Distinguishable associations of shape categories are quantitatively related to specific environments. Shape sorting, in combination with size sorting (different responses to transport processes), may extend the discriminating power.

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Global Atmospheric Circulation in Mesozoic and Cenozoic

Paleogeographic maps provide the minimum information needed to model global atmospheric circulation, that is, the size and distribution of landmasses, oceans, epeiric seas, and mountains. Numerical atmospheric circulation models require data, e.g., sea surface temperature, that are frequently unavailable in the rock record. Therefore, models of past atmospheric circulation must rely on paleogeography as the primary data base. The technique of modeling circulation on the basis of paleogeography alone is qualitative and necessitates some assumptions about certain parameters, e.g., the equator-to-poles temperature gradient. However, this technique has proved viable for the Paleozoic, and therefore it has been used to construct global circulation models for the Mesozoic and Cenozoic. The evolution of the circulation patterns since the Permian included, among other features: (1) the breakup of the Permian and Triassic cross-Pangea temperature gradient; (2) the destruction of the Permian monsoonal circulation and its eventual re-establishment late in the Cenozoic; and (3) the re-establishment of circum-polar winds, which last occurred in the Devonian. The circulation models are tested with data on the distribution of climatically controlled sediments, e.g., coals, evaporites, and carbonates, and with biogeographic patterns. The limitations of the qualitative modeling technique can be determined by comparing the late Cenozoic circulation maps with those generated by more quantitative techniques.

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Upwelling and Phosphorites in Paleozoic

The prevailing hypothesis concerning the origin of some major phosphorite deposits is that they were deposited in upwelling zones. To date, tests of this hypothesis have used criteria effective on a local scale rather than a global one, partly because reliable paleogeographic maps have not been available until recently. Good paleogeographic maps are essential because one must be able to model global atmospheric circulation patterns to predict the locations of upwelling currents, which are wind-driven. We know that today upwelling occurs primarily on west-facing coasts at about 30° latitude. Insofar as we have been able to identify such coasts in the past, attempts at predicting phosphorite localities have been successful. However, several other types of upwelling zones, unimportant to phosphorite deposition in the present world, were more important in the past when the continents were distributed differently. These other upwelling zones include zonal coastal upwelling, equatorial and high-latitude symmetrical divergence, and radial divergence. We will present atmospheric circulation and upwelling models for the Paleozoic constructed on global paleogeographic maps. The correspondence between the predicted upwelling zones and the locations of the major Paleozoic phosphorite deposits is highly significant ($p \ll .005$) for the Paleozoic as a whole, as well as for individual Paleozoic time periods, particularly the Cambrian and Lower Carboniferous.

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Reef Facies of Winnipegosis Formation (Middle Devonian), Williston Basin, North Dakota

The Winnipegosis Formation is a carbonate unit deposited in the Elk Point basin during the Middle Devonian. The Elk Point, a narrow, elongate basin extending southeastward from northern Alberta–Northwest Territories through central Saskatchewan and southwestern Manitoba to northeastern Montana and most of North Dakota, was flooded during the Kaskaskia transgression. The Winnipegosis Formation in the North Dakota part of this basin represents a transgressive-regressive stratigraphic sequence. The Winnipegosis has been studied on the basis of well cores from the Williston basin area of North Dakota. The following depositional environments are recognized: a carbonate platform in west and southwest, a platform-restricted basin in north-central, and a reef in east-central North Dakota.

The reef environment, where highly productive, has been studied in south-central Saskatchewan (Winnipegosis Formation) and northern Alberta (Keg River, an equivalent formation). To date there has been no production from the reef facies in North Dakota and only limited production from the platform environment. The reef facies is a porous and permeable dolomitized limestone; dolomitization is so extensive that the original fabric can seldom be discerned. Organisms that were present are now recognized as ghosts, as distinctive porosity patterns, and rarely as recognizable skeletons. In many parts of the reef facies, it is difficult to reconstruct the original fabric. Interpretation of the reef environment in the Winnipegosis Formation is based on comparisons of highly dolomitized fossils in the reef facies with fossils found in other facies, with fossils better preserved in less altered parts of the reef facies, with previously described reefs in Canada, and with fossils present in the reefs that crop out in Manitoba.

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Sedimentary Facies and Depositional Environments of Late Wisconsinian Glacial-Marine Deposits in Central Puget Lowland, Washington

Marine sedimentary deposits associated with relative sea level changes and the waning late Wisconsinian Cordilleran ice sheet are widely exposed above present sea level in the central Puget lowland. Some of these deposits, commonly referred to as glaciomarine drift, are traditionally interpreted as having been deposited as a rain of sediment from floating ice in water depths greater than 70 m. Deposits previously included in this drift include till-like diamictons, pebbly silt, massive well-sorted silt, and laminated silt and sand. Other glacial-marine or marine deposits include massive to crudely stratified sand and various mixtures of sand and gravel.

Recent studies indicate that all these deposits are broadly contemporaneous (14,000 to 12,000 ^{14}C yr B.P.) and that they represent a wide variety of depositional environments, many of which involved no glacier ice. In addition to marine environments receiving debris from floating ice, depositional settings may also include: (1) marine beach; (2) tidal flat and

estuary; (3) shallow (less than 10 m) subtidal marine; (4) deeper (greater than 10 m) marine; (5) marine-glaciofluvial delta; and (6) marine ice-contact glaciofluvial.

