east of the Pribilof Canyon (Fig. 1) where our reflection records indicate that the surface of this seismic unit is buried beneath several hundred meters of younger sediments.

Rocks of the basement have not yet been sampled, although Russian investigators possibly obtained specimens in the course of their extensive dredging and coring in the Bering Sea (*2*). Data from studies of seismic velocities suggest that the rocks of the acoustic basement in the areas mapped by Shor consist of volcanic or indurated sedimentary rocks or both; the few highly reverberant reflections that we received from below the surface of the basement suggest that the rocks may be strongly folded.

The Pribilof Islands consist mostly of Quaternary basaltic lava flows (*3, 4*), but our reflection records and the submarine topography adjacent to the islands suggest that the Quaternary lavas do not extend far from the Pribilof Islands and that the basement rock which is exposed on the continental slope is not likely to be Quaternary volcanic rock.

Sialic as well as mafic crystalline rocks are also exposed on the Pribilofs. Pre-Quaternary crystalline rocks, consisting of serpentinized peridotite invaded by a large aplite dike, are exposed beneath the Quaternary lavas on eastern St. George Island (*3*). Inclusions of granitic rock and quartzite are abundant in some of the lava flows on St. George, and granitic inclusions are abundant in some of those on St. Paul. Granitic rocks and crystalline metasediments generally have seismic velocities that are considerably greater than the unit, 3.1 to 3.7 km/sec, detected by Shor on the slope. Therefore it seems unlikely that the acoustic basement encountered in our study is composed of crystalline rocks, except perhaps near the islands. Possibly Shor's deeper 5.5 km/sec section is actually exposed at the base of the Pribilofs, or possibly the crystalline rocks of the Pribilof Islands represent a local intrusive and contact metamorphic zone in the rocks of the 3.1 to 3.7 km/sec layer.

Although the lithologic composition and the age of the 3.1 to 3.7 km/sec basement rocks exposed or underlying the Bering continental slope at shallow depths remain uncertain, the geology of coastal Siberia (*5*) and Alaska (*6*) and the paleogeography of the Bering shelf (*7, 8*)suggest that the 3.1 to 3.7 km/sec unit consists of folded sedimentary and volcanic rocks of late Mesozoic age, which may have been locally intruded by granite and serpentinized peridotite. Thus we tentatively correlate our acoustic basement with a generally smooth surface cut across folded volcanic and sedimentary rocks of pre-Tertiary age. Hopkins has shown that large parts of the Bering shelf and of neighboring areas in Alaska were a subaerial landscape reduced to a surface of low relief during the Tertiary epoch (*7*). At the end of the Miocene epoch, tectonic movements submerged part of the shelf to provide a short-lived connection between the Bering Sea and the Arctic Ocean; the shelf was submerged more completely and permanently at the end of the Pliocene (*9*). The slightly deformed sediments with acoustic velocities of about 1.7 km/sec which cover the rocks of the acoustic basement (3.1 to 3.7 km/sec) on the outer shelf probably consist of Tertiary sediments deposited on the much narrower continental shelf of that time. Tertiary and Quaternary sediments are included in the low-velocity materials that mantle the basement rocks on the continental slope and rise and in the Aleutian Basin. The deeper 5.5 km/sec unit encountered beneath the shelf on Shor's seismic refraction profiles may consist of metamorphosed Paleozoic and pre-Paleozoic rocks such as are exposed in many areas in western Alaska and northeastern Siberia (*10*).

If the generally smooth surface of the basement is an erosional surface which has cut across folded sedimentary and volcanic rocks of Mesozoic age, then its configuration suggests faulting and flexuring of continental rocks between the shelf edge and the deep Aleutian Basin during Cenozoic time. Strengthening this supposition is the fact that the sedimentary section overlying bedrock is a progradational structure constructed by outbuilding and upbuilding of sedimentary units (Moore's and Curry's type "C" continental structure, *10*) on a basement surface. The sedimentary section, therefore, appears to have been deposited contemporaneously with, or subsequent to, downflexing of a basement surface. Further and later tilting and faulting of the sediment-draped basement surface in late Cenozoic times may have brought about instability of the slope and initial canyon formation by the slumping of sedimentary units. During the Pleistocene, at times of lowered sea level caused by continental glaciation, canyon cutting was probably greatly accentuated by the downslope movement toward the Aleutian Basin of river-deposited sediment on the steep Bering slope.

