### 40. REGIONAL PROBLEMS

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## PATTERNS OF CRUSTAL AGE

Geological and geophysical evidences of many sorts (Takeuchi and others, 1967) support the suggestion that the earth's crust grows by the accretion of mantle – derived ultramafic rocks and basalt in the axial zone of the Mid-Oceanic Ridge to form there oceanic "basement". As newly formed basement moves away from the axial zone, to make room for new additions, it ages, subsides, and accumulates a cover of sediment (Heezen 1960).

In the Pacific Ocean, the East Pacific Ridge has generally been accepted as the site of crustal accretion, and samples obtained by the drilling on Leg 5 between San Diego and Hawaii bore out the suggested pattern – the ocean crust becoming progressively older westward, toward Hawaii (Figure 1). Although it had been presumed that the ocean crust continued to become progressively older west of Hawaii, the pattern of crustal growth could not be unequivocally inferred from the scanty data available.

Drilling on Leg 6 between Hawaii and the Philippine Sea thus provides the first direct evidence on pre-Tertiary Pacific crustal genesis. The main portion of the northwestern Pacific fits the general model of westwardly increasing crustal ages, whereas the Philippine Sea and the area of the Caroline Ridge do not, inasmuch as they appear to have a basaltic basement of Tertiary age.

Rocks as old as Cretaceous or Jurassic were reached at nine drill sites (Sites 45 through 51 and Site 59). In every case the cherty nature of the older sediments prevented penetration into the underlying basement. However, seismic reflection profiles, when taken in conjunction with the drilling data, suggest that the oldest sediments in the Shatsky Rise area are latest Jurassic, and that elsewhere in this area the crust may be older. This region appears to be within the oldest part of the Pacific Ocean, and is probably the largest remnant of Mesozoic ocean floor left in existence. It may well have been formed by the Mesozoic ancestor of the present East Pacific Ridge.

A simple westward extrapolation of these general age relations of the oceanic crust (Cenozoic in the eastern Pacific, late Cretaceous in the central Pacific, early Cretaceous to late Jurassic in the western Pacific) would call for even greater ages across the Mariana Trench in the Philippine Sea. Yet, this was not borne out by drilling there; at two sites (53 and 54) volcanic ash lay unconformably on a basaltic complex of lava



Figure 1. Basement ages in the North Pacific and drill sites of Leg 6 of Glomar Challenger.

flows, one of which (Site 53) contained interbedded, baked pelagic limestones of Oligocene or early Miocene age. The sequence is very much like that exposed in Guam and Saipan. When taken in context with earlier seismic work these findings suggest that the eastern Philippine Sea has a rough basaltic basement of Cenozoic age, which may represent the basaltic carapace over a coeval ultramafic crust. The alternative that in this relatively shallow region an earlier crust, continental or oceanic, was mantled in Paleogene time by extensive mafic volcanism remains a definite possibility. In the latter case the exceptionally deep basin of the western Philippine Sea might be underlain by Paleozoic crust.

The East Pacific Ridge might have at one time extended round the northern and western margins of the Pacific Basin and given rise to young crust west of the oldest known oceanic area. The abrupt contact of young and old sea floor along the Mariana Trench can be explained by crustal swallowing in the trench. In this model, one must allow for the disappearance of the "East Pacific Ridge" from the northern and western sides of the Pacific Ocean in late Cenozoic time. Alternatively, areas of crustal growth separate and distinct from the Mid-Oceanic Ridge system may have been located within, or on the margin of, the Philippine Sea, and may still be active. Still another possibility is that the crust of the eastern Philippine Sea may have been made by processes other than crustal accretion in specific belts, perhaps by massive ultramafic-mafic invasion of older crust.