Microfossil and macrofossil evidence constrains the interpretation of water depth, sedimentation rate, and possibly water temperature and salinity for many of these environments. Radiocarbon dating of shells preserved in glacial-marine and associated deposits indicates that the retreat of continental ice was rapid. Age differences of approximately 1,000 ^{14}C yr between shallow-marine deposits at similar altitudes suggest differential isostatic rebound, perhaps related to the regional pattern of ice retreat or to inferred crustal structure.

We propose a deglaciation model that includes: (1) a rapidly retreating continental-ice margin that calved in open marine waters along an irregular isostatically active coastline; (2) rapid eustatic changes; and (3) large sediment volumes transported into marine waters by rivers draining the recently deglaciated landscape.

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Calcium Carbonate Cementation of Tills Rich in Ultramafic Rocks, Northern Puget Sound Region, Washington

Late Pleistocene tills containing appreciable amounts of ultramafic clasts and matrix occur on and adjacent to ultramafic bodies (commonly harzburgite) in the northern Puget Sound region. Many exposures of such tills are strongly cemented, typically by aragonite, although Mg-calcite and calcite also occur; cement comprises 1 to 6% of the till.

Cementation appears to be controlled by ground water enriched in calcium derived from calcium-bearing pyroxene in the ultramafic rocks. The role of incompletely serpentinized rocks and ground water is indicated by the following observations. (1) Cementation occurs only in association with incompletely serpentinized rocks; other calcium sources (e.g., limestone) are absent. (2) Calcium-rich cemented-till halos surround fresh ultramafic clasts that were glacially transported from source outcrops; completely serpentinized clasts have no cemented halo. (3) Massively cemented till forms preferentially at topographic lows on ultramafic bodies where ground-water discharge is concentrated. At these sites the till is strongly cemented in the wetted zone at and near the bed-rock contact, and the degree of cementation decreases a few meters above the contact.

These tills are unusual in that they contain the first reported $CaCO_3$ cement in till that is not derived from preexisting carbonate materials, although the process of carbonate (ophicalcite) generation from unserpentinized ultramafic rocks has been increasingly recognized in recent years.

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Plant Megafossils at Carboniferous-Permian Boundary

Plant megafossils are relatively common below and above the Carboniferous-Permian boundary in terrestrial beds and have been used to recognize the systemic boundary in this facies. However the systemic boundary in the terrestrial realm seems to be different from that used in marine sequences. To resolve this difference, any purely terrestrial section must be correlated with one which has interfingering marine and terrestrial beds. Plant megafossils were collected from the Upper Pennsylvanian and overlying Permian(?) sequences in West Virginia, where the age assignment of the Dunkard Group has long been controversial. Similar collections in the uppermost Pennsylvanian and lowermost Permian of Kansas were used for a correlation of the two sections. The lithofacies in the two areas are generally similar and both contain indicators of both wet and dry conditions. The plants occurring in rocks formed under relatively dry conditions change more rapidly and are therefore more meaningful for stratigraphic comparisons. The changes in the flora can best be expressed by the sequence of first occurrences (and to a limited extent, extinctions). The appearance of *Callipteris,* and specifically *C. conferta,* is clearly the best recognizable event in this stratigraphic interval. Based on these findings, the Washington coal bed in the Washington Formation, lower part of the Dunkard, would correlate approximately with the Topeka Limestone (middle Virgilian) of Kansas.

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Depositional and Structural Controls on Heavy-Petroleum Tar Sands in Santa Cruz Mountains

Heavy petroleum occurs in limited amounts as tar sands within the western Santa Cruz Mountains. The largest accumulation of petroleum is in the middle and late Miocene Santa Margarita Formation. The Santa Margarita rests disconformably on pre-Tertiary Salinian basement rocks and unconformably on the Monterey Formation (middle Miocene) and older Tertiary rocks. The Santa Cruz Mudstone (late Miocene), which conformably overlies the Santa Margarita Formation, provided an initial seal for petroleum entrapment. The distribution of petroleum apparently is related to the depositional environment of the Santa Margarita and to later structural development.

The Santa Margarita Formation is a tidal dominated marine shelf deposit. An 8-km wide northeast-trending facies of unidirectional, large-scale cross-strata of uncemented sand and gravel represents a zone of intense tidal currents; this facies provided a conduit for initial petroleum migration. Westward homoclinal folding, including northeast-trending and southwest-plunging compaction anticlines, formed structures for initial petroleum entrapment within the cross-bedded facies.

Strike-slip movement on the San Gregorio fault system formed a postdepositional conjugate fault-and-fracture system in the western Santa Cruz Mountains. Where petroleum had accumulated on structures, faulting caused injection of the petroleum sand into overlying siliceous mudstone; these injections range in width from a few centimeters to 200 m. Faulting and associated clastic injections also formed partial seals across structures within the Santa Margarita Formation. The maximum thickness (30 m) of tar-saturated sandstone occurs in fault traps downdip on southwest-plunging anticlines within the cross-bedded facies. Petroleum accumulations also occur in stratigraphic traps where sand pinches out on paleotopographic highs, in structural traps in fault-bounded blocks on homoclinal folds, and in possible diagenetic traps where sandstone rests on marble.

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