Reconnaissance geology of northern Toobally Lake (95D/8), southeast Yukon

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ABSTRACT

The Toobally fault is a north-trending structure occurring along the west shore of northern Toobally Lake (95D/8) that juxtaposes Neoproterozoic-Cambrian sedimentary and volcanic rocks (to the west) against Devonian-Carboniferous sedimentary rocks (to the east). Paleozoic units east of the fault are tentatively correlated with an unnamed Devonian limestone, Besa River Formation and Mattson Formation, and are interpreted to form an asymmetric, east-verging anticline-syncline fold couplet with a sub-vertical common limb. Older units west of the fault constitute a homoclinal west-dipping succession consisting of (from oldest to youngest) an unnamed quartz sandstone, a diamictite and a basalt. The diamictite is a previously unrecognized unit, estimated to be at least 1800 m thick, for which we propose the name Toobally Formation. It is tentatively correlated with Ice Brook and Vreeland formations and is considered to be a glaciomarine succession in uppermost Windermere Supergroup. Overlying the Toobally Formation is an 850-m-thick succession of Neoproterozoic-Cambrian(?) basalt. The geochemistry of these basalts is consistent with rift volcanism in a within-plate tectonic setting.

RÉSUMÉ

La faille de Toobally est une structure à direction nord longeant la rive ouest du lac Toobally nord (95D/8). Elle juxtapose des roches sédimentaires et volcaniques (ouest) du Néoprotérozoïque-Cambrien à des roches sédimentaires (est) du Dévonien-Carbonifère. Les unités paléozoïques à l'est de la faille sont mises en corrélation avec un calcaire non désigné du Dévonien, la Formation de Besa River et la Formation de Mattson et elles sont interprétées comme un couplet d'anticlinal-synclinal asymétrique à vergence est dont le flanc vertical est commun. Les unités plus anciennes à l'ouest de la faille constituent une succession homoclinale à pendage ouest composée (du plus ancien au plus jeune) de grès quartzeux non désigné, de diamictite et de basalte. La diamictite est une unité définie antérieurement dont l'épaisseur estimée est d'au moins 1800 m et pour laquelle nous proposons l'appellation Formation de Toobally. Elle pourrait être corrélée avec les formations d'Ice Brook et de Vreeland et serait une succession glaciomarine dans le sommet du Supergroupe de Windermere. Sur la Formation de Toobally repose une succession de basalte néoprotérozoïque-cambrien(?) de 850 m d'épaisseur. La géochimie de ces basaltes est conforme à un volcanisme de rift dans un milieu tectonique intra-plaque.

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INTRODUCTION

A short field season at the northern Toobally Lake (NTS 95D/8) in southeastern Yukon was completed in the last two weeks of July, 2003. The fieldwork was intended to clarify geologic relations implied from earlier regional geology mapping (Gabrielse and Blusson, 1969). The specific objectives included sampling the Cambrian (?) volcanic rocks west of northern Toobally Lake, characterizing them in terms of geochemistry and tectonic environment, and viewing stratigraphic relations between the volcanic rocks and the enclosing sedimentary rocks.

This brief report presents the results of the 2003 field season. Reconnaissance geologic mapping identified a previously unrecognized sedimentary succession underlying the Neoproterozoic-Cambrian (?) volcanic rocks. In this report we present a revised stratigraphy. In addition we comment on the existing structural interpretation in the immediate northern Toobally Lake area. The report is based on exposures along the lake and westward along one stream which drains east into northern Toobally Lake from headwaters about 1.5 km southeast of Gusty Lakes.

LOCATION AND ACCESS

Map sheets NTS 95D/1 and 95D/8 contain several large and small lakes in a north-south trend that are collectively called Toobally Lakes. Our fieldwork was completed around the northernmost of the larger lakes in the chain; we refer to it as the northern Toobally Lake (NTS 95D/8). It is located in southeast Yukon about 150 km northeast of Watson Lake (Fig. 1). It occurs within the Hyland Plateau (Bostock, 1948), an area of subdued, north-trending ridges separated by broad, forested, drift-filled valleys. Isolated ridge tops contain cliff exposures, but areas with extensive exposure are rare (Fig. 2). Old burn with resulting cross-piled blow-downs and dense young growth make walking difficult. Slopes away from the lake are steep but vegetated. Most outcrops occur along east-trending streams which have cut down through the ridges to form steep-sided gullies.

Roads into the area are nonexistent. We were mobilized into the lake by float plane from Watson Lake. Transportation on the lake was accomplished using an inflatable boat with an outboard motor. Traverses were completed by short hikes from lakeshore. A GPS unit was

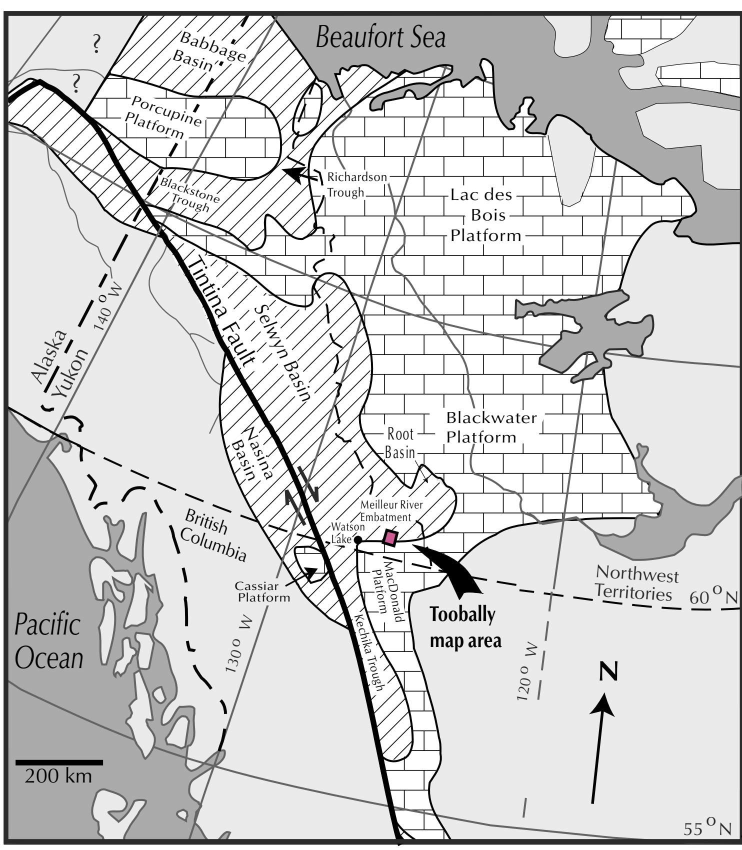


Figure 1. Location of northern Toobally Lake map area (95D/8) in southeast Yukon. General distribution of Ordovician-Silurian platform carbonate and basinal shale facies for Canadian Cordillera and Alaska are indicated. Modified from Cecile et al. (1997).

Figure 2. *View looking south of the northern Toobally Lake. Area is part of the Hyland Plateau with gentle mountains and broad drift-covered valleys.*

invaluable for reliable location fixes in the densely treed terrain.

PREVIOUS WORK

Gabrielse and Blusson (1969) completed 1:253 440-scale regional geology mapping in 1967 and published a preliminary map showing their results. The only Yukon MINFILE data record in NTS 95D/8 was reported as part of that regional mapping program (Deklerk, 2002). No active quartz claims are currently held within 95D/8. Allen et al. (2001), and Pigage and Allen (2001) reported on 1:50 000-scale geology mapping for the Pool Creek map area (NTS 95C/5) immediately east of this area.

REGIONAL GEOLOGY

The northern Toobally Lake occurs within the miogeocline of ancient North America, a prism of sedimentary rocks of Precambrian to Jurassic age deposited along the relatively stable margin of western ancient North America (Abbott et al., 1986). The area lies north of the northward facies transition (Fig. 1) from the Silurian-Devonian carbonates of the MacDonald carbonate platform to the basinal shales of the Meilleur River Embayment, a large embayment of the east margin of Selwyn Basin (Cecile et al., 1997).

Coal River map area (NTS 95D) contains stratified rocks ranging in age from late Proterozoic through Carboniferous (Gabrielse and Blusson, 1969). Gabrielse and Blusson (1969) reported Cambrian (?) volcanic rocks along the west side of northern Toobally Lake and Carboniferous sandstones of the Mattson Formation along the east side of the lake. Both units strike northerly and dip moderately to steeply to the west. They are separated by the Toobally fault, a steep fault with about 4000 m of stratigraphic throw (east-side down; Gabrielse and Blusson, 1969).

STRATIGRAPHY

We mapped six stratigraphic units during our reconnaissance work in the 2003 field season (Fig. 3). From west to east these are:

- Neoproterozoic-Cambrian (?) volcanic rocks (unnamed),
- Neoproterozoic diamictite of the Toobally Formation (new),
- Neoproterozoic sandstone (unnamed),
- black silty shale (Devonian-Carboniferous Besa River Formation ?),
- dark grey limestone (unnamed Devonian limestone ?), and
- sandstone of the Carboniferous Mattson Formation.

The black silty shale, dark grey limestone, and Mattson Formation are interpreted as occurring in the footwall (east) of the Toobally fault; and the Neoproterozoic-Cambrian (?) volcanic rocks, Toobally Formation, and Neoproterozoic sandstone are interpreted as occurring in the hanging wall (west) of the Toobally fault. Detailed descriptions of these units are presented in ascending stratigraphic order below.

NEOPROTEROZOIC SANDSTONE UNIT

The west ridge along the north part of northern Toobally Lake contains outcrop and talus of a pale pinkish grey, pale grey, or white, noncalcareous quartz sandstone with lesser granule and small-pebble conglomerate. Pebbly to granular sandstone is also common. Upper and lower contacts of the sandstone unit have not been observed. Bedding is not readily visible. Outcrops typically consist of resistant spires along streams and east-facing cliffs along the ridge.

