STRATIGRAPHY AND STRUCTURAL GEOLOGY OF THE REGION SURROUNDING BUNDE AND BUKKEN FIORDS, AXEL HEIBERG ISLAND, CANADIAN ARCTIC

Project 760024

Brian F.G. Fischer [1]
Institute of Sedimentary and Petroleum Geology, Calgary

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Abstract

The region surrounding Bunde and Bukken fiords on northwestern Axel Heiberg Island, in the Canadian Arctic Archipelago, is underlain by a thick (over 6000 m) succession of rocks, consisting primarily of sedimentary strata similar to those that exist elsewhere in the axial portion of the Sverdrup Basin. Included in this sequence are Cretaceous mafic volcanic flows, pyroclastic units, and lithic clastic strata. Numerous sills and dykes, presumably related to the volcanic activity, cut and thicken the sedimentary package.

Compression during the early Tertiary Eurekan Orogeny gently deformed the strata. There was an extensional event prior to this orogeny, and the resultant normal faults produced a horst, which may have affected the development of the later structures. The orogeny itself is defined as a compressional phase and resulted in the formation of three large, steeply dipping, reverse faults. The faults have opposing dips and opposing directions of vergence, and are associated with a number of folds. Horizontal shortening associated with each of these faults is estimated to be in the order of 3 km. Typically, the Permian carbonates are juxtaposed over Triassic sandstones and shales. The zone of detachment for these faults lies within the evaporites of the Otto Fiord Formation. A single normal fault which crosscuts one of the major reverse faults in the study area may represent a third deformational period.

Résumé

La région entourant les fjords Bunde et Bukken au nord-ouest de l'île Axel Heiberg, dans l'archipel canadien arctique, repose sur une épaisse succession rocheuse (6 000 m), formée principalement de strates sédimentaires semblables à celles qui existent ailleurs dans la partie axiale du bassin de Sverdrup. Cette séquence comprend des coulées volcaniques mafiques du Crétacé, des unités pyroclastiques et des strates clastiques lithiques. De nombreux sills et dykes, dus probablement aux activités volcaniques, coupent et épaississent les roches sédimentaires.

La déformation qui s'est produite pendant l'orogenèse d'Euréka du début du Tertiaire a légèrement déformé les strates. Avant cette orogenèse, s'était produit un vaste mouvement et les failles normales qui en résultaient ont soulevé un horst qui pourrait avoir modifié le développement de structures plus récentes. L'orogenèse en elle-même est définie comme une phase de compression et a eu pour résultat la formation de trois grandes failles inverses à fort pendage. Les failles ont des pendages et des directions opposés et sont associées à un certain nombre de plis. Le raccourcissement horizontal associé à chacune de ces failles est estimé être de l'ordre de 3 km. Selon un patron typique, les carbonates du Permien sont juxtaposés sur les grès et les schistes argileux triassiques. La zone de détachement de ces failles se trouve dans les évaporites de la formation d'Otto Fjord. Une seule faille normale qui traverse une des principales failles inverses dans la région étudiée, peut représenter une troisième période de déformation.

Introduction

During the 1983 field season, an area surrounding both Bunde Fiord and Bukken Fiord on northwestern Axel Heiberg Island, Canadian Arctic Archipelago, (Fig. 34.1) was mapped at a scale of 1:50 000. The study area is part of the Sverdrup Basin, an elongate, pericratonic depression comprising an esssentially conformable sequence of sedimentary and volcanic strata, ranging from Late Mississippian to Tertiary in age (see Balkwill, 1978). These strata were gently deformed during the Early Tertiary (Bustin, 1977) Eurekan Orogeny, resulting in the formation of predominantly gentle folds, steeply dipping normal faults, and a number of low angle thrust faults and high angle reverse faults.

The area of interest lies within the axial succession of the Sverdrup Basin and is structurally within the Tertiary Eurekan Sound Fold Belt (Fortier et al., 1963). N.J. McMillan conducted the first geological work in the area during his traverse of the width of northern Axel Heiberg Island (McMillan, 1963). Short visits to the area by a few members of the GSC resulted in the definition of much of the stratigraphy and delineation of the major structures (see Thorsteinsson, 1974; Thorsteinsson and Trettin, 1972; Tozer, 1963, 1967).

