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BULLETIN 581

BACK RIVER VOLCANIC COMPLEX: AN ARCHEAN STRATOVOLCANO, NUNAVUT–NORTHWEST TERRITORIES

M.B. Lambert

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Cover illustration

Upper photos: Panorama of southern part of the Back River Complex from near the southeastern side of Thlewycho Lake:
left – looking north to high hills of rhyolite and rhyolite breccia of the Thlewycho east lava dome. Photograph by M.B. Lambert. GSC 2005-038
right – looking northeastward toward centre of the complex across Thlewycho and Innerring sequences. Photograph by M.B. Lambert. GSC 2005-039
lower left: Blocky-jointed cliffs of flat-lying ash-flow tuff units of Innerring sequence, about 7 km northeast of Jim Magrum Lake. Photograph by M.B. Lambert. GSC 2005-040
lower right: White-weathering rhyolite derived turbidite beds on northern end of the Gold Lake lava dome, west side of Back River. Photograph by M.B. Lambert. GSC 2005-041

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CONTENTS

1 Abstract/Résumé

2 Summary/Sommaire

19 Introduction
19 Location and access
19 Physical features and glaciation
20 Previous investigations
20 Present investigations
20 Geological setting
20 Acknowledgments

21 Back Group
21 General stratigraphy
22 Innerring sequence
22 Definition and distribution
22 Lithology
22 Andesite and basalt
22 Dacite
23 Rhyolite
24 Volcaniclastic and iron-rich sedimentary rocks
25 Arcuate faults and breccia zone
26 Thlewycho sequence
26 Definition, distribution, and thickness
26 Contact relations
26 Stratigraphy
28 Flow units
28 Andesite lavas
30 Dacitic lavas and tuffs
31 Rhyolite lavas, domes, and intrusions
36 Volcaniclastic rocks
37 Epiclastic units
37 Interpretation
37 Boucher-Regan sequence
37 Definition and distribution
37 Lithology
37 Basalt lavas
39 Basalt sills
39 Andesite
40 Felsic lavas, domes, and tuffs
43 Epiclastic volcanic rocks
43 Keish Lake clastic fan
45 Valley-filling avalanche deposits
46 Detrital rocks derived from mafic lavas
46 Rhyolite turbidite
47 Interpretation
47 Carbonate units
49 Stromatolites
49 Stromatolites in felsic dome breccia
50 Stromatolites in clastic aprons around volcanic domes
51 Stromatolites in stratiform carbonate units
53 Interpretation

54 Beechey Lake Group
55 Iron-formation
56 Metagabbro dykes and sills
58 Granitic intrusions
58 Proterozoic dykes
58 Petrochemistry
59 Structural geology
59 Regional structural patterns
60 Generations of deformation
60 D_1 folds
61 D_2 folds
61 D_3 folds
62 Zones of high strain
63 Faults
64 Interpretation
64 Metamorphism
65 Economic geology
65 Interpretive summary and evolution of the Back River volcanic complex
67 Innerring sequence volcanism
68 Thlewycho sequence volcanism
69 Boucher-Regan sequence volcanism
69 Erosion, mass wasting, and the waning phases of volcanism
70 Form and deformation of the stratovolcano
70 References
73 Appendix. Modal and chemical profiles through zoned Mackenzie dyke

Illustrations

CD-ROM Map 2041A. Geology, Back River volcanic complex, Nunavut–Northwest Territories

Figures

CD-ROM 1. Generalized geology of the Back River volcanic complex
23 2. Dacite lava flows of the Innerring sequence
CD-ROM 3. Stratigraphic section of basal 20 m of the Innerring epiclastic apron, near the east end of Innerring Lake
25 4. Rhyolite breccia in the arcuate breccia zone
27 5. Detailed map of subaerial braidplain 6 km northeast of Jim Magrum Lake
CD-ROM 6. Stratigraphic sections through the Thlewycho sequence near Rusty Lake, southwest of Gold Lake
29 7. Subaerial andesite lava flows of the Thlewycho sequence, southeast side of the volcanic complex
31 8. Columnar-jointed, rhyolite lava flow on island near the east side of Rusty Lake
31 9. Facies of felsic domes
33 10. Gold Lake lava-dome complex
34 11. Breccia and evolution of the Thlewycho north dome
34 12. Flow layering in rhyolite lava at south end of Thlewycho Lake
35 13. Debris-avalanche deposit on the southwestern side of the Thlewycho east lava dome
36 14. Felsic volcaniclastic rocks of the Thlewycho sequence interbedded with the Beechy Lake Group
38 15. Undeformed basalt pillow lavas of the Boucher-Regan sequence
CD-ROM 16. First vertical derivative of residual total-field magnetic map

41	17.	Dacite boulder breccia on southwest flank of composite dome northeast of Keish Lake
42	18.	Rhyolite cobbles in volcaniclastic sediment derived from composite dome northeast of Keish Lake
43	19.	Rhyolite boulder conglomerate
44	20.	Water-laid tuffs in the Keish Lake volcaniclastic fan
45	21.	Bedded tuff between massive units of laharic breccia in the Keish Lake fan
45	22.	Fine laminated tuff in southeastern part of Keish Lake fan
CD-ROM	23.	Stratigraphic sections through rhyolite-derived turbidite at reference locality 6 and 7
48	24.	Directions of flow indicated by dome flank and debris-avalanche deposits, conglomerate, alluvial fans, rhyolite derived-turbidite, and clastic aprons
49	25.	Oolite from the east side of the volcanic complex
49	26.	Stratigraphic sequence at margin or rhyolite dome at stromatolite locality 5
50	27.	Stromatolite locality 1 (laterally linked domal stromatolites)
50	28.	Stromatolite locality 4 (linked cumulate mounds)
51	29.	Stromatolite locality 8 (pseudocolumnar stromatolites)
52	30.	Stromatolite locality 7 (microstratigraphy in laminated sequence)
53	31.	Laterally linked domal stromatolites at locality 6
54	32.	Spindle flutes on sole of a medium-bedded turbidite, Gold Lake
57	33.	Stratigraphy of iron-formation at reference locality 8, northeast of Boucher Lake
57	34.	Vertical columnar joints in metagabbro sill east of Thlewycho Lake
CD-ROM	35.	Generalized structural features in the Back Group and surrounding Beechy Lake Group
62	36.	Tight F_2 fold refolded by open F_3 fold
63	37.	Fabrics in the high-strain zone along the southwestern margin of the volcanic complex
63	38.	F_1 sheath fold in rhyolite flow breccia near Jim Magrum Lake
CD-ROM	39.	Zones of regional metamorphism
66	40.	Sketches showing the stages in the evolution of the Innerring sequence
67	41.	Sketches showing the stages in the evolution of the Thlewycho sequence
68	42.	Sketches showing the stages in the evolution of the Boucher-Regan sequence

BACK RIVER VOLCANIC COMPLEX: AN ARCHEAN STRATOVOLCANO, NUNAVUT–NORTHWEST TERRITORIES

Abstract

The Back River volcanic complex is a deformed Archean composite stratovolcano that evolved in a depositional basin in the northeastern Slave Province. Its diverse stratigraphy developed through three cycles of mafic (or intermediate) to felsic volcanism, each ending with eruption of large rhyolite to dacite dome-flow complexes from numerous centres around the volcano, followed by erosion and mass wasting from the volcanic edifice to produce extensive clastic fans and debris-avalanche deposits.

The oldest rocks in the volcanic complex are calc-alkaline andesitic lavas and ash-flow tuffs that represent the upper subaerial parts of the earliest cycle of volcanism. This cycle ended with cauldron subsidence, ring-fracture intrusion, and effusion of rhyolite domes. The second eruptive cycle involved a highly variable series of eruptions that deposited andesitic lava flows and intermittent pyroclastic and epiclastic units, to interlayered dacitic and andesitic lavas and tuffs overlain by voluminous, nonwelded, ash-flow tuffs. The last volcanic cycle marks a change to tholeiitic magmatism with the eruption mainly of basalt and andesite pillowed lavas on the submerged northern flanks of the stratovolcano.

Stromatolites developed along the margins of active lava domes that straddled the shoreline around the emergent stratovolcano. Iron-formation units mark the close of volcanism.

Three generations of folding deformed the volcanic complex and the surrounding metaturbidite units. Disharmonic folding produced tightly folded metasedimentary rocks between or against more open, folded volcanic sequences. The large dome in the southern part of the map area formed by superposition of regional strain on the core volcanic edifice.

Résumé

Le complexe volcanique de Back River est un stratovolcan déformé d'âge archéen qui s'est formé dans un bassin sédimentaire dans le nord-est de la Province des Esclaves. Trois cycles de volcanisme mafique (ou intermédiaire) à felsique ont contribué à la grande diversité stratigraphique de ce complexe. Chaque cycle s'est terminé par la mise en place de vastes complexes de dômes-coulées rhyolitiques et dacitiques émanant de nombreux centres éruptifs autour du volcan, suivie de la formation d'importants cônes de matériaux clastiques et dépôts d'avalanches de débris, résultats de l'érosion et des mouvements de masse dont a fait l'objet l'édifice volcanique.

Les roches les plus âgées du complexe volcanique sont des laves andésitiques calco-alcalines et des tufs pyroclastiques qui représentent la partie supérieure subaérienne du cycle volcanique le plus précoce. Ce cycle s'est terminé par la subsidence en chaudron, l'intrusion de filons annulaires et la formation de dômes rhyolitiques. Le deuxième cycle éruptif a comporté une série d'éruptions de nature très variée, au cours desquelles il y a eu dépôt de coulées de laves andésitiques et parfois d'unités pyroclastiques et épiclastiques, ainsi que de laves dacitiques et andésitiques et de tufs interstratifiés, lesquels sont recouverts d'abondants tufs pyroclastiques non soudés. Le dernier cycle volcanique a signalé le passage à un magmatisme tholéiitique avec l'éruption principalement de laves basaltiques et andésitiques en coussins sur les flancs nord submergés du stratovolcan.

Des stromatolites se sont formés le long des marges de dômes éruptifs actifs qui chevauchaient la ligne de rivage autour du stratovolcan émergent. Des unités de formation de fer marquent la fin du volcanisme.

Le complexe volcanique et les unités métaturbiditiques qui l'entourent ont subi trois phases de plissement. Un plissement disharmonique a entraîné la formation de plis serrés dans des roches métasédimentaires, insérés dans (ou juxtaposés à) des plis plus ouverts reprenant les séquences volcaniques. Le large dôme dans la partie sud de la région cartographique a été formé par déformation régionale de l'édifice volcanique principal.

SUMMARY

The Back River volcanic complex is a ca. 2.7 Ga composite stratovolcano, centred on 65°N and 108°E, about 480 km northeast of Yellowknife, Northwest Territories. The complex constitutes the Back Group of the Yellowknife Supergroup in east-central Slave structural province. The Slave Province contains deformed and metamorphosed supracrustal rocks of Archean age that occur between extensive complexes of granitic rocks. Supracrustal successions of the Yellowknife Supergroup comprise thick sequences of metamorphosed volcanic rocks (greenstone belts) that are generally overlain by greywacke-mudstone turbidite sequences derived from mixed felsic volcanic and granitic sources. Unlike many of the greenstone belts in the southern Slave Province, which contain dominantly thick, subaqueous, mafic successions that are close to granitic basement, the Back River complex is dominantly an intermediate to felsic centre surrounded by turbidite units, and is not associated with Archean granitic basement. The complex is somewhat anomalous in the Slave Province because much of it has undergone only a low degree of metamorphism (generally greenschist grade, but locally up to lower amphibolite grade), and an apparent low degree of deformation. Although the volcanic complex has been subjected to at least three periods of regional deformation, the southern part of the complex is exposed in an elliptical zone of low strain at the crest of a broad structural dome.

Granitic plutons and several swarms of mafic dykes have intruded the volcanic complex. Along the western side of the complex, volcanic units and Beechey Lake turbidite sequences have been intruded by northwesterly trending gabbroic dykes that have been folded and metamorphosed. A gabbroic dyke that intrudes the Boucher-Regan sequence northeast of Regan Lake yields an U-Pb (zircon) age of 2586 ± 5 Ma, which is similar to the ca. 2590 Ma granodiorite plutons that intrude the northwestern part of the volcanic complex. The southern part of the volcanic complex is intruded by ca. 2616 Ma intrusions of the Tarantula quartz diorite and about a dozen small stocks and dykes that range from quartz monzonite, tonalite, and to very coarse-grained hornblendite.

Three Proterozoic mafic dyke swarms represent the last igneous events: Malley diabase, Mackay diabase, and the Mackenzie dyke, that cut across granitic plutons and all fold structures in the area. These mafic dyke swarms are displaced by northerly to northeasterly trending faults that transect the volcanic complex.

Back Group

The diverse stratigraphy of the volcanic complex, depicted in Map 2041A and in a simplified geological map and stratigraphic sections, is divided into three

SOMMAIRE

Le complexe volcanique de Back River est un stratovolcan âgé d'environ 2,7 Ga; il est situé par 65° de latitude nord et 108° de longitude est, à environ 480 km au nord-est de Yellowknife, dans les Territoires du Nord-Ouest. Il constitue le Groupe de Back du Supergroupe de Yellowknife dans le centre est de la Province des Esclaves. Cette province comprend des roches archéennes supracrustales déformées et métamorphisées qui sont réparties entre de vastes complexes de roches granitiques. Les séries supracrustales du Supergroupe de Yellowknife comportent d'épaisses séquences de roches volcaniques métamorphisées (ceintures de roches vertes) qui sont généralement recouvertes par des séquences de grauwackes-mudstones turbiditiques provenant de sources granitiques et volcaniques felsiques mixtes. Contrairement à ce qu'on retrouve dans de nombreuses ceintures vertes dans le sud de la Province des Esclaves, qui contiennent une prépondérance d'épaisses séquences de roches mafiques d'origine subaquatique localisées à proximité du socle granitique, le complexe de Back River comporte surtout des roches intermédiaires à felsiques entourées d'unités turbiditiques et n'est pas associé au socle granitique archéen. Le complexe est quelque peu inhabituel par rapport au reste de la Province des Esclaves, car il n'a été que faiblement déformé et métamorphisé (correspondant généralement au faciès des schistes verts, mais atteignant localement celui des amphibolites inférieur). S'il est vrai que ce complexe a été repris par au moins trois épisodes de déformation régionale, les roches de la partie sud du complexe sont exposées à l'intérieur d'une zone elliptique de déformation faible à la crête d'un large dôme structural.

Des plutons granitiques et plusieurs essaims de dykes mafiques ont recoupé le complexe volcanique. Du côté ouest du complexe, des unités volcaniques et des séquences turbiditiques de Beechey Lake ont été recoupées par des dykes gabbroïques plissés et métamorphisées de direction nord-ouest. Un dyke gabbroïque qui recoupe la séquence de Boucher-Regan, au nord-est du lac Regan, donne un âge U-Pb sur zircon de 2586 ± 5 Ma, ce qui est similaire à l'âge (env. 2590 Ma) des plutons de granodiorite qui ont pénétré dans la partie nord-ouest du complexe volcanique. La partie sud du complexe est recoupé par des intrusions de la diorite quartzique de Tarantula (env. 2616 Ma) et par une douzaine de petits stocks et de dykes, dont la composition varie de la monzonite quartzique à de la tonalite et à de la hornblendite à grain très grossier.

Trois essaims de dykes du Protérozoïque représentent les derniers événements ignés : la diabase de Malley, la diabase de Mackay et le dyke de Mackenzie. Ces essaims de dykes mafiques recoupent des plutons granitiques et toutes les structures formées par plissement dans la région et sont eux-mêmes repris par des failles de direction nord à nord-est qui recoupent le complexe volcanique.

Groupe de Back

La stratigraphie variée du complexe volcanique est représentée sur la carte 2041A, sur une carte géologique simplifiée et dans des coupes géologiques; elle est divisée en trois séquences de roches

volcanic sequences, namely, the Innerring sequence, the Thlewycho sequence, and the Boucher-Regan sequence. These sequences represent three successive cycles of mafic (or intermediate) to felsic volcanism and the growth stages of this large composite stratovolcano. Each cycle is followed by or synchronous with erosion and local mass wasting, producing aprons of volcaniclastic detritus and debris-avalanche deposits from various parts of the volcanic edifice. Iron-formation (including magnetite-, sulphide- and siderite-chert iron-formation facies), oolitic and stromatolitic carbonate, sulphidic volcaniclastic rocks, and graphitic slate mark the end of constructive volcanism. Turbidite sedimentation (the Beechey Lake Group) in the surrounding basin was synchronous with, and continued after, volcanism.

Interpretation of the Back Group as a stratovolcano is based on its varied stratigraphy that comprises the calc-alkaline rock association (basalt-andesite-dacite rhyolite) with abundant products of subaerial explosive eruptions and lavas, and the many compositional and physical volcanic features that are similar to those of the volcanic edifices of the High Cascades of northwestern United States, Mexico, Alaska, and other parts of the world. The entire complex is a composite or compound stratovolcano, that developed through series of eruptions from numerous eruptive centres; it is not regarded as a simple strata cone.

The complex south of Outerring Lake (referred to as the 'southern complex') is preserved in a broad structural dome which exposes the thickest part of the volcanic 'pile'. This part of the complex, which includes the Innerring sequence and most of the Thlewycho sequence, is considered to be the main part of the volcanic edifice. It is weakly deformed, and has upward-facing stratigraphy. Although the structural dome may be superimposed on the volcanic edifice, the centre of this dome is not necessarily an eruptive centre. The part of the complex north of Outerring Lake, including the rest of the Thlewycho sequence and the Boucher-Regan sequence, represents the folded northern flanks of the stratovolcano.

Innerring sequence

The Innerring sequence is exposed in a roughly elliptical area on the crest of the structural dome. It comprises four volcanic units and volcaniclastic sedimentary rocks derived from them. The flat-lying to gently dipping volcanic units consist of a sequence of eruptive units from lower andesite lavas and tuffs (unit ABIa), minor basalt and andesite pillowed lavas (unit ABIab), dacitic tuffs and lavas (unit ABIdp,f), to rhyolite domes and flows (unit ABIr). Epiclastic volcanic rocks (unit ABIe) form a moderately to steeply dipping clastic apron on the northwestern and western sides of the sequence and debris-avalanche deposits on the eastern

volcaniques, soit les séquences d'Innerring, de Thlewycho et de Boucher-Regan. Ces séquences représentent trois cycles successifs de volcanisme mafique (ou intermédiaire) à felsique, de même que les étapes d'édification de cet imposant stratovolcan. Chaque cycle est suivi ou accompagné d'une période d'érosion et de mouvements de masse localisés, qui ont produit des nappes de débris volcanoclastiques et des dépôts d'avalanches de débris provenant de diverses parties de l'édifice volcanique. L'apparition de formations de fer de différents faciès (chert-magnétite, chert-sulfures et chert-sidérite), de roches carbonatées oolitiques et stromatolitiques, de volcanoclastites sulfurées et d'ardoise graphitique marque la fin de la phase d'édification du volcan. L'accumulation de turbidites (Groupe de Beechey Lake) dans le bassin environnant a eu lieu en même temps que le volcanisme et s'est poursuivie par la suite.

L'attribution du Groupe de Back à un stratovolcan repose sur la diversité de l'assemblage stratigraphique : l'association de roches calco-alcalines (basalte-andésite-dacite-rhyolite), la présence d'une abondance de produits résultant d'éruptions explosives et d'épanchements de laves en milieu subaérien, et une similarité dans la composition et les caractéristiques physiques du complexe volcanique et de ceux des édifices volcaniques des High Cascades dans le nord-ouest des États-Unis, au Mexique, en Alaska et ailleurs dans le monde. Il s'agit manifestement d'un stratovolcan composite formé par une série d'éruptions émanant de nombreux centres éruptifs, et non d'un simple cône.

Le complexe au sud du lac Outerring (que l'on désigne par « complexe du sud ») est préservé dans un vaste dôme structural, dans lequel est exposée la partie la plus épaisse de l'édifice volcanique. Cette partie du complexe comprend la séquence d'Innerring ainsi que la plus grande partie de la séquence de Thlewycho. Elle constitue ce que l'on croit être la partie principale de l'édifice volcanique. Elle est faiblement déformée et l'assemblage stratigraphique fait face vers le haut. Bien que le dôme structural puisse être superposé à l'édifice volcanique, son centre ne correspond pas nécessairement à un centre éruptif. La partie du complexe située au nord du lac Outerring, incluant ce qui reste de la séquence de Thlewycho ainsi que la séquence de Boucher-Regan, représente les flancs nord plissés du stratovolcan.

Séquence d'Innerring

La séquence d'Innerring affleure dans une zone plus ou moins elliptique sur la crête du dôme structural. Elle comporte quatre unités volcaniques et des roches sédimentaires volcanoclastiques qui en sont dérivées. Les unités volcaniques ont un pendage faible ou nul; elles comportent une séquence d'unités éruptives constituées de laves andésitiques et de tufs à la base (unité ABIa), de quantités mineures de laves basaltiques et andésitiques en coussins (unité ABIab), de tufs et de laves dacitiques (unité ABIdp,f), ainsi que de dômes et de coulées rhyolitiques (unité ABIr). Des volcanites épiclastiques (unité ABIe) forment une nappe de matériaux clastiques de pendage modéré à raide des côtés ouest et nord-ouest de la séquence, de même que des dépôts d'avalanches de side. Although the Innerring sequence covers a broad area, the thickness of exposed eruptive rocks is probably less than 1000 m.

An arcuate zone of brecciation and faulting around the northern and western sides of the Innerring dacite unit is interpreted as a ring-fracture zone that marks the margin of a cauldron subsidence structure.

The oldest rocks of the volcanic complex (unit ĀBIa) are dominantly subaerial, porphyritic andesite lavas (U-Pb zircon igneous age of 2708 ± 0.8 Ma), and minor crystal-lithic tuffs and epiclastic material that occur mainly in the southern parts of the unit.

Mafic pillow lavas (unit ĀBIab) form only a single, thin, basalt unit and a lens of plagioclase-phyric andesite near the western margin of the sequence. These units are interpreted to be distal, subaqueous stratigraphic equivalents of the central Innerring andesite unit.

Dacitic tuffs and lavas of unit ĀBIdp,f conformably overlies the andesitic lavas. This undifferentiated unit comprises massive lavas in the northern parts, and ash-flow tuffs, crystal-lithic tuffs, and tuff breccia with minor lava in the southwestern parts. Quartz- or quartz-plagioclase-phyric dacite units are mainly volcaniclastic rocks in the western and eastern parts.

Rhyolite of the Innerring sequence includes an approximately 1 km by 5 km lava dome overlying the northeastern side of the Innerring dacite, and a long, narrow, arcuate unit in the northern and western parts of the Innerring sequence.

The 14 km long, arcuate rhyolite unit that extends around the northern and western sides of the Innerring dacite unit is truncated by arcuate faults along the western, northern, and parts of the eastern sides. Although the widest portion of the rhyolite overlies the Innerring dacite, the northern side of the unit is intrusive. Much of the western side of this brecciated and faulted unit is sheared, carbonate-cemented breccia.

This arcuate body is interpreted to represent volcanism along ring fractures where rhyolitic magma effused at the surface. Subsequent movement and subsidence along the ring-fracture zone brecciated much of the rhyolite body and truncated it on its northern and western sides.

Intermittent thin units of black sulphidic mudstone and sulphidic volcanic rocks mark the end of the Innerring eruptive cycle on the northern and eastern sides of the Innerring sequence.

Around the northwestern side of the sequence, epiclastic volcanic rocks (unit ĀBIe) represent a broad clastic apron produced by mass wasting and erosion from the early, subaerial volcanic edifice, and deposition

débris du côté est. Même si la séquence d'Innerring recouvre une région assez vaste, l'épaisseur des roches effusives qui sont exposées dans cette région est probablement inférieure à 1000 m.

Des côtés nord et ouest de l'unité dacitique de la séquence d'Innerring, on observe une zone arquée de bréchification et de fracturation qui est interprétée comme étant une zone de failles circulaires délimitant la marge d'une structure formée par subsidence en chaudron.

La plus vieille unité du complexe volcanique (unité ĀBIa), d'origine principalement subaérienne, est constituée de laves andésitiques porphyriques (âge U-Pb sur zircon de 2708 ± 0,8 Ma pour la cristallisation) et de faibles quantités de tufs cristallo-lithiques et de matériaux épiclastiques qui se rencontrent principalement dans la partie sud de l'unité.

Près de la marge ouest de la séquence, des laves mafiques en coussins (unité ĀBIab) ne forment qu'une seule unité basaltique de faible épaisseur et une lentille d'andésites à phénocristaux de plagioclase. Ces unités sont interprétées comme étant un équivalent stratigraphique distal, d'origine subaquatique, de l'unité andésitique centrale de la séquence d'Innerring.

Des tufs et des laves dacitiques appartenant à l'unité ĀBIdp,f reposent en concordance sur les laves andésitiques. Cette unité non différenciée se compose de laves massives dans le nord, et de tufs pyroclastiques, de tufs cristallo-lithiques, de brèches tufacées et de faibles quantités de laves dans le sud-ouest. À l'est et à l'ouest, les unités dacitiques à phénocristaux de quartz ou de quartz et plagioclase sont principalement d'origine volcanoclastique.

La rhyolite de la séquence d'Innerring est représentée par un dôme éruptif d'environ 1 km sur 5 km qui recouvre le côté nord-est de la dacite de la même séquence. Elle forme aussi une unité arquée étroite et allongée dans les secteurs nord et ouest de la séquence d'Innerring.

L'unité de rhyolite a 14 km de longueur et est tronquée par des failles courbées sur les côtés ouest et nord et par endroits sur le côté est. Bien que la section la plus épaisse de la rhyolite repose sur l'unité dacitique de la séquence d'Innerring, la partie nord de l'unité est de nature intrusive. Une bonne partie du côté ouest de cette unité bréchifiée et faillée est constituée de brèche cisaillée à ciment carbonaté.

Ce massif arqué est interprété comme étant le produit d'activité volcanique survenue le long de failles circulaires où il y a eu épanchement de magma rhyolitique. Par la suite, le déplacement et l'affaissement le long de la zone de failles circulaires auraient contribué à la bréchification de la plus grande partie du massif rhyolitique et en auraient tronqué les côtés nord et ouest.

De minces unités de mudstones noir sulfurés sont intercalés avec des roches volcaniques sulfurées; leur présence signale la fin du cycle éruptif d'Innerring des côtés nord et est de la séquence d'Innerring.

Des roches volcaniques épiclastiques (unité ĀBIe) sur le côté nord-ouest de la séquence d'Innerring représentent une nappe clastique de grande ampleur formée par suite des mouvements de masse et de l'érosion dont a fait l'objet l'édifice volcanique along the shore and shallow-marine flanks, during the waning stages of Innerring volcanism. Although the northeast end of this volcaniclastic succession interfingers with dacite and andesite lavas of the Thlewycho sequence, the contact between this succession and the arcuate rhyolite unit is a zone of shearing and faulting (interpreted as a ring-fracture zone). The succession conformably overlies a pillowed basalt unit on the western side of the ring-fracture zone. The apron comprises a 600–700 m basal succession of thin- to medium-bedded volcaniclastic units with minor intervals of tuff (water-laid air-fall ash, and possibly subaqueous ash-flow tuffs), that pass upward into about 1000 m of very thick, volcaniclastic units interpreted as lahars and debris flows. Mass wasting produced local, coarse, debris-avalanche deposits (unit ĀBIed) on the eastern side of the felsic dome. All units contain abundant felsic to andesite clasts that are similar to lithologies of the Innerring eruptive sequence.

subaérien primordial, et une phase de sédimentation survenue le long du littoral et en eau peu profonde sur les flancs du volcan au cours des dernières phases du volcanisme associé à la séquence d'Innerring. Bien que l'extrémité nord-est de cette série volcanoclastique soit interdigitée avec des laves dacitiques et andésitiques de la séquence de Thlewycho, le contact entre cette série et l'unité rhyolitique arquée correspond à une zone de cisaillement et de fracturation (interprétée comme étant une zone de failles circulaires). Cette série repose en concordance sur une unité de basalte en coussins le long du flanc ouest de la zone de failles circulaires. La nappe comporte une série de base d'une épaisseur de 600 à 700 m, qui comprend des unités volcanoclastiques à lits fins et moyens et des intervalles mineurs de tufs (cendres retombées accumulées en milieu aquatique et, possiblement, tufs pyroclastiques de milieu subaquatique). Ces unités passent vers le haut à une séquence épaisse (environ 1000 m) de roches volcanoclastiques, que l'on croit être des lahars et des coulées de débris. Sur le côté est du dôme felsique, des mouvement de masse ont produits localement des dépôts à grain grossier d'avalanches de débris (unité ĀBIed). Toutes ces unités contiennent de nombreux clastes de composition felsique à andésitique, qui sont similaires aux types de roches trouvées dans la séquence volcanique d'Innerring.

An 18 km long by 50–400 m wide zone of brecciation, cataclasis, and arcuate faults, which follows around the northern and western margin of the arcuate unit of Innerring rhyolite, is interpreted as parts of a ring-fracture zone, related to a cauldron subsidence structure within the Innerring sequence. The steep preferred orientation of elongate breccia clasts and lineations indicate dip-slip movement along the arcuate faults. That the area inside the arcuate faults was the downdropped side (caldera) is inferred from the abrupt change in stratigraphy across the outer ring fault. Thus cauldron subsidence along ring faults brought upper subaerial parts of the edifice into juxtaposition with lower subaqueous parts of the stratovolcano. The fading out of the breccia zone southward, and its absence along the eastern sides of the Innerring sequence, suggest that the collapse was a one-sided 'trap door' structure.

Une zone de bréchification, de cataclase et de failles arquées, d'une longueur de 18 km et d'une largeur de 50 à 400 m, contourne les marges nord et ouest de l'unité arquée de rhyolite de la séquence d'Innerring. Elle est interprétée comme faisant partie d'une zone de failles circulaires associée à une structure formée par subsidence en chaudron au sein de la séquence d'Innerring. L'orientation préférentielle, à plongement raide, des fragments de brèche allongés et des linéations indique qu'il y a eu rejet le long des failles arquées. Un changement marqué dans la stratigraphie de part et d'autre de la faille circulaire externe laisse supposer que c'est bien la région à l'intérieur des failles arquées qui s'est affaissée (la caldeira). La subsidence en chaudron le long des failles circulaires a donc entraîné la juxtaposition des parties supérieures subaériennes de l'édifice et des parties inférieures subaquatiques du stratovolcan. La disparition progressive de la zone de brèches vers le sud, et son absence le long de la marge est de la séquence d'Innerring, militent en faveur d'un mécanisme d'effondrement unilatéral de type « charnière ».

Thlewycho sequence

The Thlewycho sequence represents the main constructional phase of the stratovolcano. It is exposed for 50 km from southeast of Jim Magrum Lake to northwest of Regan Lake, and comprises all products of an intermediate to felsic eruptive cycle and synchronous epiclastic deposits that lie above the Innerring sequence and below mafic lavas of the Boucher-Regan sequence. Although cumulative stratigraphic thickness is between 2500 m and 4000 m, the units probably formed an onlapping succession on the stratovolcano, and presumably no single vertical sequence with that thickness ever existed.

The stratigraphy of this sequence is most completely displayed around the structural dome in the southern half of the volcanic complex. The complex

Séquence de Thlewycho

La séquence de Thlewycho représente la phase principale dans l'édification du stratovolcan. Elle affleure sur une distance de 50 km, depuis au sud-est du lac Jim Magrum jusqu'au nord-ouest du lac Regan. Elle comprend tous les produits générés au cours d'un cycle éruptif de composition intermédiaire à felsique, ainsi que des sédiments épiclastiques contemporains qui reposent sur la séquence d'Innerring et sous des laves mafiques de la séquence de Boucher-Regan. Bien que l'épaisseur stratigraphique cumulative se situe entre 2500 et 4000 m, il est probable que les unités ont formé un biseau d'aggradation sur le stratovolcan et qu'aucune série verticale n'aurait atteint à elle seule une telle épaisseur.

Les coupes stratigraphiques les plus complètes de cette séquence se rencontrent autour du dôme structural dans la moitié sud du complexe volcanique. La complexité dans la distribution des map pattern and highly variable stratigraphy, indicate: 1) four cycles of lava effusion followed by deposition of volcaniclastic debris on the north side (the Rusty Lake section); to 2) effusion of about 30 subaerial, dominantly andesitic lava flows and a few intermittent pyroclastic and epivolcaniclastic units on the eastern side (Gold Lake section); and 3) interlayered dacitic and andesitic lavas and tuffs overlain by a thick succession of voluminous nonwelded to welded, ash-flow tuffs and volcaniclastic rocks around the southern sides. Volcanism in this sequence generally progressed from basal andesitic lavas and tuffs, through dacitic tuffs and lavas, and ended with the effusion of large rhyolite-dacite dome-flow complexes from numerous centres around the periphery of the volcano. One dome, on the southeastern side of the stratovolcano, has been dated at 2692 ± 2 Ma.

Where the Thlewycho sequence thins out northward, between Outerring and Regan lakes, it contains distal facies of the volcaniclastic unit (mainly undifferentiated) that in places are interbedded with sedimentary rocks of the Beechey Lake Group.

Porphyritic andesite lavas (unit ABTa) occur mainly at the base of the sequence as pillowed to massive units and breccia. The base of the andesite lava series, overlying the southeastern side of the Innerring sequence, is marked by an approximately 7 km long zone of carbonate-cemented flow breccia, that grades upward into massive units that are typical subaerial lava flows. Thus the basal subaqueous flow units passed upwards abruptly into voluminous subaerial andesitic lavas, presumably as the pile emerged above sea level.

Dacitic rocks of the Thlewycho sequence (unit ABTd) form dominantly lavas or domes except for near the northwest side of Gold Lake where they are mainly ash-flow tuffs and tuff breccia. A lens of pillowed dacite east of Rusty Lake indicates local subaqueous deposition. The large dacite unit between Outerring Lake and the Back River is mainly lava-flow or flow-breccia material. Southeast of Jim Magrum Lake, quartz- and feldspar-phyric dacite forms the lower part of a composite dome. About 2 km northeast of Jim Magrum Lake, three units of ash-flow tuffs and bedded crystal tuffs occur within Thlewycho volcaniclastic unit.

The numerous discrete rhyolite units of the Thlewycho sequence are mostly domes exposed at various levels of erosion, except for the 2 km by 15 km rhyolite unit northeast of Rusty Lake, that comprises five extensive shallow-dipping, locally columnar-jointed, lava-flow units, and a large unit of intrusive rhyolite.

unités cartographiques et la variabilité stratigraphique indiquent qu'il y a eu (1) quatre cycles d'épanchement de laves suivis du dépôt de débris volcanoclastiques sur le côté nord (la coupe du lac Rusty); (2) épanchement d'une trentaine de coulés subaériennes de laves principalement andésitiques et accumulation de quelques unités pyroclastiques et épivolcanoclastiques locales sur le côté est (la coupe du lac Gold); et (3) interstratification de laves dacitiques et andésitiques et de tufs et accumulation d'une épaisse série sus-jacente constituée d'abondants tufs pyroclastiques et roches volcanoclastiques soudés et non soudés sur le côté sud. On reconnaît une progression générale dans la nature du volcanisme à l'origine de cette séquence : l'éruption de laves et de tufs andésitiques à la base de la séquence a été suivie par des tufs et des laves dacitiques et, finalement, par l'effusion de complexes de dômes-coulées dacitiques à partir de nombreux centres à la périphérie du volcan. Un de ces dômes, du côté sud-est du stratovolcan, a été daté à 2692 ± 2 Ma.

À l'endroit où la séquence de Thlewycho s'amincit vers le nord, entre le lac Outerring et le lac Regan, on observe un faciès distal de l'unité volcanoclastique (généralement non différencié) qui, par endroits, est interstratifié avec des roches sédimentaires du Groupe de Beechey Lake.

Des andésites porphyriques (unité ABTa) se rencontrent surtout à la base de la séquence, sous forme de brèches et d'unités en coussins et massives. La base de la série de laves andésitiques, qui repose sur le côté sud-est de la séquence d'Innerring, est mise en évidence par une zone d'environ 7 km de longueur de brèche éruptive à ciment carbonatée qui passe vers le haut à des unités massives typiques de coulées de laves subaériennes. Il existe donc une transition nette entre les coulées à la base, d'origine subaquatique, et les laves andésitiques sus-jacentes volumineuses, d'origine subaérienne. On présume que cette transition marque la période où l'édifice volcanique émergeait de la mer.

Les roches dacitiques de la séquence de Thlewycho (unité ABTd) se présentent principalement sous forme de laves ou de dômes, à l'exception d'un endroit près de la rive nord-ouest du lac Gold, où elles sont représentées en majorité par des tufs pyroclastiques et des brèches tufacées. Une lentille de dacite en coussins à l'est du lac Rusty témoigne d'une accumulation locale en milieu subaquatique. La grosse unité dacitique retrouvée entre le lac Outerring et la rivière Back est surtout constituée de laves ou de brèches éruptives. Au sud-est du lac Jim Magrum, une dacite à phénocristaux de quartz et de feldspath forme la partie inférieure d'un dôme composite. À environ 2 km au nord-est du lac Jim Magrum, trois unités de tufs pyroclastiques et de tufs cristallins lités se rencontrent dans l'unité volcanoclastique de la séquence de Thlewycho.

Les nombreuses unités rhyolitiques individuelles dans la séquence de Thlewycho sont en majorité des dômes à divers stades d'érosion. Il existe cependant deux exceptions : une unité rhyolitique de 2 km sur 15 km au nord-est du lac Rusty qui comprend cinq vastes coulées de laves localement prismées et à faible pendage, et une imposante unité de rhyolite intrusive.

The Gold Lake lava-dome complex (5 km southwest of Gold Lake) is an assemblage of seven rhyolite to dacite lava flows separated by rhyolitic volcaniclastic units and related coarse breccia. Flow and carapace breccia are carbonate cemented (and locally stromatolite bearing) on the eastern (seaward) side but devoid of carbonate on the western (landward side). A clastic apron, containing pebbly sandstone and rhyolite turbidite, lies on flow breccia along the southeastern side of the dome.

The narrow body of rhyolite at the north end of Thlewycho Lake is a remnant of a rhyolite dome that rose along a linear fracture through a greywacke-siltstone succession at the margin of the main volcanic complex. The present level of erosion exposes only the roots of this dome and the folded, voluminous rhyolite breccia aprons that represent its destruction probably by massive landsliding and by violent explosions.

The lava dome along the southeast side of Thlewycho Lake comprises variably massive to flow-layered rhyolite, but is mainly autobrecciated and contains an apron of coarse felsic breccia, debris-avalanche deposits, and rhyolitic volcrudite to volcarenite, around the northern, western, and southern sides. Clastic units related to the dome interfinger with shale, siltstone, and iron-formation of the overlying Beechey Lake Group.

Northeast of Innerring Lake, a 7 km long body of rhyolite that has intruded the volcaniclastic apron of the Innerring sequence is interpreted as a ring-fracture intrusion.

Volcaniclastic rocks (unit ĀBTp) that make up a major portion of the Thlewycho sequence comprise a variety of tuffs and tuff breccia, breccia, volcanic arenite, conglomerate, and debris-avalanche deposits. Pyroclastic rocks dominate the unit in the 'southern complex' although the proportion of epiclastic material increases on the northeastern side. The unit north of Outerring Lake is mainly undifferentiated, but includes tuffs, tuff breccia, and polymictic breccia that contain ubiquitous clasts of porphyritic andesite.

On the southeastern side of the volcanic complex, the volcaniclastic unit between the basal andesite lavas of the Thlewycho sequence and the Gold Lake dome comprises about 300 m of pyroclastic flows.

Boucher-Regan sequence

The Boucher-Regan sequence comprises basalt, andesite, dacite, and rhyolite that overlie the Thlewycho sequence mainly in the northern parts of the volcanic complex. The sequence not only represents the only major effusion of basalt units of the volcanic complex, but also a fundamental change of magma composition from calc-alkaline (volcanism of the Innerring and Thlewycho sequences) to tholeiitic.

Le complexe de dômes éruptifs du lac Gold se situe à 5 km au sud-ouest du lac Gold; c'est un assemblage de sept coulées de laves rhyolitiques à dacitiques que séparent des unités volcanoclastiques rhyolitiques et des brèches à grain grossier apparentées. Du côté est (côté mer), les brèches éruptives et les carapaces bréchiques contiennent du ciment carbonaté et, par endroits, des stromatolites alors que du côté ouest (côté terre), elles sont dépourvues de carbonates. Une nappe clastique, qui contient du grès caillouteux et de la turbidite rhyolitique, repose sur une brèche éruptive du côté sud-est du dôme.

L'étroit massif de rhyolite à l'extrémité nord du lac Thlewycho représente les vestiges d'un dôme rhyolitique qui s'est formé le long d'une fracture linéaire dans une séquence de grauwacke et de siltstone à la marge du complexe volcanique principal. Le niveau d'érosion actuel ne laisse apparaître que la racine de ce dôme ainsi que les nappes volumineuses plissées de brèches rhyolitiques qui témoignent de la destruction du dôme, probablement sous l'action de glissements de terrain majeurs et de violentes explosions.

Le dôme éruptif sur le côté sud-est du lac Thlewycho se compose de rhyolite massive ou à litage de flux; toutefois, sur les côtés nord, ouest et sud du lac, il est surtout autobréchifié et contient une nappe de brèche felsique à grain grossier, de dépôts d'avalanches de débris et de volcrudites et de volcarénites rhyolitiques. Des unités clastiques apparentées au dôme sont interdigitées avec du shale, du siltstone et de la formation de fer du Groupe de Beechey Lake sus-jacent.

Au nord-est du lac Innerring, un massif de rhyolite d'une longueur de 7 km a fait intrusion dans la nappe volcanoclastique de la séquence d'Innerring. On croit qu'il s'agit d'un filon annulaire.

Une portion considérable de la séquence de Thlewycho est constituée de roches volcanoclastiques (unité ĀBTp), y compris une variété de tufs et de brèches tufacées, de brèches, de volcarénites, de conglomérats et de dépôts d'avalanches de débris. Des roches pyroclastiques prédominent dans le « complexe du sud », bien que la proportion de roches épiclastiques augmente du côté nord-est. L'unité au nord du lac Outerring est généralement non différenciée, mais elle comporte des tufs, des brèches tufacées et des brèches polygéniques dans lesquelles des clastes d'andésite porphyrique sont omniprésents.

Du côté sud-est du complexe volcanique, l'unité volcanoclastique entre les laves andésitiques à la base de la séquence de Thlewycho et le dôme du lac Gold comprend environ 300 m de coulées pyroclastiques.

Séquence de Boucher-Regan

La séquence de Boucher-Regan comprend du basalte, de l'andésite, de la dacite et de la rhyolite qui reposent sur la séquence de Thlewycho surtout dans le nord du complexe volcanique. Cette séquence représente l'unique épanchement majeur de basalte du complexe volcanique et marque un changement fondamental dans la composition du magma, qui a passé de calco-alcaline (volcanisme associé aux séquences d'Innerring et de Thlewycho) à tholéiitique.

The basalt and andesite units generally contain mafic phenocrysts (with or without plagioclase) in contrast to dominantly feldspar-phyric calc-alkaline andesite of the Thlewycho sequence. The mafic units ascribed to this sequence form: massive to pillowed lavas, breccia, and related sills that stretch for 40 km along the northern margin of the volcanic complex; units of pillow lava and pillow breccia between Outerring Lake and Boucher Lake; and small, discrete lava-flow units within the 'Keish Lake volcaniclastic fan', north of Gold Lake and southeast of Thlewycho Lake. Abundance of pillow-lava and pillow-breccia units indicate that lavas of the Boucher-Regan sequence effused in a mainly subaqueous environment.

Rhyolitic to dacitic members of this sequence (units ĀBBr and ĀBBd) include a series of discrete domes and lava flows (around the northern and northwestern parts of the volcanic complex) that overlie the mafic lavas that lie at or near the top of the Keish Lake volcaniclastic fan or occur within Beechey Lake Group turbidite sequences along the northwestern side of the complex. Around Boucher Lake, massive, fine-grained dacite units containing pumice and shards may be ash-flow tuffs.

Rhyolite units of the Boucher-Regan sequence have trace-element chemistry that distinguishes them from rhyolite of the Thlewycho sequence, in the southern part of the volcanic complex.

Near Quartermoon Lake, the largest dome of the volcanic complex (7 km by 13 km across) overlies basalt of the Boucher-Regan sequence, and dacitic and volcaniclastic rocks of Thlewycho affinity. The rhyolite also intrudes and encloses parts of these units as well as the basalt sills. Thus the sills are related to the basalt lavas that they intrude, and not some postvolcanic event.

Epiclastic volcanic rocks

This diverse map unit (units ĀBe, ĀBed, ĀBer, ĀBert) comprises volcaniclastic rocks that represent detritus eroded from the volcanic pile from the end of Thlewycho volcanism to the end of Boucher-Regan volcanism. It includes the 'Keish Lake clastic fan', valley-filling avalanche deposits on sides of felsic domes, clastic aprons derived from mafic lavas, and rhyolite-derived turbidite sequences and other volcarenite and tuff within the Beechey Lake Group.

The Keish Lake clastic fan forms a broad unit on the western-central side of the volcanic complex between Keish Lake and Thlewycho Lake. It comprises large aprons of debris-avalanche deposits on the northern and southeastern margins, and a succession of westward-thinning and -fining, well bedded to crudely bedded volcrudite to volcarenite in the central and southwestern parts of the fan. Greywacke-mudstone units of the

Les unités basaltiques et andésitiques contiennent généralement des phénocristaux mafiques (avec ou sans plagioclase), à l'opposé des andésites calco-alcalines de la séquence de Thlewycho, qui renferment principalement des phénocristaux de feldspath. Les unités mafiques de cette séquence comprennent des laves massives ou en coussins, des brèches et des filons-couches qui s'étalent sur une distance de 40 km le long de la bordure nord du complexe volcanique; des unités de laves en coussins et de brèches en coussins entre les lacs Outerring et Boucher; et de petites unités distinctes formées de laves au sein du cône volcanoclastique du lac Keish, au nord du lac Gold et au sud-est du lac Thlewycho. L'abondance des laves en coussins et des brèches en coussins indique que les laves de la séquence de Boucher-Regan se sont épanchées principalement en milieu aquatique.

Les membres rhyolitiques et dacitiques de cette séquence (unités ĀBBr et ĀBBd) comprennent une série de dômes et de coulées distinctes (autour des parties nord et nord-ouest du complexe volcanique), qui recouvrent les laves mafiques que l'on retrouve au sommet ou près du sommet du cône volcanoclastique du lac Keish ou se rencontrent au sein de séquences turbiditiques du Groupe de Beechey Lake du côté nord-ouest du complexe. À proximité du lac Boucher, des unités dacitiques massives à grain fin, qui contiennent de la ponce et des fragments volcaniques, pourraient être des tufs pyroclastiques.

La chimie des éléments traces permet de distinguer les rhyolites de la séquence de Boucher-Regan des rhyolites de la séquence de Thlewycho dans le sud du complexe volcanique.

