occurs. The end product, seen in ancient lithified analogues, is understandably difficult to interpret.

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Directional Relationships Between Primary Structures and Current Systems in a Tide-Dominated Environment[1]

Directional current structures occurring in the intertidal zone of the Minas basin at Five Islands, Nova Scotia, include sand waves, megaripples, current ripples, cross-stratification, micro-cross-laminae, scour striae, and flute markings. Their orientation is controlled either by ebb tidal currents or by sheet runoff at low tide. Depth of water, local topographic obstructions, and presence or absence of strong winds exert local influences on the orientation of these directional current structures.

Tidal currents flow at an average velocity of 1.3 knots during flood stage and 1.5 knots at ebb stage. Flood currents flow in an average direction of 60°, whereas ebb currents flow toward an average direction of 255° (readings given in azimuths). Locally, however (such as on the northwestern side of some east-west-oriented islands), ebb currents continue to flow toward the northeast for 2 hours after the shift from the flood to the ebb phase. Such a time lag in shift of flow direction is reflected in the orientation of primary structures. In the northwest lee of these islands, sand waves were observed to be face-oriented toward the northeast. Because sand-wave migration occurs at maximum water depths during the 2 hours before and after the shift from flood to ebb stage, they continue to be face-oriented toward the northeast at the northwest sides of islands. The megaripples and current ripples are formed by ebb tidal currents at lower water depths and are oriented southwestward. In open reaches where change in flow direction coincides with the change from the flood to ebb phase, sand waves as well as superimposed megaripples and current ripples are oriented southwestward.

During the 15 minutes preceding emergence of the intertidal zone, slope-controlled sheet runoff and channel flow in sand-wave troughs dominate the flow systems and form current ripples and flute markings. Their orientation reflects local slope changes. The depth of reworking of such sheet runoff seldom exceeds 1 inch. Consequently, although current ripples formed by sheet runoff may be superimposed on sand waves and megaripples, the internal micro-cross-laminae so produced are, in very few cases, of any consequence in box cores or trenches. Preserved internal cross-stratification, oriented in the same direction as steep faces of sand waves and megaripples, is produced by ebb currents of considerable velocity.

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Integrated Method of Facies and Reservoir Analysis as Applied to Redwater Field, Alberta

Integration of facies and reservoir analyses presents three main difficulties: (1) the volume of data is huge; (2) few causal relations between petrographic and reservoir properties are known; and (3) geologic data range from quantitative to purely qualitative.

Multivariate statistical methods offer a fruitful approach to the problem. A mathematically derived index allows determination of the similarity between two rock samples by simultaneously considering many environmentally significant variables which may be measured on different scales. A factor analysis of those similar coefficients portrays groups of rock samples that are environmentally distinct (environmental facies).

This same procedure can be used to determine reservoir facies (groups of rock samples with similar reservoir properties). Also, the reservoir properties in each of the environmental facies can be characterized and tested for distinctness. These environmental and reservoir facies must be established before relations between rock properties and reservoir properties can be established. These can be effectively determined by multiple regression and canonical correlation.

This approach was applied to the Redwater field; part of an Upper Devonian reef complex and nine environmental facies were outlined. This gave a detailed picture of reef zonation, from which the mechanics of reef growth could be interpreted. Analysis of the reservoir properties within these facies showed only four reservoir facies.

The study showed that the reservoir properties are controlled primarily by variables sensitive to the original environment of deposition. Porosity-permeability variation also is controlled by properties which reflect the amount and type of diagenesis. Diagenesis, in turn, is shown to be related to original environment.

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Diagenetic Versus Post-Diagenetic Dolomitization

The kinetics of the reaction, Biogenic carbonate $+ \mathrm{Mg}^{++} \rightarrow$ Dolomite $+ \mathrm{Ca}^{++}$, have been studied at 300°C. in aqueous solution. Within the dolomite stability field the rate of dolomitization is increased by the following.

a. Increased instability of the reactant.
b. Increased calcium plus magnesium concentration of the dolomitizing solution.
c. Increased magnesium/calcium ratio of the dolomitizing solution.
d. Increased molar solution/solid ratio.
e. Increased temperature.

Each of the above five kinetic variables favors dolomitization in hypersaline environments. However, dolomitization has not yet been precluded in a normal marine environment.

Present carbonate-forming sediments consist predominantly of the metastable minerals aragonite and magnesium calcite. At 300°C. these minerals, compared with calcite, are preferentially dolomitized. In nature, at lower temperatures, similar preferential reaction is observed. In limestone from Bonaire and Jamaica, the magnesium calcite components, in most cases red algae, have been replaced selectively by dolomite. Such preferential dolomitization indicates the penecontemporaneity of the process. The dolomitizing reaction is the mechanism whereby the

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[1] This work was supported by the Office of Naval Research, Contract Nonr-266(84). Reproduction in whole or in part is permitted for any purpose of the United States Government. Hudson Laboratories of Columbia University Informal Documentation No. 100.

metastable mineral equilibrated.

Because aragonite and magnesium calcites, in most cases, equilibrate moderately rapidly in time, either by replacement, inversion, exsolution, or dissolution. their disappearance from a rock might be a logical process of carbonate diagenesis. If true, diagenetic processes, as opposed to post-diagenetic processes, would in many cases reflect the environment of deposition.

