related to the development of the Neogene (and modern) water mass regimes at that time. One of the major radiolarian zoogeographic anomalies, since the initiation of the Neogene water mass regimes and their contained radiolarian faunas, has been the isolation of relict radiolarian species in the warm water sphere of the North Atlantic. This oceanographic realm has been semi-isolated from the world ocean for about the last 3 to 3.5 m.y. and contains a relict (and expatriated) radiolarian fauna. Of special interest in the relict fauna are the presence of the species *Lamprocyrtis heteroporos*, *Didymocyrtis penultimus*, *D. avitus*, and *Spongaster pentas*—all, until recently, thought to be extinct.

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Regional Aspects of Diagenesis in Niagaran Pinnacle Reefs, Northwest Michigan: Evidence for Differential Fluid Migration

The Middle Silurian pinnacle reef system of northwest Michigan consists of a narrow, northeast-southwest-trending band of isolated reefs encased in thick Upper Silurian evaporites. All reefs display a similar pattern of diagenetic evolution: neomorphism of metastable carbonate components followed by precipitation of a closure cement; modification of porosity by a combination of cementation, solution and dolomitization; and emplacement of hydrocarbons and stylolitization. The exact sequence of diagenetic events and the resulting texture of the carbonate rock vary considerably from reef to reef, but several regional trends can be identified.

There is an obvious change in reef mineralogy *across* the reef trend, from predominantly calcitic reefs basinward to predominantly dolomitic reefs near the shelf. There appears to be a corresponding increase in $\delta^{13}C$ and $\delta^{18}O$ isotopic ratios shelfward, both in matrix limestone, according to Sears and Lucia in 1979, and in the neomorphic replacement of former marine cements. A change in the mineralogy of closure cements is observed *along* the reef trend, from calcite-pyrite in the southwest to pyrite or dolomite-quartz in the northeast. Oil emplacement also varies along the reef trend. Sparry dolomite and pyrite mineralization are associated with bitumen in the southwest parts of the reef trend, whereas leaching appears to accompany or just predate oil entry in the northeast. Finally, the dominant pore-filling phases in each reef vary in an irregular fashion throughout the trend from calcite and halite in some reefs to anhydrite and laminated dolomite in others.

These variations on a diagenetic theme appear to be related only to the presence or absence of diagenetic fluids in the reef's history, not to the lithology involved. Differential migration of fluids, caused by different hydrostatic heads on each fluid or migration through different pathways, would account for the diversity of diagenetic sequences in the pinnacle reef system. Careful petrographic and chemical analysis of each individual reef is needed to identify the local diagenetic history, and these local histories must be correlated in order to infer the larger picture of basin development.

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Freshwater Carbonate Cements

Freshwater carbonate cements in nonmarine sediments form in a diverse assemblage of settings, including fluvial, lacustrine, pedologic, spring, and spelean environments, giving rise to a plethora of textures and structures. Many deposits exhibit both phreatic and vadose zone textures. Cement mineralogy and composition vary considerably from deposit to deposit, as well as within individual deposits, depending on water chemistry and environmental setting. Similarly, cement habits range from highly acicular to nearly equant. The wide variety of textures, mineralogies, and compositions exhibited by both cement and associated sediments suggests that freshwater carbonate precipitation may involve complex processes. A survey of our present knowledge indicates that such cements are most commonly composed of low magnesian calcite as crystals with rhombohedral terminations. Among those features which appear to be unique to freshwater carbonate cements are crystals displaying trigonal prisms, rhombohedrons ornamented with parallel sharp spikes, and crystals with thorn-shaped vacuoles. Although variation in crystal habit may be influenced by either magnesium or total cation or anion concentrations in the precipitating fluid, the concentration of solutes does not appear to be the sole controlling factor. Growth rate, influenced by a variety of parameters, such as P_{CO_2}, may be the most important factor in predicting crystal habits in freshwater carbonate cements.

