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9. The Bear Creek exploration group explored the Mount Tolman area between 1964 and 1978; the Amax exploration group subsequently explored the property and proceeded with mine planning. Amax reportedly discontinued plans for mining this and other molybdenum properties subsequent to the initial submission of this report (W. Utterback, personal communication).
10. R. Babcock, personal communication.
11. W. Utterback, Mount Tolman project geologist for Amax, provided the data for Fig. 5 (December 1981). The Amax exploration group has highly specialized expertise in porphyry molybdenum, which includes and exceeds the kind of expertise incorporated into PROSPECTOR. PROSPECTOR is intended to help groups that do not have highly specialized expertise in the prospect type they are working with, which is commonly the case.
12. By "ore grade" we mean an ore mineral content greater than the planned mine cutoff grade. Because of a multiplicity of engineering, economic, environmental, and social factors, not all ore-grade rock is profitable to mine.
13. The development of PROSPECTOR occurred over several years with efforts from many people including both computer scientists at SRI International and consulting geologists. In particular, R. Reboh, the current project director, was responsible for system implementation and personally contributed many key technical innovations. K. Konolige developed the inference network compiler and P. Barrett the map data facilities that enable PROSPECTOR to work with and display map-based information. M. Einaudi contributed substantially to the design of many logical constructs fundamental to the accurate expression of geological judgment and reasoning. This test would not have been possible without gracious and extensive assistance from the Collville Confederated Tribes exploration group, the Bear Creek exploration group, and the Amax exploration group. This work was sponsored by the U.S. Geological Survey under a series of contracts and by the National Science Foundation under grant AER 77-04499; any opinions, findings, conclusions, or recommendations in this report are ours and do not necessarily reflect the views of either the U.S. Geological Survey or the National Science Foundation.

20 April 1982

Carbonate Dissolution and Sedimentation on the Mid-Atlantic Continental Margin

Abstract. *The calcium carbonate content was determined for core tops from two transects on the upper slope to lower rise on the mid-Atlantic continental margin. Carbonate content in the sediment increases from ~ 5 percent (by weight) on the upper slope to more than 30 percent on the upper rise. A zone of low-carbonate content extends from 3000 to 4400 meters. Below 4400 meters, the percent carbonate increases. An examination of dissolution indices in these core tops indicates that the low-carbonate zone is associated with intense dissolution. Below 4400 meters, dissolution decreases and carbonate is well preserved. The decrease in dissolution occurs where the high-velocity core of the Western Boundary Undercurrent is first encountered.*

In an effort to examine the effects of dissolution on carbonate sedimentation, gravity-core tops from two transects on the upper slope to lower rise on the mid-Atlantic continental margin—one off Chesapeake Bay and the other north of Hudson Canyon—were analyzed (Fig. 1). The southern transect includes 26 cores at depths from 1378 to 4647 m; the northern transect includes 30 cores at depths from 593 to 4974 m, but no samples were recovered from 3319 to 4371 m.

The percentage (by weight) of calcium carbonate for each core top was plotted against water depth (Fig. 2A). Both transects show similar variations in the carbonate content with depth. Values increased from ~ 5 percent on the upper slope to ~ 35 percent on the upper rise. On the southern transect, carbonate reached its maximum value, 33.1 percent, at 2900 m and then dropped to 21.5 percent at 3210 m. A similar decrease occurred on the northern transect, where the carbonate content reached its maximum, 35.7 percent, at 3100 m and then dropped to 23.5 percent at 3319 m. Because of the sampling gap, the full extent of the carbonate drop on the northern transect cannot be determined. Below 3200 m on the southern transect, the carbonate content increased to 29.4 percent at 3800 m, decreased to 22.5 percent at 4300 m, and increased to more than 30 percent below 4500 m. On the northern transect, below the sampling gap, carbonate values were high (> 25 percent) but variable.

