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LOWER TO MIDDLE PALEOZOIC STRATIGRAPHY OF SOUTHWESTERN MANITOBA

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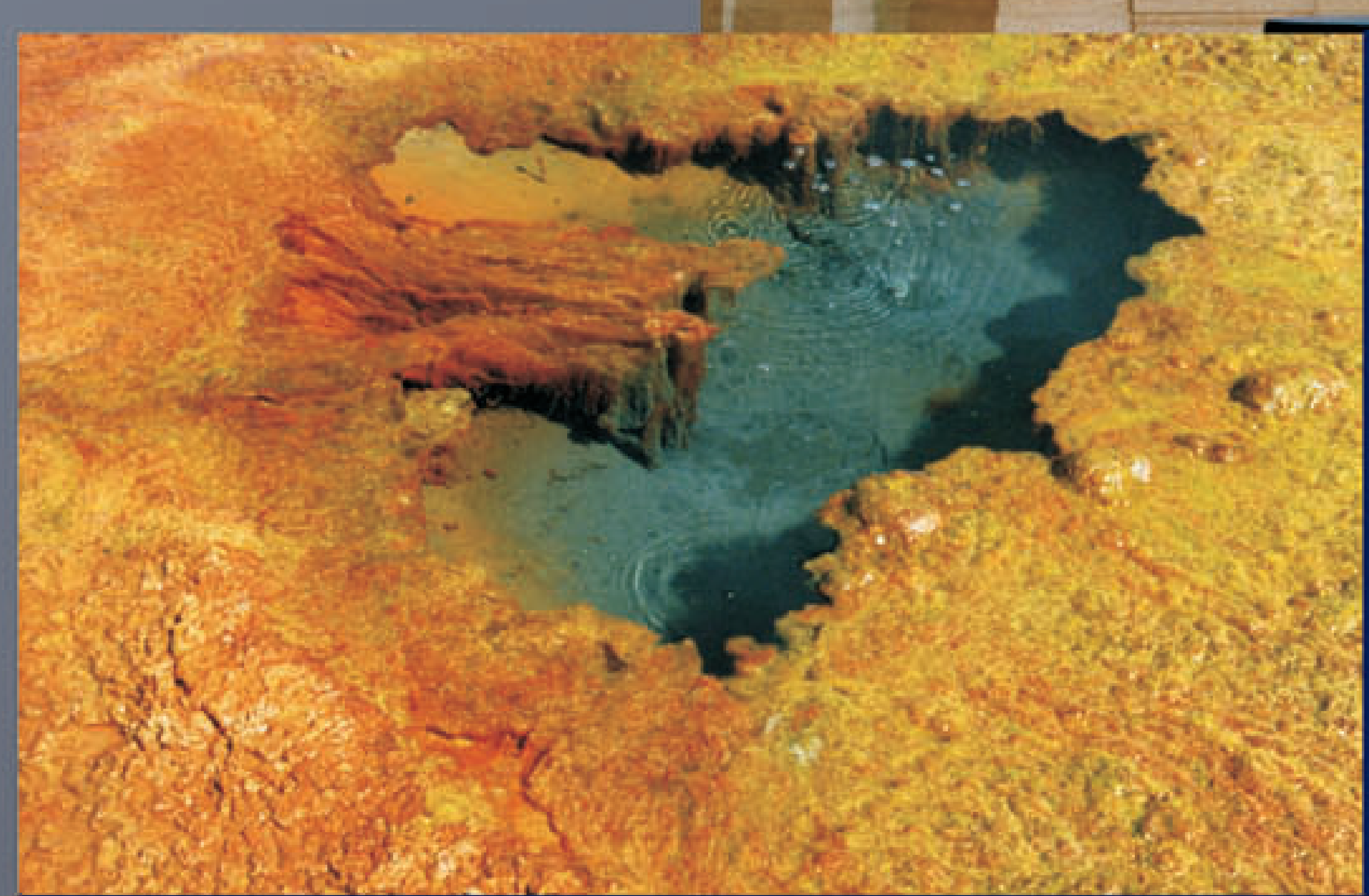

Manitoba
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PART I

INTRODUCTION

This field trip is designed to cover most of the accessible Ordovician, Silurian and Devonian outcrops in southwestern Manitoba. Ordovician and Silurian outcrops are examined on the first day; the more remote Devonian outcrops, of the Lake Winnipegosis - Lake Manitoba area, are examined on the second to fourth days. The stratigraphic nomenclature chart for southern Manitoba is shown in Figure 1.

The Paleozoic outcrop belt of Manitoba occurs within the Manitoba Lowland or First Prairie Level (Figures 2 and 3). The Paleozoic succession dips gently to the southwest at approximately 2.8 m per km. South of the City of Winnipeg, within the Manitoba Lowland, a large area of Jurassic rocks occur as infill of a major pre-Mesozoic channel in the Paleozoic erosion surface. The Manitoba Lowland is bounded on the east by the Precambrian Shield, and on the west by the Manitoba Escarpment.

The Escarpment forms the eastern edge of the Second Prairie Level, which is underlain by Cretaceous strata dipping gently to the southwest at 1.5 to 1.9 m per km. The actual Escarpment is composed of soft, easily eroded sands and shales in the lower part of the Cretaceous, underlying a resistant shale cap (Odanah Member of the Pierre Shale). The Manitoba outcrop belt is located on the northeastern edge of the Western Canada Sedimentary Basin - a composite feature which includes both the Elk Point Basin, centered in south-central Saskatchewan (which controlled Devonian deposition), and the Williston Basin, centered in northwestern North Dakota (which controlled the depositional patterns throughout the remainder of post-Cambrian time) (Fig. 4). Since the Manitoba outcrop belt appears to be situated on the northeastern edge of the sedimentary basin, and roughly parallels the regional structure contours, one might surmise that the strata comprising the outcrop belt would be relatively uniform in lithology. The outcrop would also represent marginal shelf-type deposits relative to the thicker, more basinal sedimentary sequence found to the southwest in the subsurface. However, this is not the case for most Paleozoic formations in southwest Manitoba. The outcrop belts, particularly the Ordovician and Devonian, show marked changes in both thickness and lithology, indicating a complex and varied tectonic and depositional framework.

The outcrop succession is not marginal to the depositional basin, but rather exposes a series of dip sections of the basin, which show the maximum possible isopach and lithofacies variation. As well, the directions of the dip sections are opposite: basinal Ordovician outcrops occur at the southern end of the outcrop belt, whereas basinal Devonian outcrops occur at the northern (or northwestern) end of the outcrop belt. The following discussion will attempt to outline how this complex pattern evolved, and will suggest a possible regional tectonic control for apparent anomalies in facies trends, as well as other related structural and stratigraphic anomalies.

ERA	PERIOD	FORMATION	MEMBER	MAXIMUM THICKNESS (m)	BASIC LITHOLOGY
CENOZOIC	QUATER-NARY	(Recent)			Top soil, dune sands, lake clays, peat
CENOZOIC	QUATER-NARY	Glacial Drift		140	Clay, sand, gravel, boulders, till
CENOZOIC	TERTIARY				
CENOZOIC	TERTIARY	Turtle Mountain	Peace Garden Goodlands	160	Shale, clay, sand, lignite
MESOZOIC	CRETACEOUS	Boissevain		45	Sand, sandstone, greenish grey
MESOZOIC	CRETACEOUS	Pierre Shale (First White Specks)	Coulter Odanah Millwood Pembina Gammon Ferruginous	400	Grey shales, non-calcareous, local ironstone, bentonitic, carbonaceous
MESOZOIC	CRETACEOUS	Niobrara		75	Grey speckled shale, calcareous, bentonitic
MESOZOIC	CRETACEOUS	Morden Shale		55	Dark grey shale, non-calcareous, concretions, local sand and silt
MESOZOIC	CRETACEOUS	Favel (Second White Specks)	Assiniboine Keld	45	Grey shale with calcareous specks, bands of limestone and bentonite
MESOZOIC	CRETACEOUS	Ashville	Belle Fourche Shale Westgate Newcastle Skull Creek	80	Dark grey shale, non-calcareous, silty, Newcastle (sand zone)-quartz sandstone
MESOZOIC	CRETACEOUS	Swan River		150	Sandstone and sand, quartzose, pyritic shale, non-calcareous
MESOZOIC	JURASSIC	Waskada		60	Banded green shale and calcareous sandstone, bands of limestone, varicoloured shale
MESOZOIC	JURASSIC	Melita		145	
MESOZOIC	JURASSIC	Reston		45	Limestone, buff, and grey shales
MESOZOIC	JURASSIC	Amaranth	Evaporite	55	White anhydrite and/or gypsum and banded dolomite and shale
MESOZOIC	TRIASSIC	Amaranth	Red Beds	45	Red shale to siltstone, dolomitic
PALEOZOIC	PERMIAN PENNSYL-VANIAN	St. Martin Complex		265(+)	Carbonate breccia, trachyandesite (crypto-explosion structure?)
PALEOZOIC	MISSISSIPPIAN	Madison Group – Charles		20	Massive anhydrite and dolomite
PALEOZOIC	MISSISSIPPIAN	Madison Group – Mission Canyon	MC-5 MC-4 MC-3 MC-2 MC-1	120	Light buff limestone, oolitic, fossiliferous, fragmental, cherty, bands of shale and anhydrite
PALEOZOIC	MISSISSIPPIAN	Madison Group – Lodgepole	Flossie Lake Whitewater Lake Virden Scallion Daly	185	Limestone and argillaceous limestone, light brown and reddish mottled, zones of shaley, oolitic, crinoidal and cherty limestone
PALEOZOIC	MISSISSIPPIAN	Bakken	Upper Middle Lower	20	Two black shale zones separated by siltstone
PALEOZOIC	DEVONIAN	Qu'Appelle Group – Three Forks		55	Red siltstone and shale, dolomitic
PALEOZOIC	DEVONIAN	SASK. GROUP – Birdbear		40	Limestone and dolomite, yellow-grey, fossiliferous, porous, some anhydrite
PALEOZOIC	DEVONIAN	SASK. GROUP – Duperow		120	Limestone and dolomite, argillaceous and anhydritic in places
PALEOZOIC	DEVONIAN	MAN. GROUP – Souris River (First Red)		90	Cyclical shale, limestone and dolomite, anhydritic
PALEOZOIC	DEVONIAN	MAN. GROUP – Dawson Bay (Second Red)		50	Limestone and dolomite, porous, anhydritic, local red and green shale
PALEOZOIC	DEVONIAN	ELK PT. GROUP – Prairie Evap.		120	Halite, potash and anhydrite, interbedded dolomite
PALEOZOIC	DEVONIAN	ELK PT. GROUP – Winnipegosis		75	Dolomite, yellow brown, reefy
PALEOZOIC	DEVONIAN	ELK PT. GROUP – Elm Point			Limestone, fossiliferous, high-calcium
PALEOZOIC	DEVONIAN	ELK PT. GROUP – Ashern		12	Dolomite and shale, brick red
PALEOZOIC	SILURIAN	Interlake Group		110	Dolomite, yellow buff, fossiliferous, several argillaceous marker beds
PALEOZOIC	ORDOVICIAN	Stonewall	t-marker zone Williams	25	Dolomite, sparsely fossiliferous, t-marker defines Ordovician-Silurian boundary
PALEOZOIC	ORDOVICIAN	Stony Mountain	Gunton Penitentiary Gunn	45	Dolomite, yellow buff Dolomite, dusky yellow, fossiliferous, red shale, green fossiliferous limestone bands (Gunn)
PALEOZOIC	ORDOVICIAN	Red River	Fort Garry Selkirk ?— Cat Head Dog Head	170	Dolomitic limestone and dolomite, mottled (Tyndall Stone within Selkirk)
PALEOZOIC	ORDOVICIAN	Winnipeg	Upper Unit Lower Unit	65	Green shale, waxy, interbedded sandstone Sand, sandstone and quartzose
PALEOZOIC	CAMBRIAN	Deadwood		25	Black to green grey sand, waxy, glauconitic siltstone and shale
PRECAMBRIAN					Metamorphic and crystalline rock

Figure 1: Geological formations in Manitoba.

Cross-section Showing Paleozoic to Cenozoic Formations in Southern Manitoba

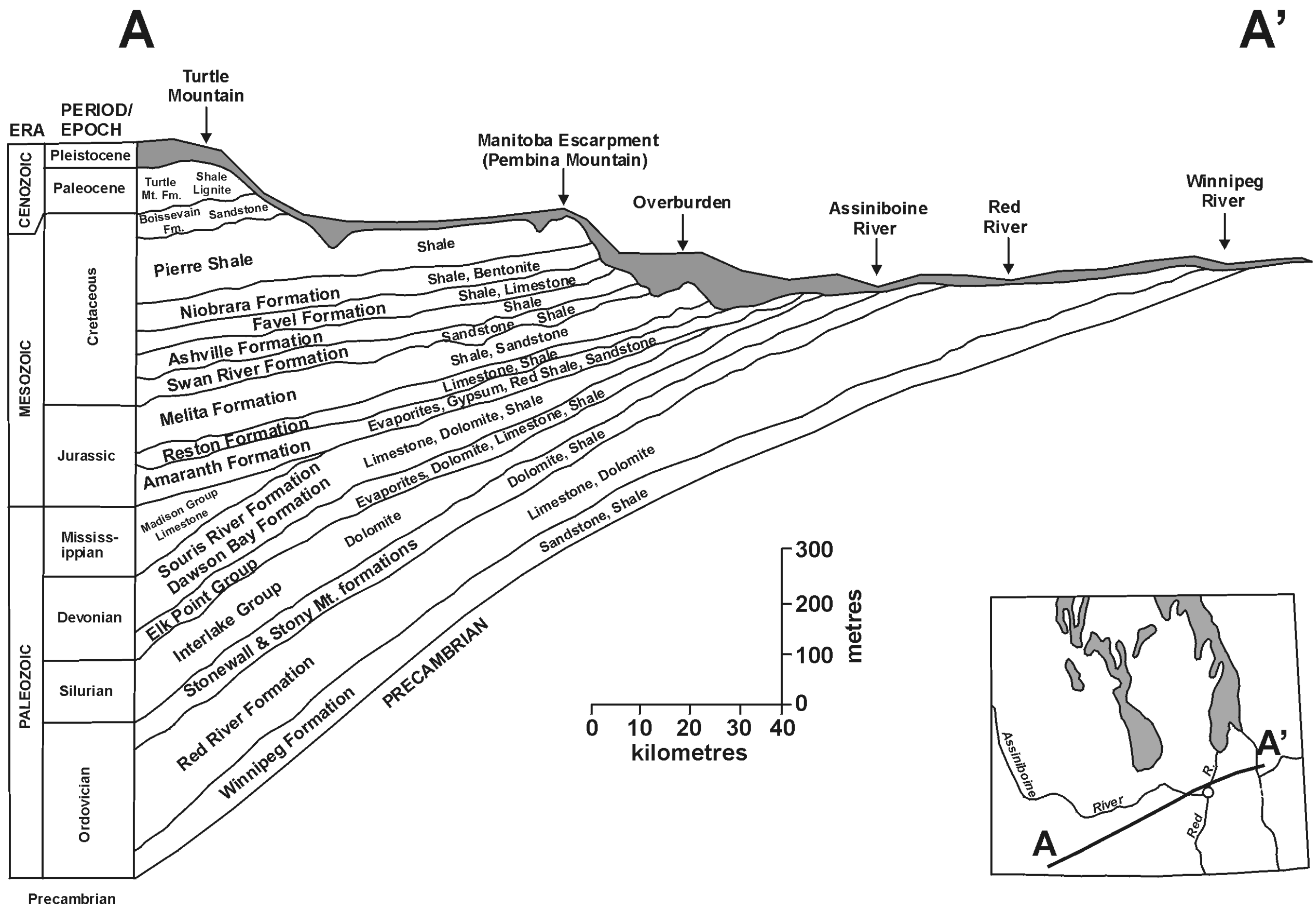


Figure 2: Structure cross section, southern Manitoba.

ORDOVICIAN PALEOGEOGRAPHIC FRAMEWORK

The regional depositional (isopach) trends for Ordovician strata of southwestern Manitoba are approximately east-west to slightly northeast, as shown in Figures 5, 6, 7 and 8. The easterly trend is evident for all Ordovician strata. This trend is markedly discordant to the present structural trend, and to the overall Williston Basin depositional trends. This may be the result of a higher rate of subsidence in the Manitoba portion of the basin.

However, the rate of basinward thickening (*i.e.* basin differentiation) decreased progressively throughout Ordovician time. In addition, the interbedding of calcareous and dolomitic lithologies suggests that a cyclical fluctuation of depositional conditions (eustatic effect?) have been superimposed on the overall pattern of basin subsidence (tectonic effect).

The basal Ordovician Winnipeg Formation shows the highest degree of isopach and lithofacies differentiation (Fig. 5). It thins irregularly from a maximum of about 60 m near the U.S. border to zero at the its northern limit of occurrence, a thinning of 17% per 100 km. This thinning is accompanied by an irregular surface lithofacies change from dominantly shale in the south to almost totally sandstone in the north (Andrichuk, 1959; McCabe, 1978; Norford, *et al.*, 1994). The isopach pattern is complicated by the effects of differential compaction associated with complex local lithofacies changes.

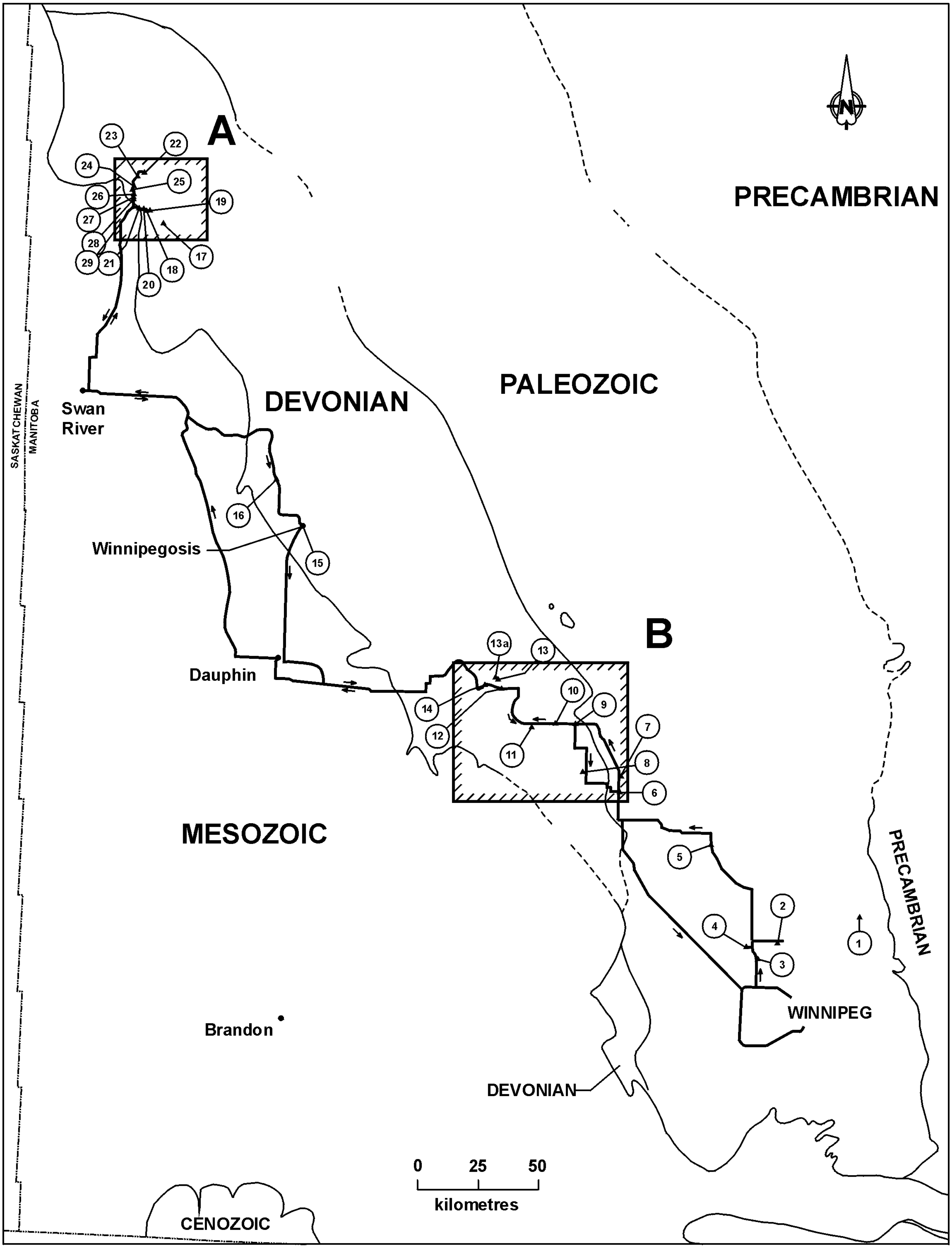


Figure 3: Regional geology and route map: see Figure 28 for insert A; see Figure 27 for insert B.

Major Structural Features
Williston Basin and Southeastern Elk Point Basin

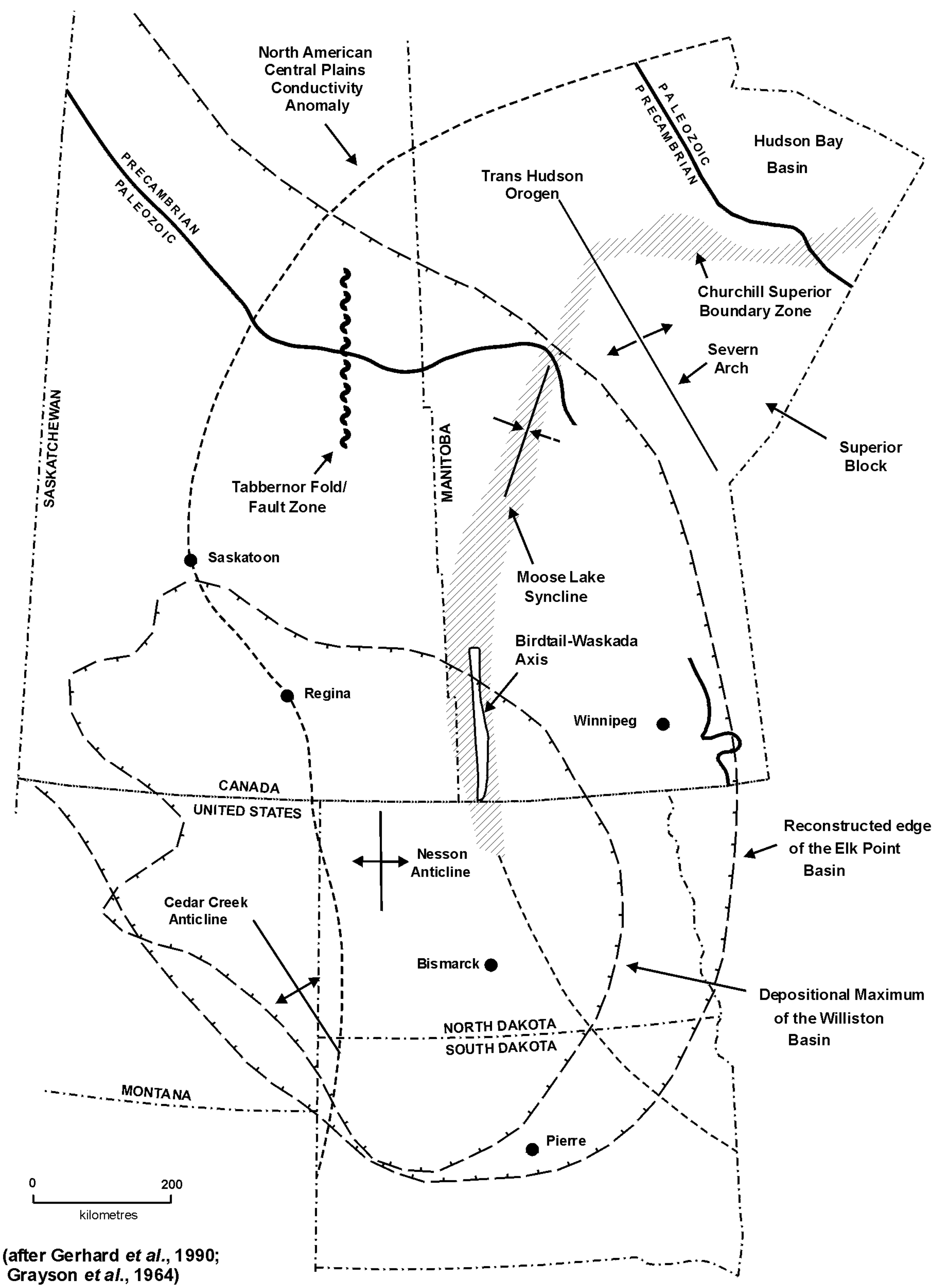


Figure 4: Major structural features of the Williston and Elk Point basins.

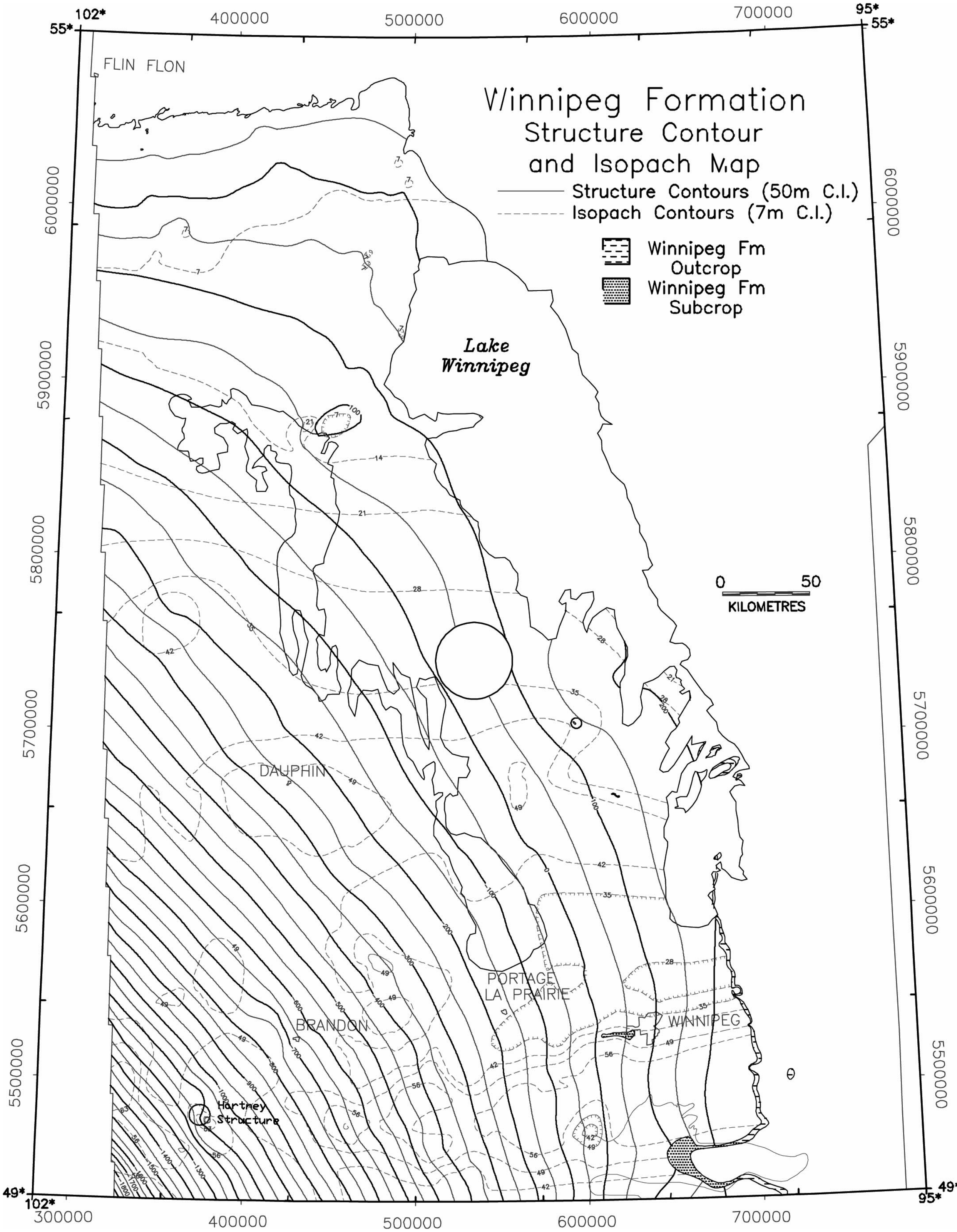


Figure 5: Winnipeg Formation structure contour and isopach map.

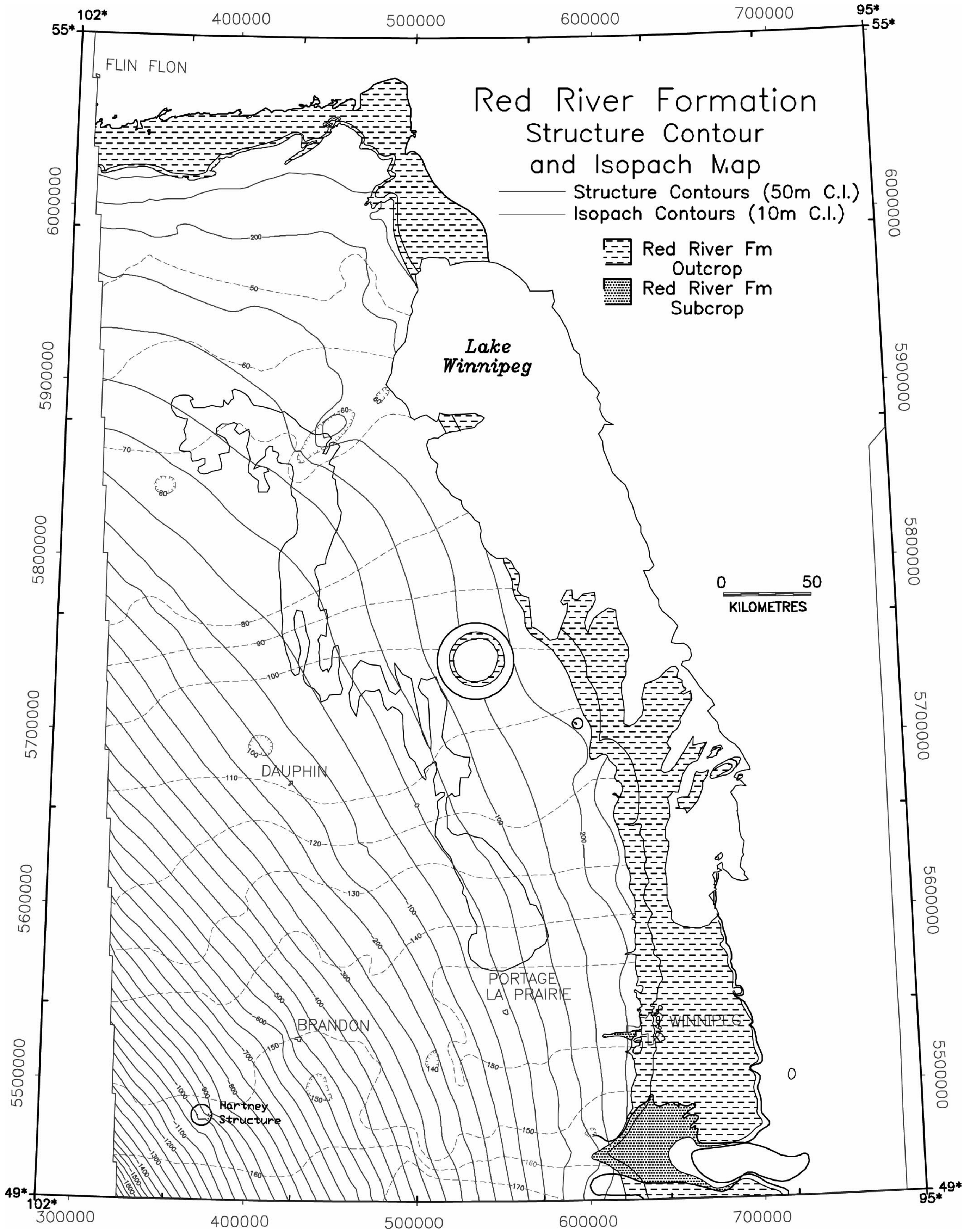


Figure 6: Red River Formation structure contour and isopach map.

