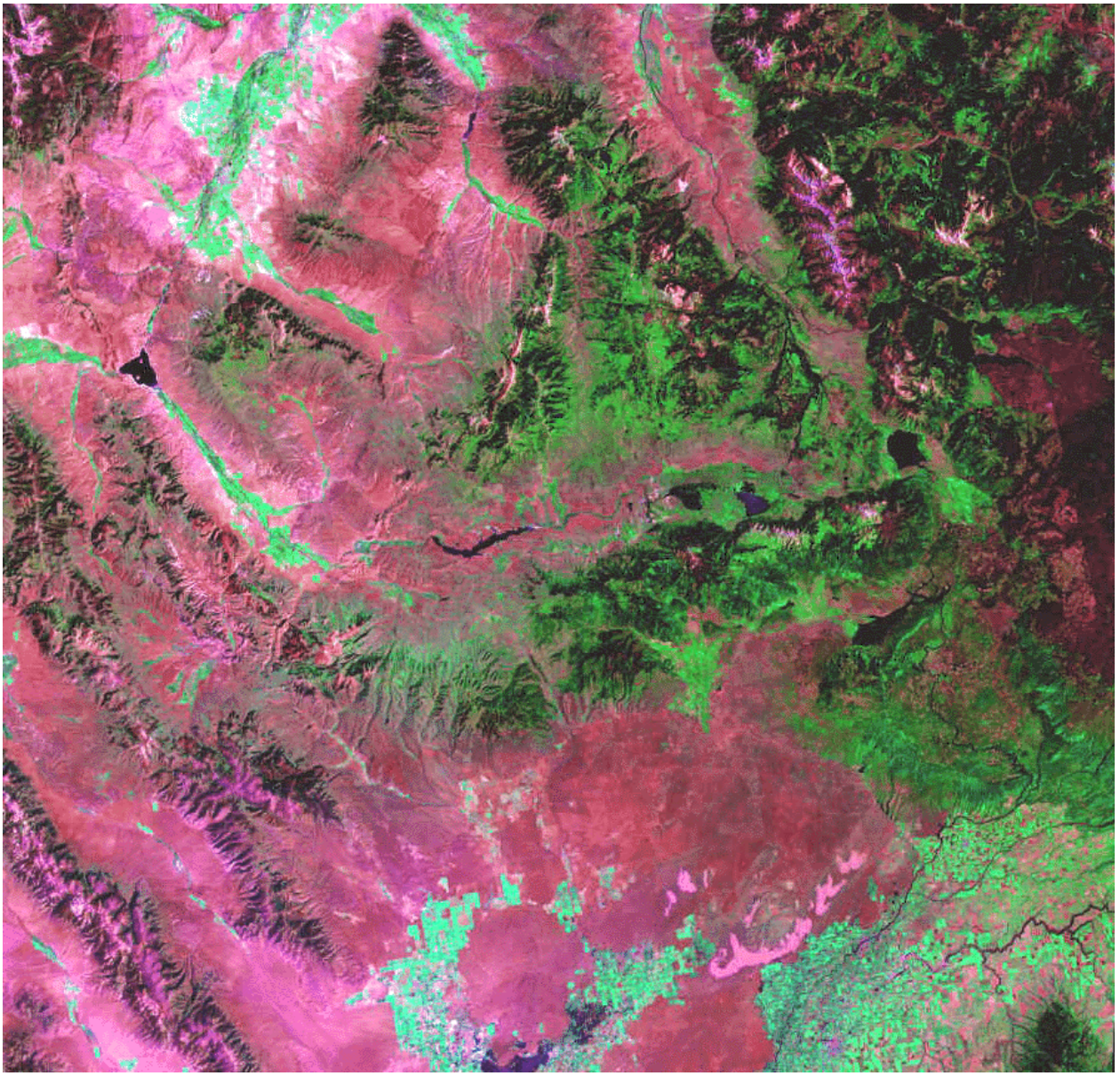
GEOLOGY AND GEOCHEMISTRY OF AU-AG-MINERALIZATIONS IN THE VIRGINIA CITY MINING DISTRICT (VCMD), MONTANA, U.S.A.

by

Pero Despotovic



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Title page: False colour satellite image of southwestern Montana and adjacent regions; Source: Clifton-Campbell Imaging; URL: http://www.tmarchieve.com (see Fig. 4 on page 11 for location).

ZUSAMMENFASSUNG

Der Virginia City Mining District (VCMD), im Südwesten Montanas gelegen, ist eine der reichsten Seifenlagerstätten der U.S.A. gewesen. Diese Arbeit versucht die bisher ungelöste Frage der Mineralisationsart im VCMD zu beantworten. Basierend auf einer detaillierten Kartierung der umgebenden Nebengesteine bietet diese Arbeit geologische, strukturelle, petrologische und geochemische Informationen über das Lucas/Atlas und South Bachelor Gold-Silber System. Es ist eine geodynamische Interpretation der Platznahme, des Protoliths und der tektonischen Bildungsbedingungen der Gneise, Amphibolite und der goldführenden Quarzgänge im VCMD durchgeführt, sowie ein beschreibendes geologisches Modell der Mineralisation im VCMD entwickelt worden.

Die Zusammensetzung der unalterierten Gneise des Nebengesteins im Lucas/Atlas und South Bachelor Bereich ist hauptsächlich "granitisch" mit oder ohne Magnetit (Aggm, bzw. Agg) und erreichte die obere Amphibolit- bis untere Granulit-Fazies. In geringerem Maße stellen "tonalitische" Gneise, Hornblende-Plagioklas-Gneise und Amphibolite, besonders in der Nähe der Kearsarge Mine, Nebengesteine dar. Foliationen des Nebengesteins sind von zahlreichen granitischen Pegmatiten und einigen Aplitgängen durchschlagen, und diese wiederum vom Gangsystem und dem dazugehörigen Alterationshalo. Es sind keine großen Intrusivkörper festgestellt worden, obwohl eine Aplit/Alaskit-Intrusion in der Nähe der Easton/Pacific Minen im Westen des Distrikts als die Dachregion eines möglicherweise tiefer liegenden Intrusivskörpers interpretiert werden könnten.

Die Klassifizierung und Differenzierung der Nebengesteine im Lucas/Atlas und South Bachelor Bereich legen Protolithe von dominierend vulkanischer Herkunft nahe. Die Gesteinsabfolge könnte durch subduktionsbezogene Prozesse erzeugt worden sein. Beobachtungen im Gelände lassen jedoch keinen Zweifel, daß diese Vulkanite mit Sedimenten, insbesondere im Westen des Alder Gulchs, wechsellagern. Daher müssen diese im selben Volcanic Arc System abgelagert worden sein und durch Kollisionstektonik angeschweißt worden sein, ohne weit transportiert worden zu sein.

Fünf Deformations- und drei Metamorphoseereignisse konnten in den Nebengesteinen festgestellt werden. Die ersten beiden Deformationsereignisse führten zu isolklinalem Faltenbau (vor 2,7-2,9 Ga, obere Amphibolit- bis untere Granulit-Fazies) und offenem Faltenbau (vor 1,6-1,9 Ga, obere Amphibolit-Fazies). Grünschieferfazielle Mineralparagenesen bildeten sich während spröd deformativen Hebungsphasen im Sinium (Oberes Proterozoikum), Laramisch (Oberkreide-Unteres Tertiär) und während der Tertiären Extension.

Strukturgeologisch gesehen, kann die Mineralisation im VCMD der zweiten Hebung von metamorphen Grundgebirgseinheiten im Südwesten Montanas zugeordnet werden, die infolge eines komplexen Zusammenwirkens von gepaarten Strörungssystemen zwischen nordwest-streichenden sinistralen Blattverschiebungen und Überschiebungen als positive Blumenstrukturen während der Laramischen Orogenese entstanden sind. Dieses mag von nicht anstehenden gleichzeitig entstandenen Intrusionen, ähnlich zum Tobacco Root Batholith, begleitet worden sein, obwohl sie für die Erklärung der Mineralisation nicht unbedingt benötigt werden. Die Gänge könnten in einer en echelon-Anordnung zwischen großen sinistralen Blattverschiebungen als untergeordnete Scherbrüche und Riedel-Scherflächen, die einen kleinen Winkel (ca. 10-20°) synthetisch zur Hauptstörung bilden, entstanden sein.

Die Gold-Silber-Vererzung im VCMD kann als gering sulfidführende und meso- bis epithermale epigenetische Lagerstätte betrachtet werden, in der die Ablagerung von Edelmetallen mit der Entwicklung von hochthermalen potassischen Alterationshalos einhergeht. Gewöhnlich finden sich jüngere Texturen, wie Karbonatbreccien und -bruchfüllungen, wie auch argillische Alteration in anderen Bereichen des Distrikts. Diese indizieren mehrfache hydrothermale Aktivität während wiederholter Reaktivierung älterer Gangsysteme, möglicherweise während erneuter Hebungsereignisse, infolge von herausgehobenen oder abgesunkenen Teilbereichen früherer Mineralisationen oder infolge von Teleskoping-Effekten.

Vulkanisch-sedimentäre Gesteine könnten als primäre Quelle für das Gold betrachtet werden, das syngenetisch abgelagert, nachfolgend umgelagert und in günstigen Strukturen angereichert worden ist.

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ABSTRACT

The Virginia City Mining District (VCMD) in southwestern Montana was one of the richest placer deposits in the U.S.A. This study tries to resolve the yet unresolved question on the nature of mineralization of the VCMD. Based on detailed geologic mapping of the surrounding host rocks this study reveals geological, structural, petrological and geochemical information on the Lucas/Atlas and South Bachelor gold-silver system. A geodynamic interpretation of the emplacement, protolith and tectonic setting of the gneisses/amphibolites and the gold bearing quartz veins in the VCMD has been made and a descriptive genetic model for the gold mineralization in the VCMD has been achieved.

Composition of unaltered wallrock gneiss in Lucas/Atlas and South Bachelor areas is dominantly „granitic“ with or without magnetite (Aggm or Agg, respectively) which reached upper amphibolite to lower granulite facies. Minor host rocks are represented by „tonalitic“ gneisses and hornblende-plagioclase gneisses and amphibolites, especially in the vicinity of the Kearsarge mine. Numerous granitic pegmatites and several aplite dikes transect wallrock foliation and are in turn crosscut by the vein system (and the related alteration halo). No large intrusive bodies have been observed in the district, though an aplite/alaskite intrusive close to the Easton/Pacific mines in the western part of the district could be interpreted as the top region of a possible deeper seated intrusive body.

Classification and discrimination of country rocks of the Lucas/Atlas and South Bachelor areas suggest protoliths of dominantly volcanic origin. This suite of rocks possibly have been generated by subduction-like processes. Field observations, however, leave no doubt that the volcanics are intercalated with sedimentary rocks especially to the west of Alder Gulch. Therefore, they must have been deposited in the same volcanic arc tectonic setting and accreted by collosional though not far-travelled tectonics.

Five deformational and three metamorphic events could be defined in the host rocks. The first two deformational events produced ductile isoclinal folds (at 2.7-2.9 Ga, upper amphibolite to lower granulite facies) and open folds (at 1.6-1.9 Ga, upper amphibolite facies). Greenschist facies assemblages accompanied brittle deformation during Sinian (Late Proterozoic) and Laramide (Late Cretaceous-Early Tertiary) uplift and Tertiary extension.

Structurally, mineralization in the VCMD can be assigned to the second uplift of metamorphic core complexes in southwestern Montana due to complex interaction of paired fault systems between thrust belt structures and northwest-trending left-lateral strike-slip faults and development of positive flower structures during Laramide crustal shortening. This may have been accompanied by unexposed coeval intrusions similar to the Tobacco Root Batholith although they are not necessarily needed to explain mineralizations. Veins could have been emplaced in an en echelon array between major left-lateral strike-slip faults as subsidiary shear fractures and Riedel shears which developed at a small angle (roughly 10-20°) synthetic to the main strike-slip fault.

The gold-silver mineralization in the VCMD is considered to be a low-sulfide and meso- to epithermal epigenetic deposit in which deposition of precious metals coincides with the formation of high temperature potassic alteration halos. Superimposed textures such as later carbonate brecciation and fracture fillings are common, as well as argillic alteration in other parts of the district. They indicate multistage hydrothermal activity during repeated reactivation of earlier vein structures possibly due to renewed uplift, popped-up or tilted parts of earlier mineralization or due to telescoping.

Volcano-sedimentary rocks may be considered as the primary source of gold that was deposited syngenetically, redistributed subsequently, and concentrated to ores in favorable structures.

ACKNOWLEDGEMENTS

Without the extensive logistic and technical support by Hanover Gold Comp. Inc.[1], and the permission to publish this information, this thesis would not have been possible. Mrs. Doris Kitchen, office manager of Hanover Gold, opened initially the way for two aspiring students from Berlin. Generous access to data and core was made possible by the senior geologist of Hanover Gold, Mr. Bill Neal. Thanks for fruitful discussions with him, consulting geologists Mr. David Odt and Mr. Dan Truckle. Special thanks are in order to the „Soul of Montana“, Mr. Wayne Tichenor. Professor David W. Mogk[2] from Montana State University helped with his efforts in the field to understand Archean geology and metamorphic processes in southwestern Montana. Prof. Klitzsch[3], Prof. Franz[3] and Prof. Germann[3] supervised this project from the very beginning to the end. Mr. Matthias Karg has been my partner in this project. I would like to thank him for organization, realization, and final completion of this effort. Critical review of this M.Sc. study by Mr. Matthias Karg was significant and is gratefully acknowledged.

Very special thanks to many friendly people at the Technical University of Berlin who helped to finish the project and this study successfully. This is in order to Dr. Matheis and Mr. Domin at the geochemical lab, Mrs. v. Engelhard and Mrs. Müllers, who did most of the preparation of thin and polished sections, and Mrs. Günther for photographs.

This project has been granted by a scholarship of the Technical University of Berlin. I would like to thank Mrs. Jutta Gbur for her enthusiastic support of this project. Additionally, field work assistance was granted by the Department of Earth Sciences of the Technical University of Berlin.

PREFACE AND PURPOSE OF THIS STUDY

In co-operation with Hanover Gold, an active North American company focused on gold exploration, and David W. Mogk, professor for geology and metamorphic petrology at the Montana State University in Bozeman, a great opportunity to combine working on a concrete exploration project with the Master of Science thesis has been offered. This work integrates detailed mapping and further studies for the Master of Science thesis. This project was designed to

- provide and document basic data (geology, structure, petrography, and geochemistry) relevant to the various aspects of mineralization alteration, and metamorphic episodes affecting the deposit
- determine the pre-mineralization composition of the host rocks (protoliths)
- model the timing and genesis of the deposit in terms of the source of the gold and other ore elements, the transport and precipitation mechanisms, and the overall hydrothermal evolution with respect to the various geological events
- discuss the conflicting views on ore genesis to provide a metallogenetic model that satisfactorily describes and explains the various features of the deposit

The immediate proximity to the area of investigation of Mr. Matthias Karg allowed a comparative study of the mineralization regarding the protolith of the host rock, its tectonic and metamorphic setting and the development of a genetic model of the mineralization in the VCMD.

I. INTRODUCTION

1.1. Location

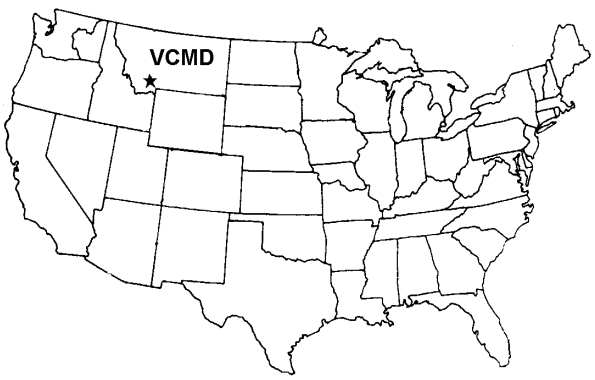


Fig. 1: Location of the VCMD, U.S.A. (taken and modified from JAMES, 1954).

The study area, “Virginia City Mining District” (VCMD), is part of the northern Rocky Mountains and is located southwest of Virginia City, Madison County, southwest Montana, U.S.A. (fig. 1). The capital city of Montana, Helena, is located about 150 km north of Virginia City. Roughly, the area is located at 45° N latitude and 112° W longitude in southwest Montana (fig. 2, next page).

