage and destruction, which is a function of the density of the skeletal element and of its placement within or projection from the cranium as a whole; (2) the breakage of immature hominid crania is intimately related to the placement and physical nature of sutures; (3) although crania of younger individuals were generally less complete, the taphonomic vulnerability grouping of most cranial landmarks does not change dramatically between the ages of 0-13 years.

High taphonomic vulnerability

Landmarks with high taphonomic vulnerability are illustrated in Figure 3 and listed in Table 2a. Several landmarks in the facial region are missing with remarkably high frequency in the Krovitz sample. These most vulnerable landmarks are missing in almost 70% of individuals in the youngest age group and are absent in 40-47% of the specimens across all age groups. All of the most vulnerable facial landmarks are associated with the nasal bones (NAL), the zygomatic arch (SZA, IZA), and the vomer (VSJ). Each of these bones has sutures with other bones that cover small linear distances and which therefore probably break or separate more easily than do more extensive sutures. The nasals and the vomer are thin and fragile bones prone to damage, and both have an edge projecting into open space. In contrast, the zygomatic is not a particularly fragile bone but the zygomatic arch projects from the generally ovoid shape of the cranium, which makes it vulnerable to breakage. The anterior portion of the zygomatic arch is also a thin strut of bone that is very susceptible to crushing. In cadaver experiments, McElhaney and colleagues found that the zygomatic arch will break under as little as 130 psi (McElhaney et al., 1976; Mackey, 1984), whereas the pressure required to fracture the cranial vault is much greater: 450 to 750 psi (Cox et al., 1987). On dry crania, the zygomatic arch encloses empty space and requires even less force to break.

Out of the 272 individuals inventoried, 163 (60%) had a face judged to be in good condition, while preservation of the face was judged to be fair or poor in the remaining specimens. The entire face was missing in 25 specimens (9% of the sample), suggesting that loss of the entire face, usually from nasion downwards, is only moderately common in archaeological remains. This

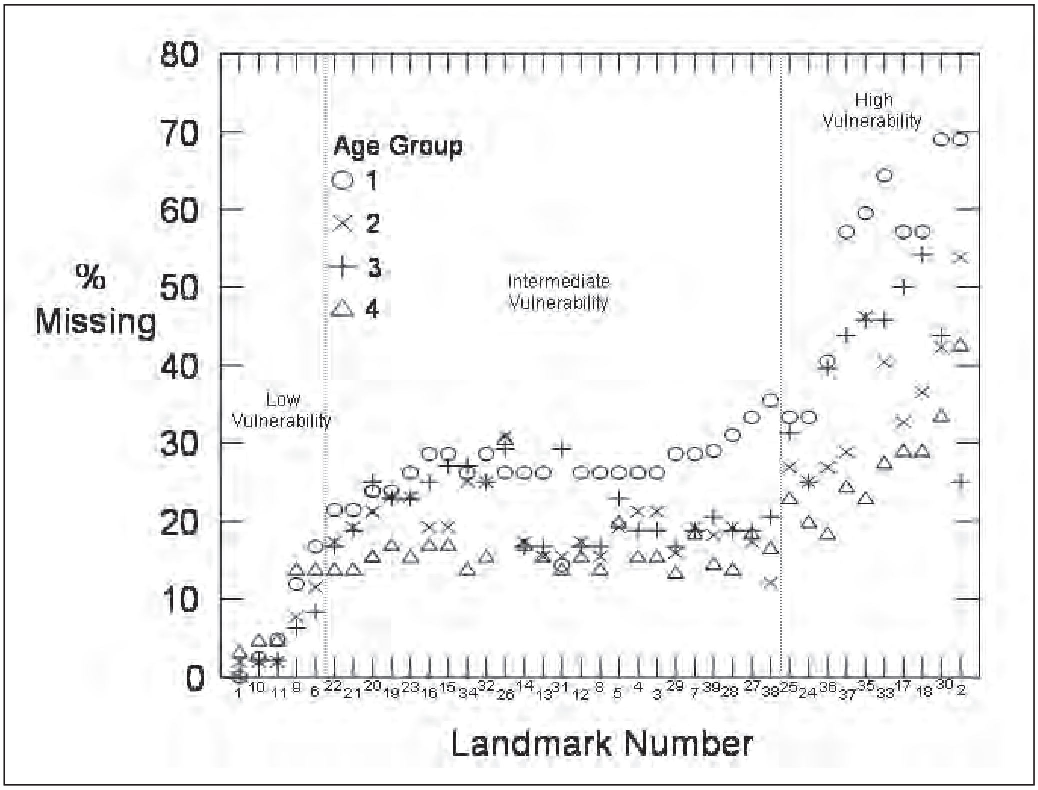

Figure 2. Percentage of landmarks missing for each age group, ordered into low, intermediate and high taphonomic vulnerability. Landmark numbers as in Table 1.

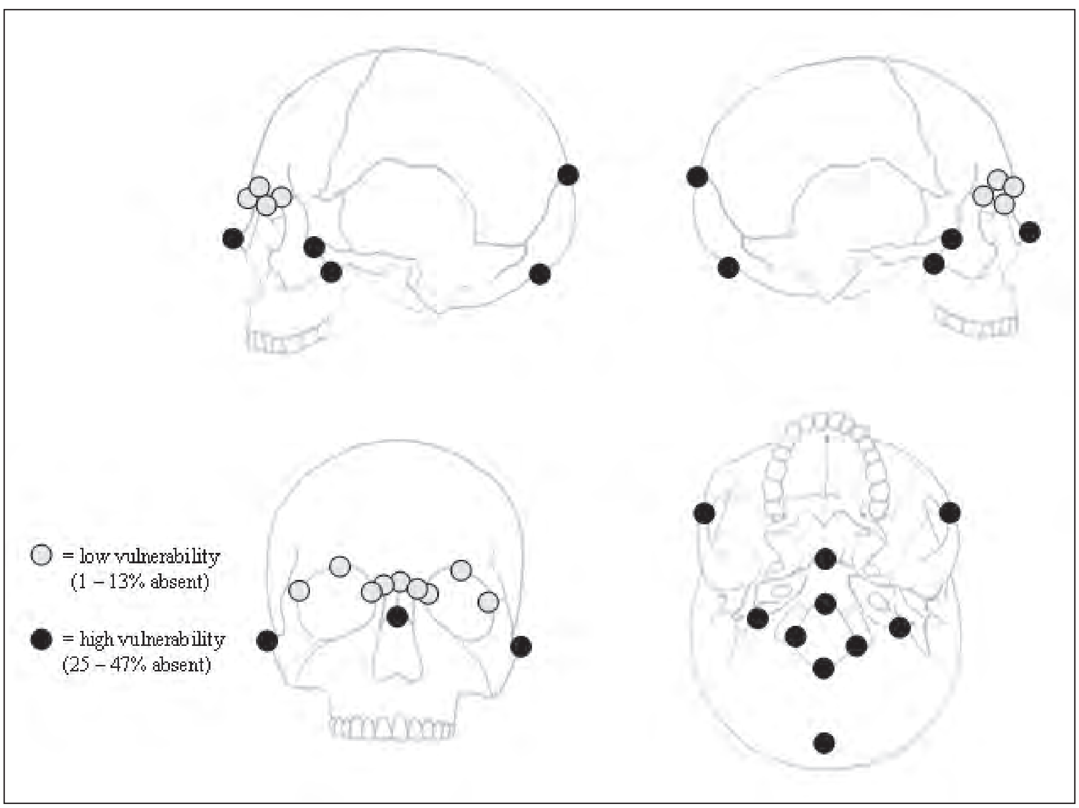

Figure 3. Landmarks with high and low taphonomic vulnerability (see Table 2).

Table 2. Taphonomic vulnerability of landmarks, separated into High (a), Intermediate (b) and Low (c) taphonomic vulnerability. Landmark abbreviations and numbers as in Table 1.

2a. High Taphonomic Vulnerability						
	Landmark (number)	% Absent 0-3 years	% Absent 3-6 years	% Absent 6-9 years	% Absent 9-13 years	Mean % All ages
Facial:	NAL(2)	69	53.8	25	42.2	47
	VSJ(30)	69	42.3	43.8	33.3	45
	SZA(17)	57.1	32.7	50	28.8	40
	IZA(18)	57.1	36.5	54.2	28.8	42
Basal:	JUG(33)	64.3	40.4	45.8	27.3	42
	BAS(35)	59.5	46.2	45.8	22.7	41
	CFM(37)	57.1	28.8	43.8	24.2	37
	OPI(36)	40.5	26.9	36.9	18.2	30
Vault:	LAM(24)	33.3	25	25	19.7	28
	L-O(25)	33.3	26.9	31.3	22.7	25

2b. Intermediate Taphonomic Vulnerability						
	Landmark (number)	% Absent 0-3 years	% Absent 3-6 years	% Absent 6-9 years	% Absent 9-13 years	Mean % All ages
Facial:	ICF(26)	26.2	30.8	29.2	30.3	29
	PNS(27)	33.3	17.3	18.8	18.2	22
	PMM(5)	26.2	19.2	22.9	19.7	22
	MXP(38)	35.5	12.1	20.5	16.3	21
	MXT(28)	31	19.2	18.8	13.6	21
	NMB(7)	8.6	19.2	18.8	18.2	21
	ANS(3)	26.2	21.2	18.8	15.2	21
	IDS(4)	26.2	21.2	18.8	15.2	21
	ZYI(14)	26.2	17.3	16.7	16.7	19
	DPM(39)	29	18.2	20.5	14.3	19
	PAL(29)	8.7	15.9	16.7	13.2	18
	IF(12)	26.2	17.3	16.7	15.2	18
	ZYS(13)	26.2	15.4	16.7	15.2	18
	ALA(8)	26.2	15.4	16.7	13.6	17
Basal:	CAR(32)	28.6	25	25	15.2	23
	STY(34)	26.2	25	27.1	13.6	22
	FOV(31)	14.3	15.4	29.2	13.6	18
Vault:	PTN(15)	28.6	19.2	27.1	16.7	22
	SPH(16)	28.6	19.2	25	16.7	22
	B-L(23)	26.2	23.1	22.9	15.2	22
	EAM(19)	23.8	23.1	22.9	16.7	22
	AST(20)	23.8	21.2	25	15.2	21
	N-B(21)	21.4	19.2	18.8	13.6	18
	BRG(22)	21.4	16.7	13.6	13.6	17

2c. Low Taphonomic Vulnerability						
	Landmark (number)	% Absent 0-3 years	% Absent 3-6 years	% Absent 6-9 years	% Absent 9-13 years	Mean % All ages
Facial:	NMT(6)	16.7	11.5	8.3	13.6	13
	FMO(9)	11.9	7.7	6.3	13.6	10
	FZJ(11)	4.8	1.9	2.1	4.5	3
	ORB(10)	2.4	1.9	2.1	4.5	3
	NAS(1)	0	1.9	0	3	1
Basal: None						
Vault: None						

pattern of damage is known in the forensic literature as a LeFort III fracture (described below, after Rogers, 1992) and occurs in about 10% of patients seeking medical attention for cranial fractures (Richardson, 2000). A LeFort III fracture leaves the cranium in two pieces, the face and the skullcap (neurocranium plus basicranium). The thinness and vulnerability of the facial bones to taphonomic forces means that once these two portions of the cranium have separated, the skullcap is much more likely to survive and be recovered than the face. Additionally, the sphenoid is extremely likely to be broken or missing in crania missing the face.

Three landmarks in the basicranial region are also consistently missing in high frequencies (25-42% across all age groups): the anterior part of the jugular process (JUG); the anterior point of the foramen magnum on the midline or basion (BAS); and the posterior border of the occipital condyle with the foramen magnum (CFM). All are clustered spatially and are intimately related to the basilar and lateral parts of the occipital bone. The sutures between these ossification centers and the squamous occipital are short and vulnerable to separation; the squamous fuses to the basilar portion at about five years, and the lateral and basilar parts fuse in the sixth year (Byers, 2002). The basilar suture is vulnerable to separation until it fuses to the sphenoid between 18-21 years.

