APPENDIX II: SEDIMENT PHYSICAL PROPERTIES

NATURAL GAMMA RADIATION

Natural gamma radiation measurements have the potential of detecting significant concentrations of radionuclides. These gamma measurements simply distinguish different sediment types, which naturally concentrate differing amounts and types of isotopes. Natural gamma radiation generally distinguishes argillaceous from non-argillaceous formations (Lynch, 1962). In fine-grained sediments, clay and zeolite minerals have ion exchange capacities which may hold gamma-ray emitting isotopes, in addition to isotopes which may be contained in the original mineral structures. According to Lynch (1962), gamma radiation from sands tends to be low unless potassium feldspars are abundant. Silica and calcium carbonate from organisms usually have low radiation, although radionuclides can be concentrated by some organisms (Koczy, 1963), and dolomites are more likely to contain radioactive elements.

These gamma measurements, in general, do not distinguish between any particular isotopes. In sediments the potassium isotope series typically contributes most of the total natural gamma radiation, with the remainder usually being emitted from the uranium and thorium isotopes (Evans and Lucia, 1970). Natural radiation in the form of gamma rays can be emitted from isotopes like U^{235}, Ra^{226}, Pb^{212}, P^{214}, K^{40}, Th^{208}, Bi^{214}, P^{36} and other isotopes. Radioactive particles in marine sediments are discussed by Koczy and Rosholt (1962), Koczy (1963), Mauchline and Templeton (1964), Prospero and Koczy (1966), and Lal and Peters (1967), which contain comprehensive reviews and references.

Methods

Aboard the *Glomar Challenger,* natural radiation is recorded at intervals of 7.62 centimeters (3 inches) along the core during a 1.25 minute period. The volume of core segment scanned, however, is greater than the 7.6-centimeter core segment. Radiation counts are reproducible within ±50. Radiation counts at the ends of the cores are low because the volume of sediment scanned is reduced. Detailed equipment descriptions are in the DSDP Manual and in Evans and Lucia (1970).

Discussion

These natural gamma radiation data have been measured, in general, from disturbed sediment samples, thus they do not accurately represent *in situ* values. In unconsolidated sediments these values may represent crude approximations of *in situ* conditions, especially when high radiation is typically emitted from very porous samples, because if the sediment were consolidated the radiation emitted would be even higher. The density and porosity of these cores has been continuously measured, therefore the reader may estimate the amount of solid material being scanned, and estimate which values he believes to be most probable of *in situ* conditions.

POROSITY-WET BULK DENSITY-WATER CONTENT

Porosities and wet-bulk densities have been studied by the petroleum industries for years as they are obviously related to oil production and other physical properties of sediments. Correlations of porosity and wet-bulk density to other properties of sediment, such as sound velocity, encouraged Hamilton *et al.* (1956), Laughton (1954; 1957), Sutton *et al.* (1957), Shumway (1960), Schreiber (1968), Horn *et al.* (1969), Kermabon *et al.* (1969), and Hamilton *et al.* (1969) to collect marine sediment samples and analyze their porosities, densities and other physical properties of the sediments and their interrelationships. Porosity-density interrelationships have been reported with respect to "soil mechanics" of marine sediments (Hamilton, 1959; Moore and Shumway, 1959; Richards, 1962; Hamilton, 1969), heat conductivity in marine sediments (Bullard *et al.,* 1956; Bullard and Day, 1961; Ratcliffe, 1960), and electrical conductivity in marine sediments (Boyce, 1968, and Kermabon *et al.,* 1969). In general, these were mainly "surface" sediments.

Porosity and wet-bulk density relationships to consolidation have been studied by Hamilton (1956; 1970) in an investigation of the thickness, consolidation, ages, and the amounts of original sediments in the ocean basins. Actual measurements of porosity, wet-bulk density, and related properties of sediment samples, which were buried to depths of 130 meters, from the Guadalupe Mohole site, were reported by Igeleman and Hamilton (1963), Moore (1964), and Hamilton (1964; 1965).

