25 A PRELIMINARY INVESTIGATION OF THE CRANIAL BREAKAGE PATTERNS OF THE LATE MIDDLE PLEISTOCENE CRANIA FROM APIDIMA CAVE, GREECE

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25.1 THE APIDIMA SITE AND HOMININ FOSSILS

The Apidima site is located in close proximity to the village Areopolis on the coast of the Mani peninsula in the southern Peloponnese, Greece (Harvati et al., 2009; Harvati, 2016, 2022). The site consists of five caves (A, B, C, D, and E), which are located directly on the coast and can today only be reached by boat. The caves are filled with sediments from the Middle and Late Pleistocene, which are eroding out of the caves (Pitsios, 1999; Harvati et al., 2011; Bräuer et al., 2019). In the late 1970s, a team of researchers from the Museum of Anthropology of the School of Medicine, National and Kapodistrian University of Athens, unearthed two incomplete hominin crania [Apidima 1 (or LAO1/S1) and Apidima 2 (or LAO1/S2)] from the breccia of the cave wall of cave A. The remains were excavated *en bloc* and then prepared in the laboratory to free them mechanically from the surrounding breccia (Pitsios, 1999). Both crania are fragmentary, but the breccia matrix still holds the fragments in place and together.

Apidima 1 preserves a major part of the left parietal bone, the superior right parietal, as well as parts of the occipital and left temporal bones. A large piece of rock is still attached to it (cf. Figure

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1; Harvati et al., 2019). The second cranium, Apidima 2, is more complete and comprises large parts of the facial skeleton and a near complete cranial vault, but no mandible. The cranial base and occipital bone are not preserved (cf. Figure 1; Harvati et al., 2019). Apidima 2 represents a Neanderthal specimen and is dated to >170 thousand years ago (ka BP) (Harvati et al., 2011; Bartsiokas et al., 2017; Bräuer et al., 2019; Harvati et al., 2019), whereas Apidima 1 was classified by Harvati et al. (2019) as early *Homo sapiens*, dating to >210 ka BP (see also Harvati et al., 2020; Harvati, 2022).

25.2 OBJECTIVES AND METHODS

A previous anthropological examination of Apidima 2 has concluded that some of the fractures on the frontal bone are the result of traumatic blows (Coutselinis et al., 1991, 1995). Later, it was suggested that all fractures result from sediment pressure during deposition and thus represent taphonomic damage (Geanacos, 2001; Pitsios, 2007; Pitsios et al., 2007). The fractures of the less complete cranium, Apidima 1, have not been studied until now.

Feature (references)	Description	Fresh bone	Dry bone	Inconclusive	Criteria evaluated in this study
Outline	Course of breakage line on ectocranial surface	Curved	Stepped	Straight	Classification of each breakage line as curved, stepped, or straight
Path of least resistance (Symes et al., 2012; Fleming-Farrell et al., 2013; Galloway and Wedel, 2014; Loe, 2016)	Propagation of breakage line towards a biomechanically weaker area of the skull	Present	Absent	-	Evaluation of whether a breakage line runs towards a biomechanically weaker skull area (yes, no)
Angle (Fleming-Farrell et al., 2013; Jordana et al., 2013b; Kranioti, 2015; Sala et al., 2016)	Angulation between ectocranial cortical bone table and the breakage edge (surface of outer and inner table and diploë exposed by breakage)	Oblique (acute: <70°, or obtuse: >110°)	Right (70°-110°)	-	Measurement of the angle between the ectocranial and breakage edge surfaces at several points along one breakage line or defect in 2D cross sections
Texture (Fleming-Farrell et al., 2013; Jordana et al., 2013a; Sala et al., 2016)	Texture of breakage edge (surface of outer and inner table and diploë exposed by breakage)	Smooth	Jagged	-	Classification of the texture as smooth or jagged at the same points, where angles were measured
Plastic response (Symes et al., 2012; Fleming-Farrell et al., 2013; Kranioti, 2015)	Permanent plastic deformation (elastic capacity of bone exceeded)	Present	-	Absent	Assessment if breakage lines show signs of a plastic response (yes, no)

Table 1: Criteria used to distinguish peri- from postmortem timing of cranial breakages in the Apidima crania.

In this preliminary investigation, we examined the cranial breakage patterns of Apidima 1 and 2 to assess the timing of breakage and to evaluate whether the fractures represent postmortem taphonomic damage (dry bone breakage) or perimortem (fresh bone) fractures and, thus, could possibly be traumatic injuries.

To evaluate the timing of breakage of the two Apidima fossils, we employed virtual anthropological methods and used medical computed tomography (CT) scans of the two crania, kindly provided by the Museum of Anthropology and the First Department of Radiology of the National and Kapodistrian University of Athens. Using CT scans, the crania could be investigated in virtual cross-sections, allowing for the examination of internal structures or otherwise macroscopically inaccessible areas. This way, we were able to perform a non-destructive examination of the endo- and ectocranial morphology of the fracture lines even though most of them are still covered by breccia. For each breakage line, we evaluated five morphological breakage features: (1) breakage outline, (2) path of least resistance, (3) breakage angle (measured in CT cross sections and on several points along one breakage line), (4) texture (assessed at the same points where also angles were measured), and (5) plastic response. For details see Table 1 and references therein. We assessed these five features on 15 breakage lines in Apidima 1, and 37 breakage lines in Apidima 2 (Figure 1). In addition, we evaluated the edges of four defects (i.e., visible damages on the ectocranial surface, most of which also covered by breccia or plaster) in Apidima 2, using a reduced set of three features (breakage angle, texture, plastic response). Given the assessments of the single features, we then concluded for every breakage line whether its morphology conforms more to a fresh or a dry bone breakage, or is inconclusive regarding its timing of breakage.