[1] Hanover Gold Co. Inc.; corporate office: 424 S. Sullivan Rd., Suite # 300, Veradale, WA 99037, U.S.A..
[2] Prof. David W. Mogk; Montana State University, Department of Earth Sciences, Bozeman, MT 59717, U.S.A..
[3] Technical University of Berlin, Ernst-Reuter-Platz 1, Sekr. BH 4, 10587 Berlin, Germany

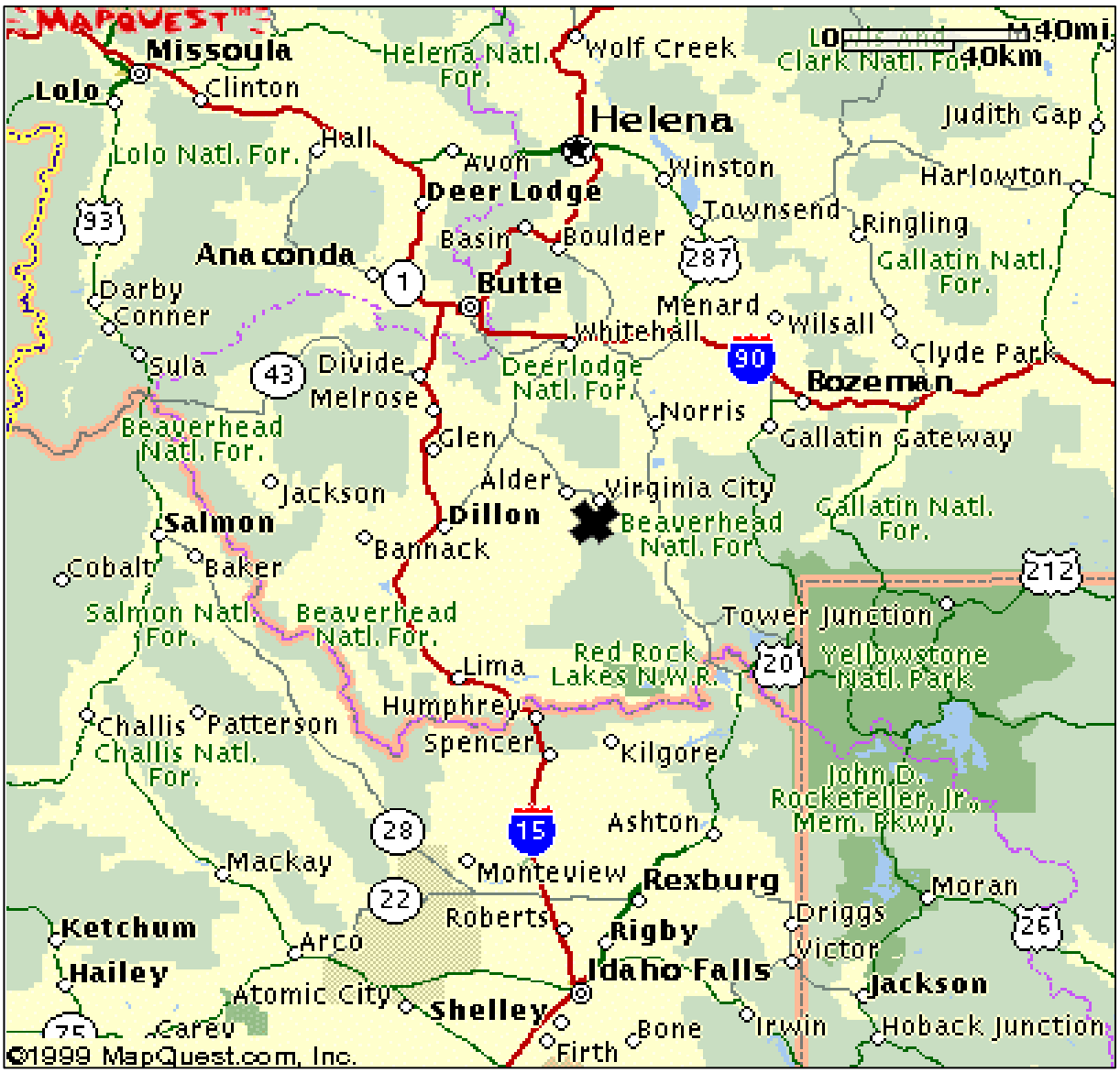


Fig. 2: Location of the VCMD, southwestern Montana (black cross represents approximate location of study area; modified after Mapquest.com, 1999).

1.2. Geography

The VCMD extends from Alder Gulch on the north and east, to west of Brown's Gulch, and to the flanks of the Gravelly Range on the south. It covers an area of approximately 90 km^2.

The topography is mountainous. Virginia City, elevation 1767 m, sits in a topographic low between two major mountain ranges. The Tobacco Root Mountains (summit elevations 3000-3200 m) are located to the north, and the Gravelly Range (summit elevations exceed 2900 m) to the south. The valley to the west of Virginia City is the Ruby River Valley, elevations about 1525 m, and the valley to the east is the Madison River Valley, elevations about 1500 m. The mapping area elevations range from 1980 m to 2440 m.

Basalts in the surroundings of Virginia City develop plateaus and moderate hills. Alpine morphology is best developed where plutonic rocks occur, e.g. in the Tobacco Root Mountains, or where sedimentary rocks rest upon the Archean basement.

The study area is part of the Greenhorn Range, though some authors name it either part of the Gravelly Range or Ruby Range. The distinct geologic and geomorpholgic features allow to use a proper name for it.

Drainage

The major drainages of the district, Alder and Brown's Gulch, head on the east side of the Continental Divide in the southern portion of the district, at the foothills of the Gravelly Range. Alder Creek flows north to Virginia City where it turns and flows northwest for 16 km until it joins the Ruby River. Brown's Gulch flows north until it joins

Alder Creek at Nevada City (3 km northwest of Virginia City). The Ruby River flows into the Jefferson River near Twin Bridges (48 km northwest of Virginia City). The Jefferson River together with the Gallatin River and Madison River form the headwaters of the great Missouri River at Three Forks (about 94 km north-northeast of Virginia City) which finally terminates in the Gulf of Texas, Atlantic Ocean.

Climate

Nestled in a small pocket of the Greenhorn Range, Virginia City has its own micro-climate. Temperatures range from a normal minimum of 10.6°F (-11.9°C) in January to a normal maximum of 81.3°F (27.4°C) in July. The coldest month on record was January 1875, with an average temperature of 1.7°F (-16.8°C). July 1916 had the warmest average, 73.5°F (23.1°C). The record low at the nearest weather station, in Dillon, was 36°F below zero (-37.8°C) in 1937; the record high was 101°F (38.3°C), in 1961. The average annual precipitation in Virginia City, 413 mm (1.64 inches), is more than that of the nearby valley floors, but less than falls on the adjacent mountain tops. Therefore the climate can be described as semi-aride in the valleys and semi-humide in higher elevations. Weather records from Virginia City suggest that approximately 60 percent of the precipitation is in the form of snow. Average annual snowfall is 120 cm (3.91 feet; SIEVERT, 1993).

Vegetation

The Tobacco Root Mountains are steep, incised and alpine. The Gravelly Range exhibits more rounded geomorphologic features, and is not as heavily timbered exhibiting vegetation more closely related to mountain steppe environments. The study area in the Greenhorn Range lies in between them but is heavily timbered. The Madison and the Ruby Valleys represent ancient inland seas of which the ancient shorelines can still be seen along the flanks of the ranges.

Vegetation in the low-lands, e.g. in the valleys, is scarce and mainly composed of sage brush, shrubs, other low ground cover, and grass. Elevations higher than 1900 m, e.g. mountain slopes, are commonly heavily timbered with conifers. Very high elevations and steep mountains higher than 2500 m exhibit almost no vegetation. Mining in this region led to denudation of the flora, removing trees and shrubs both to gain access to the ground and to provide materials for crude shelters. Thus trees in the VCMD are not older than 80 years.

Vegetation can be used as an indicator for underlying lithologies. Usually gneisses are timbered with conifers and sage brush, basalt allows very green grass to grow.

Demography and infra-structure

According to the census in 1990 the population of Virginia City is 140, a total of 6,000 in the Madison County and about 850,000 in the State of Montana). The resemblence of Virginia City today to Virginia City of the 1860s (e.g. „ghost town“) attracts tourists in summer and offers seasonal work in restaurants, hotels, theaters, shops and as outfitters for rafting and hunting trips. Some residents work at talc mines in the nearby Ruby Range and at some small scale mining activities in the Alder Gulch. The Madison County government is seated in Virginia City. Bovey Restorations, a company once created and founded by Charlie Bovey, who began in the 1940s to rebuild and collect remnants of the mining era, offers seasonal work in the construction sector. The valleys in the greater surroundings are extensively used by cattle and are scarcely irrigated (SIEVERT, 1993).

Accessibility

Virginia City is approachable via Montana Highway 287. For residents of Virginia City have to travel to outlying communities for access to schools, medical attention, and supplies, Highway 287 is kept well plowed. A series of dry weather roads, e.g. dirt roads, exist within the district, but with limited winter access.

1.3. Method of investigation

Field work

The project encompasses a total area of about 5.5 km^2. Geological lithostratic and structural surface mapping took place from July to November 1998 at 1:1,200 scale based on digitalized topographic maps, which were obtained from Hanover Gold. For orientation USGS topographic maps, the Virginia City and Cirque Lake 7.5-minute quadrangles (1988), were used, too. Geologic maps from different authors and series of areal photographs published by the USGS in 1992 were used in the field. Vegetation and heavy timbering highly prevented obtaining litho-structural informations, thus areal photographs were used rather as an orientation help.

Areas mapped by KELLOGG (1992-1996) for the USGS in nearby Archean basement were investigated, too, in order to obtain reliable mapping units. Thus definitions of them follow broadly definitions used by the USGS. The altitude was measured by an barometric altimeter.

During field work six H-size cores (approximately 6.2 cm in diameter) totaling 3088 ft (about 941 m) and 137 RC-chipsamples, all located north of the Bachelor Gulch, close to Kearsarge mine, have been relogged with main emphasis on the relationship between lithology, structure, wallrock alteration, and gold mineralization, and 200 host rock and 9 mineralized core samples have been collected for further investigations. Samples from cores were split: one half for thin and polished sections, the other for geochemical analysis. The vast majority of underground workings in the study area are caved and inaccessible, though some adits and trenches allowed limited subsurfacial information.

Professor Mogk of the Montana State University supervised and attended field work on two days during mapping by giving substantial introduction to the general geology of southwestern Montana.

Laboratory work

Further laboratory examinations in Germany at the Technical University of Berlin followed the field work. For petrographic studies, 36 thin sections and seven polished sections have been prepared partly by the author. The majority of this preparation work has been done by laboratory technicians at the Technical University of Berlin.

For petrologic and minerogenic examinations, 36 whole rock geochemical analyses to define composition of rocks, protolith, mineralization and alteration effects have been performed by the author. Firstly, the samples were sent into the jaw crusher, reduced by quartering, and milled for three minutes in a tungsten carbide disk mill to a particle size of <63 µm for analysis (therefore W, Co and Ta values should not be considered as critical for discussion). Major elements and trace elements for all samples were analysed by X-ray-fluorescence (XRF) at the geochemical laboratory of the Technical University of Berlin. Trace elements were determined on pressed powder pellets (6 g C-wax mixed with 1.5 g sample), whereas major elements and some trace elements like Hf, La, Ce, and Nd were determined on inductively fused pellets prepared in a Spetec-Roto-Melt inductively coupled oven (3.6 g lithiummetaborate, $Li_2B_4O_7$, mixed with 0.6 g sample). Analyses were completed by determination of the loss on ignition (L.O.I.) on milled samples weighing about 3 g by heating them at 1000°C in an air oven during one hour continuously. For geochemical results see appendix 5.

Core samples KS 11-3, KS 12-2, KS 13-2, and KS 14-3 are representative of lower grade mineralizations (0,5 to 1 ppm Au; yellow / light gray symbol), KS 11-1, KS 11-2, KS 12-1, KS 13-1, and KS 14-2 of higher grade mineralization (1 to 10 ppm Au; red / dark gray symbol in appendix 3). See appendix 3 for schematic petrographic description taken from more detailed relogging results on these cores done at the mine site.

2. REGIONAL GEOLOGIC SETTING

2.1. Geologic provinces of North America

The North American Precambrian crustal structure was termed by HOFFMAN (1989) a *tectonic collage* in order to describe the collection of diverse tectonic elements which originated independently of each other and which were subsequently assembled by accretional tectonics. North America's basement collage consists of five distinct tectonic elements (fig. 3):

Fig. 3: Major Precambrian geological provinces of North America. Symbols are as follows: 1) Archean cratons (S, Slave; K, Kaminak; W, Wyoming; N, North Atlantic); 2) pre-1.9-Ga Proterozoic orogens and reactivated Archean areas; 3) middle Proterozoic orogens; 4) 1.6- to 1.3-Ga igneous intrusions and related volcanics; 5) Grenville orogen; CNAR, Central North American Rift. Greenland has been restored to predrift position by fitting adjacent continental slopes (taken from FRAZIER and SCHWIMMER, 1987).

1) Archean cratonic blocks (Superior, Kaminak, Slave, Wyoming, and North Atlantic cratons); 2) pre-1.9-Ga Proterozoic orogens and reactivated

Archean crust (the Comitee, Rinkian, and Nagssugtoqidian fold belts); 3) middle Proterozoic mobile belts (the Wopmay, Circum-Ungava, Reindeer, Ketilidian, and Penokean orogens); 4) intracratonic igneous and sedimentary rocks which formed between 1.6 and 1.3 Ga; and 5) the Grenville orogen. A sixth Proterozoic element of the basement collage, not usually considered a separate geological province, is a major rift system called the Central North American Rift (CNAR) extending to both the southwest and the southeast of the Great Lakes. It was formed during the later Middle Proterozoic in association with voluminous basaltic volcanism, possibly as the result of a beginning continental rifting.

2.2. Regional geology of the northern Rocky Mountains and the Wyoming Craton

The study area is part of the Archean Wyoming Craton. Figure 4 shows the fragmented distribution of large, variously oriented Laramide-age (Late Cretaceous–Early Tertiary) structural fault blocks and domal uplifts exposing Archean rocks of the Wyoming province. The only exposed terrane boundary of the Wyoming province is the Cheyenne belt of southeastern Wyoming, south of which juvenile 1.8- to 1.6-Ga terranes were accreted. The eastern and northern margins of the province are bounded, mainly in the subsurface, by the approximately 1.8-Ga Trans-Hudson orogen and Great Falls tectonic zone, respectively. Archean

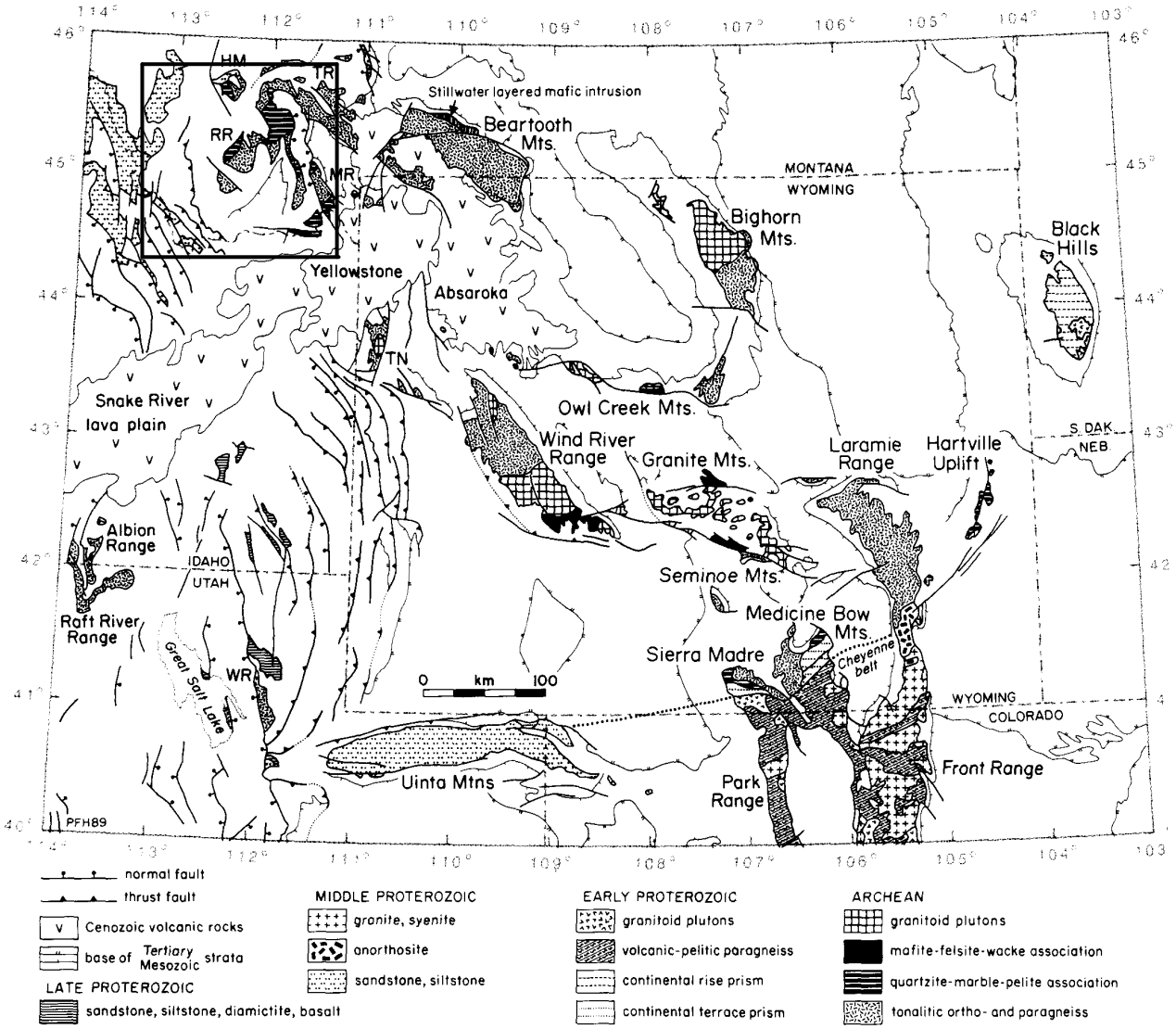


Fig. 4: Laramide uplifts exposing Archean rocks of Wyoming province. MR, Madison Range; RR, Ruby Range; TN, Teton Range; TR, Tobacco Root Mountains; HM, Highland Mountains (taken from HOFFMAN, 1989; square inlet represents approximately the area shown on the TM false colour satellite image on the title page).

rocks extend westward beneath the Snake River Plain in south-central Idaho and into the Great Basin as far as northeastern Nevada (HOFFMAN, 1989).

Comparing to other Archean provinces of North America, e.g. the Superior province, the Wyoming

province differs in having abundant shelf-type metasedimentary rocks (MMT = Montana Metasedimentary Terrane) and isotopic evidence for widespread continental crust older than 3.1 Ga. Besides these crust-formation ages, it is not yet clear whether the province has been coherent since that time or represents a tectonic collage assembled about 2.9 to 2.6 Ga. A northeasterly trending mylonite zone which crosses the southern Madison and northwestern Beartooth Ranges is also postulated to be a Late Archean suture zone based on obvious lithologic contrasts between the adjacent crustal blocks (HOFFMAN, 1989), though MOGK, et al. (1992) negated terrane boundary interpretations.

The ancient crust is predominately represented by more or less retrogressed upper amphibolite- to granulite-grade, around 2.9- to 2.7-Ga complexly deformed quartzo-feldspathic gneisses, hornblende-biotite-garnet gneisses, and amphibolites, with lesser amounts of quartzites, meta-ultramafic rocks, dolomitic marbles, and iron-formations. In contrast to shelf-facies metasediments of the MMT, protoliths of metamorphic belts in central Wyoming comprise subaqueous basalt, greywacke-pelite, and subordinate intermediate to felsic volcanics. Earlier separations of metamorphic rocks into Pony and Cherry Creek Series are not necessary, for they have similar mineralogy and ages (HOFFMAN, 1989).

