Cordilleran Foreland Tectono-Sedimentary Element, Canadian Northern Interior Plains

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Abstract: Upper Jurassic–Paleocene siliciclastic strata comprise the Cordilleran Foreland Tectono-Sedimentary Element of Canada’s northern Interior Plains. These strata record four major packages deposited on top of Paleozoic shelf strata on the NW margin of the Canadian craton. These packages are a Jurassic interval interpreted to record deposition associated with extension at the Arctic Ocean margin, a Lower Cretaceous, dominantly marine, interval deposited on the flexural margin of the foreland basin, and two Upper Cretaceous intervals of west-to-east progradational marine and non-marine strata deposited on the orogenic margin. The full succession has been affected by Cordilleran deformation within the Mackenzie Plain, Franklin Mountains and Colville Hills. Organic-rich shale is documented from Lower and Upper Cretaceous successions but these strata only reach thermal maturity in deeper parts of the basin, close to the Canadian Cordillera. Potential reservoirs exist within sandstone-dominated intervals throughout the succession, although some locally lack a top seal. One natural gas discovery has been reported from Upper Cretaceous sandstone of the Little Bear Formation at the Stewart D-57 well in the southeastern Mackenzie Plain. Oil sourced from Upper Cretaceous shale is reported from the Mackenzie Plain East Mackay B-45 well.

The Cordilleran Foreland Tectono-Sedimentary Element (TSE) comprises the Upper Jurassic–Paleogene succession of the northern Canadian mainland plains. This succession overpreserves Proterozoic–Paleozoic sedimentary strata deposited on older crystalline basement of the NW margin of the Canadian Shield (Cook and MacLean 2004). The Cordilleran Foreland TSE corresponds to the ‘Mackenzie Coastal Plain and Shelf Basin’ defined in Grantz et al. (2011), and includes the Anderson Basin, Peel Trough and Great Bear Basin of Yorath and Cook (1981). The Anderson Basin underlies the northern Anderson Plain, the Peel Trough underlies the Peel Plateau, Peel Plain and Mackenzie Plain, and the Great Bear Basin underlies the Great Bear Plain and SW Horton Plain (Fig. 1). Dixon (1999) also used this basin terminology, with the addition of the Brackett Basin in the southeastern Mackenzie Plain, to designate a complete succession of Upper Cretaceous–Paleocene units. In the Franklin Mountains and Colville Hills, a region of uplifted Paleocene strata, separating the Peel Trough and Great Bear Basin, is known as Keele Arch. A thin succession of Lower Cretaceous strata underlining the southern Anderson Plain and western Colville Hills is known as the Carnwath Platform (Dixon 1999).

Age

Upper Jurassic–Paleocene or possibly Eocene strata are preserved within the Cordilleran Foreland TSE but numerous regional unconformities limit the distribution of some units. Upper Jurassic strata are known only from a single well (Horton River G-02) in the northern Anderson Plain (Fig. 1). The most extensively preserved strata are Albian (Lower Cretaceous), with a more restricted preservation of Cenomanian (Upper Cretaceous)–Paleogene strata.

Geographical location and dimensions

The Cordilleran Foreland TSE is found in the northern Interior Plains of the northwestern mainland of Canada’s Northwest Territories, east of the Canadian Cordillera, west of the Canadian Shield and SE of the Mackenzie Delta (Fig. 1; Enclosure A). The TSE is made up of a series of separate sub-basins, which together form a composite basin of approximately 800 × 400 km, with a long axis orientated NW–SE. The TSE extends from approximately 63° N to 70° N and from 119° W to 136° W.

Principal datasets

Wells

Companies are required to submit copies of data for wells drilled in Canada to the Government of Canada; after a confidentiality period, these data may be accessed by the public. There are 178 petroleum exploration wells intersecting Mesozoic strata within the Interior Plains of Canada north of 64° N (Fig. 2; Enclosure F). The bulk of these are found in the Peel Plateau/Plain and the Mackenzie Plain regions. To date, exploration wells targeting Mesozoic reservoirs are few, focusing primarily on sandstone at the base of the Lower Cretaceous in the Martin House Formation, and within the Upper Cretaceous Little Bear Formation. Most of these wells were drilled in the mid–late twentieth century. The few that were drilled much earlier are mostly in the vicinity of Norman Wells, and commonly have only primitive electric logs and sample descriptions. Younger wells have more modern log suites, better-preserved cuttings samples and, in some cases, cored intervals.

