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The Imperial anticline, a fault-bend fold above a bedding-parallel thrust ramp, Northwest Territories, Canada☆

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Abstract

The Imperial anticline, about 50 km west of Norman Wells, Northwest Territories, Canada is a fault-bend fold which overlies an unusual thrust ramp, totally dictated by stratigraphy and not at all like those in text books. The lower-flat/ramp/upper-flat geometry of the underlying thrust fault is decreed by the stratigraphic configuration, which is that of a southward dipping, gently flexed, Neoproterozoic Mackenzie Mountains Supergroup (MMS) succession truncated unconformably by a flat-lying Phanerozoic succession. The lower flat and ramp are controlled by a bedding-parallel glide zone in the flexed MMS, whereas the upper flat is controlled by another bedding-parallel glide zone in salt beds in the lower part of the flat-lying Phanerozoic.

This study provides new insight into a type of stratigraphically dictated thrust ramp that may well be present in other thrust belts. Angular truncations at unconformities are to be expected at craton margins and stratigraphic configurations similar to the one documented here may be the cause for other large, low-angle thrust ramps.

Understanding the Imperial anticline and its underlying thrust permits a logical linkage of an inferred deep detachment in Proterozoic strata beneath the Mackenzie Mountains with the much shallower detachment in Upper Cambrian salt beds beneath the northern Franklin Mountains. Represented on the seismic lines are at least 1.5 km of basal MMS strata that do not outcrop in Mackenzie Mountains. They probably correlate with the Pinguicula Group that is exposed in the Wernecke Mountains about 250 km to the west.

1. Introduction

Thrust ramps are of interest to many structural geologists and what localizes them remains an important problem in structural geology. We document, here, a large stratigraphically dictated ramp of a type that very probably will be found in other foreland thrust belts.

The northern Mackenzie Mountains primarily comprise a fold-belt with large flexural folds involving Proterozoic and Phanerozoic strata. The folds must overlie an unseen detachment deep in the Proterozoic strata (Aitken et al., 1982). In contrast, the northern Franklin Mountains, which form an arcuate belt external to the northern Mackenzie Mountains (Fig. 1), are detached on salt beds in the much shallower Upper Cambrian Saline River Formation (Cook and Aitken, 1973). A step from the deep detachment to the shallow one is required (Aitken et al., 1982), but until recently was poorly understood because of conceptual problems related to the Imperial anticline, situated about 50 km west of Norman Wells and lying between the Mackenzie and the Franklin mountains (Fig. 1). The anticline is similar in structural style to the Franklin Mountains but has greater structural relief. Aitken and Cook (1979) were unable to convincingly link it to either the deep detachment beneath the Mackenzie Mountains or the shallow detachment beneath the Franklin Mountains.

Vann et al. (1986) showed a largely schematic duplex of Proterozoic strata overlying a horizontal detachment under the Mackenzie Mountains, and linked to a shallower detachment in Paleozoic beds under the Franklin Mountains via two intermediate thrust ramps under the Imperial anticline. Their interpretation thus recognized the problem, but did not resolve it because their cross-section was unbalanced and failed to reproduce the fold geometry known from surface mapping.

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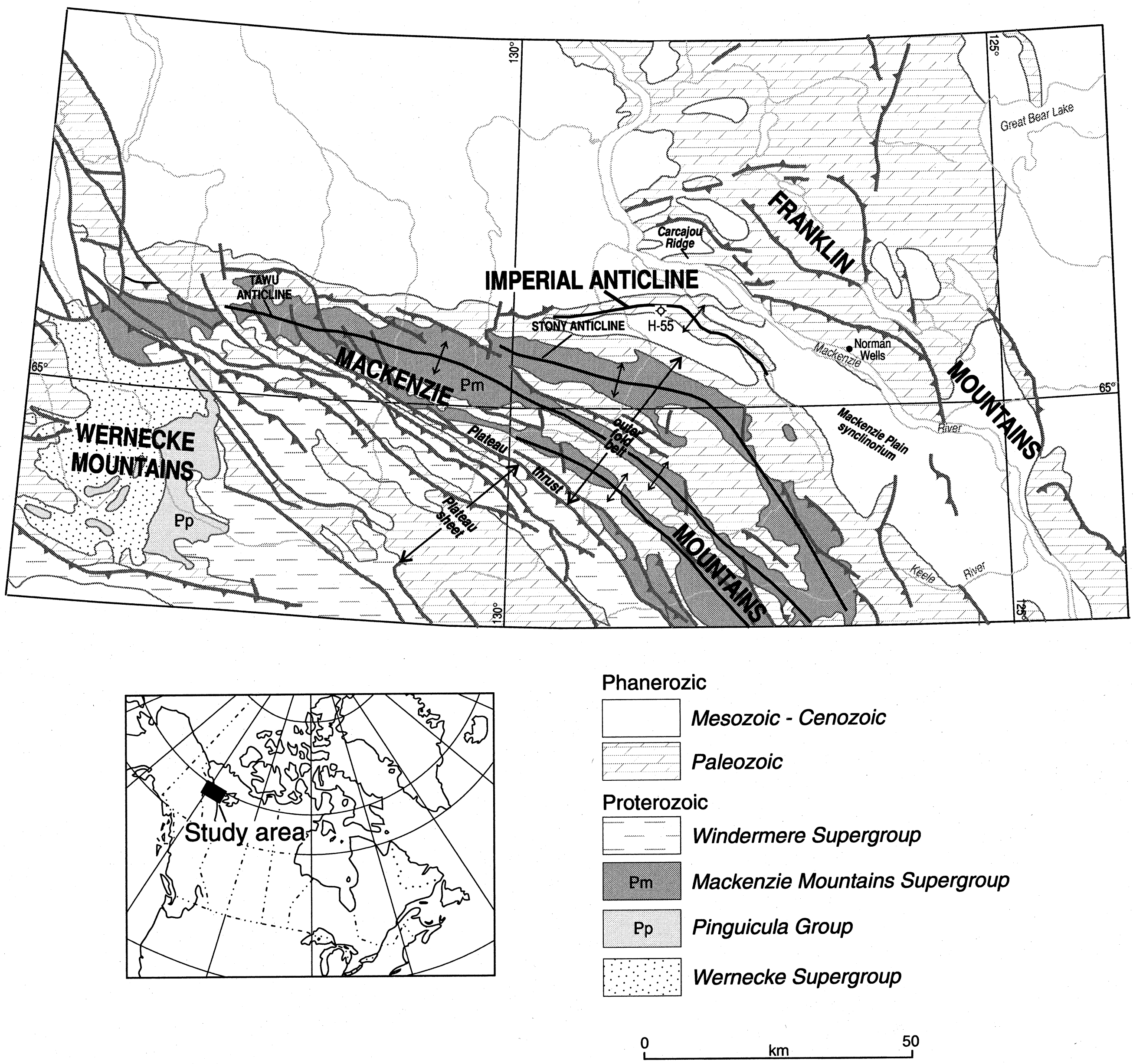

Fig. 1. Location map showing position of the Imperial anticline relative to the Mackenzie and Franklin mountains.

As part of a regional study of Proterozoic stratigraphy and structure (see Cook and MacLean, 1995) based on industry seismic data, a data set was encountered that elucidates the subsurface deformational geometry of the post-Cretaceous Imperial anticline. It is revealed to be a fault-bend fold above an unusual thrust ramp, the understanding of which enables interpretation of a logical linkage of the inferred deep detachment in Proterozoic strata beneath the Mackenzie Mountains with the much shallower Upper Cambrian salt beds detachment beneath the northern Franklin Mountains.

Fault-bend folds (Suppe, 1983) are formed by the bending of sedimentary strata as they ride over non-planar faults. Classic 'text book' fault-bend folds (Fig. 2) are caused by displacement on a fault which deflects from a bedding-parallel 'lower flat', to a bedding-transverse 'ramp', to a bedding-parallel 'upper flat' with, generally, no clear control for localization of the ramp. The thrust underlying the Imperial anticline is unusual, because the lower-flat, ramp, and upper-flat of the fault are each dictated by the stratigraphic configuration, which is that of a southward dipping, gently flexed MMS succession truncated unconformably by a flat-lying Phanerozoic succession (Fig. 3). The lower flat and ramp are controlled by a bedding-parallel glide zone in the flexed MMS, whereas the upper flat is controlled by another bedding-parallel

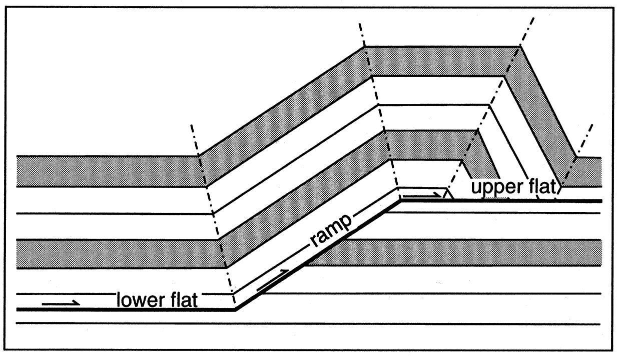

Fig. 2. A classic fault-bend fold (after Suppe, 1983).

glide zone in the lower part of the flat-lying Phanerozoic. Documentation of this stratigraphically controlled ramp is important because depositional overlap of dipping older sequences is to be expected at craton margins and such thrust ramps may be more common, world-wide, than currently recognized.