Weathered surfaces are pale grey, orange, pink or white. Sand grains range from fine to very coarse, although they are dominantly medium to coarse. The grains are subangular to round, most commonly subround to round.

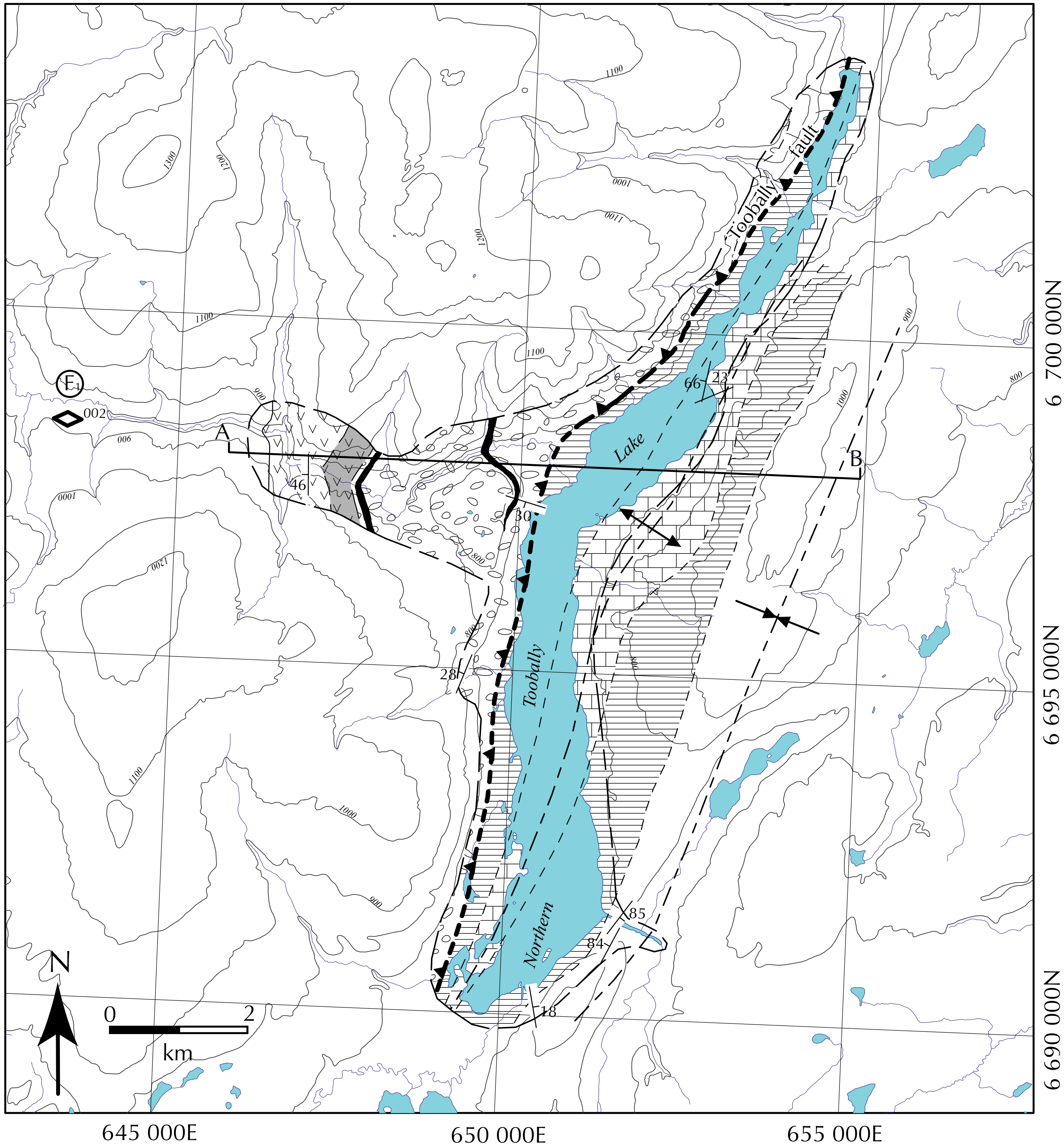
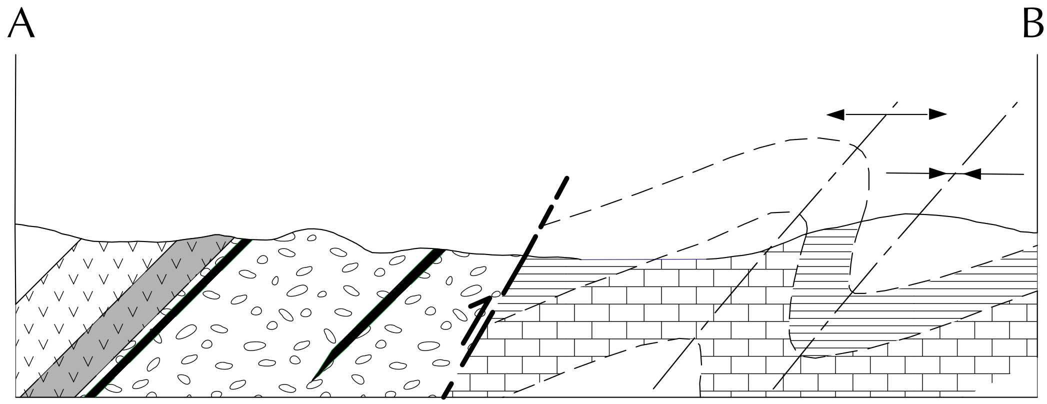
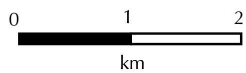


Figure 3. Reconnaissance geology of northern Toobally Lake area. Coordinates are zone 9, UTM NAD83. Grid lines are spaced every 5 km. Legend on facing page. Diamond in west part of map indicates the Gusty Yukon MINFILE occurrence 95D 002 (Deklerk, 2002).





INTRUSIVE ROCKS

Neoproterozoic-Cambrian(?)

gabbro / diabase

medium-grained, dark green, equigranular gabbro to diabase; subvolcanic feeder dykes and sills for Neoproterozoic-Cambrian(?) mafic volcanic rocks.

LAYERED ROCKS

Early Carboniferous

Mattson Formation

pale grey, strongly indurated, fine-grained quartz sandstone

Devonian to Early Carboniferous

Besa River Formation

black shale and argillite (from Gabrielse and Blusson, 1969)

Devonian

limestone

dark grey to black, finely crystalline, laminated to thin-bedded, locally bioturbated limestone

Early Cambrian

sandstone

varicoloured quartzitic sandstone; arkosic, pebbly sandstone (from Gabrielse and Blusson, 1969)

Neoproterozoic-Cambrian (?)

mafic volcanic rocks

grey-weathering, thick-bedded, basaltic volcaniclastic sandstones and breccias interbedded with amygdaloidal to vesicular flows

altered mafic volcanic rocks

pale grey, red to orange-brown weathering, fine-grained, slightly pyritic massive to brecciated, strongly carbonate-altered mafic volcanic rocks

Neoproterozoic

Toobally Formation

dark grey to black, orange-brown weathering, polymictic, matrix-supported, mudstone conglomerate

sandstone and pebbly sandstone

pale cream-weathering, pale grey to off-white, moderately indurated, quartz sandstone

SYMBOLS

geological contacts (defined, approximate, assumed)

reverse fault (assumed)

limit of mapping

bedding

fold axial surface trace (anticline: upright; syncline: upright)

line of cross-section A B

fossil locality (Lower Cambrian trilobites) F1

Yukon MINFILE (2002) record 002

Figure 3. *Legend for map on facing page.*

At one locality some samples contained less than 10% orange- to cream-coloured chalky grains intermixed with the quartz grains. In thin section these grains consist of fine-grained aggregates of sericite (former feldspar?). At another locality one sample contained minor dark pink clasts of reworked quartz sandstone. The sandstone unit is cut by thin (1-cm-thick) miarolitic quartz veins.

The absence of recognizable primary sedimentary structures precludes determining a detailed depositional setting for this unit. The dominance of quartz clasts and absence of interbedded shale or siltstone suggest a relatively high-energy, broadly nonmarine to shallow marine setting.

Fossils were not noted in the outcrops we visited. This unit occurs approximately 8750 m east of the closest fossil locality, a collection of Lower Cambrian trilobites and *Skolithos* trace fossils (Gabrielse and Blusson, 1969). Assuming structural continuity with the fossil locality and a homoclinal west-dipping succession with an average dip of 45 degrees, the quartz sandstone unit occurs approximately 6200 m structurally beneath the Lower Cambrian fossil locality. With these assumptions this unit cannot be younger than Lower Cambrian. We tentatively correlate the structurally overlying unit with upper Windermere Supergroup strata (see below). Consequently this unit would also be part of the Windermere and would therefore be Neoproterozoic in age.

The lithological description of this quartz sandstone is very similar to that of the Cambrian sandstone as presented by Gabrielse and Blusson (1969). A possible alternative structural interpretation is that this sandstone unit is a fold repeat of the Cambrian sandstone on the east limb of a large anticline, with its axial trace west of the lake and east of the Neoproterozoic-Cambrian (?) basalt (see Fig. 3). Due to time constraints we were not able to view the Cambrian sandstone immediately overlying (west of) the Neoproterozoic-Cambrian (?) basalt to ascertain the similarities and differences between these two sandstones. Further geology mapping is required to confidently select between these two structural interpretations. For now, we tentatively consider the rocks west of the northern Toobally Lake to be a homoclinal, west-dipping succession.