Outside the trenches on the northern flank of the Caroline Ridge, Oligocene sediments rest on basalt (Sites 55 through 58). Unlike the mountainous basaltic basement of the Philippine Sea and the Mid-Oceanic Ridge, these basalts have a smooth, flat surface, displaced by simple step faults. Surfaces of this character underlie the sediments over parts of the Atlantic and Pacific Oceans, and have been referred to as Horizon B or B'. Leg 6 drilling has shown that such surfaces can occur on top of oceanic-volcanic complexes. These basalts may overlie coeval ultramafic rocks and, thus, represent true juvenile crust; but, it is perhaps more likely that they mantle on older crust with its superimposed sediments in the manner of the continental plateau basalts, or in the manner in which Hawaii's active volcanoes apparently are covering Cretaceous crust. This Caroline Ridge province abuts the Philippine Sea along the southern side of the Mariana Trench and the old Pacific crust along a major east-trending fracture zone.

#### CARBONATES AND SUBSIDENCE

The areas drilled were so remote from the major land masses that terrigenous influence on sedimentation was principally eolian. Only in the absence of volcanism is the windblown contribution a significant factor in midocean sediment acculumation. The sediments are either of pelagic type, or dominated by volcanic material chiefly pumice ash and tuffaceous silt in varying grades of alteration to clays and zeolites. Volcanic components can be deposited at any depth. The pelagic sediments, on the other hand, are strongly influenced by the carbonate compensation depth, which today in the lower and middle latitudes of the Pacific Ocean lies at about 4000 meters. The shallower pelagic sediments are generally dominated by the calcareous skeletal elements of planktonic plants (Coccolithophyceae) and, to a lesser extent, Protozoa - a state that has existed at least since development of this calcareous plankton in Jurassic time. On deeper bottoms, the greater solubility of carbonate at lower temperatures and higher pressures results in the destruction of most of these minute calcareous particles either during settling or, more likely, on the sea floor; and, the sediment is an insoluble or less soluble residue - generally the "red clay" (actually brown) of oceanographic literature. The boundary is, of course, not a sharp and invariable one; and the statistics of carbonate distribution relative to depth are further complicated by another factor, that is, carbonate sediments can be, and are commonly laid down and preserved at greater depths, when brought in by rapid bottom transport mechanisms. Thus carbonates are commonly deposited on deep abyssal plains and in trenches, where carbonate-producing banks and continental shelves give rise to massive episodes of transport and resedimentation by turbidity currents, mud flows and possibly other means. Such resedimented carbonates, abundantly encountered on Legs 1 and 4 in the western Atlantic, were found only at one site in the western Pacific (Site 58).

The sediments encountered near the ocean floor strongly reflect the present compensation depth. All of the seven sites drilled at water depths less than 4000 meters yielded calcareous sediments throughout. Of the ten sites drilled in water over 4000 meters deep, eight show brown clay in the upper part of the sedimentary sequence; of the remaining two, one did not recover sediment near the surface, and the other (Site 58) is the only site which showed evidence of massive transport of carbonates and other material from nearby island area.

Of these ten sites now located in water more than 4000 meters deep, three yielded only brown clay which may or may not be underlain by calcareous sediments, and five yielded both brown clay and calcareous sediments. Four of these show a distinct lower carbonate sequence and upper brown clay sequence, while one on the outer ridge of the Mariana Trench (Site 59) yielded traces of Paleogene carbonate interbedded between older (Cretaceous) and younger brown clays, suggesting either a turbidite influx or a brief fluctuation back and forth across the compensation depth.

Thus not one of the sites shows, as part of its history, a clear-cut change from below compensation depth to above, that is, an apparent shoaling (uplift). Four sites, on the other hand, began above and ended below it, recording an apparent deepening of the overlying water mass (subsidence); in fact, all of the sites may have undergone such deepening in their history.