They are intruded by relatively undeformed 2.7- to 2.6-Ga granite-granodiorite batholiths, which are broadly coeval in age with the Stillwater layered mafic intrusion (2.71 Ga) in Montana and other Kenoran orogenies.

The basement rocks are cut by a swarm of northwest-trending tholeiitic dikes ranging from few meters to 30 m in diameter. Three sets of mafic dikes have been identified by WOODEN, et al. (1978). These mafic dikes range in age from 1.4 Ga to 1.1 Ga and their $^{87}Sr/^{86}Sr$ ratios range from 0.702 to 0.703 which indicate a probable derivation from mantle material. This could be presumably related to the opening of the Middle Proterozoic Belt Basin which is located further to the northwest.

Numerous concordant and discordant cm- to dm-sized pegmatite bodies and dikes are found within the Archean metamorphic rocks though with uncertain ages. The discordant character of many pegmatites favors an emplacement after the main deformation in Archean times. The appearance of pegmatite cobbles in basal conglomerates of the Mid-Proterozoic Belt-Supergroup reveals, that some pegmatites are of Archean age (VITALIANO, et al., 1979). COLE (1983) did $^{40}K/^{40}Ar$ radiometric age-dating on biotites from a pegmatite dike in the U.S. Grant mine which revealed an age of 1572 +/- 51 Ma. WIER (1982) reports that the pegmatite dikes are approximately 1.9 Ga old. Many pegmatites, which do occur within and close to the Tobacco Root Batholith indicate according to KELLOGG (1994) that they could have been emplaced in Late Cretaceous time for they seem to be associated with aplites.

Archean rocks of Wyoming province, along with surrounding Proterozoic rocks, were deeply eroded prior to the Cambrian period and acted as continental basement, upon which Paleozoic and Mesozoic strata were unconformably deposited.

Discordant Laramide Late Cretaceous- to Early Tertiary-aged calc-alcaline intrusions, e.g. the 77-72 Ma quartz monzonite Tobacco Root Batholith, are associated with or led to domal uplifts of their surroundings. The Tobacco Root Batholith is thought to be genetically related to the Boulder Batholith located 22 km to the northwest. This interpretation is supported by low $^{87}Sr/^{86}Sr$ values (indicative of a lower-crust or upper-mantle magma origin) for the Boulder Batholith as well as for the Tobacco Root Batholith (VITALIANO, et al., 1980). The VCMD is located in the southern part of such an northwest-plunging domal uplift, the Tobacco Root mountains. Scattered throughout the Archean pre-Belt and Proterozoic Belt rocks are numerous smaller plutons similar in age and composition to the Tobacco Root Batholith. Numerous base- and precious-metal deposits are associated with these igneous bodies (e.g. Butte, Montana, lies within the Boulder Batholith).

Tertiary extensional tectonics overprinted intense Laramide contraction which had led to the formation of ranges. In the basins, Tertiary inland lake sediments and conglomerates were deposited. These unconsolidated and poorly consolidated sediments were accompanied by volcanic and volcaniclastic rocks. MARVIN and DOBSON (1979) reported a whole rock $^{40}K/^{40}Ar$ age from volcanics in the area of Virginia City to be 51.1 +/- 1.2 Ma (e.g. Middle Eocene).

3. GEOLOGY AND PETROLOGY OF THE VCMD

3.1. Previous work

Despite the important relationship of the host rocks and the well known mineralizations and a long ongoing mining history in the VCMD (over 130 years) little detailed work on the geology of this famous precious metal mining district has been done. Therefore a complete and unified map of the area for use as a base for detailed further studies has not been available. The Tobacco Root Mountains and adjacent areas to the east of the VCMD were mapped first by PEALE (1896). Brief descriptions of the general geology and production numbers of

various mines of the Tobacco Root region and the VCMD can be found in the papers of DOUGLASS (1905), WINCHELL (1914), and LORAIN (1937). The southern part of the district was mapped by HADLEY (1969). A preliminary bedrock map of the northern part of the district was published by WIER (1982). VITALIANO, et al. (1979) mapped the southern Tobacco Root Mountains, located north of the mining district (see fig. 5). M.Sc. studies on the VCMD are represented by thesis' of COLE (1983) and LOCKWOOD (1990), who studied vein mineralogy in the U.S. Grant and Easton/Pacific mines, respectively. Recently, the USGS (KELLOGG, 1992-1996) mapped parts of the Madison Range east of the study area. In definition of the map units, this study is broadly oriented at this work. Two consulting geologists (STEININGER, 1997; HENRICKSEN, 1997) presented in their reports for Hanover Gold compilations on the results of previous exploration and mining activities prior to the engagement of Hanover Gold in this area.

Hanover Gold mapped their property, about 54 km^2, in detail at a 1:6,000 scale in the summer of 1997, flew an airborne geophysical survey over 105 km^2 the same year and explored extensions of the proven or known mineralized structures in 1998 and 1999.

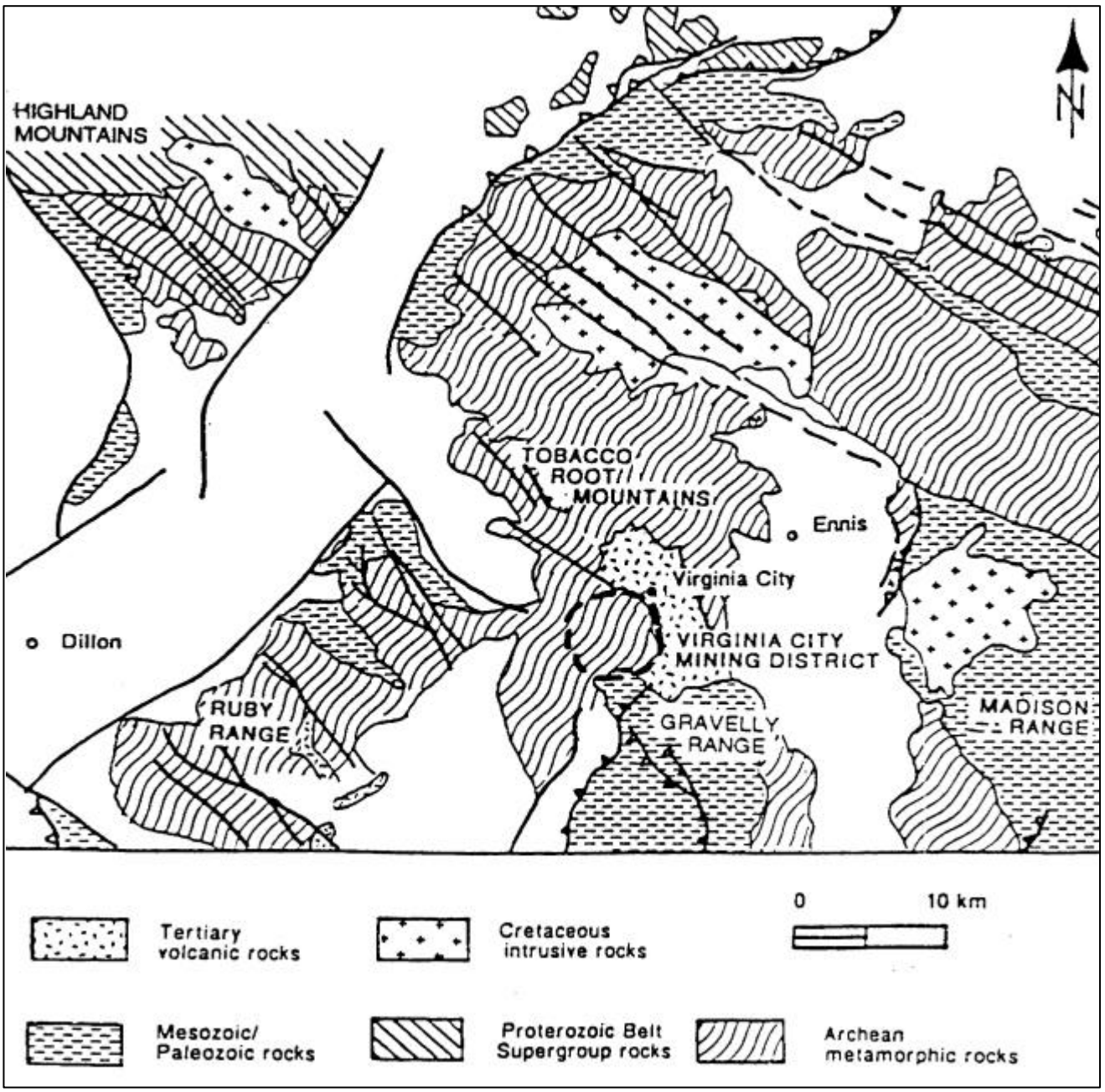


Fig. 5: Sketch map showing general geology of the Tobacco Root Mountains and adjacent areas (taken from SCHMIDT, et al., 1986).

3.2. Lithostratigraphy in the VCMD

Preface

The description of map units used in this work follows broadly USGS-mapping by KELLOGG (1992-1996) within adjacent Archean uplifted blocks using main characteristics in hand specimen, like grain size, colour, approximate modal composition, fabric, weathering, and typical outcrops. Details, like grain contact relationships, and accessories are described as seen in thin sections. Moreover, results from re-logging of 137 RC-chipsamples and six H-size cores are incorporated, too (see appendices 1, 2, and 3).

Thickness' for all below described Archean units are unknown as well as their stratigraphic order for metamorphism has transposed all primary structures and textures. Thus Archean rock units are described in the order of abundance and not necessarily in stratigraphic sequence. The following definition of grain sizes was used in this thesis:

fine grained	< 1 mm
medium grained	1 – 6 mm
coarse grained	6 – 20 mm
very coarse grained	20 – 60 mm
"mega" grained	> 60 mm

Description of mapping units

PRECAMBRIAN

ARCHEAN

The following units, Agg, Aggm, and Atg, generally correspond to "quartzo-feldspathic gneisses" of VITALIANO, et al. (1979), HADLEY (1969), and WIER (1982). Although the igneous rock names follow STRECKEISEN (1976), they do not necessarily imply an igneous, exactly plutonic origin.

"granitic" gneiss without magnetite (Agg)

This unit encompasses white to pinkish-white, leucocratic, fine- to medium-grained, inequigranular, granoblastic, weakly to moderately foliated (mm- to cm-scale) gneisses of granitic composition showing typical light-brown (tan, maroon) weathering. They usually contain about 30-45% perthitic and anhedral K-spar (microcline), 25-30% semihedral plagioclase (A_{10-20}, oligoclase), 25-35% quartz (anhedral, partly undulatory, serrated grain margins), 0-5% semihedral biotite, and 0-5% euhedral almandine garnet porphyroblasts (red, mm-size; smaller than in Atg, poikiloblastic with inclusions of quartz). Accessory minerals are mainly zircon and titanite. Sillimanite or staurolite could not be found in thin sections as other authors suggested for their gneisses, for example GARIHAN (1979) in the nearby Ruby Range. Secondary sericite on plagioclase, and partly alteration of biotite and garnet to chlorite is observable in thin sections.

The texture is commonly migmatitic (striatic texture after MEHNERT, 1968) with up to 20% of usually coarser grained leucosome (thus less than in Atg) consisting of K-spar, quartz, and plagioclase. Partly foam texture has been observed in thin sections. The universally conformable nature of its contacts with enclosing units is supported by observations of concordant Aam-lenses (cm-dm in diameter) within this unit though many of them are too small or discontinuous to be mapped separately. This unit makes up approximately 20% of the mapped area and may include minor amounts of all other Archean units (especially Aam) except dolomitic marble. Typical outcrops can be seen in road cuts on both sides of the Spring Gulch (outcrops 294-297 and 49, 55).

magnetic "granitic" gneiss (Aggm)

This unit is the same as described previously in the Agg section. It was mapped separately where the majority of outcrop or float revealed considerable magnetite which gave high enough susceptibility to be measured in the field by a magnetic pen. Magnetite content usually ranges from <1% to 2-3%, with a maximum of 5%. Separating this unit is reasonable due to the observation that altered magnetic rocks of granitic modal composition show no susceptibility in the vicinity of quartz veins but do often show wide areas of iron oxide staining on joints. Moreover geophysical observations of high magnetic susceptibility are closely related to outcrops of "granitic" gneisses with magnetite. This map unit is the most widespread and makes up approximately 40% of the mapped area. Typical outcrops can bee seen north of the Bachelor Gulch (outcrops 231-241).

"tonalitic" gneiss (Atg)

This unit encompasses light gray, fine- to medium-grained, inequigranular, moderately to strongly foliated (mm- to cm-scale compositionally layered) "tonalitic" gneiss, which may include some "trondhejmitic" and "granodioritic" gneisses. Though it does not develop banding continuously, it could be named "biotite gneiss" either, similar to the "banded biotite gneiss" mapped in the Bear Trap Creek to the east in the nearby Madison Range (KELLOGG, 1995) and to "gray gneisses" that are

common in Archean high-grade terranes (WINDLEY and BRIDGWATER, 1971). These gneisses show well developed gneissic or migmatitic banding. They are often injected lit-par-lit by stringers of granitic composition. The stringers locally transgress banding of the gneisses.

It typically contains 30-50% semihedral plagioclase (averages An_{20-35}, oligoclase or andesine, partly sericitized), 20-30% undulose anhedral quartz with serrated grain margins, 10-15% semihedral biotite (partly deformed; commonly, though not extensively, retrogressed to chlorite), 10-20% K-spar (microcline), 0-5% hornblende, euhedral almandine garnet porphyroblasts (red, mm-3cm-size, especially in leucosomes, partly chloritized), and traces of zircon and opaque minerals. Cordierite is rare and associated with garnet.

Distinction between K-spar and plagioclase in the field was based on the light flesh-colour of K-spars, (contrasting to strong reddish K-spars from alteration), and usually white to yellowish colour of plagioclases in hand specimen. Thin section investigations revealed comparable results, indicating slightly more K-spar (microcline) than estimated in the field. Thus some of the previously defined "tonalitic" gneisses can be described as "granodioritic" in modal composition.

The Atg unit grades into hornblende-plagioclase gneisses when carrying hornblende. It is commonly migmatitic (striatic leucosomes (after MEHNERT, 1968) up to 30% of outcrop which have granitic compositions, are medium-grained and equigranular). The major S-surface is developed by subparallel orientation of biotite bands and quartz-feldspar bands. Locally it develops „Augen"-texture of single K-spars without resembling Augen gneisses at outcrop scale. This unit may include minor amounts of all other Archean units especially Aam with which it occurs interlayered. The contacts are usually gradational.

On the western side of Alder Gulch (study area of M. Karg) remnants of numerous and extended dolomitic marble and iron-formations can be traced over several hundred meters and can therefore be used as marker horizons for deformation. The Atg unit makes up approximately 30% of the mapped area. Typical outcrops are 379, 380.

hornblende-plagioclase gneiss and amphibolite (Aam)

This unit encompasses medium-gray to black, medium-grained, equigranular, moderately foliated to well foliated (mm- to cm-scale) hornblende-plagioclase gneiss and amphibolite (amphibolite contains more than 50% hornblende).

Compositional varieties range from hornblende gneisses, with 40-50% black hornblende in alternating hornblende-rich and quartz-plagioclase-rich layers which are a few millimeters thick, to amphibolites (e.g. hornblendites), where plagioclase and quartz are accessory minerals. This unit usually contains 20-40% plagioclase (An_{25-45}, andesine-labradorite), 5-10% quartz, 0-10% partly deformed biotite, and is usually garnetiferous with highly variable amounts (red, rarely pink, see appendix 3; garnets are up to 3 cm in size; euhedral and poikiloblastic with quartz and plagioclase inclusions). Accessories are opaque minerals and secondary sericite and chlorite.

Hornblende gneisses and amphibolites usually represent small discontinuous lenses which pinch out especially within "granitic" gneisses. It is commonly migmatitic (nebulitic and striatic leucosomes after MEHNERT, 1968) consisting of plagioclase and quartz leucogneiss bands as thick as 10 cm). This unit may occur in and include minor amounts of other Archean units especially "tonalitic" gneiss with which it occurs interlayered. Thickness' of the lenses vary from about dm-size up to several tens of meters. This unit makes up approximately 5% of the mapped area. Typical outcrops are 16 and 24.

meta-ultramafic rocks (Aum)

This unit contains black, fine- to medium-grained, and massive ultramafic rocks. Two samples consist almost entirely (approximately 90%) of semihedral, colorless orthopyroxene (indicating enstatite) and greenish spinel in wedges. They can be named orthopyroxenites. Surprisingly, this two samples are completely unserpentinized and show no magnetite.

Foam-texture indicates an intrusive origin, although no metasomatic contact effects have been observed around the two ultramafic elongated lenses which are found within the tonalitic gneiss in the field. They are less than about 10-30 m in diameter tending to parallel regional foliation and reach approximately 300-500 m in this direction. This unit underlies less than 1% of the mapped area and is especially exposed north of Spring Gulch in outcrops 108 and 18.

PROTEROZOIC

Pegmatite (Peg)

Numerous concordant and discordant, white to pink colored, coarse grained to very coarse grained, mainly massive (simple) to rarely complex, and unfoliated dikes and sills (showing graphic textures)

with sharp, discordant boundaries lie within the Archean metamorphic rocks. Their composition is mainly K-spar, quartz, plagioclase, and biotite. No enrichment in tourmaline or other rare minerals could be observed, thus they should be considered to be mobilized pegmatites. They occur as lenses, streaks, and tabular bodies rarely larger than 10 m in diameter, more often they are at cm- to dm-scale. Therefore, pegmatites were not mapped separately.

The age of the pegmatites is uncertain. The discordant character of many pegmatites favors an emplacement after the main deformation in Archean times. The appearance of pegmatite cobbles in basal conglomerates of the mid-Proterozoic Belt-Supergroup reveals, that some pegmatites are of Archean age (VITALIANO, et al., 1979). COLE (1983) did $^{40}K/^{40}Ar$ radiometric age-dating on biotites from a pegmatite dike in the U.S. Grant mine which revealed an age of 1572 +/- 51 Ma. WIER (1982) reports the pegmatite dikes to be approximately 1.9 Ga old. Pegmatites and aplites could be the result of local partial melting of quartzo-feldspathic rocks and unprobably by intrusion. On the other hand, many pegmatites, which do occur in and close to the Tobacco Root Batholith indicate after KELLOGG (1994) that they could have been emplaced in Late Cretaceous time for they seem to be associated with aplites, whereas the Precambrian dikes and sills probably not.

