

seems to be a downgrading factor, at least for parts of the basin explored.

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Origin of Regional Pre-Middle Devonian Dolomitization in Williston Basin

Lower Paleozoic limestones in the Williston basin are only preserved from complete dolomitization where they are overlain by an argillaceous member of the Ordovician Stony Mountain Formation. This umbrellalike relation was originally interpreted as indicating that dolomitization resulted from the actions of descending brines. Basin-wide dolomitization of overlying strata (including the Middle Devonian Winnipegosis Formation) and an absence of Upper Devonian and higher regional dolomitization suggest that dolomitization was also a Middle Devonian event, which occurred during deposition of the overlying Prairie Evaporite.

Winnipegosis-Prairie Evaporite relations in Saskatchewan, however, indicate that a different genetic link existed between evaporite deposition and the regional dolomitization of subjacent carbonate rocks. It is believed that the Prairie evaporites were precipitated largely from groundwaters that entered the basin by means of carbonate buildups in the Winnipegosis Formation. Groundwater seepage first deposited travertine, "vadose" pisolites, and carbonate muds on mound tops and flanks, then caused massive precipitation and growth of interstitial, sediment-replacing and sediment-displacing gypsum in the mound-flanking beds. Concentration and processing of brines during their downward migration allowed final precipitation of chevron halite in salt flats on the basin floor. Groundwater movements also caused regional dolomitization of pre-Prairie Evaporite carbonate rocks which lay along flow paths. Groundwaters beneath the relatively impermeable Stony Mountain shale were stagnant and, consequently, did not cause dolomitization of their carbonate hosts.

Dolomitization of lower Winnipegosis blanket ("platform") limestones occurred concurrently with early compaction. This timing is consistent with the suggested dolomitization model.

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Late Cenozoic Calcareous Microfossil Biostratigraphy, Paleo-oceanography, and Biogeography—Poles to Tropics

Deep-sea drilling has provided a set of marine sedimentary sequences for global Cenozoic paleo-oceanographic studies. The CENOP (Cenozoic Paleo-oceanography) program is conducting paleo-oceanographic studies of the late Cenozoic from tropics to poles within the framework of plate tectonism and polar-glacial evolution. This requires detailed correlations between high- and low-latitude regions using different approaches.

Quantitative planktonic investigations have been conducted on late Cenozoic sequences in the South Pacific ranging from temperate to warm subtropi-

cal latitudes (41 to 26°S). Previous nonquantitative biostratigraphic studies have enabled the establishment of biostratigraphic schemes and correlation between the sequences which differ markedly in faunal characteristics as a result of the latitudinal range. Species frequency, diversity, faunal groupings (principal component and factor analyses), and coiling directions of *Neoglobobulimina pachyderma* have been determined for each sequence. Oxygen- and carbon-isotopic stratigraphy also has aided in intersite correlation.

During the Cenozoic, major changes have occurred in planktonic microfossil biogeography as reflected in the biostratigraphic sequences. These changes have been created largely in response to evolution of the Southern Ocean circulation system as obstructing landmasses moved apart. Included in these changes are the development of the Antarctic and Subantarctic water masses and the Antarctic Convergence and the evolution of cold, high-latitude climates. Nearly all evolution of calcareous planktonic microfossils has occurred outside of the Antarctic-Subantarctic, in subtropical-tropical areas, followed by limited migration into high latitudes. Virtually no endemism occurs among calcareous microfossils at high latitudes, but it is marked in late Cenozoic siliceous forms.

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Potential Resources of Natural Gas in United States—Case History of Potential Gas Committee

Since the early 1960s the Potential Gas Committee (PGC) has been preparing periodic estimates of potential resources of natural gas in the United States. The committee operates independently from any other group, either industry or government, and its published estimates represent the consensus of the working members who are organized into committees, one for each major producing area of the United States. Over the years, many different people have participated. The total U.S. natural gas resource consists of cumulative past production plus present proved reserves plus undiscovered potential resources. The work of the PGC involves the estimation of the potential resources only. With time the various components of the total recoverable resource should reflect a gradual shift from the potential category through proved reserves into production. Indeed, as the cumulative production in the United States has increased and the proved reserves have gradually decreased in recent years, the potential estimated independently by the PGC has changed gradually and the estimate of the total recoverable resource has remained remarkably consistent. Within individual areas the estimate of the undiscovered potential has shifted rather markedly, but the overall picture for the entire country has varied within close limits. Variations in the estimate of potential for the individual areas can be attributed to the progress of exploration and the exploration philosophy of the members of the committee.

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### Geochemistry of Oil-Field Waters from Northern Gulf of Mexico Basin

Detailed chemical analyses of 120 formation-water samples from 25 oil and gas fields in coastal Texas and Louisiana show that the salinity of water in the geopressured zones ranges from about 10,000 to 270,000 mg/L dissolved solids and may be higher or lower than the salinity of water in the overlying normally pressured zones. All the waters are of the Na-Cl type; Na generally constitutes more than 90% of the total cations and Cl constitutes more than 90% and up to 99.8% of the total anions. Ca concentrations increase with increasing salinity and bicarbonate increases with decreasing Ca concentrations. Magnesium and sulfate concentrations are generally low. The concentrations of copper, lead, and other heavy metals are generally less than 10  $\mu\text{g/L}$ .