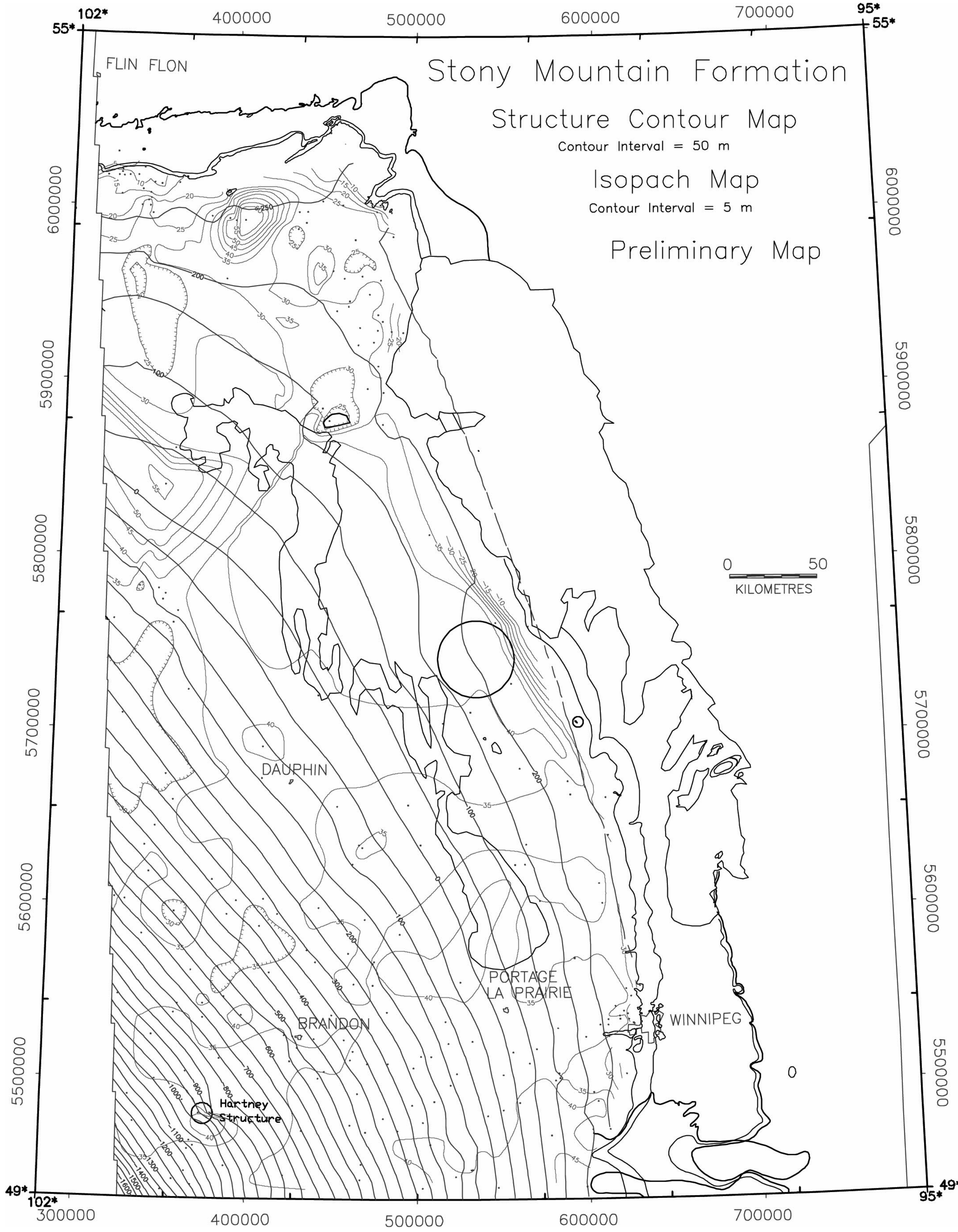


Figure 7: Stony Mountain Formation structure contour and isopach map.

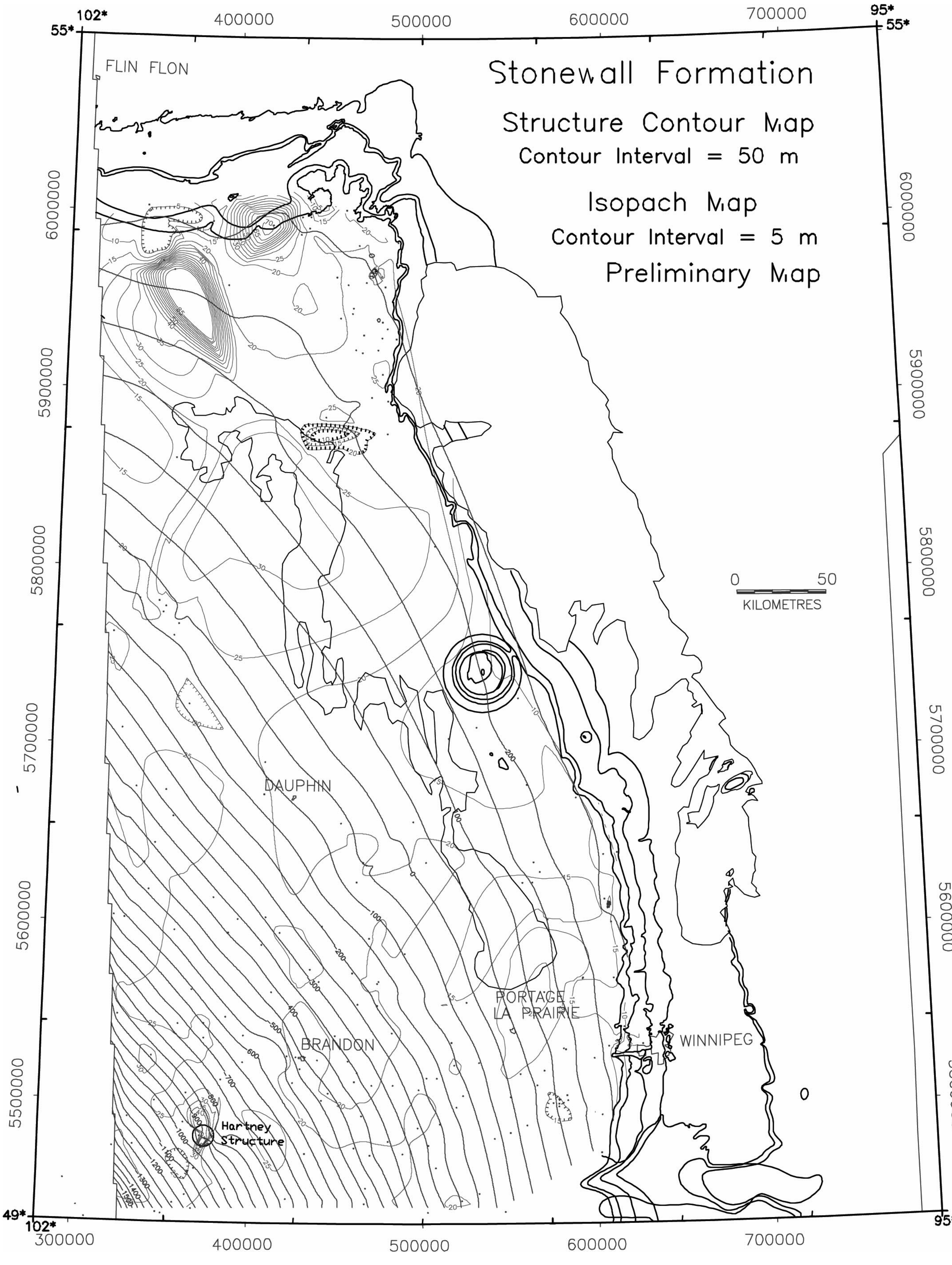


Figure 8: Stonewall Formation structure contour and isopach map.

The Red River Formation thins from about 175 m in the south to 40 m in the north, at its erosional limit (Fig. 6), a thinning of about 13% per 100 km that affects all members of the formation. In the lower part of the Red River Formation (Dog Head, Cat Head, and Selkirk members, in ascending stratigraphic sequence), the thinning is accompanied by a lithologic change from dolomitic limestone in the south to dolomitic in the north. It is not clear if the lithologic change in the lower Red River carbonates is due to primary lithofacies variation related to basin differentiation, or if it results entirely from secondary diagenetic effects.

Kendall (1976) suggests that total dolomitization of lower Red River strata (=Yeoman Formation in Saskatchewan) in the northern area could possibly be related to the northward decrease in shale content of the lower Stony Mountain Formation (Gunn Member). The presence of relatively impermeable shaly beds would have inhibited or prevented downward movement of saline dolomitizing solutions. However, data acquired to date in the Manitoba Energy and Mines stratigraphic corehole program do not seem to support this suggestion. Dolomitization of the Red River strata is erratic and is not coincident with the northward limit of the Gunn shale. This is not to say that the Gunn shale was not a factor in controlling later dolomitization; rather it does not seem to be the principal or only factor. Kendall (1976) also suggests that impermeable anhydrite beds in the Upper Ordovician strata could have limited subsequent dolomitization. This factor is not possible to evaluate in southwestern Manitoba, where the evaporites have been removed by later solution, and their original extent is difficult or impossible to determine.

In contrast to the pronounced limestone-dolomite facies changes in the lower Red River strata, the Upper Red River (Fort Garry Member = Herald Formation in Saskatchewan) maintains a relatively uniform dolomite lithology throughout the outcrop belt despite regional changes in thickness comparable to those shown by the lower Red River (the lower Red River is not formally defined). Locally, two thin beds of high-calcium limestone occur in the upper part of the Fort Garry Member in the Winnipeg area. The uppermost high-calcium limestone bed probably represents the Hartaven Member (Stony Mountain Formation) in Saskatchewan.

The Stony Mountain Formation thins from approximately 50 m in the south to about 30 m at its northern limit of occurrence (Fig. 7), a relatively low rate of thinning of only 7% per 100 km. This is reflected in the lithofacies change in the lower part of the formation, from interbedded limestone and calcareous shale (*i.e.* Gunn-type lithology) in the south to dolomite (Penitentiary-type lithology) in the north. Differential compaction related to the shaly component of the Stony Mountain Formation probably has acted to reduce the apparent rate of northward thinning. This could explain, in part, the rather pronounced lithofacies change resulting from an apparently low degree of basin differentiation, or basinward thickening.

The Stonewall Formation (Fig. 8) is relatively uniform in thickness and lithology throughout southwestern Manitoba, and reflects a relative stabilization of the tectonic framework in latest Ordovician time. In many ways, the Stonewall Formation seems more closely related to the Silurian stable shelf deposits than to the more basinal Ordovician strata.

Although the above-noted regional northward thinning affects all Ordovician units except the Stonewall, not all of the stratigraphic units show prominent lithofacies changes. The Gunton, Fort Garry, and to a lesser extent, Cat Head members, all are relatively uniform throughout the outcrop belt and all consist mainly of dolomite. In the subsurface, all of these strata, except the Cat Head, are associated with anhydrites and represent a series of cyclical evaporitic deposits (Kendall, 1976). All of these dolomitic units appear to have been deposited under at least partially restricted, relatively shallow water conditions, suggesting a fluctuating eustatic overprint on the continuing tectonic differentiation of the Williston Basin.

During late Paleozoic to early Mesozoic time, a period of differential uplift and erosion appears to have occurred in the same general area of southern Manitoba where isopach data indicate that differential subsidence had taken place in Ordovician time. The erosional event is evidenced by the distribution of Middle Jurassic red beds and evaporites which, at least locally, overstep deeply eroded Paleozoic strata to rest directly on Precambrian basement in the area southeast of Winnipeg (Geological Highway Map of Manitoba). The Precambrian Shield of eastern Manitoba thus came into existence as a post-Cambrian paleogeographic feature at this time. This erosional event probably was largely responsible for establishing the present north-south trend of the Ordovician outcrop belts, which <u>cuts directly across the depositional trend of all Ordovician strata</u> (Figs. 5, 6, 7 and 8). As a result, the Ordovician outcrop belts, from the U.S. border to the north end of Lake Winnipeg, expose a precise dip-section of the basin, with the more "basinal" facies occurring to the south. It must be noted, however, that the term “basinal” in this context is only relative. Specifically, the 130 m to 145 m thickness of the Red River Formation in the vicinity of Garson ***(STOP 1)*** and Winnipeg Beach outcrops contrasts with a minimum thickness of 40 m at the northern limit of occurrence, and thicknesses of 180 m at the U.S. border and 215 m in the deepest part of the basin. In absolute terms, the "basinal" portion of the Manitoba outcrop belt is more properly described as “basin flank”.

Relationship of Outcrop Stops to Regional Depositional Framework

The well known burrow-mottled dolomitic limestones (biomicrites) of the Selkirk Member (upper Yeoman Formation) (*i.e.* "Tyndall Stone"), as seen in the Garson Quarry (***STOP 1***), are fairly typical of the more basinal facies of this unit. It was thought (*e.g.* Cumming, 1975) that the Selkirk Member formed part of a uniform sequence of strata that extended from the southern United States to the Hudson Bay Basin area. Drilling in southern Manitoba, however, has shown that the Selkirk Member and equivalent strata show local prominent facies variations. For example, at the Winnipeg Beach Quarry ***(Not Visited)*** the entire Selkirk sequence is totally dolomitized. It is not clear if this change reflects a primary lithofacies change, or if it results from later post-depositional dolomitization. The presence of a relict, mottled texture suggests a later, second-stage dolomitization of the normal Tyndall Stone (Selkirk). Other areas show development of distinctly primary lithofacies variations, such as Lake St. Martin, where bedded micritic and calcarentic limestones occur, with no evidence of burrow-mottling or dolomitization. Thus, the previously noted regional lithofacies variation, from totally dolomite in the north to limestone in the south, is much more complex when examined in detail.

The dolomites of the Fort Garry Member, as seen in the Mowatt Farm Quarry at ***STOP 2***, are fairly representative of the member. Exposure of the Fort Garry Member in the quarry is approximately 7.4 m of the estimated 35-40 m of the thickness of the member in the area. The section exposed in the quarry comprises the medial portion of the unit and shows both the cherty granular dolomite and the upper zone and dense micritic dolomite of the lower zone. The shale-breccia zone near the middle of the exposed section marks the position of an anhydrite bed that was dissolved by later solution, with attendant brecciation (*<u>Lake Alma Anhydrite</u>* of Kendall, 1976; Noiseux, 1992; Betcher *et al.*, 1993).

The Gunn Member (Stony Mountain Formation) exposures seen at the City of Winnipeg quarries in the Town of Stony Mountain ***(STOP 3)*** also represent a basinal facies. Drilling has shown that the Gunn-type lithology (*i.e.* the interbedded limestones and calcareous shales) thins rapidly to the north and disappears within about 60 km. These beds are replaced laterally by burrow-mottled argillaceous dolomites similar to those of the Penitentiary Member. Thus the vertical outcrop succession seen in the quarry reflects the regional north-south facies variation. The Gunton Member maintains a relatively uniform nodular dolomite lithology throughout the outcrop belt.

The sparsely fossiliferous dolomites of the Stonewall Formation, seen at the type section at Stonewall Quarry Park ***(STOP 4)***, represent the uppermost beds of the Ordovician succession. The complete Stonewall section, as defined in the subsurface, includes a lower and an upper unit separated by a thin sandy argillaceous marker (*T-zone* of Porter and Fuller, 1959). Only the lower unit is seen in Stonewall Quarry Park. Porter and Fuller (1959) and Brindle (1960) have suggested that the mid-Stonewall marker (t-zone) may in fact mark the Ordovician/Silurian boundary and this position has been adopted for this guidebook. This marker, if present, occurs only a few feet (half a metre) above the top of the quarry section. The type Williams Member is exposed in a pit at this quarry, and the unit maintains a relatively uniform lithology as an argillaceous dolomite throughout the outcrop belt.

Ordovician Correlation and Nomenclature Problems

The prominent northward facies changes in the Red River and Stony Mountain formations have given rise to a number of correlation problems. This has been further complicated by the recessive nature of some units, resulting in the inadvertent omission of these units from Dowling's (1900) outcrop succession . A detailed discussion of these problems is beyond the scope of this guidebook, but the following points should be noted:

1) As correctly proposed in the original outcrop mapping (Dowling, 1900), the Cat Head Member occurs stratigraphically between the Dog Head (Lower Mottled) and Selkirk (Upper Mottled) Members. It is <u>not</u> correlative with the upper dolomite unit of the Red River Formation (*i.e.* Fort Garry Member) as proposed by Sinclair (1959). Placement of the Cat Head fauna based on Sinclair's correlations (*e.g.* McGregor *et al.*, 1971) is stratigraphically in error by as much as 100 m.

2) The recessive upper dolomite unit of the Red River (the Fort Garry Member of Manitoba or the Herald Formation of Saskatchewan) is only rarely seen in outcrop and hence was omitted from the outcrop succession in early mapping. It follows that the associated fauna also were omitted from the Ordovician faunal succession, possibly giving rise to an apparent gap in the faunal succession. This could be a significant omission since the Fort Garry Member comprises a considerable portion (25%) of the Red River Formation.

3) The "Upper Mottled" or "Selkirk" outcrops at the north end of Lake Winnipeg, as reported in the early mapping, are <u>not</u> Upper Mottled but rather are Stony Mountain Formation, as correctly noted by Sinclair (1959). Also, the "Cat Head" beds in this same area are not Cat Head but rather belong to the Fort Garry Member. These correlations have resulted in miscorrelation of any fauna reported from these outcrops.

Possible Basement Control of Lower Paleozoic Tectonic Framework

The apparently anomalous east-west depositional trend of Ordovician strata, relative to the overall Williston Basin framework, is possibly related can be related to the effect of a major structural disconformity in the underlying Precambrian basement. The disconformity may have served to modify or distort subsequent Paleozoic tectonic events. Devonian depositional trends, as discussed later, appear to have been modified even more significantly than the Ordovician, but there is little evidence of any significant effect on Silurian depositional trends.

The suggested basement control relates to the Churchill-Superior Boundary Zone (CSBZ) (Fig. 4), which marks the juncture of two major Precambrian cratonic blocks, or plates. These blocks exhibit distinctly different tectonic and lithostratigraphic patterns, and also, and more importantly, distinctly different crustal thickness and composition (Green *et al*., 1980). The trend of this major Precambrian structure, as it is traced by its associated geophysical anomalies (gravity and magnetic) beneath the Paleozoic cover of western Manitoba, cuts deeply into the eastern flank of the Williston Basin, and roughly defines the extent of anomalous Ordovician thickening.

Since the major Paleozoic tectonic element represented by the Williston Basin straddles the major basement (crustal) discontinuity of the CSBZ, it seems inevitable that the discontinuity should have had some modifying or distortional effect on the "normal" pattern of basin subsidence. However, structure contour maps of the individual Paleozoic formations and on top of the Precambrian basement (Figs. 5, 6, 7, 8 and 9) show little or no apparent deviation along the boundary zone, except for the small synclinal flexure (Moose Lake Syncline) near the northern limit of Paleozoic cover (McCabe, 1967) and along the northern extent of the CSBZ. This would seem to indicate that little or no permanent dislocation or distortion of the crust has occurred. Paleozoic isopachs, however, show a considerable number of anomalies that are approximately coincident with the CSBZ, suggesting that distortion has occurred at certain times. (The structure contours reflect only the cumulative effects of subsequent tectonism, whereas the isopachs reflect, in part, tectonism during a specific time interval). The isopach anomalies apparently cancel out over time so that the end result is little or no overall distortion of the structural framework. For example, the previously described thickening of Ordovician strata in southern Manitoba apparently has been compensated for by the late Paleozoic uplift and erosional event that exposed the Precambrian Shield area of eastern Manitoba.

Basement control of the Paleozoic depositional framework seems to result from crustal blocks reacting with slight differences to the imposed tectonic forces. Relative to the Churchill block, the Superior block apparently has undergone greater subsidence during depositional episodes, compensated for by relatively greater uplift during erosional episodes.

The suggestion that basement tectonic elements in southern Manitoba may have exerted some control over the Paleozoic depositional/tectonic framework is not new. McCabe (1967) originally proposed this idea. Subsequent data, primarily from stratigraphic corehole drilling, are either directly supportive of the idea, or at least compatible with it. The proposal is stressed in this guidebook because of the major effect this mechanism may have had in controlling not only the depositional framework in the which the outcropping sediments were deposited; but also the distribution of the outcrop belts themselves, and the unusual dip-section configuration the outcrops have relative to the depositional framework.

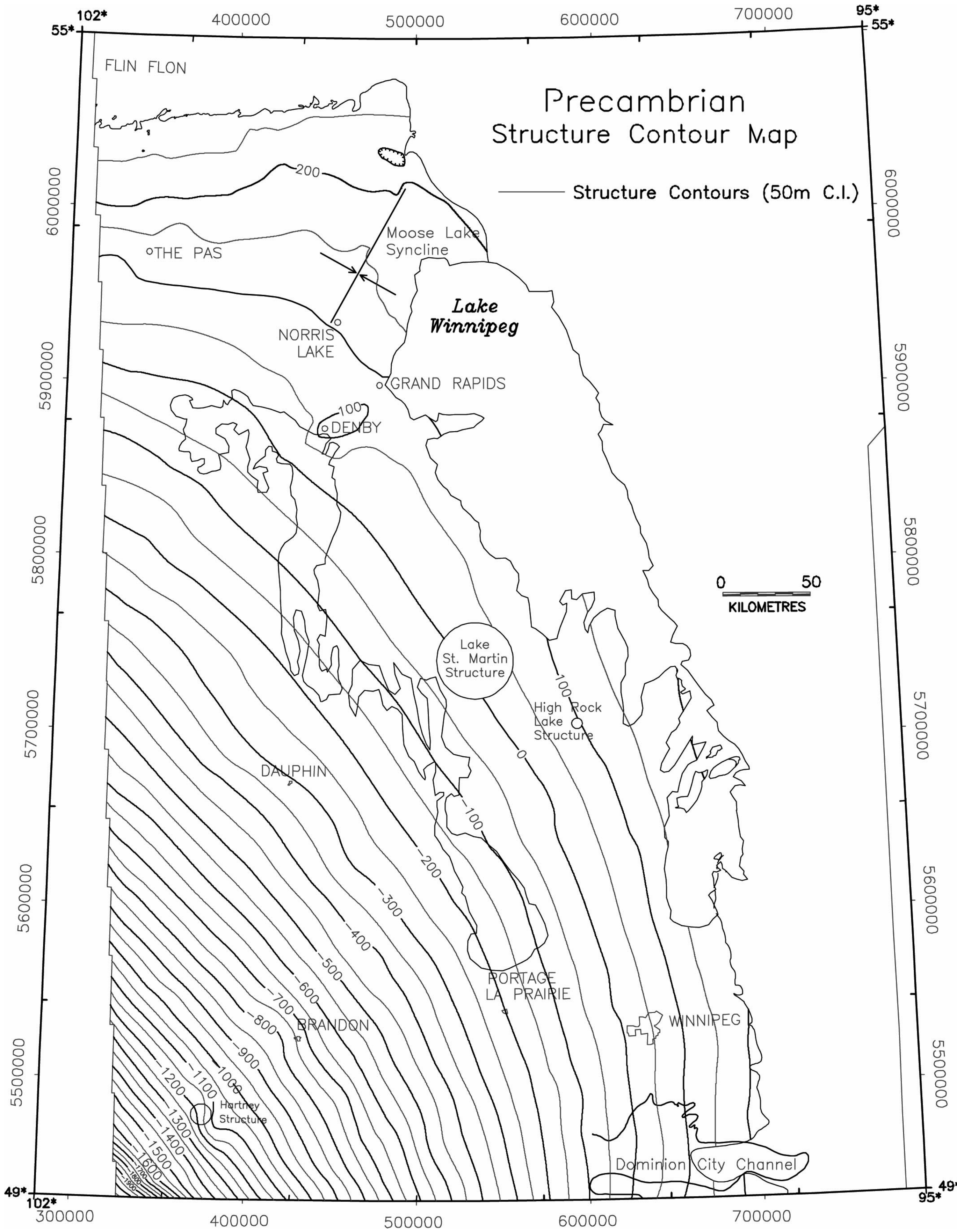


Figure 9: Precambrian structure contour map.

SILURIAN DEPOSITIONAL FRAMEWORK

Detailed maps have not yet been compiled for subunits within the Silurian, because of correlation uncertainties. Available data (Figs. 10 and 11) suggest that the tectonic framework was relatively stable throughout Silurian time, with almost no evidence of basin differentiation in the Manitoba portion of the basin. This is evidenced also by the relative lithologic uniformity of the Silurian strata, which consist almost entirely of micritic to intraclastic and stromatolitic dolomites with scattered fossil-fragmental interbeds. These strata are generally representative of deposition under shallow-water, in part slightly restricted conditions, and have been interpreted by Roehl (1967) and others as intertidal to supratidal deposits. In the central part of the basin, the uppermost Silurian beds, stratigraphically above the beds comprising the Manitoba sequence consists of dolomites with brecciated textures, desiccation cracks, fenestral fabrics, dolomite cements and erosion surfaces (= Upper Interlake). These features indicate periodic subaerial exposure and vadose diagenesis of carbonate deposited under marine or fresh water conditions (Roehl, 1967; Magathan, 1987; Haidl, 1987).

The relatively monotonous dolomite sequence is interrupted only by a number of thin sandy argillaceous marker beds that are believed to represent para-time-stratigraphic markers, minor depositional hiatuses that are very persistent and can be traced throughout most of the Williston Basin area (Porter and Fuller, 1959; King, 1964). The uniformity of Silurian lithology and the persistence of the marker beds attest to the tectonic stability during Silurian time.

The position of the Ordovician-Silurian boundary in the Williston Basin has been traditionally placed at the t-marker within the upper part of the Stonewall Formation (Porter and Fuller, 1959; Brindle, 1960; McCabe, 1988). Recent biostratigraphic studies confirm this as an approximate placement, both in outcrop (Cormorant Hill roadcut (Bezys, 1991)) and in subsurface (Esterhazy 3SWD well, 16-26-20-33WPM1, Haidl, 1991; corehole M-1-86, Warren, Manitoba, McCabe, 1986a; Nowlan *et al.*, 1998).

Only two Silurian outcrops are visited on this trip, but these are representative of the two principal lithofacies. The micritic stromatolitic and intraclastic lithology is well shown in the Inwood Quarry ***(STOP 5)***, and the bioclastic/biostromal lithology is seen at the Lundar Quarries ***(STOP 6)***.

Silurian Correlation Problems

The relative uniformity of the Silurian succession, combined with the large area of no outcrop between the northern Grand Rapids area and the southern Fisher Branch area, have resulted in some miscorrelations and resultant problems in stratigraphic nomenclature.

The present stratigraphic subdivision of the Silurian outcrop belt is that proposed by Stearn (1956), with slight modification. This detailed subdivision is applicable only to the Manitoba outcrop belt, and cannot satisfactorily be extended to the subsurface. Thus the correlation problems have little stratigraphic significance other than in the outcrop belt itself. The problem arises, however, that the Silurian faunal succession, as derived from the outcrop belt by Stearn, has incorporated these stratigraphic errors so that the faunal elements, in some instances, have been misplaced. A detailed corehole program initiated in 1980 was designed to clarify the correlation problems (McCabe, 1980a). These

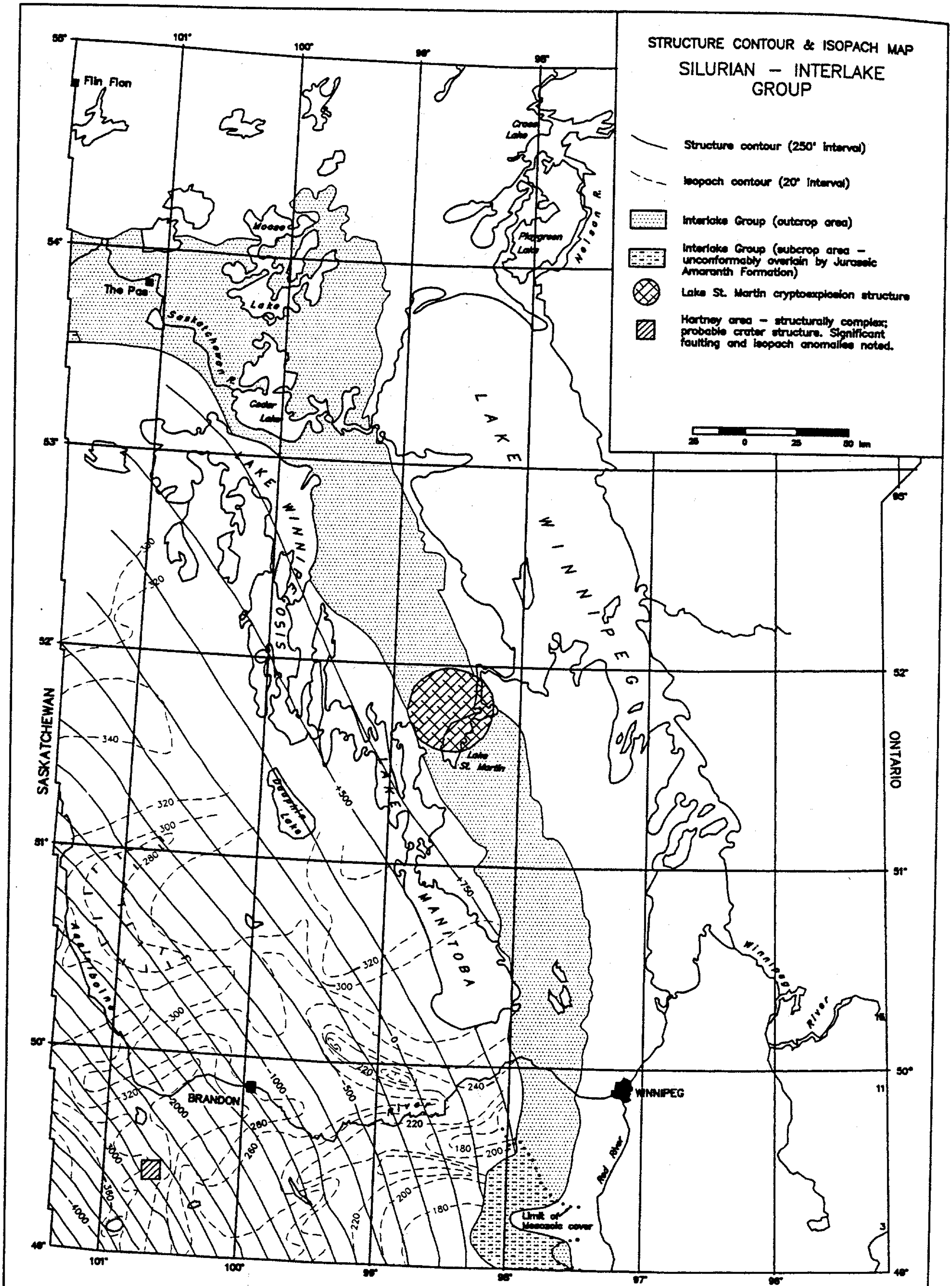


Figure 10: Interlake Group structure contour and isopach map.