PHANEROZOIC

CENOZOIC

Tertiary

Eocene tephritic dikes (Tv)

Two black, dark brown weathered, very fine-grained (aphanitic), dense and vesicular tephritic dikes cross-cutting Archean and Proterozoic rocks occur northeast of the Kearsarge mine. They are undeformed, near vertical, strike approximately SE-NW (along ac-joints within the Archean metamorphic rocks), and have well-defined chill margins.

The dikes are composed primarily of long semihedral plagioclase blades (An_{40-50}, andesine or labradorite), euhedral olivine and pyroxene (augite). Opaque minerals are mainly euhedral magnetite and ilmenite (blades). Generally, high weathering of the dikes to chlorite and sericite in irregular aggregates restricted obtaining more detailed information on composition, texture and accessories.

These dikes can best be seen in outcrops 90 and 264. This unit underlies less than 1% of the mapped area. They could be interpreted as feeder dikes for the basaltic plateau developed east of Virginia City. An andesite plug dated at 51.1 +/- 1.2 Ma (whole rock $^{40}K/^{40}Ar$ date by MARVIN and DOBSON, 1979) cuts the El Fleeda vein system in the northern part of the district about 1.5 km south of Virginia City.

Quaternary

Pleistocene moraine (Qm)

Unconsolidated glacial debris in the form of terminal and lateral moraines is exposed only at the head of the Bachelor Gulch. The components are typically weakly rounded and very poorly sorted. The moraines typically fill the valley of the Bachelor Creek with large blocks up to 3 m in diameter which consist of Tertiary basalt and Paleozoic limestones within Archean metamorphic rocks. It could be interpreted as a Quaternary terrace for it lies approximately 15 m above the present stream level. Upstream the mapped moraine and at the foot of Baldy Mountain in the south of the district, outside of the mapped area, much larger Quaternary moraines which have been driven by mountain glaciations can be seen. This unit underlies less than 1% of the mapped area.

Holocene alluvium (Qal)

Alluvium in the mapped part of the VCMD is moderately sorted to well sorted, moderately rounded to well-rounded pebble to boulder gravel in a sand or silt matrix. This includes small alluvial fans. The components are usually gneiss and limestone cobbles though due to dredging operations in the Alder Gulch, alluvium there is very much disturbed. Maximum thickness could reach probably more than 10 m. This unit makes up 1-2% of the mapped area.

3.3. Conclusions of mapping results

In order to obtain reliable information concerning bedrock geology in areas with no or little outcrops and to support mapping, relogging of 137 RC-chipsamples (reversed current), which Hanover Gold drilled in 1998, has been done. Methodically it has been drilled until hard rock has been reached and continued to sample 5 feet. The spacing between two drillholes has been 20 feet. The size of the chips ranges from few millimeters to 1 cm. For complete results see appendix 2. Figure 6 (next page) summarizes estimated modal compositions of hornblende-free gneisses in the VCMD as seen in outcrops plotted together with results from RC-chipsamples, core relogging and modal analyses observed in thin

sections into the QAP-diagram for plutonic rocks (after STRECKEISEN, 1976).

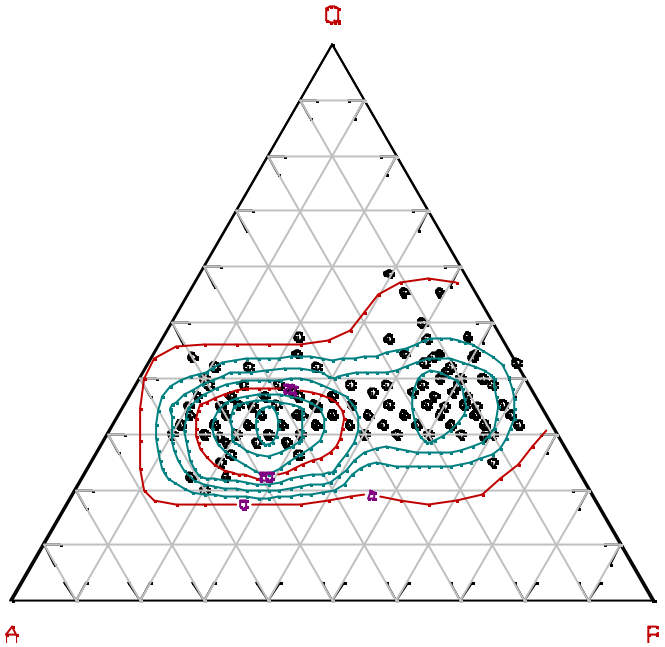


Fig. 6: Estimated modal compositions of hornblende-free gneisses in the Lucas/Atlas and South Bachelor areas, VCMD (QAP-diagram following STRECKEISEN, 1976; 747 samples, contour intervals represent 0%, 5%, 10%, 15%, 20% 25%, 30% and 35%).

Minimum and maximum estimates of modal compositions in outcrops, RC-chipsamples, core re-logging, and thin sections were taken and plotted as samples. Therefore the total number of plotted samples is higher than the total number of described outcrops, RC-chipsamples and thin sections altogether.

Hornblende-free gneisses are typically granitic and granodioritic to tonalitic in composition, which supports the definition of main units. For leucosomes are typically granitic in composition in both units, the contact in between "granitic" and "tonalitic" gneisses appears to be transitional.

Problems occur where the mapped units are of small thickness', e.g. 10-20 m. Further problems exist in the description of the units. "Tonalitic" gneiss (Atg) with a lot of leucosome resembles "granitic" gneiss (Agg) in chip samples. The difference in between Agg and Aggm is the magnetite content and is therefore not exactly reconstructable within chip samples. Variations in modal compositions in RC-chipsamples result from uncertainties in estimating the content and from summaries of several samples into units which were defined as mapable units. Therefore estimates of modal composition in RC-chipsamples are more speculative than in outcrops. Variations in modal content estimated in outcrops symbolize more variability of the rock unit. Thus the STRECKEISEN-diagram shows firstly uncertainties and secondly variability from outcrop to outcrop, but variability within one outcrop, too.

Another problem is the widespread and pervasive K-spar alteration. Thus the K-spar content may be overestimated, e.g. some K-spar belongs to the alteration and is not primarily. A distinction in between those two K-spars were not made in the estimate, but usually the secondary K-spar from the alteration is markedly different through its strong red color due to a higher iron (hematite) content. The author attempted to abstract K-spar on joints and the strong reddish color of the second, alteration-derived K-spar.

The mapped area encompasses about 5.5 km^2. Less than 3% of it is exposed in outcrops. In the western part of the mapped area the interlayering of the Atg and Aam units becomes more intense which makes it difficult to map them in detail, especially in areas with no exposure and a great amount of float in steep mountains. Besides few outcrops, grass cover or heavy timbering prevented obtaining detailed structural data.

3.4. Geochemical characterization

In this section, analytical results are presented for each of the host rock suites (complete results can be seen in appendix 5). Main element geochemistry in the Lucas/Atlas and South Bachelor areas, VCMD, is summarized in the spider diagram in figure 7 (next page).

Geochemically, "granitic" gneisses with or without magnetite do not differ very much and are characterized by SiO_2 contents ranging from 74-77 wt.-%, Al_2O_3 contents ranging from 10-12 wt.-%, and Fe_2O_3 contents ranging from 2.6-3.6 wt.-%. The MnO contents are about 0.3 wt.-%, while MgO shows a wide variation from 0.07-0.38 wt.-% in "granitic" gneisses. CaO contents show distinct compositional ranges (0.3-0.9 wt.-%) while Na_2O and K_2O values remain almost constant (around 3 wt.-%, and 5 wt.-%, respectively). TiO_2 and P_2O_5 values exhibit virtually no variation and are about 0.3 wt.-%, and 0.05 wt.-%, respectively. "Granitic" gneisses are further characterized by K_2O/Na_2O ratios which are always greater than 1.

"Tonalitic" gneisses are typically higher in Al_2O_3 content than the "granitic" gneisses and range from 10-15 wt.-%, while SiO_2 contents vary from 69-77 wt.-%. More variation is represented by P_2O_5 values, which range 0.01-0.17 wt.-%, Fe_2O_3 values which range from 1.2-5.2 wt.-%, and MgO values, which range from 0.18-2.27 wt.-%, whereas MnO, CaO, Na_2O, K_2O, and TiO_2 contents show only little variation (around 0.3, 1.0, 3.0, and 0.3 wt.-%, respectively). Compared to "granitic" gneisses, the "tonalitic" gneisses differ additionally in having greater concentrations of MgO and slightly more CaO (see

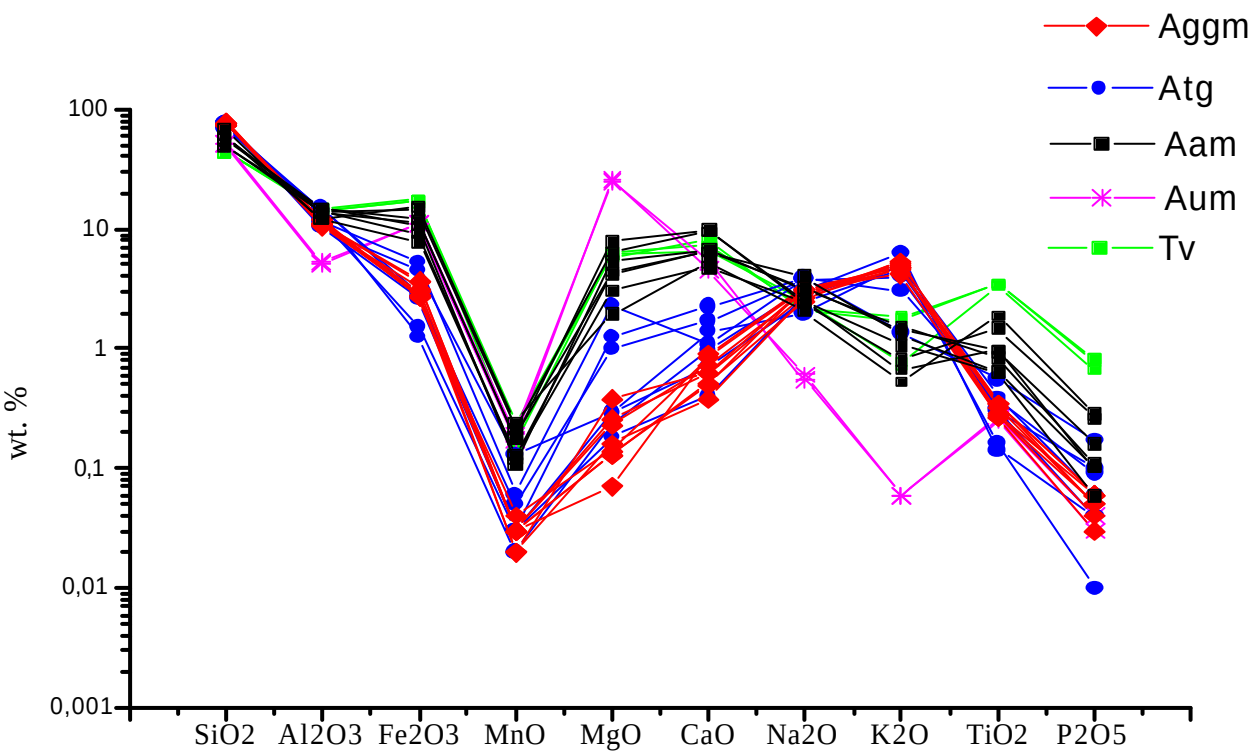
fig. 7). The K_2O/Na_2O ratio is not that much persistent like in "granitic" gneisses and a wide range of K_2O/Na_2O ratios from 0.3 to 2.4 occur. This is broadly consistent with the more "granodioritic" nature of the named "tonalitic" gneiss unit and could partly be explained by the high "granitic" leucosome content of the migmatitic "tonalitic" gneisses.

Hornblende-plagioclase gneisses and amphibolites in the Lucas/Atlas and South Bachelor areas contain 49-67 wt.-% SiO_2, which is broadly representative of basaltic to andesitic compositions, although the lower limit would represent ultramafic compositions. Low concentrations of MgO, chromium and nickel in these samples, which are usually indicative of ultramafic rocks, and similarities in main element concentrations allow subsumation to other rocks of this unit. Moreover, this classification is supported by similar textures. Main elements are broadly in same range and do not show large variations. Al_2O_3 contents are similar to "tonalitic" gneisses ranging from 12-15 wt.-%. Slightly higher variations are found for Fe_2O_3 (7-15 wt.-%). MnO, Na_2O, K_2O, and TiO_2 values do not show high variation (around 0.2, 3.0, 1.0, and 1.0 wt.-%, respectively), whereas MgO, CaO, and P_2O_5 show wider ranges of concentrations (2-8, 5-10, and 0.1-0.3 wt.-%, respectively). K_2O/Na_2O ratios are always lower than 1 and generally around 0.3.

Fig. 7: Spider diagram for main element geochemistry of all unaltered host rock suites within the Lucas/Atlas and South Bachelor areas, VCMD, southwestern Montana.

Only two samples of ultramafic rocks from two outcrops have been analysed. Thus, it is not possible to determine variations within this unit. These rocks are poor in SiO_2 (around 51 wt.-%), and even Al_2O_3 contents are markedly low (5 wt.-%), whereas MgO contents are exceptionally high (around 25 wt.-%). Fe_2O_3 contents are around 11 wt.-%. CaO contents around 5 wt.-% indicate that there could be clinopyroxene within these rocks, though it was not observed in thin sections. Possibly these CaO contents are partly present as solid-solution in pigeonite. The values for MnO, Na_2O, K_2O, TiO_2, and P_2O_5 (around 0.2, 0.6, 0.06, 0.27, and 0.04 wt.-%, respectively) are generally the lowest of all rock suites.

Three samples of volcanic dikes with SiO_2 contents around 43 wt.-% and combined K_2O+Na_2O values around 4 wt.-% represent tephritic compositions. Al_2O_3 contents are in the range of "tonalitic" gneisses and amphibolites (around 14 wt.-%) and MgO and MnO are only slightly higher (around 6.0 and 0.2 wt.-%), whereas Fe_2O_3, CaO, TiO_2, and P_2O_5 contents are the highest of the country rocks (around 17, 7.2, 3.3, and 0.8 wt.-%, respectively). P_2O_5 could have been fixed in apatite, which, due to high weathering of the samples, could not be observed. High TiO_2 contents are supported by the observation of ilmenite. It should be noted that these volcanic rocks are the only country rocks which carry sulfides in detectable amounts (0.02-0.2 wt.-%).



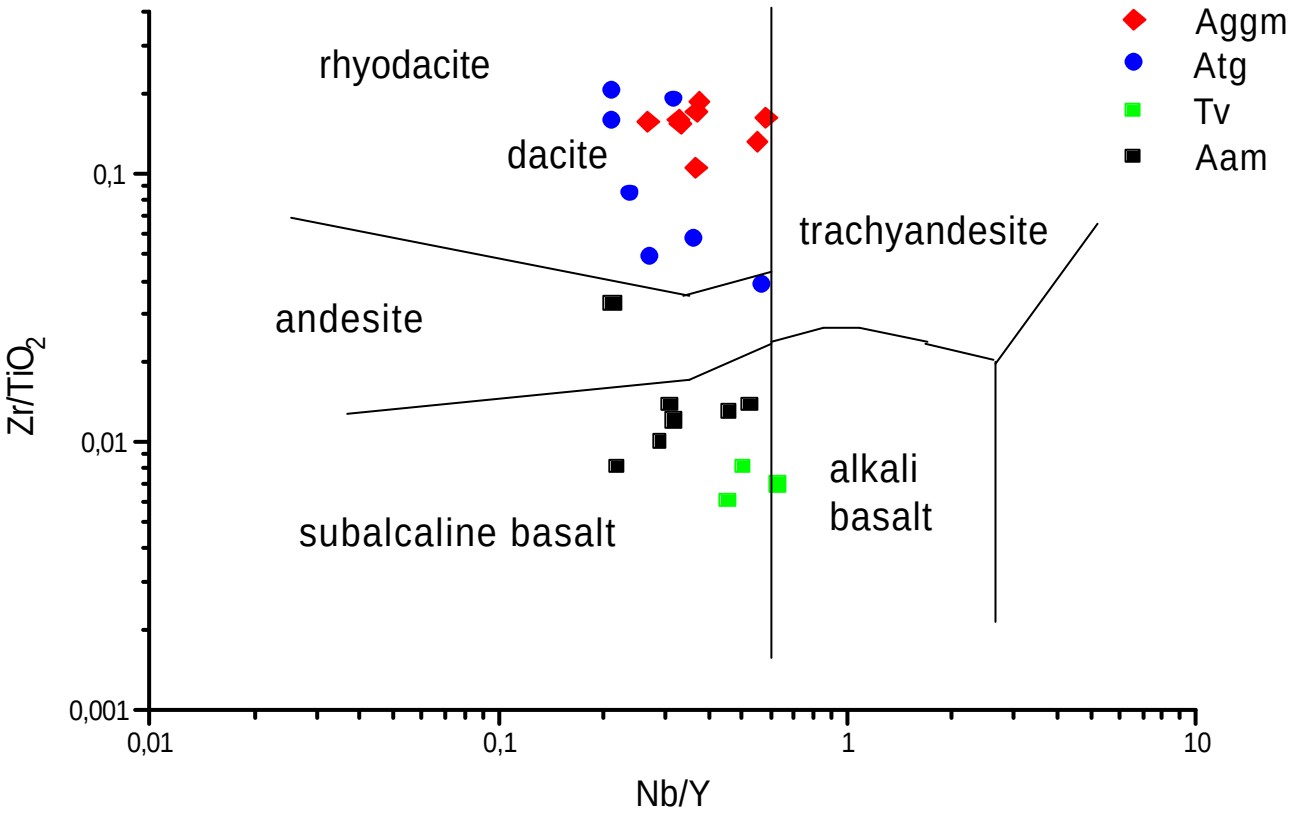
Concerning trace element geochemistry of host rocks in the Lucas/Atlas and South Bachelor areas, it should be mentioned, that the samples have been milled in a tungsten carbide disk mill. Therefore, tungsten, cobalt and tantalum values should not be considered as critical for discussion. Especially remarkable high chromium and nickel values can be found within the ultramafic rock suite (3600 and 700 ppm, respectively) which can be linked to spinel. All hornblende-free gneisses carry elevated barium values (around 500-2000 ppm). Tertiary volcanic rocks have higher vanadium contents (300-350 ppm) which is similar to some of the amphibolites and hornblende-plagioclase gneisses.