TOOBALLY FORMATION (NEW UNIT)

The most distinctive and areally extensive map unit examined during 2003 fieldwork is a thick succession of polymictic muddy conglomerate to pebbly mudstone (Fig. 3). This unit occupies much of the area previously considered to have been underlain by Neoproterozoic-Cambrian (?) volcanic rocks (Gabrielse and Blusson, 1969). It is exposed in numerous cliffs and hillside outcrops along the western edge of the northern Toobally Lake. It also outcrops extensively on the north- and south-facing walls of the valley cut by an unnamed stream that flows eastward into the lake roughly along grid reference line 6698000N (all coordinates are Zone 9, NAD83 UTM).

This unit is lithologically distinct and is demonstrably mappable at 1:50 000 scale. It has not previously been documented within Coal River map area (NTS 95D), nor has any similar lithology in a comparable stratigraphic position been reported in map areas adjacent along strike to the north (Flat River, NTS 95E; Gabrielse et al., 1973) or south (Rabbit River, NTS 94M; Gabrielse, 1962; Ferri et al., 1999). This unit thus merits establishment as a new formation, and in view of its exposure adjacent to the northern Toobally Lake, we propose the name “Toobally Formation”. No completely exposed section through this unit is currently known, and none is likely to be forthcoming in view of the extensive bush cover in this region. Therefore we propose the formation’s stratotype consist of exposures of this unit within the valley cut by the unnamed stream referred to above. These outcrops expose the formation’s characteristic lithologies, and air-photograph analysis shows the valley contains the most extensive, cross-strike exposures of the unit. We also propose a cliff exposure along another stream further south (UTM coordinates 649320E, 6694834N) as a reference section because this is one of the few localities where bedding can be recognized.

The easternmost (stratigraphically lowest) exposure of the Toobally Formation studied during our fieldwork is at coordinates 650123E, 6698395N. Additional exposures of this unit were observed from a distance in cliffs extending northeast along the lake from those coordinates. The Neoproterozoic quartz sandstone unit described above occurs east of these exposures and is tentatively considered to be the unit underlying the Toobally Formation. The basal contact of the Toobally Formation was not observed and is presently poorly constrained. We propose that the basal contact be placed at the base of the lowest bed of matrix-supported conglomerate or pebbly mudstone typical of the unit. The top of the unit is within a covered interval between the westernmost outcrop of pebbly mudstone (coordinates 647579E, 6697595N) and an overlying outcrop of the brecciated volcanic unit (coordinates 647452E, 6697600N) that occurs approximately 127 m upstream. No evidence was seen for interbedding of these lithologies, suggesting a relatively abrupt contact. We consider the upper limit of the Toobally Formation to be defined by the highest occurrence of pebbly mudstone.

The lack of continuous exposure, particularly at the upper and lower contacts of the unit, presents a less-than-ideal situation for establishing a new formation. However, we emphasize that the Toobally Formation can be both "distinguished and delimited on the basis of lithic characteristics and stratigraphic position" (North American Commission on Stratigraphic Nomenclature, 1983, p. 848), and we consider this to be the ultimate test of a formal lithostratigraphic unit.

Previous mapping by Gabrielse and Blusson (1969) indicated that surface exposures of their volcanic-dominated map unit 3, the lower part of which corresponds to the Toobally Formation, does not extend significantly south of the northern Toobally Lake. Likewise the upper contact of their map unit 3 is truncated against the Toobally fault approximately 5 km north of the northern Toobally Lake. Thus the Toobally Formation may extend for approximately 16 km along strike. We have mapped outcrops or observed exposures from a distance over most of the belt likely to contain outcrop. The minimum thickness of the Toobally Formation along the 'type' valley is 1800 m, assuming structural continuity and a uniform dip of 45 degrees to the west (cf., Gabrielse and Blusson, 1969). Unrecognized structural repetition by folding and/or faulting may cause this thickness estimate to be too large.

Internally the Toobally Formation consists almost entirely of a monotonous succession of polymictic, matrix-supported conglomerate to pebbly mudstone (Fig. 4). The matrix consists of dark brown to dark grey, brown-, buff-, or orange-weathering silty shale to siltstone and accounts for 50 to 80 % of total rock volume. Clasts are most commonly within the granule to pebble size range; cobbles are rarely present. One cliff face, inaccessible to us, exposed a probable olistolith (exotic block transported by submarine slumping) estimated to be 1 m by 2 m in size. Other blocks of olistolith scale may also be present (see discussion of the buff carbonate below). Clasts are angular to subrounded and show no preferred orientation (Fig. 5). Numerous clast compositions were observed, including quartzitic meta-sandstone, calcareous sandstone, lithic sandstone, mudstone, massive lime mudstone and dolomudstone, laminated lime mudstone, massive grainstone, and rare fragments of vesicular to amygdaloidal basalt (Fig. 6). A lithogeochemical analysis of the large basalt clast shown in Figure 6 is presented in Table 1 and will be discussed further in the following section on Geochemistry.

Bedding generally cannot be recognized within this unit at outcrop scale. The unit is generally well preserved, affected only by a moderately developed, pervasive slaty cleavage, which suggests that the unit is very thickly bedded. In rare cases, normally graded to massive beds

Figure 4. *Polymictic muddy conglomerate of the Toobally Formation. Hammer for scale. Marks on hammer handle are 10 cm apart. Slaty cleavage dips gently down from right to left (west-dipping). Photo taken looking north.*

Figure 5. *Randomly oriented, angular carbonate clasts (circled) in silty mudstone matrix, Toobally Formation. Scale divisions are in centimetres.*

Figure 6. *Amygdaloidal basalt clast in mudstone conglomerate, Toobally Formation. Scale divisions are in centimetres.*

Figure 7. *Rare bedding in Toobally Formation.*

that are less than 10 cm thick are preserved (Fig. 7). These beds consist of a lower, massive to graded horizon of granules to small pebbles in a silty/muddy matrix and an upper, massive, mudstone horizon. In another area, within an apparently unbedded succession of pebbly mudstone, we observed a gradational change upward from a silty mudstone matrix to a siltstone matrix.

In a streamcut outcrop along the 'type' valley (coordinates 649705E, 6698302N) the conglomeratic mudstone appears to be overlain by a succession of cream- to orange-weathering, microcrystalline to very finely crystalline dolostone at least 20 m thick. Fresh surfaces of the dolostone are buff coloured. This lithofacies is parallel-bedded, with beds from 10 to 40 cm thick. Internally, beds are massive or display parallel lamination, low-angle cross-lamination, or ripple cross-lamination (Fig. 8). Rare, bedding-parallel stylolites are also present. The contact between this unit and the conglomeratic mudstone is sharp and stained red (possibly by goethite or hematite). The dolostone

Figure 8. *Closeup of finely parallel-laminated dolostone forming large olistolith in Toobally Formation.*

immediately above the contact is highly fractured and generally harder than that further upsection, suggesting that it has been silicified. The upper contact of the dolostone has not been observed. This dolostone is also present at one other small outcrop (coordinates 649877E, 6698326N) slightly further downstream.

The dolostone presents something of a conundrum. Although it may be a stratigraphic unit lying comformably upon the Toobally Formation, this interpretation carries stratigraphic difficulties. Bedding within the dolostone dips to the northeast, whereas regional dip within the succession west of the northern Toobally Lake is to the west. Although folding might explain the variable dip, the dolostone is absent as one proceeds upstream to the west for some 2.2 km through massive pebbly mudstones of the Toobally Formation. For these reasons we suggest that the buff dolostone is a large olistolith within the Toobally Formation. The presence of at least one other recognizable olistolith within the Toobally Formation (see above) supports this interpretation.

The Toobally Formation is cut by scattered dark green, orange-weathering, fine-grained, diabase to gabbro dykes and sills from less than 10 cm to greater than 10 m thick. In many outcrops the dykes and sills are extensively altered to a pale grey, orange-weathering, pyritic carbonate-sericite assemblage. Lithogeochemical analyses of samples collected from several locations within the Toobally Formation are listed in Table 1 (Geochemistry section). The chemistry of the dykes and sills will be discussed further in the Geochemistry section. Similar dykes and sills have intruded Proterozoic and/or Cambrian strata to the south in Rabbit River map area (Gabrielse, 1962).

Further detailed work is needed to ascertain the Toobally Formation's precise depositional environment and paleophysiographic setting. Outcrops consist of a mud-rich, matrix-supported, polymictic conglomerate with no preferred orientation to the clasts; this lithotype can be deposited readily under glacial and/or non-glacial conditions (Eyles, 1990). In the 2003 fieldwork we found no definitive evidence for glacial deposition (e.g., dropstones and lonestones in associated sediments, till pellets, striated clasts). The great thickness and lack of associated high-energy outwash facies also implies the unit is not a terrestrial till (Flint, 1961), as does the lack of preferred orientation of clasts (Eyles and Eyles, 1992). Therefore, we interpret the Toobally diamictites as deposits produced by relatively viscous, sediment-gravity flows, probably debris flows. The rare, thin, normally graded to massive beds may be thin-bedded turbidites in which the grainy interval represents the A horizon and the mudstone interval the E horizon (i.e., Ta,e). Thick accumulations of debris flows associated with turbidites are typical of marine slope to toe-of-slope settings.

