crystals exhibited the topotaxy predicted by Poirier's model, but other crystals displayed the octahedral crystal habit and lacked the topotaxy, making interpretation difficult. In the light of our annealing results, we believe that the simplest explanation for their observations is that stress concentrations produced during pressurization in their apparatus led to production of martensitic nuclei in the earliest stages of their experiments and that coarsening of those nuclei by normal phase-boundary migration during the experiment produced their large, euhedral, crystals. At the temperatures of their experiments, incoherent nuclei were also produced, leading to the crystals that did not display topotaxy with the olivine.

The present results resolve the discrepancies in the literature concerning the mechanism of the transformation in static or quasi-static experiments. The results also imply that the nucleation mechanism should always be martensitic in shock experiments. Indeed, the extreme stresses in shock deformation might lead to complete transformation by the martensitic mechanism rather than the coarsening by normal phase-boundary migration reported here.

One must use caution, however, when extrapolating these results to natural environments, because none of the studies summarized above includes the complication of the β phase[1,17] (which does not exist for most of the analogue materials, including Mg_2GeO_4). We believe, however, that under most circumstances extrapolation to natural environments should be straightforward. At high temperature and low stress, α transforms to γ by incoherent nucleation and growth in all systems studied, and $\gamma \rightarrow \alpha$ in Mg_2GeO_4 (ref. 21) and $\alpha \rightarrow \beta$ in Co_2SiO_4 (ref. 25) also follow this mechanism. Therefore, in normal mantle environments, where the temperature is high and stresses are very low, the forward or reverse transformation to either β or γ should be accomplished by the reconstructive mechanism. On the other hand, in shocked meteorites the common circumstance should be sudden transport into the γ stability field at low temperature and high stress (that is, by martensitic nucleation). Immediately thereafter, the stress and pressure will fall and the temperature will rise, in some cases leading to the β-phase before the reaction is quenched[26-28]. Downgoing lithospheric slabs present an environment in which both temperatures and stresses are intermediate between these other two environments. Under such conditions, the data are not yet sufficiently comprehensive to rule out either mechanism. We are continuing our experiments at intermediate temperatures and stresses to pursue this question.

It follows from these results that the level of stress could be a factor in experiments aimed at determination of the mechanism or kinetics of other transformations occurring in the deep Earth. In particular, if a martensitic mechanism is possible, then it is to be expected in shock experiments and also is likely in the laser-heated diamond cell. If such mechanisms are observed, their geophysical significance should be interpreted with caution. ☐

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ESR dates for the hominid burial site of Es Skhul in Israel

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THE Middle East has been critical to our understanding of recent human evolution ever since the recovery of Neanderthal and early anatomically modern fossils from the caves of Tabun and Skhul (Mount Carmel) over 50 years ago[1–3]. It was generally believed, on archaeological and morphological grounds, that middle eastern Neanderthals (such as those from Tabun, Amud and Kebara) probably dated from more than 50,000 years ago, whereas the earliest anatomically modern specimens (from Skhul and Qafzeh) probably dated from about 40,000 years[3]. Recent thermoluminescence and electron spin resonance (ESR) determinations, however, have supported biostratigraphy in dating the Qafzeh deposits to an earlier part of the late Pleistocene, probably more than 90,000 years ago[4–6]. These dates have been questioned on unspecified technical grounds[7,8], and it has also been argued that they create explanatory problems by separating the morphologically similar Qafzeh and Skhul samples by some 50,000 years, thus implying a long-term coexistence of early modern humans and Neanderthals in the area[3,7,8]. Here we report the first radiometric dating analysis for Skhul, using ESR on bovine teeth from the hominid burial levels. Early uptake and linear uptake ages average 81 ± 15 and 101 ± 12 kyr respectively. These analyses suggest that the Skhul and Qafzeh samples are of a similar age and therefore it is possible that the presence of early modern humans in the area was episodic, rather than long term during the early late Pleistocene.

The Israeli site of Es Skhul is located in the canyon of Nahal Mearot (Wadi el-Mughareh), near the site of Tabun which has yielded Neanderthal hominid remains. The site of Skhul originally consisted of a 2.5-m thick accumulation of densely cemented, reddish-brown breccia deposited on a triangular rock-cut platform about 11 m above the present level of the wadi floor. McCown[9], who excavated the site, identified three successively older units. Layer A (<60 cm thick) contained a mixed assemblage of Middle and Upper Palaeolithic artefacts as well as some potsherds. Layer B (a breccia 2 m thick) contained the cranial and post-cranial remains of at least 10 hominids, the majority of which seem to have been intentionally buried, and over 9,800 lithic artefacts representing a Levallois-Mousterian (Middle Palaeolithic) industry. Layer C (a breccia <30-cm thick) contained a sparse industry similar to that in layer B, but no faunal material.

