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Stratigraphy of Lower and Middle Devonian carbonate rocks of northeastern British Columbia[1]

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Abstract: Devonian carbonate rocks of northeastern British Columbia overlie the "sub-Devonian unconformity" and pass upward to shale of the Besa River Formation. Lowermost of these carbonate rocks is the thick Muncho-McConnell Formation shallow marine carbonate rocks. In the northern part of the study area the Wokkpash Formation, a dolomitic, quartz arenite sandstone displaying soft-sediment deformation, separates the Muncho-McConnell from the overlying Stone Formation, but in the south the Wokkpash is absent. The thick, uniformly grey and bluish-grey dolomite units of the Stone Formation display fenestral fabric, mud-chip breccias, and finely laminated beds. The gas-bearing Dunedin, Keg River, and Slave Point formations, overlying the Stone Formation in outcrop, are dominantly micritic to fine-grained fossiliferous marine limestone. Transitions from off-reef to reefal in these strata are accompanied by an increase in fossil abundance and size, and increased dolomitization. Several different breccia types are found within the Dunedin and Stone formations associated with dolomitization.

Résumé : Dans le nord-est de la Colombie-Britannique, des roches carbonatées dévoniennes recouvrent la «discordance subdévonienne» et passent vers le haut au shale de la Formation de Besa River. Les roches carbonatées épaisses de mer peu profonde de la Formation de Muncho-McConnel constituent l'unité inférieure. Dans la partie nord de la région à l'étude, la Formation de Wokkpash, quartzarénite dolomitique présentant une déformation caractéristique des sédiments tendres, sépare les roches de la Formation de Muncho-McConnel de la formation sus-jacente de Stone; au sud, la Formation de Wokkpash est absente. Les épaisses dolomies uniformément grises et bleu-gris de la Formation de Stone présentent une structure vacuolaire, des brèches avec fragments de boue et des lits en fines lamines. Les formations gazéifères de Dunedin, de Keg River et de Slave Point, qui recouvrent en affleurements la Formation de Stone, se composent principalement de calcaires marins fossilifères micritiques ou à grain très fin. Les transitions de milieux non récifal à récifal dans ces strates s'accompagnent d'un accroissement de l'abondance et de la taille des fossiles et d'une dolomitisation accrue. Des brèches de plusieurs types différents associées à la dolomitisation sont présentes à l'intérieur des formations de Dunedin et de Stone.

[1] Contribution to the Central Forelands NATMAP Project

INTRODUCTION

A stratigraphic study of the Lower and Middle Devonian carbonate rocks of northeastern British Columbia was performed in conjunction with the NATMAP Central Foreland Project. Four weeks in the summer of 1998 and two weeks in the summer of 1999 were spent doing fieldwork in the Halfway River (NTS 94 B), Trutch (NTS 94 G), Tuchodi Lakes (NTS 94 K), and Toad River (NTS 94 N) map areas (Fig. 1). Twenty stratigraphic sections were measured, each ranging in thickness from 144 m to 1495 m. The sections included rocks of the Muncho-McConnell, Wokkpash, Stone, and Dunedin formations. In addition to outcrop sections, cores from the studied map areas were described, and geophysical logs of all wells that penetrated the Devonian were assembled.

The purpose of this study is to examine and characterize Devonian facies changes, particularly within the economically important Dunedin Formation, and to correlate these rocks with correlative strata in the subsurface to the east. This paper discusses some preliminary observations and interpretations based on fieldwork.

STRATIGRAPHY

Devonian strata in northeast British Columbia were deposited in tropical to subtropical marine waters, within two major tectono-sedimentological provinces in the Canadian Cordilleran Miogeocline (Morrow and Geldsetzer, 1988).