The field study was conducted to gather further stratigraphic data and, more importantly, to map in detail the various structures in the area, particularly the reverse faults of opposing vergence, in an attempt to determine the timing and mechanisms of the deformational events that made up the Eurekan Orogeny in this area.

Acknowledgments

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[1] Department of Geology, University of Calgary, Calgary, Alberta T2L 2A7

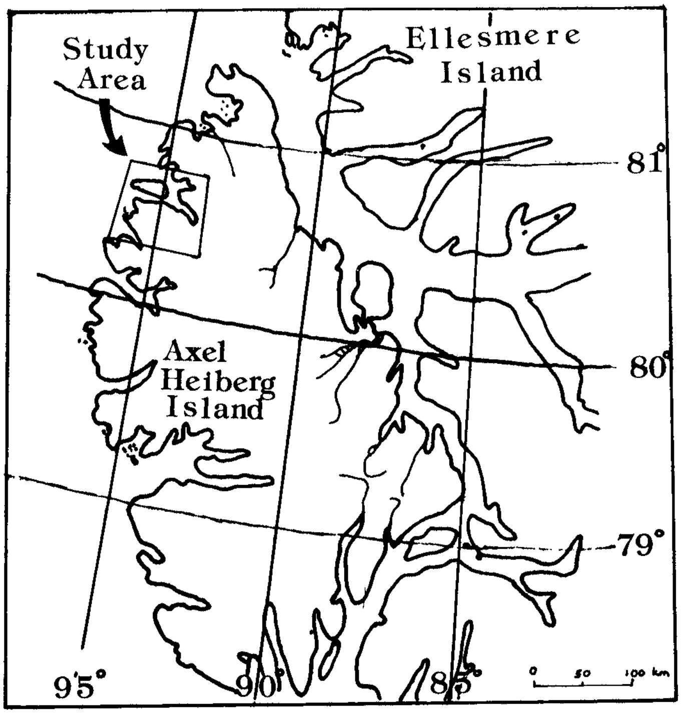

Figure 34.1. *Location map.*

Stratigraphy

A thick sequence of strata, typical of that found within the axial succession of the Sverdrup Basin, is present within the study area (Fig. 34.2). The oldest rocks exposed are the anhydrites and limestones of the Upper Mississippian to Lower Pennsylvanian (Thorsteinsson, 1974) Otto Fiord Formation. These evaporites are not usually found in normal stratigraphic position here, but rather are exposed as a number of small diapiric structures located along major fault traces. The oldest strata to crop out in normal stratigraphic succession are the limestone beds of the Nansen Formation. All exposures of this formation are found in the immediate hanging wall of large reverse faults. In the study area, the Nansen Formation is approximately 830 m thick and is characterized by a cyclical pattern of light grey, fossiliferous, micritic limestones, cherty limestones, and argillaceous limestones. Algal mounds are present in a number of localities (B. Beauchamps, personal communication, 1983). The Van Hauen Formation directly overlies the Nansen Formation and comprises some 70 m of very recessive, fossiliferous, brown weathering, argillaceous limestones. Above this recessive unit are the more competent, interbedded, orange weathering, micritic limestones and dark, bedded cherts of the Degerbols Formation. This latter formation varies in thickness from some 400 m in the south to about 50 m in the north and grades into a thin, massive, white chert unit north of Bukken Fiord.

The basal bed of the overlying Blind Fiord Formation is a thin, conglomeratic band that overlies the basin-wide Permo-Triassic unconformity (Nassichuck et al., 1973). The Blind Fiord Formation is characterized by light grey-green weathering siltstones and silty shales, with a few beds of pelecypod-bearing, fine grained, brown weathering sandstones in the lower portion of the formation. A thick succession of dark grey to black shales and silty shales overlies the Blind Fiord Formation and makes up the Blaa Mountain Formation. Thin, laterally discontinuous beds of pelecypod-bearing, micritic limestones are a distinctive part of this unit.