Près du lac Quartermoon, le dôme le plus important du complexe volcanique (d'une superficie de 7 km sur 13 km) repose sur des basaltes de la séquence de Boucher-Regan et sur des roches dacitiques et volcanoclastiques similaires à celles de la séquence de Thlewycho. La rhyolite recoupe aussi ces unités et renferme des fragments de ces roches et des filons-couches de basalte. L'origine des filons-couches est donc reliée à celle des laves basaltiques qu'ils recoupent, et non à un événement post-volcanique.

Roches volcaniques épiclastiques

Cette unité cartographique variée (unités ĀBe, ĀBed, ĀBer et ĀBert) comprend des roches volcanoclastiques qui représentent des produits de l'érosion de l'édifice volcanique depuis la fin du volcanisme associé à la séquence de Thlewycho jusqu'à la fin du volcanisme associé à la séquence de Boucher-Regan. Elle comprend le « cône volcanoclastique du lac Keish », des dépôts d'avalanches ayant comblé des vallées le long des flancs de dômes felsiques, des nappes de matériaux clastiques dérivés de laves mafiques, ainsi que des séquences de turbidites dérivées de rhyolites et d'autres volcarénites et tufs du Groupe de Beechey Lake.

Le cône volcanoclastique du lac Keish est une vaste unité sur le côté centre ouest du complexe volcanique, entre le lac Keish et le lac Thlewycho. Il comprend de larges nappes de dépôts d'avalanches de débris, sur les marges nord et sud-est du cône, ainsi qu'une séquence de volcrudites et de volcarénites à litage bien à grossièrement défini, qui deviennent moins épaisses et moins grossières vers l'ouest, dans les secteurs central et sud-ouest du cône. Des unités de grauwacke-mudstone du Groupe de Beechey

Beechey Lake Group conformably overlie the western side of the fan, although locally volcarenite and turbidite interfinger. Debris-avalanche deposits of the fan form thick, massive aprons along the southern side of the Quartermoon Lake rhyolite dome, and on the western side of the rhyolite dome at the north end of Thlewycho Lake. They are polymictic breccia units (containing dominantly rhyolite blocks) that have abundant dark green to grey, gritty, pebbly arenaceous matrix. Although the debris-avalanche deposits were derived by mass wasting mainly from the rhyolite domes, the bedded portion of the fan was derived from a more varied terrane, presumably from the complex volcanic edifice to the east. The tholeiitic basalt lava flow within the bedded succession indicates that part of the Keish Lake fan was deposited during Boucher-Regan sequence volcanism.

Megabreccia units are interpreted as valley-filling avalanche deposits at one place on the side of the Quartermoon Lake dome, and near the north end of the Gold Lake rhyolite dome. At the north end of the Gold Lake rhyolite dome, a southeasterly trending, elongate unit of megabreccia that thickens eastward and tails out westward and was deposited in a steep-sided valley incised into the side of the volcano, indicates eastward mass flow from a high volcanic terrane to the west.

Detrital rocks derived mainly from mafic lavas occur in three main areas. 1) A broad easterly trending band of volcaniclastic rocks, which overlies lavas of the Boucher-Regan sequence about 7 km northeast of Keish Lake, comprises volcanic siltstone to rudaceous volcarenite and breccia that contain varied amounts of fragments, mainly of andesite and basalt, and minor rhyolite. 2) Northwest of Fidler Lake, a 4 km lens of well bedded andesitic breccia, volcarenite, siltstone, and minor conglomerate lies between andesite pillow breccia, and slate and wacke of the overlying Beechey Lake Group. 3) Southeast of Fidler Lake, volcanic sedimentary rocks within the Beechey Lake turbidite sequences comprise coarse wacke, pebbly arenite, and rudite, that contain clasts of hornblende- and plagioclase-phyric andesite, rare rhyolite and dacite, and crystals of plagioclase and hornblende.

Rhyolite-derived turbidite (unit ĀBert) forms a 24 km long, white- to pale grey-weathering unit within Beechey Lake turbidite sequence north and east of Boucher Lake. Two stratigraphic sections measured through this approximately 300 m thick, northward-facing unit show numerous thinning- and fining-upward cycles that are interpreted to represent a narrow, rhyolitic epiclastic fan or channel deposit within the Beechey Lake turbidite sequence that was derived from the large Quartermoon Lake dome to the west.

Lake reposent en concordance sur le côté ouest du cône avec, par endroits, des volcarénites et des turbidites interdigitées. Les dépôts d'avalanches de débris faisant partie du cône forment des nappes épaisses et massives le long de la marge sud du dôme rhyolitique du lac Quartermoon et sur le côté ouest du dôme rhyolitique à l'extrémité nord du lac Thlewycho. Ce sont des unités de brèches polygéniques (contenant surtout des blocs de rhyolite) dont la matrice arénacée, caillouteuse, graveleuse, vert foncé à grise constitue une composante importante de la roche. Bien que les dépôts d'avalanches de débris soient dérivés de mouvements de masse principalement sur les dômes rhyolitiques, les composantes litées du cône proviennent d'un terrane plus varié, vraisemblablement de l'édifice volcanique complexe situé à l'est. La présence de la coulée de basalte tholéiitique au sein de la série litée indique qu'une partie du cône du lac Keish a été déposé en même temps que le volcanisme associé à la séquence de Boucher-Regan.

Des unités de mégabrèches observées à un endroit sur un versant du dôme du lac Quartermoon et près de l'extrémité nord du dôme rhyolitique du lac Gold sont interprétées comme étant des dépôts d'avalanches comblant des vallées. À l'extrémité nord du dôme rhyolitique du lac Gold, une unité allongée de mégabrèche de direction sud-est, qui s'épaissit vers l'est et disparaît vers l'ouest, a été déposée dans une vallée aux parois raides qui était encaissée dans le flanc du volcan; elle témoigne d'un mouvement de masse vers l'est depuis un terrane volcanique élevé situé à l'ouest.

Des roches clastiques dérivées en majeure partie de laves mafiques se rencontrent dans trois régions principales : (1) à environ 7 km au nord-est du lac Keish, une large bande de roches volcanoclastiques, de direction est, repose sur des laves de la séquence de Boucher-Regan; elle est constituée de siltstones volcaniques passant à des volcrudites et volcarénites et à des brèches contenant des quantités variées de fragments d'andésite, de basalte et, dans une moindre mesure, de rhyolite; (2) au nord-ouest du lac Fidler, une lentille de 4 km constituée de brèche andésitique bien litée, de volcarénite, de siltstone et d'un peu de conglomérat, repose entre une brèche d'andésite en coussins, d'une part, et de l'ardoise et du wacke du Groupe de Beechey Lake sus-jacent, d'autre part; (3) au sud-est du lac Fidler, des roches volcanosédimentaires au sein des séquences turbiditiques de Beechey Lake comprennent des wackes grossiers, des arénites caillouteuses et des rudites, lesquels contiennent des clastes d'andésite à phénocristaux de hornblende et de plagioclase, de rares clastes de rhyolite et de dacite et des cristaux de plagioclase et de hornblende.

Au nord et à l'est du lac Boucher, une turbidite dérivée de rhyolite (unité ĀBert) forme une unité de 24 km de longueur et d'environ 300 m d'épaisseur au sein de la séquence turbiditique de Beechey Lake. Elle fait face au nord et prend une couleur blanche à gris pâle à l'altération. Deux coupes géologiques dans l'unité présentent de nombreuses séquences positives qui sont interpétées comme représentant un étroit dépôt de chenal ou cône épiclastique de composition rhyolitique au sein de la séquence turbiditique de Beechey Lake, lequel est dérivé du vaste dôme du lac Quartermoon à l'ouest.

The various debris-avalanche deposits, flank deposits, stream deposits, and clastic fans signify degradation of the volcanic pile during and following each cycle of volcanism. Directions of sediment transport and mass movement can be inferred from the disposition of these units relative to their source terrane. These directions provide a basis for interpreting paleotopographic high areas of the original stratovolcano. Debris-avalanche, landslide, and scree deposits prevail mainly on the seaward sides of felsic dome complexes around the southern and western sides of the volcanic complex. Two valley-filling avalanche deposits support these movement directions. The Keish Lake fan on the northwestern side, combined with locations of major debris-avalanche deposits indicate high terrain to the east or northeast. The largest epiclastic aprons formed on the northwestern flanks of the volcanic complex, following both Innerring sequence volcanism and Thlewycho and Boucher-Regan sequence volcanism (Keish Lake fan). This pattern is similar to that of some modern volcanoes, where erosion and mass wasting are prevalent on one side of a complex throughout its history.

La présence d'une variété de dépôts (dépôts d'avalanches de débris, dépôts de flancs, dépôts fluviatiles et cônes de matériaux clastiques) témoigne de la dégradation de l'édifice volcanique durant et après chaque cycle de volcanisme. La répartition des unités par rapport aux terranes sources permet de déduire les directions de transport des sédiments et des mouvements de masse. Ces directions servent de base à l'interprétation des hauteurs paléotopographiques du stratovolcan d'origine. Les dépôts d'avalanches de débris, de glissements de terrains et d'éboulis prédominent surtout des côtés mer des complexes de dômes felsiques autour des côtés sud et ouest du complexe volcanique. La présence de deux dépôts d'avalanches de débris comblant des vallées laisse supposer que ces directions de mouvement sont correctes. La présence du cône du lac Keish sur le côté ouest ainsi que l'emplacement des principaux dépôts d'avalanches de débris indiquent que le terrain était plus élevé à l'est ou au nord-est. Les plus importantes nappes de matérieux épiclastiques se sont formées sur les flancs nord-ouest du complexe volcanique, à la suite du volcanisme associé à la séquence d'Innerring et du volcanisme associé aux séquences de Thlewycho et de Boucher-Regan (cône du lac Keish). Cette configuration est similaire à celle que l'on observe pour certains volcans modernes, où l'érosion et les mouvements de masse prédominent sur un côté du complexe volcanique.

Carbonate units

Carbonate (mainly calcite and dolomite, but also siderite) occurs throughout the volcanic complex as cement in fractures, faults, and shear zones, but is most abundant as cement in breccia related to domes and lava flows. Near these breccia units, beds and laminae of massive carbonate, and stromatolitic and oolitic units indicate primary chemical sedimentation and biological activity. Stratified clastic carbonate and some debris flows containing blocks of carbonate suggest erosion from primary carbonate deposits.

Extensive zones of carbonate-cemented breccia mark the end of both Innerring and Thlewycho sequences. Carbonate-rich zones almost encircle the Innerring sequence — occurring both in rhyolite flows and debris-avalanche deposits at the top of the Innerring sequence, in andesite flow breccia at the base of the Thlewycho sequence, and in andesite and basalt pillow lavas and breccia of the Boucher-Regan sequence.

The carbonate deposits occur almost exclusively on the seaward sides of felsic lava domes: it is lacking in breccia on the landward side of the domes, where lavas and pyroclastic units of the Thlewycho sequence almost all have features characteristic of subaerial deposition. Similarly, carbonate is associated with iron-formation where it lies immediately above dome and/or flow rocks of the volcanic complex, but it is notably lacking where the iron-formation is not in contact with flow units, or is wholly within turbidite units of the Beechey Lake Group (i.e. northeast of Boucher and Regan lakes).

Unités carbonatées

On retrouve des carbonates (principalement de la calcite et de la dolomite, mais aussi de la sidérite) partout dans le complexe volcanique sous forme de ciment dans les fractures, les failles et les zones de cisaillement. Ce ciment est particulièrement abondant dans des brèches associées aux dômes et aux coulées de laves. À proximité des ces unités de brèches, la présence de lits et de lamines de carbonates massives, ainsi que d'unités stromatolitiques et oolitiques, témoigne d'une sédimentation chimique primaire et d'une activité biologique. La présence de roches clastiques carbonatées stratifiées et d'un certain nombre de coulées de débris contenant des blocs carbonatées laisse supposer qu'il y a eu érosion de dépôts carbonatés primaires.

La présence de vastes zones de brèches à ciment carbonaté signale la fin de la séquence d'Innnering et de celle de Thlewycho. Des zones riches en carbonates entourent presque toute la séquence d'Innerring; on en retrouve dans des coulées de laves rhyolitiques et des dépôts d'avalanche de débris, au sommet de la séquence d'Innerring, dans des brèches éruptives andésitiques à la base de la séquence de Thlewycho, et dans des laves et des brèches andésitiques et basaltiques en coussins de la séquence de Boucher-Regan.

Les dépôts carbonatés se rencontrent presque exclusivement du côté des dômes de laves felsiques faisant face à la mer. Du côté de la terre, les dômes sont dépourvus de brèches et les laves et les unités pyroclastiques de la séquence de Thlewycho présentent presque toutes des caractéristiques d'une accumulation en milieu subaérien. De même, des carbonates sont associés à des formations de fer aux endroits où ces dépôts reposent directement sur des dômes et des roches éruptives du complexe volcanique, mais ils sont notablement absents aux endroits où les formations de fer ne sont pas en contact avec les unités éruptives ou encore lorsqu'elles sont entièrement encaissées dans des unités turbiditiques du Groupe de Beechey Lake (par exemple, au nord-est des lacs Boucher et Regan).

Stromatolites occur in the small carbonate-rich interval at the margin of a large rhyolitic to dacitic lava dome, at the boundary between either the Thlewycho or Boucher-Regan sequences and turbiditic sedimentary rocks of the Beechey Lake Group. They occur in three types of units: 1) in megabreccia units, or lenses within them, that form dome margins (stromatolite localities 1, 2, 4, 5, 10); 2) in clastic aprons around the megabreccia (stromatolite localities 3, 8); and 3) in bedded carbonate units immediately overlying the clastic dome margin sequence (stromatolite localities 6, 7, 9).

Stromatolites are a relatively rare local phenomena within the fairly extensive carbonate-bearing volcaniclastic rocks and bedded carbonate units around the volcanic complex. Even though the localities all occur at the same stratigraphic level, they probably never formed an extensive continuous unit. Most occurrences may represent isolated microbial communities that developed in areas of fumarolic (or hydrothermal) activity at the margins of each dome or flow complex. Such a situation would provide a source of warm solutions and heat that would drive convective circulation in both the sea water and highly porous rubble on submerged flanks of domes, similar to drowned fumaroles active today on the island of Vulcano, Italy. In the Back River complex, this is the site of localized carbonate deposition. It is conceivable that stromatolite growth would be stimulated by warm marine waters and volcanic emanations that could provide abundant nutrients for the production of local bacterial plumes.

Beechey Lake Group

Sedimentary rocks of the Beechey Lake Group generally overlie and completely surround the volcanic complex. They interfinger with volcanic formations on a large scale in the northern parts of the complex, and on a smaller scale they interfinger with volcaniclastic rocks forming aprons on the sides of the numerous felsic lava domes. Generally, turbidite sequences of the Beechey Lake Group lie conformably on the volcanic complex. Although parts of the contact between the Back Group and the Beechey Lake Group (the volcanic-sedimentary contact) are sheared or represent a zone of high strain, there is no evidence for a general unconformity between the two groups.

Sedimentary rocks of the Beechey Lake Group consist mainly of greywacke-mudstone turbidite, siltstone, grit, and minor conglomerate, graphitic shale (or slate) and carbonate-rich beds, and iron-formation.

Greywacke units near the eastern side of the volcanic complex are texturally immature, quartz-rich rocks that contain a variety of clast types including quartz (as euhedral to embayed crystals and fine, polycrystalline grains of volcanic origin, and coarse, polycrystalline

Des stromatolites sont observés dans le petit intervalle riche en carbonates à la marge d'un vaste dôme de laves rhyolitiques à dacitiques, à la limite entre la séquence de Thlewycho ou de Boucher-Regan et les roches sédimentaires turbiditiques du Groupe de Beechey Lake. On les retrouve dans trois types d'unités : (1) des mégabrèches, ou des lentilles qui en font partie, qui définissent les marges du dôme (les localités de stromatolites 1, 2, 4, 5 et 10); (2) des nappes de matériaux clastiques autour des mégabrèches (les localités de stromatolites 3 et 8); et (3) des unités carbonatées litées sus-jacentes à la séquence de la marge du dôme clastique (localités de stromatolites 6, 7 et 9).

Les stromatolites sont une composante locale relativement rare des roches volcanoclastiques carbonatées et des unités carbonatées litées relativement vastes en périphérie du complexe volcanique. Même si on les rencontre tous au même niveau stratigraphique, il est peu probable qu'ils aient constitué une unité continue de grande étendue. Dans l'ensemble, ils témoigneraient plutôt de communautés microbiennes isolées, établies dans des zones d'activité fumerolienne (ou hydrothermale) sur les marges de chaque dôme ou complexe éruptif. Les solutions chaudes et la chaleur générées dans de tels milieux favoriseraient le maintien d'une circulation convective dans l'eau de mer et dans les débris très poreux sur les flancs submergés des dômes. Cette situation est similaire à celle que l'on observe aujourd'hui dans les fumerolles submergées actives de l'île de Vulcano, en Italie. Dans le complexe de Back River, cela correspondrait à un site d'accumulation locale de carbonates. Il est possible qu'en fournissant une source d'alimentation abondante pour la production de panaches d'activité bactérienne, un environnement caractérisé par la présence d'eau de mer chaude et d'émanations volcaniques ait favorisé la croissance de stromatolites.

Groupe de Beechey Lake

En général, les roches sédimentaires du Groupe de Beechey Lake reposent sur les séquences du complexe volcanique et les entourent complètement. À grande échelle, elles sont interdigitées avec les formations volcaniques dans la partie nord du complexe. À une échelle plus petite, elles sont interdigitées avec les roches volcanoclastiques qui forment des nappes sur les flancs des nombreux dômes de laves felsiques. En général, les séquences turbiditiques du Groupe de Beechey Lake reposent en concordance sur le complexe volcanique. S'il est vrai que le contact entre le Groupe de Back et le Groupe de Beechey Lake (le contact entre les roches volcaniques et sédimentaires) est localement cisaillé ou représente une zone de déformation intense, il n'y a pas lieu d'invoquer la présence d'une discordance générale entre les deux groupes.

Les roches sédimentaires du Groupe de Beechey Lake se composent surtout de turbidites à grauwacke-mudstone, de siltstone, de grès, de petites quantités de conglomérat, de shale graphitique (ou ardoise) et de lits riches en carbonates, ainsi que de formations de fer.

Les unités de grauwacke près du côté est du complexe volcanique sont des roches à texture peu évoluée qui sont riches en quartz et contiennent des clastes de types divers, notamment du quartz (cristaux euédriques à corrodés, structure polycristalline à grain fin d'origine volcanique, et structure polycristalline à grain grains probably of plutonic origin), feldspar (plagioclase, microcline, and perthite — probably from both volcanic and plutonic sources), and lithic fragments (including rhyolite-dacite, andesite, iron-formation, siltstone and mudstone, chert, plutonic rock fragments, and rare carbonate). Volcanic ash interbedded with the turbidite units establishes a temporal link between volcanism and deposition of the Beechey Lake turbidite sequence. Both the clast composition of turbidite beds and the limited paleocurrent data support the concept that much of the material within Beechey Lake Group immediately adjacent the volcanic complex was derived from the stratovolcano, whereas the turbidite units farther from the complex that show northwesterly paleocurrent directions were derived from a partly granitoid terrane to the southeast of the stratovolcano. A possible source terrane could be the Healey complex.

Iron-rich sedimentary sequences record chemical sedimentary events at times of volcanic quiescence following each eruptive cycle, and provide distinctive marker horizons that trace complex fold geometries within sedimentary rocks. Iron-rich strata that mark the close of Innerring volcanism (unit ĀBli) are sulphidic mudstone and siltstone, and no laminated iron-formation is represented.

Laminated iron-formation of unit ĀBLia, which occurs almost continuously around the southern portion of the volcanic complex, marks the end of Thlewycho and Boucher-Regan volcanism. This iron-formation lies conformably on carbonate-cemented volcaniclastic rocks at or near the contact between Back Group volcanic rocks and overlying turbidite-dominated strata of the Beechey Lake Group. The laminated iron-formation typically occurs within a stratigraphic sequence that is consistent around the eastern and southern sides of the complex as follows. 1) Carbonate-cemented volcanic breccia and grit, locally massive, oolitic or stromatolitic carbonate, is in some places interbedded with black chert. This is overlain by 2) laminated iron-formation, that varies from quartz-magnetite-, chert-jasper-carbonate-actinolite-tremolite-, magnetite-, to sulphide-chert-iron-formation that is interbedded with shale, chert, carbonate-rich iron-formation, volcaniclastic or carbonate-cemented arenite. This is followed by: 3) black, carbonaceous shale (slate) and argillite with pervasive finely disseminated pyrite and locally massive lenses and concretions of concentrically banded pyrite. Although the black shale units contain graphite, much of the carbon is probably in the amorphous state. Although shown as a single unit, the iron-formation comprises several laminated units interbedded with greywacke and mudstone.

East of Keish Lake, the iron-formation is a chert-jasper-siderite facies that does not show anomalous magnetic signature. Near Esker Lake, the iron-formation outlines a large syncline within Beechey Lake turbidite, and changes from intensely magnetic chert-

grossier probablement d'origine plutonique), du feldspath (plagioclase, microcline et perthite, probablement de sources volcaniques et plutoniques) et des fragments lithiques (notamment rhyolite-dacite, andésite, formation de fer, siltstone et mudstone, chert, fragments de roches plutoniques et, exceptionnellement, roches carbonatées). La présence de cendres volcaniques interstratifiées dans les unités turbiditiques permet d'établir une relation temporelle entre le volcanisme et la sédimentation de la séquence turbiditique de Beechey Lake. La composition des clastes dans les lits turbiditiques et les données limitées sur les paléocourants portent à croire qu'une bonne partie des matériaux du Groupe de Beechey Lake directement attenants au complexe volcanique sont dérivés du stratovolcan, alors que les unités turbiditiques qui sont plus éloignées du complexe et dont les directions des paléocourants sont nord-ouest, sont dérivées d'un terrane de composition en partie granitoïde qui était situé au sud-est du stratovolcan. Le complexe de Healy serait une source possible de ces matériaux.

Des séquences sédimentaires riches en fer témoignent de changements survenus dans la composition chimique du milieu de sédimentation durant les périodes de repos volcanique à la fin de chaque cycle éruptif. Elles servent également d'horizons repères permettant d'éclaircir la géométrie complexe des plis dans les roches sédimentaires. Les strates riches en fer qui marquent la fin du volcanisme associé à la séquence d'Innerring (unité ĀBli) sont des mudstones et des siltstones sulfurés; elles ne comprennent aucune formation de fer laminée.

La formation de fer laminée de l'unité ĀBLia, qui contourne de façon presque continue la portion sud du complexe volcanique, signale la fin du volcanisme associé aux séquences de Thlewycho et de Boucher-Regan. Elle repose en concordance sur des roches volcanoclastiques à ciment carbonaté au contact entre les roches volcaniques du Groupe de Back et les séquences sus-jacentes à prédominance turbiditique du Groupe de Beechey Lake, ou à proximité de ce contact. Elle se rencontre typiquement dans une séquence stratigraphique que l'on retrouve des côtés est et sud du complexe volcanique et qui comporte les roches suivantes, présentées en ordre ascendant : (1) des brèches et des grès grossiers volcaniques à ciment carbonaté, et des roches carbonatées oolitiques et stromatolitiques localement massifs avec, par endroits, du chert noir interlité; (2) une formation de fer laminée allant d'une formation de fer à quartz et magnétite, à chert, jaspe, carbonate, actinote et trémolite ou à magnétite à une formation de fer à sulfures et chert interlitée avec du shale, du chert, de la formation de fer riche en carbonates et de l'arénite volcanoclastique ou à ciment carbonaté; (3) du shale noir carboné (ardoise) et de l'argilite contenant de la pyrite finement disséminée répandue et des concrétion et lentilles localement massives de pyrite en bandes concentriques. Les unités de shale noir contiennent du graphite, mais le carbone est probablement en majeure partie à l'état amorphe. Bien qu'elle soit représentée comme unité unique sur la carte, la formation de fer comprend plusieurs unités laminées qui sont interstratifiées avec du grauwacke et du mudstone.

À l'est du lac Keish, la formation de fer est un faciès à chert, jaspe et sidérite qui ne présente aucune signature magnétique anomale. Près du lac Esker, la formation de fer permet de délimiter un important synclinal dans les unités turbiditiques de Beechey Lake; elle passe d'un faciès à sulfures et magnétite fortement magnetite facies on the north side of the lake to sulphide-silicate facies (hornblende-garnet-pyrrhotite) (with subdued magnetic expression) containing chert nodules on the south side.

Although the iron-formation is designated as two units, ĀBLib may be a distal facies of unit ĀBLia that is buried within turbidite.

Structural geology

The dominant regional structures of the map area include a dome, about 15 km by 25 km across, centred on the southern half of the volcanic complex (south of Outerring Lake), and two doubly plunging anticlinoria and an intervening synclinorium, that arc northward across the northern half of the area from Back River in the east, to near Keish Lake in the west.

Although deformation has affected all units, its expression is much less intense in volcanic units than in sedimentary rocks of the surrounding Beechey Lake Group. In much of the dome, for example, deformation is weak, rocks generally lack foliation, and volcanic structures and textures are essentially in a pristine state. On the southeastern side of the dome, the gentle attitudes of mildly deformed volcanic units persist right up to the volcanic-sedimentary contact, where they change abruptly to the ubiquitous steep attitudes in highly deformed metasedimentary rocks. This contrasting style of deformation suggests that the volcanic rocks were rheologically more competent than the sedimentary rocks. Disharmonic folding occurs on all scales, and results in tightly folded metasedimentary rocks against or between open, folded volcanic rocks.

Three generations of regional deformation (D_1, D_2, and D_3) have affected the volcanic complex and surrounding metaturbidite units of the Beechey Lake Group: D_1 produced open, regional warps to upright isoclinal F_1 folds that have varied orientation; D_2 produced open warps to tight marginal folding of the volcanic complex, tight to isoclinal F_2 similar folds in the turbidite, which have a well developed axial-planar cleavage (S_2) that overprints F_1 structures, and local zones of high strain; and D_3 produced moderately to steeply plunging, open F_3 folds that trend approximately east.

The variable degrees of deformation and contrasting patterns of deformation, within both the volcanic complex and the surrounding Beechey Lake Group, suggest that paleotopography of the relict volcanic pile played a significant role in defining the structural patterns. Stratigraphy indicates that the thickest part of the volcanic pile (interpreted as the main volcanic mass and/or edifice) corresponds to the present regional

magnétique, du côté nord du lac, à un faciès à sulfures et silicates (hornblende, grenat et pyrrhotite) dont le magnétisme est atténué et qui contient des nodules de chert, du côté sud du lac.

Bien que la formation de fer soit divisée en deux unités, l'unité ĀBLib pourrait correspondre à un faciès distal de l'unité ĀBLia, laquelle est enfouie dans des turbidites.

Géologie structurale

Dans la région cartographique, les structures les plus importantes à l'échelle régionale comprennent un dôme d'environ 15 km sur 25 km, dont le centre est situé dans la moitié sud du complexe volcanique (au sud du lac Outerring), et deux anticlinoriums à double plongement séparés par un synclinorium qui sont courbés vers le nord dans la moitié nord de la région, depuis la rivière Back, à l'est, jusqu'à près du lac Keish, à l'ouest.

Bien que toutes les unités soit déformées, cette déformation est beaucoup moins intense dans les unités volcaniques que dans les roches sédimentaires du groupe avoisinant de Beechey Lake. Dans une grande partie du dôme, par exemple, la déformation est faible, les roches n'ont généralement aucune foliation et les textures et structures volcaniques sont essentiellement intactes. Sur le côté sud-est du dôme, le faible pendage des unités volcaniques peu déformées se maintient jusqu'au contact de ces unités avec les roches sédimentaires. Ce contact marque le passage brusque à un pendage très incliné dans des roches métasédimentaires fortement déformées. Cette différence dans le style de déformation s'explique par une différence dans le comportement rhéologique des roches, les unités volcaniques étant plus compétentes que les roches sédimentaires. Un plissement disharmonique, observé à toutes les échelles, a produit des plis serrés dans les roches métasédimentaires, lesquelles sont insérées entre des volcanites à plis ouverts, ou juxtaposées à ces volcanites.

Trois phases de déformation régionale (D_1, D_2 et D_3) sont reconnues dans le complexe volcanique et les séquences métaturbiditiques avoisinantes du Groupe de Beechey Lake. La déformation D_1 a engendré des plis allant de gauchissements régionaux ouverts à des plis isoclinaux droits F_1 à orientations diverses. La déformation D_2 a produit des plis allant de gauchissements ouverts à des plis serrés à isolinaux F_2 dans les roches volcaniques le long des marges du complexe, des plis semblables serrés à isoclinaux F_2 dans la turbidite lesquels présentent une schistosité de plan axial (S_2) bien développée qui se superpose aux structures F_1, de même que des zones locales de forte déformation. La déformation D_3 a produit des plis ouverts F_3 à plongement modéré à raide et de direction approximativement est.

La variation dans l'intensité et le style de la déformation, tant au sein du complexe volcanique que dans le groupe avoisinant de Beechey Lake, suggère que la paléotopographie de l'édifice volcanique résiduel a joué un rôle considérable dans l'établissement de la géométrie structurale. Les données stratigraphiques révèlent que la portion la plus épaisse de l'édifice volcanique (que l'on interprète comme étant la masse ou l'édifice volcanique principal) coïncide avec l'actuel dôme régional, que dome, that the pile thinned northward, and that there likely was a secondary topographic high over the Quartermoon Lake rhyolite dome.

Although the southern complex was deformed by all periods of folding, several features suggest that the volcanic core controlled structural patterns and that the present dome is not simply a culmination of intersecting regional folds: 1) the abrupt deflection of fold structures that trend perpendicular to the volcanic complex, into near parallelism with the eastern margin; 2) the tightening of F_1 and F_2 fold structures into parallelism with the western side of the dome; 3) the verging of folded volcanic and sedimentary rocks toward the dome on the northern and western sides; and 4) the marked contrast in strain between the highly deformed turbidite sequences and the mildly deformed massive volcanic units of the dome.

The gross regional pattern was established possibly during the first episode of deformation that produced westerly to west-northwesterly trending, open, regional warps, and on a smaller scale, shallow-plunging, tight, upright folds. These horizontal to shallow-plunging folds may have produced the ubiquitous steep dips of the Beechey Lake Group strata. The deformation progressively warped open folds around and over the irregular topography of the remnant volcanic complex, folded thin flank successions, and probably steepened margins of the thick main edifice.

The second period of deformation: 1) arched early F_1 anticlinoria and synclinoria and parts of the main edifice; 2) refolded and tightened F_1 folds in the Beechey Lake Group against the core volcanic edifice while steepening the western side of the dome and folding its margins; and 3) refolded shallowly to moderately plunging, tight F_1 folds about steeply plunging F_2 axes to produce complex interference geometries. During deformation, strain partitioned along the margin of the volcanic complex to develop localized, high-strain zones within the metavolcanic rocks and immediately overlying metasedimentary rocks.

D_3 produced open folds that warped the margin of the southern complex and steepened plunges of F_2 folds about westerly to northwesterly trending axes.

Thus, the present southern part of the map area is a large dome formed by superposition of regional strain on the core volcanic edifice. The remnant volcanic edifice was partially deformed, but essentially behaved as a competent core (buttress), around which relatively incompetent sedimentary rocks and the northern parts of the complex folded.

l'épaisseur de l'édifice volcanique diminuait vers le nord et qu'il existait vraisemblablement une deuxième hauteur au-dessus du dôme rhyolitique du lac Quartermoon.

Bien que toutes les phases de plissement aient déformé le complexe du sud, les éléments suivants laissent supposer que le noyau de l'édifice volcanique a contrôlé la géométrie structurale et que le dôme actuel ne représente pas une simple culmination résultant d'un croisement entre des plis régionaux : (1) une déviation nette dans la direction des plis, laquelle passe de perpendiculaire au complexe volcanique à presque parallèle à la marge est du complexe; (2) un serrement des plis F_1 and F_2, lesquels deviennent parallèles au côté ouest du dôme; (3) la vergence vers le dôme des plis dans les roches volcaniques et sédimentaires des côtés nord et ouest du dôme; et (4) le contraste marqué entre les séquences de turbidites fortement déformées et les unités volcaniques massives légèrement déformées dans le dôme.

La géométrie régionale générale aurait été établie durant le premier épisode de déformation qui a produit des gauchissements régionaux ouverts, à direction ouest à ouest-nord-ouest, et, à plus petite échelle, des plis droits serrés, à plongement faible. Ces plis horizontaux ou à plongement faible pourraient être à l'origine des pendages raides retrouvés partout dans les strates du Groupe de Beechey Lake. La déformation a progressivement gauchi et rabattu les plis ouverts autour de la masse irrégulière du complexe volcanique résiduel, plissé les séquences minces qui reposaient sur les flancs du complexe et redressé les marges de l'épais édifice principal.

La deuxième phase de déformation a provoqué les phénomènes suivants : (1) le fléchissement des premiers anticlinoriums et synclinoriums F_1 et de certaines parties de l'édifice principal; (2) la reprise et l'intensification des plis F_1 dans le Groupe de Beechey Lake, le rabattement de ces plis autour de l'édifice volcanique principal, le redressement du flanc ouest du dôme et le plissement de la bordure de celui-ci; et (3) la reprise de plis serrés F_1 à plongement faible ou modéré autour de plis F_2 à plongement raide, ce qui a produit une géométrie d'interférence complexe. Durant cette phase, il y a eu partition de la déformation le long de la marge de l'édifice volcanique, ce qui a produit des zones localisées à haute déformation dans les roches métavolcaniques de même que dans les roches métasédimentaires sus-jacentes.

La déformation D_3 a produit des plis ouverts qui ont engendré le gauchissement de la marge du complexe du sud et accentué le plongement des plis F_2 autour d'axes de direction ouest à nord-ouest.

Ainsi, la partie sud de la région cartographique est actuellement un large dôme attribué à l'effet d'une déformation régionale sur l'édifice volcanique principal. Les vestiges de cet édifice volcanique ont été partiellement déformés, tout en se comportant essentiellement comme un noyau compétent (contrefort) autour duquel des roches sédimentaires relativement incompétentes et les unités de la partie nord du complexe volcanique ont été plissées.

Interpretive summary and evolution of the Back River volcanic complex

The Back River volcanic complex is the product of three successive cycles of mafic (or intermediate) to felsic volcanism, represented by the Innerring, Thlewycho, and Boucher-Regan sequences. These sequences accumulated during the late Archean to form a major composite stratovolcano in a depositional basin, represented by the Beechey Lake Group of the Yellowknife Supergroup in the northeastern Slave Province. The dominance of intermediate and felsic volcanic rock compositions, not only in the Back Group, but also in the Hackett River and High Lake volcanic belts to the north, and enormous swarms of granitic plutons, suggests that the Late Archean was a time of high-level intrusion of salic, calc-alkaline magma in the northeastern Slave Province.

The following account summarizes interpretations contained herein, and speculates on the volcanic phenomena and resulting landforms that probably developed during the evolution of the stratovolcano.

Although the base of this volcanic pile is not exposed, presumably the earliest eruptions were submarine effusions of mafic to intermediate lava on the sea floor. Lava probably accumulated to form a subaqueous shield that eventually emerged above sea level. Subaerial effusion of andesitic lava and explosive eruption of andesitic ash-flow tuffs formed the oldest deposits exposed in the present volcanic complex. The presently exposed Innerring sequence represents only the upper subaerial parts, and probably only a fraction of the total volume, of this early phase of the volcano.

Regional tumescence above a high-level magma chamber may have distended the shield and generated concentric and possibly radial fractures; the generation of ring- and radial-fracture systems, resulting from upward push due to increased magma pressure, has been proposed from experimental and theoretical studies. Explosive eruption of gas-charged magma from such fractures erupted as a succession of andesitic to dacitic pyroclastic flows that spread out on the eastern, southern, and western slopes of the emergent volcano, while quiet effusion of thick dacite lava flows took place on north-central slopes. Such eruptions probably destroyed parts of the central cone that may have existed during the earlier andesitic effusions. Between flows, streams locally deposited fluvial gravel and sand on the slopes of the volcano, and clastic fans started to accumulate in shallow, northern flanks of the volcano. Ash-flow tuffs that entered the sea, and water-laid air-fall ash deposited ash beds within clastic aprons that were developing by erosion from the Innerring edifice.

Sommaire et interprétation de l'évolution du complexe volcanique de Back River

Le complexe volcanique de Back River est le produit de trois cycles successifs de volcanisme mafique (ou intermédiaire) à felsique, que représentent les séquences d'Innerring, de Thlewycho et de Boucher-Regan. Ces séquences se sont accumulées à l'Archéen tardif et ont formé un imposnat stratovolcan situé dans un bassin sédimentaire représenté par le Groupe de Beechey Lake du Supergroupe de Yellowknife, dans le nord-est de la Province des Esclaves. La prédominance de roches volcaniques de composition intermédiaire à felsique, aussi bien dans le Groupe de Back que dans les ceintures volcaniques de Hackett River et de High Lake, au nord, et la présence d'énormes plutons granitiques suggèrent que, durant l'Archéen tardif, le nord-est de la Province des Esclaves était le théâtre de l'intrusion massive, à faible profondeur, de magma salique calco-alcalin.

Les paragraphes suivants résument les interprétations présentées dans cet article et les conjectures quant aux phénomènes volcaniques qui ont produit le stratovolcan et aux formes de relief qui ont été façonnées au cours de son évolution.

Même si la base de l'édifice volcanique n'est pas exposée, il nous est permis de supposer que les premières éruptions étaient des épanchements de laves mafiques à intermédiaires sur un fond océanique. Les laves se sont probablement accumulées pour former un volcan-bouclier subaquatique, lequel a éventuellement émergé de la mer. L'épanchement de laves andésitiques en milieu subaérien et l'éruption explosive de tufs pyroclastiques andésitiques ont produit les plus anciens dépôts exposés dans le complexe volcanique actuel. La séquence d'Innerring, telle qu'elle apparaît aujourd'hui, ne représente que la partie supérieure du volcanisme subaérien et vraisemblablement qu'une fraction du volume total de roches produites durant cette première phase volcanique.

Une intumescence régionale au-dessus d'une chambre magmatique à faible profondeur a pu provoquer la distension du volcan-bouclier, ce qui aurait alors entraîné la formation de fractures concentriques et, possiblement, de fractures radiales (la formation de réseaux de failles circulaires et radiales sous l'action d'une poussée verticale, causée par l'accroissement de la pression dans la chambre magmatique, est un mécanisme qui a été proposé en s'inspirant d'études expérimentales et théoriques). L'éruption explosive de magma saturé en gaz depuis ces fractures a produit une succession de coulées pyroclastiques, de composition andésitique à dacitique, sur les flancs est, sud et ouest du volcan émergent, alors qu'il y a eu épanchement relativement calme d'épaisses coulées de laves dacitiques sur les pentes du centre nord. De telles éruptions ont probablement occasionné la destruction d'une partie du cône central qui existait peut-être durant la phase de volcanisme andésitique antérieure. Entre les épisodes d'éruption, des cours d'eau ont déposé du gravier et du sable fluviatiles par endroits sur les flancs du volcan, alors que des cônes de matériaux clastiques commençaient à s'accumuler en eau peu profonde sur les flancs nord du volcan. Des tufs pyroclastiques accumulés en mer et des cendres retombées déposées en milieu aquatique ont formé des lits de cendres au sein de nappes de matériaux clastiques qui se formaient par suite de l'érosion de l'édifice volcanique d'Innerring.

Rapid evacuation of the upper part of the magma chamber by the previous eruptions was followed by caldera collapse on the northern portions of the volcano. This was an asymmetrical, 'trap door' type of caldera in which maximum subsidence occurred on the northern side, and diminished southward. Subsidence probably began before the previous volcanic activity ceased, such that rhyolite magma continued to rise along bounding ring fractures and escaped at the surface as lava domes — the last of Innerring volcanism. Rock falls avalanched down from growing caldera walls and from unstable rhyolite domes, and combined with fluvial activity to produce debris-avalanche material and conglomerate. During the waning phases of explosive activity, erosion and mass wasting from the Innerring edifice formed a broad clastic apron on the northwestern side of the volcano. Sand, silt, and mud accumulated on shores and shallow flanks of the volcano, and fumarolic activity associated with late-stage felsic domes may have contributed sulphide to mud and silt. As the apron emerged above sea level, the main deposits of mass wasting were thick, massive debris flows and lahars.

The Thlewycho sequence volcanism began with major effusion of porphyritic andesite lavas on the southeastern, western, and northwestern, shallow submarine margins of the Innerring volcano. The rapidly growing pile emerged above sea level where the eruptive sequence varied from several cycles of lava effusions interrupted by extensive volcaniclastic deposits on the present northern flanks, to rapid effusion of about 30 subaerial lava flows on the eastern side.

The main effusions of lavas were followed by explosive eruptions that produced voluminous, andesitic pyroclastic flows that spread across much of the southern and northeastern slopes of the volcano, and beyond the main edifice onto the northern flanks. On the northern side of the volcano, composition of the explosive eruptions changed from andesitic to dacitic pyroclastic flow and lavas, while isolated dacitic lavas effused on the southern parts of the edifice. With the addition of these voluminous lavas and tuffs, the volcanic island grew upwards and outwards.

Thlewycho sequence volcanism ended with effusion of a series of rhyolitic flows and dome complexes around the periphery of the volcanic edifice, and a large rhyolite body intruded parallel to ring fractures associated with Innerring volcanism. Assuming that rhyolite domes mark local eruptive centres, the locus of these bodies may outline a second ring-fracture system. Partial destruction of the domes by explosion, autoclastic fragmentation, gravity collapse, mass wasting, and erosion produced aprons of coarse breccia and felsic volcaniclastic detritus that interfingered with turbidite sequences in the adjacent sea.

L'évacuation rapide de la partie supérieure de la chambre magmatique par les éruptions antérieures a été suivie par la formation d'une caldeira dans la partie nord du volcan. La subsidence était maximale du côté nord de la caldeira et diminuait vers le sud, de sorte que l'affaissement de la caldeira s'est effectué de façon asymétrique, suivant un mécanisme de type « charnière ». La subsidence a probablement débuté avant la fin de la période d'activité volcanique qui la précédait, de sorte que le magma rhyolitique a pu poursuivre son ascension le long des failles circulaires et atteindre la surface sous forme de dômes éruptifs — la phase terminale du volcanisme associé à la séquence d'Innerring. Ensemble, des chutes de pierres provenant des parois de la caldeira en édification et des dômes de rhyolite instables et l'activité fluviatile ont formé des dépôts d'avalanches de débris et des conglomérats. Durant les dernières phases du volcanisme explosif, l'érosion et les mouvements de masse provenant de l'édifice volcanique d'Innerring ont engendré une vaste nappe de matériaux clastiques sur le côté nord-ouest du volcan. Des sables, des silts et des boues se sont accumulés sur les flancs en eau peu profonde et les rives du volcan; l'activité fumerolienne associée à des dômes felsiques de la phase tardive aurait contribué un apport en sulfures aux boues et aux silts. Au moment où la surface de la nappe a émergé, les dépôts principaux résultant des mouvements de masse étaient constitués de coulées de débris et de lahars épais.

L'activité volcanique à l'origine de la séquence de Thlewycho a débuté avec l'épanchement majeur de laves andésitiques porphyriques sur les flancs en eau peu profonde des côtés sud-est, ouest et nord-ouest du volcan de l'Innerring. L'édifice volcanique en croissance rapide a émergé de la mer; la séquence éruptive a passé de plusieurs cycles d'épanchement de laves interrompus par de vastes dépôts volcanoclastiques, sur les flancs nords actuels du volcan, à l'épanchement rapide en milieu subaérien d'une trentaine de coulées de laves, sur le flanc est.

Les phases principales d'épanchement de laves ont été suivies d'éruptions explosives qui ont produit d'abondantes coulées pyroclastiques andésitiques, lesquelles se sont répandues sur la plus grande partie des flancs sud et nord-est du volcan et au-delà de l'édifice volcanique principal jusque sur les flancs nord. Du côté nord du volcan, la composition des laves et des coulées pyroclastiques des éruptions explosives a passé d'andésitique à dacitique alors qu'au sud, il y a eu épanchement de laves dacitiques isolées. Cet apport considérable de laves et de tufs a permis à l'île volcanique de gagner en élévation et en étendue.

Le volcanisme qui a engendré la séquence de Thlewycho s'est terminé avec l'extrusion d'une série de coulées de laves rhyolitiques et de complexes de dômes rhyolitiques à la périphérie de l'édifice volcanique, et l'intrusion d'un important massif rhyolitique parallèlement à des failles circulaires associées au volcanisme de la séquence d'Innerring. En supposant que les dômes rhyolitiques représentent l'emplacement de centres éruptifs locaux, ils pourraient délimiter un deuxième système de failles circulaires. La destruction partielle des dômes par volcanisme explosif, fragmentation autoclastique, effondrement, mouvement de masse et érosion est à l'origine des nappes de brèches grossières et de débris volcanoclastiques felsiques qui se sont interdigités avec des séquences turbiditiques dans la mer adjacente.

On the submerged northern flanks of the stratovolcano, tholeiitic mafic magma of Boucher-Regan sequence volcanism effused from submarine fissures to form an extensive field or domal ridge of pillowed lava flows, hyaloclastite, and associated breccia. This signifies a change of magma source from differentiating, high-level, crustal calc-alkaline magma chambers to deeper, mantle-derived tholeiitic sources.

Lava spread southwards, or erupted from other vents, and lapped onto the northern margin of the emergent Thlewycho edifice, or erupted as isolated, monogenetic eruptions to form discrete flows on the eastern and western sides of the stratovolcano. Sills intruded the accumulating major basaltic pile (and parts of the Thlewycho sequence and the Beechy Lake turbidite sequences), probably forming subsurface lava tubes that surfaced as flows.

Volcanism of the Boucher-Regan sequence was more bimodal than the Innerring and Thlewycho sequences. The voluminous mafic volcanism was followed by minor eruptions of dacitic tuffs, then by the eruption of numerous rhyolite to dacite felsic domes and flows. The felsic domes intruded portions of the basaltic pile to form the major Quartermoon Lake dome complex and a series of volcanic mounds around the northern and western margins of the volcanic complex and within the adjacent sedimentary basin. Although some may never have emerged above sea level, others were emergent domes that probably formed ephemeral islands. These emergent domes were partly reduced by mass wasting to from banks of debris, talus, conglomerate, and rudaceous sand on their flanks. Minor explosions associated with these domes deposited crystal-rich ash beds within the adjacent turbidite deposits. The general lack of sediments between Boucher-Regan and Thlewycho sequence units, suggests that Boucher-Regan volcanism followed immediately after, or possibly was synchronous with, the late stages of Thlewycho volcanism.