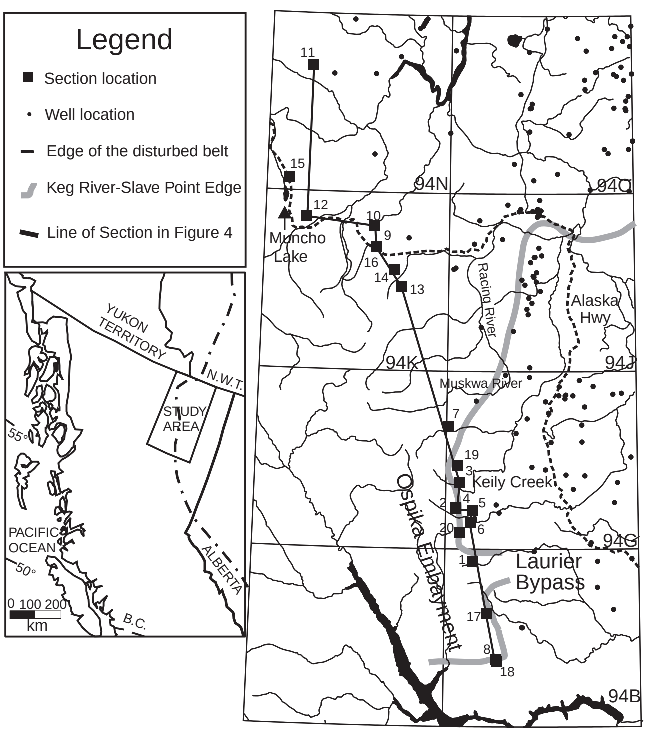

Figure 1. Location of study area. Section 9 of the Stone Formation and section 16 of the Dunedin Formation were measured along the previously defined type-sections for the two formations (Taylor and Mackenzie, 1970).

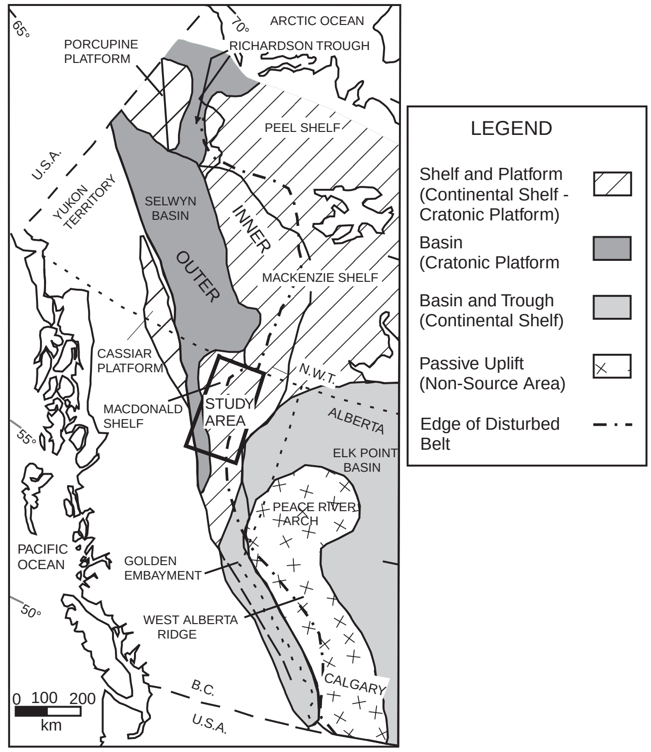

***Figure 2.** Tectono-sedimentological map during the Devonian. The study area lies within the MacDonald Shelf, an area within the Inner Continental Shelf and Cratonic Platform. To the north, the MacDonald Shelf borders the Meilleur Embayment, an extension of the Selwyn Basin.* Modified from *Morrow and Geldsetzer, 1988.*

The strata in the outcrop belt were deposited on an inner continental shelf, whereas most correlative subsurface strata were deposited on the more slowly subsiding cratonic platform to the east. All of these rocks were deposited on the MacDonald Shelf, an area of uniformly shallow marine deposition that extended across both of these tectono-sedimentological provinces (Fig. 2).

In the Late Silurian, with termination of the Tippecanoe Sequence, marine waters retreated and exposed strata of the Silurian Nonda Formation. The Kaskaskia transgression began in latest Silurian time and marine waters once again covered the Nonda Formation. This caused deposition of the Lower Devonian Muncho-McConnell Formation, a thick unit of shallow marine carbonate rocks unconformably overlying the Nonda Formation (Taylor and Mackenzie, 1970). Basal Muncho-McConnell strata are recessive, slightly argillaceous, and pass upward to a succession of alternating light and dark grey, finely crystalline to microcrystalline, medium-bedded dolostone. Floating quartz sand, desiccation breccia, rarity of fossils, and additional primary sedimentary structures indicate deposition in peritidal environments, particularly eastwards (Taylor and Stott, 1973).

North of Keily Creek, in the Trutch map area (Fig. 1), the Muncho-McConnell Formation is overlain abruptly by dolomitic quartz arenite of the Wokkpash Formation. South of Keily Creek, the Wokkpash Formation is missing, and basal sandy dolomite of the Stone Formation directly overlie the Muncho-McConnell Formation (Taylor and Mackenzie, 1970; Fig. 3).

