THE MID-CRETACEOUS ROCKY RIDGE FORMATION – IMPORTANT HOST ROCKS FOR VMS AND RELATED DEPOSITS IN CENTRAL BRITISH COLUMBIA

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KEYWORDS

Skeena Arch, Skeena Group, Rocky Ridge Formation, volcanogenic massive sulphide, Eskay Creek, shallow marine, rhyolite domes, geochronology, lithogeochemistry, U/Pb age-dating, Ar/Ar age-dating, Rocks to Riches program

INTRODUCTION

The recognition of remnants of large cauldron subsidence complexes along the trend of the Skeena Arch first occurred in the Tahtsa Lake area (MacIntyre, 1985). In subsequent years, evidence for other large subsidence complexes was documented in the Rocher DeBoule, Babine Mountains, Buck Creek and Babine Lake areas (MacIntyre, 2001; Church and Barakso, 1990). Originally all of these structures were believed to be Late Cretaceous in age based on the ages of nearby plutonic bodies. However, recent isotopic age-dating in the Babine Lake area suggests that the evolution of these subsidence structures began in the mid-Cretaceous with eruption of the Rocky Ridge volcanics and that this volcanism was at least in part submarine in nature (MacIntyre, 2001).

The importance of the Rocky Ridge volcanic succession of the Lower Cretaceous Skeena Group as potential host rocks for volcanogenic massive sulphide (VMS) deposits was first recognized while conducting regional mapping and geochronologic dating as part of the Nechako NATMAP project (MacIntyre and Struik, 1999; MacIntyre and Villeneuve, 2001). This work was followed up in the 2000 field season with additional lithogeochemistry and collection of samples for Ar-Ar and U-Pb isotopic age-dating from a number of key sites along the Skeena Arch (Figure 1). Unfortunately, due to budget constraints many of the samples collected for age-dating could not be processed and remained in storage at the Geological Survey of Canada's Ottawa geochronology lab. In 2003,

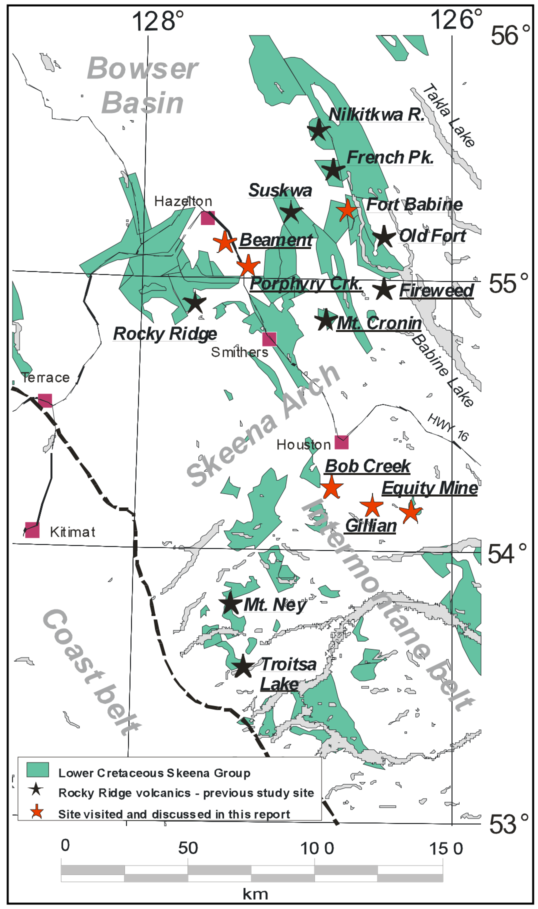

Figure 1. Map showing the areal extent of the Skeena Group (solid pattern) in west central British Columbia relative to major tectonic elements. Stars mark sites where Rocky Ridge volcanic rocks of the Skeena Group were sampled as part of this study.

a proposal was submitted to the Rocks to Riches program for funding to process these samples and to collect additional samples from the study area. The project was approved and $30,000 was provided to cover the analytical and field-related costs of the project. This report summarizes the work completed in 2003. Additional background information on the project is covered in MacIntyre (2001).

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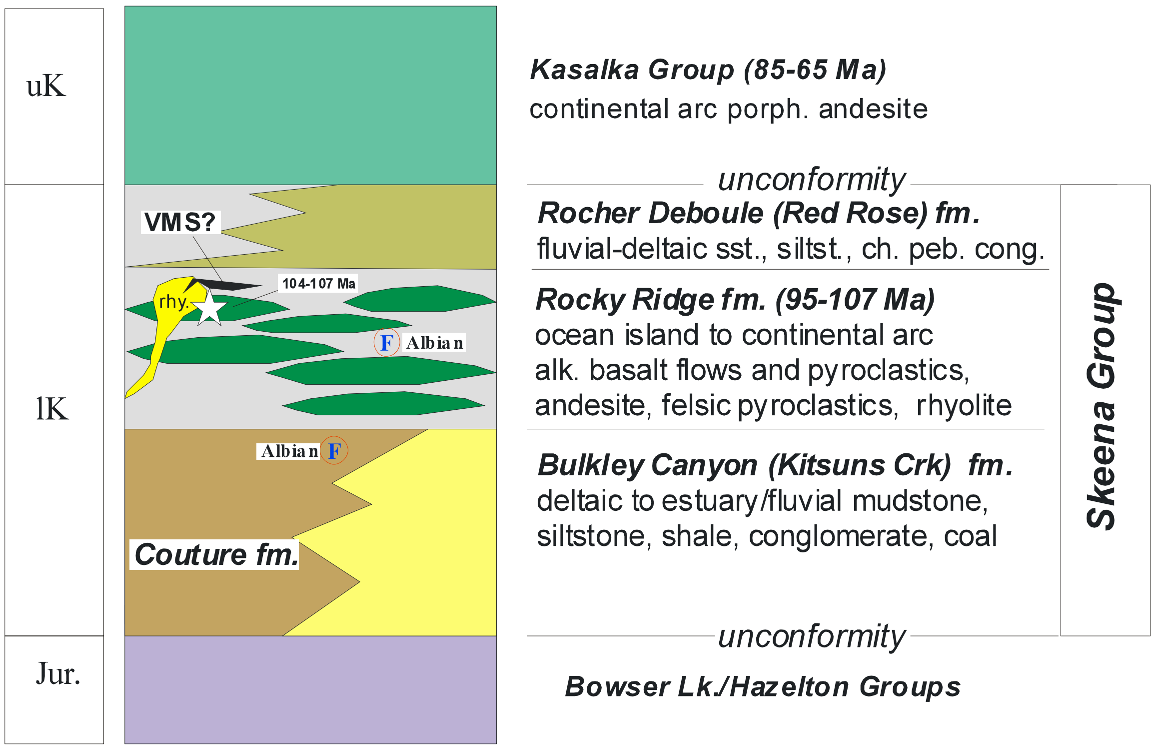

Figure 2. Schematic stratigraphy for the Skeena Group showing stratigraphic position of rhyolite domes and Rocky Ridge volcanic rocks discussed in this report. Stratigraphic nomenclature after Bassett and Kleinspehn, 1996). Stratigraphic units of Richards (1990) are shown in brackets.

The main objective of the current project is to define areas underlain by the Rocky Ridge volcanic succession which may have potential for the discovery of additional volcanogenic massive sulphide and related deposits. In order to demonstrate the occurrence of favourable volcanic stratigraphy and associated vein and massive sulphide mineralization within the Rocky Ridge Formation, several key areas were visited and sampled in the 2000 field season. These included Nilkitkwa River, French Peak, Fort Babine, Fireweed, Suskwa River, Mt. Cronin, Beament, Rocky Ridge, Mt. Ney and Troitsa Lake (Figure 1). Samples for geochronology and lithogeochemistry were collected at all of these sites. Follow-up work in 2003, supported by funding from the Rocks to Riches program concentrated on the Fort Babine, Beament, Equity Silver mine, and Bob Creek areas. Dr. Neil Church generously provided additional material for lithogeochemistry from the Gillian and Equity Silver mine properties from his personal mineral property collection.

GEOLOGIC SETTING

The study area is within the Stikine Terrane of the Intermontane geomorphological belt (Figure 1) which is well-exposed along the Skeena Arch, a northeast-trending uplift that forms the southern margin of the Bowser Basin. The core of the uplift exposes volcanic arc assemblages of the Early Permian Asitka, Late Triassic Takla and Early to Middle Jurassic Hazelton groups. Coeval plutonic rocks include the Late Triassic to Early Jurassic Topley and the newly recognized Early to Middle Jurassic Spike Peak intrusive suites (MacIntyre *et al.*, 2001). North of the Skeena Arch, the older volcanic arc rocks are onlapped by marine to non-marine sedimentary strata of the Late Jurassic Bowser Lake and Early Cretaceous Skeena groups; to the south the arch is covered by Tertiary volcanic rocks.

