Notes to accompany maps and cross-sections,

Middle Devonian barrier-complex of western Canada

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Descriptions of the barrier-complex and its relation to the Elk Point basin sediments appear in many publications. To mention only a few: Grayston, Sherwin and Allan, 1964; Griffin, 1965; Bassett and Stout, 1967. Some examples of publications that relate to the barrier-complex but focus on the Elk Point basin are: Hriskevich, 1967; Klingspor, 1967; McCamis and Griffith, 1967; Bebout and Maiklem, 1973.

This set of six maps and two cross-sections constitute an up-dated summary of the barrier-complex. They are intended for use by geologists who are familiar with the literature. These notes, therefore, are brief and references minimal.

Sources of data

The information used to construct these figures comes primarily from published reports and commercially available well logs and well cards.

In Alberta, except for the flanks of the Cordova embayment, markers were taken directly from well cards (Well Information Services Ltd.). Facies lines in Alberta, with minor modification, were copied from Belyea, 1971 (line d) and Hriskevich, 1967, (lines h and t).

For the remainder of the map area the following sources of lithologic data were available: Canadian Stratigraphic Services Ltd.; unpublished core descriptions for some wells in British Columbia by D.W. Morrow (ISPG, Calgary); core studies, British Columbia and Northwest Territories by G.O. Raasch, 1971, 1973; sample and core descriptions for many wells in the Northwest Territories by H.R. Belyea and E.J. Tassonyi (formerly ISPG, Calgary). Other important references are noted on the maps. In addition I have examined cores and samples from perhaps 50 per cent of the wells in the Northwest and Yukon Territories.

Assumptions underlying the construction of the figures

The term 'barrier-complex' is used for all clean carbonate strata that extend, vertically from the Keg River to Slave Point Formations inclusive and separate, in a lateral sense, the evaporitic deposits of the Elk Point basin from the argillaceous rocks of the Horn River Formation.

Usually the barrier-complex and related Elk Point basin strata have been described in terms of three sedimentary episodes. In Grayston et al., 1964 the subdivisions are 1) Keg River - Winnipegosis, 2) Presqu'ile - Muskeg, 3) Slave Point. In Bassett and Stout, 1967, the subdivisions are 1) Keg River - Winnipegosis - lower Muskeg, 2) Presqu'ile/Sulphur Point - upper Muskeg - Dawson Bay, 3) Slave Point. In the above, as in most descriptions, the relation of the Watt Mountain Formation to rocks of the barrier-complex is left rather vague.

These maps and cross-sections depict the barrier-complex in terms of only two unconformity bounded depositional sequences (in the sense of Vail, et al., p. 206). It is believed that these sequences were in response to eustatic fluctuations. The first sequence, a response to what is herein called the Keg River transgression, is bracketed by the Ebbutt regression below (within Eifelian) and the Watt Mountain regression above (mid-late Givetian). Only the initial deposits of the next transgressive sequence contributed to the barrier-complex. The Slave Point Formation (latest Givetian and/or earliest Frasnian) was deposited, then drowned in the deepening water of this transgression.

During the Ebbutt regression the entire map area, except the western most part, was above sea level. During the Watt Mountain regression the Elk Point basin was above sea level but the shelf to the north and west was not. Marine sediment, clastic as well as carbonate, prograded seaward along the edge of this drowned shelf during the Watt Mountain regression.

The barrier-complex crosses several cratonic sags and swells, the largest of which is the Tathlina High. It is believed that the differential crustal movements controlling these cells remained more or less continuous and proceeded at a more or less constant rate throughout the life of the barrier-complex. In other words there were no reversals, no sudden bursts of movement, no piano-key tectonics. These remarks apply to the major arches and sub-basins; it is not denied that local faulting or flexing (measured in metres or fractions of metres) influenced the course of sedimentation. It is also believed that the forces causing the sags and swells were independent of the forces causing the major transgressions and regressions.

Map 1, Pre-Devonian surface, paleogeology, paleotopography and present structure

This is three maps in one. Beneath the clutter caused by structural contours is a geological map. Flanking the precambrian shield progressively younger rocks subcrop below the Devonian to the north, west and southwest. Within the Northwest Territories all cores of basement rocks have been sampled and thin sectioned. In addition thin sections have been prepared from samples of a few non-cored wells, especially those that drilled what appear to be granite dykes cutting Proterozoic sediments. The thin sections are available for study at the ISPG.