Three landmarks on the vault are also missing in moderately high frequencies (25-30% across all age groups). These are: lambda (LAM) at the junction of the lambdoid and sagittal sutures; a point (L-O) halfway between lambda and opisthion on the midline; and opisthion (OPI), the posterior midline point of the foramen magnum. All are associated with the squamous occipital. One of the most likely types of taphonomic damage to occur to an immature cranium is the loss of the occipital bone due to separation of the lambdoid suture.

The high frequency with which both basilar and squamous occipital landmarks are missing shows that loss of part or all of the occipital must be considered one of the most common types of cranial damage among immature individuals, as is loss of the vomer, nasals, and zygomatic arches. Separation at the coronal suture seemed common in the Krovitz sample but was not specifically quantified.

Intermediate taphonomic vulnerability

This grouping includes most of the neurocranial landmarks and a mixture of facial and basicranial landmarks (Table 2b). Because these landmarks exhibit the greatest variability, both within and between age groups, we suggest that the preservation of and damage to these landmarks tends to reflect particular differences in individual growth and taphonomic history.

Because the squamous temporal suture is beveled and not interdigitated, we expected that this suture would be more likely to open and fall apart than other neurocranial sutures. Contrary to our expectations, the landmarks along this suture (AST, PTN, and SPH) fell into the intermediate vulnerability group; just over 20% of the specimens (regardless of age group) were missing at least one of the landmarks on the squamous temporal suture.

Low taphonomic vulnerability

Landmarks with low taphonomic vulnerability are illustrated in Figure 3 and listed in Table 2c. These landmarks were present in nearly all of the specimens in the samples examined here regardless of the age at death of the individual. All of the landmarks with the lowest taphonomic vulnerability are facial and all are located on the sturdy orbital rim of the frontal bone. They are nasion (NAS), orbitale (ORB), the top of the nasomaxillary suture at the frontal bone (NMT), the frontomaxillary suture at the orbit (FMO), and the frontozygomatic junction at the orbit (FZJ). It is apparent that the robustness and structural strength of the orbital rim of the frontal bone has a substantial impact on the frequency of preservation of this region of the cranium.

We also believe that the frontal bone acts as a physical keystone in holding the cranium together and is critical in determining how an immature cranium will break. The frontal has sutural connections with the parietals, temporals, sphenoid, maxillae, zygomatics, nasals, and ethmoid. The frontal bone plays a key role in hafting the face onto the neurocranium and in reinforcing and strengthening sutural connections (such as the sagittal suture) within the neurocranium. If the coronal suture opens and the face and frontal separate as a unit from the rest of the cranium, then the face has an improved chance of survival, although the rest of the cranium will almost certainly disarticulate. However, if the face breaks off below nasion in a LeFort II or III fracture (discussed below), then the neurocranium has a better chance of survival, but the facial bones will almost certainly disarticulate.

In general, once a cranial bone is isolated its individual chance of survival is lessened. However, isolated cranial elements vary in their likelihood of survival due to their structural or mechanical properties. Sturdier bones (or bone parts, such as the petrous temporal, suitably named for its rocklike properties) almost always survive in higher frequencies and with less damage than delicate bones (such as the nasals or vomer), thin bones with a complex shape (such as the sphenoid), or bones with projecting processes (such as the zygomatic).

The Krovitz sample considered only fairly well articulated crania; thus most individuals preserved the frontal bone, which explains the apparent low taphonomic vulnerability of the landmarks on the frontal bone. Individuals with a missing or badly broken frontal bone probably did not survive to be included in the Krovitz sample. Because of its general robustness and its many sutural attachments to other bones, the frontal has an unusually large effect on the taphonomic survival of the cranium.

Application of taphonomic vulnerability categories

The categories described above represent three levels of taphonomic vulnerability. In general terms, knowing which cranial parts are missing from a specimen can be used with the taphonomic vulnerability categories to judge the intensity of the taphonomic damage to which a specimen was exposed.

Specimens showing only a few fractures or absences in the high vulnerability category have probably been subjected to *minimal* taphonomic destruction. Those showing breaks in high and intermediate categories (but not necessarily the loss of all landmarks in those categories) have been subjected to *moderate* taphonomic destruction. Those crania showing some fractures to or loss of some landmarks in all three groupings have been subjected to *extensive* taphonomic destruction. The categories of taphonomic vulnerability are nested, so that specimens subjected to any level of taphonomic destruction have also, by definition, been subjected to the less severe types of damage as well. Especially indicative of intense taphonomic destruction is the breakage and partial loss of the orbital margin on the frontal bone or separation of the frontal bone from other parts of the cranium. As argued above, once the frontal is absent, the cranium as a whole is less likely to be preserved in the archaeological or fossil record. However, it is important to note that the response of a cranium to taphonomic agents is highly variable according to the particular circumstances of burial. Further, these categories do not necessarily represent three widely separated points in the time (relative to death) at which damage occurred. For example, extensive damage can and does occur early in a specimen's taphonomic history while the bone is fresh and the cranium is fully fleshed; conversely, minimal damage can and does occur after fossilization.

If the age at death of an immature cranium can be determined with some precision, then a more refined deduction can be made using both age at death and taphonomic vulnerability data. Within the Krovitz sample, most landmarks show decreasing vulnerability as age increases (Table 2), although landmarks rarely shift from one vulnerability category to another. Only four landmarks change taphonomic vulnerability categories with increased age: the juncture of the palatine suture with the edges or curve of the palate (PAL); the top of the zygomatic-maxillary suture at the inferior orbital rim (ZYS); the foramen ovale (FOV); and the incisive foramen (ICF).

The taphonomic vulnerability of PAL is intermediate in the youngest individuals and steadily diminishes as age increases, until PAL eventually ranks among the landmarks showing the lowest vulnerability in individuals aged 9-13 years. Between the ages of 0-13 years, the palate lengthens and strengthens considerably and, between ages of 5-12 years, the first and second permanent molars erupt. We hypothesize that the presence of these molars may partially shield the palatine suture from destruction in older individuals. A similar drop in vulnerability is shown in ZYS, which is in the intermediate vulnerability group in the youngest group of individuals and drops to the low vulnerability group in individuals older than 3 years. This change may be related to the increasing strength and buttressing in the face as adulthood is approached. We can offer no hypotheses for the change in taphonomic vulnerability of FOV and ICF in the different age groups other than individual variability or some inadvertent sampling bias.

Comparison of breakage in the Krovitz and SHARP samples

The results of the Krovitz landmark inventory were compared with those of the SHARP bone inventory to see if these patterns of survival were consistent between immature and adult crania. To calculate frequency of damage/absence in the SHARP sample, we added the numbers of bones that were entirely missing to those in which a significant portion (25% or more) of the bone was missing (Table 3). As there are only three immature crania in the sample (Reid, 2004, pers. comm. to P.S.), we did not subdivide the sample into age groups.

Generally, the frequency and location of cranial damage is similar between the two samples. The Krovitz data showed that the category of high taphonomic vulnerability included facial landmarks associated with the maxilla, nasals, zygomatic arches, and vomer. Although

Table 3. Completeness of bones in the SHARP sample (N=82; 79 adults and 3 immature crania). Completeness data represent an average of lefts and rights for each bone. Bone abbreviations as follows: Front = frontal, Pariet = parietal, Occipit = occipital, Temp = temporal, Sphen = sphenoid, Zygo = zygomatic, Max = maxilla, and Pal = palatine.

Completeness	Front	Pariet	Occipit	Temp	Sphen	Zygo	Max	Pal
75–100%	55	54	55	36.5	31.5	30	38.5	42
26–74%	11	12	10	16	10.5	10.5	13.5	6.5
1–25%	7.5	7	7	10	8	11.5	8.5	6
0%	8	9	8	19.5	32	30	21.5	27.5
0–74% combined	25	27.5	26	45.5	50.5	43.5	43.5	42
% damaged or absent	33%	34%	32%	55%	62%	63%	53%	51%

data on the nasals and vomer were not available for the SHARP sample, facial bones (zygomatics and maxillae) were damaged or absent in a high number of individuals (63% and 53% respectively). Thus, in both the immature sample inventoried by Krovitz and in the largely adult SHARP sample, aspects of the facial bones were among the most highly vulnerable to taphonomic destruction. Landmarks in the category of lowest taphonomic vulnerability, based on the Krovitz sample, were related to the sturdy superior margin of the orbit and the crucial role of structural keystone that the frontal bone plays within the cranium. This is consistent with the observation that only 33% of individuals in the SHARP sample had seriously damaged or absent frontals, making the frontal the second least vulnerable bone after the occipital.

The two samples differed strikingly in the vulnerability of the occipital bone. Landmarks in this region were among the most highly vulnerable in immature individuals in the Krovitz sample. In the largely adult SHARP sample, the occipital bone was the least vulnerable bone, being missing or seriously damaged in only 32% of individuals. We hypothesize that this difference is related to the adult nature of the SHARP sample. Despite considerable variability in the timing of the closure of cranial sutures in adults (Todd and Lyon, 1924; Todd and Lyon, 1925a, b, c; McKern and Stewart, 1957; Meindl and Lovejoy, 1985), the lambdoid sutures in adults of the SHARP sample would have fused to some degree, and sutures between the basilar and lateral occipital elements would be completely fused. Stronger bony attachments between the occipital and other cranial bones would make the occipital bone itself less likely to separate from the rest of the cranium and less vulnerable to damage.

Another marked difference in the survival of cranial bones in these two samples involves the sphenoid and the temporal bones. In the Krovitz sample, landmarks associated with the sphenoid and temporal bones fall into the intermediate category. In the SHARP sample, these bones are highly vulnerable, showing serious damage or destruction in 62% and 55% of the individuals respectively. Thus the sphenoid is the second most vulnerable bone and the temporal is the third most vulnerable bone in the SHARP sample. We hypothesize that the beveled nature of the squamous temporal suture is a more important source of vulnerability in adults because the other endocranial sutures are partially or wholly fused. In contrast, in immature individuals, the squamous temporal suture is not distinctly more vulnerable to separation than the other cranial sutures. Similarly, the sphenoid is relatively more vulnerable in adults than in immature individuals. The sphenoid is a very thin and fragile bone in adults compared to the other vault bones, which have thickened and acquired greater robustness with age; in immature crania, the sphenoid is not so markedly different in robustness from the other cranial bones. This difference could also be due to sampling differences between the Krovitz and SHARP samples, as the SHARP sample included disarticulated bones and the Krovitz sample did not. If a large number of the sphenoids and temporals contained in the SHARP sample were from disarticulated crania then they would likely be less well preserved than those from the more articulated crania in the Krovitz sample.

In summary, cranial breakage and survival in the immature sample studied by Krovitz and the adult SHARP sample show a generally similar pattern. There are important exceptions pertaining to the survival of the occipital, the sphenoid, and the temporal bones.

Qualitative Breakage Patterns in Immature Fossil Crania

Qualitative observations on patterns of fracture location and morphology provided additional tools with which to deduce the approximate timing of damage in an immature cranium. We examined some original specimens but more usually photographs and casts of 20 fossilized immature hominid crania that were relatively complete and thus might be comparable to the Krovitz sample (Appendix I). These data were compared with similar observations on crania in the forensic and medical literature (primarily representing damage to living or recently dead individuals) and with archaeological specimens from the inventory sample (representing primarily post-burial damage).

For each fossil specimen we observed, we noted the general frequency of damage, the location of fractures, and the attributes (length, course, texture, and type) of fractures and of the fractured surfaces. We used standardized terminology from the forensic literature, where possible, to describe fracture type and morphology and to deduce the time of fracture relative to death. Appendix I summarizes our observations for each of the 20 immature fossil specimens considered.

Chronology of taphonomic damage

We divide the taphonomic history of an immature cranium into three phases at which breakage can occur. In chronological order, these are:

Stage 1) Wet or fresh bone breakage, incorporating antemortem and perimortem breakage, generally takes place while the bone is partially or wholly fleshed. Antemortem breakage is recognized by the fact that healing began before death; under controlled conditions, grossly detectible healing may be evident in as little as one to two weeks after the time of injury (Sauer, 1998; Galloway, 1999: 15, citing Murphy et al., 1990 and Rogers, 1992). Identifying perimortem breakage (occurring at the time of death) can be less straightforward than antemortem damage, but still incorporates fresh bone fracture patterns (Sauer, 1998). Although antemortem and perimortem fractures can be differentiated by evidence of healing, they both occur on wet, fresh bone and both have similar fracture characteristics; therefore, they are considered together in stage 1.