The ramp portion, and consequently the fault-bend fold geometry, are complicated locally by the development of a small bedding-transverse 'classic' ramp superimposed on the larger scale bedding-parallel ramp. Salt in the Cambrian section played a primary role in localizing the upper detachment level, and halotectonic effects contributed to back-limb complexities related to the small bedding-transverse ramp.

As a side issue, the analysis also contributes significantly to our understanding of the stratigraphic extent and subsurface distribution of the Neoproterozoic Mackenzie Mountains Supergroup (MMS). The MMS wedge imaged on the seismic lines includes at least 1.5 km of basal beds that do not outcrop in Mackenzie Mountains. They probably correlate with the Pinguicula Group exposed in the Wernecke Mountains to the west.

2. Regional stratigraphy

Within the northern Mackenzie and Franklin mountains, a southwestward thickening wedge of Neoproterozoic strata, comprising the younger Windermere Supergroup rift sequence and the older Mackenzie Mountains Supergroup (MMS) platformal sequence, is truncated by the sub-Cambrian unconformity such that, from southwest to northeast, Cambrian strata rest on progressively older Proterozoic units (Fig. 4). At the mountain front the entire Windermere Supergroup, and the Coates Lake

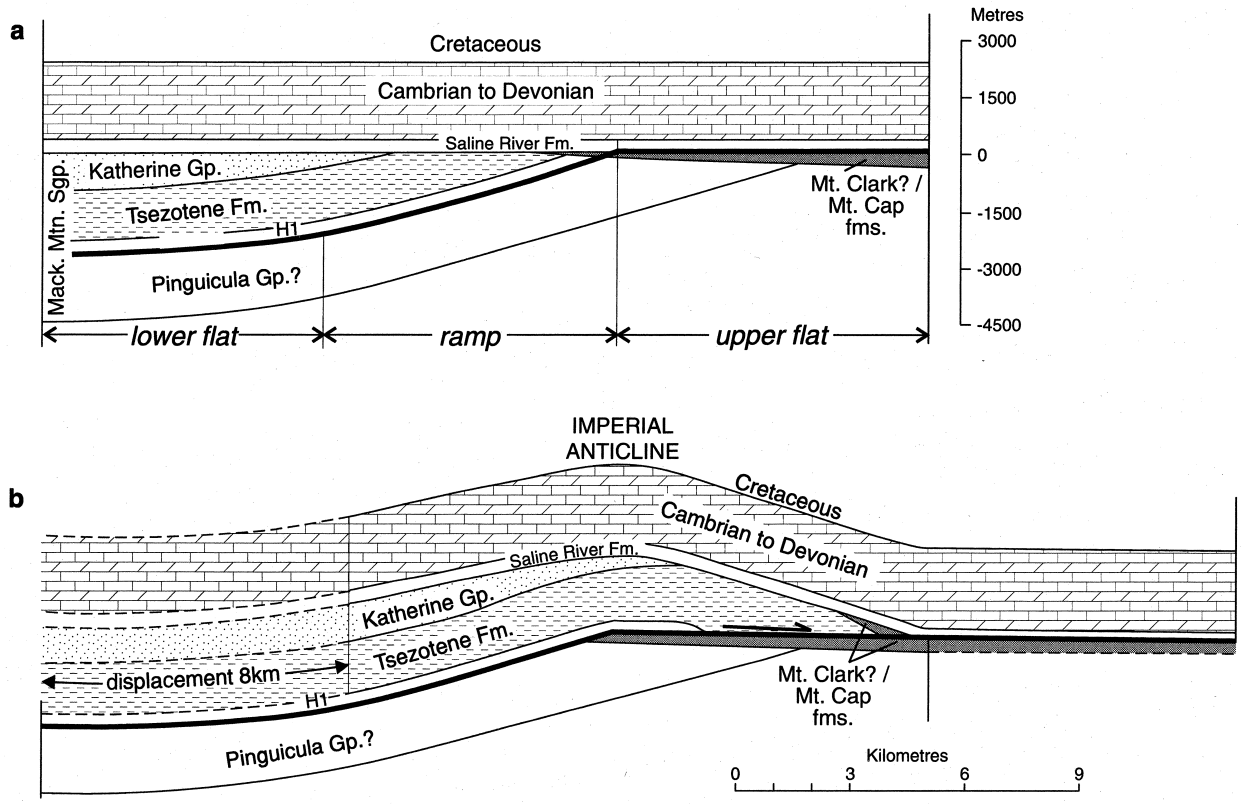

Fig. 3. A schematic of a fault-bend fold wherein the lower flat, ramp, and upper flat, are all bedding-parallel. Compare with the classic fault-bend fold of Fig. 2. Section is approximately to scale for the Imperial anticline. (a) Pre-thrust geometry. A bedding-parallel fault in **flexed** Mackenzie Mountains Supergroup strata intersects the sub-Cambrian unconformity and diverts into flat-lying Saline River Formation salt beds. (b) Post-thrust geometry after displacement of about 8 km. Compare with seismic sections of Figs. 9 and 10.

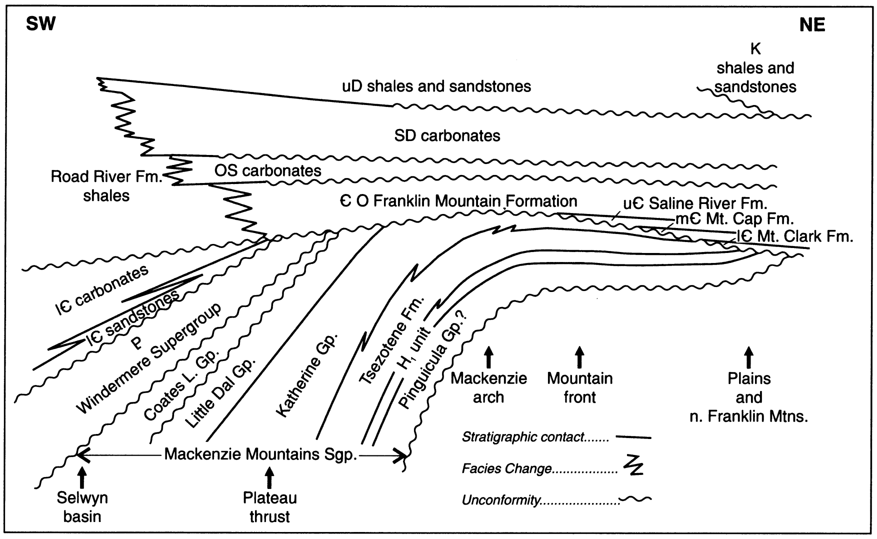

Fig. 4. Stratigraphic relationships in the northern Mackenzie and northern Franklin mountains (adapted from Aitken et al., 1982, fig. 2). **P**—Proterozoic; **lЄ**—Lower Cambrian; **mЄ**—Middle Cambrian; **uЄ**—Upper Cambrian; **ЄO**—Cambrian/Ordovician; **OS**—Ordovician/Silurian; **SD**—Silurian/Devonian; **uD**—Upper Devonian; **K**—Cretaceous.

and Little Dal groups of the MMS are missing, and the sub-Cambrian unconformity directly overlies Katherine Group quartzites. Consequently, among units exposed in the Mackenzie Mountains, only the Katherine Group, Tsezotene Formation, and informal H1 dolomite are relevant to interpreting Proterozoic strata imaged on seismic lines across the Imperial anticline. In the following discussion stratigraphic thicknesses and lithologies are taken from Aitken et al. (1982) unless otherwise noted.

2.1. Pertinent Proterozoic Units

The Katherine Group, a thick (712+ m) quartzite-dominated succession, is one of the most widespread and easily recognized units in the Mackenzie Mountains. The Katherine is underlain by the Tsezotene Formation, a thick succession (748+ m) of mud-rocks (shale, mudstone, argillite) with intervals of sandstone or quartzite, siltstone, and orange weathering dolomite. Of importance for correlating to the seismic sections which cross the Imperial anticline is the observation (Aitken et al., 1982) that gabbro sills have been observed only in the Tsezotene Formation. Beneath the Tsezotene is the oldest unit mapped, the informally-named H1 dolomite which outcrops in the core of the Tawu anticline (Fig. 1). It is a resistant unit of pale grey weathering dolomite with minor amounts of chert. The unit is at least 370 m thick but the base is not exposed.