3.5. Geochemical classification

Under medium to high grades of metamorphism involving hydrous fluids some degree of selective element mobility is to be expected especially for the large-ion-lithophile (LIL) elements (THOMPSON, 1991). Thus characterization and discrimination of host rocks into different suites as well as assignment to particular environmental settings has been done on the basis of trace elements which are considered relatively stable during alteration such as the high field strength group (HFS). Therefore the Nb/Y versus Zr/TiO_2 geochemical classification diagram of WINCHESTER and FLOYD (1977) has been preferred.

Hornblende-free country rocks in the Lucas/Atlas and South Bachelor areas plot, with one exception, into the rhyodacite and dacite field of the diagram of WINCHESTER and FLOYD (1977, see fig. 8) and reflect calc-alcaline trends in the AFM diagram of IRVINE and BARAGAR (1971, see fig. 9, next page). Most hornblende-plagioclase gneisses and amphibolites represent geochemically metamorphosed subalcaline basalts, beside one sample which is plotting into the andesite field. In the AFM diagram of IRVINE and BARAGAR (1971) amphibolites in the VCMD show both calc-alcaline and tholeiitic types, although tholeiitic types dominate. Tertiary volcanic rocks could be considered subalcaline to alkali basalt, and in the AFM diagram of IRVINE and BARAGAR (1971) all three samples of volcanic dikes plot into the tholeiitic field. In the AFM diagram, ultramafic rocks trend to komatiites.

Fig. 8: Zr/TiO_2 versus Nb/Y diagram of WINCHESTER and FLOYD (1977) used for geochemical classification of all country rock suites in the Lucas/Atlas and South Bachelor areas, VCMD, southwestern Montana.



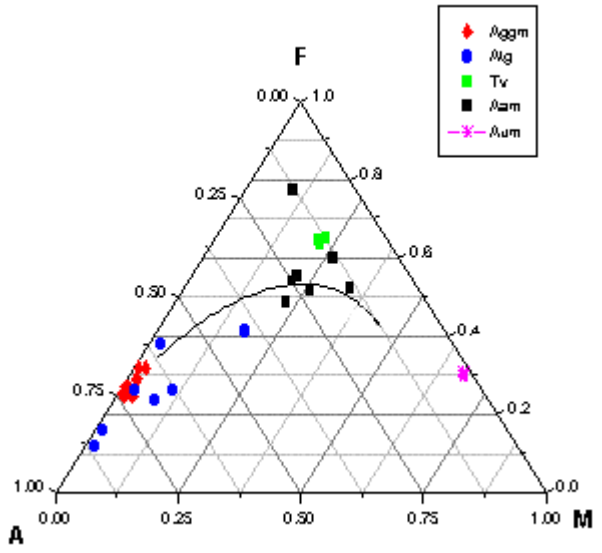


Fig. 9: AFM-diagram after IRVINE and BARAGAR (1971) for country rocks in the Lucas/Atlas and South Bachelor areas, VCMD.

Fig. 10: Geochemical discrimination diagram used to distinguish sedimentary from igneous rocks in the VCMD, southwest Montana (after GARRELS and MACKENZIE, 1971). Note the isochemical nature especially of the tonalitic gneisses.

3.6. Protolith and tectonic setting discrimination

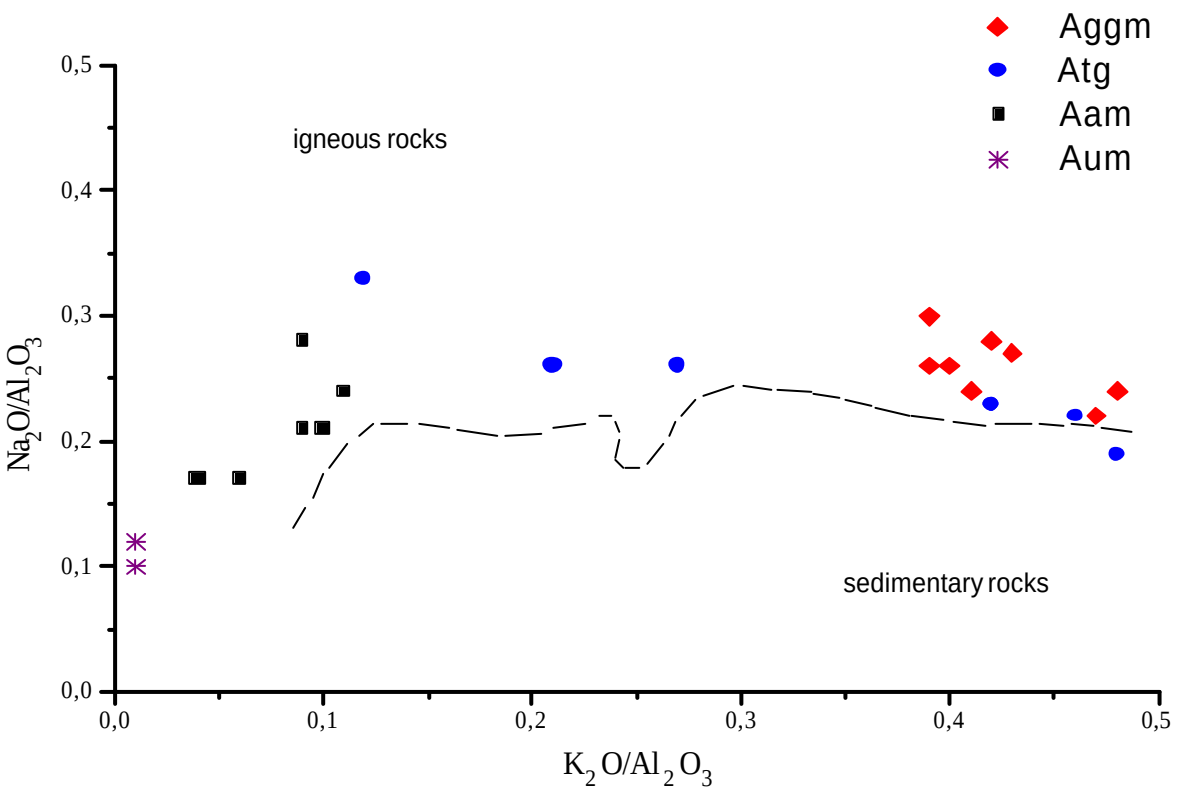
Using major- and trace element-geochemistry, an effort has been made to compare host rocks of the VCMD to modern rocks in order to determine protoliths and to understand their tectonic setting within the Wyoming Craton.

Protolith discrimination

The presence of marbles, metaquartzites and iron formations in the VCMD, especially to the west of the Alder Gulch (see M.Sc. thesis of M. Karg), clearly indicates a sedimentary origin for these rocks. Another indication for sedimentary protoliths has been mentioned by CORDUA (1973) who observed rounded zircon grains within quartzo-feldspathic gneisses in the southern Tobacco Root Mountains.

Using the geochemical discrimination diagram of GARRELS and MACKENZIE (1971) to distinguish sedimentary from igneous rocks, almost all samples plot into the igneous field (see fig. 10). One exception is represented by sample number 152, which is located close to the Alder Gulch.

This observation is supported by a second discrimination plot which is adapted from ROSER and KORSCH (1988, fig. 11, next page), who used



major elements to discriminate provenance signatures of sandstone-mudstone suites. The discriminant functions are:

discriminant function 1 = – 1.773 TiO_2 + 0.607 Al_2O_3 + 0.76 $Fe_2O_{3(total)}$ – 1.5 MgO + 0.616 CaO + 0.509 Na_2O – 1.224 K_2O – 9.09

discriminant function 2 = 0.445 TiO_2 + 0.07 Al_2O_3 – 0.25 $Fe_2O_{3(total)}$ – 1.142 MgO + 0.438 CaO + 1.475 Na_2O + 1.426 K_2O – 6.861

All hornblende-free gneisses plot in the field of felsic igneous provenance, beside one sample which shows quartzose sedimentary provenance. Thus hornblende-free gneisses most probably represent a mixture of extrusive igneous rocks which dominate the eastern part of the Alder Gulch.

Amphibolites and hornblende-plagioclase gneisses plot all with one exception into the mafic igneous provenance field, or the intermediate igneous provenance field. Therefore they possibly represent stratiform flows or layers of basaltic volcanic precursors, although VITALIANO, et al. (1979), mentioned that the nature of the hornblende-plagioclase gneisses, e.g. their concordant contacts, their gradational character, the frequent alternation with quartzo-feldspathic layers, and common association with marble suggest for some at least a sedimentary origin and initial composition of clay-rich dolomite.

Fig. 11: Discrimanant function diagram for the provenance signatures of sandstone-mudstone suites using major elements (after ROSER and KORSCH., 1988). Adapted for gneissic rocks and amphibolites of the Lucas/Atlas and South Bachelor areas, VCMD.

Arkose-shale sequences probably were the protoliths in the western part of the Alder Gulch (see M.Sc. thesis of M. Karg). Thus, the Alder Gulch might be interpreted as a major lithostratigraphic contact zone in between metasedimentary rocks to the west and metavolcanic bimodal rocks to the east.

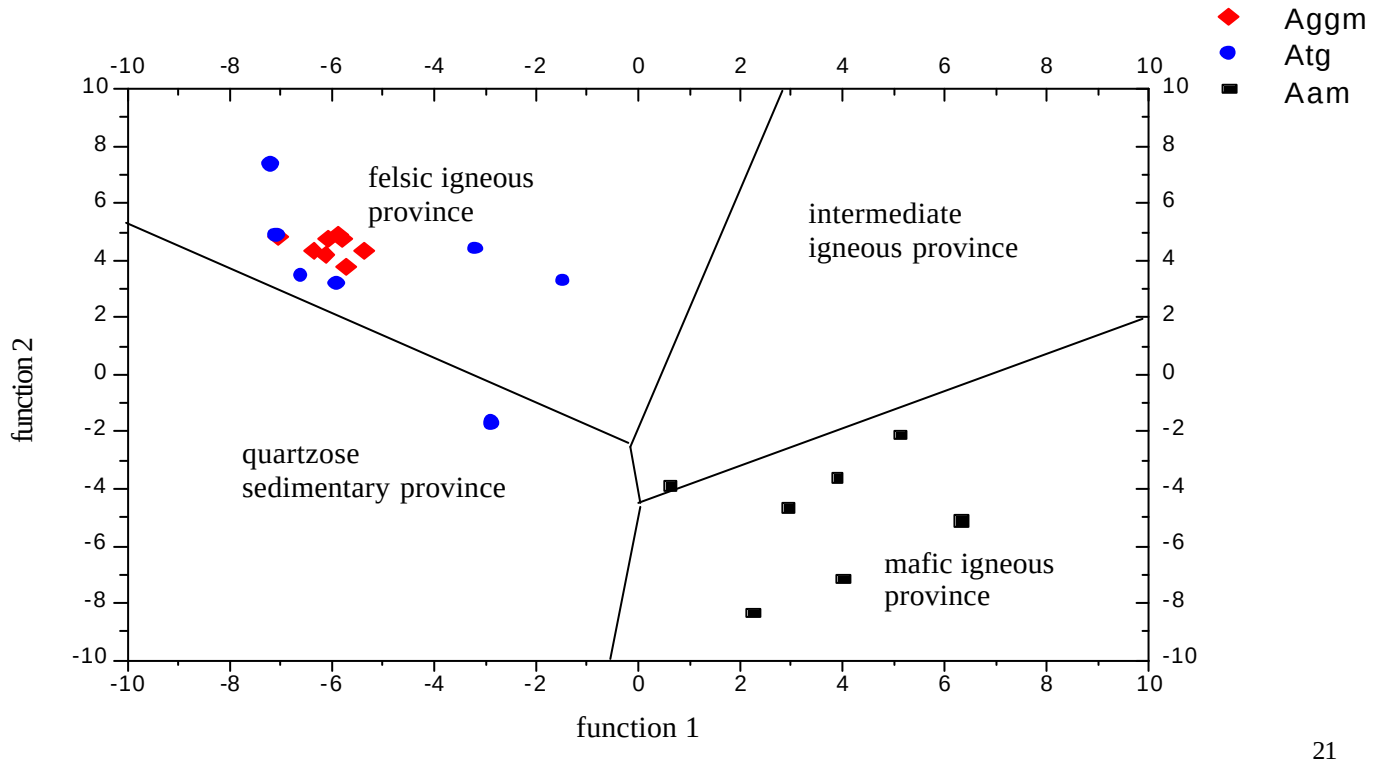
TENDALL (1978) investigated the origin of meta-ultramafic rocks and the nature of their protoliths in the Tobacco Root Mountains and developed three possible models for their origin:

a) tectonically emplaced slices of the upper mantle
b) refractory residues from partially melted solid upper mantle, and
c) cumulates of a differentiating melt.

The sharp contacts, the lack of evidence for migmatization, the nonlinear distribution of the meta-ultramafic bodies, and the strong domination of orthopyroxene appear to favor an origin from a deep-seated magma. The lack of visible layering can be attributed to destruction by internal deformation and recrystallization during diapiric uplift. For metasomatic effects around the ultramafic bodies are lacking, an emplacement as almost solid bodies could be assumed.

Tectonic setting discrimination

Despite the scattered outcrops of Archean Wyoming province, three separate Late Archean subprovinces have been proposed by MOGK, et al. (1992) for the Wyoming Craton. From southeast to northwest they are: Wyoming greenstone terrane,



Beartooth-Big Horn magmatic terrane (BBMT), and Montana Metasedimentary terrane (MMT), in which the VCMD lies. The boundary between the BBMT and MMT is constrained geographically to be within the southern Madison Range, where a broad, 3 km wide zone of mylonites occur.

Using the Y versus Nb granitoid discrimination diagram after PEARCE, et al. (1984) for hornblende-free gneisses of the Lucas Atlas and South Bachelor areas, it is obvious that they mostly represent rocks of volcanic arc and syn-collisional settings (see fig. 12), and five samples plot in the field of within plate granitoids.

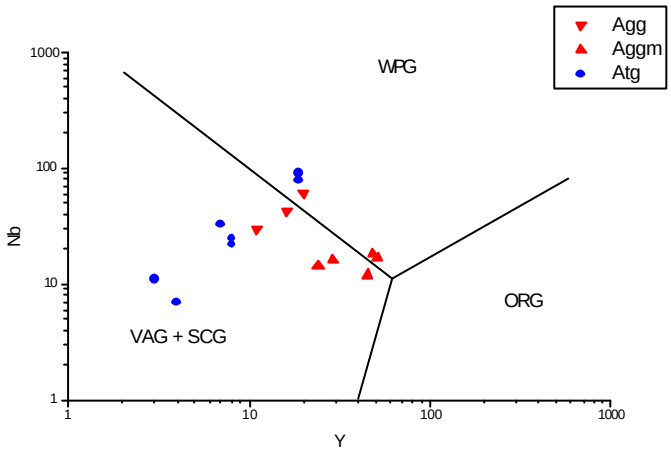


Fig. 12: Y versus Nb granitoid discrimination diagram after PEARCE, et al. (1984) for hornblende-free gneisses of the Lucas/Atlas area, VCMD, southwestern Montana. WPG = within plate granites, VAG = volcanic arc granites, SCG = syn-collision granites, ORG = ocean ridge granites.

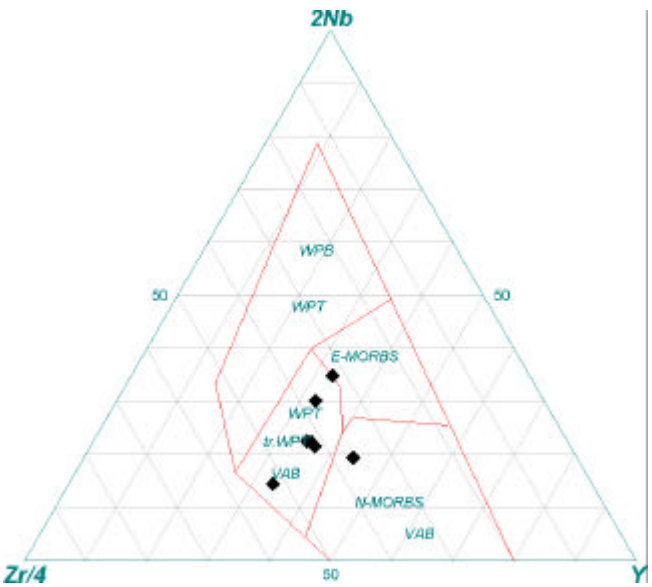


Fig. 13: Discrimination diagram of MESCHEDE (1986) for geodynamic setting of basaltic rocks. *WPB*: within plate basalt; *WPT*: within plate tholeiite; *VAB*: volcanic arc basalt; *E-MORBS*: E-type MORB; *N-MORB*: N-type MORB.

The tectonic setting after the diagram of MESCHEDE (1986) point to a within-plate setting of the hornblende-plagioclase gneisses and amphibolites in the VCMD with small possible incipient rifting (N-MORB and E-MORB associations (fig. 13).

These arguments support suggestions that separate Late Archean terranes or subprovinces exist within the northern Wyoming Craton. Based on chemical and isotopic data (in particular, similarities in age, Pb isotopic signatures, Sm-Nd and Sr systematics), MUELLER, et al. (1993) proposed that contrasts between subprovinces in the Wyoming Craton are not compatible with models involving far-traveled terranes. The alternative, that all presently recognized subprovinces of the Wyoming Craton initially evolved within a single crustal growth regime, implies that boundaries such as that between the MMT and BBMT possibly represent intracratonic reorganizations.

Classification and discrimination of the country rocks of the Lucas/Atlas and South Bachelor areas suggest that this suite of rocks possibly have been generated by subduction-like processes. Field observations, however, leave no doubt that the volcanics are intercalated with sedimentary rocks especially to the west of Alder Gulch. Therefore, they must have been deposited in the same volcanic arc tectonic setting and accreted by collosional though not far-travelled tectonics.

The northwestern Wyoming province can be considered as an interesting place to study Archean collosional tectonics which may have had partly more similarities with modern tectonics than previously assumed.