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Petroleum in Time and Space

Conditions favorable to the formation of petroleum precursors have been in existence since early Precambrian time. Indigenous petroleum in commercial quantities is known today in strata ranging in age from Cambrian to early Quaternary. Discoveries of indigenous oil in the Precambrian can be anticipated where the limitations of space are met. Petroleum in space has no limitation in latitude, longitude, or present shoreline. It is limited to continental platforms and other sedimentary environments. It is also limited by a low tolerance for metamorphism. For this reason there is a "twilight zone" where oil and gas give way to gas only, both laterally in those basins that are bordered by tectonically disturbed belts, and with depth in deeper basins. Where coal is present, the degree of incipient metamorphism, or eometamorphism, can be determined roughly by carbon ratios, and more accurately by reflectance.

The lateral phase-out of oil caused by eometamorphism is found in many basins, including the Appalachian, Arkoma, and Alberta. Vertical phase-out occurs in the Gulf Coast, Permian basin, Anadarko basin, and the Baku district. During the last 16 years, 68 per cent of the new discoveries in the United States below 15,000 feet were gas (or gas and condensate); during the same period, only 30 per cent of the new discoveries above 15,000 feet were gas. Because of wide differences from place to place in thermal gradients and down-hole pressures, the depth of the oil "floor" changes considerably from place to place. In some areas oil phase-out can be expected from 15,000 feet (or above) to 17,000 feet; in others oil can exist a few thousand feet deeper. There is a distinct possibility that there is very little commercial oil below 22,000 feet.

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New Look at Geology and Petroleum Potential of Northern Alaska

Three terranes in northern Alaska have potential for petroleum: a Tertiary basin in the eastern Arctic Plain, a post-Neocomian Cretaceous basin in the Northern Foothills and western Arctic Plain, and a complex of thrust-faulted late Paleozoic and pre-Albian Mesozoic rocks in the Brooks Range and Southern Foothills. Recent re-analysis of these terranes suggests that the disposition of extensive thrust sheets may have controlled the distribution of petroleum reservoirs in much of the area. This interpretation has significant implications in evaluating the petroleum potential of northern Alaska.

The Tertiary basin contains interfingering marine and non-marine clastics. A few open folds are present and may provide structural traps. Stratigraphic traps may be expected along the tectonically active southern margin and along the stable basement rise under the present continental shelf. Elements of the Brooks Range may have been thrust over the southern margin of the basin in late Pliocene time. This basin awaits exploratory drilling. In the post-Neocomian Cretaceous basin, interfingering marine and non-marine terrigenous clastic sediments in open folds offer a host of structural and stratigraphic traps. Some of these have been drilled, and a few contain sizable reserves of high-quality oil and gas. Stratigraphic traps may be expected also in pre-Cretaceous rocks along the basement rise that forms the northern margin of the basin. Buried detachment fault planes may underlie some of the southern folds, offering the possibility of different, and possibly equally interesting, structures and stratigraphic sections.

The Brooks Range and Southern Foothills terrane is the most complex and difficult to assess, but its geology and oil potential are the most intriguing. The distribution of formations and facies is the result of northward movement of extensive thrust sheets during at least two major episodes of thrusting in mid-Early Cretaceous (pre-Albian) and early Tertiary times. Tectonic movement may have been as much as 75 miles, thus telescoping facies trends in all formations. As a result, Upper Devonian through Lower Cretaceous (Neocomian) rocks of numerous facies are now exposed in a belt of imbricate thrust plates. Holes drilled in this terrane can test a variety of structures and numerous facies of several formations, but the geology is so complex that paleogeographical and palinspastic reconstructions must precede the drilling. Similar terranes elsewhere have been very productive.

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Pennsylvanian and Permian Influence on Tensleep Oil Traps, Bighorn Basin, Wyoming

The Bighorn basin is located in northwestern Wyoming in the central Rocky Mountain province. Near the close of Desmoinesian time, regional uplift on the west and north elevated the Tensleep Sandstone of the Bighorn basin above sea-level. Broad, low-relief, northeast-trending folds developed during this orogenic uplift. Drainage patterns superimposed on the exposed Tensleep surface provided stream courses which furnished eroded Tensleep Sandstone sediment for the younger, upper Minnelusa Formation deposited in the east and southeast. During Middle Permian time, the Phosphoria sea transgressed the area, and the stream channels which had been incised in the Tensleep surface were filled with impervious shale, anhydrite, and reworked Tensleep Sandstone. Subsequent Phosphoria deposition onlapped post-Tensleep cuestas and monadnocks.

The majority of Tensleep accumulation discovered to date has been in traps which are structurally controlled. The effects of hydrodynamics have been recognized by many as factors in anomalous oil-water contact conditions. However, it is proposed here that accumulations in several of these traps are the result, partly or wholly, of three stratigraphic variables: (1) an intraformational change in permeability and (or) lithofacies, thereby providing a stratigraphic trap; (2) incised channels in the Tensleep surface which were later filled with impervious sediments, providing a truncational subcrop trap; and (3) a combination of (1) and (2) with later Laramide anticlinal folding superimposed on or near these primary traps, which commonly results in tilted oil-water contacts. Meteor-