mineralogic, paleontologic, petrophysical, and geochemical techniques. Extractable heavy hydrocarbon and organic carbon contents were used as standards to which the other techniques were compared. It was found that lithic characteristics, particularly sedimentary structures and thin-section properties, correlate quite well with the standards. Test-tube pyrolysis, followed by careful measurement of the amount of fluorescence produced by the condensed liquids, was the most useful method developed.

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ELONGATE CONCRETIONS AS PALEOCHANNEL INDICATORS, TONGUE RIVER FORMATION, NORTH DAKOTA

Two types of sand bodies occur in the nonmarine Tongue River Formation (Paleocene) of western North Dakota, linear and tabular. The tabular sand bodies have sharply scoured bases, become finer upward, and the vertical sequence of sedimentary structures shows a decrease in the flow regime upward. These bodies are overlain by gray lignitic silts and clays, and they are interpreted as high-sinuosity stream deposits.

Linear sand bodies are the most common type in the Tongue River Formation. They are usually straight and have deeply channeled bases and flat tops. Vertical changes in grain size show no consistent pattern, but the upper parts become finer upward in many places. Sedimentary structures are about 60 % planar (omikron) cross-stratification, 25% horizontal or low-angle planar laminae (plane bed) with parting lineation, and 15 % small-scale ripple cross-stratification. Paleocurrent indicators parallel the axes of these bodies, which are interpreted as low-sinuosity stream deposits.

Elongate concretions, up to about 15 ft wide and hundreds of feet long, occur only in the linear bodies. They consist of calcite-cemented sandstone, and they usually occur at or near the tops of the bodies. They help to protect the bodies from erosion so that in places the bodies exist as exhumed paleochannel systems that form an inverted topography. The axes of the concretions parallel both paleocurrent indicators and the axes of the sand bodies. The concretions are clearly visible on air photos and can easily be used to map paleochannel patterns either on the air photos or in the field.

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SILURIAN CARBONATE RECYCLING: EXPLANATION FOR ANOMALOUS SUB-DEVONIAN UNCONFORMITY IN WILLISTON BASIN

Conventional electric-log correlations of the lower Paleozoic sequence in southern Saskatchewan express the sub-Devonian boundary as a major unconformity which has traditionally been interpreted as an erosion surface involving the removal of large volumes of Interlake carbonate rock between Late Silurian and Middle Devonian times. The amount of sediment removal invoked by this concept seems anomalous for the Williston basin, in terms of the short timespan involved.

Based on facies analysis, an evolutionary model is presented involving marginal upwarp and erosion throughout the span of Interlake deposition, augmented by sediment recycling in the latter part of Interlake times. Marginal attenuation of Interlake units is coupled with the passage of normal marine to supratidal carbonate facies on a gradient which predicates the emergence of a broad surrounding hinterland at least by mid-Interlake time. This area emerged gradually and a corresponding regression of Interlake seas exposed increasingly greater surface areas of lithified carbonate sediment to subaerial processes. Chemical and mechanical erosion of this terrain caused a natural recycling of carbonate material toward the marine basin, both as clastic and dissolved particles. These were redeposited as part of a broad coastal plain complex which prograded into the shrinking marine area and eventually covered all of southern Saskatchewan. Hence, long before Interlake sedimentation had ceased, erosion had strongly beveled preexisting sediments around the Williston Basin margin, developing the unconformity which separates Silurian from younger rocks in this basin. Much of the sediment removed by this erosion was recycled during Late Interlake time and post-Silurian erosion caused only slight modification of the terrain.

Exploration of the Interlake Group for petroleum should be based on an understanding of the evolutionary changes accompanying Interlake sedimentation. Because the most favorable porosity occurs in dolomitized marine carbonates, exploration efforts should be directed toward southeastern Saskatchewan, where marine deposition prevailed over the longest period of time and accordingly potential reservoirs should be thickest.

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LOW- AND HIGH-SINUOSITY STREAM DEPOSITS OF SENTINEL BUTTE FORMATION (PALEOCENE), MACKENZIE COUNTY, NORTH DAKOTA

Low-sinuosity stream-channel sands in the study area are 8–20 m thick and up to 400 m wide. They are lens-shaped, with flat tops and concave-upward, deeply channeled bases. Paleocurrent directions are subparallel to sand-body axes. Epsilon cross-strata are rare, but numerous other types are common. The sands are fine- to very fine-grained and moderately sorted. Cross-stratification and grain size changes suggest one or more episodes of upward decrease in flow regime.