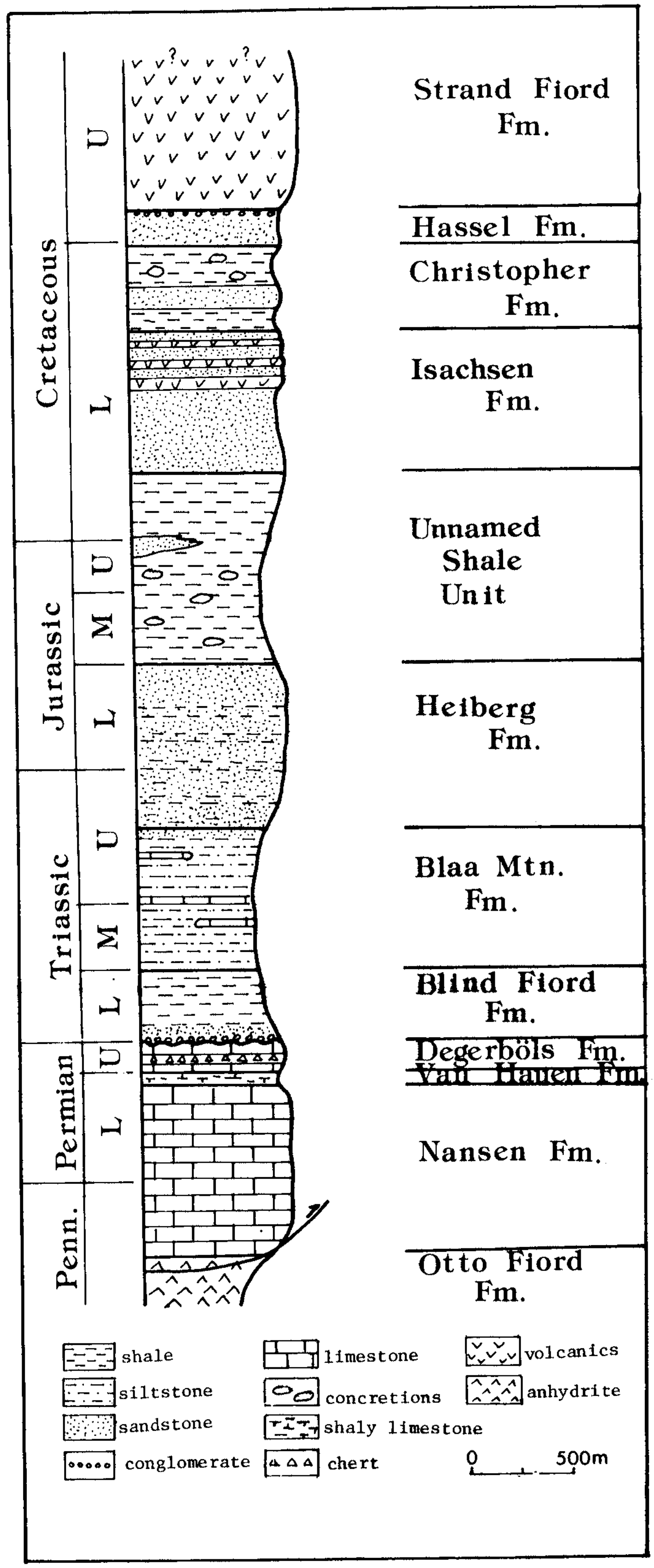

Figure 34.2. *Stratigraphic column.*

Fine sandstones appear near the top of the formation and the upper contact is gradational with the sandstones of the lower Heiberg Formation.

The Heiberg Formation comprises approximately 800 m of interbedded fine grained sandstones, siltstones, and carbonaceous shales. The grained sandstones are typically medium bedded, locally burrowed or crossbedded, and commonly contain mud chips and lenticular bedding. The shales and silts commonly display flaser bedding. Within the upper portion of this formation, root casts and rootlets are common and suggest a marine to nonmarine progression through the formation.

A thick succession of black shales overlies the Heiberg Formation, and is characterized by the presence of large ironstone and limestone concretions in the lower portion. Ammonities found near the base of this sequence have been dated as Early Callovian (T.P. Poulton, personal communication, 1984). The upper portion of this thick shale sequence lacks the large concretions. These strata are referred to an unnamed formation that contains equivalents of the Savik, Deer Bay and Awingak formations (Thorsteinsson and Trettin, 1972). A thin, fine grained, brown sandstone unit was mapped within these shales (marked JKr in Fig. 34.3) just south of Bunde Fiord and may represent a tongue of the Awingak Formation.

The coarse grained to conglomeratic, white weathering sandstones of the Isachsen Formation are found above the unnamed formation. These sandstones display excellent trough crossbedding and ripple crosslamination. Burrowing is common. Mafic volcanic flows, commonly vesicular or amygdaloidal, are found interbedded with the sandstones of the Isachsen Formation throughout the upper third of the unit. Well preserved paleosols are commonly found at the base of these flows. A number of pyroclastic units, presumably related to this volcanic activity, are present in the upper portion of this formation.