The Wokkpash Formation is a thin sequence of shallow-water, dolomitic, quartz arenite sandstone, easily recognized in outcrop and in regional mapping due to its yellow-brown weathering (Taylor and Mackenzie, 1966, 1970). A shallow water depositional environment is indicated by crossbedding, shrinkage cracks and desiccation breccia, and evidence of anhydrite and collapse breccia near Muncho Lake (Taylor and Stott, 1973). The upper contact with the Stone Formation is sharp and unconformable (Taylor and Stott, 1973), but shows little erosion.

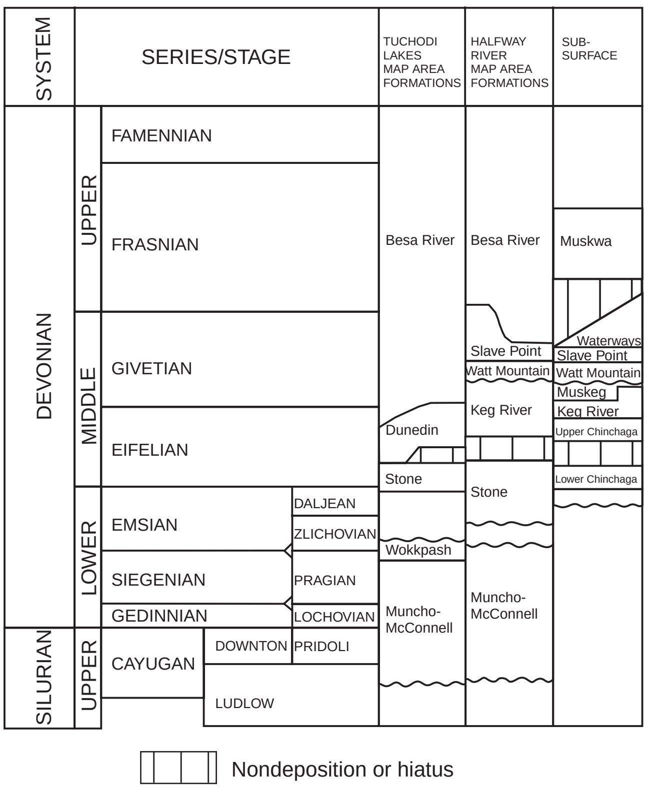

Figure 3. *Stratigraphy of the study area. Tuchodi Lakes map area (NTS 94 K) represents the northern part of the study area whereas the Halfway River map area (NTS 94 B)*

Three main facies are recognized in the thick, uniformly grey and bluish-grey dolomite beds of the Stone Formation (Taylor and Mackenzie, 1970). The first facies occurs in areas where the Wokkpash Formation is absent. It is developed in the lower part of the Stone Formation and is characterized by a high proportion of well rounded quartz sand grains scattered throughout dolostone beds. In central regions, between the Racing and Muskwa rivers, the second facies contains a high proportion of dolomite breccia, with tabular and largely conformable breccia sheets up to 4 m thick and several hundreds of metres long. The breccia, with angular clasts cemented by coarse white calcite or dolomite, and less commonly barite, was likely formed along subsurface conduits or channelways that were largely stratigraphically controlled. Brecciation likely took place before the overlying Dunedin Formation was deposited (Taylor et al., 1975). The third facies occurs northwest of the Racing River in the Toad River map area, and consists of a prominent cyclic alternation of medium and light grey, finely crystalline dolostone units. The Stone Formation reaches a maximum thickness of 1000 m in this area. Fossils and distinguishing sedimentary features are very rare throughout the formation, but fenestral fabric indicates deposition in a shallow water peritidal environment.

During deposition of the Stone Formation, marine waters had transgressed far enough inland to allow deposition of the first Devonian formation on the cratonic platform. The correlative Lower Chinchaga Formation is a thin succession of light grey to brown, sandy anhydrite, dolomite, and sandstone (Norris, 1965). Deposition ended with the mid-Eifelian regressive interlude, which deposited a clastic marker above the Lower Chinchaga Formation, the mid-Chinchaga detrital break (Williams, 1981). This disconformity may be the same as that found at the contact between the Stone and Dunedin formations (Morrow, 1978), though of much greater magnitude. The contact is marked by an abrupt change from dolomite to limestone, and is apparently conformable in the north and west of the study region in the Toad River map area (NTS 94 N), but becomes more clearly disconformable to the south (Taylor and Mackenzie, 1970).