On the northern and western flanks of the stratovolcano there was a complicated interplay of volcanic and sedimentary processes during the waning stages of volcanism. The numerous felsic domes of the Boucher-Regan sequence represent the last major eruptive events of the volcanic complex. Degradation of the volcanic edifice was taking place by landsliding, avalanching, lahars, and fluvial erosion to form enormous debris-avalanche deposits, scree, and finer volcanic detritus, and a broad volcaniclastic fan along the western sides of the complex. Elsewhere, tuffs, rhyolite-derived turbidite, debris flows, and clastic fans, which interfinger with Beechy Lake turbidite deposits, indicate erosion from the still-active and emergent volcano while turbidite units were being deposited in the immediately adjacent sea. Debris-avalanche deposits and

Sur les flancs nord submergés du stratovolcan, du magma mafique tholéiitique associé au volcanisme qui a produit la séquence de Boucher-Regan s'est épanché depuis des fissures sous-marines pour former un vaste champ ou crête en dôme constitué de coulées de laves en coussins, de hyaloclastites et de brèches associées. Celà signale un changement dans la source de magma : de chambres magmatiques de niveau élevé d'origine crustale contenant du magma calco-alcalin différencié, on passe à une source profonde de composition tholéiitique et d'origine mantellique.

Les laves se sont répandues vers le sud (ou se sont épanchées à partir d'autres évents) jusque sur la marge nord de l'édifice volcanique émergent associé à la séquence de Thlewycho, ou elles ont été émises lors d'éruptions monogéniques isolées pour former des coulées distinctes sur les côtés est et ouest du stratovolcan. Des filons ont percé cet important édifice basaltique en édification (ainsi que des parties de la séquence de Thlewycho et des séquences turbiditiques du Groupe de Beechey Lake) et ont probablement formé des tunnels sous-terrains grâce auxquels le magma à fait surface.

Le caractère bimodal du volcanisme associé à la séquence de Boucher-Regan était plus prononcé que celui du volcanisme associé aux séquences d'Innerring et de Thlewycho. Après avoir engendré un énorme volume de laves mafiques, l'activité volcanique a fait place à des éruptions mineures de tufs dacitiques, suivies de l'éruption de nombreux dômes et de nombreuses coulées de composition rhyolitique à dacitique. Par endroits, les dômes felsiques ont pénétré l'édifice basaltique, formant ainsi l'important complexe du lac Quartermoon et une série de monticules volcaniques autour des marges nord et ouest du complexe volcanique et dans le bassin sédimentaire avoisinant. En atteignant le niveau de la mer, un certain nombre de ces intrusions auraient probablement formé des îles éphémères, que des mouvements de masse auraient ensuite partiellement réduit à l'état d'amas de débris, d'éboulis, de conglomérats et de sables grossiers déposés sur leurs flancs. Un volcanisme explosif de faible envergure associé à ces dômes a déposé des lits de cendres riches en cristaux au sein des dépôts turbiditiques avoisinants. L'absence générale de sédiments entre les unités des séquences de Boucher-Regan et de Thlewycho laisse penser que le volcanisme associé à la séquence de Boucher-Regan a eu lieu immédiatement après, ou peut-être même durant, les phases finales du volcanisme associé à la séquence de Thlewycho.

Sur les flancs nord et ouest du stratovolcan, il y a eu interaction complexe entre le volcanisme et les processus de sédimentation au cours des phases ultimes de l'activité volcanique. Les nombreux dômes felsiques de la séquence de Boucher-Regan représentent les dernières phases éruptives majeures dans l'évolution du complexe volcanique. La destruction de l'édifice volcanique, sous l'action de glissements de terrain, d'avalanches, de lahars et de l'érosion fluviale, est à l'origine d'énormes dépôts d'avalanches de débris, de cailloutis et de débris volcaniques plus fins, de même que d'un vaste cône volcanoclastique, le long de la marge ouest du complexe. Ailleurs, la présence de tufs, de turbidites dérivées de rhyolites, de coulées de débris et de cônes de matériaux clastiques, interdigités avec les turbidites du Groupe de Beechey Lake, indique que l'érosion du volcan se produisait alors que celui-ci était encore actif et en stade d'émergence et que les unités turbiditiques s'accumulaient dans la mer adjacente. Des avalanches de débris et des lahars

lahars carried coarse detritus for distances up to 5 km from the Quartermoon Lake dome and contributed thick, voluminous breccia units to the Keish Lake clastic fan that was developing on the western sides of the volcanic complex.

Carbonate production in the Back River complex probably resulted from interaction of lava flows with sea water, supplemented by hydrothermal systems (?fumaroles) related to local felsic centres. Within this environment, stromatolites developed on the flanks of felsic dome-flow complexes that erupted on shores around the partly emergent stratovolcano. Similarly volcanic fumaroles debouching onto the sea floor may have precipitated pyrite and pyrrhotite in the H_2S^--rich environment (low fO_2, acid to neutral pH) to form sulphide-rich iron-formation.

Stromatolites preserved in carbonate along the shallow margins of the volcano record that life flourished during the waning stages of this Archean stratovolcano. The overlying sulphidic iron-rich mudstone-siltstone sequences and laminated iron-formation mark the end of volcanism. These units lapped onto the shallow flanks of the volcano and extended out into the adjacent basin.

The present level of erosion and low topographic relief exposes only a thin slice though this deformed, very complex compound stratovolcano. As such, the precise form or elevation of the primary volcanic edifice will never be known. The present stratigraphy, however, is interpreted to indicate that the southern half of the complex is a section through the thickest part of the main volcanic edifice; possibly there was a secondary area of high relief over the Quartermoon Lake dome, and was a submarine ridge off the northern side of the stratovolcano. Although it is easy to assume that Beechy Lake sediments completely covered this major emergent volcanic edifice, there is no evidence to suggest that this was the case, nor is there evidence for any major stratigraphic or structural unconformity between the Beechy Lake Group and the Back Group. At the present level of erosion, rocks of the volcanic complex interfinger with surrounding turbidite.

Three generations of folding have deformed the volcanic complex and the surrounding metaturbidite of the Beechy Lake Group. The marked contrast in style of deformation between the weakly deformed southern half of the volcanic complex and the highly deformed surrounding metasedimentary rocks is interpreted to indicate that the volcanic edifice behaved as a competent mass around which relatively incompetent sedimentary rocks folded. This disharmonic folding produced tightly folded metasedimentary rocks in contact with more open, folded volcanic sequences. During deformation, strain partitioned along parts of the margin of the volcanic complex to develop localized, high-strain zones within the metavolcanic and immediately overlying metasedimentary rocks. Thus

ont charrié des débris grossiers sur jusqu'à 5 km depuis le dôme du lac Quartermoon; ils ont fourni un volume considérable de brèches au cône volcanoclastique du lac Keish qui se formait du côté ouest du complexe volcanique.

La production de carbonates dans le complexe de Back River a probablement été le résultat de l'interaction entre les coulées de laves et l'eau de mer, avec un apport supplémentaire provenant de systèmes hydrothermaux (possiblement des fumerolles) apparentés à des sites localisés de volcanisme felsique. Ce milieu était propice au développement de stromatolites sur les flancs des complexes de dômes-coulées felsiques, lesquels s'épanchaient sur les rives du stratovolcan partiellement émergé. Dans cet environnement riche en H_2S^- (fO_2 peu élevée, pH acide à neutre), il est possible que des fumerolles sur le fond océanique, associées au volcanisme, aient favorisé la précipitation de la pyrite et de la pyrrhotite pour former des formations de fer riches en sulfures.

Des stromatolites, préservés dans des carbonates sur les marges peu profondes du volcan, témoignent d'une vie florissante durant les phases ultimes de ce stratovolcan archéen. Les séquences sus-jacentes de mudstones et de siltstones sulfurés riches en fer et de formations de fer laminées marquent la fin du volcanisme. Ces unités ont formé un biseau d'aggradation sur les marges peu profondes du volcan et se sont étalées dans le bassin adjacent.

Le niveau d'érosion actuel et le relief peu accidenté ne laissent entrevoir qu'une mince section de ce stratovolcan déformé très complexe. Nous ne connaîtrons donc jamais la forme exacte et la hauteur de l'édifice principal. Toutefois, une analyse de la stratigraphie actuelle de ce complexe révèle que la moitié sud du complexe représente la partie la plus épaisse de l'édifice volcanique principal. Il est possible qu'une deuxième hauteur se soit élevée au-dessus du dôme du lac Quatermoon et qu'une crête sous-marine ait existé au large du flanc nord du stratovolcan. Bien que l'on puisse supposer que cet important édifice volcanique émergent était entièrement recouvert par les sédiments du Groupe de Beechey Lake, il n'existe aucun indice permettant de corroborer cette hypothèse ou de conclure à la présence d'une discordance érosionnelle ou angulaire majeure entre le Groupe de Beechey Lake et le Groupe de Back. En effet, au niveau d'érosion actuel, les roches du complexe volcanique sont interdigitées avec les turbidites avoisinantes.

Trois générations de plis ont repris le complexe volcanique et les métaturbidites du Groupe de Beechey Lake dont il est entouré. Le contraste marqué dans le style de déformation des roches volcaniques peu déformées de la moitié sud du complexe et des roches métasédimentaires avoisinantes fortement déformées laisse entendre que l'édifice volcanique s'est comporté comme un noyau rigide autour duquel des roches sédimentaires relativement incompétentes ont été plissées. Ce plissement disharmonique a produit des plis serrés dans les roches métasédimentaires, juxtaposés à des plis plus ouverts dans les séquences volcaniques. Le long de certains segments des marges du complexe, la déformation s'est fortement concentrée dans des zones localisées au sein des séquences métavolcaniques et des roches sédimentaires sus-jacentes. La partie sud de la région cartographique comporte the present southern part of the map area is a large structural dome formed by superposition of two major episodes of folding on the core volcanic edifice.

The major structural geometry of the Beechy Lake Group results mainly from two major deformations (D_1 and D_2), coupled with the buttressing effect of the rheologically competent Back Group. Refolding of shallowly to moderately plunging, tight F_1 folds by steeply plunging F_2 folds produced interference geometries ranging from mushroom to dome-and-basin geometries.

Regional deformation modified the primary volcanic edifice by steepening and folding strata along eastern and western margins, and producing regional F_1 and F_2 folds of the stratigraphically thinner northern flanks of the stratovolcano. D_3 produced open folds that steepened plunges of F_2 folds about westerly to northwesterly trending axes. At the present level of erosion, the southern half of the complex is an asymmetrical section through the main volcanic edifice.

Mapping of the Back River volcanic complex has resulted not only in the rare detailed documentation of an Archean stratovolcano, but also in establishing the physical environment where some of the earliest life forms developed: along the margins of active rhyolite lava domes that straddled the shoreline around this emergent volcano.

donc un vaste dôme structural, qui a été engendré par la superposition de deux épisodes majeurs de plissement sur l'édifice volcanique principal.

La géométrie structurale principale reconnue dans le Groupe de Beechey Lake est en majorité le produit de deux phases majeures de déformation (D_1 et D_2), combinées au rôle de contrefort joué par le groupe compétent de Back River. La reprise des plis serrés F_1, à plongement faible à modéré, par des plis F_2, à plongement raide, a entraîné la formation d'une géométrie d'interférence variant d'une structure en forme de champignon à une alternance de dômes et de bassins.

La déformation régionale a modifié l'édifice volcanique principal en redressant et en plissant les strates le long de ses marges est et ouest, et en provoquant la formation de plis régionaux F_1 et F_2 dans les flancs nord stratigraphiqument moins épais du stratovolcan. La phase D_3 a produit des plis ouverts qui ont accentué le plongement des plis F_2 autour d'axes de direction ouest à nord-ouest. Au niveau actuel d'érosion, la partie sud du complexe nous présente une coupe asymétrique de l'édifice volcanique principal.

La cartographie du complexe volcanique de Back River a permis la documentation détaillée peu commune d'un stratovolcan datant de l'Archéen. Elle a également contribué à mieux comprendre l'environnement physique dans lequel se sont développées certaines des formes de vie les plus anciennes : les marges de dômes rhyolitiques en activité qui chevauchaient la ligne de rivage autour de ce volcan émergent.

INTRODUCTION

Location and access

The Back River volcanic complex is a ca. 2.7 Ga stratovolcano, centred on 65°N and 108°E , about 480 km northeast of Yellowknife, Northwest Territories (inset on Map 2041A, on CD-ROM). Most parts of the complex are accessible by fixed-wing aircraft on floats, available for charter at Yellowknife.

The northward-flowing Back River, which provides excellent access to the eastern side of the volcanic complex, is navigable by boat, requiring only short portages around rapids and one waterfall about 5 km east of Jim Magrum Lake. Thlewycho, Rusty, and Outerring lakes provide good access to the southwestern and central parts of the volcanic complex and Regan, Fidler, and Boucher lakes provide access to the northern parts. From these waterways, all parts of the complex can be reached by foot. The lakes and rivers generally are free of ice by the end of June.

Physical features and glaciation

Physical features of this area are typical of the Precambrian shield with low relief, gently rolling hills, and ridges. The southern parts of the volcanic complex stands in glacially scoured relief about 100 m above the generally low-lying, surrounding sedimentary terrain.

Glacial deposits cover substantial parts of the volcanic complex between Rusty and Regan lakes. These mapped deposits include kames, eskers, and alluvial fans, that have a prominent southwesterly trend. Thick drift lobes occur on the southwest sides of drumlinoid ridges. Gravel benches and boulder trains near the southwestern shore of Fidler Lake are interpreted as Holocene raised beach deposits. Glacial overburden is sparse in the southern half of the complex where outcrop exposure ranges from 80–100% of the area. Because of the generally sparse overburden, poorly developed soil horizons, and lack of forest vegetation, the lithological units shown on the map are essentially areas of continuous outcrop.

Previous investigations

In 1834 Captain George Back led an expedition to reach the Arctic Ocean from Great Slave Lake by way of the "Thlewy - cho - dezeth" or Great Fish River, that was reported by a Chipewyan Indian. Back located the headwaters of "Thlewy - cho - dezeth" on August 29, 1834, and explored the river to its mouth in Chantry Inlet. Narratives of this historical expedition were written by Back (1836) and by Back's surgeon and naturalist, Richard King (King, 1836). When Back returned to England in 1835, he was awarded the gold medal of the Geographical Society, promoted to captain by the Admiralty, and the river that he explored was renamed in his honour. The name "Thlewycho" (derived from the original river name) is applied to the long lake on the western side of the volcanic complex. Two other lakes, Boucher and Keish, are named after members of James Anderson's 1855 expedition (Canadian Field-Naturalist, 1940, 1941) down the Back River in search of remnants of Sir John Franklin's expedition.

Geological observations made by Back include the presence of numerous "sand hills" (probably eskers), some slate, and "gneiss" near the headwaters of the Back River. He had no inkling that he was travelling around the remnants of a huge ancient volcano the footprint of which was the size of Mount Etna.

Previous regional mapping of parts of the volcanic complex by the Geological Survey of Canada, was undertaken by Barnes and Lord (1954), Fraser (1964), Wright (1967), Tremblay (1971), Frith (1987), and Henderson et al. (1999).

The volcanic complex has been a target for mineral exploration since 1961, when gold was first discovered along the shores of the Back River (Moore, 1977), and the area has attracted numerous canoe expeditions retracing Back's route, and people seeking adventure and solitude (Perkins, 1991).

Present investigations

This Archean volcanic complex was chosen for thorough documentation because of its exceptional outcrop exposure, low grade of metamorphism, and apparent low degree of deformation that was suggested by preliminary investigations of Baragar (1975) and Henderson (1975b). Present investigations involved detailed mapping of the volcanic complex at a scale of 1:25 000 during parts of nine field seasons between 1976 and 1995. Numerous publications from this work (Lambert, 1976, 1977, 1978, 1982a, b, 1996, 1998; Lambert et al., 1990, 1992; Jefferson et al., 1989) provided descriptions of rock units and outlined stratigraphy, structure, and interpretation of the volcanic complex at various stages of the mapping. As work progressed, map units have changed, sequences have been redefined, stratigraphic nomenclature has been revised, and preliminary interpretations have been refined or abandoned. The present map and bulletin provide a complete and revised compilation of the work; nomenclature, definition of stratigraphic sequences, and interpretations presented herein supercede all previously published versions.

Since all rocks of the volcanic complex are metamorphosed, the prefix 'meta' generally will be dropped (from metavolcanic, metabasalt, etc.) both in the text and on Map 2041A, in many places for simplicity.

Geological setting

The volcanic complex constitutes the Back Group (Frith and Percival, 1978) of the Yellowknife Supergroup (Henderson, 1970) in east-central Slave structural province. The Slave Province (inset on Map 2041A) contains deformed and metamorphosed supracrustal rocks of Archean age that occur between extensive complexes of granitic rocks. Supracrustal successions of the Yellowknife Supergroup comprise thick sequences of metamorphosed volcanic rocks (greenstone belts) that are generally overlain by greywacke-mudstone turbidite sequences derived from mixed felsic volcanic and granitic sources. Unlike many of the greenstone belts in the southern Slave Province, which contain dominantly thick, subaqueous mafic successions that are close to granitic basement, the Back River complex is dominantly an intermediate to felsic centre surrounded by turbidite sequences, and is not associated with Archean granitic basement. The complex is somewhat anomalous in the Slave Province because it has undergone only a low degree of metamorphism (generally greenschist grade, but locally up to lower amphibolite grade), and an apparent low degree of deformation. Although the volcanic complex has been subjected to at least three periods of regional deformation, the southern part of the complex is exposed in an elliptical zone of low strain at the crest of a broad structural dome. The regional setting of the Back River complex is well depicted by Henderson and others (1999).

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Dianne Paul and Deborah Lemkow prepared original figures and J. Tuffly initiated digitization of original hand-drawn maps. Dianne Paul worked with extraordinary dedication in transforming numerous hand-drawn and digital versions of the data into the present map.

The manuscript and map were critically reviewed by John Henderson and Sally Pehrsson. I particularly thank John Henderson is for his reviews of the many publications associated with the mapping, and for numerous thoughtful discussions and continual encouragement and support throughout the length of this project.

BACK GROUP

General stratigraphy

The volcanic complex (depicted in Map 2041A and in simplified geological map (Fig. 1, on CD-ROM) and stratigraphic sections) constitutes the Back Group of the Yellowknife Supergroup. Its diverse stratigraphy is divided into three volcanic sequences, namely, the Innerring, the Thlewycho, and the Boucher-Regan sequences. These sequences represent three successive cycles of mafic (or intermediate) to felsic volcanism and the growth stages of this large composite stratovolcano (Thorpe et al., 1982) and its related flank eruptions. Each cycle is followed by, or synchronous with, erosion and local mass wasting, producing aprons of volcaniclastic detritus and debris-avalanche deposits from various parts of the volcanic edifice. The complex and varied stratigraphy of the stratovolcano comprises mainly the calc-alkaline rock association (basalt-andesite-dacite rhyolite) with abundant products of subaerial explosive eruptions and lavas. The complex has many compositional and physical volcanic features that are similar to the highly complex volcanic edifices of the South American Andes, the High Cascades of northwestern United States, Mexico, Alaska, and other parts of the world (*see* Thorpe (1982) and papers therein). The entire complex is a composite (or compound) stratovolcano, that developed through a series of eruptions from numerous eruptive centres: it is not regarded as a simple strata cone. Thorpe et al. (1982) used the term ‘compound volcano’ to describe those volcanoes in which two or more morphological units can be recognized, and which generally lack radial symmetry; they are the most abundant type of central Andean composite volcano (for fundamentals of volcanic forms, structures, processes, and products *see* Fisher et al. (1997) and Francis (1993)).

The complex south of Outerring Lake (referred to hereafter as the ‘southern part of the complex’ or the ‘southern complex’) is preserved in a broad structural dome which exposes the thickest part of the volcanic ‘pile’. This part of the complex, which includes the Innerring sequence and most of the Thlewycho sequence, is considered to be the main part of the volcanic edifice. It is weakly deformed, and has upward-facing stratigraphy. Although the structural dome may be superimposed on the volcanic edifice, the centre of this dome is not necessarily an eruptive centre. The part of the complex north of Outerring Lake, including the rest of the Thlewycho sequence and the Boucher-Regan sequence, is considered to be the folded northern flanks of the stratovolcano.

The base of the volcanic complex is not exposed. Presumably the earliest eruptions were submarine effusions in a depositional basin where the volcano would eventually evolve. The oldest exposed rocks of the complex are andesite of the Innerring sequence (U-Pb zircon crystallization age of 2708 ± 0.8 Ma, reference locality 3, Fig. 1 (Villeneuve et al., 2001)). Because most eruptive units of the Innerring sequence have features consistent with subaerial deposition, this sequence probably represents only the upper parts of an early phase of the stratovolcano that had emerged above sea level. Volcanic arenite and rudite, and thin units of iron-rich shale and siltstone mark the end of the Innerring eruptive cycle and indicate erosion and marine sedimentation during a pause in eruption before the beginning of the next cycle of intermediate to felsic volcanism — the Thlewycho sequence.

The Thlewycho sequence represents the main constructional phase of the stratovolcano. In the southern complex, it forms an outward-dipping succession around the Innerring sequence. Its stratigraphy varies around the southern complex from 1) four cycles of lava effusion followed by deposition of volcaniclastic debris on the north side; to 2) effusion of about 30 subaerial, dominantly andesitic lava flows and a few intermittent pyroclastic and epivolcaniclastic units on the eastern side, to 3) interlayered dacitic and andesitic lavas and tuffs overlain by a thick succession of voluminous nonwelded ash-flow tuffs and volcaniclastic rocks around the southern sides. Volcanism in this sequence ended with eruption of large rhyolite-dacite dome and/or flow complexes from numerous centres around the periphery of the volcano. A dome related to this event, on the southeastern side of the stratovolcano, has been dated at 2692 ± 2 Ma (reference locality 16, Fig. 1) (van Breemen et al., 1987).

The Boucher-Regan sequence comprises dominantly basalt and andesite pillowed lavas and breccia (and minor, late-stage felsic lava domes) that effused mainly on the submerged northern flanks of the stratovolcano. These lavas and consanguineous sills overlie and intrude felsic lavas and volcaniclastic rocks of the Thlewycho sequence. The Boucher-Regan sequence not only represents the only major effusion of basalt of the volcanic complex, but also a fundamental change of magma composition from calc-alkaline (volcanism of the Innerring and Thlewycho sequences) to tholeiitic.

Volcaniclastic sediments, including a broad clastic fan on the northwestern side of the complex (herein referred to as the Keish Lake fan), local valley-filling debris, and rhyolite-derived turbidite sequences, represent erosion and mass wasting following the main construction phase of the stratovolcano.

Iron-formation (including magnetite-, sulphide-, and siderite-chert-iron-formation facies), oolitic and stromatolitic carbonate, sulphidic volcaniclastic rocks, and graphitic slate mark the end of constructive volcanism. Turbidite sedimentation (the Beechey Lake Group) in the surrounding basin was synchronous with, and continued after, volcanism.

Granitic plutons and several swarms of mafic dykes intrude the volcanic complex. Along the western side of the complex, volcanic units and Beechey Lake turbidite have been intruded by roughly northwesterly trending gabbroic dykes that have been folded and metamorphosed. A large east-trending gabbroic dyke, which intrudes the Boucher-Regan sequence northeast of Regan Lake, yields an U-Pb (zircon) age of 2586 ± 5 Ma that has been interpreted as the age of emplacement (Villeneuve et al., 2001). The relationship of this dyke to deformation has not been clearly established, but it is similar in age to ca. 2590 Ma granodiorite plutons (Frith and Loveridge, 1982) that intrude the northwestern part of the volcanic complex. The southern part of the volcanic complex is intruded by ca. 2616 Ma intrusions of the Tarantula quartz diorite (Henderson et al., 1999). The last igneous events are represented by three Proterozoic mafic dyke swarms: Malley diabase, Mackay diabase, and Mackenzie dykes.

Innerring sequence

Definition and distribution

The Innerring sequence occurs in a 10 km by 15 km, roughly elliptical area, exposed on the crest of the broad structural dome in the southern half of the volcanic complex. It comprises four volcanic units and volcaniclastic sedimentary rocks derived from them. The flat-lying to gently dipping volcanic units comprise lower andesite lavas and tuffs (unit ĀBIa), minor basalt and andesite pillowed lavas (unit ĀBIab), dacitic tuffs and lavas (unit ĀBIdp,f), to rhyolite domes and flows (unit ĀBIr). Epiclastic volcanic rocks (unit ĀBIe) form a moderately to steeply dipping clastic apron on the northwestern and western sides of the sequence and debris-avalanche deposits on the eastern side. Although the Innerring sequence covers a broad area, the thickness of exposed eruptive rocks is probably less than 1000 m.

An arcuate zone of brecciation and faulting around the northern and western sides of the Innerring dacite unit, is interpreted as a ring-fracture zone that marks the margin of a cauldron subsidence structure.

Lithology

Andesite and basalt

The oldest rocks of the volcanic complex are dominantly porphyritic andesite lavas, and minor andesitic volcaniclastic rocks that are exposed in the centre of the structural dome (unit ĀBIa).

The andesitic lavas have features of subaerial flows; they are massive, blocky to columnar-jointed, cliff-forming units with recessive-weathering flow breccia and minor volcaniclastic material marking flow boundaries (and lack pillowed forms, pillow breccia, and hyaloclastite typical of subaqueous flows). These lavas typically contain up to 25% plagioclase phenocrysts, 3–5 mm across. Volcaniclastic facies occur mainly in the southern parts of the unit. They are dark grey- to medium grey-green-weathering, plagioclase-crystal-rich rocks, having high mafic mineral content and abundant andesitic clasts (commonly 1–5 cm across) and blocks up to 15 cm. These massive units may contain crystal-lithic tuffs as well as epiclastic material.

Basalt to andesitic pillow lavas (unit ĀBIab) form only a single, thin, 4 km long basalt unit and a lens of plagioclase-phyric andesite pillow lava near the western margin of the Innerring sequence. The dark green-weathering basalt pillows have equant to elongate oval forms with well developed selvages. Contact between this basalt unit with the western side of the arcuate Innerring rhyolite is a fault (*see* 'Arcuate faults and breccia zone' below). Along the fault, basalt pillows are elongate, sheared, and strongly foliated.

These pillow lava units are interpreted to be distal, subaqueous stratigraphic equivalents of the Innerring andesite unit that are on the western side of a ring fault. The basalt unit is the only evidence for early mafic eruptions in a subaqueous environment in the Innerring sequence.

Dacite

Dacitic tuffs and lavas (unit ĀBIdp,f) conformably overlie the central andesitic lavas. This unit has the following general distribution of lithological types: the northern parts contain massive lava; the south and southwestern parts are dominantly ash-flow tuffs, crystal-lithic tuffs, and tuff breccia with dacite clasts, and minor lava. In the western and eastern parts, the physical types generally have not been differentiated, but the quartz- or quartz-plagioclase-phyric dacite units probably are mainly volcaniclastic rocks. Near the southwestern side of the unit, dacite is locally well bedded. The western side of the dacite unit is sheared and brecciated where it is overprinted by the ring-fracture breccia zone.

The lavas typically are massive, blocky-jointed to crudely columnar-jointed, cliff-forming units (Fig. 2a) with top- and bottom-flow breccia units that contain quartz, feldspar, and biotite phenocrysts up to 2 mm in a dark grey to dark green, aphanitic matrix. One homogeneous, single flow unit, more than 25 m thick, shows no lithological change except for slight variation in coarseness and autobrecciation at the top (Fig. 2b).

Ash-flow tuffs are massive, buff-, grey-, to pinkish-grey-weathering, crystal and lithic tuffs that locally contain flattened, cuspidate shards and pumice with preferred orientation that define eutaxitic foliation (flattening of pumice is interpreted as a primary feature since lithic clasts within the same rock are virtually undeformed). Air-fall tuffs form 1–20 cm thick, well sorted beds that have sharp to gradational contacts. Other unsorted, medium-bedded (to 50 cm thick) units carrying 10–20 cm dacite blocks in a green matrix, are probably of epiclastic origin. In the north-central parts of this unit, the massive ash-flow tuffs have a distinctive blocky fracture pattern (discernable on airphotos) that results in prominent tombstone-like, frost-heaved blocks in outcrop.

In the southern parts of the Innerring sequence, dacitic tuffs are distinguished from the underlying crystal-lithic-rich andesite volcaniclastic unit by being pale grey- to white-weathering, very fine-grained, crystal-poor quartz-bearing dacite units containing sparse, mainly dacite clasts. The very fine clastic texture and massive character of these dacitic rocks suggest that they are fine ash, ash-flow tuffs.

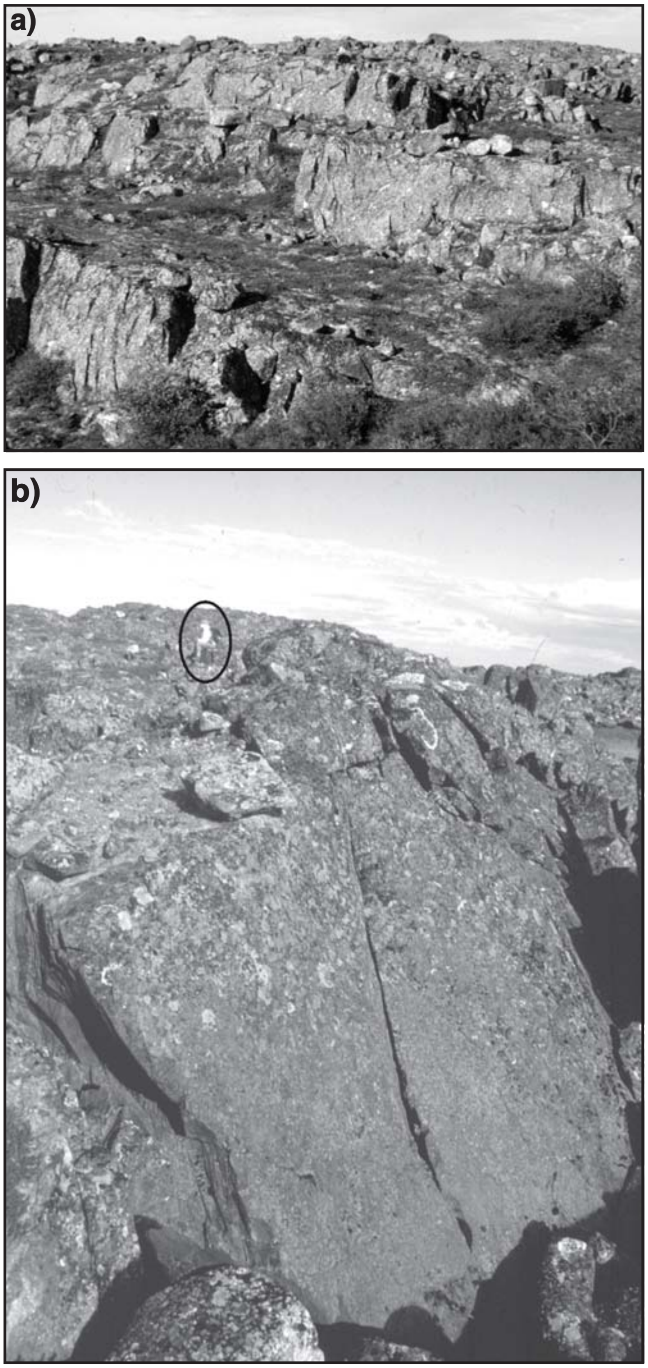


Figure 2. Dacite lava flows of the Innerring sequence. ***a****) Rows of cliffs, 5–15 m high, mark nearly flat-lying individual lava-flow units about 1 km east of reference locality 3. Photograph by M.B. Lambert. GSC 2002-764.* ***b****) Single massive lava flow more than 25 m thick (person at top, circled, for scale). Photograph by M.B. Lambert. GSC 2002-765*

Rhyolite

Rhyolite of the Innerring sequence includes 1) an approximately 1 km by 5 km lava dome overlying the northeastern side of the Innerring dacite, 2) a long narrow arcuate unit in the northern and western parts of the Innerring sequence, and 3) minor northerly trending dykes in the east-central and southern parts of the sequence.

Lava dome. The lava dome near the eastern side of the sequence comprises a dominantly massive northern portion and a broad carapace of megabreccia forming the southern half. The separate narrow (150 m by 1500 m) unit east of the dome is probably a flow unit related to the dome. Although exact contact relations were not observed, the rhyolite overlies the dacitic tuffs.

The northern portion of the dome generally has a massive interior and autobrecciated margins along the western side. Here the unit grades from massive rhyolite to rhyolite block breccia, locally to areas of pebbly grit. Brecciated parts commonly have a carbonate-cemented matrix. The rhyolite is chalky white, pale-grey- and pinkish-grey-weathering with sparse quartz and minor feldspar phenocrysts, generally less than 2 mm that make up only 1–3% of the rock. Phenocrysts are in a dark grey, aphanitic matrix that locally breaks with a conchoidal fracture. In one place, however, the unit is grey, feldspar-phyric dacite containing 20% feldspar phenocrysts.

The monomictic carapace breccia comprises rhyolite blocks commonly up to 1 m, and locally up to 20 m across, enclosed in a matrix of angular to subangular, cobble- to pebble-sized clasts. The eastern margin of this breccia grades outwards from coarse, closely packed megabreccia to rhyolite fragment breccia and pebble conglomerate. These clastic rocks have a poorly sorted, carbonate-cemented, felsic granule matrix with no distinct bedding.

Numerous small areas of aphanitic rhyolite and carbonate-cemented rhyolite breccia that are scattered within dacitic volcaniclastic rocks (of unit ĀBIdp,f) southwest of this dome appear to cap ridges and hills. Although their contacts have not been observed, the lack of continuity suggests that they are outliers possibly related to the major lava dome rather than dykes.

Arcuate rhyolite unit. This 14 km long continuous unit of rhyolite extends from Innerring Lake and follows around the western side of the Innerring dacite unit. It is 1200 m wide south of Innerring Lake, narrows to 150–300 m along the western parts, and tapers out southward. The unit is truncated by arcuate faults along the western, northern, and parts of the eastern sides.

Southeast of Innerring Lake, where the rhyolite unit widens, it appears to be an extrusive unit that lies on the Innerring dacite. At one place near the northern side of the rhyolite body, however, a steeply dipping (about 60° northward), finely flow-layered, porcelaneous, chilled margin on the rhyolite suggests that part of the unit is intrusive.

This white-weathering felsite is mainly sparsely quartz-phyric rhyolite with minor quartz-feldspar dacite. The rhyolite is generally massive, but contains areas of primary flow or carapace breccia that locally pass into rhyolite-cobble conglomerate and well bedded, coarse arenite. For example, at one place, near the western side of the unit, a 50 m clastic section contains the following stratigraphy from bottom to top: 1) more than 13 m of massive, very poorly sorted, coarse rhyolite-block breccia and minor conglomerate; 2) 8 m of fine-laminated to thin-bedded, trough-crossbedded sand; and 3) 29 m of crudely thin- to thick-bedded, rhyolite pebble to boulder conglomerate. The well rounded clasts in the conglomerate and the sedimentary structures in sandy units are dramatically accentuated by selective carbonate replacement of the conglomerate matrix.

Because this body has been subjected to brecciation and faulting, much of it, particularly along the western side, is sheared carbonate-cemented breccia. Generally, these tectonic breccia units, with their steeply dipping slivers and foliation are distinct from autoclastic breccia of rhyolite flows that have equant blocks and lack foliation.

This arcuate body is interpreted to represent volcanism along ring fractures where rhyolitic magma effused at the surface. Erosion from the rhyolite produced local rhyolite fragment conglomerate and arenite. Subsequent movement and subsidence along the ring-fracture zone brecciated much of the rhyolite body and truncated it on its northern and western sides.

Volcaniclastic and iron-rich sedimentary rocks

These rocks form 1) a variety of bedded volcaniclastic rocks (unit ĀBle) that comprise an epiclastic apron around the northwestern side of the Innerring sequence, between Innerring Lake and basal andesite lavas of the Thlewycho sequence, 2) isolated areas of debris-avalanche deposits (unit ĀBled) that overlie the Innerring dacite, along the eastern margin of the Innerring sequence, and 3) minor units of iron-rich sedimentary rocks (unit ĀBli).

Iron-rich sedimentary rocks. Thin units of black sulphidic mudstone, or thin- to medium-bedded sulphidic volcanic siltstone (unit ĀBli) occur intermittently at the base of the volcaniclastic sedimentary succession near Innerring Lake, and at the top of the Innerring sequence on its eastern side. On the eastern side of the sequence, where the epiclastic apron is missing, the iron-rich sediments mark the end of Innerring volcanism. At reference locality 1 (Fig. 1) a 35 m sedimentary succession consists upward of laminated siltstone, black slate and graphitic shale, black siltstone, and green volcanic siltstone. The units contain abundant disseminated pyrite and pyrite-rich layers that weather as prominent gossans. Pyrite also occurs as decimetre-size nodules (largest seen 15 cm by 35 cm) in underlying rhyolite. No laminated chert-magnetite iron-formation is exposed.

Epiclastic apron. This apron comprises well bedded to thick, massive epiclastic volcaniclastic units, with minor intervals of tuff that all contain abundant felsic clasts, including white-weathering rhyolite, quartz-feldspar-phyric dacite and aphanitic dacite, and lesser amounts of porphyritic andesite. Lithologies of clasts are all similar to units of the Innerring eruptive sequence.

The northeast end of this volcaniclastic succession interfingers with dacite and andesite lavas of the Thlewycho sequence. In general, contact between this succession and the arcuate rhyolite unit is either not exposed or is a zone of shearing and faulting (interpreted as a ring-fracture zone). The succession conformably overlies a pillowed basalt unit on the western side of the ring-fracture zone. At the east end of Innerring Lake, the succession conformably overlies two small rhyolite to dacite flow units that are on the north side of the ring-fracture zone.

Above these flow units, the succession comprises 600–700 m of thin- to medium-bedded, volcaniclastic units that pass upward into about 1000 m of very thick volcaniclastic units and debris flows. A basal section of more than 20 m of the lower well bedded portion has been measured in detail (Fig. 3, on CD-ROM). This section contains laminated to crossbedded sand and silt, volcanic turbidite (30 cm to 5 m thick), and small (about 2 m thick), subaqueous debris flows (Fig. 3a). Many thin (1–2 cm) layers of fine, water-laid ash are dispersed throughout the succession (Fig. 3b, c). Massive tuff units that grade upward into well bedded tuff are interpreted as subaqueous pyroclastic flow units (features of subaqueous pyroclastic flows may be seen in Fiske (1963), Fiske and Matsuda (1964), Yamada (1973), and Cas and Wright (1988)).

The overlying, very thick units are massive, blocky-jointed units that range from 50 m to 300 m thick. These completely unbedded units typically are unsorted to poorly sorted, polymictic breccia commonly containing angular to subrounded lithic clasts, averaging 1–10 cm, and commonly up to 30 cm across, in a finer, clastic, grey- to green-weathering matrix. Clasts include mainly feldspar-phyric dacite and aphanitic white rhyolite, but also porphyritic and green aphanitic andesite. The matrix commonly appears crystal-rich because of the abundance of phenocrysts in finer clasts. Thin-bedded volcarenite (and possible ash) horizons, in some cases only 20 cm thick, mark boundaries between major depositional units. Some of the thick massive units, composed mainly of fine-grained clastic material (and sparse large blocks), superficially resemble nonwelded ash-flow tuffs. The lack of ash-size material and pumiceous fragments, however, suggests that they may represent lahars rather than ash flows.

Debris-avalanche deposits. Debris-avalanche deposits overlie dacite units in four discontinuous areas along the eastern margin of the Innerring sequence. These deposits are massive, unsorted, very coarse polymictic breccia comprising a variety of felsic clasts (rhyolite, quartz-plagioclase-phyric dacite, and aphanitic dacite) in a brown-weathering, carbonate-cemented, felsic grit matrix that contains abundant mafic minerals. These deposits typically contain up to 75% angular to subrounded clasts, ranging from 1–30 cm (but up to 100 cm). Locally, variation of block size suggests crude layering in an otherwise massive unit.

Interpretation. The compositions of clasts throughout these volcaniclastic sediments suggests that they were derived from formations of the Innerring sequence. The succession represents a broad, clastic apron produced by mass wasting and erosion, mainly from the northwestern side of the early subaerial volcanic edifice, and deposition along the shore and shallow-marine flanks. Ash layers within the lower, thin-bedded succession, are water-laid air-fall ash, and possibly subaqueous ash-flow tuffs, that indicate numerous minor explosive events during the waning stages of Innerring volcanism. The change within the volcaniclastic succession from well bedded, basal units to thick, massive, upper units may denote emergence of the pile above sea level. Mass wasting, mainly from felsic domes, produced local, coarse, debris-avalanche deposits on the eastern side of the sequence.

Arcuate faults and breccia zone

An 18 km long by 50–400 m wide zone of brecciation starts near the east end of Innerring Lake, follows around the northern and western margin of the arcuate unit of Innerring rhyolite, and fades out near the southwestern side of the Innerring sequence. Although the brecciation is mainly within the rhyolite unit, it is not completely contained within it. The southern end of the breccia zone transects lithologies and extends into bedded volcaniclastic sedimentary rocks (of unit ABle) and the Innerring dacite unit.

The breccia zone is partially fault bounded. The faults are defined by narrow zones of shearing and cataclasis that weather out as steep-sided arcuate and linear valleys along the northern and western sides of the breccia zone. Along the western side, at the fault contact between brecciated rhyolite and basalt pillow lavas, pillows are sheared and elongate parallel to the contact, and the rhyolite breccia comprises closely packed slivers of rock (commonly 10 cm by 60 cm size with near-vertical preferred orientation; Fig. 4). Some irregular zones of intense shearing have clasts aligned within flow-differentiated, carbonate-rich grit that define a steep (about 70–90°) lineation within a foliation that trends roughly parallel to the valleys and the overall trend of the breccia zone.

About 500 m southeast of Innerring Lake, a second zone of intense cataclasis defines a fault along the eastern side of the arcuate rhyolite unit. This 70 m wide zone, which in one place has a near-vertical attitude, arcs northeastward and passes into the northern part of the rhyolite body.

Breccia generally grades progressively away from the faulted western edge of the breccia zone, such that masses of huge angular to subrounded blocks in an unsorted matrix of fine breccia, pass into intensely fractured and massive rock. Locally, blocks of rhyolite breccia within rhyolite breccia indicate more than one period of disruption: either two periods of tectonic movement or brecciation of primary flow

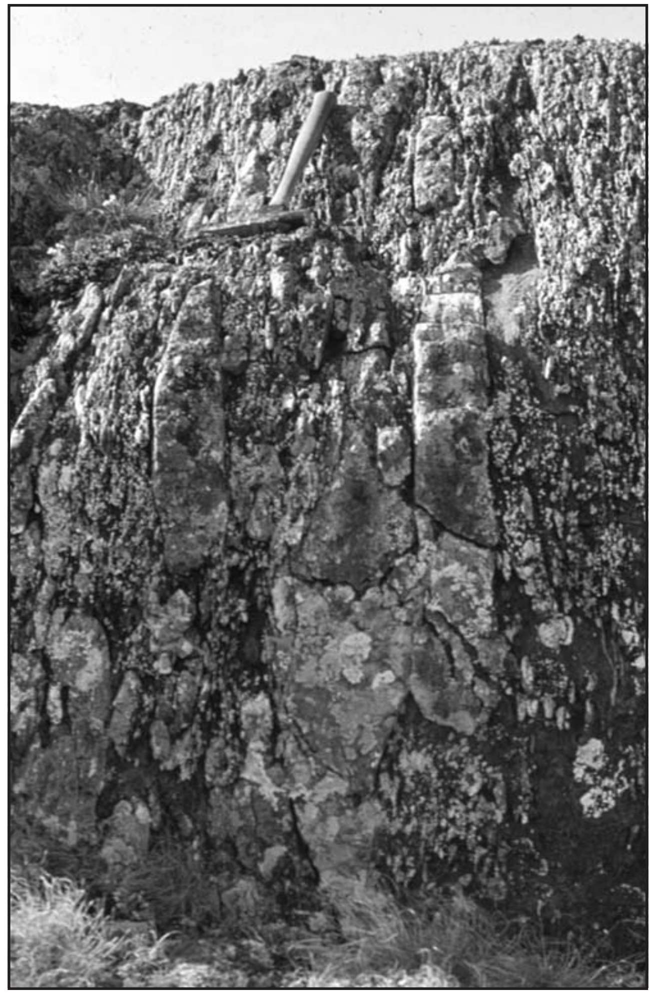


Figure 4*. Rhyolite breccia in the arcuate breccia zone (about 3 km south of reference locality 15). Intense cataclasis in carbonate-cemented breccia that contains nearly vertical clast and block lineation and foliation. Hammer is 33 cm long. Photograph by M.B. Lambert. GSC 2002-766*

breccia. At locality 15 (Fig. 1), where brecciation extends into bedded volcaniclastic rocks, breccia grades into rocks that appear shattered, characterized by irregular fractures with no movement between them — i.e. the large angular blocks fit together. These outcrops resemble shattered granite along caldera walls of the Eocene Bennett Lake cauldron subsidence complex (Lambert, 1974).

These arcuate zones of brecciation, cataclasis, and faulting are interpreted as parts of a ring-fracture zone, related to a cauldron subsidence structure within the Innerring sequence (Smith and Bailey, 1968; Lambert 1974; Lipman, 1997; Troll et al., 2002). The steep preferred orientation of elongate breccia clasts and lineations indicate vertical rather than lateral movement along the arcuate faults. That the area inside the arcuate faults was the downdropped side (caldera) is inferred from the abrupt change in stratigraphy across the outer ring fault. Across this fault, lithology changes from the thick, massive, subaerial tuffs and lavas of the Innerring sequence on the inner (southern) side, to subaqueous pillow lavas, mudstone, and well bedded rocks of the volcaniclastic apron on the northern and western sides. Thus, cauldron subsidence along ring faults brought upper, subaerial parts of the edifice into juxtaposition with lower, subaqueous parts of the stratovolcano. The fading out of the breccia zone southward, and its absence along the eastern sides of the Innerring sequence, suggest that caldera collapse was a one-sided 'trap door' structure.

Thlewycho sequence

Definition, distribution, and thickness

The Thlewycho sequence comprises all products of an intermediate to felsic eruptive cycle, and synchronous epiclastic deposits, that lie above the Innerring sequence and below mafic lavas of the Boucher-Regan sequence. In general, the stratigraphy progresses from basal andesitic lavas and tuffs, through dacitic tuffs and lavas, to rhyolite domes and flows. The sequence is exposed for 50 km from southeast of Jim Magrum Lake to northwest of Regan Lake. It includes the bulk of the volcanic complex, and thus represents the main constructional phase of the stratovolcano.

The stratigraphy of this sequence is thickest around the structural dome in the southern half of the volcanic complex, where it dips radially outward from the central Innerring sequence; attitudes of units vary from 25–30° on the eastern side, to 35–50° on the northern side (to about Outerring Lake), and 60–75° along the western side. Although cumulative stratigraphic thickness in this area is between 2500 m and 4000 m, the units probably formed an onlapping succession on the stratovolcano, and presumably no single vertical sequence with that thickness ever existed.

This thick part of the volcanic complex, which has been modified by regional deformation, is considered to be a portion of the main volcanic edifice.

Between Outerring and Regan lakes, units of the Thlewycho sequence thin out northward and in places becomes interbedded with sedimentary rocks of the Beechey Lake Group. This part of the complex represents the folded northern flanks of the stratovolcano.