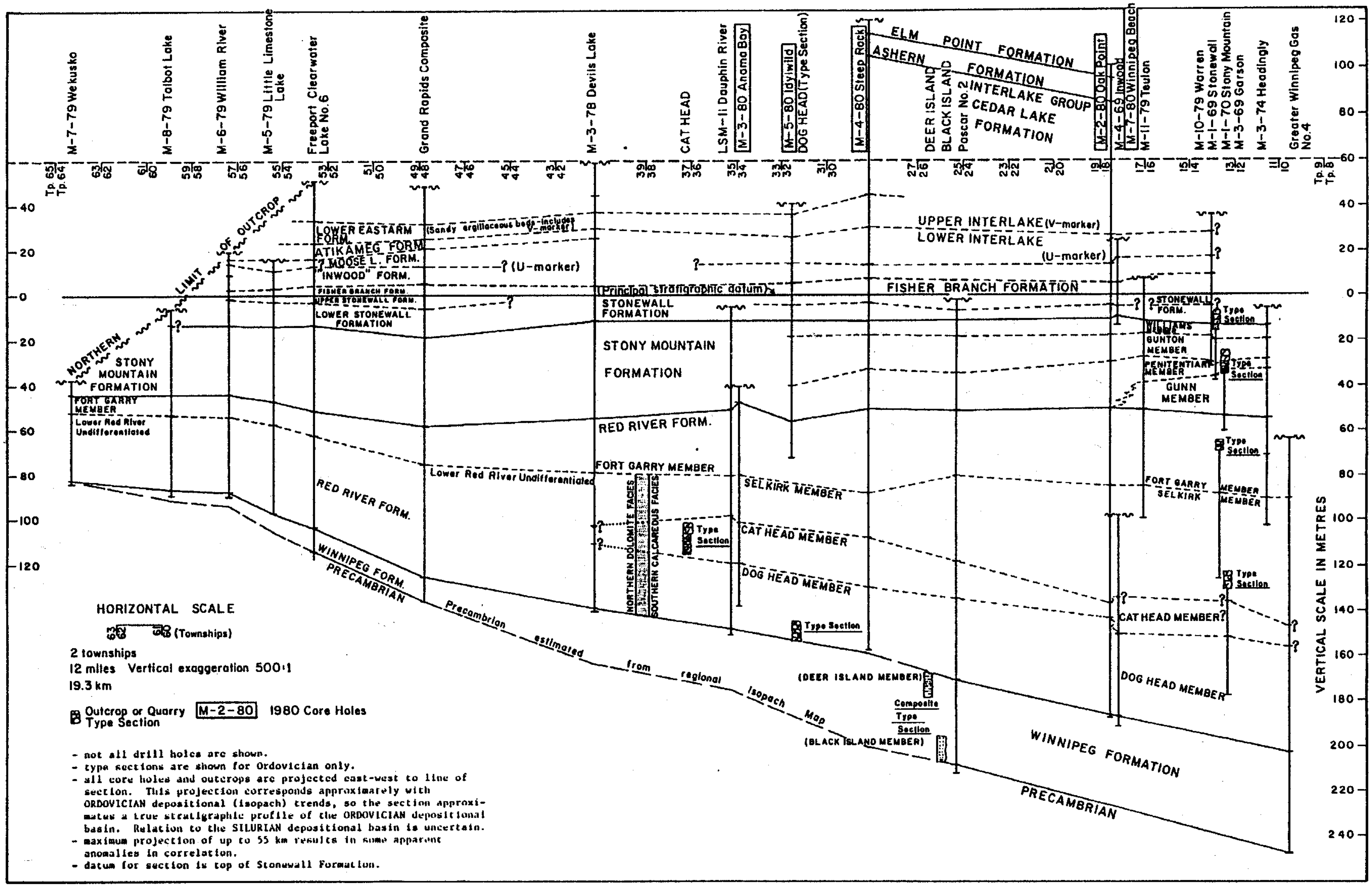


Figure 11: North-south correlation profile, Lower Paleozoic formations, southwestern Manitoba.

preliminary results indicate that the type "Inwood Formation" of the southern area is stratigraphically higher than reported by Stearn, and in fact, may be correlative with the Moose Lake/Atikameg formations of the northern area. Other so-called Inwood and Fisher Branch outcrops in the southern Interlake also may not be stratigraphically consistent. Due to these correlation problems, the term "Inwood" has been dropped (Lammers, 1988) (Fig. 12).

DEVONIAN DEPOSITIONAL FRAMEWORK

Devonian deposition was marked by a major change in the tectonic framework of the Western Canada Sedimentary Basin (Fig. 13). The Williston Basin, which had been the centre of subsidence during Ordovician and Silurian time, was no longer the centre of subsidence, but rather, Devonian deposition was related to the Elk Point Basin, centered in south-central Saskatchewan, approximately 500 km northwest of the depocentre of the Williston Basin (Baillie, 1951b; 1953). Because of extensive late Paleozoic erosion, and also because of complex facies changes and associated isopach anomalies affecting Devonian strata, it is difficult to determine the precise depositional trends for the Manitoba portion of the basin. Isopachs for the outcropping Devonian formations are shown in Figures 14-17.

In general, the outcropping portion of the Devonian sequence comprises a series of complex carbonate-evaporite cycles, although in all cases the evaporites have subsequently been dissolved from the outcrop areas (Figure 18). The first, thickest and best defined cycle comprises the Elk Point Group. The basal unit of this cycle consists of a red bed unit, the Ashern Formation, succeeded by the Winnipegosis/Elm Point Formation and the Prairie Evaporite. The second depositional cycle is represented by the Dawson Bay Formation, initiated by the Second Red Beds and culminating with the Hubbard Evaporite (in the central portion of the basin). The third cycle comprises the Point Wilkins Member of the Souris River Formation (Davidson Member of Saskatchewan), initiated by the First Red Beds, and culminating with the Davidson Evaporite (in the central portion of the basin).

Elk Point Group

The red dolomitic shales and breccias of the Ashern Formation represent the basal deposits of the major Middle Devonian transgressive sequence. The irregular isopach pattern of the Ashern Formation reflects the gentle irregularity of the underlying Silurian erosion surface (Fig. 14). The major period of uplift and erosion in late Silurian to early Devonian time, resulted in complete removal in Manitoba of the Upper Interlake strata, which attain a maximum thickness of about 175 m in the central part of the Williston Basin. However, despite the probable erosion of up to several hundred metres of upper Silurian strata in Manitoba, there is no evidence of any appreciable angular truncation of Silurian beds in southern Manitoba.

Locally, in the subsurface, some suggestion of incipient karst development has been noted at the erosion surface, although this is not obvious in the outcrop belt due to glacial scouring and infill. Minor infiltration of Ashern-related shale into the upper Silurian beds can be seen locally, as at ***STOP 9***, the Oatfield Quarry. The uniformity of the pre-Devonian erosion surface is exposed in the middle of the quarry section.

The rather poorly defined depositional trends of the Elk Point Group, as shown by the Winnipegosis Formation isopach, appear to be approximately northeast (Fig. 15). The general pattern is one of gradual, fairly uniform thickening to the west and northwest, up to a maximum of about 55 m. This facies was deposited in a shelf to fringing bank

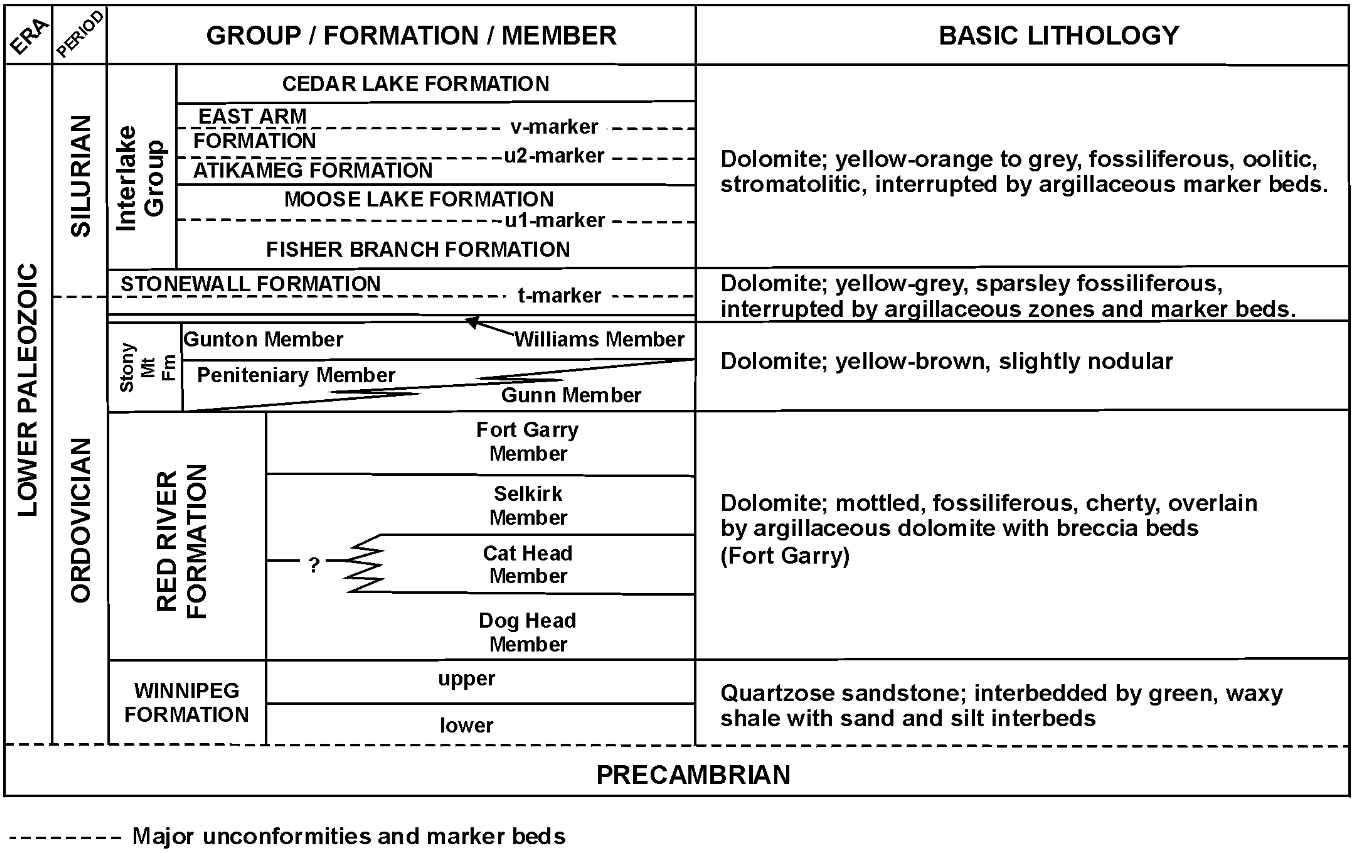


Figure 12: Detailed stratigraphic succession lithology of Lower Paleozoic formations.

environment. West and northwest from this bank, the Winnipegosis Formation is seen to thin, in places very abruptly, to as little as 12 m, but with local areas of thickening to as much as 105 m. This latter area of variable thickness represents a basinal reef-interreef complex. Apparently, basin subsidence and differentiation was sufficiently rapid so that only in certain areas (original organic mounds?) was organic growth able to keep pace with subsidence. Reefs developed in these areas, but in the intervening interreef areas, the only (remaining) deposits are a thin sequence of dark, organic rich (5-6% TOC – total organic carbon content), finely banded to laminated sediments, referred to as bituminous laminites (= Ratner Member in Saskatchewan).

Stratigraphically, the Winnipegosis can be subdivided into two units, a Lower Winnipegosis Member which comprises a relatively uniform blanket type of deposit, or platform, and an Upper Winnipegosis Member which, in the more basinal areas, consists of either thick "reefal" carbonates or a thin sequence of interreef bituminous laminites.

Lower Winnipegosis (Elm Point) Formation

Throughout the northern part of the outcrop belt, and in almost all of the subsurface, the Lower Winnipegosis consists entirely of a medium to coarsely crystalline granular to subsaccharoidal, vuggy, sparsely fossiliferous dolomite. In the southern part of the outcrop belt, however, application of the term Lower Winnipegosis poses a problem. From the Oak Point Quarry ***(Not visited)*** to north of the Town of Winnipegosis, the Lower Winnipegosis has not been completely dolomitized, and consists of strata ranging from partially dolomitized fossiliferous micrite (Lily Bay West Quarry, ***STOP 8***), to pure, high-calcium biomicrite (Steep Rock Quarry; Bannatyne, 1975). Until recently, limestone from Steep Rock was used to make cement in Winnipeg.

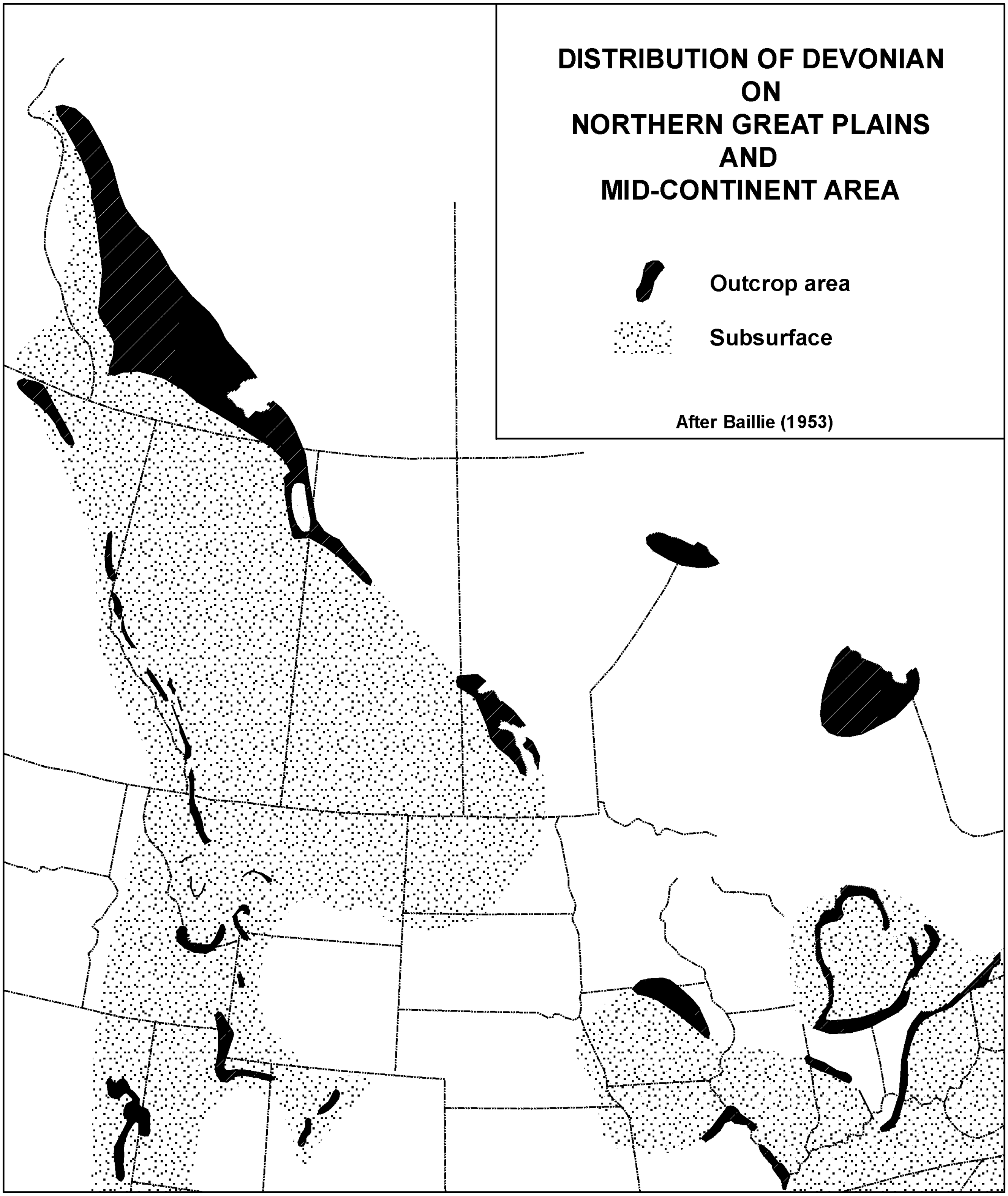


Figure 13: Distribution of Devonian strata, northern Great Plains and mid-continent area.

The relict limestone facies of the Lower Winnipegosis has been named the Elm Point Formation (Kindle, 1914). Limited core data suggest that the degree of dolomitization of the platform beds (*i.e.* Lower Winnipegosis/Elm Point) may have been controlled by proximity to reef sites in the overlying Upper Winnipegosis.

A recent study by Chow and Longstaffe (1995) tentatively suggests that the microdolomites and microcrystalline

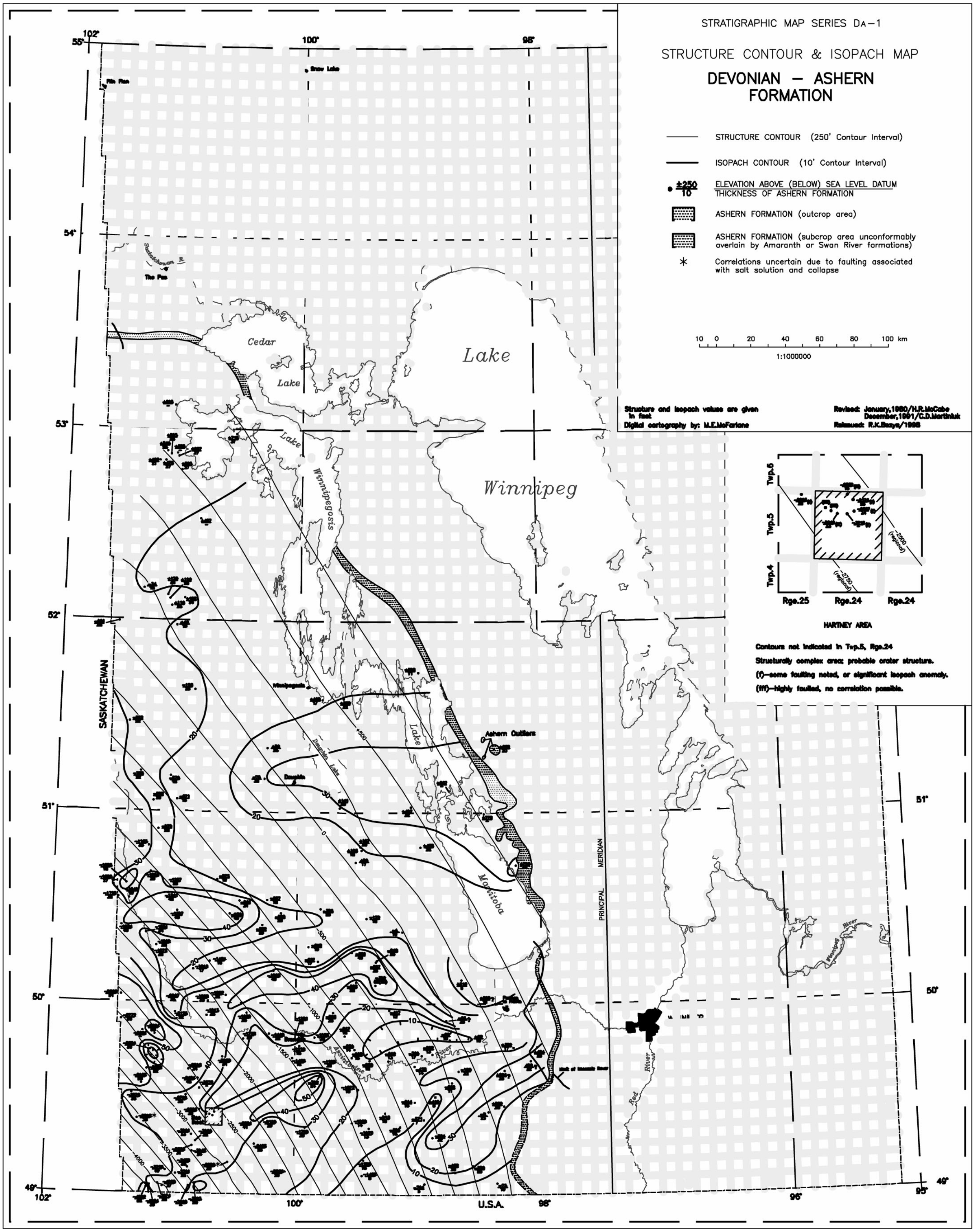


Figure 14: Ashern Formation structure contour and isopach map.

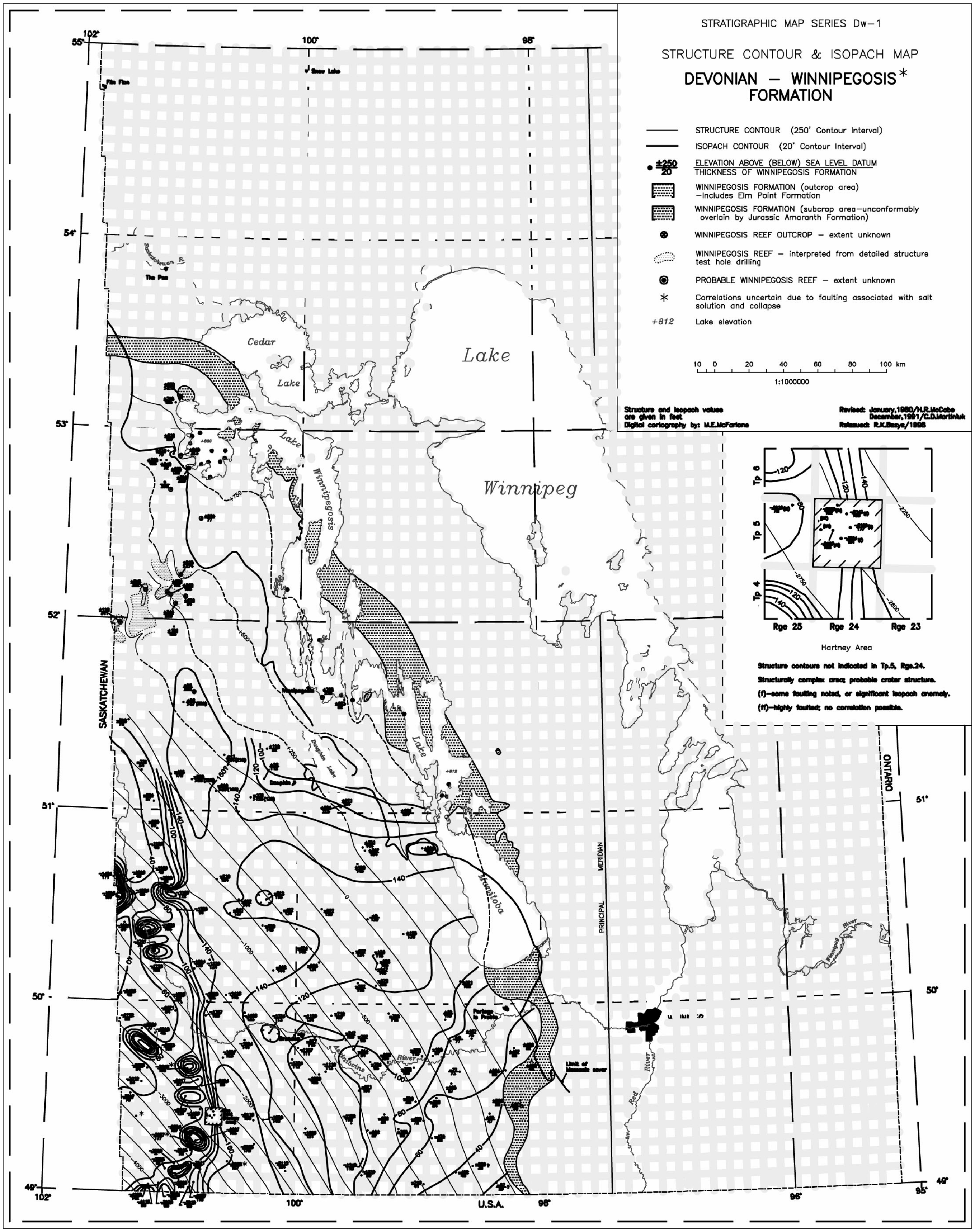


Figure 15: Winnipegosis Formation structure contour and isopach map.

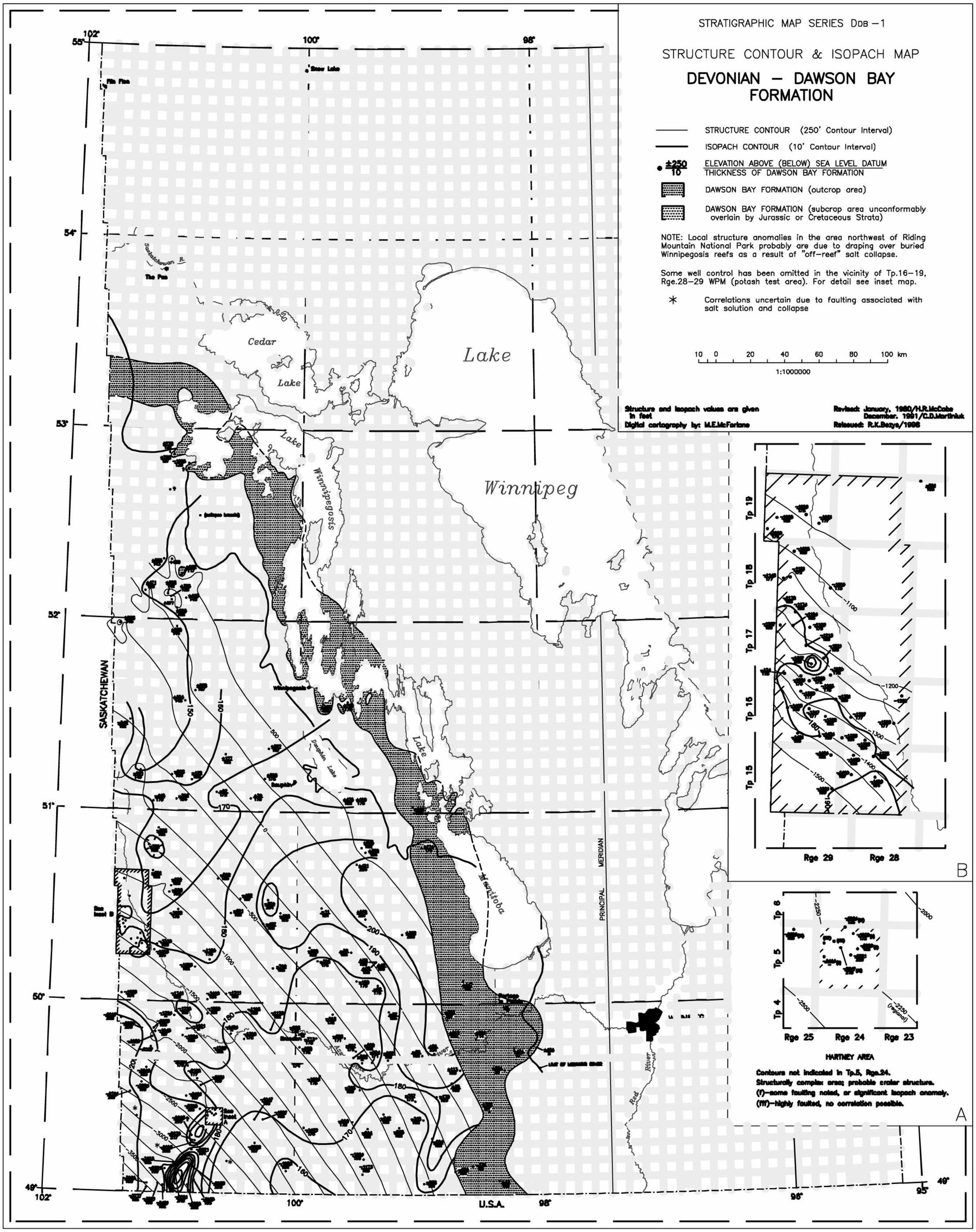


Figure 16: Dawson Bay Formation structure contour and isopach map.

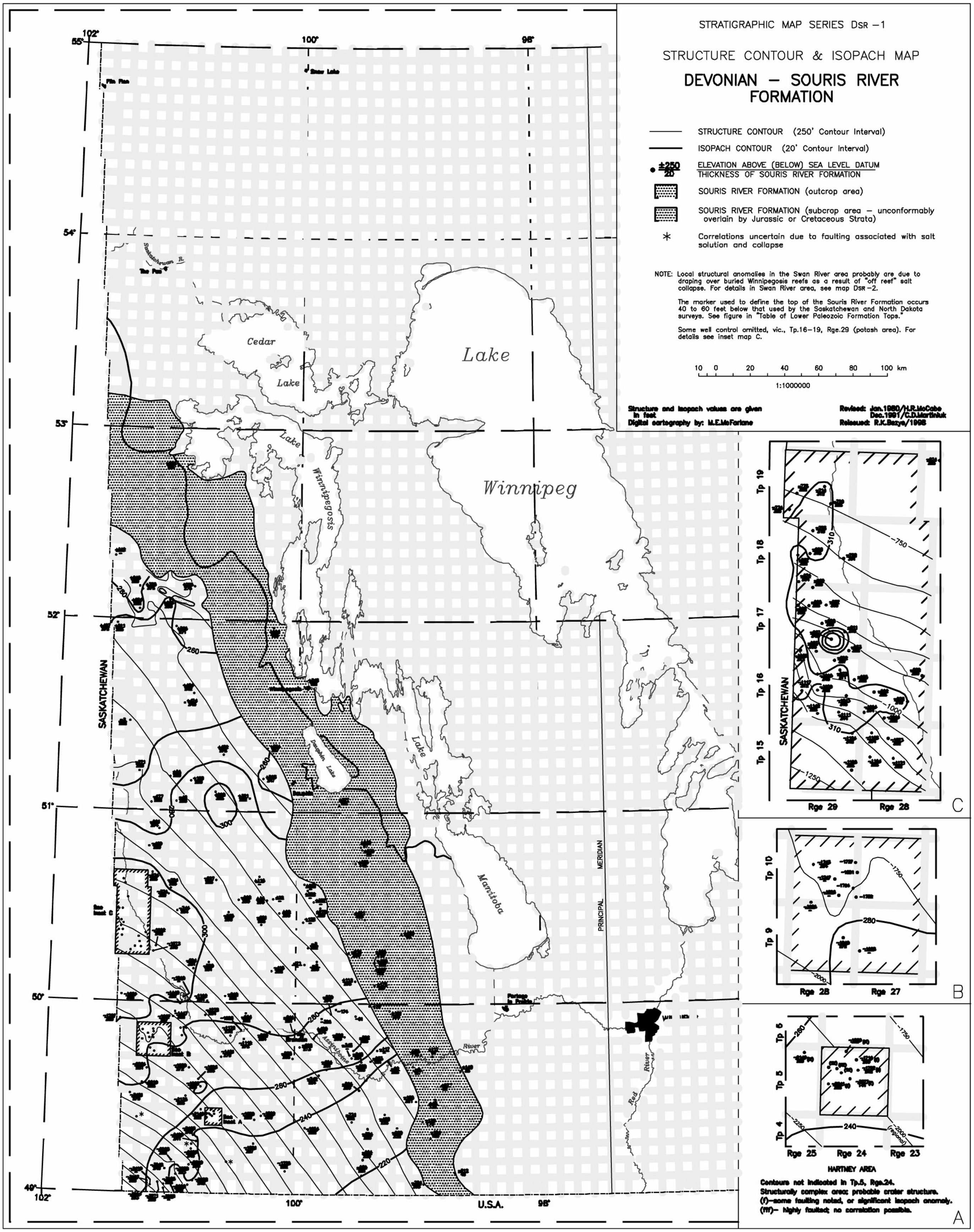


Figure 17: Souris River Formation structure contour and isopach map.