Methods

Porosities of the cores were measured continuously with the Gamma Ray Attenuation Porosity Evaluator, which will hereafter be referred to by its acronym, GRAPE, and individual small samples removed from these cores. Porosity is defined in this report as the [(volume of pore space)/(volume of wet sample)] x 100. Individual sample porosities were determined from the volume of the wet sample and weights of the wet and dry sediment sample. Water content is defined as the weight of water in the sediment divided by the total weight of the saturated sediment, expressed as a percentage without salt corrections.

Wet-bulk densities were measured by two methods: (1) individual samples (porosity sample), and (2) with the GRAPE unit. The GRAPE data are approximations based on electron/density ratios of minerals [(number of electrons per atom)/(atomic weight of the absorber)]. This ratio is assumed to be 0.5, which is applicable for most minerals (Lynch, 1962; Evans, 1965; Evans and Cotteral, 1970). See Evans (1965), Harms and Choquette (1965), Evans and Cotteral (1970) for a detailed equipment description. Problems arise when matrix minerals, such as some opaline and clay minerals, have water included in their mineral structure which could be misconstrued as pore space.

GRAPE information is presented in the form of continuous analog graphs. These graphs are calibrated with an uncorrected sea water density of 1.03 g/cc and an aluminum bar using a corrected density of 2.6 g/cc (Schlumberger, 1966), which allows the best graphical approximation of bulk density data. Porosities are calculated from the GRAPE densities via approximated grain matrix densities of cores or sections. But, these sections may have layers of sediment with high (dolomite) or low (opaline silica) grain matrices. However, the reader, interested in specific individual porosities with a distinct matrix density may easily calculate them via the wet-bulk density and grain matrix density. The GRAPE porosity values typically agreed with independently measured porosities within ±5 per cent.

Discussion

Almost all of these measurements were on disturbed sediments, thus they may represent nominal packings of different grain size distributions, but not precise data of *in situ* conditions, however, they may represent overall approximate conditions. Maximum porosities and water contents, and minimum wet-bulk densities are always suspect of being highly disturbed sediments.

SEDIMENT SOUND VELOCITY

Knowledge of sound velocity through marine sediments is obviously important for its use in interpretation of reflection profiles, refraction assumptions, and future well-log correlations and predictions. Velocities in marine sediments have been measured previously under laboratory conditions—and in some cases have included *in situ* measurement – by Hamilton (1956; 1963), Hamilton *et al.* (1956), Laughton (1954; 1957), Sutton *et al.* (1957), Shumway (1960), Schreiber (1968), Horn *et al.* (1969), Brier *et al.* (1969), Hamilton *et al.* (1969), and others. These investigations, and Nafe and Drake (1957; 1963), related surface sediment sound velocities to other mass physical properties of surface sediments. Subsurface sediment sound velocities have been analyzed by Hamilton (1965) with samples retrieved from the experimental Mohole (Guadalupe Site). These velocities were presented at laboratory pressures and temperatures, along with the corresponding velocities corrected to *in situ* temperatures and pressures.

Methods

The sound velocities measured on Leg 6 of the Deep Sea Drilling Project were not corrected to *in situ* temperatures and pressures, but are reported at ambient laboratory conditions. The application of such corrections is discussed by Hamilton *et al.* (1956), Hamilton (1963; 1965; 1969), Sutton *et al.* (1957), Laughton (1954; 1957), and Shumway (1958; 1960).

Deep Sea Drilling (DSD) sound velocities were determined through the core liner using a pulse method, which is described in detail by Winokur and Chanesman (1966). The pulse technique has either been used or described in slightly different equipment setups by Paterson (1956), Laughton (1957), Sutton *et al.* (1957), Abernethy (1965), and others.

The Winokur and Chanesman (1966) method essentially measures the differences in time for sound (400 kHz) to travel through a standard water sample and the unknown sediment sample at known temperatures and pressure. The sound velocity of the water is known, and the dimensions of the sediment and water samples are assumed to be the same; thus velocity can be calculated.