The Dunedin Formation, the main formation of interest to this study (Fig. 3, 4), is a sequence of bedded, dark grey, and argillaceous, dominantly micritic to fine-grained fossiliferous marine limestone (Taylor and Mackenzie, 1970). North of Keily Creek, the formation consists of two main

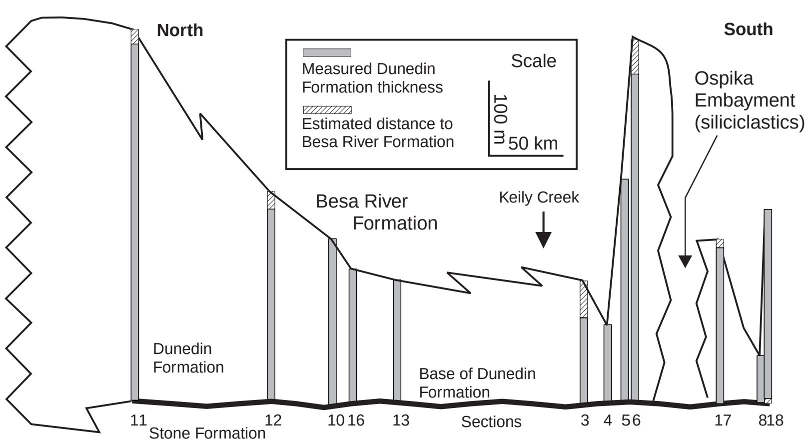

Figure 4.

Thickness changes within the Dunedin Formation throughout the study area. The steady thickness decrease from north to south has been affected by the proximity of the Keg River Barrier.

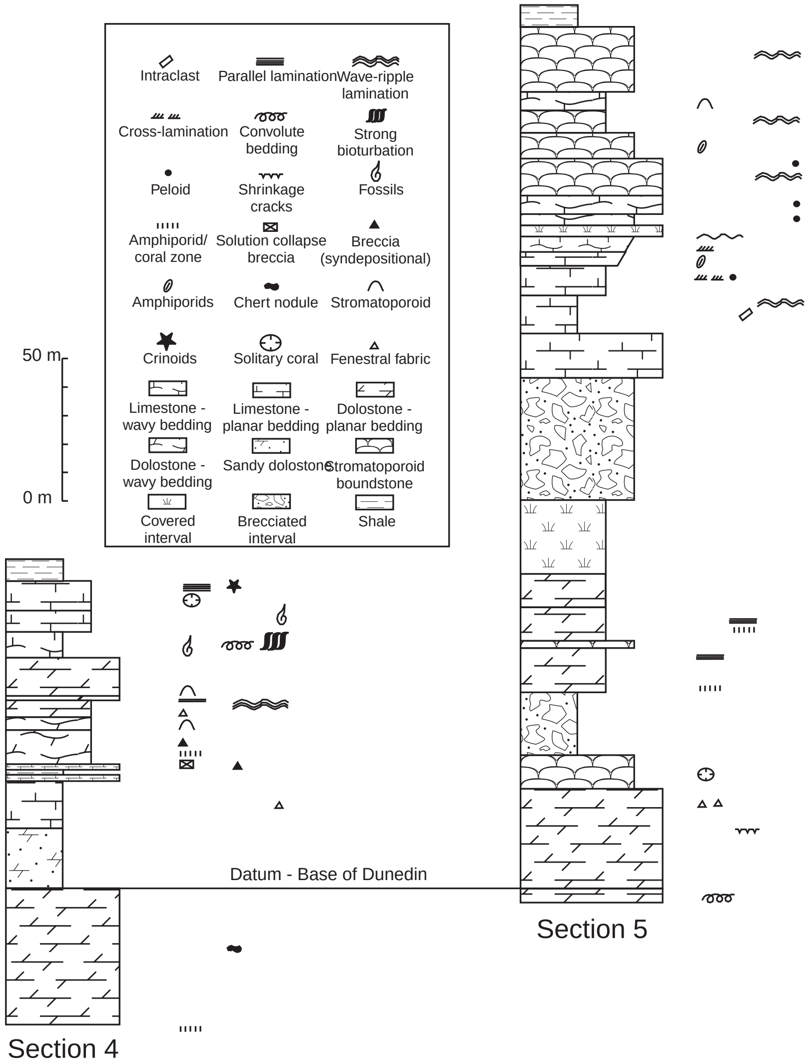

Figure 5.