Fresh or living bone is a composite tissue comprised of flexible protein (mostly collagen) and brittle hydroxy-apatite. In both antemortem and perimortem breakage, the bony tissue and the sutures between bones contain intact collagen and other organic components that give bone its elasticity, meaning that it is able to bend or deform under load before failure (breaking) occurs. The flexible collagen and membranes surrounding unfused sutures stop cracks from propagating through the bony tissue by deforming and dissipating force (Currey, 1984).

The mechanical properties of one square inch samples of fresh tissue from long bones has been measured. In tension, such a sample of whole fresh bone fractures or fails at only about two-thirds the pressure that is required to fracture bone under compression (Gordon, 1968: 42-44). This is why, in fresh bone subjected to blows, fractures are initiated not at the point of impact where the bone is compressed but in the surrounding bone which is placed under tension (Rogers, 1992). Whole, fresh bone has a low modulus of elasticity, which means it has a tendency to bend without breaking (Gordon, 1968: 42-44). Younger individuals with bones that are more cartilaginous and less mineralized will have an even lower modulus of elasticity than adults.

Stage 2) Dry bone breakage occurs postmortem after the bone has lost much of its organic content, and is usually defleshed, although dried or mummified flesh can be found on stage 2 crania. Dry bone breakage may occur during a lengthy time span ranging from shortly after death to centuries later, depending on specific preservation conditions; the organic component of bone will also vary according to the time since death and preservation conditions. The archaeological sample we inventoried had been subjected primarily or exclusively to stage 2 damage.

Immature crania in stage 2 are substantially more vulnerable to separation along unfused sutures than stage 1 bones since the connective tissue holding the sutures together is degraded or decayed in stage 2. Therefore, the modulus of elasticity of the bone tissue is compromised as is the crack-stopping ability of the flexible components of bone. Thus breakage will occur in stage 2 bones at lower loads than in stage 1 bones (Lyman, 1994; Galloway, 1999). The loss of elastic tissue from the bone not only lowers the force needed to produce failure in bone but also alters the morphology of the resulting fracture. As elastic tissue degrades, the fracture surface becomes progressively flatter, more planar, and less likely to splinter or bevel. The course of vault fractures is more likely to be curvilinear and longer in fresher crania and straighter and shorter in dried crania.

Stage 3) Post-fossilization breakage occurs after the bone has been mineralized, but fossilization is not an all-or-nothing event. Bones at a single site may range from fully mineralized to a condition close to that of dry bones with only minimal geochemical changes. What typifies this stage is that the bone has no significant elastic or soft tissue left and behaves more like a brittle, inorganic material, such as stone or ceramic, than like fresh bone. We do not know of anyone who has measured of mechanical strength of fossilized bone; strength would presumably vary with the degree of mineralization. As a crude approximation, we might expect fossilized bone to have the very low tensile strength, very low modulus of elasticity, and high compressive strength of stony substances such as brick or concrete.

Another issue in breakage is microstructure. Living bone is riddled with osteons and other spaces that house bone cells; these "holes" can and do serve as the sites of fracture origin because they are inherently weak places in the tissue. Similarly, foramina act as stress concentrators where fractures often initiate (Currey, 1984). In fossilized bone, these "holes" are more or less completely filled with mineral. The increased strength caused by the absence of holes seems to be more than offset by the complete lack of flexibility.

Both the diminished flexibility and the geometry or morphology of the bone(s) assumes greater importance in determining breakage in stages 2 and 3 than in stage 1. It is also important to appreciate that breakage of stage 1 crania is more likely to be the result of accident or human violence than breakage in older crania. Fractures caused by violence are more likely to be directed at the face than fractures caused in other ways during stages 2 or 3.

Review of the forensic and medical terminology: fracture types

Six basic types of cranial fractures, differentiated on the basis of location and morphology, are frequently discussed in the medical and forensic literature (e.g., Galloway, 1999; Byers, 2000; Richardson, 2000). Three combined fracture patterns are frequently identified in the face (i.e., LeFort fractures), and disarticulation of cranial sutures is also noted. These types of cranial damage are reviewed here with particular focus on immature crania.

(1) *Linear fractures* are elongated, single breaks that go through the outer table of the bone, the diploe, and the inner table of the cranial vault bones. Linear fractures comprise 70-80% of observed fractures in the forensic context (Gurdjian, 1975; Rogers, 1992), which usually involves stage 1 breakage. Linear fractures are often the result of impact with objects having a large mass, such as heavy weapons or automobiles. In forensic cases, linear fractures occur less commonly in children than in adults due to the greater elasticity of immature bone (Duncan, 1993) but are known to occur in cases of child abuse, especially in children under the age of three years (Naim-Ur-Rahman et al., 1994). In fresh crania, linear fractures occur as a result of forces between 450 to 750 psi (Cox et al., 1987) although there is considerable individual variation.

(2) *Diastatic fractures* are linear fractures that follow the course of sutures, fused or unfused, in stage 1 crania. In antemortem or perimortem circumstances, diastatic fractures cause traumatic interruptions of sutures,

sometimes leading to the springing outward of the vault bone on one side of the fracture and the evulsion of brain tissue through the crack. This springing out is a result of the release of the inherent tension of the intact cranial vault by a fracture. This phenomenon is very unlikely to occur in dry or fossilized crania because elasticity of the bones is so diminished that fracture is more likely to occur than a rebounding outward of part of the cranium.

In the forensic context, diastatic fractures constitute about 5% of all fractures and occur most commonly in the coronal and lambdoid sutures (Galloway, 1999). Blount (1955, 1977) observed that true diastatic fractures are rare in children in stage 1. He postulated that linear fractures made on fresh or wet bone very rarely cross a suture because the area of the suture has different mechanical properties from the bone surrounding it. The greater flexibility of connective tissue in and near sutures in immature crania acts to stop cracks by dissipating force through deformation.

(3) *Depressed fractures*, together with comminuted and stellate fractures (discussed below), comprise 15% of fractures in forensic contexts (Gurdjian, 1975). Depressed fractures involve deformation of the cranial vault in response to impact, usually of high velocity by a blunt object of small or moderate diameter. The bone at the point of impact is pushed inward while the area immediately surrounding the impact is bent outward, placing the bone under tension and initiating fractures (Gurdjian et al., 1953; Gurdjian, 1975; Rogers, 1992). The fragments of bone pushed inward by the impact in stage 1 remain attached to the cranium; Byers (2002) refers to this phenomenon as *hinging* and regards it as diagnostic of stage 1 breakage from depressed fractures. We have observed a specimen that received a depressed fracture in stage 1 with the fragments still in place some 200 years later, well after the cranium had reached stage 2 (G. Milner, personal communication to authors, 2003). Depending on the strength of the blow, a depressed fracture may be surrounded by a number of linear breaks that radiate outward from the depressed area known as *radiating fractures*. A depressed fracture surrounded by radiating fractures is one typical result of blunt force trauma under stage 1 conditions. Radiating fractures are unlikely to occur in dry stage 2 bone (Byers, 2002: 270) or in fossilized bone.

Depressed fractures are 3.5 times more common in stage 1 children than in stage 1 adults (Zimmerman and Bilaniuk, 1981). Even though an immature cranium is more flexible than an adult's, the absolute thinness of the cranial vault bones makes immature crania more prone to fracture. Sometimes depressed fractures occurring in young individuals do not break through both inner and outer bony tables of the vault but may simply dimple the surface; this stage 1 phenomenon is known as a *ping-pong fracture* because similar depressions occur on ping-pong balls. Among the immature fossil crania we examined through photographs, Qafzeh 11 shows a clear depressed fracture on the frontal just above the left orbit (Tillier, 1999), but this does not appear to be a ping-pong fracture and the individual is older than those who typically incur such fractures. Close-up photographs in Tillier (1999) support her suggestion that some healing had occurred at the time of death, proving that this fracture was antemortem by at least a few weeks.

(4) *Stellate fractures* are a set of linear fractures radiating in a star-shaped pattern from a single point where impact occurred. Gurdjian (1975) found that stellate fractures are typical of heavy loads of relatively low velocity on stage 1 crania and are somewhat more common on upper parietals than elsewhere. Where stellate fractures are centered on a depressed fracture, they are functionally identical to radiating fractures.

Although radiating fractures do not usually occur later than stage 1, we observed stellate fractures without depressed fractures on crania in stages 2 and 3. We inferred that these were caused by the slow crushing or flattening of curved bones or parts of bones probably under sedimentary load. Examples of stellate fractures centered at inion but not involving a depressed fracture, which probably occurred in stage 2 or 3, can be seen on the immature fossil crania from Engis, Pech de l'Azé, or Roc de Marsal.

(5) *Communited fractures* of the vault involve large numbers of small fragments, usually produced by low velocity/heavy impact force. Crushing incidents are one common cause of comminuted fractures of fresh (stage 1) crania. We suggest that comminuted fractures may also result from sedimentary pressures acting on stage 2 or 3 (dry or fossilized) crania. The fossil crania Dederiyeh 1 and 2, Qafzeh 11, and KNM-WT 15000, among others, exemplify an overall comminution of the cranial vault (which we call a mosaic fracture pattern, see below). We discuss below ways in which stage 1 and stage 2 comminuted fractures may be distinguished.

(6) The *tripod* or *zygomatic-maxillary fracture* is one of the most common cranial fractures observed in medical and forensic circumstances (Rogers, 1992; Richardson, 2000). Frequently caused by a blow to the malar eminence, the tripod fracture separates the zygomatic bone from the rest of the cranium by breaks in the zygomatic arch, at or near the zygomatic-maxillary suture, and at or near the zygomatic-frontal suture (Rogers, 1992).

In addition to the six types of cranial fracture described above, forensic experts distinguish three combined fracture patterns involving the face called LeFort fractures (see Figure 4) (Galloway, 1999; Byers, 2002). These fractures may occur in combination as well as separately. A *LeFort I fracture* is an approximately horizontal break above the alveolar processes of the maxillae and below the nasal aperture. The typical cause of a LeFort I fracture is a blow to the lower face from the front or side. A *LeFort II fracture* isolates the midface from the vault, with breakage passing through the maxilla, the infraorbital foramen, and nasion; these fractures typically result from a blow to the midface at midline. A *LeFort III*