25.3 RESULTS AND DISCUSSION

The evaluation of five morphological breakage features to distinguish perimortem (fresh) from postmortem (dry) bone fractures performed in this preliminary study revealed mostly inconclusive breakage lines and defects in both Apidima crania (Beier, 2021). 66.7% (10 of 15) of breakage lines in Apidima 1, and 73.0% (27 of 37) plus four defects in Apidima 2 are inconclusive regarding their timing of breakage. In Apidima 1, 26.7% (4 of 15) of the breakages exhibit a morphology that is rather in agreement with fresh bone breakage, while the morphology of 6.7% (1 of 15) of the breakages is rather in agreement with dry bone breakages. In Apidima 2, the morphology of 13.5% (5 of 37) of the breakages conforms or rather conforms with fresh bone breakage, while another 13.5% (5 of 37) of breakages are rather in agreement with a dry bone breakage morphology.

The frontal bone fractures of Apidima 2, previously assumed to result from traumatic blows (Coutselinis et al., 1991, 1995), and later assigned to a taphonomic origin (Geanacos, 2001; Pitsios, 2007; Pitsios et al., 2007), exhibit an inconclusive breakage morphology. We therefore cannot contribute additional support for any of the two previous interpretations.

Apart from the many inconclusive breakage morphologies, we found both fresh and dry bone breakage morphologies within one single breakage line in nearly half of all breakages assessed (53.3% in Apidima 1, as well as 43.2% of fractures and 25.0% of defects in Apidima 2). This is a puzzling and unexpected finding because the same fracture or defect should show a (predominantly) fresh or dry bone breakage morphology, but not a mix of both. Our findings were also inconsistent regarding the features 'breakage angle' and 'texture'. Their morphology should be correlated: by definition,

