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Mid-Plate, Mid-Gyre Seabed Assessment Program for Nuclear Waste Disposal

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MASTER

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Task Outline:

- I. Acoustic experiments for lateral and vertical consistency determinations.
- II. Design, fabricate and interface core launch and recovery system for C. S. LONG LINES.
- III. Field test Giant Piston Core (GPC) on Bermuda Rise with LONG LINES, summer of 1976.
- IV. GPC cruise to MPG-1 in October 1976.
- V. Core sample analysis and data synthesis for vertical consistency.
- VI. Acoustic mapping of MPG-1 for horizontal consistency.

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Task I. Acoustic experiments for Lateral and Vertical Consistency Determinations.

For the C. S. LONG LINES cruise to MPG-1 several acoustic experiments were conceived:

(1) Corehead pingers were to be installed in the GPC for bottom detection and resolution of sub-bottom reflectors.

(2) A FM-Link was to be included in the corehead to improve the signal-to-noise ratio of the 12 kHz pinger.

(3) Acoustic tripping was planned for the GPC to improve the chances of successful lowerings without pre-trips.

(4) Underway 3.5 kHz profiling was to be established upon the C. S. LONG LINES to aid in the final selection of coring sites.

(1) Corehead pingers. In order to detect the approach of the GPC to the seafloor for safe coring operations and to resolve sub-bottom reflecting horizons it was decided to purchase and install both 3.5 kHz and 12 kHz pingers manufactured by Ocean Research Equipment, Inc. Both pingers were purchased with the suitable options for high resolution; constant output phase and short pulse lengths. Dockside tests in the summer of 1976 showed that both instruments were operating up to specifications as far as sound pressure levels, pulse lengths, etc. with the exception of the 3.5 kHz pinger, which was unable to maintain a constant phase in its output signal. The instrument was returned to the manufacturer and the defect located and corrected to our satisfaction. Both instruments were installed in the GPC with the electronics pressure cases in the compartments in the tail of the corer and the transducers in the nose in special openings facing downwards when the core was vertical.

On board the C/S LONG LINES the 12 kHz pinger was received, amplified, and displayed on the ship's 12 kHz sonar equipment. The 3.5 kHz pinger was received using the towed fish we provided, amplified on our own transceiver, and displayed on either a ship's or our own graphic recorders.

On the Bermuda test cruise both pingers were installed in the GPC. The 3.5 kHz pinger performed extremely well and excellent sub-bottom records were obtained for the entire lowering. The signal from the 12 kHz pinger was not of high

enough level to be received more than 800 fathoms from the ship. Upon retesting at Woods Hole the instrument was proved to be operating up to specifications and no clear reasons for failure were ever diagnosed.

Operations in MPG-1. The surface receiving, amplifying, and display operations were the same as for the Bermuda test cruise with the exception that a tape recorder was added to record signals during the operations. Only the 3.5 kHz pinger was installed during the deployment of GPC-1 and it performed as excellently as it had on the test cruise. Sub-bottom penetration to acoustic basement was easily obtained and bottom detection was no problem. This instrument was lost with the loss of the GPC.

For GPC-2 the 12 kHz pinger was installed and it, too, performed well. Penetration was not as deep, i.e. acoustic basement was not reached; however, good resolution of the upper sub-bottom reflector was obtained and bottom detection was easily accomplished.

A failure of a portion of the power supply in the pinger during the lowering of GPC-3 made bottom detection impossible and no sub-bottom reflectors were resolved. This failure was partially repaired by the time of the launching of GPC-4 and records of intermediate quality between GPC-2 and GPC-3 were obtained. This pinger was also lost with the corer.

(2) FM-Link. Because of the signal-to-noise environment in which most surface receivers must operate the relatively weak pulses of reflected energy that return to the surface from corehead pingers are many times of too low of a level to be useful for quantitative studies. For this reason it was decided to implement an FM Acoustic Link in which the 12 kHz reflected signal would be received and encoded at depth and transmitted to the surface in the form of a frequency modulated signal upon a 22 kHz carrier. Because of the short lead time and the slowness of suppliers to deliver parts due to the UPS strike, it was not possible to fully test and use the FM-Link for the MPG-1 operations. By the time of the cruise, the surface receiving and decoding equipment were ready and tested, but the proper modification to the 12 kHz pinger were not yet complete. The deep-encoding and transmitting package were, however, ready and it was thought that a test of the reception of the carrier signal could be done on one of the lowerings. This was planned for GPC-4, but the repairs on the 12 kHz pinger took priority and the system was never installed.

