Introduction

The Famennian subsurface strata of Saskatchewan, Alberta, and British Columbia consist of a series of stacked cyclical ramp and shelf carbonates and associated evaporites of the Wabamun Group. These rocks are coeval with Palliser Formation strata exposed in the Rocky Mountain Front Ranges. In northeastern British Columbia the ramp carbonates and shelf carbonates are coeval with the Local Area of the Wabamun Basin. There is some evidence of a shelf-out of the Palliser to the west in southeastern British Columbia (Richards, 1988), although stratigraphic relations have been obscured by later tectonic deformation. The eastern and northern margins of the Wabamun Group are defined by pre-Mesozoic erosion. Famennian sedimentary rocks subcrop beneath Mesozoic clastic rocks from Alberta to Manitoba along a belt extending some 700 km (Fig. 13.1).

The outcrops of the Palliser Formation are subdivided into two member: the Moro and the overlying Costigan. These correspond respectively to the Stettler and Big Valley formations of the subsurface Wabamun Group (Fig. 13.2). A major unconformity separates these units in both surface outcrops and the subsurface. Moro carbonates overlie Famennian Sandbian sandstones in the southern Rocky Mountains and Famennian Sinisima limestones in the northern outcrop areas. Subsurface Wabamun strata overlie the Famennian upper Grania Formation. Contact between the Famennian upper Grania Formation and the Wabamun carbonates is gradational, a result of reworking of upper Grania strata during the Wabamun transgression (see Switzer et al., this volume, Chapter 12).

In the Lizard Basin the Famennian part of the Bens River shales grades eastward into carbonates and shales of the Tetcho and overlying Kotcho formations (Fig. 13.2). These sediments intertongue with shallower-water shelf carbonates of the Stettler Formation via a ramp relationship. Stettler cycle shelf carbonates grade southeastward into evaporite-dominated sediments. In Saskatchewan, equivalent strata are silicilastics and dolomites of the Torquay Formation, and in Manitoba, redbed strata of the Lyleton Formation (Fig. 13.2). Sediments of the overlying Costigan-Big Valley interval are less widespread than those of the Stettler Formation. A shallow sea spread southeastward across the shelf from Montana through southwestern Saskatchewan and southern Alberta into north-central Alberta. Open-marine fossiliferous limestones and shales were deposited, with restricted sediments occurring locally; for example, in the Coleville Basin in Saskatchewan. The northern and eastern present-day limits of Costigan and Big Valley sediments are erosional (Fig. 13.1).

Costigan-Big Valley carbonates and shales are overlain by the Essexwah/Bakken shales and the Bariff silicilastics and carbonates.

Previous Work

The regional distribution and geology of Palliser-Wabamun strata was described in the previous atlas - Geological History of Western Canada (Belyea, 1984). Much of the knowledge that at that time came from the work of Beales (1956) and Sutterlin (1958), and the regional work of Andrichuk (1960) in west-central Alberta, and Christopher (1961) in Saskatchewan.

More recently, regional aspects of Palliser sedimentation were discussed by Morrow and Geldsetzer (1988) and regional Wabamun stratigraphy by Moore (1988). Their work complements work on equivalent strata in the Western United States by Sandberg et al. (1988). Recently, Richards et al. (1991) published significant conodont data, which improved correlations from the United States into Canada.

The early work by Andrichuk (1960) was extended by Metherell and Workman (1969) and Workman and Metherell (1969), with a detailed study of the Crossfield Member in the Stettler Formation of central Alberta. A depositional model for the Crossfield was developed by Eliuk (1984). The concept of sequence stratigraphy was applied to the Palliser Formation in the Moose Mountain area by Styan (1984).


Stratigraphic Nomenclature

Stratigraphic units in Palliser/Wabamun strata are illustrated in the correlation chart (Fig. 13.2). Major unconformities, apparently equivalent in age, separate the onlapping Palliser Formation into the Moro and Costigan members and the subsurface Wabamun into the Stettler and Big Valley formations (Woronoff and Andrichuk, 1956; Richards et al., 1991). The Tetcho Formation and overlying Kotcho Formation of northwestern British Columbia are coeval with the Stettler Formation of Alberta. In north-central Alberta, Stettler carbonates are subdivided into four members. In ascending order they are the Devonville, Whiteclay, Normandville and Cardinal Lake members (Halbertsma and Meijer Drees, 1987). The Crossfield Member is...
WABAMUN/PALLISER ISOPACH AND LITHOFACIES

Thickness contours for the interval from the top Wabamun to the base of the upper Graminia silt (top Blue Ridge and equivalents), and generalized lithology

Contour interval = 50 metres

- Control well
- Well with Cenozoic coverage

- Techo-Katcho outcrop

- Shale, grey, calcareous, with interbedded grey-brown, micritic limestone and minor silts at base

- Limestone, grey-brown, argillaceous and slightly silty, micritic, bioclastic in part; grading upward to calcareous shale, grey-green, marly

- Limestone, buff-brown, massive, micritic, pelleted, with interbedded bryozoan/crystaline dolomite at base

- Dolomite, brown, thinly crystalline, porcellaneous in part; with subparallel lamination of brown, micritic, pelleted limestone

- Interbedded dolomite, brown, microcrystalline, and anhydrite, slightly argillaceous top

- Anhydrite, nodular; overlain by interbedded anhydrite and dolomite; minor bioclastic laminations at top

- Shale, red, clay, slightly marly, with lesser interbedded silt dolomite and anhydrite

Variable lithology in the thinner zones

Scale: 1:5 000 000

Figure 13.3 Wabamun/Palliser isopach (including Graminia silt) and lithofacies map.
Figure 13.4 Distribution of various lithological components in the Wabamun interval (including Graminia silt): a. fine clastics; b. limestone; c. dolomite and d. anhydrite. All are shown as percentages of total thickness.
Figure 13.5 Stettler Formation isopach (a) and lithofacies (b) maps, including Greminits shl.