High-sinuosity stream-channel sands may also reach 20 m in thickness but may be a kilometer or more in width. They are tabular bodies with scoured bases. Paleocurrent directions are parallel to sand body axes. Cross-strata types are less varied than in low-sinuosity stream sands but epsilon cross-strata are more common. The high-sinuosity sands are generally coarser grained and better sorted than the low-sinuosity deposits, and grain-size changes along with cross-stratification changes show an upward decrease in flow regime.

Alternate thin beds of tan and rust-colored sands, silts, and clays in wedge-shaped bodies overlie the high-sinuosity sand, but occur adjacent to and slightly above the low-sinuosity sands. These characteristics, plus low organic content, numerous thick concretionary layers and abundant climbing ripples suggest that these are natural levee deposits.

The natural levee deposits grade laterally and vertically to the disturbed and dark-colored clays of the flood basin. These laterally extensive deposits commonly become fine upward and become organic, and are overlain by beds of lignite.

Thin, very fine-grained sands occur in either the natural levee or flood-basin deposits of the low-sinuosity streams. They have channeled bases, pinch out laterally, and show highly variable current directions. They are probably crevasse-splay deposits.

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LAMINATED ("VARVITIC") CARBONATES AND ANHYDRITES FROM ORDOVICIAN AND DEVONIAN OF SASKATCHEWAN

Bituminous-laminated (or "varvitic") carbonates, which grade upward into laminated anhydrites, are of particular interest to the petroleum geologist, because the carbonates may act as source, carrier, and reservoir rocks whereas the overlying anhydrites form impermeable caprocks. Commonly, such sediments exceed 10 ft in thickness and are traceable over thousands of square miles, but have been interpreted as of upper intertidal (algal mat) and supratidal (sabkha) origin.

Carbonate-anhydrite laminites occur as a basin facies of the Middle Devonian Winnipegosis Formation in Saskatchewan and are located on the basin floor between large carbonate banks. The laminites grade downward into a thin (1–10 ft) unit of black, highly bituminous, laminated mudstone containing a pelagic fauna. Near carbonate banks this mudstone thickens and includes carbonate beds interpreted as turbidites or mud-

slide deposits. The overlying laminites also are interpreted as turbidites (or deposits of salinity-driven bottom currents). Calcium carbonate and sulfate precipitated over shoals (the former banks) were transported basinward. Initially, basin-floor waters were undersaturated with calcium sulfate and only carbonate laminites persisted. With increasing basin-floor hypersalinity the sulfate persisted and carbonate-anhydrite (later, anhydrite) laminites formed.

Identical carbonate-anhydrite laminites occur within the Ordovician Red River, Stony Mountain and Stonewall Formations, forming the upper members of carbonate-evaporite cycles. Starved basin bituminous mudstones are absent or poorly developed. The thickness, lateral persistence (across and along depositional strike), and the absence of structures indicating emergence suggest that Ordovician laminites did not form in intertidal-supratidal environments.

The Ordovician laminites are believed to have accumulated within local depressions (perhaps quite shallow) which collect hypersaline brines. Brines were generated on neighboring platforms, sites of essentially no net deposition. Carbonates and gypsum, precipitated on the platform, were episodically introduced into depressions by high-energy events (storms, turbidite? flows).

In both Devonian and Ordovician laminites, mass-movement of sediment downslope, the incompetency of sulfate laminae, partial or extensive replacement of carbonate by anhydrite, and possible dehydration of primary gypsum to anhydrite caused local deformation and disruption of laminated sediments, converting them to rocks superficially resembling those formed in sabkha environments.

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PETROLOGY AND PALEOGEOGRAPHY OF MISSISSIPPIAN MADISON FORMATION IN WESTERN SASKATCHEWAN

In western Saskatchewan the Mississippian carbonate rocks may be categorized into 5 lithofacies, which individually or collectively can be used to assist the interpretation of the various environments of deposition. The five categories are: (1) impoverished calcareous mudstone, (2) skeletal calcareous mudstone, (3) micritic skeletal or nonskeletal sandstone, (4) poorly washed skeletal sandstone, and (5) calcite-cemented skeletal or nonskeletal sandstone.

The impoverished calcareous mudstones dominate the lower part of the Mississippian succession, particularly in the southern part of the study area, where they are composed of bituminous and argillaceous materials as well as nonargillaceous calcareous mudstones. The impoverished calcareous mudstones probably represent sediments deposited in water below wave base on the seaward side of the shelf edge.