It can be inferred from these data that the major break in carbonate sedimentation occurs on the upper rise, at about 2900 m on the southern transect and 3100 m on the northern transect. Below this sedimentation break, carbonate values are generally lower but do not exhibit the expected monotonic decrease with depth (*1–4*). In fact, the carbonate content ac-

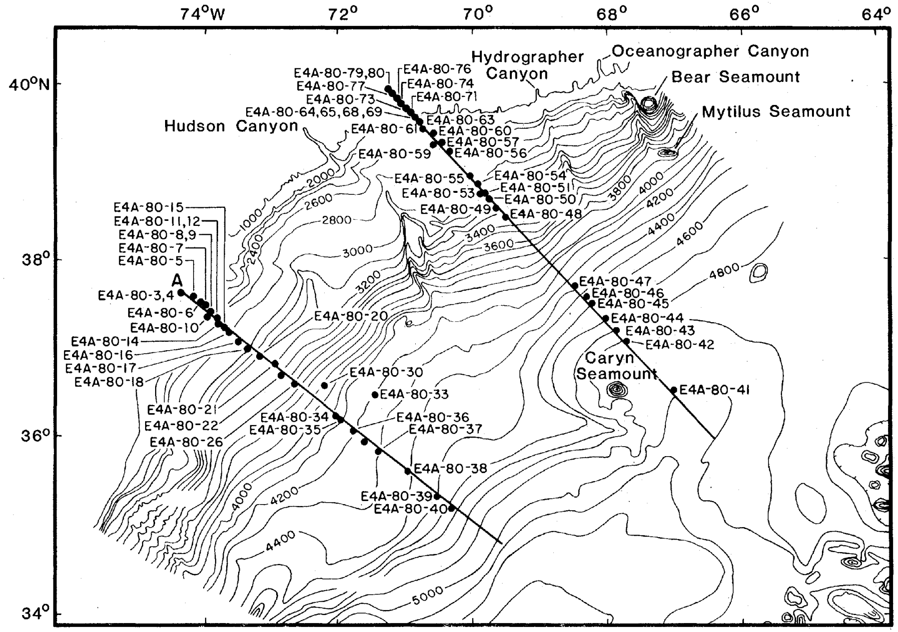

Fig. 1. Locality map showing the distribution of cores used to examine the depth distribution of calcium carbonate (Fig. 2A). Dissolution indices (Fig. 2B) were calculated from a subset of these cores and includes all the R.V. *Eastward* samples analyzed by Bulfinch *et al.* (*15*) for evidence of high-velocity bottom currents.

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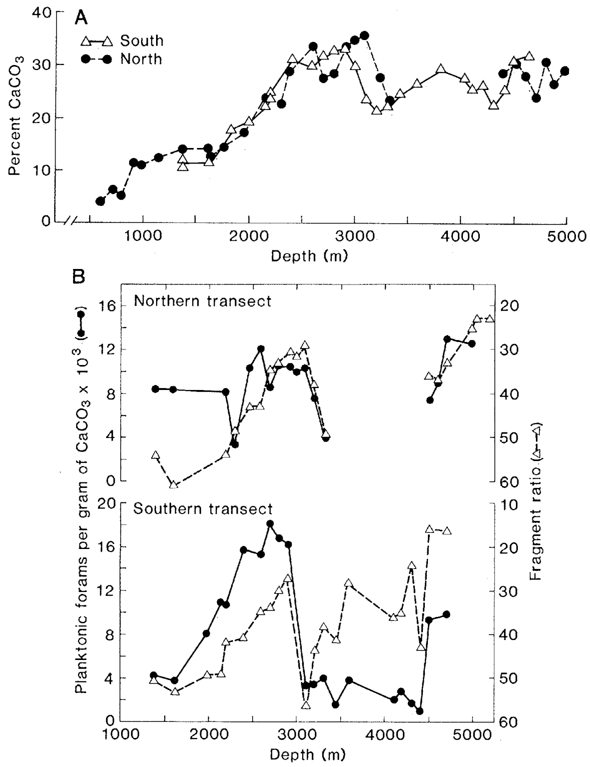

Fig. 2. (A) Percentage (by weight) of calcium carbonate ($CaCO_3$) plotted as a function of water depth. (B) Two dissolution indices plotted as a function of depth on the transects. For both the foraminiferal concentration and the fragment ratio, dissolution increases toward the bottom of the diagram.

tually shows a tendency to increase below 4400 m.

Several factors could affect the carbonate content and produce the pattern shown in Fig. 2A. Carbonate content is a function of the accumulation rate of both terrigenous and carbonate sediment. The carbonate accumulation rate is determined both by its sedimentation rate and by its dissolution rate. In order to monitor carbonate dissolution and sedimentation, two additional indices, planktonic foraminiferal fragmentation (fragmentation ratio) and the number of whole planktonic forams per gram of carbonate sediment (foraminiferal concentration), were used. These indices measure unrelated aspects of foraminiferal sedimentation and are independent except in so far as both are affected by dissolution. Neither index is sensitive to terrigenous influx (*5*). Planktonic foraminiferal fragmentation is widely used as an index of dissolution (*1, 6, 7*). As dissolution increases, whole tests of planktonic foraminifera are fragmented and the ratio of fragments to whole tests increases. However, in cases of intense dissolution the fragmentation ratio may actually decrease (*8*) as the dissolution of fragments causes their accumulation rate to decline. As fragments are formed, whole tests are destroyed and the number of tests per gram of carbonate should decrease (*1, 3, 7*). By examining both fragmentation ratios and the foraminiferal concentrations, one should be able to determine the severity of dissolution.

