16. SILICIFIED LIMESTONE-CHERT SEQUENCES CORED DURING LEG 8 OF THE DEEP SEA DRILLING PROJECT: A PETROLOGIC STUDY

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ABSTRACT

The east central Pacific basin sediments were sampled at eight sites during DSDP Leg 8, and siliceous limestones with cherts were cored at five of the sites. Generally speaking, uppermost cherts occur as thin stringers or nodules within Oligocene calcareous sediments. The bulk of the chert, usually intergrown with siliceous limestone, invariably occurs in middle and upper Eocene radiolarian-rich sediments.

In all cases the chert is composed of both cristobalite and quartz and contains ghosts of foraminifera and/or Radiolaria. It is considered likely that the source of silica required for the chert formation was from local dissolution of siliceous microfossils during diagenesis. A change in oceanographic conditions is postulated for lower Oligocene times to account for the lithologic change from radiolarian-rich sediments of the Eocene to the carbonate-rich sediments of the later Tertiary. This may be the reason for the restriction of most of the cherts to Eocene sediments.

INTRODUCTION

Eocene silicified limestones containing chert intergrowths and beds were cored at five sites (69, 70, 71, 72 and 73) of Leg 8 of the Deep Sea Drilling Project. Cherts (of a possibly nodular nature) of Oligocene age, along with silicified limestones were cored at three sites (70, 71 and 72).

The general lithologic and stratigraphic relationships of the above material are documented elsewhere in this volume (Tracey *et al.*, 1970).

This report is a preliminary microscopic study of thin sections of the limestones and associated cherts. X-ray diffraction studies have not been carried out to date on the material and tentative mineral identifications have been made solely by optical means. These interpretations lean somewhat on X-ray diffraction studies of comparable deep-sea cherts made during previous legs of the Project, in particular those of Heath and Moberly (1970).

OLIGOCENE CHERTS

Oligocene cherts, which were cored at Sites 70, 71 and 72, appear typically to occur as thin beds or nodules, a few centimeters in thickness, within calcareous ooze sequences. Radiolaria and diatoms are present in the associated oozes but are not major constituents, with calcareous nannoplankton and planktonic foraminifera forming the bulk of the sediment. The three occurrences of Oligocene chert are described below. For additional information regarding these sites refer to Part I, Site Reports in this volume.

Site 70

From Site 70 at a sediment depth of 188 meters, two fragments of light green, dull-lustered chert were cored. These contain inclusions of white calcareous ooze.

In thin section the matrix of the chert appears essentially isotropic and may be largely composed of opaline silica or cristobalite. Well-preserved planktonic foraminifera are numerous within the chert, generally partly or wholly pseudomorphed by chalcedonic quartz. Siliceous organic remains are rare but occasionally occur as pyrite pseudomorphs after Radiolaria.

Site 71

At least five resistant layers, ranging in age from upper to lower Oligocene, were noted during drilling of Site 71. One of these layers was sampled. It occurs within a foraminiferal-nannoplankton semi-indurated ooze interval at a sediment depth of 469 meters, and appears as a 3-centimeter thick stringer of medium gray translucent chert with adhering indurated calcareous ooze.

The boundary between the calcareous ooze and the chert is sharp. Within the chert, a 1-millimeter wide zone composed chiefly of isotropic silica occurs parallel to the ooze contact (Plate 1, Figure 4). This is possibly composed of cristobalite and represents the initial stage of chertification of the calcareous sediment. Foraminifera and rare Radiolaria present within this zone are generally replaced by chalcedonic quartz, which has replaced the calcium carbonate and opaline silica of the tests.

Plate 1, Figure 4 shows the irregular boundary which typically separates the cristobalite zone from the bulk of the chert. The best crystallized chert appears as a microcrystalline mosaic of anhedral chalcedonic quartz crystals which are clearly visible in the illustration. Typically, in this phase foraminifera and rare Radiolaria are present as diffuse ghosts, and are composed entirely of chalcedonic quartz. In most cases, they have been almost entirely obliterated by crystallization of the quartz.