Nevertheless, the Toobally Formation resembles Neoproterozoic glacial diamictites that have been documented in western Canada: the Shezal Formation (Eisbacher, 1978, 1981), the Ice Brook Formation (Aitken, 1991), the Vreeland Formation (McMechan, 2000), and the Toby Formation (Aalto, 1971). The diamictites in these other formations are massive; however they are visibly interbedded with rhythmically bedded marine and nonmarine sediments. Maximum thickness of Shezal Formation diamictite is 200 m (Eisbacher, 1981), and that of the Ice Brook Formation diamictite is 300 m (Aitken, 1991). McMechan (2000) described diamictite sheets up to 40 m thick with a maximum of 1500 m of the Vreeland Formation consisting largely of massive diamictite. Aalto (1971) described diamictite beds in the Toby conglomerate as occurring in lenses up to 16 m thick and not laterally persistent beyond 100 m. Glacially striated clasts are common in the Shezal Formation (Eisbacher, 1981). By contrast, Aitken (1991) noted that glacially striated clasts are extremely rare in the Ice Brook Formation. The inferred thickness of at least 1800 m for the Toobally Formation is much greater than the measured thicknesses of either the Ice Brook Formation or the Shezal Formation but is similar to that indicated for the Vreeland Formation. It may be that associated bedded sedimentary rocks in the Toobally Formation are present but not observed because of outcrop gaps. McMechan (2000) suggested that the glacial diamictites of the Vreeland Formation formed as large, unconfined debris flows in a distal glaciomarine environment. A similar deposition mechanism could be envisioned here to allow for the extensive massive succession represented by the Toobally Formation.

Fossils have not been recognized within the Toobally Formation. In the valley containing its stratotype, its upper contact is structurally 2900 m beneath a Lower Cambrian fossil locality reported by Gabrielse and Blusson (1969). Therefore it has a minimum Early Cambrian age and is more likely to be Neoproterozoic. Of the Neoproterozoic diamictite units in western Canada, the Shezal and Toby formations occur in the lower part of the Windermere Supergroup, and the Ice Brook and Vreeland formations occur in its upper part. The stratigraphic position of the Toobally Formation beneath Lower Cambrian strata suggests that it is more likely to be correlative with the Ice Brook and Vreeland formations. Variable cutout beneath the sub-Cambrian unconformity in northwestern Canada (Aitken, 1989; MacNaughton et al., 2000) necessitates caution regarding this suggestion. The depositional age indicated by this tentative correlation is just after the appearance of Ediacaran fauna (Aitken, 1991), around 570 Ma (Okulitch, 2002).

With this correlation the Toobally Formation may represent another example of Neoproterozoic glacial deposits (Kennedy et al., 1998). The Ice Brook and Vreeland formations are both locally overlain by a 'cap carbonate' (Aitken, 1991; McMechan, 2000). A similar carbonate is not observed at the top of the Toobally Formation, although a finely parallel-laminated dolostone does occur as a large, probable olistolith low in the succession. The absence of a cap carbonate does not necessarily preclude the correlation of the Toobally Formation with these other units; rather it might indicate non-deposition or that the upper contact of the Toobally Formation is a disconformity.

NEOPROTEROZOIC-CAMBRIAN (?) VOLCANIC ROCK UNIT

Gabrielse and Blusson (1969) recognized an extensive succession of basic volcanic rocks consisting of amygdaloidal volcanic flows, tuffs and breccias immediately west of the northern Toobally Lake (their map unit 3). They estimated an aggregate thickness of volcanic rocks exceeding 2700 m in this immediate area. Our 2003 fieldwork shows that the Toobally Formation forms the lower part of this succession as previously mapped (approximately 70% of the unit). The revised thickness of the volcanic rock unit is approximately 850 m. Four stations within the lower part of the volcanic rock unit were examined during the 2003 mapping.

The lower contact of the unit is within a covered interval between the westernmost outcrop of pebbly mudstone (coordinates 647579E, 6697595N) and an overlying outcrop of the brecciated volcanic unit (coordinates 647452E, 6697600N). The upper contact was not observed during our fieldwork but was located as a defined contact by Gabrielse and Blusson (1969) at coordinates 646219E, 6698317N.

Outcrops visited in 2003 consist of volcaniclastic rocks: predominantly lapilli tuffs with lesser interbedded, thin maroon mudstones and volcanic breccias. No volcanic flows were observed in the few outcrops visited. Fresh exposures are dark green; weathered surfaces are greyish green with purple, maroon, and blue-green hues. Lapilli tuffs are poorly bedded on a scale of 50 cm to several metres (Fig. 9). Thin maroon mudstone intervals in the tuffs have normally graded beds and load casts, which indicate the unit is structurally upright with tops being to the west (Fig. 10). Volcanic breccias range from centimetres to metres in thickness. Breccias are clast-supported with a dark green, fine-grained, interstitial matrix; clasts are up to 5 cm across and consist entirely of varieties of basalt.

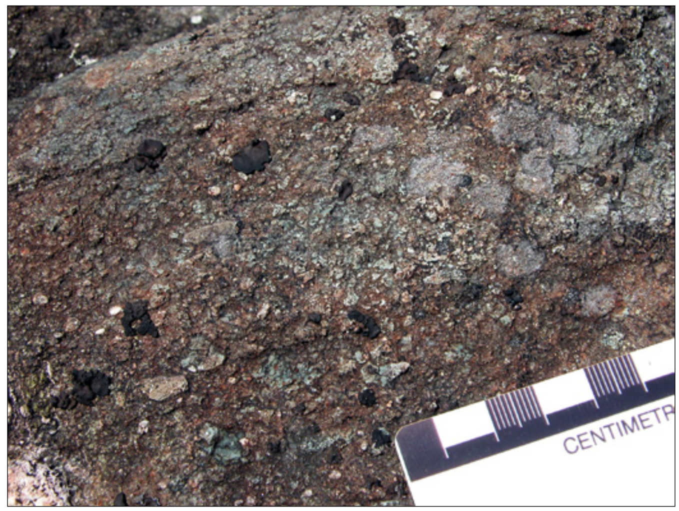


Figure 9. *Closeup of lapilli tuff in Neoproterozoic-Cambrian(?) volcanic rock unit.*

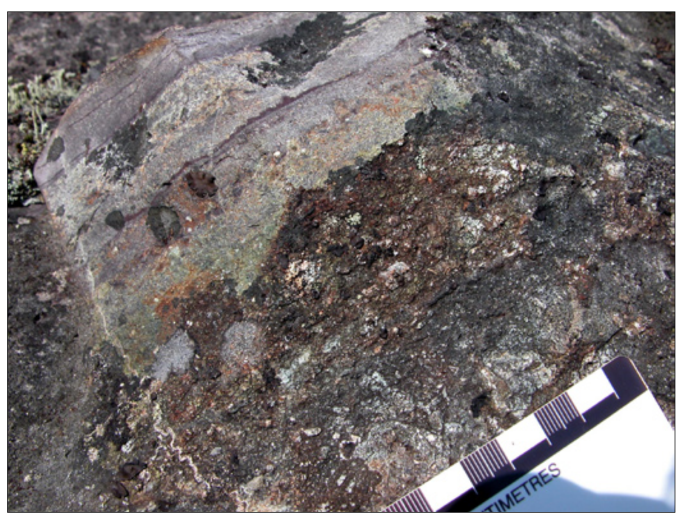


Figure 10. *Closeup of thin, maroon mudstone horizon in Neoproterozoic-Cambrian(?) volcanic rock unit. Load casts and graded bedding indicate beds are structurally upright. Photo taken looking west.*

Two basalt lithotypes predominate in the clasts of the lapilli tuffs and the volcanic breccias. In the first lithotype, plagioclase phenocrysts are contained within a fine-grained, brown matrix of felted feldspar microlites with lesser opaques. The other lithotype contains plagioclase phenocrysts in a matrix of devitrified glass. The latter clasts are typically amygdaloidal. Primary mineralogy is not preserved; metamorphic minerals include chlorite, epidote, sericite and carbonate.

The lowermost outcrops of this unit are highly carbonate- and sericite-altered. Fresh surfaces are pale grey, and weathered exposures are dark orange-brown. Rocks are fine-grained. Exposures are massive to thick-bedded. Breccia textures are locally visible on weathered surfaces, with clasts being up to 3 cm across (Fig. 11).

No fossils were found in the volcanic unit. The top of the unit is structurally 2080 m below a fossil site containing Lower Cambrian trilobites located 2940 m upstream. Volcanic rocks therefore have a minimum age of Lower Cambrian; a more appropriate age would probably be Neoproterozoic. The source area for the volcaniclastic material is uncertain. If flows are present (as described by Gabrielse and Blusson, 1969) exposures west of the northern Toobally Lake are proximal to source vents. The presence of devitrified glass clasts in the tuffs and breccias supports the inferred proximal nature of the volcanic rocks. Analyses of the Neoproterozoic-Cambrian volcanic rocks are listed in Table 1. These analyses will be further discussed in the section on Geochemistry.

Other occurrences of volcanic rocks in the same general area are limited. Gabrielse and Blusson (1969) documented the same volcanic unit in a few scattered outcrops 16 km southeast of the present occurrence. Approximately 18 km east of the present occurrence, in NTS 95C/5 (Pool Creek map sheet), Allen et al. (2001) described a green laminated argillaceous siltstone unit containing a significant volcaniclastic component. This siltstone is approximately 500 metres thick and contains interbeds of volcanic breccia. It is slightly hornfelsed by the Pool Creek syenite; isotopic dating of the Pool Creek syenite at about 650 Ma (J.K. Mortensen, pers. comm., 2003) places the siltstone as being older than 650 Ma and therefore significantly older than the Toobally volcanic rocks.

DARK GREY LIMESTONE MAP UNIT (DEVONIAN?)

This map unit is exposed in two lake-shore outcrops on the northeastern side of the lake at approximate coordinates 652710E, 6699208N. Its base and top have not been observed. It is dominated (>80%) by limestone and silty limestone, with lesser (<20%) silty shale interbeds. The limestone is medium to dark grey on fresh surfaces and weathers light to dark grey, buff or brown (Fig. 12). It is very finely crystalline or, locally, finely particulate. Bedding is irregular and ranges in thickness from 1 cm to 30 cm, most commonly 1 cm to 10 cm. Beds are massive to parallel-laminated. Locally the beds

Figure 11. *Carbonate-altered breccia at base of Neoproterozoic-Cambrian(?) volcanic rock unit.*

Figure 12. *Devonian (?) limestone outcrop on northeast lake shore of northern Toobally Lake. André Lebel for scale.*

are bioturbated. When treated with dilute (10%) HCl, the limestone gives off a strong smell of sulphur. The silty shale lithofacies is fissile and is dark grey on fresh and weathered surfaces.