Seismic data

The 2D multichannel seismic reflection data coverage for this TSE was acquired by more than 30 companies between 1960 and 2010. Companies are required to submit copies of seismic reflection data acquired in the Northwest Territories to the Government of Canada; after a confidentiality period, paper copies of these data may be accessed by the public through the National Energy Board (NEB) of Canada. Of the more than 1400 2D seismic reflection profiles on the public record with the NEB for the northern Interior Plains and northern Mackenzie River Valley, approximately 1200 include Mesozoic–Cenozoic strata. Higher-density line spacing is found in deformed areas along the Mackenzie Valley and around the Colville Hills (Fig. 2).
Outcrop studies

Outcrops of the Cordilleran Foreland TSE succession are mostly limited to stream banks and shorelines. Unconsolidated Quaternary deposits and vegetation obscure bedrock across low-lying plains between stream exposures. In the Franklin Mountains and Colville Hills (Fig. 1), strata of this TSE generally have been erosionally removed from topographically high areas, but within the Peel Plateau, SE Mackenzie Plain and southern Anderson Plain coarser siliciclastic deposits are locally exposed on hilltops and slopes. A useful regional map showing the distribution of the TSE succession within the northern Interior Plains was included in Yorath and Cook (1981).

Tectonic setting, boundaries and main tectonic/erosional/depositional phases

The Cordilleran Foreland TSE occupies the northwestern Interior Plains of Canada and the eastern Foreland fold-and-thrust belt of the Canadian Cordilleran Orogen (Franklin Mountains) (Enclosures D and E). It encompasses the Mesozoic–Cenozoic succession preserved east of the Mackenzie and Richardson Mountains, and west of the Canadian Shield (Fig. 1). The southern boundary is a preservational zero edge north of 62° N, where exposures of underlying Paleozoic strata along the Mackenzie River separate these foreland deposits from the remainder of the Western Canada Sedimentary Basin to the south. At the northwestern boundary, the Cordilleran Foreland TSE is separated from the Mackenzie Delta and the Beaufort–Mackenzie TSE of Grantz et al. (2011) by the Eskimo Lakes Arch, underlying the Tuktoyaktuk Peninsula (Fig. 1), where Jurassic and Cretaceous strata are thinned or absent (Yorath and Cook 1981; Dixon 1982). To the north, strata of the Cordilleran Foreland TSE are interpreted to merge with strata of the Banks TSE beneath the Amundsen Gulf (Dixon 1999).

Above the sub-Mesozoic unconformity, isolated Upper Jurassic strata found in the northern Anderson Plain are interpreted to be preserved in a small graben or half-graben that is linked to documented graben to the north on Banks Island that...
also preserve Jurassic strata (Miall 1979; Dixon 1999). Preservation only in localized extensional features explains the lack of Jurassic strata in the remainder of the Cordilleran Foreland TSE.

Following a period of major regional erosion, widespread foreland basin subsidence and deposition began in the Early Cretaceous, probably the Aptian, and continued into the Albian (Fig. 3), in response to and following the onset of deformation in the eastern Canadian Cordillera (Hadlari et al. 2014). Coarser-grained and non-marine facies found on the east side of the basin (Yorath and Cook 1981; Hadlari et al. 2014) indicate east to west progradation of Lower Cretaceous depositional packages. Provenance studies using detrital zircon support this interpretation, as outcrops of the Martin House Formation in the Peel Plateau share affinities with sources along the edge of the Canadian Shield, suggesting deposition on the flexural margin of the foreland basin (Hadlari et al. 2014). Near the Albian–Cenomanian boundary, a regional pause in deposition is recorded, which was accompanied by localized uplift and erosion on the Keele Arch (Fig. 4) (MacLean et al. 2014) and Cordilleran structures that were beginning to form east of the Mackenzie Mountains. As a result, the Cordilleran Foreland TSE became compartmentalized into separate depocentres during subsequent deposition.