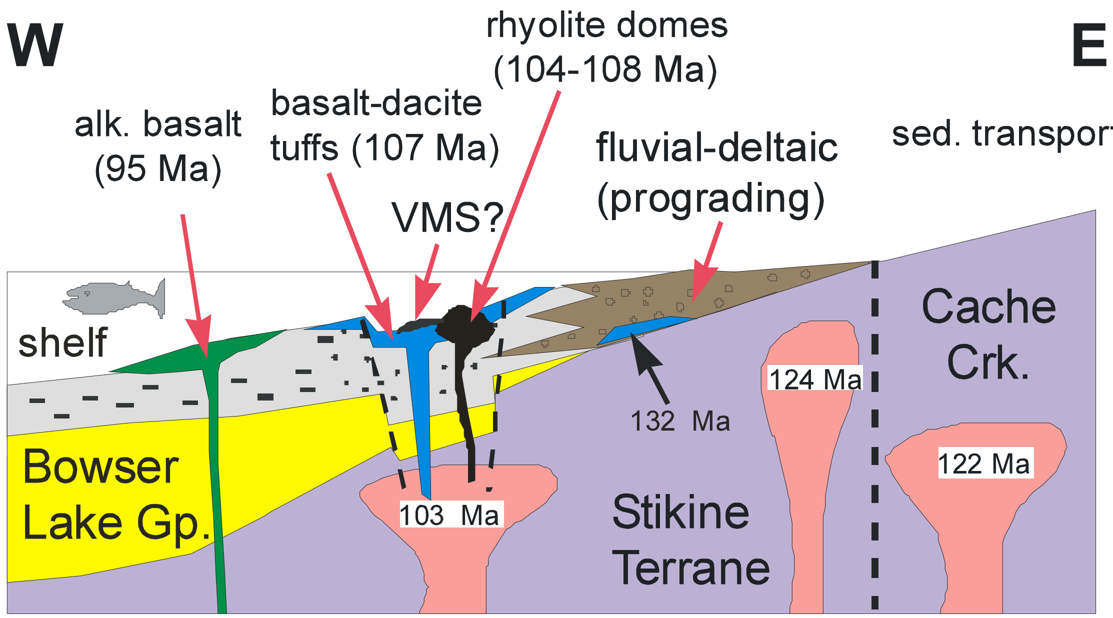

Figure 3. Schematic diagram illustrating the postulated depositional environment for the Skeena Group as suggested by Bassett and Kleinspehn (1996). Also shown are geochronologic controls determined during the Nechako Natmap and Rocky Ridge projects.

SKEENA GROUP STRATIGRAPHY

The Skeena Group is comprised of marine and non-marine sedimentary rocks that overlap Jurassic and older rocks along the southern margin of the Bowser Basin. Although the base of the Skeena Group is rarely seen, where it is exposed it is an angular unconformity with the underlying Hazelton or Bowser Lake group. The Skeena Group is unconformably overlain by continental volcanic arc rocks of the Late Cretaceous Kasalka and Early Eocene Ootsa Lake groups. In general the lower Skeena Group is fluvial to fluvial-deltaic mudstone, siltstone, and sandstone. Higher in the stratigraphy are the volcanic rocks of the Rocky Ridge Formation (Figure 2) as first recognized by Tipper and Richards (1976). Overlying these rocks, and in part interbedded with them, are chert-quartz bearing conglomerates, quartzo-feldspathic wackes and siltstones that were deposited in a fluvial-deltaic environment (Tipper and Richards, 1976; Richards, 1980; 1990; Bassett 1991).

The main Skeena lithologies are dark grey shaly siltstone, greywacke, carbonaceous mudstone and chert-pebble conglomerate. These sedimentary rocks were deposited in a fluviodeltaic, near-shore to shallow marine environment (Basset, 1991). Although fossils are rare, the Skeena Group appears to range from Hauterivian to late Albian or early Cenomanian in age. Paleocurrent measurements indicate north, west and southwest sediment transport with the source area located in the Omineca belt to the east. Bassett and Kleinspehn (1996) suggest that this belt was the main axis of a mid-Cretaceous continental arc and that the Skeena Group is a forearc succession (Figure 3). The Skeena rocks were folded, uplifted and eroded during a mid to late Cretaceous contractional event related to evolution of the Skeena Fold Belt (Evenchick, 1999).

In a recent paper, Bassett and Kleinspehn (1996) proposed a new stratigraphic nomenclature based on lithofacies. In their stratigraphy the lowest unit of the Skeena Group succession is the predominantly deltaic Bulkley Canyon Formation which includes, in the east, the fluvial Kitsuns Creek Member and to the west the subtidal, turbiditic Couture Formation. Locally these rocks are overlain by and in part interbedded with the volcanic arc rocks of the Rocky Ridge Formation, the main subject of this paper. The fluvial to deltaic Rocher Deboule Formation which would include the former Red Rose Formation and Hanawald conglomerate comprises the upper part of the Skeena Group succession.

Rocky Ridge Formation

The Rocky Ridge Formation is comprised of submarine alkali basalt flows, breccias, and lapilli tuffs that were erupted along the southern margin of the Bowser Basin (Bassett and Kleinspehn, 1996) as part of a nascent volcanic arc assemblage. Evidence for a submarine depositional environment includes the occurrence of inter-bedded marine shales, siltstones and conglomerates and local occurrence of pillowed flows. Marine sedimentary inter-beds contain Early Albian to Early Cenomanian macrofossils. The thickness and lateral continuity of the Rocky Ridge Formation varies from thin and discontinuous to over 1000 metres thick. These variations probably reflect proximity to major eruptive centers. At least 5 major mid-Cretaceous volcanic centers have been recognized in central British Columbia. These are located in the vicinity of Old Fort Mountain at Babine Lake, Mt. Cronin in the Babine Range, the Rocher Deboule Range and the Buck Creek and Tahtsa Lake areas. In all of these areas the Rocky Ridge formation is thick, bimodal (basalt-rhyolite), has inter-bedded marine sedimentary beds and displays rapid facies changes consistent with mass movement on unstable escarpments. Numerous base and precious metal mineral occurrences are spatially associated with these suspected cauldron subsidence complexes including classical vein, subvolcanic epithermal and volcanogenic massive sulphide.

One of the key results of the geochronologic dating completed as part of the Nechako NATMAP project was the recognition of mid-Cretaceous rhyolite domes in the Rocky Ridge succession (MacIntyre and Villeneuve, 2001). These domes may be the remnants of submarine cauldron subsidence complexes (MacIntyre, 2001; Tackaberry, 1998). The rhyolite domes were previously mapped as part of the Eocene Babine intrusions (Richards, 1990), but are now mapped as Rocky Ridge Formation because they yield U/Pb and Ar/Ar isotopic ages between 104 and 108 Ma (MacIntyre and Villeneuve, 2001). These ages suggest eruption of the domes occurred during Albian time. Marine sedimentary rocks that are intruded by the rhyolite domes contain Albian macrofossils and abundant angular rhyolite clasts suggesting the domes and sedimentary rocks are coeval. Important epithermal and VMS type mineralization is spatially and most likely temporally associated with development of these felsic volcanic centers.

CURRENT STUDY AREAS

The main focus of this study is to identify the location of Rocky Ridge volcanic centers that may have potential for the discovery of Au-Ag rich volcanogenic massive sulphide and related vein deposits (Figure 1). A preliminary assessment of this area identified several areas with high potential for this type of deposit (Massey, 1999; Massey *et al.*, 1999) and three occurrences were subsequently classified as VMS deposits - Fireweed, Mt. Cronin and the Knoll. These properties all have massive Pb-Zn-Ag mineralization spatially associated with rhyolitic intrusions that are emplaced into marine sedimentary strata of the Lower Cretaceous Skeena Group. The rhyolitic intrusions were previously mapped as Eocene or Late Cretaceous but detailed mapping and isotopic age-dating of rhyolite domes in the Babine Lake area has shown that these rhyolites are part of the mid-Cretaceous Rocky Ridge Formation of the Skeena Group (MacIntyre and Villeneuve, 2001) and are therefore coeval with surrounding sedimentary rocks.

In 2000, the geology and mineral occurrences of the areas shown on Figure 1 were discussed. As part of the current project the Fort Babine, Beament, Bob Creek and Equity Silver mine areas were visited. These areas are underlain by volcanic rocks that are believed to be correlative with the Rocky Ridge Formation. These areas are discussed briefly in this report.