CRET. / JUR.	GROUP/FORMATION/MEMBER			M	DEPOSITIONAL THICKNESS (METRES) AND SUMMARY LITHOLOGY
DEVONIAN	SOURIS RIVER FORMATION		Sagemace Member	20+	Limestone, pale yellowish brown to reddish grey, microcrystalline, dense, minor argillaceous interbeds. Passes laterally to totally dolomitized sequence.
DEVONIAN	SOURIS RIVER FORMATION		basal shale	2-14	Shale, dolomitic, massive, medium brownish red with some greenish mottling.
DEVONIAN	SOURIS RIVER FORMATION	Point Wilkins Member	(evaporite dissolved)		(Davidson Evaporite)
DEVONIAN	SOURIS RIVER FORMATION	Point Wilkins Member	Upper Point Wilkins	10	Dolomite and dolomitic limestone, light grey to medium yellowish brown, partly mottled, coarsely microcrystalline, subsaccharoidal with remnant calcareous biomicrite.
DEVONIAN	SOURIS RIVER FORMATION	Point Wilkins Member	Middle Point Wilkins	14-21	Limestone (pure high-calcium), pale yellowish brown, faintly mottled, finely microcrystalline to cryptocrystalline, dense and tight (sublithographic), fossiliferous, in part intraclastic.
DEVONIAN	SOURIS RIVER FORMATION	Point Wilkins Member	Lower Point Wilkins	9-15	Limestone, slightly to moderately argillaceous with some interbeds calcareous shale, medium to light reddish and purplish grey, fossiliferous intramicrite, locally calcarenitic.
DEVONIAN	SOURIS RIVER FORMATION	Point Wilkins Member	First Red Beds	3-14	Shale, dolomitic, medium reddish grey to dark brownish red, in part mottled and brecciated. Several interbeds buff argillaceous limestone to brown argillaceous dolomite.
DEVONIAN	DAWSON BAY FORMATION		(evaporite dissolved)		(Hubbard Evaporite)
DEVONIAN	DAWSON BAY FORMATION		Upper Dawson Bay	6-17	Limestone, white to pale yellowish brown, highly fossiliferous with corals and stromatoporoids, in places grading to stromatoporoid biolithite. In part extremely pure high-calcium limestone (99.8% $CaCO_3$), but in places variably dolomitized, especially lower part of unit.
DEVONIAN	DAWSON BAY FORMATION		Middle Dawson Bay	11-18	Calcareous shale, fossiliferous, medium grey to dark greyish red, massive (recessive).
DEVONIAN	DAWSON BAY FORMATION		Lower Dawson Bay	9-25	Gradational sequence passing upward from brown partly laminated and bituminous dolomite to grey and reddish grey dense slightly argillaceous micrite and fossiliferous micrite, which in turn grades upward to highly fossiliferous brachiopod biomicrite at top. Lower two zones thin markedly to the north.
DEVONIAN	DAWSON BAY FORMATION		Second Red Beds	6-15	Red to greenish grey dolomitic shale, commonly brecciated as a result of salt collapse.
DEVONIAN	ELK POINT GROUP	WINNIPEGOSIS FORMATION	PRAIRIE EVAPORITE	0-129	Prairie Evaporite: dominantly salt with potash interbeds and minor anhydrite in basinal areas; entirely anhydrite in shelf areas (at present). Originally present throughout the entire Devonian outcrop belt, but subsequently removed by subsurface salt solution. Where preserved in subsurface, overlaps and completely buries Winnipegosis reefs with resultant thinning of evaporite section.
DEVONIAN	ELK POINT GROUP	WINNIPEGOSIS FORMATION	Upper Winnipegosis (reef)	0-90	Reefal facies: dolomite, very fine to medium crystalline, ranges from compact dense to subsaccharoidal, massive to medium/thick bedded, variably fossiliferous but texture largely obscured by dolomitization. Reef thicknesses tend to be relatively uniform in a given area.
DEVONIAN	ELK POINT GROUP	WINNIPEGOSIS FORMATION	(interreef)	35	Interreef facies: dolomite, brown to black, finely laminated with black bituminous partings, in places calcareous. Lamination best defined towards top of unit.
DEVONIAN	ELK POINT GROUP	WINNIPEGOSIS FORMATION	Lower Winnipegosis	10-20	Lower Winnipegosis: dolomite, fine to medium crystalline, moderately granular to saccharoidal, medium to thin bedded. In part calcareous and grades laterally to Elm Point limestone facies.
DEVONIAN	ELK POINT GROUP	WINNIPEGOSIS FORMATION	ELM POINT FORM.	10-20	Elm Point: limestone, pale yellowish brown dense fine grained biomicrite. In part shows lighter yellowish dolomitic mottling. Pure high-calcium limestone to calcareous dolomite.
DEVONIAN	ELK POINT GROUP		ASHERN FORMATION	3-18	Argillaceous dolomite and dolomitic shale, medium to dark greyish and brownish red, in places reduced to greenish grey. Local basal dolomite breccia.
SIL.	INTERLAKE GROUP				Dolomite, white to pale yellowish buff, mostly microcrystalline dense, thin bedded, sublithographic, in part stromatolitic. Some porous biostromal interbeds towards top.

Figure 18: Detailed stratigraphic succession and lithology, Devonian formations.

dolomite of the Elm Point Formation are geochemically distinct from those of the Winnipegosis Formation, discounting any genetic linkage between these dolomites. The fabric-selective nature of the Elm Point dolomite suggests that the nature of the host rock, *i.e.*, intrinsic factors, played a major role in determining the extent of dolomitization within the Elm Point Formation. The implication that the Elm Point was not a major conduit for dolomitizing fluids into the Winnipegosis buildups in Manitoba contrasts the idea that there was a genetic connection.

The common occurrence of limestone in the Lower Winnipegosis (*i.e.* Elm Point) of the Manitoba outcrop belt probably is significant, inasmuch as this is the only area in the Elk Point Basin where such relict limestones are common, if not dominant. A possible explanation is that this area comprises the distal end of the Elk Point Basin, farthest removed from the area of influxing brines, which is believed to have been in northwestern Alberta. Consequently, the tendency for brine circulation and resultant dolomitization would have been minimized. Dolomitization possibly was reduced further by influx of fresh meteoric water from the hinterlands to the east and southeast. Also, the paleogeography of the northeastern flank of the basin is completely unknown. The preservation of a thick section of Elm Point limestone as a tectonic slump block within the Lake St. Martin crater structure (Fig. 9) (the most northeasterly known occurrence of Devonian strata) is additional evidence of reduced brine circulation on this flank of the basin.

Upper Winnipegosis Formation

Distinction between the Upper Winnipegosis and the Lower Winnipegosis is obvious in the basinal interreef areas where the massive granular vuggy dolomites of the Lower Winnipegosis platform pass sharply into the distinctive thinly bedded bituminous laminites of the Upper Winnipegosis. In marked contrast, for reefal areas, there is generally no appreciable lithologic change between Lower Winnipegosis platform beds and Upper Winnipegosis "reefal" facies. An increase in fossil content, especially corals and stromatoporoids may be evident but the extreme effects of dolomitization have, for the most part, obscured the primary textures, making stratigraphic separation of Lower and Upper Winnipegosis beds difficult. In effect, the Upper Winnipegosis reefs appear to comprise local thickening of the Lower Winnipegosis platform. Details of Winnipegosis reef morphology and development is discussed later.

Interpretation of the "bituminous laminites" of the interreef facies of the Upper Winnipegosis is somewhat controversial, and the differences in interpretation pose considerable question to the evolution of the reefs, and in particular the precise correlation between the reefs and the off reef deposits - the bituminous laminites and evaporites. It is important to note that the Prairie Evaporite beds have been totally dissolved from the outcrop area so that precise relationship between the reefs and the complete interreef sequence cannot be determined definitively in the outcrop belt.

In part, the different interpretations of the "bituminous laminites" arise from the fact that these beds actually consist of at least two distinctly different lithologies, indicative of two different modes of origin. The lower part of the "bituminous laminite" unit consists of finely banded or laminated bituminous mudstone, in places containing carbonate (detrital) interbeds. These are probably correlative to the Ratner Member in Saskatchewan. The upper part of the unit consists of finely laminated, almost varvitic carbonate with fine black, bituminous, in part microstylolitic partings (= Brightholme Member in Saskatchewan). Laminae average about 2 mm in thickness and range from very uniform in the lower part to increasingly irregular in the upper part. Relict enterolithic structure is evident in some laminae, and some thin interbeds of detrital carbonate also are present.

Baillie (1987, pers. comm.) and others note that "bituminous laminites" associated with comparable Devonian reefs in the Rainbow, Zama and Virgo areas of Alberta are postulated to be very shallow, intertidal algal-matte, sabka-type deposits. They suggest a similar origin for some of the bituminous laminites associated with the Winnipegosis reefs in the Manitoba outcrop belt. Other workers (*e.g.* Wardlaw and Reinson, 1971; Kendall, 1975) have postulated a deep-water, starved-basin environment for deposition of at least the lower portion of the bituminous laminite sequence.

A detailed discussion of deep-water/shallow-water origin for the bituminous laminites is beyond the scope of this guide, as is a detailed comparison with comparable Devonian reefs in other others (Rainbow, Zama, etc.).

Although the shallow-water/deep-water problem has not been resolved, most workers currently dealing directly with the Winnipegosis reefs of the Elk Point Basin favor a deep-water, euxinic, starved-basin origin for at least the lower portion of the bituminous laminite sequence (Kendall, 1975; Kent, 1987, pers. comm.; Christopher, 1987, pers. comm.). The authors also favor this interpretation; and most of the suggestions as to reef development presented in this guide are based on the premise of a deep-water origin for the bituminous mudstone, and consequently a deep-water setting for the reefs.

One of the principal factors favoring a deep-water origin is the interfingering of the thin bituminous mudstones with progressively thicker interbeds of reef-derived carbonate detritus as the reef is approached, suggesting that the reefs and bituminous mudstone are contemporaneous lithologies. Kendall (1975) reports an outcrop occurrence in Saskatchewan "where steeply-dipping, fore-bank deposits pass downward and laterally into a thin-bedded laminated styliolinid-rich argillaceous unit." The same situation is shown by corehole drilling in the Manitoba outcrop belt. Kendall also points out that the bituminous, argillaceous interreef lithology "must have accumulated under water at least as deep as the thickness of the neighboring banks, up to 75 m. It therefore represents a starved-basin deposit." Comparable water depths are indicated for the Dawson Bay and Winnipegosis portions of the Manitoba outcrop belt.

The relatively unknown effect of differential compaction could possibly alter the aforementioned water depth estimates and thickness estimates. The bituminous sediments may well have undergone a higher degree of compaction than the carbonate reef complexes, in particular bioconstructed reef framework (assuming such framework exists). This factor would reduce the estimates of true water depths during Winnipegosis time. (A possible example of the effect of differential compaction is noted in Norris *et al.* (1982, p. 124) where spherical *Tasmanites* is preserved in a thin carbonate interbed whereas *Tasmanites* in the enclosing bituminous sediments are totally compressed and flatten). Differential compaction within the reef complexes could also have given rise to apparent (present) variation in reef thickness. Possibly the thinner sequences associated with the central portions of the reef complexes (*e.g.* Salt Point) may result, in part, from differential compaction of finer grained lagoonal deposits.

The origin of the varve-like bituminous laminites of the upper part of the Upper Winnipegosis interreef facies (*i.e.* Ratner/Brightholme members) is somewhat uncertain. Both relatively deep subtidal, and shallow water to supratidal (sabkha) origins have been proposed, but most workers in the area tend to favor a subtidal origin. However, all would indicate a considerable shallowing of water relative to the level maintained during organic reef growth (Wardlaw and Reinson, 1971; Kendall, 1975). Kendall (1975) suggested that the Ratner Member (*i.e.* the upper part of the Upper

Winnipegosis interreef facies in Manitoba) should more properly be designated as the basal unit of the Prairie Evaporite appears to be valid, but is difficult to apply to the Manitoba outcrop belt because of evaporite solution. These laminated beds probably postdate biogenic reef development, although inorganic reef "growth" (*i.e.* caliche development) and concurrent reef erosion probably continued throughout deposition of the interreef evaporitic laminites and the lower halites of the Prairie Evaporite, until such time as the upper Prairie Evaporite salts buried the Winnipegosis reefs.

Relationship of Outcrop Stops to the Regional Depositional Framework

Examination of the Winnipegosis isopach map shows that the northwesterly strike of the outcrop belt cuts directly across the northwesterly depositional trend of the basin. The outcrop belt thus constitutes a dip section of the basin, a situation similar to that noted for the Ordovician outcrop belt. However, in marked contrast to the Ordovician pattern, the Devonian sequence thickens to the north rather that to the south - a complete reversal of the tectonic/stratigraphic framework.

The effect of the changing tectonic framework is well shown in outcrop. The southeastern portion of the outcrop belt, in the vicinity of the Oak Point Quarry ***(Not visited)***, falls within the shelf or fringing bank facies. The edge of the fringing bank appears to intersect the outcrop belt just south of the Narrows of Lake Manitoba immediately northeast of the Dog Lake Quarry ***(Stop 11)***, and the gentle mound-like "reefs" seen in The Narrows area ***(STOPS 13, 14)*** (Figure 18) probably represent a shelf-edge complex. Flanking dips on the reefs are only a few degrees (Narrows West Quarry, ***STOP 14***), although primary bedding in reef-flank beds (foreset beds) can be much steeper (Rosehill Quarry, ***Stop 13***). Regional data suggest approximately 35 m of reef-interreef relief with a maximum Winnipegosis thickness of about 70 m. The presence of a zone of sand-filled (Cretaceous?) solution caverns ***(STOP 10,*** Overton Quarry) throughout much of The Narrows area has severely limited drilling for deeper structural/stratigraphic data, and in particular has prevented deep drilling of reefal occurrences to determine if dolomitization of the platform beds is associated with reefal occurrence in the overlying Upper Winnipegosis.

The configuration of the numerous reef-related structures near the Town of Winnipegosis suggests a basin-flank facies compared to the shelf-edge reefs of The Narrows area. Flank dips on the reef structures area steeper, averaging about 10°. On the basis of limited corehole data, reefal sections appear to be 85 m in thickness (total Winnipegosis), and interreef sections about 28 m. Maximum reef-interreef relief is thus approximately 60 m, as compared to only 35 m in The Narrows area.

The estimated thickness of 105 m for a reef drilled near the Camperville junction (Hole M-9-79, 16-32-33-19W1; McCabe, 1980) is anomalously high and suggests a relatively deep-water setting in contrast to the relatively gentle, shallow-water reef configuration typical for most reefs in this general area. Surprisingly, the outcropping Lower Dawson Bay Formation beds overlying the Camperville junction reef are relatively flat-lying with no evidence of the typical domal structures characteristic of most reef-supported outcrops (see following section on salt collapse).

The Dawson Bay portion of the Winnipegosis outcrop belt represents a relatively deep basinal facies. The indicated reef thickness (total Winnipegosis) range from 82 m to 98 m. Interreef thickness are about 25 m, reef-interreef relief

50-74 m, and flank dips up to 20° ***(STOPS 23 – Highway 10 Dome; 21 – Steeprock Road Dome; 20 – Steeprock Bridge Dome; 19 – Steeprock Bay Reef)***. The indicated reef thickness in the Dawson Bay area are approximately the same as those reported for the central portion of the Elk Point Basin, in central Saskatchewan (Wardlaw and Reinson, 1971), testifying to the relatively deep basinal facies developed in the Dawson Bay area.

Figure 19 presents a diagrammatic summary of the various Winnipegosis reef configurations outlined above.

Salt Collapse Structures

Before further discussion of the relation of Devonian outcrops to the depositional basin, it is necessary to note the extreme effect of salt solution and collapse on the outcrop geology. As noted above, Devonian reefs occur from the Dawson Bay area south to The Narrows (Lake Manitoba). During late Elk Point time, all of these reefs were buried by evaporites (primarily halite) of the Prairie Evaporite, which overlapped an unknown distance from the fringing bank and shelf area. Flat-lying, uniform Dawson Bay strata were then deposited over the evaporites, with no evidence of

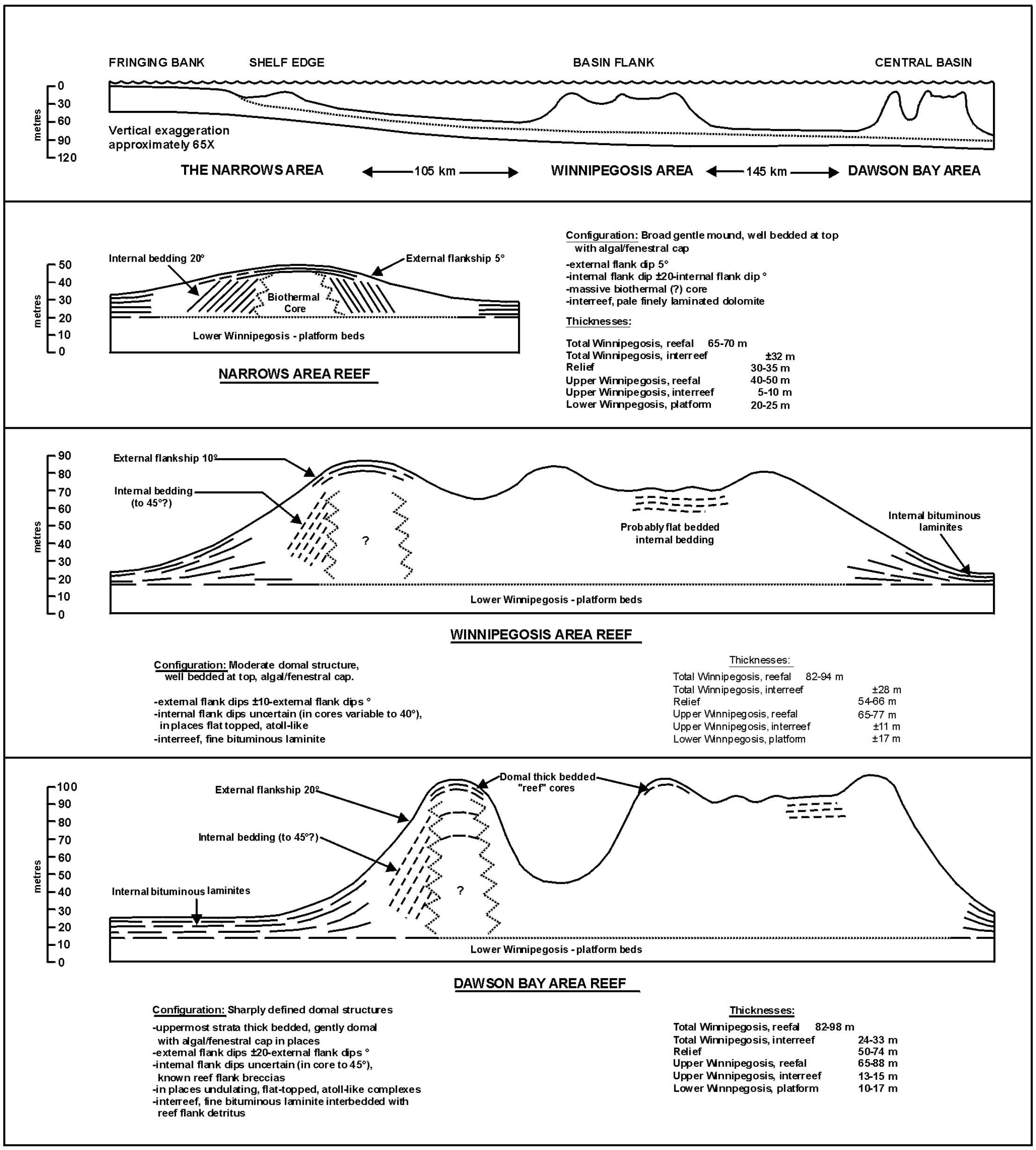


Figure 19: Winnipegosis Formation reef configurations (inferred) and known reef parameters.

influence by underlying reefs. The uniformity of the Dawson Bay beds shows that burial of Winnipegosis reefs was complete. In western Manitoba and Saskatchewan, within the remaining portion of the salt basin, reefs are overlain by 60 m to 100 m of salt, but there is no way to accurately estimate the original salt thickness (and hence the amount of salt collapse) in the area of the Manitoba outcrop belt.

Subsequent to burial by Dawson Bay strata, the Prairie Evaporite was dissolved from the entire outcrop area as well as a large portion of the subsurface (Fig. 20). Most of this solution is believed to have occurred during the period of late Paleozoic to early Mesozoic uplift and erosion, but localized episodes of evaporite solution also occurred throughout late Paleozoic and Mesozoic time. The earliest (Late Devonian and Mississippian) collapse episodes appear to have been local features, possibly fracture or fault controlled, whereas the main pre-Mesozoic solution episode appears to have resulted from widespread regional solution, possibly related to regional groundwater flow through the underlying Winnipegosis and Interlake strata. The salt solution process is continuing at the present time, as evidenced by the outflow of brine from the numerous salt springs along the Devonian outcrop belt (***STOP 24, Red Deer River Salt Spring***).

As a result of salt solution, all of the post-evaporite strata collapsed and were draped over the underlying Winnipegosis reef-interreef complexes. The minimum amount of subsidence or collapse in a given area is equal to the reef-interreef relief. All of the Dawson Bay and Souris River outcrop occurrences have thus been subjected to varying degrees of salt collapse, and more importantly, the structural configuration shown by these strata reflects precisely the topography of the underlying Winnipegosis surface. Local, reef-controlled structural relief ranges from 35 m in The Narrows area to 75 m in the Dawson Bay area. The superficial structure effectively masks the gentle uniform true structural dip, which averages only about 2.0 m/km (0.1°). To date, there is no evidence of true structural deformation associated with local Winnipegosis reef development, but a possible regional tectonic control for reef development will be suggested later.

Not only can the Winnipegosis reef configuration be determined from the structural configuration of the overlying Devonian strata, but the thickness of the Winnipegosis can be estimated if the precise stratigraphic position of the post-Winnipegosis outcropping strata is known. Several Dawson Bay and Souris River beds form excellent markers for such estimates of Winnipegosis thickness, and estimates will be noted wherever possible for outcrop stops.

The process of salt collapse has been, in places, a series of two or more collapse events, rather than a single event. Evidence for multiple-event collapse will be seen in the Winnipegosis Quarry ***(STOP 15)***. Collapse can be extremely uniform with no visible evidence of structural deformation, or it can be a "catastrophic" event giving rise to a chaotic mega-breccia. Both types are seen at the Winnipegosis Quarry.

The salt collapse scenario is complicated further by the probable original occurrence of multiple salt horizons. In the deeper parts of the Elk Point Basin, additional evaporite units occur both at the top of the Dawson Bay Formation and at the top of the Point Wilkins Member of the Souris River Formation (Figure 18). Breccia zones at these horizons in the Manitoba outcrop sequence indicate that these evaporites, as well as the Prairie Evaporite, extended throughout most, if not all of the outcrop belt. Dissolution of these younger evaporites occurred as well, but identification of

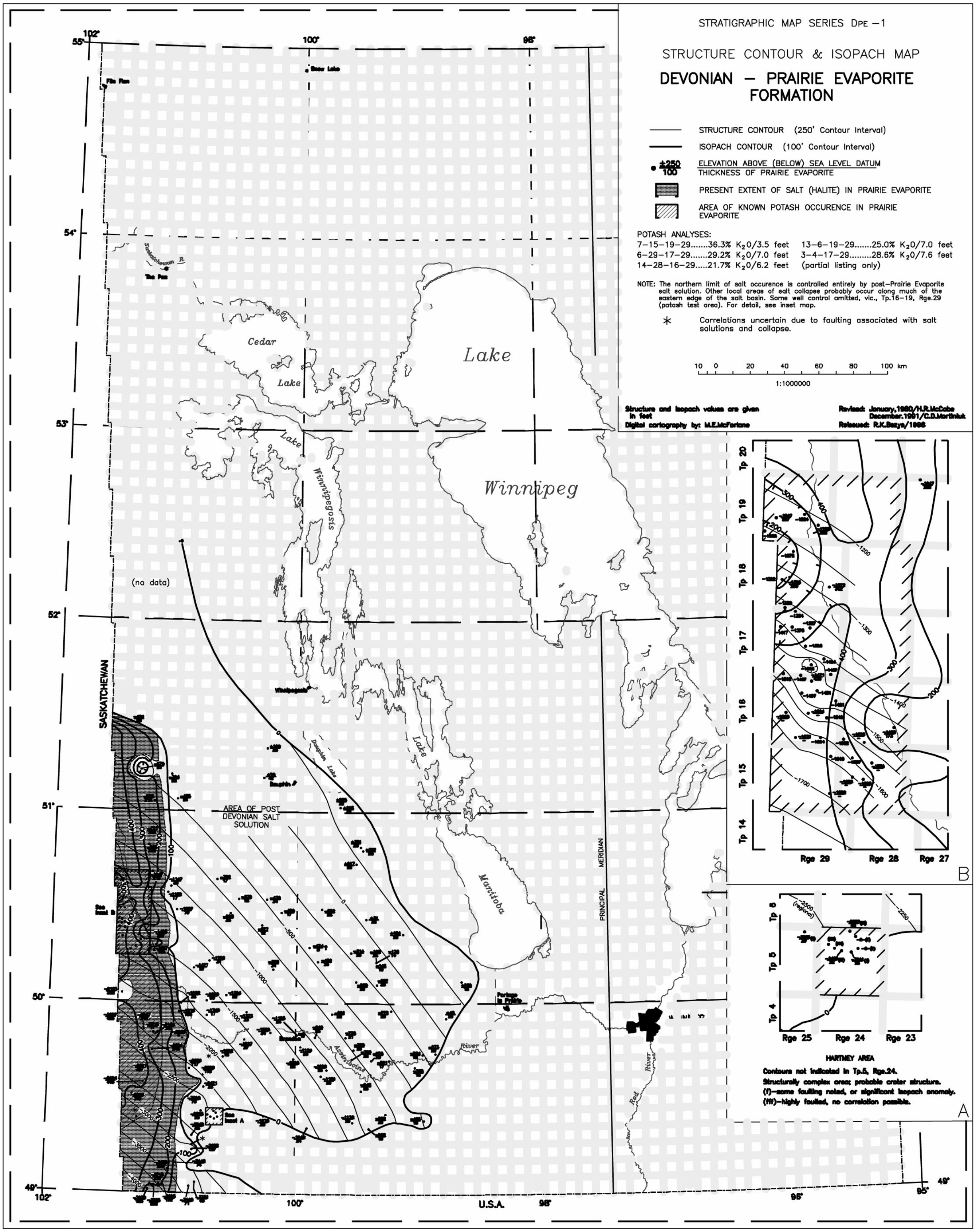


Figure 20: Prairie Evaporite structure contour and isopach map.

collapse structures related specifically to these younger evaporites is not possible because of the lack of pre-evaporite paleotopographic relief.

Winnipegosis Reef Morphology (Subsurface) Swan River Area

Although some of the regional variations in Upper Winnipegosis reef configuration have been noted, the details as to size, shape and distribution of individual buildups are largely unknown. In the outcrop belt we have only a very limited insight, and even this is largely indirect, as will be described later. The only area where the size and shape of a portion of a reef complex can be determined (other than in seismic studies) is in the Swan River area, 80 km south-west of the Dawson Bay outcrop belt. In 1951-52, Shell Oil Co. drilled 108 shallow structure test holes to Devonian markers, mainly the Upper Devonian Souris River and Duperow formations. Seismic interpretations for salt solution areas are questionable because of the extremely complex velocity anomalies resulting from both primary lithofacies variations and secondary brecciation effects (McCabe, 1985). Two deep test holes were subsequently drilled by Shell to test structural highs outlined by this study, and still later, five additional deep test holes were completed (including 4 holes completely cored). All deep holes indicate a very uniform regional dip for pre-Winnipegosis strata, but complex structure is evident in the younger Devonian beds (Fig. 21). All of this shallow structure can be attributed to variations in Winnipegosis thickness, as a result of younger Devonian strata being draped over Winnipegosis reefs due to post-Devonian solution of the Prairie Evaporite.

A "Winnipegosis anomaly map" was derived from structure test hole data for the Swan River area (Fig. 22) (Norris *et al.*, 1982). The "anomaly value" represents the local reefal thickening of the Winnipegosis, a maximum of 200-300 ft (61-70 m), and is effectively the reef-interreef paleotopographic relief at the end of Winnipegosis time. The deep test holes indicate that the zero anomaly values correspond to a Winnipegosis thickness of approximately 80 ft (24 m). This represents the average interreef thickness and includes both Lower Winnipegosis platform beds and Upper Winnipegosis interreef beds. Several distinct reef characteristics can be derived from the anomalies outlined in Figure 23, and it seems reasonable to suggest that these characteristics may also apply to the Dawson Bay outcrop area covered by this field trip. These characteristics may be applicable to the entire central Elk Point Basin area.

A) The reefs are relatively small and sharply defined. Even with the closely spaced drilling (1-5 km) the individual reef configuration cannot be defined precisely. Maximum reef size is in the order of 5 km by 15 km, and the reefs appear to be elongate; but no preferred reef orientation is evident from the limited data available.

B) All reefs shown in Figure 22 have approximately the same relief of 61 to 67 m (total thickness 85-91 m). This characteristic is shown more clearly by the sharply defined bimodal nature of the histogram plot of the Winnipegosis anomaly values (Fig. 23). The same type of thickness plot can be derived for well data compiled for the entire central portion of the Elk Point Basin of Saskatchewan (Wardlaw and Reinson, 1971) (Fig. 23). This implies that the reef modal shown for the Swan River area possibly is applicable to the entire Elk Point Basin area. The slope or spread of the "reefal" values in the histograms for the Saskatchewan basin could be interpreted as the range of "uniform" reef thickness (82-107 m) over a broad basinal area, as contrasted to the more sharply defined maximum for the locally derived Swan River area (85-91 m).