4. Structural and metamorphic chronology

This section deals with structural and metamorphic chronology which had been observable in the field. These observations are compared to other Archean uplifted blocks in southwestern Montana. The description of the tectonic setting in the mapped part of the district, folding and other deformational events would be interesting in order to elucidate the metamorphic history if there is a stratigraphic compound or structural relationship to mineralizations in the VCMD. However, the palinspastic reconstruction is limited due to high coverage, little exposure, and little significance of strongly uniform striatic foliation defined by compositional layering within the gneisses and amphibolites. Primary bedding planes have not been observed.

Structural data is measured using the 360° azimutal notation.

4.1. Deformational history

Chemically evolved continental crust in southwest Montana was established in the early to middle Archean, at least 3.5 Ga (MOGK, et al., 1992). Deposition of volcano-sedimentary rocks probably occurred in an environment similar to a modern magmatic arc. Deformation which accompanied the 2.9-2.7 Ga (Late Archean) metamorphism yielded tight isoclinal ("fish-hook") folds with axial plane foliation trending uniformly northeast (D1, fig. 14). Somewhat after this first deformational event but prior to 1.6 Ga, coaxial refolding of the pre-existing foliation produced northeast-striking and gently northeast and to a lesser amount southwest dipping upright open folds at m-dm-scale (D2, fig. 14, 15). Axial planes of the second fold phase are subvertical. At outcrop 50 (Spring Gulch), a very prominent open fold hinge (antiform) can be observed. This antiform is striking northeast and is dipping gently (20°) to the same direction. Measurements of several smaller fold hinges led to the observed picture, which reveals that both isoclinal and open folds strike and even dip in the same direction.

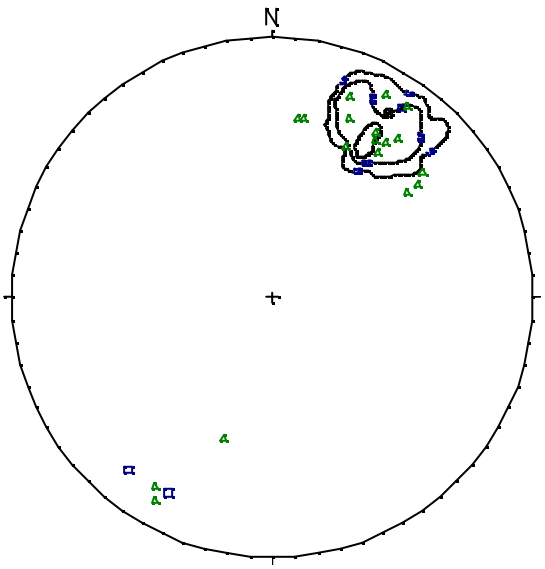


Fig. 14: Lower hemisphere, equal area projection of ductile structural lineation features in the Lucas/Atlas and South Bachelor areas, VCMD, southwestern Montana: fold axes of isoclinal (D1, squares) and open folds (D2, triangles); contour intervals: 1, 2, and 3%.

CORDUA (1973) supported assumptions that the second deformational event occurred at 1.9-1.6 Ga, as did $^{40}K/^{40}Ar$ measurements on pegmatites by COLE (1983), too. This event is recorded throughout southwestern Montana (GILETTI, 1966), and is suggested to be linked to Proterozoic E-W rifting of the Belt Basin in northwest America, especially Idaho and British Columbia.

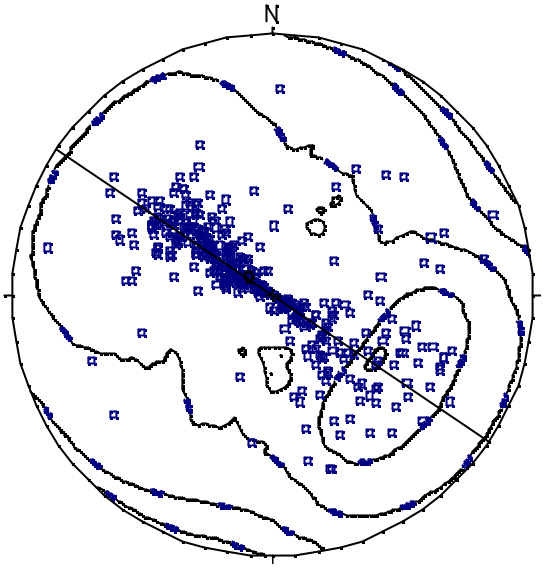


Fig. 15: Lower hemisphere, equal area projection of ductile structural features in the Lucas/Atlas and South Bachelor areas, VCMD, southwestern Montana: D2, planes of foliation (402 points) representing open folds, contour intervals 25%, and plotted great circle.

Detailed geometry of folding is still poorly defined in the VCMD because of the limited extent of outcrop in the southern portion of the district and the homogenous nature of quartzo-feldspathic gneiss, which makes up the majority of the country rock. On a small scale, folding does not appear to be a major factor in the localization of mineralization.

Paleomagnetic and geochronologic data of HARLAN, et al. (1997) indicate that a second swarm of northwest-trending mafic dikes, subparallel to the Middle Proterozoic dikes, which initiated rifting in the Belt basin, was emplaced at about 780 Ma. The dikes are part of a regional mafic magmatic event that affected the western margin of Proterozoic North America. These mafic dikes and sills are part of a regional extensional event that affected the western part of the Laurentian Craton at about 780 Ma. This magmatism may record an early stage of the breakup of the supercontinent Rodinia (HARLAN, et al. 1997).

Opening of the Iapetus ocean (the so called "Proto-Atlantic") at the eastern margin of North America during Late Proterozoic (Sinium time after SCHÖNENBERG and NEUGEBAUER, 1987) may have initiated subduction processes at the western margin of the North American Craton and thus led to first uplifts of Archean metasedimentary rocks of the Wyoming province (D3). The tectonic style of this uplift is not clearly understood, but may have been similar to the Laramide orogeny, possibly along predefined Proterozoic faults. This processes took place until Cambrian time, when stable platform clastics and sediments were unconformably deposited.

During the Paleozoic and Mesozoic eras, carbonates and minor clastic rocks of a stable shelf environment were probably deposited in the whole mining district. The Cretaceous Madison Limestone was observed in the eastern part of the district but was in thrust contact with underlying Precambrian rocks. In the southern part of the district, Cambrian Flathead quartzite lies unconformably over Precambrian gneisses and the depositional sequence reaches up to the Mississippian (Lower Carboniferous) Madison limestone sequence (HADLEY, 1969).

By 175 Ma (Middle Jurassic), opening of the Atlantic Ocean led to subduction of the Pacific plate under the North American plate (MARCOUX and JÉBRAK, 1999). This initiated the Laramide orogeny in western North America which subsequently propagated easterly until Early Tertiary (D4). Generally, this corresponds to an E-W compression during this time. During the Laramide orogeny, Archean basement was uplifted for about 8 km, mainly during the Paleocene. Fission track dates record sudden cooling by exhumation at 52 Ma (WISE, 2000). Along the edges of uplifts, many parts of the Phanerozoic sedimentary sequence were thrusted and folded. Drag folds along thrust faults has been recognized by VITALIANO, et al. (1979) in the southern Tobacco Root Mountains and by KELLOGG (1995). Southeast plunging broad open folds and thrusts in the Paleozoic cover can be observed in the Baldy Mountain syncline (HADLEY, 1969) in the southernmost part of the district and further to the south. Although, no recognition of new fold systems in the metamorphic rocks have been recorded in the VCMD, as mentioned by TILFORD (1978) for the southern Greenhorn Range.

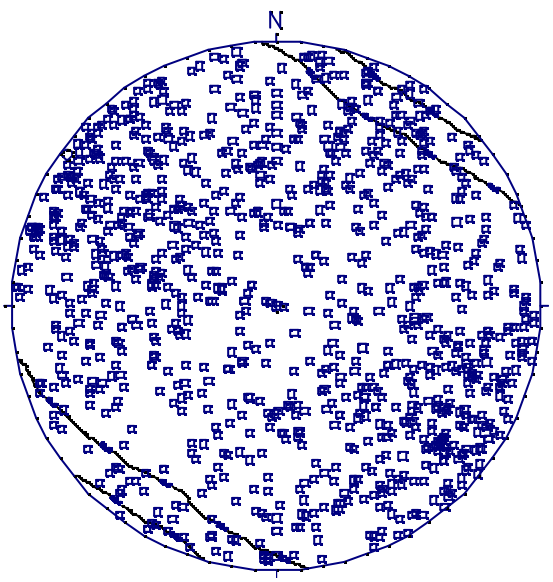


Fig. 16: Lower hemisphere, equal area projection of brittle structural features in the Lucas/Atlas and South Bachelor areas, VCMD, southwestern Montana: joints (1038 points; contour intervals 5%).

Figure 16 shows brittle jointing in the VCMD where virtually no specified direction can be observed. This supports the idea that these directions may represent a composite of more than one stress-strain episode. Another possibility may be constant rotation of the stress field during uplift.

Generally, jointing is very well expressed in "granitic" and "tonalitic" gneisses, whereas less in hornblende-plagioclase gneisses and amphibolites. Quartzo-feldspathic, e.g. „granitic" and „tonalitic" gneisses, generally appear to have behaved competently during deformation. This could have lead to preferred emplacement of quartz veins within these rocks. Some stream valleys depict structural patterns (e.g. northwest jointing and faults by Bachelor Gulch, west-trending joints by Three Mile Creek; northeast-trending foliation by Alder Gulch). Faults are indicated by slickenslides on clay-covered surfaces. The amount of offset in the metamorphic rocks along northwest-trending faults in the Lucas/Atlas and South Bachelor areas are generally little, several tenths of meters. Presumably, several small horsetail type faults seem to have accommodated the stress.

Figure 17 is a graphic summary of pegmatite contacts, faults and quartz veins in the Lucas/Atlas and South Bachelor areas.

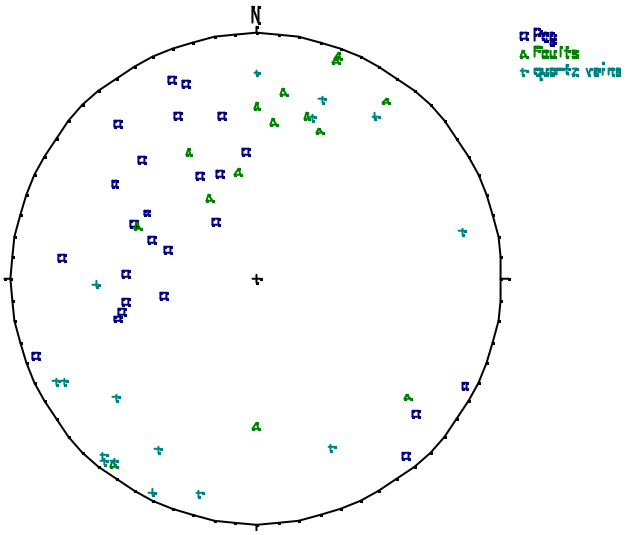


Fig. 17: Lower hemisphere, equal area projection of brittle structural features in the Lucas/Atlas and South Bachelor areas, VCMD, southwestern Montana: pegmatites (squares), faults (triangles), quartz veins (crosses).

Pegmatites are usually northwest-trending, as are some measured faults, whereas quartz veins in the Lucas/Atlas and South Bachelor areas trend northeast parallel to foliation, though differing in dips. Fewer veins trend northwest. The northwest-trending faults occur roughly at right angles to the general northeast trend of foliation and can be assumed to be aligned at ac-joints. They usually can be traced into

the Paleozoic units as done by GARIHAN (1973) in the nearby Ruby Range and are generally parallel to the Spanish Peaks fault which has been observed by GARIHAN, et al. (1983) to be the most continuous member of a set of parallel, northwest-striking strike-slip faults that cross southwestern Montana (see fig. 18).

active since the Middle Proterozoic, based on the observation of the occurrence of Middle Proterozoic dikes that trend approximately parallel to, and locally intrude the faults. This is indicated by northwest-trending Proterozoic pegmatites, too (SCHMIDT and GARIHAN, 1986; VITALIANO, et al., 1979).

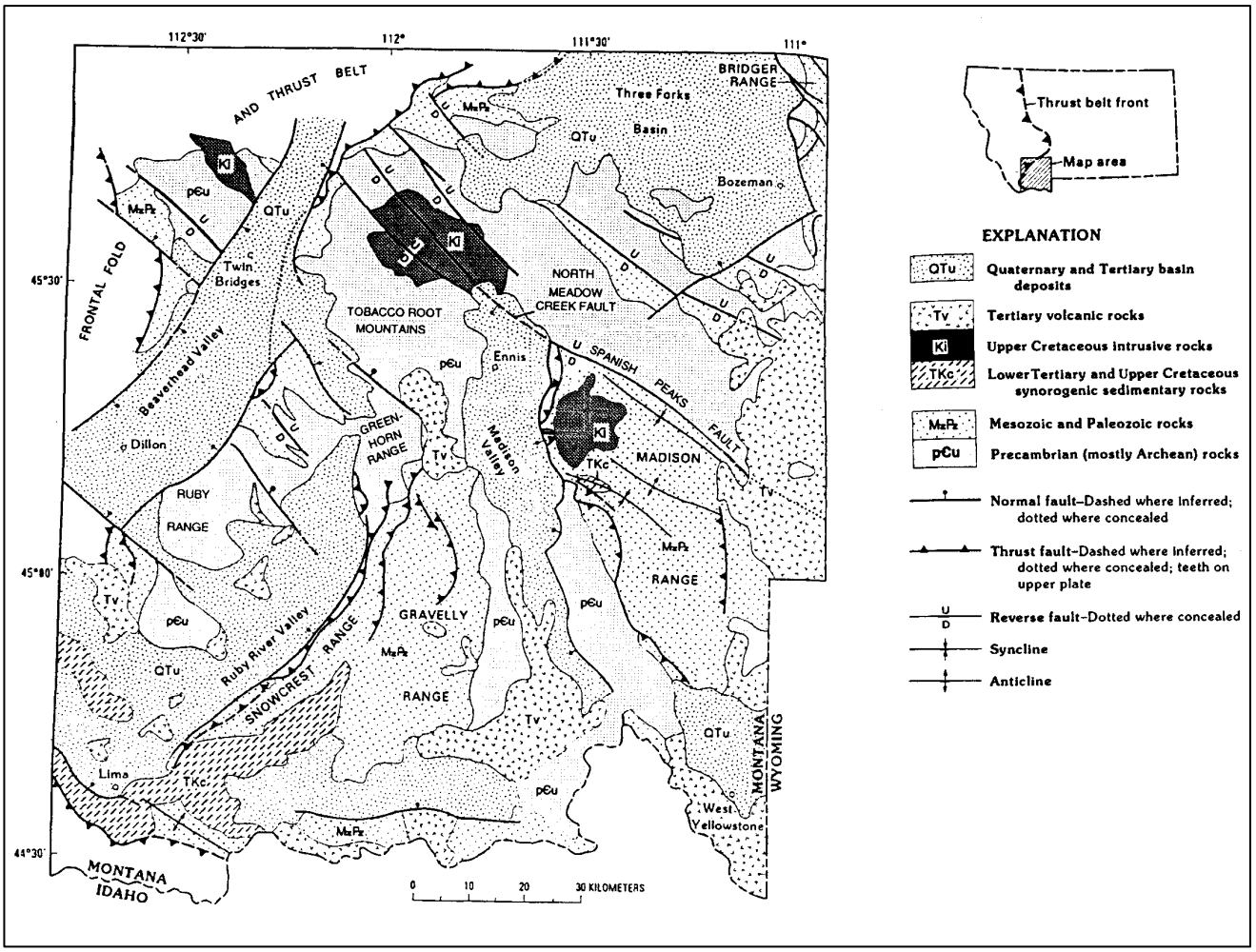


Fig. 18: Simplified geologic map of the southwestern Montana foreland uplift, modified after KELLOGG, et al. (1995).

The majority of these faults are on the order of 10's of kilometers long. Most faults dip 50° to 70° to the northeast. SCHMIDT and GARIHAN (1986) show that fault dips are usually 5° to 10° greater in Paleozoic rocks than in older Archean rocks. They also suggest a slightly listric geometry for Precambrian faults as evidenced in the southern High-land Mountains and the Ruby Range.

The age of these northwest-trending faults is at least Early Tertiary due to observed offsets of upper Cretaceous Tobacco Root Batholith and because unfaulted volcanic rocks of the Eocene Yellowstone-Absaroka volcanic field overlap the southeastern end of the fault. These faults are thought to have been

Thus, these second order structures (shear zones and joints) could have been developed during first uplifts in Late Proterozoic time and second uplifts in Laramide (Late Cretaceous-Early Tertiary) times after transition from ductile to brittle deformation (D3). This transition was passed presumably during the first uplift, for no ductile shear zones could be detected in the mapped area. Usually depths of the brittle-ductile transition range from 10 to 12 km (MOGK, 1990).

The front margin of the thrust belt in Montana reflects mainly thin-skinned tectonic features which overlapped and initiated coeval high-angle strike-slip faults in the foreland. The faults of strike-slip duplexes may converge downwards and appear in vertical sections as flower structures. Thus, this complex interaction of paired fault systems between thrust belt structures and basement uplifts during

Laramide crustal shortening is thought to have led to domal uplifts of Archean and Proterozoic crust in southwestern Montana, and has already been proposed by O'NEILL, et al. (1990) and KELLOGG (1995). Figure 19 shows schematic left-lateral positive flower structure, which has been modified in the sense, that thrusting in the west changed to strike-slip faults in front of the thrust. Therefore, there is no dominance of horizontal versus vertical motion, but an interaction.

