1. INTRODUCTION

G. Ross Heath, Department of Oceanography, Oregon State University, Corvallis, Oregon
Richard H. Bennett, NOAA Atlantic Oceanographic and Meteorological Labs, Miami, Florida
and
Kelvin S. Rodolfo, University of Illinois at Chicago Circle, Chicago, Illinois

OBJECTIVES

The main objectives of Leg 16, between the Panama Canal and Hawaii, were: (a) to examine the ages of volcanic basement, the stratigraphic sections, and the depositional histories of the ridges surrounding the Panama Basin; (b) to supplement the series of holes begun on Legs 5, 7, 8, and 9 to examine the depositional and tectonic histories of the eastern equatorial Pacific; (c) to study the metalliferous sediments reported above basalt basement on Legs 5, 7, and 9; and (d) to critically evaluate the physical properties measurements made on board the *Glomar Challenger*.

Panama Basin Ridges

Recent work by van Andel et al. (1971) suggests that the ridges surrounding the Panama Basin formed by fragmentation of a single ancestral ridge of which the present Carnegie Ridge is the largest remnant. This hypothesis is based on the acoustic character of the sediment cover of the various ridges and on the seismicity and morphology of the area. Sites DSDP 155, 157, and 158 of Leg 18 (Figure 1-in pocket at back of volume) were designed to test the hypothesis by comparing the lithologies, microfossil assemblages, and basement ages at the three sites.

Eastern Equatorial Pacific

Legs 8 and 9 of DSDP drilled a north-south series of sites along 140°E and an east-west series near the equator south of the Clipperton Fracture Zone. Sites DSDP 159 through 163 of Leg 16 (Figure 1) were designed to complement the earlier array of Leg 8 by filling gaps in the 140°W profile, and to sample the sedimentary record between the Clarion and Clipperton fracture zones, providing an east-west section parallel to the equatorial section of Leg 9. Because of the improved bits available on Leg 16 compared to those used on Leg 8, we expected to penetrate the Middle Eocene cherts that terminated most of the earlier 140°W holes.

Metalliferous Sediments

Sites DSDP 37 through 39 of Leg 5 and DSDP 77, 78, and 80 through 83 of Leg 9 encountered high concentrations of brown, finely divided "amorphous" iron oxides in the sediments directly above basalt basement. These deposits, now scattered over the west flank of the East Pacific Rise, are thought to have formed at the crest of the rise by processes associated with the formation of new oceanic crust (Boström and Peterson, 1966). If so, the metalliferous deposits have been carried to their present positions by sea floor spreading.

DSDP 159 and 160 of Leg 16 were located between the Leg 5 and 9 site clusters listed above. DSDP 159 and 160 were designed to test the continuity of the band of metalliferous sediments, as well as to provide more data on the nature of these deposits.

Physical Properties

As the sediment cores come on board, a number of physical properties such as gamma-ray attenuation, compressional sound wave velocity, and porosity have routinely been determined by the shipboard technicians. Despite the almost ubiquitous core disturbance reported by all scientific parties, the appropriateness and scientific value of the shipboard measurements have not been fully evaluated. The mass physical properties program of Leg 16 was focused on two basic objectives: critical evaluation of analytical techniques, instrumentation, and sediment core quality as they influence the mass physical properties, and measurement of sediment shear strength using a vane shear apparatus and Swedish Fall Cone over selected intervals of the cores. As an integral part of the evaluation study, approximately 400 ten- to fifteen-gram subsamples were taken from the least disturbed portions of the cores, as well as from zones of significant lithologic change, for analysis in a shore-based laboratory.

Standard shipboard techiques and procedures of previous legs were employed (Peterson, Edgar et al., 1970), with the exception of the AP-210 penetrometer and the velocimeter. A decision was made to abandon the penetrometer for shear strength tests and to use a vane shear apparatus with complementary measurements made with a Swedish Fall Cone penetrometer. The AP-210 penetrometer has provided no quantitative or definitive strength measurements but only very rough approximations of relative sediment strength, and, in some instances, even these have been questioned. Vane shear measurements on the unconsolidated sediments with the least apparent disturbance are the most reliable strength tests. Vane shear measurements can be related to sediment shear strength and are particularly useful in determining cohesion of high-porosity unconsolidated clays. Shear strength can be converted to cohesion in the case of fine-grained cohesive sediments by

$$S = c + \overline{\sigma} \tan \phi$$

where c is the cohesion, $\overline{\sigma}$ is the effective stress normal to the shear plane, and ϕ is the angle of internal friction. The Swedish Fall Cone was used for comparison with vane shear tests on a number of samples. Fall cone determinations can be related to undrained shear strength by

$$S = K \ Q/h$$

where Q is the weight of the cone, K is a constant which depends on the cone angle and the sampler type, which in turn determines the degree of disturbance. The factor h is the depth of penetration of the cone (Hansbo, 1957). For the purpose of this study, K is considered as unity, and thus the values reported here may be easily converted by choice of the reader. Commonly, the fall cone is calibrated with the vane shear in order to determine the correct K value for a particular type of coring device and sediment type. A number of vane shears were measured normal to the split core sections in close proximity to fall cone tests. In some cases the K values proved to be very close to unity, and in other instances the values deviated significantly from unity. This undoubtedly results from varying degrees of disturbance. Fall cone measurements are most useful as a relative measure of sediment strength and care must be exercised in the interpretation of the values. The sediment closest to the drill bit proved to be the least disturbed; therefore, most vane shear tests were made in sediment trapped between the core catchers or at the lower end of the core barrel. These areas were particularly suitable for vane shear testing, inasmuch as the vane could be inserted normal to bedding and the test performed prior to removal of sediment from the retaining sleeve or catchers. The sediment was extruded after shearing, examined for coring disturbance, and sampled for other physical properties.

Bulk density and porosity were determined by three techniques, two of which were standard shipboard procedures–Gamma-Ray Attenuation Porosity Evaluator (GRAPE) and syringe techniques. The third technique, developed by Bennett and Lambert (1971), was used for all the shore-based measurements. Bulk density (γ) and porosity (n) by the latter method are found by determining the water content (per cent dry weight) and the average grain density and are related by

$$\gamma = \frac{w_d D_g}{w_d + w_w D_g}$$

$$n = \frac{w_w}{\frac{w_d}{D_g} + w_w} \times 100 \text{ (uncorrected for salt)}$$

or

$$n = \frac{w_w + Vss}{\frac{w_d}{D_g} + w_w} \times 100 \text{ (corrected for salt)}$$

where w_t is the total weight of the sample; w_w is the weight of the water, determined by oven drying at 100°C for 24 hours; w_d is the weight of dry solids; D_g is the average grain density; and Vss is the volume of the salts in solution. The technique for determining average grain density can be found in Lambe (1951). The syringe technique was found to be unreliable and the GRAPE system was plagued with various problems, rendering bulk density and porosity determinations at selected intervals unreliable. These problems and others are discussed in detail in Chapter 13 of this volume, which gives a detailed analytical treatment and evaluation of the techniques used aboard the *Glomar Challenger*. In addition to the methods noted above, a very rough approximation of bulk density was determined for an entire core section (1.5 m) by weighing it and assuming a constant volume for the plastic liner (Peterson, Edgar et al., 1970).

Considerable core disturbance was apparent throughout the majority of barrels (9 m) at each drilling site. Consequently, GRAPE porosity and bulk density values may be in error by varying degrees depending upon the amount of vertical mixing, disturbance (such as core separation), and changes in water content of the sediment during periods of pumping while drilling. Comparison of GRAPE porosity and bulk density values with values obtained for carefully selected samples by the onshore laboratory technique, has shown that approximately 30 per cent of the bulk density measurements do not agree within ±0.05 g/cc and 10 per cent of the porosity measurements do not agree within ±5 per cent. The onshore technique is considered reliable and reproducible to ±0.01 g/cc for bulk density and ±0.42 per cent for porosity (Bennett and Lambert, 1971). Furthermore, the extreme deviations of the GRAPE data from the laboratory values appear to be unpredictable. A similar discrepancy has also been found by Brier et al. (1969) and is apparently an inherent characteristic of the GRAPE unit.