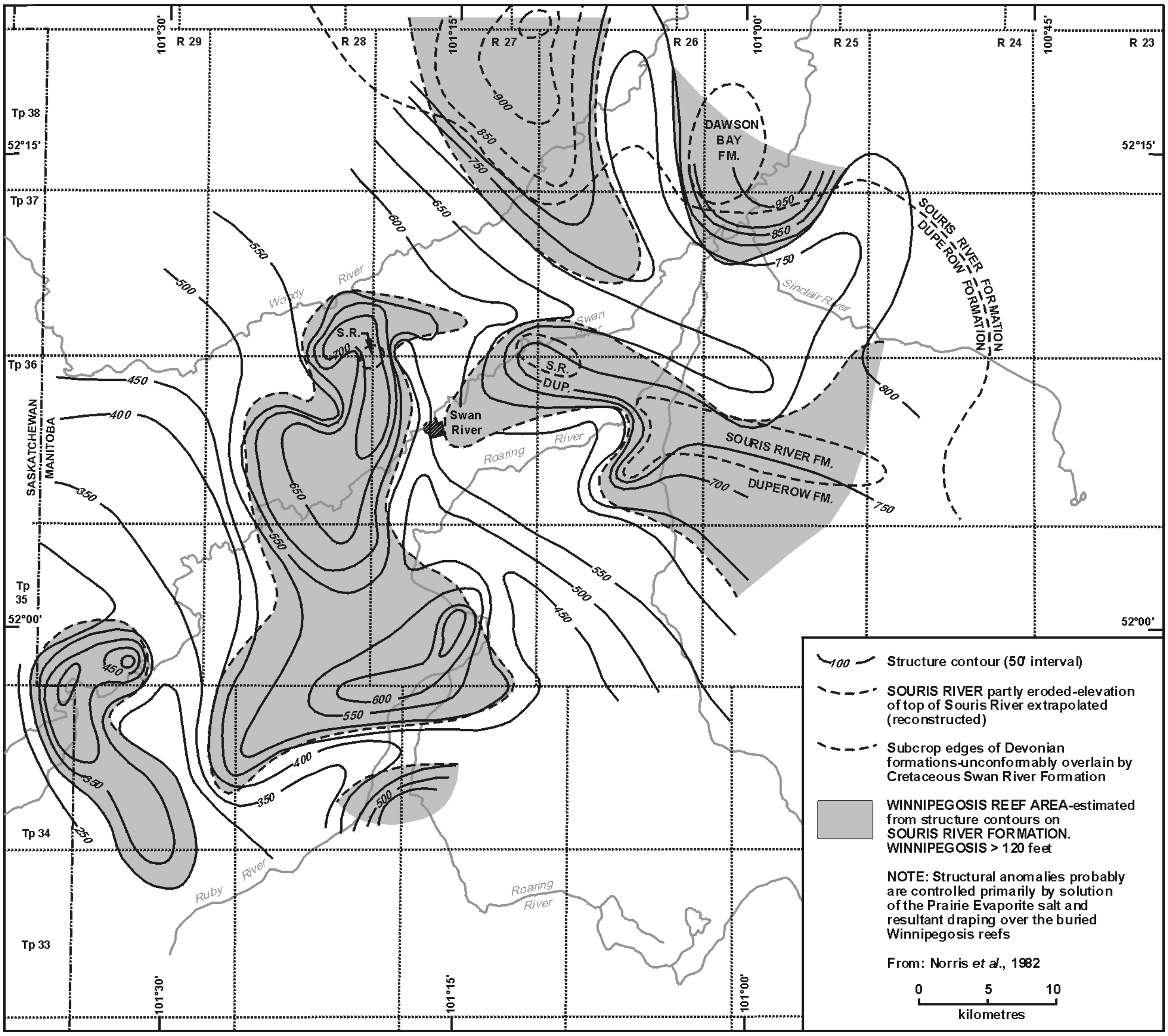


Figure 21: Detailed structure contour map, Souris River Formation, Swan River area (modified from Norford et al.*, 1982).*

It is worth noting that reef thickness in the Swan River area falls well within the thickness range of the central-basin reefs of Saskatchewan, supporting the suggestion that the Swan River-Dawson Bay area of Manitoba represents a central basinal facies. In fact, the thickest reef sections in Manitoba (Shell Swan River 09-01-37-28W1, 107 m; Camperville South Quarry, 105 m, estimated) are close to the maximum reported for Winnipegosis reefs anywhere in the southeastern part of the Elk Point Basin.

The distribution of Winnipegosis reefs and reef-controlled structures, as seen in the outcrop areas, supports the concept of a relatively uniform reef height or thickness.

C) The Winnipegosis reefs, in their final configuration, appear to be at least in part flat-topped, as suggested by the cumulative histograms for both the Saskatchewan and Swan River areas. The cumulative histogram can be interpreted, in general terms, as an average reef profile. It must be noted, however, that the data from which these histograms are derived are not completely representative, and may be rather strongly biased. The very low percentage of reef-flank (intermediate thickness) values in the Saskatchewan data probably results in part from the selective drilling of seismically determined structural highs, in which case the histogram is

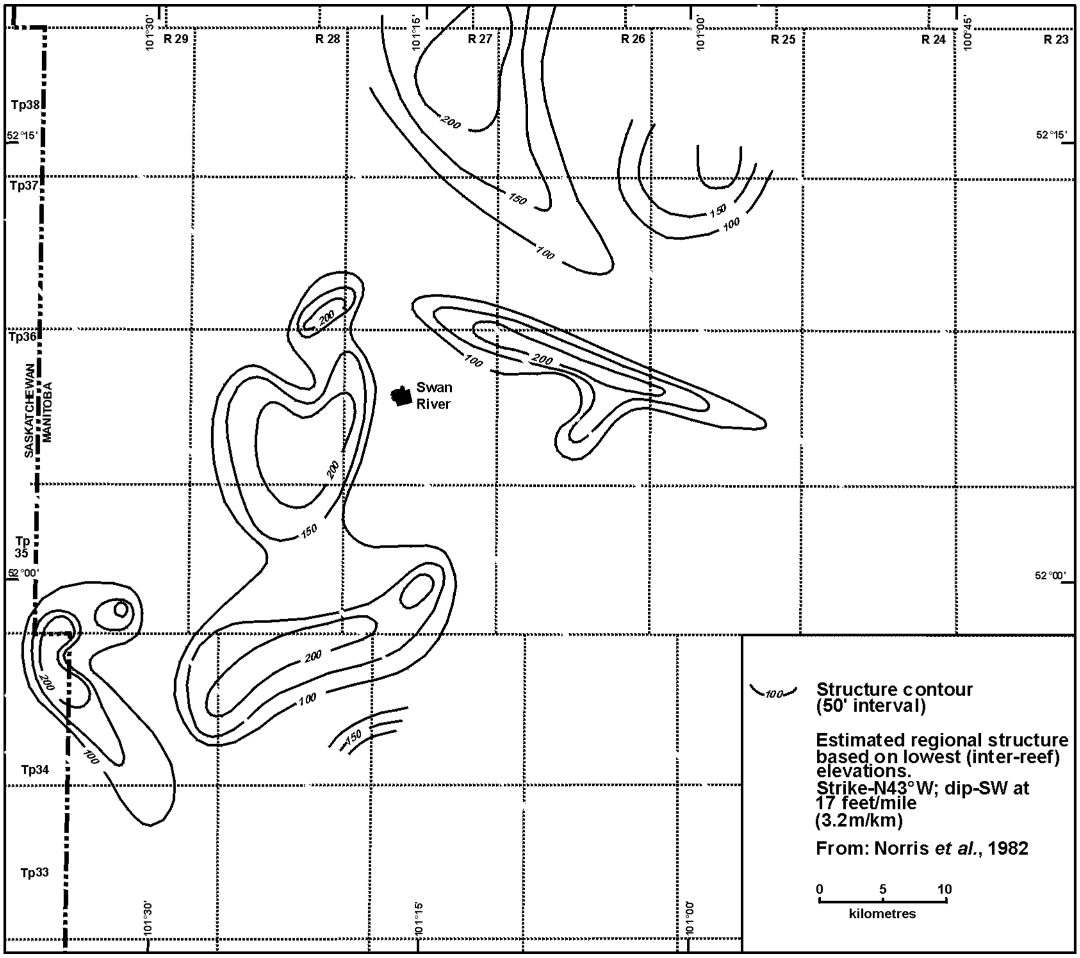


Figure 22: Winnipegosis Formation anomaly map, Swan River area (modified from Norford et al.*, 1982).*

largely a measure of seismic accuracy. This does not invalidate the concept of uniform reef thickness, but severely limits the suggestion that the cumulative plot reflects a flat-topped reef profile. In the case of the Swan River area data, however, most of the structure test holes were drilled on a systematic grid so data are unbiased, although even in the Swan River map area, infill drilling in the vicinity of the structural highs will have introduced some degree of bias.

Some Winnipegosis reefs appear to be small isolated "pinnacle-type" reefs, whereas others, in particular the larger reef complexes (*i.e.* Salt Point area), appear to be partly flat-topped, possibly atoll-like in configuration.

Effects of Reef Morphology on Outcrop Patterns

The above noted reef characteristics, as determined for the Swan River area, especially the uniformity in reef thickness, have had a pronounced effect on the Devonian outcrop patterns. Specifically, for the Dawson Bay area, where the regional dip is only 1.8 m/km, the 60 m of structural relief associated with reef development (and as reflected by subsequent salt solution) can give rise to an up dip or down dip shift of about 32 km in expected location of an outcrop unit. Because of the uniformity of reef thickness, two completely separate "outcrop belts" can be established for each unit; a structurally high, reef-supported belt, and a structurally low (normal) interreef outcrop belt. Thus, the interreef outcrop belt of the Souris River Formation, Point Wilkins Member ***(STOPS 26 – Tower Roadcut; 29 – Mafeking Quarry)*** coincides with the reef-supported outcrop belt of the lower member of the Dawson Bay Formation

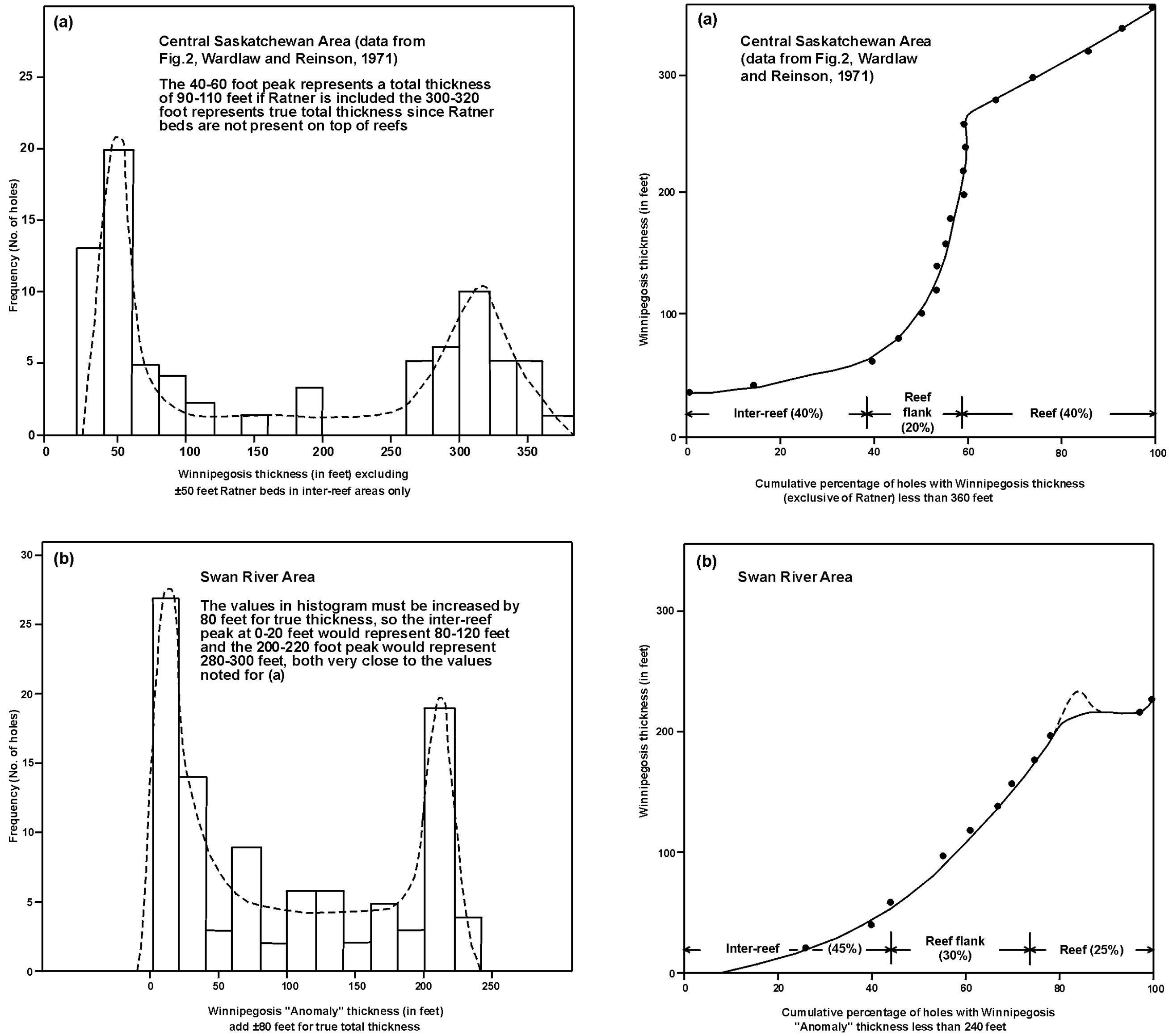


Figure 23: Winnipegosis Formation histograms: a) and b) histograms showing frequency of occurrence of Winnipegosis Formation thickness values; c) and d) cumulative histograms showing distribution thickness data for Winnipegosis Formation (modified from Norford et al.*, 1982).*

(STOPS 19, 20, 23, 25). Most Lower Dawson Bay occurrences along this reef-supported outcrop belt consist of structural/topographic domes, providing direct evidence of the underlying "pinnacle-type" reef. A few Lower Dawson Bay outcrops along this belt are seen to be flat-lying, indicating that they are underlain by flat-topped portions of a reef complex. Flat-lying Lower Dawson Bay outcrops in a "normal" or interreef setting, occur 32 km to the northeast, on Cameron and Pelican Bays (Lake Winnipegosis). Very few other stratigraphic intervals are represented within this "composite outcrop belt" indicating the relative scarcity of reef flank deposits or reefs other than "normal" thickness.

On the same basis, an outcrop belt of Upper Dawson Bay reef-supported structural-topographic domes ***(STOPS 20, 21, 23)*** occurs immediately down dip from the belt of Lower Dawson Bay domes, and coincident with the interreef outcrop belt of the upper part of the Point Wilkins Member. Similar outcrop patterns can be shown throughout the Devonian outcrop belt, but are not as well defined as in the Dawson Bay area because of the sparse well control.

An important inference can be made if the Winnipegosis reefs of the Dawson Bay area are of a uniform height. As the reefal outcrops exposed on the islands of Dawson Bay are traced to the northeast, up regional dip, the partially eroded reefal outcrops could expose sections that became progressively lower, stratigraphically, within the reefal succession. Thus, the Steeprock Bay Reef ***(STOP 19)*** is the most southwesterly, structurally lowest and stratigraphically highest reef occurrence; the outcropping strata represent beds at the apex of the reef, with essentially no post-reef erosion. In contrast, the Mason Island outcrop (not visited), the most up dip of the Winnipegosis reefs, probably represents a section relatively low stratigraphically within the reef, with an estimated 25-30 m of upper reefal beds having been removed by (Pleistocene?) erosion. Regional structural extrapolation would place the Mason Island section 25-30 m above the base of the reef (*i.e.* platform).

It should be noted that most reefal island outcrops show some evidence of domed bedding, suggesting that most or all of these occurrences represent central reef or reef core positions. The sequence of island outcrops could possibly be considered to represent the evolution of a reef core through time, from an earlier dominantly crinoid-*Amphipora* phase (Mason Island) through a dominantly coral-stromatoporoid phase (Simon Island) to a final algal-stromatolitic phase (possibly in part supratidal) at the Steeprock Bay Reef.

Detailed Reef Morphology, Outcrop Belt

Some larger-scale aspects of reef morphology have been outlined, based largely on the test hole data from the Swan River area. Within the Devonian outcrop belt, a reflection of some of these aspects of reef morphology can be seen, but only indirectly and incompletely. Most Winnipegosis reef outcrops are small isolated occurrences that provide almost no clue as to the original size, shape or extent of the reef. These reef characteristics can only be determined where the Winnipegosis surface is mirrored by structure in the overlying strata, which have been draped over uneroded Winnipegosis reefs as a result of salt solution and collapse. It will be seen that even where outcrops are relatively abundant, as in the Dawson Bay area, reef configuration is so complex and small scale that determination of reef morphology is almost impossible.

By far the best insight into local complexity of reef morphology is seen along the old Pelican Rapids Road where, for considerable distances, the road bed consists of an undulating bedding-plane surface of Lower Dawson Bay limestone that is believed to mirror precisely the shape of the underlying reef complex. This complex appears to extend for approximately 16 km along a northwesterly trend.

A second, northeasterly trending reef complex appears to underlie Salt Point and a third complex appears to trend northeast, coincident with the lower reaches of the Red Deer River and continuing through to The Bluff ***(STOP 22)***. Discrete dome-like structures along these trends indicate the presence of isolated pinnacle-type reefs (of a concordant height), but elsewhere on these trends, closely spaced undulating structures such as those seen on the old Pelican Rapids Road suggest a more or less continuous reef complex possibly formed by merging of smaller, closely spaced reefs. In a few places, these complexes appear to have developed into flat-topped "atoll-like" complexes, as shown by the flat-lying Dawson Bay strata seen at Salt Point.

The above comments apply primarily to the morphology of reefs occurring in the relatively deep basinal facies of the Dawson Bay area, where reefs probably attain a maximum complexity. In the shallower basin-flank areas (Town of

Winnipegosis area) and the basin margin areas (The Narrows area) the outcrop configuration generally is not as complex, but even in these latter areas the outcrop data are not sufficient to fully define the reefs or reef complexes.

Internal Structure of Reefs and Implications for Pattern of Reef Growth

The authors have noted the differences in reef configuration as the reefs are traced from the shelf edge (The Narrows area) to the deeper basinal areas of Dawson Bay (Fig. 19). The inference could be that the basic type of "reef" development changed from gentle bioclastic mounds in The Narrows area to possibly true bioconstructed "pinnacle-type" reefs in the Dawson Bay area. This scenario may be true, but limited data on internal structure of the reefs suggest a somewhat different hypothesis. The above scenario is based on the present gross reef configuration, the final shape immediately prior to burial by the Prairie Evaporite.

Almost certainly the final reef configuration differs from its configuration during earlier stages of reef development. At the Rosehill Reef, in The Narrows area ***(STOP 13)***, we see evidence for development of a massive "reef" core with flanking beds of well bedded reef flank detritus dipping off at about 20°, but the final configuration, as shown at ***STOP 14*** (The Narrows West Quarry), is that of a gentle mound with flank dips of only a few degrees. Interestingly, the early flank dips in The Narrows area are the same as the final reef configuration of some of the "pinnacle-type" reefs in the Dawson Bay area. The difference in final reef configuration as noted for the progression from The Narrows (shelf edge) to Dawson Bay (basin) (Fig. 19) may thus represent largely a measure of the degree of lateral reef growth or accretion in these areas, which in turn was controlled by the amount of subsidence. Late Winnipegosis (or early Prairie Evaporite) erosion may have affected final reef configuration.

From the above, one could infer that all Winnipegosis reefs were essentially the same in their initial stages of growth: all were probably sharply defined bioconstructed true reefs. The overall configuration of the reefs, however, changed through time as lateral accretion occurred, subduing the reef profile and eventually developing broad gentle bioclastic mounds in the basin margin areas. Lateral accretion would have had much less effect on the small isolated pinnacle reefs in the deeper basinal areas, because the supply of detritus was not sufficient to cause significant lateral accretion in deeper-water conditions. Subsidence during Upper Winnipegosis time may thus have been marked by a strong initial episode of subsidence (giving rise to sharply defined pinnacle-type bioconstructed reefs), followed by a prolonged period of relatively stable or gently subsiding conditions dominated by lateral accretion. This model accounts for the relatively steep flanking dips and bioconstructed core in the shallow basin margin setting at The Narrows.

Indirect evidence for sharply defined initial reef growth also can be noted for the more basinal areas in the vicinity of the Town of Winnipegosis and Dawson Bay. In proximal reef flank locations, a thin interbed of bituminous mudstone is present above the platform, but is buried beneath a thick sequence of reef flank carbonates. This seems to reflect initial deposition of relatively deep-water bituminous sediments very close to the shallow-water reef core, with subsequent burial of bituminous beds during lateral reef growth. In stratigraphic corehole S-5-75 (Figs. 24, 25) one such bituminous interbed occurs within 75 m of the centre of the reefal structure at Steeprock Bridge Dome ***(STOP 20)***. This provides some measure of the rapid differentiation into reef and interreef facies. Several other coreholes have intersected reef flank deposits, which include large reef-derived detrital blocks mixed with fine interreef bituminous beds. Such occurrences, combined with internal flanking dips of up to 45°, also suggest sharp reef/interreef differentiation and development of a true wave resistant, possibly bioconstructed reef framework, although such a framework is only rarely distinguishable in outcrop.

A diagrammatic basin profile is shown in Figure 19, based on the above model. It must be stressed that this profile is based on very limited internal structural data for the reefs.

Supplemental Notes Based on Recent Corehole Data

Steeprock Bridge Reef

One of the problems with interpretation of widely spaced oil well cores for the Manitoba-Saskatchewan portion of the

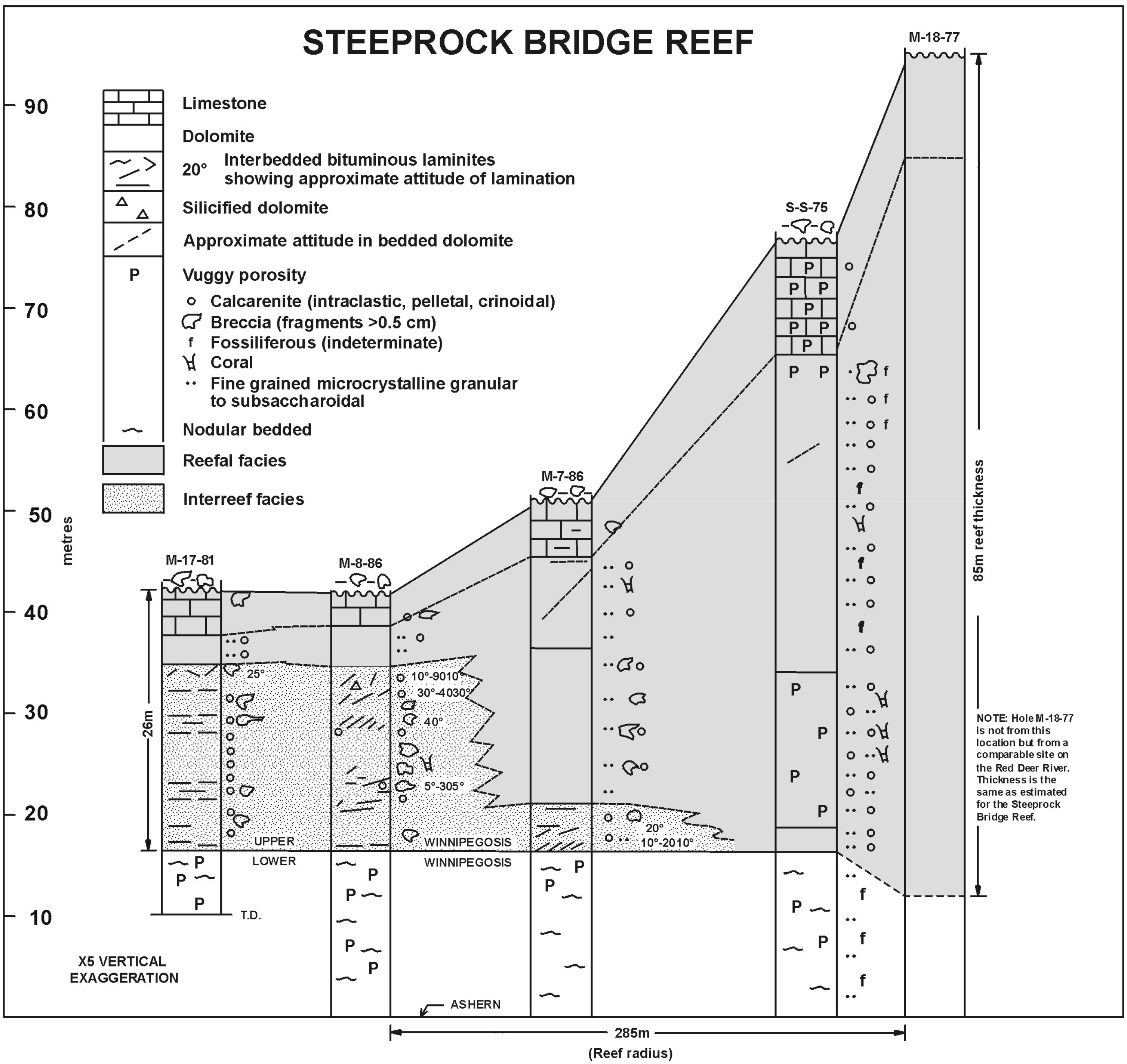


Figure 24: Exaggerated Devonian reef profile, Steeprock Bridge Dome.

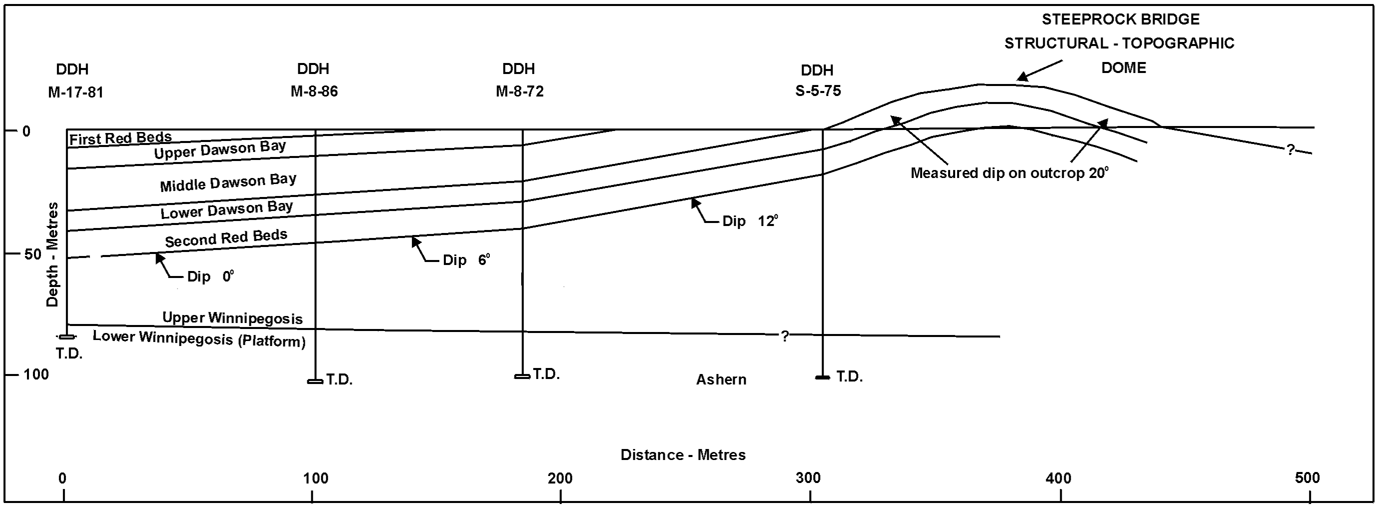


Figure 25: True-scale Devonian reef profile, Steeprock Bridge Dome.

Elk Point Basin is that the precise location of the core in relation to the reef is difficult or impossible to determine. At some localities in the Manitoba outcrop belt, however, the precise relation of the coreholes to the reef is known, and it is hoped that closely spaced corehole profiles may eventually define the precise reef-interreef relationships. Two coreholes were drilled in 1986 on the flank of the Steeprock Bridge Reef to determine reef flank structure and stratigraphy (***STOP 20***; McCabe, 1986a). These holes, along with two previously drilled coreholes provide a detailed four-hole profile on approximately 100 m spacing, on the western flank of the above reef. A summary profile is shown in Figures 24 and 25. To the author's knowledge (McCabe), this is the only detailed profile available for a Winnipegosis reef in the southern portion of the Elk Point Basin area. Although detailed bed-by-bed correlations are not possible, the general stratigraphic relationships strongly suggest that the laminated bituminous mudstones and interbedded fragmental carbonates (reef flank detritus) are equivalent to the active biogenic phase of reef growth.

The almost complete lack of varvitic laminites in the section suggests that laminites of this type are not formed during the biogenic phase of reef growth, and most probably are younger, possibly deposited during the earliest phases of Prairie Evaporite deposition.

Salt Point Reef Complex – Dawson Bay Area

Two coreholes (M-4-87 and M-5-87) were located within what is now believed to be a flat-topped reef complex or platform reef, which seems to underlie all of Salt Point. Initially, the occurrence of two small outcrops of flat-lying Lower Dawson Bay strata on Salt Point was the only indication of the presence of an underlying flat-topped Winnipegosis reef. However, ground access along forestry trails has permitted more detailed mapping as well as corehole drilling.

Preliminary mapping in 1987 showed that the Lower Dawson Bay caprock is relatively widespread in the Salt Point area, suggesting that all of Salt Point probably is underlain by a large reef complex. In addition, it was possible to trace outcrops at one of the massive reefal knobs on the north shore of Salt Point and show that the reefal knob passes laterally to flat-lying bedded dolomites.

In 1985, Inco drilled three shallow coreholes on Salt Point as part as a mineral exploration program. Unfortunately these holes did not penetrate the complete reefal sequence. As a follow up to the Inco drilling, two deeper stratigraphic test holes were drilled in 1987 by the Geological Services Branch to determine true structure, reefal thickness, and the nature of the lower part of the reef and platform beds. These holes also provide an accurate frame of reference for the Inco holes. Results show uniform regional structure, total Winnipegosis of 82-93 m, and Upper Winnipegosis reefal buildup of 65-75 m on a relatively uniform Lower Winnipegosis platform sequence approximately 17 m thick.

Lithology of the entire Upper Winnipegosis sequence in hole M-4-87 and M-5-87 consists of fragmental beds (algal, pelletal, oolitic, fossiliferous), apparently flat-lying, and passing almost imperceptibly into the underlying platform beds. Corals and large crinoids (in part intact stems to several centimetres in length) become common towards the base of the reefal sequence, suggesting a vertical zonation within the reef, possibly a shoaling-upward, catch-up type of reef development. Evidence is lacking for any black bituminous mudstones characteristic of the interreef facies, as described above for the reef-flank profile drilled in 1986. Thus the large platform-type reefs for the Dawson Bay area also appear to have developed form inception of reef growth and are not the result of merging of smaller, closely spaced pinnacles.

Except for Salt Point itself, there is little evidence in the Dawson Bay area of extensive flat-topped reefs; only a few small outcrops of flat-lying Lower Dawson Bay strata are indirectly indicative of underlying, locally flat-topped reefs. The abundance of small, closely spaced Lower Dawson Bay domes, in areas such as the old Pelican Rapids Road between Steeprock and Bell rivers, and to a lesser extent Salt Point itself, suggests that these domes represent small mounds on top of (or along the rim of) a more extensive platform-type reef. Despite this, many of the more isolated pinnacle-type reefs rising sharply from the platform, and surrounded by black bituminous laminites of the interreef facies.

The Salt Point reef complex may possibly shed some light on distribution of the thicker reefal mounds that appear to fringe the larger reef complexes. At Salt Point, these thicker mounds (shore cliffs, Fig. 18) occur along the northern shore of the point, where they rise at least 15-20 m above the main reef platform (interior lagoon?). This distribution possibly reflects preferential fringing reef development on the northern (windward?) flank of the complex.

The paleo-wind direction, and possible resultant asymmetry of reefs such as the Salt Point complex, may have relevance for the reef-flank profile of the Steeprock Bridge Reef (McCabe, 1986a). This profile is for the western flank of the reef, and the reef itself, which appears to be an isolated pinnacle, is situated within a broader complex of reefs; other reefs occur within 1 km to the east and northwest. The reef-flank profile noted above for the Steeprock Bridge Reef thus may represent a sheltered or leeward-flank profile. Outcrop data are not presently available for windward-flank deposits, and the present geographic distribution of reefs indicated that such data are not likely to be obtainable in the Dawson Bay area. Indirect evidence possibly can be seen in a thick reef-flank breccia sequence found in the Gulf Minitonas 13-10-36-26W1 corehole.