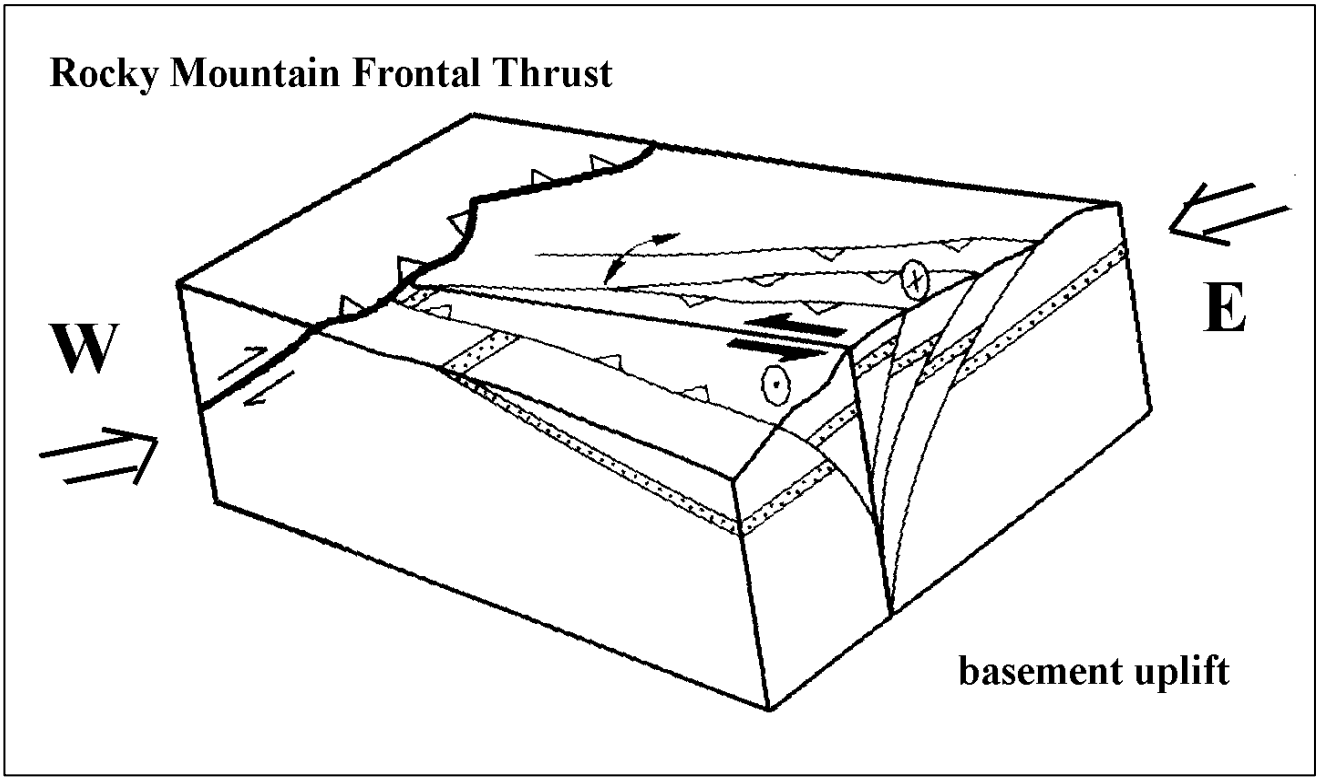


Fig. 19: Schematic postulated three-dimensional form of a left-lateral positive flower structure driven by Rocky Mountain foreland thrusts; modified after EISBACHER (1991).

It should be noted that other authors suspect detachment related tectonics to be the reason for uplifts of cordilleran metamorphic core complexes, e.g. KETNER, et al. (1998), TWISS and MOORES (1992). This cannot be ruled out completely, especially for the Basin and Range province of Nevada, although this proposed tectonic evolution model respects the distinct situation and various aspects of southwestern Montana's uplifts and thrust tectonics and is thus believed to be more differentiated and very much competitive. In this proposed model, Tertiary extensional tectonics are considered just to be modifiers of earlier Laramide-age uplifts. Compressional tectonics are necessary to rise metamorphic rocks of such high metamorphic grade from depths of 20 km to present elevations up to 3 km above sea level (Beartooth Mountains).

An interesting observation has been made by SEYFERT (1987) who recognized that metamorphic core complexes (a term which has been introduced by CONEY, 1980) which lie to the south of the Snake River plain are of Oligocene and Miocene age, thus younger to those north of the Snake River Plain which are of Eocene age. This is very much consistent with the propagation of subduction related heat transfer and tectonic style from northwest to southeast, e.g. the Basin and Range extensional tectonics in Nevada and associated mineralizations are part of this. The normal faults in core complexes have an extensional origin, mainly due do stretching of the entire crust.

A different explanation of this feature has been proposed by LIPMAN, et al. (1971). Based on K_2O contents of Tertiary volcanics from the western United States, he proposed that there was a double subduction zone under western North America during the Tertiary. Examination of their data shows that the double subduction zone was active during the Eocene north of the Snake River plain and during the Oligocene and Miocene south of the Snake River Plain. These are precisely the same intervals during which the core complexes were active. It is possible to explain it by a significant transform fault which has been activated from the subducted Pacific plate into the continental North American plate. This shearing can be considered similar to the shearing that occurs along the plate margins in the vicinity of subducted transform faults, e.g. the San Andreas fault in California.

Most of Precambrian basement uplifts of the Wyoming Craton are associated with Cretaceous-

Tertiary intrusive rocks, as is very prominently represented by the Boulder and Tobacco Root Batholiths in southwestern Montana (VITALIANO, et al., 1979). No large intrusive bodies have been observed in the VCMD, although an aplite/alaskite intrusive close to the Easton/Pacific mines in the western part of the district could be interpreted as top regions of a possible deeper seated intrusive body. Some authors, e.g. EIMON (1997), speculate that beneath the Paleozoic cover of the Baldy Mountain in the south of the VCMD, an intrusion could be assumed based on limited drilling in the Garrison mine. Whether this intrusions followed uplift or initiated it, is not clearly distinguishable, because of the long period of activity along the northwest-trending faults. In the proposed tectonic evolutionary model, it is suggested that fault movement and intrusions were coeval. SCHMIDT, et al. (1990) inferred that the Spanish Peaks fault influenced emplacement of the Tobacco Root Batholith with the magma injected mostly in a pull-apart area bounded by these northwest-trending strike-slip faults. Granitic intrusions were emplaced during a prolonged period, from Early Jurassic until Late Cretaceous. They become younger and more silicic eastward (SEYFERT, 1987). This Laramide model is partly supported by observations which HARLAN, et al. (1997) made.

Laramide structures were overprinted by Tertiary normal faulting during Middle Eocene to Miocene extension (D5) which formed and filled clastic, commonly conglomeratic, and lacustrine sedimentary basins. This was accompanied by eruption of Mid Eocene bimodal stratified volcanics which mark the eastern limits of Precambrian outcrops. Two tephritic dikes are found to crosscut all Precambrian rocks. They could be interpreted as feeder dikes for these volcanic extrusives. Both are 6-7 m in diameter and strike approximately northwest (along ac-joints within the Archean metamorphic rocks).

Some $^{40}K/^{40}Ar$ ages have been determined for volcanic rocks in the vicinity of Virginia City (MARVIN and DOBSON, 1979). Two samples collected from a unit that ranges from andesite to dacite porphyry in the bimodal volcanic rocks exposed just northeast of the town of Virginia City yielded ages of 49 and 51 Ma (Middle Eocene). Porphyritic rhyolite collected near the Ruby River Reservoir southeast of Virginia City yielded an age of 45 Ma. Samples of basalt collected at two localities south and southeast of the town were determined as 33 an 34 Ma, respectively, and a basalt sample collected southeast of the town of Alder was determined to be 30 Ma old (SHAWE and WIER, 1989).

This indicates that the entire sedimentary cover (6,000-10,000 feet minimum after TILFORD, 1978) and an unspecified portion of Archean metamorphic rocks must have been removed at least by middle Eocene time. Thus the uplift must have been earlier. Detritus from these uplifts in southwestern Montana formed the syntectonic Beaverhead conglomerates, a sequence up to 15,000 feet thick in the intramontane basins. Pollen and spore assemblages dated by RYDER and SCHOLTEN (1973) suggested that the rise of the ranges in southwestern Montana occurred between Late Cretaceous (Albian) and Early Cretaceous (Cenomanian) time with the final phases of uplift occurring during Early Paleocene.

These extensional faults may be listric for their angle of dip decreases with depth and approaches the angle of dip of the decollement. This has been proposed by KELLOGG, et al. (1995) for the Madison Valley (see fig. 20).

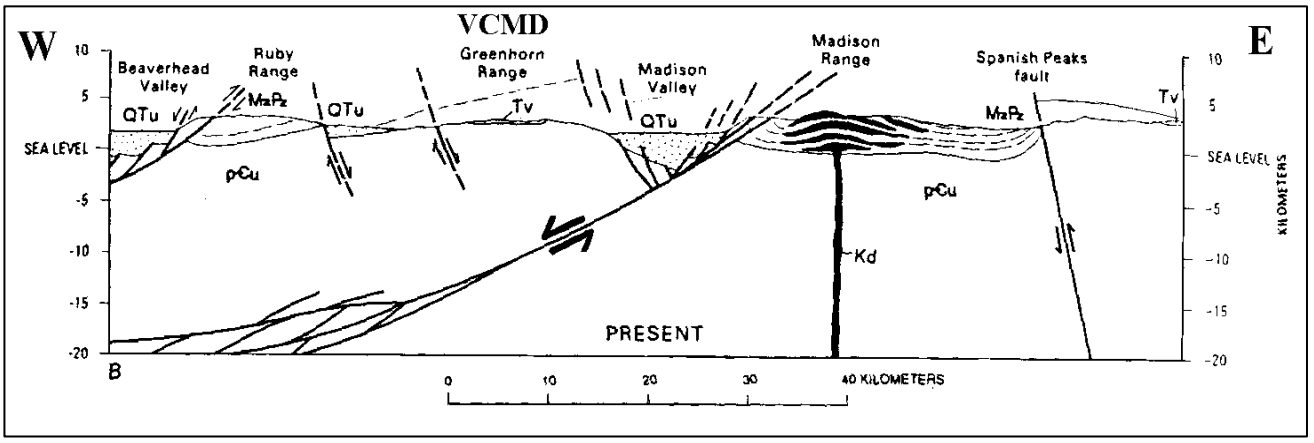


Fig. 20: East-west cross section across a portion of southwestern Montana showing major Tertiary extensional features; pCu = Precambrian undivided, Tv = Tertiary volcanics (modified after KELLOGG, et al., 1995).

This was the beginning of the Basin and Range deformation style along detachment faults after the compressional uplift event. These range building normal faults in southwestern Montana trend mainly northeast as can be seen on the general geologic map

of southwest Montana (fig. 18), although the Madison Range strikes approximately north-south.

Tertiary basins may be a direct consequence of Laramide thrusting, e.g. the thrust faults may have been reactivated as westward-dipping normal faults (structural inversion). Maximum depths of Tertiary basin fill has been estimated to be 2-3 km in southwestern Montana, the Madison Valley fill reaches 4.5 km (KELLOGG, et al. 1995).

On the other hand, fault movement and basalt volcanism as young as Pleistocene (or perhaps Holocene) may be related to reactivation of old structural weakness' during passage of the Yellowstone hotspot (HARLAN, et al., 1996). It migrated from southwest North America in Early Miocene (after MARCOUX, et al., 1999) to its present position in northwestern Wyoming and its hydrothermal activity. This is proposed to be linked to propagation of the subducted Pacific plate. OPPLIGER, et al. (1996) assumed, mineralizations of the Carlin trend in Nevada could be associated to slower movement of the Yellowstone hotspot between 43 and 34 Ma due to more stationary conditions of the Pacific plate.

Southwestern Montana is still tectonically active as major earthquakes prove. The last big earthquake occurred in 1959. It had had a intensity of 7.6 on the Richter scale and produced a landslide which formed the Hebgen Lake in the southern Madison Range (USGS, 1964). Even during the field work in 1998, a smaller earthquake with an approximate intensity of 4 at the Richter scale occurred near Whitehall.

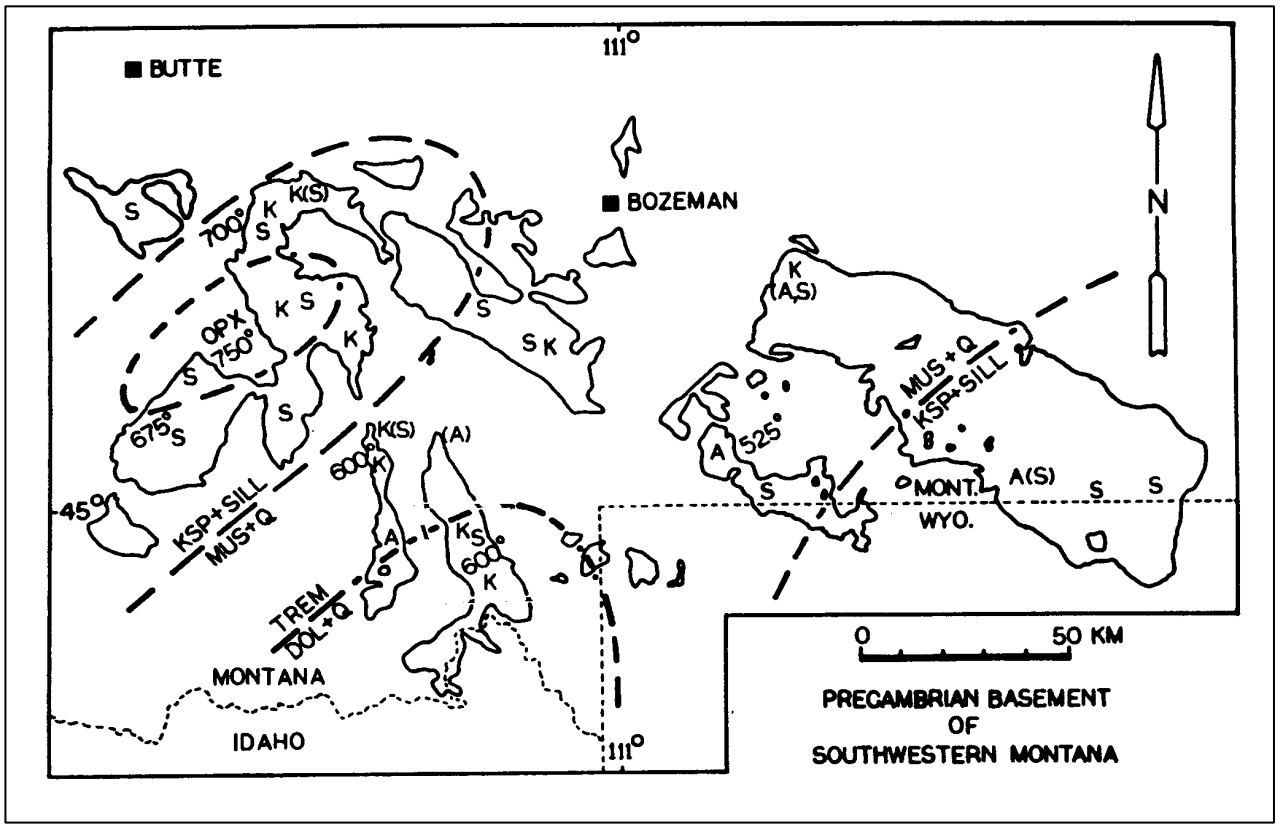
4.2. Metamorphic history

Most metamorphic rocks in the VCMD show little evidence of retrograde alteration. Thus the high-grade metamorphic assemblage still can be recognized. Moreover, granitoid composition of gneisses in the VCMD is less critical for determination of the metamorphic rank. During the earliest observable deformation event (isoclinal folding in D1), metamorphism reached upper amphibolite to lower granulite facies (M1). This is evidenced partly by extensive migmatization of all metamorphic rocks units in the VCMD and especially by the lack of muscovite within the „granitic" and „tonalitic" gneisses (reaction 1) and the formation of enstatite within ultramafic rocks (reaction 2).

in pelitic assemblages:
1) muscovite + quartz --> K-spar + sillimanite
in ultramafic assemblages:
2) anthophyllite --> enstatite + vapor

The sketch map of pre-Beltian metamorphism in southwestern Montana shows regional scale isograds (fig. 21) and indicates different intensities of metamorphic grade concentric to the Tobacco Root Mountains.

Fig. 21: Sketch map of pre-Beltian metamorphism in southwestern Montana. Dashed lines mark isograds. Occurrences of Al_2SiO_5 polymorphs kyanite (K), sillimanite (S), and andalusite (A) in brackets are indicating an earlier, partially reabsorbed polymorph (taken from ERSLEV, 1981).



Rocks of basaltic composition usually have hornblende-plagioclase-garnet assemblages over broad temperature and pressure ranges. No garnet-clinopyroxene-plagioclase assemblage, which would suggest lower granulite facies conditions, could be found (after MOGK, 1990). Lower granulite facies conditions would enclose lithologic associations that have equilibrated in the middle-to lower crust (ca. 8-9 kbar and up to 800°C (MOGK, 1990). The presence of staurolite as an inclusion in garnets has been mentioned by MOGK (1990) to be the only evidence of the prograde metamorphic path. This couldn't be found in thin sections of the observed metamorphic rocks, though GARIHAN (1979) described occurrences of kyanite and staurolite within the nearby Ruby Range.

Observed growth of cordierite close to garnets in "tonalitic" gneisses presumably on behalf of sillimanite indicate post-kinematic heating after obtaining peak pressures (M2). Higher temperatures may be due to K, U, Th enriched crust during tectonic thickening. Additionally, intrusions may have contributed to heat production. A longer stable stage, possibly during D2, may have led to the obliteration of previous high-grade assemblages. MOGK (1990) proposed that mineral assemblages of the second metamorphic event indicate temperatures around 650-700 °C and pressures of 4-5 kbar.

Retrograde metamorphic assemblages (M3) developed later in shear zones which are commonly of greenschist-facies rank. Usually retrograde metamorphism does not show everywhere for H_2O is missing during fast uplifts but usually biotites and garnet are partly retrogressed to chlorite. Surprisingly enough, ultramafic assemblages appear not to be retrogressed to greenschist facies conditions (e.g. serpentinites). Rapid decompression and cooling during Laramide uplift indicated by inferred broadly open clockwise P-T-t path led to present almost unchanged assemblages (MOGK, 1990).

5. METALLOGENETIC STUDIES

5.1. Regional base- and precious metal mineralization patterns in SW Montana

Several historically important base- and precious metal districts lie within, close to or in the vicinity of the Tobacco Root Batholith in southwestern Montana (fig. 22). Usually lode mining in those districts began shortly after the discovery of placer gold in 1863/1864. The following section is a brief description of host rocks and the mineralization in some of the districts in the Tobacco Root region.