Contact relations

The base of the Thlewycho sequence is drawn at the first andesitic lavas that overlie dacitic tuffs or volcaniclastic sediments of the Innerring sequence. Along the eastern side of the Innerring sequence the iron-rich shale and volcanic siltstone of unit ABli mark this boundary. On the northwest side, the thick clastic apron of the Innerring sequence indicates a period of erosion between the two eruptive sequences. On the northeastern side of the Innerring sequence (and locally on the southern end), where andesite lavas are absent, and there is no clear sedimentary break between the two volcanic sequences, the boundary between sequences is drawn where dacitic tuffs of the Innerring sequence give way to dominantly andesitic volcaniclastic rocks of the Thlewycho sequence. Except for local minor unconformities, suggested by channel-filling rudite, the two sequences appear to be conformable.

On the crest of the broad anticline near the southern end of the Innerring sequence, the boundary between units of the two sequences is very irregular and small outliers of Thlewycho flows occur within Innerring sequence rocks. This irregularity results from erosion through nearly flat-lying strata rather than from interfingering relationships. Figure 5 shows details of the transition between units of the two sequences in this area. Here, seriate, plagioclase-phyric (30–70% phenocrysts) andesite lavas (or possibly crystal tuffs) overlie exhumed braided stream deposits within dacitic, crystal-lithic, ash-flow tuff of the Innerring sequence. The fluvial deposits contain carbonate-fragment breccia and crossbedded, coarse-grained carbonate sand, indicating erosion from a pre-existing carbonate horizon. In areas such as this, contacts between nearly flat-lying units meander over broad areas (the braided stream deposits are less than 10 m thick, yet units extend over an area 400 m across) and their details are too fine to be resolved at the scale of mapping; hence, boundaries are generalized on Map 2041A.

Stratigraphy

The stratigraphy of this sequence is most completely displayed around the structural dome in the southern half of the volcanic complex. The complex map pattern and two columnar sections near Rusty Lake and Gold Lake (Fig. 1, 6 on CD-ROM), illustrate stratigraphic variations within the Thlewycho sequence.

The Gold Lake section comprises dominantly subaerial andesitic lavas and few intermittent pyroclastic and epivolcaniclastic units totalling about 2500 m thick, plus felsic domes to the north and south of the section amounting to another 300–500 m. The section documents the sequence resulting from the following eruptive events:

1) Eruption of three 5–10 m andesitic to dacitic lavas, each separated by bedded felsic volcaniclastic siltstone or tuff;

2) Continuous subaerial effusion of about 1100 m of andesitic lavas (about ten flows) ranging from 7 m to 110 m thick;

3) Explosive eruptions produced about 300 m of pyroclastic flows interrupted by one or two thin lavas;

4) Deposition of about 400 m of breccia, air-fall tuff, and agglomerate;

5) Effusion of eight andesitic lava flows (totalling about 600 m thick) topped by two 50–60 m thick dacite lavas; and

6) Effusion of a large rhyolite-dacite dome-flow complex (the 1500 m by 7300 m Gold Lake dome; *see* 'Rhyolite lavas, domes, and intrusions') that tapers out abruptly northward between dacite lavas.

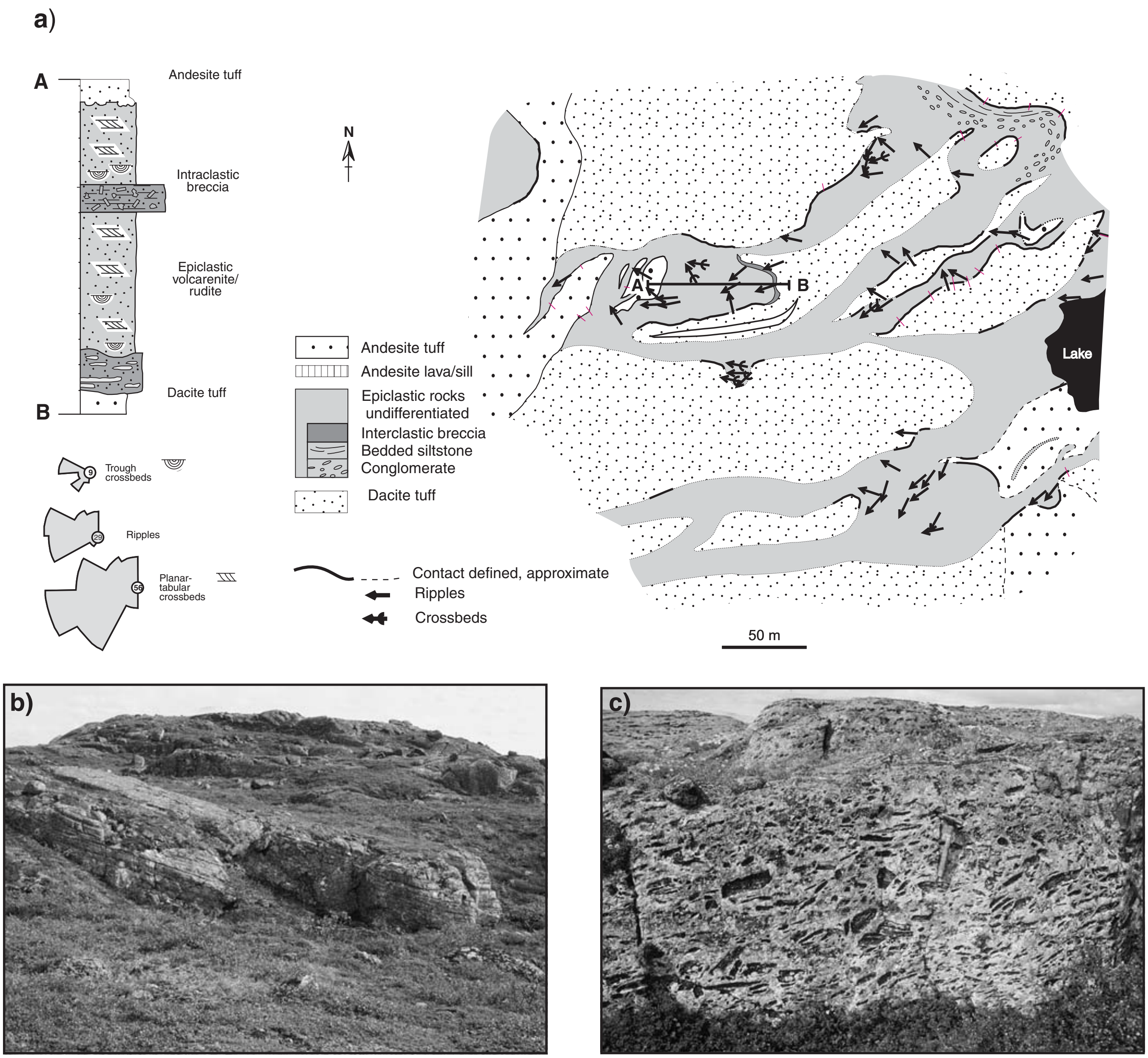


***Figure 5. a**) Detailed map of area outlined by square on Figure 1, 6 km northeast of Jim Magrum Lake interpreted as a subaerial braidplain. Nearly flat-lying stratigraphy containing crossbedded volcanic sandstone and conglomerate (epiclastic volcarenite and rudite unit) separate dacitic ash-flow tuff of the Innerring sequence and plagioclase-rich andesitic tuff of the Thlewycho sequence. Beds showing large planar tabular beds and trough crossbeds, intraclastic breccia, and scours define a braided cluster of westerly trending channels cut into a dacitic ash-flow tuff. This deposit and paleocurrent data support erosion from a predeformational topographic high during a short hiatus in ash-flow volcanism on the southwest flank of the stratovolcano. **b**) Large planar-tabular crossbeds in pebbly rhyolite volcarenite. Crossbeds are emphasized by selective carbonate replacement along tops of foresets. Distance across outcrop is about 15 m. Locality 1. Photograph by M.B. Lambert. GSC 205025-I. **c)** Intraclastic breccia unit 1.8 m thick containing clasts of carbonate (dark) in poorly sorted, coarse-grained volcarenite matrix. Hammer is 33 cm long. Photograph by M.B. Lambert. GSC 205025-G*

Avalanches locally spread across and filled valleys in the lava sequence with coarse debris (*see* 'Epiclastic volcanic rocks'), followed by deposition of a clastic fan represented by polymictic, pebbly volcarenite.

The Rusty Lake section is close to 3500 m thick. The thick units shown in this section are lenticular and taper out or change facies around the eastern and western sides of the complex. Compared to the Gold Lake section, the Rusty Lake section has a higher proportion of volcaniclastic units, fewer but much thicker lava-flow units, a higher proportion of felsic lavas, and shows a change in depositional environment from subaqueous in the lower part to subaerial in the upper parts.

This section illustrates several cycles of lava effusion followed by volcaniclastic sedimentation and the following sequence of events:

1) Subaqueous eruption of dacitic then andesitic pillow lavas that overlie and interfinger with bedded Innerring volcaniclastic rocks;
2) Eruption of massive plagioclase-phyric andesite lava flows forming units 150–300 m thick;
3) Eruption of a small monogenetic rhyolite dome, 700 m across;
4) Continued eruption of porphyritic andesite lava and related breccia overlain by, and interbedded with, massive volcaniclastic rocks, possibly pyroclastic flows and debris flows;
5) Effusion of a thick, andesitic lava;
6) Deposition of a thick succession of volcaniclastic units including pyroclastic flows and debris flows and turbidite-like units; they were interrupted by eruption of local, small, rhyolite lava flows; and
7) Major effusion of seven rhyolite and dacite lava flows with a total thickness about 1100–1400 m.

Along the western side of the stratovolcano, eruption began with thick, lenticular units and extensive flows of plagioclase- and plagioclase-hornblende-phyric andesite lava. Flows are overlain by a thick volcaniclastic succession interpreted to be mainly andesitic, ash-flow tuffs, including both nonwelded and welded varieties, but also contains epiclastic material. An extensive rhyolite lava succession about 1.5 km wide by 10 km long (with estimated stratigraphic thickness of 800 m) forms the top of the Thlewycho sequence (*see* 'Thlewycho east lava dome' section below). Thinner (80–200 m thick) rhyolite units, that are more or less synchronous with the larger unit, continue for another 7 km around the southern side of the volcanic complex near Jim Magrum Lake. These rhyolite flows and related coarse-grained carbonate-cemented breccia, which occur at the top of the sequence, are highly sheared and tectonically brecciated along their western sides. In spite of this deformation, there are 'windows' where spectacular flow layering is preserved. Bedded volcaniclastic rocks divide the rhyolite succession longitudinally in the northern parts of this unit.

In general, the Thlewycho sequence in the southern half of the complex begins with basal porphyritic andesite and dacite lavas interlayered with tuffs of similar composition. These units are overlain by a thick (about 400 m) succession of ash-flow tuffs and volcaniclastic rocks of epiclastic origin that extend around the southern and southeastern sides of the complex and interfinger with major lobes of the Gold Lake lava dome. Numerous rhyolite domes mark the end of Thlewycho sequence volcanism.

In the folded northern parts of the volcanic complex, the Thlewycho sequence comprises distal facies of the volcaniclastic unit (mainly undifferentiated).

Flow units

Andesite lavas

Porphyritic andesite lavas (unit ĀBTa) at the base of the sequence form 1) a thick series of flows on the southeastern and southern sides of the Innerring sequence, 2) an extensive flow unit above Innerring epiclastic unit on the western side, and 3) pillowed to massive andesite on the northern side. Andesite also forms the basal part of a composite lava dome southeast of Jim Magrum Lake.

The base of the andesite lava series, overlying the southeastern side of the Innerring sequence, is marked by a 1 km wide by approximately 7 km long zone of carbonate-cemented flow breccia. This unit is variably brown-, green- to pale grey- and white-weathering, monolithological andesite breccia that grades in and out of massive feldspar-phyric andesite. Angular to subrounded blocks, 10–50 cm across, have carbonate-cemented, interstitial crush of 1–5 cm clasts and coarse, andesitic grit. Locally carbonate makes up 50% of the rock. Pyrite and pyrrhotite are common throughout these breccia units. This basal flow breccia grades upward into massive andesite flows.

The overlying series of flows characterized by massive, columnar-jointed interiors and thick, blocky, flow-top breccia (and by absence of pillowed units and hyaloclastite), are typical subaerial lava flows (Fig. 7). Individual flow units, some of which have been traced as far as 3 km, range from 5 m to 110 m thick. Massive interiors commonly form columnar- to blocky- jointed cliffs, whereas the flow breccia weathers in recession to form gullies or broad, receding areas that give an erroneous impression of a high proportion of flow breccia. Hence, the broad zone of shallow-dipping flow breccia at the base of the lava series is less than about 100 m thick. When seen from a distance, these recessive zones contour around hills expressing the overall gentle easterly dipping attitudes of the units.

At reference locality 2 (Fig. 1), a 7 m cliff displays a complete section through a classic subaerial lava flow that appears to have baked underlying green volcanic siltstone. The lower 0.5 m of the flow is vesicular flow breccia. The massive centre of the flow, which contains sparse angular vesicles, displays a lower colonnade of widely spaced, columnar joints that changes abruptly about half way through the flow to an upper colonnade of closely spaced, columnar

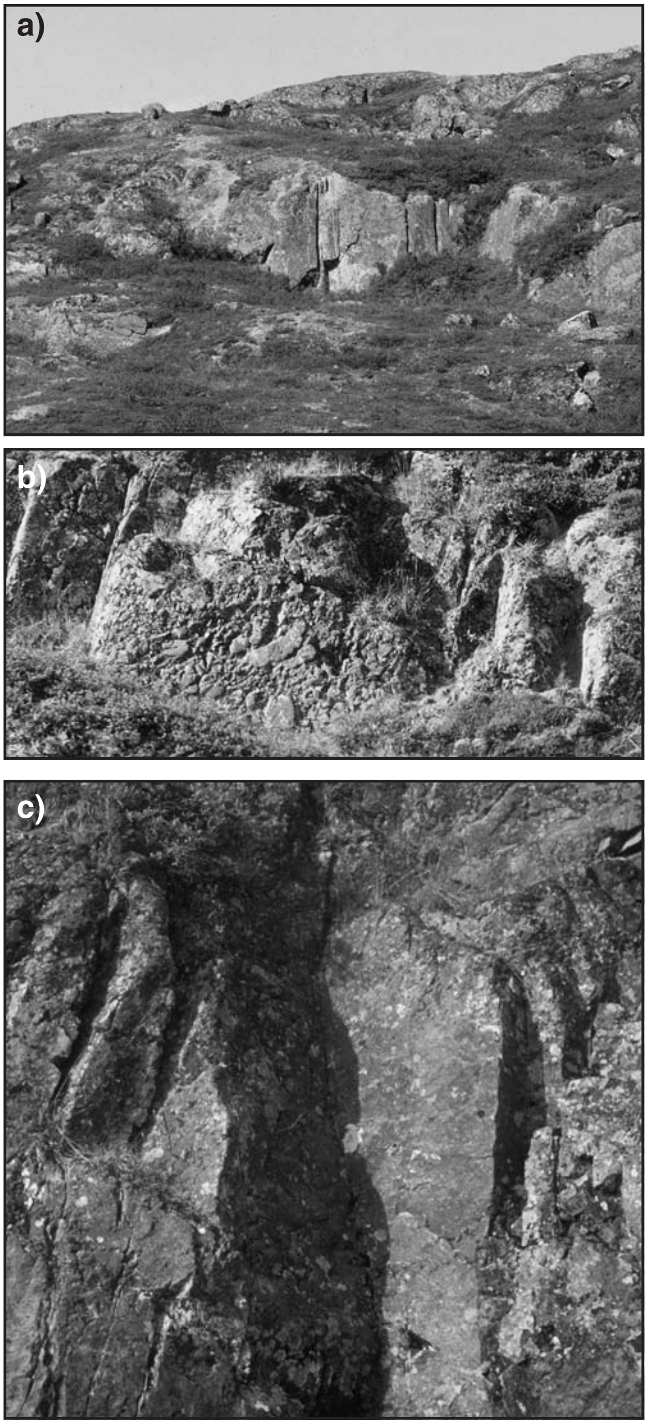


Figure 7. *Subaerial andesite lava flows of the Thlewycho sequence, southeast side of the volcanic complex.* ***a****) Cliff-forming massive flow units, recessive areas are flow breccia. Field of view about 300 m. Photograph by M.B. Lambert. GSC 2002-767.* ***b****) Flow-top breccia (vertical exposure 2 m). Photograph by M.B. Lambert. GSC 2002-768.* ***c****) Jointed, massive interior of flow (vertical exposure 1.5 m). Photograph by M.B. Lambert. GSC 2002-769*

joints. The upper colonnade grades upward into irregular, blocky-jointed lava then into a thick, flow-top breccia comprising subangular to subrounded blocks that have abundant coarse vesicles. In the lower part of the lava sequence in this area, where interflow volcaniclastic rocks contain abundant pyrite, prominent gossans are present. Sulphidic alteration spread laterally along interflow sediments for as much as 1700 m and locally has completely altered parts of several lava-flow units. Alteration stops abruptly at the base of one lava-flow unit that makes a baked contact with the underlying pyrite-rich volcanic sand. This area of intense alteration, which has sulphidized and bleached part of the lava sequence, may indicate fumarolic activity and thus mark a relict vent.

The 9 km long andesite unit, 2.5 km east of Thlewycho Lake, is massive to brecciated plagioclase and hornblende-phyric andesite that typically contains 15–25% phenocrysts (hornblende is <1%). Although these appear to be subaerial lavas, complete flow units have not been distinguished.

The andesite unit near the eastern side of Jim Magrum Lake is massive to flow-brecciated, subaerial lava flows. Individual flow units are distinguishable by coarsely amygdaloidal (calcite), flow-top and basal breccia units that grade into blocky-jointed, massive interiors.

Near the south side of Rusty Lake, a 6 km long by about 300 m thick unit of andesite pillow lava forms the base of a large andesite lens within well bedded, volcaniclastic rocks. In the eastern and central parts of the pillowed unit, large (5–15 m) pillow lobes, that in one place plunge 58° toward the northeast, are interpreted as foreset pillow lobes that formed at the front of an advancing flow, since the plunge is steeper than the attitude of the unit as a whole, which is estimated to be about 40°. Pillow rims typically have 2–5 cm thick selvages and an approximately 15 cm wide rim of coarse quartz- and calcite-filled amygdales. Near the eastern end of the unit, the andesite pillow lava contains angular blocks of dacite (commonly 5–15 cm, but up to 100 cm across) and segments of vesicular dacite pillow rims. The adjacent dacite unit also contains some lobes of intruded andesite lava. In the central portion of the unit, pillow lavas and pillow breccia pass downward into a basal massive flow unit containing coarse quartz and calcite amygdales, generally less than 1 cm, but up to 10 cm long, that have preferred orientation roughly parallel to the flow boundary.

The overlying andesite units are very thick, extremely massive, blocky-jointed porphyritic andesite flows containing variable amounts (up to 35%) of euhedral plagioclase phenocrysts (2–5 mm). The only indications of flow boundaries within this massive unit are zones of coarse vesicles, interflow volcaniclastic sediments, and in one place, a small rhyolite flow. Flow units are estimated to be 150–300 m thick and may represent ponded lavas.

The lowermost andesite lavas of the Thlewycho sequence were probably deposited in a shallow-marine environment around the Innerring sequence core. This is suggested by basal pillowed flow units and extensive carbonate-cemented flow breccia that pass upwards abruptly into voluminous, subaerial, andesitic lavas; presumably as the pile emerged above sea level. At this stratigraphic level, carbonate is prominent as cement in breccia units of all types and compositions, not only in the lower units of the Thlewycho sequence, but in underlying felsic flow units of the Innerring sequence. Possibly this carbonate formed during interaction of flow units with sea water (temperature increase in saturated sea water would aid precipitation), and possible associated hydrothermal springs, on the shallow flanks of the old Innerring edifice.

Dacitic lavas and tuffs

Dacitic rocks of the Thlewycho sequence (unit ĀBTd) form dominantly lavas or domes except for near the northwest side of Gold Lake where they are mainly ash-flow tuffs and tuff-breccia units. Ash-flow units near Gold Lake are massive, unsorted, vitric (relict), lithic tuff comprising angular dacite fragments and feldspar crystals in a matrix of relict vitric material, which locally is seen to be tightly packed, cuspidate to lenticular shards and flattened pumice with fiamme terminations, suggesting that the deposits were welded tuffs (ignimbrites). Tuff-breccia units have angular dacite blocks (5–10 cm across) in a grey, very fine, ash-tuff to aphanitic matrix. These massive units are unsorted and show little lithological variation except for varying proportions of crystals and lithic clasts.

Where this dacite unit tapers out at the southern end, it comprises at least three discrete lava-flow units having cliff-forming, massive centres and recessive-weathering, intervening flow-breccia units. Several more dacite flow units also occur about 1 km westward interbedded with volcaniclastic rocks and andesite lavas. Individual flow units range from 15 m to 80 m thick. In some places, rocks of the flows are very dark grey, almost glassy in appearance, and break with a subconchoidal fracture. Flow breccia are monomictic breccia with dacite fragments ranging from coarse blocks to dacite grit that fills interstices between blocks. Polymictic breccia containing dacite and some andesite blocks occurs within interflow breccia.

East of Rusty Lake, a 3 km long lens of pillowed dacite indicates local subaqueous deposition of the felsic lavas. The lens comprises large pillow lobes that grade into smaller pillows, pillow breccia, and coarse volcrudite near margins of the unit. Pillow lobes have coarsely vesicular margins (gradually becoming finer and sparser inward) and well developed, chilled selvages. This sparsely plagioclase-phyric dacite is lithologically very similar to the cliff-forming subaerial lava units at the east end of Innerring Lake which also have zones of coarse vesicles (some are up to 5 cm across and filled with chlorite).

The dacite unit in the nose of a northwest-plunging, broad, open fold, between the southwest side of Rusty Lake and Thlewycho Lake, is dominantly a flow breccia that is massive only locally in its thickest part. The central part is a monomictic dacite breccia with angular fragments up to 25 cm across, but generally less than 10 cm across. Toward its margins, fragments become more subrounded and the breccia tends to be polymictic, carrying a small amount of andesite clasts. The dacite is white-, grey-, and buff-weathering, with 1–3 mm feldspar phenocrysts (about 3%) and fine, acicular hornblende flecks in a dark grey, aphanitic, almost glassy matrix.

The southern and western sides of the unit is a white- to pale grey-weathering breccia apron comprising monomict to polymict felsic breccia that fines westward to thick-bedded successions. Coarse, felsic breccia units are cemented with carbonate and form knobby-weathering units that are considered part of the dome and/or flow stratigraphy. The finer clastic parts are gradational into the overlying volcaniclastic succession, such that locally the distinction between the two is somewhat subjective and boundaries are shown as assumed contacts. This could be considered part of the main volcaniclastic unit, but is separated out from the surrounding volcaniclastic unit because of its high amount of dacite fragments and its gradation into dacite breccia of the main flow from which it is clearly derived.

The large dacite unit between Outerring Lake and the Back River is mainly pale grey- to pale green-weathering, greenish-grey aphanitic to sparsely feldspar- and quartz-phyric, massive to brecciated dacite, interpreted as flow or flow-breccia material. Near the top of the unit, northwest of the lake, it comprises massive to vaguely bedded epiclastic dacite breccia, tuff breccia, lithic tuff, and conglomerate. Thin-bedded, dacitic arenite facies occur near the contact with the siltstone and iron-formation of the overlying Beechey Lake sedimentary rocks.

West of Regan Lake, quartz- and locally hornblende-phyric dacitic rocks could be fine volcaniclastic units, although they have not been distinguished as flows or tuffs.

Near the southeast side of Jim Magrum Lake, quartz- and feldspar-phyric, massive to brecciated dacite form the lower part of a composite dacite-rhyolite dome complex. The monolithic flow or carapace breccia has abundant carbonate in the matrix.

About 2 km northeast of Jim Magrum Lake, three lenticular dacite units (within volcaniclastic unit ĀBTp) are ash-flow tuffs and locally bedded crystal tuffs. The westernmost unit is welded tuff: rare lichen-free weathered surfaces locally display eutaxitic foliation defined by flattened pumice and shards (up to 1 cm by 3 cm) that have cuspidate boundaries and wispy tapering ends (fiamme) that mould around phenocrysts. The pale bluish-grey- to greenish-grey-weathering rock contains quartz and feldspar phenocrysts (1–2 mm) in dark grey aphanitic matrix; tuffaceous texture is seen clearly only on weathered surface. In some places the tuff contains lithic clasts of dacite, rhyolite, and andesite. Near the base of the unit, crystal-rich layers are interpreted as air-fall crystal tuff. Locally these tuffs are associated with felsic volcanic arenite.

The eastern two units are pale grey, greenish-grey to pinkish-grey, quartz- and feldspar-phyric tuffs that vary from coarsely porphyritic (phenocrysts up to 8 mm) K-feldspar- and quartz-rich crystal (up to 60% crystals) tuffs, to buff- and grey-weathering, finely porphyritic (quartz, feldspar, and hornblende; 1–3 mm), dark grey dacite. Massive ash-flow tuffs have dark grey, almost glassy-looking lenticles and lensoid clots of crystal-rich material in pale grey-weathering aphanitic, dark grey matrix. Some areas contain blocks of crystal tuff 10–20 cm across. The northern unit commonly has angular to subrounded, 1–4 cm clasts that make up to 20% of the rock.

Rhyolite lavas, domes, and intrusions

The numerous discrete felsic units of the Thlewycho sequence include three dome and lava flow complexes that have been documented in detail (described separately below, and referred to as the Gold Lake lava dome complex, the Thlewycho north dome, and the Thlewycho east lava dome); a composite dome complex southeast of Jim Magrum Lake, where dacite and rhyolite flows have accumulated on an andesite base; rhyolite lavas northeast of Rusty Lake; and a unit of intrusive rhyolite.

Northeast of Rusty Lake, the 2 km by 15 km rhyolite unit comprises five extensive shallow-dipping lava-flow units (some with well developed columnar joints; Fig. 8). Contacts between flow units are defined by flow breccia and beds of rhyolitic volcarenite and rudite. This unit may be a section through a major rhyolite lava field.

Felsic (rhyolite to dacite) domes of all sequences generally comprise 'massive' portions that may include several lithological phases (aphanitic, porphyritic rhyolite to dacite compositions) and various textural and/or structural phases (massive, flow-layered, autoclastic breccia). The term 'carapace breccia' is used to designate areas along margins, top, and locally within a body, where massive felsite grades from a highly fractured rock to 'in situ' breccia (tightly packed blocks of felsite with intervening crush of finer breccia; Fig. 9). These breccia units represent autoclastic flow breccia or crumble breccia at the top and sides of domes. They commonly grade into breccia aprons comprising monolithological rhyolite and dacite derived from the dome and minor

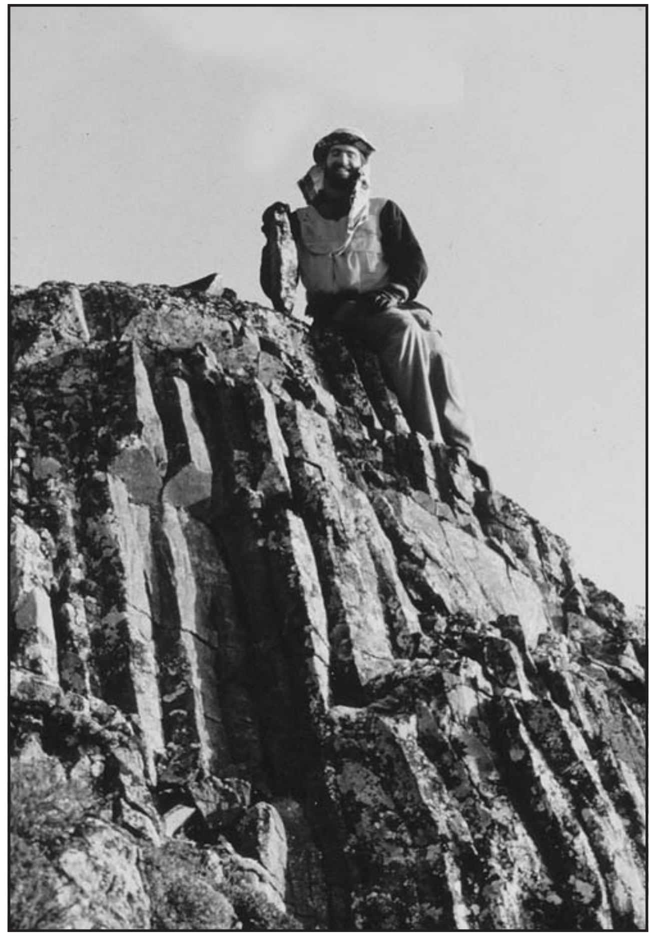


Figure 8. *Columnar-jointed, rhyolite lava flow on island near the east side of Rusty Lake. Near-vertical columns attest to the shallow attitude of flows in this area. Photograph by M.B. Lambert. GSC 2002-770*

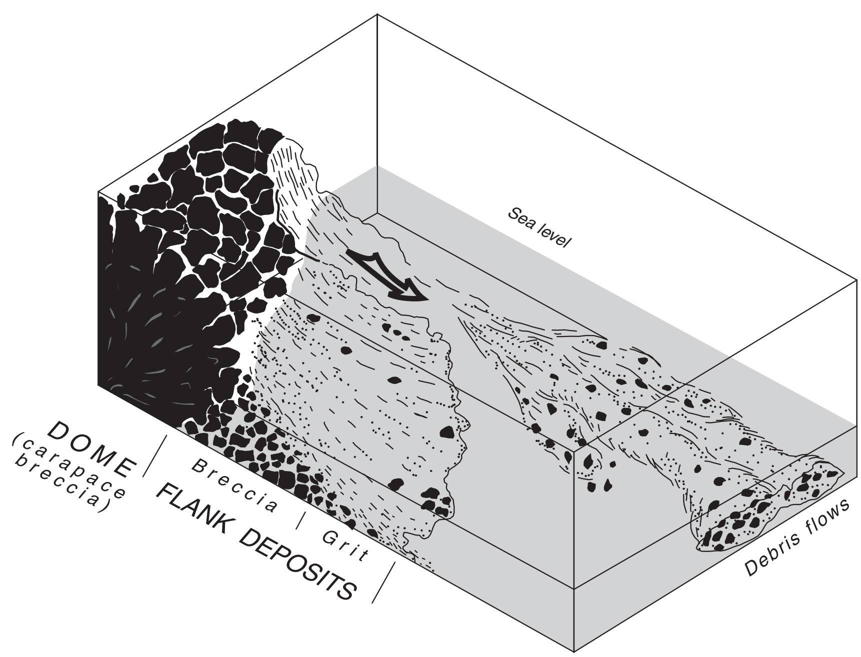


Figure 9.

Facies of felsic domes.

exotic fragments. Aprons probably represent rock falls, landside, and scree that spalled off the unstable dome-flow margin. These aprons, which are considered to be an integral part of the eruption and/or emplacement process, are referred to as 'flank deposits' and are mapped as facies of the parent dome. Portions of domes and/or flows that erupted in a subaqueous environment invariably have carapace breccia and flank deposits cemented with carbonate material and usually contain minor bedded rudite, grit, and carbonate. Most flank deposits, however, are unsorted to poorly sorted, unbedded, massive units.

Clastic material derived mainly from felsic domes, but which has been transported away by mass flows (such as paraconglomerate, debris-avalanche breccia, laharic breccia Fig. 9); is mapped as volcaniclastic sedimentary rocks. In some places, however, where flow breccia appear to grade into avalanche deposits, the distinction is somewhat arbitrary, and is judged on the basis of proximity to domes, populations of clast types, proportion of clasts to matrix, and nature of matrix.

Gold Lake lava-dome complex. The Gold Lake lava-dome complex is an assemblage of rhyolite to dacite lava flows, intervening volcaniclastic units, and related coarse breccia, that occupy a 1.5 km by 8 km area centred about 5 km southwest of Gold Lake. It is one of the best exposed and least deformed major felsic bodies of the Back River volcanic complex. Internal stratigraphy is variable because of the overlapping nature of numerous lenticular units. The central portion of the complex comprises at least seven lava-flow units separated by rhyolitic volcaniclastic units (*see* columnar sections, Fig. 10a, and the following section on 'Volcaniclastic rocks' of the Thlewycho sequence). The southwestern side of the complex fingers out into four flow lobes. The complex has a clastic apron along its southern side where it makes contact with turbiditic rocks of the generally overlying Beechey Lake Group.

Units of the dome have gentle southeasterly dips. Where interflow clastic units display recessive weathering and mark flow boundaries, the general inclination of large units, as seen from a distance, is about 10–20°. Dips steepen to about 40° within the eastern clastic apron. In downdip panoramic views, some of the distinctive, blocky, cliff-forming flow units have gentle undulations that define broad open folds. Assuming average dips, the thickness of the lava-dome complex is about 550 m.

Individual lava-flow units range from 25 m to 60 m thick. The white-, buff-, and pink-weathering, massive lavas are aphanitic to quartz- and feldspar-phyric. Rocks containing abundant coarse phenocrysts (such as a dacite flow unit near the base of the dome succession that contains 35% phenocrysts up to 5 mm) are the only distinctive felsic flow lithologies within the complex. Flow layering (Fig. 10b) is rarely visible except in exceptionally clean, smooth, lichen-free exposures. Although coarse flow breccia occurs throughout the lava succession, it is mainly along the eastern side of the complex.

Rocks of the 200–280 m wide (70 and 150 m thick) clastic apron along the southeastern side of the lava dome vary along strike from carbonate-cemented megabreccia (flow breccia), coarse rudite to fine, pebbly sandstone and rhyolite turbidite (Fig. 10c, d). They are unsorted to poorly sorted rocks with clasts derived mainly from adjacent felsic flows. At one location, the flow breccia overlies massive carbonate and crossbedded, clastic carbonate beds. Similarly, at the southwestern end of the lava dome, rhyolitic volcaniclastic rocks overlie greywacke-mudstone turbidite of the Beechey Lake Group. At the northeastern end of the dome, however, carbonate, iron-formation, and turbidite clearly overlie the rhyolite dome. Thus, the margin of the dome complex interfingers with Beechey Lake turbidite.

Near the northern end of the dome, lava flows make sharp contact with volcaniclastic rocks (unit ĀBTp) or grade over distances of 50–100 m from the brecciated margin of the lava to rhyolite-rich debris flows.

Thlewycho north dome. A 2800 m by 400 m rhyolite body, exposed in a 45 m cliff at the northwestern end of Thlewycho Lake, is a remnant of a rhyolite dome. An extensive apron of rhyolitic breccia derived from the dome is preserved in a syncline on its west side. The massive portion of the rhyolite body has a blocky joint pattern in the lower part of the cliff face, and gently to moderately plunging, five- to six-sided, primary columnar joints in upper parts. At the southeastern end, the dome narrows to a 150 m wide neck that makes sharp intrusive contact with sediments. Rhyolite has chilled margins and siltstone bodies are hornfelsic in contact with the rhyolite.

The white- to pink-weathering rhyolite contains 2–15% albite and quartz phenocrysts (0.5 mm) in a pale- to medium-grey, aphanitic matrix. Grain size of the matrix (dominantly of albite microlites and quartz; 0.5–0.15 mm) is coarser than the microfelsic matrix of many extrusive rhyolite units in the map area.

Rhyolite fragment breccia, conglomerate, and grit extend for 3000 m southwest of the dome. If unfolded, the restored apron of breccia would extend for about 4500 m. The unit is thickest (about 400 m) in its central part, thins slightly toward the dome, and tapers out at the northern and western extremities.

Figure 11 shows internal stratigraphy through the breccia on the east limb of the syncline. The section contains three massive units of felsic breccia (90–170 m thick), each overlain by pebbly volcanic wackes, or grits. The breccia comprises coarse (15–20 cm, but to 60 cm across) angular to rounded boulders and blocks of abundantly porphyritic, white-weathering rhyolite (similar to the adjacent dome, although some are more abundantly porphyritic than any rhyolite exposed) and minor andesite in a matrix of fine breccia to coarse grit. Large clasts may form an open to intact framework, but clasts less than 10 cm across usually are closely packed. In spite of the crude upward grading of clasts, all parts of the units are unsorted and unstratified. Elongation and strong preferred orientation of clasts parallel to axial trace of the fold, are interpreted to result from flattening.

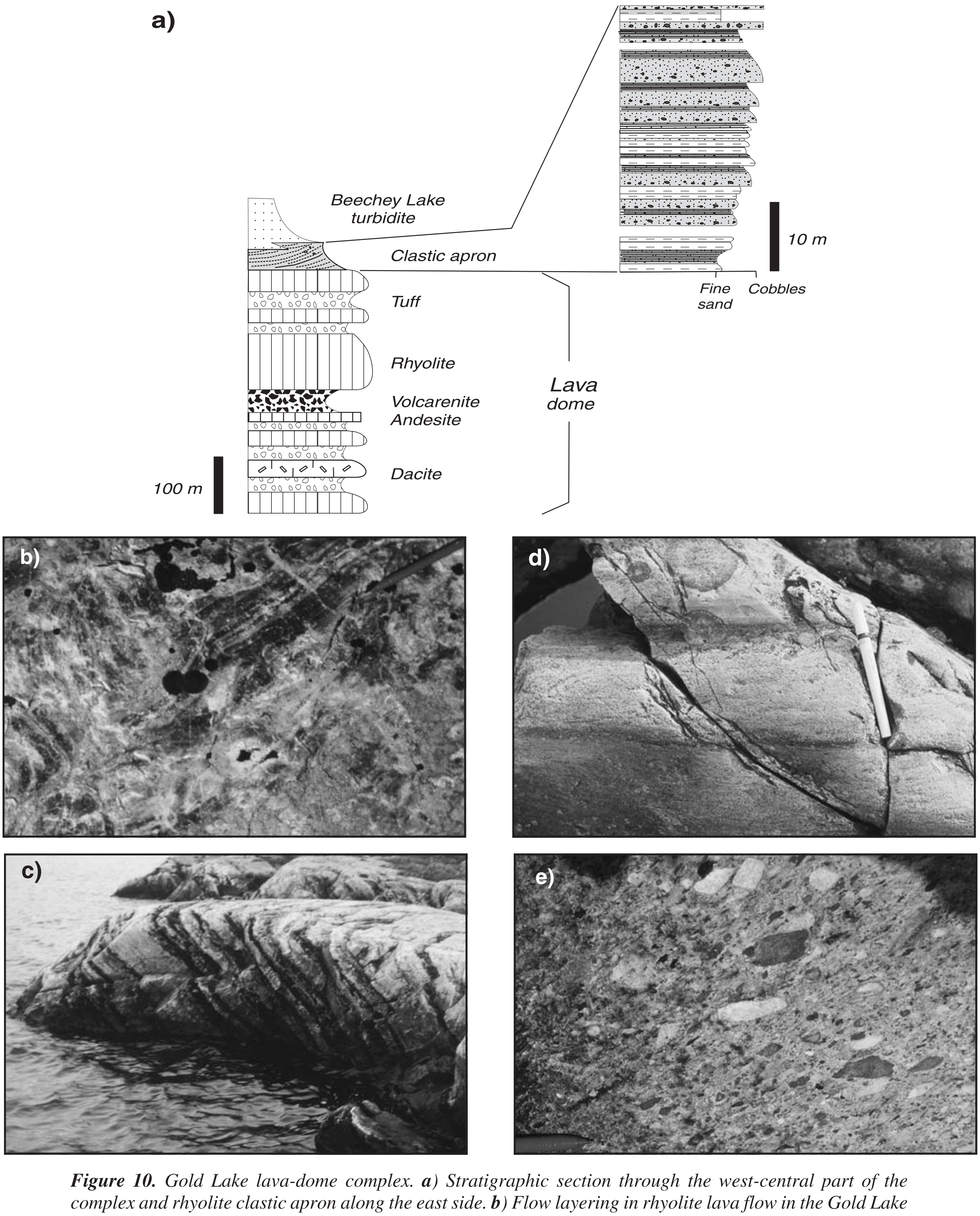


Figure 10. Gold Lake lava-dome complex. ***a***) Stratigraphic section through the west-central part of the complex and rhyolite clastic apron along the east side. ***b***) Flow layering in rhyolite lava flow in the Gold Lake lava dome. Pen (in upper right) is 8 mm thick. Photograph by M.B. Lambert. GSC 1995-244I. ***c***) Rhyolite turbidite beds in clastic apron on east side of Gold Lake dome, dipping 40°SE. Exposure is about 20 m across. Photograph by M.B. Lambert. GSC 1995-244A. ***d***) Detail of rhyolite turbidite beds shown in Figure 10c. Photograph by M.B. Lambert. GSC 2002-771. ***e***) Polymictic pebble breccia (unit ĀBer) in detrital apron near the northeast end of Gold Lake dome. Pencil is 8 mm thick. Photograph by M.B. Lambert. GSC 1995-244F

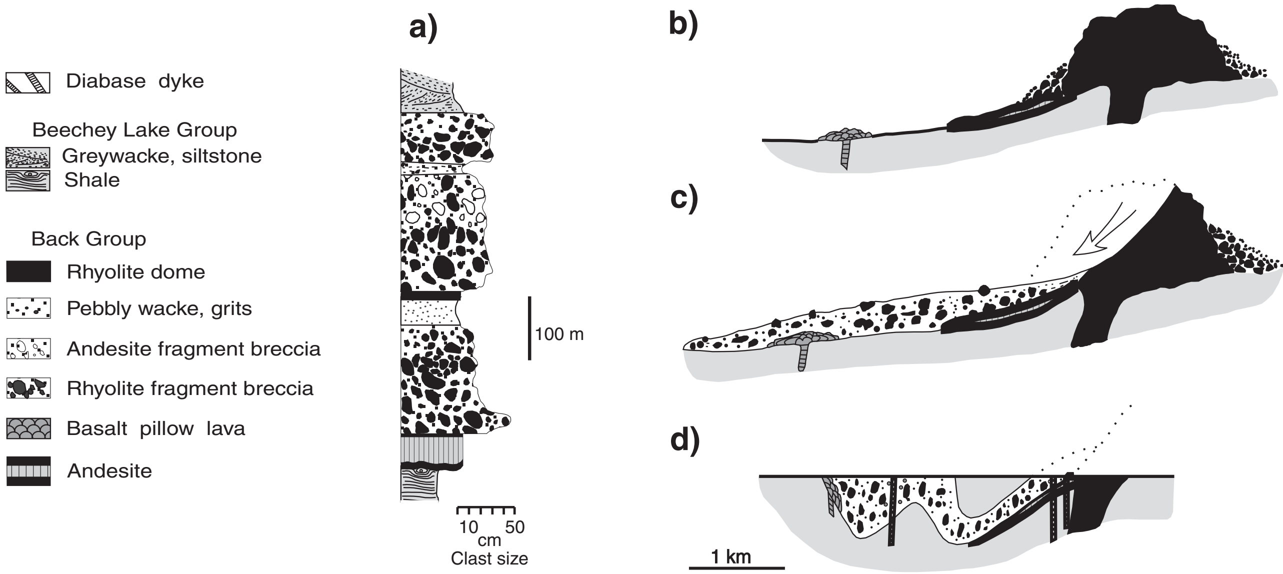


__Figure 11.__ Breccia and evolution of the Thlewycho north dome. __a__) Stratigraphic section through the breccia on the east limb of the syncline. Evolution of the dome and flank deposits: __b__) effusion of dome, __c__) destruction by mass wasting, and __d__) present level of erosion.

Near the fold nose, breccia grades laterally into interbedded felsic fragment conglomerate and pebbly wackes, then into interbedded pebbly wacke, coarse grit, and massive wacke. Bedding becomes increasingly better developed as the size and abundance of pebbles decreases and the proportion of wacke increases. Wacke varies from thick massive beds to graded and cross-stratified units. It carries subrounded to subangular rhyolite and andesite pebbles, (generally <4 cm but to 10 cm) that are suspended in massive beds, entrained to define crude cross-stratification, or concentrated at the bottoms of beds.

In one place on the southwestern side of the dome, well sorted clastic rocks, comprising closely packed rhyolite fragments and 30–45% plagioclase crystals in very fine matrix, may be crystal-lithic lapilli tuffs rather than epiclastic rocks.

This dome rose through a greywacke-siltstone succession along the margin of the main volcanic complex (Fig. 11b). The elongate form of the present remnant of the dome suggests that it may have risen along a linear fracture. Felsic volcanism began with explosive (possibly phreatomagmatic) eruption in which phenocryst-rich magma exploded to form crystal-lithic tuffs. As the dome rose, it probably shed aprons of coarse detritus along its flanks. The dome was likely destroyed by massive landsliding (and possibly by violent explosions) which produced extensive debris flows into the sedimentary basins to the west (Fig. 11c). The present level of erosion exposes the roots of the rhyolite dome and the folded voluminous breccia aprons that represent its destruction (Fig. 11d). The bulk of the original dome is no longer exposed.

__Figure 12.__ Flow layering in rhyolite lava at south end of Thlewycho Lake. Exposure is 80 cm high. Photograph by M.B. Lambert. GSC 1995-244L

Thlewycho east lava dome. The 1.5 km by 10 km rhyolite complex along the southeast side of Thlewycho Lake comprises massive flow units that are flow-layered (Fig. 12) and autobrecciated rhyolite along the western margin (the dominant variety). The grey- to white-weathering rhyolite contains 1 mm quartz phenocrysts (5%) in microfelsitic matrix. The rhyolite weathers pink adjacent to large gabbro dykes where it has been affected by thermal alteration. Numerous zones of intense shearing mark faults within the rhyolite.

Figure 13. *Debris-avalanche deposit on the southwestern side of the Thlewycho east lava dome.* ***a***) *Brecciated blocks, slabs, boulders, and pebbles of rhyolite in a massive, carbonate-cemented, unsorted, coarse grit matrix. Photograph by M.B. Lambert. GSC 2002-772.* ***b***) *Detail of unsorted matrix. Knife is 23 cm long. Photograph by M.B. Lambert. GSC 2002-773*

Shear zones generally contain abundant brown- to grey-weathering carbonate, disseminated pyrite, and locally contain galena, sphalerite, and chalcopyrite mineralization.

A volcaniclastic apron (not distinguished on the map) around northern, western, and southern sides of the lava complex include coarse, felsic breccia, debris-avalanche deposits (Fig. 13), and rhyolitic volcrudite to volcarenite. At the northern end, these coarse, rhyolitic volcaniclastic units (included within the rhyolite unit) merge with volcaniclastic rocks (unit ĀBTp), which here are mainly polymictic breccia.