In the adjacent subsurface, seismic and well data show the sub-Cambrian unconformity to continue to cut down-section northeastward across a wedge of MMS strata which is itself floored by an unconformity. Tsezotene Formation strata are identified in the PCI H-55 well and the H1 dolomite and Katherine quartzite can be inferred on some seismic lines. An additional 1.5 km of strata, imaged below H1, have no outcropping counterpart in the Mackenzie Mountains, but as will be discussed later, probably correlate with the Pinguicula Group which outcrops in the Wernecke Mountains about 300 km to the west-southwest (Fig. 1). The MMS zero-edge, traceable from line to line, is east–west trending (Fig. 5). Correlation of subsurface strata depends, in part, on resolution of structural geometry and a full discussion will be presented later. Key to understanding the development of the Imperial anticline is the observation that strata in the MMS wedge were flexed prior to pre-Cambrian erosion such that the sub-Cambrian unconformity is partly parallel and partly at an angle to Proterozoic beds.

2.2. Phanerozoic

Phanerozoic strata include Paleozoic and Mesozoic rocks. A Lower Cambrian to Middle Devonian platformal succession, clastic and evaporitic at its base, is otherwise dominantly carbonate, and punctuated with unconformities. The carbonate formations all change facies southwestward to deeper water shales and carbonates of the Selwyn basin (see Fig. 4). Platformal carbonate deposition, which continued intermittently until the Middle Devonian, was superseded by deposition of an Upper Devonian clastic wedge of shales, siltstones, and sandstones, which is unconformably overlain in turn by Cretaceous sandstones and shales. The basal Paleozoic clastic and evaporite units warrant

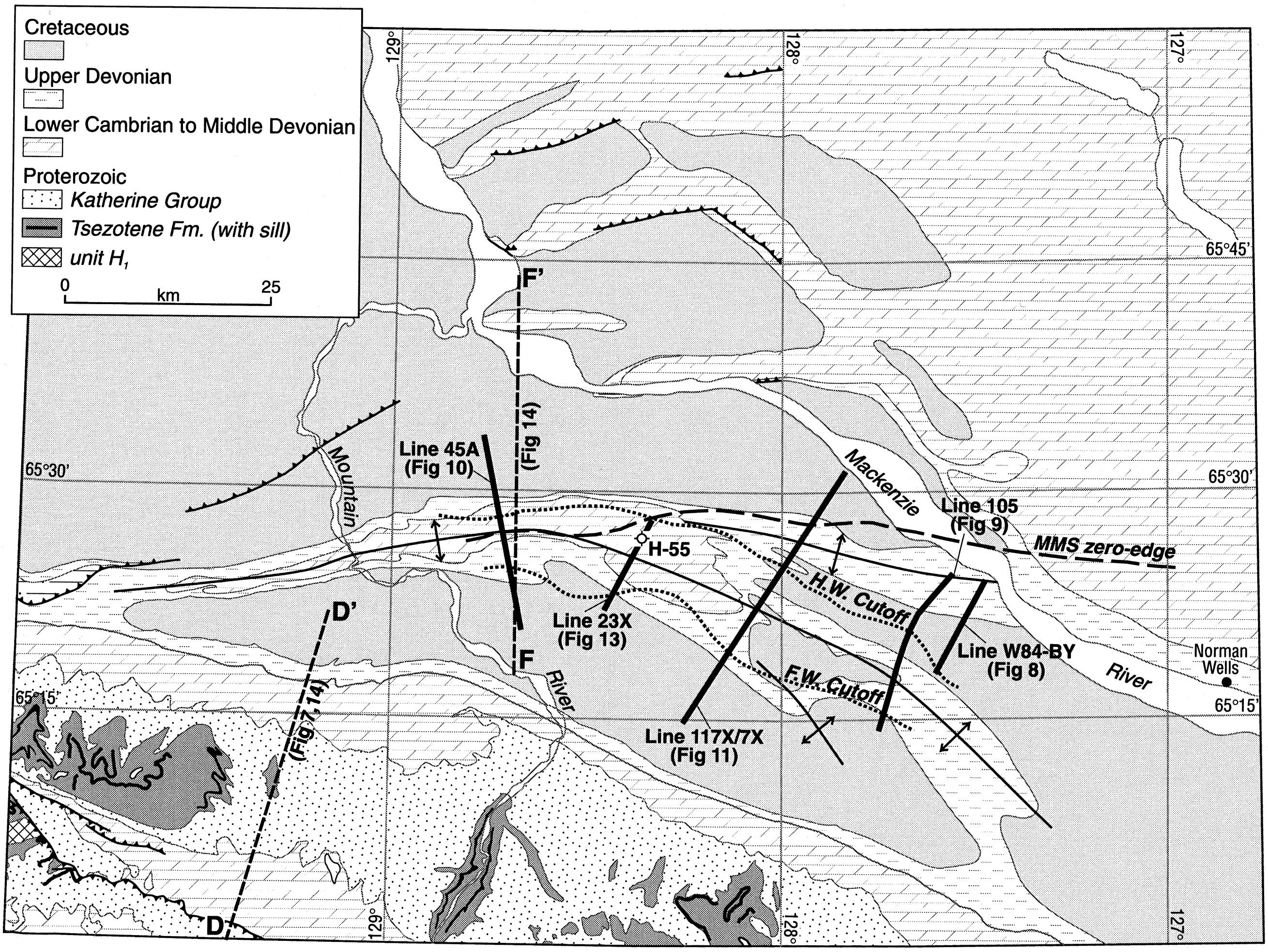

Fig. 5. Map of the Imperial anticline showing: seismic line locations, cross-sections DD′ and FF′ from Aitken et al. (1982), zero-edge of the Mackenzie Mountains Supergroup (MMS), hanging wall (HW) and footwall (FW) cutoffs.

more detailed description because the clastics are caught in the footwall of the Imperial anticline thrust and the evaporites localized the detachment that underlies the Franklin Mountains.

2.2.1. Basal Paleozoic clastic and evaporite units

An important tectonic feature of the Paleozoic platform was the Mackenzie arch onto which Lower and Middle Cambrian strata onlapped from both the southwest and northeast (Figs. 4 and 6). The crest of the arch follows the Mackenzie Mountains front for part of its length, but departs into the subsurface northwestward. The arch persisted into the Late Cambrian and served as the southwestern shoreline to deposition of three formations, Mount Clark, Mount Cap (Lower and Middle Cambrian), and Saline River (Upper Cambrian) which comprise an epicontinental transgressive assemblage of clastics and evaporites. The Lower Cambrian Mount Clark Formation, a basal sandstone up to 80 m thick, is overlain by Lower and Middle Cambrian Mount Cap Formation, which consists of up to 180 m of shale and siltstone with subsidiary sandstone and dolomite. The Mount Cap is in turn overlain by the Upper Cambrian Saline River Formation which is up to 500 m thick. In the subsurface the Saline River has three members, lower and upper members of shale, anhydrite, and dolomite, and the tectonically important middle salt member. The Saline River is succeeded by platformal dolomites of the Cambro-Ordovician Franklin Mountain Formation.

From east to west onto the Mackenzie arch (Figs. 4 and 6) the Mount Clark, Mount Cap, and Saline River formations are each overlapped by the next younger unit such that on the flank of the arch the outcropping Saline River Formation unconformably overlies Proterozoic Katherine Group quartzites, and on the crest of the arch, Franklin Mountain dolomites directly overlie the Katherine Group. The structurally incompetent salt was tectonically significant because it provided a natural detachment level above which the northern Franklin Mountains developed (Cook and