The fine crystal and grain size of both the carbonate and shale lithofacies, together with the predominance of carbonate, suggest deposition in a low-energy, marine environment. Previous mapping in Coal River (Gabrielse and Blusson, 1969) and La Biche River (Pigage and Allen, 2001) outlines major carbonate successions as Sunblood Formation (Ordovician) or an unnamed Devonian limestone. Because of the proximity of these outcrops to Mattson Formation located on the ridge top to the east, it is suggested that these carbonates are correlative with the unnamed Devonian limestone as mapped in the Pool Creek area (Pigage and Allen, 2001; unit Dl), some 18 km to the east. A sample has been submitted for conodont analysis to test this correlation.

BESA RIVER FORMATION (?) – BLACK SILTY SHALE

A single hillside locality on the northwestern side of the lake (coordinates 651721E, 6699162N) exposes a shale-dominated map unit. The lithofacies at this locality include black, dark grey, and greenish-grey shale to silty shale that weathers black, dark grey, and medium greenish-grey (Fig. 13). Mica is locally visible as small flakes on the slaty cleavage surface of the shale. Also present are very thin beds of very fine-grained sandstone that are medium greenish-grey on fresh surfaces and weather greenish grey with rusty patches. The sandstone makes up 10% or less of the exposed strata and preserves small load casts and possible gutter casts. The shale and sandstone are both locally concretionary, with concretions in the black shale reaching diameters in excess of 10 cm.

Figure 13. *Outcrop of black silty shale of Devonian Besa River Formation (?) on northwest side of northern Toobally Lake. Outcrop is presumed to be in immediate footwall of Toobally fault.*

Rare trace fossils are preserved in the sandstone and consist of horizontal burrows with poorly preserved, external scratch ornamentation. No other fossils were observed. The base and top of this unit have not been observed. The presence within this unit of burrows displaying external scratch traces indicates that these strata are of Early Cambrian age or younger (Crimes, 1987). Major black shale successions in the immediate area include the Silurian-Devonian Road River Group and the Devonian-Carboniferous Besa River Formation. This succession has been tentatively interpreted as Besa River Formation (Kidd, 1963) on the west limb of an east-verging anticline. A palynology sample has been collected to test this tentative correlation.

The prevalence of shale and paucity of sandstone in this unit suggest deposition under low-energy conditions. Load casts and gutter casts are typical features of deposition in continental-shelf settings, although gutter casts are more typical of shallow-water environments on mud-dominated shelves (Myrow, 1992).

MATTSON FORMATION

The Mattson Formation (Patton, 1958) was mapped by Gabrielse and Blusson (1969) as occurring extensively on the ridges immediately to the east of the lake. Our observations are based on outcrops and talus trains along the lake's eastern shore. Exposures higher on the ridges are visible on aerial photographs but were not visited as part of this work.

Compact, very well cemented, very fine- to fine-grained quartz sandstone dominates outcrops of Mattson Formation in the study area (Fig. 14). Grains are highly rounded and spherical. The only accessory phase observed consists of sporadic, very fine to fine blebs of black material, probably pyrobitumen. Fresh surfaces are white or light, medium, or dark grey. Weathering tones are dominantly light to medium grey, with local orange-weathering zones. Orange, red and brown liesegang banding is present on some fracture surfaces.

Bedding is commonly difficult to recognize in exposures of Mattson Formation visited during this work. It is generally best recognized based on the presence of a distinctive bedding-plane texture of uncertain origin,

Figure 14. *Outcrop of Mattson Formation at southeast end of northern Toobally Lake. Bedding is vertical. André Lebel is standing on outcrop for scale.*

consisting of a network of pits and bumps that are of centimetre-scale diameter in plan view and show a few millimetres of relief. This texture is also common in exposures of Mattson Formation in Larsen Lake map area (NTS 95C/4; MacNaughton and Pigage, 2003), immediately southeast of the current study area. Poorly preserved cross-bedding was also recognized in one outcrop during the current study.

Further east, in La Biche River (NTS 95C) and Fort Liard (NTS 95B) map areas, the Mattson records a variety of shallow-marine and nonmarine depositional environments (Richards et al., 1993), and can be subdivided into up to three informal members (Douglas and Norris, 1959; Douglas, 1976; Currie et al., 1998; MacNaughton and Pigage, 2003). No such subdivision is currently possible in the Toobally Lakes region and poor exposure of primary sedimentary structures precludes any meaningful statement of depositional setting.

GEOCHEMISTRY

Table 1 lists analyses for four samples of the Neoproterozoic-Cambrian (?) volcanic unit, five samples of dykes/sills within the Toobally Formation, and one sample of an amygdaloidal basalt clast from the Toobally Formation. It also presents three analyses of Neoproterozoic basalt and volcaniclastic rocks from the Pool Creek map area (95C/5) immediately to the east. In spite of the excellent preservation of primary textures in hand sample, thin section studies indicate many of the primary minerals have been replaced during subsequent alteration and/or metamorphism. Locally extensive alteration and/or metamorphism are also reflected in the large loss on ignition (LOI) for several of the samples. The alteration and metamorphism implies that some of the elements have been mobilized to varying degrees (Rollinson, 1993). In contrast, several elements have been shown to be immobile during alteration and metamorphism (Pearce and Cann, 1973; Wood, 1980; Jenner, 1996). To test for immobility of elements commonly used in discriminant diagrams, we have plotted LOI against several key elements and element ratios for the Toobally dyke/sill and Neoproterozoic-Cambrian volcanic unit samples (Fig. 15). With these plots we are inferring that increasing LOI corresponds to an increasing extent of alteration and/or metamorphism. Figure 15a shows an inverse correlation between SiO_2 and LOI, indicating mobility and loss of SiO_2 with increasing LOI. Systematic increasing or decreasing linear patterns for elements niobium, zironium, titanium dioxide, yttrium and thorium (Nb, Zr, TiO_2, Y and Th) when plotted vs LOI are not obvious (Figs. 15b,c,d,e,g). Element ratios Nb/Y and Zr/TiO_2 (Figs. 15f,h) are even more robust and show no variation when plotted against LOI. From these plots we conclude that alteration and metamorphism have not significantly affected the validity of discriminant diagrams utilizing immobile elements from all of the analyses presented in Table 1.

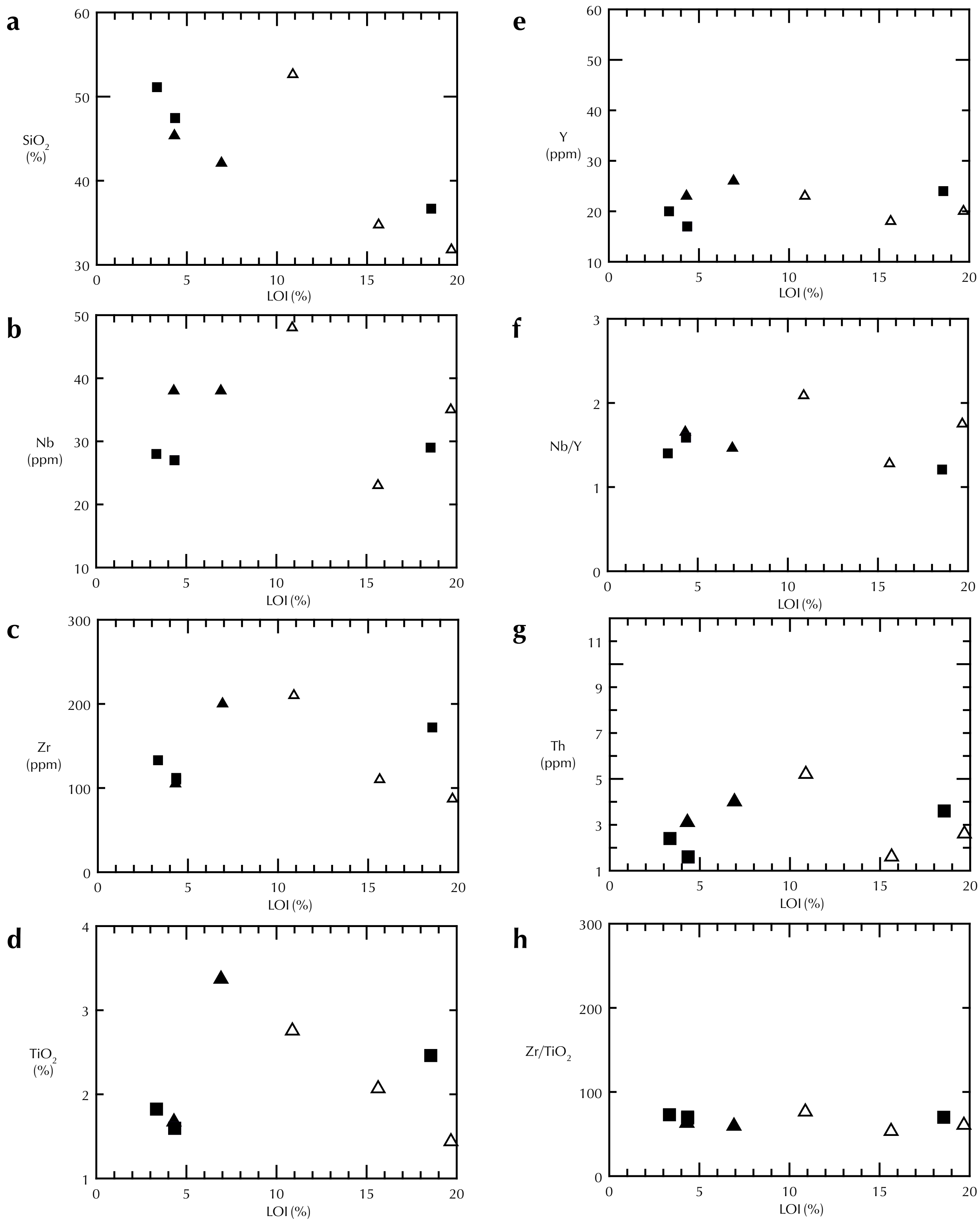
The Neoproterozoic-Cambrian (?) volcanic rock unit samples plot in the alkali basalt field in a Zr/TiO_2-Nb/Y diagram (Fig. 16a; Winchester and Floyd, 1977; modified by Pearce, 1996). The altered and unaltered dykes/sills in the Toobally Formation plot within the same tight alkali basalt cluster as the overlying Neoproterozoic-Cambrian (?) volcanic rock unit (Fig. 16a). In contrast, the Pool Creek basalt clast plots in the basalt field and the Pool Creek volcaniclastic siltstone unit plots in the andesite/basalt field. Displacement of the Pool Creek volcaniclastic siltstone samples to higher Zr/TiO_2 values