A 72 m volcaniclastic section divides the north end of the rhyolite complex. It comprises parallel-bedded, finely laminated to medium-bedded, white porcellanite (rhyolite ash); dark grey to green, chloritized, quartz-phyric, dacitic tuff; heterolithic volcaniclastic rock (lithic tuff or epiclastic rock); 1.5 m of thin-bedded couplets with porcellanite grading to shale; and 3 m of black mudstone. This succession is interpreted as dominantly air-fall, fine, rhyolitic ash. It represents a temporary hiatus in rhyolite lava effusion, during which frequent and probably minor explosions from a rhyolite centre deposited fine ash. At about the same stratigraphic horizon to the south, a basalt unit, whose western side is in part fault-bounded against the rhyolite, but whose eastern side lies on beds of wacke, shale, and quartz-rich sandstone above rhyolite, may lie within a depression in the rhyolite dome rather than divide it. The 47–60° westward dip of these beds suggests steep attitude of the flow complex.

Along the western side of this rhyolite complex, a series of thick- to thin-bedded felsic volcaniclastic units (conglomerate, volcarenite, and tuff) interfinger with shale, siltstone, and iron-formation of the overlying Beechey Lake Group (Fig. 14).

Intrusive rhyolite. A 7 km by 800 m rhyolite body intrudes, but is completely contained within, the volcaniclastic apron on the northwestern side of the Innerring sequence northeast of Innerring Lake. It tapers out abruptly at both ends and forms a complex interdigitating pattern at its west end. This white-weathering, massive rhyolite has up to 25% feldspar phenocrysts in central parts, but dark greenish-grey, fine-grained, sparsely porphyritic to aphanitic chilled margins. In contrast to typical rhyolite lavas in the area, which invariably have broad autobrecciated carapace and margins, this unit is generally not brecciated, except in local shear zones. The unit makes sharp, irregular contacts with enclosing volcaniclastic units, has aphanitic chilled margins, and in one place encloses xenoliths of andesite. Sharp intrusive contacts are common at the western end where a swarm of 1–3 m wide dykes inject volcaniclastic rocks and major contacts cut across stratigraphy at high angles. Contacts are steep (about 60–70° toward north) in contrast to shallower dipping (30–50°N) bedding in volcaniclastic units. This intrusive rhyolite may be the roots of a rhyolite dome and/or lava that effused at a higher stratigraphic level. It possibly intruded along ring fractures related to cauldron subsidence. Several fractions of zircon from this body yield highly scattered data that suggest a poorly defined age between 2690 Ma and 2660 Ma (Villeneuve et al., 2001);

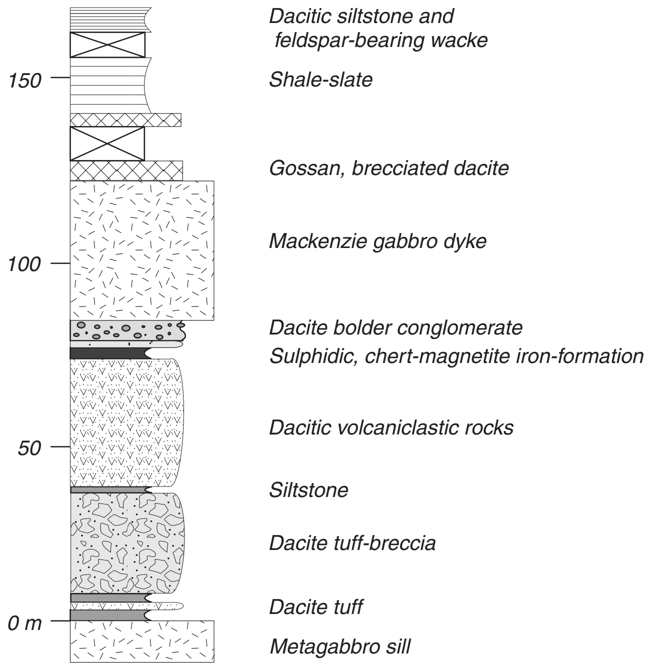


Figure 14. *Felsic volcaniclastic rocks of the Thlewycho sequence interbedded with steeply dipping shale, siltstone, conglomerate, and iron-formation of the Beechy Lake Group on the east side of Thlewycho Lake, reference locality 14.*

the age of the oldest fraction is in accordance with the 2692 ± 2 Ma age of late Thlewycho sequence rhyolite east of Jim Magrum Lake (van Breemen et al., 1987).

Numerous small rhyolite dykes that transect stratigraphy of both the Innerring and Thlewycho sequences are presumed to be related to the many dome-flow complexes. At the southeast end of Rusty Lake, a thin rhyolite dyke can be traced continuously for 1200 m, cutting through andesite lavas and volcaniclastic rocks to where is effused at the surface to form a small dome and its clastic carapace-apron measuring about 100 m thick and 700 m across.

Interpretation. The numerous, discrete rhyolite domes and flows at the top of the Thlewycho sequence are part of an episode of felsic magma effusion from several eruptive centres around the stratovolcano. Historically, rhyolite domes represent effusion of viscous magma immediately above eruptive centres, that form stubby flows and local thick accumulations rather than laterally extensive lava fields (*see* Williams and McBirney, 1979). The circular arrangement of the domes and flows of the Thlewycho sequence around the southern complex may indicate eruption from a series of vents whose locus marks a ring-fracture system (Smith and Bailey, 1968). The large intrusive rhyolite body southeast of Rusty Lake probably is a ring-fracture intrusion similar to ring dykes of well established cauldron subsidence complexes (Lambert, 1974; Smith and Bailey, 1968). Although the southern part of the volcanic complex is a broad structural dome, the numerous rhyolite units are not considered simply to represent a folded layer of rhyolite (that would have been about 30 km across).

Volcaniclastic rocks

Volcaniclastic rocks (unit ĀBTp), make up a major portion of the Thlewycho sequence. They comprise a variety of tuffs and tuff breccia, breccia, volcanic arenite, conglomerate, and debris-avalanche deposits. Volcaniclastic rocks of pyroclastic origin dominate the unit in the 'southern complex' although the proportion of epiclastic material increases on the northeastern side. Much of the volcaniclastic unit north of Outerring Lake is undifferentiated. Volcaniclastic rocks between Outerring and Boucher lakes contain polymictic breccia and possible tuff breccia that have ubiquitous clasts of porphyritic andesite.

On the southeastern side of the 'southern complex', the main volcaniclastic unit between the basal andesite lavas and the Gold Lake rhyolite dome comprise about 300 m of pyroclastic flow deposits interrupted by one or two thin lavas. In one place, the uppermost 15 m of this unit comprises four air-fall pyroclastic cycles, each comprising crudely layered agglomerate overlain by fine-ash tuffs (*see* enlarged part of Gold Lake section, Fig. 6). The agglomerate units (Fig. 6c) contain scoriaceous bombs and blocks, 1–15 cm across, in a matrix of fine ash to lapilli tuff. These cycles document four explosions that occurred before the effusion of the next lava series.

Units interpreted as nonwelded ash-flow tuffs (west and north of the Gold Lake dome), are pale green-grey- to medium green-grey-weathering, blocky-fractured, very massive, fine- to coarse-ash tuffs and lapilli tuffs that contain variable amounts of dacite and porphyritic andesite fragments in tuffaceous matrix resembling andesite, locally with abundant feldspar crystals to 2 mm. Composition probably ranges from andesite to dacite. Some areas of tuff breccia comprising andesite and dacite fragments in green-grey tuffaceous matrix may be laharic breccia.

The broad unit of volcaniclastic rocks east of Rusty Lake contains pyroclastic flows, epiclastic volcarenite, and debris-avalanche deposits. These units commonly contain abundant porphyritic, felsic clasts of similar lithology to units of the Innerring sequence. They lie at the same stratigraphic horizon as the dominantly pyroclastic rocks of the Thlewycho sequence to the south, and lie above the epiclastic apron of the Innerring sequence.

Numerous pyroclastic and epiclastic horizons (up to 30 m thick) mark boundaries between flow units within the Gold Lake lava-dome complex. The pyroclastic rocks vary from fine-grained ash- or crystal-ash-tuffs to crystal-lithic lapilli tuffs. They are hard, white- to buff-weathering rocks like the massive rhyolite. In general, tuffs form thinner layers than the epiclastic horizons. Coarse tuffs contain relicts of glass shards; lapilli with cuspidate margins, suggesting broken bubble walls or pumiceous material; fragments of broken feldspar crystals; and in some cases, lithic lapilli of porphyritic andesite. Clast sizes range from 1–2 mm to 10 cm, with most large clast sizes between 5 mm to 20 mm. Most units are massive; bedding is rare. Poorly sorted, massive units are interpreted as nonwelded ash-flow tuffs. Rare, thin-layered units are probably air-fall tuffs.

Beds of crystal-rich volcarenite and crystal tuffs occur within the Beechey Lake turbidite on islands in Gold Lake, and on the eastern side of the lake. These units are possibly related to the nearby Gold Lake dome complex.

On the western side of the 'southern complex', the thick volcaniclastic succession contains both pyroclastic and epiclastic material, but most is interpreted to be andesitic ash-flow tuffs, including both nonwelded and welded varieties. On the northeastern side of Thlewycho Lake, felsic volcaniclastic rocks are interbedded with shale, carbonaceous siltstone, and locally iron-formation of the Beachy Lake Group. They appear to be of dacitic composition and include possible tuffs, dacite cobble conglomerate and epiclastic volcaniclastic sediment (Fig. 14). Invariably the shale or siltstone are pyritic and weather as gossans in the order of 15 m wide.

Northeast of Jim Magrum Lake, basal andesite and dacite lavas of the Thlewycho sequence are interlayered with tuffs of similar composition. These units are overlain by a thick (about 400 m) succession of nonwelded ash-flow tuffs (Fig. 6e, crystal tuffs (some containing 60% crystals of quartz and feldspar)) and volcaniclastic rocks of epiclastic origin that extend around the southern and southeastern sides of the complex and interfinger with major lobes of the Gold Lake lava dome.

Epiclastic units

Epiclastic rocks form the wide band of volcaniclastic rocks within the central part of the Gold Lake dome complex, and also lie between the northwestern sides of the rhyolite complex and the underlying andesite to dacite lava-flow sequence. These units are grey-, greenish-grey-, to dark grey-weathering, poorly sorted, polymictic volcarenite that have knobby to pitted weathering surfaces. The silty matrix is notably much softer than that of white-weathering rhyolitic tuffs. Clasts of porphyritic andesite (2–5 cm and locally up to 10 cm across) and feldspar crystal fragments are much more abundant than rhyolitic clasts, except in the wide central band, where rhyolite clasts dominate.

A clastic apron that lies on rhyolite flow breccia along the southeastern side of the Gold Lake lava dome includes unsorted to poorly sorted coarse rudite to fine pebbly sandstone, with clasts derived mainly from adjacent felsic flows and rhyolite turbidite (Fig. 10c, d).

Interpretation

Pyroclastic deposits of the Thlewycho sequence represent a period of major explosive volcanism, mainly in the southern part of the complex that deposited hot, welded-ash flows and frequent air-fall deposits of agglomerate and tuff. They document numerous explosive events during effusion of the felsic dome complexes.

The numerous epiclastic units mainly denote areas of local erosion (possibly fluvial activity) and mass wasting that took place throughout Thlewycho volcanism, but mainly during the waning phases of the volcanism.

Boucher-Regan sequence

Definition and distribution

The Boucher-Regan sequence comprises tholeiitic basalt, andesite, dacite, and rhyolite units that overlie the Thlewycho sequence mainly in the northern parts of the volcanic complex. The tholeiitic basalt and andesite generally contain mafic phenocrysts (with or without plagioclase phenocrysts) in contrast to dominantly feldspar-phyric calc-alkaline andesite of the Thlewycho sequence. The mafic units ascribed to the Boucher-Regan sequence form: 1) massive to pillowed lavas, breccia, and related sills in a 40 km long area, stretching along the northern margin of the complex from Fidler Lake to north of Keish Lake; 2) units of pillow lava and pillow breccia that overlie Thlewycho dacitic and volcaniclastic rocks, between Outerring Lake and Boucher Lake; 3) basalt lava flow units within the 'Keish Lake volcaniclastic fan', south of Quartermoon Lake; and 4) two small basalt flows at the top of the Thlewycho sequence, north of Gold Lake and southeast of Thlewycho Lake, in the southern part of the complex. Felsic members of this sequence include rhyolite to dacite lava flows, domes, and tuffs that overlie the mafic lavas, lie at or near the top of the Keish Lake volcaniclastic fan, and occur within Beechey Lake Group turbidite units along the northwestern side of the complex.

Lithology

Basalt lavas

Most of the basaltic rocks of the volcanic complex are exposed in two east-northeast-trending anticlines between Keish Lake and the northwest end of Regan Lake (Fig. 1). This lava succession comprises massive to brecciated flows, pillow lavas, and pillow breccia. Large metagabbro units within the main basaltic succession, which are intruded by Boucher-Regan rhyolite, are interpreted as shallow sills related to the main basaltic lava pile. Massive flows are dark green, dense, aphanitic to fine-grained, hornblende-phyric basalt. On the crest of the northern anticline, where basalt units have a nearly horizontal disposition, massive units have well developed columnar joints, with four- to six-sided vertical columns that are 1–2 m across.

The basalt lava-flow succession, however, is predominantly pillow lavas and pillow breccia. Pillowed units at the crest of the northern anticline contain upward-facing, undeformed pillow lobes and tubes (Fig. 15a). Pillows also appear virtually undeformed along the southern side of this anticline, and near the east end of the southern anticline: they vary from equant, round forms to an assemblage of elongate tubes that resemble foreset lava toes (Fig. 15b). Pillow breccia typically comprise a jumble of 5–10 cm (but up to 100 cm), rounded, angular and elongate blocks, some pillows or flakes of pillow selvages in a basaltic matrix containing variable amounts of carbonate.

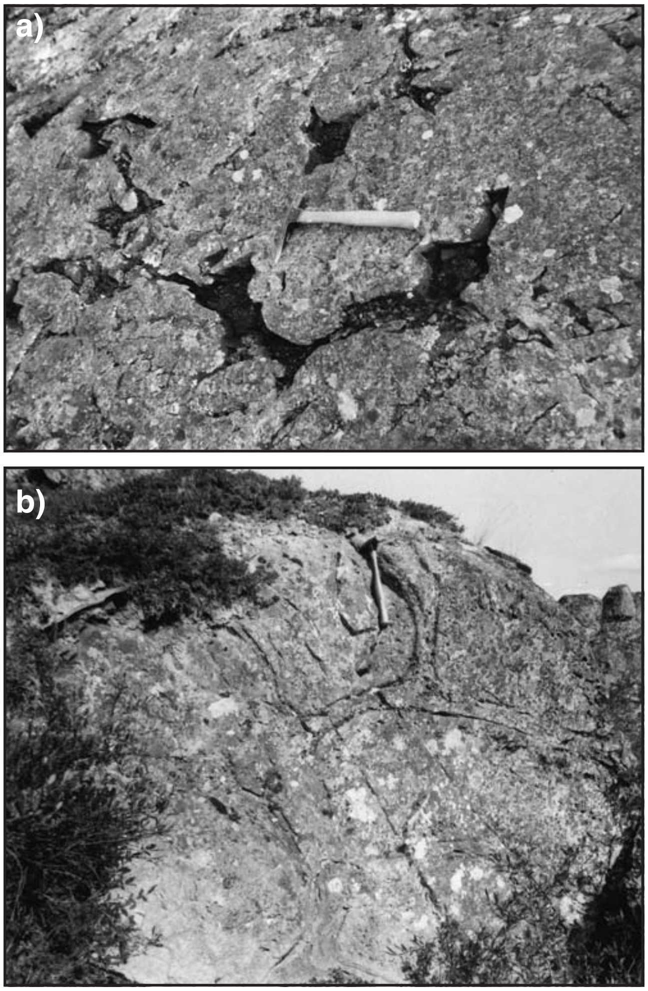


Figure 15. Undeformed basalt pillow lavas of the Boucher-Regan sequence. ***a****) Pillow lobes; top view of nearly horizontal unit at crest of major anticline north of Keish Lake. Hammer is 33 cm long. Photograph by M.B. Lambert. GSC 2002-774.* ***b****) Pillow tubes on south side of the major anticline; coarse vesicular upper margins. Hammer is 33 cm long. Photograph by M.B. Lambert. GSC 2002-775*

Along the northern margin of the main basaltic succession, flow breccia and pillow breccia contain ubiquitous carbonate. Within 100 m of the contact with the overlying Beechey Lake Group, carbonate forms veins and brown-weathering interstitial cement and pods. In some areas where carbonate is abundant, basalts weather pale greenish-grey to almost white. The amount of carbonate increases toward the northern contact. In some places, breccia blocks are supported in the carbonate matrix. Locally such units are overlain by massive carbonate beds up to 10 m thick.

Sedimentary rocks of the Beechey Lake Group overlying these volcanic breccia units are shale, siliceous argillite, wacke, and locally polymictic conglomerate (that contain clasts of basalt, and minor ?chert and felsic volcanic material). Locally the adjacent basalt breccia contains units of mafic volcaniclastic sedimentary rocks, as well as beds of argillite; possibly indicating interbedding of flows with the Beechey Lake Group. Such interbedding suggests that there was no significant time break between mafic volcanism and sedimentation of the Beechey Lake Group. Gossans, containing abundant disseminated pyrite and pyrrhotite, occur in both sedimentary and volcanic rocks all along the northern side of the basalt succession.

Volcaniclastic material composes most of the mafic unit, exposed in the crest of an anticline in the Beechey Lake Group, in the northwestern corner of the map area. Although massive hornblende basalt forms a central ridge, the surrounding rocks are green-weathering, foliated, and sheared volcrudite, comprising lenticular to elongate fragments (1–5 cm long) in a dark green matrix. White-weathering felsic fragments are common in the eastern end of the unit. Carbonate-bearing breccia weathers variably white, grey, to mottled dark green, and pyrite- and pyrrhotite-bearing sheared matrix of breccia weathers reddish brown. Crude layering within the units may mark flow boundaries, whereas layering near contacts with Beechey Lake sedimentary rocks may be bedding, or in some cases, a 'pseudo bedding' related to shearing. Although much of this unit may be sheared, mafic flow breccia, parts of it (that contains small clasts of both mafic and felsic fragments in a fine basaltic clastic matrix) probably represent epiclastic detritus, derived mainly form the underlying basaltic lava flows and nearby rhyolite bodies.

Between Outerring Lake and Boucher Lake, the sporadic areas of basalt pillow lavas that overlie the volcaniclastic rocks of the Thlewycho sequence cap ridges and thus possibly are erosional remnants of a widespread flow unit.

About 5 km south of Quartermoon Lake, a thick basalt lava flow unit lies conformably within folded volcaniclastic sedimentary rocks of the Keish Lake volcaniclastic fan. Fold repetition of this distinctive flow accounts for the four or five northerly trending map units. The western unit is 175 m thick for most of its 8 km strike length, but tapers to 15 m thick within 1 km of its northern end. Strike lengths of the other units diminish eastward to less than 3 km. This single flow unit is porphyritic basalt, containing black hornblende (possibly retrogressed pyroxene or primary hornblende phenocrysts) phenocrysts (3–10 mm) in a green to almost black aphanitic matrix. The eastern end of the longest map unit contains well developed pillows (0.5–2 m across) with distinct selvages (5–7 mm wide). Within 200 m of this end, the unit changes from a pillowed flow to a massive columnar-jointed flow with amygdaloidal margins. This change in flow characteristics suggests that the southern side of a primarily subaerial lava flow entered water; subaqueous environment at this end of the flow is also indicated by adjacent bedded volcarenite that have scour, load-cast, and crossbedding structures. The change in strike length of the folded components of this unit suggests variation in width of a fan-shaped lava flow that spread out in a westward direction.

In the southern part of the volcanic complex, two units of basalt at the top of the Thlewycho sequence are correlated with the Boucher-Regan sequence: a lava unit on the rhyolite lava succession on the southeast side of Thlewycho Lake; and a folded unit overlying Thlewycho sequence volcaniclastic rocks north of Gold Lake.

The basalt unit southeast of Thlewycho Lake is an approximately 100 m thick by 3500 m long lava-flow unit that trends obliquely across the Thlewycho east lava dome. Part of the western side of this basalt is sheared and may be in fault contact with the adjacent rhyolite. The eastern side of the flow is underlain by a 10 m carbonate-cemented clastic sequence that includes thick-bedded, unsorted basalt breccia with two thin interbeds of graded, ripple-marked basaltic wacke, and thin basal lenses of shale and quartz-rich sandstone. This basal sedimentary stratigraphy, and the rhyolite inclusions in the base of the flow, suggest that the unit lies stratigraphically above the rhyolite rather than within it. The unit comprises a coarsely amygdaloidal massive flow with basal flow breccia, as well as areas of elongate lobes. Basal flow breccia includes clasts of rhyolite up to 10 cm across. The 0.5 m diameter lobes have abundantly amygdaloidal margins and thin (2 mm) selvages. Carbonate-filled vesicles, from 1–10 mm, are round to elongate parallel to flow boundaries. The flow lobes are interpreted as subaerial pahoehoe lava toes rather than pillow lavas.

The basalt north of Gold Lake is a poorly exposed, rubbly unit that lies between volcaniclastic rocks and iron-formation. The unit comprises dark green, massive, amygdaloidal basaltic rocks and associated breccia, and minor mafic volcaniclastic rocks. Coarse breccia and volcaniclastic material may be flow breccia, scree, and detritus derived from mafic flow.

Basalt sills

Large basalt sills are folded within the mafic succession north of Keish Lake and within immediately overlying turbidite of the Beechy Lake Group. They have intruded conformably, or at a shallow angles to the pillow lavas and bedding. Northeast of Quartermoon Lake, rhyolite of the Quartermoon Lake dome has intruded and enclosed both mafic sills and the basalt lavas they intrude. These sills, which are older than the Boucher-Regan rhyolite, are interpreted as shallow intrusions within the lava pile that fed the basalt flows; thus they are considered to be an integral part of the basalt succession.

North of Keish Lake, the massive, blocky-jointed sills are dark grey- to brownish-grey-weathering, fine- to coarse-grained, amphibole-rich diabase to mafic porphyry containing 3–10 mm poikilitic amphibole phenocrysts in a grey to dark green, fine subophitic matrix. Sills have aphanitic to fine-grained margins that lack the flow breccia that are typical of the massive lava flows of the succession. The southern margin of the sill is locally sheared and carbonate bearing in contact with turbidite, and invariably contains about 1% disseminated pyrite and pyrrhotite, and locally chalcopyrite.

Within 2 km east of Keish Lake, a massive basaltic unit, exposed in a large synclinal keel, and other smaller units folded in the Beechey Lake Group, are interpreted as sills because of their structural and lithological similarity to the sills to the north, and because they completely lack breccia or pillow breccia characteristic of basalt flows in the area. These units could be shallow sills related to the large sill within the basalt pile to the north that intruded into Beechey Lake turbidite flanking the volcanic belt.

Andesite

Andesite units of the Boucher Regan sequence (unit ĀBBa) occur mainly in a southeasterly trending belt about 2.5 km wide and 20 km long north of Regan Lake; along the southern side and northeast ends of large northeast-trending anticlines, between Regan and Keish lakes; and in the noses of folds near Northring Lake. Andesite units of this sequence have very flat to negative magnetic expression in contrast to the intensely magnetic basalt lavas. The units contain massive porphyritic lavas and sills, pillow lavas, pillow breccia, and andesitic volcarenite and tuff (this map unit possibly contains basaltic rocks in some areas where compositional types have not been distinguished). Lithologies include pale green- to dark green-weathering hornblende (? retrograde pyroxene)-, or hornblende-plagioclase-phyric andesite. In some areas, altered carbonate-bearing breccia weathers pale grey to white in contrast to the normal green-weathering breccia.

The belt north of Regan Lake is dominantly flow breccia, pillow lavas, pillow breccia, and hyaloclastite. Breccia comprises angular to subangular blocks of porphyritic andesite (generally 5–20 cm, but up to 50 cm), in a green, andesitic groundmass of fine breccia and grit. Constituents are unsorted and the rocks generally are not layered. The few bedding symbols shown on the map mark rare occurrences of bedded (in one place crossbedded) volcaniclastic sedimentary rocks, that indicate boundaries between flow units. In some cases, top-unknown bedding symbols within the breccia indicate a crude layering or clast orientation that may be related to flow mechanism rather than sedimentary bedding. Clast orientation, however, that is parallel to the main foliation in these rocks is regarded as a tectonic feature. Well bedded volcaniclastic sedimentary rocks are common near the northern and southern sides of this belt. In one place along the southern side, crystal-rich, andesitic, bedded rocks may be water-laid crystal tuffs.

Between Regan and Keish lakes, andesite along the southern side of the northern anticline are massive porphyries and columnar-jointed lavas, locally with coarse, calcite-filled amygdales. These rocks contain up to 30% plagioclase phenocrysts, with lesser amounts of amphibole phenocrysts, in an aphanitic, green to grey matrix. About 3 km to the south, andesite units are slightly deformed pillow lavas and pillow breccia.

East and north of Outerring Lake, andesite units are amygdaloidal, hornblende-phyric andesite pillow lava and pillow breccia. Breccia units within 50 m of the contact with overlying iron-formation and Beechey Lake sedimentary rocks contain abundant carbonate cement. Andesitic units exposed intermittently in crests of anticlines within the Beechey Lake Group are mainly light brown-weathering volcanic siltstone. They contain hornblende, plagioclase, and minor quartz and pyrite. These siltstone units probably represent a volcaniclastic apron on the sides of the pillow-lava sequence.

Two kilometres northeast of Boucher Lake, the andesite unit within Beechey Lake sediments is a columnar-jointed sill that has trachytic texture defined by alignment of acicular, quenched, swallow-tailed plagioclase phenocrysts. Sedimentary rocks at the chilled contact of the sill are hornfels.

Abundance of pillow lavas and pillow breccia indicate that the andesite lavas of the Boucher-Regan sequence effused in a mainly subaqueous environment. Near Regan Lake, they may have erupted from major fissures to produce a domal ridge on the submerged northern flanks of the stratovolcano. A few small areas of shale and siltstone in the centre of this belt suggest that the crest of the anticline is very near the contact with Beechey Lake sedimentary rocks.

Felsic lavas, domes, and tuffs

Rhyolitic to dacitic units (ĀBBr and ĀBBd) that lie above mafic lavas of the Boucher-Regan sequence include a series of discrete domes and lava-flow units around the northern and northwestern parts of the volcanic complex, a large rhyolite dome between Boucher Lake and Keish Lake, and units of tuff near Boucher Lake. Strong magnetic anomalies occur over some of these domes (Fig. 16 on CD-ROM).

Tuffs occur on the southern and northwestern sides of Boucher Lake. South of the lake, massive, fine-grained dacite units, containing pumice and shards, are possibly ash-flow tuffs. One well bedded and graded unit of air-fall tuff lies within these rocks. Northwest of the lake, massive dacite units containing up to 25% K-feldspar and plagioclase may be crystal tuffs. Many of the other areas of dacitic rocks scattered west of Regan Lake have not been subdivided; they contain quartz- and locally hornblende-phyric dacite.

The numerous felsic domes and flows make up a significant portion of the Boucher-Regan sequence. Some units have trace-element chemistry that distinguishes them from the rhyolite bodies of the Thlewycho sequence in the southern part of the volcanic complex (*see* 'Petrochemistry'). One of the domes, a composite rhyolite-dacite dome northeast of Keish Lake, is documented in detail below. The numerous rhyolite outcrops protruding through abundant drift cover between Quartermoon Lake and Boucher Lake mark the largest lava dome of the volcanic complex, herein referred to as the Quartermoon Lake dome.

Quartermoon Lake dome. The Quartermoon Lake dome is 7 km by 13 km at surface. Much of its central part is obscured by thick lobes of glacial drift, but large areas of continuous outcrop occur on the eastern and western sides. Although the rhyolite overlies basalt of the Boucher-Regan sequence near the northern part of the dome and dacitic rocks and volcaniclastic rocks of Thlewycho affinity on its eastern sides, it also intrudes and encloses parts of these units. The dome is overlain by argillite and siltstone of the Beechey Lake Group on its northeastern and western sides. Sporadically exposed carbonate units associated with rhyolitic volcaniclastic aprons along this contact host three of the stromatolite localities. Rhyolite fragment debris-avalanche deposits and megabreccia that form an extensive apron on the southwestern side of this dome are described as part of the Keish Lake clastic fan.

Near the western side of this dome, where rhyolite has intruded and enclosed large irregular areas of basaltic rocks (mainly sills but also basaltic lavas) and formed swarms of dykes in the basalt lavas, contacts with basaltic rocks are irregular and sharp. Near these contacts, rhyolite includes blocks (up to 2 m across) and screens of aphanitic basalt, and fine- to medium- grained, ophitic gabbro. Near one contact, a 70 m wide swarm of thin, irregular rhyolite dykes has injected the basalt. Small rhyolite dykes also have intruded basalt flows and sills on the north side of the dome and volcaniclastic units on the southeast side.

The rhyolite outcrops comprising this dome are remarkably uniform; they are massive, blocky jointed, and almost devoid of any primary structures. Although autobrecciation occurs along the western and southwestern sides, and in very few small areas on the eastern and northen sides of the dome, there is no brecciation or layering throughout most of the dome to indicate internal flow boundaries. The white-, buff-, to pinkish-weathering rhyolite forms aphanitic to sparsely porphyritic rocks comprising fine (<2 mm) phenocrysts of plagioclase (5–25%), potassic feldspar (<5%), quartz (2–5%), and an altered mafic mineral (<1%, now chlorite, biotite) in an aphanitic grey matrix. Matrix is a microfelsic mass of equigranular quartz, feldspar, and sericite. The rhyolite units show little lithological variation, except for varying proportions of phenocrysts, and for some areas where matrix is relatively coarse grained (about 0.4 mm).

The uniform, massive, and generally unbrecciated nature of most of the rhyolite, and the areas of unusually coarse matrix grain size, may indicate that the present level of erosion is through the lower interior portion of this large dome, below the outer brecciated carapace. It is unlikely that a dome of this size would form as a single extrusive unit. Presumably some internal boundaries are hidden beneath the drift that covers much of this dome. The large apron of rhyolite-fragment debris-avalanche deposits in the adjacent Keish Lake fan suggests that part of the brecciated dome margin was stripped away by mass wasting during or immediately following eruption.

The intrusive relationship of rhyolite into basaltic lavas and sills constrains the age of the mafic sills and supports the interpretation that they are related to the basalt lavas that they intrude and not some postvolcanic intrusive event.

Composite dome. Three kilometres northeast of Keish Lake, a 1500 m by 2200 m, oval composite dome complex comprises remnants of an early rhyolite dome, a dacite dome that intruded the rhyolite, and epiclastic flank deposits. The northeastern margin of the dome is deformed and intensely sheared, with a small unit of shale and/or slate that appears to be folded into the northeastern margin of the dacite. The central part is only weakly deformed and appears to be preserved essentially in its upright position. Although structure in surrounding turbidite units suggests that Beechey Lake turbidite sequences generally overlie the dome, coarse flank deposits on the southwestern side of the dome overlie sedimentary rocks: these relationships again emphasize the contemporaneity of volcanic and sedimentary processes.

Remnants of an early rhyolite phase of the dome form an irregular margin (100–500 m wide) along the north and east sides of the complex; a wedge-shaped body near the west side; and lobes, 200–300 m across, in surrounding sedimentary rocks on the southeast side. This distribution suggests that the ancestral rhyolite dome may have been about 2100 m by 1000 m. The white-weathering rhyolite is aphanitic to sparsely porphyritic (but locally contains up to 20% fine-grained quartz and feldspar phenocrysts) and almost entirely brecciated. Most rocks are monomictic autoclastic breccia that is unsorted, unlayered, tightly packed masses of rhyolite clasts. Steep northwesterly trending shear planes on the northeastern side of the rhyolite divide the breccia into masses of lenticles and large slivers that locally give outcrops a crude banded appearance.

Dacite, which makes up about 60% of the present dome complex, has intruded and partly enclosed large portions of the rhyolite. At the northwestern end of the dome, small dacite dykes in black slate indicate that it has also intruded the surrounding sedimentary rocks. In contrast to the rhyolite, the dacite portion of the dome is massive, except for autobrecciation along part of its margin and local shear zones in northern parts. The distinctive, smooth, rounded dacite outcrops are devoid of layering, and have widely spaced, blocky joint patterns defined by three sets of fractures. The uniform dark-grey-weathering, dark-grey, aphanitic to plagioclase-phyric (1–2%) dacite contains inclusions of rhyolite (less than 5 cm across) that are scattered randomly throughout the body. Near contacts with rhyolite, however, the pebble- to cobble-sized (occasionally up to 3 m across) inclusions make up to 15% of the rock, and locally, they choke the dacite so that the contact between rhyolite breccia and inclusion-laden dacite can be distinguished only within about 30 m. Rare xenoliths of carbonate-cemented grit occur near contact zones.

Flank deposits are dominantly aprons of coarse breccia that pass upwards into fine breccia, pebbly grit, and wacke, all of which may be cemented with carbonate. In some places, the coarse deposits appear to lie on or against the dome, whereas in other places the transition from brecciated dome to coarse flank breccia is gradational. The coarse basal breccia units are massive, unsorted deposits in which clasts reflect the composition in the immediately adjacent dome. The deposit on the southwest side of the dome, for example, is a 200 m by 500 m wedge of dominantly dacite boulder breccia composed of closely packed blocks and boulders up to 50 cm across (but generally between 1 cm and 20 cm) (Fig. 17). Clast sizes dwindle laterally toward both ends of the deposit where the rock is a pebbly to bouldery grit. Minor constituents include rhyolite boulders and rare blocks of brown-weathering carbonate-cemented grit. The southern side of this apron conformably overlies shale and siltstone, suggesting interfingering of the flank deposits with the generally overlying Beechey Lake Group.

Along the northeastern margin of the dome, flank deposits are monolithic rhyolite block grit to pebbly grit. These approximately 10 m thick units vary from massive, unsorted beds to crudely bedded units in which rounded to subangular clasts show crude grading or basal concentrations. Matrix generally is unlayered, carbonate-cemented, fine- to coarse-grained, rhyolitic grit.

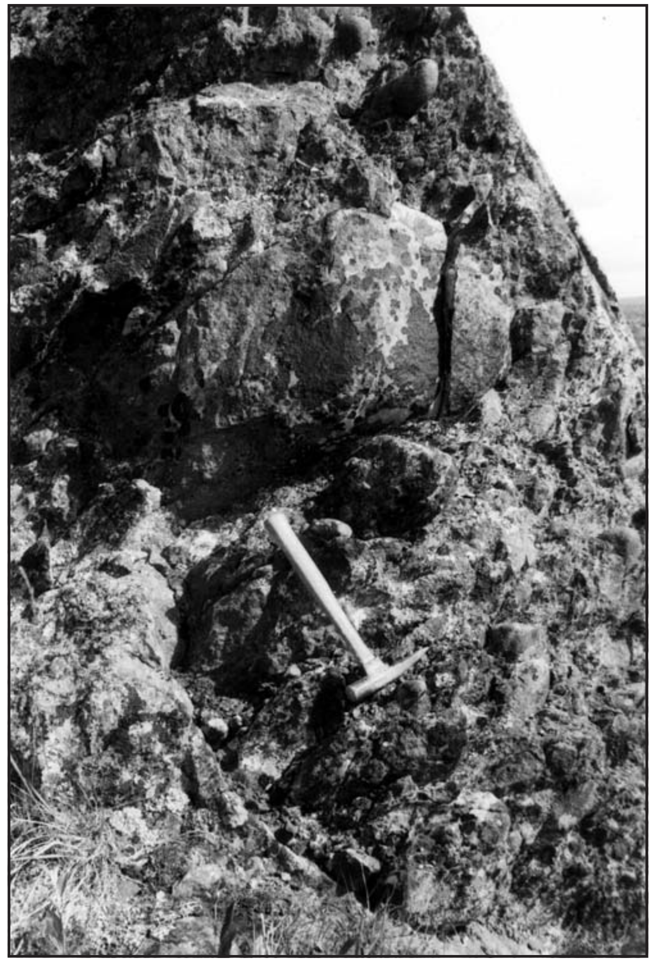


Figure 17. *Dacite boulder breccia on southwest flank of composite dome 3 km northeast of Keish Lake. Hammer is 33 cm long. Photograph by M.B. Lambert. GSC 2002-776*

Breccia along the northern margin of the dome is polymictic, but clasts are dominantly rhyolite. The angular to subangular clasts generally range from 1 cm to 10 cm. Rarely, large slabs (about 15 cm by 100 cm) are suspended in the finer breccia. In this area clasts include the dominant white rhyolite, as well as grey, aphanitic dacite, feldspar-phyric dacite, and medium green, aphanitic volcanic rock. Matrix is carbonate-cemented, coarse grit (comprising fine clasts of the same composition as the blocks).

On the southeast side of the dome, some coarse breccia forms elongate lobes in shallow troughs radial to the dome.

In contrast to the coarse flank deposits, volcaniclastic sediments on the southeast side of this dome and on the peninsula 300 m east of the dome are grey- to green-weathering, matrix-rich paraconglomerate units comprising subangular to well rounded rhyolite to dacite cobbles and boulders (10–30 cm) that are suspended randomly in massive volcaniclastic grit (Fig. 18), or form cobble-rich horizons that define crude beds up to 20 cm thick. At one place on the peninsula, a crudely graded, arenaceous bed at the top of a paraconglomerate contains up to 70% feldspar crystals. These paraconglomerate units are interpreted as laharic deposits derived from the dome and the feldspar-rich unit could be a water-laid crystal tuff.

This dome represents two stages of magma effusion. The initial rhyolite effusions probably were largely destroyed by explosive shattering, crumbling, and landsliding, during the subsequent emplacement of an upward-expanding dacite dome. Mass wasting from the complex produced banks of debris, talus, conglomerate, and rudaceous grit. Carbonate that cements flank deposits may have precipitated from late-stage fumaroles during the waning stages of volcanism from this centre. Landsliding, debris flows, and lahars carried coarse detritus on to basalt lavas for distances of at least 1500 m from the dome on the east side. Quartzite pebbles in some grits may have been derived from siliceous sinters related to the rhyolite dome.

Figure 18. *Rhyolite cobbles in massive grit in volcaniclastic sediment derived from southeast side of composite dome, 3 km northeast of Keish Lake. Hammer is 33 cm long. Photograph by J. Percival. GSC 2002-777*

Other felsic domes and flows. On the southwest side of Fidler Lake, a felsic lava flow (having a chemical composition of tholeiitic dacite) lies between andesite pillow lava and pyrite-rich (gossan-forming), black siltstone of the Beechey Lake Group. It is a homogeneous, dominantly autoclastic flow breccia, made up of tightly packed, equant, angular fragments (10–30 cm across) with interstitial fine breccia matrix. Clasts are elongate and have strong preferred orientation only where the unit is sheared, along parts of its northern and southern boundaries. The dacite is a pale greenish-grey- to white-weathering, porphyritic rock containing pink to white K-feldspar phenocrysts, and locally 1–2% fine (1 mm) hornblende phenocrysts, in dark greenish-grey, aphanitic matrix. Where the unit thins, near its northwestern end, it is locally a flow-layered autoclastic breccia comprising angular to round dacite blocks in a finely laminated matrix; laminations mold around fragments. This almost entirely brecciated unit, which lies between pillow lavas and siltstone, is interpreted as a subaqueous lava flow.

At reference locality 10 (Fig. 1), a 5 km long continuous unit of minimally or undeformed rhyolite overlies andesite pillow lavas and pillow breccia of the Boucher-Regan sequence. This rhyolite flow unit lies directly on the irregular upper surface of a pillowed lava flow (Fig. 15b) that undulates over a distance of about 100 m. No sedimentary rocks occur along this contact. The rhyolite is a finely porphyritic (2% quartz and 5% feldspar phenocrysts to 3 mm), white-weathering rock that is dominantly autoclastic flow breccia, except for some massive areas in the interior of its widest part. At the top of the flow, rhyolite grades over a distance of 2–10 m, from the massive rhyolite interior, through fractured rhyolite to flow breccia. The top of the flow, near its central part, is conformably overlain by rhyolite pebble and boulder conglomerate and a carbonate unit. In one place, rhyolite flow breccia grades into the overlying conglomerate (Fig. 19). Although these units are on the side of a broad major anticline, the lack of deformation is indicated by the sphericity of clasts, lack of penetrative foliation, and the virtually undeformed pillows of the andesite unit.

Seven kilometres north of Keish Lake, a highly deformed rhyolite body occurs amidst basin-and-dome interference structures within the Beechey Lake Group. The eastern end of this autobrecciated to massive rhyolite contains large slabs of sedimentary rock (one inclusion is 2 m by 8 m). On the western side, inclusions occur as streaks of sediment within the deformed margin of brecciated rhyolite. Attitudes of sedimentary rocks are steep (80–90°) near the eastern and western sides of the rhyolite, and the eastern side of the rhyolite is probably steeply overturned to the east. Argillite and wacke in contact with the rhyolite are invariably gossanous, containing disseminated pyrite, pyrrhotite, and also galena and sphalerite at one place on the northern end of the rhyolite. This body represents a portion of a rhyolite dome or flow preserved at the crest of a complex fold interference structure.

On the southeast side of Keish Lake, the rhyolite body surrounded by Beechey Lake Group rocks is mainly rhyolite breccia with massive areas in the north-central parts. This white-weathering rhyolite is generally aphanitic, almost resembling chert, with a few, fine-grained quartz and feldspar

__Figure 19.__ Rhyolite boulder conglomerate overlying rhyolite flow at reference locality 10. Pen is 13 cm long. Photograph by M.B. Lambert. GSC 2002-778

phenocrysts. Rhyolite boulder conglomerate occurs with breccia near northern and southern margins. Near the margins, carbonate cements breccia and forms small pods. Sedimentary rocks dip beneath the rhyolite at one place along the western side, and locally rhyolite along the eastern margin interfingers with argillite of the Beechey Lake Group. The contact is sheared in some places.

Six kilometres northwest of Thlewycho Lake, a rhyolite unit lies at the contact between epiclastic rocks of the Keish Lake fan and Beechey Lake sedimentary rocks. All exposures of this body are white-weathering, aphanitic, massive rhyolite. The contact with Beechey Lake sediments is exposed only in one place at the northwest end. Here, grey-weathering argillite and greywacke and minor conglomerate are in contact with massive, unsheared rhyolite. Nearby, well bedded volcaniclastic sediments, 200–300 m to the north contain rhyolite clasts, which could have been derived from this body.

Epiclastic volcanic rocks

This diverse map unit (ABe, ABed, ABer, ABert) comprises volcaniclastic rocks, which represent detritus eroded from the volcanic pile, from the end of Thlewycho volcanism to the end of Boucher-Regan volcanism. It includes the 'Keish Lake clastic fan', valley-filling avalanche deposits and deposits on sides of felsic domes, clastic aprons derived from mafic lavas, and rhyolite-derived turbidite and other volcarenite and tuff within the Beechey Lake Group.

Keish Lake clastic fan

This broad clastic fan (formerly the Keish sequence; Lambert et al. (1992), Lambert (1996, 1998), Villeneuve et al. (2001)) lies along the western margins of the volcanic complex between Keish Lake and Thlewycho Lake. The fan comprises large aprons of debris-avalanche deposits on the northern and southeastern margins, and a succession of westward-thinning and -fining, well bedded to crudely bedded volcrudite to volcarenite and minor bedded tuff in the central and southwestern parts. Greywacke-mudstone units of the Beechey Lake Group conformably overlie the western side of the fan, although locally, volcarenite and turbidite interfinger on a small scale. The moderately to steeply dipping beds of this succession are folded about northwesterly trending axes, and the western margin of the fan is steeply overturned to the southwest. Distinctive units within the fan, such as some debris-avalanche deposits and a basalt lava flow, show repetition by folding.

Debris-avalanche deposits of the Keish Lake fan form thick, massive aprons along the southern side of the Quartermoon Lake rhyolite dome, and on the western side of the rhyolite dome at the north end of Thlewycho Lake. They are polymictic breccia units (containing dominantly rhyolite blocks) that have abundant dark green to grey, gritty, pebbly arenaceous matrix. Although the breccia units were derived mainly from felsic domes, a variety of clast compositions indicates that they were eroded from a more varied source terrane; thus these units are mapped as rudite of the volcaniclastic succession. In contrast, the autobrecciated margins of the adjacent felsic domes are monomictic breccia units (containing about 80–90% rhyolite and/or dacite blocks) that have little matrix, comprising a crush of felsic material similar to the blocks. These breccia units (and related scree), which grade into the domes, essentially are products of the eruption processes, and are considered to be flank facies of the domes. In some places, however, where flow breccia appears to grade into avalanche deposits, the distinction is somewhat arbitrary, and is based on dominant populations of clast types, proportion of clasts to matrix, and lithology of matrix.

On the south side of the Quartermoon Lake rhyolite dome, debris-avalanche deposits form an apron about 5 km wide that extends about 2 km from the dome (considering folding, this apron probably extended 4–5 km southward from the dome). A smaller debris-avalanche deposit extends southeasterly for about 5 km along strike from a small rhyolite dome on the northwestern side of the Keish Lake fan.

Characteristics of debris-avalanche deposits vary systematically with distance away from the Quartermoon Lake dome: average clast size decreases (huge blocks, 50–200 m across are absent except for very close to the dome (*see* 'Valley-filling avalanche deposits')); proportions of rhyolite clasts decrease and andesite clasts increase; and thickness of units decreases. Although units remain massive, they become more sorted, and clasts become more rounded.

Within about 300 m of the dome (as measured on the map, disregarding folding) rare bedded intervals are the only indication of boundaries between depositional units. The debris-avalanche units are polymictic, unsorted to poorly sorted, boulder-and-block breccia, that contains various proportions of clasts including white- to cream-weathering, aphanitic to sparsely porphyritic rhyolite and dacite, grey to green porphyritic to aphanitic andesite, and rarely carbonate. Clasts have a complete range of shapes from angular to well rounded, range from 5 cm to 45 cm (averaging about 10 cm), and make up 20–75% of the rock. Largest clasts generally are the best rounded, and clasts less than 5 cm are angular. Although units are commonly matrix supported, where the proportion of large clasts is high, blocks may be closely packed, and the unit is clast supported. Matrix is medium grey to dark grey, dark green- to brown-weathering, poorly sorted pebbly grit or volcarenite.

Between about 500 m and 2 km away from the dome, debris-avalanche units are thinner, but still massive and poorly sorted. Their clasts are subangular to rounded, generally less than 5 cm across and rarely up to 20 cm, and have compositions mainly of andesite and only minor amounts of rhyolite. These units are interbedded with well bedded volcarenite as well as some water-laid and reworked tuffs (Fig. 20).

The boundaries around debris-avalanche deposits are drawn approximately where units become dominantly well bedded pebbly volcanic arenite, showing typical sedimentary structures (sorting, graded bedding, and crossbedding). The bedded volcaniclastic sediments of the fan include polymictic boulder-and-block breccia, crudely to well bedded conglomerate, coarse grit, and pebbly arenite, containing clasts of rhyolite, dacite, and andesite. Rare beds of crystal-rich andesitic rock and finely laminated units may be water-laid tuffs (Fig. 21, 22). Generally, toward the western margin of the fan beds become thinner, finer grained, and more sorted; clast population becomes dominantly andesitic, with only a small amount of rhyolite; and units commonly show graded bedding and crossbedding.