Figure 13.6 Costigan Member-Big Valley Formation isopach contours and generalized lithofacies. Note open-marine conditions in the western part of the basin.

Figure 13.7 Schematic cross section of Wabamun facies from northeastern British Columbia (NW) to southern Alberta (SE).
developed as a wedge in the middle of the evaporitic facies of the Stettler Formation in central and southern Alberta. It is considered equivalent to the combined Whitclaw and Normandville members of north-central Alberta. The Torquay Formation in Saskatchewan is the equivalent of the Stettler succession and can be subdivided into six units, each of which the middle unit (No. 3) is possibly the equivalent of the Normandville Member of Alberta (Christopher, 1961). The Big Valley Formation is eroded over and north of the Peace River Arch. It is, however, widely developed over central and southern Alberta and overlies the Stettler-equivalent Torquay Formation in Saskatchewan. The Torquay, Big Valley and Bakken formations of Saskatchewan together comprise the Three Forks Group.

Geological and Tectonic Framework

Famennian Palliser/Wabamun cratonic basins can be subdivided into several major elements, reflecting their varied structural history (Fig. 13.1). The farthest basinward sediments are found in the Liard Basin and in outer shelf or basin slope settings in northeastem British Columbia. Shelf sediments occur on the Hay River and Alberta inner shelf areas, separated by the Peace River Arch. The Smoky River Sub-basin is developed on the Alberta inner shelf area just south of the Peace River Arch. Infilling carbonates reflect a slight deepening of the environment. Along the deformed belt, the Sukunka Uplift in the northern Rocky Mountains separates deeper sediments of the Liard Basin from those of the Sassenach Sub-basin in southeastern British Columbia. Inner shelf carbonates, evaporites (Sweetgrass Arch area) and clastics occur to the southeast and east in a more landward position. More restricted clastics occur in the eastern-most Coeville Sub-basin, which is developed on the Saskatchewan inner shelf.

Unravelling relations show that the Peace River Arch remained high-standing but relatively inactive during Stettler sedimentation. This tectonic stability during Stettler deposition holds true for much of the shelf area.

Relative sea-level changes during Stettler deposition appear to be more erosional. This is certainly the case for transgressive upper Morrow/Normandville patch reef and mud-mound carbonates, which can be correlated with similar age mud-mounds in Utah, Nevada and Belgium.

A major erosional unconformity, however, separates the Costigan/Big Valley and Morrow/Stettler strata (Fig. 13.2) and very likely represents the onset of a period of structural instability. This tectonism, which continued well into the Carboniferous (Antler Orogeny), is evidenced by post-Stettler uplift and erosion of the Costigan/Big Valley section in the northern Rocky Mountains, the Liard Basin and the Peace River Arch. Geldsetzer (1982) reported erosional removal of the entire Palliser section north of latitude 54°N and west of longitude 121°W. Bentonites in Big Valley mudstones in Saskatchewan and volcanic ash interbedded with Eocene shales in southeastern and northeastern British Columbia indicate volcanism.

Thicknes and Lithology

The total Wabamun isopach map (Fig. 13.3) reflects true stratigraphic thickness of about 50 m in Saskatchewan, thickening to over 200 m in large parts of Alberta, with further thickening in the northwest in the Liard Basin. There is pronounced thinning over the Peace River Arch (east of Fort St. John). Closely spaced contours along the eastern subcrop edge reflect erosional bevelling at the sub-Cretaceous unconformity. The thickness anomaly near the subcrop zero edge in northernmost Alberta relates to the Peace River impact structure (Glotfelty et al., this volume, Chapter 5). It should be emphasized that the Figure 13.3 isopach interval includes the whole of the Wabamun and equivalents plus the upper Cretaceous silt, down to the top of the Blue Ridge carbonates and equivalents. This top Blue Ridge section (sometimes referred to informally as the F Horizon, because it closely approximates the Quaternary-Frasian boundary) is used in Atlas mapping as the most reliable marker for separating strata of Wabamun basin (Chapter 12) from succeeding strata of Winterburn basin affinity. The stratigraphic base used in constructing Figure 13.3 is thus identical to the stratigraphic top in the maps illustrated in Chapter 12 (see Switzer et al., this volume).

Wabamun thickness trends are not projected into the disturbed belt because of structural complications. Thickness greater than 500 m were reported by Geldsetzer (1982) in the southern Rocky Mountains. These values were, however, measured on fault-repeated sections where accuracy is difficult.

Lithofacies depicted in Figure 13.3, manifest the whole of the Wabamun isopach interval, reflect generalized but cogent trends—such as sandstones and argillaceous carbonates in the northwest, through siltstones and sandstones in the central Alberta, to red beds and dolomite siltstones in the southeast. The percentage distributions of selected lithological components are shown in The maps of Figure 13.4. Isopachs of the two principal stratigraphic units of the Wabamun in the subsurface, namely the Stettler and Big Valley, are shown in Figures 13.5 and 13.6. The Stettler reaches a maximum thickness in Alberta of 250 m, in the depositional east of the Peace River Arch. The Stettler thins to about 30 to 50 m toward the south, into Montana. The overlying Big Valley unit maintains a relatively uniform thickness of 15 to 20 m over most of Alberta and Saskatchewan, with thickness anomalies confined to local areas.