Table 1. *Lithogeochemical analyses 95D/8 and 95C/5.*

Sample rock	03LP007v basalt clast	03LP003 dyke/sill altered	03LP004 dyke/sill	03LP010 dyke/sill altered	03LP017 dyke/sill altered	03LP021 dyke/sill	03LP023 breccia altered	03LP028 lapilli tuff	03LP028[4] lapilli tuff	03LP029 lapilli tuff	00LP033 siltstone	00LP034 siltstone	00LP009 basalt clast
Formation	Toobally	Toobally	Toobally	Toobally	Toobally	Toobally	Volcanic unit	Volcanic unit	Volcanic unit	Volcanic unit	Pool Creek	Pool Creek	Pool Creek
UTM E[1]	649 694	649 516	649 441	649 320	650 123	647 628	647 538	647 053	647 053	646 909	345 833	345 601	345 458
UTM N	6 696 296	6 698 177	6 698 146	6 694 834	6 698 395	6 697 581	6 697 584	6 697 555	6 697 555	6 697 722	6 695 449	6 695 823	6 694 401
UTM Zone	9	9	9	9	9	9	9	9	9	9	10	10	10
SiO_2 (%)	39.44	31.79	45.35	34.74	52.62	42.08	36.67	47.45		51.12	54.95	57.03	48.46
Al_2O_3 (%)	11.49	13.45	15.26	14.98	14.85	14.68	10.18	14.62		12.90	12.85	12.47	11.02
Fe_2O_3 (%)[2]	8.96	11.55	11.24	10.61	10.59	15.01	15.90	11.39		10.11	8.58	7.68	13.28
MnO (%)	0.123	0.183	0.184	0.125	0.045	0.176	0.230	0.162		0.209	0.097	0.114	0.130
MgO (%)	7.44	8.04	7.57	3.72	2.26	4.65	4.66	8.55		8.55	8.06	8.29	5.77
CaO (%)	11.40	8.57	8.72	12.15	1.95	8.23	7.99	6.21		6.54	6.30	5.13	6.01
Na_2O (%)	0.54	1.62	2.41	2.91	0.16	2.88	0.12	3.87		3.10	1.51	1.31	2.96
K_2O (%)	2.26	2.00	2.07	1.45	2.71	0.47	1.43	0.63		0.76	2.01	3.61	1.26
TiO_2 (%)	2.592	1.438	1.672	2.067	2.753	3.369	2.461	1.596		1.824	1.427	1.064	2.207
P_2O_5 (%)	0.63	0.31	0.32	0.20	0.34	0.37	0.43	0.18		0.25	0.23	0.15	0.30
LOI (%)[3]	13.84	19.68	4.31	15.64	10.88	6.92	18.56	4.35		3.34	2.81	2.02	7.52
Total	98.72	98.63	99.11	98.59	99.16	98.84	98.63	99.01		98.70	98.82	98.87	98.92
Ba (ppm)	750	389	814	268	260	337	92	326		295			
Sr (ppm)	221	198	257	526	52	698	76	380		732			
Y (ppm)	42	21	27	21	22	24	27	16		18			
Sc (ppm)	17	31	34	30	32	20	16	31		29			
Zr (ppm)	253	83	95	97	201	177	159	105		122			
Be (ppm)	2	2	1	1	2	2	1	1		1			
V (ppm)	172	226	258	249	272	270	178	193		156			
V (ppm)	159	211	247	237	249	257	162	178	181	143	180	153	292
Cr (ppm)	31	314	271	528	254	-20	-20	279	291	250	77	89	36
Co (ppm)	20	39	38	52	69	47	26	45	45	34	26	41	33
Ni (ppm)	112	100	80	198	103	52	25	130	136	69	26	43	-20
Cu (ppm)	390	-10	51	317	635	28	13	60	69	-10	48	14	13
Zn (ppm)	86	62	91	80	67	125	42	83	112	122	70	64	102
Ga (ppm)	14	14	16	18	17	20	14	15	15	15	19	18	19
Ge (ppm)	2	2	2	2	3	2	2	1	2	2	1.6	1.8	1.4
As (ppm)	23	-5	12	115	60	-5	21	-5	-5	-5	-5	-5	-5
Rb (ppm)	63	50	27	54	69	14	36	10	10	13	86	134	30
Sr (ppm)	216	196	249	503	51	735	75	378	387	746	104	97	114
Y (ppm)	40	20	23	18	23	26	24	17	17	20	43.2	37.4	52.4
Zr (ppm)	275	87	105	110	210	200	172	110	112	133	249	236	202
Nb (ppm)	28	35	38	23	48	38	29	27	27	28	16.3	14.7	15.9
Mo (ppm)	>100	3	>100	>100	2	2	>100	-2	-2	-2	-2	-2	-2
Ag (ppm)	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
In (ppm)	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.1	-0.1	-0.1
Sn (ppm)	2	-1	-1	1	2	2	1	1	2	1	2	2	2
Sb (ppm)	0.7	-0.5	-0.5	-0.5	1.5	0.7	1.9	-0.5	0.7	-0.5	0.7	2.1	1.3
Cs (ppm)	1.7	7.8	3.3	3.1	4.1	2.2	1.4	0.8	0.8	-0.5	5.9	9.2	2.2
Ba (ppm)	773	396	828	275	264	362	95	336	340	313	208	400	296
La (ppm)	17.0	29.9	31.4	15.7	23.6	34.1	21.6	14.9	15.6	25.3	33.5	34.2	22.3
Ce (ppm)	39	59.9	62.5	33.8	49.8	73.2	46.3	32.8	34.3	50.4	69.4	69.8	50.8
Pr (ppm)	4.98	6.53	6.86	4.12	5.58	8.19	5.45	3.92	4.02	5.64	7.69	7.48	6.18
Nd (ppm)	24.5	27.9	28.8	19.5	24.5	35.6	24.6	18.0	18.1	25.3	31.4	30.7	28.5
Sm (ppm)	6.8	5.0	5.6	4.4	4.9	6.8	6.0	3.9	3.9	5.0	6.73	6.36	6.96
Eu (ppm)	2.35	1.88	2.10	1.29	1.53	2.83	2.15	1.73	1.71	2.17	1.53	1.41	2.01
Gd (ppm)	8.4	5.0	5.8	4.6	5.4	6.8	6.5	4.3	4.2	5.3	6.26	5.46	7.24
Tb (ppm)	1.4	0.8	0.9	0.7	0.9	1.1	1.0	0.7	0.7	0.8	1.06	1.01	1.31
Dy (ppm)	7.8	4.1	4.7	3.8	5.0	5.5	5.0	3.6	3.6	4.3	6.34	5.93	8.07
Ho (pmm)	1.5	0.8	0.9	0.7	0.9	1.0	0.9	0.7	0.7	0.8	1.24	1.16	1.57
Er (ppm)	4.4	2.3	2.7	2.0	2.7	2.9	2.7	1.9	1.9	2.1	3.81	3.56	4.78
Tm (ppm)	0.66	0.32	0.36	0.27	0.39	0.38	0.36	0.26	0.26	0.28	0.569	0.526	0.671
Yb (ppm)	3.9	1.8	2.1	1.5	2.2	2.3	2.2	1.5	1.5	1.7	3.66	3.51	4.37
Lu (ppm)	0.62	0.3	0.32	0.23	0.33	0.34	0.33	0.23	0.23	0.25	0.546	0.511	0.637
Hf (ppm)	7.4	2.3	2.7	3.2	5.5	5.1	4.4	2.9	2.9	3.5	7.2	7.0	6.0
Ta (ppm)	1.5	1.9	2.2	1.3	3.2	2.3	1.8	1.7	1.5	1.6	1.37	1.32	1.2
W (ppm)	-1	1	-1	-1	2	-1	-1	-1	-1	-1	1.2	1.5	0.6
Tl (ppm)	0.2	0.2	0.2	0.2	0.3	-0.1	0.3	-0.1	-0.1	-0.1	0.27	0.52	0.13
Pb (ppm)	25	-5	10	18	-5	7	14	-5	10	9	6	9	14
Bi (ppm)	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	0.4	0.3	0.3
Th (ppm)	6.2	2.6	3.1	1.6	5.2	4.0	3.6	1.6	1.6	2.4	10.80	11.50	5.85
U (ppm)	2.5	0.7	0.8	0.4	1.4	0.9	0.8	0.4	0.4	0.6	2.44	2.45	1.42

[1]all coordinates NAD83 UTM   [2]total iron as Fe_2O_3 [3]loss on ignition   [4]replicate analysis