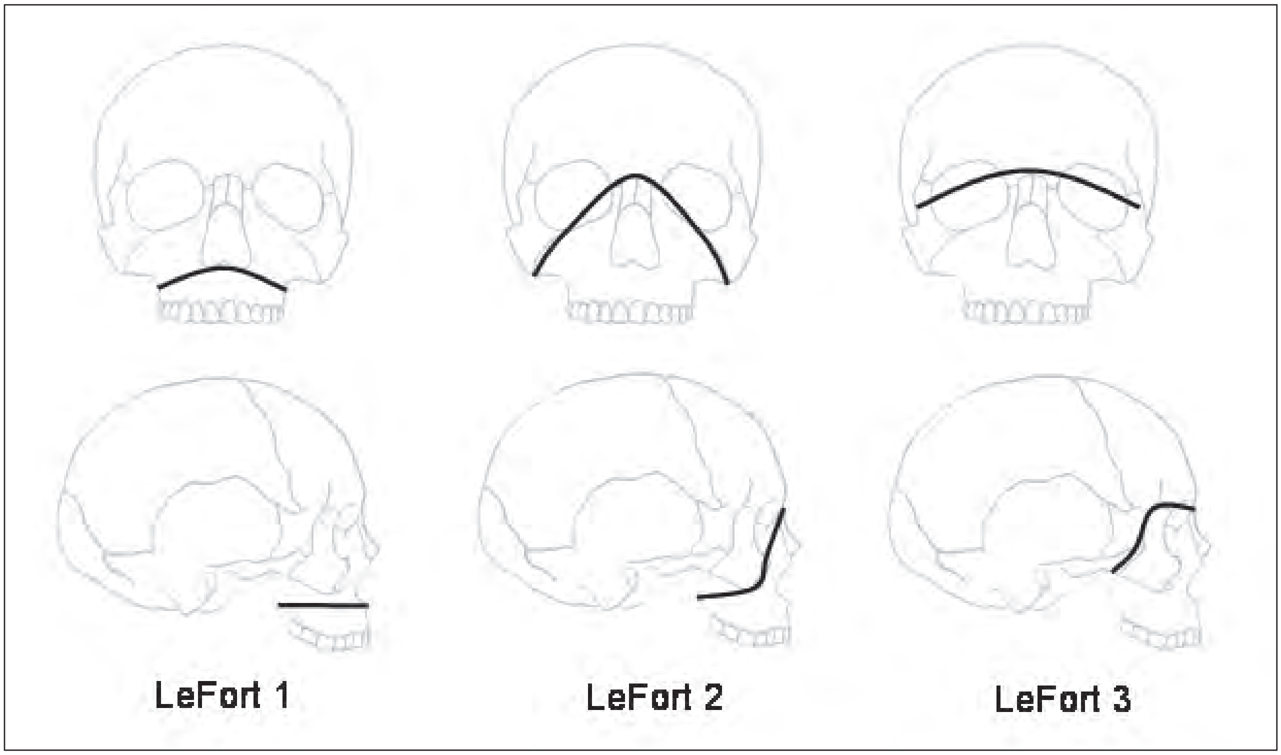

Figure 4: Illustration of LeFort fractures (after Byers, 2002, and Galloway, 1999).

fracture passes through nasion, through the bony orbits below the superciliary ridge, back through the sphenoid and zygomatic arch. This fracture separates the cranium into a skullcap and a facial portion and occurs in forensic circumstances when a blow is struck to the upper central part of the face.

In the Krovitz sample, 9% of the crania showed breaks that appeared to be LeFort III fractures, i.e., the specimens were neurocrania without faces. Eight percent of the SHARP sample showed LeFort III fractures, as judged by the simultaneous absence of right and left maxillae, zygomatics, and palatines. However, because we did not have data on isolated cranial bones (those not associated with skeletons) in the SHARP sample, the actual frequency of LeFort III fractures may have been higher.

Breakage that appears as a LeFort III fracture seems to be relatively common among fossil hominids. Numerous adult crania of *Homo erectus* show this pattern as do immature crania including Engis 2, Subalyuk 2, Mojokerto 1, and Skhul 1. We hypothesize that during burial and taphonomic destruction, crania with LeFort I and II fractures (or other facial damage) are so weakened that they tend to deteriorate further and present as LeFort III fractures by the time of excavation and study. It is uncommon to find fossil crania with LeFort I or II types of damage.

Finally, *sutural separations* are another type of cranial “damage” that is commonly observed in immature crania. A sutural separation involves the falling apart of an unfused or open suture due to the loss or degradation of the collagen component of bone tissue and of the sutural membranes themselves. Although diastatic fractures are breaks that follow the course of a suture, they differ from sutural separations in that the application of force is necessary to produce a diastatic fracture; while sutural separations occur naturally as a by-product of decompositional changes in an immature cranium. Sutural separations occur in stage 2 rather than stage 1 unless there is some processing of the fresh cranium (such as cooking or chemical treatment) that destroys or degrades the organic component of the bone. Sutural separations yield cranial fragments that may be entirely unbroken but which are separated from the rest of the cranium. The vast majority of crania from individuals who die under the age of one year (and many older immature individuals as well) will come apart along sutural lines once the collagen and membrane at the sutures has broken down (i.e., once stage 2 is reached). However, since the exposed sutural edges involve many small, protruding points that are vulnerable to further breakage, not all cranial bones isolated by sutural separation will be complete. Close inspection of the sutural edge should reveal whether the breakage is a single diastatic fracture or a series of fractures subsequent to a sutural separation.

The Taung 1 cranium shows a separation of the coronal suture, with subsequent minor breakage of the frontal. Gibraltar 2, the Devil’s Tower Neandertal, also experienced a separation of the coronal, sagittal, and temporal sutures; subsequent to that separation, there has been some breakage of the exposed sutural edges. The Amud 7 specimen preserves the occipital bone of a young Neandertal which was isolated by sutural separation; the rest of the cranium was not recovered.

In summary, six types of fracture, three patterns of facial fracture, and sutural separations are distinguished in the forensic and medical literature. Many but not all of these were recognized in the archaeological or fossil samples we surveyed.

Influence of chronological stage on fracture morphology

Stage 1

To assess stage 1 fractures, we turned again to the medical and forensic literature. Richardson (2000), a radiologist, reports the frequency of different fractures for a hospital population. Less than 10% of the injuries in his sample were incurred by children. Most probably, his sample was biased toward adults and toward young males, since in many medical reports young males are found to sustain a higher frequency of facial fractures than other age and sex categories (Barker et al., 2003). In Richardson's sample, automobile accidents and assaults were the two most common causes of the facial fractures.

Richardson found that the most common type of midfacial fracture is a tripod fracture of the zygomatic and maxilla (40%). LeFort I fractures comprise 15%; LeFort II, III, simple zygomatic arch fractures, and comminuted fractures each comprise another 10%; and alveolar fractures, often associated with fractured teeth, make up the last 5%. Richardson points out that 60-70% of all facial fractures (the tripod fractures plus LeFort II and III) involve the orbit.

Any of the cranial fractures described above may occur on stage 1 crania, with the exception of sutural separations (see discussion on sutural separations above). Since most stage 1 crania do not sustain trauma prior to death, Richardson's sample is not expected to parallel the incidence of facial fractures in a general cemetery population. Prior to the invention of mechanized forms of transport, an individual cranium probably experienced few breaks during stage 1 except in cases of attack, warfare, or a major accident. Even then, the point or points of impact may be evident. The effects and sequence of a series of blows or impacts can be deduced by a skilled examiner in forensic or archaeological cases (e.g., Sauer, 1998; Marks et al., 1999).

The morphology of fractures is helpful in deducing the chronological stage of the cranium at the time of breakage. Linear fractures in stage 1 crania are usually long and curved rather than straight; their course relates more to the direction and magnitude of force applied than to the geometry of the cranium per se. The outline of a depressed fracture is also often curved into a rounded or oval shape, reflecting the shape of the object which impacted the cranium. Concentric rings of fracture may encircle a depressed fracture. Stage 1 fractures of crania are often beveled, with the direction of the bevel indicating the direction of movement of the force causing the fracture (Berryman and Symes, 1998).

Burial per se may protect the cranium from further damage by many taphonomic agents. Although crania buried in stage 1 may undergo non-traumatic sutural separations, especially on very young (<1 year old) individuals, it is important to remember that these sutural separations do not normally occur at the time of burial but after burial, during stage 2, when the organic components of the cranial bone have decayed. Stage 1 crania do not generally show sutural separations unless there is some processing of the fresh cranium that destroys or degrades the organic component of the bone.

In summary, stage 1 fractures are usually few in number per specimen, except in cases of warfare, violent attack, or accidents. Stage 1 depressed fractures frequently show a rounded outline that reflects the shape of the object responsible for the damage; depressed fractures often show hinged pieces or retention of the pushed-in fragments. Linear fractures occur and are elongated and curving in course; where they intersect sutures, the course may change abruptly to follow the plane of weakness represented by the suture, becoming a diastatic fracture. Stage 1 breaks are often beveled and the fracture surface itself will show irregularities caused by microscopic variations in the amount of elastic tissue in the bone. The fracture itself is sharp-edged and appears crisp and cleanly defined. Sutural separations are generally absent.

Stage 2

Breakage occurring after the bony tissue has dried and its organic component has decayed differs from that in stage 1 because the material properties of the bone tissue have changed (as discussed above). Generally, the edges of fragments fractured during stage 2 are flatter and more planar than those resulting from stage 1 fractures, indicating that the bone is responding more uniformly to pressure since it is no longer elastic. Stage 2 fractures of the cranial vault may or may not be beveled.

Synthesizing our original observations of immature archaeological and fossil crania with those reported in the literature, we observed meaningful differences in the general frequency of the different fracture types on crania in different temporal stages. Long, linear fractures with a curving course across the cranial vault are rare in crania that were dry (stage 2 or 3) when broken, as are true diastatic fractures. In contrast, sutural separations commonly occur in immature crania during stage 2, judging from the Krovitz sample. Fully or partially separated sutures, especially interdigitated ones, are very vulnerable to further breakage because of the irregularity of the exposed edge. One common consequence of this post-separation breakage is the loss of an angular piece of vault bone at bregma, as in the specimen from Le Figuier or Qafzeh 11. Another is the loss of small fragments along the course of separated coronal, sagittal, or lambdoid sutures, such as in the Mojokerto specimen. The lack of a linear course in such sutural fragments distinguishes them from true diastatic fractures.

Dry crania (stage 2) show fewer discrete depressed fractures than wet ones (stage 1). Oval or curving holes where pieces are missing—holes which might represent depressed fractures that have lost their small fragments—are uncommon in stage 2 breakage. An exemplar might be the rounded hole on the right side of the Roc de Marsal cranium. However, if this was originally a depressed fracture, there is no hinging nor are the depressed fragments still attached. Holes in stage 2 are much more commonly geometric or angular in outline. Comminuted fractures in stage 2 crania may separate into fragments. Their recovery and recognition depends largely on excavation and curation techniques. Cases where large numbers of fragments have been reassembled into partial fossil crania include Dederiyeh 1 and 2, KNM-WT 15000, and Herto BOU-VP-16/5.

A comparison of the frequency of various fracture types in stage 1 and stage 2 crania is instructive. It is important to remember, however, that breaks occurring in stage 1 crania are likely to weaken the specimen and make it more vulnerable to further breakage. This means that the initial fractures may be obscured by later damage, and if stage 1 damage is significant, the specimens may not survive to be examined as archaeological (stage 2) or fossil (stage 3) specimens.

The frequency of tripod and zygomatic arch fractures (together 50%) in stage 1 crania reported by Richardson matches closely with the high frequency of fractures to the zygomatic arch, 40-47% across all age groups in the Krovitz stage 2 crania (Table 2a). The zygomatic fractures observed in the Krovitz sample were not sutural separations but fractures of the zygomatic arch. In the SHARP sample, 27% of the individuals showed zygomatic breakage and another 37% were missing the zygomatic bones altogether.

In contrast, the high frequency of orbital fractures (60-70%) cited by Richardson is not paralleled by the frequency of orbital fractures in stage 2 crania. Richardson does not specify where the orbits are fractured, simply that fractures involving the orbit are very common in patients seeking medical attention for cranial trauma. In the Krovitz sample, four landmarks (ORB, FZJ, ZYS, and FMO) reflect damage to the superior, lateral, inferior, and medial parts of the orbital rim respectively. Three of these landmarks (ORB, FZJ, and FMO) are so rarely missing in the Krovitz sample that they are in the low taphonomic vulnerability category. The fourth landmark, ZYS, falls into the intermediate taphonomic vulnerability category, being missing in 18% of the 272 specimens in the landmark sample. Clearly, then, either orbital fractures are substantially less common in stage 2 than in stage 1 immature crania or, because of the important structural role the frontal bone plays in protecting crania from breakage (as discussed above), crania with frontal or orbital fractures that occurred during stage 1 did not survive to be inventoried in stage 2.

This conclusion is supported by the SHARP sample data which do not show high levels of breakage on bones involved in the orbital rim. The frequency of orbital fractures in this sample can be assessed only from data on the completeness of the frontal and maxilla. Twenty-two percent of the SHARP individuals show breakage to some part of the frontal bone and an additional 11% are missing their frontal bones. Twenty-seven percent of the SHARP individuals show maxillary breakage, with an additional 26% percent missing the maxillae entirely.