Such apparent deepening could reflect either a marked depression of the carbonate compensation depth, or an actual deepening of the ocean above the respective site. At Sites 49 and 50 on the Shatsky Plateau the compensation depth was crossed in mid-Cretaceous time: Sites 45 and 51 in the abyssal basin crossed from ooze to clay in the late Cretaceous, and at Site 53 on the west flank of the Mariana Arc carbonate deposition ended in Miocene or Pliocene. Response to an ocean-wide gradual change in the compensation depth would have provided a consistent relationship between the present water depth of the drill sites and the time at which they dropped below the carbonate compensation depth. This is not the case. The authors therefore conclude that the main factor recorded has been subsidence of the sea floor relative to sea level. This subsidence may be that which is now normally expected to accompany the lateral drift on the sea-floor away from the axis of crustal accretion. This is not to deny fluctuations in compensation depth - rather to suggest that such changes played a minor and modifying role at most.

Darwin recognized that the atolls of the Pacific represent subsided volcanic peaks on which coralline animals have built extensive limestone caps. Later, Hess (1946) recognized that guyots are truncated and deeply submerged volcanic cones; and, subsequently, Hamilton (1956) dated corals dredged from several guyots as early Cretaceous. Since then most geologists have recognized that the area of the mid-Pacific guyots has been deep sea since early Cretaceous, that the underlying crust is at least that old, and that a wide area has subsided one or two kilometers in the past one hundred million years. Thus, the subsidence inferred from the drilling results can be added to the subsidence deduced from atolls and guyots.

### ACOUSTIC STRATIGRAPHY

Seismic reflection profiles from the abyssal Pacific characteristically record an upper layer with few internal reflecting horizons. This upper "transparent" unit generally overlies a sequence of closely spaced highly reflective interfaces collectively referred to as the "opaque layer," which in turn overlies a so called "lower transparent layer". This later member lies on a highly reflective lower most reflector which is generally accepted as the oceanic crust.

Before drilling commenced the thin beds of the "opaque layer" had been assumed by some workers to be turbidities possibly derived from a hypothetical nearby elevation. For instance, Ewing and others, (1968) state that:

Although we have only a few examples, there is definite evidence that the opaque sediments thicken toward major elevations, such as the Hawaiian, Marcus-Necker, and Caroline ridges. Because of the broad distribution and gradual thinning away from the volcanic centers, we judge that the opaque layer consists mainly of material derived from the volcanoes, distributed by transport along the bottom in the water. It would thus appear that the distinct boundary between the opaque layer and the upper transparent layer may correspond to the time when the volcanic ridge subsided and ceased to be a source of detrital material, when slow accumulation of pelagic clays commenced.

Leg 6 results do not support this hypothesis, but suggest rather that the base of the upper transparent layer is of varying ages and lithologies. The assumed existence of world wide or even ocean wide reflectors of uniform age and composition, in fact, seems incompatible with the results obtained so far by deep sea drilling. The facies boundaries observed appear to be broadly transgressive. There is at least a suggestion (Sites 51 and 52) that the age of sediments at the base of the upper transparent layer increases from mid-Tertiary near Midway to Middle-Cretaceous near the west Pacific trench system.

The presence of the Pacific opaque acoustic layer of an assumed uniform age and of a detrital origin has been taken as further support for the existence of the hypothetical Darwin Rise. Menard had envisioned that:

... the Darwin Rise developed as a broad upward bulge of the mantle.

As the mantle bulged upward, it fractured the thin, overlying crust, with the formation of longitudinal ridges and troughs in the center and transverse faults reaching toward the flanks. Vertical movement occurred on both kinds of faults, but there is no direct evidence bearing on the possibility of large lateral movement of crustal blocks on the transverse faults. The fact that the transverse features appear to be straight suggests at least some component of horizontal motion.

Simultaneously or after the faulting, large volcances began to build up from the deep sea, primarily along two parallel lines on the flanks of the rise [Ridge].

After they reached sea level, fissure flows emerged from the bases of the volcanoes. The load of the

volcanoes depressed a moat around them, and the downbending of the crust opened tension cracks which were the site of other fissure flows. The flows were of an enormous extent and buried most of the faulted topography on the surface of the rise.