Existent pre-existing topography produced onlap thinning of the Wabamun over the Peace River Arch. Later bevelling further thinned the Wabamun in this area (Fig. 13.5). Post-Stettler uplift due to the Antler Orogeny resulted in considerable erosion and total removal of the Big Valley unit in northwestern Alberta and the Liard Basin areas.

Lithologically the Wabamun shows considerable variation. Morrow/Stettler strata, which form the bulk of Wabamun strata, comprise a distinct suite of lithologies that change laterally according to the environment of deposition (Fig. 13.5a). Dark gray to black coal beds are present in the western Liard Basin, grading to black shale in the central Alberta, and grading to red sandstone and siltstones in the southern, and to sandstone and siltstone in the northernmost Alberta, and thence to the Peace River Arch.
cal, tan to brown, extensively bioturbated wackestones, peloidal packstones and grainstones, which were deposited on a large, semi-restricted shelf, cover most of northern and central Alberta. These strata grade eastward and southward into belts of dolomite and intertidal and supratidal stromatolites, cryptalgal laminates and evaporites in southern and southeastern Alberta, reflecting more restricted and shallower water environments. Further landward, to the east across Saskatchewan and into western Manitoba, restricted nearshore silstones, red beds, dolomites and anhydrites comprise the Stettler-equivalent strata.

One lithofacies is of particular interest, namely the peloidal grainstone. According to Beales (1956), the peloidal grains in the Stettler grainstones and packstones were formed by rolling and accretion in tidal surf and were subsequently deposited in the interior of banks where currents were slack. During the Doorville and Normandyville transgressions the peloids may have been picked up by longshore currents and deposited elsewhere.

In contrast to the Munro/Stettler interval, overlying Costigan-Big Valley sediments consist of mostly gray, argillaceous, highly fossiliferous and finely pyritic limestones. Among the macrofossils, crinoids and brachiopods are most common and are associated with gastropods, bryozoans and possibly corals (Beales, 1956). Humid conditions were possibly more conducive to organic growth (Koets, 1959, p. 26) and the lack of siltka evaporites may well be related to reduced salinity as a result of fresh water influx when supply of aerated salt water at the northern threshold decreased. In Saskatchewan (Fig. 13.6), a Big Valley, highly fossiliferous limestone, the “Crystal limestone”, interfingers with varicolored to green-black, noncalcareous, pyritic shales of the Coleville Sub-basin.
Depositional and Stratigraphic History

Famennian Wabamun sedimentation in the Western Canada Sedimentary Basin represents an overall regressive sequence punctuated by several important transgressive pulses.

The initial Dioxville transgression is particularly well manifested on the Liard Basin slope, as a westward-thinning wedge of open-marine carbonates (Tetcho Formation). The Normandville transgression forms a similar wedge of sediments higher up the ramp and on the shelf, where it is best known as the upper part of the Crossfield Member. Close-of-Wabamun sedimentation was marked by a final transgression during Big Valley deposition. The facies cross section shown in Figure 13.7 schematically depicts the basic relations. The reader is referred to the location map (Fig. 13.1) and the generalized Stettler facies map (Fig. 13.3b) for clarification of the paleogeographic extent of these transgressive events. Basin subsidence or eustatic sea-level rise at the beginning of Stettler deposition resulted in an incursion equated to the first Famennian transgression of Sandberg et al. (1988). Resulting deposits were laid down in environments shallowing to the southeast across Alberta into Saskatchewan. Open-marine carbonates comprising skeletal lime mudstones and wackestones were deposited on the Liard Basin slope as the Tetcho Formation (Fig. 13.7). Mudstones and wackestones were laid down on the outer shelf side of the grainstone barrier complex and higher energy packstones and grainstones deposited in the barrier area. Coeval inner shelf carbonate deposits of the Dioxville Member include peloidal packstones, wackestones and an abundance of peloidal grainstone tidal sand bars (Fig. 13.7). The distribution of peloidal grainstones is represented in Figure 13.8, a lower Stettler net peloid isopach map. Of interest is the concentration of peloids in the Smoky River Sub-basin area.

In southern Alberta, dolomites attain their greatest areal extent in the Dioxville Member. Distribution of dolomites in the Dioxville and overlying Whiteclay members is shown in the composite dolomite isopach map of the Lower Stettler (Fig. 13.9). Evaporites were deposited in a limited area in southeast Alberta (Fig. 13.30). Whiteclay deposits are largely regressive and consist mostly of shallow-water laminated marls, particularly in the northern outer shelf and Liard Basin slope areas (Fig. 13.7). These sediments grade to the southeast into bioturbated wackestones, which in turn shallower upward into lagoonal carbonates, dolomites and evaporites in central and southern Alberta. During lower Stettler deposition the Peace River Arch was still a significant landmass, against which Dioxville and Whiteclay carbonates onlap (Fig. 13.10).

Further details of the lower to upper Stettler transition can be gleaned from outcrops in the Sukisaka area of the northern Rocky Mountains (Fig. 13.1). Here the base of the upper Morro is formed by a black, nonfossiliferous, laminated, 10 mm thick lime mudstone, the so-called “Black Band.” This unit rests with an abrupt contact (hardground) on typical nodular, bedded lower Morro limestones (Geldsetzer, 1982, p. 63). Geldsetzer (op. cit.) suggested that the association of a black laminated lime mudstone grading upsection into beds with algal structures indicates shallow lagoonal conditions. Alternatively, Shoakes (1986, p. 367) argued that these sediments represent accumulation in deep-water, low-energy conditions. Lamination appears to consist of very fine carbonate material and dark organic-rich layers that were essentially undisturbed in the oxygen-starved euxinic conditions found in basin deeps.