The dark grey, concretion-bearing shales of the Christopher Formation lie above the Isachsen Formation. A very coarse grained lithic sandstone unit in the middle of the Christopher Formation is an excellent marker bed. An ammonite collected from the top of this unit has been dated

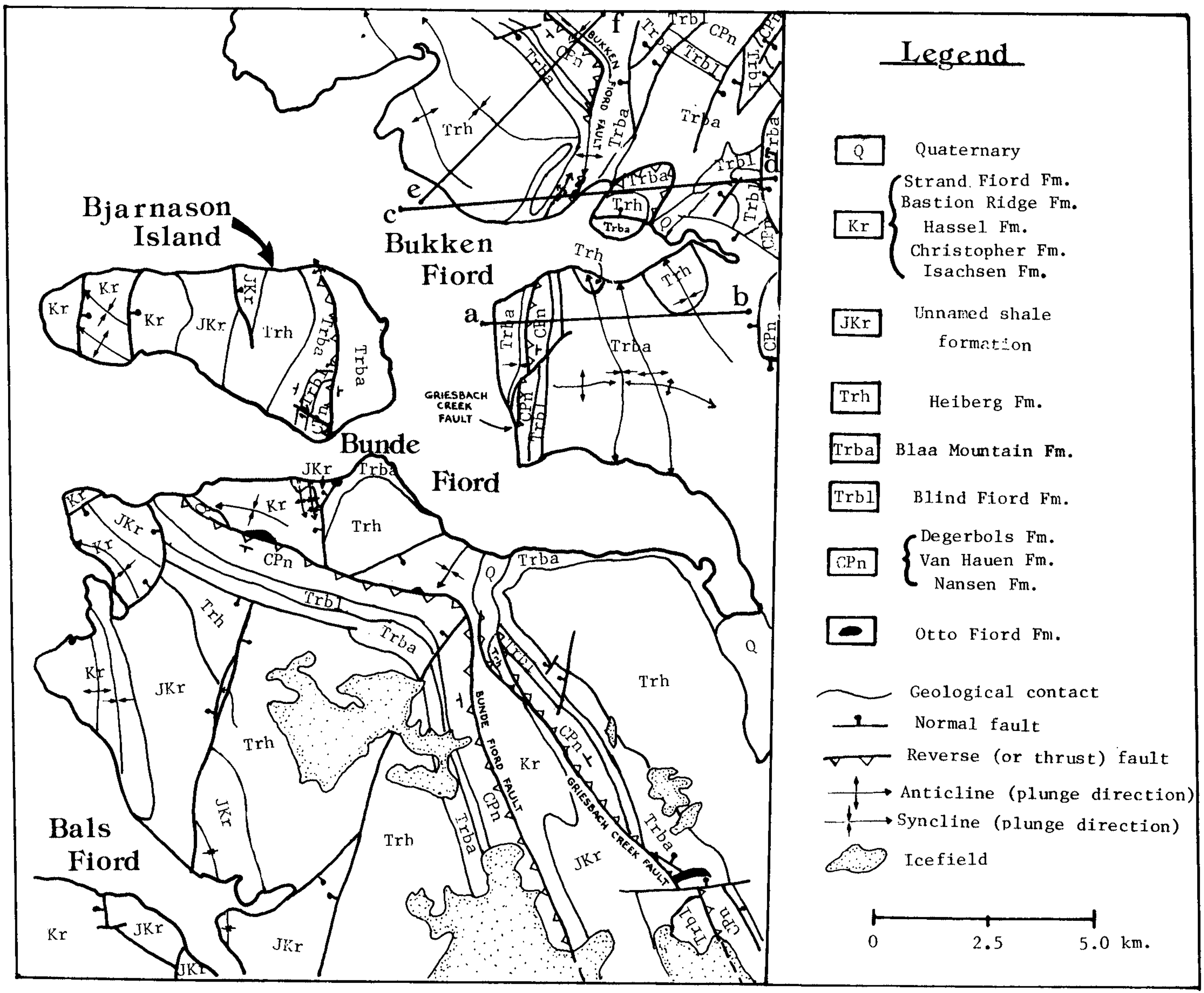

Figure 34.3. Geology of the study area, showing location of lines of cross-section.