Fort Babine

An east trending, steeply-dipping, fault-bounded panel of Rocky Ridge volcanic rocks is sporadically exposed in clearcuts west of the northern tip of Babine Lake, near Fort Babine (Figure 1). Mapping in this area in 1997 and 1998 suggests a number of rhyolite domes and rhyolite breccia bodies occur within a mixed mafic volcanic and marine sedimentary succession (Richards, 1980, 1990; MacIntyre, 2001a). As at Old Fort Mountain, further to the south, these rocks are believed to be related to formation of a large cauldron subsidence complex in mid-Cretaceous time. Although there are no isotopic age dates available for the Fort Babine section, black shales and siltstones interbedded with mafic and felsic volcanic rocks reportedly contain Albian macrofossils. Based on these fossil ages, the volcanic rocks are mapped as part of the Rocky Ridge Formation.

Due to time and weather constraints, only one day was spent examining exposures in the Fort Babine area. Although there are no known mineral occurrences associated with the Rocky Ridge volcanic rocks at this locality, the occurrence of a felsic component within the volcanic succession is considered evidence for a favourable environment for VMS type deposits. A sample of a porphyritic andesite, typical of exposures in the area was collected and submitted for lithogeochemical analysis (No.2, Table 2). Further prospecting in this area combined with soil and silt sampling might result in new targets for further exploration.

Beament

A south-dipping section of feldspar phyric mafic volcanic rocks that overlie and are in part interbedded with quartzo-feldspathic wacke and chert-bearing heterolithic conglomerate is exposed in a 2 kilometre long road cut north of Beament station on Highway 16 (Photo 1a). The volcanic rocks have been mapped as Late Cretaceous Kasalka Group (Richards 1980, 1990) but are lithologically identical to mid-Cretaceous Rocky Ridge volcanic rocks elsewhere in the area. Sedimentary strata exposed at the north end of the road cut dip to the south and have been mapped as Lower Cretaceous Skeena Group (Photo 1b). The contact with the overlying volcanic rocks appears to be conformable. Although no rhyolitic domes occur in the volcanic succession as they do elsewhere, debris flows underlying the mafic volcanic rocks contain angular rhyolite clasts (Photo 1e), a common lithology found near rhyolite domes in the Babine Lake, Suskwa River and Mt. Cronin localities (MacIntyre, 2001). This is indirect evidence for explosive rhyolitic volcanism in the area prior to eruption of thick piles of alkali basalt flows. This inferred bimodal volcanic succession suggests rocks in the vicinity of Beament may have potential for VMS deposits associated with emplacement of rhyolitic flow domes.

As part of the current study, five samples were collected from strongly altered volcanic rocks exposed along Highway 16 between Porphyry Creek and Beament (Nos. 3-7, Table 2). Additional samples were collected east of the Bulkley River (Nos. 8-9, Table 2). These samples were submitted for lithogeochemical analysis. Although there is an extensive zone of intense phyllic and argillic alteration exposed along the highway and at river level, the age of this mineralization is not certain. Although host rocks are most likely Rocky Ridge volcanic rocks, mineralization may be related to a younger intrusive event. More detailed work is required to resolve the age and genesis of mineralization.

Equity Silver Mine

One of the areas selected for study as part of the current project was the area around the now defunct Equity silver mine. Previous studies suggested that the host rocks at Equity might be correlative with the Skeena Group (Wojdak and Sinclair, 1984; Church and Barakso, 1990). Also of interest is the idea put forth by Church and Barakso (1990) that Equity and other occurrences in the area are within the Buck Creek basin, interpreted to represent an area of volcanic subsidence (cauldron subsidence complex?). In this area, as observed elsewhere along the Skeena Arch, the history of subsidence and associated volcanic activity may have begun in the mid-Cretaceous with eruption of the bimodal, Rocky Ridge volcanic rocks and emplacement of rhyolite flow domes in a shallow, submarine environment.

The Equity silver-copper-gold-antimony deposit is located 38 kilometers southeast of Houston B.C. (Figure 1). Equity Silver Mines Ltd. ceased milling in January 1994, after thirteen years of open pit and underground production. Production was mainly from the Main Zone and Southern Tail open pits and totaled 2,219,480 kilograms of silver, 15,802 kilograms of gold and 84,086 kilograms of copper, from over 33.8 million tonnes mined at an average grade of 0.4 per cent copper, 64.9 grams per tonne silver and 0.46 gram per tonne gold. The Equity Silver mine was British Columbia's largest producing silver mine (Minfile 93L 001).

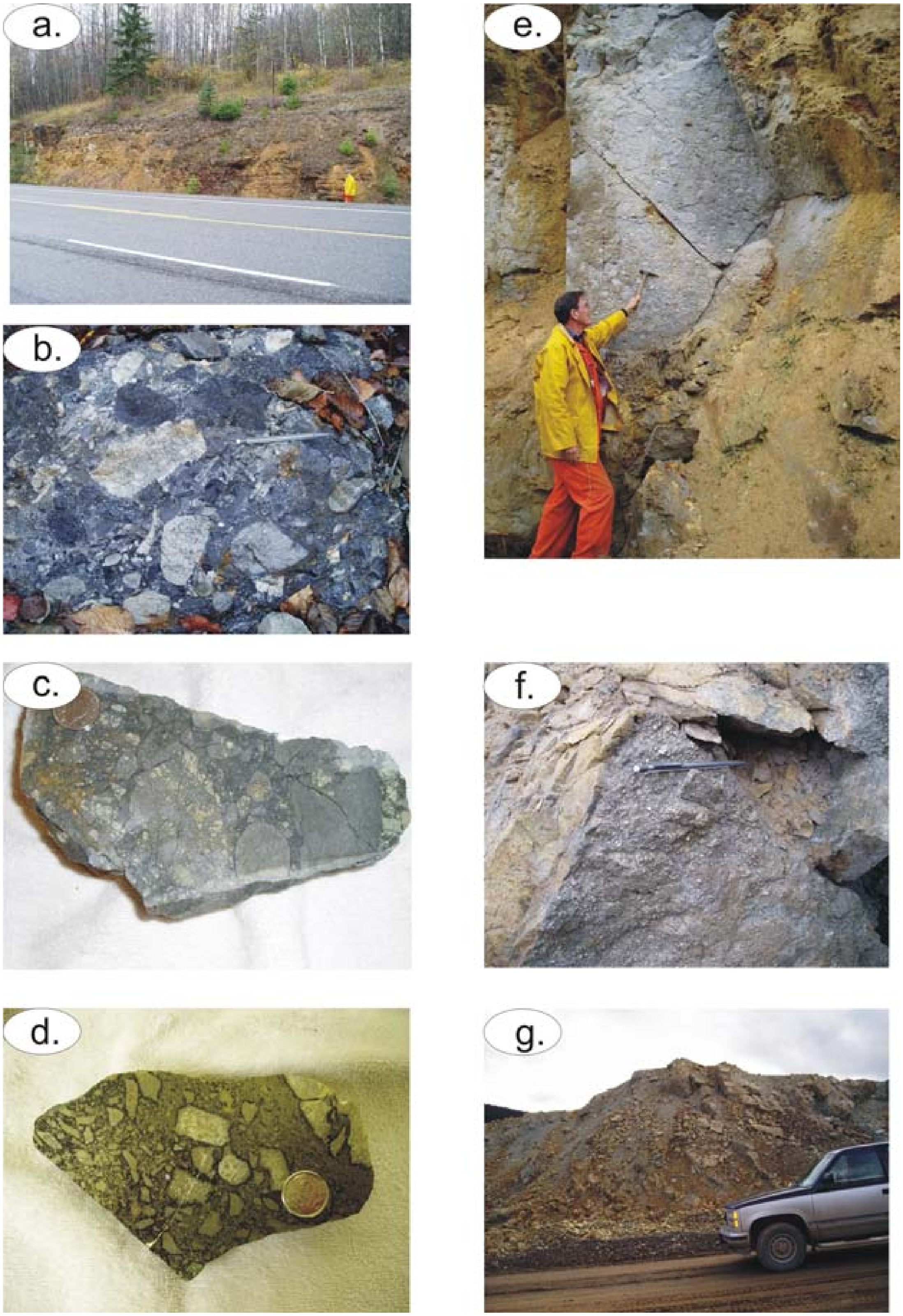

Photo 1. pervasive sericite-clay altered, well-bedded pyritic tuffs or sediments exposed in a road cut near Beament, Highway 16; b. Skeena Group conglomerate with angular rhyolite clasts, Beament section, Highway 16; c. rounded clasts of massive pyrite in a finer-grained sulphide rich mud matrix. Note angular clasts of white “dust tuff” in larger clasts. Sample from the Equity Silver mine main zone pit; d. angular massive sulphide clasts with black tourmaline rinds in a finer-grained massive sulphide matrix, Equity silver mine; e. debris flow with angular rhyolite clasts underlying massive alkali basalt flows, north end of Beament section, Highway 16; f. lense of fragmental massive sulphide (grey) in contact with felsic lapilli tuff, Equity Silver mine, Main Zone pit, west ramp area;g. outcrop off felsic lapilli tuff that was sampled for U-Pb age dating, western ramp, Main Zone pit, Equity Silver mine.