Pure LeFort I fractures, which comprised 15% of Richardson's sample, were not observed in the Krovitz sample and LeFort II fractures appeared to be rare, suggesting that both types probably progressed to LeFort III fractures by the time they were observed in archaeological or fossil samples. In other words, specimens missing the landmarks near the maxillary teeth were invariably also missing much more of the face. LeFort III fractures occurred in 9% of the Krovitz specimens versus 10% in Richardson's sample. Our inventory data show that the nasal sutures and the zygomatic arches are especially likely to open or break in dry immature crania. Loss of both of these regions would encourage the separation of the face and vault in a LeFort III pattern. The number of LeFort I and II fractures could not be readily estimated from the SHARP data. LeFort III fractures, as judged by the simultaneous absence of maxillae, palatines, and zygomatics, apparently occurred in 8.5% (N=7 out of 82) of the SHARP sample. Among the immature fossilized crania, there was only one LeFort I fracture (Herto BOU-VP-16/5). LeFort II or III fractures occurred in 8 of 20 (40%) of the specimens. Because the original specimens were not examined in most cases and the sample size is small, we do not know if this difference between the archaeological and fossil samples is meaningful.

In the Krovitz sample, common sutural separations in stage 2 crania occur at the basilar suture (37-64% of the specimens according to age) and, less frequently, along the lambdoid suture. Separation along the basilar suture contributes to further breakage of the basicranium; separation along the basilar and lambdoid sutures results in the isolation of the occipital from the rest of the cranium. Separation at the coronal suture occurred, separating the face and frontal bone from the rest of the cranium in 38 specimens (14% of the Krovitz sample); note that in these individuals the rest of the cranium did not survive intact once the face and frontal bones separated. Other observed (though not quantified) sutural separations include the zygomatic-temporal suture (contributing to zygomatic arch breakage), zygomatic-maxillary suture (contributing to loss of the maxilla or zygomatic), and springing out of the beveled parietal-temporal suture (contributing to loss of the temporal bone, especially if the occipital bone is also missing).

We observed two new forms of linear fracture regularly in stage 2 crania although we did not quantify their occurrence. We call the first of these a *temporal line fracture*. This fracture differs from an elongated, curving linear fracture by its anatomical placement. A true linear fracture occurring on a stage 1 cranium curves across the vault of the cranium with no characteristic placement. A temporal line fracture is found on one or both sides of a cranium or skullcap that has been subjected to a compressive force after burial and drying. Dry crania can be considered ovoids that may be hollow, incompletely filled with sediments, or filled with unconsolidated sediments. Slow compression, such as the weight of accumulating sediments overlying the cranium, will tend to flatten the cranial vault from side to side. Such compression will produce a linear fracture that follows the approximate course of the temporal line on one or both sides of the specimen. It is not the location of this muscle marking but the more acute curvature of the cranial vault in this region that renders it especially vulnerable to fracture. This acuteness of curvature is especially evident in posterior view, where modern human crania show parietal bosses or the typical "en maison" shape. Temporal line fractures typically pass from the superior margin of the orbit (or from the coronal suture) through the parietal and stop when the fracture encounters the lambdoid suture, as in the La Quina H18 and Teshik Tash specimens.

The second new type of fracture we observed in stage 2 crania is a *perpendicular fracture* in our terminology. These fractures run perpendicular to the sagittal suture inferiorly from that suture until they encounter the temporal suture or a temporal line fracture. Single specimens often show two or more perpendicular fractures, which are the natural result of diffuse pressure applied to the ovoid cranium. Perpendicular fractures are common in archaeological specimens (G. Milner, 2004, personal communication to G.K. and P.S.). Longitudinal bending stress tends to flatten the curvature toward the front and back of the cranium, causing the perpendicular fractures, as in the Teshik Tash, Engis 2, Grotte des Enfants 6, and Skhul 1 specimens, among others.

The intersection of temporal line and perpendicular fractures effectively breaks the parietal into large, roughly rectangular or trapezoidal fragments. We hypothesize that continued sedimentary pressure (or some other type of diffuse compressive load) will break these rectangular fragments further until most or all of the cranial vault surface is broken into triangular or irregularly geometric fragments in what we call a *mosaic fracture pattern.* This pattern differs from a comminuted fracture in that the mosaic fracture pattern covers a large area of the cranial vault and has no clear outline or point of impact. The mosaic fracture pattern can be observed in KNM-WT 15000, Mojokerto, Herto BOU-VP-16/5, Dederiyeh 1 and 2, Subalyuk 2, and Qafzeh 10 and 11.

Another new type of fracture we saw in stage 2 crania is the *metopic* or *parametopic fracture.* Younger individuals, under the age of about four years, may show a vertical fracture of the frontal bone either along the metopic suture or parallel to it. Although Cobain et al. (2002) report that the metopic suture is fused in most individuals by the time of birth, the site of the former suture may be weaker than the adjacent bone over the orbits, which is reinforced by the superciliary ridge. Additionally, the cause might be due to the change in curvature which becomes more acute at or near the midline of the frontal bone, thus rendering this region especially vulnerable to breakage. The Le Figuier and Qafzeh 10 specimens show metopic or parametopic breaks, which are distinct from patent metopic sutures such as in Pech de l'Azé.

During our reading of descriptions of fossil crania, we noted a disturbing tendency for any fracture along the midline of the frontal bone to be described as a patent metopic suture, even when the edge of the break was planar and not interdigitated. Similarly, missing fragments at bregma were sometimes labeled as patent anterior fontanelles without anatomical evidence. Great caution is needed in concluding that missing bone indicates a natural anatomical consequence of immaturity rather than breakage.

A *stellate fracture* of the squamous occipital, centering on inion, occurred in a number of fossil crania although the bone tissue is thicker at inion. This pattern of breakage is common on stage 2 specimens. The cause of such breaks would seem to be the geometry of the occipital, which is effectively a very blunt cone the point of which is at inion. Virtually any diffuse pressure on such a structure will tend to flatten the cone, producing a stellate fracture at inion, as in Engis 2 and Amud 7.

We may make some broad generalizations in comparing stage 1 and stage 2 fractures. Breakage in stage 2 typically involves the orbit much less often than in stage 1, and in stage 2 the lateral or inferior orbital margins are more often damaged than the superior margin. Temporal line, perpendicular, and metopic/parametopic fractures are typical stage 2 breaks. Sedimentary pressure during stage 2 may cause a widespread mosaic fracture pattern comprised of numerous geometric fragments lacking a discrete area of impact, as distinct from a circumscribed area with a comminuted or depressed fracture, which is more typical of stage 1. The surfaces of stage 2 fractures are usually planar with blunt edges lacking beveling or hinging. The course of stage 2 fractures is not curved or rounded. Immature crania damaged during stage 2 sustain more breaks per specimen and frequently show nontraumatic sutural separations. Overall, stage 2 breaks rarely show a discrete point of impact and instead result from more diffuse pressure.

Stage 3

Post-fossilization breakage occurs after the bone has been mineralized. Though rarely of concern in forensics, post-fossilization breakage is important to paleoanthropologists as it may yield clues to the circumstances under which a hominid died and became buried in sediments. In this stage, the cranium acts very much like a ceramic vessel of similar shape. The primary influences on breakage of a stage 3 cranium seem to be the geometry of the cranium or parts of the cranium in question, as in stage 2, and the lack of bony elasticity. Bone density per se is a less important issue in post-fossilization breakage than in earlier breakage because stage 3 bone tissue is mineralized.

Determining the timing of postmortem fractures relative to the time of death can be difficult; we are not confident of our ability to distinguish between stage 2 and stage 3 breakage in most cases. Stage 3 breakage may reveal internal surfaces of the fossil that are different (often lighter) in color than those that have been exposed longer; thus fresh breaks on fossils are often readily recognizable. Some fossil specimens we examined showed mosaic fracture patterns generally similar to those produced in stage 2 with many discrete, short, and straight fractures yielding numerous geometric fragments. These specimens generally lacked either a long temporal fracture or perpendicular fracture, which we believe are more common in stage 2 crania. We hypothesize that crania subjected primarily to stage 3 damage are more likely to show an overall diffuse shattering rather than the creation of longer, more linear fractures along geometric planes of weakness. As a subjective impression, we believe that the average fragment size is somewhat smaller in stage 3 mosaic fracture patterns than in stage 2 patterns, but it will be difficult to test this because we cannot reliably separate stage 2 and 3 breakage. Fragment edges, where visible, are generally planar in both stage 2 and 3 mosaic fracture patterns.

Another taphonomic factor that has a considerable influence upon the breakage of stage 3 crania is the presence or absence of a consolidated natural endocast that was formed while the cranium or a portion of the cranium was still intact. A cranium that is largely intact when it becomes a sedimentary particle in an open air or cave site is likely to become filled with sediment which will eventually harden into an endocast. At least some deliberately buried crania also develop natural endocasts (i.e., Skhul 1, see McCown and Keith 1939: 299-301). Because these sedimentary infillings obscure the internal surfaces of the fossilized bones, they are usually removed during preparation. The exceptions are cases where the sedimentary infilling (endocast) preserves an impression of bones which were not recovered or where the endocast separates naturally from the fossilized bone without causing damage, as in Taung 1.

We have few examples to generalize from in which endocasts have been recovered intact or where their extent and placement at the time of discovery is documented. However it is intuitively obvious that the presence and nature of a consolidated natural endocast effectively transforms a fossilized cranium from a hollow ovoid, structurally similar to a ceramic vessel in terms of potential for breakage, into a solid comprised of a dense center (the endocast) and a relatively thin outer covering (the fossilized bone). We suggest that a consolidated, natural endocast will not necessarily prevent fragmentation of a fossilized cranium as pressure is exerted but will act to keep fragments together and in or near their original anatomical position. Although a fossilized cranium with a complete endocast may be more vulnerable to breakage than the surrounding rock, the endocast helps the cranium resist flattening with the result that the vault bone shatters but the pieces are not destroyed. A partial endocast, as in Taung 1 or Skhul 1, obviously leaves the portion of the cranium without the endocast extremely vulnerable to fragmentation and loss.

Three Case Studies

Taung 1

Taung 1, the type specimen of *Australopithecus africanus*, was collected during quarrying of a South African limestone cave and was recognized by Raymond Dart as a previously unknown species of hominid (Dart, 1925). The specimen is that of a young individual about 3-4 years old (Bromage, 1985); only the partial cranium and mandible have been recovered. There are no other hominid remains to date from the site. Subsequent studies of the remaining portions of the Taung deposits and similar caves nearby suggest a complex taphonomic history for the bones preserved in those caves. It is most probable that the Taung 1 skull was washed or dropped into a cave in the tufa by a leopard or other mammalian predator, while the skull was both fresh and fleshed (Brain, 1981; McKee and Tobias, 1994; McKee, 2001; McKee, 2004, personal communication to P.S.). An alternative interpretation made by Berger and Clarke (1995), that the Taung individual was preyed upon by a large avian raptor, is less likely (McKee 2001). Whatever the precise cause of death, the skull became a sedimentary particle while it was largely or completely intact and the mandible was attached to the cranium by soft tissue.

The Taung skull is one of those rare specimens with a natural endocast, which preserves the impression of the entire right side of the cranial vault and occiput although those parts of the cranium are now missing. The endocast did not fill the skull completely and does not preserve the left side of the cranium, which was not recovered. The face, frontal bone, and mandible of the individual were intact and in anatomical position when found. Because the venous markings and the sulci and gyri of the interior surface of the right side of the braincase are clearly preserved on the endocast, it is obvious that the skeletal elements of this side of the cranium were also present in the rock. The vault fragments from the right side and occiput were either destroyed by the blast that exposed the skull or were not collected by the workmen who retrieved the skull.

Remarkably, the face and frontal bone show no weathering and no fractures; very fragile regions of the skull with high taphonomic vulnerability are preserved (such as the nasal bones and zygomatic arch). The coronal suture has separated neatly and there is only minimal additional breakage on the frontal. The right zygomatic arch is intact. The mandible was found in place, attached to the maxilla by sediment (Dart, 1925). This is strong evidence that the cranium and mandible were deposited shortly after death while the bone was in stage 1 condition and held together by soft tissue. Burial in alkaline sediments and the partial infilling of the skull protected it from further damage until the specimen was exposed during a mining operation.