Collectively, the skeletal lithofacies probably represent shelf-edge deposits. Calcite-cemented crinoidal sandstones accumulated as thick, elongate banks. The poorly washed sandstones are generally at the top and bottom of the banks and the interbank areas show outward gradations from micrite skeletal sandstones on the flanks of the banks to skeletal calcareous mudstones in the centers of the interbank areas. Micritic skeletal sandstones also form blanket deposits that commonly act as platforms upon which the crinoidal banks were built.

The nonskeletal sandstones (primarily composed of oolites) probably represent subtidal deposits on the shoreward side of the shelf edge. In the central part of western Saskatchewan they are present in the lower part of the succession and pass laterally southward into shelf-edge deposits. Farther south they are found at higher stratigraphic levels, and they are in lateral continuity with and overlie shelf-edge deposits. The relationships suggest a regression of open marine conditions from north to south.

If the Mississippian sequence of southeastern Saskatchewan is used as an analogy, a dolomite-evaporite facies representing a supratidal environment probably existed north of the subtidal deposits, that is, beyond the present subcrop edge of the Mississippian in western Saskatchewan.

This postulated distribution of facies suggests that possible hydrocarbon reservoirs similar to those of the Virden area of Manitoba are present in subtidal and shelf-edge deposits along the Mississippian subcrop in Saskatchewan.

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WATTENBERG FIELD, DENVER BASIN, COLORADO

Wattenberg field is a large gas accumulation (1.1 Tcf) in the "J" sandstone of Cretaceous age. The trap was formed in the delta-front environment of a northwesterly prograding delta.

The field is a stratigraphic trap straddling the axis of the Denver basin. Reservoir rock quality is poor and fracturing by artificial means is necessary to test a well.

Large extensions to the field may be made by following the delta-front environment trend. Industry exploration efforts will be dependent on gas price economics.

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SEDIMENTARY FACIES AND CORRELATIONS OF GALLUP SANDSTONE AND ASSOCIATED FORMATIONS, NORTHWESTERN NEW MEXICO

The Gallup Sandstone of Late Cretaceous age is a regressive clastic wedge that prograded about halfway across the San Juan basin from a probable source in southwestern Arizona. Numerous closely spaced detailed surface sections, measured along the outcrop belt on the west and south sides of the San Juan basin and extending about 70 mi south of Gallup, New Mexico, into the Zuni basin, have facilitated detailed correlations of the complex of marine, coastal-barrier sandstones and associated nonmarine paludal mudstones and fluvial channel sandstones that comprise the formation. South of Gallup the Pescado Tongue of the Mancos Shale separates the Gallup into two parts; a lower part called the Atarque Member of early Carlile to early-late Carlile age, and an upper part of latest Carlile to possibly earliest Niobrara (?) age. Only the upper part is present in the San Juan basin.

Physical tracing of some of the units indicates discrepancies of former correlations. The Horsehead Tongue of the Mancos was found to be the same unit as the Pescado Tongue, and hence the term should be abandoned. The widely distributed Juana Lopez (Sanostee) Member of the Mancos Shale was traced southeast of Gallup where it grades into a nonmarine sequence below the Pescado Tongue. Hence, the Pescado Tongue is younger than formerly considered, and undoubtedly is equivalent to the lower half of the D-Cross Tongue in the southeast. The upper pink fluvial sandstone of the type area near Gallup has been traced to the north where it merges with the coastal-barrier sequence north of Sanostee. The name Torrivio Sandstone Member of the Gallup is proposed for this unit. On the east, along the outcrop belt, it pinches out into nonmarine paludal mudstones of the Dilco Coal Member of the Crevasse Canyon Formation.

The basal transgressive upper Mancos Shale of early Niobrara age, which extends to a few miles northeast of Gallup, overlies the Gallup and associated nonmarine deposits of the Dilco. In the northwest corner of New Mexico and the southwest corner of Colorado, this transgression truncates as deep as the Juana Lopez interval. A belt 15-20 mi wide, in which the rate of truncation is greatest, coincides with the location of the so-called Gallup oil fields or pools which produce from lenticular marine sandstone bodies associated with Niobrara transgression. On the south side of the San Juan basin, another type of transgressive sand, which has been informally referred to as the "Stray" sandstone, is an offlap sequence associated with the Niobrara transgression. All these sands are genetically unrelated to the type Gallup Sandstone.

A northwesterly trending shoreline prevails for most of the units of the Gallup and associated formations.