The chief sulphides at the Equity Silver mine are pyrite, chalcopyrite, pyrrhotite and tetrahedrite with minor amounts of galena, sphalerite, argentite, minor pyrargyrite and other silver sulphosalts. The mineralization is generally restricted to tabular, concordant zones comprised of veins, disseminations and massive, coarse-grained fragmental sulphide lenses (Photos 1c, 1d, 1f). Alteration assemblages are characterized by advanced argillic clay minerals, chlorite, specularite and locally sericite, pyrophyllite, andalusite, tourmaline and minor amounts of scorzalite, corundum and dumortierite. Other zones of mineralization include copper-and molybdenum in a quartz stockwork in and adjacent to the quartz monzonite stock and a large zone of tourmaline-pyrite breccia located to the west and northwest of the Main zone. For a more complete description of the Equity deposit go to Cyr *et al.*, (1984) and Wojdak and Sinclair, (1984).

The Equity orebodies are located within a west-dipping panel of tuffaceous sedimentary, dacitic pyroclastic and andesitic flow rocks that have been variably correlated with the Lower Cretaceous Skeena Group (Wojdak and Sinclair, 1984) and the Upper Cretaceous Kasalka Group (Cyr *et al.*, 1984). Three major stratigraphic units have been recognized. A lower clastic division is composed of basal conglomerate, chert pebble conglomerate and argillite typical of the Lower Cretaceous Skeena Group. Conformably overlying and in part inter-bedded with the lower clastic division is a middle pyroclastic division which consists of a heterogeneous sequence of fine-grained tuff or mudstone ("dust tuff"), felsic, locally welded lapilli tuff and breccia and reworked felsic pyroclastic debris, all of which are typical of the Rocky Ridge Formation. This division hosts the main mineral deposits. The middle division grades conformably upward into an upper sedimentary-volcanic division which consists of tuff, sandstone and conglomerate also typical of the Lower Cretaceous Skeena Group.

The west-dipping panel that hosts the Equity deposit is sandwiched between two younger intrusive bodies. The oldest of these is a small, weakly mineralized quartz monzonite intrusion that has given K-Ar ages ranging from 61.1 to 56.2±2.3 Ma on biotite (Cyr *et al.*, 1984). On the east side, and in part cutting the ore zone, is an unmineralized gabbro-monzonite intrusion that gives Eocene ages around 48 Ma (Cyr *et al.*, 1984).

Bob Creek

The Bob Creek area is located some 20 kilometers due south of the town of Houston. Here, andesitic to rhyolitic tuffs, flows and breccia crop out near the junction of Bob and Buck creeks. The most common unit is a massive tuff breccia with thin intercalations of accretionary lapilli tuff and siltstone. Although these rocks have previously been mapped as Jurassic Hazelton Group, they may actually be correlative with the younger Rocky Ridge Formation.

The main exploration target is a belt of strongly pyritic, intensely sericite-clay altered rocks that are exposed over a distance of 600 metres in the Bob Creek canyon (Minfile 93L 009). Although the intensity of alteration makes it difficult to determine original rock compositions, locally the rocks exposed in the canyon show angular rhyolite clasts suggesting they are mainly volcanic breccias and lapilli tuffs. These volcanics are crosscut by quartz-feldspar porphyry dikes and breccias that give Late Cretaceous K-Ar ages. A small Late Cretaceous stock intrudes the volcanics south of the canyon.

One day was spent examining outcrops along the banks of Bob Creek. Although the occurrence of felsic clasts in the volcanic units is reminiscent of units in the Rocky Ridge Formation, there is insufficient information to make a definitive correlation. The age of mineralization is also difficult to determine but could well be Late Cretaceous as suggested by previous workers. The lack of rhyolite domes and marine sedimentary strata would suggest that overall it is unlikely that the Bob Creek occurrence is related to Rocky Ridge volcanism.

GEOCHRONOLOGY

U/Pb and ^{40}Ar/^{39}Ar isotopic-dating in the Babine Lake area of central British Columbia documents a distinct magmatic event at 107-104 Ma (MacIntyre and Villeneuve, 2001). This event involved emplacement of rhyolite domes into submarine volcanic and sedimentary rocks of the Rocky Ridge Formation. The volcanic rocks have yielded a U/Pb age of 107.9±0.2 Ma and an ^{40}Ar/^{39}Ar age of 104.8±1.2 Ma. Several samples of rhyolite were also dated but these did not give publishable ages. However, the data that was obtained is consistent with isotopic ages in the 104-108 Ma range (Mike Villeneuve, personal communication). The rhyolites, which were previously mapped as Eocene, are re-interpreted to be part of a previously unrecognized mid-Cretaceous cauldron subsidence complex (MacIntyre, 2001)

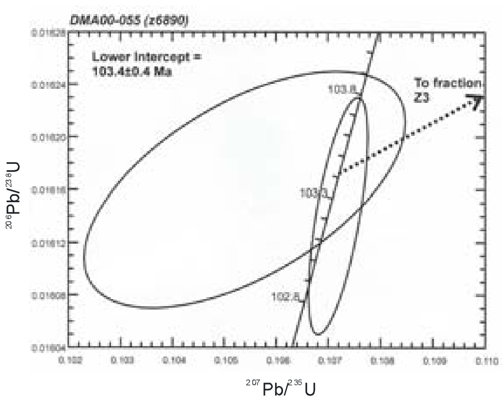

Figure 4. U-Pb concordia plot for zircons extracted from a rhyolite (Sample DMA00-055) intersected in drilling at the Fireweed Property (Minfile 93M 151).

In 2000, samples of rhyolite were collected from the Cronin Mine in the Babine Range and drill core from the Fireweed property at Babine Lake (Malott, 1988; MacIntyre, 2001). These samples were submitted to the GSC geochronology laboratory in Ottawa for U-Pb dating. The sample from the Cronin Mine did not contain sufficient zircons to determine a U-Pb date. However, the Fireweed sample did contain a small number of zircons and these were sufficient to give a lower intercept U-Pb date of 103.4±0.4 Ma (Figure 4). This age indicates that the rhyolite is the same age as marine sedimentary rocks of the Skeena Group, which are the same rocks that are believed to host the massive sulphide lenses on the Fireweed property. Pb-Zn-Ag stockwork veins that cut the rhyolite may be feeders for the massive sulphide lenses. If this interpretation is correct, then the Fireweed deposit can be classified as a typical Kuroko type volcanogenic massive sulphide deposit with a similar geologic setting to the older Eskay Creek deposit (Alldrick, 1995; Hannington, 1999; Roth 2002). As has been documented elsewhere in the Babine Lake area, emplacement of rhyolite domes and dikes occurred during formation of the mid-Cretaceous Old Fort Mountain cauldron subsidence complex (MacIntyre, 2001).

Samples of rhyolite from the Knoll, Rocky Ridge and Troitsa Lake localities were also collected for U/Pb geochronology in 2000 but could not be processed at that time. These samples are currently being processed as part of

TABLE 1. U/PB SAMPLES CURRENTLY BEING PROCESSED AT GSC, OTTAWA

No.	Station	Map	Easting	Northing	Area	Lithology	Comment
1	DMA00-017	93M7	618251	6125954	Suskwa River	rhyolite	dates rhyolite dome at the Knoll property; may be mid-Cretaceous
2	DMA00-050	93L13	596691	6090754	Rocky Ridge	rhyolite	dates large rhyolite intrusion south of Rocky Ridge; may be ring dike to caldera
3	DMA00-042	93E11	607034	5935011	Troitsa Lake	rhyolite	dates rhyolite dike on north shore of Troitsa Lake; may be ring dike to caldera
4	DMA00-043	93E11	612347	5943798	Swing Peak	feldspar phyric andesite	dates Kasalka Group volcanic rocks in the type area of the Kasalka Group; constrains age of underlying Rocky Ridge volcanic rocks
5	DMA03-002	93L1	678330	6008423	Equity Silver mine, Main Zone pit, east ramp	felsic lapilli tuff	dates host rocks at the Equity Silver mine

Notes: UTM zone 9; NAD 83 datum

the current project. This work is being done at the GSC geochronology laboratory in Ottawa, Ontario, Canada under the supervision of Dr. Mike Villeneuve. Results are expected in early 2004. Table 1 lists the samples currently being processed at the GSC Ottawa geochronology lab.