There is a large area in British Columbia and adjacent Northwest Territories where Devonian carbonates or evaporites overlie quartz sandstone or quartzite. There seems to be no way, at present, to subdivide or date these rocks. They may, in places range to Early or even Middle Devonian in age.

In the west the Silurian/Devonian boundary apparently lies within the Delorme Formation (Perry and Lenz, 1978) and, perhaps within the Muncho-McConnell Formation. Over the remainder of the map area the pre-Devonian surface is an erosional unconformity. This surface is the result of several erosional episodes ranging from sub-Cambrian to within the Devonian Period.

Several of the smaller contour anomalies, especially in Alberta, are buried hills. These may be related to ancient structures but they have little effect on the structure or facies of higher horizons. The flanks of the graben-like depression beneath Great Slave Lake were, apparently, pre-Devonian slopes as well as Devonian growth structures. The large hills south of Trout Lake may also be growth features, but information is scarce in this area. When pondering the significance of these hills, also the Fort Nelson High, it is well to remember that the sandstone mapped as 'pre-Devonian' may actually be, in part at least, of Devonian age. The Bekami Lake fault (north of Fort Nelson) was probably a long lasting growth fault or flexure, down to the west, however there is no pre-Devonian control in the area.

The structural contours are a composite of 1) pre-Devonian topography, 2) Devonian and later flexing and faulting, 3) post-Devonian cratonic tilting and finally, rejuvination along ancient lines of weakness, probably during the Laramide interval. The northeast structural grain in the eastern part of the map is documented by adequate drilling control. In the west, however (e.g. Celibeta and Liard fault zones) there is inadequate control.

Note that the Tathlina High (Map 2) is now the site of a synclinal warp. At sometime between Devonian and present the Tathlina High became the Tathlina Low.

Map 2, Pre-barrier Devonian sediments

A regressive interlude within the Eifelian Stage resulted in a thin but widespread clastic marker, the mid-Chinchaga sandy marker south of the Tathlina High (Belyea, 1970), the Ebbutt Member north of the High (Law, 1971). The isopachs show the thickness of Devonian strata that were deposited prior to, and survived erosion during, this regression.

In the Mackenzie mountains (north-central part of the map) the top of the isopached interval is the top of the Arnica Formation or equivalents - the Manetoe dolomite or Landry limestone. In the Rocky Mountains the Ebbutt equivalent is taken as the Stone/Dunedin contact; the correlation is only approximate. In the mountain areas the isopached interval includes the Muncho-McConnell and Delorme Formations, thus some Silurian strata; correlation and thicknesses in the area are uncertain, however the data suffice to illustrate the marked increase in subsidence compared to the eastern area.

In the Fort Nelson area scant control, facies and thickness changes and resulting correlation difficulties combine to render the interpretation unreliable. There is a High in the area but its extent, orientation, and relation to the Peace River High is uncertain.

The isopachs reflect 1) onlap over pre-Devonian topography, 2) differential subsidence during deposition and 3) erosion during the Ebbutt regression. Except for the small buried hills, mostly in Alberta, it is virtually impossible to evaluate the relative importance of these three influences. Individual units, as well as the total package inevitably thin or thicken in unison across the major sags and swells. On the flanks of the Tathlina High markers become vague and unreliable. It is quite possible that areas within the zero isopach were once covered by early Devonian rocks.

As far as is known the entire package consists of marine, shallow to supratidal deposits: dolomite, anhydrite, redbeds and halite. It is interesting that facies changes (lines a, b and c) seem to disregard isopach trends but to parallel the paleolatitude (index map). The edge of the Cold Lake salt, on the other hand, may be an accurate reflection of the subsidence pattern. In the northern corner of the map, however, the pinch out of the salt occurs in near surface beds and is, almost certainly, a limit of preservation, not of deposition. The apparent trough north of the Tathlina High may be spurious, a result of post-Devonian salt solution.

Map 3, The early and mid-Givetian phase of the complex

The transgression, or more likely, the series of transgressive pulses that created the sediments of the isopached interval began in the Eifelian and lasted through much of the Givetian Stage. The base of the interval is the top of the Chinchaga Formation or, west of line e, an approximately equivalent marker picked from mechanical well logs. The top of the interval is the top of the Watt Mountain Formation, a more consistent well log pick than the base. That some post-barrier sediments are included is of no consequence because, in most wells, the Watt Mountain Formation is only a few metres thick.