(3) Acoustic Tripping. The traditional trigger-arm tripping system of the GPC is subject to occasional pre-trips the result of which is sometimes loss of the corer. For this reason, it was deemed desirable to replace this system with one that would trip the corer upon acoustic command from the surface. A standard release transponder used with current meter arrays was modified to perform this task in the GPC. Dockside tests with the core in the water demonstrated the mechanical feasibility of the operation. On the Bermuda test cruise it was decided to use the simplest and most known configuration of the GPC for the first test. For this reason the acoustic release was not used; however, it was installed and armed with no mechanical connection to the actual tripping mechanism. While at depth the release command was given and the device functioned properly.

One of the constraints added to the coring operations by the addition of the parachute-drogue system was the need to trip within a few tenths of seconds. The tests on the Bermuda test cruise had demonstrated that this was not a reasonable operating condition for the acoustic release and it was not implemented on the MPG-1 cruise.

(4) 3.5 kHz Profiling. The C. S. LONG LINES is very adequately equipped with 12, 16 and 25 kHz bathymetric profiling equipment. It does not have any lower frequency seismic equipment that could obtain useful sub-bottom reflections. Because this type of information is necessary in real time to make good decisions as to coring sites, it was decided to install a 3.5 kHz profiling system aboard the C. S. LONG LINES. A dozen SQS-26 3.5 kHz transducers on loan to Woods Hole from the Navy were installed in a towed fish housing that was resurrected from the scrap heap at Woods Hole. This transducer assembly was mated to a EDO 248 C/465A 10 kW sonar transceiver and impedances were matched for optimal output levels. Dockside tests were run to establish the sea worthiness of the equipment. The transceiver was installed aboard the C. S. LONG LINES along with a Giff graphic recorder. Provisions were made to use the ship's Raytheon recorders for control and display also. The fish was deployed using the ship's port boom and was towed up to 3 knots during the Bermuda test cruise. Excellent sub-bottom profiles were obtained with this system. In fact, the profiles exceeded the quality of those taken in the area by the R/V ATLANTIS II, traditionally the best 3.5 kHz profiling ship at Woods Hole.

Similar procedures were followed on the MPG-1 cruise and about 72 hours of excellent sub-bottom profiles were obtained. These records were combined with those of the CONRAD and VEMA to produce the 3.5 kHz sub-bottom character map (Figure 2).

Task II. Design, Fabricate and Interface Core-launch and Recovery System for C. S. LONG LINES.

The GPC launch and recovery system used on the C. S. LONG LINES was designed through a co-operative effort between P. Kingston of Gibbs and Cox Company, A. Silva of University of Rhode Island and A. Driscoll of WHOI. The fabrication was completed at WHOI, fitted to the ship in Portsmouth, New Hampshire and used successfully on the Bermuda and MPG-1 cruise in the Fall of 1976. This system, now stored at WHOI, is a modified version of the standard core handling system developed for the WHOI R/V KNORR.

Task III. Field Test GPC on Bermuda Rise with LONG LINES, summer 1976.

A deep water trial cruise of the Giant Piston Core and its components, was conducted off the island of Bermuda between August 16 and August 21, 1976 and a 9.5 m (undisturbed length) core of calcareous ooze was obtained at 32°34.8'N 63°55.6'W in 4,261 m of water. This was the first core recovered with the new GPC stream lined design and it showed very distinct horizontal laminations with just a trace of wall friction effects at the outer edge. The corer clearly recovered sediment with less physical disruption than standard piston corers, however a problem with the grapnel rope was demonstrated. The discrepancy between total penetration depth (≈20 m) and core recovered was determined to be a direct result of unres-trained rebound (after core tripping) of the very elastic grapnel rope. A special ribbon parachute was attached to the GPC in all subsequent core launches and this effectively eliminated the problem by allowing all core-induced tension to be carried only by the chute prior to tripping. This is done by speeding up pay-out speed to exceed chute plus core free-fall velocity (or about 4.5 kts). (See Sandia report # this volume.

Task IV. Giant Piston Core cruise to MPG-1, October 1976.