In general, the fragmentation ratio varied inversely with foraminiferal concentrations on both transects (Fig. 2B). The decrease in carbonate between 2900 and 3200 m on the southern transect is associated with a striking increase in dissolution (Fig. 2B). Dissolution is generally severe from 3100 to 4395 m, as indicated by the low foraminiferal concentration. In this depth range the inverse relationship between foraminiferal concentration and fragment ratio breaks down because fragments are dissolved before they can accumulate. Below 4395 m, dissolution abates. A similar trend is present on the northern transect (Fig. 2B), where the decrease in carbonate between 3100 and 3300 m is also associated with an increase in dissolution. The sample gap prevents further monitoring of dissolution until 4375 m. By this depth, dissolution has already lessened on the northern transect. I interpret these data as indicating that an area of intense dissolution is present on the continental rise (~ 3000 to ~ 4400 m) between Hudson Canyon and the Chesapeake Bay. On the lower rise, dissolution lessens to the point where exceptionally well-preserved foraminiferal assemblages are common.

Well-preserved foraminiferal assemblages from lower rise or abyssal plain sediment would typically be interpreted as resulting from downslope transport. The continental margin off eastern North America is known as an area where downslope transport of sediment is common (*9*). In order to minimize the effect of downslope movement, cores were taken from intercanyon areas with a smooth bathymetry. Several lines of evidence suggest that this strategy was successful. All the core tops analyzed contained at least a few arenaceous benthic foraminifera. Arenaceous forams are generally confined to core tops (*10*). The confinement of arenaceous forams to the top 5 to 20 cm of the gravity cores suggests that the coring process did not "blow away" the surficial sediments. Any material displaced downslope must have an upslope source. For the highly dissolved sediment of the continental rise, no upslope source is likely since these samples exhibit higher fragmentation ratios or lower foraminiferal concentrations than most upslope sediments (Fig. 2B). The area where downslope transport should be most obvious is the lower rise and abyssal plain. Indeed, without additional data the carbonate increase below 4400 m might be interpreted as resulting from downslope transport. However, the state of preservation of planktonic foraminifera in these deep samples is much better than in any of the shallow samples. Even very fragile, dissolution-susceptible planktonic foraminifera such as *Globigerina digitata* (*4, 11*) were preserved. Moreover, if these deep samples with exceptional carbonate preservation were transported from shallower depths, then they should contain displaced benthic foraminifera. On the southern transect not a single displaced benthic foram was found. On the northern transect, rare displaced benthics were mixed with the in situ benthic foraminiferal fauna in the deepest samples, which suggests that some downslope transport has occurred. This mixing does not appear to have altered appreciably the fragmentation or foram concentration signal, which is similar to that found on the southern transect.

Although the observed dissolution pattern does not appear to be the result of downslope movement, neither does it conform to published accounts of dissolution (*4, 6*). If the increase in dissolution on the upper rise corresponds to the lysocline (the level at which there is a noticeable increase in the solution of the tests), then it is 1000 to 1700 m shallower than has been proposed for the western North Atlantic (*12*). However, in the western North Atlantic shallow zones of dissolution have been reported by researchers working with carbonate sediment suspended in the water column (*13*). The lysocline is also known to shallow on continental margins (*3, 14*), in part because the decay of organic matter in the sediment increases dissolution. Below the lysocline, as depth increases, dissolution should continue to increase until the calcite compensation depth is reached. The results of this study differ from those of other published accounts of dissolution because below 4400 m dissolution decreases instead of becoming more severe.

The depth at which dissolution decreases appears to be controlled by a change in deep circulation. Using samples from the same data set, Bulfinch *et al.* (*15*) encountered the inshore margin of the high-velocity core of the Western Boundary Undercurrent (WBUC) on the lower rise, below about 4450 m. The increase in grain size and alignment that marks the high-velocity core of the WBUC coincides precisely with the decrease in dissolution. I conclude from these data that water in the high-velocity core of the WBUC is not corrosive with respect to carbonate. This conclusion is surprising in light of a recent report (*16*) that suggests that the WBUC below 4000 m is predominantly southern-source bottom water that should be corrosive to carbonate. These opposing conclusions may reflect a fundamental difference between physical oceanographic and geologic data. Physical oceanographic data reflect practically instantaneous events (*17*); geologic data are time-averaged, in this case incorporating data on sediments deposited over several hundred years.