The isopachs reflect the same pattern of differential subsidence that appears in the pre-barrier Devonian sediments, Map 2. Although the northeast trend of the barrier crosses both sags and swells, the re-entrants are clearly related to the sags.

Several pre-Devonian hills cause local thins in the isopachs. Most of these appear to have been tectonically inert. The large quartzite hills south of Trout Lake, however, probably did rise somewhat during deposition. The quality of well markers in this area is such that differential uplift cannot be demonstrated through Middle Devonian time, but can be demonstrated through Late Devonian time. The apex of the hill northeast of Celibeta Lake is deduced from the rare occurrence of quartz grains within the upper part of the isopach interval (core of Celibeta No. 2 at 4100 ft).

The first deposits of the transgression were the Upper Chinchaga anhydrites and dolomites followed by the Keg River platform carbonate. A myriad of reefs and banks grew in the deepening water. In between, the platform was drowned in a sea several tens of metres deep. Carbonate banks and reefs along the barrier belt eventually coalesced to form an effective circulation barrier. For the remainder of the transgression facies belts remained more or less fixed geographically. These belts were: 1) the drowned, nearly sediment starved Horn River shelf, 2) the barrier, with a relatively steep seaward front but gradational to 3) evaporitic deposits of the Elk Point basin.

Both the seaward and landward edges of the barrier migrated back and forth through time. Line f represents the seaward edge only during the initial stages of the barrier. In some areas, such as Great Slave Lake, the seaward edge migrated seaward, probably as far as line n (limit of Watt Mountain karsting). In the southern Utahn Embayment the reverse occurred and, at one stage in its vertical growth, the barrier had retreated inland as far as line q (limit of Klua shale).

The 'inland' edge of the barrier, or carbonate-anhydrite transition belt shifted much more dramatically through time. Line g represents the most seaward position of this boundary, which prevailed at about the mid-point of the Muskeg Formation (cross-section BB'). Line h represents the position of the transition belt during the final (preserved) stage of the transgression.

The seaward edge of the barrier cannot be identified across the Tathlina High or Arrowhead salient. Possible reasons include: 1) a steep carbonate front never did develop over these positive areas, 2) it has been destroyed by intra-Givetian erosion, or 3) these areas were above sea level, island links within the barrier chain. At present it seems to be impossible to decipher the history, however there are a few clues. In both areas the initial platform limestone appears to have been deposited, this would rule out the presence of islands, at least during the initial stage of the Keg River transgression. Over the apex of the Tathlina High (stippled area) shallow water carbonates (Watt Mountain - Sulphur Point Formation, Belyea, 1971) appear to lie on eroded Platform, on Chinchaga or on basement. This seems to indicate a combination of items 2 and 3, above.

Another clue to the missing barrier edge may lie in the pattern of dolomitization. With the exception of a discontinuous upper layer of variable thickness (often designated the Sulphur Point Formation) the Keg River barrier has been dolomitized. It is as if dolomitizing fluids (penecontemporaneous reflux?) permeated most of the barrier but seldom reached its top. There is also a vaguely south of the map area, are there appreciable thicknesses of nonmarine sediments. Within the map area, southeast of line n or the barrier edge, it is convenient, and only slightly inaccurate, to think of the Watt Mountain as a plane surface, an unconformity, not a formation. Over most of this area, including the type well (Law, 1955) sediments that have been assigned to the Watt Mountain Formation can be interpreted as karsted limestone below and reworked karst products above the unconformity. The lower are part of the Sulphur Point, the higher are initial deposits of the Slave Point Formations.

The erosion has been attributed to karsting (Morrow, 1975). No drainage pattern has yet been documented. It is tempting, on the basis of the shape of the Otter Park and Buffalo River shale banks (between lines f and r) to postulate streams debouching into these areas. The rare occurrence of quartz grains, up to grannule size, in the Klua shale implies stream competence out of character with the general lack of relief on the erosion surface.

Over most of the Horn River shelf and Macdonald Platform the regression left no discernable record. Throughout a period of time before, during and after the regression the area remained covered by several tens to several hundreds of metres of water, but received very little sediment. Late Devonian fissure fill in some of the Horn Plateau reefs led Fuller and Pollock, 1972, to deduce a late Middle Devonian sea level drop.