In the southern Mackenzie Plain, within a local depocentre known as the Brackett Basin (Fig. 4), a relatively complete succession spans the late Cenomanian–Paleocene and records the filling-in of the foreland basin by a series of west-to-east prograding successions of marine shale and marine–non-marine sandstone, conglomerate and coal. The limited Santonian–Maastrichtian record in the northern Anderson Plain consists of shale-dominated strata. In the Peel Plateau, Dixon (1999) identified apparent NE-dipping clinoforms in the upper part of an interval he assigned to the Lower Cretaceous, but subsequent work by Thomson et al. (2011) has dated the clinoform interval as Cenomanian, corresponding to the eastward-prograding relationships in the Mackenzie Plain and Brackett Basin. Late Cretaceous strata are less commonly preserved east of the Franklin Mountains in the Great Bear Plain, but are dominated by marine shale where present. Folding of Upper Cretaceous and Paleocene strata in the

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Fig. 2. Map of the Cordilleran Foreland TSE area showing the distribution of petroleum exploration wells intersecting the Mesozoic and younger strata, and 2D seismic reflection profiles.

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Brackett Basin indicates that Cordilleran deformation affected those parts of the Cordillera, or western the Franklin Mountains and Colville Hills, up to and beyond Paleocene time (Fig. 3).

### Underlying and overlying rock assemblages

#### Age of underlying consolidated basement or youngest underlying unmetamorphosed rock unit

Throughout most of its extent, the Cordilleran Foreland TSE succession overlies Cambrian–Early Carboniferous formations of the Mackenzie–Peel Platform and Eslerian Foreland successions (Yorath and Cook 1981; Allen et al. 2009). However, where it extends northeastward to the Brock Inlier and Melville Hills (Fig. 1), it can overlie Neoproterozoic strata of the Shaler Supergroup. Further south along its erosional eastern edge (see above), Cretaceous strata overlie Paleoproterozoic strata of the Hornby Bay Group (Enclosure D).

#### Age of oldest overlying rock unit

The Cordilleran Foreland TSE succession contains the youngest consolidated deposits in the regions where it is found. It is overlain by extensive Quaternary glacial deposits or Recent river-terrace sediments. In the northern Anderson Plain, local occurrences of unconsolidated sand and gravel are present, and were previously assigned to the Miocene–Pliocene Beaufort Formation of Banks Island (Yorath and Cook 1981). More recently, these deposits have been tentatively correlated with the Plioene Iperk Sequence of the Beaufort–Mackenzie Basin (Dixon 1999).

### Tectonic subdivision and internal structure

Eastward migration of Cordilleran deformation during Late Cretaceous–Eocene time created folds and faults involving the Paleozoic and Mesozoic strata within the Mackenzie Plain, Franklin Mountains and Colville Hills. Deformation in these regions was post-depositional with respect to the Lower Cretaceous succession, and was syn- to post-depositional to the Upper Cretaceous–Paleocene succession. The resulting structures are important for subdividing the Cordilleran Foreland TSE into its various sub-basins. These subbasins comprise a series of tectono-sedimentary subelements, known as the Anderson Basin, Peel Trough, Brackett Basin, Great Bear Basin and Carnwath Platform (Fig. 4).

The Anderson Basin is bounded by a preservational zero edge near the Mackenzie River on its SW side; to the south and SE the boundary with the Carnwath Platform follows a Paleozoic inlier and a subtle hinge from flat-lying strata on the Carnwath Platform to broadly north-dipping strata in the Anderson Basin (Fig. 5a). Dixon (1999) interpreted the Anderson Basin as a shallow, cratonic basin initiated in the Late Jurassic, possibly as a result of localized extension...
Aside from the regional tilt towards the Arctic Ocean, Mesozoic strata in the Anderson Basin are undeformed.

The Peel Trough is bounded on the west and SW by the Richardson and Mackenzie mountains (Fig. 4), by a preservational zero edge approximately following the Mackenzie River on its NE margin, and by the Gambill Fault on its SE margin. Within the Peel Trough, Cretaceous strata generally dip to the SW, with local involvement in thrust faulting and folding in the SE (Mackenzie Plain; Fig. 5 and segment B–C of Fig. 6) associated with Cretaceous–Eocene deformation in the Mackenzie Mountains and Franklin Mountains (Powell et al. 2016). Cretaceous strata in the Peel Trough are considered to have been deposited in a foreland basin adjacent to the Mackenzie and Richardson mountains (Dixon 1999; Hadlari et al. 2014).