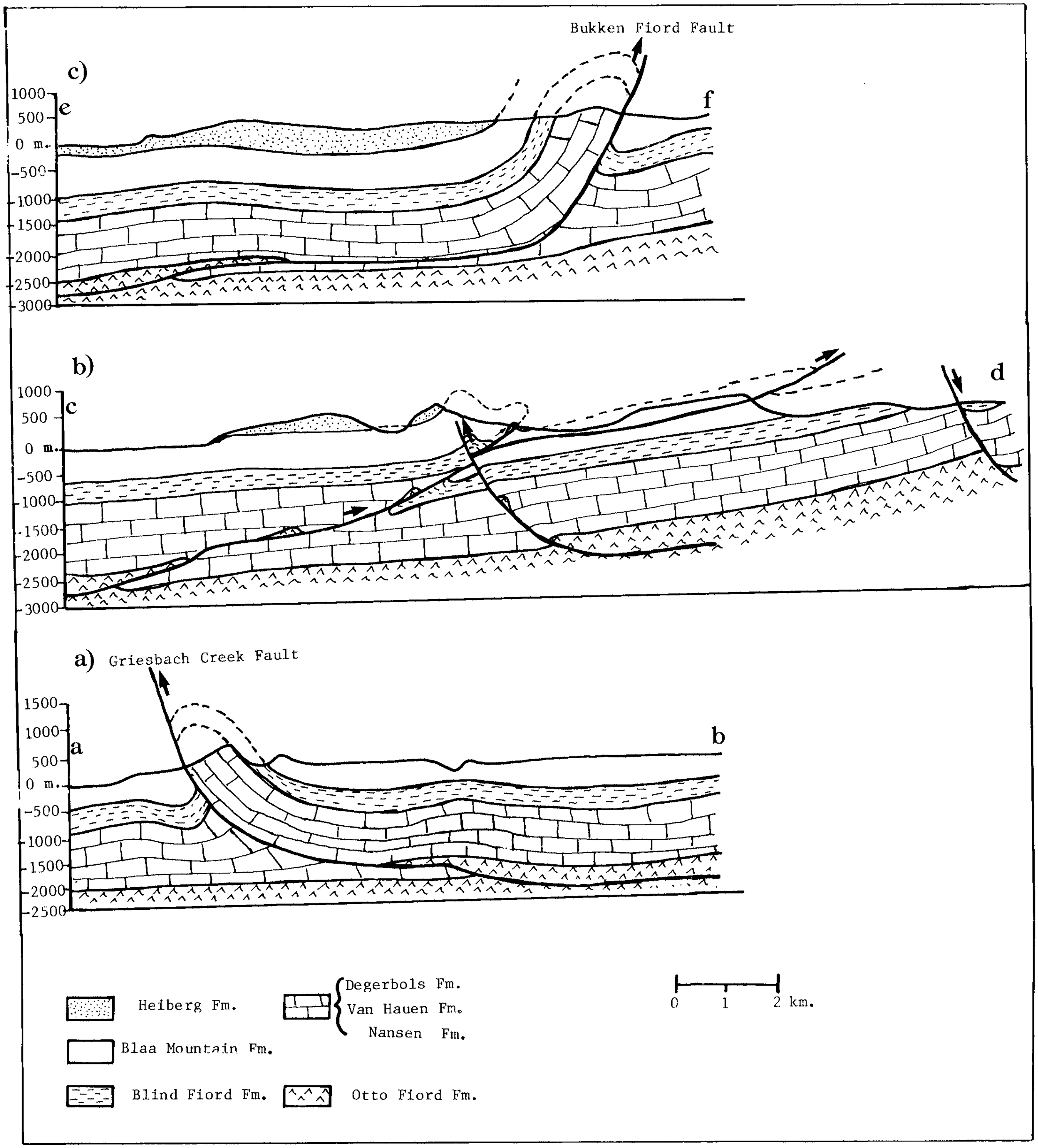

Figure 34.4. *Cross-sections through the Griesbach Creek Fault (a) and Bukken Fiord Fault (c); (b) shows the linkage between the two faults, (note that the near-horizontal thrust "slice", placing the Blaa Mountain Formation on itself, was defined by repeated sills).*

as Lower and Middle Albian (J.A. Jeletzky, personal communication, 1983). The dark brown, fine- to medium-grained sandstones of the Hassel Formation overlie the Christopher shales. The upper beds of the Hassel Formation comprise a chert-pebble conglomerate and are overlain by a thick succession of mafic volcanic flows representing the Strand Fiord Formation (K.G. Osadetz, personal communication, 1983).