Erroneous GRAPE values were sometimes due to incomplete filling of the core liner and to separations in the sediment. Low bulk densities and high porosities were common at the ends of many sections because of removal of subsamples for interstitial water analysis. Abnormally low densities and high porosities also reflect areas of possible core separation. Close examination of the core photographs should be considered by the reader in the final interpretation of physical properties data. GRAPE measurements are clearly not necessarily representative of in situ properties nor even of many of the sediment core characteristics in the disturbed state. The GRAPE section averages appear to be more reliable than any particular point value obtained from the GRAPE plot.

For consistency with previous DSDP volumes, water contents are reported as per cent total weight of sample rather than per cent dry weight as commonly used by engineering geologists.

Acoustic velocities were measured using the Hamilton Frame in combination with an oscilloscope as described in DSDP Volume 15 (in preparation). The system is reliable. In extreme cases, however, variations as high as 0.19 km/sec for the sediments and 1.0 km/sec for the basalts were found when measurements were repeated on the same sample. This variation was due primarily to technique and operator error and secondarily to variable core liner thickness. Numerous velocities were measured with the sediment retained in the split core liner. The standard correction factor for the liner thickness in the velocity equation (see Volume 15 for discussion) is therefore not always correct, especially in extreme cases of thickness variation. Corrections for temperature were not made since the quality of the data does not warrant such refinements. All the cores were stored for several hours in the lab prior to testing to ensure ambient temperature conditions.

Most of the measured velocity values are plotted; consequently, discretion should be exercised in the interpretation of these data. General trends are probably representative of the acoustic properties through a given lithologic sequence.

Natural gamma radiation counts are considered reliable on a relative basis provided vertical mixing within a given lithology is limited. Minor variation may not be representative of in situ conditions due to varying degrees of disturbance throughout the core barrel lengths. Wide ranges of radiation counts within a given core section may reflect variations in the relative concentrations of radionucleides, sediment disturbance, or argillaceous/nonargillaceous ratios. Calibration of the instrument in terms of counts per unit volume apparently has never been assessed.

Detailed treatment of the analytical aspects of the mass physical properties studies during Leg 16 is presented in Chapter 12 of this volume.

OPERATIONAL SUMMARY

Glomar Challenger left Cristobal, Panama, on February 2 and arrived in Honolulu, Hawaii, on March 30, 1971 (Figure 1). During the fifty-six-day leg, the vessel traveled about 6400 nautical miles and drilled twelve holes at nine sites. The drilling statistics are summarized in Table 1.

While under way, 12 kHz echograms, magnetometer readings, and continuous reflection profiles were recorded in analogue form. The original records are on open file at the Scripps Institution of Oceanography. Digitized versions of the navigation, and 12 kHz and magnetometer records are also available from the Scripps Institution.

Coring techniques on Leg 16 were basically the same as those of earlier legs. We experimented with an extended core barrel designed to reduce disturbance of soft sediments by coring ahead of the bit face. Although Leg 15 had some success with this barrel, we could not detect any consistent improvement in core quality as compared to the conventional barrels. Our experience at DSDP 157 and 158, where the sediments above chert were similar, but the sea state varied from flat calm to 4-foot swell, suggests that vertical movement of the ship far outweighs core-barrel design in influencing the degree of disturbance of soft cores.

Coring in all lithologies was greatly aided by the use of button bits with shaped inserts. These bits, developed since the earlier Pacific campaign, readily penetrated the lower Tertiary cherts that troubled Leg 8. In addition, they drilled soft and semi-consolidated sediments more rapidly than conventional button bits and withstood the drilling conditions well enough to allow adequate sampling of basalt basement. The combination of longer insert buttons and sealed bearings in the new bits eliminated the need for reentry that we had anticipated at Sites DSDP 161 through 163. An experimental reentry attempt at DSDP 163 was unsuccessful due to malfunction of the EDO sonar scanning transceiver while being lowered into the hole. The drilling operations at each site are summarized in the individual site reports.

EXPLANATORY NOTES

Identification System for Sites, Holes, and Samples within Holes

Each drilling site has a number, for example, DSDP 163. The number of the first hole at each site has the site number, for example, Hole 163. Subsequent holes at a site have a following letter, for example, Hole 163A is the second hole at Site DSDP 163.

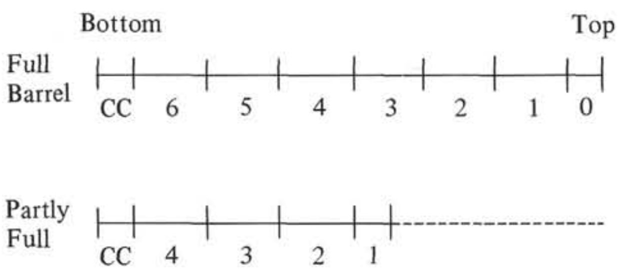
The cores recovered from each hole are numbered successively in the order in which they were taken: Core 1, Core 2, and so forth. The core barrels used on Leg 16 were 9.4-meters long. Drilling was carried out in 9-meter steps. Because of the many uncertainties in determining depths in the drill holes, the depth from which cores were taken is generally given only to the nearest meter.

When the core barrel is recovered on the deck of the drilling vessel, the core catcher is removed from the core barrel, and any material in the catcher (as much as 25 cm in

TABLE 1
Drilling and Coring Summary

Hole	Position		Drilling Dates Of	Water Depth (corr m)	Penetration (m)	No. Cores Cut	Total Cored (m)	Total Core Recovered (m)	Per Cent Recovery
	Latitude	Longitude							
155	06°07.38'N	81°02.62'W	6-8 Feb 1971	2752	536	15	102	57.0	55.8
156	01°40.80'S	85°24.06'W	11-12 Feb 1971	2369	4	2	7	0.5	7.0
157	01°45.70'S	85°54.17'W	12-15 Feb 1971	2591	437	49	427	273.6	64.1
157A	01°45.70'S	85°54.17'W	15-16 Feb 1971	2591	27	3	27	19.3	71.5
158	06°37.36'N	85°14.16'W	18-20 Feb 1971	1953	323	36	323	249.9	77.4
159	12°19.92'N	122°17.27'W	1-3 Mar 1971	4484	109	14	109	96.8	88.8
160	11°42.27'N	130°52.81'W	5-7 Mar 1971	4940	114	14	114	95.8	84.0
161	10°50.25'N	139°57.21'W	9-11 Mar 1971	4939	126	14	126	94.5	75.0
161A	10°40.27'N	139°57.27'W	11-13 Mar 1971	4939	245	15	126	87.8	69.7
162	14°52.19'N	140°02.61'W	15-17 Mar 1971	4854	153	17	153	131.6	86.0
163	11°14.66'N	150°17.52'W	20-25 Mar 1971	5320	294	29	243	155.7	64.1
163A	11°14.66'N	150°17.52'W	25-26 Mar 1971	5320	151	2	5	5.0	99.0
				Total:	2519	210	1762 (5781 ft)	1267.5 (4159 ft)	71.9

length in some cores) is labeled core catcher, or CC. The plastic core liner is withdrawn from the core barrel and cut into 150-cm lengths called Sections, beginning at the lower end of the barrel. A 9.4-meter liner can be cut into six such sections, with a short section—about 40 cm in length—at the top end. The sections are numbered according to the amount of material recovered. In a full barrel, the short uppermost section is called the zero section, and the first 150-cm section below that is Section 1, the next Section 2 and so forth. When the barrel is only partly filled with core material, the cutting of the liner into 150-cm sections proceeds as usual, starting from the bottom of the liner. The labeling, however, begins with the uppermost 150-cm section in which there is core material; that section, even if only partly full, is Section 1, the next section below is Section 2, etc. The following diagram illustrates this convention.



Within each section individual samples or observations are located by measuring in centimeters down from the top of the section. This is true even when a section is not full of material, either because of original lack of recovered material (a short Section 1, for example), or because of voids produced by compaction or shrinkage.

