1. INTRODUCTION

Studies of the Pacific Ocean had indicated that tangible evidence for its earliest history was most probably locked in the sediments and crust that now form the abyssal sea floor southeast of Japan and east of the Mariana Trench. The overall geologic history of this exceptionally deep region was the prime focus of Leg 20 of the Deep Sea Drilling Project.

The great water depths (19,800+ ft.) and the relatively great thicknesses of sediments, particularly interlayered sequences of chalk and chert, provided formidable obstacles to the prime goals. These stringent circumstances called for optimal drilling conditions both with respect to weather and equipment. Although this combination kept us from one of our main goals, the age of the oceanic crust, 13 holes were successfully drilled including 4 in deeper water and with longer drill strings (195B, 196, 197, 199) than ever previously attempted in the ocean. The stratigraphic horizons above the basement provided important new data on the early history of the Pacific Ocean, giving additional evidence on plate motions, equatorial crossings, oceanic sedimentation processes, and showing that the crust in the western Pacific is Jurassic or older.

SITES

Site 194

Site 194 (Table 1 and Figure 1) was drilled on the abyssal floor 630 km east of the Japan Trench and penetrated 227 meters of silty clays into a hard cherty layer. The sampled silty clays range from Quaternary to late Miocene in age and are rich in radiolaria, silicoflagellates, and diatoms with numerous thin ash layers, occasional pumice fragments, and abundant fragments of glass and other volcanic debris. The underlying cherts are Cretaceous in age.

Site 195

Site 195 (Figure 1) is situated 130 km south of Site 194. Three holes were drilled to a maximum total depth of 392 meters. The upper layers, which are composed of Quaternary to late Miocene diatomaceous, ash-rich, silty clays, overlie a thick sequence (200 m) of Cretaceous cherts and chalks and late Jurassic to early Cretaceous nannofossil chalks, cherts, and marls. Foraminifera occur with the nannofossils in one sample but are lacking from all subsequent samples of this unit.

Site 196

At this site (Figure 1), the longest drill string yet used in the oceans penetrated 377 meters of oceanic sediments. As at earlier sites, the stratigraphic succession consists of silty clays overlying a Mesozoic sequence of chert, nannofossil chalk, limestone, and mudstone. Although rare altered foraminifera were found with radiolarians in the Late Cretaceous deposits, foraminifera were absent in the older nannofossil chalks. The silty clays may be divided into two units: late Tertiary silty clays containing volcanic ash and a trace of radiolarians and overlying zeolitic silty clays with relatively large amounts of micronodules and iron oxides. A sharp break in the drilling rates at Sites 194, 195, 196, and 197 marks the boundary between the two clay units.

Site 197

At Site 197 (Figure 1), a two-meter section of tholeiitic basalt was recovered from 278 meters beneath Cretaceous/Jurassic cherts and chalks. Although the textures are characteristic of an ocean floor basalt, slight decrease in grain size to the top and bottom of the section leaves some ambiguity as to whether a thin sill or true oceanic basement was sampled.

Site 198

Site 198 (Figure 1) was drilled to a depth of 158 meters some 200 km north of Marcus Island. At this locality, we recovered a sequence of Late Cretaceous limonite-rich, zeolitic silty clays with abundant volcanic glass and micronodules, which overlies Late Cretaceous cherts and chalks with radiolarians and altered foraminifera, which in turn overlie a thick sequence of Jurassic to Cretaceous chalks and cherts.

Site 199

This site (Figure 1) is located at the northeast margin of the Caroline Abyssal Plain. The hole penetrated through 275 meters of an interlayered turbidite sequence. The turbidite sequence extends from the Quaternary to at least the middle Miocene and is composed of zeolitic clays with allochthonous interlayers of nannofossil chalk and occasional siltstones. Mixed fossil assemblages in the turbidites indicate two source areas, one containing carbonate oozes and the other radiolarian oozes of Miocene to Eocene age. Underlying the turbidites are 190 meters of late Paleocene to late Campanian interlayered chert and nannofossil chalks. An apparent unconformity between the late Paleocene and Danian-Maastrichtian chalk was found.