Thickness and lithological variations between the off-reef (section 4) and reef (section 5) facies of the southern Dunedin Formation. This illustrates the effect of the Keg River barrier complex.

units, lower dolomitic peritidal deposits and upper subtidal deposits, recording an upward transition to deeper water deposition (Morrow, 1978). South of Keily Creek the formation changes to reefal and off-reef facies (Fig. 4; Taylor and Mackenzie, 1970). Southern areas also contain abundant sand in the lower portion (Morrow and Geldsetzer, 1988). In the Halfway River map area (NTS 94 B), Taylor et al. (1975) correlated the reefal Dunedin facies with those found in the extensive subsurface barrier complex (*see* below), including formations that are younger than the Dunedin Formation at its type section. Thompson (1989) mapped all strata above the Stone Formation and beneath the Besa River Formation in the Halfway River map area (NTS 94 B) as “Dunedin Formation” but clearly recognized that some of his mapped Dunedin is in fact part of the Keg River (Pine Point) to Slave Point formational sequence of the reefal Keg River Barrier (Fig. 19, Thompson, 1989). As the Eifelian marine transgression continued, Dunedin Formation deposition concluded. The sharp contact between the limestone of the Dunedin Formation and shale of the overlying Besa River Formation is diachronous, representing the Eifelian in the north and the late Givetian in the south (Taylor and Mackenzie, 1970). Interfingering between the Dunedin and Besa River formations occurs in some locations in the Toad River (NTS 94 N) and Tuchodi Lakes (NTS 94 K) map areas (Fig. 5).

Correlative formations were deposited to the east along the edge of the inner shelf province, above the mid-Chinchaga detrital break. The Upper Chinchaga Formation composed of interbedded anhydrite and dolomite, is correlated with the lowermost Dunedin Formation (Williams, 1981). With continued transgression, more open-marine platform carbonate rocks of the lower Keg River Formation were deposited. These carbonate rocks are dark brown, dolomitic, fine grained, and crinoid- and brachiopod-bearing (Belyea, 1970). Stromatoporoid and coralline reefs and mounds formed in the increasingly deepening water, eventually coalescing into an extensive barrier complex (Morrow and Geldsetzer, 1988). Deposition of the Keg River barrier complex ended with the Watt Mountain regression in the mid-late Givetian (Williams, 1981). The edge of this barrier complex, referred to as the Keg River–Slave Point edge, intersects the Devonian outcrop belt in the study area (Fig. 1, 5).

The approximate north-south shelf-edge trends common to all Devonian formation were disrupted in the northern part of the Halfway River map area (NTS 94 B). A paleogeographic feature, which existed here from the mid-Ordovician through to the mid-Devonian, was described by Thompson (1989) as an extension of basinal strata of the Ospika Embayment eastward, or cratonward, through the shelf (Fig. 1). This is provisionally named here as the "Laurier Bypass" after Mount Laurier in the Halfway River map area (NTS 94 B). During the Devonian, two siliciclastic units were laid down within this bypass, or corridor, through the shelf (Williams, 1981). The basal unit is a brown siltstone, characterized by laminated calcareous and noncalcareous siltstone with some ribs of laminated grey dolostone. This unit can contain "rip-up" clasts, interbedded fine crystalline crinoidal limestone beds, and fossiliferous black chert. This unit is overlain by a dolomitic quartz sandstone unit, which contains a large proportion of rounded and frosted quartz grains. This sandstone is massive, unsorted, and relatively featureless apart from occasional cobble-sized fragments of light grey dolostone.

Extensive postdepositional dolomitization of the barrier complex into the Presqu'ile-type hydrothermal dolomite, improved the hydrocarbon reservoir quality of the barrier complex. Similar dolomitization has been found in the Dunedin Formation in the Trutch (NTS 94 G) and Halfway River (NTS 94 B) map areas.

FIELD RESULTS

Many features observed in these Lower and Middle Devonian formations are discussed in the 'General stratigraphy' section. The section entitled 'Regional facies development of the Dunedin Formation' describes more regional features of the Dunedin Formation, such as dolomitization patterns, thickness variations, and geometries of facies variations.

