Stratigraphic and Lithologic Relationships, Interlake Formation (Silurian), Southern Saskatchewan

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A study of the Interlake Formation (Silurian) in Saskatchewan was initiated in the fall of 1986. The main objectives of this study are 1) to refine the stratigraphy and 2) to investigate facies distribution and diagenesis with particular emphasis on porosity distribution. This report proposes a revised stratigraphic nomenclature for the Interlake and discusses briefly the lithologies and porosity development within it.

The Interlake Formation comprises a sequence of shallow-water carbonates and minor evaporites deposited in the Williston Basin during the Early to Middle Silurian (Johnson and Lescinsky, 1986; Carlson and Eastwood, 1962). These strata overlie Ordovician carbonates of the Bighorn Group with apparent conformity and are unconformably overlain by the argillaceous dolomites of the Middle Devonian Ashern Formation.

The Interlake Formation attains a maximum thickness of approximately 335 m in the central portion of the Williston Basin in North Dakota (LoBue, 1982). In Saskatchewan, it thins from 217 m in 10-28-1-10W2 in the southeastern area of the province to a zero edge in the west and north. This distribution of strata reflects both depositional thinning away from the centre of the basin and removal by erosion of a significant volume of rock some time between the Middle Silurian and Middle Devonian. The Interlake outcrops in Manitoba but is confined to the subsurface in the remainder of the Williston Basin. Records show that, to date, 521 wells have penetrated these strata in Saskatchewan; 86 of them are cored (71 diamond, 15 wireline). A complete Interlake section is cored (89 m) in only one well (PCS Mining Ste. Marthe 1-14-17-30W1). The remainder of the cores range from less than 3 m to 42 m in length.

To date no commercial accumulations of oil have been discovered in the Interlake Formation in Saskatchewan. However, in 1986, Interlake reservoirs in North Dakota produced 5.4 x 10^5 m^3 of oil (7.5% of the state's total production), and the data suggest that there may be reservoir potential in Saskatchewan. Zones with good to excellent porosity and permeability are present in cores and good porosity is indicated on geophysical logs in several wells. Further evidence of good porosity and permeability, at least in places, is provided by the utilization of the Interlake Formation for brine disposal at a number of potash mine sites. In addition, a number of oil shows have been recorded. The most significant show is from a drillstem test at 14-19-8-32W1 which recovered 27.4 m of oil, 30.5 m of oil-cut mud, and 36.6 m of water from an interval near the top of the Interlake.

Stratigraphy

The Interlake Group was originally defined by Baillie (1951) in the Manitoba outcrop belt as consisting of the basal Stonewall Formation overlain, in ascending order, by Units B, C, D and E. He deferred assigning formation or member names to these units until they could be established in the subsurface. Stearn (1956) removed the Stonewall Formation from the Interlake Group based on the interpretation that the Stonewall is Ordovician in age, whereas the Interlake is Silurian. He also subdivided the Interlake into the Fisher Branch, Inwood, Moose Lake, Atikameg, East Arm, and Cedar Lake Formations (in ascending order).

Porter and Fuller (1959) and Andrichuk (1959) extended the Interlake Group into the subsurface in the Williston Basin. Porter and Fuller (1959) separated the Stonewall Formation from the Interlake Group and subdivided the group into Upper, Middle, and Lower Beds based on "non-sequential" marker beds which contain terrigenous material defined by a high gamma-ray response on geophysical logs. The marker beds are interpreted as "para-time units" and a number of them can be correlated virtually basin-wide. The subdivisions thus defined are time-stratigraphic units and do not represent lithostratigraphic units (Porter and Fuller, 1959).

Further work in Manitoba by King (1964) traced the marker beds from the subsurface to the outcrop belt and defined a new set of formal lithostratigraphic units bounded by marker beds. In southern Saskatchewan, a somewhat similar stratigraphic breakdown was utilized by E.R. Jamieson in the late sixties. Her nomenclature has not been formally proposed but is outlined in a summary of well data and core descriptions (Jamieson, 1979) and in Broughton (1981).

