hydrodynamic conditions. In general, canyons in the upper slope have relatively broad flat thalwegs distinguished by relatively bright surfaces; tonal gradations indicate that the thalweg surfaces lap smoothly onto sharply etched border terrane. Terrane bordering the canyons typically has a simple gully and ridge trellis pattern; one or both sides of this bordering terrane may be spectacularly etched and extended. Individual gullies typically extend up to faceted back slopes. The extent and pattern of etched terrane, as shown in the midrange images, varies considerably from canyon to canyon suggesting the influence of multiple erosional events involving different mechanisms, and a substratum of varied erosional resistance.

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What Can Elasticity Moduli Tell Us About Lithology and Diagenesis?

Because rocks have a certain rigidity, the displacement and velocity associated with pressure waves are not, for a given density, functions of the incompressibility alone, but also of the rigidity which links particles to each other.

In the shear waves, displacement occurs without volume change and the velocity is, for a given density, a function of rigidity alone.

For isotropic media:

$$V_p = \frac{(k + 4/3\mu)^{1/2}}{\varrho} \quad \text{and} \quad V_s = (\mu/\varrho)^{1/2}$$

where V_p, V_s = velocities of pressure and shear waves; k = incompressibility modulus; μ = rigidity modulus; and ϱ = density.

The knowledge of V_p alone is not enough to separate the effects of changes of incompressibility and rigidity. Though seismic velocities are proportional to the reciprocal of the square root of the density, statistical evidence shows that pressure and shear-wave velocities increase with density.

This must be attributed mainly to the effect of cementation. Cementation fills pores with solid material, thus increasing incompressibility, and cements particles together, increasing rigidity. However, compaction, the process of volume reduction, has much less effect on the rigidity increase than on the incompressibility increase. Where cementation is not important, low shear-wave velocities can be expected. Lower shear-wave velocities can also be expected where fracturing decreases rigidity, or where the shaliness of a horizon increases. Compressibility changes can be detected in shaly intervals.

The velocity of pressure waves may remain fairly constant when ridigity increases and incompressibility decreases, as when voids occur where the matrix is better cemented than in contiguous formations. The knowledge of V_s might attract attention to such situations.

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Geochemical Prospecting for Oil and Gas: Microbiologist's Viewpoint

Microorganisms are important factors in the processes that govern the distribution of numerous chemical elements in the earth's crust. Carbon in particular undergoes an enormous variety of transformations as a consequence of microbial synthetic and degradative reactions. These reactions have importance in the study of organic geochemistry. Geochemical prospecting, however, has been limited by a lack of understanding of specific types of microbially mediated reactions and the extent to which they occur within the geosphere. Geochemical data interpretation for the purpose of finding oil and natural gas deposits would be enhanced by future research directed at: (1) defining the extent to which geochemically active microbes penetrate the earth's crust; (2) reinterpreting carbon isotope data in light of microbial reactions of formation, oxidation, and competition; (3) identifying novel microbial biomarkers; and (4) determining whether microbes can produce significant quantities of C_2+ gaseous hydrocarbons.

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Stratigraphic and Unconformity Traps in Niger Delta

Although hydrocarbons are dominantly trapped in rollover anticlines and fault closures in the Niger delta, some stratigraphic traps have also been recognized. Three types of stratigraphic accumulations are recognized in the Niger delta: (1) crestal accumulations below mature erosion surfaces; (2) canyon fill accumulations above unconformity surfaces; and (3) facies-change traps.

Several important oil discoveries in offshore southeastern Nigeria are associated with crestal accumulations below erosional surfaces. In addition, canyon fill accumulations have been observed in offshore southeastern Nigeria within the Qua Iboe Shale. Recent discoveries have also shown accumulations within the Opuama Clay in the western flank of the Niger delta. Facies-change traps have also been observed in the central part of the Niger delta. The various stratigraphic traps observed in the Niger delta are identified by interpretation of seismic data.

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Evaporites as Seals for Hydrocarbon Accumulations in Carbonate Provinces of North America: Case Histories

Evaporites are an important factor as the seal for hydrocarbon accumulations in carbonate provinces throughout North America. In the Silurian of the Michigan basin, dolomitized Niagaran pinnacle-reefs have been effectively sealed with evaporite cycles composed of anhydritic sabkha deposits of the Ruff Formation and cleaner evaporites of the Salina units. In the Williston basin of North Dakota and Saskatchewan, successive regressions of the Mississippian sea have resulted in the subsequent basinward migration of anhydritic sabkha deposits over algal-pelletal limestone banks that were formerly shoals at the seaward edge of the sabkhas. The anhydrite has halted the updip migration of hydrocarbons in these limestones. In the Permian of west Texas, over 731 million bbl of oil have been produced from the San Andres Formation against a porosity barrier along the eastern side of the Central Basin platform where anhydrite has plugged the porosity of the dolomite. The McElroy field is an excellent example of this important trend.

The environmental conditions that provide the typical setting for the formation of shallow-marine carbonates are also ideal for the formation of evaporites whenever marine waters become sufficiently restricted. The occurrence of excellent evaporite seals in close proximity to porous carbonate reservoirs can provide many opportunities for entrapment of 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 conspiciously 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.