In the following chapters, samples are identified by abbreviated notations such as 163-5-1(147). This example denotes a depth of 147 cm in Section 1 of Core 5 of Hole 163.

In using the Visual Core Description as a guide to ordering samples, the reader is cautioned that the core material, especially if it is unconsolidated or watery, has a tendency to shift up or down within the core liner, and that a feature located at, say, 43 cm on the description may be shifted to 46 cm by compaction during handling of the core.

Disturbance

In unconsolidated or semi-consolidated sediments, the bumper subs of the bottom-hole assembly are fully extended. Consequently, any vertical movement of the ship is transmitted directly to the face of the bit. Under the sea conditions encountered on Leg 16, vertical movement of the *Glomar Challenger* due to the long-period swell was as much as several feet. The effect on the cores ranged from complete homogenization of radiolarian oozes, through complex diapiric deformation of somewhat plastic calcareous oozes and clays, to alternations of deformed and relatively undeformed material in the most indurated clays and oozes. In the third case, the alternation of disturbed and undisturbed intervals may recur several times per meter.

Additional disturbance is induced by the large ratio of the area of the bit face to the core area. When the drill is punching ahead in soft sediment, only 5 per cent of the displaced sediment should directly enter the core barrel. The remaining 95 per cent is pushed aside by the face of the bit. Most of this material moves outward, but some is forced into the core barrel. Consequently, the first part of the 9-meter cored section tends to fill the barrel in such deposits, whereas the final few meters may not be sampled at all. This phenomenon explains the disproportionate number of lithologic and biostratigraphic boundaries that fall between cores.

Finally, in semi-indurated sediment, drilling fluid (seawater in most cases) is injected several times per core to prevent the drill from binding. Each such injection removes a section of sediment and also tends to mix with the cored material to produce what look like less indurated beds. True alternations of unconsolidated and semi-indurated sediment (for example, in calcareous sequences) can be distinguished with certainty only by the presence of sedimentary structures in both soft and hard intervals.

Core Processing

After recovery, cores were cut into 1.5-meter lengths and capped. One 50-cc sample per core was normally removed at this stage from the end of one of the lower sections for geochemical studies. The core sections were weighed, the gamma-ray attenuation measured (for saturated bulk density and porosity), and the natural gamma radiation measured. During continuous coring in soft sediment, when cores were arriving on deck every ninety minutes or less, only two sections per core were subjected to natural gamma radiation measurements because of the slowness of this procedure.

With the exception of a few very fluid cores, sections were then split longitudinally by sawing through the plastic liner and slicing the sediment with a wire (if soft) or band saw (if hard). One-half of the core was described by a lithologist (who made smear slides as necessary to aid in the description) and lightly scraped with a spatula to remove markings produced by the splitting technique. This half was then photographed in black and white and color before being sealed in a D-shaped tube as the archive portion of the core.

The other (working) half of the core was first checked for degree of disturbance. If it included intervals that appeared undisturbed, the compressional sound velocity of such intervals was measured by means of the Hamilton Frame and, in a few cases, vane shear strength was also measured (see Bennett and Keller, Chapter 12). The working half was then sampled for carbonate and X-ray diffraction measurements to be performed ashore, as well as for the various investigations reported by the shipboard lithologists in this volume. This half of the core was then sent to the paleontology laboratory where it was sampled for shipboard and shore-based biostratigraphic studies before being sealed in a D-tube. Both archive and working halves of cores are permanently stored at about 4°C to minimize deterioration.

In the course of the coring program, R. Bennett observed that the sediment recovered in the core catcher assembly at the bottom of the core is often less disturbed than the sediment in the plastic liner. Where possible, such core catcher samples were used for vane shear measurements.

Detailed descriptions of the theory and operation of the gamma-ray attenuation porosity evaluator (GRAPE) and natural gamma activity measuring system can be found in the Initial Reports of the Deep Sea Drilling Project, Volume II, Appendix II (Peterson, Edgar et al., 1970).

Lithologic Nomenclature

Classification of the unconsolidated sediment is shown in Table 1. Generally it follows Olausson (1960). However, pelagic clay, brown clay, or pelagic brown clay are used in lieu of red clay where the color or the origin is obvious. Nannofossil is commonly used rather than Olausson's term nannoplankton, especially for the pre-Pleistocene oozes and chalks.

Most of the consolidated rocks recovered on Leg 16 are carbonates and cherts; their classification is discussed below. For volcanic rocks, details of texture and composition generally are given in the visual core descriptions, thin section and smear slide descriptions, and shore laboratory reports on carbonate and X-ray mineralogy. They enable the reader to name the rock according to the classification he prefers.

The following descriptive terms are used for the degree of lithification of carbonate rocks. Oozes have little strength and are readily deformed under the finger or the broad blade of a spatula. Chalks are partly indurated oozes; they are friable limestones that are readily deformed under the fingernail or the edge of a spatula blade. Chalks more indurated than that are simply termed limestones. During the coring process, chalk ooze is commonly folded but remains coherent, whereas chalk fractures. Generally the chalk in cores is badly shattered, and most of the fragments have irregular tabular shapes normal to the core axis. Fragments of chalk as thick as 2 or 3 cm are rare; most chips are but a few millimeters thick. Portions of cores with these lithologies (chalk or limestone) commonly alternate with portions of mud or slurry of the same color and grain composition but which are ground up and mixed with water and injected into the core barrel during periodic motions that affect the bit on bottom, such as the ship's motion or letting out on the draw works brake. The mud so formed differs from ooze in being wetter, in showing near-vertical flow-folding and diapir-like structure, and in grading to or containing less homogenized portions that retain recognizable pieces of ooze or chalk.

The cherty rocks are subdivided on the basis of their degree of silicification. Porcelanites (porcellanites) are waxy and dull in luster and commonly show abundent pores under a hand lens. Where cored specimens are allowed to dry out, their surfaces dry to a matte or checked appearance. Thin section and X-ray analyses show that the silica in porcelanite is largely cristobalite and that much of the rock consists of montmorillonite or other nonsilica minerals. On the other hand, the name chert is more appropriately applied to the dense, glassy rocks. Cherts are markedly purer than porcelanites, and their silica is present as chalcedony or microcrystalline quartz. Both porcelanite and chert have conchoidal fracture and both can scratch steel. In contrast, only the more porous and impure porcelanites commonly can be scratched by knife point.

Color symbols are from the Munsell system. Both the soil color charts (Munsell Color Company, 1954) and the rock color charts (Goddard et al., 1948) were used for comparing with the cores. For the reds, yellows, and browns, the soil color charts had more color chips and so were used more frequently. However, the terminology in the rock color chart was always used, whether the symbol was obtained by matching to the soil chart or to the rock chart.

Terminology of sedimentary structures is generally that of the Pettijohn and Potter (1964) atlas and glossary. Grain size terminology is that of Wentworth (1922). For carbonate-rich deposits a more useful boundary would have been at 20 microns because it separates most microfossils from nannofossils.

Both optical and X-ray diffraction methods were used for mineralogical determinations. Terminology of minerals identified optically is that of Deer et al. (1962). The method of mutual standards and the degree of development of recognition criteria in the programs to interpret the digital X-ray diffraction patterns are discussed by Rex (1970).

Biostratigraphic Framework

Because a large number of paleontologists with different views are participating in the work leading to the initial core descriptions, the JOIDES Advisory Panel on Paleontology and Biostratigraphy recommended a scheme of period/system, epoch/series, age/stage classifications for uniform application in this work. It is probable that no worker will be happy with all of the details of this scheme—indeed, there was not unanimity among the members of the panel that formulated it. But it has been necessary to apply such a scheme uniformly in order that the contributions of diverse authors can be integrated into a coherent whole.