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Submarine Lithification of Carbonate Sediments

Abstract. *Recrystallized planktonic limestones from two guyots in the North Atlantic are in oxygen-isotopic equilibrium with their present ambient waters, suggesting submarine lithification and recrystallization. The early stages of submarine lithification of carbonates may involve precipitation of, and replacement by, magnesium-rich calcite; with time this may invert to magnesium-poor calcite. This type of lithification probably requires very low rates of sediment accumulation.*

It is commonly assumed that lithification of carbonates occurs only subaerially or in the intertidal zone (*1*), but increasing evidence suggests that subaqueous lithification can occur. Cemented clusters of particles ("grapestone"), found in the Bahamas and Cuba, supposedly have been lithified in warm, shallow water (2). Recently Fischer and Garrison (3) catalogued many reports of lithified sediments from the deep ocean; some of these rocks, found on the submarine slopes of continents and islands, may represent slumps or bed outcrops rather than *in situ* lithification.

The occurrence of planktonic foraminiferal limestones on the tops of guyots and seamounts (4–7), however, poses a problem for those who propound only subaerial lithification. Lying on a flat-topped mountain, these limestones are obviously not slump features; furthermore, a planktonic ooze suggests sediment deposition in water deeper than that at which reef growth occurs. Induration of the planktonic oozes by subaerial or intertidal exposure therefore would require either a great eustatic drop in sea level, or emergence followed by rapid submergence. Since neither explanation seems likely, one is left with the alternative hypothesis of submarine lithification.

Limestones from Gerda Guyot (5), Great Meteor Seamount (6), and various mid-Pacific mountains (Cape Johnson Guyot, Hess Guyot, and Guyot 19171) (7) were studied by means of petrographic and spectroscopic techniques and by $O^{18}:O^{16}$ and $C^{13}:C^{12}$ analyses. Relative percentages of aragonite and of magnesium-poor and magnesium-rich calcite were determined within 10 percent by x-ray diffraction techniques similar to those discussed by Friedman (1).

The limestones at Gerda Guyot are nearly all heavily bored, many of the borings being filled with unconsolidated sediment. The recognizable fossils, estimated to compose 30 to 50 percent of the limestone, include planktonic Foraminifera, with lesser amounts of mollusks (both pteropods and benthonic forms), benthonic Foraminifera, and echinoderm plates. Much of the fossil material appears to be recrystallized; the matrix consists of fine biologic debris and a drusy calcite cement.

On the basis of their general characteristics, two types of limestone are recognized on Gerda Guyot. Type 1 is a porous limestone, with foraminiferal assemblage of Plio-Pleistocene age (8); often incorporated are fragments of foraminiferal rock, apparently eroded from other rocks (Fig. 1). Some limestones (type 1a) are very porous; in places there is little matrix, the individual particles being encrusted with a drusy rind acting as a cement (Fig. 1). Type 1b limestone is less porous, with a drusy, sometimes micritic, matrix. Type 2 is a dense limestone, with a drusy to micritic matrix, encrusted with and penetrated by specks and veins of manganese oxide. On the basis of preliminary foraminiferal analyses, these limestones are dated as late Miocene (8). The manganese coating on several rocks is filled with younger Plio-Pleistocene Foraminifera, suggesting that the rocks are still slowly accreting.

The limestones found at Great Meteor Seamount are similar in textural properties to type 1b of Gerda Guyot but contain larger amounts of broken mollusk shells (mainly ben-

Table 1. Samples, sources, and environments.

No.	Sample: Source: Area	North latitude	West longitude	Water: Depth (m)	Temperature (°C): Surface	Bottom
GG 1-7	Gerda Guyot	22°	73°	700–800	25	8–10
GMS 1-2	Great Meteor Seamount	30°	28°30′	600	20	10–11
GMS 3-4	Great Meteor Seamount	30°	28°30′	900	20	9–10
MP 26-A	Guyot 19171	19°	171°	1400	27	3–4
MP 33-C, 33-K	Hess Guyot	18°	174°	1600–1700	27	3–4.
MP 37-C	Cape Johnson Guyot	17°	177°	2000	27	3–4