Site 72

Two layers of chert were sampled in the middle Oligocene section of Site 72, from a sediment depth of 311 meters. These occur within a foraminiferal-nannoplankton ooze. They appear as light brown semitranslucent cherts in contact with lighter brown and white porcelanite layers which in turn grade abruptly into indurated calcareous ooze. Calcareous inclusions appear to be common within the main body of the chert.

In thin section, the porcelanite layers appear to possess a predominantly isotropic matrix of cristobalite, dusted with varying amounts of fine calcite. Foraminifera within the porcelanite are generally partly replaced by pseudomorphing chalcedonic quartz, as shown in Plate 1, Figures 2 and 6.

Plate 1, Figure 5 shows the somewhat irregular but sharply defined boundary between the essentially isotropic porcelanite zone and the main body of the chert, the latter of which is a microcrystalline mosaic of chalcedonic quartz. As can be seen from the plate, remains of foraminifera are considerably more abundant in the porcelanite portion and have been largely obliterated from the chalcedony during crystallization.

EOCENE CHERTS

Siliceous limestones with chert intergrowths and interbeds occur within the upper to middle Eocene siliceous and calcareous sediments of Sites 69, 70, 71, 72 and 73. At none of these sites was the complete chert sequence cored. Of particular interest is the great diversity of the cherts between the various sites.

Site 70

At Site 70, 75 centimeters of upper Eocene and 3.7 meters of middle Eocene radiolarian chert was cored. Although there is an uncored section of 52 meters between the chert samples, the lithotype is remarkably uniform. At this site the Eocene chert sequence occurs between sediment depths of 329 meters and the bottom of the hole at 388 meters.

Generally speaking, the Eocene cherts of Site 70 are composed of dull terra-cotta colored rocks with a sub-conchoidal fracture. Vitreous cherts are rare in the samples taken and only occur in two thin horizons within the middle Eocene portion of the cherts.

In thin section the dull terra-cotta cherts appear to have a slightly birefringent and oriented matrix, possibly composed of cristobalite. In some instances the matrix appears to consist of oriented filaments of an unidentified mineral with low to moderate birefringence which may be a mica or an incipient clay mineral. Calcite microcrystals in some samples occur as a dusting within the matrix. This form of chert grades into white, porous porcelanite having an essentially isotropic cristobalite matrix which contrasts with the more birefringent matrix of the terra-cotta cherts.

Circular ghosts of almost unrecognizable microfossils are abundant in both the porcelanites and terra-cotta cherts. Within the porcelanite zones these are commonly infilled with an isotropic form of silica and occasionally can be recognized as Radiolaria. Across the chert-porcelanite boundary within the cherts, the ghosts are infilled with acicular chalcedonic quartz which apparently has inverted from the opaline material present within the porcelanite. Occasional sponge spicules are present, and are invariably composed of a mosaic of chalcedonic quartz.

The dull terra-cotta colored cherts apparently grade at depth into a vitreous, amber-colored chert that is associated with a zone of brecciation and recementation by silica. In this section, the vitreous cherts contain abundant noncalcareous porcelanite inclusions and occasionally pass directly into green cherts.

In thin section the amber-colored vitreous chert is composed of a mosaic of chalcedonic quartz which contains an abundance of fossil ghosts, possibly originally Radiolaria but now composed of acicular chalcedonic quartz (Plate 2, Figure 6). The green chert is separated from the amber by a sharp boundary (Plate 2, Figure 6), has a partly isotropic matrix and contains recognizable Radiolaria which have recrystallized to chalcedonic quartz.

The fractures in the associated brecciated chert (Plate 2, Figures 1 and 2) contain as many as three generations of acicular chalcedonic quartz infillings. In some instances hollow vugs representing open fractures are present within veins, lined with mammillar quartz.