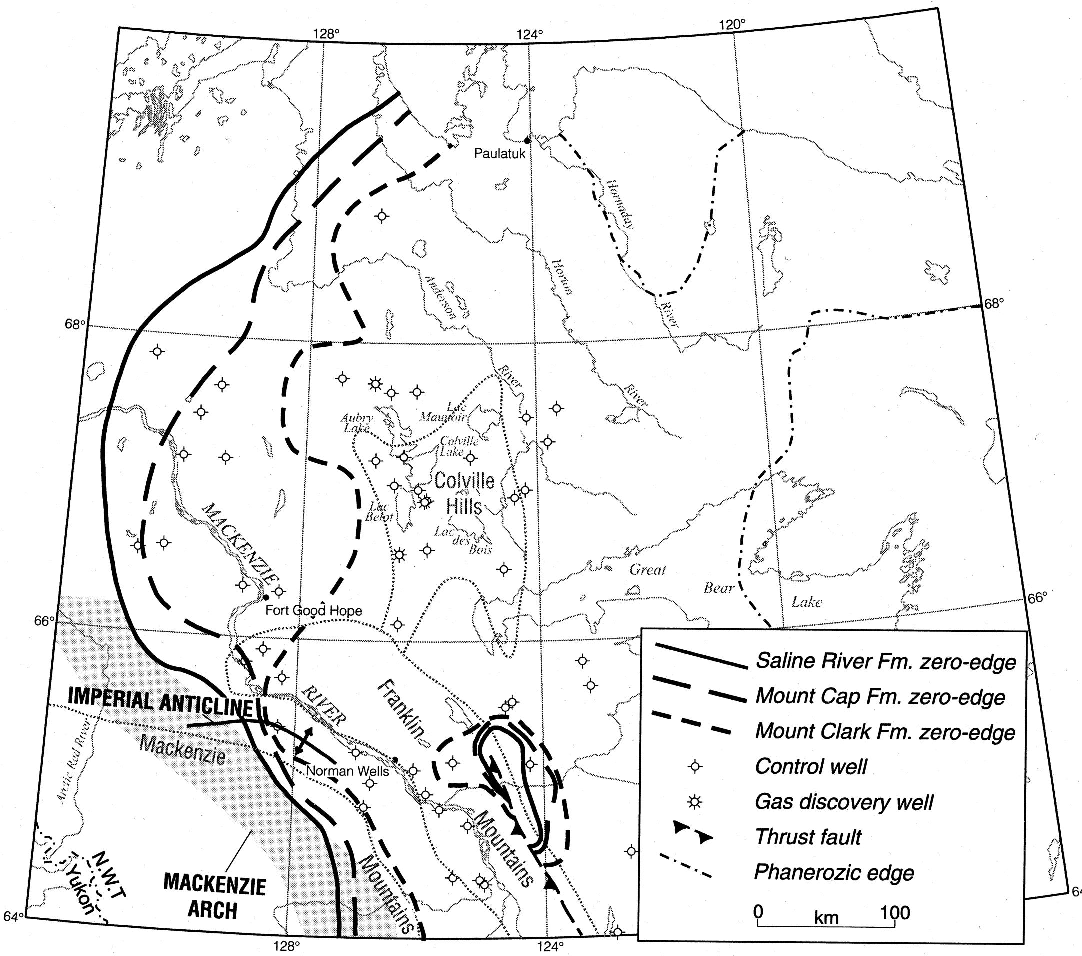

Fig. 6. Map showing the Mackenzie arch and the distribution of the Mount Clark, Mount Cap, and Saline River formations (zero-edges after Dixon, 1997).

Aitken, 1973). The salt facies zero-edge is not shown on Fig. 6 because it is poorly constrained.

3. Regional structure

Laramide (Late Cretaceous–Tertiary) structures of the region were described by Aitken et al. (1982) in terms of four tectonic provinces of differing structural styles (Fig. 1); these are, the Plateau sheet, a major thrust plate extending for 400 km along the inner arc of the Mackenzie Mountains; the outer fold belt of the Mackenzie Mountains, the Mackenzie Plain synclinorium, and the northern Franklin Mountains. Within the synclinorium the Imperial anticline comprises a structural link between the outer fold belt and the northern Franklin Mountains.

The outer fold belt is up to 80 km wide and consists of three broad and flat-topped anticlines, up to 32 km across and as much as 225 km long, with intervening, narrow, steep-limbed, generally complex synclines up to 5 km across (Fig. 1). The Stony anticline, the frontal fold of the Mackenzie Mountains adjacent to the Imperial anticline, dies out westward and is replaced en échelon by the Tawu anticline. The informal H1 dolomite is the oldest unit known to be involved in the folding (Fig. 7). The underlying structural detachment is thus at an unknown depth below H1.

The northern Franklin Mountains are characterized by narrow, linear to arcuate ridges separated by broad flat-bottomed synclines with little bedrock exposure. Some ridges are homoclines underlain by mappable thrust faults, while others appear to be simply asymmetric anticlines. One such structure, Carcajou Ridge, is known from exploration drilling to be underlain by a thrust fault whose surface trace is covered (Cook and Aitken, 1976). Probably all such anticlines are underlain by thrusts (Aitken et al., 1982). Given the narrow isolated ridges, the detachment level beneath the northern Franklin Mountains is clearly much shallower than that beneath the Mackenzie Mountains, and considering that no strata older than the Upper Cambrian Saline River Formation have been observed, Cook and Aitken (1973) and Aitken et al. (1982)

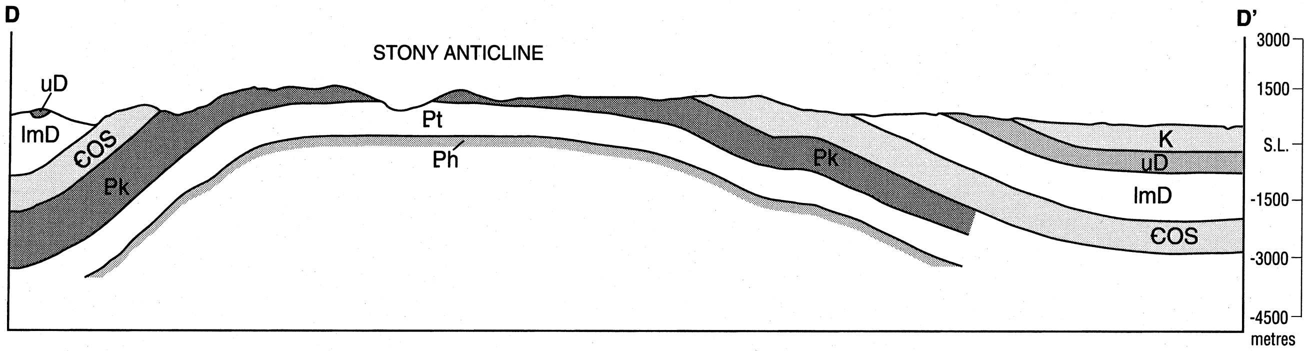

Fig. 7. Cross section DD′ across the Stony anticline, frontal anticline of the Mackenzie Mountains (after Aitken et al., 1982). The detachment is at an unknown stratigraphic level below the informal unit H1. Note the contrast in structural style with that of Fig. 8. **Ph**—informal H1 dolomite; **Pt**—Tsezotene Formation; **Pk**–Katherine Group; **ЄOS**—Cambrian/Ordovician/Silurian; **lmD**—Lower and Middle Devonian; **uD**—Upper Devonian; **K**—Cretaceous.

suggested that the detachment level lies within the incompetent salt beds of the Saline River Formation. Detachment in the Saline River Formation is confirmed by a seismic line across Hoosier Ridge anticline, a Franklin Mountains structure (Fig. 8).

4. The Imperial anticline

The Imperial anticline lies between the Mackenzie and Franklin mountains (Fig. 1). Although somewhat similar in style to the Franklins it is of greater struc-