Although the debris-avalanche deposits of this fan were derived by mass wasting mainly from the rhyolite domes, the bedded portion of the fan was derived from a more varied terrane; presumably from the complex volcanic edifice to the east. The tholeiitic basalt lava flow and tuffs within the bedded succession indicates that part of the Keish Lake fan was deposited during Boucher-Regan volcanism.

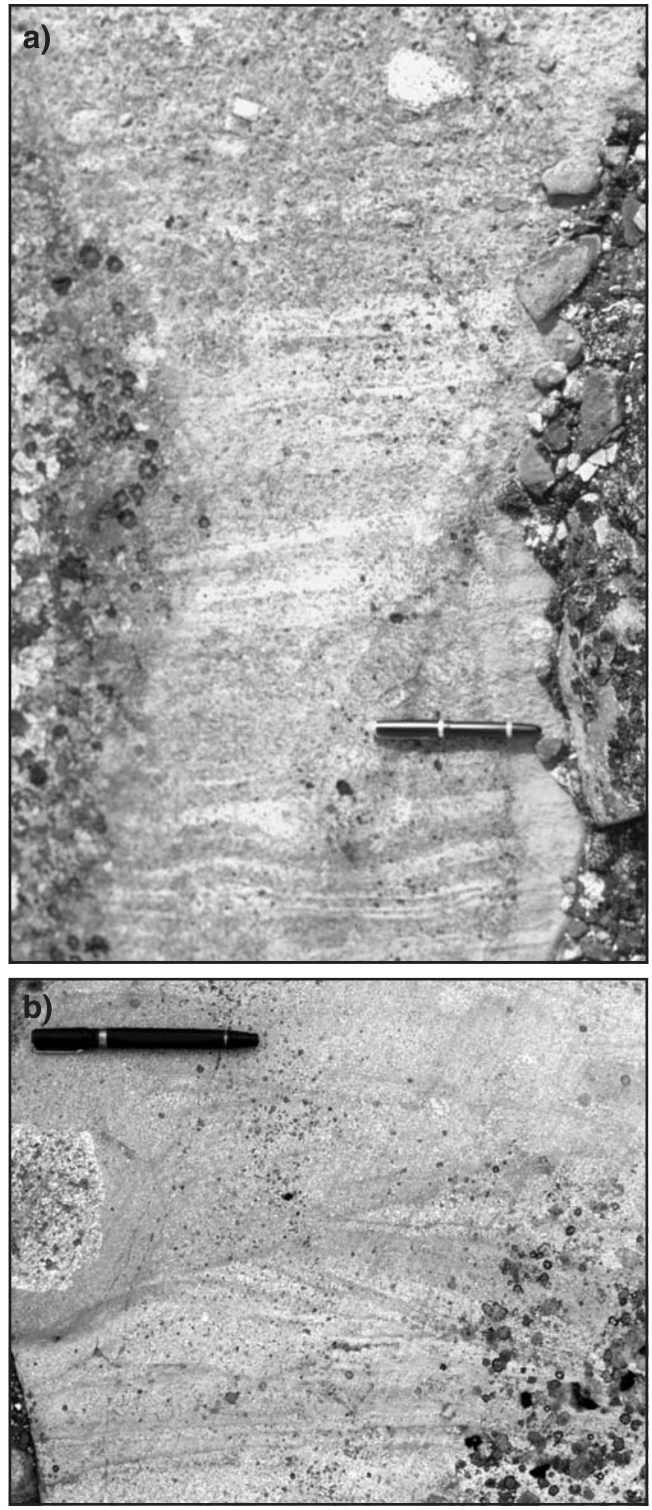


Figure 20. *Water-laid tuffs in the Keish Lake volcaniclastic fan.* ***a****) Water-laid ash-flow tuff with finely layered base that grades upward into massive, poorly sorted tuff. Pen is 13 cm long. Photograph by M.B. Lambert. GSC 2002-779.* ***b****) Reworked water-laid tuff, containing crossbedded, laminated, fine-grained ash. Pen is 13 cm long. Photograph by M.B. Lambert. GSC 2002-780*

__Figure 21.__ Bedded tuff between massive units of laharic breccia in the Keish Lake fan south of Quartermoon Lake. Pen is 13 cm long. Photograph by M.B. Lambert. GSC 2002-781

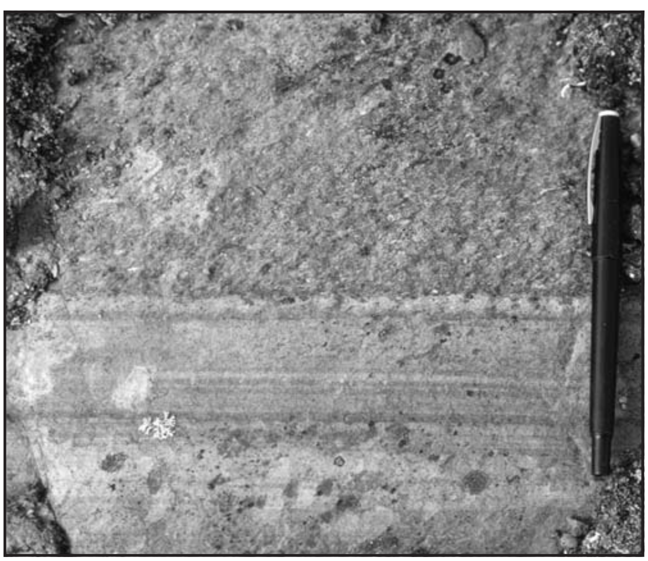


__Figure 22.__ Fine laminated tuff (possibly water-laid ash) in southeastern part of Keish Lake fan. Pen is 13 cm long. Photograph by M.B. Lambert. GSC 2002-782

Valley-filling avalanche deposits

Megabreccia units are interpreted as valley-filling avalanche deposits in two areas: on the east side of the Quartermoon Lake rhyolite dome, and near the north end of the Gold Lake rhyolite dome.

About 1.2 km northeast of Quartermoon Lake, megabreccia forms a 600 m by 1800 m area within the rhyolite dome. This area comprises a jumble of huge mappable rhyolite bodies, 50–200 m across, that are enclosed in massive, unsorted megabreccia. Megabreccia between the huge bodies contains slabs of rhyolite commonly up to 20–30 m long and 4–5 m wide, suspended in brown- to green-weathering, unsorted polymictic breccia comprising angular to rounded clasts of rhyolite and andesite (about 10 cm) in a matrix of grey grit. The matrix deforms around the megaclasts. This deposit is interpreted as an area where a portion of the rhyolite dome collapsed, and large segments of it were rafted intact within a debris avalanche that was contained within a valley or depression on the side of the dome. This deposit is analogous to block-facies hummocks of debris-avalanche deposits of the Mount St. Helens volcano, U.S.A. (Glicken, 1998) and debris-avalanche deposits of the Colima volcanic complex, Mexico (Komorowski et al., 1997). Elongation of this deposit, and its merging with the broad apron of debris-avalanche deposits along the southern side of the dome, suggest mass movement in a southwesterly direction.

At the north end of the Gold Lake rhyolite dome, an elongate unit of megabreccia trends southeasterly across the northerly trending stratigraphy of the Thlewycho sequence. Width of this unit varies from 500 m at its eastern end to about 100 m for most of its length, and the unit tapers out 1800 m west of the Back River. Although parts of the western half of this unit make fault contact with andesite lavas of the Thlewycho sequence, the southwestern side cuts unconformably across the lava succession. The unit appears to be occupying a valley cut into the older volcanic stratigraphy.

A 30 m high cliff in a bay of the Back River, exposes a cross-section through the widest part of this unit at its eastern end (Fig. 6d). This section displays two massive depositional units about 10–17 m thick. A slightly recessive zone of finer matrix-rich breccia midway up the cliffs marks the contact between the two units. Near the top of this section and farther west, lenses of volcarenite and pebble to boulder conglomerate mark contacts between depositional units.

The polymictic breccia in the cliff section comprises unsorted to poorly sorted, closely packed, angular to subrounded blocks, up to 3 m across, in a poorly sorted granule breccia matrix. Near the base of the unit, on the southeastern side, the large angular blocks are of the same composition as the adjacent rhyolite unit. The upper parts of the cliff section have fewer large blocks and more matrix. Clasts are up to 90% rhyolite and dacite, with minor grey to green porphyritic andesite and dark green, aphanitic mafic rock (?basalt). Matrix between the large blocks is a finer breccia comprising 1 cm to 10 cm fragments, with compositions similar to the large blocks; interstices between these smaller fragments are filled with a dark green to grey, carbonate-rich grit that contains abundant chlorite as well as biotite and amphibole. The polymictic nature and the abundance of dark greenish-grey matrix distinguishes these grey-weathering deposits from the white-weathering monomictic carapace and flow breccia of the rhyolite dome.

Within the unit as a whole, the largest blocks occur in the eastern cliff exposure, and the abundance and size of largest fragments decrease westward. Generally, towards the western end and eastern sides of the unit, the felsic blocks tend to be smaller (generally from 1–10 cm, but some up to 50 cm), there is a higher proportion of rounded to subangular clasts, the proportions of clast compositions is more variable (generally with a greater abundance of grey andesitic and dark green, mafic clasts), the gritty matrix becomes more abundant, and crudely bedded units are more common.

This unit represents debris-avalanche or landslide deposits, derived mainly from felsic volcanic units that were deposited in a steep-sided valley incised into the side of the volcano. The trend, eastward thickening, and westward tailing out of this unit indicate eastward mass flow from a high volcanic terrain to the west. A polymictic pebble-rich unit, near the east end of this avalanche deposit, contains angular to rounded clasts (5 mm to 15 cm) predominantly of rhyolite, but also abundant angular clasts of dark grey, micaceous siltstone and green to grey, aphanitic volcanic lithologies (Fig. 10e). This unit is interpreted as the distal end of a mass-flow deposit that was part of a shallow clastic fan at the edge of the rhyolite dome complex.

Detrital rocks derived from mafic lavas

About 7 km northeast of Keish Lake, an easterly trending band of volcaniclastic rocks overlies lavas of the Boucher-Regan sequence, in a syncline between the two major anticlines in the northwest side of the map area. The band comprises generally green-weathering, dark grey to dark green, massive, fine-grained rocks to rudaceous volcarenite and breccia. These partly sheared and carbonate-altered rocks contain varied amounts of fragments, mainly of aphanitic to porphyritic andesite, dark green basalt, and minor rhyolite, in a medium-grained to aphanitic green matrix. Fragments are generally 2–5 cm across (but some units contain random clusters of rhyolite boulders to 20 cm) and vary in amount from sparse to 20% of the rock. Fine- to medium-grained matrix consists of mafic clasts as well as of feldspar, hornblende, biotite, and minor quartz grains. Rocks of this band are interpreted as detritus derived from the immediately adjacent or underlying mafic and rhyolite lava units.

In a structural basin to the west of this band, six crystal-rich volcaniclastic layers interfinger with the Beechey Lake Group. These buff- to pale grey-weathering, 1 m to about 25 m thick, massive beds generally weather in relief or form small cliffs within the recessive weathering, dark grey to black shale and siltstone. The lowermost unit is a hornblende-plagioclase-rich andesitic rock similar to some volcaniclastic rocks in the band to the east. The upper two volcaniclastic units are buff-weathering, massive, felsic rocks containing up to 50% crystal fragments. The uppermost unit contains about 35% euhedral and broken plagioclase crystals (up to 2 mm), 15–21% subhedral quartz (0.5–1.5 mm), and 30% angular to rounded fragments of rhyolite to dacite composition, minor mafic volcanic material, and sparse amounts of biotite. These volcaniclastic layers probably represent westward fingering-out of the larger volcaniclastic band to the east. Although the upper layers could be water-laid crystal-lithic tuffs, they may also represent products of erosion from crystal-rich tuffaceous material related to the nearby rhyolite domes and flows.

Northwest of Fidler Lake, a 4 km lens of well bedded, green-weathering, andesitic breccia, volcarenite, siltstone, and minor conglomerate lies between andesite pillow breccia, and slate and wacke of the overlying Beechey Lake Group. At one place, pillow breccia grades into a massive, unsorted basal unit of this lens, confirming the affinity of the detritus to the immediately underlying volcanic belt. The basal unit comprises angular to subrounded blocks and boulders mainly of porphyritic andesite, ranging from a few millimetres to 15 cm (but up to 40 cm) across, in fine-grained, andesitic matrix. The upper units of the lens are thin- to medium-bedded rocks. Although the lens tapers out southwards, thin units of bedded, green siltstone, pebbly arenite, and conglomerate continue along the contact with Beechey Lake Group rocks, and are exposed intermittently near the northwest shore of Fidler Lake, where the volcanic belt ends in a series of southeasterly plunging folds. Conglomerate along this contact contains rounded to subrounded pebbles (generally less than 5 cm) mainly of porphyritic andesite, but also green aphanitic andesite, grey aphanitic dacite, and possibly chert. Although the contact between the volcaniclastic lens and Beechey Lake Group is sheared on the northern side of the volcanic belt, it is not sheared near the western side of Fidler Lake; in this area, thin volcaniclastic units and conglomerate are overlain conformably by shale and wacke of the Beechey Lake Group.

Southeast of Fidler Lake, volcanic sedimentary rocks within the Beechey Lake turbidite sequences comprise coarse wacke, pebbly arenite, and rudite that contain clasts of hornblende and plagioclase-phyric andesite, rare rhyolite and dacite, and crystals of plagioclase and hornblende. The green weathering colour of these units distinguishes them from the grey to dark grey greywacke-mudstone units of the enclosing turbidite. Clast compositions and the location of this unit suggests that it represents erosion from the belt of volcanic rocks north of Regan Lake. This also implies that part of the mafic belt was emergent.

Rhyolite turbidite

Rhyolite-derived turbidite (unit ABert) forms a 24 km long, white- to pale grey-weathering unit within Beechey Lake turbidite northeast of Boucher Lake. Two stratigraphic sections were measured through this northward-facing unit, with no internal evidence of repetition by folding (Fig. 23 on CD-ROM; localities 6 and 7, Fig. 1).

The eastern section (locality 6) is 300 m thick and comprises ten thinning- and fining-upward cycles averaging 19 m thick, overlain by thin-bedded, pelite-rich turbidite to mudstone. The coarsest (basal) beds of the cycles vary from very coarse-grained sandstone to fine rhyolite pebble conglomerate, which may represent minor channels in the midfan area, with the finer greywacke being deposited as suprafan lobes. The beds in the lower parts of the cycles are amalgamated; mudstone clasts are present in the basal part of three of the cycles. Sole marks and ripples in one part of this section indicate northerly paleoflow.

A second, 340 m thick section (locality 7) comprises about eight thinning- and fining-upward cycles with similar lithologies to the eastern section except that it contains a high proportion of thick (commonly 5–17 m), graded beds commonly with coarse boulders at cycle bases.

These rhyolite-derived turbidite units are poorly sorted, texturally immature rocks that typically comprise angular to subrounded grains of quartz (10% present as monocrystalline fragments or embayed phenocrysts and polycrystalline fragments), 30% feldspar (dominantly plagioclase but also K-feldspar as well as relict sanidine within rhyolite clasts) and 35% lithic fragments including porphyritic rhyolite or dacite (about one-third of lithic fragments) and 2% porphyritic andesite, and minor rounded to euhedral crystals of zircon; matrix (15%) between grains is very fine-grained intergrowth mostly of quartz, sericite, and chlorite (Emon, 1993).

Such thinning- and fining-upward cycles in turbidite sequences have been attributed to gradual abandonment of distributary channels in a midfan environment (Walker, 1970; Walker and Mutti, 1973). Although northward paleoflow is indicated in one part of the eastern section, the distribution of this unit and the lack of repetition by folding in this area suggests that the deposit represents an easterly elongate fan that possibly was restricted to a channel in the shallow turbidite basin. Except for a crude correspondence of thick shale intervals in the lower half of the sections, there is no obvious bed-by-bed correlation between the two sections. Possibly the present erosion surface exposes an oblique section across a complex turbidite fan such that individual depositional units are not present in both sections. Generally, however, the coarser and thicker nature of beds in the western section may indicate closer proximity to the source terrane. This unit is interpreted to represent a narrow rhyolitic epiclastic fan or channel deposit within the Beechey Lake turbidite derived from late-stage felsic domes — most likely the large Quartermoon Lake rhyolite dome to the west.

Interpretation

The various debris-avalanche deposits, flank deposits, stream deposits, and clastic fans signify degradation of the volcanic pile during and following each sequence of volcanism. The directions of sediment transport and mass movement can be inferred from the disposition of these units (as well as from some lava-flow units), assuming that they are on the downslope side of the volcanic mounds. These directions provide a basis for interpreting predeformational paleotopographic high areas of the original stratovolcano (Fig. 24). Debris-avalanche, landslide, and scree deposits prevail mainly on the seaward sides of felsic dome complexes around the southern and western sides of the volcanic complex. Two valley-filling avalanche deposits support these movement directions. The Keish Lake fan on the northwestern side, combined with locations of major debris-avalanche deposits indicate high terrain to the east or northeast. A folded lava flow within the Keish Lake fan, if unfolded, would form a fan-shaped unit that spread westward (downslope) from its source. Rhyolite-derived turbidite sequences probably flowed easterly from the volcanic complex. These data, combined with similar directional data from epiclastic deposits of the Innerring sequence (Fig. 5), suggest that high volcanic terrain corresponded roughly with the centre of the present structural dome. Probably there was a secondary high area in the vicinity of the large Quartermoon Lake dome. Also, the distribution of mafic lavas of the Boucher-Regan sequence, in an approximately 40 km long belt along the northern side of the volcanic complex, suggests that they were products of fissure eruption. These eruptions possibly formed a submarine ridge on the northern side of the volcano. Thus, the present structural dome appears to be superposed on the main volcanic edifice.

The largest epiclastic deposits formed on the northwestern flanks of the volcanic complex after both Innerring sequence volcanism and Thlewycho–Boucher-Regan sequence volcanism (Keish Lake fan). This pattern is similar to that of some modern volcanoes, where repetitive edifice collapse and erosion, over time intervals of several thousand years, produced debris-avalanche deposits that are prevalent on one side of the stratovolcano (Komorowski et al., 1997).

Carbonate units

Carbonate (mainly calcite and dolomite, but also siderite) occurs throughout the volcanic complex as cement in fractures, faults, and shear zones, but is most abundant as cement in breccia related to domes and lava flows. Near these breccia units, beds and laminae of massive carbonate and stromatolitic and oolitic units indicate primary chemical sedimentation and biological activity. Stratified clastic carbonate and some debris flows containing blocks of carbonate suggest erosion from primary carbonate deposits.

Extensive zones of carbonate-cemented breccia mark the end of both Innerring and Thlewycho sequences. Carbonate-rich zones almost encircle the Innerring sequence — occurring both in rhyolite flows and debris-avalanche deposits at the top of the Innerring sequence, in andesite flow breccia at the base of the Thlewycho sequence, and in andesite and basalt pillow lavas and breccia of the Boucher-Regan sequence. The carbonate forms anastomosing zones and veins or completely permeates the matrix of these breccia units. Similarly, carbonate is ubiquitous as cement in breccia and clastic deposits flanking the numerous felsic domes and flows of all sequences.

The carbonate deposits occur almost exclusively on the seaward sides of felsic lava domes: it is lacking in breccia on the landward side of the domes, where lavas and pyroclastic units of the Thlewycho sequence almost all have features characteristic of subaerial deposition. Similarly, carbonate is associated with iron-formation where it lies immediately

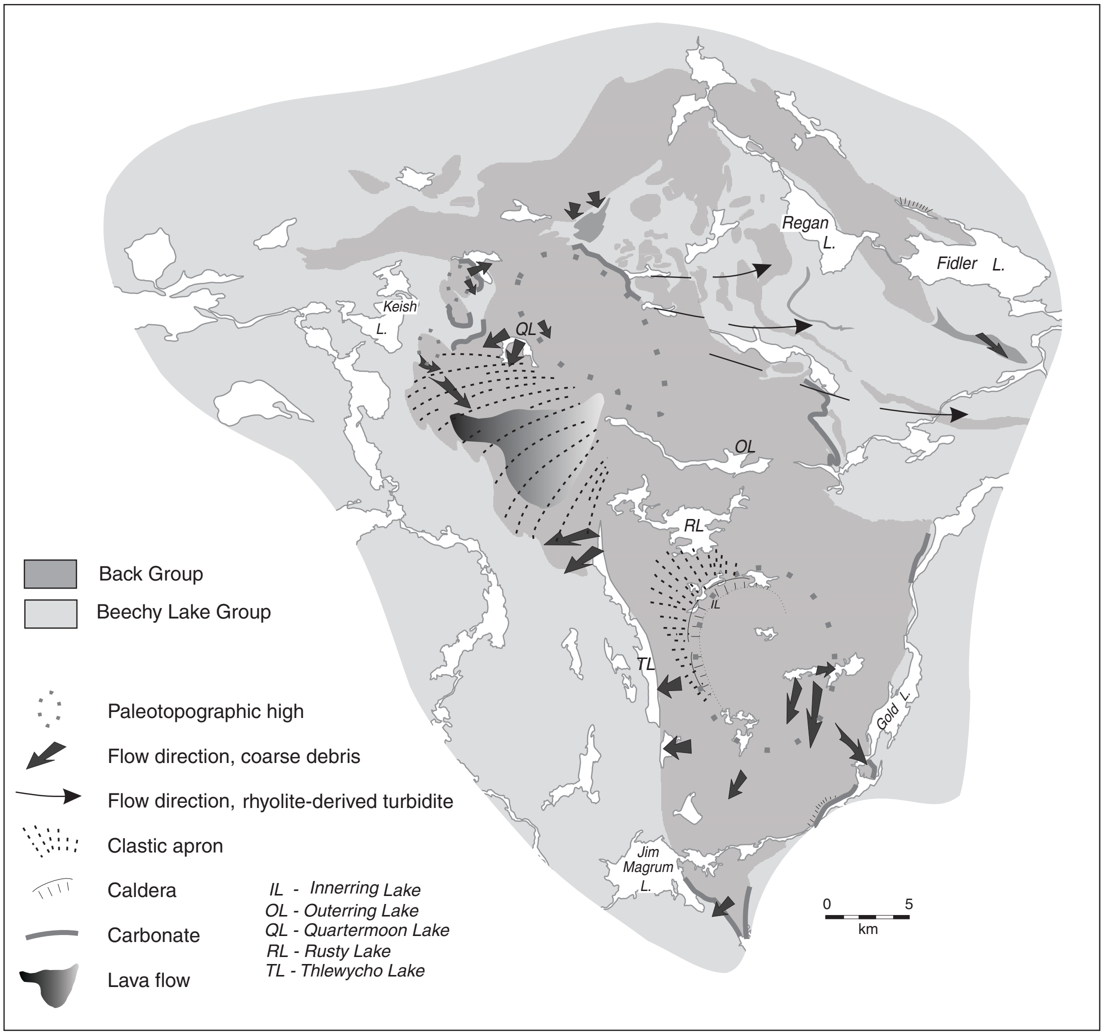


Figure 24. *Directions of flow from source terranes of dome flank deposits, debris-avalanche deposits, conglomerate, and alluvial fans, rhyolite-derived turbidite, and clastic aprons. These directions imply areas of primary high topography near the centre of the present structural dome and in the area of the Quartermoon Lake rhyolite dome.*

above dome or flow rocks of the volcanic complex, but it is notably lacking where the iron-formation is not in contact with flow units or is wholly within turbidite of the Beechey Lake Group (i.e. northeast of Boucher and Regan lakes). This carbonate, which forms a narrow zone along the base of iron-formation, variably comprises massive to finely laminated beds of very fine-grained dolomite; deep brown-weathering, iron-carbonate-cemented, coarse arenite; and rhyolite pebble grit to boulder grit, commonly with diffuse trains to densely packed beds of ooliths and pisoliths (Fig. 25) and locally stromatolites, that grade into carbonate-cemented, rhyolite flow breccia; rhyolite megabreccia with pods of carbonate; then into massive rhyolite. A debris-avalanche deposit, on the west side of the Thlewycho east rhyolite lava dome, has matrix that is variably composed of calcite, siderite, ferroan dolomite, chlorite, quartz, fibrous amphibole, and sulphide minerals (Moore, 1977).

The carbonate probably was introduced to these parts of the volcanic pile mainly by fumaroles and precipitation from hydrothermal fluids that debouched onto the sea floor. Precipitation of carbonate, as well as concentration of metals, may also have been enhanced by convective circulation of sea water through, and leaching from, the adjacent volcanic pile. Within this environment, stromatolites developed in ten localities on the flanks of felsic dome and/or flow complexes that erupted on shores around the partly emergent stratovolcano.

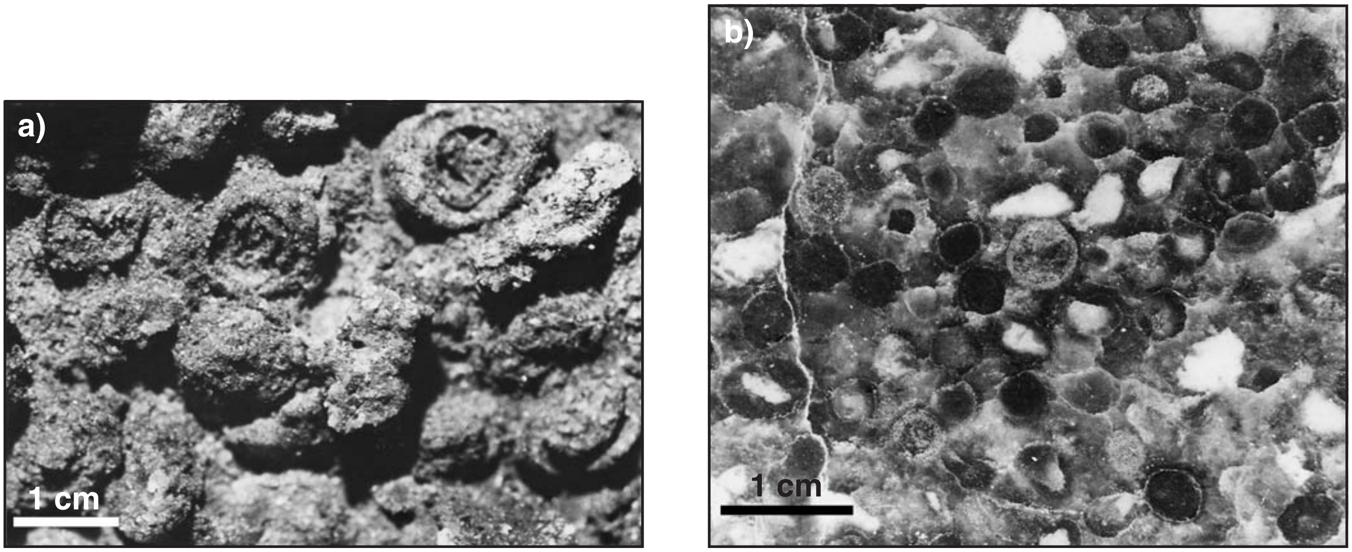


Figure 25. ***a***) *Oolite from the east side of the volcanic complex (1 km southwest of reference locality 5). This well sorted rock comprises about 75% closely packed ooids, 10% dacite and andesite fragments, and 15% sparry calcite cement. Ooids, 1.4–2 cm across, have cores of angular volcanic rock fragments and concentric shells of calcite and/or dolomite. Photograph by M.B. Lambert. GSC 2002-783* ***b***) *In thin section, arcuate streaks of mosaic-textured, microcrystalline quartz and zones rich in iron oxide define the concentric pattern. Irregular to bladed sparry calcite has an extinction pattern radial to the cores of ooids.*

Stromatolites

Stromatolites were first discovered in the Slave Province by Henderson (1975a, b, 1977) who recognized that Archean carbonate units in the Slave Province typically occur in close association with rhyolitic units and reasoned that stromatolites developed around emergent felsic volcanic islands where light conditions were right for photosynthesis and where local fumarolic activity might provide nutrients.

In the Back River complex, all stromatolites occur in the carbonate-rich small interval at the margin of large rhyolitic to dacitic lava-dome complexes (and associated intrusions, breccia, and clastic fans), at the boundary between either the Thlewycho or Boucher-Regan sequences, and turbiditic sedimentary rocks of the Beechey Lake Group (Fig. 1). They occur in three types of units: in megabreccia units, or lenses within them, that form dome margins (stromatolite localities 1, 2, 4, 5, 10); in clastic aprons around the megabreccia (stromatolite localities 3, 8); and in bedded carbonate units immediately overlying the clastic dome margin sequence (stromatolite localities 6, 7, 9). (*See* Lambert (1998) for a more detailed account of stromatolite localities). Nomenclature of stromatolites follows that of Hofmann (1969).

Stromatolites in felsic dome breccia

Megabreccia (flow and carapace breccia) along margins of felsic dome complexes invariably has a matrix that is carbonate-cemented, fine-grained breccia to grit. Stromatolite locality 5 is significant because it exposes details of stratigraphy (Fig. 26), relative to a large dome-flow complex, at the same stratigraphic interval as localities 1–4. Carbonate occurs both as cement in rhyolite carapace breccia and in the overlying

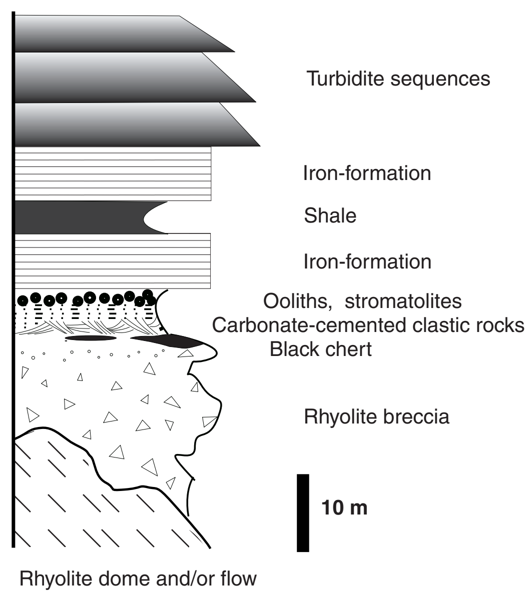


Figure 26. *Stratigraphic sequence at margin of rhyolite dome at stromatolite locality 5 showing typical location of carbonate units on east side of the Back River complex.*

9 m thick carbonate succession comprising coarsely bedded and scoured sand, and massive to irregularly laminated carbonate containing abundant ooids and pisoliths. Although local wavy-laminated carbonate within this interval may represent microbial mats, positive identification of stromatolites was not made here. Noteworthy at this locality, and at most carbonate occurrences along the eastern side of the Back River complex, is black carbonaceous shale in which the carbon is likely biogenic (cf. Henderson, 1975a).

Stromatolites are best preserved at locality 1 where they appear in plan view as a cluster of coalescing circular forms, about 15–25 cm across, comprising concentric laminae 1–3 mm thick (Fig. 27a). A single vertical section shows that they are laterally linked domes with low synoptic relief (Fig. 27b). Although this stromatolite-bearing unit is tilted, it has not suffered internal deformation as the associated ooids, which are sensitive strain indicators, are undeformed. Thus the stromatolite forms at this locality cannot reasonably be interpreted as structural domes.

Stromatolites at locality 2 are similar to those at locality 1, except they form closely packed, low-relief, ovoid to elongate domes.

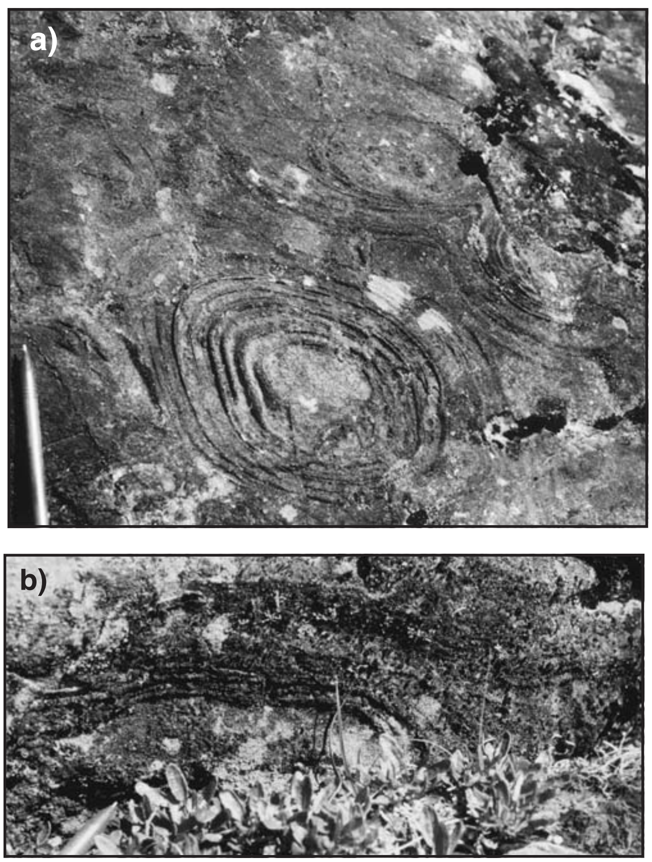


Figure 27. Stromatolite locality 1. ***a****) Plan view of laterally linked domal stromatolites. Pencil is 8 mm thick. Photograph by M.B. Lambert. GSC 1995-300D.* ***b****) Transverse section through cumulate dome. Pencil is 8 mm thick. Photograph by M.B. Lambert. GSC 1995-300C*

At locality 4 stromatolites form crusts less than 5 cm thick on coarse blocks in a poorly sorted breccia. They form wavy laminae and occasionally open-spaced linked mounds about 3 cm high that drape around the blocks (Fig. 28).

Stromatolites in clastic aprons around volcanic domes

Locality 8 (5 km east of Keish Lake) is within a well bedded succession of felsic volcaniclastic rocks (Fig. 29a) that lies on the western side of the Quartermoon Lake rhyolite dome. The thick to thin, grey- to white-weathering, volcaniclastic beds

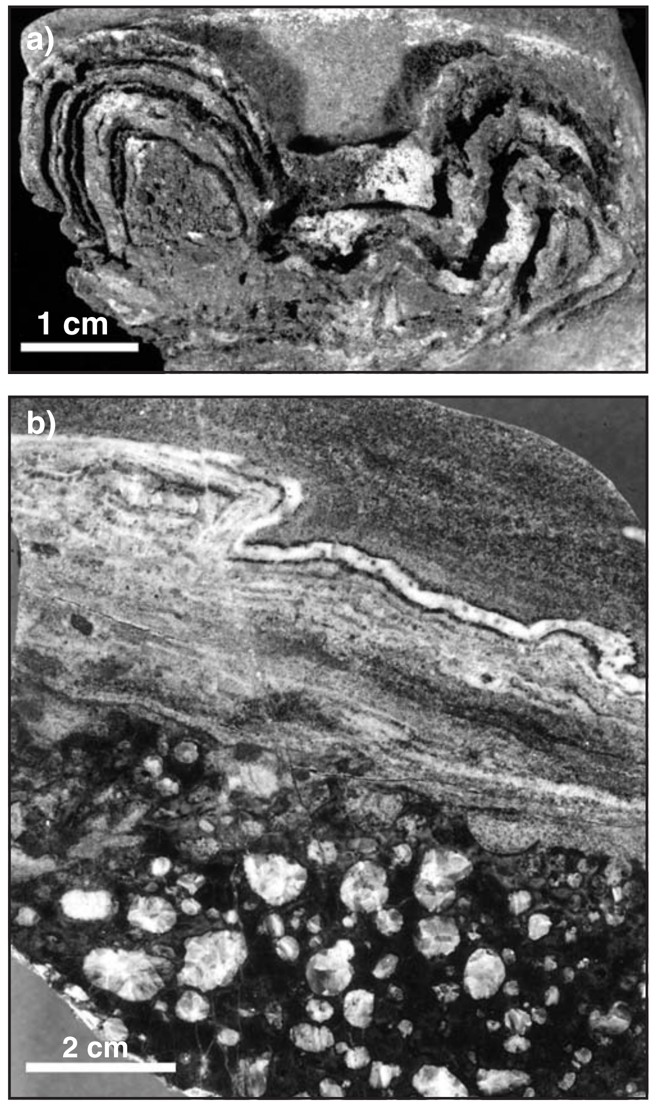


Figure 28. Stromatolite locality 4. ***a****) Open-spaced, linked cumulate mounds show recrystallized, 1–3 mm thick, siliceous laminae which stand in relief above recessive-weathering, coarse-grained (millimetre-sized) dolomite. Photograph by M.B. Lambert. GSC 1993-111B.* ***b****) Polished slab showing laminations that have grown within the delicate vesicle structure on the surface of the scoriaceous (now amygdaloidal) block of lava; amygdales of coarse-grained calcite. Photograph by M.B. Lambert. GSC 1995-301*

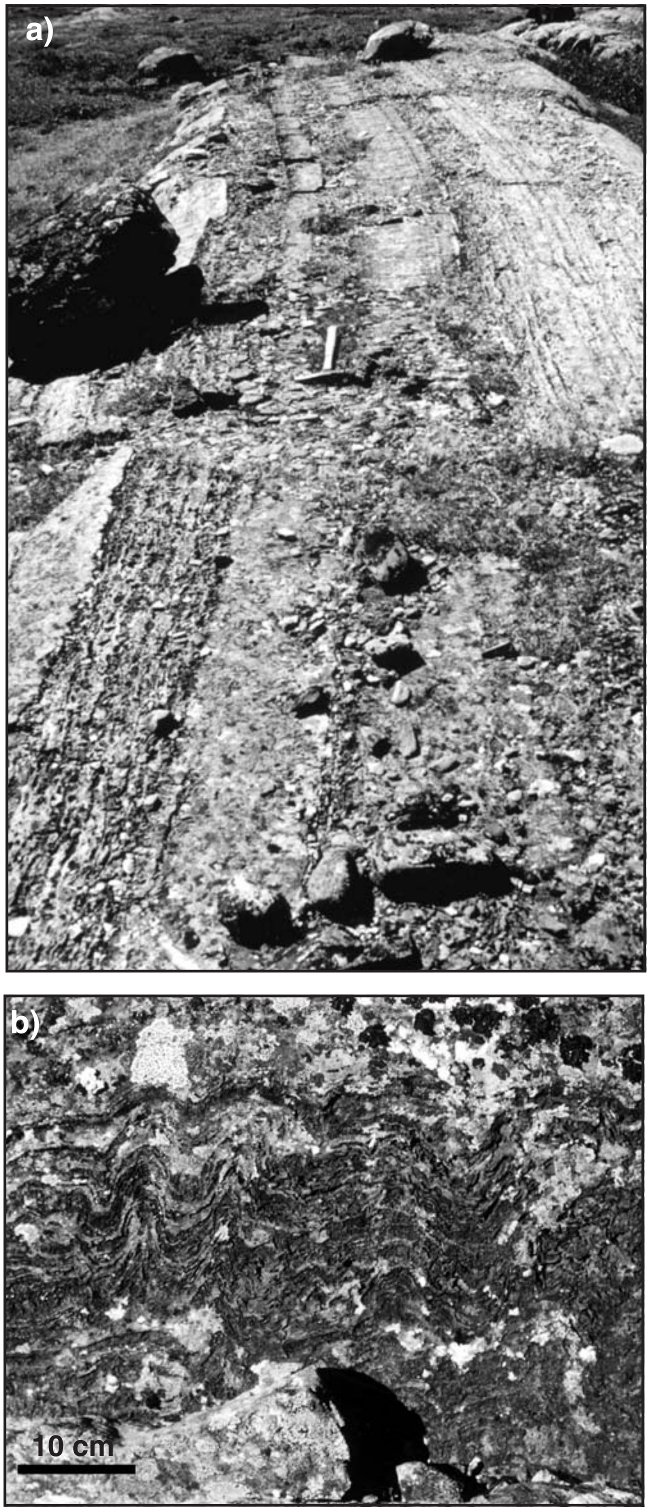


Figure 29. *Stromatolite locality 8.* ***a**) Outcrop of well bedded, felsic volaniclastic sequence containing recessive-weathering carbonate horizons. Hammer is 33 cm long. Photograph by M.B. Lambert. GSC 1993-113B.* ***b**) Pseudocolumnar stromatolites in carbonate horizons shown in Figure 29a. Photograph by M.B. Lambert. GSC 1993-113D*

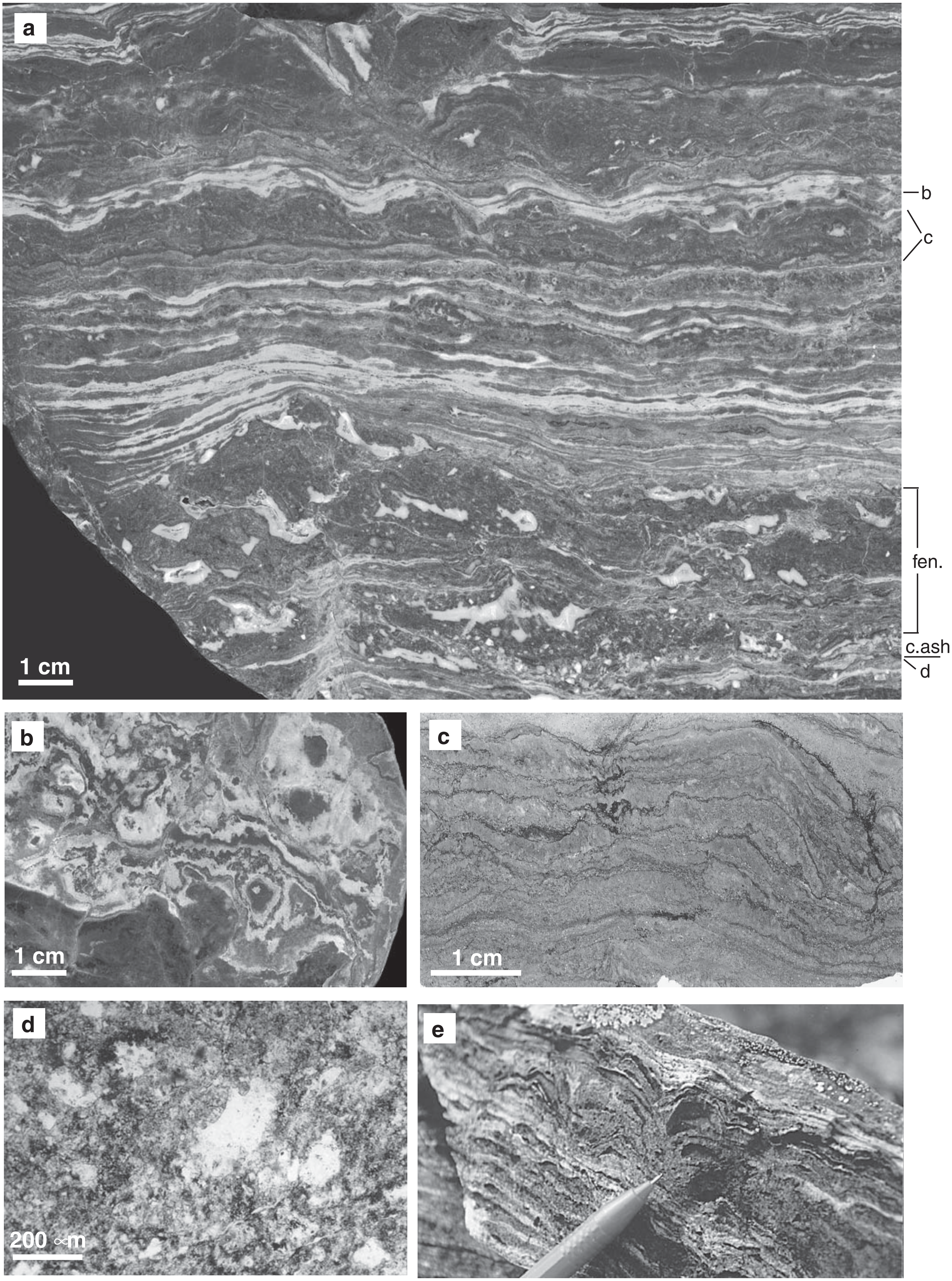
contain interbeds of finely laminated grey- to rusty brown-weathering carbonate. The undulatory carbonate laminations locally have pseudocolumnar structure defined by layering with a high degree of inheritance forming acute profiles (Fig. 29b). Although fold crenulations have been identified elsewhere in the carbonate units, this laminated carbonate is most plausibly interpreted as stratiform microbial mats because the pseudocolumnar features begin abruptly at the base of the unit, increase in amplitude upwards, and gradually die out toward the top.

Stromatolites in stratiform carbonate units

Locality 7 (5 km northwest of Boucher Lake) exposes the thickest and most extensive unit of stratiform stromatolites in the complex. Here, the 2 m thick, brown- to grey-weathering unit, which is exposed for at least 200 m along strike, dips about 10° away from a large rhyolite dome complex. The unit comprises 1–25 mm thick layers of dark grey, fine-grained dolomite and white laminae of volcanic ash. Dolomite forms wavy laminae (2–3 mm thick) that build small, laterally linked hemispheroids 0.5–2 cm high and less than 2 cm across. Some zones in the microstratigraphy contain abundant irregular fenestrae that range from 2–5 mm wide and up to 25 mm long; they are arranged roughly parallel to bedding. They are filled with white dolomite that is much coarser than the very fine, dark grey dolomite that surrounds them. Concentric zones in fenestrae suggest that the dolomite filled cavities. Related pustular features (5–15 mm across) with convex-upward surfaces (Fig. 30) may represent gas cavities that could have been generated during bacterial decomposition.

Although ash is interspersed throughout the carbonate as wispy laminae 0.5–3 mm thick, it forms its thickest accumulations (up to 10 mm) at regular intervals of 3–5 cm throughout the unit. These accumulations, which drape over the top of small hemispheroids (Fig. 30a, b), are very fine, vitric, crystal ash containing euhedral quartz crystals, angular quartz fragments, and relict shards and vesicular glass (now recrystallized to microfelsic aggregates of quartz and feldspar, but retain their angular, irregular, and cuspate outlines; Fig. 30d). Some layers are ash-rich dolomite that grades into the surrounding stromatolitic layers.

Locality 6 exposes 120 cm of finely laminated dolomite (at the same stratigraphic level as locality 7) in the form of elongate, low-relief, gently convex mounds, about 60 cm wide and 5–10 cm high which are interpreted as stromatolites. These are the largest mounds seen in carbonate units of the Back River complex (Fig. 31). Laminae defined by alternating silica-rich and carbonate-rich layers, range from 1 mm to 10 mm. Recessive-weathering, cream to grey, pinching and swelling laminae of fine ash appear throughout the carbonate at intervals of 2–4 cm. Although the unit appears undeformed, thin sections reveal a fine sericitic fabric that forms at low angle to the laminae. This fabric bears no relation to the stromatolite forms (i.e. it is not ‘axial planar’ to the undulations). Since sediment overlying the stromatolite mounds has filled in the troughs, and becomes nearly planar within 5 cm above it, the mounds cannot be interpreted as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c.ash
d
1 cm
b
1 cm
c
1 cm
d
200 ∝m
e

open folds. Stromatolite elongation is presumed to be a primary feature that may be related to current patterns during accretion of microbial laminite.