The copper-silver-gold mineralization at Equity has previously been interpreted as epigenetic in origin, possibly related to emplacement of a nearby quartz monzonite stock of Early Tertiary age. This conclusion was based on coincident K-Ar age dates for the quartz monzonite and sericitized tuffs hosting the deposit, all of which give early Tertiary ages around 58 Ma (Cyr *et al.*, 1984). However, given that the host rocks at Equity are more likely correlative with the Rocky Ridge Formation of the Skeena Group one needs to consider the possibility that the K-Ar whole rock isotopic ages determined for the Equity host rocks might be thermally reset. In order to address this issue, a sample of felsic lapilli tuff from the haulage ramp on the west side of the Main Zone pit (Photo 1g) was collected and submitted for U-Pb isotopic age-dating. Results are not expected until early 2004.

LITHOGEOCHEMISTRY

A total of 19 samples were collected for major oxide, trace and rare earth element analyses in 2000 (MacIntyre, 2001). An additional 14 samples were analyzed as part of the current project (Table 2). The analytical results are given in Table 3. All of the samples are from suspected outcrops of Rocky Ridge volcanics in the Fort Babine, Beament, Equity Silver Mine and Bob Creek areas (Figure 1). Two samples from the Gillian prospect and one sample from the Equity Southern Tail zone were generously provided by Dr. Neil Church. Analytical results for these samples (nos. 12-14) are included in Table 3.

Previous major oxide analyses indicate that mid-Cretaceous rhyolites have SiO2 values ranging from 70.61 to 76.5 weight percent (Table 3). By contrast interbedded Rocky Ridge basaltic flows contain between 47.74 to 54.61 weight percent SiO2 and 0.56 to 0.89 weight percent TiO2. Kasalka Group volcanics are more intermediate in composition with SiO2 values ranging from 59.5 to 62.18 weight percent. A standard AFM ternary plot (Figure 5a) shows the bimodal, calc-alkaline nature of Rocky Ridge basalts and coeval rhyolite domes. On an alkali-silica plot these samples range from alkaline to subalkaline in composition (Figure 5b) and plot in the rhyolite and sub-alkaline basalt to andesite fields of a Zr/TiO2 versus SiO2 diagram (Figure 5c). Of the samples analyzed in 2003, only the samples from the Southern Tail zone at Equity (No. 12, Table 3) and a sample from the Gillian prospect (No.14, Table 3) are compositionally rhyolites.

Of the mafic volcanic samples analyzed in 2003, the relatively fresh, massive flow rocks from the Fort Babine and Beament areas all have chemical signatures similar to those previously determined for Rocky Ridge basalts (Figure 5) by MacIntyre, 2001, Tackaberry, 1998 and Bassett and Kleinspehn (1996). This supports the field-based interpretation that all of these rocks are part of the Rocky Ridge Formation.

Highly altered felsic lapilli tuffs collected from the Beament and Bob Creek sections are compositionally dacite or rhyodacite (Figure 5c). This reflects the presence of rhyolitic clasts in these pyroclastic rocks. These rocks might also be correlative with the Rocky Ridge Formation, with the rhyolite clasts derived by explosive felsic volcanism or erosion of unstable rhyolite flow domes.

Rhyolite that hosts Ag-Zn-Pb veins at the Cronin, Knoll and Fireweed properties are strongly altered with nearly total removal of Na and Ca (MacIntyre, 2001). Altered rhyolites can also have anomalous concentrations of Pb, Zn, Ag and As (MacIntyre 2001). A plot of K2O versus Na2O (Figure 5d) clearly distinguishes altered from unaltered rhyolite, with altered samples having very low Na2O and relatively high K2O values. K enrichment is interpreted to reflect the presence of sericitic alteration at the expense of Na-rich plagioclase feldspar. Of the samples analyzed as part of the current project, only two samples display this type of alteration signature, the rhyolite from the Southern Tail zone (No. 12, Table 3) and a sample of strongly altered felsic lapilli tuff from Bob Creek (No. 10, Table 3)

Rare earth element concentrations for basalt and rhyolite were also determined as part of the current study. Chondrite normalized values are plotted in Figure 5e as are those previously determined by Tackaberry (1998) and MacIntyre (2001). Both basalts and rhyolites, regardless of their degree of alteration, have light rare earth element enrichment whereas rhyolites are also moderately to strongly enriched in heavy rare

TABLE 2. LITHOGEOCHEMICAL SAMPLES COLLECTED IN 2003

No.	Station	UTM Easting	UTM Northing	Location	Unit	Description
1	DMA03-001	678305	6008085	Equity Mine - Main Zone	lKSRv	dust tuff or tuffaceous mudstone
2	DMA03-003	649220	6128422	Ft. Babine	lKSRv	andesite, feldspar phyric
3	DMA03-004	603095	6112545	Beament	lKSRv	basalt
4	DMA03-005a	603090	6113131	Beament	lKSRv	andesite
5	DMA03-005b	603090	6113131	Beament	lKSRv?	lahar
6	DMA03-006a	603061	6113583	Beament	lKSRv?	bedded tuff or sediment?
7	DMA03-006b	603061	6113583	Beament	lKSRv?	bedded tuff or sediment?
8	DMA03-007	602811	6115362	Beament	lKSRv	basalt
9	DMA03-008	603497	6114919	Beament	lKSRv	basalt
10	DMA03-010	654500	6020178	Bob Creek	lKSRv?	felsic lapilli tuff
11	DMA03-011	654240	6020315	Bob Creek	lKSRv?	felsic lapilli tuff
12	DMA03-013	678000	6007000	Equity Mine - S. Tail	lKSRv	rhyolite
13	Gil 28-225	668369	6003653	Gillian	lKSRv	andesite
14	Gil 30-949	668369	6003653	Gillian	lKSRv	dacite

Notes: NAD83 datum; UTM zone 9; lKSRv = Rocky Ridge Fm.

earth elements relative to the basalts. A notable exception is the rhyolite from Cronin which has a much lower level of light rare earths compared to other rhyolites in this study.The significance of this difference is not known. All of the rhyolites, including the Cronin sample, have moderate to strong Eu depletion consistent with plagioclase fractionation (Tackaberry 1998). The rare earth patterns determined for Rocky Ridge basalts in this study are very similar to those presented in Bassett and Kleinspehn (1996) for compositionally similar rocks. One sample from the current study that has an unusual REE pattern is the “dust tuff” from the Equity main Zone pit (No. 1, Table 3). This light-coloured, aphanitic rock is probably not a volcanic per se but rather an altered, tuffaceous mudstone. This conclusion is supported by remnant graded bedding observed at the sample site. If this interpretation is correct then it suggests that some, if not all, of the “dust tuff” that hosts the Equity ore bodies is also sedimentary in origin.

DISCUSSION

The search for VMS deposits in central British Columbia has been strongly influenced by the discovery and subsequent development of the Eskay Creek property. This property, which is located 80 km north of Stewart, includes several deposits of precious metal bearing polymetallic sulphide and sulphosalt mineralization as both exhalative massive sulphides and discordant veins. The deposits are hosted by marine mudstone and rhyolite flow domes of late Lower to early Middle Jurassic age. These deposits are economically important because of their precious metal contents and polymetallic nature. As of December 31, 1998, Eskay Creek had proven and probable reserves of 1.9 Mt grading 60.2 g/t Au and 2652 g/t Ag, 3.2% Pb, 5.2% Zn and 0.7%Cu (Sherlock *et al.*, 1999).

The Eskay Creek deposit is described as an unusual precious metal rich, volcanogenic massive sulphide and sulphosalt deposit with epithermal geochemical signatures (Roth, 2002) and as a subaqueous hot spring deposit (Alldrick, 1995), representing an important new class of mineral deposit that has only recently been recognized in modern geological environments (Hannington, 1999). Although beautifully banded massive sulphide does occur, a large portion of the deposit is comprised of partially replaced clastic sulphides that probably represent collapsed, transported and reworked sulphide mounds and chimneys (Roth, 2002). Massive sulphide lenses are hosted by marine argillites that stratigraphically overlie massive, flow banded rhyolites interpreted to be flow domes. Mafic flows overlie the main sulphide horizons. Extensive stockwork mineralization and