Site 71

At Site 71, about 4.6 meters of Eocene silicified limestone, with minor chert intergrowths and interbeds, were sampled between sediment depths of 553 and 557 meters. The lithotype appears quite uniform throughout and is composed of a light green to white highly burrow-mottled silicified limestone with subordinate anastomosing intergrowths of olive green chert, generally a few centimeters thick, along with zones composed of oriented "whisks" of a similar type of chert. In rare horizons, the greenish chert is seen in complex intergrowth with a vitreous amber-colored chert. The silicified limestone is slightly porous; on treatment with acid the calcareous component is dissolved, leaving a rigid, porous network of silica.

In thin section the silicified limestone appears to be a somewhat recrystallized foraminiferal-nannoplankton ooze in which remains of siliceous organisms are not discernible. Frequently, the foraminiferal tests are infilled with sparry calcite which, in the vicinity of chert intergrowths, may be partly or wholly replaced by chalcedonic quartz.

The olive-green cherts, which are present as irregular masses within the limestones, show sharp, irregular boundaries (Plate 1, Figure 3, and Plate 2, Figures 3 and 4). The cherts are composed of an oriented, almost isotropic matrix—possibly of cristobalite composition—containing ghosts of possibly foraminifera and Radiolaria generally wholly replaced by chalcedonic quartz. In some cases foraminiferal remains still retain a small amount of the presumably original calcite of their tests and frequently the massive sparry calcite infilling is preserved as calcite within the chert, rimmed by radiating acicular chalcedony.

The amber-colored vitreous chert of Site 71, which intergrows with the olive green chert, is composed of a mosaic of cryptocrystalline chalcedonic quartz having a random orientation. Fossil ghosts are entirely replaced by chalcedonic quartz and have been largely obliterated by recrystallization of the matrix. The amber chert appears to have formed by the inversion of the cristobalite of the green chert to chalcedonic quartz.

Siliceous remains are not common within the Site 71, Eocene chert-limestone sequence, due either to complete dissolution of the opaline remains or to the fact that they were not primarily important constituents of the sediment. However, one section of the core, about 10 centimeters in thickness, may have been a diatomite. This zone occurs within the chert-limestone sequence and is a highly porous, fissile, shale-like sediment containing abundant circular and lenticular fossil ghosts and some apatitic fish debris, set in a matrix of an oriented filamentous mineral of low birefringence. The fossil ghosts are in part hollows from which the original tests have dissolved and in part are filled with chalcedonic quartz. In places Radiolaria and diatom tests and frustules can be recognized. Preliminary X-ray diffraction analyses of this sediment show a cristobalite pattern.

Sites 72 and 73

Dark brown Eocene cherts containing abundant inclusions possibly of manganese oxides were cored at Sites 72 and 73. At Site 72, two thin layers of chert were cored from an upper Eocene complex of calcareous radiolarian oozes, calcareous nannoplankton ooze and interbedded chert between 442 and 445 meters. At Site 73 from a depth of 302 meters, a 12 centimeter thick layer of chert was cored from within a semi-indurated calcareous nannoplankton ooze which contains abundant partly dissolved diatoms and Radiolaria. At both sites, the dark brown chert is in sharp contact with adhering light-colored porous limestones containing recognizable coccoliths and rare foraminifera.

Thin section studies of cherts from both sites show a transition zone, about 5 millimeters in thickness, between the limestone and the main body of the chert. The transition zone is composed of a largely isotropic oriented matrix possibly of cristobalite, that contains ghosts of former foraminifera, or radiolarians which are replaced by chalcedonic quartz. This transition zone grades into a very fine-grained microcrystalline aggregate of chalcedonic quartz. The dark color is imparted by reddish-brown granules of iron-manganese oxides which are distributed throughout the matrix.