The Darwin Rise hypothesis originated in the context of oceanic permanence. It was essentially the anti-drift alternative to axial accretion and is now an obsolete concept. That subsidence of the western Pacific occurred is not questioned, and that somewhere deep in the sediment column there exists volcanic debris deposited during existence of the volcanic islands is obvious, but that an enormous area of ancient crust bulged up, bore volcanoes, and then collapsed is neither borne out by Leg 6 data nor is it consistent with concepts of crustal drift or axial accretion.

In offering the Darwin Rise hypothesis, Menard (1964) commented upon the axial accretion hypothesis:

.... this hypothesis (Heezen, 1960) has many virtues, for it explains such varied observations as the thin sediment of ocean basins and the thin crust under some oceanic rises (Mid-Oceanic Ridge).

The central argument for this hypothesis is that a continuous median rift in the crest of rises [Mid-Oceanic Ridge] is a primary and permanent fracture in the crust and that new crustal material is extruded along the fracture by volcanism. In this form the hypothesis does not provide a general explanation of rises [Mid-Oceanic Ridge] because the East Pacific Rise [Ridge] has no major central rift and because the Darwin Rise has subsided.

The central fact on which the hypothesis is based, namely, the existence of a central rift and of longitudinal ridges and troughs produced by faulting, is not decisive. Any mechanism that arches the crust will inevitably produce longitudinal tensional faulting because of extension. Moreover, all the other diverse facts explained by the hypothesis are explained [Menard, 1964] in other ways.

The seamount data which were cited in support of the claimed bilateral symmetry of the hypothetical crustal buldge can be questioned. There is little data to support the former existence of a western flank of this hypothetical bulge. Lacking evidence for symmetry it would appear that the pattern of increasing seamount summit depths observed by Menard (1964) if confirmed might conceivably indicate a pattern of increasing subsidence with increasing age. The central idea of the Darwin Rise hypothesis was that the deeper summits mark the former axis of a broad crustal bulge upon which volcances were built during a relatively brief episode. It was that hypothetical episode of regional volcanism to which Ewing *et al.* (1968) attributed the emplacement of the supposed opaque layer clastics. The western Pacific requires much more drilling, dredging and geophysical surveys in order to delineate its geological history. In any case, however, it appears that the Darwin Rise idea can now be abandoned as a useful working hypothesis.

## DISTRIBUTION OF CHERT

Chert or flint is a common sedimentary rock which is formed mainly within sediments, after burial. Its time of formation and mode of origin are surrounded by much uncertainty. The main source of silica for chert in marine sediments is probably found in the opaline skeletons of organisms, such as diatoms, Radiolaria and sponges. Chert has been the single most serious obstacle to deep-sea drilling. With the lack of control on bitweight inherent in an unstable drilling platform and the slow rotary speeds imposed by a long unsupported drill string subject to oscillations, the best bits available destroy themselves on a few feet of chert; and, that ends the hole at the present level of technology. Chert was encountered in two main forms: as vitreous "flints" in chalky sediments, and as impure turbidite beds in sequences of brown clay, commonly containing fossil relics or radiolarian skeletons.

Opaline skeletons and chert were found to be mutually exclusive. Skeletal opal is commonly abundant in sediments extending back to the Oligocene, but is rare in older beds. A trace of chert was found in the Oligocene of Site 44, where the Eocene contains massive cherts that stopped penetration, and Cretaceous and Jurassic sediments were found to contain chert wherever encountered.

This pattern of distribution suggests alternative explanations. One explanation is that the growth of chert, at the expense of opaline silica, proceeds exceedingly slowly on the ocean floor – possibly with some built-in delay mechanism (organic matter) that keeps the opal intact for the first 25 million years – in which case, the Oligocene cherts are growing at the present time, and Miocene chert will grow in the future. Another is that environment of diagenesis on the sea floor was different in the Mesozoic and early Cenozoic – permitting chert to form quickly then, but inhibiting its growth from the Oligocene onward.

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