There is one area where a small fragment, probably of parietal, was pushed into the then-unconsolidated endocast, to which the fragment still adheres although the surrounding bone is missing. This damage could not have occurred when the specimen was fresh or the fragment would have been pushed into the brain tissue and would not now adhere to the endocast (McKee, 2001). A pointed rock or other object probably caused this small fracture before the endocast was fully consolidated.

We conclude that the Taung skull came into the ancient tufa cave during stage 1 when its flesh was still intact, as has been proposed before (e.g., Brain, 1981; McKee and Tobias, 1994). A natural endocast was formed. The specimen was subjected to minimal taphonomic destruction thereafter except for sutural separation during stage 2. Possible crushing or destruction of left side of cranium occurred during late stage 2 or early stage 3, after drying of the cranium and before consolidation of the endocast.

Mojokerto (Perning 1)

Mojokerto is an immature *Homo erectus* specimen (Anton, 1997), approximately 4-6 years old, that was discovered in Java in 1936 by Andoyo, an Indonesian geological assistant (Duyfjes, 1936; von Koenigswald, 1936a, b). The specimen was deposited in fluvial sediments (Huffman, 2001; Huffman and Zaim, 2003). To our knowledge, no one has attempted to reconstruct the taphonomic history of the Mojokerto skull as a bony specimen, although its taphonomic history as a geological and sedimentary particle has been discussed (Huffman and Zaim, 2003).

The Mojokerto cranium appears to have suffered a LeFort III fracture; the face and much of the basicranium of the specimen was lost or destroyed. Transport of the specimen after this fracture may have occurred but was probably not extensive, judging from the preservation of fragile edges of the broken right parietal, the occipital, and the frontal where it articulates with the ethmoid. Von Koenigswald (1936a) perhaps overstated the fragility of the parts that remain intact, writing: "It is in fact a miracle that such a fragile object has been so well preserved under these circumstances." Later he wrote (1937: 25): "we are certain that it [the cranium] was found in situ, because the bone is so thin that it would have been destroyed by any movement or rewashing."

The Mojokerto cranial vault is broken into many angular fragments. A piece of the frontal is missing at midline, and a fracture which runs from the edge of the missing section to bregma suggests that there was probably a metopic fracture. Small pieces of bone are missing at bregma and at various points along the coronal, sagittal, and occipital sutures. However, the main cranial sutures did not separate. Most of the small fractures along the sutures have beveled edges with the inner table being more extensive; they may represent bending and fracturing of the specimen in situ that caused small fragments to separate from the cranium. Alternatively, it is possible that this damage occurred during excavation or preparation, procedures which are not well documented. The cranium shows a possible temporal line fracture, several perpendicular fractures on the cranial vault and a stellate fracture at inion. A number of fragments of the cranial vault have beveled edges, suggesting that these fractures occurred before all organic tissue and flexibility of the bones was lost. Most of the occipital portion of the basicranium is missing although the (damaged) petrous portions of both temporals are preserved.

Once buried, the Mojokerto skullcap filled with sediment which became a natural endocast. Venous markings are visible on the better preserved (and exposed) left side of this endocast, showing that additional vault fragments were present in the rock. If these fragments survived until the moment of discovery, they were unfortunately not collected. It is important to note that the fossil was collected as an aid in geologic mapping and biostratigraphy, not for paleontological studies (Duyfjes, 1936). An alternative interpretation is based upon the fact that at least one credible report of the discovery of the cranium mentions that there were fossil fragments lying on the surface, which prompted Andoyo to excavate there and discover the cranium (Duyfjes, 1936). Possibly the now-missing fragments of the left side of the cranial vault were the surface fragments seen by Andoyo and presumably judged too small to be useful. If so, the discovery occurred after these pieces became separated from the rest of the fossilized specimen but before weathering and erosion could destroy the impression of interior surface of the parietal and temporal fragments on the endocast.

Several pieces of bone from the right side of the vault and from the occipital bone are pushed sharply into the endocast, which is not complete in this area, and there are sizeable areas where there is no preserved bone at all but only endocast. The placement of bevels and pushed-in fragments suggests that, prior to the complete consolidation of the endocast, sedimentary pressure produced numerous fractures and forced some of the resulting fragments inward.

The Mojokerto cranium is subtly but markedly deformed (Anton, 2003, pers. comm. to P.S.); symmetry could not be restored even if all of the pieces were separated from the matrix endocast. The remaining portion of the left temporal, bearing the zygomatic process, has been moved in an anterior direction and rotated in a clockwise direction from lateral view. It is possible that the plastic deformation and warping of the specimen occurred in stage 1, while the bone was still somewhat elastic. However, we cannot judge with certainty when in the taphonomic history of the specimen this plastic deformation and warping of the bony tissue occurred, since sedimentary pressures are capable of warping consolidated rock.

Fractures of the Mojokerto cranium typical of postmortem stage 2 include: the deduced metopic fracture, the perpendicular fractures, and the mosaic fracture pattern of the cranial vault. The number of angular fragments are neither as numerous nor as small as those in, for example, Herto BOU-VP-16/5 (see below). The Mojokerto specimen also shows various fragments of bone pushed into the endocast, a possible temporal line fracture, and a rotation of the temporal, all of which must have occurred after the bone had dried but before the endocast was consolidated.

Many areas of the cranium in the high and intermediate taphonomic vulnerability groups have been broken or are missing in this specimen: the entire face, the zygomatic arches, and the basilar occipital. Much of the squamous occipital is preserved, as is most of the neurocranium. The superior margin of the right orbit is broken, even though this is an area of the cranium most likely to be intact in archaeological specimens (see discussion above).

In summary, the Mojokerto cranium was probably subjected to late stage 1–early stage 2 breakage. Damage most likely occurred after sedimentary burial but before consolidation of the endocast and while the cranial bones were sufficiently elastic to warp and deform as well as break with beveled edges. Without the natural endocast, it seems likely that many of the individual fragments would have separated from one another along fracture lines. There is little or no evidence of separation along sutures. The face was broken off in a LeFort III pattern. The preservation of this cranium suggests exposure to moderate taphonomic destruction.

Herto BOU-VP-16/5

Herto BOU-VP-16/5, an immature cranium of *Homo sapiens idaltu*, was discovered in 1997 in the Herto Bouri region of Ethiopia (Clark et al., 2003; White et al., 2003). The specimen was recovered in over 180 pieces, which were found on the surface after eroding out of an indurated sandstone. In the view of the discoverers, the cranium was modified and curated by hominids after the death of the individual (Clark et al., 2003; White et al., 2003). The pieces of the Herto cranium are numerous, angular, and appear to be planar on the edges (White et al., 2003; White, 2003, personal communication to P.S.). The middle part of the face is missing but the maxillary alveoli are preserved; this is the only example of a LeFort I fracture we observed among the fossil crania. Much of the basicranium is damaged or missing with the exception of the petrous temporals. Metopic or parametopic, temporal line, and perpendicular fractures are absent as are elongated linear and diastatic fractures. Fractures of the cranial vault are numerous, short, and straight, but do not follow the sutures. Thus the entire neurocranium is comprised of angular fragments in a mosaic fracture pattern. While the coronal, sagittal, and lambdoid sutures have not separated, the temporal sutures apparently opened and portions of the temporal bones were not recovered. Only the squamous occipital is preserved; the basicranial part of the occipital and the sphenoid are both missing. These features might be expected in either in dry-bone damage or in post-fossilization fractures (stages 2 or 3).

White (2004, personal communication to P.S.) concluded that the fractures were primarily or wholly post-fossilization based on three observations. First, matrix-filled cracks between pieces and ectocranial matrix that bridged adjacent pieces indicate that the cranium was embedded whole. Second, the filling of various voids (such as sinuses, diploe spaces, etc.) with matrix shows in many cases that anatomically adjacent fragments were in place when the matrix hardened. Finally, there were plant rootcasts on the endocranial and ectocranial surfaces but none on the fracture surfaces, showing that breakage occurred well after sedimentary burial and probably after erosional exposure.

The Herto BOU-VP-16/5 cranium shows defleshing cutmarks around the perimeter of the glenoid fossa and polishing of the broken edges of the occipital and temporal bones. These alterations are taken as evidence of postmortem treatment of the cranium by hominids, perhaps as part of a mortuary ritual (Clark et al., 2003: 751). This damage was most probably inflicted during stages 1 (the defleshing) and 2 (the polishing of broken edges).

Despite the extensive fragmentation of Herto BOU-VP-16/5, which bespeaks intense exposure to taphonomic agents of destruction, large parts of the fragile facial bones are preserved. Both nasals are present; the left orbital rim is intact as is most of the left zygomatic arch; substantial parts of both maxillae are present. The survival of some (but not all) of the elements in the most taphonomically vulnerable category combined with extensive fragmentation suggests that breakage occurred after fossilization had enhanced the structural strength of elements that are fragile in stages 1 and 2. The presence of a LeFort I type fracture is very rare in immature fossils. If the specimen had been subjected to more extensive taphonomic destruction, the LeFort I fracture would have probably progressed to a LeFort III fracture. If efforts to recover fragmentary pieces of the cranium had been less intensive, the specimen might well appear to have had a LeFort III fracture.

We find no evidence that would lead us to question the interpretation that the cranium was defleshed and curated (during stage 1), resulting in polishing of edges around the broken-out basicranium (probably during stage 2). From the observations and data presented above, we deduce that most of the mosaic fragmentation and fracturing of the vault and face of Herto BOU-VP-16/5 occurred during stage 3, the post-fossilization period (White et al., 2003).

Conclusions

We have summarized and integrated quantitative and qualitative data from medical, forensic, archaeological, and paleontological sources in an attempt to characterize the taphonomic attributes of immature hominid crania. From these diverse observations, we have created a set of expectations that relate fracture patterns to taphonomic vulnerability and that describe fracture morphology and placement in relation to the time of breakage relative to the death of the individual. Data on the breakage and preservation of individuals from the Krovitz and Sedgeford samples have been used to identify key differences in breakage between immature and adult crania, respectively.

We tried to show how these expectations might be used in practical terms by re-analyzing three immature fossil crania from Taung, Mojokerto, and Herto. We regard the work reported here as a first approximation and still speculative. We encourage further research along these lines in order to produce more refined and useful diagnostic tools for the taphonomist, paleontologist, and forensic anthropologist.

Acknowledgements

We wish to gratefully acknowledge receiving information and assistance from Susan Anton, Berhane Asfaw, Frank Huffman, Patricia Reid, Alan Mann, Jeffrey McKee, George Milner, Erik Trinkaus, and Tim White on this paper. G.K. would like to thank those who gave her access to the skeletal collections in their care, or who helped her obtain or interpret the dental x-rays for the recent human samples: Hisao Baba, Pia Bennike, Jodie Blodgett, Luca Bondioli, Jennifer Clark, Kevin Conley, Jean-Marie Cordy, Kate Hesseldenz, Louise Humphrey, David Hunt, Robert Kruszynski, Helen Liversidge, Niels Lynnerup, Roberto Macchiarelli, Giorgio Manzi, Yuji Mizoguchi, Theya Molleson, Søren Nørby, Nancy O'Malley, Rosine Orban, Doug Owsley, Ildiko Pap, Rick Potts, Edourard Poty, Mary Powell, Patrick Semal, Ib Sewerin, Gabriella Spedini, Chris Stringer, and Erik Trinkaus. G.K.'s research was supported by grants from the L.S.B. Leakey Society, the National Science Foundation, and the Japanese Society for the Promotion of Science. P. S. especially wishes to thank Bob Brain for being an inspiration throughout her entire career.

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Appendix

Observations of breakage and preservation on immature fossil crania. Specimens are listed in alphabetical order. We list the sources consulted for our observations, then each specimen is briefly described, and finally a tentative diagnosis of the taphonomic history of each specimen is given.