SUMMARY

The thin chert stringers or nodule layers of upper Oligocene age cored during Leg 8 of the Deep Sea Drilling Project occur within a thick, relatively uniform carbonate sequence which has been designated the Marquesas Formation. This ooze is dominantly composed of calcareous nannoplankton with minor planktonic foraminifera, Radiolaria and diatoms. The associated cherts contain abundant foraminiferal remains in the form of ghosts that are partly or wholly replaced by chalcedonic quartz. The matrix of these cherts varies from an almost isotropic (in thin section) cristobalite to a mosaic of well-crystallized anhedral chalcedonic quartz. Siliceous microfossils are not readily apparent, but they may have been completely dissolved. Paleontological considerations at the three sites which contain upper Oligocene chert (70, 71 and 72) suggest that, at least in this area, these cherts are essentially isochronous.

The majority of the chert cored during Leg 8 of the Deep Sea Drilling Project is of middle Eocene age, with one example from the upper Eocene. These Eocene cherts, from the evidence of thin section studies, are true radiolarian cherts and are associated with radiolarian-rich sediments which typify the Eocene section. Silicified limestone is an important associate to chert at Site 71 where the chert occurs as relatively minor intergrowths and interbeds within the limestones, at least to the depth sampled. At Site 70 to the north, limestone appears to be of minor importance and the cherts have the appearance of cherty radiolarian claystones. In all cases, however, the Eocene cherts vary in composition from an almost isotropic (in thin section) matrix of cristobalite to an anhedral mosaic of chalcedonic quartz. Ghosts of possible radiolarians, diatoms and some foraminifera are ubiquitous, in varying stages of replacement by chalcedonic quartz.

ORIGIN OF THE CHERTS

The stratigraphic relationships, coupled with the paucity of obvious volcanic material, suggest that the cherts under discussion have obtained their silica locally during diagenesis from the dissolution of siliceous biogenous remains. The Eocene cherts in particular are restricted to the highly siliceous (mainly radiolarian) ooze section that occurs below the widespread hiatus between the upper Eocene and lower Oligocene. Above this hiatus lies the thick highly calcareous Marquesas Formation with its minor chert stringers of upper Oligocene age. It is therefore considered that a widespread change in oceanographic conditions during lower Oligocene times, which favored the production or preservation of a calcareous over a siliceous microfauna, explains the restriction of most of the cherts to the Eocene.

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REFERENCES

Heath, G. R. and Moberly, R., 1970. Cherts from the western Pacific: Leg 7, Deep Sea Drilling Project. **In** Winterer *et al.*, 1970. *Initial Reports of the Deep Sea Drilling Project, Volume VII.* Washington (U. S. Govt. Printing Office).

Tracey, J. I., Sutton, G. H., Beckmann, J. P., von der Borch, C. C., Galehouse, J. S., Haq, U. Z. B., Lipps, J. H., Moore, T. C. and Nesteroff, W. D., 1970. Shipboard Site Reports. **In** Tracey *et al.*, 1970. *Initial Reports of the Deep Sea Drilling Project, Volume VIII.* Washington (U. S. Govt. Printing Office), this volume.

PLATE 1

Figure 1 Sample 8-71-49, top. Mosaic of chalcedonic quartz and an almost obliterated unidentified fossil ghost now replaced by chalcedonic quartz. (X Nicols)

Figure 2 Sample 8-72-7, 0 cm. Foraminifera in matrix of chalcedonic quartz. Foraminiferal test still retains some original $CaCO_3$ which is partly pseudomorphed by chalcedonic quartz. Note irregular boundary between darker zone, which contains more apparently amorphous silica and lighter zone which is entirely a chalcedonic quartz mosaic. (X Nicols)