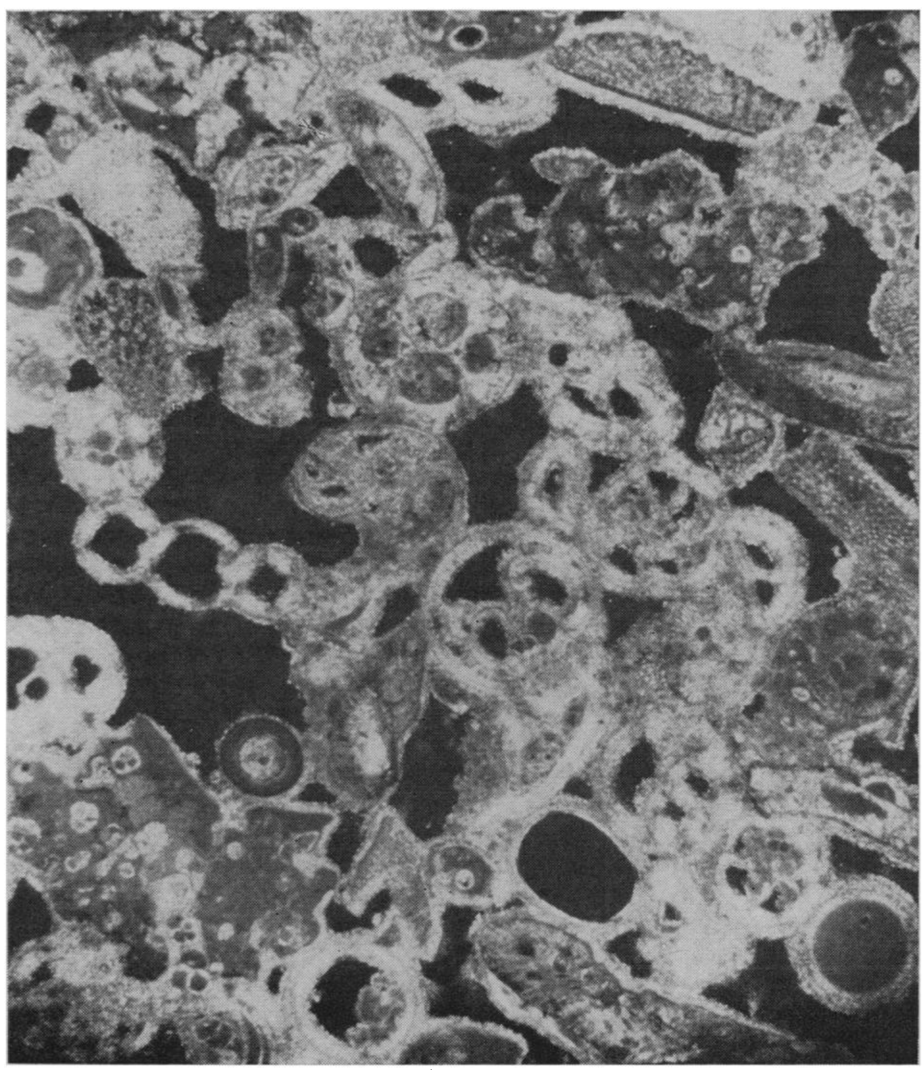

Fig. 1. Type-1a limestone, with high porosity and little matrix. Rock fragments are seen in the lower-left and upper-right corners (polarized light; × 22).

thonic); all those studied contain Plio-Pleistocene Foraminifera (*8*). The mid-Pacific mountain limestones are different in appearance, being mainly recrystallized Cretaceous reef material (MP 33-K, MP 37-C) and manganese-coated, semi-indurated Globigerina ooze (MP 33-C) (*7*); sample 26-A, a recrystallized limestone from Guyot 19171, is very similar to type 1b of Gerda Guyot and Great Meteor Seamount.

Samples GG 1-3 and GMS 1 and 2 are composed largely of magnesium-rich calcite (more than 4 mole percent $MgCO_3$ in solid solution with calcite), with lesser amounts of magnesium-poor calcite and aragonite (Table 2). Friedman (*1*) has reported similar compositions for limestones dredged from Atlantis Seamount (34°N,30°W). The rest of the limestones, excluding MP 26-A, are composed of magnesium-poor calcite (Table 2). Elemental analysis shows that the magnesium-poor limestones on Gerda Guyot contain appreciable quantities of MnO and large amounts of P_2O_5, probably in the form of apatite (*9*). MP 26-A has little calcium carbonate, being instead composed of apatite.

Emiliani (*10*) has shown that planktonic Foraminifera precipitate their tests (shells) in shallow water. The oxygen-isotope determinations show, however, that the recrystallized, Globigerina-ooze limestones at Gerda Guyot and Great Meteor Seamount are not in equilibrium with the surface waters, which have temperatures of about 25° and 20°C, respectively, but rather with the ambient deep water (Table 3). Sample GG-7, composed of recrystallized Foraminifera separated from the outer crust of a piece of limestone, shows an O^{18}:O^{16} ratio similar to that of the matrix, indicating that the whole limestone is in isotopic equilibrium with the ambient water and that recrystallization and lithification were *in situ*.