Preliminary examination by the author of available data in Saskatchewan supports the conclusion reached by several other workers: in the subsurface, the Interlake cannot readily be subdivided into formal lithostratigraphic units (e.g., Porter and Fuller, 1959; Gibbs, 1972). A general lack of lithologic diversity, together with a paucity of core (particularly in the lower part of the sequence), preclude the definition of formations which are "identified by lithic characteristics and stratigraphic position... and are traceable in the subsurface" (North American Commission on Stratigraphic Nomenclature, 1983, p. 841). The lithologic similarity between the Interlake and the underlying Stonewall Formation further complicates the definition of formal lithostratigraphic units (Kendall, 1976). Ideally, stratigraphic units within the Bighorn and Interlake Groups should be redefined so as to meet the criteria set out by the Stratigraphic Code (Kendall, 1976). However, it is unlikely that such a revision would be widely accepted, since it would necessitate extensive changes in existing data bases. Therefore, in this study, the present boundary between the Interlake and Stonewall (defined by gamma-ray log response) is retained but, because the Interlake Group cannot be subdivided into formations, it is reduced to formation rank. In North Dakota and Montana, the Interlake is already defined as a formation, although Gibbs (1972) incorporates a portion of the Stonewall interval within it (Gibbs, 1972; Carlson and Eastwood, 1962).

The stratigraphic nomenclature proposed for use in Saskatchewan is summarized in Fig. 1. The Interlake Formation is recognized as the formal lithostratigraphic unit which overlies the Stonewall Formation (Ordovician) and underlies the Ashern Formation (Middle Devonian). The informal subdivision of the lower portion of the Interlake (Lower Interlake Unit) is based on marker beds (defined by gamma-ray log response) which can be correlated with varying degrees of confidence across most of the basin. The names adopted are those utilized by Jamieson (1979), with unit boundaries similar to those of King (1964). In the upper portion of the Interlake (Upper Interlake Unit), beds defined by high gamma-ray values do not appear to correlate readily over significant distances; therefore, the division between the Middle and Upper Interlake made by Porter and Fuller (1959) on the basis of gamma-ray response is not adopted here. However, although not clearly defined by geophysical logs, distinctive lithologic characteristics observed in cores and samples of the uppermost Interlake in southeastern Saskatchewan allow delineation of the Taylorton Member as a lithostratigraphic unit. This is equivalent to the Taylorton Unit identified in core descriptions by Jamieson (1979). The subunit between the top of the Lower Interlake and the base of the Taylorton Member is named the Cedar Lake following the terminology of Jamieson (1979).

Lower Interlake Unit

The Lower Interlake Unit is composed of yellowish-grey fine-grained dolomites which have been subdivided into the Strathclair (lowermost), Fife Lake and Guernsey (uppermost) subunits by the "u" and "u_2" marker beds (Fig. 1). The base of the unit is defined by the top of the uppermost Stonewall marker bed; the upper boundary is defined by the top of the "v" marker bed. The marker beds range in thickness from 1.0 to 2.5 m and are composed of argillaceous microdolomites which commonly contain laminations and/or scattered grains of very fine to coarse-grained quartz (Plate 1A). The mechanism(s) responsible for deposition of these beds is not clear. They may represent the final stages of transgressive-regressive cycles related to eustatic sea level changes (Johnson and Lescinsky, 1986). Based on this assumption, the top of each subunit is placed at the top of the respective marker bed (i.e., at the close of a depositional cycle).