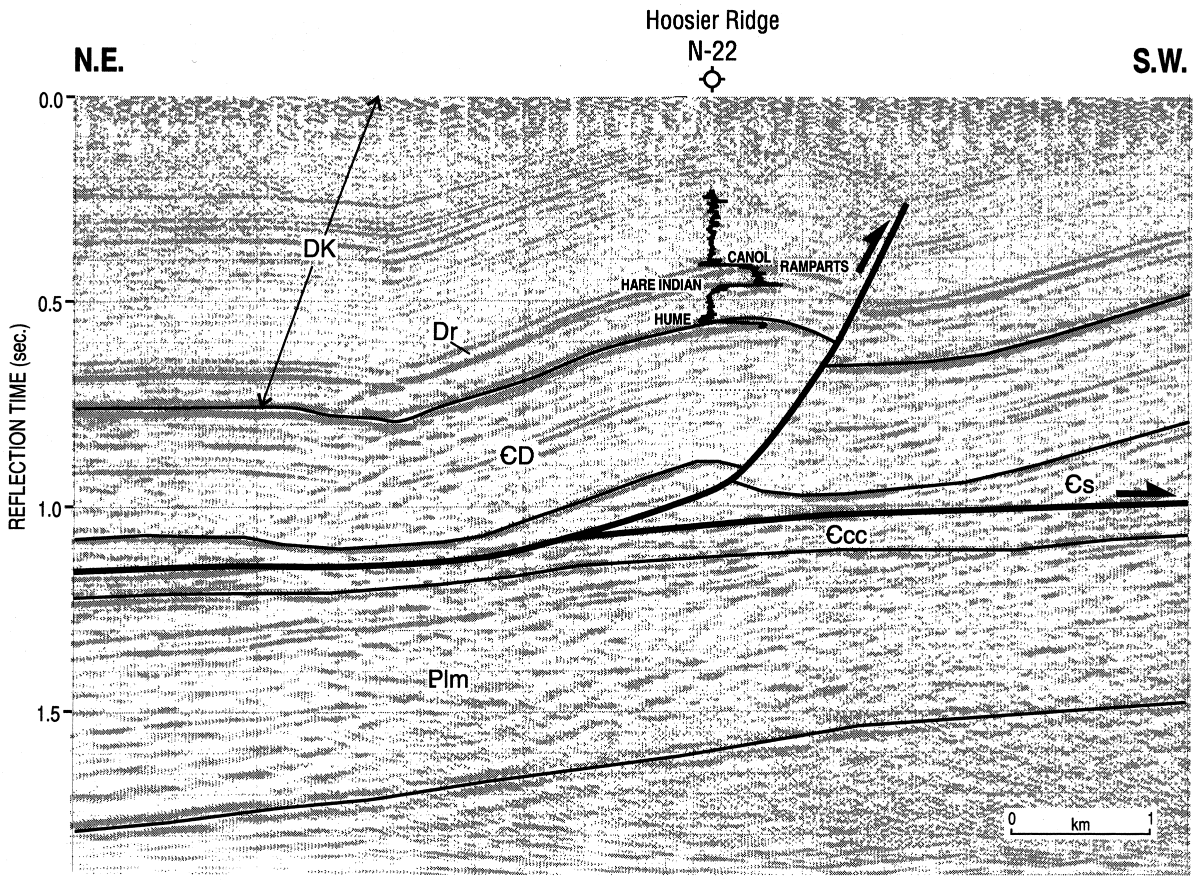

Fig. 8. Interpreted 1984 Texaco line W84-BY across the Hoosier ridge, demonstrating detachment in the Saline River Formation. Space restrictions have precluded the inclusion of uninterpreted versions in all but two seismic figures. For location, see Fig. 5. **Plm**—Proterozoic Mackenzie Mountains Supergroup; **Єcc**—Lower and Middle Cambrian Mount Clark and Mount Cap formations; **Єs**—Upper Cambrian Saline River Formation; **ЄD**—Cambrian to Devonian carbonates, undivided; **DK**—Devonian and Cretaceous clastics undivided (includes **Dr**—Devonian Ramparts Formation limestone).

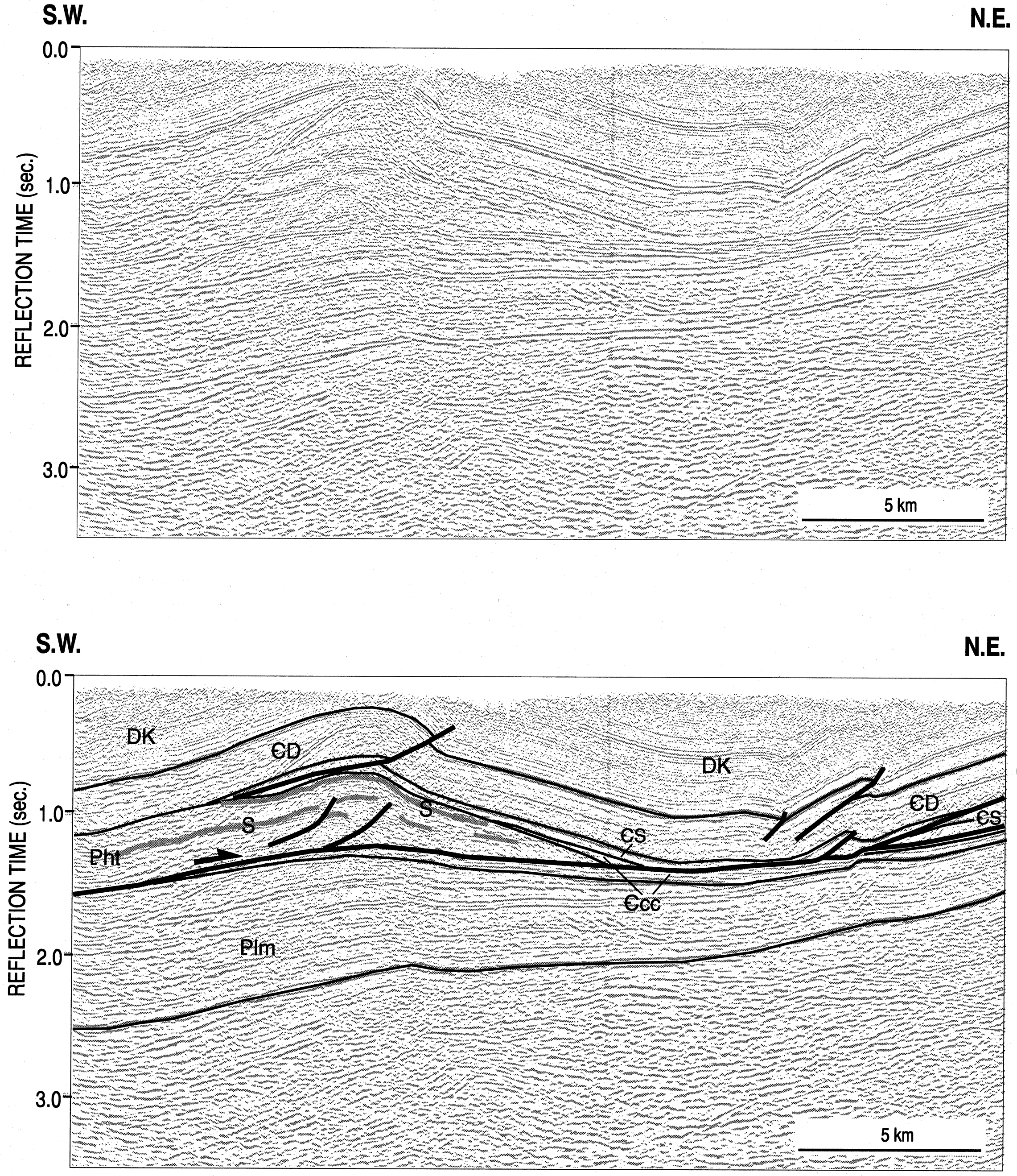

Fig. 9. Uninterpreted and interpreted 1982 Petro-Canada line 105. Compare with Fig. 3. For location, see Fig. 5. **Plm**—lower part of Mackenzie Mountains Supergroup, includes equivalents of Pinguicula Group; **Pht**—undivided H1 dolomite and Tsezotene Fm; **S**—sill; **Ꞓcc**—Lower and Middle Cambrian Mount Clark and Mount Cap formations; **Ꞓs**—Cambrian Saline River Formation; **ꞒD**—Cambrian to Devonian carbonates; **DK**—Devonian and Cretaceous clastics (includes middle Devonian limestone).

tural relief. Seismic data, key lines of which are presented here, elucidate its subsurface structure and show the anticline to be a fault-bend fold generated by displacement on an unusual thrust fault for which the lower flat, ramp, and upper flat are each bedding parallel. The gently folded, overall southward dipping wedge of Mackenzie Mountains Supergroup strata is truncated by the (originally) sub-horizontal sub-Cambrian unconformity. MMS beds are parallel to this unconformity in the south and flex upward to be truncated at 10° to 20° in the north. The thrust follows stratigraphic planes of weakness in both the MMS and the Saline River Formation, and the fault geometry was dictated by the pre-existing flexure and unconformity configuration (Fig. 3a). The thrust thus remained bedding-parallel as it progressed from horizontal Proterozoic beds (the lower flat) to dipping Proterozoic beds (the ramp) to intersect the sub-

Cambrian unconformity. At that point it crossed a few meters of basal Cambrian strata (Mount Clark and/or Mount Cap formations) and was diverted into flat-lying Saline River Formation salt (the upper flat). The fault-bend fold (Imperial Anticline) was caused by the forward displacement of the wedge of Proterozoic strata across this deflection zone (Fig. 3b).

The unconformity and a few meters of basal Cambrian beds in the footwall of the overthrust are clearly displayed on Petro-Canada Line 105 (Fig. 9), and the structural and stratigraphic relationships documented there enable the interpretation of more equivocal data. For example, on lines 45A (Fig. 10) and 117X/7X (Fig. 11) the unconformity and thin Lower/Middle Cambrian interval in the footwall of the thrust can be identified as a set of indistinct sub-horizontal reflections that truncate underlying dipping reflections. Hanging wall and footwall cutoffs of the Lower Cambrian strata outline the area of thrust overlap within the area of seismic coverage (Fig. 5) and demonstrate that displacement on the overthrust increases from 5 km in the west to 12 km in the east.