I suggest that slow accumulation of sediment is critically important in this type of submarine lithification. Pelagic oozes are reworked and mixed by burrowing organisms; therefore the planktonic tests are not effectively removed from potential contact with the ambient bottom water until a sufficient cover of sediment accumulates. On the deep-sea floor, with a sedimentation rate of about 2 to 3 cm/10^3 years (*11*), it should take about 10^4 years to remove effectively the Foraminifera from potential exposure to the bottom waters; there is little or no tendency for them to reequilibrate with their new environment (*11, 12*). On guyots and seamounts, however, currents are swift enough to limit severely the rate of sedimentation (*5–7*). Foraminifera accumulate very slowly and may be exposed to the ambient waters for an exceedingly long time, so that time available may be sufficient for ionic exchange between sediment and ambient water, resulting in recrystallization and isotopic equilibrium with surrounding waters.

Since planktonic-Foraminifera tests contain very low concentrations of $MgCO_3$ (*13*), the magnesium-rich calcite found in the type-1 limestones must be related to postdepositional precipitation and replacement. Fairbridge (*14*) has found evidence of the replacement of Ca^{++} ions by Mg^{++} ions in fairly shallow water, with the resultant formation of magnesium-rich calcite. A similar process seems to be occurring on Gerda Guyot, Great Meteor Seamount, and Atlantis Seamount. Fairbridge has argued that perhaps this metasomatism is a step in the process of submarine dolomitization, but I found no dolomite in the rocks studied.

Although it is possible that the magnesium-rich and -poor limestones represent two different modes of lithification, these two species may rather represent sequential steps in lithification. The well-lithified, magnesium-poor calcitic limestones on Gerda Guyot are tentatively dated as upper Miocene, whereas the magnesium-rich limestones are less well-lithified and are Plio-Pleistocene in age. While there is little, if any, petrographic or paleontologic distinction between the two species of Great Meteor Seamount limestone, the magnesium-poor limestones were dredged from 300 m deeper than the magnesium-rich (Table 1), suggesting that they are perhaps older. Studies by Friedman (*15*) indicate that magnesium-rich calcite is metastable in the deep sea, tending to invert to mag-

Table 2. Mineral and elemental percentages in submarine limestones.

Sample		Content (%)							
No.	Rock type	Aragonite	Calcite: Mg-rich	Calcite: Mg-poor	MnO	MgO	P_2O_5	SiO_2	Sr
GG 1	1a	Trace	83	15	0.04	6.2	0.15	1.4	0.15
GG 2a	1b	Trace	79	19	.03	5.5	.15	1.5	.16
GG 2b	1b	Trace	85	14	.02	4.8	.16	0.72	.13
GG 3	1b	5	89	5	.02	6.0	.13	.55	.15
GG 4	2			≤85	.13	1.2	≥6.3	.80	.09
GG 4b	2			≤77	.26	0.8	≥10.	.75	.15
GG 5	2			≤85	.28	.95	≥6.3	.70	.07
GG 6	2			≤85	.31	.90	≥6.5	.67	.07
GMS 1	1b	Trace	70	29	.03	3.30	0.14	.35	.11
GMS 2	1b	Trace	70	29					
GMS 3	1b		19	80	.03	1.85	.12	.81	.12
GMS 4	1b			99	.09	0.33	.08	.73	.12
MP 26-A	1b				.23	.14	Major	1.5	.16
MP 33-Ca				99	.09	.33	0.08	0.72	.09
MP 33-Cb				99	.01	.57	.02	.58	.02
MP 33-Ka				99	.01	.68	.12		.02
MP 33-Kb				99	.06	.63	.43	.72	.03
MP 37-C				99	.09	.83	.05	1.25	.02

Table 3. Oxygen- and carbon-isotopic analyses of submarine limestones; δ per mille relative to the Chicago standard PDB-1. Temperature calculated from $O^{18}:O^{16}$ on the assumption of equilibration with currently surrounding sea water. W, warm; M, meteoric.

Sample	Per mille: δO^{18}	Per mille: δC^{13}	Temp. (°C)
GG 1a	+1.87	+2.20	9.7
GG 1b	+1.88	+1.26	9.7
GG 2a	+2.07	+1.32	8.9
GG 2b	+2.05	+1.31	9.0
GG 3	+1.89	+1.48	9.7
GG4a	+1.47	+0.87	11.2
GG 4b	+1.08	+ .52	12.8
GG 5	+2.41	+1.16	7.7
GG 6	+2.25	+1.03	8.0
GG 7	+1.50		7.4
GMS 1	+2.64	+1.61	9.4
GMS 3	+2.70	+0.40	9.2
GMS 4	+3.08	+1.05	7.8
MP 33-Ca	−1.31	+1.22	W or M
MP 33-Cb	−1.45	+1.84	W or M
MP 33-Ka	−1.49	+2.04	W or M
MP 33-Kb	−1.55	+1.02	W or M
MP 37-Ca	−1.49	+1.85	23.2
MP 37-Cb	−1.64	+1.32	23.9

nesium-poor. Therefore one may speculate that the planktonic skeleta are first recrystallized to magnesium-rich calcite, with a matrix of similar composition; and that with time this metastable mineral may invert to magnesium-poor calcite.