Figure 6. *Erosional contact between the Silurian Nonda Formation (bottom) and the Siluro-Devonian Muncho-McConnell Formation (top). The pencil tip marks the contact. The contact marks the end of the Tippecanoe Sequence and the start of the Kaskaskia Sequence. Photograph from section 2, base of unit 1.*

General stratigraphy

Four field sections included strata from the Muncho-McConnell Formation, and two contained the basal contact with the Ordovician and Silurian Nonda Formation. The Nonda Formation is a dark grey, fossiliferous limestone with an abundant coral and stromatoporoid fauna. Section 2 clearly showed the unconformable contact, with up to 20 cm of relief, between darker Nonda Formation and lighter, barren, Muncho-McConnell Formation (Fig. 6).

The Wokkpash Formation was only encountered north of Keily Creek, and its distinctive weathering pattern and high quartz composition allowed for reliable field identification. Features seen included soft-sediment deformation (Fig. 7), trough crossbedding, and some sedimentary breccia units, which were most abundant near Muncho Lake in the Toad River map area (NTS 94 N).

Shallow marine to peritidal Stone Formation dolomite beds displayed fenestral fabric, mud-chip breccia, and finely laminated beds (Fig. 8). Several different types of breccia

Figure 7. *Soft-sediment deformation of the Wokkpash Formation. A thick sandstone bed with cross-stratification underlies a similar bed that has been contorted due to soft-sediment deformation (arrow). Beds are approximately 1 m thick. Photograph from section 9, unit 6.*

Figure 8. *Typical appearance of Stone Formation strata. The laminations show bird's eye fenestral fabric, and some mud-chip breccia (seen just above hammer tip). Photograph from section 9, unit 12.*

occur within the Stone Formation. Barite and calcite cemented solution-collapse breccia occur in the northern sections, mostly in the Tuchodi Lakes (NTS 94 K) and Trutch (NTS 94 G) map areas (Fig. 9). These breccia units contain fragments, poorly sorted, subangular, and cemented by coarsely crystalline barite or calcite, of the surrounding

Figure 9. *Barite-cemented solution-collapse breccia. Acicular barite crystals can be seen replacing some of the dark dolostone host rock (at pencil tip). Photograph from section 9, unit 16.*

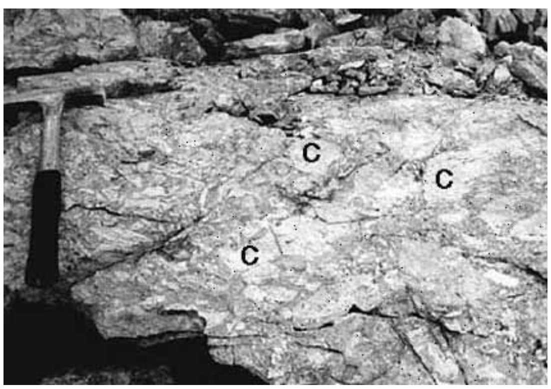

Figure 10. *Sedimentary rubble breccia within the Stone Formation. The lighter clasts (C) are dolomicrite within a darker dolomite matrix. Photograph from section 19, unit 12.*

Figure 11. *Hydrothermal dolomitization of the Dunedin Formation. Limestone has been altered to white crystalline dolomite, vugs (V) are often rimmed with saddle dolomite and late-stage quartz crystals. Photograph from section 17, unit 6.*

formation, forming a cemented rubble pack or mosaic breccia. Sedimentary breccia units (Fig. 10) occur in the more southerly sections, but also in the Tuchodi Lakes map area (NTS 94 K). Clasts within these breccia units are composed of light coloured dolomicrite in a darker dolostone groundmass. Section 17 displayed a hydrothermal dolomite breccia, similar to that seen in nearby overlying strata of the Dunedin Formation. In this case the rocks have been dolomitized, changing the grey and normally featureless strata into a mosaic of light grey dolostone patches surrounded and cemented by coarsely crystalline dolomite, with many remaining vugs and open pore spaces.

Along section 17 the majority of the Dunedin Formation displays hydrothermal dolomitization (Fig. 11). This alteration also occurs in other sections in the southern study area, usually within the reefal beds. Another type of dolomitization is alteration along bedding planes, giving the rock a zebroid appearance (Fig. 12). This alteration is also most common in the south of the study area. In the northern areas, extensive solution-collapse brecciation is common. Mosaic and rubble breccia is most common, with cements ranging from calcite (Fig. 13) to barite (Fig. 14).