A Watt Mountain - like shale break is present in some of the wells of the Deep Bay bank, and in the Yoyo and Sierra buildups (Map 3). No such break is present within Horn Plateau reefs nor within the Evie bank, although the tops of some of these are homotaxial with the Slave Point Formation.

The concept of a Watt Mountain sea level drop that left the barrier top exposed, but the seaward shelf below water leads to the concept of marine sedimentation concurrent with Watt Mountain erosion. This is not a new concept, (for example see Macauley, 1964, p. 22) however it was not until Skall, 1975, defined northern limit of dolomite (line k). North of line k strata homotaxial with the generally light coloured dolomite of the barrier are fairly dark, generally dense lime muds with a variable admixture of bioclastic debris. These limestones may be fore-barrier beds, analogous with similar strata, also undolomitized, that partially filled the Cordova embayment. Thus line k may mark the approximate position of the barrier's seaward edge where it crosses the Tathlina High and Arrowhead Salient.

Most of the evaporitic Muskeg sediments formed more or less contemporaneously with barrier growth (Bebout and Maiklem, 1973). As discussed by Maiklem, 1971, the barrier was probably cut by channels through which sea water entered the Elk Point basin. It is likely that these channels were ephemeral, refilled by carbonates between episodes of evaporitic drawdown. No such channels have yet been delineated, however the distributary-like pattern of line g south of the Utahn Embayment suggests that this was one of the main inlets. The intra-Givetian erosion on the Tathlina High could also be related to channels, as interpreted on cross-section AA'.

Map 4, The mid-Givetian regression; Watt Mountain Formation

There are many unknowns concerning the cause and nature of this event: eustatic? tectonic? duration? a single or multiple event? how far did sea level drop? how much section was eroded? Within the map area the sedimentary record can be explained (with some misgivings) in terms of a single event that caused an apparent sea level drop of several tens of metres, enough to place the entire barrier and Elk Point basin above sea level, but not enough to affect the Macdonald Platform or Horn River shelf.

The Watt Mountain Formation is usually considered to be a thin but widespread deposit of nonmarine to brackish water clastics that grade to a supposed marine equivalent. Only on the fringes of the Peace River High, well restudied the Pine Point mining area that the full significance of Watt Mountain marine sedimentation became obvious. It turns out that the type Sulphur Point Formation (not the subsurface Sulphur Point of the Elk Point basin) was deposited, for the most part, during the Watt Mountain regression. The stippled areas on the map show the extent of marine carbonate sedimentation; because there is no karst horizon, these regressive carbonates cannot easily be mapped separately from the overlying Slave Point Formation.

Skall, 1975, has speculated that Watt Mountain karsting may have had some influence on subsequent dolomitization. The dolomitization pattern, in three dimensions, of the pre-Watt Mountain beds is too complex to portray on one map. Generally speaking there is a layer of limestone, from a few metres over the Tathlina High to 100 m in places in British Columbia, between the karst surface and the highest dolomite. An exception to this generalization is in British Columbia, south of about 58°30'. In this area the reverse is true, limestone below the Watt Mountain break is unusual. The pattern of squares and triangles on the map is a crude indication of the dolomitization pattern. Dolomite, especially the Presqu'ile facies, is most common adjacent to the seaward edge of the barrier. Dolomite of any type is rare, and Presqu'ile dolomite is never present, in isolated banks and reefs.

Map 5, The late Givetian to earliest Frasnian Phase of the barrier-complex; Slave Point Formation

After the low water stage of the Watt Mountain regression apparent sea level again rose and continued to rise, apparently without any significant interruption until the end of Frasnian time. The Trout River - Calmar - Graminia clastics mark the end of this transgressive event. This event, at least continental if not global in scope, has been called the Tahganic Onlap by Johnson, 1970.

The initial carbonate deposits of this onlap were depicted on the previous map - the regressive (seaward-building) limestones north of the Keg River barrier, Map 4. The onlapping sea eventually spread over the Elk Point basin and deposition of the Slave Point Formation began. The rate of sea level rise became sufficiently rapid that carbonate sedimentation gave way to shales and shaly limestones of the Waterways Formation or to deep water shales of the Muskwa Formation. The limestone/shale contact is diachronous (Williams, 1977b). South of the map area the Swan Hills reefs and banks continued to grow in the deepening water. No analogous reefs are definitely known atop the barrier-complex, however the buildup on the northeastern rim of the Deep Bay bank may be such a reef. The somewhat erratic thickness changes of the Slave Point Formation along the Kotcho-Petitot trend could also be a result of low reefs or mounds.