Separated from the Peel Trough by the Gambill Fault, the Brackett Basin is bounded by a preservational zero edge to the SW, SE and north, and bounded by reverse faults of the eastern Franklin Mountains on its NE margin (Fig. 4). Similar to the Peel Trough, Cretaceous–Paleocene strata within the basin are involved in folds and faults developed during Cretaceous–Eocene time. Unlike the Peel Trough, Lower Cretaceous strata are thin or absent in the northern part of the Brackett Basin, where the Keele Arch was a positive tectonic element in Early Cretaceous time (Hadlari et al. 2014; MacLean et al. 2014). The Brackett Basin is considered to be a foreland basin developed adjacent to the Mackenzie Mountains (Dixon 1999; Hadlari et al. 2014).

The Great Bear Basin is bounded to the east and south by a preservational zero edge, and on its western and northwestern margins by a series of reverse faults along the eastern edge of the Franklin Mountains and Colville Hills (Fig. 4). Lower Cretaceous–Paleocene strata of the Great Bear Basin typically dip gently to the west, away from the Canadian Shield (Fig. 5b). Although the Great Bear Basin is considered to lie east of the deformed belt, rare minor thrust faults, likely to be related to Cordilleran deformation in the Franklin Mountains and
Colville Hills, are locally developed within Cretaceous strata (MacLean 2012). One notable extensional feature, the Blackwater Fault, appears to be a reactivation of a Proterozoic feature (MacLean 2012). The Great Bear Basin is considered to be the cratonic or flexural margin part of the foreland basin system linked to the development of the Richardson, Mackenzie and Franklin mountains (Dixon 1999; Hadlari et al. 2014). Detrital zircons derived from the Canadian Shield are found in Lower Cretaceous strata of the Peel Trough (Hadlari et al. 2014), indicating that the Great Bear Basin and Peel Trough may have been a continuous depositional system at that time. The central portion of the Cordilleran Foreland TSE falls within the Carnwath Platform (Fig. 4), an upland area with a thin, patchy distribution of Cretaceous–Paleogene strata. It includes flat-lying strata of the southern Anderson Plain (Fig. 5a) and western Horton Plain, as well as folded strata preserved in synclines or in the footwalls of faults in the Colville Hills and northern Franklin Mountains (Fig. 5a and segment C–D of Fig. 6). Gaps in the depositional record (Fig. 3) indicate that this region did not subside as much as adjacent basins, instead being dominated by periods of non-deposition or erosion.

In summary, Mesozoic strata within the Cordilleran Foreland TSE are generally flat lying in central and eastern regions, gently SW-dipping towards the mountains in the Mackenzie and Peel plains, and gently north- to NW-dipping on the Anderson Plain (see Figs 4 and 5a). Figure 6 shows the general style of structures involving Mesozoic strata NE of the Mackenzie Mountains, with widely spaced, detached folds and thrusts dominating the region from the Peel Plateau to the

![Fig. 5. Well cross-sections illustrating stratigraphic relationships within the Mesozoic strata. (a) Gently dipping strata between the Peel Plateau and the Anderson Plain. (b) Folded and faulted strata between the Peel Plateau and the Great Bear Plain. The gamma-ray log from each well is shown in black. Faulted structures are shown schematically. See Figure 1 for the locations of the cross-sections.](http://mem.lyellcollection.org/)

![Fig. 6. Structural cross-section from the Mackenzie Mountains to the eastern Franklin Mountains showing the folding and faulting style affecting the Cretaceous strata; the section is expanded from Cook and MacLean (1999) using map relationships. See Figure 1 for the location of the cross-section.](http://mem.lyellcollection.org/)
eastern Franklin Mountains (part of the cross-section between B and D). Larger structures between the Mackenzie and Franklin mountains are also visible in Figure 4 as local highs on the base of the Cretaceous. For further details regarding the structural style across the Franklin Mountains, see Cook (1983). Structural relationships in the Colville Hills are discussed in MacLean and Cook (1992).