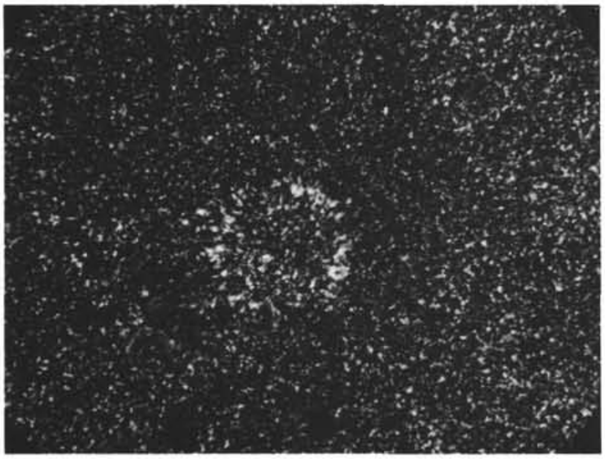
Figure 3 Sample 8-71A-2, 1 cm; piece 7. Intergrowth of chert (dark zone) with siliceous limestone. Chert in this sample has an almost isotropic, optically oriented matrix. Note sharp, irregular boundary between chert and limestone. Both chert and limestone show abundant subcircular (in section) fossil ghosts, possibly Radiolaria, now composed of chalcedonic quartz. (X Nicols)

Figure 4 Sample 8-71-49, top. Irregular boundary between chalcedonic quartz mosaic (light zone) and almost isotropic opal-cristobalite Zone. Note foraminifera, replaced by chalcedonic quartz, lying across boundary. (X Nicols)

Figure 5 Sample 8-71A-2, 1 cm; piece 7. Portion of Figure 3 enlarged. Note "dusting" of fine birefringent crystals in largely isotropic chert matrix. (X Nicols)

Figure 6 Sample 8-72-7, 0 cm. Similar to Figure 2. Foraminifera retains much of its calcareous test but is infilled by relatively coarse acicular chalcedonic quartz. (X Nicols)

PLATE 1



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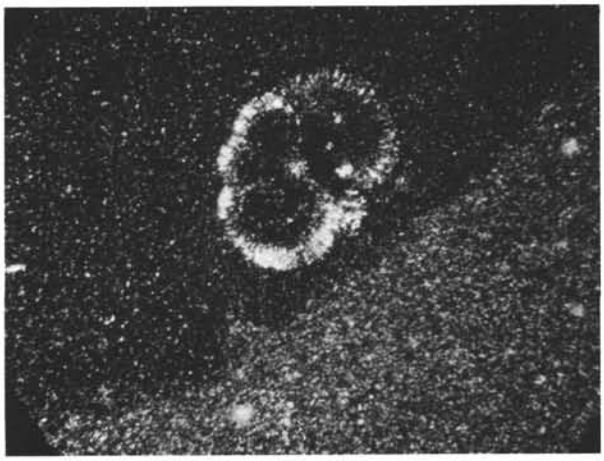

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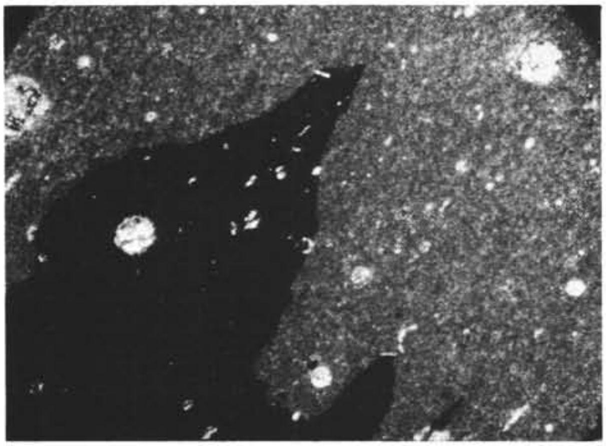

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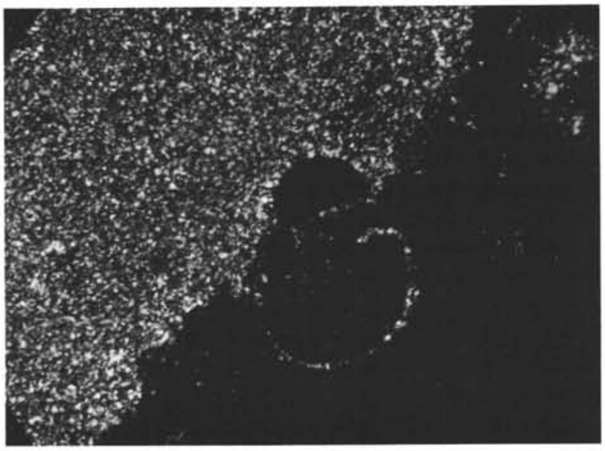