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17. The transitory nature of physical oceanographic data is illustrated in the data of Richardson *et al.* (*16*). Of their three silica plots, one is indicative of northern-source bottom water and two are indicative of southern-source bottom water.
18. I thank all those who participated in the collection of core samples on R.V. *Eastward* cruise E4A-80. Support for R.V. *Eastward* samples was provided by NSF grant OCE 77-23278A02. This report was prepared while I was on sabbatical at the University of Georgia; use of the facilities there is appreciated. M. T. Ledbetter, B. B. Ellwood, and R. Thunell reviewed the manuscript and provided valuable criticisms. F. Balsam assisted in editing the manuscript. B. Daniel drafted the figures. This research was supported in part by the Climate Dynamics Program, Division of Atmospheric Sciences, under NSF grant ATM-7817854.

20 April 1982; revised 1 June 1982

Functional Morphology of *Homo habilis*

Abstract. *Olduvai hominid (O.H.) fossils 7, 8, and 35 represent the earliest species of the genus* Homo *dated at 1.76 million years. The O.H. 7 hand, jaw, and skull and the O.H. 8 foot come from one subadult individual, and the O.H. 35 leg are also those of* Homo habilis. *The skeleton represents a mosaic of primitive and derived features, indicating an early hominid which walked bipedally and could fabricate stone tools but also retained the generalized hominoid capacity to climb trees.*

Olduvai Gorge in northern Tanzania has yielded a wealth of early human fossils and cultural remains over the last 23 years (*1, 2*). None of the questions raised by the fossil finds has been more debated than whether or not an advanced hominid, early *Homo* (*Homo habilis*), existed contemporaneously with *Australopithecus boisei* (*3–5*). As a result of corroborative evidence from East Turkana, Kenya (*6, 7*), and the Omo River Valley, Ethiopia, *Homo habilis* has been accepted as a valid taxon (*8*). Although the taxonomic controversy has abated, our understanding of the anatomy and functional morphology of *Homo habilis* is still obscure. This is in part because of conflicting functional conclusions regarding fossils assigned to *Homo habilis* (*9–15*) and in part because of uncertainty over the associations of various parts of the postcranium with one taxon or another (*2, 3, 11, 16–19*).

The most important relevant postcranial remains from Olduvai Gorge come from sites FLK (level 22) and FLK NN (level 3) (*3, 10, 11, 20–22*). In early 1960 a tibia and fibula (O.H. 35) were found at the former site. Not much later, and nearby, a hand, skull, and jaw (O.H. 7) and a foot (O.H. 8) were recovered from FLK NN (level 3). The juvenile hand, jaw, and skull fragments became the holotype of *Homo habilis* (*3, 23*); the foot, purported to be that of an elderly female (*24*), became part of the paratype. The FLK tibia and fibula (O.H. 35) were placed in taxonomic limbo (*3, 10, 11, 16, 18, 19*). In the years that followed, O.H. 35 was assigned to *Australopithecus africanus* (*7*), *A. robustus* (*15*), and *Homo habilis* (*2*). Because one study of the O.H. 7 hand (*25*) suggested that the taxonomic assessment and assignments of the bed I material might be different from those originally reported, we undertook further study of the O.H. 7, 8, and 35 fossils in order to better understand the functional morphology and habitus of *Homo habilis*.

The O.H. 7 hand has 13 bones (*7, 20, 25*). The absence of epiphyses on the middle phalanges and the presence of fused basal epiphyses on the distal phalanges indicate that the individual was of a developmental stage equivalent to a modern human female of 13 years 6 months (*26*). The morphology and length of the distal phalanges resemble those of living humans (*25, 27*), but the fossil distal phalanges differ from humans principally in the greater diameter at midshaft. The middle phalanges differ from humans by being robust and curved, with well-marked flexor digitorum superficialis insertions that suggest powerful grasping potential, such as that of living apes (*25, 28*). The broken proximal phalanges with their thick cortices and marked curvatures also suggest a powerful grasping hand similar in overall configuration to chimpanzees and female gorillas.

Two wrist bones, a scaphoid and a