In the subsurface, the “Black Band” limestone is represented by a thin, dark, nodular, muddy limestone known as the “second shale marker” (Fig. 13.10). This unit is considered to be the boundary between the Whiteclay and the Normandville members, at the lower/lower Stettler contact (see Halbertena and Mejler Drees, 1987). It is a distinctive gamma-ray log marker. The position of the “Black Band” and the shale marker are illustrated in the schematic cross section through the Suswaarch Basin, central Alberta to Saskatchawan (Fig. 13.11). The black laminated lime mudstone (“Black Band”) at the base of the upper Morro in outcrop is not developed in the subsurface Crossfield Member.

The onlapping upper Stettler Normandville Member accumulated during a transgression, the second Famennian transgression of Sandberg et al. (1988, p. 200), in a seaway that stretched from the Northwest Territories to Nevada. During this extensive transgression a primitive stromatoporoid (Labyrinthia) migrated into the inner shelf of Alberta and formed patch reefs on the northern slope of the Smoky River Sub-basin (Nishida, 1987) and mud-mounds in the upper Crossfield Member (Normandville) in southern Alberta.

The Peace River Arch was almost covered by onlapping Normandville strata (Fig. 13.10). A high percentage of the Normandville strata are grainstones of beach origin, containing peloids formed at the foreslope. Wirooned grainstones may have been transported to other parts of the shelf. Distribution of these peloidal rocks and those of the overlying Cardinal Lake Member is depicted in Figure 13.12, an isochron map of peloids in the upper Stettler. There is a high concentration of peloids in the Smoky River Sub-basin (area enclosed in the 250 m contour on the Wabamun/Palliser isopach map, Fig. 13.3A). A green shale, unit 3, in the middle of the Torquay Formation in Saskatchewan (see Fig. 13.11) suggests a correlation with Normandville transgressive deposits in Alberta (see Christopher, 1963). Dolomite is present in the Normandville and Cardinal Lake units in a north-south-trending belt through central and southern Alberta. Figure 13.13 shows this trend, as well as the distribution of the dolomite associated with the Peace River Arch. The areal extent of upper Stettler evaporites in southeastern Alberta was even less than that of the lower Stettler.

The overlying regressive Cardinal Lake deposits are muddier than the peloidal Normandville carbonates, grading from packstones to supratidal carbonates with birdseye structures, cryptalgal laminites, stromatolites, breccias and dolomites. The upper Cardinal Lake limestones in northern Alberta are particularly muddily, resembling the nodular Whiwhlaike wackestones. Eromion has moved considerable sections of the upper Cardinal Lake, in particular in the Peace River Arch area. In southeastern Alberta, Cardinal Lake carbonates grade into evaporites along the supratidal belt common to all Stettler units.

Costigan-Big Valley carbonates and calcareous shales, which unconformably overlie the Morro-Stettler strata (Richards et al., 1991), were deposited during a transgression, the third Famennian transgression of Sandberg et al. (1988). A preliminary combined isopach and facies map (Fig. 13.1) based on work by Sutterlin (1988), Christopher (1961) and Halbertena (unpublished maps), and a cross section (Fig. 13.14), illustrate the distribution of the Costigan-Big Valley carbonates and shales in southern Alberta and Saskatchewan.

An important faunal hiatus separates the Costigan-Big Valley carbonates from the underlying Morro-Stettler strata. Conodont studies by Richards et al. (1991) indicate that much of what previously has been assigned to the Costigan-Big Valley beds is in fact age equivalent to the upper Morro-Stettler strata and correlates with the subsurface Cardinal Lake.

Costigan-Big Valley carbonates are low-energy, gray lime wackestones and packstones with minor grainstone interbeds. They are fossiliferous and contain considerable amounts of clay (Sutterlin, 1988). Evaporites are rare. Important is the angulaculose character of the Big Valley carbonates in the eastern part of the basin. Abundant pyrite nodules and green shale interbeds in the
highly fossiliferous (mostly crinoids and brachiopods), argilaceous limestone suggest a reducing depositional environment for the shales (Worner and Andruchuk, 1956). A similar limestone is developed in the Coleville Sub-basin in the western part of Saskatchewan, where it is named the "Crystal Limestone" (Kemp, 1959). He described it as a gray, sandy, biotrobal limestone consisting of shell fragments and pellets. Eastward, as shown in the cross section (Fig. 13.14), this limestone gives way to varicolored to greenish-black, noncalcareous Big Valley shales. These latter shales, which were deposited under shallow, anoxic conditions, are strongly pyritic, with some pyrite layers being up to 4 cm thick. According to Christopher (1961), these Big Valley shales are very similar to the overlying green and black Bakken shales, which represent the fourth Farsenian transgression of Sandberg et al. (1988, p. 206).

In northeastern Montana the 22 m thick Trident Member of the Three Forks Formation (possibly equivalent to the Big Valley carbonates) consists largely of varicolored, greenish-gray to olive gray shale. The bottom 7 m, however, is yellow to medium gray dolomitic limestone and silty dolomite. The top 3 m is a massive bed of fossiliferous, argilloaceous limestone, and it is this limestone that is suspiciously similar to the "true" Big Valley in Alberta, whereas the shales have affinity with the Big Valley shales in the Coleville Sub-basin. Farther west, the shale is much thicker (15 m) and contains interbeds and nodules of green to gray, highly fossiliferous, argilloaceous limestone, which increase in number and thickness toward the top (Sandberg, 1965, p. N13). From these descriptions it appears that only the upper 15 m of shale and very fossiliferous, argilloaceous limestone at the top of the Trident Member may correlate with the Big Valley. The lower 7 m of dolomite and dolomitic limestone very likely belong to the underlying Logan Gulch Member of the Three Forks Formation (based on bioclastic stratigraphic data) (see subsequent discussion).