Sites 200, 201 and 202

These sites (Figure 1) were drilled on top of a 4500-meter-high seamount on the northeastern margin of the Caroline Abyssal Plain where 132 meters of Quaternary to early Eocene foraminiferal sand was recovered. Underlying the ooze is a hard oolitic limestone some 50 meters thick which in turn is underlain by coraline muds, both indicative of shallow reef-like environments.

SITE SELECTION

The deepest, and thus presumably the oldest, portion of the Pacific basin lies between the Mid-Pacific Mountains and the Asiatic island arcs. Extrapolations of crustal age gradients inferred from magnetic anomalies and supported by previous drilling further support the inference. Drilling on Leg 6, although failing to penetrate basement in the deep basin, established paleontologically that the area west

TABLE 1
Site Data and Coring Summary, Leg 20

Hole	Lat	Long	Date	Water Depth (m)	Subbottom Penetration (m)	Cores Cut	Cored (m)	Recovered (m)	Recovered (%)
194	33°58.68'N	148°48.64'E	19-22 Sept	5754	256	5	39.5	15	37.9
195	32°46.40'N	146°58.73'N	22-24 Sept	5968	292	5	31	14	45.2
195A	32°46.40'N	146°58.73'E	24-25 Sept	5968	283	0	0	–	–
195B	32°46.40'N	146°58.73'E	26-29 Sept	5968	392	3	16.5	1	6.1
196	30°06.97'N	148°34.49'E	29 Sept-2 Oct	6194	377	6	40	8.5	21.3
197	30°17.44'N	147°40.46'E	3-8 Oct	6153	278	1	9.5	1	10.5
198	25°49.54'N	154°35.05'E	10-14 Oct	5958	158	6	51	26	51
199	13°30.78'N	156°10.34'E	23-26 Oct	6100	465.5	13	123.5	59	47.8
200	12°50.20'N	156°46.96'E	27 Oct	1479	114	10	95	35.63	37.5
200A	12°50.20'N	156°46.96'E	27 Oct	1479	132	2	19	0	0
201	12°49.89'N	156°44.59'E	28 Oct	1564	96	0	0	0	–
202	12°48.90'N	156°57.15'E	28-30 Oct	1515	153.5	6	56.5	2.5	4.4
				Totals	2797	57	481.5	162.63	33.8

of the Shatsky Plateau includes crust at least as old as earliest Cretaceous. Dredging on seamounts had established that the area was an ocean basin at least 5000 meters deep at the beginning of the Late Cretaceous. Undated and somewhat conjectural patterns of magnetic anomalies suggested a roughly east-west continuation of the east Pacific pattern extending south of the Mid-Pacific Mountains and a northwest-southeast pattern east of Japan. The pinching out of seismic reflectors to the northwest and the increase in ocean depth to the southeast implied that the crust east of the Japan Trench was older to the south and southeast. Acoustic stratigraphy was an important guide in determining scientific objectives, but it must be noted that in the opaque layer area the varying clarity of the few records available resulted in considerable ambiguity in the determination of the total thickness and stratification. For example, the ARIES VII records showed deep penetration east of the Japan Trench where previous records, due to poorer penetration, recorded a thin sequence and implied a much shallower basement. However, in site selection, the objectives of learning the earliest history of the older areas of the Pacific had of necessity to be subordinated to two engineering considerations: (1) the contract limit was 22,500 feet of drill string length (thus the oldest areas were presumably excluded), and (2) at least 180 feet of upper transparent sediments were necessary for spudding-in in sediments that are easily penetrated but sufficiently strong to laterally support the bottom hole assembly when the bit encounters the first hard formation. The upper layer of unconsolidated sediment is so thin over most of the basin between the Hawaiian Chain and the western Pacific arcs that for this immense area less than a dozen prospective sites could be located on the basis of existing reflection profiles. The limitation that drilling could not exceed the contract limit of 22,500 feet of drill string length removed several otherwise attractive prospects. What remained was a fringe area extending nearly 1000 km from Japan, and a few very local areas of anomalous sediment thickness related to archipelagic aprons and other topographic anomalies.