The Mount Clark Formation is a gas reservoir in three structures in the Colville Hills (Fig. 6) about 100 km northeast of the Imperial anticline, so the discovery of sub-thrust Lower Cambrian strata has high-risk economic potential. Drawbacks include the difficulty of proving either structural closure on the footwall or the presence of Mount Clark reservoir sands this far west.

The schematic interpretation of Fig. 3 neatly represents the structure as revealed on seismic from the west (e.g. Fig. 10) and the east (e.g. Fig. 9) of our data set. In the intervening area, however, the ramp configuration is compound (e.g. Fig. 11) with a small classic bedding-transverse ramp superimposed on the primary bedding-parallel ramp. Thus, from northwest to southeast the ramp changes from bedding-parallel, to compound, to bedding-parallel again.

A triangular lozenge situated above the compound ramp (Fig. 11) is considered to be a halotectonic structure. It is floored by synclinally folded Proterozoic MMS strata, and roofed by unfolded competent Paleozoic carbonate. The MMS strata clearly were folded as they passed over the small ramp, whereas the overlying competent Paleozoic carbonates did not fold because ductile material, no doubt salt, filled the lozenge. Apparently, salt flowed from the high pressure anticlinal crest into the lower pressure synclinal lozenge and was squeezed laterally within the thrust plate as it advanced. In fact, the salt-filled lozenge remained stationary above the footwall ramp while Proterozoic strata flexed through the syncline beneath, and the competent Paleozoic carbonate roof passed unfolded above (Fig. 12). Thus, even though the salt was squeezed laterally as much as 12 km within and relative to the strata in the transported hanging wall, it maintained a fixed geographic location relative to the footwall.

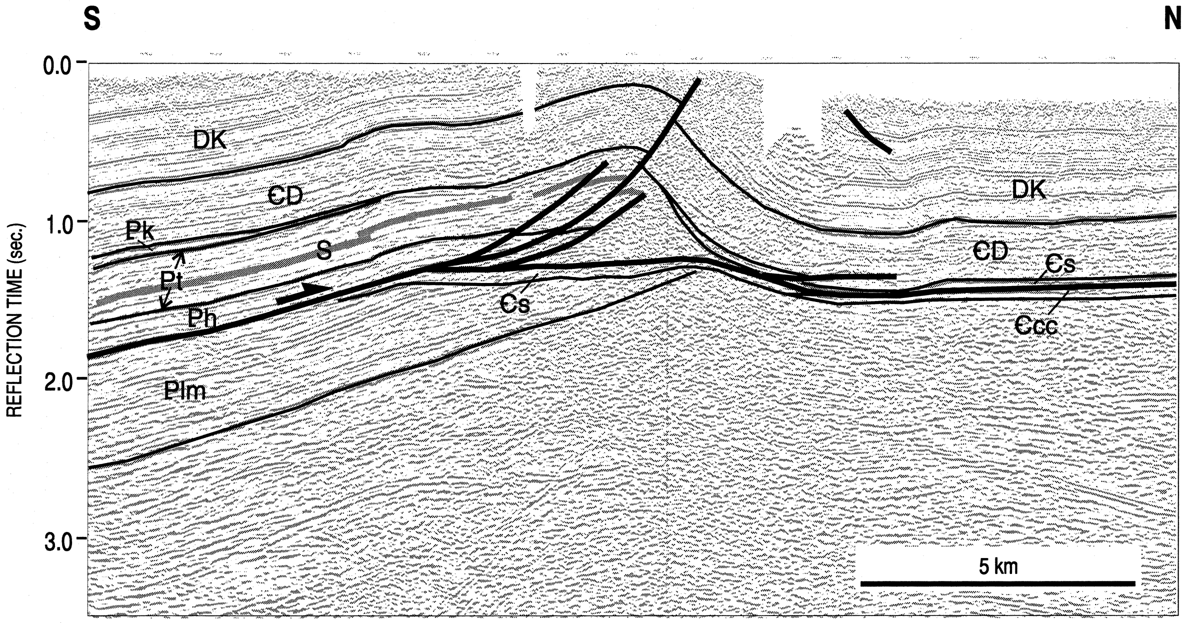

Fig. 10. Interpreted 1982 Petro-Canada line 45A. Compare with Fig. 3. For location, see Fig. 5. **Plm**—lower part of Mackenzie Mountains Supergroup, probably includes equivalents of Pinguicula Group; **Ph**—H1 dolomite; **Pt**—Tsezotene Fm; **Pk**—Katherine Gp; **S**—sill; **Єcc**—Lower and Middle Cambrian Mount Clark and Mount Cap formations; **Єs**—Cambrian Saline River Formation; **ЄD**—Cambrian to Devonian carbonates; **DK**—Devonian and Cretaceous clastics (includes middle Devonian limestone).

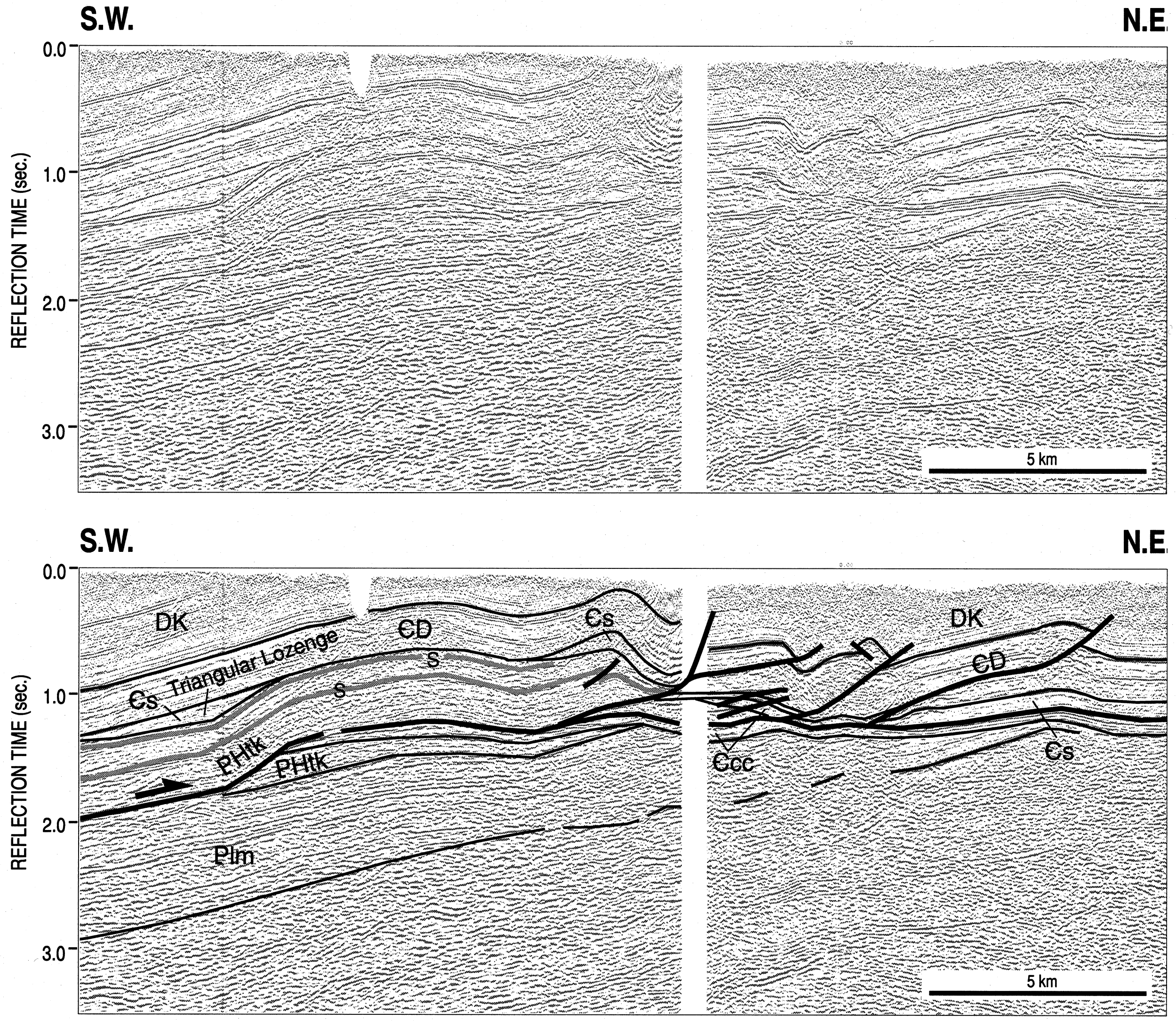

Fig. 11. Uninterpreted and interpreted 1982 Petro-Canada line 117X/7X. Note relationship of the salt-filled triangular lozenge with the small, classic footwall ramp. For location, see Fig. 5. **Plm**—lower part of Mackenzie Mountains Supergroup, probably includes equivalents of Pinguicula Group; **Phtk**—undivided H1 dolomite, Tsezotene Fm, and Katherine Gp; **S**—sill; **Єcc**—Lower and Middle Cambrian Mount Clark and Mount Cap formations; **Єs**—Cambrian Saline River Formation; **ЄD**—Cambrian to Devonian carbonates; **DK**—Devonian and Cretaceous clastics (includes middle Devonian limestone).