TIME-STRATIGRAPHIC FRAMEWORK

				Stage	Bibliographic reference to the concept of the stratotype being applied for the purposes of this manual.
CENOZOIC	QUATERNARY	PLEISTOCENE-RECENT		Calabrian	Gignoux, M., 1910. *Compt. Rend. Acad. Sci. Paris.* **150**, 841. Gignoux, M., 1913. *Ann. Univ. Lyon.* **36**. Gignoux, M., 1948. *Intern. Geol. Congr. 18th* (Report published 1950). Gignoux, M., 1952. *Congr. Geol. Intern. Compt. Rend. 19th* (Report published 1954). Gignoux, M., 1954. *Congr. Geol. Intern. Compt. Rend. 19th.* p. 249. Selli, R., 1962. *Quaternaria.* **6**, 391.
	TERTIARY	PLIOCENE	Upper	Astian	Astian: de Rouville, P. G., 1853. *Description geologique des environs de Montpellier.* Boehm (Montpellier), 185.
				Piacenzian	Piacenzian: Mayer-Eymar, C., 1858. *Verhandl. Schweig. Naturforsch. Ges.* 17-19 Aug., 1857. Pareto, L., 1865. *Bull. Soc. Geol. France.* (2) **22**, 209. Gignoux, M., 1915. *Bull. Soc. Geol. France.* (4) **14**, 338. Gignoux, M., 1924. *Boll. Soc. Geol. Ital.* **42**, 368. di Napoli-Alliata, 1954. *Congr. Geol. Intern. Compt. Rend. 19th.* p. 229-234.
			Lower	Zanclian (A)*	Seguenza, G., 1868. *Bull. Soc. Geol. France.* (2) **25**, 465. Baldacci, L., 1886. *Mem. Descrit. Carta Geol. Ital.* **1**, 1. Ogniben, L., 1954. *Mem. 1st Geol. Mineral. Univ. Padova.* **18**. Wezel, F. C., 1964. *Riv. Ital. Pal. Strat.* **70**, 307.
		MIOCENE	Upper	Messinian	Mayer-Eymar, C., 1867. *Catologue systèmatique et descriptif des fossiles des terrains tertiariris qui se trouvent au musèe fédèral de Zurich.* (Zurich) **2**, 13. Selli, R., 1960. *Giorn. Geol. Ann. Museo. Geol. Bologna.* (2) **28**, 1. d'Onofrio, S., 1964. *Giorn. Geol. Ann. Museo. Geol. Bologna.* (2) **32**, 409.
				Tortonian (B)	Mayer-Eymar, C., 1858. *Verhandl. Schweiz. Naturforsch. Ges.* 17-19 Aug., 1857. Gino. G. F. *et al.,* 1953. *Riv. Ital. Paleont., Mem. 6.* 7. Giannoti, A., 1953. *Riv. Ital. Pal. Strat.* Mem. VI, 168. Cita, M. B. *et al.,* 1965. *Riv. Ital. Pal. Strat.* **71**, 217.

*Capital letters in parentheses refer to "Notes on Concepts of Stages and Other Boundaries"

CENOZOIC	TERTIARY	MIOCENE	Middle	Serravallian	Pareto, M. F., 1865, *Bull. Soc. Geol. France,* ser. 2, vol. 22, p. 232. Vervloet, C. C., 1966, *Stratigraphical and micropaleontological data on the Tertiary of southern Piedmont (Northern Italy),* p. 11-49, Schotanus and Jens, Utrecht. Cita, M. B. and Premoli-Silva, I., 1968, *Gior, Geol.,* vol. 35 (1967), *fasc.* **3,** p. 1-23.	
			Lower	Langhian (C)	Pareto, L., 1865. *Bull. Soc. Geol. France.* (2) **22,** 229. Cita, M. B. and Silva, I. P., 1960. *Intern. Geol. Congr. 21st, Copenhagen, 1960, Rep. Session, Norden.* **22,** 39. Cita, M. B. and Elter, G., 1960. *Acad. Nazl. dei Lincei.* Ser. 8(5), **29,** 360.	
			Lower — Girondian	Burdigalian	Girondian: Vigneaux, M., Magne, A., Veillon, M. and Moyes, J., 1954. *Compt. Rend. Acad. Sci. Paris.* **239,** 818. Caralp, M. and Vigneaux, M., 1961. *Compt. Rend. Soc. Geol. France.* 140. Drooger, C. W., 1958. *83rd Congr. Soc. Sav., Sect. Sci.* p. 171.	Burdigalian: Depéret, C., 1892. *Compt. Rend. Soc. Geol. France.* (11), 145. Depéret, C., 1893. *Bull. Soc. Géol. France.* (3) **21,** 263. Dollfus, 1909. *Bull. Serv. Carte Géol. France.* (124) **19,** 380. Drooger, C. *et al.,* 1955. *Koninkl. Ned. Akad. Wetenschap. Verslag Gewone Vergader. Afdel. Nat.* Ser. 1 (2), **21,** 1.
			Lower — Girondian	Aquitanian (E)		Aquitanian: Mayer-Eymar, C., 1858. *Verhandl. Schweiz. Naturforsch. Ges.* 17-19 Aug., 1857, p. 188. Tournouer, R., 1862. *Bull. Soc. Geol. France.* Ser. 2, **19,** 1035. Drooger, C. W. *et al.,* 1955. *Koninkl. Ned. Akad. Wetenschap. Verslag Gewone Vergader. Afdel. Nat.* Szots, E., 1965. *Bull. Soc. Geol. France.* (7) **7,** 743.
		OLIGOCENE		Chattian	Fuchs, T., 1894. *Jahresber. Ungar. Geol. Anstalt.* **10,** 172. Gorgës, J., 1952. *Abhandl. Hess. Landesametes Bodenforsch.* **4,** 1. Hinsch, W., 1958. *Lexique Strat. Intern.* **I** 5hl. Anderson, H. J., 1961. *Meyniana.* **10,** 118. Hubach, H., 1957. *Ber. Naturhist. Ges. Hannover.* **103.**	
				Rupelian	Dumont, A., 1849. *Bull. Acad. Roy. Med. Belg.* (1) **16,** 370. Batjes, A., 1958. *Inst. Roy. Sci. Nat. Belg. Bull.* Mém. 143.	
				Lattorfian	Mayer-Eymar, C., 1893. *Bull. Soc. Geol. France.* (3) **21,** 8. Munier-Chalmas, E. and de Lapparent, A., 1893. *Bull. Soc. Geol. France.* **21,** 478. von Koenen, A., 1893-1894. *Abhandl. Geol. Spec. Preussen.* **10,** 1005. cf. Krutzsch, W. and Lotsch, D., 1957. *Geologie.* **6,** 476. Krutzsch, W. and Lotsch, D., 1958. *Ber. Deut. Geol. Ges.* **3,** 99.	
		EOCENE	Upper	Priabonian / Bartonian	Priabonian: Munier-Chalmas, E. P. and de Lapparent, A., 1893. *Bull. Soc. Geol. France.* (3) **21,** 471. Roveda, V., 1961. *Riv. Ital. Pal. Strat.* **67,** 153. Fabiani, R., 1915. *Mem. 1st Geol. Mineral Univ. Padova.* **3,** 1.	