The first four sites exploited the presence of a volcanogenic sediment layer east of the Japan Islands. The fifth site was located on the archipelagic apron of Marcus Island. Since none of the prospective sites located in the mid-latitudes south of Marcus Island possesses the normal minimum thickness of soft sediment specified by the drillers, prospects for the location and successful completion of holes in the area were considered dim. The failure of the main swivel during the drilling of Site 198 forced a return to port and postponed the search for spuddable sediments until after departure from Guam.

Site 199 exploited the turbidite-ponded sediments at the margin of the Caroline Abyssal Plain. Before the completion of this site, deep-water drilling was terminated by a failure of the crown block and the search for spuddable sediments was ended just when the southerly track brought the ship out of the deepest basins and to the archipelagic, equatorial, and plateau areas where adequate sites could be more readily found.

DRILLING

Leg 20 was characterized by particularly difficult drilling conditions. The major portion of the planned drilling was in water depths in excess of 19,000 feet; and the old age of this part of the Pacific resulted in generally thicker sedimentary sequences, the greater proportion of which are composed of interlayered chalks and cherts.

Each of the above pose separate but compounding adverse factors. The great depths require a long drill string whose total weight (500,000 lbs.) approaches the tensile strength of the drill pipe. Therefore, there is little margin for excursions in the total weight, and it restricts drilling to calm weather and leaves little leeway for any recovery operations when the drill string or bit is stuck or subjected to some other difficulties. Greater sediment thicknesses add to the above and also seriously increase bit wear. The cherts

Figure 1. *Physiographic diagram of the western Pacific (Heezen and Tharp, 1971) showing location of Leg 20 sites.*

pose a particularly formidable drilling obstacle since they are hard on the bits. Their brittle nature results in the formation of coarse chips which accumulate around the drill stem, finally choking it and sticking the whole assembly firmly in the hole. The latter problem could be alleviated if adequate amounts of mud were used to keep the hole clean. However, the inability to recycle the excessively large amounts of mud required, and the high cost of drilling mud all sum up to make this alternative available only under emergency conditions. In a more general sense one should also consider other potentially problematical sediments such as sand or gravels which accentuate some of the problems posed by the cherts.

In order to better guarantee drilling successes compatible with scientific ambitions, a number of conditions are required. The prevailing weather and sea states should, expectedly, be calm, the drilling equipment should be well maintained and operating close to its optimal specifications, and the drilling crew should be experienced with the problems of deep drilling. All the above conditions are operational factors which must be considered in the planning of any drilling program.

A great deal of agony must always be experienced by chief scientists in deciding how much of a hole to drill and how much to core. The uninitiated is usually shocked to learn that all holes are not continuously cored, but practical limitations deny this possibility. In coring, the 30-foot core barrel is pumped down the pipe and emplaced in the drill bit. The 30-foot section is then drilled, using as little water circulation as is deemed safe by the drillers. Then the overshot is lowered on the sand line to grab and recover the core barrel. In continuous coring, the core barrel is then again pumped down the drill pipe. In drilling, the center bit is pumped down in place of the core barrel. In abyssal depths these operations take several hours, and continuous coring proceeds at an average of a few feet per hour. If the hole is unstable and water circulation is needed to avoid sticking the drill pipe, the 30-foot core might contain only a few chips of chert and coring is continuous in only an operational engineering sense since a continuous core is not recovered.

The Leg 20 drillers believed that continuous coring encouraged hole collapse, and they would not continuously core in chert-chalk sequences due to the great risk of sticking and losing part of the drill string. Sticking was experienced in every hole. In two cases the bottom hole assembly had to be blasted off the drill pipe.

In less difficult areas, the choice of continuous or intermittent coring is usually a compromise between desired scientific data and the time allocated by the schedule. However, surmounting drilling difficulties became the prime consideration in determining the intervals to be cored on Leg 20. The option of continuous coring was not open on Leg 20.

