The Ratcliffe interval within the Williston basin in North Dakota is included in the Mississippian Madison Group. It is an informal stratigraphic subsurface unit which includes parts of the upper Mission Canyon and lower Charles Formations. Deposition of the Ratcliffe sediments occurred in an open to progressively restricted marine environment along the eastern margin of the basin. Six facies have been recognized in the study area. These are the: (1) brachiopod-bryozoan-echinoderm packstone/wackestone facies; (2) peloid-oolite packstone/wackestone facies; (3) ostracod-foraminifer wackestone facies; (4) laminated mudstone/wackestone facies; (5) anhydrite-dolomite mudstone facies; and the (6) organic quartz siltstone facies. Oil found within the Ratcliffe interval is usually associated with the peloid-oolite packstone facies. Some moldic porosity has developed by solutioning. Dolomitization has increased intercrystalline porosity. Dolomitized areas commonly are capped by less porous facies making good potential stratigraphic traps. Formation of traps and reservoir rock is highly dependent on porosity and permeability and also on the amount of diagenesis, especially secondary anhydrite, associated with the sediments.

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Production Analysis in Exploration: Stettler Field Extension, Alberta

In October 1977, a significant extension to the 50,000,000 bbl Stettler D-3 and D-2 reef oil field was made 28 years after the initial 1949 discovery and 17 years after the field was considered fully delineated by exploratory and development drilling. The Stettler field is among a number of well-documented Upper Devonian reef fields and was seismically and geologically mapped before and after discovery.

The potential of some Alberta reef field extensions became evident with the new oil economic reality following the Arab oil embargo of 1973. Attention was given to the structurally downdip, southwest closing rim of the Stettler dolomitized D-3 atoll during 1977-79 by the drilling of seven successful oil wells beginning with the Geneva Resources 6-17-38-20 W4 test on a prospect created by the speaker.

From November 1977 to January 1, 1981, 122,869 bbl of crude were produced from the 6-17 well at an average rate of 108 bbl oil/day during that period. At least 1,000,000 additional barrels of primary Stettler oil will be produced as a result of these recent extension wells.

The key to this successful prospect was the lead derived from using computer lists and decline curves of production data. By 1977, over 400,000 bbl of oil and less than 20,000 bbl of salt water had been produced from the 1960 Tenneco CPR 12-17-38-20 W4 well. This location was believed by industry in 1960 to have been close to the D-3 reef oil/water contact with an expectation of high water and low oil productivity.

This example of a significant reef extension is a reminder that abundant, economic oil reserves remain to be discovered in other areas by a more realistic use of geology and production information available in existing computer files.

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Progressive Stages of Diagenesis in Early-Middle Eocene Fore-Arc Delta, Shelf, Slope, and Basin Sandstones, Southern Coast Range, Oregon

The Flournoy and Tyee formations (early to middle Eocene) of western Oregon are a model example of pervasive diagenesis in volcanic arenites, which extend over a full range of environments: delta, shelf, slope, and basin. Although younger Eocene units in Oregon prove to be good reservoir rocks, the Flournoy and Tyee lack porosity. This is due to fore-arc basin burial and subsequent mechanical and chemical diagenesis.

Evaluation of the diagenetic phases indicate deep burial and compaction at an early stage. Unstable volcanic rock fragments and plagioclase grains from all environments show alteration to mixed-layer clays and laumontite, making them more susceptible to mechanical plastic deformation.

Cementation and replacement were most common in coarse-grained deltaic and shelf sands, where the depositional porosity was high. An early stage of calcite cementation preserved open framework-supported textures in spherical concretions. A second stage of mixed-layer clays formed cement rims. Clinoptilolite filled remaining pore space. Locally, these two phases are reversed in Flournoy sands. Rare fractures were filled by stilbite. During a late stage, calcite replaced clay rims and zeolites, or filled remaining pores. In other samples, pervasive laumontite, together with minor clays, tightly cemented the coarse-grained sandstones.

Slope and basin sandstones are finer grained and contain more matrix than coarse-grained sandstones. Original composition, grain size, and original porosity (a function of depositional setting) controlled diagenetic development. These deeper water sandstones show some clay and calcite cements, but are generally lacking zeolite cements.

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Mineral Reaction Pathways and Mass Transfer in Sandstone-Shale Sequences, Brazil

The major purpose of this study is to describe and quantify mineral reactions, reaction pathways, and mass transfer accompanying burial of passive margin sandstone-shale sequences, offshore Brazil. Four basins were investigated, encompassing a range of sandstone-shale compositions. Because these basins have similar geologic histories, the effect of original detrital mineralogy on diagenetic products could be ascertained. Standard light microscopy, X-ray diffraction, EM, SEM, and isotopic and chemical analyses provided the basis for interpretation of mineralogy, texture, and diagenetic reactions.

The initial mineral composition of the sediments was a major control of diagenetic products. Arkose and lithic arkose are the dominant sandstone types in these basins. Dioctahedral clay minerals, chlorite, and quartz characterize arkoses, whereas trioctahedral clays (saponite and corrensite) and zeolites are found in lithic sandstones. Dioctahedral smectite-rich shales exhibit the classical smectite/illite to illite burial pattern. However, mafic, trioctahedral clay-rich shales show a burial sequence of saponite to chlorite/saponite mixed-layer, a progressive increase of chlorite-rich phases with increasing burial depth.

The structural change of disordered to ordered interstratification of mixed-layer chlorite/saponite occurs in the temperature range of 60 to 80°C, and at vitrinite reflectance values around 0.7. Increasing substitution of silicon by aluminum in tetrahedral sites is the major chemical change accompanying transformation of saponite to chlorite via corrensite.