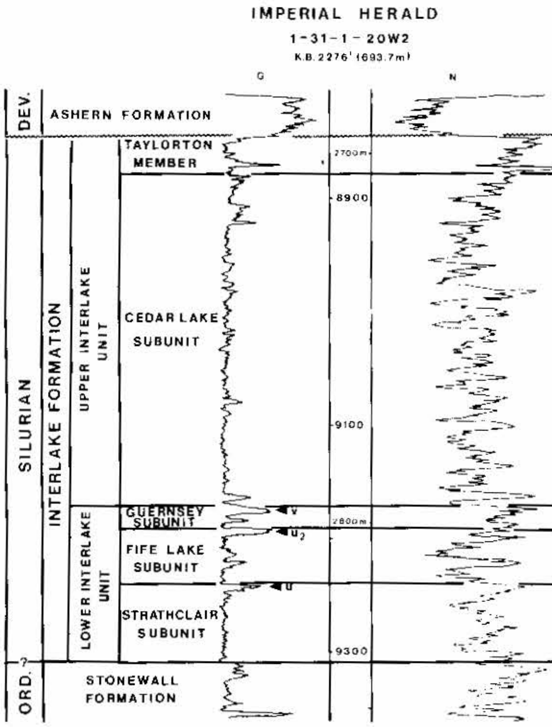

Figure 1 - Typical geophysical well log of the Interlake Formation showing the stratigraphic nomenclature proposed for Saskatchewan; location of "u", "u_2", and "v" marker beds is indicated.

Strathclair Subunit

The Strathclair subunit consists of dolomitized mudstones interbedded with dolomitized wackestones, packstones and grainstones which contain poorly preserved fossil fragments including corals, brachiopods, stromatoporoids, gastropods and ostracods (Plate 1B). The uppermost unit in the Strathclair is the "u" marker bed, which is characterized by microcrystalline dolomites with abundant argillaceous, silty and arenaceous laminae (Plate 1A). Molds of skeletal halite crystals were observed in this bed at 1830.5 m in core from