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Surface Gamma Logs: A Helpful Correlation Tool

Gamma logs of measured surface sections provide an excellent correlation tool in wildcat areas where well control is sparse and outcrops are abundant. Gamma logs of measured surface sections can be correlated with gamma logs of any nearby wells that have penetrated the same strata. Subtle changes in lithology that may have been missed during routine section measuring are detected by surface gamma measurements. Furthermore, gamma measurements over covered intervals may give clues to the nature of the buried lithology.

A portable scintillation counter is used to take gamma measurements. These measurements are recorded along with lithologic descriptions. Five-foot-intervals provide the best results.

Surface gamma logs are successfully used in correlating members of the Jurassic Twin Creek Limestone from wells in the northern Utah Overthrust to outcrops in north-central Utah. They are also useful in correlating upper Paleozoic rocks in the Basin and Range province.

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Channel-Levee-Overbank Sequence in Paleocene Submarine Canyon Fill, Point Lobos, California

Vertical sequences characterized by upward decreases in the grain size and bed thickness of turbidites are commonly attributed to laterally migrating channel-levee-overbank systems. A probable Paleocene example of such a sequence is superbly exposed at Pebbly Beach, Point Lobos, California. Contact relations indicate that the Paleocene deposits fill a steep-walled sinuous valley carved into underlying granodiorite of Late Cretaceous age. The few fossils found in the Paleocene rocks indicate deposition in water depths of 100 m (328 ft) or more and suggest that the sediment accumulated in a submarine canyon. Although most of these Paleocene deposits are conglomeratic, the upper part of the section exposed at Pebbly Beach consists of a 30-m (98-ft) thick fining-upward sequence from conglomerate through sandstone to mudstone. About 10 m (33 ft) of predominantly thick-bedded sandstone grades upward through a transitional sequence of about 2 m (6 ft) of thin-bedded sandstone into more than 15 m (49 ft) of mudstone with thin sandstone interbeds. The thick-bedded sandstone beds in the lower part of the sequence are typically several tens of centimeters thick, graded, and display Bouma T_{a-b} or T_{a-b-c} intervals. Although many of these sandstone beds are visibly lenticular, the associated thin mudstone interbeds extend laterally across the exposure, unchanged in thickness or lithology. This thin-bedded transitional sequence consists of graded sandstone beds, 5 to 15 cm (2 to 6 in.) thick, that displays Bouma T_{b-c} intervals. The mudstone unit that caps the succession consists of bioturbated mudstone with thin (mostly less than 5 cm, 2 in.) sandstone interbeds. Paleocurrents in the upper and lower parts of the succession (predominantly as recorded in ripples and ripple bedding) trend dominantly southwest. The transitional sequence, however, displays a consistent 30° deflection of currents to the south; in addition, these strata are inclined slightly more steeply to the south than the beds above or below.

I interpret this overall fining-upward sequence as resulting from lateral migration of a channel within the submarine canyon. The thick-bedded sandstone beds represent deposition on the flank of the channel; the lenticularity of these beds suggests that they were not deposited by a pure turbidity current but were carried by additional (or other) mechanisms, such as fluidized flow. The mudstone interbeds reflect predominantly pelagic deposition in the intervals between sediment gravity flows. The thin-bedded sandstone sequence represents a levee facies deposited primarily from tractive currents associated with the gravity flows that spilled over the channel and were deflected slightly to the south by the slope on the outer side of the levee. The upper, predominantly mudstone part of the section was deposited as pelagic sediment interspersed with overbank flows that traveled down the general slope of the submarine-canyon floor. An erosional surface with 3 to 4 m (10 to 13 ft) of relief near the top of the thick-bedded sandstone, covered by a mudstone breccia talus, records an episode wherein the channel reversed its migration direction and locally eroded the upper channel-flank deposits.