C) Winnipegosis Area - Paradise Beach Reef Complex

Winnipegosis strata in the vicinity of the south end of Lake Winnipegosis, including the Paradise Beach area (corehole M-3-87), are believed to comprise a basin-flank facies, midway between the shelf-edge facies of the Narrows area, and the deeper, central-basin portion of the outcrop belt in the Dawson Bay area. The Paradise Beach corehole (M-3-87) was located within what appears to be a large, flat-topped Winnipegosis reef complex (Norris *et al.*, 1982). The edge of the complex is marked by a relatively sharply defined series of elongate domal occurrences of Lower Dawson Bay strata draped over underlying Winnipegosis reefs that are up to 91.5 m thick. In contrast, the Winnipegosis in corehole M-3-87 (reef interior lagoon?) is only 74.2 m thick.

The central area of the Paradise Beach reef complex is evidenced, in outcrop, by the uniform widespread occurrence of flat-lying Upper Dawson Bay strata. Ground checking northwest of the drill site showed continuous and perfectly flat, uniform outcrop over an area at least 0.5 km^2. Regional mapping (Norris *et al.*, 1982) suggests that the reef complex (as expressed by the Upper Dawson Bay outcrop distribution) possibly extends over an area about 5 by 12 km, although outcrop control is insufficient to prove that this is one single continuous reef complex. Corehole M-3-87 is located close to the reef rimming the eastern edge of the complex, and appears to be situated on a gentle domal structure slightly higher topographically than the central, flat area described above. The strata in corehole M-3-87 thus may represent a "proximal lagoon facies" immediately within the fringing reef rim, containing a higher than average content of rim-derived detrital material.

Core for hole M-3-87 is generally massive, with traces of faint horizontal bedding, and consists largely of fossiliferous and fragmental material, totally dolomitized and with poorly preserved primary structures. The black bituminous mudstones characteristic of the interreef facies were not seen. This suggests that the entire area of the reef complex existed as a reef complex from inception, rather than forming as a result of merging of a series of smaller pinnacle-type reefs. Most reef-associated outcrops in the Winnipegosis area, however, are isolated domal occurrences. Because of insufficient data, it is still uncertain if these are discrete (pinnacle-type) reefs or merely small mounds sitting on top of larger platform-type reefs. To date, limited evidence suggests that these broad flat-topped platform reefs may be rimmed, at least on their northeastern (windward?) flanks, by fringing reefs, with a uniform flat-topped interior lagoon - essentially an atoll-type configuration.

The Narrows Area

Drilling in 1987 at the Gunnlaugson Farm Reef ***(Not visited - STOP 8a)*** determined the presence of a thin sequence of the same black bituminous mudstone characteristic of the interreef facies in the deeper basinal areas. This occurrence is very close to what is believed to be the edge of the fringing bank or shelf, and points to the possibility of the position of the shelf edge may have been determined by the extent of the anoxic bituminous mudstone facies rather than vice versa. The relatively uniform, sharply defined nature of the shelf/basin edge is rather surprising. The writer has suggested that the shelf edge marks the point where deposition could no longer keep pace with subsidence, but, on the basis of available data, the shelf edge is not marked by any kind of tectonic flexure or shelf/basin decoupling. Possibly, after an initial episode of relatively rapid subsidence and coincidental establishment of anoxic bottom-water conditions, the shelf limit would be determined by the limit of anoxic conditions, which could place a sharp and effective limit on the area of carbonate deposition (*i.e.* shelf edge).

This mechanism could also provide a basis for "reef" development. Shelf type conditions could be maintained in any basinal setting where bottom relief was sufficient to elevate the sea bottom above the anoxic level, and carbonate deposition would thereafter be limited to only these specific sites. Such deposits would give rise to "pinnacle-type" features, but such features would not necessarily be organically bound reefs. The resultant feature could more properly be designated as an anoxically contained "pinnacle mound", or "pinnacle platform" if the feature was more extensive. This mechanism could also explain the apparently uniform height and flat-topped configuration for such "reefs", as well as the very high percentage of detrital carbonate as shown by core from the Steeprock Bridge Reef profile (Figs. 24, 25) ***(Stop 20)***.

The establishment of anoxic bottom waters may thus have been an important, if not dominant factor in controlling reef/interreef deposition, rather than being merely the result of an episode of rapid subsidence, although both factors are undoubtedly important.

Post-Reef Erosion, Sedimentation, and Diagenesis

One final comment must be made regarding reef morphology as reflected in the structure of the overlying beds. It has been noted that such structure reflects only the final configuration of the Winnipegosis reef. This configuration probably reflects some degree of post-Winnipegosis/pre-Prairie Evaporite erosion, depending on the amount of sea level drop (evaporitic drawdown?) in the basin before and during Prairie Evaporite time. Some workers (Fuller and Porter, 1969a; 1969b) have suggested that the lower part of the Prairie Evaporite sequence was deposited under sabkha conditions, in which case virtually the entire Winnipegosis reef succession would have been subaerially exposed and subjected to erosion and vadose diagenesis. Evidence of limited drawdown and associated vadose diagenesis, including development of vadose pisolites, has been documented for the upper parts of Winnipegosis reefs (Maiklem, 1971; Wardlaw and Reinson, 1971).

With regard to vadose diagenesis, the reported occurrence of stratigraphically defined halos of anhydrite (Wardlaw and Reinson, 1971) surrounding some central basin reefs in Saskatchewan may be significant. Such halos must reflect locally reduced salinity and a local increase in the supply of Ca^{++} ions in solution in waters surrounding the reef. Inasmuch as the reefs are completely enclosed in salt deposits, there have been no "reduced restriction" in these areas. The entire basin sea was saturated and precipitating halite at the same time the anhydrite halos were being emplaced. One explanation for the locally reduced salinity and anhydrite precipitation would be a supply of fresh (or less saline) water and Ca^{++} ions from the reef itself. This could have been supplied by at least two mechanisms. The first would involve a regional flow of subsurface formation waters (normal marine?) through underlying strata, presumably the Winnipegosis platform beds, with discharge from these beds through overlying reefs subaerially exposed due to evaporitic drawdown. Introduction of this lower salinity water into the evaporite basin would give rise to a halo of reduced salinity and anhydrite precipitation, and the stratigraphic level of the anhydrite beds should reflect the approximate position of sea level, and show the extent of reef exposure above sea level. The input area for the subsurface flow system could have been the Presqu'ile Barrier reef complex in northwest Alberta, which is believed to have caused regional restriction of the Elk Point Basin. The driving force for the subsurface flow system could have been the difference in "sea level" between the oceanic source and the drawdown level established in the Elk Point Basin (Maiklem, 1971). Alternatively, Jodry (1969) suggested that compaction of carbonates, especially in interreef areas, resulted in expulsion of pore fluid, with the fluid discharging through the reefs and causing dolomitization of the reefs. Alternatively, this expelled connate water also could have given rise to the anhydrite halos around the reefs.

A third explanation for the anhydrite halos would be to have the reefs subaerially exposed (by evaporitic drawdown) so that the reef acted as a freshwater catchment for rainfall, which would percolate through the reef, pick up Ca^{+2} ions while subjecting the reef to vadose diagenesis, and then precipitate the Ca^{+2} as $CaSO_4$, on contact with the brines surrounding the reef. Brines saturated to the point of precipitation of NaCl are in effect supersaturated with respect to SO_4^{-2}, relative to normal sea water, so any Ca^{+2} ions introduced into such a saline environment would be precipitated immediately as $CaSO_4$, at the same time reducing the salinity in the area surrounding the reef to a point below the NaCl saturation level.

All of the above mechanisms could have been operative at the same time. The apparently considerable areal extent of the anhydrite halos around the reefs would require a relatively large flow of "fresher" water, which would probably have been supplied more easily by a regional subsurface flow system. This would have to be through the Elm Point platform and would seem to be a logical mechanism for dolomitization.

A diagenetic model has also been suggested for the formation of reef-flank anhydrites, with the anhydrite being formed by replacement of reef-flank dolomites (as has been proposed for the Keg River reefs of Alberta). However, Kendall (1975) notes that there is little evidence of a replacement origin for the anhydrites associated with the Winnipegosis reefs in the Saskatchewan portion of the Elk Point Basin. He also notes that the halite beds of the Lower Prairie Evaporite (Whitkow Member) interfinger with the reef flank anhydrites, which provides further evidence of a primary origin for the reef-flank anhydrites.

The foregoing discussion of the origin of the Winnipegosis reefs is based on limited data and hence is rather speculative. Nevertheless, in view of the sparsity of outcrops and lack of definitive reefal exposures, the authors thought is necessary to provide a framework in which the field trip participants might better evaluate the fragmentary features seen in outcrop.

Dawson Bay Formation

Dawson Bay strata comprise the second of the series of Devonian evaporite cycles. The formation is subdivided in the four units shown and described in Figure 18. These units show pronounced differences in resistance to erosion. The soft recessive shales of the Second Red Beds (***STOP 20***) and the Middle Dawson Bay Member almost never occur in outcrop, whereas outcrops of the hard resistant strata comprising the brachiopod biomicrite zone of the Lower Dawson Bay Member, and the Upper Dawson Bay Member (coral-stromatoporoid beds) are common. Because these resistant beds are thin, uniform, persistent and easily identified, precise stratigraphic correlation and structural data can be determined from these outcrops.

The interbedding of resistant and recessive units coupled with reef-related salt solution collapse structures, has had a pronounced affect on the Devonian outcrop pattern. The soft shales overlying the resistant beds have been removed by glacial erosion, exposing a smooth bedding-plane surface of the underlying resistant beds. These bedding surfaces conform to the underlying Winnipegosis reef configuration, with the result that throughout much of the outcrop belt, the exposed bedrock topography reflects the structure of the Winnipegosis reefs. This effect is quite spectacular along the old Pelican Rapids Road, in the Dawson Bay area (*e.g.* ***STOPS 22, 23)***, where the road-bed in many places is a bedding-plane surface and road undulations directly reflect the reef topography.

Because of differential erosion of Dawson Bay strata, outcrop occurrences are limited to the resistant beds; consequently, Dawson Bay outcrops along the outcrop belt do not show any appreciable lithologic variation. However, lithologic changes, determined from corehole drilling appear to reflect the presence of a distinct sub-basin during Dawson Bay time, more or less coincident with the southern portion of the outcrop belt, as indicated by isopach trends (Fig. 16). The middle calcareous shale member, although persistent and uniform throughout the outcrop belt, disappears rapidly to the west in the subsurface by thinning and facies change to relatively clean carbonates. This fossiliferous shaly unit is not recognizable in the Saskatchewan succession (Lane, 1959), and probably represents a deeper-water, lower-energy deposit directly related to the sub-basin.

Considerable thickening of the Lower Dawson Bay Member is evident to the south, along the outcrop belt. This is due primarily to thickening of the lower part of the unit, which consists largely of dark brown, partly laminated and partly bituminous microgranular dolomites and slightly argillaceous micritic limestones. The latter are seen in ***STOP 14***. These beds are also indicative of deposition under relatively deeper-water, low-energy, more basinal conditions in a depositional sub-basin. The interbedding of relatively deeper water deposits (lower part of Lower Dawson Bay and Middle Dawson Bay) with shallower water deposits (upper part of Lower Dawson Bay and Upper Dawson Bay) indicates a subdued cyclical pattern of deposition during Dawson Bay time.

Two beds of high-calcium limestone occur within the Dawson Bay Formation. One bed exists within the Lower Dawson Bay Member and consists of dolomite overlain by dolomitic limestone that grades to a high-calcium limestone. This “Dawson Bay lower limestone zone” consists of micrite and highly fossiliferous brachiopod biomicrite. The second unit of high-calcium limestone occurs within the “Dawson Bay upper limestone zone”. It is present within the upper Dawson Bay Member and consists of a coral-stromatoporoid biolithite and is an almost chemically pure limestone (Bannatyne, 1975).

Souris River Formation

Only the lower portion of the Souris River Formation outcrops in Manitoba. Two members have been defined (Figs. 17, 18), a lower Point Wilkins Member, and an upper Sagemace Member. Both units represent "evaporite cycles" comparable to the Dawson Bay cycle, and the Ashern-Winnipegosis-Prairie Evaporite cycle.

Point Wilkins Member

Outcrops of Souris River strata are sparse. The best exposure of the Point Wilkins Member are in the general area of "The Big Rock" (previously named Point Wilkins). The most accessible exposure is in the Mafeking Quarry of CBR Cement Ltd. ***(STOP 29)***. Until recently, the limestone was used to make cement in Regina. Point Wilkins strata consist of a basal red shale unit, the First Red Beds ***(STOP 27)***, overlain by a sequence of extremely fine grained, sparsely fossiliferous, micritic/intraclastic high-calcium limestones. Some admixture of argillaceous and silty material is evident in the Lower Point Wilkins. The very fine sediment grain size and the delicate nature of the contained fauna suggest deposition under quiet, low-energy conditions, with periodic disruption indicated by the intraclastic beds. These strata probably were deposited under relatively deep water conditions, with periodic storm effects.

In the southern part of the outcrop belt exposures are sparse, and lithologic data have been obtained primarily from core. The Point Wilkins beds thin markedly to the south, from over 50 m in the Dawson Bay area to about 35 m in the Winnipegosis area, although correlations based on shaly marker beds are somewhat uncertain. The apparent southward thinning of the Point Wilkins portion of the Souris River Formation, shown by the coreholes, is not evident in the regional isopach pattern for the total Souris River sequence (Fig. 17). Correlations and isopach variations are further complicated by extensive salt-collapse brecciation that occurs in many coreholes. Nevertheless, the lithology of the Point Wilkins strata appears to change markedly to the south, where stromatoporoidal calcarentic limestones become abundant, in places including coral biolithites and calcirudites. Local dolomitization is common but erratic, and lithofacies are quite variable. The lithology of this southerly area probably reflects a shallower-water, higher energy environment than for the Dawson Bay area. This is consistent with the pattern of regional basinward thickening to the north suggested for the Winnipegosis, but inconsistent with the pattern of local sub-basin development indicated for Dawson Bay strata. Additional corehole studies are required before the regional lithofacies and isopach patterns of the Point Wilkins strata can be established with any degree of confidence.

Sagemace Member

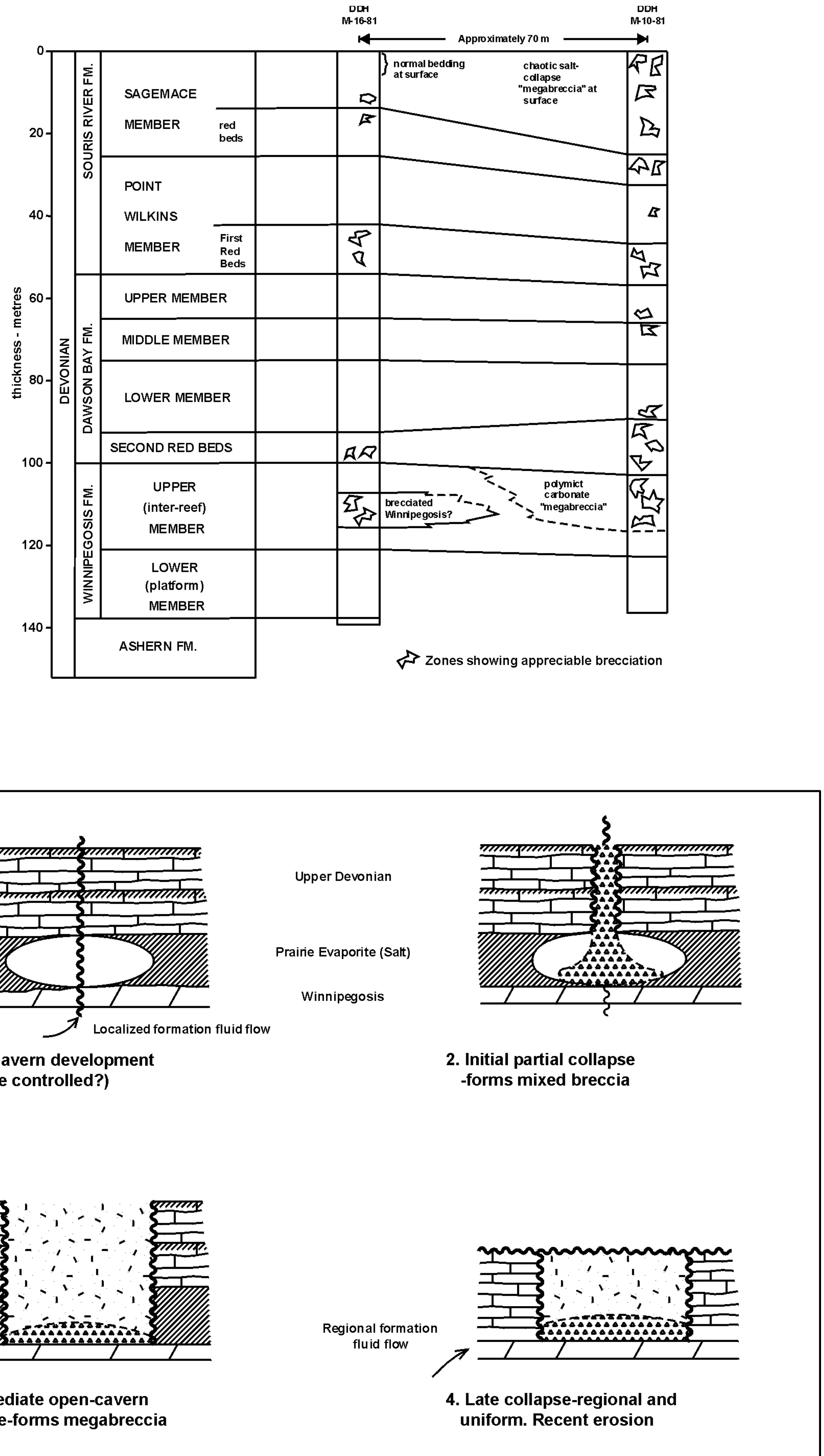
The Sagemace Member comprises the second full depositional cycle of the Souris River Formation (Fig. 18). It occurs only in that portion of the outcrop belt near the Town of Winnipegosis. The only significant exposures are the Pine River Road Quarry ***(STOP 16)***, the Winnipegosis Quarry ***(STOP 15)*** and possibly, the exposure at the Mossy River Bridge in the Town of Winnipegosis.

The lithology of the Sagemace Member is highly variable, but is generally similar to that of the Point Wilkins Member in the same area; the Sagemace beds also are brecciated to varying degrees. An excellent example of a salt-collapse plug is seen in the central part of the Winnipegosis Quarry ***(STOP 15)***; it is the result of several separate episodes or periods of salt collapse, as outlined diagrammatically in Figure 26.

Possible Basement Control of Devonian Tectonic Framework

The possible effect of the Churchill Superior Boundary Zone (CSBZ) on the Ordovician tectonic framework has been noted, and the same feature appears to have influenced the Devonian framework as well. The well defined north-trending edge of the Winnipegosis fringing bank (approximately Townships 1-15, Range 25WPM; Fig. 15), and the coincident limit of the Prairie Evaporite salt beds (Figs. 20) both fall on the projection of the boundary zone. Furthermore, the clusters of Winnipegosis reefs in the Swan River and Dawson Bay areas also occur along this boundary zone, although reefs are by no means limited to this zone. Also, the only known early salt collapse events, evidenced by local thickening of specific Devonian to Mississippian intervals, fall along the CSBZ.

A prominent isopach thinning (Fig. 16) of the Dawson Bay Formation occurs roughly along the boundary zone, and a well defined thickening is present to the east, centered on the southern portion of the outcrop belt. Local thickening of the Second Red Beds, probably related to very early salt solution, occurs along the southern part of the boundary zone. The area of thickened Dawson Bay and the associated lithofacies variations suggest that a sub-basin existed



Possible sequence of salt collapse events

Figure 26: Multiple-sequence salt collapse, Winnipegosis Quarry.

east of the CSBZ. As a result, the carbonate thickness of the Dawson Bay Formation along the southern part of the outcrop belt exceeds the maximum reported Dawson Bay carbonate thickness in the central part of the basin (Lane, 1959). This is further evidence for greater subsidence in that portion of the basin underlain by the Superior crustal block.

There is little evidence for basement control of the Souris River isopach (Fig. 17) although slight thickening is evident in the same area as for the Dawson Bay Formation.

PALEOTECTONIC FRAMEWORK: A FOOTNOTE

The authors have proposed a basic tectonic framework to explain a number of isopach anomalies that occur in the Paleozoic succession. This proposal possibly can be carried a step farther.

One of the principal post-Paleozoic anomalies relates to the regional configuration of the Pre-Jurassic erosion surface. If an east-west structural projection is drawn on the base of the Amaranth Evaporite (the lowest Mesozoic unit that approximates a time-stratigraphic marker) the structure is seen to be rather uniform as far east as the present erosional edge of the unit. However, when the elevations of known Jurassic outliers and embayments to the east (e.g. Lake St. Martin) are plotted, they are found to fall markedly below the regional projection, and indicate a pronounced structural flexure (perhaps even a structural reversal) at a point east of the main Mesozoic erosional edge. If these outliers are representative of regional Mesozoic structure, they indicate that the pre-Mesozoic erosion surface approximately paralleled present Paleozoic surface. Surprisingly, no evidence can be seen of any structural flexure in the Paleozoic sequence. Possibly the flexure is masked by the superimposed regional gradient, or possibly this represents a further case of structural flexing and later reversal related to the CSBZ.

If the suggested mechanism of differential uplift and subsidence related to the boundary zone is valid, and the pre-Mesozoic unconformity surface developed during a period because of maximum uplift, the regional structural profile on the unconformity surface should be "normal" only for the tectonically positive setting. Later reversal or normalization of the tectonic framework would have caused a negative deflection of the erosion surface, which is what seems to be evidenced by the structurally low Mesozoic outliers.

The authors hope that this review of the regional paleogeographic setting will provide a framework within which the rather complex lithofacies variations observed along the outcrop belts may be better understood by the field trip participants. The suggested basement tectonic control for some of the sedimentary/isopach anomalies in the Paleozoic succession is presented as a working hypothesis. It is by no means proven on the basis of presently available data, but deserves consideration in view of the pronounced effect it may have had on the development of the entire Paleozoic outcrop succession.

PART II:

GENERAL ROADLOG AND OUTCROP DESCRIPTIONS

DAY 1

ORDOVICIAN AND SILURIAN STRATIGRAPHY OF SOUTHERN MANITOBA

Day 1 will cover the Ordovician and Silurian stratigraphy of the southern part of the Manitoba outcrop belt. The complete Ordovician-Silurian succession of southern Manitoba ranges in thickness up to a maximum of approximately 430 m at the U.S. border. No more than approximately 50% of the total section is observable in outcrop because of the highly recessive character of some strata. The total thickness and lithology of the various units has been determined as a result of the Manitoba Geological Survey stratigraphic corehole drilling program. The complete stratigraphic succession and lithology are shown in Figure 11, including the stratigraphic position of all outcrop stops. The correlation profile shows the prominent southward thickening of the Lower Ordovician strata.

Proceed to junction of Highway 59 and Perimeter Highway 101. Continue northeast on Highway 59 for 18.5 km to Highway 44, turn east on cloverleaf. Continue for 11.5 km to exit for the Town of Garson. Drive through town and quarry entrance is located to your right. Quarry is active and permission is required to enter (Donna Gillis, Manager, 204-268-2934).

STOP 1: GILLIS QUARRY (Garson, MB). Selkirk Member, Red River Formation. Quarry exposes approximately 8 m of pale yellowish brown, dolomite mottled, burrowed, fossiliferous micrite. Beds are quarried for ornamental dimension stone – the well known "Tyndall Stone" – which is noted for its well-preserved fauna of large cephalopods, gastropods, corals, etc.

There is no blasting in this quarry and all stone is cut out by saws. A waste pile is available to hunt for fossils.

References: Corehole M-3-69 (Garson Quarry, 15-3-13-6EPM)

Return to Highway 44. Proceed west for 18 km to intersection with Highway 9 (cross the Red River at Lockport), and turn north for 3 km to intersection with Highway 67. To your right is Lower Fort Garry, a Hudson Bay Company post with the stone coming from the banks of the Red River (Red River Formation). At Highway 67 turn west for 14 km to entrance of farmyard (third house from the corner, #1158). Quarry is abandoned, but permission to enter is required (E. Johnson, 204-482-7316). Note wildlife sanctuary at Oak Hammock Marsh.

STOP 2 - MOWATT FARM QUARRY. Type section of the Fort Garry Member, Red River Formation. The upper 2.5 m consists of pale yellowish brown, mottled, massive, finely crystalline, dense to slightly granular cherty dolomite. This is underlain by 5 m of medium- to thin-bedded sublithographic dolomite, mostly pale greyish buff, in part showing fine, irregular grey red lamination, and pronounced oxidation/reduction effects. A prominent red shaly bed occurs 0.40 m below the top of this unit, and considerable minor structural undulation and associated micro-faulting and brecciation is evident above the shaly zone. This results from evaporite solution at this horizon (Lake Alma Anhydrite of Kendall, 1976). A second, 0.20 m thick reddish argillaceous zone occurs near the base of the section. The exposed quarry beds comprise the middle portion of the Fort Garry Member (Fig. 12). See thin section descriptions in Appendix 1. See outcrop description in Appendix 2.

References: Coreholes M-1-70 (Mowatt Quarry, 10-27-13-3EPM); M-3-74 (Headingly, 1-21-11-1EPM); McCabe and Bannatyne (1970); Cowan (1971); Wallace (1979); Elias *et al.*, (1988); Noiseux (1992); (Betcher *et al.*, 1993).

Return to Highway 67 and proceed west for 10.8 km to Highway 7. Turn south for 5.9 km to the first exit for the Town of Stony Mountain. Proceed 1.3 km to quarry entrance on east side. Quarry is abandoned, but permission is required for large groups from the City of Winnipeg.

STOP 3: STONY MOUNTAIN QUARRY (East Quarry). Type section of the Stony Mountain Formation (Fig. 12). This quarry was a source of aggregate material for the City of Winnipeg; usable material is largely depleted. The "mountain" forms an isolated outlier of Stony Mountain Formation approximately 2 km east of the main outcrop belt (Gunton Escarpment).

The cap rock of the "mountain" consists of 7 m of pale yellow brown, faintly mottled, very finely crystalline, nodular dolomite of the Gunton Member; the upper 4 m of the Gunton has been eroded. This is underlain by 6.5 m of dusky yellow to grey orange and red brown argillaceous dolomite of the Penitentiary Member, showing abundant moldic fossil solution porosity; clay content is 12-25%, increasing downward. These beds form the main quarry floor. A deeper pit exposes approximately 2 m of Gunn Member, consisting of interbedded light grey, hard fossiliferous limestone (packstone), and soft highly argillaceous, calcareous dolomite containing an abundant, well-preserved fauna (brachiopods, horn corals, crinoid fragments, bryozoa, etc.).

The nearby Stony Mountain Federal Penitentiary consists of blocks from the Gunton Member which were quarried locally from penitentiary quarries (off limits to the public). The penitentiary hires a full-time stonemason to do the required repairs on the structure.

References: Corehole M-2-69 (Stony Mountain Quarry, 2-14-13-2EPM); Baillie (1952); Smith (1963); Wallace (1979).

Return to Highway 7. Proceed north for 5.9 km to intersection with Highway 67, and turn west for 4.8 km to Town of Stonewall. At 4th Street East turn north for 0.2 km to entrance to Quarry Park. The quarry is abandoned and completely rehabilitated. Permission to enter is required.

STOP 4: STONEWALL QUARRY PARK. Type section of the Lower Stonewall Formation and Williams Member. Formerly operated by Winnipeg Supply and Fuel Ltd. as a source of dolomite for high-magnesium lime. Note abandoned lime kilns. Section comprises of an upper unit of up to 6.6 m of pale yellowish grey to yellowish brown, faintly mottled medium bedded dolomite; very finely crystalline, conglomeratic in some layers and variably fossiliferous; the basal 0.3 m bed is arenaceous. These strata comprise the lower half, approximately, of the Stonewall Formation.

Poorly exposed in a pit near the north edge of the quarry is a 1.3 m section of interbedded grey to reddish brown, arenaceous, fossiliferous, dolomitic shale which comprise the type section of the Williams Member of the Stonewall Formation. The bottom 3.0 m of the member are not exposed. Insoluble content ranges from 30 to 33 percent. The Williams Member represents the first of a series of basinwide sandy, argillaceous, para-time-stratigraphic marker horizons noted by Porter and Fuller (1959).

References: Coreholes M-1-69 (Stonewall Quarry, 13-30-13-2EPM); M-10-79 (Warren, 13-31-13-1WPM); Baillie (1951a); Stearn (1956); Cowan (1971).

Return to junction of Highway 67 and Provincial Road 236. Continue north on Provincial Road 236 for 1.6 km to intersection of first section road. Turn right (east) for 3.2 km. This is not a stop, but a drive through Winnipeg's present source of crushed stone (Gunton Member, Stony Mountain Formation). Approximately $5,000,000 of stone is extracted from this area yearly.

Continue north on Highway 7, turn left on Highway 17 to Inwood. Road turns north past Inwood. Continue north for 1.9 km to access trail east of quarry.

STOP 5: INWOOD QUARRY. Moose Lake Formation, Interlake Group. The quarry is abandoned and owned by the Municipality. Exposes 4.0 m of dolomites referred to Stearn (1956) as the type section of the lower member of the Inwood Formation (Interlake Group). The basal 2.5 m consists of relatively uniform micro-crystalline, sublithographic dolomite, in places showing abundant spheroidal raindrop-like impressions of uncertain origin. The upper 1.5 m consists of irregular stromatolitic mounds to 1.0 m, overlain by intraclastic breccia and passing laterally into fine-crystalline, bedded dolomite.

Recent corehole data show that the "Inwood" strata are stratigraphically higher than indicated by Stearn, and are be equivalent to the Moose Lake Formation, as defined in the area north of Grand Rapids. The observed lithologies are typical of much of the Interlake succession and represent deposition under shallow water, slightly restricted, stable shelf conditions.

References: Corehole M-4-69 (Inwood Quarry, 4-11-18-1WPM); M-2-80 (Oak Point Quarry, 4-18-18-4WPM); Stearn (1956); Cowan (1971).

Return to P.R. 229 and continue north and west to junction of Highway 6. Turn north on Highway 6 to inter-section with P.R. 419 just north of the town of Lundar. Proceed east on P.R. 419 for 2.3 km to quarries, north and south sides of road

STOP 6: LUNDAR QUARRIES. Silurian, Interlake Group, Cedar Lake Formation. Two shallow, water-filled aggregate quarries north of the road (abandoned and owned by the Municipality), and one south of the road (inactive). Accessibility may be poor because of high water level. The upper 2.0 m of the section is a highly organic biolithite, composed largely of corals and stromatoporoids, notably *Clathrodictyon cystosum*. These beds are underlain by 3.0 m of thin bedded, pale yellow brown, finely crystalline, sparsely fossiliferous dolomite showing gentle structural undulation; patches and lenses of red shale have been noted.

The quarries are located on a broad, gentle bedrock-floored topographic ridge which Baillie (1951a) suggested could represent the expression of a buried Silurian reef. The vertical and lateral extent of the highly organic beds cannot, however, be determined. The location is close to the contact with the Devonian Ashern Formation, and the red shaly component may represent infill related to the major pre-Ashern unconformity.

References: Corehole M-8-69 (Lundar Quarry, 3-7-20-4WPM); Baillie (1951a); Stearn (1956); King (1964); Cowan (1971).

Continue north to Deerhorn on Highway 6 and turn west for 1 km to quarry.