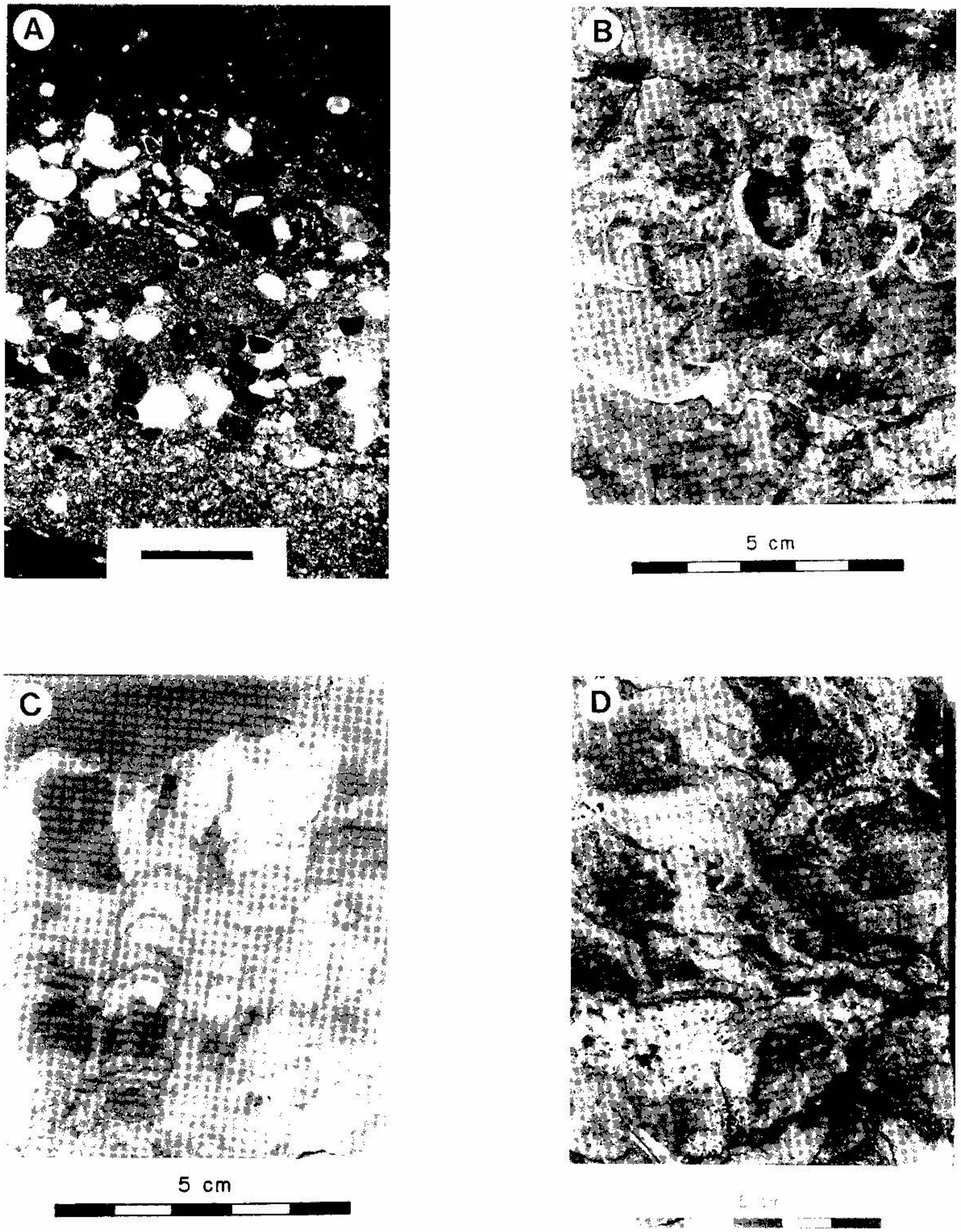

Plate 1 - A) Thin section photomicrograph of an irregular lamination of quartz grains in the "u" marker bed at the top of the Strathclair subunit 16-10-4-4W3, 2423.6 m; several grains display corrosion rims (arrows), a product of chemical interaction between carbonate and quartz; scale bar is 1.0 mm. B) Dolomitized skeletal wackestone containing corals, brachiopods and gastropods, Strathclair subunit, 1-14-17-30W1, 1186.1 m; poor intraparticle and biomoldic porosity. C) Small linked columnar stromatolites overlain by skeletal wackestone with good biomoldic porosity, Fife Lake subunit, 1-14-17-30W1, 1158.5 m; stromatolites with very similar morphology are present in outcrop at the Inwood Quarry, Manitoba. D) Coral-stromatoporoid boundstone composed predominantly of favositid corals and tabular encrusting stromatoporoids, Cedar Lake subunit, 12-21-2-29W3, 2455.2 m; good intraparticle and biomoldic porosity.