The hominids represent an archaic type of modern *Homo sapiens* and studies of their skeletal morphology demonstrate

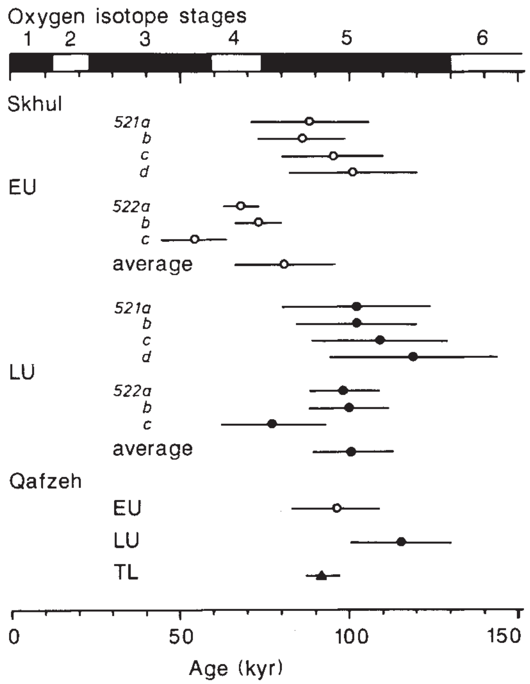

FIG. 1 Horizontal bars represent the ESR ages of two teeth from Skhul. Open circles, ESR ages according to early U-uptake; closed circles, ESR ages according to linear, continuous U-accumulation. The ESR and TL dates on Qafzeh are averages as given by Schwarcz *et al.*[6] and Valladas *et al.*[4]. The boundaries of the oxygen isotope stages were taken from Martinson *et al.*[15].

clear affinities to those from Qafzeh cave, Israel[3,10,11]. To establish an absolute age for Skhul we made ESR measurements on two well-preserved bovid teeth from the British Museum (Natural History) collection. Although the exact positions from which the teeth were recovered is not recorded, it is known that they came from the relatively uniform layer B, which contained the hominids.

The procedures of ESR dating have been described by Grün *et al.*[12,13]. The additive dose method was used to determine the acquired dose (AD). The U concentrations of enamel and dentine were determined by neutron activation analyses (Table 1). The external cosmic dose rate was calculated on the assumption that a maximum of 2 m of sediment covered the site. The external β-doses were estimated from analyses of the matrix adjacent to the teeth. Unfortunately, the enclosing matrix had been almost entirely removed by the excavators, so that it was not possible to measure the environmental γ-dose rate at the original site. We collected 16 samples of breccia matrix from the 'Mousterian Layers' of the original 1932 excavation as stored in the British Museum. These samples, plus the sediment samples adjacent to the teeth, were analysed for U (1.86 ± 0.62 p.p.m.), Th (2.18 ± 1.31 p.p.m.), and K (0.451 ± 0.225%). These values correspond to a total external dose rate of 507 ± 123 μGy a^{-1}, when including a cosmic dose rate of 120 ± 20 μGy a^{-1} and a water content of 10 ± 10%.

The present-day U content of the enamel (0.3–3.2 p.p.m.) and dentine (6–12 p.p.m.) must have been acquired post-mortem: in calculating the ESR age it can be assumed that U was taken up either soon after burial (early uptake, EU), or gradually (linear uptake, LU; see Fig. 1)[12,13]. For a given site, LU ages are generally closer to independently determined ages[14] than the minimum possible age defined by EU. The LU and EU ages of the present samples from Skhul average 101,000 ± 12,000 years (101 ± 12 kyr) and 81 ± 15 kyr, respectively. The former of these lies between the ESR (LU) and thermoluminescence (TL) dates obtained for Qafzeh (115 ± 15 kyr[6] and 92 ± 5 kyr[4], respectively) and is indicative of an early late-Pleistocene age for both sites, corresponding to oxygen isotope stage 5 of the deep-sea record[15].

Schwarcz *et al.*[16] obtained U-series dates on stalagmitic calcite layers adhering to the bedrock or apparently interlaminated with the breccia. The youngest of a series of calcite layers was dated to 79 ± 4 kyr. Although this agrees with the EU age, calcite may have continued to be deposited in this site after the burial was emplaced.