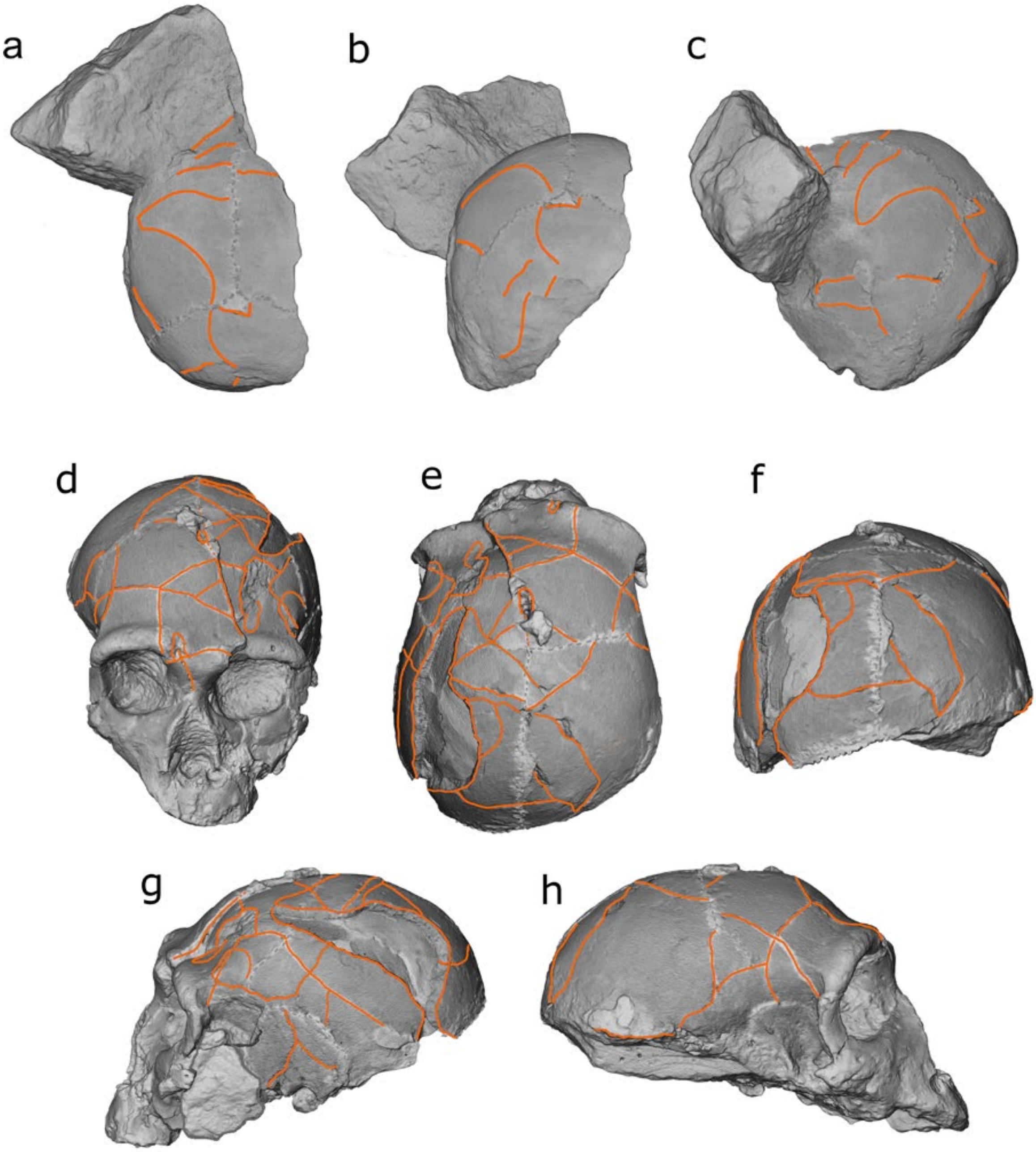

Figure 1: a-c: Overview of the 15 breakage lines examined in Apidima 1 (a: superior view, b: posterior view. c: left superolateral view). d-h: Overview of the 37 breakage lines and four defects examined in Apidima 2 (d: frontal view, e: superior view, f: posterior view, g: left lateral view, h. right lateral view)

fresh bone breakage edges should be oblique and smooth, and dry bone breakage edges should be right-angled and jagged. Here, only 53.3% of the evaluated breakages in Apidima 1, and 62.6% of the evaluated edges in Apidima 2 corresponded to the expected association between the two features 'breakage angle' and 'texture'.

At this preliminary stage of the study, we can think of different reasons that could explain these ambiguous findings. First, it is possible that the morphological features we used to distinguish fresh from dry bone breakage were too few or too unspecific. Some additional small and subtle features suggested to be good indicators of fresh bone breakage when present could not be assessed so far because of the low resolution of the available medical CT scans. These include, for example, small osseous flake defects on the fracture edges, incomplete fractures with broken cortical layers (fissures) held in place by trabecular bone bridges, cortical bone scales resembling fish scales, and fracture hinging, i.e., broken fragments that remain partially attached to the main body of the bone (for details and additional features see Fleming-Farrell et al., 2013; Jordana et al., 2013a; Kranioti, 2015; Sala et al., 2016; Ribeiro et al., 2020). In a similar vein, very fine, possibly only superficial breakage lines observable on the original crania could often not be detected in the CT scans used here. Using high-resolution micro-CT scans of the crania instead of medical CT scans, when such might be available in the future, could have the potential to improve the analysis threefold: (1) by increasing the overall number of observable breakage lines, (2) by raising the number of successful observations of the features assessed, and (3) by enabling us to include additional features in the evaluation of the timing of breakage.

Further possible explanations for the heterogeneous and inconsistent findings of fresh and dry bone breakages between and within features could relate to the mineralized condition of the Apidima cranial remains and their depositional history. Wet depositional conditions can affect and obscure the timing of breakage through changed decomposition rates (Haglund and Sorg, 2002; Galloway et al., 2014; Augias et al., 2017; Stuart and Ueland, 2017), alterations in the breakage behavior of dry bone after rehydration (Broz et al., 1993; Moraitis and Spiliopoulou, 2006; Augias et al., 2017; King, 2017), and the increased abrasion of characteristic breakage edges in water environments (Haglund and Sorg, 2002; Moraitis and Spiliopoulou, 2006). From what we currently know about the depositional history of the Apidima crania, wet depositional conditions likely occurred on several occasions. The two crania were found only a few centimeters apart from each other, but may in fact be separated by about 40 thousand years (Harvati et al., 2019). It has been suggested that the crania were displaced from the locations where they were originally deposited at distinct times following washing out of underlying sediments, and got mixed up, perhaps by a mudflow event (Harvati et al., 2019). Moreover, sea level changes have been affecting the erosion of cave sediments in the Apidima caves, nowadays located only a few meters above sea level, since Pleistocene times (Pitsios, 1999; Harvati et al., 2011; Bräuer et al., 2019). The timing of breakage of the Apidima cranial breakages is further complicated by the possibility, that (some of) the breakages could have occurred after fossilization. If so, using fresh and dry bone breakage characteristics to determine the timing of breakage might be inadequate and could account for our inconclusive findings. Fossilized bone is assumed to break differently when impacted than both fresh and dry bone (Morlan, 1984; L'Abbé et al., 2015; Gifford-Gonzalez, 2018). To be able to identify fossilized bone breakage and distinguish it from fresh and dry bone breakage, distinct morphological characteristics would be needed, which, to our knowledge, have not been studied and described in as much detail as for dry and fresh bone breakage so far.

Our findings of the cranial breakage patterns of the Apidima fossil crania are therefore preliminary and we caution against overinterpretation of our results. Further methodological work, as well as future geoarchaeological and taphonomic investigations, will help to further clarify the breakage patterns and depositional history of the remains.

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