TABLE 3. LITHOGEOCHEMICAL RESULTS

Elem.	Units	Limit	Meth.	1	2	3	4	5	6	7
SiO_2	%	0.02	1	61.20	57.60	53.60	61.50	62.70	68.60	57.80
TiO_2	%	0.01	1	1.16	1.06	0.84	0.60	0.64	0.15	0.69
$A_{l2}O_3$	%	0.03	1	22.90	18.20	17.10	15.80	16.70	12.80	14.40
Fe_2O_3	%	0.04	1	2.52	8.81	7.75	3.97	2.02	4.35	8.71
MnO	%	0.01	1	0.01	0.16	0.11	0.09	0.05	0.10	0.07
MgO	%	0.01	1	0.56	1.13	1.58	1.38	1.10	0.98	2.07
CaO	%	0.01	1	0.09	0.85	4.56	3.14	3.54	1.78	2.26
Na_2O	%	0.01	1	0.67	8.65	3.20	1.69	1.97	0.39	0.80
K_2O	%	0.04	1	5.33	0.46	2.08	2.92	3.26	3.32	3.77
P_2O_5	%	0.01	1	0.13	0.50	0.49	0.18	0.15	0.05	0.08
Cr_2O_3	%	0.001	1	0.01	0.01	0.01	0.01	0.02	0.01	0.01
LOI	%	0.1	1	3.93	2.86	6.39	7.49	6.13	6.40	7.87
Total	%	--	--	98.51	100.29	97.71	98.77	98.28	98.93	98.53
Ag	ppb	2	2	2413	17	75	89	33	12	40
As	ppm	0.1	2	20.9	0.8	5.6	3.6	3.1	33.1	10.4
Au	ppb	0.2	2	13.7	0.9	0.4	1.2	0.5	0.5	1.2
B	ppm	1	2	1	1	1	1	2	1	1
Ba	ppm	0.5	2	121.7	133.8	66.3	53.0	136.0	85.7	40.3
Bi	ppm	0.02	2	2.61	0.06	0.02	0.40	1.39	0.07	0.37
Cd	ppm	0.01	2	1.63	0.12	0.18	0.63	0.08	0.01	0.01
Co	ppm	0.1	2	17.3	6.0	11.3	9.9	6.7	20.0	44.3
Cr	ppm	0.5	2	0.7	2.5	2.9	3.9	2.2	1.1	4.2
Cu	ppm	0.01	2	47.92	11.87	11.28	50.24	27.58	12.39	22.87
Mo	ppm	0.01	2	1.77	0.3	1.79	1.89	8.01	0.97	1.71
Ni	ppm	0.1	2	3.8	2.0	1.1	18.8	7.9	43.5	83.3
Pb	ppm	0.01	2	10.83	1.79	5.18	17.07	15.13	2.98	3.28
Sb	ppm	0.02	2	17.79	0.07	0.09	0.54	0.51	2.15	1.20
Sc	ppm	0.1	2	0.5	4.8	3.1	2.1	1.4	0.7	1.2
Sr	ppm	0.5	2	6.2	8.1	61.4	79.0	57.4	53.2	77.4
Th	ppm	0.1	2	0.7	0.5	1.1	4.3	3.6	6.0	2.7
Tl	ppm	0.02	2	0.19	0.02	0.11	0.16	0.15	0.13	0.18
U	ppm	0.1	2	0.1	0.2	0.2	0.9	0.2	0.6	0.2
V	ppm	2	2	2	10	50	9	6	7	8
W	ppm	0.1	2	0.4	0.1	0.1	0.1	0.1	0.1	0.3
Zn	ppm	0.1	2	15.3	73.9	87.5	90.3	10.6	10.4	3.7
Be	ppm	1	3	2	2	1	1	2	2	1
Cs	ppm	0.1	3	6.1	0.1	2.9	5.9	4.0	4.2	5.2
Hf	ppm	0.02	3	0.46	2.69	2.97	0.77	1.85	1.1	0.55
Li	ppm	0.1	3	2.9	11.2	9.5	19.4	8.8	11.8	11.2
Nb	ppm	0.04	3	3.23	10.62	8.42	4.64	5.21	10.49	9.98
Rb	ppm	0.1	3	268.7	1.2	39.6	82.0	114.3	140.7	186.5
Sn	ppm	0.1	3	3.5	2.0	1.1	1.2	0.9	1.7	2.4
Ta	ppm	0.1	3	0.3	0.9	0.6	0.5	0.5	1.0	0.8
Y	ppm	0.1	3	2.9	17.6	13.6	8.1	9.3	11.1	18.0
Zr	ppm	0.2	3	14.9	76.9	106.3	22.3	59.0	26.5	18.0
La	ppm	0.1	3	0.5	21.5	17.0	11.2	15.7	12.2	7.7
Ce	ppm	0.02	3	5.38	24.0	30.85	31.48	41.35	48.23	41.28
Pr	ppm	0.1	3	0.6	3.1	3.8	3.3	4.2	4.9	5.8
Nd	ppm	0.1	3	2.7	13.5	16.9	12.3	16.6	17.5	25.0
Sm	ppm	0.1	3	0.6	3.6	3.9	2.5	3.3	3.5	5.9
Eu	ppm	0.1	3	0.1	1.1	0.9	0.6	0.7	0.7	1.2
Gd	ppm	0.1	3	0.6	3.4	3.6	2.0	2.5	3.0	4.8
Tb	ppm	0.1	3	0.1	0.5	0.5	0.2	0.3	0.4	0.7
Dy	ppm	0.1	3	0.6	3.8	2.7	1.5	1.8	1.9	3.8
Ho	ppm	0.1	3	0.1	0.7	0.4	0.3	0.3	0.3	0.6
Er	ppm	0.1	3	0.4	2.4	1.5	0.7	1.0	1.1	1.8
Tm	ppm	0.1	3	0.1	0.3	0.2	0.1	0.1	0.1	0.2
Yb	ppm	0.1	3	0.5	1.9	1.2	0.7	0.9	1.1	1.5
Lu	ppm	0.1	3	0.1	0.2	0.1	0.1	0.1	0.1	0.2

Notes: See Table 2 for sample descriptions and location information.
All analyses done at Acme Analytical Laboratories, Vancouver, B.C.
ppm = parts per million; ppb = parts per billion
1 - LiBO2 fusion followed by XRF analysis for major oxides and LOI (Group 4X).
2 - ICP Mass Spectrometer analysis after aqua regia digestion (Group IF-MS Basic).
3 - ICP Mass Spectrometer analysis of a 4-acid digestion (Group IT-MS).

TABLE 3 (CONTINUED)

