bers on the basis of a regionally developed, argillaceous interval which forms the uppermost part of the lower member.

The lower member consists of regionally dolomitized marine carbonate rock of relatively consistent thickness and lithology, and has a maximum observed thickness of 54 feet. The upper member is a varied marine carbonate sequence, with three major facies. In the southwest, a wedge of lithologically relatively consistent carbonate rocks has a maximum thickness of about 130 feet along a northwestward-trending axis extending through the Weyburn district in the southeast and the Elbow district in the northwest. This wedge thins somewhat irregularly, though gradually, to a depositional edge in the extreme southwestern part of the area. North and east of the basin, finely laminated carbonate rocks are regionally developed, together with numerous interspersed biofragmental-pelletoidal carbonate banks with biohermal zones. The former have a maximum observed thickness of about 70 feet; the latter may be as thick as 345 feet.

Data indicate that the lower member was deposited as a whole in a broad epicontinental sea. The relatively shallow, open-marine conditions culminated at two different times in basin-wide, reducing, lagoonal conditions, as evidenced by the upper and medial bituminous, argillaceous intervals containing impoverished faunas.

The upper member appears to have been deposited in a shallow sea which deepened toward the northeast. Using a regionally developed, vertically restricted *Amphipora* zone as a datum, three pre-*Amphipora* tectonic provinces are discernible. In the southwest, the Elbow-Weyburn basin subsided relatively rapidly as thick shallow-water carbonate sediments accumulated. In the north and east, the comparatively stable Saskatoon shelf was the site of deposition of thin, laminated carbonate sediments and basal bank-carbonate sediments. Flanking the shelf on the north, the Meadow Lake-Sayese basin complex was a depositional site for similar sediments, except that bank sedimentation was further advanced, in response to more rapid, or more prolonged, subsidence.

In post-*Amphipora* time, subsidence continued in the north and was accelerated in the shelf area which received thick bank accumulations, whereas, in the southwestern basin, carbonate deposition was almost complete.

The consistently developed carbonate wedge occupying the Elbow-Weyburn basin would seem to offer the better prospects for large hydrocarbon accumulations. The abundance of localized carbonate build-ups north and east of this basin presents opportunities for multiple, if comparatively small-scale, accumulations of hydrocarbons.

KENT, P. E., British Petroleum, London, England

EXPLORATION PROGRESS IN NORTH SEA

The general structure and the type of prospects which have resulted from aerial magnetometer surveys and seismic work, including the location of the major evaporite basins of Permo-Triassic age, are now known. The expanded sedimentary column in the north and east, which probably includes a thick Tertiary sequence, and the occurrence of major unconformities may now be evaluated.

The general stratigraphic sequence is illustrated by reference to some of the first holes drilled in the western (British) sector of the North Sea.

KINSMAN, DAVID J. J., Princeton University, Department of Geology, Princeton, New Jersey

SUPRATIDAL DIAGENESIS OF CARBONATE AND NON-CARBONATE SEDIMENTS IN ARID REGIONS

A supratidal sediment surface is the common end-product of shallow-marine and intertidal sedimentation. Such surfaces normally increase in area as sedimentation proceeds, and may have a variety of geometric shapes. Furthermore, they may be either attached to a coastline or be unattached. The sediments deposited may range from almost entirely carbonate to non-carbonate and may be fine- or coarse-grained. The original mineralogy of the sediments represents a relatively stable assemblage for the temperature and solution conditions of the marine environment. When in the supratidal position, under a different physical and chemical regime, diagenetic changes may occur.

Many of the climatic variables which affect the marine environment affect the supratidal environment in a more severe manner. Solution compositions normally show small fluctuations in the marine environment, but pore solutions may undergo substantial dilution or concentration in supratidal areas. Solution changes depend largely on the balance between rainfall and rates of evaporation and evapotranspiration. The addition of land-derived waters may occur in inner parts of attached supratidal areas.

In areas of diluted pore waters, the probable diagenetic trend in carbonate sediments will be toward formation of low-magnesium calcite. Where pore-water concentration occurs, dolomitization of the original carbonate sediments takes place. The dolomitization of coarse-grained skeletal carbonate sediments is slower than that of finer-grained materials. Dolomitization normally is preceded by a fairly large calcium loss from the pore solution as a result of interstitial precipitation of aragonite or gypsum, the latter occurring under more extreme conditions of evaporation. Gypsum may be formed seasonally, being leached during the wet season, and is likely to be preserved only under conditions of net evaporation. Under high net-evaporation conditions, anhydrite, typically of the nodular type, is a possible development. Under an extreme net-evaporation regime, halite is formed, but higher salts are unlikely. In non-carbonate environments the evaporite mineral developments will be similar. In carbonate sequences larger amounts of calcium sulfate minerals are commonly present as a direct result of dolomitization.

The chemical evolution of the pore fluids in carbonate and non-carbonate sediments under net-evaporation conditions will vary greatly. In the carbonate sequence, a large magnesium loss results from dolomitization; sulfate can be removed almost completely because of the excessive amounts of calcium available, and the final solution is essentially a calcium chloride-type brine. In non-carbonate sediments there is little or no magnesium loss, but almost complete loss of calcium, largely as carbonate and sulfate minerals; less than 40 per cent of the available sulfate is removed, and the final solution is essentially a magnesium sulfate-type brine. An important variable which may have a critical effect on brine evolution is the bacterial reduction of sulfate.

Early diagenetic changes which may occur in supratidal environments are controlled largely by original sediment characteristics and climatic variables. The variation in possible diagenetic developments is large. Overprinting of different diagenetic facies commonly occurs. The end product, seen in ancient lithified analogues, is understandably difficult to interpret.

KLEIN, GEORGE DEV., University of Pennsylvania, Philadelphia, Pennsylvania

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.

KLOVAN, J. E., Imperial Oil Enterprises Ltd., Calgary, Alberta

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.

LAND, LYNTON S., Lehigh University, Bethlehem, Pennsylvania

DIAGENETIC VERSUS POST-DIAGENETIC DOLOMITIZATION

The kinetics of the reaction, Biogenic carbonate $+ Mg^{++} \rightarrow$ Dolomite $+ Ca^{++}$, 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

[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.