Local and Sub-regional Relations

Two different areas of Wabamun sedimentation are discussed below, to illustrate details of Wabamun stratigraphic and depositional relations.

Peace River Arch

Although high-standing, there are no indications that the Peace River Arch was tectonically active during Sewart deposition. Discoville-Whiteclaw carbonates only partly overlap the arch (see Figs. 13.10 and 13.15). The Discoville Member also thins toward the slope deposits of the Liard Basin, where equivalent strata are named the Tecto Formation.

Distribution of facies and stratigraphic thickness of the Whitelaw Member (Fig. 13.16) appear to be controlled by underlying relief on the arch. For example, silty siliciclastics and marls are closely associated with the exposed portion of Precambrian basement along the crest of the arch, as are dolomites of closely surrounding carbonates. These facies are in turn rimmed by shallow, high-energy peloidal grainstones. Slightly deeper (thicker) parts of the area accumulated bioclastic wackestones. To the east, in the Smoky River Sub-basin, mudstones were deposited.

Normandville carbonates, however, practically cover the Arch (Fig. 13.17). Shallowing of the environment characterizes this unit. Again, close association of facies, isopach values and distance from the creast areas can be seen. Dolomites are surrounded by grainstones, which grade, in the deeper water parts, to bioclastic limestones. The peloidal grainstones are very likely foreshore beach deposits that were further distributed by longshore and tidal currents. Associated with the Normandville transgression was the development of stromatoporoid patch reefs (Nishida, 1987). One example is situated in the Normandville area of west-central Alberta, (Tp 79, R 22, W5M) on the northern slope of the Smoky River Sub-basin and on the lee side of the Peace River Arch. The overall geometry of the patch reef is uncertain, but it appears to trend northeast-southwest. Its length is approximately 4 km, width more than 1 km, and height 10 m (see cross section, Fig. 13.18).

Nishida (1987) established six facies types associated with the patch reef: open shelf, platform, reef, reef flank, off-reef and cap facies. The open shelf facies consists of peloidal and skeletal grainstone and nodular wackestone. The platform facies comprises tabular biostrome to fossilite with peloidal and skeletal mudstone, wackestone and packstone matrix. The reef facies consists of bulbous and tabular stromatoporoid framstone, rudstone and bindstone with a peloidal grainstone and packstone matrix. The reef flank facies is similar to that of the patch reef except it has more grainstone to packstone matrix. The off-reef, grainstone to packstone grades to wackestone. The cap facies is peloidal skeletal grainstone grading to packstone.

The patch reefs are positioned slightly basinward, on the lee side of the Peace River Arch. This is different from the mud-mounds in southern Alberta, which are nearshore (see Fig. 13.19). The patch reefs occur in the Normandville Member, which correlates approximatively with the producing zone in the upper Crossfield Member.
Figure 13.24 Northwest portion of Atlas cross section A-A'. Datum is the Banff Formation. Dashed line in the Banff is the so-called "limestone mark".

Figure 13.25 Western portion of Atlas cross section B-B'.

DEVONIAN WABAMUN GROUP
Regional Stratigraphic Cross Sections

Four Atlas regional cross sections of the Wabamun depositional basin illustrate various lithological and stratigraphic relations of these Fennoscandian sediments. The lithology in these sections, taken from Caronrat logs, is somewhat simplified. These sections are illustrated in Figures 13.24 to 13.27 (sections A-A* to D-D*) and their positions are shown in the general location map (Fig. 13.31).

Cross section A-A* (Fig. 13.24), which extends from the Lard Basin to central Alberta, illustrates possible growth faulting with rapid subsidence on the Lard Basin slope. Thick sections of Tetzio, deep-water fan mudstones and Kootenay shales were deposited, followed by accumulation of radiolarian-shale black shales. The erosional unconformity at the top of the Big Valley, removing it over significant areas, is an important feature of the cross section. Erosion on the unconformity completely removed the Big Valley over significant areas, leaving the Barf Formation (lying directly on up Sediment strata) although in the a-79-B/94-011 well, the contact of the Big Valley with the overlying Euxhah is the Lard Basin slope deposits also is considered to be unconformable.

Cross section B-B* (Fig. 13.25) trends southwest-northeast and is oblique to strike. It illustrates transgressive onlap of Tetzio lobe mudrocks onto the Lard Basin slope and Duxor grainstone deposition in the shelf areas. Of interest is the absence by erosion of Big Valley carbonates, and the lowstand deposition of radiolarian Euxhah black shales infilling erosional depressions (cross sections Fig. 13.32 and B-B* Fig. 13.25).

Cross Section C-C* (Fig. 13.26) is a dip section in the Peace River Arch area. It illustrates considerable uplift to the west, in an area of the northern Rocky Mountains, where the upper Palliser is extensively eroded. Post-Wabamun basement faulting may have allowed the upthrow of brines which delaminated Palliser-Wabamun carbonates. A similar process may have taken place in the Smoky River Sub-basin to the east where horsts were dewatered along southeast-northwest-trending tectonic faults (Packard et al., 1992). Reservoirs created this way are fundamental to the Wabamun oil and gas plays in the Peace River area.