CENOZOIC	TERTIARY	EOCENE	UPPER	Priabonian / Bartonian (F)	Bartonian: Mayer-Eymar, C., 1858. *Verhandl. Schweiz. Naturforsch. Ges.* 178. Prestwich, J., 1847. *Quart. J. Geol. Soc., London.* **3**, 354. Prestwich, J., 1857. *Quart. J. Geol. Soc., London.* **13**, 108. Curry, D., 1958. *Lexique Strat. Intern.* I 3a 12.
			Middle	Lutetian	de Lapparent, A., 1883. *Traite de Geologie.* 1st Ed., p. 989. Blondeau, A. and Curry, D., 1964. *Bull. Soc. Geol. France.* (7) **5**, 275. Blondeau, A. *et al.*, 1966. *Bull. Soc. Geol. France.* (7) **7**, 200. Blondeau, A., 1964. *Mem. Bur. Rech. Geol. Min. No. 28.* 21.
			Lower	Ypresian	Dumont, A., 1849. *Bull. Acad. Roy. Med. Belg.* (1) **16**, 368. Kaasschieter, J. P. H., 1961. *Inst. Roy. Sci. Nat. Belg. Bull.* Mem. 147.
		PALEOCENE	UPPER	Thanetian	Renèvier, E., 1873. *Tableau des terraines sédimentaires (in 4°) et un texte explicatif.* Lausanne (G. Bridel). Renèvier, E., 1897. *Chronogr. Geol.* Prestwich, J., 1852. *Quart. J. Geol. Soc., London.* **8**, 235. Barr, F. T. and Berggren, W. A., 1965. *Stockholm Contrib. Geol.* (2) **13**, 9.
			LOWER	Montian	Dewalque, G., 1868. *Prodrome d'une description geologique de la Belgique.* p. 185. Cornet and Briart, 1866. *Bull. Acad. Roy. Med. Belg.* (2) **20**, 757. Briart and Cornet, 1880. *Ann. Soc. Geol. Belg.* **7**, 139. Rutot, A. and von den Broeck, E., 1885. *Ann. Soc. Roy. Malac. Belg.* **20**, 108. Rutot, A. and von den Broeck, E., 1886. *Ann. Soc. Geol. Belg.* **13**, 94. Rutot, A. and von den Broeck, E., 1887. *Bull. Soc. Geol. France.* (3) **15**, 157. Marlière, R., 1955. *Ann. Soc. Geol. Belg.* **78**, 297. Berggren, W. A., 1964. *Stockholm Contrib. Geol.* (5) **11**, 135.
Tertiary / Cretaceous				Danian	Tertiary: de Grossovure, A., 1897. *Bull. Soc. Geol. France.* Ser. 3, **25**, 57. Loeblich, A. R., Jr. and Tappan, H., 1957. *U. S. Nat. Museum Bull.* **215**, 173. Troelsen, J., 1957. *U. S. Nat. Museum Bull.* 125. Berggren, W. A., 1962. *Stockholm Contrib. Geol.* (2) **9**, 103. Berggren, W. A., 1964. *Stockholm Contrib. Geol.* (5) **11**, 103. Cretaceous: Eames, F. E. (in press), 1968. *J. Geol. Soc. India.* Desor, E., 1847. *Bull. Soc. Geol. France.* Ser. 2, **4**, 179. Brotzen, F., 1959. *Sveriges Geol. Undersokn Arsbok, Ser. C.* (571), 81 pp. Rasmussen, H. W., 1965. *Mededel. Geol. Sticht.* N. S., (17), 33. (Supplemented by M. Meijer, *loc. cit.*, pp. 21-25).
MESOZOIC	CRETACEOUS	Upper		Maestrichtian	Dumont, A., 1849. *Bull. Acad. Roy. Sci.* Lettres, Beaux-Arts, Belgique, 351. Hofker, J., 1966. *Paleontographica.* Supplement-Band 10, Atlas of Foraminifera, 5. Jeletzsky, J., 1951. *Beih. Geol. Jahrb.* (1), 1.
				Campanian (G)	Coquand. H., 1857. *Bull. Soc. Geol. France.* 749. Van Hinte, J., 1965. *Koninkl. Ned. Akad. Wetenschap. Proc., Ser. B.* (1) **68**, 14. Marie, P., 1941. *Mem. Museum Nat. Hist. Nat. (Paris).* **12**, 1.

MESOZOIC	CRETACEOUS	UPPER	Santonian S.S. (H)	Coquand, H., 1857. *Bull. Soc. Geol. France,* 749. Seronie-Vivien, M., 1959. *Colloque sur le Crétacé Supérieur Francais rendus de Congrès des Societes Savantes de Paris et des Depártments, Comité des Travaux historiques et scientifiques, section des sciences, sous-section de géologie, tenu a Dijon.* Paris (Gauthier-Villars). 581.
			Lower Santonian – Coniacian (I)	Coquand, H., 1857. *Bull. Soc. Geol. France.* 748. Seronie-Vivien, M., 1959. *Colloque sur le Crétacé Supérieur Francais rendus de Congrès des Societes Savantes de Paris et des Depárt-ments, Comité des Travaux historiques et scientifiques, section des sciences sous-section de geologie, tenu a Dijon.* Paris (Gauthier-Villars). p. 581. Schijsfma, E., 1946. *Mededel. Geol. Sticht.* Ser. C-V (7), 1.
			Turonian	D'Orbigny, 1842. *Les Cephalopodes.* (Published by author) 622 pp. D'Orbigny, 1842. *Les Animaux Mollusques et Raronnes.* (Published by author) 456 pp. Lacointre, 1959. *Colloque sur le Crétacé Supérieur Francais rendus de Congrès des Societes Savantes de Paris et des Depártments, Comité des Travaux historiques et scientifiques, section des sciences, sous-section de géologie, tenu a Dijon.* Paris (Gauthier-Villars). 415. Butt, A. A., 1966. *Micropaleontology.* (2) **12**, 168.
			Cenomanian	D'Orbigny, 1842. *Les Cephalopodes.* (Published by author) 622 pp. D'Orbigny, 1842. *Les Animaux Mollusques et Raronnes.* (Published by author) 456 pp. Marks, P., 1967. *Koninkl. Ned. Akad. Wetenschap., Proc., Ser. B* (3), **70**, 264.
		LOWER	Albian	Collignon, 1965. Rapport sur L'Etage Albian. **In** Colloque sur le Crétacé Inferiéur, Lyon. *Mem. Bur. Rech. Geol. Min.* (34) (Lyon), 313. Casey, 1961. The stratigraphical paleontology of the Lower Creen-sand. *Paleontology.* **3**, 487.
			Aptian	Fabre-Taxy, S., Moullade, M. and Thomel, G., 1965. A-Les strato-types de l'Aptien. **In** Colloque sur le Crétacé Inferiéur, Lyon. *Mem. Bur. Rech. Geol. Min.* (34), 173. Casey, R., 1961. The stratigraphical paleontology of the Lower Green-sand. *Paleontology.* **3**, 487.
			Barremian	Busnardo, R. 1965. Le stratotype de Barremien. **In** Colloque sur le Crétacé Inferiéur, Lyon. *Mem. Bur. Rech. Geol. Min.* (34) (Lyon), 101.
			Hauterivian	Debelmas, J. and Thieuloy, J., 1965. E'tage Hauterivian. **In** Colloque sur le Crétacé Inferiéur, Lyon. *Mem. Bur. Rech. Geol. Min.* (34), 85.
			Valanginian	Barbier, R. and Thieuloy, J., 1965. E'tage Valanginien. **In** Colloque sur le Crétacé Inferiéur, Lyon. *Mem. Bur. Rech. Geol. Min.* (34), 79.
			Berriasian	Busnardo, R., Hegaret, G. L. and Magne, J., 1965. Le stratotype du Berriasien. **In** Colloque sur le Crétacé Inferiéur, Lyon. *Mem. Bur. Rech. Geol. Min.* (34) (Lyon), 5.