A successful Giant Piston Core cruise was conducted in the MPG-1 area of the central North Pacific between October 7 and October 15, 1976 (see Silva cruise report for detailed cruise summary). The decision to go directly to the MPG-1 area without another deep water trial was made after a thorough search of seismic data from University of Hawaii and Lamont. This

investigation showed that there were no areas closer to Hawaii that contained MPG type sediment of sufficient thickness in comparable water depths. Certain regions were however identified, south of Hawaii, where approximately 20 to 50 meters of seismically laminated material which, from other core data, indicate a deposit of volcanogenic turbidite; a sediment type that is characteristically very hard to penetrate with conventional cores. It was concluded that a GPC trial in this material might be very likely to damage all or part of our system.

Task V. Core Sample Analysis and Data Synthesis for Vertical Consistency.

Analysis of the Giant Piston Core (2438 cm long) recovered from MPG-1 is only partially complete however certain observations can, at least in a preliminary way be stated here (Figure 1). This core penetrated to approximately three times the depth of the standard Ewing core which was utilized to obtain a suite of 8-9 meter long cores. The lithology of the GPC is primarily a smectite, oxidized abyssal brown lutite (mean grain size $2-3\mu$). Mottling, due in part to burrowing organisms is distinguishable by subtle changes in the dark brown color. Numerous very altered volcanic ash layers provide the only distinct evidence for bedding. Some of these layers are very disturbed, presumably by burrowing organisms, and others are comparatively intact. One of the thickest layers is also partially coated with a crust of manganese oxide. The depth of this crusted layer ($\approx 11m$) corresponds with the approximate depth of a more or less persistent sub-bottom acoustic reflector seen on 3.5 kHz record obtained over the core site and through the southern portion of the MPG-1 area (Figure 2). The crusting on the ash layer might indicate that it was left unburied for a significant period of time and might thus represent a basin-wide period of non-deposition but not erosion.

The data we have so far obtained from this very important core, shows no evidence for any significant past erosional effects or unconformities nor does it reveal any evidence for significant changes in the ocean floor environment of this region that would have altered the sites suitability as a repository since the sediment at the bottom of the core was deposited approximately 65 to 70 million years ago. This is the longest undisturbed record of continuous sedimentation, from the present, ever recovered from the deep sea.

Some specific details concerning the GPC-3 data and the interpretation of vertical sediment consistency follow (Figures 1a,b,c). Grain size, bulk clay mineralogy and smear slide analyses of the sediment from C. S. LONG LINES GPC-3 were conducted at Woods Hole Oceanographic Institution.

The grain size distribution (105 each) was done with a model TA II Coulter Counter following the guidelines set forth by Schideler (USGS, Corpus Christi). A two aperture tube method (30 + 200 μ) was used yielding a range from .63 μ - 80.6 μ . Since the fraction of material greater than 12.7 μ generally comprised 1% by volume of the sample--a single tube (30 μ) analysis with a range of .63 μ - 12.7 μ was preferred.

The bulk clay mineralogy (28 each) of the sediment was determined with x-ray diffraction methods. The sample was washed to remove salt, ground to an overall particle size of 10 μ , the clay was expanded with amines, and bulk x-ray diffraction patterns were obtained. The data is represented by a bar-graph plot. Each bar ranges in size from 0 to 1 and represents the normalized (to the maximum peak height down core for a particular mineral) peak height. Peak height is assumed to be proportional to amount, so the graph qualitatively portrays normalized amount of each particular mineral down core.

Smear slide analysis, (30 each) was used to determine the percentage of detrital grains, micromodules, zeolites, volcanic shards, clay, forams, nanofossils and iron hydroxide nodular spheres. No significant variation in these components has yet been observed, however we are continuing a search for possible concentrations of micro-tetites.

Task VI. Acoustic Mapping of MPG-1 for Horizontal Consistency.

The 3.5 kHz data obtained with the towed fish (from C. S. LONG LINES) in MPG-1 was combined with all of the other acoustic profiles taken in that area in order to prepare an acoustic character map (Figure 2). The purpose of this exercise was to begin a detailed analysis of the lateral coherence of acoustic properties of the MPG-1 area. This analysis requires the use of the highest quality surface-ship transceivers available in a configuration designed for penetration through the entire unlithified sediment section of up to 60 meters. A high resolution (<1m) high powered (10 kw) 3.5 kHz seismic reflection profiling system was designed and used for this effort. The first sea trials were remarkably successful. Full penetration to acoustic basement (lithified chert or basalt) was achieved everywhere the system was deployed and its vertical resolution was consistently less than 1m. Thus we could detect, in nearly 20,000 feet of water, vertical inconsistencies in layering of this order. Horizontal variations of the order of 100 m could also be detected. Fine resolution will require a deeply towed-near bottom instrument package such as the MPL Deep-Tow.