The intervals cored on Leg 20 principally represent the judgment of the drillers as to what they were able to core rather than the scientific priorities placed by the chief scientist in consideration of what was scientifically desirable to core. It was the drillers' opinion that frequent attempts to core the chert-chalk sequence would jeopardize any hope of penetrating to the presumably less cherty beds of the lower transparent layer, and they were strongly of the belief, supported by Leg 20 experience, that such coring would drastically increase the risk of a catastrophic loss of drill string and drill collars. In addition to preventing us from recovering the lower sequences the drilling difficulties also limited sampling in the sedimentary sections penetrated by the Leg 20 holes.

As with other legs, Leg 20 was characterized by a number of successes and failures. The above problems are very real, and in one form or another we experienced varying combinations. Often, we were forced to abandon the hole while still short of our prime scientific objective. The major result was our failure to get sufficient data on the age of the western Pacific crust. However, despite these formidable obstacles the drillers were still able to set a record using the longest drill string yet attempted in the program (21,558 feet or 6571 meters) which recovered the oldest rocks found in the Pacific.

SEDIMENTS

Northern Drilling Sites

The sediments drilled in the general area 1000-2000 km southeast of Japan may be divided into two lithologies (Figure 1): Cretaceous to Tertiary silty clays, and an interlayered sequence of Jurassic to Cretaceous cherts, chalks, limestones, and marls. The silty clays may be separated into two units on the basis of drilling rates and zeolite content. The upper unit is composed of Quaternary to late Miocene silty clays which have abundant evidence of their volcanic source. Glass fragments, palagonite, detrital plagioclase grains, and occasional pyroxenes make up the major component of the clay, while ash layers are ubiquitous and pumice fragments common. No calcareous fossils are present, but both high- and low-latitude species of silicoflagellates, diatoms, and radiolarians invariably occur (except at Site 196 where only robust radiolaria were found in the late Pliocene sample). The lower silty clay unit, which near its base is Late Cretaceous in age, characteristically contains abundant zeolites. Micronodules and iron hydroxides are common, and it is largely unfossiliferous although minor numbers of radiolarians occasionally occur. The silty clays may be correlated with the acoustic upper transparent layer, which in the area drilled thins from approximately 150 meters to 10 meters eastward from the Japan Trench. Where this layer is thicker, the upper portion is well stratified with the stratified layer thinning eastward. The lower portion is generally structureless, thin (10 m to 50 m), and exists as a thin layer throughout the area. The upper stratified layer is correlated with the late Tertiary ashy clays and the structureless layer with the early Tertiary and late Mesozoic zeolitic clays. Presumably, the layering reflects the large number of ash units in the upper horizon. Commensurate with the drilling data, the stratified layer thins away from the trench and is interpreted as a wedge of volcanic debris whose source is the Tertiary andesitic volcanoes of the Asiatic arcs. The structureless unit extends as a thin (10 to 50 m) layer throughout the western Pacific and is interpreted as the normal abyssal clay component.

Beneath the early Tertiary and Late Cretaceous zeolitic clays is a sequence of Jurassic to Late Cretaceous cherts, chalks, limestones, and marls. Drilling with the 3- and

4-cone roller bits resulted in poor recovery of the limestones and cherts while the intervening softer chalks and clays were washed away. Drilling rate changes in these units suggest that the cherts do not exceed a few meters in thickness while the calcareous units are probably tens of meters thick. The cherts show a wide range of colors and are usually dense hard fragments which break with a conchoidal fracture. Occasional fragments are more porous and slightly limy. Thin layers were often seen. The calcareous interlayers vary in induration from soft chalks to dense limestones and siliceous limestones. The carbonate sequence is interrupted by a zone in which drilling rates markedly increased and which apparently lacks cherts. This relatively thin layer, although unsampled, is assumed to consist of mid-Cretaceous abyssal clay. The carbonate units are thought to result from the detrital remains of siliceous and calcareous organisms, accumulating on this portion of the ocean floor at times when it was above the effective local carbonate compensation depth. As discussed later the excessive thickness is thought to result from the increased organic sedimentation associated with the equatorial regions.