Amud 7

Descriptions and pictures in: Rak et al. (1994, 1996); Schwartz and Tattersall (2003). Neandertal aged 10 months (Rak et al., 1994). The specimen primarily consists of the occipital bone with a tiny piece of the sphenoid at basion, and a piece of the left petrous attached. Complete foramen magnum, condyles unfused and missing. Diagnosis: Possible mosaic fracture pattern (specimen broken into >20 fragments) but specimen too incomplete to be sure. Large, irregular, angular pieces are missing where the basilar occipital joins the squamous occipital. Possible radiating fractures centering on inion. Probably there was a separation at the lambdoid suture, isolating the occipital during stage 2, and later the occipital was flattened with resultant mosaic fractures.

Dederiyeh 1

Descriptions and pictures in: Akazawa et al. (1995); Dodo et al.(1998); Web site: http://www.nichibun.ac.jp/dederiyeh. Neandertal aged ~2 years (Akazawa et al., 1995). Many small fragments reconstructed into a cranium. Mostly neurocranium preserved from coronal suture posteriorly; few fragments of frontal and face; incomplete basicranium. Diagnosis: Extensive crushing resulting in mosaic fractures with many small angular pieces, and the loss or destruction of many pieces. Sutural separations at coronal and temporal sutures resulting in loss of frontal and temporal bones. Separation of zygomatic-maxillary sutures and then presumed damage to facial bones. All breakage probably stage 2 (sutural separations) or 3 (possible crushing).

Dederiyeh 2

Descriptions and pictures in: Ishida et al. (2000); Web site: http://www.nichibun.ac.jp/dederiyeh. Neandertal aged ~ 2 years (Ishida et al., 2000). Crushed and heavily fragmented cranium; most of frontal preserved; superior and lateral orbital margins pieced back together from many fragments; orbital portion of right zygomatic preserved but neither zygomatic arch complete. Parts of both parietals preserved, left more complete than right. Right temporal present. Some facial fragments present including parts of both nasals. Most of occipital missing; no basicranium. Diagnosis: Most vault bones fragmented with mosaic crushing, although with larger angular pieces and more beveled edges than seen in Dederiyeh 1. Many possible sutural separations (sagittal, lambdoid, temporal, zygomatic-maxillary, and coronal) before crushing. Small hole at bregma, judged to be an open anterior fontanelle because of irregularities in bone texture. Piece of alveolar maxilla preserved with teeth. Zygomatic-maxillary sutures separated and/or LeFort I or II fractures. The cranium is extensively damaged and crushed, possibly during stages 1 and 2.

Devil's Tower/ Gibraltar 2

Descriptions and pictures in: Tillier (1982); Schwartz and Tattersall (2003); inspection of original. Neandertal aged 4.5-5 years (Minugh-Purvis, 1988). The specimen consists of isolated, disarticulated bones (frontal, maxilla, parietal, temporal, occipital) and is not an intact cranium. Diagnosis: Probable separation at all sutures, but certainly separation occurred at the coronal, sagittal, and squamous temporal sutures, followed by mosaic cracking. Frontal largely intact but showing many small angular fragments due to cracking. Left parietal is complete, with some angular cracking but no bone loss at bregma; broken at lambdoid suture. Right temporal largely preserved. The left partial maxilla is preserved but its median palatine suture is open. It is impossible to know if the face broke off with a LeFort I, II, or III fracture or if the maxilla separated at the zygomatic-maxillary suture and then broke further. Primarily stage 2 damage.

Engis 2

Descriptions and pictures in: Fraipont (1936); Schwartz and Tattersall (2002). Neandertal aged 4-5 years (Minugh-Purvis, 1988); inspection of cast and original. The specimen is a partial neuro- and basicranium without a face. The rim of the foramen magnum is intact. Diagnosis: The face is missing in a LeFort III pattern except for a small piece of the right zygomatic which is preserved to form the lateral rim of the right orbit. The frontal is broken into several small fragments over the right orbit; the left orbital rim is broken in the middle and the adjacent left parietal and sphenoid are missing, as is the vomer. The alveolar portions of both maxillae are preserved separately. The vault is comprised of large angular fragments in a mosaic breakage pattern. A large angular piece is missing at bregma on the right side, accompanied by breakage along the coronal and sagittal sutures. Perpendicular fractures of the left and right parietals are present but do not cross the sagittal suture. Most of the right temporal is present but the squamous suture appears to be open; both squamous and petrous portions of the temporal are present on the right side only. The left half of the squamous occipital is present; a straight, planar fracture runs vertically through the occipital to the lambdoid suture and the right half of the squamous occipital is missing. A stellate fracture can be observed at inion. Damage occurred during stage 2 or 3.

Le Figuier

Descriptions and pictures in: Billy (1979). *Homo sapiens* aged ~ 3 years (Billy, 1979). The face and a fragmentary vault are present; some parts of the parietals are preserved; the temporals, occipital, and basicranium are missing. Diagnosis: The frontal is broken in a metopic fracture and a piece missing at midline. A piece is missing at bregma, but this is not judged to be an open fontanelle as its edges are planar. The orbits are relatively complete and the zygomatics and maxilla are complete to the midline. A LeFort III fracture separated the lower face from the vault. The vault bones are broken into large, rectangular fragments by fractures which include several perpendicular fractures and a possible temporal line fracture on the left. Separations occurred along the coronal, sagittal and lambdoid sutures with subsequent damage to the lambdoid suture. Damage occurred during stages 2 or 3.

Grotte des Enfants 6

Descriptions and pictures in: Schwartz and Tattersall (2002). *Homo sapiens* aged 12-14 years based upon presence of erupted M2s and unerupted M3s. This is a cracked and very fragmented cranium with all bones present and relatively few pieces missing. Both zygomatic arches are broken. Diagnosis: The frontal is intact, with the nasal bones present, although the frontal-zygomatic suture opened. The face is largely intact except for the left inferior orbital margin where most of the zygomatic is missing. The left side of the vault and face were pushed inward and cannot be articulated properly. A large piece is missing from the left parietal towards the squamous temporal suture, but bregma is intact. The sphenoid is missing inferiorly but some lateral pieces are still present. There is a large break around the foramen magnum on the left side and up to opisthion. Although fundamentally intact, the right side of the cranium is broken into large angular pieces that do not quite fit back together, possibly due to plastic deformation. The squamous temporal suture separated and then sustained some damage. Perpendicular fractures on the parietals are very clear, as are planar and angular fractures, especially around asterion. The squamous occipital appears undamaged but the basilar portion is missing angular pieces. The cranium was probably intact when it was squashed from side to side during late stage 1, causing plastic deformation, and the cranium was then crushed during stage 2 or 3.

Herto BOU-VP-16/5

Descriptions and pictures in: Clark et al. (2003); White et al. (2003). *Homo sapiens idaltu* aged 6-7 years (White et al., 2003). The specimen is a highly fragmented cranium with significant pieces missing from the basicranium, temporals, parietals, and face. Diagnosis: Mosaic fractures producing numerous angular fragments with clear planar edges cover the vault. All bones, including the frontal and occipital, are broken into many fragments. There is a possible stellate fracture at inion. The coronal, sagittal, and lambdoid sutures did not apparently open, although squamous temporal suture separated and the squamous temporal is missing. One perpendicular fracture across the vault crosses the sagittal suture. An apparent LeFort I (alveolar fracture) occurred; the maxillae and alveoli are preserved separately. Most fractures appear to be post-fossilization (stage 3) damage. See further discussion in Part III of this paper.

La Quina 18

Descriptions and pictures in: Schwartz and Tattersall (2002); inspection of cast. Neandertal aged 7.5-8 years (Minugh-Purvis, 1988). The cranium is basically fragmented but intact with large portions of the basicranium and most of sphenoid missing. Both zygomatic arches are broken. Diagnosis: The cranium was mostly intact when it was crushed. The face is in very good condition and even the fragile nasal bones are intact; however the face shows some distortion and minor fracturing. Separations occurred along the coronal, sagittal, squamous temporal, and lambdoid sutures. Small missing pieces show that damage occurred after the sutural separation along the coronal suture and there are larger breaks along the sagittal suture. A right temporal line fracture extends from the coronal to the lambdoid suture and possibly into the occipital. There are perpendicular fractures on the parietals, one of which crosses the sagittal suture, resulting in very large angular pieces with planar edges. Separation of the lambdoid suture caused or contributed to the loss of the occipital and the basicranium. Most of the edges surrounding the missing pieces show straight, planar fractures not simple sutural separations. The squamous occipital is heavily fragmented and shows the most crushing and reconstruction. Probably this specimen was subjected to anterior-posterior crushing that detached or destroyed most of the inferior and posterior parts of the cranium. Most of damage probably occurred during stage 2, either before the sutural separations happened or after the separations but before displacement of the constituent bones occurred.

Mojokerto (Perning 1)

Descriptions and pictures in: von Koenigswald, (1936a, b); Anton (1997); Schwartz and Tattersall (2003); inspection of cast. *Homo erectus* aged 4-6 years (Anton, 1997). The specimen is a skullcap lacking a face and most of the basicranium. Diagnosis: A LeFort III fracture separated or destroyed the face. The only parts of the orbits that remain are the superior margins and those are incomplete, with pieces missing; none of the lateral or inferior orbital margins are preserved. The frontal is cracked into angular fragments and is also missing a piece or pieces at midline. The vault sutures show minimal or no separation; small pieces along the sutures are missing, whether due to preparation, excavation, or natural causes is unknown. All of the vault bones show mosaic cracking into small angular pieces. Among the fracture edges that are visible, some are planar and others are clearly beveled. There is at least one perpendicular fracture and there may have been temporal line fractures on both right and left sides but missing pieces of the parietal make this uncertain. There is a stellate fracture centered on inion. The occipital was slightly "folded" along a horizontal plane, bending the basioccipital under at an unnatural angle. The basilar occipital is broken off posterior to the foramen magnum. A natural endocast held the cranial pieces together during the crushing and cracking process. This endocast preserved impressions of the meningeal vessels of the left parietal and temporal where there is no longer any bone. The fracture edges are distinctly beveled on the right side of the vault and fragments of the right parietal were pushed into the unconsolidated sedimentary infill, which later hardened into an endocast. There is some displacement of the petrous temporal on each side and the left temporal is rotated and pushed forwards. Very little of either zygomatic is preserved. Sides of the neurocranium are more heavily fragmented than is top of the vault. The beveling of some fracture edges and plastic deformation suggest that most damage occurred in late stage 1-early stage 2. See further description in Part III of this paper.

KNM-WT 15000

Descriptions and pictures in: Walker and Leakey (1993); inspection of cast and original. *Homo erectus* aged 8-11 years (Smith, 1993; Dean et al., 2001). A largely complete cranium fragmented into many pieces and glued back together. Diagnosis: The frontal is missing a fragment at midline and shows planar fractures but the superior part of the nasals is intact. The face is essentially complete but the zygomatic-maxillary sutures opened and sustained some damage thereafter. Both zygomatic arches are broken and missing, though the body of each zygomatic bone is preserved to form the inferior and lateral orbital margins. The median palatine suture opened and subsequently a few small fragments became lost. All of the vault sutures separated and the exposed edges were then slightly damaged by erosion or weathering. The vault is crushed into many angular mosaic fragments, especially the parietals and frontal. Many fractures have planar edges and rarely if ever cross sutures. A large angular piece of the right parietal is missing where the sagittal and lambdoid sutures intersect. Inferiorly, the sphenoid and parts of the petrous temporals are broken away. Probably the sutures separated and then the individual bones were fragmented and weathered mostly or entirely during stage 3 without being transported significant distances.