The precision of this method is markedly decreased if the dimensions of the standard water core and the sediment core are not identical. The dimensions of the core liner were physically distorted in many cases. This problem was compounded by the oil in the transducer heads having a lower sound velocity than that of the sediment or water. Thus, the short axis of an elliptical core would have a longer travel time than the long axis, which is the reverse of what should occur. This particular arrangement had a reproducibility of about ±5 per cent, but on the average the error was less than ±1.5 per cent.

Discussion

Almost all of the sound velocities were measured through disturbed sediment samples, thus they do not accurately represent *in situ* conditions. They probably reflect nominal packings and porosities of the sediment's particular grain size. However, they are still of interest as they may be rough approximations of the velocities through the unconsolidated sediments. The velocities are reported at ambient laboratory temperatures and pressures. Laboratory temperatures were within 25 to 30°C, which were recorded for each set of measurements. Sediment temperatures were within 5°C of the room temperature.

PENETROMETER

The purpose of the penetration measurements is to indicate only relative differences of the sediment strength for purposes of lithologic description. Penetrometer values are in units of 0.1 millimeter that a standard needle will penetrate under a fixed load of 50 grams ±0.1 gram. The standard needle is about 5 centimeters in length and 1.00 to 1.02 millimeters in diameter. This equipment is described in detail in American Society of Testing and Materials (1965). These measurements were not designed to be a specific unit of strength for calculations such as shear strength.

Discussion

Because of disturbance of sediments during coring operations, these values are not necessarily representative of *in situ* conditions.

THERMAL CONDUCTIVITY

According to Langseth (1965):

> The measurement of heat flow through the surface of the Earth is fundamental to the study of the thermal state that exists at depth in the crust and the upper mantle. The heat flux at the surface can be determined by measuring the temperature gradient and multiplying by the conductivity of the material between the two points of measurement.

The extent to which the temperature distribution at depth can be extrapolated via conductivity measurements depends on (1) whether the interval of temperature measurement is free from the flow of mass such as circulating interstitial water, which would greatly disturb the conductive heat transfer; (2) whether the conductivities of the rocks at the site are homogeneous enough to allow meaningful extrapolations of the observed heat flux; and, (3) whether the actual conductivity measurements are representative of *in situ* conditions. For detailed discussions of heat flow, heat conductivity, and references, see Geophysical Monograph, No. 8, of the American Geophysical Union entitled "Terrestrial Heat Flow."

At the present time heat flow measurements have not been successful, however, heat conductivity measurements have been continued. These measurements combined with continuous porosity measurements, hopefully, supply good approximate average heat conductivities that must be known in order to extrapolate temperatures with increasing depth. This would be useful for geochemists and students of mantle convection.

Methods

Aboard the *Glomar Challenger* the transient-needle method was used to measure the heat conductivity of the sediments. This needle is 7.5 centimeters long and 1.0 millimeter in diameter, and contains a heater and a thermister within it. The sediment is heated by the needle and the temperature is measured by the thermister. The rate at which the sediment dissipates this heat is a function of its thermal conductivity. This method is described in detail by Von Herzen and Maxwell (1959) and Langseth (1965). The method has a reproducibility within 2.5 per cent.

Discussion

Because of drilling deformation, heat conductivity measurements were performed in most cases on disturbed sediment samples. The reader may wish to attempt recalculating the porosities and heat conductivities to what he believes to be *in situ* conditions. These conductivities measured from disturbed samples of true unconsolidated sediments may in part reflect approximations of gross *in situ* conditions and, in part, reflect the coring disturbance and grain size distribution. Some of the firmer sediments appear to be cored in a relatively undisturbed condition. These heat conductivities are reported at ambient laboratory temperatures and pressures. The temperature limits of these measurements were about 23° to 31°C. The sediment was normally heated over a range of 4°C.

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