The sedimentary features within the Dunedin Formation are more varied than those which occur in the other Lower and Middle Devonian formations. In the lower Dunedin strata throughout the study area, the rocks are thin- to medium-bedded, pelletal to micritic limestone with abundant crinoid ossicles, ostracodes, brachiopods, and gastropods. Beds also contain microbial laminations and fenestral fabric, indicating deposition in a shallow subtidal to peritidal environment. Higher in the formation, particularly towards the north, the Dunedin is thicker bedded and tidal flat indicators become

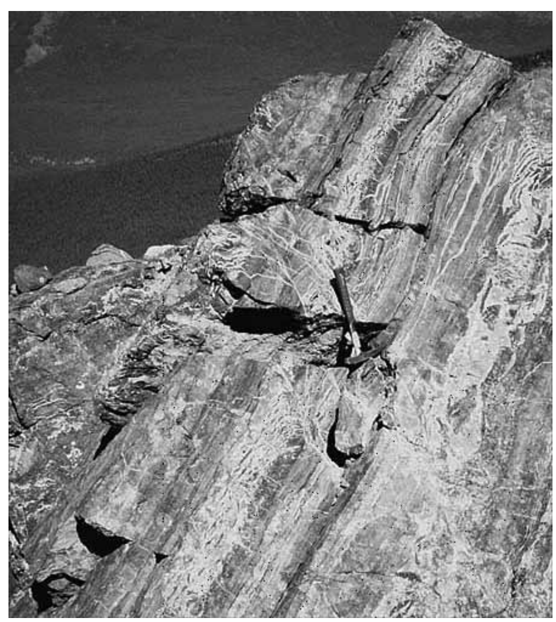

Figure 12. *Dolomitization of the Dunedin Formation. Bedding planes largely controlled the alteration, giving the rock a striped appearance. Photograph from section 6, unit 4.*

less frequent. Grainstone and wackestone are the dominant lithologies of the upper Dunedin. Fauna are more abundant in the subtidal beds, are clearly seen in hand samples, and many are composed of a comminuted shell hash (Fig. 15).

In the southern map areas, the influence of the nearby Keg River Barrier can clearly be seen by a change in both sedimentary structures and faunal associations within the Dunedin Formation. Disaggregated fossiliferous beds are common, and contain fauna clearly from the barrier edge to the east (Fig. 16) such as stromatoporoids, large robust brachiopods, and large crinoid ossicles (Fig. 17). Most fauna seen in the south are larger, more robust, and more abundant

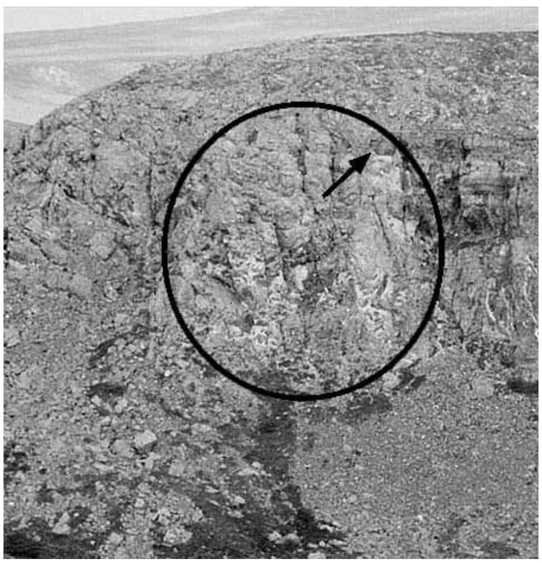

Figure 13. *Large-scale brecciation of the Dunedin Formation. The circled area highlights the brecciated pillar, and the arrow indicates where the bedding has been disrupted by the brecciation. Photograph taken of bluff opposite section 11, near top of the formation.*

Figure 14. *Calcite and barite cemented rubble breccia within the Dunedin Formation. The breccia mass extends for about 50 m, through the middle portion of the Dunedin Formation, and appears to be cavern solution. Photograph from section 10, unit 6.*

Figure 15. *Bed containing a shell hash of brachiopods and gastropods (arrows), as well as some crinoid ossicles and ostracode shells. All are thin shelled, and many are comminuted. Photograph from section 10, unit 8.*

Figure 16. *A packstone flow deposit composed of amphiporids, thick shelled brachiopods, and some broken domal stromatoporoids. The unit has been dolomitized. Photograph from section 20, unit 3.*

Figure 17. *Large robust brachiopods, Stringocephalus sp., in lime mudstone. This fauna indicates a late Givetian age for the upper Dunedin Formation in this section. Photograph from section 3, unit 23.*

than in the north. Higher energy conditions are evident near the barrier edge, for example crossbedding seen in some amphiporid rudstones (Fig. 18).