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Relative Role of Waves and Tides in Development of Transgressive and Regressive Coastal Sequences

Close examination of coastal morphology and related sediment bodies reveals that the commonly used terms "wave dominated" and "tide dominated" are in many places applied improperly. Such terminology provides little data that the geologist can use in establishing the various process parameters that prevailed in ancient coastal depositional environments. In addition to the absolute and relative size of waves and tides, it is also necessary to consider other factors which contribute to coastal morphology such as tidal prism, sediment availability, topographic relief, and rates of relative sea level change. Interaction of these factors may create a wide variety of stratigraphic sequences.

Several of these additional factors differ strikingly depending on whether or not the setting is one of shoreline progradation or marine transgression. In the absence of a delta, progradation generally leads to a simple, relatively straight shoreline, which tends to limit tidal currents to inlets, if present. Transgression caused by a relative rise in sea level may promote shoreline irregularity and embayment, and thus the potential for a larger tidal influence. Progradation occurs under conditions of ample sediment supply relative to the rate of sea level change, whereas transgression causes entrapment of sediment in coastal bays and rivers, thus reducing the amount of sediment available to the open marine setting.

Nondeltaic progradational deposits, accordingly, are likely to be considered wave dominated regardless of wave size or tidal range. Waves are more effective in distributing and reworking the sediment along a straight progradational coast than are tidal currents, and, in addition an ample amount of sand is available on the shoreface for this reworking. Shoreface deposits typically are the major component of a nearshore progradational sequence.

Transgressive deposits, however, are more likely to be considered tide-dominated even where wave size and regional tidal range are unchanged from those prevailing under conditions of progradation. Coastal irregularity creates refraction patterns that dissipate wave energy over broad areas, and so tidal flow within embayments becomes an important process. Most of the available sediment resides in these embayments and bears the stamp of reworking by tidal currents. Shoreface deposits are likely to be sporadically distributed and of inconsequential volume.

Deltas constitute a potential exception to the foregoing generalization. Many deltas are dominated by riverine processes and little influenced by either waves or tides. Moreover, deltas that form in areas of extreme tidal range can generate a complex shoreline during progradation and thereby mimic the embayed coast. Such tide-dominated deltas, however, typically form in areas of broader irregularity of coastline. Sufficient progradation may smooth this larger scale coastal configuration and thereby diminish the tidal influence.

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Stratigraphy and Sedimentology of Ledge Sandstone in Arctic National Wildlife Refuge Northeastern Alaska

Data collected from four measured sections of the Ledge Sandstone member of the Ivishak Formation are presented. These sections are located in the Arctic National Wildlife Refuge (ANWR) in northeastern Alaska. The Ledge Sandstone is the time equivalent of the Ivishak sandstones that form the reservoir in the Prudhoe Bay field, east of the study area. The ANWR region is of interest for oil and gas exploration owing to the numerous oil seeps on the coastal plain and surficial expression of possible subsurface antiforms.

The Ledge Sandstone in ANWR consists primarily of a massive, thickly bedded, very fine to fine-grained, well-sorted quartz sandstone. Thin beds of silt occur locally. Rare conglomeratic and pebbly zones are found within the unit. Porosity is negligible in the Ledge, owing to siliceous cementation. Bedding planes, where discernible, are predominantly planar with some low-angle cross-bedding. The bases of beds typically contain load features.

The thick sandstones are separated by thin siltstone intervals ranging from less than an inch to several feet in thickness. Although the thicker siltstones appear laterally continuous, the thinner beds generally are lenticular over short distances (10 to 20 ft; 3 to 6 m). Cementation of the siltstone appears sporadic, varying laterally and vertically within the unit. Burrowing is extensive in the siltstone intervals. Typically, burrowing cannot be detected in the sandstones because of the obliteration by lithification and diagenetic processes. Fossils are sparse throughout the unit, even in the poorly lithified silts. Some bivalve shells have been preserved intact, but lack any distinct orientation.

These data are consistent with a shallow marine environment, within wave base. This contrasts with the nonmarine conglomerates and sandstones of Prudhoe Bay. Time-equivalent units to the south and west consist primarily of cherts and shales of probable deep marine origin, with some arkosic sandstones and dolomites