In contrast, isotopic data show that the recrystallized Cretaceous reef material at Cape Johnson and Hess Guyot was lithified in shallow, warm water, or perhaps subaerially (Table 3). The fact that these limestones have remained in disequilibrium with the ambient deep water suggests that once they are recrystallized there is little tendency toward reequilibration with the new conditions. Sample MP 33-C, from Hess Guyot, does not appear to have recrystallized, so that its Foraminifera still display the $O^{18}:O^{16}$ ratios of the warm surface waters.

Admittedly this concept of submarine lithification raises many questions that remain unanswered. Perhaps most puzzling are the process of recrystallization itself and the (presumably) inorganic precipitation of magnesium-rich calcite in relatively deep water.

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Electron Microscopy: Attachment Sites between Connective Tissue Cells

Abstract. *Regions of attachment have been observed between connective tissue cells from four different structures: fibroblasts in embryonic and fetal tendons, fibroblasts in fetal ligamentum nuchae, odontoblasts, and osteoblasts. Morphologically these sites appear to be focal and to consist of an approximation of the plasma membranes of adjacent cells to within approximately 200 Å. In the region of approximation both the extracellular space and the cytoplasm adjacent to the plasmalemma are increased in density. We have postulated a role for these sites in the maintenance of structural integrity.*

Functional sites of attachment between epithelial cells have been recognized for some time. The attachments of epithelial cells observed with the light microscope have been further defined with the electron microscope and in many epithelia have been subdivided into a junctional complex consisting of three distinct regions: (i) The tight junction (*zonula occludens*), a region in which the outer components of the unit membranes of opposing cells appear to fuse and to act as a seal preventing passage of substances between cells. (ii) An adherent or intermediate zone (*zonula adherens*) in which the plasma membranes of adjacent cells approach each other within a distance of approximately 200 Å. In these regions the space between the cells appears to be of increased density, as does the cytoplasm immediately subjacent to the plasma membrane; these two zones appear to represent continuous circumferential attachment regions between cells. (iii) A desmosome, an attachment plaque (*macula adherens*), ellipsoidal in shape, that appears to be analogous to a "spot weld" between adjacent cells (*1*).

No similar regions of cell attachment have been reported between connective tissue cells in vivo, except for the nexus between adjacent smooth muscle cells (*2*). We have made numerous observations of specific regions of attachment between developing connective tissue cells.

We fixed all tissues in 2 percent osmium tetroxide (*p*H 7.4) buffered with *s*-collidine (*3*). Some of the tissues were further fixed in neutral buffered formalin. They were then dehydrated in a graded series of alcohols, embedded in epoxy resin (*3*), sectioned, stained with uranyl acetate and lead, and examined in an RCA-EMU 3 G electron microscope.

We have repeatedly and consistently observed a region of cell specialization and attachment in developing connective tissue cells from several different sources. These sites consist of an approximation of the plasma membranes of adjacent cells to within a distance of approximately 200 Å. In these regions both the extra-cellular space and the cytoplasm immediately adjacent to the plasma membranes are increased in density. The density of the cytoplasm is often due to numerous, fine filaments at these sites. Such attachment sites occur between fibroblasts from fetal rat tendon (Fig. 1), between those of fetal bovine ligamentum nuchae (Fig. 2), between odontoblasts in the tooth buds of rat embryos (Fig. 3), and between osteoblasts. In the fibroblasts of both the tendon and ligamentum nuchae and in the osteoblasts, these attachment sites appear to be macular or delimited to relatively short distances, whereas in the odontoblasts they were much longer. No highly specialized structures analogous to either the tight junctions or the desmosomes observed in various epithelia were ever seen between any of these connective tissue cells.

During the formation of the digital flexor tendon in the rat, the tendon fibroblasts are continually displaced by the accumulation and enlargement of intercellular collagen fibrils. As these cells are forced apart, they remain attached by relatively long, slender cytoplasmic processes at the end of which are zones of attachment.

Odontoblasts (*4*) in developing tooth buds are attached by similar regions both near their apexes and close to their bases. No such attachment sites