The study area has a large number of diabase dykes and sills which have thickened the stratigraphic section substantially. They were noted in all formations found in the area up to the level of the Strand Fiord volcanics, and are most predominant within the less competent units, such as the unnamed formation (JKr) and the Blaa Mountain Formation. Slickensiding associated with bedding plane slip is found on these intrusive rocks, indicating that their emplacement occurred prior to deformation. It is suggested that these intrusions acted as feeder systems for the Cretaceous volcanic activity displayed in both the Isachsen and Strand Fiord formations.

Structure

The thick sequence of rocks described above was gently deformed during at least two, and possibly three, episodes (Fig. 34.3). An early extensional phase resulted in the formation of steep normal faults. This is evident on the south shore of Bunde Fiord, where two steeply dipping normal faults bring Triassic strata up against the surrounding Cretaceous rocks, forming a horst. These two faults are crosscut by the later Bunde Fiord Fault, and their continuations in the hanging wall of the latter fault have been removed by erosion.

The east and northeast verging Bunde Fiord Fault, the westerly verging Griesbach Creek Fault, and the northeast verging Bukken Fiord Fault, along with their associated folds, were formed during the Eurekan Orogeny. These steeply dipping reverse faults are the dominant structural elements within the study area. Both the Bukken Fiord Fault, and the probable northern extension of the Bunde Fiord Fault, located on Bjarnason Island, had previously been mapped as normal faults (Thorsteinsson and Trettin, 1972). However, bedding measurements taken from both the hanging walls and footwalls of these faults make it geometrically difficult to interpret them as normal faults. Further evidence supporting the reverse fault interpretation includes the apparent westerly dips of the fault planes as the fault traces cut across topography, and the fact that each fault dies out into the core of an anticline.

Away from the Bunde Fiord, Griesbach Creek and Bukken Fiord faults the strata are gently warped, with dips of 3 to 5° being common. In the vicinity of these faults, however, bedding steepens dramatically, defining the flanks of faulted, tight, asymmetric folds (Fig. 34.4a, c). Although exposures of the fault planes occur in only two locations, showing dips of around 50° for the Bunde Fiord Fault, the geometry of the large associated folds allows one to locate the fault planes in areas where they do not crop out. As each fault must cut upsection through previously undeformed or mildly deformed strata, the rocks in the hanging wall must dip at an angle that is less than, or equal to, the angle of dip of the fault plane. As a result, the dips of all the fault planes at the surface are between 50 and 70° as a minimum. A thick unit of cataclastic limestone is found along the trace of each of these three reverse faults, indicating a fault zone at least 10 m thick.

Although the exact mechanism behind the formation of these reverse faults of opposed dip has yet to be determined, linkage between these faults can be demonstrated north of Bukken Fiord (Fig. 34.3, 34.4b). At this locality, the easterly dipping Griesbach Creek Fault terminates within a northeasterly plunging anticline, and the *en echelon*, northwesterly dipping Bukken Fiord Fault terminates within the adjacent southerly plunging anticline. The difference in shortening in the interval between the two faults was compensated by the generation of these folds. This can be demonstrated by comparing shortening shown on the three structural cross-sections in Figure 34.4. The northernmost section and the southernmost section (Fig. 34.4a and c respectively) show horizontal shortening of around 3.0 km, with the central cross-section displaying the linkage between these two faults.

This central cross-section shows minor offset of the Bukken Fiord Fault by the Griesbach Creek Fault, but these two reverse faults are believed to be of the same age. The crosscutting relationship depicted in this figure is attributed to the time required for the lateral propagation of the two faults.

As drawn, the Bukken Fiord Fault, having propagated southward from its initial point of fracture, reached the location of the line of section earlier than the Griesbach Creek Fault, which presumably had a greater lateral distance to propagate northward from its initial point of fracture to the locations marked by the lines of sections C, D. The possibility then exists that farther south of the section, below Bukken Fiord, the Griesbach Creek Fault may be offset by the Bukken Fiord Fault. This would be a function of the increased southward lateral propagation distance for the Bukken Fiord Fault, along with a corresponding decrease in the northward lateral propagation of the Griesbach Creek Fault.