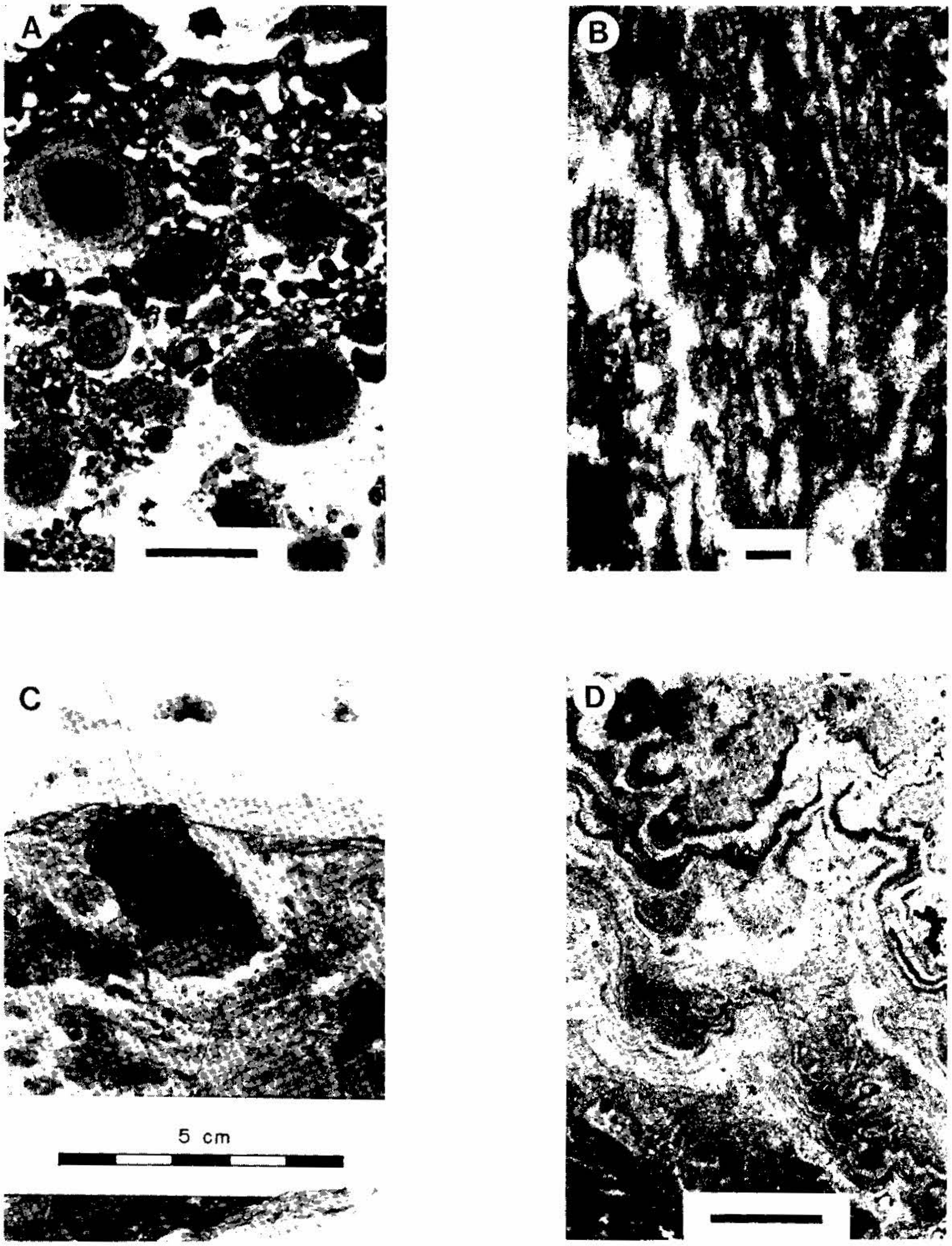

Plate 2 - A) Thin section photomicrograph of a grainstone composed of peloids and coated grains, Taylorton Member, 9-34-3-4W2, 2390.9 m; irregular laminations on coated grains and the presence of microstalactitic cement in adjacent fenestral pores suggest formation in a vadose environment; scale bar is 1.0 mm. **B)** Thin section photomicrograph of filaments of cyanobacteria (blue-green algae) Ortonella(?), Taylorton Member, 9-34-3-4W2, 2367.5 m; scale bar is 0.1 mm. **C)** Cyclic sequence in the Taylorton Member, 9-34-3-4W2, 2388.4 m; contact between brecciated mudstone (with abundant white dolomite cement) at top of one cycle and lithoclastic wackestone at base of overlying cycle. **D)** Thin section photomicrograph of inclusion-rich microstalactitic cement (dolomitized) which infills a sub-horizontal crack in a peloidal-algal wackestone/packstone, Taylorton Member, 9-34-3-4W2, 2367.5 m; scale bar is 1.0 mm; crossed nicols.

15-28-12-2W2. The marker bed is also partially iron stained in this core and in others from 12-21-2-29W2 and 16-10-4-4W3.

Zones with good to excellent porosity are developed in the Strathclair in several wells. A porosity of 14 percent was measured in a sample of skeletal wackestone from 1-14-17-30W1 (1181.7 m); the permeability is 21 millidarcies. Intercrystalline, intraparticle, biomoldic, vuggy and fracture porosity types were all observed in core.

Fife Lake Subunit

The Fife Lake subunit is composed predominantly of dolomitized laminated mudstones. Interbeds of wackestones and packstones containing corals, crinoids, stromatoporoids, brachiopods and gastropods are common, particularly in the upper and lower portions of this interval. Thin beds of oolites and skeletal grainstones are also present. An algal origin is interpreted for some of the laminated sequences. Small columnar stromatolites occur in a core from 1-14-17-30W1 (Plate 1C). The top of the "u_2" marker bed defines the top of the Fife Lake. Additional beds with high readings on gamma-ray logs are present in this subunit in some wells in the central portion of the province (e.g., 13-34-33-23W2).