STOP 7: DEERHORN QUARRY. Silurian, Interlake Group, Cedar Lake Formation. This water-filled quarry exposes 3 m of buff yellow, fossiliferous reefal dolomite. Possible stromatoporoid fragments present.

References: Corehole M-12-91 (Deerhorn Quarry, 9-3-21-5WPM)

DEVONIAN OF THE NARROWS AREA (SHELF EDGE FACIES)

The following stops include portions of all Devonian stratigraphic units known to occur along the 400 km of the Manitoba outcrop belt, although exposures are widely scattered and generally incomplete. See Figure 27 for outcrop stops.

Only the lower portion of the Devonian succession is exposed in outcrop in southern Manitoba, that is, the section ranging from Middle Devonian (upper Eifelian) to early Upper Devonian (early Frasnian). The remainder of the Devonian succession (upper Frasnian and Famennian) is known only from the subsurface, because of the overstep and burial by the thick sequence of Mesozoic clastics at the Paleozoic unconformity (Fig. 2). Lower Devonian (Emsian) strata are not present in southwestern Manitoba, and were not deposited in the Williston Basin area. The earliest Devonian strata in southwestern Manitoba, the Ashern Formation of the Elk Point Group, probably are Middle Devonian in age (upper Eifelian). The Eifelian/Givetian boundary is believed to occur within the Winnipegosis Formation, possibly near the top of the Lower Winnipegosis (Elm Point) platform beds. The boundary between Middle and Upper Devonian (Givetian/Frasnian) is believed to occur within the Souris River Formation, possibly near the top of the lower argillaceous unit of the Point Wilkins Member (Norris et al., 1982).

Faunal lists for the various stratigraphic units are not included in this guide, but comprehensive listings for all formations and most outcrops are included in Norris et al. (1982). Earlier faunal lists are presented in Baillie (1951b; 1953) and in McCammon (1960).

For a detailed itinerary with descriptions of all accessible Devonian outcrops, including boat accessible reefal outcrops on Dawson Bay (Lake Winnipegosis), the reader is referred to the International Devonian Symposium Guidebook (McCabe, 1987).

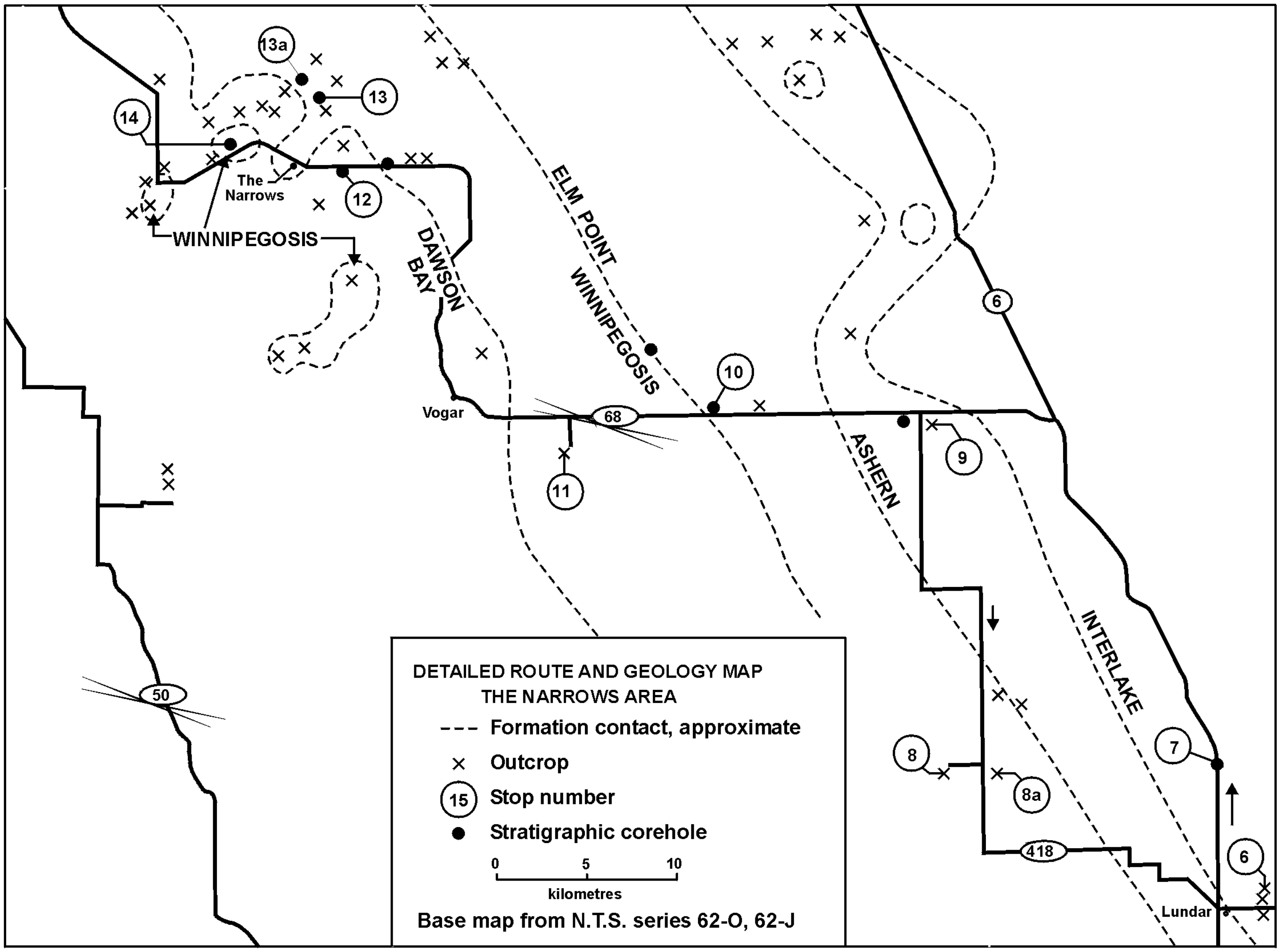


Figure 27: Detailed route and geologic map, The Narrows area.

Note: Winnipegosis Reef Lithofacies:

"It should be noted that the lithofacies described by Baillie (1951a) for each individual build-up in outcrop were from one point only because of limited accessibility, landing sites and drift cover. Probably each build-up would include much more lithofacies diversity if it were studied more intensively. The lithofacies association in a composite build-up could include colonial corals of several types, amphipora concentrations, stromatoporoids, algal stromatolites with fenestral porosity, dolomite muds with large brachiopods, algal-mat organic-rich laminites and calcarenites; all of these lithofacies were observed in at least one outcrop. In several outcrops, in the upper part, a cavernous horizon with pisolites and "cave pearls" separated the more massive "reef" rock from a more bedded limestone, presumably a "vadose" phenomenon. A paleoecological pattern may be present in these isolated build-ups as in several places certain lithofacies such as the colonial coral groupings and the algal stromatolites seemed to be confined to certain parts of the build-up. Although erosion has removed much of the flanking and marginal parts of the region, it offers an excellent, easily accessible area for a study of these outcrops that have in many respects markedly similar aspects to Middle Devonian isolated reefs at Rainbow, Zama and the occurrences northeast of Senex Creek reef in Alberta."

"A.D. Baillie"

CSPG Field Guidebook (McCabe, 1986)

Continue west to P.R. 418. Turn right (north) to an east-west section road (just north of small abandoned church). Turn west on section road for 1.7 km to inactive quarry, south side of road.

STOP 8: LILY BAY QUARRY. Devonian Elm Point Formation (= Lower Member, Winnipegosis Formation). Now abandoned, the quarry previously supplied high-calcium (but not high quality) limestone to the Cement LaFarge cement plant in Winnipeg. The quarry exposes 4.5 m of limestone. The upper 3 m is prominently mottled, yellow grey to yellow brown, with the brownish granular patches strongly dolomitized. Intensity of mottling and degree of dolomitization decrease downward. The limestone is a hard, dense, fossiliferous micrite. Note the thin 8-10 cm interbed of undolomitized conglomeratic limestone. Approximately 1.5 m above the base of the exposed section, a fairly sharp change occurs, to a faintly mottled, slightly reddish grey, almost non-dolomitic limestone. Brachiopods are abundant at the top of this unit.

A corehole immediately northeast of the quarry (M-2-70) intersected a total of 12.8 m of Elm Point limestone above the Ashern Formation. These limestones showed an appreciably lower overall degree of dolomitization. The beds in the Lily Bay Quarry are thus seen to represent and intermediate stage of dolomitization of the Lower Winnipegosis platform beds, part way between the almost pure high-calcium limestone quarried at Steep Rock (Bannatyne, 1975), and the almost totally dolomitized strata seen at the Overton Quarry ***(STOP 10)***.

This quarry is now rehabilitated and the face is not exposed. See Lily Bay East Quarry (below) (8a).

References: Corehole M-2-70 (1-5-21-6W1); Bannatyne (1975).

Another quarry, Lily Bay East Quarry, is present 1.9 km southeast of intersection with P.R. 418. It is an abandoned aggregate quarry exposes the contact between the Elm Point and Ashern formations. This quarry (and another quarry across the road) is water-filled. This is an optional stop.

Return to P.R. 418 and continue north for 10 km to P.R. 417/418. Turn west (left) and continue for 3.3 km to intersection of P.R. 418 (Clydebank Corner). Turn north (right) and continue 9.4 km due north onto a section road. Large, fenced-in quarry is present on the east side.

STOP 9: OATFIELD QUARRY. Silurian-Devonian boundary. The quarry exposes 1.5 m of red argillaceous dolomite or dolomitic shale of the basal Devonian Ashern Formation, resting with sharp but uniform unconformity on 2 m of massive to faintly thin bedded, hard, dense, finely crystalline dolomite of the Silurian Interlake Group. The dolomite appears highly organic, but the texture has been obscured by dolomitization. Only slight gentle relief is evident on the unconformity surface, a maximum of about 1 m for the entire quarry area. A thin zone of basal dolomite breccia can be seen in places, and unusually large (1-2 cm) clay-infilled vermiform solution channels cut the underlying dolomite. The red Ashern colouration has been reduced locally to pale greenish grey along fractures, and where the quarry face consists largely of bleached fracture faces, the unconformity is largely obscured.

The unconformity spans the stratigraphic interval from Middle Silurian to Middle Devonian, and as much as several hundred metres of Upper Silurian strata may have been eroded.

Continue north on section road for 0.6 km and turn west (left) on P.R. 68. Proceed for 12 km to access trail to abandoned quarry north of the road.

End of Day 1 - Overnight at Lake Manitoba Narrows Lodge

DAY 2

DEVONIAN STRATIGRAPHY OF SOUTHERN MANITOBA, THE NARROWS AREA

Continue 40 km east on Highway 68 to trail to the north (left). Small, abandoned quarry is present.

STOP 10: OVERTON QUARRY. Winnipegosis Formation (Lower Member, platform facies). Quarry exposes approximately 5 m of dolomite, medium light yellowish brown, mottled, finely crystalline, slightly granular with large yellow, coarsely granular patches as well as small darker grey mottles (burrows?) and faint relict, fine calcarenite texture. It is thick bedded to massive in upper part, becoming thin bedded towards the base. A large sand-filled channel occurs in the northeast corner, overlain by till, and several other lenses and pockets of sandy shaly material have been noted. This material possibly represents Cretaceous infill of incipient karst solution features.

Corehole M-8-81 at this location intersected 13.3 m of vuggy granular dolomites underlain by 7.6 m of dolomitic limestone grading downward to dolomite. Regional data indicate that the entire section is Lower Winnipegosis and represents a dolomitized facies of the Elm Point Formation. (Dolomitization possibly reflects proximity to a reef site that is now eroded).

References: Corehole M-8-81 (4-6-23-7W1).

Return to P.R. 68 and continue west for 8 km to intersection with access road to south (just east of first Nation Reserve boundary). Proceed for 1.9 km to access trail (to quarry west of road).

STOP 11: DOG LAKE QUARRY. Winnipegosis Formation (Upper Member?). Quarry exposes approximately 3 m of medium- to thin-bedded, very finely crystalline, sparsely fossiliferous dolomite. The Dog Lake Quarry Reef, like the Gunnlaugson Reef, differs from the predominantly dome-like reefs in the area, exposing flat-lying to irregularly undulating beds with no obvious reef buildups. Initially the writer believed that this outcrop represented the more deeply eroded portion of a larger platform-type reef such as Gunnlaugson. Corehole M-1-87 yielded inconclusive results, showing only largely textureless, apparently flat-bedded dolomite with no obvious break between platform and reef. The total Lower Winnipegosis section, however, is 27 m thick, which is thicker that the Lower Winnipegosis platform beds at Rosehill Reef (20 m) and Gunnlaugson Reef (23.2 m), indicating that the upper few metres of the Dog Lake sequence probably are Upper Winnipegosis. A Lower Dawson Bay limestone outcrop, which occurs almost on strike, 6.4 km to the northwest, also indicates "reefal" setting for the Dog Lake beds.

Lower water levels in late summer expose considerable irregularity in structure, with what appears to be minor angular unconformity in one place. This unusual internal structure suggests that the Upper Winnipegosis strata at Dog Lake may not represent reefal strata, but rather may represent Upper Winnipegosis of the shelf facies, where distinct reef-interreef differentiation has not occurred (***i.e.*** beyond the limit of anoxic basin conditions). More detailed examination of the quarry and surrounding area is required to clarify the exact stratigraphic relationship. Figure 32 shows a generalized cross section from the Gunnlaugson Reef to Rosehill to Dog Lake.

References: M-1-87 (16-30-22-8W1); McCabe (1987).

Continue west on Highway 68 for 25 km. Stop just before intersection with Richards Point Road (north).

STOP 12: NARROWS DITCH OUTCROP. Dawson Bay Formation (Lower Member). Ditch pavement exposes a flat bedding-plane surface of greyish red to yellowish brown microcrystalline, dense, almost lithographic limestone, thin bedded and fossiliferous in some beds. Note particularly the delicately frilled brachiopod *Artypa*. These beds were not present in the Lower Dawson Bay section seen in the Dawson Bay area. In this southern area, highly fossiliferous brachiopod biomicrites, the same as seen in the north, are underlain by sparsely fossiliferous micrites, as seen at this stop, which are in turn underlain by brown, partly laminated fine-grained dolomites. This added section results in southward thickening of Lower Dawson Bay strata from about 10 m in the northern area to 20 m in the south.

At this location, Dawson Bay strata are preserved in a structurally low interreef setting, estimated Winnipegosis thickness is only about 35 m.

References: Corehole M-9-69; Baillie (1951a); Norris *at al.* (1982).

Turn north on Richards Point Road for 4.2 km, then west for 1.0 km to abandoned lime kiln adjacent to a small abandoned, overgrown quarry.

STOP 13: ROSEHILL QUARRY. Winnipegosis Formation (Upper Member, reefal facies). A small quarry, approximately 2 m deep, immediately south of road exposes medium bedded reef-flank dolomites dipping north at approximately 20°. About 150 m to the south, just east of the cleared section line, a small pit exposes a massive, fossiliferous dolomite probably representing a "reef core". A corehole at the quarry site (M-1-72) intersected 27 m of Upper Winnipegosis dolomite underlain by 20 m of partly dolomitized Elm Point limestone (*i.e.* Lower Winnipegosis platform beds). Partial dolomitization of the Elm Point beds probably may reflect proximity to the Winnipegosis reef core. See Figure 32 for reef cross section.

This is the only known outcrop exposure showing well developed internal reef flank structure. Another small quarry just east of the Narrows causeway at one time provided an even better example of internal reef structure, showing beds dipping off at 20° on both the western and southern flanks of a relatively massive core. This quarry unfortunately has been partially infilled, and the bedding almost entirely obscured, but is nevertheless provides evidence that the reef flank bedding seen at Rosehill is probably the normal reef structure in this area.

The occurrence of such relatively steep internal dips within the gentle mound-like "reefs" in the Narrows area seems highly significant. Such bedding seems to suggest that even in this relatively shallow basin-margin environment, the early stages of reef growth were truly biohermal. These bioherms subsequently evolved by lateral reef growth or accretion into the broad gentle mounds we see today.

Continue west on the Richards Point Road for about 2 km to the Gunnlaugson Farm. This is private land, the road is gated, and permission to enter is required.

OPTIONAL STOP (13a): GUNNLAUGSON FARM REEF. Winnipegosis Formation (Upper Member, reefal facies). *This site, in the past, has been difficult to access due the locked gate and no direct phone line to the farm. If the gate is open, drive through and try to get permission form the owner*.

Several small bedrock mounds are exposed in the pasture, and others occur in the nearby woods. Baillie (1951a; 1951b) reports that a total of about 20 such mounds occur in the area, some up to 10 m long and one metre high. The mounds appear to trend northeasterly at approximately 25° roughly parallel to the postulated depositional trends in this area (Fig. 19). They are believed to be algal in origin, and stromatolitic structures are evident, particularly in the middle mound. The small algal mounds scattered around the Gunnlaugson Farm represent minor features within the larger mound or reefal structure, reflected topographically by the Gunnlaugson peninsula. The "Gunnlaugson Reef" appears to represent a separate reefal feature, as does the Rosehill Reef ***(STOP 13)***, the Narrows East Reef (not visited), and the Narrows West Reef ***(STOP 14)***.

The relative stratigraphic position of the Gunnlaugson Reef beds is uncertain. The structurally up dip position of the reef would seem to indicate that the algal dolomites of the Gunnlaugson Reef should occur stratigraphically below the biostromal beds of the Narrows West Reef (assuming uniform reef thickness). However, the occurrences of algal beds at the top of the Narrows West Reef section suggests that the algal dolomites could be uppermost Winnipegosis. This would seem to fit the model noted for the Dawson Bay area. The dipping reef flank beds at the Rosehill Quarry appear to be older than either the Gunnlaugson or Narrows West Quarry beds.

Core hole drilling in 1987, including a corehole on the edge of the Gunnlaugson Farm Reef, has provided new and somewhat unexpected data. The writer now believes that the Gunnlaugson Reef represents a much larger, flat-topped reef, distinctly different from the pinnacle-type reefs such as Rosehill.

Corehole M-2-87 was located beside one of the small algal mounds near the western edge of the peninsula. Most of the Upper Winnipegosis dolomite (19 m) consists of fragmental to micritic dolomites. Several zones of relict limestones in the lower part of the sequence show a well preserved texture of fossiliferous wackestone with sparse to abundant fossil debris (brachiopod, crinoid, gastropod). This lithology is almost identical to the underlying platform beds (Elm Point Formation). Preservation of such relict limestone in the dolomites of an Upper Winnipegosis reef complex is uncommon in the Manitoba outcrop belt.

The most unexpected feature is the occurrence at the base of the Upper Winnipegosis of a 2 m section containing well developed, black, laminated bituminous mudstone intervals (= Ratner Member) interbedded with fossil fragmental limestones and dolomite; bedding is subhorizontal. Lithologically these bituminous beds appear identical to the bituminous interreef facies developed in the deeper portions of the basin, in the Winnipegosis and Dawson Bay areas.

This lithology had not previously been known to occur in this area, and the writer had assumed that shallower water conditions towards the edge of the basin would have raised the depositional interface above the anoxic level and precluded preservation of the bituminous material. Apparently the anoxic level within the Elk Point Basin must have been rather high (*i.e.* surface oxygenated zone relatively shallow). Total thickness of Upper Winnipegosis reef buildups in this area is no more that about 35 m (a minimum water depth) so depth of the anoxic zone must have been less than this, possibly only 20-25 m.

Three additional coreholes were drilled in 1990 at Gunnlaugson Farm as a follow-up to the 1987 drilling (McCabe, 1987a). The limestone were variably fossiliferous with brachiopod, crinoid and gastropod debris. Towards the middle of the Winnipegosis Formation, 2 to 8 m thick, black bituminous, laminated, argillaceous dolomitic limestones were intersected that probably represent the Ratner Member.

References: Coreholes M-2-87 (12-35-24-10W1); M-2-90 (6-35-24-10W1); M-3-90 (3-35-24-10W1); M-4-90 (12-35-24-10W1); McCabe (1987); Teare (1990); Bezys (1990).

Return to P.R. 68 and proceed west past The Narrows. Proceed 1.6 km west of the Narrows causeway on P.R. 68 to small quarry on north side of highway.

STOP 14: NARROWS WEST QUARRY. Winnipegosis Quarry (Upper Member, reefal facies). The quarry is located on top of a broad gentle topographic dome, exposes approximately 4 m of medium- to thick-bedded dolomite showing gentle structural undulation that probably reflects primary depositional topography. The lower beds are fine grained, sparsely fossiliferous, and pass upwards to increasingly fossiliferous orange-brown wackestone, with several interbeds of packstone dominated by molds of the large brachiopod *Stringocephalus*, and showing excellent fossil solution porosity. The section is capped in places by fine grained, finely laminated algal (?) dolomite showing fenestral porosity. Detailed mapping of the quarry by Davison (1981) showed that significant lateral and vertical lithofacies changes occur within the bedding-defined units. Skeletal wackestones and boundstones are associated with the structurally higher locations, and mudstones are common in the depressions, which may also contain lenses of packstone. The abundant fauna include coral (*Disphyllum, Favosites, Coenites, Mesophyllum*), stromatoporoids (***Amphipora, Actinostroma, Stromatoporella***), brachiopods (***Stringocephalus***), molluscs, cephalopods, bryozoa and echinoids.

The broad topographic rise on which the quarry is located probably reflects a structural/topographic dome similar to those seen in the Dawson Bay and Winnipegosis areas, but with a much more gentle configuration. Poorly exposed ditch outcrops to the southwest suggests gentle dip in that direction (less than 5°). Flanking Lower Dawson Bay strata can be seen to the north, on the lakeshore (Fig. 32), and also to the southwest. Coreholes at the site failed to reach the base of the Devonian because of drilling problems associated with sand-filled caves, but regional data indicate a total Winnipegosis thickness of only about 30-35 m. This broad gentle reef or mound apparently occupies a shelf-edge position, a short distance northwest of the fringing bank (Fig. 19).
Compare the gentle "reef" configuration (dips ±5°) and low relief (30-35 m) with the progressively more pronounced reef topography seen to the northwest in the more basinal areas of southern Lake Winnipegosis and Dawson Bay.

Very little erosion of Winnipegosis strata has occurred at this locality as shown by preserved flanking deposits of Lower Dawson Bay. The preserved quarry beds probably are close to the true depositional top of the "reef" and must represent a late stage in "reef" growth. Most likely they represent a post-bioherm stage of biostromal development, as suggested in the introductory section. Contrast this occurrence with the section to be seen at the Rosehill Quarry ***(STOP 13)*** where a massive biohermal core with flanking beds dipping at 20° reflects an earlier, possibly biohermal phase of "reef" development.

References: Corehole M-5-69 (3-21-24-10WPM); Davison (1981); Norris *et al.* (1982).

Proceed 67.1 km west on P.R. 68/Hwy 15 to intersection with Highway 20. Turn north (right) and continue for 60.3 km to the Town of Winnipegosis. Continue for 1.6 km north of town to a trail on left (west side) of highway to an abandoned quarry.

STOP 15: WINNIPEGOSIS QUARRY. Souris River Formation (Sagemace Member) (Figs. 17, 26). Two quarries immediately south of Highway 20 expose approximately 6 m of light buff to reddish and purplish grey limestone, medium- to thin-bedded, very fine grained, dense (sublithographic), in part fossiliferous and stylolitic. Beds show gentle structural undulation with up to 2 m of relief. The Winnipegosis Quarry beds are about 5 m stratigraphically below the dolomites of ***STOP 16***, so the lithologic difference between the two locations is not unexpected. However, corehole data show pronounced differences in lithology throughout the entire Sagemace Member; the unit is totally dolomitic at ***STOP 16***, whereas at the Winnipegosis Quarry the unit is predominantly limestone. The limited data do not permit an explanation of the pronounced lithologic change.

Note especially the large abutment on the west side of the eastern quarry, directly opposite the entrance ramp. Much of this abutment consists of a chaotic megabreccia resulting from open-cavern salt collapse. The exposed dimensions of this breccia "plug" are 10 x 40 m. The plug does not extend to the east face of the quarry, but another poorly exposed occurrence of the breccia near the center of the western quarry possibly represents a continuation of the breccia plug.

Two coreholes have been drilled at this location, one in the center of the breccia plug and a second in a "normal" area about 40 m north of the plug. Figure 26 shows a cross section of the two holes and a sketch of the probable sequence of salt collapse. The upper part of the breccia plug consists of monomict breccias that can be correlated stratigraphically with the normal hole. Little evidence of vertical mixing is seen. However, the monomict breccias are underlain by a well-defined basal unit of mixed breccia containing fragments derived from zones up to 50 m stratigraphically above the mixed breccia zone. The mixed breccia could only have been formed by collapse into an open salt-solution cavern. The "normal" quarry beds also have collapsed (a later event), but with relatively little disruption. The coreholes confirmed the presence of a relatively thin interreef Winnipegosis section of only about 25 m, indicating salt collapse in excess of 70 m.

References: Coreholes M-10-81 (Winnipegosis Quarry, 15-9-31-18WPM); M-16-81 (Winnipegosis Quarry, 15-9-31-18WPM); McCabe (1981a).

Return to Highway 20 and continue north for 25 km to junction of Pine River Road (section road). Abandoned quarry is present northwest of intersection.

STOP 16: PINE RIVER ROAD QUARRY. Quarry on the northwest side of intersection exposes 2.5 m of dolomite of the Sagemace Member (Souris River Formation) (Figs. 17, 18). The dolomite is mottled, yellowish to grey buff, dense to moderately granular with some blade-like and cubic pores (evaporite solution?), and in places finely banded to laminated, with some fossiliferous calcarenite. Beds are medium- to thin-bedded with considerable structural undulation, showing dips up to 15°. These are stratigraphically the highest known Devonian beds outcropping in southwestern Manitoba (Fig. 18). The quarry is located in a structurally low interreef setting, and corehole M-6-80 at this location intersected a total Winnipegosis section of only 27.7 m. Note the presence immediately north of the quarry of a large salt flat, probably indicative of a thick underlying Winnipegosis reef. A corehole 10 km north of this location intersected a Winnipegosis reef believed to be approximately 105 m thick - one of the thickest known reef occurrences in Manitoba.

<u>References</u>: Corehole M-6-80 (Pine River Road Quarry, 1-5-33-19WPM).

End of Day 2 - Overnight in Swan River

DAY 3

DEVONIAN STRATIGRAPHY OF SOUTHERN MANITOBA, DAWSON BAY AREA

Proceed 80 km north on Highway 10 to Pelican Rapids Road. Turn left, east, and proceed for another 10 km to a salt flat to your right (south). See Figure 28 for detailed route map.

STOP 17: GERMAN CREEK SALT FLAT. DEVONIAN DAWSON BAY FORMATION (Lower member). This 300 x 400 m diameter salt flat is not the largest in the area, but it is the most accessible. Two treed hummocks in the centre of the flat expose near surface outcrop of the Lower Dawson Bay - lime mudstone fragments. The domal expression of the hummocks reflects probable Winnipegosis reef domes in the subsurface, although this has not been confirmed by drilling. Numerous brine discharge sites are present in the southeast corner of the flat. They are usually rimmed with boulders of various origins and are also corroded by the brine.

Proceed 5 km west to a roadcut.

OLD ROAD: For the first 3.4 km, the road traverses or skirts and upland area underlain primarily by Point Wilkins strata, although one inlier of reef-supported stromatoporoidal Upper Dawson Bay limestone occurs at 1.0 km. The low swampy area to the south is underlain, at least in part, by Mesozoic channel-fill deposits resting on structurally low (i.e. interreef), deeply eroded Dawson Bay strata as indicated by Husky Mafeking DDH #1 (6-16-44-25WPM) (Norris et al., 1982). From 3.4 to 5.6 m, the road becomes undulating as it traverses a topographically high bedding-plane pavement of reef-supported Upper Dawson Bay strata. The sharp topographic drop off to the east also conforms to a bedding dip, as can be seen along the power line right-of-way.

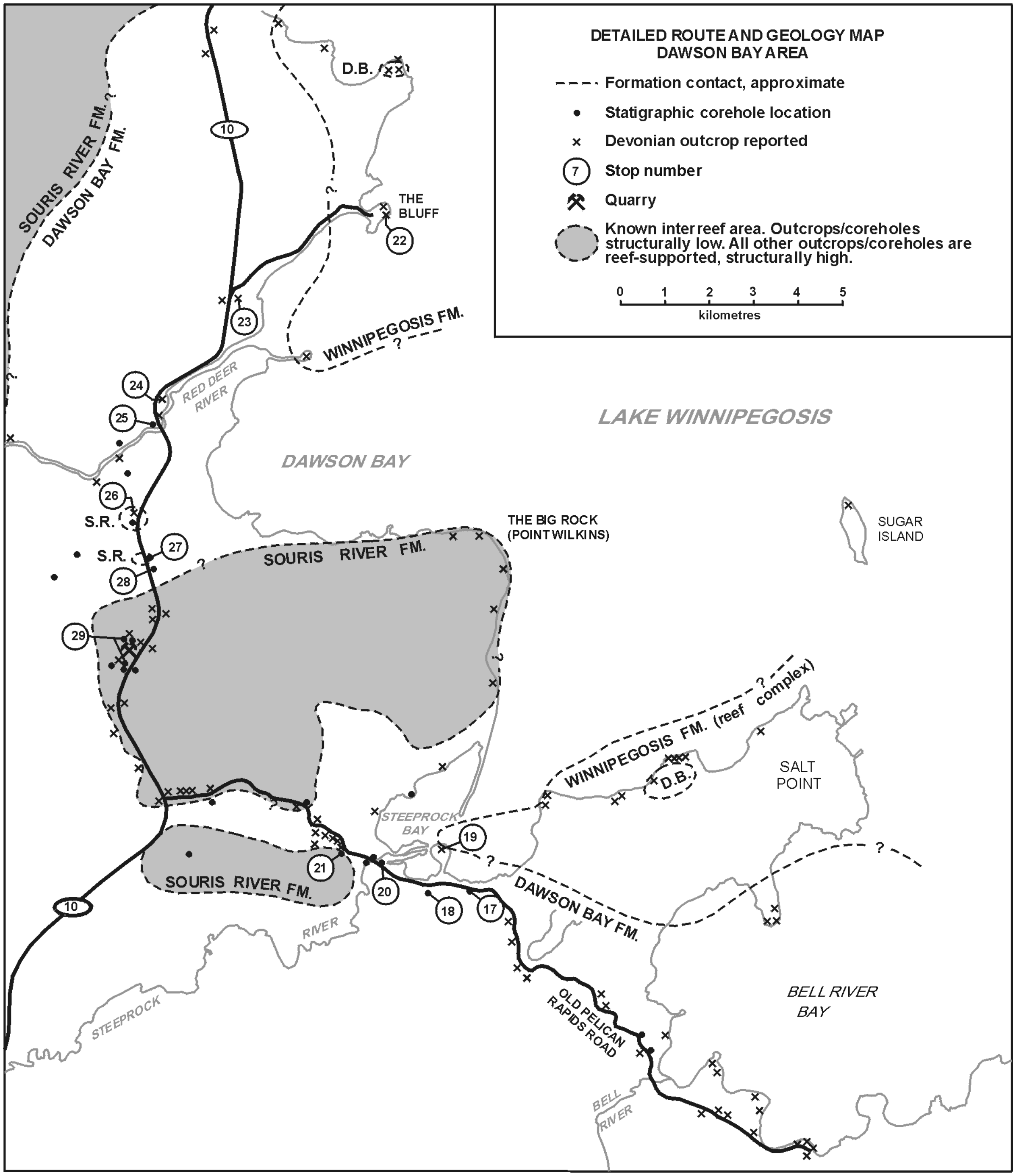


Figure 28: Detailed route and geologic map, Dawson Bay area.