To generate the successive displacements of Fig. 12, we employed 'FaultII' software of Wilkerson and Associates (1990) with cartographic adjustments of the carbonate roof panel. The successive displacements (Fig. 12b–d) neatly illustrate the fixed location of the synclinal lozenge above the classic ramp. The Saline River Formation salt was not encountered in PCI Sammons H-55, a well drilled on the crest of the anticline. We suggest that salt is missing there because it was tectonically squeezed from the crest to the flanks of the anticline.

5. Correlation of subsurface Proterozoic

The single well drilled on the Imperial anticline (Figs. 5 and 13), passed through Saline River Formation shales into a 407 m thick sequence of Proterozoic siltstone and shale with interbeds of quartzitic sandstone and dolomite. Wissner (1986) assigned the interval to the Tsezotene Formation, and that correlation is strongly supported by the presence of a mafic igneous sill (Canadian Stratigraphic Services Ltd., 1988). Within the Mackenzie Mountains, sills are

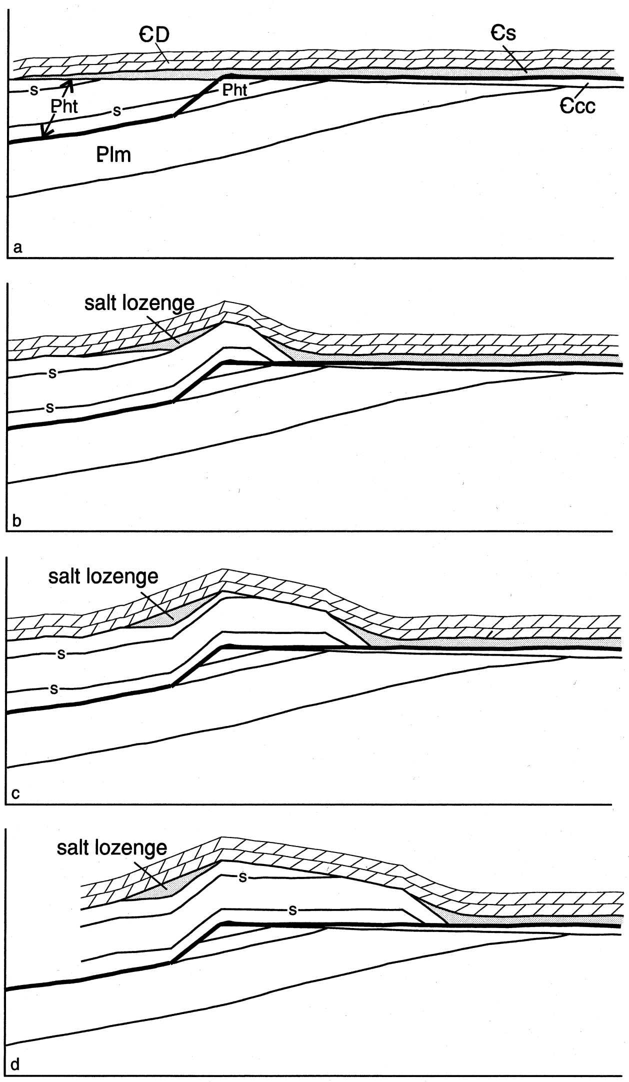

Fig. 12. A 'FaultII' (Wilkerson and Associates, 1990) simulation of progressive displacements on a compound detachment surface comprised of a bedding-parallel segment, in a dipping Proterozoic sequence, linked, by a small classic fault ramp, to a horizontal décollement surface in Cambrian salt beds. **Plm**—lower part of Mackenzie Mountains Supergroup (Pinguicula Group?); **Pht**—undivided H1 unit and Tsezotene Fm; **S**—sill; **Єcc**—Lower and Middle Cambrian Mount Clark and Mount Cap formations; **Єs**—Cambrian Saline River Formation; **ЄD**—Cambrian to Devonian carbonates. (a) Pre-displacement; (b), (c), and (d) successive, increasing, forward displacements. In the simulation a small syncline maintains at a fixed position above the small ramp regardless of the magnitude of displacement. This computer generated model was mechanically modified to show the competent Paleozoic carbonate strut as unfolded in the syncline. Compare this model with seismic line 117X/7X (Fig. 11).

exposed only in the Tsezotene Formation. We identify sills on the seismic sections in this interval based on the seismic tie with the Sammons well where the high velocity (> 6000 m/s) sill correlates with a strong continuous reflection (Fig. 13). Rainbird et al. (1996b) considered the uppermost part of the drilled interval to be of the Katherine Group on the basis of quartzite lithology and an assemblage of 'Grenville' age (ca. 1000 Ma) detrital zircons obtained from drill-core. Recent work, however, (Villeneuve et al., 1998) indicates that 'Grenville' age detrital zircons are a correlation indicator for the Mackenzie Mountains Supergroup in general, but are not reliable as a specific indicator of the Katherine Group. Considering that the quartz arenite core, from which the zircons were extracted, is only 3 m thick, and considering that no formational break is obvious on the seismic record, we follow Wissner and assign the entire drilled Proterozoic interval to the Tsezotene Formation.

Aitken et al. (1982) reported a thickness of 749 + m for the Tsezotene in the adjacent Mackenzie Mountains. Applying an average velocity of 5000 m/s for Proterozoic beds, as derived from the Sammons H-55 velocity log, the Tsezotene would be about 0.3 s thick. The H1/Tsezotene contact is not particularly reflective in Fig. 13. Therefore it is placed at a weak marker about 0.3 s down from the sub-Cambrian unconformity. Unit H1 and the Katherine Group are much more readily identified on line 45a (Fig. 10). There, we interpret that H1 is represented by a distinctive set of reflections in the hanging wall of the thrust, and the base of the Katherine Formation is imaged as a single sharp reflection, on the left side of the figure, truncated by the sub-Cambrian unconformity. This interpretation is supported by the observation that the intervening sill-bearing Tsezotene is the predicted 0.3 s thick. All of these considerations lead to the conclusion that the important Proterozoic glide zone must occur under (or possibly within) the H1 dolomite.

At least 0.6 s (1.5 km) of parallel MMS strata imaged under the detachment surface are thus older than most or all of H1. These strata are nowhere represented in outcrop in the Mackenzie Mountains but are, nonetheless, a conformable part of the MMS wedge. At least the lower part of this interval probably correlates with the Pinguicula Group (Fig. 1) a sequence about 1 km thick of carbonates and quartzites with lesser shales and volcanics (Eisbacher, 1981) which outcrops 300 km to the west-southwest in the Wernecke Mountains. An in-depth discussion is beyond the scope of this paper, but briefly, the Pinguicula Group is correlated in a general way with the MMS (e.g. Young et al., 1979; Aitken, 1982; Rainbird et al., 1996a); the sub-Pinguicula Group unconformably overlies the deformed Wernecke Supergroup so if it correlates with MMS it is basal to the sequence and must, therefore, be represented by some of the 1.5 km of basal strata imaged on the seismic section (Fig. 13).