The upper chalk, chert, and limestone sequence equates with the acoustic upper opaque layer. At least 250 meters of carbonates were drilled, but the seismic reflection profiles suggest that they are often up to 400 meters thick in the area. The upper opaque layer is found throughout the region drilled. It appears to lie on the basement rocks to the west but is underlain by a lower transparent and lower opaque horizon to the east. Since we did not penetrate the lowest horizons, our age of Late Jurassic for the base of the opaque layer points to the crust in this area being at least Jurassic in age.

Mean sedimentation rates for the upper three units are significantly different. They are 20, <2, and 10 meters per million years for the late Tertiary clays, Late Cretaceous to early Tertiary clays and Late Cretaceous chalks and cherts, respectively (Figure 2). These rates then must reflect the volume of sediments being deposited on the ocean floor during its passage from a ridge crest to an opposing continental margin. The 10-meter-per-year value represents the rate of organic accumulation, the <2-meter-per-million-year value relates to abyssal clay sedimentation, and the 20-meter-per-million-year value relates to the addition of volcanic debris from active volcanoes on the Asiatic arcs.

Southern Drilling Sites

Four sites were drilled near the eastern edge of the Caroline Abyssal Plain: one at the edge of the plain, and three on a seamount along its eastern margin. The site at

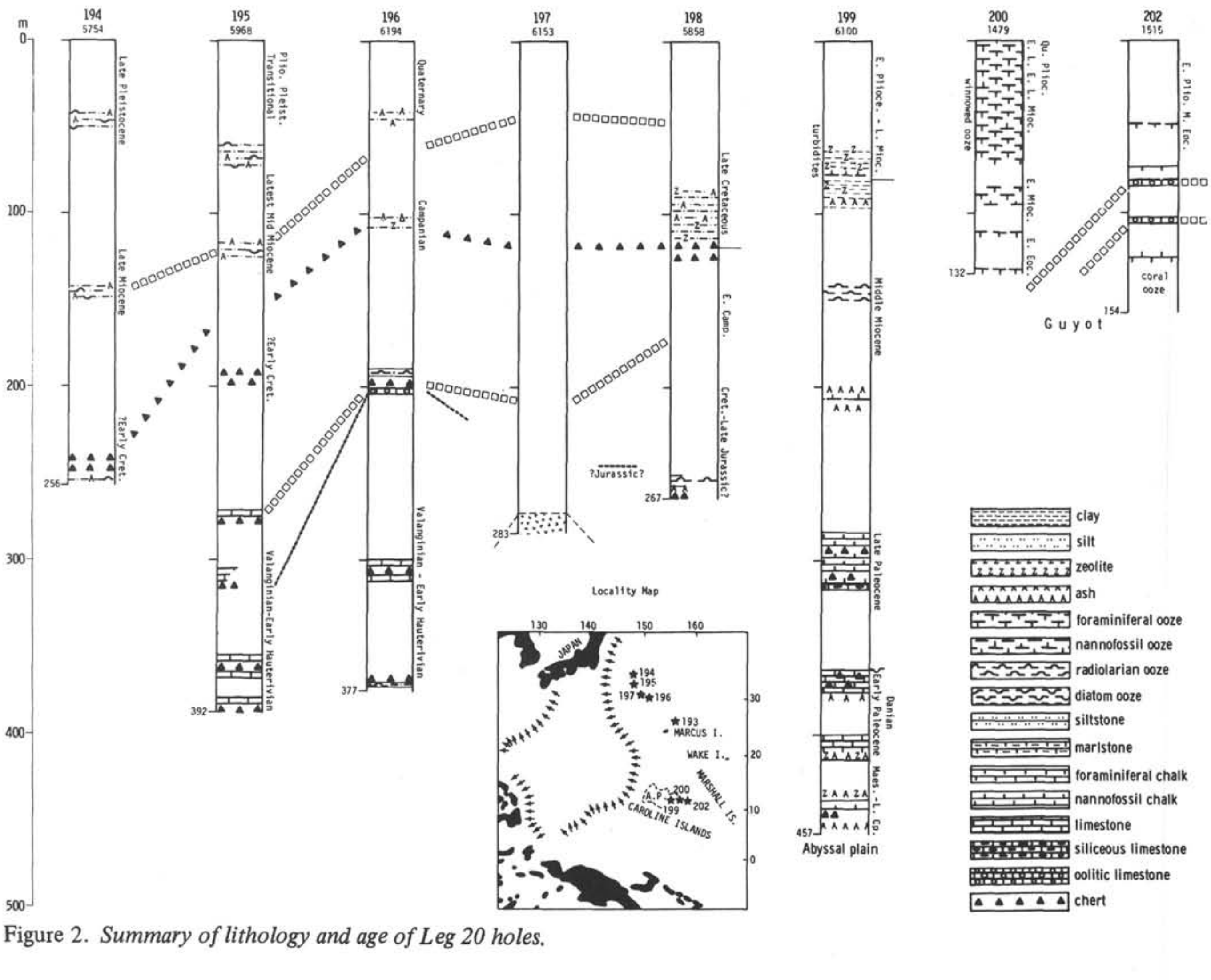

Figure 2. *Summary of lithology and age of Leg 20 holes.*

the edge of the plain penetrated two main lithologies (Figure 1), a Quaternary to Eocene turbidite sequence overlying interlayered, late Paleocene to late Campanian chalks, cherts, and limestone. The turbidites are made up of 210 meters of interlayered zeolitic clay, nannofossil ooze, and radiolarian ooze. The zeolitic silty clay has associated thin ash layers, plagioclase, glass shards, and palagonite, and is thought to be equivalent to the normal abyssal clay being deposited in the oceans. It is stratigraphycally equivalent to the late Tertiary clay of the northern sites. The turbidites consist of allochthonous nannofossil ooze with mixed fossil assemblages ranging from Quaternary to Eocene in age, and a layer of radiolarian ooze. The fossil assemblages indicate at least two source areas for these sediments. The interlayered turbidites have a well-defined acoustic signature which may be traced across the whole of the Caroline Abyssal Plain and suggest that the Tertiary deposition in this region is characterized by turbidite sedimentation originating from shallower sources along the Caroline Ridge.