MESOZOIC	JURASSIC	UPPER	Tithonian	Enay, R., 1964. L'etage Tithonique. **In** Colloq. du Jurassique (Luxembourg, 1962). *Compt. Rend. Mem., Luxembourg.* 355.
			Kimmeridgian	Ziegler, B., 1964. Das Untere Kimeridgien in Europa. **In** Colloque du Jurassic (Luxembourg, 1962). *Compt. Rend. Mem., Luxembourg.* 345.
			Oxfordian	Callomon, J. H., 1964. Notes on the Callovian and Oxfordian Stages. **In** Colloque du Jurassique (Luxembourg, 1962). *Compt. Rend. Mem., Luxembourg.* 269. Enay, R. *et al.* (in press). Les Faunes Oxfordiennes d'Europe Meridionale. Essai de Zonation. **In** *Colloque International du Jurassique (Luxembourg, 1967).*
		MIDDLE	Callovian	Callomon, J. H., 1964. Notes on the Callovian and Oxfordian Stages. **In** Colloque du Jurassique (Luxembourg, 1962). *Compt. Rend. Mem., Luxembourg.* 269.
			Bathonian	Cox, L. R. 1964. The type Bathonian. **In** Colloque du Jurassique (Luxembourg, 1962). *Compt. Rend. Mem., Luxembourg.* 265. Torrens, H. S. (in press). Standard zones of the Bathonian. **In** *Colloque International de Jurassique (Luxembourg, 1967).* Elmi, S., 1964. Précisions stratigraphieques sur la Bathonien supérieur du nord de l'Ardèche. **In** Colloque du Jurassique (Luxembourg, 1962). *Compt. Rend. Mem., Luxembourg.* 535.
			Bajocian	Elmi, S., Enay, R. and Mangold, C., 1964. La stratigraphie et les variations de faciès du Bajocien de l'Ile Crémieu (Jura meridional tabulaire). **In** Colloque du Jurassique (Luxembourg, 1962). *Compt. Rend. Mem., Luxembourg.* 539.
		LOWER	Aalénian	Enay, R. and Elmi, S., 1964. Précision sur la stratigraphie de l'Aalénien dans le Bugey occidental. **In** Colloque du Jurassique (Luxembourg, 1962). *Compt. Rend. Mem., Luxembourg.* 559. Maubeuge, P. L., 1963. La position stratigraphique du gisement Ferrifère Lorrain (Le problème de l'Aalénien). *Bull. Tech. Chambre Syndicale Min. Fer France.* (72).
			Toarcian	Elmi, S. *et al.* (in press). L'etage Toarcien. Zones et Sous-Zones d'Ammonites. **In** *Colloque International de Jurassique (Luxembourg, 1967).* Howarth, M. K., 1964. Whilbian and Yeovilian Substages. **In** Colloque du Jurassique (Luxembourg, 1962). *Compt. Rend. Mem., Luxembourg.* 189.
			Pleinsbachian	Geyer, O. F., 1964. Die typuslokalitat des Pleinsbachian in Württemburg (Südwer deutchland). **In** Colloque du Jurassique (Luxembourg, 1962). *Compt. Rend. Mem., Luxembourg.* 161.
			Sinemurian	Maubeuge, P. L., 1964. Quelques remarquès a propos de l'Hettangien du Sinemurien et du Lotharingien. **In** Colloque du Jurassique (Luxembourg, 1962). *Compt. Rend. Mem., Luxembourg.* 127.
			Hettangian	Elmi, S. *et al.* (in press). Les Subdivisions biostratigraphiques de l'Hettangien en France. **In** *Colloque International du Jurassique (Luxembourg, 1967).*

NOTES ON CONCEPTS OF STAGE– AND OTHER BOUNDARIES

(A) Zanclian is used in preference to Tabianian because the former has been shown to contain a better and more diverse marine fauna which can be used in regional stratigraphic correlation.

(B) Tortonian is placed in the Upper Miocene because:
1) This was its original placement.
2) Although subsequently placed in Middle Miocene, it has now been returned to its original position because the Langhian has been moved up from the top of the Lower Miocene into the Middle Miocene. The type Tortonian is subsequent to beds called "Elveziano" or "Tortonian of Vienna basin", from which many species of Mollusca, especially, have been described as typical of the Middle Miocene. These "Vienna beds" are within the same stratigraphic interval as the beds of the Langhian (=Serravallian of Vervloet, 1966).

(C) The Langhian is restricted, for the purposes of this Manual, to the beds included in the Cessole Formation, and excludes the older horizons included in the Langhian by Cita and Elter.

This essentially follows the usage of Pareto (1865), who directly referred only to the section north of Cessole, which commences with the Cessole Formation. This is in accordance with the results of the work carried out by Drooger and colleagues, who recommended that the first evolutionary appearance of the genus *Orbulina* occurs from the base of the Middle Miocene, which is a few meters above the base of the exposed Cessole Formation at Cessole.

This is supported by the fact that the base of the French stage Sallomacian (which falls within the Langhian Stage) has always been regarded by the French as the commencement of the Middle Miocene. (The name "Sallomacina" has two years' priority over the term "Vindobonian".) The beds included in the Langhian and Sallomacian Stages are also equivalent to the Badenian Stage of Reiss and Gvirtzman, which covers beds included in the Vindobonian from which virtually all the typical Middle Miocene molluscs were obtained.

(D) The Girondian Stage (Vigneaux *et al.,* 1954) is coextensive with the Aquitanian and Burdigalian, and forms a stratigraphic unit well defined in terms of larger Foraminifera and Mollusca.

(E) Regarding the position of the Oligocene-Miocene boundary, for the purposes of this Manual, the panel has accepted (by majority opinion) the base of the stratotype Aquitanian to represent the base of the Neogene (Oligocene-Miocene boundary), as recommended by the Comité du Néogène Mediterranéen in 1959 (published 1960), 1961 (published 1964), 1964 (published 1966) and 1967 (in press), but not yet formally approved by the IUGS.

There is a radical dichotomy of opinion represented among the panel members, and the two viewpoints are explained below, labelled 1 and 2.

1. It has been recommended that the base of the stratotype Aquitanian should be taken as the base of the Miocene (and, therefore, the base of the Neogene). The following points apply:
   (1) When originally proposed, the Bormidian was regarded as Miocene, and one of the latest publications (Lorenz, 1964), also regarded it as Miocene.
   (2) The Bormidian is highly conglomeratic and rests directly upon the Triassic; normally it would not be considered suitable for a stratotype for a standard stage. There has been no indication whether any of the fossils recorded are derived or not (the pebbles of phyllites, schists, etc. obviously are derived). Some fossils were believed later to be Oligocene, but some have been found elsewhere *only* in beds of Miocene age. To the east of the area the Bormidian is cut out, and the overlying Aquitanian rests directly on nummulitic Oligocene (not present to the west) so that there is an unconformity at the base of the Bormidian–the Triassic underlying it in one area, and nummulitic Oligocene underlying it in another area.
   (3) The European stage names on the Tertiary Chart prepared by this panel were all based upon marine megafossil faunas such as Mollusca, Echinoidea, larger Foraminifera, etc. (except for the Paleocene, which originally was based upon plant evidence). The evidence of planktonic foraminifera, however important an asset it may be in the refinement of zonation within and correlation of these stages, did *not* enter into the primary definitions. It seems quite wrong *arbitrarily* to select one level of planktonic foraminiferal zonation to define the Miocene-Oligocene boundary; it remains but one part of a much larger field for synthesis. In any case, terms such as "Miocene" and "Oligocene" are time-stratigraphic units, and cannot be stratotypified. Consequently, the evidence of megafossils should be considered when

attempting to find a suitable position for the Miocene-Oligocene boundary.

(4) In the Marnes Blanches de Bernachon, which immediately and conformably underlie the stratotype Aquitanian, there are 7 species of Gastropoda, 9 species of bivalvia, and 20 species and 1 subspecies of Ostracoda, all of which occurred in the overlying Miocene faunas, but have not been found anywhere else in beds regarded as being of Oligocene age. There were a few Ostracoda having known long ranges, but *not a single* mollusc or ostracod previously known only from the Oligocene or from Oligocene and older beds. This fauna is to be regarded as Neogene and Miocene. In the same beds are found Miogypsina at a more advanced stage of evolution than those of the Eochattian of Bunde. These beds rest unconformably upon nummulitic Middle Oligocene.

(5) In the Nordic Province of Northwestern Europe, the fauna of the Vierländer Stage, although originally regarded as Aquitanian, was later regarded by Kautsky (1925) as being of Burdigalian or even younger age. Consequently, in this Nordic province, there are *no* basal Miocene megafossil faunas at all available for comparison with the megafossil faunas of the stratotypes of the Chattian, Eochattian and Neochattian. Furthermore, it is evident that the top ends of the ranges of the megafossils in the stratotype Chattian are completely unknown since some of them may well (and probably do) range up into basal Miocene age of much of the Eochattian-Neochattian succession were not realized, such extensions of ranges would never come to light.