Previous indirect estimates of the age of this site have been based on comparisons of the lithic industry, fauna and hominid remains with those from other nearby sites, especially Tabun. Higgs[17] surmised, on the basis of a faunal analysis, that layer

TABLE 1 ESR results and analytical data for teeth from Skhul

Sample	U(EN) (p.p.m.)	U(DE) (p.p.m.)	U(SED) (p.p.m.)	Th(SED) (p.p.m.)	K(SED) (%)	Thickness* (μm)	Removed* (μm)
521a	0.3	6.0	2.3	1.3	0.27	1200	50
521b	0.3	7.3	2.3	1.3	0.27	1200	50
521c	0.2	7.1	2.2	1.3	0.27	1700	50
521d	0.3	7.5	2.2	1.3	0.27	1500	50
522a	3.2	11.3	3.8	4.2	0.79	1200	20
522b	2.0	10.7	3.8	4.2	0.79	1200	20
522c	3.0	11.5	3.8	4.2	0.79	1200	20

				Early U-uptake				Linear U-uptake			
Sample	AD† (Gy)	γ-(SED)‡ (μGy a^{-1})	β-(SED)§‖ (μGy a^{-1})	β-(DE)‖ (μGy a^{-1})	Int.‖ (μGy a^{-1})	Total (μGy a^{-1})	Age (kyr)	β-(DE)‖ (μGy a^{-1})	Int.‖ (μGy a^{-1})	Total (μGy a^{-1})	Age (kyr)
521a	71.8 ± 9.7	507 ± 123	96.4 ± 11.8	121.3	90.5	815.2 ± 124	88.1 ± 17.9	57.0	40.5	700.9 ± 124	102.0 ± 22.7
521b	72.3 ± 2.6	507 ± 123	96.4 ± 11.8	146.9	89.8	840.1 ± 124	86.1 ± 13.1	68.9	40.0	712.3 ± 124	102.0 ± 18.1
521c	71.9 ± 1.9	507 ± 123	71.7 ± 8.7	115.2	64.0	757.9 ± 123	94.9 ± 15.6	53.9	28.4	661.0 ± 123	109.0 ± 20.5
521d	82.7 ± 9.4	507 ± 123	79.3 ± 9.7	135.2	97.5	807.6 ± 123	101.0 ± 19.0	63.4	43.5	693.2 ± 123	119.0 ± 25.1
522a	123.0 ± 4.7	507 ± 123	213.7 ± 26.1	217.9	869.2	1,807.6 ± 126	68.0 ± 5.4	107.3	422.7	1,250.7 ± 126	98.3 ± 10.6
522b	108.7 ± 4.8	507 ± 123	213.7 ± 26.1	209.6	559.0	1,489.3 ± 127	73.0 ± 7.0	102.0	265.9	1,088.6 ± 126	99.9 ± 12.4
522c	91.5 ± 15.9	507 ± 123	213.7 ± 26.9	211.3	745.3	1,677.3 ± 126	54.6 ± 10.3	104.0	361.2	1,185.9 ± 126	77.2 ± 15.7

EN = enamel; DE = dentine; SED = sediment; β-( ) = β-dose rate; γ-( ) = γ-dose rate; int. = internal dose rate.

* The values for thickness of enamel and the layers removed from both sides (to eliminate the volume irradiated by external α-rays) were used to calculate the β-attenuation factors[22].

† ADs and uncertainties were calculated with the computer program FITT[23].

‡ The uncertainty of the external γ-dose rate consists of the variation of radioactive elements in the sediment samples analysed by NAA and a systematic error for variation of water content[4].

§ The uncertainty of the external β-dose is caused by a systematic error of water content[4].

‖ The analytical error in the determination of U, Th, and K is negligible for the calculation of the respective dose rates.

B at Skhul might be 10 kyr younger than layer C at Tabun, for which a ^{14}C date of 51 kyr has been obtained[18]. Jelinek[18] compared the Tabun and Skhul artefacts and concluded that those from Skhul were less than 50 kyr old. Such estimates, as well as morphological dating, have been used to place the Skhul hominids at about 40 kyr[3].