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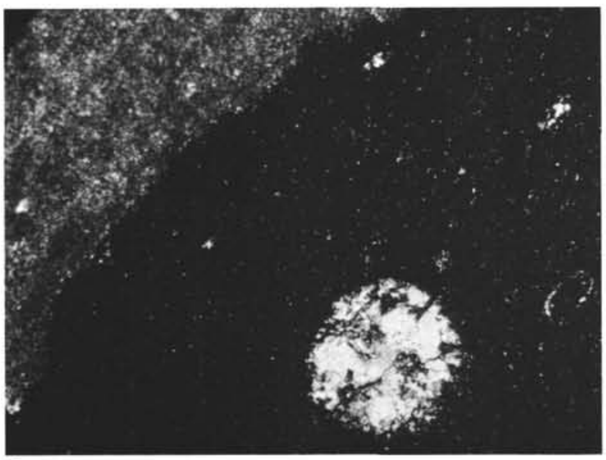

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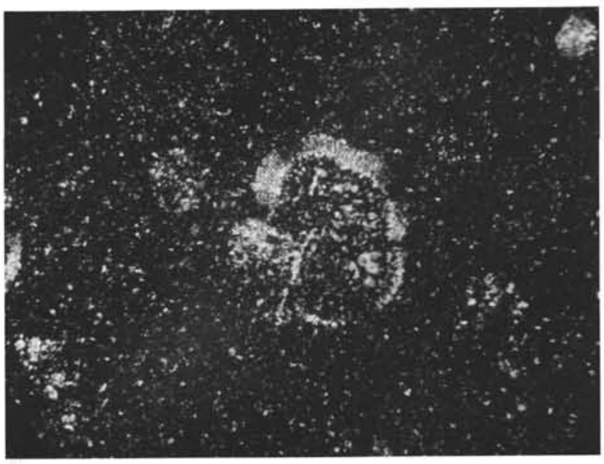

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PLATE 2

Figure 1 — Sample 8-70B-1, 1 cm; piece 22. Fracture filling composed of two generations of acicular chalcedonic quartz, in brecciated radiolarian chert. (X Nicols)

Figure 2 — Sample 8-70B-1, 1 cm; piece 22. Branching fractures in brecciated radiolarian chert filled with 1 and 2 generations of acicular chalcedonic quartz. (X Nicols)

Figure 3 — Sample 8-71A-2, 1 cm; piece 10. Irregular chert "whisp" (lighter shade) intergrowing with siliceous limestone. Fossil ghosts (Radiolaria or foraminifera) throughout, composed of chalcedonic quartz.

Figure 4 — Sample 8-71A-2, 1 cm; piece 10. Same as Figure 3 but viewed under crossed nicols. The chert, which has an almost isotropic but oriented matrix, appears as the darker area.

Figure 5 — Sample 8-72-7, 0 cm; piece 2. Microcrystalline birefringent matrix of chalcedonic quartz (left portion) containing relict ghosts of foraminifera replaced by chalcedonic quartz. Almost isotropic, optically oriented matrix of opal-cristobalite (right portion, dark) with foraminifera which are partly calcareous and partly replaced by chalcedonic quartz. Note irregular but sharp boundary between the two zones. The chalcedonic quartz mosaic to the left has formed progressively by inversion from the opal cristobalite. (X Nicols)

Figure 6 — Sample 8-70B-2, 1 cm; piece 18. Contact between essentially isotropic opal-cristobalite (dark area) and chalcedonic quartz. The chalcedonic quartz zone constitutes one of the amber-colored vitreous cherts. Note numerous ghosts of Radiolaria, now replaced by chalcedonic quartz. Note also how the boundary between the isotropic and chalcedonic zones is controlled by a quartz-filled microfault. (X Nicols)

PLATE 2