Some pertinent observations concerning the horizontal consistency of MPG-1 follow:

There is a distinct change in acoustic character on either side of a N-S trending basement ridge which roughly parallels $157^{\circ}45'W$. To the west of this line the 10-11 meter deep sub-bottom reflector is generally continuous whereas to the east it is weak and discontinuous. We took GPC-3 in the area where this reflection is continuous.

A second sub-bottom, which is usually diffuse and patchy in appearance occurs along latitude $30^{\circ}10'N$ between $157^{\circ}30'W$ and $158^{\circ}10'W$.

The exact cause of the different reflectivity characteristics of the sub-bottom reflectors is not known. One possible explanation for the E-W difference in the 10 m sub-bottom reflector might be related to bottom current flow patterns that were topographically controlled when the ash, with manganese oxide coating, was on the seafloor surface. That is, bottom current might have been more vigorous on the west side of the basement high, and thus provided more cation exchange per unit time to the exposed ash in this region. Clearly we would need to obtain Giant Piston Cores in both provinces before drawing any concrete conclusions.

A detailed paleoenvironmental and predictive model (using data from GPC-3) of the region will be finished as part of the FY'78 task.

STRATIGRAPHIC DETERMINATIONS IN
UNFOSSILIFEROUS ABYSSAL RED CLAY:
A REVIEW

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(Appendix to 1976 Annual Report)

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STRATIGRAPHIC DETERMINATIONS IN
UNFOSSILIFEROUS ABYSSAL RED CLAY:

A REVIEW

The mid-plate, mid-gyre region of the Pacific is considered to be a geologically stable area, possibly a suitable region for a repository of high level radioactive wastes (Oceanus, Vol. 20, #1, 1977). Presently, the sediments of this area are being studied to determine if they are:

(1) laterally homogeneous, (2) vertically homogeneous, and most importantly (3) representative of a stable environment over a time span on the order of 10^6 years.

Lateral homogeneity was studied with a 3.5 kHz system on C.S. LONG LINES cruise 44. This data compiled with 3.5 kHz records from Lamont and previous ERDA sponsored cruises revealed an area of 10^5 km² of acoustically transparent sediments draped over strong hyperbolic echoes. One often discontinuous reflector at approximately 10 meters sub-bottom was seen throughout the southern portion of MPG-1 (30°N, 159°W) and later correlated with a manganese crusted ash layer. Sediment thickness was variable, averaging approximately 40 meters. Further to the north, the sediment was thinner with an average thickness of about 25 meters.

The vertical homogeneity of the sediments is being studied with a long, wide-diameter piston core. The major triumph of LL 44 was the recovery of a 24 meter core from MPG-1. The description of the core (figure 1) gives an impression of vertical homogeneity

of the core. The core is dark yellowish brown through the first six meters grading into a darker brown clay for the remainder of the core. Two phillipsite (?) layers at 10 meters and 11 meters, approximately 3 mm in thickness, are seen as well as one layer of manganese coating over altered ash at approximately 10.8 meters corresponding to the depth of the strong reflector on the 3.5 kHz records. The sediment increases in shear strength (figure 1b) down core. Mottling is seen throughout the core with some sections more intensely mottled than others. Intense shearing of the sediments is seen in the lowermost section of the core, however, it is uncertain if this is actually an accurate representation of the sediments or, more likely, an artifact of the coring process, as this is the sediment directly above flow-in. A conclusion regarding the vertical homogeneity of the core is left until all of the physical and geochemical properties are determined.

The other objective of the ERDA program is to determine if this area is representative of a stable environment over long time spans. To determine the answer to this question, the age of the sediment vs. depth in the core must be known. This information gives the sedimentary history, i.e. deposition vs. hiatus vs. erosion. However, a major problem lies in determining the age of these sediments down core. The normal tools used in dating deep sea sediments, which include biostratigraphy, radiometric dating, fission track dating, paleomagnetism, and amino acid racemization, are not all useful in a Pacific "red clay" core. The remainder

of this paper will be to look at the applicability of each of these dating techniques in turn, to the dating of a core of "red clay" in particular, LL 44 GPC-3.