STOP 18: NEW PELICAN ROAD ROADCUT. DEVONIAN DAWSON BAY FORMATION (Lower Member) and SECOND RED BEDS. The following description of the roadcut is from Kent (1991) and the measurements are from the base of the exposed cliff face:

0.00-1.16 m: SECOND RED BEDS: Lime mudstone - medium grey; argillaceous; microcrystalline; medium bedded. Grades to very calcareous, medium grey, flaky to slabby claystone in the upper 20 cm.

1.16-1.26 m: SECOND RED BEDS: Lime mudstone - medium grey; argillaceous; microcrystalline; subangular to rounded clasts of lime mudstone that weather light yellowish grey. Clasts 2-33 mm in diameter. Contact with underlying strata is sharp. Becomes yellowish grey and slightly argillaceous toward top.

1.26-4.80 m: DAWSON BAY FORMATION - LOWER MEMBER: Lime mudstone - light grey; thinly bedded; microcrystalline; 20-20 cm thick layers of atrypid brachiopod wackestones about 20-30 cm apart - mostly disarticulated valves, some convex up, others convex down. Intervals between wackestones have scattered articulated atrypids.

On Old Pelican Rapids Road, 2.1 km east of the bridge, and on intersection with road leading north. Turn north for 1 km and follow (to right) to shoreline. Proceed north on foot along shore to cliff at north tip of peninsula.

STOP 19: STEEPROCK BAY REEF. DEVONIAN DAWSON BAY FORMATION (Lower Member) AND WINNIPEGOSIS FORMATION (Upper Member - reefal facies). At the end of the trail, on the southern flank of the reefal dome, truncated Lower Dawson Bay strata are preserved. These beds are seen to dip to the south at about 20°, comparable to the flank dips beds at **STOP 20**. Although no actual outcrop can be seen between the flanking Dawson Bay outcrop and the shoreline reef exposure, reddish soil between these two outcrops indicate the presence of the recessive shales of the Second Red Beds, and excavation on the top of the mound would probably expose the true cap rock of the reef. Extrapolation of flank dips indicates that at most a few metres of uppermost Winnipegosis strata have been eroded from the shore cliff, although there is no sign of the thin sequence of calcareous transition beds commonly found at the top of the Winnipegosis.

The outcropping Winnipegosis strata thus represent the stratigraphically highest occurrence of any known Winnipegosis beds, and must reflect the final stage in "reef" growth, possibly even a post-reefal stage developed after the main episode of organic development had ceased. The uppermost algal and fragmental beds may possibly have been deposited during the initial stages of increased salinity (and possibly lowered sea level) associated with eventual deposition of the Prairie Evaporite. Compare the lithology if the uppermost beds of this reef with the uppermost, preserved, highly organic beds at The Bluff reef (**STOP 22**).

A newly exposed, relatively fresh and clean shore cliff consists of approximately 7 m of massive to thick bedded dolomite, relatively flat lying but with a slight dip away from the center of the outcrop. Dolomitization has largely obscured the primary texture, but the relatively clean weathered surface shows a complex relict texture with laminated algal stromatolites (?) at the top of the section, considerable calcarenite, patches of coarse intraclastic algal breccia forming small channel-type deposits, and several mudstone seams showing contortion and rip-up deformation. Fossils are common, including corals, gastropods and brachiopods (including *Stringocephalus*). Except for the stromatolitic content, especially in the cap rock, evidence of bioconstruction is not apparent, although some loose blocks of coral biolithite, possibly derived from flanking beds, have been noted. Algae may have been the principal sediment-binding factor in this late stage of reefal development.

The Steeprock Bay Reef apparently is a "pinnacle-type", similar in configuration to the reef underlying the Lower Dawson Bay dome at **STOP 20**. The diameter of the reef at this level of erosion, as indicated by the diameter of the peninsula, is approximately 300 m, and the estimated total Winnipegosis thickness is approximately 97 m.

Return to Pelican Rapids Road and continue to Steeprock River bridge. Stop at foot of structural/topographic dome.

STOP 20: STEEPROCK BRIDGE DOME. Dawson Bay Formation (Lower Member). The outcrop forms a sharply defined structural/topographic dome, circular in configuration and approximately 150 m in diameter. Bedding dips on the flanks of the dome are uniformly 20°, except for the north side, which has been truncated. A small salt flat occurs below the truncated flank at water level. This feature is similar to the dome seen at ***STOP 23***, but has a much more prominent topographic expression.

A total of 5 m of variably fossiliferous brachiopod biomicrite is exposed on the truncated face. The top of the underlying reef is not exposed but occurs approximately at lake level. Corehole S-5-75, drilled on the edge of the dome, intersected 76 m of Winnipegosis strata (massive, mostly textureless dolomite) indicating a total reef thickness, at the center of the dome, of almost 90 m. True reef shape is shown in Figures 24, 25. True diameter of the reef probably is about 400 m. M-17-81 shows a Winnipegosis thickness of approximately 42 m, slightly greater than the estimated "normal" interreef thickness of about 30 m. This particular reef appears to be an isolated, symmetrical, pinnacle-type feature.

Looking northwest from the viewpoint on the top of the dome, several other Lower Dawson Bay reef-supported structural/topographic domes can be seen; the highland in the background is underlain by Point Wilkins strata (indicative of an interreef setting). To the northeast, the mound-like peninsula ***(STOP 18)*** is an exhumed Winnipegosis reefal structure, probably comparable to, but somewhat thicker than, the reef underlying this stop.

References: Coreholes S-5-75, M-8-72, M-17-81, M-7-86, M-8-8e boundary zone, and a well defined thickening is present to the east, centered on the southern portion of the outcrop belt. Local thickening of the Second Red Beds, probably related to very early salt solution, occurs along the southern part of the boundary zone. The area of thickened Dawson Bay and the associated lithofacies variations suggest that a sub-basin existed east of the CSBZ, and as a result the carbonate thickness of the Dawson Bay.

On the New Pelican Rapids Road, continue west over bridge, 0.3 km to the dome.

STOP 21: STEEPROCK ROAD DOME. Dawson Bay Formation (Upper Member). Outcrop forms a broad, irregular, dome-like topographic high exposing a bedding surface roughly paralleling the topographic surface. This structural/topographic dome is similar to the Lower Dawson Bay dome at ***STOP 23***, but is broader, asymmetrical, and generally more irregular. Drilling at this location intersected a total of 5.2 m of Upper Dawson Bay strata consisting of an upper unit 2.3 m thick of yellowish brown, medium crystalline limestone, variably fossiliferous with corals and stromatoporoids. This is underlain by 2.9 m of yellowish brown, finely crystalline granular dolomite. Estimated thickness of the underlying Winnipegosis reef is 80 m.

References: Corehole M-7-72; Norris et al. (1982).

Continue west on Pelican Rapids Road to Highway 10. At intersection with road to "The Bluff", turn east and follow main road to water's edge for 3.8 km. Park and proceed by foot through open woodland to north end of peninsula forming "The Bluff".

STOP 22: THE BLUFF REEF. Devonian Winnipegosis Formation (Upper Member - reefal facies). Accessible shore cliffs occur on the eastern and northern extremities of The Bluff (Fig. 28 - Dawson Bay map), and several small but clean outcrop mounds can be seen on the top of The Bluff, at the northern end. The Bluff comprises a slightly eroded reefal mound, or klint, although, as is typical for almost all Winnipegosis outcrops, dolomitization has largely obscured the primary organic textures. In places, however, excellent samples of bioconstructed lithologies can be seen, especially in the open area on top of The Bluff. The maximum exposed section consists of 9 m of white to pale yellowish brown, massive, compact, tough dolomite. At one place, a relatively thin-bedded zone is seen to occur between two massive (reefal?) abutments, and flanking dips to the south can be seen a the south end of the outcrop. Large talus blocks along the foot of the cliff are representative of the outcrop lithology. During periods of low water, bedrock pavement extends about 20 m from the foot of the cliff.

Pisolitic features can be seen filling cavities in the upper part of the outcrop. These are believed to be vadose pisolites, formed in the vadose (meteoric) zone during early diagenesis as a result of lowered sea level conditions subsequent to reef development but prior to burial of the reefs beneath salt beds of the Prairie Evaporite.

Since 1980, nine coreholes have penetrated the lithologies exposed on the Bluff. Figure 29 is a schematic drawing of the Bluff and the location of cross section A-A'. Figure 30 is a cross section of the Winnipegosis reef and its associated lithologies. The shape of the peninsula closely imitates the outline of the Winnipegosis reef, whereas the southern half is overlain by 26-38 m of Dawson Bay Formation, Second Red Beds and a collapse breccia. Therefore, the reef thickness at the northern end is approximately 70 m thick, and in the southern half it varies from 43 to 51 m.

References: Coreholes M-4-88, M-5-88, M-6-88, M-7-88, M-8-88, M-8-90, M-9-90, M-1-91, M-2-91 (various locations on the Bluff); Baillie (1951a); Norris *et al.* (1982); McCabe (1988a); Bezys (1990; 1991); Kent *et al.* (1992); Teare (1990).

Return to Highway 10. Turn south (left) and stop at first roadcut.

STOP 23: HIGHWAY 10 DOME. (Dawson Bay Formation). Lower Member (biomicrite) and basal Second Red Beds. Road-cut through well defined structural/topographic dome exposes an upper 6.0 m unit of light grey, thin bedded, dense, highly fossiliferous brachiopod biomicrite (high-calcium limestone). A lower unit consists of 2.6 m of reddish to yellowish brown and greenish grey argillaceous dolomite and dolomitic shale - Second Red Beds (Fig. 31). The domal configuration, with flank dips of up to 20°, is due to salt solution and resultant collapse of the Dawson Bay beds, which are draped over an underlying Winnipegosis reef. The top of the reef occurs within 5 m of the roadbed. Note the minor faulting and brecciation resulting from collapse; also that the topography conforms roughly with the structure; such structural/topographic domes are common features of the Devonian outcrop belt. The structure of the Dawson Bay strata closely reflects the configuration of the uppermost part of the underlying reef. Note the asymmetry of the structure, with a secondary small structural roll immediately north of the main dome. Estimated underlying reef thickness from the outcrop is about 80 m.

Corehole drilling in 1992 targeted the Highway 10 Dome to determine the reef thickness. Figure 31 illustrates the

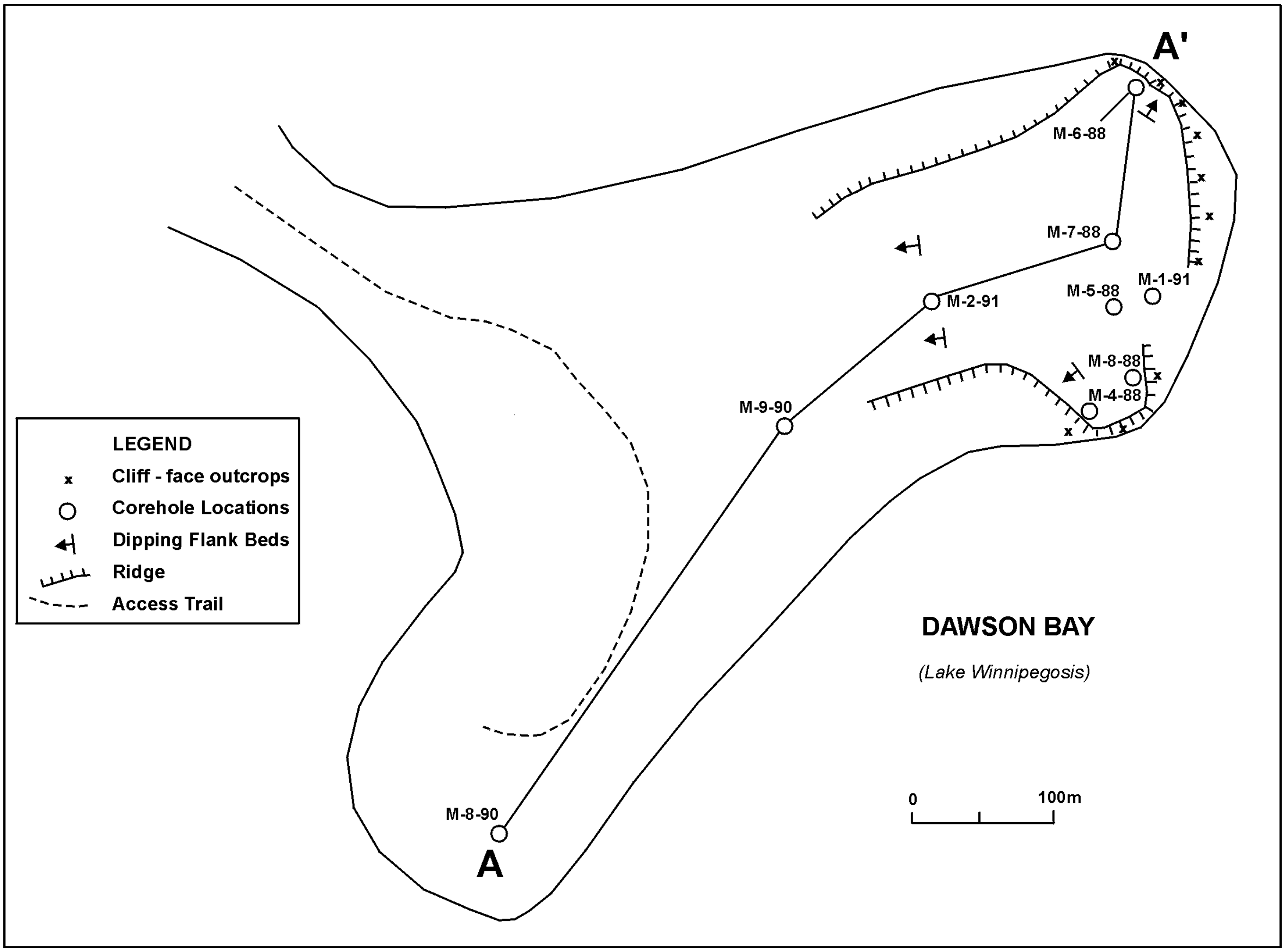


Figure 29: Location of coreholes on The Bluff and cross section for Figure 30 (modified after Kent, 1991).

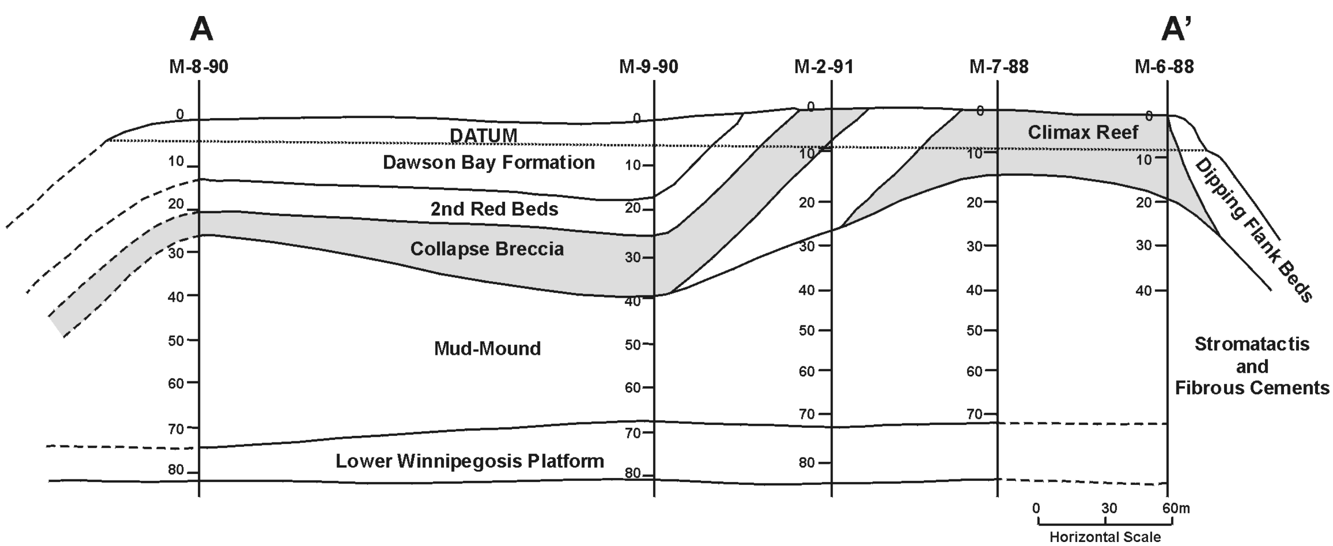


Figure 30: The Bluff cross section (modified after Kent, 1991).

depositional settings of the two coreholes. These settings can be applied to other Winnipegosis Formation reef localities in the Dawson Bay area. The beds making up the "algal rim" are similar to those found in outcrop at the Steeprock Bay Reef ***(STOP 19)***, 15 km to the south. The beds at the base of that exposure are similar to those identified in Figure 31 as "reef flat". Penetration of the Winnipegosis Formation was incomplete due to sand infill problems.

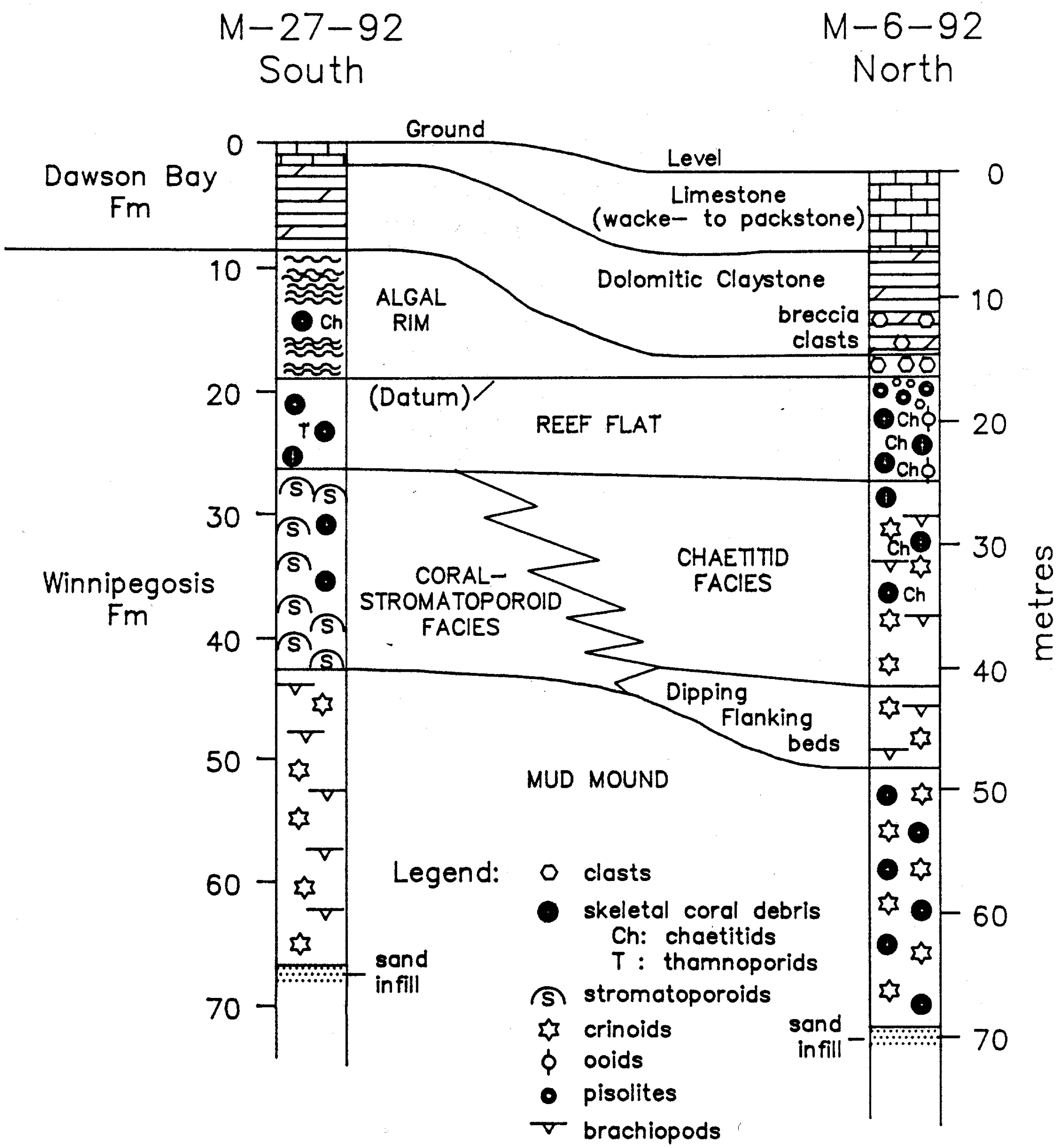


Figure 31: Highway 10 Dome cross section.

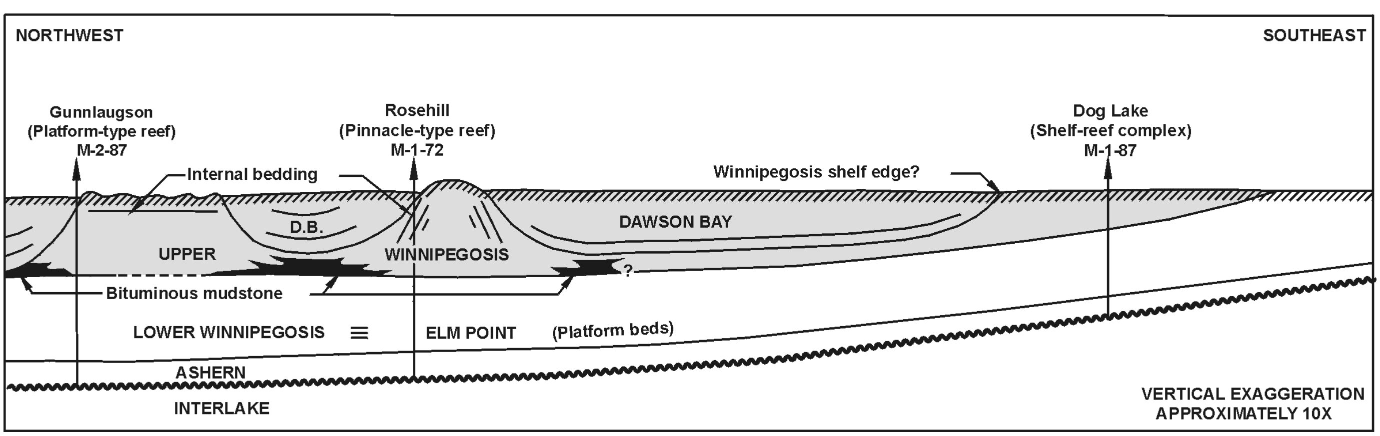


Figure 32: Diagrammatic cross section, Winnipegosis Formation reefs, The Narrows area.

References: Coreholes M-6-92 (2-28-45-25W1); M-27-92 (2-28-45-25W1); Baillie (1951a); Norris *et al*. (1982); Bezys (1992); Kent *et al.* (1992).

Proceed south for 2.8 km to small salt flat adjacent to Red Deer River, 1.0 km north of Red Deer River bridge.

STOP 24: RED DEER RIVER SALT SPRING. Dawson Bay Formation (Lower Member). One of the smaller salt springs or salt flats that occur throughout the Devonian outcrop belt, from the Dawson Bay area southeast as far as Toutes Aides (Township 29, Range 15WPM). This is one of the few salt springs where associated outcrops permits identification of the stratigraphic source of the brine flow. A small outcrop of the Lower Dawson Bay limestone, similar to ***STOP 23***, occurs on the river bank, indicating the presence of a partly truncated domal structure, and hence the presence of an underlying Winnipegosis reef with, at most, a thin cover of basal Dawson Bay Second Red Beds. It seems probable that most salt springs are indicative of underlying Winnipegosis reefs with only a thin cover of basal Dawson Bay strata. (Drilling of salt flats to confirm this has not yet been undertaken because of potential problems involving control of heavy flows of artesian water from shallow depths). Deeper Silurian strata also may be involved in the artesian flow system.

Analysis of the brine indicated salinity of 45,000 PPM with a variable flow rate of ±10 litres per minute. The numerous salt springs along the Dawson Bay/Winnipegosis outcrop belt probably represent the discharge area for a regional subsurface flow system which is continuing the process of subsurface salt solution initiated in late Paleozoic time.

References: Baillie (1951a); McCammon (1960); Norris *et al.* (1982).

End of Day 3 - Overnight in Swan River

DAY 4
DEVONIAN STRATIGRAPHY OF SOUTHERN MANITOBA, DAWSON BAY AREA

Return to Swan River for the night. Return to Highway 10 and go north to the Red Deer River bridge.

STOP 25: RED DEER RIVER BRIDGE. Dawson Bay Formation (Middle and Lower members). North bank of the Red Deer River, approximately 100 m west of the bridge. Outcrop extends for about 30 m with beds dipping to the southwest at about 6°, exposing a 10 m section of fossiliferous limestone, argillaceous limestone and calcareous shale. These strata represent a portion of a truncated structural (reef-supported) dome comparable to those seen at **STOP 23**. Estimated minimum thickness of the underlying Winnipegosis reef is about 80 m. A small brine flow is evident at the edge of the picnic area.

Two test holes were drilled a short distance upstream, one (M-18-77) on the top of a reef-supported structural dome of Lower Dawson Bay strata, and the other (Husky Mafeking 11-8-45-25WPM) on a large salt flat. Both holes intersected Winnipegosis reefs 96 m thick. In contrast, two other holes drilled 7 km upstream intersected thin interreef Winnipegosis sequences of 24.1 and 32.7 m. Thus minimum reef-interreef relief in this area is 72 m.

Several other Lower Dawson Bay reef-supported structural domes can be seen in this general area, as ditch outcrops along Highway 10 and as riverbank outcrop a short distance downstream from the bridge.

References: Corehole M-10-72; Baillie (1951a, p.40); McCammon (1960); Norris *et al.* (1982).

Continue south on Highway 10 for 2.2 km to large roadcut at microwave tower.

STOP 26: TOWER ROADCUT. Point Wilkins Member (middle unit). Roadcut exposes a 5 m section of medium- to thin-bedded pale yellowish brown, faintly mottled, finely crystalline, dense to sublithographic fossiliferous micrite. The mottling reflects, in part, an intraclastic texture. Fossils, dominantly brachiopods, are fragile and thin shelled, and the rock is a pure high-calcium limestone. Strata are flat-lying and gently undulating in the roadcut, but back from the highway, on the northern edge of the bedrock ridge, the beds fold upward sharply with dips of up to 33°, exposing basal Souris River-First Red Beds. Recent drilling has shown that the beds rise sharply to the south, exposing Upper Dawson Bay strata a short distance south of the roadcut. The flat-lying Point Wilkins strata thus represent an isolated, structurally low (collapsed) "outlier" of Souris River strata surrounded by a complex of structurally high, reef-supported Dawson Bay strata. Estimated thickness of the underlying Winnipegosis interreef strata is 44 m.

Detailed outcrop and corehole descriptions and analyses for the Point Wilkins strata are presented by Bannatyne (1975).

References: Coreholes M-11-71, M-13-71, M-15-81; Baillie (1951a); Bannatyne (1975); McCammon (1960); Norris *et al.* (1982).

Continue south on Highway 10 for approximately 0.8 km to small borrow pit east of highway.

STOP 27: HIGHWAY 10 BORROW PIT. Souris River Formation (Point Wilkins Member - First Red Beds). Bedrock pavement at the edge of a small abandoned borrow pit east of the highway exposes an undulating, slightly truncated domal bedding plane surface. The thinly bedded strata show a fairly wide range of lithologies: brown granular, mottled, dolomitic limestone; light grey, dense, fossiliferous micrite; pale yellowish buff granular dolomitic limestone; and white to buff argillaceous, fossiliferous micrite. In places, irregularity of bedding suggests coarse brecciation. Total thickness of the First Red Beds in this area is approximately 10 m, and a corehole at this location (M-18-81) intersected 5.5 m of First Red Beds overlying Dawson Bay strata, indicating that the outcrop section comprises a more resistant interval near the middle of the Red Bed sequence.

The First Red Beds at this locality are structurally about 22 m high relative to the Point Wilkins strata at ***STOP 26***. Estimated thickness of the underlying Winnipegosis is approximately 67 m. This is one of the few instances of a Winnipegosis build-up of intermediate thickness. This location is on regional strike with the Lower Dawson Bay domes noted previously on the Red Deer River, but "reef" thickness has only been sufficient to bring First Red Beds to surface.

Continue south on Highway 10 for 0.1 km to small roadcut.

STOP 28: HIGHWAY 10 ROADCUT. Dawson Bay Formation (Upper Member). Roadcut through small structural dome exposes approximately 2 m of limestone and dolomite of the Upper Dawson Bay Member. This is the only outcrop of the Upper Dawson Bay strata in the Dawson Bay area to expose any appreciable thickness of section; all other outcrops approximate bedding pale surfaces. The upper 1.0 m consists of relatively coarsely crystalline (recrystallized) brownish buff fossiliferous (coral-stromatoporoid) limestone, and is underlain by approximately 1.0 m of finely crystalline brown granular dolomite with numerous calcite-lined vugs.

Corehole data show that the dolomite content in the lower part of the Upper Dawson Bay is extremely variable, and the dolomite is believed to be entirely secondary in origin. Corehole M-14-81 at this location intersected an upper Dawson Bay sequence consisting of 4.75 m of limestone overlying 2.05 m of granular porous dolomite. These beds are structurally about 7 m higher than at **STOP 27** indicating and underlying Winnipegosis thickness of about 75 m.

References: Corehole M-14-81; Norris *et al.* (1982).

Continue south on Highway 10 for 3.0 km to access road to quarry west of highway.

STOP 29: MAFEKING QUARRY. Abandoned quarry. SOURIS RIVER FORMATION (Point Wilkins Member). Quarry supplies high-calcium limestone used in the manufacture of Portland cement by Genstar Limited in Regina. There are two quarries at this location. The original, deeper quarry is now abandoned and mostly flooded and infilled (rehabilitated). It provides a good view of the gentle structural undulation affecting Point Wilkins strata; this structure reflects Winnipegosis interreef paleotopography. Detailed descriptions of the 27 m of section exposed in the old quarry are presented by Bannatyne (1975).

The new quarry exposes the same sequence as seen in the upper part of the old quarry, except for a 3 m cap of brown granular dolomite that occurs above the limestone and forms the uppermost unit of the revised Point Wilkins Member (Norris et al., 1982) (Fig. 19). These dolomites are the youngest Devonian strata known to occur in the area. The main quarry beds consist of light yellowish brown, faintly mottled, dense, micritic limestones similar to the beds at ***STOP 26***, which are correlative with the upper part of the quarry section approximately 5 m below the dolomite cap (Bannatyne, 1975). The lower part of the Point Wilkins Member consists of 10 m of reddish to purplish grey, mottled, argillaceous limestone, which was quarried in the old quarry. However, these argillaceous beds are of lower grade and are not being utilized in the new quarry.

Note the presence of the large sand-filled cave in the north quarry wall. Numerous such caves have been intersected during quarry operations and are believed to represent pre-Mesozoic karstic solution, with infilling by Cretaceous (Swan River?) quartzose sand.

The quarry beds have been subjected to a minimum of about 70 m of salt collapse, but associated disruption is relatively minor. Estimated thickness of the underlying Winnipegosis (interreef) strata is approximately 44 m. This thickness is somewhat unusual in comparison with the "normal" interreef thickness of 25-35 m. No coreholes have been drilled to the base of the Devonian in the quarry area because of potential problems with high pressure astesian salt water.

References: Coreholes M-9-70, M-9B-70; Bannatyne (1975); Norris et al. (1982); Fedikow *et al.* (1996)

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