Pech de l'Azé

Descriptions and pictures in: Ferembach (1970); Patté (1957); Schwartz and Tattersall (2002); inspection of cast. Neandertal aged 2.5-3 years (Minugh-Purvis, 1988). The specimen is a fragmented cranium missing the posterior surface and the base of the neurocranium. The nasal processes and most of the maxillary body are missing, and only alveolar parts of the maxilla remain. The zygomatics still articulate with the frontal to form the lateral side of the orbits but both zygomatic arches are broken and missing. Diagnosis: The alveolar/palatal region was isolated from the neurocranium by a Le-Fort II fracture which may have started as separations at the zygomatic-maxillary sutures. The frontal is largely complete though it is fragmented and missing pieces on the left side. The frontal bears a patent metopic suture, judging from radiographs in Patté (1957), although the individual is unusually old for this condition. There are angular fragments missing along the coronal and sagittal sutures which opened and separated. A large fragment is missing at bregma; this hole is said to encompass a late-closing fontanelle (Tillier, 1999) which cannot be verified from the available photographs. The left side of the neurocranium shows many large angular fragments, some missing, from the left sphenoid suture to lambda. Both temporal squamous sutures appear to have separated but the temporal bones are partly preserved. The anterior half of the right parietal is complete; a perpendicular fracture with a clear planar edge splits the bone approximately in half and the posterior portion is missing. Most of the squamous and basilar occipital is missing. There is a consistent pattern of sutural separation followed by mosaic breakage, probably in stage 2, resulting in many angular fragments.

Qafzeh 10

Descriptions and pictures in: Tillier (1999); inspection of cast. *Homo sapiens* aged 6 years (Tillier, 1999). This largely complete cranium was found lying on its left side in situ, crushed into numerous pieces. Diagnosis: The face, especially the left side, is preserved but broken into fragments, and the nasals are missing. The face is somewhat asymmetrical suggesting possible plastic deformation. Most of the frontal has been reconstructed or glued back together from many fragments, which include fractures to the superior orbital margins. Where they are visible the fracture edges look planar. Both zygomatic arches are broken but the bodies of the zygomatic bones are preserved to form the inferior and lateral margins of the orbit. The vault shows mosaic cracking caused by crushing, which was followed by erosion and weathering; fracture edges are more rounded and less crisp than usually observed. The vault fragments are relatively small. There are no clear signs of separations on the coronal and sagittal sutures. In fact Tillier (1999: 78, 165) suggested premature closure of the coronal suture and the sagittal suture is offset from the midline. There is probably a right side temporal line fracture with some pieces missing; pieces are also missing along the lambdoid suture, which probably separated. The basilar occipital is largely intact and the rim of the foramen magnum is complete, but the sphenoid and petrous temporals are damaged. Sutural separations followed by crushing, probably in stage 3.

Qafzeh 11

Descriptions and pictures in: Tillier (1984, 1999); inspection of cast. *Homo sapiens* aged 12 years (Minugh-Purvis, 1988; Tillier, 1999). Overall the neurocranium is relatively complete save for the lower face and part of the base. The alveolar portion of the maxilla is preserved separately. The sphenoid, zygomatic, vomer and palatine bones are missing; there is no cranial base anterior to the occipital. The petrous temporals are heavily damaged. Diagnosis: Most of the face is missing, possibly due to a LeFort III and/or tripod fracture. Alveolar portions of the maxilla survive but there are no zygomatic bones. The frontal lacks a few small pieces above the left orbit; there are other small cracks in the orbits but no fragments are missing. The nasal region between the orbits is intact. A large angular fragment or fragments are missing from the right parietal at the coronal suture, and there is a hole at bregma. If this began as a coronal separation, then additional breakage occurred subsequently; however the left side of the coronal suture appears to be intact. There is a depressed fracture to the left frontal bone which possibly shows healing (our observations of Figure 63 in Tillier, 1999: 165), indicating it was an antemortem fracture. Parietal pieces are missing along the open sagittal, lambdoid, and squamous temporal sutures. At least one and possibly more fractures of the parietals cross the sagittal suture, showing that the bones were in anatomical position when the crushing and fragmentation occurred. The mosaic cracking of the vault was more intensive on the right side. The squamous occipital is heavily cracked, with subsequent damage to the fracture edges. The basilar occipital is fragmented and missing many pieces on left side, although almost the entire rim of the foramen magnum is preserved. Sutural separation occurred in stage 2 but the bones remained in approximate anatomical position before they were subjected to crushing.

Qafzeh 12

Descriptions and pictures in: Tillier (1999). *Homo sapiens* aged 3-4 years (Tillier, 1999). This very fragmentary cranium consists of a partial superior surface of the vault with separate occipital and petrous temporal bones and alveolar fragments of the maxilla accompanying some of the right teeth. Diagnosis: Very little of the frontal survives as several angular fragments; nothing of the orbital margins remains. The patent metopic, coronal and sagittal sutures apparently separated, although a patent metopic suture at 3-4 years is unusual. Tillier (1999: 165) suggests this individual was also possibly hydrocephalic. The anterior fontanelle at bregma was clearly still patent: another unusual feature for a juvenile of this age. The vault bones are highly fragmented into angular fragments due to crushing following sutural separations in stage 2. Perpendicular fractures are also seen on the parietals, with some planar fracture edges visible. The petrous temporals survive separately in damaged form, as do the zygomatic bodies, but the zygomatic-maxillary sutures apparently opened and only very small alveolar portions of the maxillae are preserved. The lambdoid suture separated although a few fragments of parietal remain attached to occipital fragments; in other places, breakage removed pieces of the occipital subsequent to the opening of the lambdoid suture. The squamous occipital is broken into large, angular fragments, probably because of flattening after it separated from the rest of the neurocranium. Most damage probably occurred in stage 2.

Roc de Marsal 1

Descriptions and pictures in: Tillier (1983); Madre-Dupouy (1992). Neandertal aged ~3 years (Minugh-Purvis, 1988; Madre-Dupouy, 1992). This specimen was part of a skeleton found lying on its right side with the cranium crushed almost flat. The neurocranium is fragmentary; the lower face is preserved and is less damaged on the right side. Both zygomatic arches are broken and incomplete although the articulation between the zygomatic and maxilla is intact on both sides. Most of the superior surface and left side of the vault are missing on the left side, as is the left side of the basicranium. Diagnosis: The face is nearly undamaged including the nasals and fragile processes of the maxillae. The median palatine suture is open with some small breaks that occurred after separation. The face was apparently separated from the neurocranium by a LeFort II fracture or by sutural separations followed by damage to approximate a LeFort II fracture. The frontal is broken into several large fragments and is missing a large piece at midline. Two parametopic fractures break the superior rim of each orbit and each intersects a hole produced by roughly horizontal fractures above the superciliary ridges and the subsequent loss of pieces. The left parametopic fracture joins with a massive hole encompassing bregma and most of the superior surface of the vault. Tillier (1999) indicates that the anterior fontanelle was open; although this cannot be verified from photographs and Madre-Dupouy (1992) indicates uncertainty on this point. Cracks radiate from the missing area of the parietals anteriorly, inferiorly, and posteriorly; these fractures divide the right parietal into angular fragments but do not appear to cross sutures. There is a discrete round hole in the right sphenoid at the intersection with the coronal suture. The edges of this hole look planar and not beveled; a few cracks surrounding the hole do not suggest radiating cracks from a stage 1 fracture but breakage later in the specimen's taphonomic history. The vault is comprised of many small angular fragments now held together with wax. The neurocranium was obviously flattened or crushed, probably after many or most of the sutures had opened but while the bones were essentially still in something approximating anatomical position. The cranial damage is progressively worse from the frontal, which is fragmented but largely preserved, posteriorly to what remains of the pieces of the occipital. Most damage probably occurred during stages 2 or 3.

Skhul 1

Descriptions and pictures in: McCown and Keith (1939); Schwartz and Tattersall (2003); inspection of cast. *Homo sapiens* aged 4.5 years (McCown and Keith, 1939; Minugh-Purvis, 1988). The specimen is a cranial vault lacking most of the face, although isolated maxillary teeth were recovered. The specimen was part of a skeleton found lying on its left side (McCown and Keith, 1939). As excavated, the left radius protruded into the interior of the braincase. McCown and Keith suggest (p. 301) postmortem disturbance occurred prior to consolidation of the endocast. Diagnosis: No facial bones below the superior orbital margins are preserved due to an apparent LeFort III fracture. Pieces of the superior orbital margin are missing from the frontal at the midline and the fractures run posteriorly through the frontal. The frontal shows extensive mosaic cracking with small fragments now joined together by plaster. McCown and Keith suggest (1939) that there was a depressed fracture 30 mm by 13 mm on the frontal at midline that must have occurred when the bone was fresh, saying that "the bone on one side of the gap—the bone over the inner part of the right orbit—has 'sprung' or been lifted forwards its own thickness" (p. 309-310). In the cranium's current state, these observations are impossible to verify and what is visible does not convincingly support their hypothesis. The coronal suture opened and the frontal bone was discovered separated from the parietals with its interior surface uppermost, lying near the rest of the cranial vault. There was breakage along the coronal suture and at bregma subsequent to the separation. There are perpendicular cracks in the parietals and the right parietal is missing substantial pieces inferiorly. Only the right squamous temporal is present; the right petrous is broken. The sagittal and lambdoid sutures are intact and the squamous occipital is little broken; the basilar portion of the occipital shows much cracking and loss of the bone surrounding the foramen magnum. McCown and Keith (p. 299, Figs. 214, 215) discuss a natural endocast that filled the posterior part of the skull. This endocast preserved impressions of right parietal pieces that are now missing; the endocast was destroyed during preparation of the interior vault surface. The endocast probably accounts for the fact that the posterior skull stayed intact despite extensive cracking into mosaic fragments. The protection offered by the endocast did not prevent the shattering of the anterior, basilar and lateral portions of the skull probably caused by sedimentary pressure in stages 2 or 3.

Subalyuk 2

Descriptions and pictures in: Pap et al. (1996); Schwartz and Tattersall (2002); inspection of original. Neandertal aged 2.5 years (Minugh-Purvis, 1988). The specimen consists of a neurocranium lacking most of its base and a separately preserved maxilla. Diagnosis: An apparent LeFort III fracture separated the maxilla from the neurocranium. The coronal suture did not separate and the sagittal suture is intact to lambda; there is some separation along the lambdoid suture and loss of large pieces from the left parietal. The frontal is missing a sizeable fragment at midline, however, the right fronto-nasal suture is intact. The metopic suture was probably patent (Tillier 1999). Both parietals show perpendicular fractures and the right parietal is missing several large, angular pieces. There is a possible left temporal line fracture from the orbit to the lambdoid suture. The occipital is cracked into many small pieces, some of which are missing, suggesting that the face and the occipital bore the brunt of the crushing force in stage 2 or 3.

Descriptions and pictures in: Dart (1925); inspection of cast. *Australopithecus africanus* aged 3-4 years (Bromage, 1985). The specimen is a face articulated with a mandible and frontal and a natural endocast to which is attached much of the basicranium. The endocast also preserves the impressions of the internal surface of the right parietal and temporal bones. The right parietal and temporal were not collected or were destroyed during the blasting process that revealed the specimen. A coronal separation apparently isolated the articulated frontal, face, and mandible from the rest of the skull. The natural face of the endocast shows that the skull did not fill with sediments completely as it lay in situ on its right side. The articulation of face and mandible and the complete absence of cracking or fragmentation of the preserved bones shows that the skull entered the tufa cave with soft tissues holding it together and protecting it from damage. The articulated position of the bones was preserved after the soft tissue decayed and while the cranial vault was infilled with sediments, which consolidated to form the natural endocast. The specimen became a sedimentary particle in stage 1 and suffered little damage thereafter. See further discussion in Part III of paper

Teshik Tash

Descriptions and pictures in: Schwartz and Tattersall (2002). Neandertal aged 9-11 years (Minugh-Purvis, 1988). The cranium is largely complete as restored but the zygomatic arches are incomplete. Diagnosis: The cranium is comprised of large angular fragments produced by mosaic cracking. The frontal is cracked into large angular fragments but no pieces are missing; some fractures originate at the orbital rims. Bregma is intact but the parietals are fragmented. Small pieces are missing along the coronal, sagittal, and lambdoid sutures. Some fractures cross sutures uninterrupted, showing that the vault bones remained in articulated position or nearly so after the soft tissue deteriorated. There is one perpendicular fracture of the left parietal, and a clear left temporal line fracture from the coronal to the lambdoid suture. The face is largely intact including the nasal bones, which show only minor breakage. The zygomatic-maxillary suture apparently opened and then some additional breakage occurred. The median palatal suture is open but not separated. Most or all fractures occurred in stage 2 or 3.