(6) With regard to the Eochattian-Neochattian succession it is perhaps significant that: (a) there are several common molluscan species in the Neochattian of which there is no sign in the Eochattian, and (b) there are three levels in the Eochattian at which derived Liassic ammonites occur.

(7) The fauna of the Escornebéou beds as published by Butt (1966) was regarded by him (and Drooger) as late Oligocene ("Chattian"). Not only does this material contain derived material from at least two older levels, and not only do the beds in the area rest unconformably on the Cretaceous, but the faunas include good *Globigerinoides* which correlate the material with material *within* the type Aquitanian at the *oldest.* This material is therefore *younger* than the Neochattian.

(8) Conclusions: The terms "Miocene" and "Oligocene" are time-stratigraphic units and cannot be stratotypified. Miocene faunas occur *beneath* the stratotype Aquitanian, and at Escornebéou (where they were called Oligocene). Much of the Eochattian-Neochattian succession can reasonably be regarded as basal Miocene. Useful levels of changes in planktonic foraminiferal faunas are certainly to be used to refine the time-limits within which successions of megafossil faunas occur, but any single one of these *alone* should *not* be taken to define a boundary such as "Miocene-Oligocene" without synthesizing the planktonic foraminiferal faunal evidence with that of the megafossils. Any attempt to take the "Miocene-Oligocene" boundary at the incoming of *Globigerinoides* (i.e., base of stratotype Aquitanian) would result in a large number of molluscan, echinoid, larger foraminiferal, etc. faunas having their ranges extended a very short distance down into the "Oligocene" (*sic*), at which level there is not only a very noticeable faunal change in many groups of fossils (justifiably taken as the Neogene-Palaeogene boundary) but very often evidence of unconformity in the Alpine-Himalayan region (used in a broad sense). It seems to be highly undesirable to have a major faunal change occurring a short distance below one of relatively minor significance, and to use the latter rather than the former as a "Miocene-Oligocene" boundary.

2. The stratigraphic extent of the Bormidian can be shown in terms of planktonic foraminiferal zones to include much of the interval ascribed to the Eochattian and Neochattian of Northern Germany. The uppermost part of the Bormidian is approximately at the same level as the middle part of the Neochattian, and both are prior to the *Globigerinoides* datum which can be recognized at the base of the stratotype Aquitanian. This *Globigerinoides* datum, as expressed in the stratotype Aquitanian, was recommended in 1959 and reaffirmed in 1963 and 1967, by the Neogene Commission on Mediterranean Neogene as the horizon to be taken to mark the base of the Miocene. The base of the Bormidian falls within the upper part of the Eochattian succession, while the lower part of Eochattian succession, has been correlated, Hubach

(1957), and Anderson (1961) with the type Kassel Sands representing the type Chattian. Therefore, there is a *prima* facie case for regarding the Bormidian as post-Chattian, but pre-Aquitanian. German workers have long regarded the successions seen at Kassel, Doberg and Astrup as being a single major lithological unit, and have considered them as Oligocene. However, where Beyrich (1854 and 1858) did not discuss the present exposure at Astrup, he did discuss the beds at Doberg which include both Eochattian and Neochattian. Therefore, in Beyrich's terminology, the term "Oligocene" should be applied, not only to the Kassel Sands, but also to the succession at Doberg. *Miogypsina septentrionalis* occurs from near the exposed base of the succession at Doberg (Bed Number 10 of Hubach). This horizon is referable to Zone P.19 of Blow, and also was correlated by Hubach and Anderson to be within the interval of the type Kassel Sands. Furthermore, the latest horizon recognized within the Boom Clay of Belgium (type Rupelian) is also within Zone P. 19. Thus, in agreement with the work of Batjes (1958), there is a reasonable case for considering the Chattian as part equivalent, at least, of the later parts of the Rupelian. The range of *Miogypsina* ss. must include a part of the Oligocene, and, therefore, cannot be used to decide Neogene or Paleogene affinities.

(F) The Biarritzian Stage has been shown to be partly upper Lutetian and partly lower Auversian. Curry (1967) has suggested that the term "Auversian" covers a recognizable and useful sequence, although it is not quite as extensive stratigraphically as suggested by its usage by some previous French workers. Since the terms Biarritzian and Auversian are provincial in nature they are not used in this manual.

(G) Van Hinte (1965) erected a neostratotype for the Campanian which contains planktonic foraminiferal faunas in the lower part and orbitoids in the higher part. The Campanian planktonic foraminiferal faunas are, from analysis of Van Hinte's figured forms (by Pessagno and Blow), an assemblage which is long-ranging in the broad concept of Campanian, but is not likely to be that which occurs in immediately pre-Maestrichtian horizons. There is no justification for accepting Van Hinte's supposition that *G. calcarata* bearing beds (his Unit G), immediately overlie the neostratotype G of Van Hinte. In support of this, Blow (unpublished) has observed a single broken specimen of *G. calcarata* presumably from the same Unit G from which Van Hinte recorded his planktonic faunas. In view of the fact that the occurrence of *G. calcarata* is sporadic and the fauna from the neostratotype is very much restricted in diversity and in number of species, it appears that Van Hinte's Unit G is in part, at least, representative of the *G. calcarata* zone. However, there is an interval between the top of Unit G and the first horizon of occurrence of undoubted orbitoids (e.g. *Orbitoides media*) which have been accepted by many authors as characteristic of Maestrichtian.

It should be noted that many small *"Orbitoides"* occur in the interval between the first occurrence of *O. media* and the top of the planktonic foraminiferal fauna of Bed G. These forms (e.g. *Schlumbergeria*) have been accepted as Campanian forms by many authors; therefore, at least the lower half of Van Hinte's Unit F must be considered as Campanian, whereas the upper half of Unit F and the younger horizons should be ascribed to Maestrichtian. Because of this, this manual shows *G. calcarata* disappearing just prior to the Campanian-Maestrichtian boundary and *G. ventricosa* disappearing at or very near the Campanian-Maestrichtian boundary.

(H) Santonian s.s. is that part of the Santonian represented by the stratotype.

(I) Beneath the exposed beds of the stratotype Santonian is an interval, part of which is undoubtedly Coniacian as represented in its "stratotype", but between the two there are both beds and faunas which have not been unambiguously differentiated.

(J) The Vraconian of certain Continental authors is here artibrarily included as low Cenomanian.