At locality 9 (near the eastern side of a large rhyolite lava complex along the western margin of the stratovolcano), a 2.5 m cliff exposes brown-weathering, massive to clastic carbonate. Features interpreted as stromatolites were seen only in coarse blocks of carbonate rubble at the base of this cliff. They form a 10 cm thick, distinctive zone of 1–4 cm thick beds comprising very finely wrinkled, 1 mm laminations similar to those at locality 8.

Figure 31. *Laterally linked domal stromatolites at locality 6. **a**) Bedding surface of low-relief elongate stromatolite mounds. Pen is 13.5 cm long. Photograph by M.B. Lambert. GSC 1995-300A. **b**) Sectional view of mounds in Figure 31a. Scale is marked in decimetres. Photograph by M.B. Lambert. GSC 1995-300B*

Interpretation

Because the carbonate has all been recrystallized, no evidence of microfossils has been found and it is not possible to demonstrate that any of the stromatoid structures are attributable to biological factors. This is the case for most Precambrian occurrences of stromatolites.

At each locality in the Back River complex, however, the gross morphology of stromatolites and their distinctive fine laminae are different from features formed by structural deformation within these units or in adjacent sedimentary units. Structures within centimetre- to decimetre-scale layers of the stromatoid carbonate that are characteristic of known or accepted stromatolites include wrinkled, pustular and irregular corrugated laminae, linked hemispheroids, and small mounds. These are most plausibly interpreted as biologically induced growth phenomena rather than structural or current features.

Growth morphology and nature of laminae are the most important characteristics used in stromatolite classification (Hofmann, 1969). In all localities, the stromatolites are stratiform to nodular types. Fine, crenulated laminae that contain pustules and fenestrae and small hemispheroids and encrusting forms are typical of *Stratifera* forms (for forms and interpretations of ancient stromatolites, *see* Komar (1966), Hofmann (1969), and Walter (1983, 1996)). Although fine pseudocolumnar structures are present in some layers, no true columnar or branching forms were identified. Clusters of closely linked hemispheroidal mounds (such as at locality 1) do not resemble basin-and-dome fold interference structures. Such deformation structures have not been found within the carbonate units.

Stromatolites are a relatively rare local phenomena within the fairly extensive carbonate-bearing volcaniclastic rocks and bedded carbonate units around the volcanic complex. Even though the localities all occur at the same stratigraphic level, they probably never formed an extensive continuous unit (except for the closely spaced localities, such as localities 1 to 4, that occur around the same dome). Most occurrences may represent isolated microbial communities that developed around areas of fumarolic (or hydrothermal) activity at the margins of each dome or flow complex. Such a situation would provide a source of warm solutions and heat that would drive convective circulation in both the sea water and highly porous rubble on submerged flanks of domes, similar to drowned fumaroles active today on the island of Vulcano, Italy. In the Back River complex, this is the site of localized

Figure 30 (previous page). *Stromatolite locality 7. **a**) Polished slab from outcrop in Figure 30e showing microstratigraphy in this laminated sequence. Undulating white layers are fine-grained ash; 'fen' = zone containing abundant fenestrae (irregular white areas); 'c. ash' = coarse ash; b, c, and d refer to Figures 30b, c, d. Photograph by M.B. Lambert. GSC 2002-817. **b**) Polished slab cut perpendicular to Figure 30a showing small hemispheroidal mounds in plan view. White, fine-grained volcanic ash outlines the mounds. Photograph by M.B. Lambert. GSC 2002-818. **c**) Details of microstructure that make up small stromatolitic mounds. Laminae are almost entirely dolomite. Diffuse iron oxide commonly with scattered particles of fine-grained ash define boundaries between layers. Photograph by M.B. Lambert. GSC 2002-819. **d**) Photomicrograph showing relict shards (centre) in coarse ash. Photograph by M.B. Lambert. GSC 1995-300E. **e**) Pustules, interpreted as gas cavities, in microbiolaminite. Pencil is 8 mm thick. Photograph by M.B. Lambert. GSC 205025B* carbonate deposition. It is conceivable that stromatolite growth would be stimulated by warm, marine waters and volcanic emanations that could provide abundant nutrients for the production of local bacterial plumes.

The thickest and most extensive stromatolite units at localities 6 and 7 were probably part of a continuous bed. Since no vestige of carbonate can be found among the folded sedimentary succession to the south and east of this unit, it is likely that carbonate was restricted to the vicinity of the rhyolite dome, and that the stromatolites formed a narrow bioherm along the southeast side of the dome complex. The ash accumulations at regular intervals record intermittent explosive activity while the microbial mats were developing on the submerged flank of an active dome. Assuming that the tephra was derived from this dome, the fine grain size and thinness of ash layers suggest that these were minor explosions that produced low volumes of ash. The fine ash could also have been derived from more distal sources, related to any of the several rhyolitic centres (now marked by large dome and/or flow complexes) that were erupting during waning stages of Thlewycho volcanism.

Although there is no way of dating the duration of carbonate deposition in the Back River complex, the thinness of stromatolite units and their position among coarse detritus is indicative of rapid mass wasting and suggest a brief period of local deposition. This contrasts with the longer lived carbonate platforms in the Proterozoic. Around the Back River stratovolcano, sudden termination of stromatolite growth would be caused by volcanic ash falls, rapid influx of high-energy detritus, and landslide debris from disintegrating active volcanic domes.

Contrasting depositional conditions created unique sediment combinations at transitions from subaerial to subaqueous environments around the active volcano. Movement and autofragmentation of viscous felsic lava flows as they entered the sea, and high-energy, rapid mass wasting from the pulsating growth of active volcanic domes, combined with explosive activity, produced megabreccia, coarse sand detritus, and periodic ash falls. High-energy sedimentation in the shallow sea immediately around the lava domes coupled with fumarolic activity fostered growth of oolites and stromatolites. Subsequent quiet conditions allowed deposition of banded iron-formation and black carbonaceous shale, probably as narrow aprons on shallow flanks of the emergent stratovolcano, as the sea encroached on the volcanic edifice.

BEECHEY LAKE GROUP

Sedimentary rocks of the Beechey Lake Group generally overlie and completely surround the volcanic complex. They interfinger with volcanic formations on a large scale in the northern parts of the complex, and on a smaller scale they interfinger with volcaniclastic rocks forming aprons on the sides of the numerous felsic lava domes. Generally, turbidite sequences of the Beechey Lake Group lie conformably on the volcanic complex. Although parts of the contact between the Back Group and the Beechey Lake Group (the volcanic-sedimentary contact) are sheared or highly strained (particularly on the southeastern, southwestern, and northern sides of the complex) where shearing is lacking, there is no direct evidence for a general unconformity between the two groups.

Sedimentary rocks of the Beechey Lake Group consist mainly of greywacke-mudstone turbidite, siltstone, grit, and minor conglomerate, graphitic shale (or slate), carbonate-rich beds, and iron-formation.

In the Gold Lake area, the turbidite sequences occur in bedding styles that can be related to Bouma's cycle (1962): 1) thin-bedded, bottom- to mid-cut-out 'distal' turbidite; 2) medium- to thick-bedded T_{ae} to (rarely) T_{abcde} turbidite sequences; 3) thickly bedded, amalgamated, crosslaminated, medium- to coarse-grained sandstone; 4) thick to very thick mudshale and very thin- to thick-bedded muddy turbidite; 5) medium to very thick beds of disrupted (slumped) turbidite; and 6) very thin sand-mud couplets. These thick- to thin-bedded units typically show graded bedding, small crossbeds, and ripples in Bouma 'C' units. Both simple asymmetrical ripples and climbing ripples have been identified with wavelengths up to 8 cm and amplitudes to 2 cm. Flute casts and scour marks occur at the base of thick graded beds, where they contain finely laminated or graded coarse silt to fine sand (Fig. 32). Common soft-sediment deformation structures include load casts, flame structures, and disrupted and convoluted beds. Thin pelitic beds lying between thick sandy beds may be disrupted, resulting in a group of imbricated angular pelitic clasts within the thick, sandy layer.

Greywacke units near the eastern side of the volcanic complex are texturally immature, quartz-rich rocks that contain a variety of clast types in the following approximate amounts (from point counts by Ostler (1977) and Emon (1993)): 50% quartz (including 2–3% euhedral to embayed crystals of volcanic origin, coarse polycrystalline grains probably of plutonic origin, and fine polycrystalline grains), 10–20% feldspar (plagioclase, microcline, and perthite — probably from both volcanic and plutonic sources), and 10–15% (rarely up to 35%) lithic fragments (including rhyolite-dacite (8% of fragments), andesite, iron-formation (3%),

Figure 32. *Spindle flutes on sole of a medium-bedded turbidite at Gold Lake. Pen is 1 cm wide. Photograph by G. Burbidge. GSC 205025-C*

siltstone or mudstone, chert, plutonic rock fragments (medium-grained, hypidiomorphic-granular aggregates of quartz, plagioclase, and K-feldspar, myrmekite), and rare carbonate). Sedimentary clasts compose less than 5% of the total lithic fragments. Minor components include rounded to euhedral zircon, rutile, tourmaline, apatite, detrital iron oxides, and detrital muscovite. The matrix, making up about 27% of the rock on average, comprises very fine-grained intergrowths of quartz and locally abundant sericite, chlorite, and minor feldspar.

Black-weathering argillite units up to 10 m thick (composed of about 20 cm thick layers) are useful marker horizons within the otherwise monotonous greywacke-mudstone turbidite succession. Rare, carbonate-rich beds (to 10 m thick) occur in the turbidite within 1 km of the volcanic complex. These are homogeneous units with blue-grey, pitted weathering surfaces, and contain about 30% quartz and feldspar (as fine, 0.05 mm mosaics, possibly felsic volcanic material) and rare quartz grains in a chlorite, biotite-rich matrix containing about 20% dolomite.

Volcanic ash interbedded with the turbidite establishes a temporal link between volcanism and deposition of the Beechey Lake turbidite. On an island in Gold Lake a thick, massive, ungraded, moderately sorted, crystal-rich bed occurs within thin- to medium-bedded Beechey Lake turbidite. It comprises 35% euhedral, blocky feldspar crystals and crystal fragments and minor quartz crystals in a grey aphanitic matrix. The crystal content of this rock is similar to an abundantly porphyritic phase of the Gold Lake rhyolite-dacite dome 2 km to the west. This unit could be either water-laid crystal tuff or an epiclastic crystal-rich volcarenite derived from the volcanic complex.

Ostler (1977) attempted to determine paleocurrent directions from crosslaminations at the bases of Bouma ‘C’ units in turbidite within 1 km of the volcanic complex around Gold Lake. He concluded (assuming that attempts to restore the measurements to original positions are correct in this structurally complex area) that paleocurrents were eastward to southward near the volcanic complex to northwestward farther from the complex. Similarly, Burbidge (*in* Lambert et al., 1990) measured paleocurrent data (from flutes, ripples, and crossbedding in turbidite) around Gold Lake and suggested paleoflow was directed both southeasterly away from the complex and toward the complex. Burbidge also interpreted (*in* Lambert et al., 1990) that some thick amalgamated turbidite sequences were deposited within submarine fan channels directed away from the complex. A few measurements from turbidite units along the western volcanic-sedimentary contact at Thlewycho Lake and near Jim Magrum Lake suggest paleoflow away from the complex, with a significant component perpendicular to these directions along the margins of the complex.

Although much of the crystal and lithic material within Beechey Lake Group turbidite sequences may have been derived from the volcanic complex (particularly coarse-grained wacke units that contain abundant volcanic rock fragments as well as iron-formation and chert), the very high amount of quartz and presence of granitoid fragments, myrmekite, and detrital muscovite suggest a granitoid source.

Both the clast composition of turbidite and the limited paleocurrent data support the concept that much of the material within the Beechey Lake Group immediately adjacent the volcanic complex was derived from the stratovolcano, whereas the turbidite farther from the complex that show northwesterly paleocurrent directions were derived from a partly granitoid terrane to the southeast of the stratovolcano. A possible source terrane could be the Healey complex to the southeast of the volcanic complex, which has yielded dates between ca. 2.72 Ga to 2.6 Ga (*see* van Breemen et al., 1987; Davis and Hegner, 1992; Henderson and van Breemen, 1992).

Detrital zircons from the Beechey Lake Group adjacent to the volcanic complex yield ages that support the dual source for the turbidite. Coarse greywacke (containing abundant felsic volcanic fragments) 1 km from the east side of the complex (locality 5, Fig. 1) gives a $^{207}Pb/^{206}Pb$ age of 2672 ± 7 Ma (Lambert and Henderson, 1980). A coarse felsic wacke (containing volcanic and plutonic rock fragments) interbedded with Beechey Lake turbidite in the northwestern corner of the map area (reference locality 11) yields a U-Pb detrital zircon age of ca. 2690 Ma as well as a single zircon age of 2620 ± 5 Ma (Villeneuve et al., 2001). These dates suggest components derived from the volcanic pile as well as from younger, possibly granitoid sources. A felsic sill in Beechey Lake turbidite near Esker Lake (Fig. 1) has a U-Pb zircon age of 2637 +8/-6 Ma (Villeneuve et al., 2001), which places a lower age on the time of deposition in this part of the Beechy Lake Group.

Iron-formation

Iron-rich sedimentary sequences record chemical sedimentary events at times of volcanic quiescence following each eruptive cycle, and provide distinctive marker horizons that trace complex fold geometries within sedimentary rocks (Jefferson et al., 1989; Lambert et al., 1990). Iron-rich strata that mark the close of Innerring volcanism (unit ĀBLi) are sulphidic mudstone and siltstone and no laminated iron-formation is represented.

Laminated iron-formation of unit ĀBLia that occurs almost continuously around the southern portion of the volcanic complex marks the end of Thlewycho and Boucher-Regan volcanism. This iron-formation lies conformably on carbonate-cemented volcaniclastic rocks at or near the contact between Back Group volcanic rocks and overlying turbidite-dominated strata of the Beechey Lake Group. It is exposed almost continuously around the east side of the complex from about 2 km south of Boucher Lake to 2 km south of Gold Lake. South of Gold Lake, two small exposures on the west shore of the Back River and a magnetic anomaly suggest that the iron-formation coincides with the river. It was noted again around the southern tip of the complex and intermittently along the east sides of Jim Magrum and Thlewycho lakes. Along the Back River, where iron-formation is shown on the map by dashed or dotted lines through drift covered areas or frost-heaved rubble, its presence is assumed to follow prominent gossans or has been determined from drill-hole data (*see* Moore, 1977).

The laminated iron-formation occurs within a stratigraphic sequence that is consistent around the eastern and southern sides of the complex as follows (*see* Fig. 26). Carbonate-cemented volcanic breccia and grit, and locally massive, oolitic- or stromatolitic- carbonate, is in some places interbedded with black chert. This is overlain by laminated iron-formation that varies mineralogically along strike, including quartz-magnetite–, chert-jasper-carbonate-actinolite-tremolite–, magnetite–, and sulphide-chert–iron-formation that is commonly interbedded with thin layers of shale, chert, carbonate-rich iron-formation and volcaniclastic or carbonate-cemented arenite. This is overlain by black, carbonaceous shale (slate) and argillite typically with pervasive finely disseminated pyrite and locally massive lenses and concretions of concentrically banded pyrite up to 10 cm across. Although the black shale contains graphite, much of the carbon is probably in the amorphous state. According to Moore (1977), free carbon ranges from about 1% to 13% and averages about 5%, and the mean CO_2 content is about 5%.

The iron-formation, which ranges from 1 m to 20 m thick, generally contains more than one unit made up of 1–20 mm laminae. Commonly laminae are disrupted and contain angular chert or chert-magnetite fragments in a quartz-carbonate-magnetite-sulphide matrix, and locally abundant fragments of banded pyrite and pyrrhotite. Since such brecciated units are usually interlayered with finely laminated chert-magnetite beds (Moore 1977), they probably formed by syndepositional slumping or flowage. The oxide-rich iron-formation commonly comprises alternating quartz-magnetite and quartz-carbonate-actinolite-tremolite bands. It is locally interlayered with beds of chert, carbonate-rich iron-formation, or laminated chert-sulphide beds. According to Moore (1977) the average composition of oxide-rich iron-formation is 47% quartz, 17% magnetite, 19% tremolite-actinolite, 10% carbonate, and 7% chlorite.

> Carbonate-rich iron formation is similar to chert-magnetite iron formation except that the relative mineral abundances are different. Average composition of carbonate-rich iron formation is 40% quartz, 30% carbonate, 15% tremolite-actinolite, 10% chlorite, and 5% magnetite, pyrite, and pyrrhotite. Carbonate minerals present are calcite, ferroan calcite, dolomite and siderite (Moore, 1977).

Locally, along the west side of Gold Lake, iron-formation contains layers of garnet and amphibole (tremolite-actinolite, riebeckite, grunerite, hornblende), and siderite-quartz-chlorite. Sulphide-rich iron-formation ranges from massive sulphide (sulphide >50% to ferriferous carbonaceous argillite (Moore, 1977) (*see also* 'Mineral occurrences', below).

Dark grey quartz veins, which appear to be stratabound (Jefferson et al., 1989) above the iron-formation, locally contain abundant chalcopyrite and sphalerite and rarely bornite, native copper, native gold, arsenopyrite, and hedleyite (Moore, 1977). The various facies (oxide-rich, carbonate-rich, silicate-rich, sulphide-rich) of iron-formation are not distinguished on the map.

Iron-formation that occurs within Beechey Lake Group sediments (unit ĀBLib) is about 200–300 m above the main volcanic formations, around the northeastern and northwestern sides of the complex. Near the east end of Boucher Lake it is estimated to be 400–500 m above the volcanic complex and about 200 m below the rhyolite turbidite sequence. Between A-B in the north-south cross-section (Map 2041A), the iron-formation is interpreted (from a strong magnetic high and stratigraphic extrapolation) to extend beneath Fidler Lake.

North of Boucher Lake, the iron-formation outlines an overturned fold and causes a prominent east-southeast-trending magnetic anomaly (Fig. 16). This unit is extrapolated through the unmapped area east of Boucher Lake and north of Regan and Fidler lakes along a magnetic anomaly. Magnetite-bearing green-grey siltstone beds occurring 4 km northwest of the nose of the folded iron-formation also contribute to the strong magnetic anomaly in this area.

Although shown as a single unit, the iron-formation comprises several laminated units interbedded with greywacke and mudstone and changes facies and magnetic signature over distances of a few kilometres. On the north limb of the fold (locality 8) an iron-rich sequence comprises six units of banded iron-formation, ranging from 30 cm to 7.5 m thick, separated by turbidite units and finely laminated siltstone (Fig. 33). Cumulative thickness of iron-formation is 20 m. The group of iron-formation strata is overlain and underlain by 10–15 m of finely laminated siltstone forming a package about 50 m thick within thin- to thick-bedded turbidite.

East of Keish Lake, the iron-formation is a chert-jasper-siderite (with alteration to hematite) facies that does not show anomalous magnetic signature. Near Esker Lake (west of Keish Lake, outside the map area; Fig. 1), where the iron-formation has been traced around a large syncline within Beechey Lake turbidite by Sirius Energy Corporation and partners (Jefferson et al., 1989; Lambert et al., 1990), it changes from intensely magnetic chert-magnetite facies on the north side of the lake to sulphide-silicate facies (hornblende-garnet-pyrrhotite) containing chert nodules that has subdued magnetic expression on the south side.

Although the iron-formation is designated as two units, unit ĀBLib may be a distal facies of unit ĀBLia that is buried within turbidite sequences that lapped onto the flanks of the stratovolcano.

METAGABBRO DYKES AND SILLS

Metamorphosed mafic dykes and sills of Archean age (unit Āmd), but mostly of uncertain affinity, have intruded the volcanic complex and the adjacent Beechey Lake Group. These metadiabase-gabbro and metadiabase–quartz gabbro intrusions occur folded within the Boucher-Regan andesite units northwest of Fidler Lake; the western margin of the volcanic complex northeast of Thlewycho Lake; turbidite of the Beechey Lake Group within about 5 km of the western side of the volcanic complex; and a mafic body in the Beechey Lake Group, 5 km south of Gold Lake.

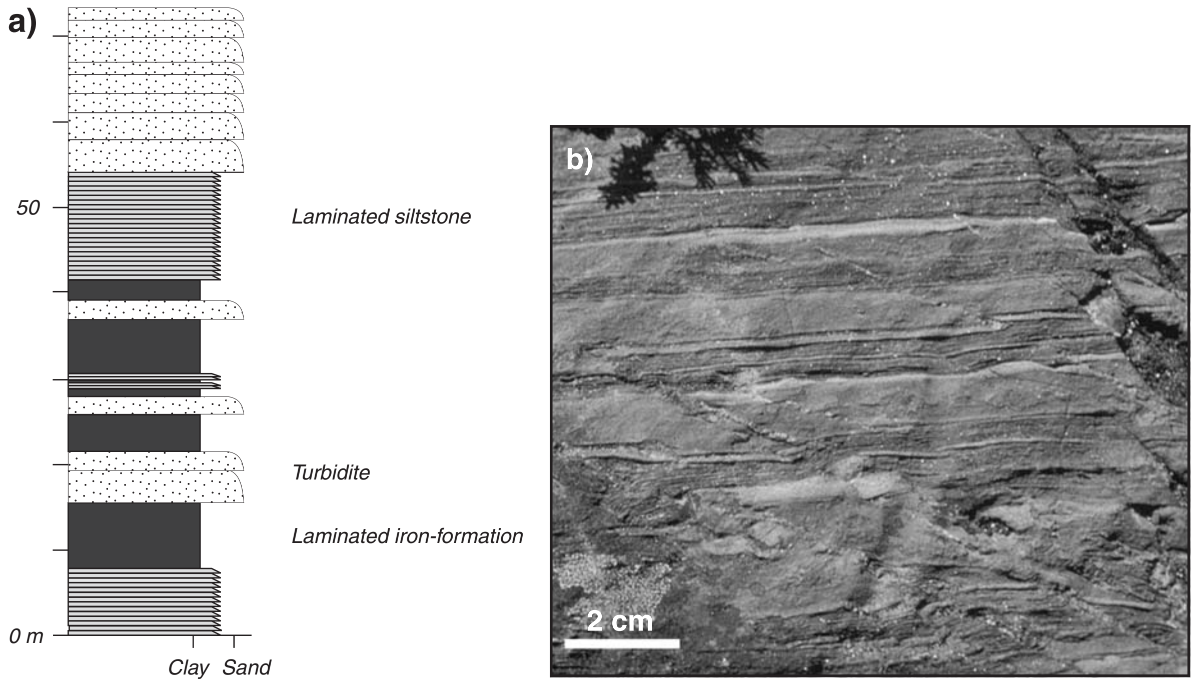


Figure 33. *a) Stratigraphy of iron-formation at reference locality 8, northeast of Boucher Lake.* ***b****) Iron-formation comprising several intervals of thinly laminated chert and magnetite, interlayered with centimetre-scale siltstone (recessive units). Photograph by M.B. Lambert. GSC 1999-579A*

The metamorphosed mafic units form dark grey- to brown-weathering, massive, blocky-jointed to columnar-jointed outcrops, with lithology ranging from dark green, aphanitic to very fine-grained diabase (at relict chilled margins), to ophitic, coarse-grained metagabbro. The rocks comprise about 40–70% hornblende and chlorite (alteration of the primary mafic minerals; clinopyroxene forms rare, small cores in hornblende, and relict olivine is inferred from blocky forms completely replaced by chlorite) that form ophitic intergrowths with plagioclase (20–60%). Quartz (2–10%), which is interstitial to hornblende and plagioclase, may be a product of recrystallization during metamorphism. Most rocks contain 3–5% magnetite, minor calcite and epidote, and traces of pyrite.

Northeast of Regan Lake, a large northwesterly trending metagabbro unit, which has intruded andesite lavas and pillow breccia, yielded a preliminary U-Pb baddeleyite age of 2586 ± 5 Ma. (Villeneuve et al., 2001). If this age is meaningful, it would indicate an Archean mafic intrusive event that is younger than, and unrelated to Back Group volcanism.

Between Thlewycho Lake and Rusty Lake, an array of metagabbro units outlines an approximately 9 km long doubly plunging antiform within the western margin of the volcanic complex. In the southern fold nose, gabbro is highly altered, sheared, and contains two generations of foliations. At the crests and noses of this fold, where the intrusions have shallow attitudes, they cap ridges and follow contours around high hills. Here they form broad areas of fine-grained diabase (chilled margins) with prominent nearly vertical columnar jointing (Fig. 34). Near Thlewycho Lake these sills (or dykes) have intruded an interval of interbedded felsic volcaniclastic

Figure 34. *Vertical columnar joints (40–50 cm across) in fine-grained margin of large metagabbro sill east of Thlewycho Lake. Hammer is 33 cm long. Photograph by A. Miller. GSC 2002-784*

rocks of the Thlewycho sequence and shale and iron-formation of the Beechey Lake Group, as well as into the Thlewycho east rhyolite lava dome. The sills include screens of laminated iron-formation, graphitic shale, and felsic volcaniclastic rocks, and units of iron-formation occur intermittently along sill margins. Although intrusive contacts are roughly parallel to, or at low angles to bedding near Thlewycho Lake, some dykes near Rusty Lake clearly transect stratigraphy at high angles. Because these sills are almost entirely within the Thlewycho sequence, and in close proximity to a basalt flow on the Thlewycho east lava dome, they could be synchronous with Boucher-Regan mafic volcanism, like the sills to the north.

Northwesterly trending folded units of metagabbro, which occur within the Beechy Lake Group 2–5 km west of the volcanic complex, from Jim Magrum Lake to Keish Lake, and scattered units southeast of the complex, have not been dated. Although they likely are related to the younger Archean mafic event, some could be synchronous with mafic intrusions related to Boucher-Regan basalt flows.

GRANITIC INTRUSIONS

Granitic plutons intrude the southern and northwestern sides of the volcanic complex. Following the nomenclature of Henderson et al. (1999), those in the southern portions of the complex are assigned to the 'Tarantula quartz diorite'. Compositions of the two large bodies (only the margins have been mapped) vary from granodiorite to quartz monzonite and grade into tonalite and gabbro compositions at the margins. Sedimentary rocks are hornfelsic at the contact with the pluton on the northern side of the Back River.

About ten small (100–300 m across) stocks or dykes are scattered within the southern part of the Thlewycho sequence. While they range from quartz monzonite, tonalite, and monzonite (Beaumont, 1978), several are hornblende-rich diorite to very coarse-grained hornblendite (unit Ah). Two northwesterly trending dyke-like bodies that intrude the Gold Lake rhyolite dome, are zoned intrusions having dark green, coarse- to very coarse-grained (crystals to 1 cm) hornblendite centres grading to grey, fine-grained, hornblende diorite margins. A nearby 100 m across circular body comprises 90% fresh hornblende up to 3 cm across with interstitial feldspar and quartz and trace amounts of epidote and chalcopyrite. These bodies are similar to some marginal phases of the pluton to the south (unit ATqd), which have hornblende-rich (about 30–50%) and gabbroic phases, and may represent differentiates from the same magma.

Plutons on the northwestern side of the complex, which vary from quartz monzonite to granodiorite, are part of a major swarm of large, zoned intrusions (including quartz diorite, tonalite, melagranodiorite, leucogranodiorite, and granite) the petrology and chemistry of which have been studied by Hill (1980) and Hill and Frith (1982) and were mapped by Frith (1987).

PROTEROZOIC DYKES

Mesoproterozoic Mackenzie dykes (U-Pb igneous age of Mackenzie dykes is 1267 ± 2 Ma; LeCheminant and Heaman (1989)) and Paleoproterozoic Malley and Mackay dykes cut across granitic plutons and all fold structures in the area. These mafic dyke swarms are displaced by northerly to northeasterly trending faults that transect the volcanic complex.

Mackenzie dykes (unit mPM) in this area have northwesterly trends and pronounced aeromagnetic expression. Single dykes have been mapped for 25 km and range up to 75 m wide. They are brown-weathering gabbro, quartz gabbro, and diabase that are coarse, equigranular to fine ophitic in hand specimen. Rocks are fresh to slightly altered; pyroxene is slightly altered to amphibole and minor chlorite. Almost all thin sections from these rocks contain trace amounts of baddeleyite. The dyke 1 km east of Jim Magrum Lake displays pronounced zoning ranging from aphanitic basalt margins, through coarse gabbro, to coarse-grained granophyric centre (Appendix shows mineralogical and chemical profiles through this dyke). Generally, these dykes are higher in TiO_2, Zr, Sr and P_2O_5, and Na_2O+ K_2O and lower in Al_2O_3 and Y than other mafic dykes in the area.

Weakly metamorphosed gabbro and basalt dykes (unit pPmd) include northeasterly trending Malley diabase (U-Pb zircon igneous age 2232 +11/-6 Ma, reference locality 13, Fig. 1; O. van Breemen, pers. comm. (1992)) and easterly to east-northeasterly trending Mackay diabase (2.21 Ga; LeCheminant and van Breemen (1994)). These dykes do not have any distinctive aeromagnetic expression. They are mineralogically and texturally similar to Mackenzie dykes except they are altered (pyroxene is partially altered to amphibole, biotite, epidote, and chlorite). Baddeleyite was seen in one thin section.

PETROCHEMISTRY

Samples from most lithologies of the Back River complex have been analyzed (by laboratories of the Geological Survey of Canada, between 1976 to 1982) for major elements, by X-ray fluorescence spectroscopy, and selected trace elements by quantitative spectrochemistry. Although these analyses are unpublished, cursory features and preliminary interpretations of the data are reported herein.

The volcanic and intrusive rocks within the Back River complex can be separated into three broad chemical groupings on the basis of FeO/MgO: 1) tholeiitic basalt, characterized by high FeO/MgO ratios (Miyashiro, 1974) and/or Fe enrichment (Irvine and Baragar, 1971); 2) transitional tholeiitic–calc-alkaline andesite to rhyolite, characterized by relatively high FeO/MgO ratios and trends on the AFM diagram which cross from the tholeiitic to the calc-alkaline field; and 3) calc-alkaline andesite to rhyolite, characterized by moderate FeO/MgO ratios and typical trends in the AFM diagram. Intrusive rocks are all calc-alkaline.

Tholeiitic rocks can be divided into three groups based on field relationships and/or chemical criteria.

1) Basaltic to andesitic pillow lava and related intrusive rocks of the Boucher-Regan sequence. The basalt to basaltic andesite samples range from 47.8 to 54.9% SiO_2 (anhydrous) and are characterized by generally high Al_2O_3 and very low K_2O (0.17–0.65%). Most of these rocks plot within the tholeiitic field on the AFM and the FeO/MgO versus SiO_2 diagrams. The more andesitic samples from within this sequence plot within the calc-alkaline field.

2) Metamorphosed gabbro (unit Amd).

3) Mackenzie dykes are more evolved than older basalt and gabbro and have distinctly higher Zr, K_2O, and TiO_2 and lower Ni and Cr contents. Rare-earth elements show a slightly LREE-enriched trend and HREE contents two to three times chondrite.

The more mafic basalt units of the Boucher-Regan sequence have high MgO (9.5%), Ni (240 ppm), and Cr (366 ppm), values typical of basalts in equilibrium with a peridotitic mantle. These samples may be considered to be representative of a primitive, mantle-derived magma. Compositionally more evolved rocks may represent fractionates along a liquid line of descent as most elements co-vary linearly with SiO_2.

The majority of rocks within the Back River complex are either calc-alkaline or transitional tholeiitic–calc-alkaline. They span the spectrum of compositions from andesite to rhyolite and comprise rocks of both the Innerring and Thlewycho volcanic sequences. The transitional trend reflects high FeOt /MgO ratios principally owing to low MgO contents rather than high FeO. Most transitional rocks are dacitic in composition (63–70% SiO_2) although some are rhyolitic and andesitic.

Rare-earth-element data corroborates the above-mentioned subdivisions made on the basis of major- and trace-element data, and show further distinction between the Boucher-Regan sequence and the Innerring-Thlewycho sequence rocks. Basaltic rocks have flat, near-chondrite-value REE patterns. Andesitic rocks of the Boucher-Regan sequence have higher Ce/Yb and Sm/Yb ratios and lower Yb and Lu than those from the Innerring-Thlewycho sequences. Rhyolitic rocks of the Boucher-Regan sequence have distinctly depleted patterns and lower REE abundances than those of the Thlewycho sequence.

In detail the chemical trends do not seem to be related by any simple fractionation model. Andesitic rocks, however, are similar to island-arc–continental-arc-type andesite. Petrogenesis of the Back River rocks appears to be quite complex, and must involve different source areas of melting, different degrees of melting, and possible mixing of felsic and mafic magmas.

STRUCTURAL GEOLOGY

Regional structural patterns

The dominant regional structures of map area include a dome, about 15 km by 25 km across, centred on the southern half of the volcanic complex (south of Outerring Lake), and two doubly plunging anticlinoria, and an intervening synclinorium, which arc northward across the northern half of the area from the Back River in the east, to near Keish Lake in the west (Fig. 35, on CD-ROM). The most prominent and reliable structural markers that define these features are the contact between the Back Group volcanic rocks and the Beechey Lake Group sedimentary rocks (henceforth referred to as the 'volcanic-sedimentary contact'), and major stratigraphic boundaries and younging sequences within the Back Group.

The dome is centred on the thickest portion of the volcanic succession (combined thickness of Innerring and Thlewycho sequences is estimated to be between 2500 m and 4000 m) that contains stratigraphy and volcanic structures that are interpreted to have been part of the main volcanic edifice of the stratovolcano. The dome is an asymmetrical structure in which the inclination of outward dipping and younging strata change gradually from horizontal in the broad central parts, to 10–25° towards the eastern sides, 35–50° towards the northern side, and 45–70° towards the western side. Although the bulk of the central part of the dome is only weakly deformed, its margins are folded as indicated by the moderate to steep attitudes, anticlines at the southern tip and northeastern corner of the southern complex, folded sills along the western margin, local dip reversals in volcaniclastic units, and a folded outlier of interbedded turbidite sequences on the eastern side.

On the north side of the dome, essentially homoclinal volcanic strata transform northward into a series of east-trending folds, the undulating axial traces of which wrap around the northwestern side of the dome. An east-trending syncline that follows Outerring Lake marks this transition. Farther north, the arcuate axial traces of the anticlinoria and synclinorium roughly follow this trend. The doubly plunging southern anticlinorium and synclinorium culminate near the Quartermoon Lake rhyolite dome, defining a northwesterly trending arch. This arch aligns with the axis of an open fold on the northwest side of the dome.

Along the western side of the volcanic complex, tightly folded Beechey Lake Group turbidite sequences consistently have northerly to northwesterly trending structural trends that roughly parallel the side of the volcanic complex. Along the southeast side of the volcanic complex, however, complexly folded turbidite sequences have highly variable orientations that appear to have been crumpled against the volcanic complex.

Although deformation has affected all units, its expression is much less intense in volcanic units than in sedimentary rocks of the surrounding Beechey Lake Group. In much of the dome, for example, deformation is weak, rocks generally lack foliation, and volcanic structures and textures are essentially in a pristine state. On the southeastern side of the dome, the gentle attitudes of mildly deformed volcanic units persist right up to the volcanic-sedimentary contact, where they change abruptly to the ubiquitous steep attitudes in highly deformed metasedimentary rocks. This contrasting style of deformation suggests that the volcanic rocks were rheologically more competent than the sedimentary rocks. Disharmonic folding occurs on all scales and results in tightly folded metasedimentary rocks against or between open-folded volcanic rocks.

Narrow zones of high strain, which contain non-cylindrical folds and strongly foliated mylonitic rocks, mark this change around the southeastern and southwestern sides of the southern complex. Shearing, however, is not ubiquitous along the volcanic-sedimentary contact. It is common where the volcanic succession is thickest (in parts of the southern complex), less well developed along the contact between turbidite and the basalt succession in the northern anticlinorium, and is absent where volcanic units thin and interfinger with metasedimentary rocks.

Generations of deformation

Three generations of regional deformation (D_1, D_2, and D_3) have affected the volcanic complex and surrounding metaturbidite sequences of the Beechey Lake Group. D_1 produced open, regional warps to upright isoclinal F_1 folds that have varied orientation. D_2 produced open warps to tight marginal folding of the volcanic complex, tight to isoclinal F_2 similar folds in the turbidite sequences, which have a well developed axial-planar cleavage (S_2) that overprints F_1 structures, and local zones of high strain. D_3 produced moderately to steeply plunging, open, F_3 folds that trend approximately east throughout the area. These generations were defined from overprinting relationships of folds and foliations in metaturbidite around the southern part of the volcanic complex (Beaumont-Smith *in* Lambert et al., 1990, 1992; C. Beaumont-Smith, unpub. work in progress). Fabric elements are best developed in pelitic units of the turbidite. Deformational fabrics, however, are moderately to poorly developed in the massive units which dominate the volcanic complex. Commonly, outcrops of volcanic rock contain only one (if any) penetrative fabric. Generation of such fabrics may be inferred from orientation of foliations in nearby metasedimentary rocks, or from their orientation with respect to mapped folds, or regional foliation trends of known generation (most foliations in volcanic rocks were mapped as 'main foliation, generation unspecified').

D_1 folds

The oldest deformation observed in the turbidite produced tight to isoclinal, upright to steeply overturned F_1 folds that have shallowly to moderately plunging axes. In the absence of marker horizons within metasedimentary rocks, F_1 folds are inferred from abrupt changes in dip and stratigraphic younging direction that are overprinted by the ubiquitous S_2 slaty cleavage. Tight F_1 folds have been mapped in turbidite, exposed on islands in Gold Lake and in the complexly folded area to the southeast of the lake (Ostler, 1977; C. Beaumont-Smith, unpub. work in progress), where they are folded by F_2 folds and crosscut at a high angle by S_2 cleavage. Mesoscopic axial-planar cleavage (S_1), however, does not seem to be developed in these F_1 folds.

F_1 folds are difficult to identify in turbidite along the western side of the volcanic complex, where the regional structure consists of tight isoclinal folds with axial traces and long limbs that are subparallel to the north-northwesterly trending side of the complex. Within turbidite, mesoscopic F_1 folds are rarely identified with certainty, partly because S_1 is either not developed or indistinguishable from the strongly developed S_2 fabric. Locally, mesoscopic F_1 isoclines have a bedding-parallel fissility that could represent a weak foliation (or a compaction fabric). S_1, however, is identifiable in thin sections of metapelite as a bedding-parallel slaty cleavage, as a micro-crenulation in F_2 fold hinges, and as a foliation (defined by quartz inclusion trails preserved within pre-S_2 biotite porphyroblasts) that shows angular discordance with S_2 (C. Beaumont-Smith, unpub. work in progress). Beaumont-Smith (unpub. work in progress) suggested that foliations on this side of the volcanic complex are a composite S_1/S_2 feature formed by transposition of S_1 into S_2 trend during D_2 tightening of the earlier folds. West of Thlewycho Lake, shallow-plunging, upright, regional folds that have kilometre-scale tight, narrow hinge zones and long limbs (but are wrinkled by F_2 minor folds) are interpreted as F_1 structures.

Between the north end of Thlewycho Lake and the east end of Outerring Lake, northerly trending, tight F_1 synclines within the volcanic complex are crosscut by northwesterly trending S_2. The easterly trending, undulating syncline, marked by Beechey Lake Group rocks that follows Outerring Lake on the north side of the dome, is a well documented F_1 fold. The undulation of its axis and numerous folds of its margin result from overprinting of the syncline by northwest-trending F_2 folds. This complex structure marks a synclinal 'trough' between the north side of the regional dome and the southern anticlinorium. Although the north side of the dome appears to be a homocline, local reversals in bedding within broad volcaniclastic units suggest that it contains minor, internal F_1 folding.

Iron-formation units in the synclinorium 2 km northeast of Boucher Lake and 3.5 km northeast of Regan Lake outline tight, upright to steeply overturned F_1 isoclinal folds. Both are folded by F_2 and cut by north-northwesterly trending S_2 cleavage. The exceptionally long strike length of their limbs indicates that axes of these isoclines are nearly horizontal or very shallowly plunging for distances of about 15 km. The vertical to steeply dipping foliation parallel to the fold axes in the southern iron-formation, suggest that S_1 is developed in metasedimentary rocks in the northern part of the complex.

The anticlinoria and synclinorium are interpreted as major F_1 features because they are overprinted by penetrative northwesterly trending S_2. Foliation in the volcanic belt that makes high angle with S_2 and trends parallel to the undulating axial trace of the northern anticlinorium are interpreted as S_1. Similar, roughly bedding-parallel foliations, that also trend along F_1 axial traces within the synclinorium and southern anticlinorium, are also assumed to be S_1 (although some of these foliations could be S_3).

It appears that D_1 deformation produced the main deformational pattern in the northen half of the volcanic complex. Probably most of the steep dips in the Beechey Lake Group metaturbidite sequences result from this period of deformation (C. Beaumont-Smith, pers. comm., 1996). D_1 also likely contributed to steepening of the margins of the southern complex.

D_2 folds

The most commonly observed mesoscopic folds in the area are second-generation structures that form tight to isoclinal similar folds with well developed axial-planar cleavage (S_2). These folds have moderate to steep plunges and vertical to steeply inclined axial planes. Most folds are strongly asymmetrical and commonly have highly attenuated and sheared limbs resulting from displacement along the S_2 cleavage. S_2 is a ubiquitous, penetrative slaty cleavage that has a strong northwesterly regional trend across the complex. This cleavage, which is oblique to bedding in metasedimentary rocks, and commonly the only cleavage observed in metavolcanic rocks, is a key feature in identifying first- and second-generation fold structures.

The second generation of deformation produced regional warps and arching of the D_1 anticlinoria and synclinorium about northwesterly axes in the northern part of the volcanic complex, open folding of the northwestern side of the southern complex, folding and steepening of margins of the southern complex, and refolding and tightening of D_1 structures in metasedimentary rocks around the southern complex.

Regional D_2 warping is expressed by the undulations of the northern anticlinorium, of the rhyolite-derived turbidite unit, of the F_1 isoclinally folded iron-formation north of Boucher Lake, and of the F_1 syncline along Outerring Lake. Margins of this Outerring Lake syncline are also deformed by northwesterly trending F_2 folds. D_1/D_2 fold inference resulted in a series of doubly plunging folds along the length of this syncline, and 'en echelon' basins (outlined by iron-formation) near the east end of Outerring Lake.

In the northwest corner of the map area, D_1/D_2 fold interference has produced prominent basin-and-dome structures (involving a primary rhyolite dome) that are 'Type II' interference patterns (Ramsay, 1967). The tight basin in metasedimentary rocks beside a more open-folded and warped volcanic belt is an example of disharmonic fold interference.

In metaturbidite units west of Thlewycho and Jim Magrum lakes, where regional trend of folds, bedding, and S_2 are approximately parallel to the western side of the southern complex, F_2 forms mesoscopic and minor folds on the long limbs of shallow-plunging, regional folds (interpreted as F_1). The mesoscopic folds have strongly developed S_2 cleavage that is oblique to bedding. As previously proposed, tight D_2 folding with the pervasive development of S_2, has transposed S_1 to form a composite S_1/S_2 cleavage (Williams and Zwart, 1977; Wilson and DeHouville, 1985; C. Beaumont-Smith, unpub. work in progress). An S_2 crenulation cleavage is also observed in low-strain domains, such as in F_2 fold hinges and in pressure shadows around boudinaged veins. Minor F_2 folds with moderate to steeply plunging axes have a constant s-asymmetry along the western side of the volcanic complex. Their axes plunge consistently southward from the south end of the complex to half-way along Thlewycho Lake. North of this point, plunge directions vary from southward to north-northwestward.

In this area, all folds verge toward the volcanic complex. Between Thlewycho Lake and Keish Lake, however, where turbidite units and sedimentary rocks of the Keish Lake fan are folded about northwesterly trending axes, fold vergence changes to southwesterly; F_2 folds maintain the s-asymmetry.

The eastward fold vergence and near parallelism of all structures to the western side of the southern complex may have resulted from tightening of F_1 structures against the volcanic complex during D_2 deformation. Constant s-asymmetry of F_2 folds all along the western side of the volcanic complex could result from refolding of F_1 about northwesterly trending axes (i.e. northeast-southwest compression).

Southeast of Jim Magrum Lake, D_2 produced a tight anticline in the southern margin of the volcanic complex.

In the complexly folded metasedimentary rocks along the southeast side of the volcanic complex D_2 has deformed axial traces of upright F_1 folds into tight F_2 folds that have well developed S_2 foliation oblique to bedding. The trends of S_2 describe a diverging fan; they change gradually from the regional northwesterly trend (which is almost perpendicular to the sedimentary-volcanic contact) 3 km from the complex towards subparallelism with the margin of the volcanic complex (Fig. 35). S_2 changes to west-southwesterly trends south of Gold Lake. North of Gold Lake, S_2 trends swing northerly to northeasterly at the northeastern 'corner' of the southern complex. This deflection of foliation and bedding towards the volcanic complex is interpreted to indicate that the turbidite sequences were deformed around the apparently rheologically competent Back Group.

North of Gold Lake, D_1/D_2 produced complex fold interference structures within the margin of the volcanic complex; notably, the doubly plunging syncline, containing an outlier of Beechy Lake sedimentary rocks in the Thlewycho sequence, and a northeasterly plunging anticline. The interpretation of these structures through the Quaternary cover is depicted in Figure 1.

D_3 folds

The third generation of folding was less intense than the preceding deformations and produced open folds, box folds, and local kink bands (Fig. 36). F_3 folds are upright structures that plunge moderately to steeply down the dip of previously folded surfaces. They trend approximately east throughout the area, with the exception of the northeast part of the southern complex, where kink bands trend northwest. Although S_3 is penetrative on a regional scale, morphology varies from a fracture-cleavage–kink-band boundary to differentiated crenulation cleavage developed in pelitic horizons (C. Beaumont-Smith, unpub. work in progress.). At amphibolite facies, S_3 forms isolated, undifferentiated crenulations frequently nucleating along biotite and cordierite porphyroblasts

Figure 36. Tight F_2 fold refolded by open F_3 fold (axis parallel to pen) in psammitic layers, near Gold Lake. Pen is 13 cm long. Photograph by C. Beaumont-Smith. GSC 2002-785

(cf. Hanmer, 1979). At subamphibolite facies, S_3 forms a weakly differentiated crenulation cleavage, most notably along the southern and eastern sides of the complex (C. Beaumont-Smith, unpub. work in progress). Most commonly, S is difficult to observe in outcrop, but can be identified by a moderately to steeply plunging crenulation lineation on the bedding surface.

In the Gold Lake area, interference between S_2 and S_3 forms a 'herringbone' structure. In outcrops where pelitic and psammitic layers have equal thickness, the two cleavages developed symmetrically around the bedding traces (C. Beaumont-Smith, unpub. work in progress).

S_3 foliations, although sparse, show the following general trends around the southern half of the volcanic complex (Fig. 35). They fan from west-southwest near Jim Magrum Lake, through westerly along the eastern and western sides of the southern complex, to northwesterly in the northeastern sides. These trends generally make high angles with trends of S_2 and axes of F_2 folds.