Cross Section D-D* (Fig. 13.27) illustrates the mainly dolomitic and anhydritic facies of the various members of the Stettler Formation in central Alberta. The Duxor Member consists mainly of anhydrite but the overlying Whiteclay comprises a restricted facies with bioturbated wackestones at the base grading upward into peloidal grainstones. The Normandville Member consists mainly of peloidal grainstones and dolomites. Anhydrite and dolomites with bioturbated wackestones comprise the lower Cardinal Lake, but the upper section of this member consists entirely of bioturbated wackestones. Only small remnants of the partly eroded Big Valley Formation are preserved.

In Saskatchewan, Cross Section H-H* (Fig. 13.28) illustrates the subdivision of the Tongue Formation into six units (Christopher, 1961). These are extensively weathered saskatchewan type silty dolomite and anhydrite facies separated by possible unconformities. Of interest are the varicolored to green-black noncalcareous shales of the Big Valley Formation, which probably were deposited in a tidal-flat environment but are similar to the overlying lower Bakken green and black shales.
Figure 13.28 Three Forks Group cross section H-H'. Modified after Christopher, 1981. Note that the vertical scale (1:1600) is considerably expanded from the Atlas cross section standard (1:6000).
Well Reference Sections

Five well reference sections (numbered 1 to 5 on Figure 13.3) illustrate a variety of lithofacies representing the various depositional environments of the Wabamun. These sections are shown in Figures 13.29 - 13.33.

Section 1 (Fig. 13.29) shows the muddy subtidal character of the Whitemud and upper Cardium Lake vertebrate units. These are in direct contrast to the laterally progradational Dixieville and Normandville members, which comprise clean peloidal grainstones.

Section 2 (Fig. 13.30) shows shoaling grainstones and dolomite in the Dixieville. The thick Whiteleaf contains very muddy, fossiliferous carbonates, which are characteristic of the Smoky River Subbasin. Most of the producing wells (Tangent, Terper, etc.), which are on horsts at the northern limits of the basin, have this thick Whiteleaf interval. Stromatoporoids and grainstones are common in the Normandville patch reefs (Nishida, 1967) and well developed in this borehole. Cardinal Lake strata are muddy with some local grainstone beds.

Section 3 (Fig. 13.31) represents the more evaporitic facies of the Dixieville and Whiteleaf units in an area where dolomites and anhydrites are more common in the Wabamun. Grainstones are common in the Normandville and the lower Cardinal Lake units but the muddy upper Cardinal Lake and the fossiliferous, muddy Big Valley suggest very shallow-water environments.

The composite outcrop section by Stony (1984), Section 4, (Fig. 13.32) is correlated with a nearby outcrop well, Shell Moose, 10-32-22-6W5. Facies in the Shell well are far more evaporitic than the outcrop section, which has more similarities to the Smoky River subsurface (Fig. 13.30). In outcrop the Dixieville is dolomitic but it in the Shell well is more evaporitic, with massive anhydrite. The restricted Whiteleaf equivalent is muddy and lacks grainstones in outcrop but is very dolomitic in the Shell well. The resistant weathering of the transgressive Normandville equivalent in outcrop is due to the abundance of early cemented grainstones. Thin bedded characterizes the restricted Cardinal Lake equivalent limestones and dolomites in outcrop and is common in the upper parts of major regressive carbonate sequences (Wilson, 1975, p. 281). The Cardinal Lake unit in the Shell well contains regressive, massive anhydritic dolomite and anhydrite.

Figure 13.30 Reference section 2 - Supero Saxsmith 9-33-73-5W6 (Grande Prairie-Tasppee area, Alberta).

Figure 13.31 Reference section 3 - Imperial Cynthia 3-152-11-WS (west-central Alberta).

Figure 13.32 Reference section 4 - Shell Moose (7) 10-32-22-6W5 (Moose Mountain area, Alberta foothills). Modified after Stony (1984).
Section 5 (Fig. 13.33) illustrates Wabamun-equivalent stratigraphy and lithology in western Saskatchewan. The T3 shale unit in the middle of the Toolebay Formation is probably the equivalent of the transgressive Normandville Member in Alberta. According to Christopher (1961), this green shale was widely deposited over the unconformity that separates T3 from the underlying T2 unit, during a transgressive pulse. The other five units in the Toolebay are weathered, silty dolomites and anhydrites (regoliths), separated by discontinuities (Christopher, 1961).

Stratigraphic Analysis

Geophysical Well Log Correlations

Geophysical well logs are amongst the most important tools available along with the evidence provided by the log trace patterns, in conjunction with sample and core data, help define stratigraphic subdivisions, lithologies and depositional environments. Log characteristics of various Wabamun lithologies include:

1) high-energy deposits such as packstones and grainstones related to b还原 states and shallow environments of the Normandville Member, with higher than average porosity compared to other Wabamun carbonates, appear "clean" on the gamma-ray log, that is, they show a weak radioactivity of 10 API units maximum;
2) low-energy and restricted subtidal deposits, rich in micrite and clay, such as the Whitelaw and upper Cardinall Lake members are "dirty" on the gamma-ray log, with radioactivity readings varying between 10 and 40 API units.

Regional gamma-ray markers form the basis for correlation of units. In the outer parts of the basin these regional markers occur at the base of the Whitelaw, upper Normandville, upper Cardinall Lake and Big Valley units. In the more open-marine part of the basin, however, some units are not correlated. In the middle Cretaceous deposits are less obvious (Meijer Drees and Geldsetzer, 1984). The use of shale-potential logs is more effective for correlation purposes (Fig. 13.34). These shales indicate slightly regressive, normally laminated conditions and the unit boundaries are picked at the highest gamma-ray and lowest self-potential readings (maximum organic matter).