Sedimentary fill

Total thickness

The Upper Jurassic–Paleocene succession (Dixon 1999) varies from zero on structural highs to >2000 m along the deepest axis close to the eastern margin of the Mackenzie Mountains (Fig. 4). The succession is typically less than 250 m thick over much of the area. The succession also thickens northwards towards the Amundsen Gulf and Beaufort Sea to more than 500 m.

Lithostratigraphy/seismic stratigraphy

Mesozoic–Cenozoic strata are predominantly siliciclastic (Fig. 3), consisting of shale- and sandstone-rich formations (Dixon 1999; Hadlari et al. 2009). Although the bulk of the strata are late Aptian–Albian and younger, there is an erosional remnant of Upper Jurassic shale and sandstone in the subsurface of the Anderson Plain (Brideaux and Fisher 1976) that is correlated with the Husky Formation of the adjacent Beaufort Mackenzie area (Dixon 1999). The remnant of Jurassic strata suggests there may have been more extensively distributed older Mesozoic strata that were subsequently eroded prior to late Aptian–early Albian deposition. However, facies characteristics of these Jurassic strata in the northern Anderson Plain suggest that they were deposited close to the shoreline of the time, whereas equivalent strata to the west in the Mackenzie Delta record a deeper-water setting (Dixon 1992, 1999). This argues against derivation from the Canadian Cordillera and supports the suggestion by Dixon (1992) that deposition may have been controlled by localized extension along the north coast. South of the Anderson Plain, Triassic–early Aptian strata are absent (Fig. 5). Cretaceous strata are organized as shale–sandstone transgressive–regressive (T–R) sequences, separated from strata above and below by unconformities (either transgressive surfaces of erosion or transgressively modified subaerial unconformities). These repeated successions are interpreted to represent periods of uplift and erosion, followed by subsidence and transgression, in turn succeeded by regressive sedimentation.

The most profound unconformity lies below the Martin House/Langton Bay formations (Fig. 3), where the absence of Triassic–Aptian strata suggests a long period of uplift and erosion. At the base of the oldest Cretaceous sequence, non-marine beds are preserved in palaeotopographical depressions (these strata rest on a subaerial unconformity, possibly palaeovalleys) in the Anderson Plain and NE Peel Plain (Gilmore River Formation; Yorath and Cook 1981; and Tukweye Member of the Martin House Formation in the NE Peel Plain: Dixon 1999, p. 20; Hadlari et al. 2009). Elsewhere, marine strata of the Martin House or Langton Bay formations rest directly on Paleozoic beds. The overlying Arctic Red–Trevor formations were originally considered to represent continuous Albian–Turonian sedimentation (Yorath and Cook 1981). Based on regional considerations, Dixon (1999) speculated that there should be a major pre-Cenomanian discontinuity, and suggested that it could be at the base of a prominent shale unit within the Trevor Formation. Dixon’s speculation was confirmed by Thomson et al. (2011) but their more detailed palaeontological and sedimentological data placed the discontinuity at a lower stratigraphic level, within the upper Arctic Red Formation. The identified Cenomanian strata were correlated with, and named, the Slater River Formation.

Although the outcrop exposure in the Peel Plateau area shows the Albian-aged Arctic Red Formation to be a single shale-dominant succession grading upwards into siltstone and very-fine sandstone at the top of the formation (Thomson et al. 2011), Dixon (1999, fig. 28) recognized at least three internal packages, interpreted as coarsening-up successions, on seismic reflection profiles in the same area. These coarsening-up intervals appear not to contain any significant sandstone. However, west of Norman Wells and in the Great Bear Plain, marine Albian sandstone intervals have been identified overlying Arctic Red Formation shale; these are the Sans Sault Member of the Arctic Red Formation in the Peel and Mackenzie plains, and the Mahony Lake Formation in the Great Bear Plain (Dixon 1999). The Albian succession represents a westward-prograding T-R sequence deposited on the flexural margin of the foredeep of the Cordilleran Orogen (Hadlari et al. 2014). 

