

hydrocarbons in this province. However, a thorough understanding of facies relations is essential for success in the search for this type of subtle stratigraphic trap.

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Petrologic History of Late Cretaceous Nanaimo Group in Nanaimo Basin, Western Washington and British Columbia: Implications for Cretaceous Tectonics

The tectonic development of the Late Cretaceous Nanaimo basin is an important factor in determining plate interactions along the northwest Pacific Coast where the basin was formed within an orogenic collage, surrounded by the North Cascades, coastal plutonic belt, insular belt, and San Juan Island terranes. The Nanaimo basin may have been an intramassif fore-arc basin or a pull-apart basin, which developed within a proto-Queen Charlotte transform zone.

Paleocurrent and petrographic data from the Nanaimo basin indicate derivation of plutonic debris from the coastal plutonic belt and intermediate volcanic and low-grade metamorphic rock fragments from the North Cascades. Plutonic debris and silicic to basic volcanic rock fragments were derived from the insular belt. Chert and subordinate intermediate-volcanic and argillaceous rock fragments were contributed by terranes of the San Juan Islands. Nanaimo sandstones contrast greatly with Late Jurassic to middle Cretaceous fore-arc basin sandstones in this region. Contemporaneous volcanic rock fragments are conspicuously absent in Nanaimo rocks and the dominance of plutonic over volcanic debris from the coastal plutonic belt suggests deep dissection of the massif.

Subduction along the continental margin of British Columbia and Washington may have greatly slowed or ceased during the Late Cretaceous. The tectonic setting was probably characterized by a broad zone of right-lateral transcurrent faulting. Cretaceous and early Tertiary structures of southern Vancouver Island are similar to structures observed along the San Andreas transform zone. Additionally, a magmatic gap is noted in the southern coastal plutonic belt during Nanaimo basin development.

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Submarine-Fan Facies of Late Cretaceous Nanaimo Group in Restricted Nanaimo Basin, Washington and British Columbia

Geometry of submarine fan facies in the Nanaimo basin contrasts greatly with fans developed along unrestricted continental margins. The latter fans are characterized by sediment deposited in distributary channels extending radially outward from a single-point source, forming fining-upward sequences. At the termini of these channels, nonchannelized sandy lobes are developed, forming coarsening-upward sequences. The surrounding basin-plain is characterized by noncyclic shale-rich sequences.

A large part of the Nanaimo Group was deposited as coalescing submarine fans, from several areas, in the restricted Nanaimo basin. These strata are dominated by fining-upward sequences, which indicate most sediment was transported by channelized flow. However, channels trend parallel with basin margins, not radially from them. Sediment transport was largely controlled by regional slope of the basin floor and not by the slope of the basin margins. Coarsening-upward sequences in the Nanaimo Group are not always located at the termini of channels. Some coarsening-upward sequences in the

Nanaimo Group are developed in proximal regions of particular fans, alongside time-equivalent, conglomerate-rich, fining-upward sequences. These coarsening-upward sequences may be crevasse splays. Noncyclic, shale-rich sequences are present throughout the Nanaimo basin. Some of these sequences are deposited by overflow from nearby conglomerate- and sandstone-filled channels in large interchannel areas. Others are distal fan deposits.

Much of the hydrocarbon found in submarine fan facies occurs in restricted basins. The Nanaimo basin may serve as an important analog to predict reservoir location and trapping mechanisms.

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Exploration for Geothermal Resources in Dixie Valley, Nevada: Case History

After several years of reconnaissance geology in Nevada, an exploration program to evaluate the geothermal resource potential of Dixie Valley was begun in 1974. Between 1974 and 1978 Sunoco Energy Development Co. conducted two heat-flow drilling programs, a resistivity survey, a seismic emission study, a ground noise survey, two magnetotelluric surveys, a hydrology study, and a surface geology survey. The synthesis of the data resulting from these projects into the regional geologic framework led to the acquisition of geothermal resource leases from fee property owners, through open-file application of federal lands, and by participation in the federal KGRA competitive lease sale of May 1976.

On September 15, 1978, Sunedco began drilling the No. 1 S.W. Lamb which became the discovery well.

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Recognition of Sand Body Depositional Environments: Limitations of Fourier Analysis and New Approach to Grain-Shape Analysis

In searching for subtle depositional traps, it would be useful to have a reliable method for determining the depositional environment of sand bodies from internal evidence. Attempts using various grain-size parameters have met with limited success. Recent advances in grain-shape analysis have not lived up to initial hopes. The potential of Fourier analysis is reduced when harmonic amplitudes are used without considering phase angles. Two types of errors can occur: (1) dissimilar shapes can produce similar sets of amplitudes, and (2) similar (but not identical) shapes can produce dissimilar sets of amplitudes. Phase angles can be compared between grains only when the grains are rotated to comparable positions; this can be accomplished by cross-correlation with an empirical asymmetric reference shape. Data reduction is desirable, but paired variables cannot be easily handled by standard multivariate techniques.

After rotation to standard position, raw shape data (sets of radial lengths) are adequate shape descriptors. These can be reduced by factor analysis that can be compared between grains and between large sets of grains more meaningfully than can Fourier descriptors (which provide a poor basis for comparisons between grains).

Results from the two approaches are compared in a preliminary re-study of the river-beach-dune discrimination problem. Gross grain shapes are classified into natural categories by multivariate analysis of rotated radials.

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 <sup>14</sup>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