Depositional Analogue

Depositional sequences in the Stettler Formation of the Western Canada Sedimentary Basin closely resemble the middle Cretaceous Mshibat Formation of the Middle East (Revel, 1982, p. 161-173). The Mshibat Formation is a regressive carbonate sequence underlain by basinal facies and capped by a regional unconformity. It can be subdivided into two sequences, both of which have a transgressive-regressive couplet: 1) the basal sequence, which ranges from open marine to restricted lacustrine and 2) the upper sequence, composed of outer shelf deposits overlain by inner shelf deposits. A sedimentary discontinuity apparently separates the two sequences. The basal sequence is similar to the transgressive-regressive Tertiary-Lower Kootenay sequence at the Lizard Basin slope or the transgressive-regressive Door County-Whitehorse sequence on the shelf. The upper sequence, however, is similar to the transgressive-regressive Normandville-Cardinall Lake sequence on the outer and inner shelves.

As a result of the extensive block faulting, the net deposition of the Mshibat carbonates was more heterogeneous than that of the Stettler. Subsidiary removal and leaching of carbonates associated with the regional unconformity-capping the Mshibat was significant and created excellent reservoir conditions, not matched in the Stettler (Harris et al., 1984).

Regional Biostratigraphy and Correlations

Correlation of Palliser/Wabamun rocks with age-equivalent units in the United States is handicapped by lack of faunal evidence in Canada, condordants in particular. Recently, efforts have been made by Richards et al. (1991) and Meijer Drees and Johnston (1992) to rectify this problem. Derived from condordant zones, their correlations, based on the work of Sandberg et al. (1986), are illustrated in Fig. 13.34.

The following is a summary of the main points of biostratigraphic correlation issues relating the Fmmeanum of Canada to apparent counterparts in the United States (1982).

In the United States, the Middle Triangularis Zone is regarded as the beginning of the first Famennian transgression. Although in Canada condordants have not been found in the lower Morrow Member (unit 1 of Meijer Drees and Johnston, 1992) or the lower Drouinville Member, it is possible that they correlate with the lower Logan Gulch Member (Three Forks Formation). The Middle Logan Gulch Member in Montana contains the cephalopod Zone and correlates with the Whitelaw Member in the subsurface of Alberta and unit 2 of the Palliser Formation (lower Morrow) of Meijer Drees and Johnston (1992).

In the United States, rocks of the Lower marginalosa Zone of Sandberg et al. (1986, p. 202) record a significant global rise in sea level, the second Famennian transgression of Sandberg et al. (1986). Correlation of this zone in this zone includes the upper part of the Logan Gulch Member in Montana, which correlates with the Normandville Member of the Stettler Formation and the lower part of the upper Morrow Member of the Palliser Formation in Canada. Meijer Drees and Johnston (1992) reported that the latter unit, which correlates with unit 3 of the Palliser member, contains Lower marginalosa zone fossils. Stromatoporoid mounds in the Normandville (upper part of the Crossfield Member) in southern Alberta are similar in shape to similar mounds in the age-equivalent Gilmerton Formation in northwest British Columbia (Dreessen et al., 1989, p. 203) and in Belgium (Dreessen et al., 1985). The interbedded dolostones, carbonate breccias, laminated and silty limestones, and carbonaceous limestones of unit 4 (Meijer Drees and Johnston, 1992) probably correlate with the Cardinal Lake Member of the Stettler; however, no condordants have been found in the latter to confirm the correlation.

The upper marginalosa Zone has not been recognized in the United States and is considered to be absent or non-existent in the Canadian basin. The Central Brook Valley is of significant magnitude in the Western Canada Sedimentary Basin. In Canada, only the upper five metres of which was originally identified as the Canadian Member of the Palliser correlates with the Big Valley Formation in the subsurface. These are highly fossiliferous and argillaceous siliciclastic limestones that have no affinity with the underlying interbedded dolostones and silty limestones, which are most likely of upper Morrow equivalents (Worster and Andrichuk, 1986, p. 106; Richards et al., 1991). In the Triassic type section, only the upper 15 m are of dark grey fossiliferous shale and argillaceous argillaceous limestone. At the bottom are 7 m of silty dolomite and dolostone. The argillaceous argillaceous limestone at the base of the black shale section at Logan Lake, which is normally either not searched for condordants or did not yield any, but it is possible that only the upper 15 m correlate with the Big Valley and the lower 7 m belong to the Logan Gulch.

According to Richards et al. (1991), both the Costigan/Big Valley and the overlying Eshwav are within the exposure Zone. In the United States only the Sinopah Member of the Three Forks, which correlates with the Eshawak and Bakken formations in Canada, is identified as containing the lower exposure Zone (Sandberg et al., 1986, p. 203). Richards et al. (1991, p. 53) included the Famennian Eshwak in the "Barron assemblage", because of its shallow-water to supraflidal siliciclastic affluity with the overlying Eshwav Formation. It is proposed that the Costigan/Big Valley units also be added to the "Barron assemblage" for the same reason. They not only unconformably overlap the upper Costigan/Big Valley assemblage, they also contain the exposure Zone as the overlying Eshwav/Bakken formations. Furthermore, the Big Valley shales in Saskatchewan are practically identical to the overlying lower Bakken shales.

Structure and Hydrocarbon Occurrences

Structure

A structural map of the top of the Wabamun Group is displayed in Figure 13.35. The map shows the structural development of the underlying craton platform basins by tectonic loading during the Late Cretaceous and early Tertiary.