Upper Cretaceous–Paleocene strata are present in the Brackett Basin of the southern Mackenzie Plain, and Upper Cretaceous beds are present in the remainder of the Cordilleran Foreland TSE, including isolated exposures in the Franklin Mountains and Colville Hills (Fig. 3). In the Brackett Basin, shale of the Cenomanian–Turonian Slater River Formation rests unconformably on mostly Albian strata, but on the Keele Arch it rests on Paleozoic strata (Dixon 1999, fig. 8; Hadlari et al. 2014, fig. 4). A distinct organic-rich interval occurs near the base of the Slater River Formation and is commonly seen on well logs as a radioactive interval. Gradationally overlying the Slater River Formation are shale–sandstone, coarsening-upward units of the Coniacian–Campanian Little Bear Formation. Dixon (1999) divided the Little Bear Formation into Lower and Upper members, based on the presence of thicker sandstone intervals and coal in the Upper member. Based on regional correlations and stratigraphic relationships, he suggested that the Little Bear Formation contained a major discontinuity between the Lower and Upper members. Although older than the Little Bear Formation, the Trevor Formation has the same lithological characteristics and the same gradational lower boundary with the Slater River, suggesting that these three units may represent a unified, west-to-east prograding stratigraphic package from the Peel Plateau to the Mackenzie Plain or, perhaps, multiple prograding packages (Hadlari et al. 2014). In the northern Anderson Plain, strata time equivalent to the Little Bear Formation are represented by the Smoking Hills Formation, an organic-rich shale unit with thin interbeds of bentonite and fossil remains of marine reptiles (Yorath and Cook 1981; Dixon 1999). These strata are preserved in an area separated from the Little Bear Formation by Paleozoic exposures along the Mackenzie River (compare the Mackenzie Plain and the northern Anderson Plain in Fig. 1), and therefore lateral facies relationships are not known. However, Dixon (1999) noted that the Smoking Hills Formation represents a lower-energy, deeper-marine setting than the Little Bear Formation.

Abruptly overlying the Little Bear sandstone is the shale-dominant, late Campanian–early Maastrichtian East Fork Formation, which in turn is gradationally overlain by interbedded shale and sandstone of the Maastrichtian–Paleocene Summit Creek Formation. The abrupt contact between the Little Bear and East Fork formations has been interpreted as a maximum flooding surface (Dixon 1999, p. 30). If this is correct, then a transgressive surface of erosion or unconformity should
be present in the upper beds of the Little Bear Formation, which Dixon (1999) suggested was at the base of the uppermost thick sandstone of the Little Bear Formation. This interpretation would be consistent with the stratigraphy of the Anderson Plain, where the late Campanian–early Maastrichtian Mason River Formation rests unconformably on older beds (Fig. 3) (Dixon 1999). The East Fork–Summit Creek succession appears to be gradational, changing upwards from shale to shale–sandstone coarsening-upward units of the lower Summit Creek Formation. The upper part of the Summit Creek Formation consists of thick units of interbedded non-marine sandstone, conglomerate, shale and coal. In the Beaufort–Mackenzie TSE to the NW, there is a major pre-late Maastrichtian unconformity (Dixon et al. 1992) and Dixon (1999) suggested that the Summit Creek succession must contain an equivalent unconformity, which he speculated was located where the conglomeratic beds become common.

Scattered outcrops of Upper Cretaceous strata are known from the Colville Hills and Great Bear Basin underlying the Great Bear Plain, but their exact ages, distribution and stratigraphic relationships are poorly known (e.g. Cook and Aitken 1971).

In seismic reflection profiles, unconformities at the base of the Lower Cretaceous and at the base of the Upper Cretaceous successions are generally recognizable, typically as low-angle truncations of underlying strata. Within the Brackett Basin, the boundary between the sandstone of the Little Bear Formation and the overlying shale of the East Fork Formation can also be identified by a change from a reflective interval below to a non-reflective interval above. Cretaceous siliciclastic strata commonly have both parallel reflectors and dipping reflectors (clinoforms) illustrating progradational sequences. Clinoforms dipping NE, within an interval 200–500 m thick, have been noted regionally on seismic reflection profiles within the Upper Cretaceous Slater River Formation (Hadlari et al. 2014, figs 5 and 6).