Hydraulic fluid potentials and  $\delta\text{D}$  and  $\delta^{18}\text{O}$  values indicate that the formation waters are most probably modified connate waters representing the original marine water of deposition. The chemistry of these waters, however, is markedly different from that of ocean water. The differences in composition are shown to result from (1) interaction of the waters with evaporites, (2) interaction of the waters with minerals and organic matter present in the enclosing sedimentary rocks, and (3) membrane-squeezing and membrane-filtration properties of shales.

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### Stable Carbon Isotopes in Oil-Field Waters and Origin of Carbon Dioxide

The  $\delta^{13}\text{C}$  values of dissolved  $\text{HCO}_3^-$  in 75 water samples from 15 oil and gas fields were determined in a study of the source of carbon dioxide of the dissolved species and the carbonate cements that modify the porosity and permeability of many petroleum reservoir rocks. The fields are located in the San Joaquin Valley, California, and the Houston-Galveston and Corpus Christi areas of Texas. The reservoir rocks are sandstones ranging in age from Eocene through Miocene. The  $\delta^{13}\text{C}$  values of total  $\text{HCO}_3^-$  indicate that the carbon in the dissolved carbonate species and carbonate cements is mainly of organic origin.

The range of  $\delta^{13}\text{C}$  values for the  $\text{HCO}_3^-$  of these waters is  $-20$  to  $28$  permil relative to the PDB standard. This wide range of values is explained by three mechanisms. Microbiologic degradation of organic matter appears to be the dominant process controlling the extremely low and high  $\delta^{13}\text{C}$  values ( $-20$  to  $28$  permil) of  $\text{HCO}_3^-$  in the shallow production zones where the subsurface temperatures are less than  $80^\circ\text{C}$ . The extremely low  $\delta^{13}\text{C}$  values are obtained in waters where the concentration of  $\text{SO}_4$  is more than  $25$  mg/L and probably result from the degradation of organic acid anions by sulfate-reducing bacteria ( $\text{SO}_4^{2-} + \text{CH}_3\text{COO}^- \rightarrow 2\text{HCO}_3^- + \text{HS}^-$ ). The high  $\delta^{13}\text{C}$  values probably result from the degradation of acetate by methanogenic bacteria ( $\text{CH}_3\text{COO}^- + \text{H}_2\text{O} \rightleftharpoons \text{HCO}_3^- + \text{CH}_4$ ).

For samples from production zones with subsurface

temperatures greater than  $80^\circ\text{C}$ , thermal decarboxylation of short-chain aliphatic acid anions (principally acetate) to produce  $\text{CO}_2$  and  $\text{CH}_4$  is probably the major source of  $\text{CO}_2$ . The  $\delta^{13}\text{C}$  values of  $\text{HCO}_3^-$  for waters from zones with temperatures greater than  $100^\circ\text{C}$  result from isotopic equilibration between  $\text{CO}_2$  and  $\text{CH}_4$ . At these high temperatures,  $\delta^{13}\text{C}$  values of  $\text{HCO}_3^-$  decrease with increasing temperatures and decreasing concentrations of these acid anions.

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### Deposition of Marble Falls Formation, Central Texas

The Marble Falls Formation (Lower Pennsylvanian) records normal marine conditions and widespread limestone deposition over the Llano uplift and the adjacent Concho platform in Texas. Examination of depositional environments of the outcropping Marble Falls facilitates interpretation of the oil-producing Lower Pennsylvanian shelf and shelf-edge carbonate rocks along the western margin of the Fort Worth basin.

Most of the outcropping Marble Falls can be divided into two units separated by an unconformity. Lower Marble Falls is entirely Morrowan. Upper Marble Falls becomes younger westward: Morrowan in the east and Atokan in the west.

Marble Falls deposition began with establishment of an open marine platform centered at the Llano uplift. Incipient calcarenite shoals developed at some slight break in slope. The northeast part of the platform resembled the modern Bahamian Platform, although platform-off platform relief was less than  $9$  m. Platform margins were approximately coincident with present outcrops on the north and east sides of the Llano uplift.

The upper Marble Falls was deposited primarily as algal buildups and calcarenite shoals and as shale and spiculitic biomicrite in topographic lows. While the older lower Marble Falls Platform was subaerially exposed, deposition continued on the off-platform shelf adjacent to the rapidly filling Fort Worth basin. Progressive subsidence of the old platform allowed these facies to onlap the erosional surface. Strawn deltas simultaneously prograded across the upper Marble Falls shelf from the east. Marine energy levels and depositional relief were less than during deposition of the lower Marble Falls.

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### Statfjord Field, North Sea Giant

Statfjord, the largest single oil field in the North Sea, is located on the United Kingdom-Norwegian boundary between  $61$  and  $61^\circ 30'$  N lat. About 11% of the field extends into United Kingdom waters. Its discovery, in March 1974, was based on interpretation of seismic reflection surveys and extrapolation of a productive regional trend. Two principle sandstone reservoirs, Middle Jurassic Brent and Lower Jurassic to Upper Triassic Statfjord, contain reserves on the order of 3 billion bbl within a productive area of approximately 20,000 acres (8,094 ha.). Reservoir properties are excellent with permeabilities in darcys. The field extends northeastward 15.5 mi (24.9 km) and averages 2.5 mi (4 km) in width.