Biostratigraphy

Calcareous and siliceous microfossils are the most commonly used for biostratigraphy on deep-sea cores. However, due to the low productivity of this mid-plate, mid-gyre regions, and the depth being deeper than the level of dissolution for these microfossils, they are lacking in this core. Should the core have been long enough to penetrate down to just above basement, the sediment which was deposited when the area was much closer to the spreading ridge, and therefore in shallower waters, would have been retrieved. This sediment may have contained calcareous microfossils. Since the core didn't penetrate that far, this method of dating is not usable for this core.

Another type of biostratigraphy used on deep sea cores, in particular "red clay" cores, is fish teeth stratigraphy. Helms and Riedel have found that fish skeletal debris, primarily bone fragments, "placoid scales" and teeth are found as a predominant constituent of the coarse fraction, $>63\mu$ of red clay cores. The characteristics used to identify different forms of teeth include: shape of the tooth, its relationship to the bone, shape and extent of the pulp cavity, and the area of the tooth covered by modified

dentine or enamel (Helms and Riedel, 1971). The size of the tooth is not a consistent factor. From the fish teeth characteristics noted above and age correlation with radiolarian zones in the same DSDP holes, a time scale has been set up (Helms and Riedel, 1971; Doyle et al., 1974; Doyle et al., 1975; Ramsey et al., 1976). Some fish teeth are known to extend over a period of up to 40 million years, and others to just a few million. The resolution of this technique is limited by the quantity of fish teeth in a sample. The more teeth there are, the better chance there is for finding the types which have more limited time spans. Sieving at least 100 cc is necessary to obtain a reasonable number of fish teeth for an age determination. With this much sediment, Riedel's group feel that they can give an age as early, middle, or late, followed by a Cenozoic epoch, for example, early Eocene. The Mesozoic is more difficult to get ages for as not much correlation of fish teeth to other microfossils time zones has been done in sediment that old (Ramsey et al., 1976).

Paleomagnetism

Paleomagnetism as a means of dating red clay cores has seen variable amounts of success. Opdyke and Foster (1970) have studied the paleomagnetism of some Pacific "red clay" cores. They sampled their cores at 10 cm intervals. They partially demagnetized the sediment in 50 to 150 oersted peak field, to remove the unstable

components of magnetization. They found that the coercivity of the red clays from their cores from the central part of the North Pacific decreases with depth in the core. This coercivity decrease is correlated strongly with an inconsistency in the inclination data. This is felt to represent the end of reliable paleomagnetic ages. The depths of this breakdown in the reliability occurs at 475 cm in one core and 250 cm in another. This corresponds to the Gauss and Matuyama epochs, respectively. Heath (1976) in measuring the natural remnant magnetization on cores from MPG-2, also in the central North Pacific, but on younger crust, found them to be magnetically stable into the Gilbert epoch, up to approximately 4 million years. Below this age in the core, chemical remnant magnetization causes the sediment to be magnetically unstable. Heath correlates this breakdown in the reliable magnetics with the color changes in the core from dark yellowish brown clay to darker brown clay. If this correlation is correct, it seems unlikely that the sediment will prove to be magnetically stable anywhere else down core, as the sediment continues to darken with depth.

Magnetic stratigraphy can be considered accurate in cores from this area for 700,000 years, the Bruhnes/Matuyama boundary and perhaps to as much as 4 million years. At a sedimentation rate of $1-1\frac{1}{2}$ mm per 1000 years, determined by the level of the Bruhnes/Matuyama boundary (Heath 1976) and independently by radiometric dating with ^{210}Po (Anderson, personal communication), magnetic stratigraphy is usable for between 1 and 5 meters of core.

Radiometric Dating

Radiometric dating of deep-sea cores is frequently done using the Uranium decay series. In particular, ^{231}Pa , ^{230}Th , and ^{210}Po have been used with varied amounts of success. ^{10}Be and ^{26}Al , both of cosmogenic origin, have been used on low sedimentation rate pelagic sediments primarily because of their longer half lives; 1.5×10^6 yr for ^{10}Be with respect to a half life of 75,000 yr for ^{230}Th . ^{40}K - ^{40}Ar and Fission track dating methods have been used on pelagic sediments containing ash horizons. These methods are only suitable for use on the volcanic glass shards of fresh ash horizons.