The broad undulations of the volcanic-sedimentary contact on the eastern and western sides of the southern complex, as well as the changing plunge of F_2 folds (from southerly to northerly) in turbidite units along the western margin, are inferred to be the result of large-scale, open F_3 folding about westerly trending axes. It is also possible that F_3 folding steepened the plunges of the anticlines at the south end and northeast corner of the southern complex.

Zones of high strain

Narrow zones of high strain (generally less than 100 m wide but up to 200 m) are exposed around the southern parts of the complex, continuously from the southern tip (they occur on both sides of the F_2 fold that forms this tip) to Jim Magrum Lake, intermittently from the northeast end of Jim Magrum Lake to the southeast side of Thlewycho Lake, and intermittently along the eastern side of the Gold Lake dome to about 6 km south of Gold Lake. High-strain zones also occur locally along the northern side of the complex, as narrow shear zones along the contact between mafic flows and sills of the Boucher-Regan sequence and turbidite units of the Beechey Lake Group, and have been reported in drill core along the east-central side of the volcanic complex (Moore, 1977).

Around the southern parts of the volcanic complex, high strain occurred mainly within carbonate-cemented breccia on the margins of felsic domes and flows that are at the interface between the Back Group and the Beechey Lake Group. High strain, however, is not ubiquitous along the volcanic-sedimentary rock contact. Most rocks in these zones are tectonically brecciated and sheared, primary flow-breccia units, that are highly strained, lineated, and locally have mylonitic carbonate matrix. Generally the shear zones contain pronounced planar fabric defined by preferred orientation of slivers and flattened volcanic clasts parallel to intensely developed S_2 foliation that envelopes the clasts (Fig. 37). The subangular to elongate clasts define a lineation that plunges roughly downdip from or obliquely to S_2. The planar fabric is roughly parallel to the volcanic complex margin. Where rhyolite is massive (i.e. the primary rock was not breccia), high strain produced narrow zones of protomylonite to mylonite. In these rocks, c-planes are defined by strong preferred orientation of phyllosilicate minerals, stretched volcanic clasts, and thin seams of recrystallized calcite and quartz including abundant ribbon quartz (C. Beaumont-Smith, unpub. work in progress).

Commonly, stained rhyolite flow breccia units have matrix carbonate (which is light grey weathering, in contrast to the normal dark brownish-grey-weathering carbonate cement in undeformed breccia) that has deformed ductilely, whereas felsic clasts have deformed in a brittle fashion. The resulting calc-mylonite forms anastomosing networks to discrete zones less than 1 m wide. Calc-mylonite zones generally transect S_2 and in some places, S_2 in metaturbidite can be traced into shear zones in the volcanic rocks, where it is reoriented parallel to the c-planes (C. Beaumont-Smith, unpub. work in progress).

Folds in the calc-mylonite bodies are isoclinal, strongly noncylindrical, and lack consistent fold asymmetry. Sheath folds (Fig. 38) developed both in mylonitic rocks and in carbonate between blocks of breccia. There appears to be a rough correlation between the long axis of sheath folds and clast-stretching lineation in some shear zones.

C. Beaumont-Smith (pers. comm., 1996) analyzed the shear zones, and concluded that 1) along the southwestern margin of the complex, shear zones have sinistral shear-sense indicators and northwest-plunging stretching lineations that correspond to the S-asymmetry of F_2 folds in the area; and 2) mylonitization was a product of late-stage D_2 deformation and the high-strain zones represent areas of transpressional strain partitioning that developed in narrow zones along the margin of the southern complex where there was a significant rheology contrast between the Back Group volcanic complex and the surrounding Beechey Lake Group turbidite. The limited distribution of the high-strain zones, however, suggests that this was a local phenomena.

Faults

Most faults in the map area formed after deformation by folding. They form two trends: 1) northwesterly faults that cut across the southern part of the complex, displacing the folded eastern volcanic-sedimentary contact and the Malley diabase dykes; and 2) northeasterly trending faults that displace the Mackenzie dyke swarm as well as northern parts of the volcanic belt. The only synvolcanic faults are the arcuate faults inferred to be part of a ring-fracture system within the Innerring sequence. Presumably there were innumerable, small,

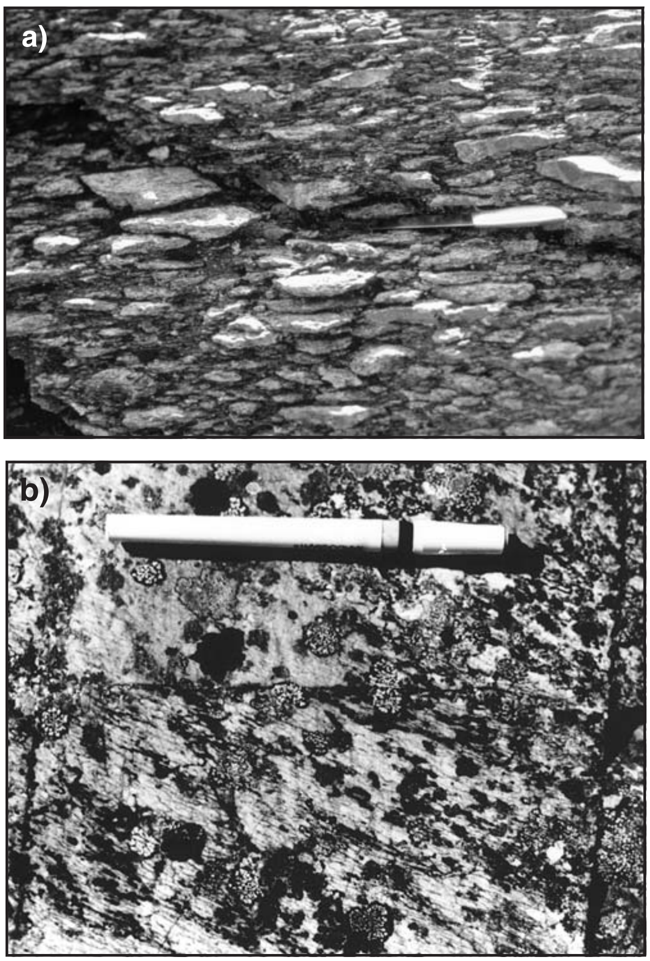


__Figure 37.__ Fabrics in the high-strain zone along the southwestern margin of the volcanic complex. __a__) Shear breccia in Thlewycho dacite along the northeast side of Jim Magrum Lake. Strong planar fabric, defined by preferred orientation of dacite slivers, is parallel to the volcanic complex margin. Knife is 20 cm long. Photograph by M.B. Lambert. GSC 2002-789. __b__) Mylonitized rhyolite with well developed shape fabric, 1.5 km north of Jim Magrum Lake. Pen is 13 cm long. Photograph by C. Beaumont-Smith. GSC 2002-790

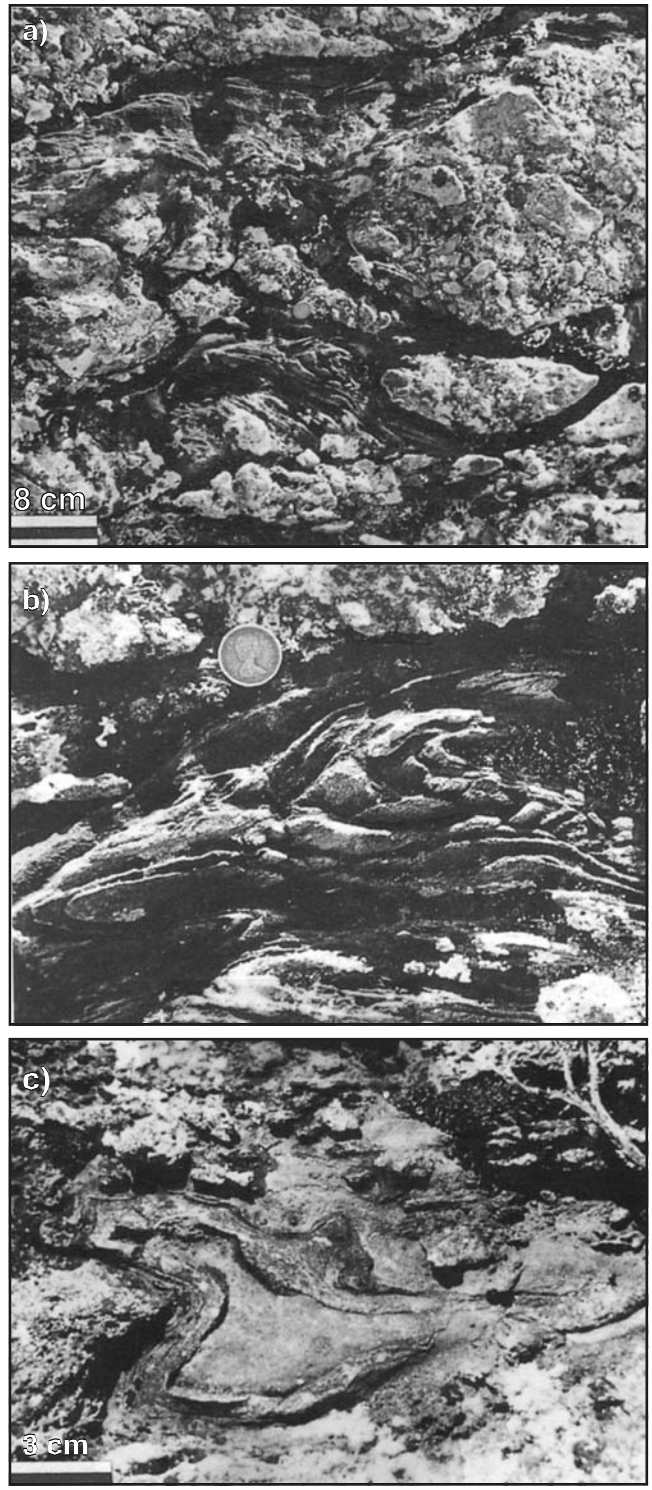


***Figure 38.** **a**) F_1 sheath fold in tectonically brecciated rhyolite flow breccia with calc-mylonite matrix east of Jim Magrum Lake. Photograph by C. Beaumont-Smith GSC 2002-786. **b**) Close-up view of sheath fold in Figure 38a. Coin is 18 mm across. Photograph by C. Beaumont-Smith. GSC 2002-787. **c**) Sheath fold within carbonate matrix of rhyolite flow breccia, northeast side of Jim Magrum Lake. Photograph by C. Beaumont-Smith. GSC 2002-788*

synvolcanic faults and fractures related to inflation before major eruptions that have not been distinguished. Such events are well documented among almost all modern eruptions.

Interpretation

Three generations of regional deformation have folded the volcanic complex. The variable degrees of deformation and contrasting patterns of deformation, within both the volcanic complex and the surrounding Beechey Lake Group, suggest that paleotopography of the relict volcanic pile played a significant role in defining the structural patterns. Stratigraphy indicates that the thickest part of the volcanic pile (interpreted as the main volcanic mass and edifice) corresponds to the present regional dome, that the pile thinned northward, and that there likely was a secondary topographic high over the Quartermoon Lake rhyolite dome.

Although the southern complex was deformed by all periods of folding, several features suggest that the volcanic core controlled structural patterns and that the present dome is not simply a culmination of intersecting regional folds: the abrupt deflection of fold structures that trend perpendicular to the volcanic complex into near parallelism with the eastern margin; the tightening of F_1 and F_2 fold structures into parallelism with the western side of the dome; the verging of folded volcanic and sedimentary rocks toward the dome on the northern and western sides; and the marked contrast in strain between the highly deformed turbidite and the mildly deformed, massive volcanic units of the dome.

Possibly, the gross regional pattern was established during the first episode of deformation that produced westerly to west-northwesterly trending, open, regional warps, and on a smaller scale shallow-plunging, tight, upright folds. These horizontal to shallow-plunging folds may have produced the ubiquitous steep dips of the Beechey Lake Group strata. The deformation progressively warped open folds around and over the irregular topography of the remnant volcanic complex, folded thin flank successions, and probably steepened margins of the thick main edifice.

The second period of deformation: 1) arched early F_1 anticlinoria and synclinoria and parts of the main edifice; 2) refolded and tightened F_1 folds in the Beechey Lake Group against the core volcanic edifice while steepening the western side of the dome and folding its margins; and 3) refolded shallowly to moderately plunging, tight F_1 folds about steeply plunging F_2 axes to produce complex interference geometries. During deformation, strain was partitioned along the margin of the volcanic complex to develop localized high-strain zones within the metavolcanic rocks and immediately overlying metasedimentary rocks.

D_3 produced open folds that warped the margin of the southern complex and steepened plunges of F_2 folds about westerly to northwesterly trending axes.

Thus, the present southern part of the map area is a large dome formed by superposition of regional strain on the core volcanic edifice. The remnant volcanic edifice was partially deformed, but essentially behaved as a competent core (buttress) around which relatively incompetent sedimentary rocks and the northern parts of the complex folded.

METAMORPHISM

Metamorphism accompanying deformation increases from lower greenschist facies in the northern parts of the volcanic complex to lower amphibolite facies in the southern parts (Fig. 39, on CD-ROM). It is characterized by low-pressure assemblages similar to those seen throughout the Slave Province (Thompson, 1978, 1989). Sedimentary rocks, mainly of the Beechey Lake Group, are most sensitive to metamorphic changes and thus provide the main basis for establishing metamorphic zones. The lowest grades of metamorphism correspond roughly to a broad, shallow synclinorium across the northern side of the map area between Outerring and Regan lakes.

The cordierite isograd is precisely defined around Jim Magrum Lake. Here, metasedimentary rocks change from mica-rich (biotite, muscovite) schist, to garnet and/or amphibole biotite schist very near the cordierite isograd, to cordierite-andalusite±staurolite-biotite schist. Near the northeast side of the Back River, metasedimentary rocks become increasingly more schistose (biotite, muscovite) eastward towards Tarantula pluton, and become hornfelsic (containing cordierite) at its contact. In this area the amphibolite-facies boundary corresponds roughly with the first appearance of cordierite.

Three periods of porphyroblast growth define the metamorphic history within metasedimentary rocks of the Beechey Lake Group (C. Beaumont-Smith, unpub. work in progress): 1) an early period of biotite porphyroblastesis followed by 2) a post S_2, second generation of biotite and formation of cordierite from chlorite, and 3) peak of metamorphic conditions, with andalusite and minor sillimanite growth near the most southern end of the complex. Cordierite-amphibolite isograds are closely related to granitic plutons in the northwestern and eastern parts of the map area. Near Jim Magrum Lake, the cordierite isograd is not obviously related to plutons, and the estimated amphibolite-facies boundary appears to cross the regional structural trends and show little evidence of significant folding.

In metasedimentary rocks around the southern and western parts of the volcanic complex, S_2 foliation is overprinted by lower amphibolite-facies metamorphic assemblages characterized by the development of coarse-grained, second-generation biotite, cordierite, and andalusite. The last two minerals form poikiloblasts, locally more than 10 cm long, that are randomly oriented in the S_2 foliation surface. These rocks are commonly referred to as 'knotted schists' (Wright, 1967; Tremblay, 1971; Thompson, 1978) in the literature, with the first appearance of coarse knotted texture mapped as the cordierite isograd. Two generations of biotite are found in the amphibolite-facies rocks (C. Beaumont-Smith, unpub. work in progress). The first generation formed prior to F_2 and were subsequently aligned parallel to S_2. These early biotite porphyroblasts were locally overgrown by second-generation biotite that accompanied the growth of cordierite. Cordierite poikiloblasts contain an internal foliation that is concordant with S_2 in the matrix where they have not been rotated during D_3, suggesting that the cordierite-biotite assemblage grew during or after D_2. Locally, large ovoid cordierite porphyroblasts preserve graded bedding seen as variations in the density of inclusions and include first-generation biotite porphyroblasts oriented parallel to S_2 in the matrix.

ECONOMIC GEOLOGY

Pyrite and pyrrhotite are very common throughout the map area. Since gossans all contain pyrite, the mineral may not be noted unless it is unusually abundant, or forms concretions (nodules) (such as those associated with iron-formation at the northeast corner of the southern domal complex) or local bedded sulphide horizons between lava flows where sulphide nodules weather out to form cavities up to 30 cm across. Pyrite and pyrrhotite are commonly finely disseminated in carbonate-cemented breccia, in quartz veins in areas of carbonate, and in quartz veins near iron-formation.

Northeast of Keish Lake, pyrrhotite, pyrite, and chalcopyrite are abundant where hornblende-phyric basalt sills and flows make contact with sedimentary rocks of the Beechey Lake Group.

Chalcopyrite and sphalerite are also rare accessory minerals within iron-formation (unit ĀBLia).

Near the southeast end of Thlewycho Lake, massive sulphide (including galena, sphalerite, pyrite, and chalcopyrite) containing Ag-Pb-Zn occurs in a shear zone within the Thlewycho east rhyolite lava-dome complex (Seaton et al., 1987).

Iron-formation has been the main focus of exploration since 1961, when Au was first discovered by COMINCO Ltd. along the shores of the Back River. Rocks associated with iron-formation unit ĀBLia, along the contact between the volcanic complex and the Beechey Lake Group, contain the most auriferous rocks in the area. This iron-formation has been studied thoroughly by Moore (1977), mainly along the eastern side of the volcanic complex, with the aim of determining the nature of gold mineralization and the environment in which it occurs. Much of the significant data was gleaned from diamond-drill core. All gold locations shown on the map, as well as the following abstractions and interpretations, are taken from Moore (1977). He concluded that gold mineralization is stratabound within the iron-formation, and that "Toby quartz veins and sulphide-rich breccia, both of which bear a strong spatial relationship to the iron-formation zone, carry the highest mean gold contents of all rocks in the area. Sulphide-rich and oxide-rich iron-formation also have strongly anomalous gold abundances."

Toby quartz veins (ranging from 1 mm to 10 m wide) are grey to almost black, commonly highly fractured quartz that are restricted to a zone about 60 m thick stratigraphically above oxide-rich iron-formation (Moore, 1977, p. 60). "Pyrite and pyrrhotite...may comprise as much as 20% of the veins and chalcopyrite and sphalerite are locally abundant...rare bornite, native copper, native gold, arsenopyrite and hedleyite...are also present" (Moore, 1977, p. 61). Moore reported Au (250–10 000 ppb) associated with these veins and iron-formation, and the distribution of other significant elements (S, Mn, Cu, Zn, Ni, Co, Cr, Se, Hg) in the various facies of the iron-formation.

Moore (1977) interpreted mean homogenization-temperature on fluid inclusions in Toby quartz veins of 369°C to indicate that

> "... veins were emplaced during the waning states of greenschist-grade metamorphism. The sulfide-isotope distribution pattern in the sulfide-rich iron formation indicates that the sulfides were probably formed by volcanic fumaroles debouching onto the sea floor and precipitating pyrite and pyrrhotite in the H_2S^- predominant field (low f O_2, acid to neutral pH). The sulfur isotopic patterns....[suggest]....that the sulfides in the veins were remobilised during metamorphism from preexisting sulfides in the iron formation."

Moore (1977) regarded gold enrichment to have formed in a two-stage concentration process.

> "The first stage... may have been produced by convective circulation of hot brines, possibly recycled sea water, leaching gold and base metals from the volcanic pile. These metal-enriched brines debouched onto the sea floor, causing deposition of metalliferous sediments. The second stage.... mobilization of silica, sulfides and gold from iron formation during regional metamorphism, producing quartz veins carrying sulfides and minor native gold."

INTERPRETIVE SUMMARY AND EVOLUTION OF THE BACK RIVER VOLCANIC COMPLEX

The Back River volcanic complex is the product of three successive cycles of mafic (or intermediate) to felsic volcanism, represented by the Innerring, Thlewycho, and Boucher-Regan sequences. These sequences accumulated during late Archean time to form a major composite stratovolcano in a depositional basin, represented by the Beechey Lake Group of the Yellowknife Supergroup in the northeastern Slave Province. The dominance of intermediate and felsic volcanic rock compositions, not only in the Back Group, but also in the Hackett River and High Lake volcanic belts (Frith, 1987; J.R. Henderson, 1997) to the north, and enormous swarms of granitic plutons (Frith, 1987; Henderson et al., 1999), suggests that the Late Archean was a time of high-level intrusion of salic, calc-alkaline magma in the northeastern Slave Province.

The following account summarizes interpretations contained herein, and speculates on the volcanic phenomena and resulting landforms that probably developed during the evolution of the stratovolcano. Figures 40 to 42 schematically depict the stages in the evolution of the complex.

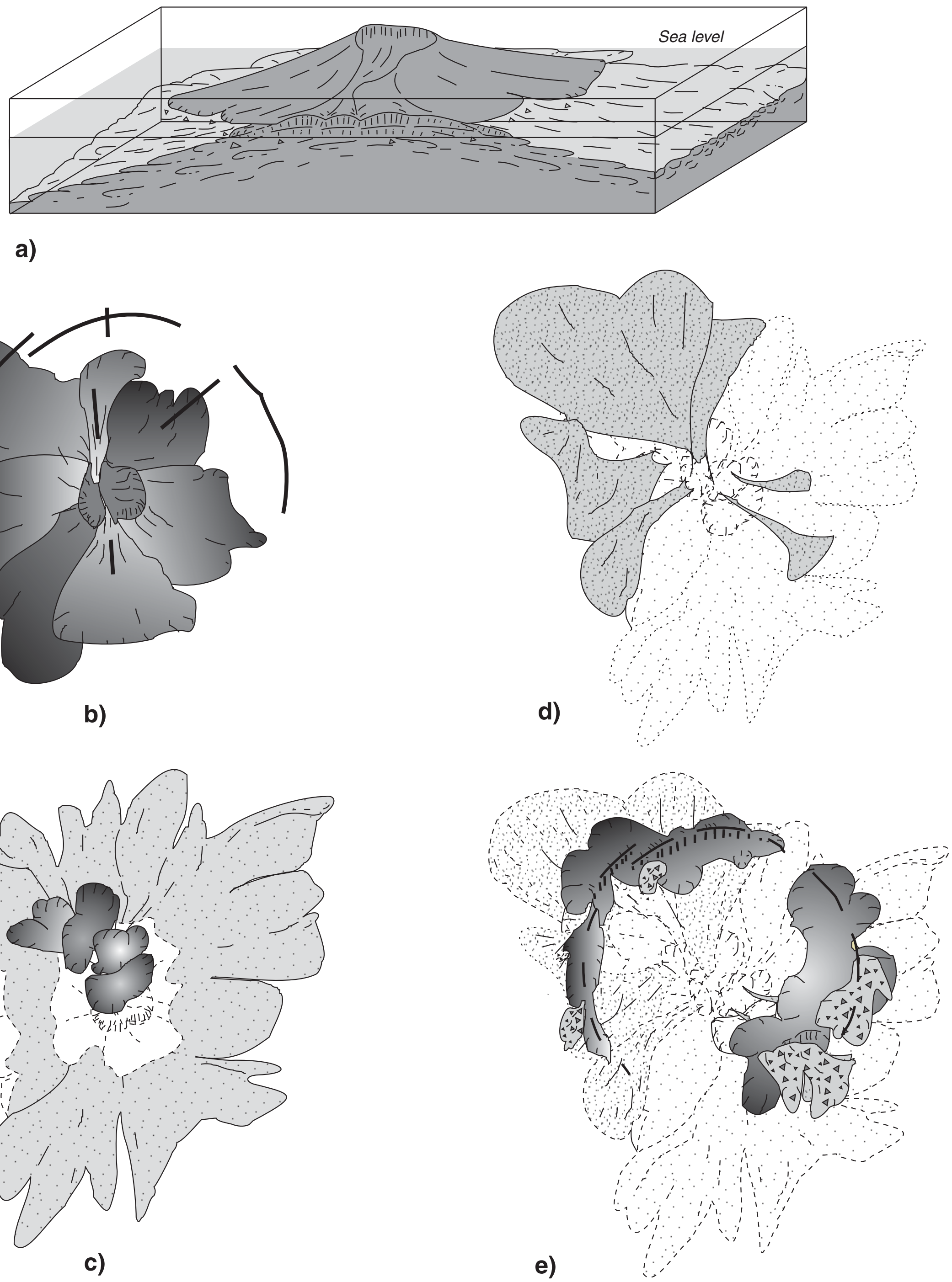
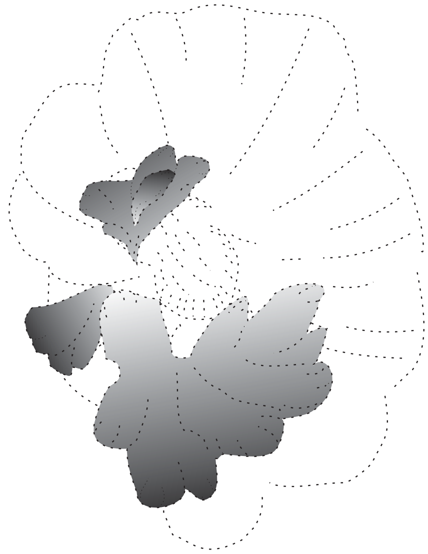


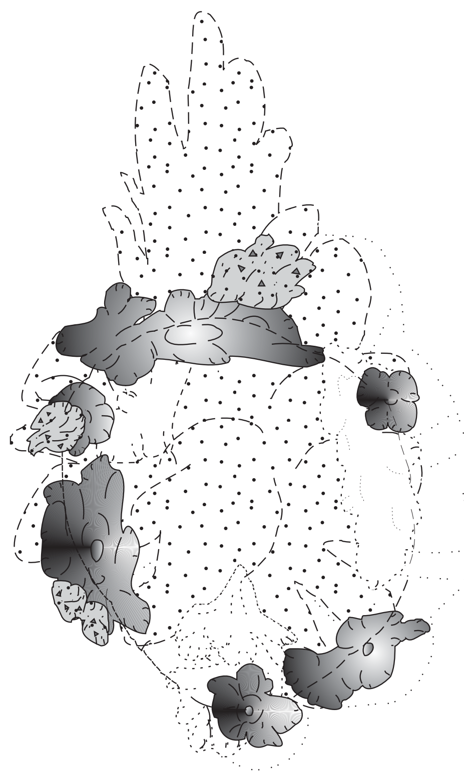
Figure 40. *Sketches showing the stages in the evolution of the Innerring sequence.* ***a****) Earliest mafic to intermediate lavas accumulated to form a subaqueous shield that emerged above sea level.* ***b****) Concentric and radial fracture systems (heavy lines) in early andesite lava cone (plan view).* ***c****) Explosive eruption of andesitic to dacitic pyroclastic flows (stippled) followed by effusion of dacite lavas (dark grey).* ***d****) Erosion of Innerring edifice to form clastic aprons, mainly on the northern slopes of the volcano.* ***e****) Caldera collapse followed the voluminous ash-flow tuff eruptions to produce an asymmetrical caldera (heavy lines) with greatest subsidence on the northen side. Rhyolite magma leaked from ring fractures and effused as thick domes (grey) with related collapse breccia (triangle pattern).*

Innerring sequence volcanism

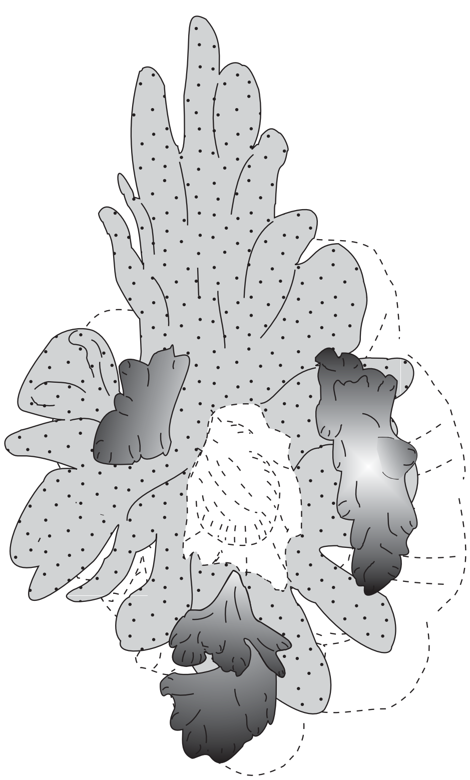
Although the base of this volcanic pile is not exposed, presumably the earliest eruptions were submarine effusions of mafic to intermediate lava on the sea floor. Lava probably accumulated to form a subaqueous shield that eventually emerged above sea level (Fig. 40a). Subaerial effusion of andesitic lava and explosive eruption of andesitic ash-flow tuffs formed the oldest deposits exposed in the present volcanic complex. The presently exposed Innerring sequence represents only the upper subaerial parts, and probably only a fraction of the total volume, of this early phase of the volcano.



a)



c)



b)

Figure 41.

Sketches showing the stages in the evolution of the Thlewycho sequence. ***a****) Effusion of porphyritic andesite lavas on the southern and northwestern sides of the Innerring volcano.* ***b****) Explosive eruptions produced voluminous andesitic pyroclastic flows (grey, stippled) that spread across much of the southern and northeastern slopes of the volcano and onto the northern flanks. Pyroclastic flows were followed by effusion of dacite lavas (dark grey).* ***c****) Generation of ring fractures (dashed lines) along which rhyolite domes and flows rose around the periphery of the main volcanic edifice. Collapse of domes produced local megabreccia and debris-avalanche deposits (stippled and triangle pattern).*

a)

b)

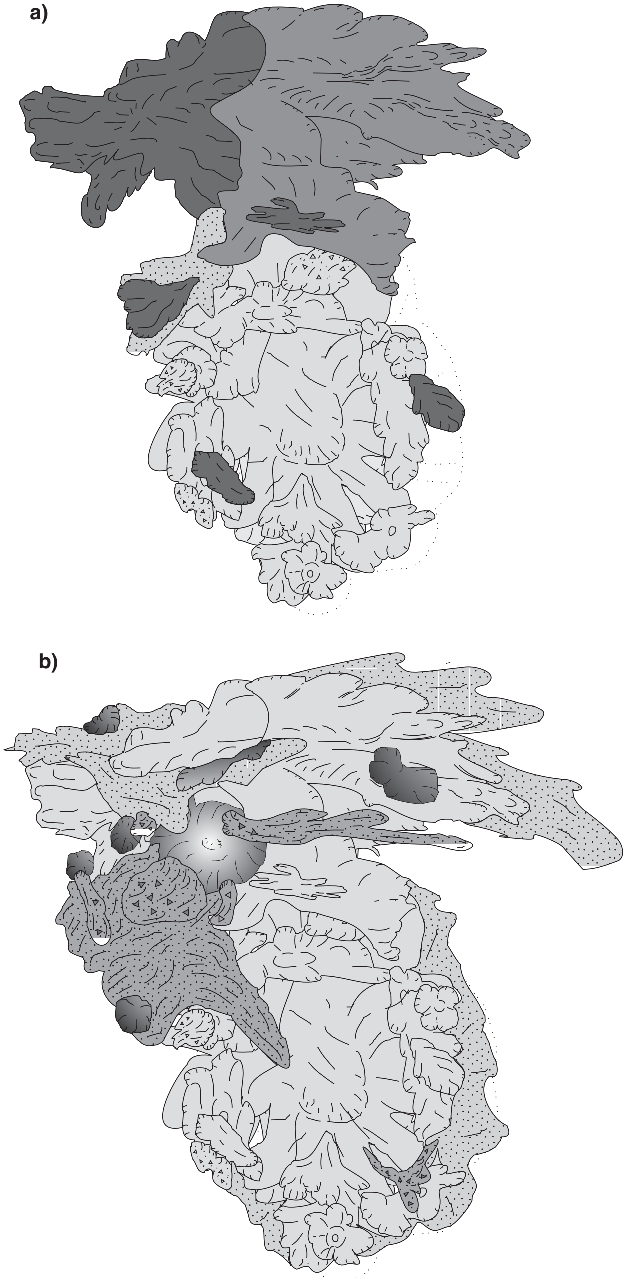


Figure 42. *Sketches showing the stages in the evolution of the Boucher-Regan sequence.* ***a****) Effusion of tholeiitic basalt (dark grey) and andesite lavas (medium grey) from fissures off the northern flanks of the stratovolcano formed a submerged domal ridge. Lavas spread southwards and lapped onto the shallow, northern margin of the emergent Thlewycho edifice (pale grey), and erupted as isolated monogenetic flows on the eastern and western sides.* ***b****) Rhyolite and dacite domes (dark grey) intruded and effused on the basaltic pile to produce the major Quartermoon Lake dome and a series of volcanic mounds around the northern and western flanks of the stratovolcano and in the adjacent basin. Mass wasting from domes produced banks of coarse debris, fans of rudaceous sandstone, and rhyolite-derived turbidite. Erosion formed clastic aprons (medium greys) in shallow-marine flanks around the periphery of the composite stratovolcano.*

Regional tumescence above a high-level magma chamber may have distended the shield and generated concentric and possibly radial fractures (Fig. 40b); the generation of ring- and radial fracture systems resulting from upward push due to increased magma pressure has been proposed from experimental and theoretical studies (Anderson (1936), Roberts (1970), and Troll et al. (2002), to name a few). Explosive eruption of gas-charged magma from such fractures erupted as a succession of andesitic to dacitic pyroclastic flows, which spread out on the eastern, southern, and western slopes of the emergent volcano, while quiet effusion of thick dacite lava flows took place on north-central slopes (Fig. 40c). Such eruptions probably destroyed parts of the central cone that may have existed during the earlier andesitic effusions. Between flows, streams locally deposited fluvial gravel and sand on the slopes of the volcano and clastic fans started to accumulate in shallow northern flanks of the volcano. Ash-flow tuffs that entered the sea, and water-laid air-fall ash deposited ash beds within clastic aprons that were developing by erosion from the Innerring edifice (Fig. 40d).

Presumably the rapid evacuation of the upper part of the magma chamber, caused by the previous voluminous ash-flow eruptions, was followed by caldera collapse on the northern portions of the volcano (Fig. 40e). This was an asymmetrical, 'trap door' type of caldera in which maximum subsidence occurred on the northern side, and diminished southward. Subsidence probably began before the previous volcanic activity ceased, such that rhyolite magma continued to rise along bounding ring fractures and escaped at the surface as lava domes — the last of Innerring volcanism. Rock falls from caldera walls, and from unstable rhyolite domes, combined with fluvial activity, produced debris-avalanche deposits and conglomerate.

During the waning phases of explosive activity, erosion and mass wasting from the Innerring edifice extended the broad clastic apron on the northwestern side of the volcano. Sand, silt, and mud accumulated on shores and shallow flanks of the volcano, and fumarolic activity associated with late-stage felsic domes may have contributed the sulphide component to mud and silt. As the apron emerged above sea level, the main deposits of mass wasting were thick, massive debris flows and lahars. Probably there were local erosional unconformities on portions of the Innerring edifice, but they are not exposed (or have not been recognized) in the present complex.

Thlewycho sequence volcanism

The Thlewycho sequence volcanism began with major effusion of porphyritic andesite lavas on the southeastern, western, and northwestern shallow submarine margins of the Innerring volcano (Fig. 41a). Rapid emergence is suggested by the abrupt change from thin, pillowed, and carbonate-cemented flow breccia to massive subaerial flows. The eruptive sequence varied from several cycles of lava effusions interrupted by extensive volcaniclastic deposits on the present northern flanks, to rapid effusion of about 30 subaerial lava flows on the eastern side.

The main effusions of lavas were followed by explosive eruptions that produced voluminous andesitic pyroclastic flows that spread across much of the southern and northeastern slopes of the volcano, and beyond the main edifice onto the northern flanks (Fig. 41b). On the northern side of the volcano, composition of the explosive eruptions changed from andesitic to dacitic pyroclastic flow and lavas, while isolated dacitic lavas effused on the southern parts of the edifice. With the addition of these voluminous lavas and tuffs, the volcanic island grew upwards and outwards.

Although this voluminous rapid expulsion of andesitic and dacitic magma may have been associated with magma resurgence, further ring fracturing, and subsidence, these events have not been documented. Thlewycho sequence volcanism, however, ended with effusion of a series of rhyolitic flows and dome complexes around the periphery of the volcanic edifice (Fig. 41c), and a large rhyolite body intruded along ring fractures associated with Innerring volcanism. Assuming that rhyolite domes mark local eruptive centres, the locus of these bodies may outline a second ring-fracture system. Although the present distribution of Thlewycho rhyolite might be interpreted as the result of structural doming of expansive fields of rhyolite, this scenario is considered unlikely, because of the general tendency of viscous rhyolite magma to effuse as thick, stubby flows or domes around their vents. Partial destruction of the domes by explosion, autoclastic fragmentation, gravity collapse, mass wasting, and erosion produced aprons of coarse breccia and felsic volcaniclastic detritus that interfingered with turbidite in the adjacent sea. A close spatial relationship between carbonate units, stromatolites, and carbonate-cemented rhyolite flow breccia, suggests that carbonate prevailed mainly where the lava flows entered the sea.

Boucher-Regan sequence volcanism

On the submerged northern flanks of the stratovolcano, mafic magma effused from submarine fissures to form an extensive field of pillowed lava flows, hyaloclastite, and associated breccia (Fig. 42a). These eruptions, which represent a fundamental change of magma composition from the dominantly felsic calc-alkaline volcanism of the Innerring and Thlewycho sequences to tholeiitic volcanism, signify a change of magma source from differentiating high-level crustal magma chambers to deeper mantle-derived tholeiitic sources.

The present 40 km belt of basaltic to basaltic andesite flows may represent a folded remnant of a major domal ridge that developed above submarine fissures. Lava spread southwards, or erupted from other vents and lapped onto the northern margin of the emergent Thlewycho edifice, or erupted as isolated, monogenetic eruptions to from discrete flows on the eastern and western sides of the stratovolcano. Sills intruded the accumulating major basaltic pile, probably evolving into subsurface lava tubes that surfaced as flows. Similarly, basaltic sills and dykes intruded parts of the Thlewycho sequence and the Beechey Lake turbidite on the flanks of the volcanic pile.

Volcanism of the Boucher-Regan sequence was more bimodal than the Innerring and Thlewycho sequences. The voluminous mafic volcanism was followed by minor eruptions of dacitic tuffs, then by the eruption of numerous rhyolite to dacite, felsic domes and flows (Fig. 42b). The felsic domes intruded portions of the basaltic pile to form the major Quartermoon Lake dome complex and a series of volcanic mounds around the northern and western margins of the volcanic complex and within the adjacent sedimentary basin. Although some may never have emerged above sea level, others were emergent domes that probably formed ephemeral islands. These emergent domes were partly reduced by mass wasting to form banks of debris, talus, conglomerate, and rudaceous sands on their flanks. Minor explosions associated with these domes deposited crystal-rich ash beds within the adjacent turbidite sequences. The general lack of sedimentary rocks between Boucher-Regan and Thlewycho sequence units suggests that Boucher-Regan volcanism followed immediately after, or possibly was synchronous with, the late stages of Thlewycho volcanism.

Erosion, mass wasting, and the waning phases of volcanism

On the northern and western flanks of the stratovolcano there was a complicated interplay of volcanic and sedimentary processes during the waning stages of volcanism. The numerous felsic domes of the Boucher-Regan sequence represent the last major eruptive events of the volcanic complex. Degradation and probably repetitive collapse of the volcanic edifice was taking place by landsliding, avalanching, lahars, and fluvial erosion to form enormous debris-avalanche deposits, scree and finer volcanic detritus, and a broad volcaniclastic fan along the western sides of the complex (Fig. 42b). Elsewhere, tuffs, rhyolite-derived turbidite, debris flows, and clastic fans, which interfinger with Beechey Lake turbidite, indicate erosion from the still-active and emergent volcano while turbidite sequences were being deposited in the immediately adjacent sea. Felsic, fragment-dominated debris-avalanche deposits and lahars from the Quartermoon Lake dome contributed thick, voluminous breccia to the Keish Lake clastic fan that was developing on the western sides of the volcanic complex. Debris-avalanche deposits carried coarse detritus for distances up to 5 km from their sources.

The carbonate deposits occur almost exclusively on the seaward sides of felsic lava domes. Similarly, carbonate is associated with iron-formation where it lies immediately above dome and flow rocks of the volcanic complex, but it is notably lacking where the iron-formation is not in contact with flow units, or is wholly within turbidite sequences of the Beechey Lake Group (i.e. northeast of Boucher and Regan lakes).

The carbonate probably was introduced to parts of the volcanic pile mainly by fumaroles and precipitation from hydrothermal fluids that debouched onto the sea floor. Precipitation of carbonate, as well as concentration of metals, may also have been enhanced by convective circulation of sea water through, and leaching from, the adjacent volcanic pile. Within this environment, stromatolites developed in ten localities on the flanks of felsic dome-flow complexes that erupted on shores around the partly emergent stratovolcano. Similarly, volcanic fumaroles debouching onto the sea floor may have precipitated pyrite and pyrrhotite in the H_2S^--rich environment (low fO_2, acid to neutral pH) to form sulphide-rich iron-formation.

Stromatolites composed of carbonate along the shallow margins of the volcano record that life flourished during the waning stages of this Archean stratovolcano. The overlying sulphidic iron-rich mudstone-siltstone sequences and laminated iron-formation mark the close of volcanism. These units lapped onto the shallow flanks of the volcano and extended out into the adjacent basin.

Form and deformation of the stratovolcano

The present level of erosion and low topographic relief exposes only a thin slice though this deformed, very complex compound stratovolcano. As such, the precise form or elevation of the primary volcanic edifice will never be known. The stratigraphy, however, indicates that the southern half of the complex is a section through the thickest part of the main volcanic edifice, the Quartermoon Lake dome, was an area of secondary high relief, and probably there was a submarine ridge in the sea off the northern side of the stratovolcano. The irregular topography of this enormous stratovolcano likely included not only the erosional remnants of the main edifice, but also numerous local troughs and depressions between the major and minor topographic high areas. This topography probably dictated the location where the first anticlines and synclines formed. Primary troughs may account for some local divergences of some F_1 folds from regional trends.

Although it is easy to assume that Beechey Lake sediments completely covered this major emergent volcanic edifice, there is no evidence to suggest that this was the case, nor is there evidence for any overall stratigraphic or structural unconformity between the Beechey Lake Group and the Back Group.

Three generations of folding deformed the volcanic complex and the surrounding metaturbidite units of the Beechey Lake Group. The marked contrast in style of deformation between the weakly deformed southern half of the volcanic complex and the highly deformed surrounding metasedimentary rocks, is interpreted to indicate that the volcanic edifice was rheologically competent relative to the sedimentary rocks. This disharmonic folding produced tightly folded metasedimentary rocks in contact with more open-folded volcanic sequences.

Thus, the large dome in the southern part of the map area formed by superposition of regional strain on the core volcanic edifice. Although the volcanic edifice is deformed, it behaved as a buttress around which relatively incompetent sedimentary rocks and the northern parts of the volcanic complex folded. Regional deformation modified the primary edifice by steepening and folding strata within its margins.

Mapping of the Back River volcanic complex has resulted not only in the rare detailed documentation of an Archean stratovolcano, but also in establishing the physical environment where some of the earliest life forms developed: along the margins of active rhyolite lava domes that straddled the shoreline around this emergent volcano.

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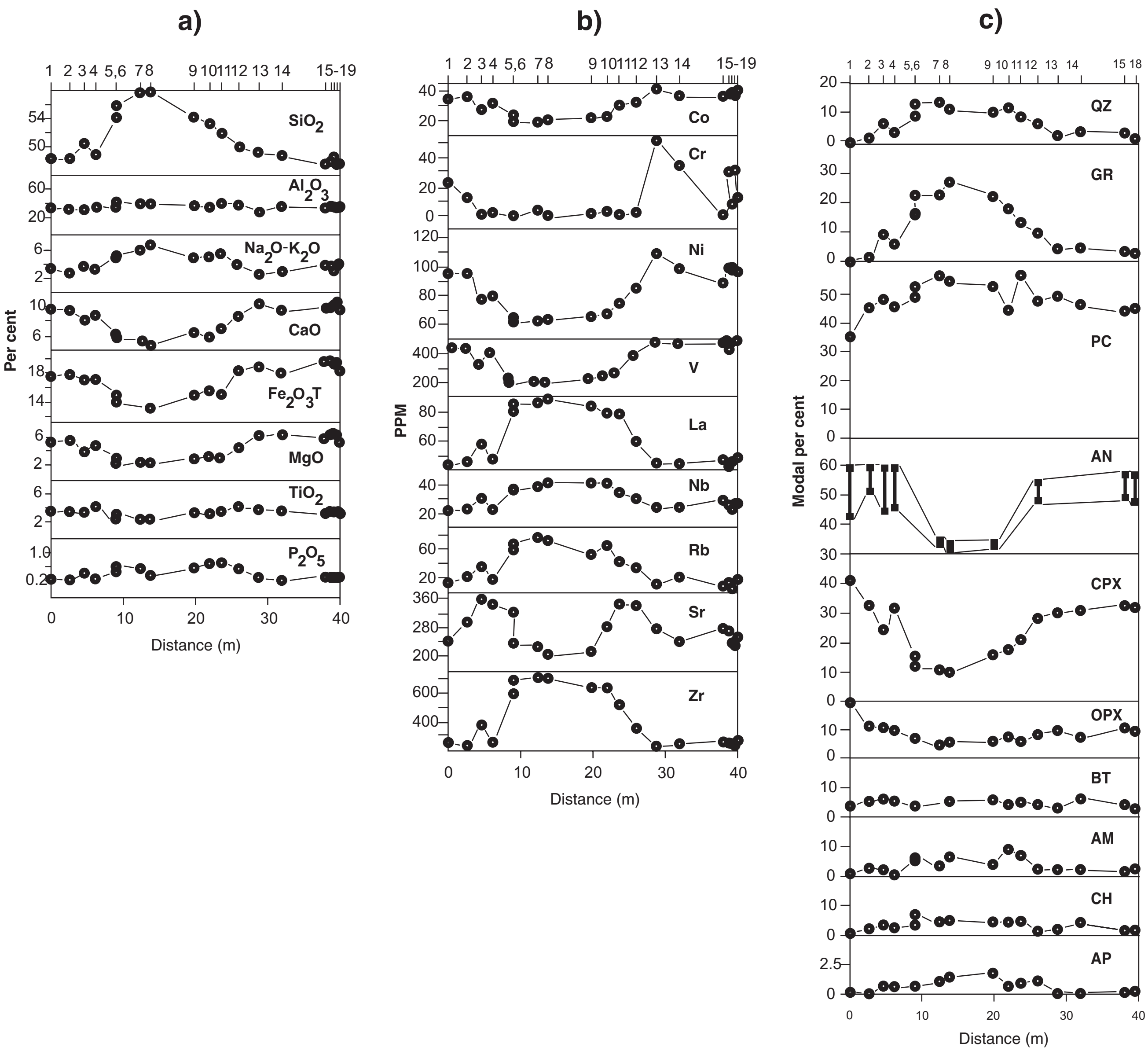
Appendix

Modal and chemical profiles through 40 m thick zoned Mackenzie dyke 2 km south of reference locality 16: a) major oxides, b) minor and trace elements, and c) modal composition.

QZ = quartz, GR = garnet, PC = plagioclase, AN = anorthite, CPX = clinopyroxene, OPX = orthopyroxene, BT = biotite, AM = amphibole, CH = chlorite, AP = apatite.



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