Elem.	Units	Limit	Meth.	8	9	10	11	12	13	14
SiO_2	%	0.02	1	54.70	53.70	63.60	68.40	81.10	60.20	67.80
TiO_2	%	0.01	1	0.97	1.18	0.46	0.79	0.75	0.47	0.36
Al_2O_3	%	0.03	1	19.10	17.60	14.20	14.50	11.30	13.10	15.30
Fe_2O_3	%	0.04	1	7.66	9.38	6.28	5.02	0.66	5.76	3.86
MnO	%	0.01	1	0.27	0.06	0.55	0.08	0.01	0.04	0.04
MgO	%	0.01	1	2.64	2.22	1.03	0.13	0.18	2.50	2.02
CaO	%	0.01	1	3.97	4.87	1.49	0.89	0.04	3.76	1.14
Na_2O	%	0.01	1	6.61	2.99	0.09	5.83	0.17	0.86	3.74
K_2O	%	0.04	1	1.06	3.45	5.31	1.87	3.16	1.18	1.50
P_2O_5	%	0.01	1	0.48	0.44	0.25	0.20	0.01	0.07	0.09
Cr_2O_3	%	0.001	1	0.01	0.01	0.01	0.01	0.05	0.02	0.01
LOI	%	0.1	1	2.61	3.36	6.01	1.93	1.94	9.83	3.93
Total	%	--	--	100.08	99.26	99.28	99.65	99.37	97.79	99.79
Ag	ppb	2	2	48	27	849	56	379	118	31
As	ppm	0.1	2	3.3	4.7	95.4	5.1	3.6	26.8	0.5
Au	ppb	0.2	2	0.2	1.3	48.9	1.0	7.3	1.1	0.4
B	ppm	1	2	3	4	3	3	1	3	5
Ba	ppm	0.5	2	27.2	235.9	19.7	122.3	49.6	54.0	106.1
Bi	ppm	0.02	2	0.02	0.11	1.08	0.02	0.97	0.14	0.17
Cd	ppm	0.01	2	0.28	0.02	6.71	0.38	0.04	0.14	0.03
Co	ppm	0.1	2	18.3	23.9	1.6	3.3	0.5	12.6	8.4
Cr	ppm	0.5	2	1.9	13.7	0.8	4.2	7.7	11.6	7.9
Cu	ppm	0.01	2	11.49	46.84	85.56	2.32	4.39	34.51	18.70
Mo	ppm	0.01	2	0.25	1.55	3.71	0.74	0.45	1.93	1.21
Ni	ppm	0.1	2	6.1	16.0	2.4	1.1	1.5	76.3	7.7
Pb	ppm	0.01	2	2.89	1.65	24.07	8.43	3.14	20.66	9.47
Sb	ppm	0.02	2	0.51	2.58	2.29	1.28	2.53	0.19	0.05
Sc	ppm	0.1	2	3.3	9.1	1.0	6.2	0.3	3.3	2.9
Sr	ppm	0.5	2	34.0	92.4	6.4	7.7	9.4	93.2	74.5
Th	ppm	0.1	2	1.4	0.9	1.2	1.3	1.1	3.2	4.9
Tl	ppm	0.02	2	0.02	0.12	0.34	0.08	0.08	0.13	0.03
U	ppm	0.1	2	0.3	0.1	0.7	0.1	0.1	1.2	1.0
V	ppm	2	2	76	132	8	28	5	19	28
W	ppm	0.1	2	0.1	0.3	0.2	1.6	0.4	0.1	0.1
Zn	ppm	0.1	2	89.2	20.7	915.5	123.2	8.1	88.0	38.2
Be	ppm	1	3	2	1	1	1	1	1	1
Cs	ppm	0.1	3	3.1	12.5	7.8	2.6	3.3	1.0	1.4
Hf	ppm	0.02	3	0.91	1.87	1.7	2.0	0.58	2.03	3.93
Li	ppm	0.1	3	30.1	29.7	8.4	6.7	1.7	39.0	31.9
Nb	ppm	0.04	3	13.65	13.41	4.4	5.29	2.29	2.62	5.83
Rb	ppm	0.1	3	18.4	58.7	212.5	58.4	159.9	30.4	31.8
Sn	ppm	0.1	3	1.0	1.1	1.4	0.5	4.4	1.3	1.1
Ta	ppm	0.1	3	1.1	1.2	0.3	0.4	0.2	0.2	0.9
Y	ppm	0.1	3	14.6	15.3	9.2	17.6	5.3	22.0	15.0
Zr	ppm	0.2	3	25.0	54.2	52.1	66.4	19.0	58.3	121.1
La	ppm	0.1	3	9.2	6.5	4.0	18.9	8.4	1.8	13.6
Ce	ppm	0.02	3	42.9	39.53	27.6	45.94	41.21	34.58	25.07
Pr	ppm	0.1	3	5.1	5.0	3.4	6.1	5.1	4.1	2.9
Nd	ppm	0.1	3	21.8	21.0	14.0	26.9	20.8	16.3	11.6
Sm	ppm	0.1	3	5.1	4.8	3.2	5.9	4.4	3.9	2.9
Eu	ppm	0.1	3	1.4	1.4	0.8	1.1	1.0	0.8	0.5
Gd	ppm	0.1	3	4.1	4.6	2.5	4.7	2.3	3.8	2.5
Tb	ppm	0.1	3	0.6	0.6	0.3	0.5	0.2	0.5	0.4
Dy	ppm	0.1	3	3.4	3.4	1.8	3.3	1.1	3.8	2.6
Ho	ppm	0.1	3	0.5	0.6	0.3	0.6	0.2	0.7	0.5
Er	ppm	0.1	3	1.7	1.7	0.8	2.1	0.6	2.6	1.8
Tm	ppm	0.1	3	0.2	0.2	0.1	0.3	0.1	0.4	0.2
Yb	ppm	0.1	3	1.2	1.5	0.9	2.2	0.6	2.4	2.1
Lu	ppm	0.1	3	0.1	0.2	0.1	0.3	0.1	0.3	0.3

Notes: See Table 2 for sample descriptions and location information.
All analyses done at Acme Analytical Laboratories, Vancouver, B.C.
ppm = parts per million; ppb = parts per billion
1 - LiBO2 fusion followed by XRF analysis for major oxides and LOI (Group 4X).
2 - ICP Mass Spectrometer analysis after aqua regia digestion (Group IF-MS Basic).
3 - ICP Mass Spectrometer analysis of a 4-acid digestion (Group IT-MS).

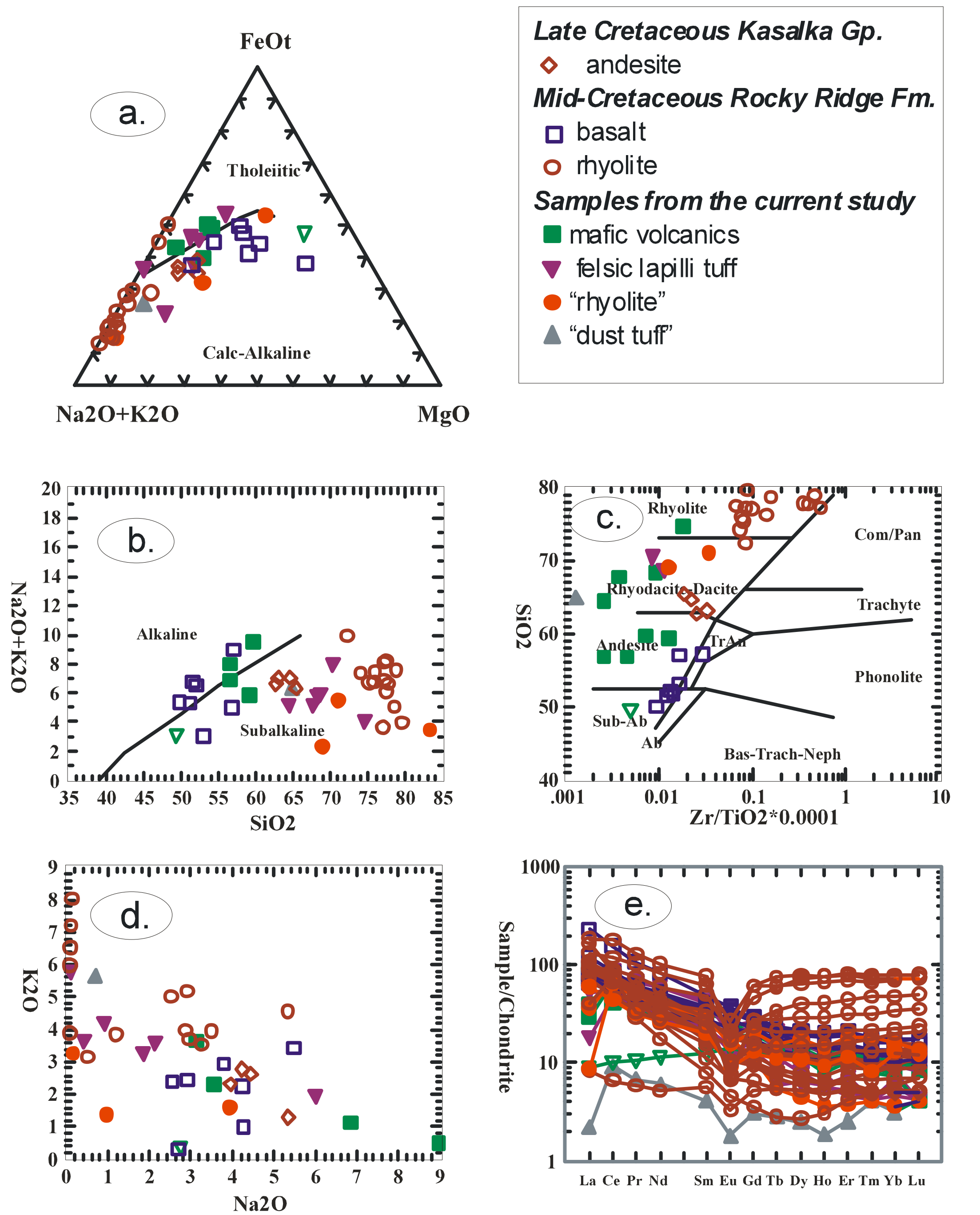

Figure 5. a. AFM ternary plot showing calc-alkaline nature of Rocky Ridge and Kasalka volcanic rocks; b. alkali-silica plot showing subalkaline to alkaline compositional trend; c. SiO2 versus Zr/TiO2 plot showing compositional range and classification of Rocky Ridge volcanic rocks and rhyolite domes; d. K20 versus Na2O plot showing Na depletion of altered rhyolite samples; e. plot of chondrite normalized rare earth element abundances for Rocky Ridge basalts and rhyolites.

pervasive chlorite-sericite alteration occur in the footwall rhyolites. The Eskay Creek deposit shares mineralogical, geochemical and other characteristics of both subaerial epithermal Au-Ag hot spring deposits and deeper water Kuroko and Besshi type volcanogenic massive sulphide deposits (Roth, 2002). Many deposits appear to be associated with bimodal (basalt-rhyolite) submarine volcanic centers, including sea-flooded, breached calderas in an active volcanic arc setting. Given the inferred shallow submarine