By contrast, our results show that the ESR dates for teeth associated with the Skhul hominids are indistinguishable from, or only slightly younger than those previously obtained[6] for anatomically similar hominids from Qafzeh. As at Qafzeh, the hominids are associated with a Middle Palaeolithic industry similar to that used at a later time by morphologically distinct Neanderthals elsewhere in this region[19,20]. It is unclear whether this precludes important behavioural differences between the early modern humans and Neanderthals in respects other than lithic industry. The Skhul and Qafzeh dates indicate the existence of anatomically modern hominids in south-west Asia long before their appearance in Europe, and at approximately the same time as their estimated earliest appearance in Africa[5,21]. The extent of any coexistence between early modern humans and Neanderthals in south-west Asia remains unknown, and documentation will depend on further dating work, particularly for Neanderthal sites such as Tabun, Amud and Shanidar. Clarification of the chronological and phylogenetic relationships between the Skhul-Qafzeh hominids and the more fragmentary and archaic humans known from sites such as Gesher Benot Ya'acov, Zuttiyeh and Tabun E is also required[3].

An early late-Pleistocene age for both the Qafzeh and Skhul samples suggests at least two possibilities for this period of human evolution in south-west Asia. First, the presence of the early moderns might reflect a brief episodic occupation in the area (perhaps from north Africa), preceded by archaic humans associated with the Acheulo-Yabrudian, and followed by archaic humans (Neanderthals), also associated with the Middle Palaeolithic. Alternatively, archaic and early modern humans may have alternated or overlapped in occupation of the area through the Middle Palaeolithic. It remains unclear, however, whether the early late-Pleistocene presence of modern humans in south-west Asia presaged an early spread to east Asia (and much later, into Europe), or whether the further radiation of modern people into both Eurasia and the Far East was later, and unconnected with the evidence from Skhul and Qafzeh[5]. ☐

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A Middle Palaeolithic human hyoid bone

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THE origin of human language, and in particular the question of whether or not Neanderthal man was capable of language/speech, is of major interest to anthropologists but remains an area of great controversy[1,2]. Despite palaeoneurological evidence to the contrary[3,4], many researchers hold to the view that Neanderthals were incapable of language/speech, basing their arguments largely on studies of laryngeal/basicranial morphology[1,5,6]. Studies, however, have been hampered by the absence of unambiguous fossil evidence. We now report the discovery of a well-preserved human hyoid bone from Middle Palaeolithic layers of Kebara Cave, Mount Carmel, Israel, dating from about 60,000 years BP. The bone is almost identical in size and shape to the hyoid of present-day populations, suggesting that there has been little or no change in the visceral skeleton (including the hyoid, middle ear ossicles, and inferentially the larynx) during the past 60,000 years of human evolution. We conclude that the morphological basis for human speech capability appears to have been fully developed during the Middle Palaeolithic.

The Kebara hyoid is part of a nearly complete Middle Palaeolithic skeleton (Kebara 2) unearthed during the 1983 joint French-Israel excavations[7,8]. Figure 1 gives an anterior view of the bone. It is nearly complete—the body and the two greater horns are preserved. The latter are not fused to the body of the bone and the lesser horns are missing. Both of these features are also common in collections of modern human hyoids, because synostosis between the various elements of the hyoid is not always achieved, and in fact the small horns may remain cartilaginous during an individual's lifetime.

The ventral surface of the body presents two deep superior fossae separated by a median crest for the attachment of the geniohyoid muscle, and two less marked latero-inferior fossae for the omohyoid muscle. In a posterior (dorsal) view, the facets for the greater horns are very evident and the surface of the hyoid body is concave and rugged.

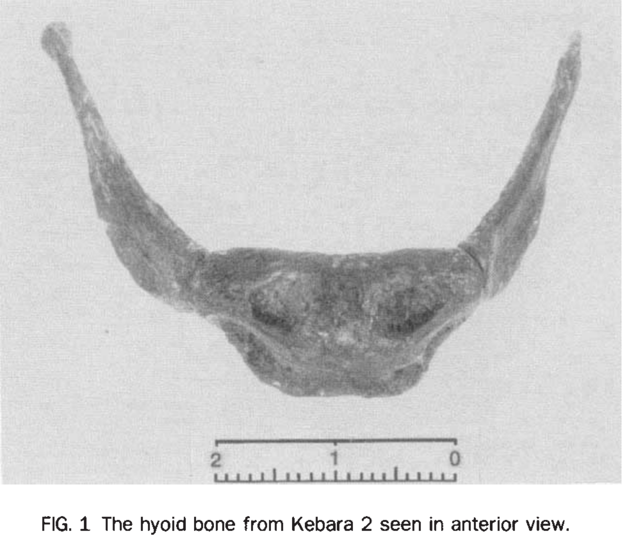

FIG. 1 The hyoid bone from Kebara 2 seen in anterior view.