The gentle warping of the strata in the hanging walls of these faults is attributed to ramps on the fault surfaces in the basal portion of the Nansen Formation. Lateral ramps are also found within the study area north of Bukken Fiord along the Bukken Fiord Fault trace. It is believed that a combination of these two types of ramps result in the subtle "saddle" and "dome" structures mapped in the hanging wall of the Griesbach Creek Fault on the peninsula between Bunde and Bukken fiords.

The fault traces of these reverse faults locally show offsets, such as on the previously mentioned peninsula. These offsets however, are confined to strata in the hanging wall with no evidence of offset in the footwall rocks. It is suggested that these structures also are a result of lateral ramping. It is possible that the horst, which formed during the earlier extensional phase, could have influenced the direction of later faulting and therefore caused the deflection displayed by the Bunde Fiord Fault. The geometry of the reverse fault on Bjarnason Island remains to be analyzed.

Small anhydrite bodies are also found along the traces of these major faults. Foliations and lineations measured from the distorted, nodular, mosaic fabric of these rocks, and their position out of stratigraphic sequence, are consistent with diapiric movement of the anhydrite up along the fault zone during compression. These anhydrite bodies have been correlated, on the basis of lithology, with the evaporites of the Otto Fiord Formation. The presence of a distinctive, red, gypsiferous unit, which has also been observed by Fischer in the type section of the Otto Fiord Formation, further suggests this correlation. On the basis of the position of these diapirs along the major fault traces of the area, and because the oldest strata exposed in normal stratigraphic succession in the hanging wall of any of these reverse faults is that of the Nansen Formation, it is concluded that the zone of detachment for these faults lies within the evaporites of the Otto Fiord Formation.

In the southeast corner of the map area, a normal fault offsets the strata both above and below the Griesbach Creek Fault. This may represent a third deformation event. However, as mentioned earlier, the most probable mechanism for the formation of the reverse faults has yet to be determined, and if this second period of deformation involved a large component of shear, the possibility exists that the normal fault in the southeast corner of the map area formed syntectonically with the reverse faults (Sales, 1968).

Balkwill (1978) defines three major pulses of Eurekan orogenic activity within the Sverdrup Basin: an early phase of uplift and erosion, followed by a period dominated by compressive forces, and, lastly, a phase of renewed uplift and erosion. The most prominent structural features present in the study area are compressional features, in particular the three large reverse faults. Although in the area studied the reverse faults cut rocks as young as Late Cretaceous (and they are therefore Late Cretaceous or younger in age), they are most probably related to Balkwill's (op. cit) second pulse of orogenic activity, and as such formed between the middle Eocene and early Miocene.

As the early extensional structures in the study area also offset the Late Cretaceous Strand Fiord Formation, and as these extensional structures pre-date the reverse faults, they must be Late Cretaceous to middle Eocene in age. It is possible, therefore, that the formation of the horst south of Bunde Fiord may have been associated with Late Cretaceous to late Paleocene uplift along the Princess Margaret Arch.

Conclusions

The study area is underlain by a thick sequence of sedimentary and volcanic rocks typical of the stratigraphy found on the northwest rim of the Sverdrup Basin. Prior to deformation, the strata were thickened substantially by the intrusion of numerous diabasic dykes and sills which are presumably related to the Cretaceous volcanic flows.

The Late Cretaceous and Tertiary movements gently deformed the strata, and did so during at least two, and possibly three, deformational episodes. The first of these episodes probably occurred sometime between the Late Cretaceous to middle Eocene and was extensional in nature, causing the formation of a horst which may have affected the formation of later structures. The second episode was compressional, most likely related to the middle Eocene to early Miocene phase of the Eurekan Orogeny. This phase resulted in the formation of three large, steeply dipping reverse faults, which display opposing directions of vergence. Minimal shortening took place along these faults, and, because of the steepness of the fault zone itself, stratigraphic throw is approximately half as great as the horizontal shortening.

These faults merge into a detachment zone within the evaporites of the Otto Fiord Formation. Folding throughout the study area can be attributed to the movement along the reverse faults. Ramps, both perpendicular and parallel to the slip direction, result in the unusual map pattern of many of these folds. Most of the apparent offsets of the reverse fault traces can also be attributed to laterally discontinuous ramps. However, in at least one instance, the offset may represent normal faulting due to a third period of deformation.

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