Beneath the turbidites is a thicker (at least 250 m) sequence of interlayered chalks, cherts, and limestones of late Paleocene and Maastrichtian age. Within the chalk/chert sequence there is an apparent unconformity, early Paleocene and Danian time being represented by a few meters of red cherty sediments. The seismic profiler results suggest that there is still a lower transparent, and possibly a lower opaque, horizon yet undrilled, indicating that the crust is of at least pre-late-Campanian age.

The three sites on Ita Mai Tai Guyot (Figure 1) show that the guyot is covered with Quaternary to early Eocene foraminiferal sand which overlies a pre-early-Eocene oolitic limestone indicating that this guyot was formed and eroded to sea level before this time and has since sunk 1600 meters to its present depth. Combining the seamount data with that of the adjacent abyssal plain site (199) it may be concluded that the local effective carbonate compensation depth at this location was at least as great as 5000 meters at the beginning of Eocene time.

THE FUTURE

The deep basin of the western Pacific still holds as its secret the earliest records remaining of the history of the Pacific basin. These secrets are at the limit of, or perhaps beyond, the present engineering capabilities of the Deep Sea Drilling Project and because of this have regrettably been temporarily put aside in deference to objectives more easily obtainable which do not require optimum conditions or an increase in engineering capabilities. Ultimately, another serious attempt must be made to solve the immensely important problems to which Legs 6 and 20 were devoted but to which contemporary engineering limitations denied a fuller solution. Progress in drilling bits allowed a dramatic advance in the two years between 1969 (Leg 6) and 1971 (Leg 20), and we should be able to anticipate a similar increase in capabilities between 1971 and that hopefully not too distant year when new engineering advances will allow the launching of another serious attack on the secrets held on, and in, the oldest oceanic crust.