Zones with good porosity are developed in the Fife Lake in a number of wells. Fair to good interparticle and biomoldic porosity was observed in a few cored intervals. Fracture porosity is well developed in 1-14-17-30W1.

Guernsey Subunit

The Guernsey subunit is dominated by dolomitized mudstones which are commonly laminated (possibly algal). The argillaceous microdolomites of the "v" marker bed represent the uppermost strata in the Guernsey. Low porosity is prevalent throughout this interval except where fracture porosity is present.

Upper Interlake Unit

Over most of the study area, the Upper Interlake Unit is composed entirely of the Cedar Lake subunit, a sequence of yellowish-grey to yellowish-brown dolomites similar to those in the Lower Interlake. In southeastern Saskatchewan, where the thickest intervals of Interlake strata are preserved below the unconformity, the Cedar Lake is overlain by the Taylorton Member, a heterogeneous unit which includes intraclast and lithoclast breccias, fenestral fabrics and abundant dolomite cements.

Cedar Lake Subunit

The Cedar Lake subunit is dominated by dolomitized mudstone (commonly laminated), with interbeds of dolomitized skeletal-peloidal wackestones and packstones. Fossils (usually poorly preserved) include brachiopods, gastropods, crinoids, corals, stromatoporoids and algae. Coral-stromatoporoid boundstones up to 4.5 m thick are present in a few cores (Plate 1D).

Zones with fair to good biomoldic, intraparticle, vuggy and interparticle porosity are developed primarily in packstone and boundstone intervals. In 1-14-7-30W1, five full-diameter samples have an average porosity of 11 percent and an average permeability of 489 millidarcies.

Argillaceous beds with high gamma-ray log readings similar to those which characterize the Lower Interlake occur in the Cedar Lake but they have a more limited lateral extent. A thin (<1 m) bed, 1.5 to 3.0 m above the "v" marker bed, appears to be the most laterally extensive of these (Fig. 1). It is lithologically similar to the "v" bed, and the close vertical proximity of the two commonly results in uncertainties in correlation (cf. Porter and Fuller, 1959, Fig. 7; Brindle, 1960, Fig. 2). Other beds with similar log responses are seen in core to be thin (<0.1 to 0.3 m) beds of shale. Some of these probably represent quiet water deposition of terrigenous material, but other intervals of red and green coloured shales may represent terra rosa deposits which have infiltrated fractures or developed in situ.

Taylorton Member

The Taylorton Member is composed of dolomites in which primary textures are commonly obliterated by brecciation and complex diagenesis. The member is characterized by brecciated textures, fenestral fabrics and multiple generations of dolomite cement in a variety of habits. Peloids, ooids, pisolites and laminated mudstones can be identified in both brecciated and unbrecciated sequences (Plate 2A). Algal fragments, ostracods and gastropods are the most commonly observed fossils (Plate 2B). Many different varieties of fenestral fabrics are present, including laminoid, irregular and tubular (Havard and Oldershaw, 1976; Read, 1973; Tebbutt et al., 1965). A number of cores include cyclic sequences which grade up from lithoclastic wackestone/packstone to mudstone; the upper portion of each sequence is commonly brecciated (Plate 2C).

Cementation is common in Taylorton strata. On a macroscopic scale, dolomite cements form "crusts" around intraclasts, and infill fenestral pores and horizontal and vertical cracks (Plate 2C). In thin section, observed fabrics of dolomite cements include microstalactitic and isopachous rims, and subequant mosaics (Plate 2D). Anhydrite cement is also present; in most cases, it appears to be the latest generation of cement.