**Magmatism**

There are no known igneous intrusive or extrusive rocks in the Cordilleran Foreland TSE but there are numerous bentonite beds in the Albian Arctic Red Formation, and in the Upper Cretaceous Slater River and Smoking Hills formations. These are interpreted as ashfalls from volcanic activity in the Cordilleran Orogen to the south and west, blown by wind over the Late Cretaceous interior seaway.

**Heat flow**

Although published heat-flow data for the Cordilleran Foreland TSE are limited, the work of Majorowicz et al. (1988) suggests that geothermal gradients for regions with significant preserved thicknesses of Cretaceous strata are generally 25–35 mK m⁻¹. Background heat-flow values across the northern plains, where Cretaceous strata are absent or thin (<300 m thick), vary between 40 and 60 mW m⁻², but within the northern Mackenzie Plain, Peel Plain and Peel Plateau, where Cretaceous strata vary in thickness between a few hundred metres and 1000 m, the heat flow exceeds 80 mW m⁻².

**Petroleum geology**

**Discovered and potential petroleum resources**

There has been no hydrocarbon production from the Cordilleran Foreland TSE. In 2006, a natural gas discovery was made in the Cretaceous Little Bear Formation in the Stewart D-57 well, located near the southern limit of the TSE, in the Summit Creek area of the Mackenzie Plain (Figs 3 and 7). This is the only hydrocarbon discovery in the Cretaceous succession to date. The well intersected a subsurface anticline and yielded a combined flow rate of 140 Mm³/day (5 MMcf/day) of sweet gas in two drill stem tests from a hydrocarbon-bearing column of at least 50 m (Husky Energy Limited news release on 17 May 2006). The initial estimate of the closure area at Stewart D-57 is 1792 hectares (Hannigan et al. 2011). The natural gas at Stewart D-57 has not been typed to a specific source rock and could have been the result of hydrocarbon migration from older Devonian shale. The only documented occurrence of probable Mesozoic-sourced hydrocarbons is heavy oil recovered at the East Mackay B-45 well (Fig. 7); this oil is found in a reservoir of brecciated Paleozoic carbonate, which is unconformably overlain by shale of the Upper Cretaceous Slater River Formation (Feinstein et al. 1988a; Issler et al. 2005, fig. 3).

The estimated total mean in-place resource potential is derived from a comprehensive study of the Mackenzie Corridor region of the northern mainland of Canada (Hannigan et al. 2011). This study evaluated the potential of the area of the Mackenzie River drainage system from the provincial–territorial boundary (60° N) northwards to, but not including, the Mackenzie Delta–Beaufort region. Derived from that report, the Cordilleran Foreland TSE portion of the Mackenzie Corridor has the total mean in-place potential of 5.4 MMm⁻³ (34 MMbbl) of oil and 13.6 Bm⁻³ (500 Bcf) of natural gas. The Stewart D-57 discovery is estimated to have an in-place natural gas resource of 750 MMm⁻³ (27 Bcf).

**Current exploration status**

We are unaware of any exploration activity focused on the Cordilleran Foreland TSE.

**Hydrocarbon systems and plays**

Hannigan et al. (2011) identified potential plays focused on sandstone reservoirs in the Lower Cretaceous and the Middle–Upper Cretaceous of the Interior Plains and the northern Cordilleran Foreland Belt (Figs 3 and 7). However, only the ‘Mid–Upper Cretaceous siliciclastics’ play of the Foreland Belt has been established by a discovery (Stewart D-57; see above).

**Source rocks.** Organic-rich, marine shale of the Arctic Red, Slater River and Martin House formations are potential source rocks. The Arctic Red Formation strata vary from 0.51 to 6.84% total organic carbon (TOC) (Feinstein et al. 1988a; b; Link et al. 1989; Gal et al. 2007; Hadlari et al. 2009). Shale intervals within the Martin House Formation have TOC values of 0.28–1.49% (Feinstein et al. 1988b; Hadlari et al. 2009). The Martin House and Arctic Red formations are mature based on reported pyrolysis T_max values of 432–447 and 429–450°C, respectively (Hadlari et al. 2009). The Slater River shale has reported TOC values of 0.53–8.81% and the rocks are low to moderately mature (T_max values of 421–444°C) with respect to the oil-generation window (Feinstein et al. 1988b; Hadlari et al. 2009), although occurrences in the Great Bear Plain may be insufficiently buried to generate oil. Thermochronological modelling of a bentonite collected low in the Slater River Formation in the Mackenzie Plain (Fig. 7) records maximum burial temperatures of 65–90°C in Maastrichtian–Paleocene time (Powell et al. 2018). This is consistent with palaeotemperatures of 88–106°C during
the same time interval reported for an Upper Devonian sample overlain by the Slater River Formation in the East Mackay I-77 well of the SE Mackenzie Plain (Issler et al. 2005). These burial temperatures indicate the same level of thermal maturity as the pyrolysis $T_{\text{max}}$ values cited above.