The application of uranium series isotopes to the dating of marine sediments has been applied by several workers (Moore and Sackett, 1964; Rosholt et al., 1961; Goldberg, 1964; Somayamulu and Goldberg, 1966; Ku et al., 1968; Goldberg and Koide, 1968; Koide, 1973; Anderson, in press). ^{231}Pa , ^{230}Th , and ^{210}Po are the isotopes most frequently used.

Unsupported ^{230}Th or excess ^{230}Th is the activity of ^{230}Th minus the measured ^{234}U activity. Using the decay equation

$$C = C_0 e^{-\lambda x/s}$$

where C_0 is the initial activity of excess ^{230}Th at the top in the fresh sediments
 C is the activity of excess ^{230}Th at depth x
 s is the sedimentation rate
 λ is the decay constant for ^{230}Th

ages of marine sediments have been determined. This analysis assumes that over the time scale being considered, the supply of ^{230}Th in sea water is constant, and the rate of sedimentation remains constant. The validity of these assumptions can always be questioned. However, in an area such as MPG-1 where pelagic sedimentation, a continuous type of deposition, appears to be occurring, it is likely that these assumptions are valid.

Comparison of this method with paleomagnetic dating down core as well as with ^{14}C dates (Ku et al., 1968) has shown it to be a reliable way of dating marine sediments for up to 300,000 to 400,000 years.

The ionium/thorium ($^{230}\text{Th}/^{232}\text{Th}$) method differs from the excess ^{230}Th method in that it does not require the assumption of a constant sedimentation rate of ionium. Furthermore, it deals with only one element, unlike the ^{231}Pa method, so that the possibility of chemical separation in the sediments is diminished. However, the underlying assumptions of this method should be stressed. It does assume that the $^{230}\text{Th}/^{232}\text{Th}$ ratio is constant in the water for the dating period being considered, that both ^{230}Th and ^{232}Th form the same chemical species in sea water, that the sediments do not contain significant contributions of ionium or thorium from continents or volcanoes, and that there is no migration of thorium in the sediments (Goldberg and Koide, 1968).

Measuring the ionium and thorium and using an equation similar to that for excess thorium

$$R/R_0 = e^{-\lambda I_0 t} \quad \text{where } R = (I_0 - I_{0u})/Th$$

ages of the sediment can be determined. The slope of the $\log I_0/Th$ vs. depth curve gives the sedimentation rate. Deviations of this curve from a straight line indicate changing sedimentation rates or possibly, invalid assumptions. This method is usable for 500,000 years maximum.

The third uranium decay series method used is the $^{231}Pa/^{230}Th$ dating technique. $^{231}Pa/^{230}Th$ ratio shows a decrease with depth in a core (Goldberg and Koide, 1968; Rosholt et al., 1961). This decrease is due to decay of the isotopes and therefore is a possible dating tool. Since these isotopes are daughters of uranium, it is thought that this method eliminates the possibility of differing geochemical histories of the isotopes measured (Rosholt et al., 1961). The method does assume that ^{238}U , ^{235}U , and ^{234}U have had the same relative abundances over the dating period, that U and its decay products are in equilibrium in the sediments, that Th and Pa having similar residence times of less than 300 years. Rosholt et al. (1961) have used this method and compared their results to ^{14}C and biostratigraphic dates from the same core. Their dates are in reasonable agreement with the ^{14}C and biostratigraphic dates, but slightly older. They attribute this to contamination by reworked clays, or invalid assumptions. The difficulty in using this method on red clay cores is that it has a limit of 175,000 years, which dates only a fraction of the top meter of core, assuming a sedimentation rate of 1 mm/1000 years.

The final uranium series method to be discussed is the ^{210}Po method. ^{210}Po has been used successfully to date "red clay" and other marine sediments, for the past .3-.4 million years. The ^{210}Po method is a variation of the excess ^{230}Th method described above in which ^{210}Po and ^{238}U are measured (Anderson et al., in press). It is used primarily because of the ease of measuring the ^{210}Po . Additional assumptions (all the assumptions applying to the excess ^{230}Th method also apply to this method) are that the disequilibrium of $^{234}\text{U}/^{238}\text{U}$ is unimportant and that ^{230}Th and its daughter are in secular equilibrium. This latter assumption has been shown to be justified for a mid-Atlantic ridge core, on which ^{210}Po dates were compared with direct $^{230}\text{Th}/^{234}\text{U}$ dates with reasonable agreement (Anderson et al., in press). However, in the ^{230}Th decay series, ^{226}Ra (half-life 1622 yrs.) is produced, which has been known to migrate and diffuse through the sediments (Arrhenius, 1963). If ^{226}Ra does migrate through the sediments then the method of dating has to be abandoned.