More reefal facies occur mainly in the southern end of the study area. Beds are composed of stromatoporoid rudstones and grainstones, and grainstones with assemblages of large brachiopods, hemispherical and laminar stromatoporoids, amphiporids, large crinoid ossicles, and colonial and solitary corals. Section 3, measured in a cirque above Redfern Lake in the Trutch map area (NTS 94 G), contains a reef mass, indicating proximity of the Keg River Barrier (Fig. 19).

Chert lenses and nodules are common throughout the study area in the upper most beds of the Dunedin Formation (Fig. 20). In the south, some fauna, particularly globular stromatoporoids, are preferentially silicified.

The top surface of the Dunedin Formation is marked by a facies transition between shallow marine subtidal deposits and overlying deeper marine shale. At the type section,

Figure 18. *Amphiporid thickets with crossbedding (arrow). Photograph from section 6, unit 9.*

Figure 19. *Reef mass within Dunedin Formation. Photograph from wall in cirque adjacent to section 3.*

Figure 20. *Chert nodules (some circled) lying along bedding planes. Similar nodules were seen throughout the study area. Photograph from section 11, unit 16.*

Figure 21. *Top surface of the Dunedin Formation. This bed surface contains numerous coral heads, and the shale units of the Besa River Formation immediately overlie it. Photograph from section 16, unit 15.*

Figure 22. *Contact between the Dunedin and Besa River formations, marked by arrows. The contact is marked by a change from dark grey limestone to black argillaceous shale, sometimes with limestone concretions in the lower 20 m. Photograph from section 10, unit 10.*

section 16, the contact is characterized by an accumulation of coral heads on the top bedding surface (Fig. 21). In a few sections interfingering is evident between the Dunedin and Besa River formations (Fig. 22), but commonly this transition is covered.

Regional facies development of the Dunedin Formation

The most striking change noticed within the Dunedin Formation within the study area is the increase in dolomitization to the south. In the northern areas, any dolomite is contained within the lowest beds of the formation, or in areas of brecciation. In the south, in addition to localized areas of hydrothermal brecciation and alteration, large portions of the formation have been dolomitized, obliterating any sedimentary features.

A steady decrease in thickness occurs within the Dunedin Formation as it changes from shallow shoals in the north to shallow subtidal and peritidal environments in the south (Fig. 4). The maximum thickness occurs at the northern limit of the study area, where the platform faces the deeper water of the Meilleur River Embayment. Thickness steadily decreases to about 180 m at sections 7 and 19 (near Keily Creek). This trend is interrupted south of section 19, where the influence of the Keg River–Slave Point depositional edge affects the Dunedin Formation (sections 3, 5, 6, 17, and 18). These sections are thicker than their off-reef equivalents to the west, and if only off-reef, open-shelf sections are considered, the trend of diminishing thickness would continue south to section 8, with a thickness of 65 m.

Several sections in the south of the Trutch map area (NTS 94 G) lie along the edge of the barrier complex (Fig. 1, sections 19, 4, 5, 6, 20). Sections 4 and 5, containing complete Dunedin sections, are representative of the reef and off-reef depositional environments found in the southern sections (Fig. 5). Section 4 is the thinner of the two, and contains a fauna of disaggregated stromatoporoids, corals, amphiporids, and broken brachiopod and gastropod debris. A shallow subtidal environment with debris from the nearby barrier is found within this section, with a few small (4 m thick) mound build-ups near the top of the section. Section 5, located on the north flank of Mount Bertha, is much thicker, and contains abundant reefal beds. Stromatoporoid grainstone and rudstone units alternate with pelletal brachiopod and amphiporid grainstone. Large portions of the section have been altered by hydrothermal dolomitization, and little original fabric remains. The two sections are only 11 km apart, and the difference between the barrier facies and the off-barrier facies within the Dunedin Formation is conspicuous.

FUTURE WORK

The motivation for this study is the relationship between the Dunedin Formation and the Keg River Formation throughout the study area. Facies relationships and depositional trends are being analyzed with the aid of field descriptions, hand samples, and transmitted light petrography. An endeavor for more complete correlation than previously attempted between the two formations is also underway. Both formations, surface and subsurface, appear in places to have undergone similar diagenesis, particularly hydrothermal dolomitization. Through transmitted light petrography and cathodoluminescent petrography, fluid inclusion investigation, and stable isotope analysis, a contrast and correlation of the diagenesis of these formations will be compared.

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