There are excellent Upper Cretaceous oil-prone source rocks on the Anderson and Horton plains. Outcrops of burning bituminous shale of the Smoking Hills Formation are immature with vitrinite reflectance ($R_o$) values of 0.25%, falling well below the oil window (Mathews and Buttin 1984).

Underlying organic-rich intervals in the Devonian Canol and Imperial formations are also potential source rocks where overlain unconformably by Cretaceous sandstone or structurally juxtaposed against them. The Canol Formation is oil prone with median TOC values of 3.7–6.8% (Terlaky 2017) and is thermally mature in the Mackenzie Plain ($R_o = 0.6–1.2$), where Cretaceous strata may be in contact with the Canol Formation. The Imperial Formation is gas prone with TOC values of 0.5–7.0% and vitrinite reflectance data indicating a range from immature to overmaturity (Hannigan et al. 2011).

**Reservoirs.** Lower Cretaceous sandstone units, specifically the basal sandstone of the Martin House Formation and the Mahony Lake and Sans Sault formations, are potential reservoirs (Fig. 3). Core analyses show the Martin House Formation to have widely varying reservoir quality, with porosity ranging from 1.9 to 24.4% and permeability from <0.01 to 13 000 mD. Petrophysical log analyses suggest that Lower Cretaceous sandstone may have porosities up to 31% (Hu and Hannigan 2009; Fraser 2010). The Martin House outcrop samples also exhibit widely ranging reservoir qualities: porosities from 5.5 to 21.5% and permeabilities from 0.06 to 95.5 mD (Haddari et al. 2009).
Upper Cretaceous sandstone units (Summit Creek, Little Bear, Trevor and basal Slater River formations) exhibit porosities from 0 to 20% (Hadlari et al. 2009; Hu and Hannigan 2009). Permeability is generally low due to the presence of abundant clay minerals within the sands, but the presence of numerous friable or unconsolidated sandstone and conglomerate horizons implies intervals of good porosity. However, many of these coarse-grained intervals are saturated with freshwater, indicating that any previously generated hydrocarbons have not been preserved. No core analyses are available but well-log analyses show porosities averaging close to 16% (maximum of 32%) and permeabilities >1000 mD over minor thin intervals (Hu and Hannigan 2009). Within the northern portion of the Cordilleran Foreland TSE, Horton Plain and northern Anderson Plain, sandstone intervals in the Upper Cretaceous succession are absent (Fig. 3); so, potential reservoir facies are limited to the Lower Cretaceous succession.

Seals. Shale-dominated successions within the Arctic Red, Slater River and East Fork formations may provide top and lateral seals for potential reservoirs (Fig. 3). The Arctic Red Formation ranges in thickness from 350 to 900 m, Slater River strata vary from 200 to 500 m, and East Fork strata are 500–800 m thick. Shale intervals in the Little Bear Formation also have potential as seals. Erosion of shale-dominated intervals across significant portions of the Cordilleran Foreland TSE has locally removed the top seal from potential sandstone reservoirs.

Traps. The Stewart D-57 gas discovery is within an anticlinal structural trap. Both Hadlari et al. (2009) and Hannigan et al. (2011) noted that additional structural and stratigraphic trapping mechanisms and play types are possible within the Cretaceous succession, such as fault-bounded traps, stratigraphic valley fills and channel fills, marine sandstone pinch-outs, and onlap traps. Potential stratigraphic traps would have been formed in Albian–Campanian time, and structural traps would have been likely to have formed in Cenomanian–Eocene time (Fig. 3).

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