Zones with good porosity are not common in the Taylorton Member. In general, porosity appears to be associated with open fractures and with fenestrae which are only partially filled with cement. Analysis of 19 samples from 14-19-8-32W1 (the well in which 27.4 m of oil was recovered in a drillstem test) yielded an average porosity of 8.6 percent; maximum porosity is 11.8 percent. Average permeability is 6.7 millidarcies; maximum permeability is 44 millidarcies. However, the core displays abundant natural fractures which should significantly enhance effective permeability in the subsurface. In contrast, in 9-34-3-4W2, 45 samples were analyzed and only 8 recorded porosity values of 5 percent or greater; maximum porosity is 6.3 percent. Measured permeabilities exceeded 10 millidarcies in only 7 samples and were less than 1.0 millidarcy in 20 samples.

Beds characterized by high readings on gamma-ray logs are present in the Taylorton Member but, as in the Cedar Lake subunit, they cannot be easily correlated from well to well. Some of the thicker beds (2.5 m) are composed of large dolomite clasts in a green and red shale matrix; these may represent solution collapse breccias (e.g., 2578.3 m, 8-23-3-24W2).

Ashern/Interlake Contact

In core, the contact between the Ashern and Interlake is defined by a sharp erosional contact at which the reddish-brown or greenish-grey argillaceous dolomites of the Ashern overlie the grey, commonly pink-stained dolomites of the Interlake. Angular clasts of Interlake are commonly incorporated in the lower few metres of the Ashern. Beds of nodular to massive anhydrites may also occur in the lowermost Ashern. The uppermost Interlake commonly contains fractures filled with red and green shales.

Correlation of cores and geophysical logs indicates that this contact is usually clearly defined on logs by a sharp increase in values on gamma, neutron and sonic logs (Fig. 1). However, the lowermost Ashern is in places no more argillaceous than the uppermost Interlake, making it difficult to pick the contact on gamma logs. In addition, the presence of anhydrite in the Ashern results in less of a contrast between the Ashern and Interlake on neutron and sonic logs. These factors may result in the top of the Interlake being picked too high on logs; it is estimated that this error is generally less than 2 m and seldom more than 5 m.

Discussion

More detailed sedimentologic, petrographic and geophysical log correlation studies are required to improve the interpretation of the depositional and diagenetic history of Interlake strata in Saskatchewan. However, some generalizations can be made based on preliminary observations and data provided by other workers. Lower Interlake and Cedar Lake strata were deposited in shallow marine environments ranging from subtidal to supratidal with salinities ranging from stenohaline to hypersaline (Johnson and Lescinsky, 1986; Kent, 1984; Jamieson, 1968; Roehl, 1967). Reef development is indicated by coral-stromatoporoid boundstone intervals in the Cedar Lake subunit in a number of cores (Jamieson, 1968, 1979; Kent, 1984). This entire sequence probably represents a number of transgressive-regressive cycles related to sea level changes (Johnson and Lescinsky, 1986). Diagenesis in the Lower Interlake Unit and the Cedar Lake subunit includes cementation, recrystallization, dissolution of fossils and cements, and pervasive dolomitization.

Interpretation of the depositional and diagenetic history of the Taylorton Member is difficult. Primary textures are commonly destroyed by early diagenesis and brecciation; pervasive dolomitization has further obscured the entire sequence. Lithologic and petrographic evidence, including dessication cracks, microstalactitic cements, pisolites, common erosional surfaces, possible root casts, teepee structures and incipient soil breccias, indicate that Taylorton strata in Saskatchewan have undergone periodic subaerial exposure and vadose diagenesis. The restricted fauna (gastropods, ostracods and algae) suggest hypersaline to fresh water. E.R. Jamieson Magathan (pers. comm. 1987; Jamieson, 1973) interprets these strata as fluvial and lacustrine deposits which have been subjected to subaerial exposure. Alternatively, these deposits may represent restricted marine deposits with a complex diagenetic history including periodic subaerial exposure and vadose diagenesis (Roehl, 1967). Similar diagenetic features are reported in marine deposits by other authors (e.g., Assereto and Folk, 1980; Havard and Oldershaw, 1976; Read, 1973).

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