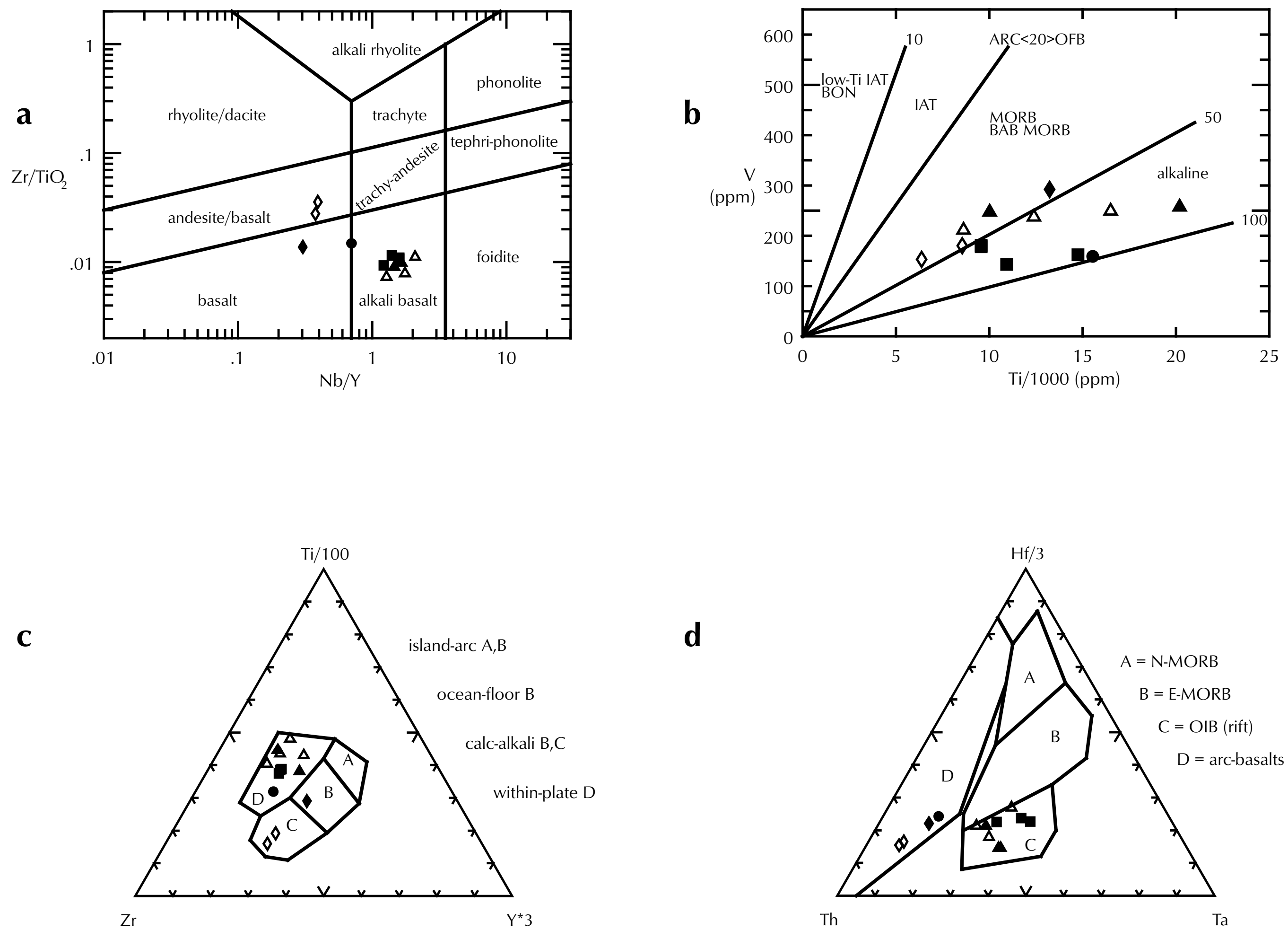
Samples were prepared using a ceramic mill and analysed for major, trace, and rare-earth elements at Activation Laboratories Ltd. in Ancaster, Ontario.
Major elements and first seven trace elements were determined with lithium metaborate/tetraborate fusion X-ray fluorescence (XRF).
Remaining trace and rare-earth elements were determined with lithium metaborate/tetraborate fusion inductively coupled plasma mass spectrometry (ICP-MS).
Analysis below detection limit shown with detection limit as negative number.



■ Neoproterozoic(?) volcanic rocks west of Toobally Lakes
▲ gabbro/diabase dykes and sills in Toobally Formation
△ altered dykes and sills in Toobally Formation

Figure 15. *XY plots of mobile and immobile elements and element ratios vs LOI for samples from northern Toobally Lake (NTS 95D/8).*

may be caused by addition of detrital zircon to the samples. Interestingly, the basalt clast in the Toobally Formation is transitional between the Pool Creek and Toobally basalt samples. These fields are consistent with plotted locations of the samples in the titanium-vanadium (Ti-V) diagram (Fig. 16b; Shervais, 1982). The Ti-Zr-Y diagram plots all the Toobally samples in the within-plate basalt field (Fig. 16c; Pearce and Cann, 1973). Pool Creek samples plot in the ocean-floor and calc-alkali fields in the same diagram. Pool Creek volcaniclastic siltstone samples are displaced toward higher Zr values (as in Fig. 16a). Using the hafnium-tantalium-thorium (Hf-Ta-Th) diagram (Fig. 16d; Wood, 1980), the only Toobally sample not contained within the oceanic island basalt field is the



northern Toobally Lake - 95D/8

- ■ Neoproterozoic(?) volcanic rocks west of Toobally Lakes
- ▲ gabbro/diabase dykes and sills in Toobally Formation
- △ altered dykes and sills in Toobally Formation
- ● basalt clast in Toobally Formation

Pool Creek - 95C/5

- ◊ Neoproterozoic green laminated siltstone (Pls)
- ♦ basalt clast in Neoproterozoic green laminated siltstone (Pls)

Figure 16. *Discriminant diagrams for Toobally and Pool Creek analyses using immobile elements.* ***(a)*** *Winchester and Floyd (1977) composition diagram of Zr/TiO_2 vs Nb/Y as modified by Pearce (1996);* ***(b)*** *Ti-V diagram from Shervais (1982);* ***(c)*** *Ti-Zr-Y diagram from Pearce and Cann (1973);* ***(d)*** *Hf-Th-Ta diagram from Wood (1980).*
Abbreviations: IAT – island arc tholeites; BON – boninites; MORB – mid-ocean ridge basalt, N – normal, E – enriched; BAB – back-arc basin; ARC – island arc basalt; OIB – ocean island basalt; OFB – ocean floor basalt.

basalt clast in the Toobally Formation. The Pool Creek samples plot in the same arc-basalt field as the Toobally basalt clast sample. The Pool Creek volcaniclastic siltstone samples are displaced toward higher Th values; this may also be related to incorporation of a detrital component in the Pool Creek samples.

All samples have an oceanic island basalt signature in multi-element diagrams normalized to primitive mantle (Fig. 17). As in Figure 16, the pattern for the altered and unaltered dykes/sills in the Toobally Formation is essentially identical to that of the samples from the overlying Neoproterozoic-Cambrian (?) volcanic rock unit (Fig. 17b). The Pool Creek samples (Fig. 17d) have a different chemistry than the Toobally samples, being more strongly enriched in Th and heavy rare earth elements (REE) and showing a negative Nb anomaly. The basalt clast in the Toobally Formation (Fig. 17c) lacks a negative Nb anomaly but has a similar Th and heavy REE pattern to that in the Pool Creek samples. It also displays a marked positive Zr anomaly.

Dykes/sills in the Toobally Formation are inferred to be subvolcanic equivalents of the extrusive Neoproterozoic-Cambrian (?) volcanic rock unit because of the strong similarity of immobile element patterns in Figures 16 and 17. Geochemistry of the samples is consistent with alkalic volcanism associated with rifting in a within-plate tectonic setting. Geochemistry of the Pool Creek samples and Toobally clast sample is also consistent with rift volcanism. In the above discussion we have suggested that the Pool Creek samples and the Toobally clast sample may be skewed into unrepresentative fields because of crustal contamination. Enrichment in Th/Yb ratio relative to the mantle array in Figure 18 (Pearce and Peate, 1995) is related to either crustal contamination or subducted slab