Material balance calculations indicate that sandstones lose less than 2% K^+, which probably enters interstratified shales, and gain less than 3% H_2O, H^+, and CO_2 during burial diagenesis. Therefore, the burial pathway of Brazilian sandstone

diagenesis is nearly isochemical.

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Relation of Lithofacies and Diagenesis to Porosity Development, Mission Canyon Formation (Mississippian), Eastern Montana and Western North Dakota

The ability to map lithofacies trends suitable for hydrocarbon reservoirs is critical for a successful exploration program. In exploring basins with carbonate reservoirs, diagenetic alterations must also be understood in relation to porosity development. The Mission Canyon Formation (Mississippian) of the Williston basin provides an excellent example of the need to understand the lithofacies/diagenesis relation.

During the Mississippian, the Williston basin was the site of subtidal to supratidal carbonate deposition. In general, depositional environments became more restricted from Montana, eastward into North Dakota. Subsurface mapping suggests a strong relation between the degree of marine restriction and diagenesis and porosity development in carbonate sediments. Two fields that produce from the Mission Canyon interval illustrate this relation.

MonDak field, situated on the Montana-North Dakota border, lies west of the limit of massive Mission Canyon anhydrite, in a sequence of normal marine sediments. Reservoir porosity is due to fracturing of tight, fine-grained limestones. Low matrix porosity and sparse, erratic fracturing are responsible for low daily production rates.

The Billings Nose–Little Knife trend (Billings, Dunn, and McKenzie Counties, North Dakota) lies well within the limit of massive anhydrite. Reservoir porosity in this case consists of a thick sequence of intertidal-supratidal sucrosic dolomites which are sealed by 20 to 25 m of massive anhydrite. Reflux of Mg-rich brines is believed to be the process leading to dolomitization.

Good matrix porosity and permeability allow for higher daily production rates. Regional mapping indicates that the presence or absence of anhydrite is in direct correlation with the development of good matrix porosity.

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Regional Assessment and Interregional Comparison of Oil Exploration Potential—Breaking the Time Barrier

At any time, the degree of exploration may vary widely within a region or between regions. Regional assessments or interregional comparisons based on projections of field-size distributions in time-series discovery data are therefore dependent upon non-uniform evaluation of oil potentials. In this study, drilling history data from wells in Kansas are used to identify the various times at which all locations within regions of the state achieve selected exploration levels. Maps of the regional variation in time associated with a uniform level of exploration demonstrate the historical step-out pattern of the industry.

Known oil fields in Kansas are ranked in relation to prior exploration in the vicinity of discovery wells, with low-rank values corresponding to low density of prior exploration. All known fields within a region are classified into sets. Each set consists of fields discovered at various times, but at a uniform exploration level. Probabilities of discovering fields at different levels of exploration are developed in relation to field size. Projections of the ultimate number of fields in each size class expected within a region are then obtained through analysis of field-size distributions within each of the uniform exploration sets. By subtracting known fields from the ultimate number expected in each size class, a measure of future regional potential for continued exploration is obtained. Measurements of the success of exploration by the petroleum industry relative to the potential success from random drilling are also obtained.

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Arumbera Sandstone: A Possible Late Proterozoic-Early Cambrian Deltaic Complex, Central Australia

A detailed investigation of the Arumbera Sandstone was undertaken in the northeastern Amadeus basin, central Australia, where the unit forms distinctive strike ridges with orange-white cliffs and dark reddish slopes. The Arumbera is divisible into four informal, readily mappable units.

Approximately 80% of the "average" stratigraphic section is composed of recessive, pale-red, thin to medium-bedded, fine to medium-grained arkose with major proportions of siltstone and mudstone. These sediments are interpreted as a complex assemblage of coastal and nearshore marine environments including tidal flats, tidal channels, estuaries, and beaches. Evidence includes: (1) predominance of alpha, beta, and xi cross-stratification with common herringbone laminae, hummocky cross-strata, planar foreshore stratification, and flaser bedding; (2) bimodal paleocurrents; (3) records of intermittent subaerial exposure; and (4) rare to abundant marine trace fossils.

The remaining 20% of the Arumbera is composed of cliff-forming orange-white thick-bedded, fine to medium-grained arkose and lithic arkose with pebble to cobble conglomerate. This facies probably is a fluvial sheet sandstone. It is characterized by: (1) pi and omicron cross-stratification; (2) general paucity of mudrocks, but abundant shale pebbles; (3) unimodal, northeast-oriented paleocurrents; (4) wedging channel-sand bodies; (5) absence or extreme rarity of trace fossils; (6) sheet-like geometry; and (7) decrease in maximum grain size to the northeast.

The Arumbera probably was deposited in a coastal environment unrestricted by vascular land plants, but perhaps analogous in other ways to the delta of the modern Godavari River of India. Evidence includes: (1) a pronounced depocenter for the unit in the central part of the study area (thickness northeasterly from 216 to 1,123 m in 80 km); (2) unidirectional paleocurrents from fluvial sheet sands that radiate to the north, northeast, east, and southeast; (3) fluvial and coastal deposits in vertical, repetitive succession; and (4) east and northeast-trending zones of thicker deposits within fluvial sheet sands which may be distributary lobes.

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Diagenesis of Lime Mud, Mississippian-Age Bioherms, Sacramento Mountains, New Mexico

Samples from six Waulsortian bioherms were examined from the Mississippian Lake Valley Formation, Sacramento Mountains, New Mexico, to determine the timing and mechanisms of lime-mud cementation and to evaluate the role of this cementation in biohermal stabilization and growth.

Petrography and cathodoluminescence of bioherm and interbioherm muds defined distinct diagenetic mud types. Each mud type is characterized by a distinct grain size, mud color, and cathodoluminescence. Bioherm *type 1* mud is dark gray, fine-