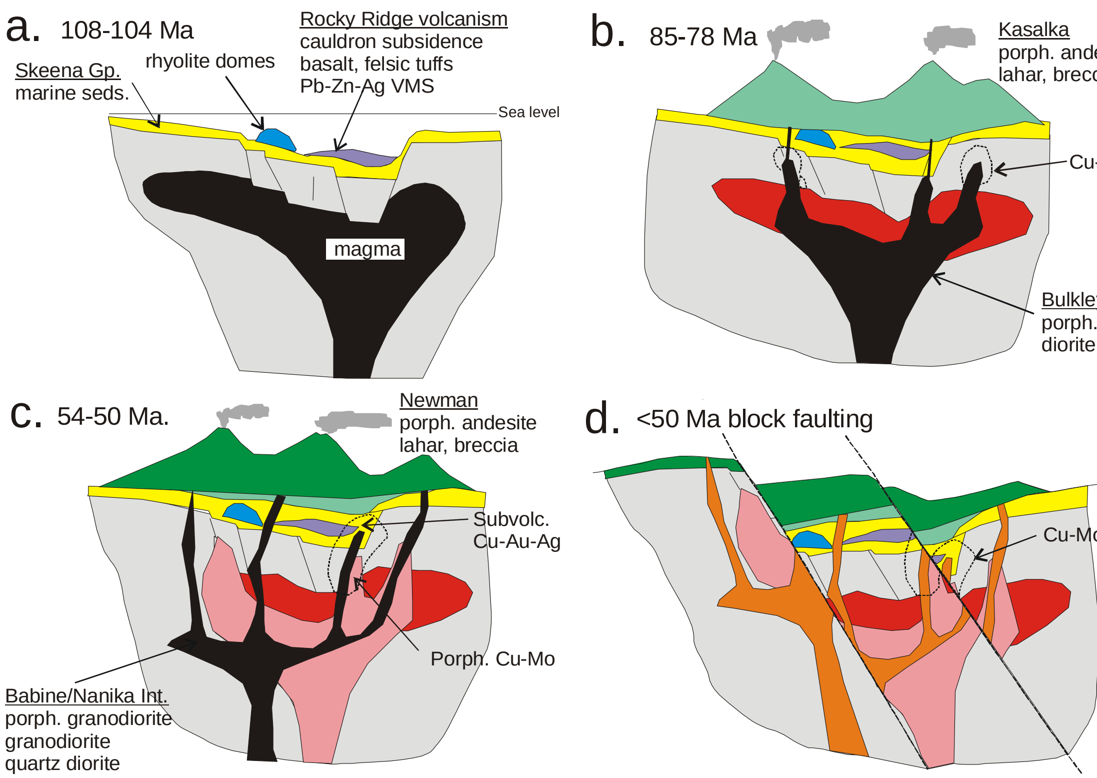

Figure 6. Stages in the evolution of Cretaceous-Tertiary volcanic centers in central BC.; a. nascent island arc (108-104 Ma); b. Late Cretaceous continental arc (85-78 Ma); c. Eocene continental arc; d. post Eocene extension and block faulting.

setting, bimodal composition and apparent spatial association of precious metal rich massive sulphide and vein deposits, the Rocky Ridge Formation is considered to be a favourable host for Eskay Creek type deposits.

The focus of the current study was to demonstrate that rhyolite domes similar to those dated in the Babine Lake area occur elsewhere in the Rocky Ridge succession and that these represent local, felsic volcanic centers in a bimodal, submarine volcanic environment that is favourable for the formation of VMS and/or Eskay Creek type deposits. Based on the presence of strong alteration in the host rhyolites as determined by lithogeochemical analyses and the presence of known mineral occurrences, the most favourable areas identified in a previous study are at the Fireweed, Cronin and Knoll properties. Other, less well-explored areas such as south of Rocky Ridge and at Troitsa Lake may also prove to be favourable. In all of these areas the rhyolite intrusions appear to be emplaced along ring structures related to the development of large submarine cauldron subsidence complexes. Isotopic dating of the rhyolitic intrusions will help constrain the timing of cauldron subsidence and thus demonstrate or repudiate correlation with Rocky Ridge volcanic rocks elsewhere in the study area.

Mineralization and alteration at Beament, Bob Creek and Equity Silver mine suggests a subvolcanic, epithermal environment probably associated with emplacement of nearby intrusions as postulated by previous workers (Cyr *et al.*, 1984). This is the Subvolcanic Cu-Au-Ag (As-Sb) deposit model described by Panteleyev (1995). However, in the authors opinion, some ore at Equity is clearly a fragmental massive sulphide with similarities to Eskay creek and other classical VMS deposits. If this interpretation is correct and the host rocks at Equity prove to be mid-Cretaceous Rocky Ridge Formation then at least some of the massive sulphide at Equity is also this age. Early Tertiary whole rock K-Ar ages determined for sericitized volcanic rocks (Cyr *et al.*, 1984) at Equity might reflect either overprinting of a younger sericite-clay alteration or thermal resetting related to emplacement of nearby Early Tertiary intrusions. A younger Early Tertiary hydrothermal event is appealing as it could explain both the younger ages for sericitized rocks and the replacement textures observed in fragmental massive sulphide beds.

It seems likely that both the mid-Cretaceous Pb-Zn-Ag mineralization at the Knoll, Cronin and Fireweed prospects and possible younger Late Cretaceous or Early Tertiary mineralization at Equity, Beamont and Bob Creek are related to the evolution of major volcanic centers that were periodically active from the mid-Cretaceous to Eocene time. Earliest stages of volcanism, as represented by the Rocky Ridge formation, involved cauldron subsidence in a nascent island arc setting with attendant Pb-Zn-Ag VMS and related epithermal mineralization associated with shallow, submarine eruption of rhyolite flow domes. Younger, Late Cretaceous or Early Tertiary magmatic events resulted in building of stratovolcanoes in an Andean continental arc setting with attendant subvolcanic Cu-Au-Ag and porphyry Cu-Mo type mineralization. A genetic model depicting these evolutionary stages is presented in Figure 6.

CONCLUSIONS

1. Precious metal rich, massive sulphide occurrences at the Fireweed, Knoll and Cronin properties appear to be related to submarine rhyolite flow domes that were emplaced along rifts that formed during mid-Cretaceous cauldron subsidence. This was followed by eruption of thick piles of alkali basalt. The inferred geologic setting (nascent arc, bimodal, submarine, rift related) is similar to that proposed for classical Kuroko and Eskay Creek-type VMS deposits and therefore, areas of Rocky Ridge volcanics in central British Columbia are interpreted to be highly prospective for these types of deposits.
2. Rocks at the Fort Babine, Beament and Bob Creek localities are compositionally and lithologically similar to the Rocky Ridge Formation and a tentative correlation is suggested. Isotopic age-dating is needed to further confirm this correlation.
3. Felsic pyroclastic rocks at Beament, Bob Creek and Equity are strongly pyritic, have elevated base and precious metal concentrations and are pervasively altered to sericite and clay. This style of alteration and mineralization is characteristic of subvolcanic epithermal systems associated with emplacement of porphyritic intrusions. The age of this hydrothermal activity is not known but it is likely younger than, and therefore unrelated to, the Rocky Ridge host rocks.
4. The authors believe that a least some of the fragmental massive sulphide at the Equity mine is syngenetic and is hosted by the mid-Cretaceous Rocky Ridge Formation. A sample of felsic lapilli tuff from Equity has been submitted for U-Pb dating and this may help to confirm or repudiate this correlation.

ACKNOWLEDGMENTS

The authors wish to thank the Rocks to Riches management committee for providing financial support to continue this study. Mike Villeneuve, Geological Survey of Canada, Ottawa has provided invaluable assistance to this project by providing technical and interpretive assistance with U/Pb and Ar/Ar age-dating. Dr. Neil Church generously provided information and samples from the Equity Silver Mine area and Mike Assiz of Placer Dome provided valuable assistance in acquiring samples at the Equity mine site. Assistance in researching information and viewing type collections for properties in the area was kindly provided by Paul Wojdak in the Ministry of Energy and Mines Smithers office

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APPENDIX A. U/PB ISOTOPIC AGE-DATING METHODOLOGY

Following the separation of heavy minerals using heavy liquids, samples were passed through a Frantz LB-1™ magnetic separator to purify zircon and titanite. Zircon crystals were selected for analysis based on criteria that optimised for their clarity, lack of cloudiness and colour, and lack of fractures. All zircons were abraded prior to analysis to increase concordance by removing the outer portions of the grains where much of the Pb-loss and alteration take place (Krogh, 1982).

Following abrasion, photography, and final mineral selection, mineral fractions were analysed according to methods summarised in Parrish *et al.* (1987). Data have been reduced and errors have been propagated using software written by J. C. Roddick; error propagation was done by numerical methods (Roddick *et al.* 1987; Parrish *et al.*, 1987). Error ellipses on concordia diagrams are shown at the 2-sigma (95% confidence) level of uncertainty. Linear regressions on discordant arrays of data use a modified York (1969) method that takes into account the scatter of the points about the line (see a discussion in Parrish *et al.* 1987).