Most paleontologists now believe that the Horn Plateau reefs are entirely older than the Slave Point Formation although Norris (in McLaren and Norris, 1964) noted faunal affinities with basal Waterways Formation. Most fossil collections come from the outcropping top of the reef at Fawn Lake, which is remote from the nearest occurrence of definite Slave Point limestone. Wherever reefs lie near the barrier-complex their tops are homotaxial with the Slave Point Formation (cross-section BB'). In some of the reefs and banks in the Utahn Embayment a Watt Mountain - like shale break occurs at the appropriate stratigraphic level. It seems probable that at least the upper parts of at least some of the reefs are Slave Point in age. If not, some very unusual piano-key tectonics would have to be invoked to explain their geometry.

Along the flanks of the Utahn Embayment as well as the Great Slave Lake area the seaward edge of the Slave Point Formation has been dolomitized extensively. Flanking the Cordova Embayment the dolomitization pattern seems to be related to the limit of Watt Mountain karsting (coincident with the Keg River edge) rather than to the seaward edge of the Slave Point Formation. Dolomite-related porosity is an important element in most, but not all, of the Slave Point gas accumulations.

Map 6, The fore-barrier sediments, Horn River Formation

The base of the isopach interval is the top of the widespread platform carbonate known as the Keg River, Lonely Bay, Hume, Nahanni or Dunedin Formations. The top of the interval is the top of the highest regionally mappable radioactive shale below the non-radioactive Fort Simpson - Besa River shales. Within the Cordova Embayment the isopach interval (values in round brackets) includes the thick layer of Slave Point and older limestone.

How much of the isopach pattern reflects differential subsidence and how much it reflects the mode of deposition is uncertain. If differential subsidence was the main control one would conclude that much of the Horn River shelf as well as an area west of Fort Nelson were broad highs. Northwest of Deep Bay where there is fairly close well control well log markers suggest a pattern of seaward sloping clinoforms which tail-off into fondoforms over the Horn River shelf. A similar pattern west of Fort Nelson was deduced by Pelzer, 1966. If true, the thickness pattern bears little relation to subsidence.

A feature that may be related to subsidence or at least to submarine topography, is the distribution of the dark coloured, radioactive Evie limestone (cross-sections A and B). This distinctive lithology is only mappable as a discrete unit within the embayments or depressions. A tentative explanation might be as follows. Refluxing Elk Point basin brines seeped through the Keg River barrier carbonates and, because of their density, collected in depressions. These toxic, anoxic bottom waters were ideal for the preservation of organic matter, hence the highly bituminous nature of the Evie limestone. Theoretically the evaporation process should have enriched these brines in metals. However, unless the Pine Point lead-zinc ore is somehow related, the only mineral enrichment so far detected is the one (species unknown) that causes the high radioactivity.

Adjacent the seaward edge of the barrier-complex the thickness of the Horn River Formation, regardless of its lithology, is always approximately equal to the height of the composite barrier. It is as if the shaly strata could only accumulate into thick banks in the shelter of the barriers seaward wall. Note the rapid westward thinning of the formation in the southern Yukon, clinoforms adjacent an undiscovered carbonate bank? or a local tectonic trough?

Adjacent the barrier-complex the Horn River 'shale' is mostly a mixture of carbonate, silica (quartz silt?) and, in the radioactive layers, a high content of organic carbon (see Macqueen et al., 1975, for the few available analyses). With the possible exception of the scattered sand grains in the upper Klua shale (Can. Strat. Services Ltd. lithologs) the terrigenous material could have been delivered either by long shore currents or by wind. It is probable, however, that some of the terrigenous material was derived from the Elk Point basin during the Watt Mountain regression.

In cored wells no break that could be attributed to subaereal exposure has ever been found. Some sharp bedding breaks show evidence of scour but these can be attributed to submarine erosion. The entire formation seems to have formed in fairly deep water with the exception of a few layers of light coloured fossil fragmental limestone near the barrier edge. These are probably debris flows.

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