Structurally high areas are preserved north of the Peace River Arch and flanking the Peace River. The areas are possibly reflect pre-Middle Devonian compressive deformation due to an intracontinental high (see Roser and Englemann, 1989). Further evidence of this deformation is provided by an extensive northeast-southwest transverse faulting in the area of the Peace River Arch (Saknak and Rogers, 1959).

Hydrocarbon Occurrences

Commercial production of oil and gas from the Wabamun Group occurs frequently. Locations of the major oil and gas fields are set out in Figure 13.35.

Gas fields with the largest reserves are those associated with stratigraphic entrapment in the Crossfield Member. The Crossfield productive trend extends from Olds to Otolocks in the southern Alberta plains and is parallel to the main facies trends in the area (Figs. 13.33 and 13.34). Seis gas is trapped in modolic and vaggy porosity occurring in dolomitized stromatoporoid mounds and gastropod mounds. Up dip seals are provided by nonporous evaporitic dolomites and anhydrites (McNamara and Wandel, 1992). The positioning of mounds is closely related to maximum tidal erosion of the Whitelaw subastratum at the foreshore (Fig. 13.23).

The paleo-high in the Edmonton area between latitudes 52 and 54°, illustrated on the Wabamun/Palliser isopach and lithofacies map (Fig. 13.33), appears to define the dry gas productive trend of subcrop traps. These fields are flanked by pre-Cretaceous truncation of the older sediments. Gas is trapped in intercaloidal and dolomite-associated porosity, sealed by overlying impermeable Mesozoic carbonates.

In the southern Alberta foothills the Wabamun is involved in thrusting. Where dolomitized (most of the reservoirs are associated with the Crossfield Member) and in structural closure, these traps make good fields, especially where permeability is enhanced by fracturing.

In the Peace River Arch area, Wabamun oil and gas fields occur in, and are associated with, faulted and horst structures. These features occur at the northern edge of the Smoky River Sub-basin, branching the crestal portions of the Peace River Arch (Fig. 13.36). Most reservoirs occur in fault-controlled, hydrothermal, white dolomites (Stokes, 1987; Packard and Pellegrin, 1989). Two dominant fault trends can be recognized in this area: northwest-trending synclinal units and south-southwest transverse faults, possibly associated with compression (Chuchur and Majd, 1989). The tension faults were involved in the formation of the extensive Peace River rift basin (Peace River Embayment) after Wabamun deposition. Movement of the hangingwall allowed hot, magnesium-rich, dolomites to be exhumed by fracturing. These features occur in particular Normandville grainstones (Packard et al., 1992; Halim-Dhadhia and Montoury, 1992). However, the present-day disposition of Wabamun oil and gas fields is probably the result of inversion of the Peace River basin in Laramide time by reactivation of the extensive fault system in compression. Similar tectonic positions of the Peace River Arch (Figs. 13.30 and 13.36) at the western edge of the Peace River Arch in northeast British Columbia.
Figure 13.35 Wabamun/Palliser structure map, showing nomenclature at the subcrop surface and prominent oil and gas fields.
Discussion

The stratigraphic history of Stettler carbonates indicates that eustatic sea-level fluctuations had a major influence on sedimentation rates. Graisstones and other clean carbonates deposited during rapid build-up relate to transgression, whereas argillaceous carbonate and shale lithologies represent periods of slower deposition during regression or transition. During the first Famennian transgression (Sandberg et al., 1980) Tetcho carbonates covered much of the Hay River outer shelf (Hard Basin slope), at about the same geographic position as the carbonates of the upper Frasnian Kakisa Formation (Morrow and Geldsether, 1988). These Tetcho reefs interdigitate up-stream with the Duvvavine inner shelf carbonates, the lowest unit of Palliser-Wabamun strata. Overlying regressive Lower Kotcho calcareous siliciclastics on the outer shelf interfinger with restricted argillaceous Whitlawn carbonates on the inner shelf.

During the following and most important highstand, brought on by the second Famennian transgression of Sandberg et al. (1980). Normandville-Cardinal Lake shelf carbonates produced platform-like systems, characterized by rapid build-up. Consisting mainly of prograding, shoaling graisstones, these sediments bear remarkable similarity to the Mishrif model of Reidel (1982, p. 169).

On the comparatively open carbonate shelf in northwestern Alberta, the Stettler succession correlates very well to Wilson's (1975, p. 252) model for carbonate build-up cycles. Further east, where carbonate and evaporite deposits intermingle, the succession reflects persistently hot and dry climatic conditions, in a system that reacted sensitively to intermitten sea-level fluctuations. On the innermost shelf, in southeastern Alberta and Saskatchewan, the succession is dominated by stacked supratidal facies. All of the Stettler evaporite-carbonate-shale sequences thus have a similar history, but they were developed at different positions on the platform.

The pyritic, gray, argillaceous, Costigan/Big Valley limstones and shales unconformably overlie the Stettler succession and appear to have little reef affinity to it. Indeed, Big Valley lithologies and depositional environments appear to be more akin to clastics and carbonates of the overlying Exshaw-Barr and Banff-Lodgepole successions ("Barr formation" of Richards et al., 1991, p. 55). In particular the noncarbonates, varicolored and green black shale facies of the Big Valley in the Williston Basin are, according to Christopher (1961), very similar to the overlying noncalcareous Lower Bakken (McQuarrie and Sandberg, 1970).

Because of their lack of evaporites, Costigan/Big Valley strata were considered to represent highstand transgression (Andrichuk, 1980; Richards et al., 1991). An alternative model involves lowstand conditions, with the most pyritic black shales deposited in stagnant and anoxic environments on the confined shelf. Volcanic activity, as evidenced by bentonites in the Saskatchewan Big Valley, may have contributed to the anoxia.

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