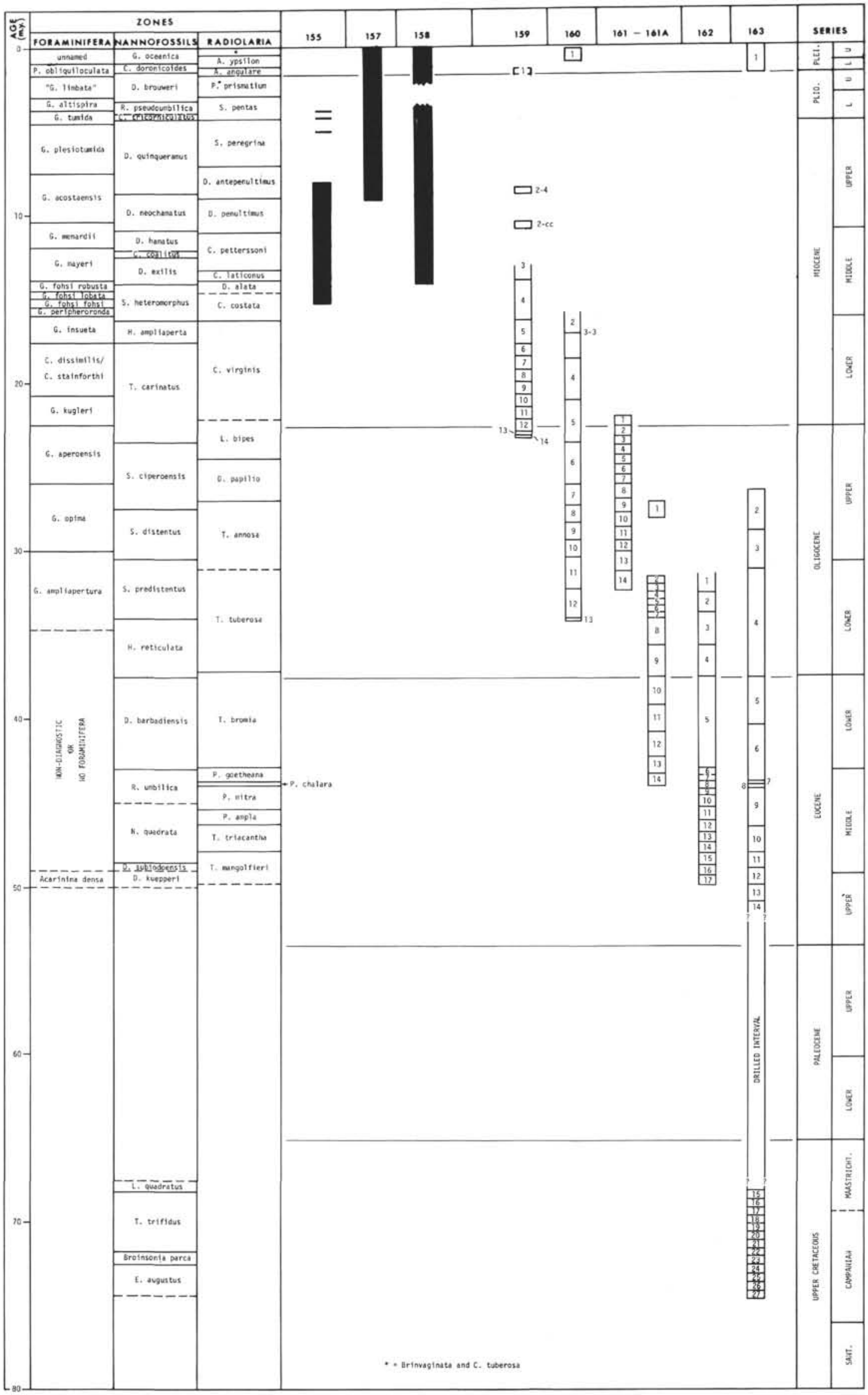
Basis for Age Determinations

Based on earlier legs of the Deep Sea Drilling Project and on observations made during Leg 16, the correlation of microfossil zones shown in Table 2 is used throughout this volume. The absolute ages of the major boundaries shown in Table 2 are from Laughton, Berggren et al. (1972). The uncertainty of any of the values shown is probably less than 4 my, based on the various compilations published during the past four years.

Data Presentation

As far as possible, raw data are presented in the various site reports and specialized studies included in this volume. Because of space limitations, however, the core descriptions represent a condensation of the detailed section and smear slide descriptions made on the ship. The original descriptions are on open file at DSDP headquarters in La Jolla. Limitations on the accuracy and precision of the various types of data are mentioned in this chapter and in the various integrated reports of the shore laboratory studies of Part II of this volume (particularly those on physical properties and biostratigraphy). They should be consulted before attempting to synthesize data from the site chapters.

TABLE 2
Absolute Ages of Major Boundaries



ACKNOWLEDGMENTS

The material presented in this chapter, particularly the Explanatory Notes, draws heavily on comments and suggestions of our colleagues on Leg 16 and on earlier introductory sections of Initial Reports of the Deep Sea Drilling Project (particularly those of the Leg 7 report). We gratefully acknowledge the assistance provided by these various sources.

REFERENCES

Anderson, H. J. 1961. Meyniana. **10**, 118.

Batjes, D. A. J., 1958. Foraminifera of the Oligocene of Belgium. Inst. Roy. Sci. Nat. Belg., Mem. 143.

Bennett, R. H. and Lambert, D. N., 1971. Rapid and reliable technique for determining unit weight and porosity of deep-sea sediments. Marine Geol. **11**, 201.

Beyrich, E., 1854. Über die Stellung der Hessischen Tertiarbildung. Verhandl. Preussen Akad. Wiss. Berlin. 640.

_______, 1858. Über die Abgrenzung der Oligocänen Tertiärzeit. Monatsber. Preussen Akad. Wiss. Berlin. **54**.

Boström, K. and Peterson, M. N. A., 1966. Precipitates from hydrothermal exhalations on the East Pacific Rise. Econ. Geol. **61** 1258.

Brier, C., Bennin, R. and Rono, P. A., 1969. Preliminary evaluation of a core scintillation counter for bulk density measurement in marine sediment cores. J. Sediment. Petrol. **39**, 1509.

Butt, A. A., 1966. Late Oligocene Foraminifera from Escornebéou, S. W. France. Utrecht (Schotanus & Jens).

Curry, D. 1966. Correlations within the Anglo-Paris-Belgian Palaeogene Basin. Proc. Geologists' Assoc. London. **77**, 437.

Deer, W. A., Howie, R. A. and Zussman, J., 1962. Rock-Forming Minerals. Vol. 1-5. London (Longmans, Green and Co., Ltd.).

Goddard, E. N. et al., 1948. Rock color charts. Natl. Res. Council. Washington, D.C. (republished by Geol. Soc. Am.), 8 p.

Hansbo, S., 1957. A new approach to the determination of the shear strength of clay by the fall-cone test. Royal Swedish Geotech. Inst. Proc. **8**, 1.

Hubach, H., 1957. Das Oberoligocän des Doberges bei Bunde in Westf. Ber. Naturhist. Gesell. Hannover. **103**, 1.

Kautsky, 1925. Abhandl. Geol. Landesamst. Ber. N.F., **97**, 1.

Lambe, T.W., 1951. Soil Testing for Engineers. New York (John Wiley and Sons), 165 p.

Laughton, A.S. and Berggren, W.A. et al., 1972. Initial Reports of the Deep Sea Drilling Project, Volume XII. Washington (U.S. Government Printing Office). 15

Lorenz, L., 1964. Bull. Soc. Geol. France. Ser. 7, **6**, 192.

Munsell Color Company, 1954. Munsell Soil Color Charts. Baltimore (Munsell Color Co., Inc.), 23 p.

Olausson, E., 1960. Descriptions of sediment cores from the central and western Pacific with adjacent Indonesian region. Rept. Swedish Deep-Sea Exped., 1947-1948. **6**(5), 161.

Pareto, L., 1865, Bull. Soc. Geol, France. **2**(22), 229.

Peterson, M.N.A., Edgar, N.T. et al., 1970. Shipboard scientific procedures. *In* Initial Reports of the Deep Sea Drilling Project, Volume II. Washington. (U.S. Government Printing Office). 452.

Pettijohn, F.J. and Potter, P.E., 1964. Atlas and Glossary of Primary Sedimentary Structures. New York (Springer-Verlag). 305 p.

Rex, R.W., 1970. Shore-based laboratory procedures (X-ray mineralogy). *In* Bader, R.G., Gerard, R.D. et al., 1970. Initial Reports of the Deep Sea Drilling Project, Volume IV. Washington (U.S. Government Printing Office). 748.

van Andel, Tj. H., Heath, G.R., Malfait, B.T., Heinrichs, D.F. and Ewing, J.I., 1971. Tectonics of the Panama Basin, eastern equatorial Pacific. Bull. Geol. Soc. Am. **82**, 1489.

Van Hinte, J.E., 1965. The type Campanian and its planktonic Foraminifera. Koninkl. Ned. Akad. Wetenschap. Proc. Ser. B, **68** (1), 8.

Vervloet, C.C., 1966. Stratigraphical and Micropaleontological Data on the Tertiary of Southern Piedmont (Northern Italy). Thesis, Univ. Utrecht. Utrecht (Schotanus & Jens).

Vigneaux, M., Magne, A., Veillon, M. and Moyes, J., 1954. Compt. Rend. Acad. Sci. Paris. **239**, 818.

Wentworth, C.K., 1922. A scale of grade and class terms of clastic sediments. J. Geol. **30**, 377.