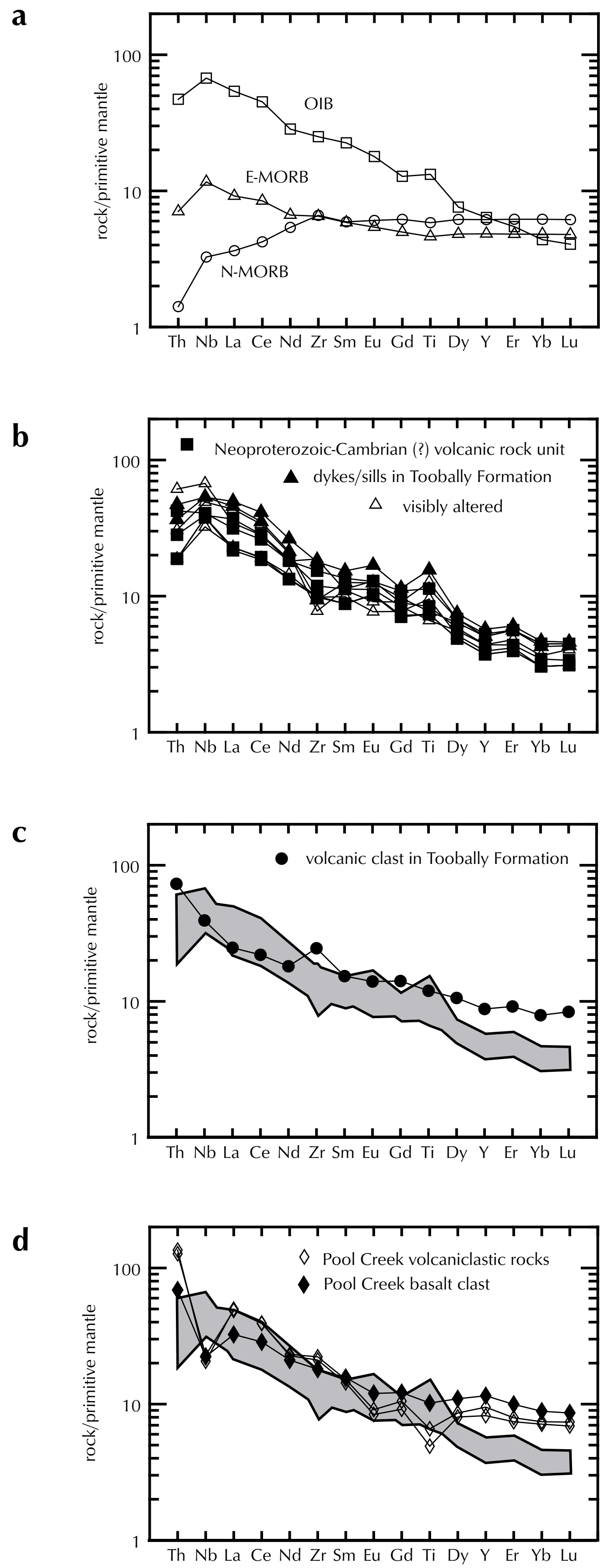


Figure 17. *Multi-element plots normalized to primitive mantle. Primitive mantle values are from Sun and McDonough (1989).*

(a) *reference diagrams for average OIB, E-MORB and N-MORB. Values are from Sun and McDonough (1989). Abbreviations in Figure 16 caption;*

(b) *dykes/sills in Toobally Formation and extrusive rocks from Neoproterozoic-Cambrian (?) volcanic rock unit;*

(c) *volcanic clast in Toobally Formation. Shaded area is envelope of values plotted in 17b;*

(d) *Pool Creek volcaniclastic rocks and Pool Creek basalt clast. Shaded area is envelope of values plotted in 17b.*

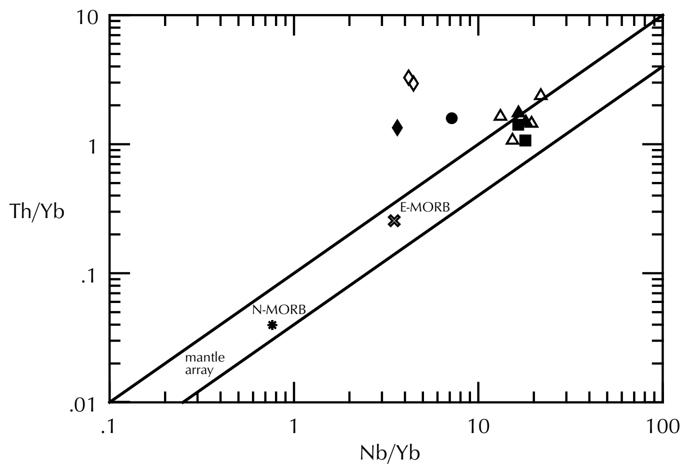


Figure 18. Discriminant diagram Th/Yb vs Nb/Yb (Pearce and Peate, 1995) for Toobally and Pool Creek samples. Average values for E-MORB and N-MORB (Sun and McDonough, 1989) are shown for reference. Legend same as for Figure 16.

metasomatism. The Pool Creek samples and Toobally basalt clast both are offset away from the mantle array, supporting our suggestion of crustal contamination and/or influx of a detrital crustal component.

In an earlier study of volcanism within the northern Canadian Cordilleran miogeocline, Goodfellow et al. (1995) studied volcanic successions ranging in age from Cambrian through Devonian. They subdivided the volcanic rocks into four main groups. The volcanic rocks from the Toobally and Pool Creek areas are most consistent with their alkali basalts of Group IV. In all groups, volcanism was associated with episodic rifting within Selwyn Basin.

STRUCTURAL GEOLOGY

The Toobally fault (Gabrielse and Blusson, 1969) is the dominant structural element in the area (Fig. 3). The inferred trace of the fault trends north to northeast in the major valley containing the northern Toobally Lake. Outcrop of dark shale (Besa River Formation ?) near shoreline on the west margin of the lake indicates that the fault trace occurs west of the lake in that immediate area (Fig. 3). Gabrielse and Blusson (1969) estimated a maximum stratigraphic throw of approximately 3950 m (9000 ft) with the east side down. In this report, it is interpreted as an east-verging reverse fault, placing Neoproterozoic sedimentary rocks on Paleozoic sedimentary rocks.

The hanging wall of the Toobally fault in the field area has been interpreted as a west-dipping, homoclinal succession of Neoproterozoic through Cambrian(?) sedimentary and volcanic rocks. Bedding through much of the succession is difficult to find. Eastward dipping beds in streamcuts just west of the lake are not considered representative because the observed bedding is within a dolostone interpreted as a large olistolith. The one other observed bedding measurement in the Toobally Formation near the lake has a moderate to gentle west dip (28 degrees), in keeping with regional westward dip west of the Toobally fault.

Only a few outcrops of sedimentary rocks in the footwall of the Toobally fault were observed during the summer fieldwork. Bedding in sandstones of the Mattson Formation in the southeast corner of the map area is essentially vertical. Based on the regional map pattern (Gabrielse and Blusson, 1969), this suggests that the Mattson Formation on the ridge top immediately east of the northern Toobally Lake outcrops in the core of an asymmetric to overturned, east-verging syncline. Bedding in limestone on the east shoreline dips steeply to gently to the west. Assuming this bedding is structurally upright, the limestone on the lakeshore is considered to be on the upright limb of an anticline occurring immediately west of the Mattson syncline. This interpretation is shown in cross-section in Figure 3b.

ECONOMIC GEOLOGY

Following their regional mapping program, Gabrielse and Blusson (1969) reported the occurrence of disseminated chalcopyrite in all of the volcanic rock units. Their map showed a copper occurrence in Cambrian strata west of the northern Toobally Lake; this represents the only Yukon MINFILE database record for 95D/8 map sheet (Fig. 3; Gusty occurrence, 95D 002, Deklerk, 2002).

One outcrop of Toobally Formation (coordinates 650123E, 6698395N) contains quartz veins up to 5 cm thick cross-cutting both the pebbly mudstone and carbonate-altered mafic dykes. Quartz veins are oriented subparallel to the slaty cleavage. These veins are internally fractured with quartz infilling the fractures. Veins contain fine pyrite and lesser disseminated chalcopyrite. Although not economic, sulphide-mineral-bearing veins, carbonate-altered mafic dykes, and a basalt volcanic unit all suggest the possibility of mineralizing systems in the area, possibly related to volcanism.

CONCLUSIONS

Fieldwork around northern Toobally Lake yielded some surprising results relative to expectations based on previous mapping. Toobally fault juxtaposes Neoproterozoic-Cambrian sediments on the west against Devonian-Carboniferous sedimentary rocks on the east. Neoproterozoic-Cambrian sedimentary rocks and volcanic rocks on the west side of the lake have a consistent westward dip. Devonian-Carboniferous sedimentary rocks on the east side of the lake are interpreted as folded into an anticline-syncline couplet.

The structurally lowest and therefore oldest unit in the hanging wall of Toobally fault is a coarse-grained, noncalcareous sandstone unit, presumably Neoproterozoic on the basis of stratigraphic and structural position. Stratigraphically and structurally overlying the sandstone unit is a thick unit of orange-weathering, matrix-supported, muddy conglomerate to conglomeratic mudstone which has not been previously mapped. This new unit is herein called the Toobally Formation. We have tentatively correlated the Toobally Formation with upper Windermere Supergroup glacial deposits represented by the Ice Brook and Vreeland formations. If this correlation is correct, deposition occurred at approximately 570 Ma, probably in a relatively deep-water, glaciomarine setting.

Overlying the Toobally Formation is a Neoproterozoic-Cambrian (?) volcanic rock unit consisting largely of volcaniclastic rocks, dominantly lapilli tuffs with lesser breccias and mudstones. Thickness of the volcanic unit has been revised downward from earlier mapping to approximately 850 m. The volcanic rocks are alkali basalts that chemically correspond to light rare earth element (LREE)-enriched within-plate basalts, consistent with a rift setting. Although these rocks are similar in general lithology to volcaniclastic rocks in Pool Creek area (95C/5), chemistries of the two suites are different and suggest that the volcaniclastic units from Toobally Lakes and Pool Creek should not be correlated. This is substantiated by the implied age difference if the Toobally Formation is correlated with the Ice Brook and Vreeland formations.

Mafic dykes and sills, some extensively carbonate-altered, are present in the underlying Toobally Formation. These are chemically similar to the overlying Neoproterozoic-Cambrian (?) volcanic rock unit and are considered their subvolcanic equivalents.

Toobally Formation contains cross-cutting quartz veins with disseminated pyrite and chalcopyrite. These, together with carbonate-altered dykes and sills in the Toobally Formation, suggest the possibility of mineralizing systems, perhaps associated with volcanism.

Exposures in the footwall of the Toobally fault consist of dark shale; dark, locally bioturbated limestone; and fine-grained, noncalcareous, quartz sandstone. The shale, limestone, and sandstone are assigned to Besa River Formation, an unnamed Devonian limestone (map unit Dl of Pigage and Allen, 2001), and Carboniferous Mattson Formation, respectively.

Discontinuous and patchy outcrop presented challenges in completing detailed structural and stratigraphic studies in a short field season. Stratigraphic relations and correlations presented in this report are tentative pending further detailed studies, including additional fieldwork, micropaleontology and palynology.

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