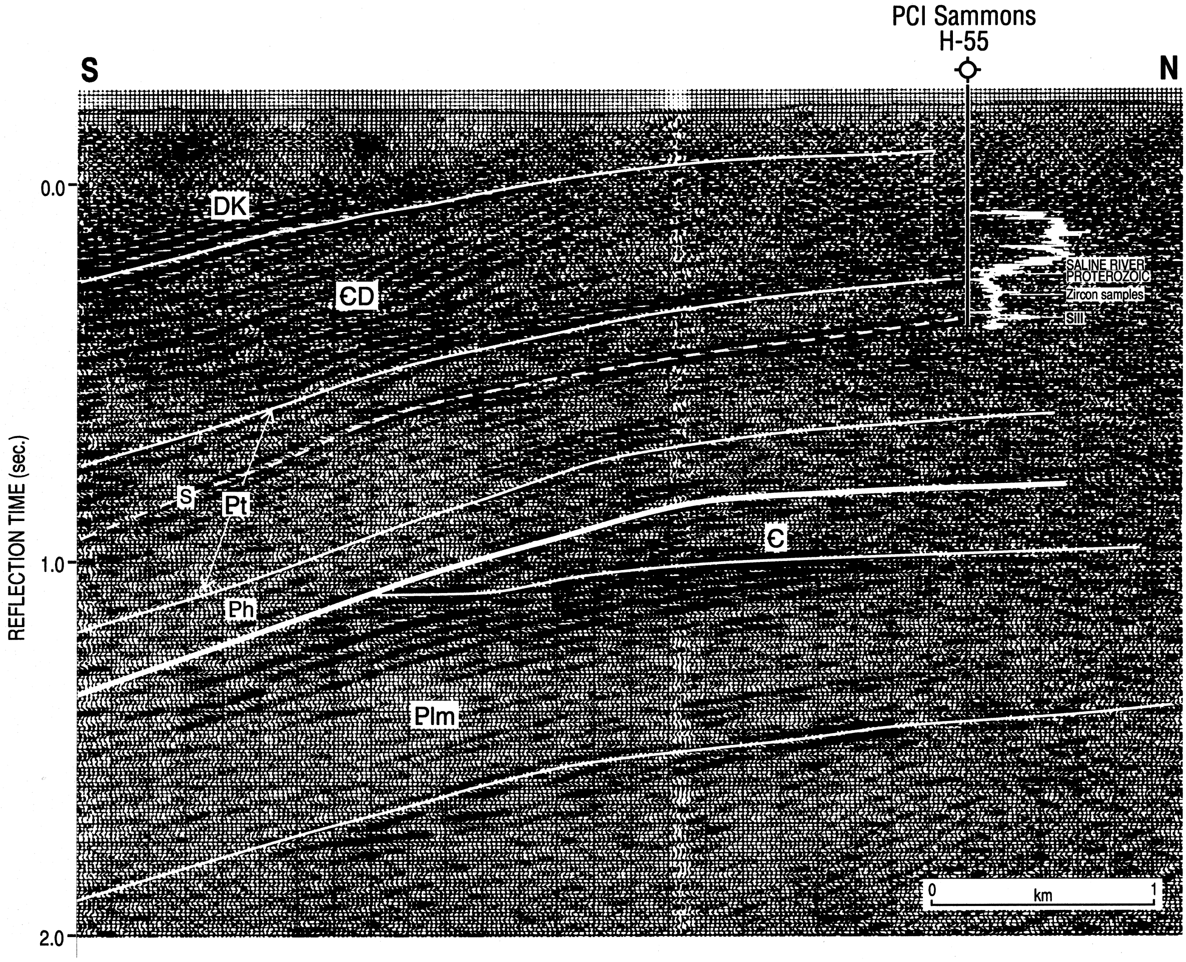

Fig. 13. A portion of 1982 Petro-Canada line 23X, with the velocity log and picks from PCI Sammons H-55 superimposed, showing correlations with the outcropping Proterozoic Mackenzie Mountains Supergroup. For location, see Fig. 5. **Plm**—lower part of Mackenzie Mountains Supergroup, probably includes equivalents of Pinguicula Group; **Ph**—informal H1 dolomite; **Pt**—Tsezotene Fm; **S**—sill; **Є**—basal Cambrian clastics and/or Salt; **ЄD**—Cambrian to Devonian carbonates; **DK**—Devonian and Cretaceous clastics (includes middle Devonian carbonate).

6. Linkage: Mackenzie Mountains to Franklin Mountains

Understanding the thrust beneath the Imperial anticline permits interpretation of a regional detachment surface climbing in two steps from an inferred deep level under the Mackenzie Mountains to a shallower level, in Saline River Formation salt, under the northern Franklin Mountains. The southernmost step is interpreted (Fig. 14) on the assumption that the Stony anticline, the frontal Mackenzie Mountains anticline is *also* a large fault-bend fold. Given the southwestward thickening truncated wedge of Proterozoic strata (Fig. 4), the Stony anticline might be a larger version of the Imperial anticline model, but in the absence of adequate control we have interpreted a conventional ramp which cuts across 'basement' rocks and the lower part of the Mackenzie Mountains Supergroup to the bedding-parallel detachment beneath the informal H1 dolomite. That bedding-parallel fault progresses up the MMS wedge to intersect sub-horizontal Cambrian strata where it is diverted into salt beds of the Saline River Formation to form the second step, the one imaged under the Imperial anticline (e.g. Fig. 3). Once into the salt beds the detachment propagated to the north and northeast to form the northern Franklin Mountains.

7. Conclusions

The Imperial anticline is a fault-bend fold localized above an unusual bedding-parallel thrust ramp controlled by a sub-H1 bedding-parallel glide-zone in a flexed Proterozoic section that is unconformably truncated by sub-horizontal Paleozoic strata. Understanding the Imperial anticline thrust permits conceptual linkage of a deep detachment beneath the Mackenzie Mountains with a much shallower detach-

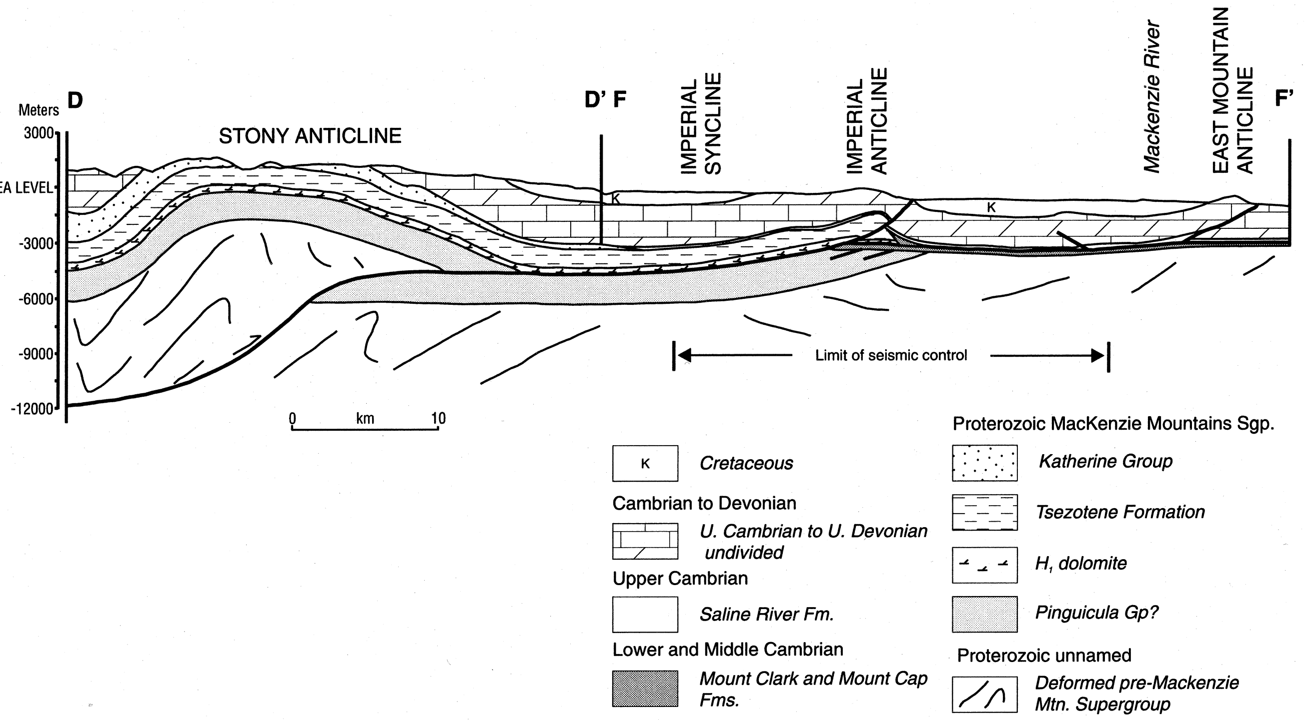

Fig. 14. A regional schematic cross-section illustrating a two-step link from a deep detachment under the Mackenzie Mountains to a shallow detachment under the northern Franklin Mountains. Surface geology is a composite after sections D–D′ and F–F′ of Aitken et al. (1982). For locations, see Fig. 5. Depth structure under the Stony anticline is schematic; under the Imperial anticline it is based on seismic interpretation.

ment in Upper Cambrian salt beds beneath the northern Franklin Mountains.

About 1.5 km of strata imaged at the base of the Mackenzie Mountains Supergroup are not seen at the surface in the Mackenzie Mountains, but equivalent strata probably do outcrop as the Pinguicula Group exposed in the Wernecke Mountains some 300 km to the west-southwest.

Understanding the Imperial anticline gives us new insight into a type of stratigraphically dictated thrust ramp that may well be present in other thrust belts.

8. Unlinked References

Wissner (1986) not cited in reference list?

Acknowledgements

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