This method has been applied by Anderson to cores from MPG-2 yielding sedimentation rates on the order of $1\frac{1}{2}$ mm/1000 yrs. in agreement with Heath's magnetics data indicating a similar rate (Anderson, personal communication). However, difficulty was experienced in determining ages within the top 30 cm of the core. This method is also limited to approximately 400,000 years.

The cosmogenic nuclides used for dating pelagic sediments are ^{10}Be and ^{26}Al (Amin et al., 1966; Amin et al., 1975). Due to its

longer half-life (1.5 million years) ^{10}Be can possibly be used to date sediments which are too old to be dated with uranium series isotopes. In using the ^{10}Be method, Amin (1975) has found agreement of the ^{10}Be method and ionium/thorium method and paleomagnetism in the top 30-50 cm of 4 of 5 cores. Through his work, he feels justified in applying the ^{10}Be method for up to 3-4 half-lives, approximately 4 million years. ^{26}Al , however, showed low activity in his cores, and a clear signal down core was not discernable. Lingenfelter's (1976) work is at variance with that of Amin. Lingenfelter sees increases in ^{10}Be and ^{26}Al activities at 1.5 and 3 million years, and feels that the activities of ^{10}Be and ^{26}Al have not remained constant over the time period considered for dating. He hypothesizes nearby supernovae (Lingenfelter, 1976) which would cause an increase in the activities of both ^{10}Be and ^{26}Al , formed by cosmic ray spallation. Major disadvantages of this method are that 100 grams of sediment are needed for each analysis due to the low activities present, and the underlying assumption of constant activity over time is questionable. Even if these problems are ignored, the maximum valid date would be on the order of 4 million years, which gives no older ages than those from paleomagnetism.

The ^{40}K - ^{40}Ar method and variations on it have been used to date old, but unaltered ash horizons in deep-sea sediments. ^{40}K - ^{40}Ar method assumes that at time t_0 , when the glass was formed,

the system contained no extraneous ^{40}Ar and that the system has remained closed. ^{40}Ar is formed from ^{40}K by electron capture. By measuring the amounts of potassium and argon, the age of the glass is determined.

$$^{40}\text{Ar}_r = (\lambda_e/\lambda) \cdot ^{40}\text{K} (e^{\lambda t} - 1)$$

$$^{40}\text{Ar}_r = ^{40}\text{Ar produced by decay of } ^{40}\text{K}$$

t = radiometric age

λ = $\lambda_e + \lambda_b$, the sum of the partial decay constants of ^{40}K due to electron capture and beta decay respectively.

$$\lambda_b = 4.72 \times 10^{-10} \text{ yr}^{-1}$$

$$\lambda_e = 0.584 \times 10^{-10} \text{ yr}^{-1} \text{ (Dymond, 1966)}$$

This method has been used successfully on deep-sea ash horizons (Dymond, 1966; Dymond, 1969), however, these horizons were fresh, unaltered material. Since the material of the ash horizons found in the Pacific red clay cores is highly altered to phillipsite, the probability of the loss of argon is unity, which eliminates this method as a means of dating the LL 44 core. A major advantage of this method over uranium decay series methods is the long half life which, if the assumptions were valid would allow for dates on the order of millions of years, instead of 100,000's of years on the core.

FISSION TRACK DATING

Fission track dating on deep sea sediments is done primarily on the volcanic glass present in ash horizons (Fisher, 1969;

Fleisher and Price, 1964; MacDougall, 1971). MacDougall studied the feasibility of this method on barite, phillipsite, fish teeth, and glass shards from volcanic ash layers and found major difficulties with all of them, except the volcanic glass shards. This method involves counting the number of irradiation damage tracks caused by the spontaneous fission of uranium in the glass. An equation has been formulated which gives the age of the glass determined by the ratio of naturally occurring tracks, ρ_s , to tracks produced by a known amount of thermal neutrons, ρ_i .

$$\rho_s/\rho_i = \exp (\lambda_D A - 1) (\lambda_f/\lambda_D \phi \sigma I)$$

where

λ_f = fission decay constant for ^{238}U $6.85 \times 10^{-17} \text{yr}^{-1}$

λ_D = total decay constant ($1.54 \times 10^{-10} \text{yr}^{-1}$) of uranium

σ = cross section for thermal neutron-induced fission of ^{235}U

I = isotopic ratio of ^{235}U to ^{238}U

Problems involved with this method are correctly differentiating between the fission tracks and other marks in the glass, and the problem of thermal annealing of the tracks, if the glass has been heated since its formation. The latter problem seems unlikely for deep sea sediment cores where the bottom water temperature is close to freezing, however, the former problem is evident. The ash horizons of the core being studied are highly altered to phillipsite, which eliminates the chances of being able to distinguish fission tracks. The limiting factor in using this method on red clay cores

from the Pacific, is in finding suitably unaltered ash horizons. Since these type of layers do not exist in the cores of the Pacific, this dating method is not viable.

Amino Acid Racemization

The racemization of amino acids has been used successfully as a method of dating both fossil bones and marine sediments (Wehmler and Hare, 1971; Bada and Schroeder, 1972; Kvenvolden et al., 1973; Bada et al., 1973; Schroeder and Bada, 1973). The process of racemization is the changing of an optically active compound into an optically inactive or racemic mixture. Biological amino acids are primarily of the L form (the optically active form) and with time racemize to an equilibrium mixture of D (optically inactive form) and L forms. By measuring the amounts of L and D forms of a particular type of amino acid present and knowing the half life of the racemization process for that amino acid absolute dates are found.

The racemization of amino acids has been found to be highly temperature dependent (Bada et al., 1973). Therefore, the temperature must be known throughout the history of the racemization process or must be assumed constant. Since the bottom water temperature is close to freezing now during an inter-glacial, only if the bottom water temperature increased by more than 2°C during a glacial, would a temperature effect on the racemization of amino acids be important. This hypothetical temperature increase seems unlikely.

However, there are problems with amino acid racemization in marine sediments. The amino acids must be in the solid, non-diffusible part of the sediment. Should the amino acids be largely present in the pore water or as exchangeable ions on clay particles, diffusion of the amino acids throughout the sediment would obliterate the increase in racemization with depth.

Isoleucine with a half life of 4.4×10^6 years, epimerizes (the technically correct term applied to amino acids which "racemize", but have more than one center of asymmetry) to alloisoleucine. These are easily distinguishable amino acids to analyze. Due to its long half life, as compared to other amino acids, aspartic acid has a half life of 15-20,000 years, isoleucine has been used for dating marine sediments. However, it is found to be reliable only for samples less than 400,000 years (Wehmiller and Hare, 1971). This constraint limits its usefulness for use in a long red clay core. Moreover, preliminary studies on amino acids from a red clay core from the central equatorial Pacific indicate that substantial amounts of amino acids are present only in the first 10-20 cm of the sedimentary column (Bada and Schroeder, 1974). Those found below this level (β -alanine and γ -aminobutyric acid) are seldom found in abundance in living organisms, and are thought to be products of microbial activity (Schroeder, 1975). Due to the low concentration of amino acids available in red clay, it would be necessary to use large samples, and guard extremely well against contamination to be able to get reliable dates down core. Even if this is possible, the age limit is 400,000 years.

Conclusions

As can be seen from looking at figure 2 which shows the reliable time ranges for the various methods of dating a long Pacific red clay core, the situation look tenuous at best. Since at least two and often three methods are intercompared as a check on each other and at most two methods have been shown reliable for red clay, and only for 400,000 years, getting intercalibrated age control down core is impossible. The most viable option then is to use magnetic stratigraphy and radiometric dating for the top of the core, where these methods are indeed usable. The remainder of the core is best dated with fish teeth stratigraphy, whereby approximate ages can be determined and some control on the sedimentation rates down core is possible. The bottom of the core at 24 meters has been dated with fish teeth as greater than 63 million years. This would indicate an overall sedimentation rate of at most .5 mm/1000 years. Dates throughout the core are necessary to determine a sedimentary history of the North Pacific red clay environment.

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Figure 2