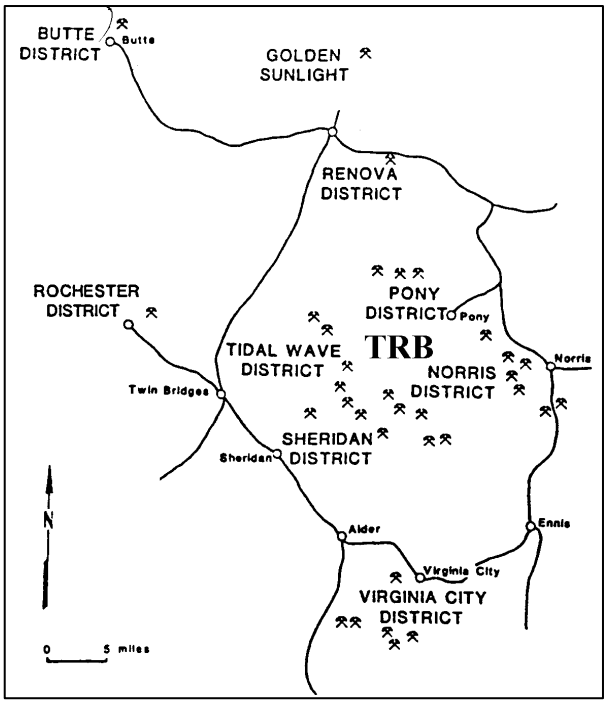


Fig. 22: Mining districts of the Tobacco Root precious metal mining region (TRB: Tobacco Root Batholith; modified from LOCKWOOD, 1990).

The Pony district has been one of the most important producers of lode gold in the Tobacco Root region and is located north of the Tobacco Root Batholith at the contact to this Upper Cretaceous monzonite intrusion. Usually mineralizations occur as quartz veins in fracture zones which are parallel to the gneiss-quartz monzonite contact or the foliation in the gneiss with poor development of wall rock alteration.

The majority of the deposits in the Norris district occur east of the Tobacco Root Batholith in Precambrian gneisses. Some quartz veins and narrow stringers lie within the quartz monzonite intrusion that has been cut by shear zones. High-grade gold is reportedly present at intersections of veins and shear zones (LOCKWOOD, 1990).

Deposits in the Sheridan and Tidal Wave districts are veins and replacements in dolomitic marbles which seem to have been the most important factor in controlling the mineralization. The Tobacco Root Batholith is exposed in a few small areas in the eastern portion of the districts. District scale zoning patterns have been observed. Deposits close to the batholith contain pyrite-chalcopyrite, whereas pyrite-galena becomes more abundant with distance (LOCKWOOD, 1990).

The Renova District is located in the northern end of the Tobacco Root Mountains. Mines lie within Beltian arkosic sandstones which are crosscut by porphyritic dikes in which mineralization occurs as fissure veins which crosscut bedding (LOCKWOOD, 1990).

The Butte Cu-Mo-Au-deposit, located approximately 50-60 km to the northwest of the Tobacco Root Batholith, is thought to be genetically related to the Cretaceous Boulder Batholith within which it lies. Moreover, recent publications (MARCOUX and JÉBRAK, 1999) mentioned mineralization over a long period thus developing telescoping patterns.

The Golden Sunlight mine is located approximately 30 km north of the Tobacco Root Batholith. It is classified as a low-sulphidation type epithermal deposit. Genetically it is not related to one of the batholiths or satellite stocks, but to late Cretaceous rhyolite breccia pipes (DEWITT, et al., 1996).

The Rochester precious metal mining district lies in the Highland Mountains closely related to northwest-trending shear zones within Precambrian metamorphic rocks, and the nearby Silver Star mining district to the east is closer related to a smaller Cretaceous satellite stock of the Boulder Batholith within Proterozoic Belt sedimentary rocks (O'NEILL, 1989).

COLE (1983) described regional metal zoning patterns with respect to the Tobacco Root Batholith in the form of low Ag/Au and high Cu/Ag ratios near the main exposure of the batholith (Pony district), and high Ag/Au and low Cu/Ag ratios far from the batholith (VCMD). LOCKWOOD (1990) mentioned that mineralization closest to the contact was typically gold-containing pyrite, chalcopyrite, and quartz grading into a galena- and silver-dominant zone. Mineralization that occurred within the intrusion characteristically carried fluorite and huebnerite.

Ore minerals commonly are native gold (rare flakes), abundant pyrite, moderate amounts of galena, sphalerite, and minor chalcopyrite (COLE, 1983). Gangue usually consists of ubiquitous quartz, K-spar, and calcite/ankerite.

Almost all near-surface portions of Tobacco Root ore bodies are secondarily enriched by oxidation which was an important factor in developing higher grade ores near the surface. These oxidized ores may contain secondary silver, lead, copper, zinc, and iron minerals at the expense of primary sulfides.

5.2. Virginia City Mining District (VCMD)

The Virginia City Mining District, VCMD, is the southernmost district in the Tobacco Root base- and precious metal mining region. Several mines and prospects are located within this district of which the Easton/Pacific, Kearsarge, Bartlett and Lucas/Atlas mines are the most prominent ones and which will be described in the following sections (see fig. 23 for location).

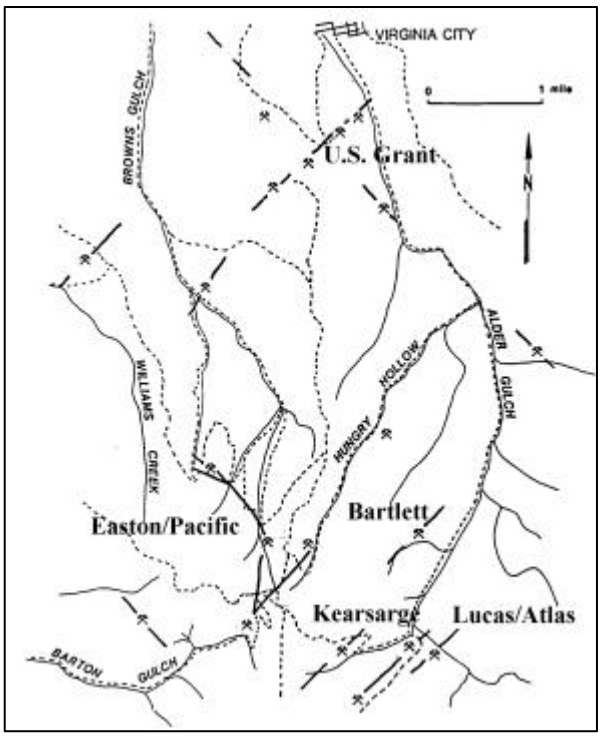


Fig. 23: Location of major mines and mineralization trends in the VCMD (modified after LOCKWOOD, 1990).

Exploration and mining history

Mining history of the VCMD begins with the discovery of placer gold deposits in the Alder and Brown's Gulchs in the spring of 1863 by prospectors who came from the nearest mining camp in Bannack which had been discovered a year or two earlier. The new discovery attracted thousands of miners similar to many earlier discovered gold districts, e.g. the Californian Gold Rush in 1849. By autumn of the same year, an estimated number of 10.000 miners were working on the placers in the „fourteen mile city" and „The Greatest Natural Sluice Box in America", how the Alder Gulch was newly nicknamed (SIEVERT, 1993). These placer deposits produced over 2.6 million ounces (80.9 t) of gold and 350,000 ounces (10.9 t) of silver making it one of the richest placer deposits in the United States.

Virginia City became the territorial capital of Montana from 1864 to 1875. For the new discoveries attracted not just honorable miners, Virginia City became the birthplace of the vigilante movement.

Lode mines were found at the Kearsarge and Oro Cache mines in the upper Alder Gulch in the same year as miners searched for the source of the placer gold discovered downstream. An estimated 170,000 ounces (5.3 t) of gold and 2.4 million ounces (74.6 t) of silver were produced from lode deposits in the district. Base metal production from lode mining is incompletely reported, but apparently was not

significant. Selected secondary enriched high-grade ores were sent to Swansea, Wales, via San Francisco. When these ores were exhausted and subsequently lower grade primary ores were encountered, many of the mines were abandoned (SIEVERT, 1993).

A second intense mining period started in 1897 when dredging techniques were developed and continued exploiting the gulch until 1922.

In the 30s of the 20th century the rising price of the precious commodity encouraged companies to restart lode gold mining. Lode production in the district continued sporadically until it was halted by the U.S. government at the start of World War II for precious metal mining was labeled a nonessential industry.

The most recent exploration efforts began in 1989 and were focused on the southern half of the district. Besides other major mining companies these investigations included exploration in the Easton-Pacific area by BHP-Utah; Kennecott in the Kearsarge, South Bachelor and Lucas areas, and Noranda in the Winnetka area north of Kearsarge. They initiated exploration programs including soil sampling, geologic mapping, VLF-EM-mag survey, trenching, and core drilling. Nearly 2,000 from over 6,000 rock and dump surface samples in the vicinity of Kearsarge-Apex and Pacific mines yielded an average grade of 0.11 opt Au. Anomalous gold could be followed for 18,000 feet along strike (HANOVER GOLD, 1998b). The production failed until 1996 due to lack of a unified area in which one company has the control and is able to use the whole potential of the district and develop a bulk-tonnage resource.

In 1997 Hanover Gold managed to merge with two other partners who held significant properties in the district. Thus the total area controlled by Hanover Gold rose to 54 km^2 by 1998. In 1997, the company contracted five independent consulting geologists to map the surface geology and Geo-terrex-Dighem to conduct an airborne geophysical survey which has been encompassing an area of about 105 km^2 of the district and surrounding areas. Hanover Gold continued core and rotary drilling in 1998 in order to verify known and to find new extensions of structures. Check assays showed very good correlation with original assays and several promising new targets have been identified (HANOVER GOLD, 1998b).

5.3. Types of mineralization in the VCMD

Four different types of mineralization have been recognized by previous authors in the VCMD and are summarized here:

a) Easton/Pacific type

Northwest trending curvilinear and steeply dipping quartz veins and breccias within pervasively highly argillic altered Archean metamorphic rocks is the main mineralization within the Easton/Pacific mines. The veins show horsetail geometry. Fluid inclusion studies and illite/smectite ratios performed by LOCKWOOD (1990) revealed fluid temperatures which evolved with time from moderate temperature (275°C), low salinity (3-6 eq. wt.-% NaCl) solutions to lower temperature (175°C) higher salinity (10-12 eq. wt.-% NaCl) solutions. This suggests that Virginia City mineralization involved the mixing of fluids from different sources. Mineralogy within this type is dominated by silver sulfides and native gold. Gangue is mainly quartz and feldspar.

b) Bartlett type

Mineralization occurs in a quartz vein system within silicified dolomitic marble and along contacts between marble and quartzo-feldspathic gneiss. The ore and gangue minerals include: gold, pyrite, chalcopyrite, tetrahedrite, graphite, quartz and ankerite. Graphite is present as disseminated flecks in marble and as stringers along shear zones which offset mineralized quartz in the vein. In being closely related to the occurrence of reactive host rocks like dolomitic marbles and having abundant base metals, the style of mineralization is similar to some mines in the Sheridan district.

c) Kearsarge type

Within the NNE-trending Kearsarge/Apex shear zone that strike parallel to rock foliation, several quartz veins occur together with graphite in faulted cataclastic rubble zones of Archean rock enclosed in clay gauge. The host rocks consist of inter-layered garnet-biotite gneiss, amphibolite, dolomite, iron formation, and graphitic schist.

d) Lucas/Atlas type

Fracture-controlled quartz veins which are discordant, but parallel to foliation occur with strong K-spar, chloritic, and carbonate alteration in the eastern part of the district. The South Bachelor mineralization has the same type of mineralization and is thus appearing to be the southern extension of the Lucas/Atlas zone.

District scale mineralization patterns

BARNARD (1993) described zonation patterns within the VCMD, based on interpretation of hypogene Ag/Au ratios (fig. 24). Their pattern shows northwest-trending Ag/Au ratios, with the high (>50:1) in the Easton/Pacific area, and lowest in the southeastern part of the district (1:1).

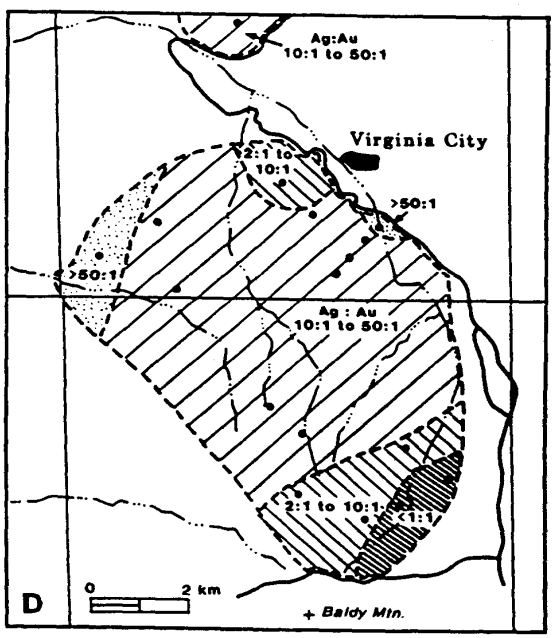


Fig. 24: Silver/gold ratio zonation in the VCMD, southwestern Montana (from BARNARD, 1993).

This overall picture is partly supported by observations of Ag/Au ratios by Hanover Gold within core samples in the Lucas/Atlas and South Bachelor areas (fig. 25). The gold and silver values are approximately in the same range though the bivariate Pearson correlation is 0.5334 and thus too low to be considered as 1:1.

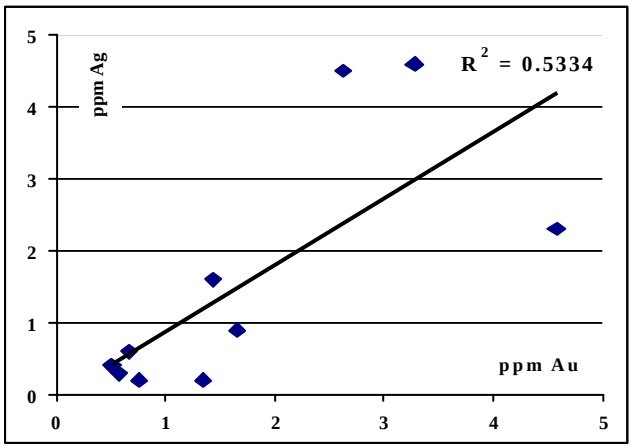


Fig. 25: Silver to gold correlation of core samples in the Lucas/Atlas and South Bachelor areas, VCMD, southwestern Montana (data from Hanover Gold, 1998b).

5.4. Mineralization in the Lucas/Atlas and South Bachelor areas

Mineralization in the southeastern part of the VCMD has been the target of this study for it lies within the mapped area and was previously described in chapter 3. For this purpose six H-size cores, which are intersecting the Lucas/Atlas and South Bachelor veins, have been relogged. Results of this relogging has already been partly incorporated within the discussion of general geology.

Elevation of the mineralized outcrops range between 2100 and 2440 m. Most of the workings are caved. Limited access is given in several adits spread over the study area, and give occasionally subsurfacial details up to 20 m of the drift. The South Bachelor target may be the southwest extension of the Lucas and Atlas "veins" exposed along the north side of Bachelor Gulch. The geologic setting is identical to the Lucas/Atlas zone and is thus considered to be mentioned together with the Lucas/Atlas mineralization.

Geologic environment

Composition of unaltered wallrock gneiss in Lucas/Atlas and South Bachelor area is dominantly „granitic“ with or without magnetite (Aggm or Agg, respectively) which reached upper amphibolite to lower granulite facies. Numerous granitic pegmatites and several aplite dikes transect wallrock foliation and are in turn subsequently crosscut by the vein system (and the related alteration halo). Pegmatite lithology is dominantly quartz-K-spar-plagioclase-biotite. Minor host rocks are represented by „tonalitic“ gneisses and hornblende-plagioclase gneisses and amphibolites, especially close to the Kearsarge mine. No large intrusive bodies have been observed in the district, though an aplite/alaskite intrusive close to the Easton/Pacific mines in the western part of the district could be interpreted as top regions of a possible deeper seated intrusive body. Some authors, e.g. EIMON (1997), speculate that beneath the Paleozoic cover of the Baldy Mountain in the south of the VCMD, an intrusion could be assumed based on limited drilling at the Garrison mine.

Mineralogy and textures

Ore mineralogy in the Lucas/Atlas and South Bachelor areas is very simple and typical of low-sulfidation epithermal gold deposits. Pyrite occurs as the major sulfide phase in small euhedral grains both

in veins and in proximal alteration zones. Three different types of mineralization and spatial positions of pyrite has been observed:

a) very fine grained dispersly distributed euhedral pyrite at the rims of the quartz veins (fig. 42 in appendix 4)

2. euhedral fine-grained pyrite, which floats freely in the quartz vein matrix (fig. 39 in appendix 4)

3. replacement of magnetite by pyrite within magnetite bearing „granitic“ country rocks (Aggm, figs. 41 and 43 in appendix 4).

The third type of mineralization indicates the reduced nature of the rising fluids and would explain the observed loss of magnetic susceptibility and the overall high iron staining close to quartz veins due to replacement and destruction of the oxidic iron mineral magnetite. Moreover, elevated primary Fe-contents appear to have favored pyrite precipitation.

Gold is possibly submicroscopic („invisible gold“) in auriferous pyrite, for free gold has not been observed in hand specimen nor in polished sections and no other gold mineral has been observed (e.g. tellurides, selenides). This is indicating gold transport as bisulfide complexes. No base metals are present, although they have been mentioned by COLE (1983) in overall district-wide ore mineralogy.

Gangue mineral is dominantly quartz which occurs as euhedral to semihedral crystals, generally 3-5 mm in diameter and 1-5 cm long, oriented perpendicularly to the vein trend. The crystals are clear to somewhat milky white, sometimes zoned from clear in the cores to milky on the rims. K-spars are usually part of the alteration halos, though one sample, H1, shows large euhedral K-spar (orthoclase) crystals which grew into the quartz vein perpendicularly to the rim (see fig. 37 in appendix 4). Subordinate carbonate occurs as a late fracture filling.

Structures

Though beginning of lode mining already started in 1863 and reserves are still supposed to be economically mineable, a comprehensive geologic study of mineralization and development of a genetic model of the mineralization for the whole district hasn’t been done yet.

Lode mines in the district may be roughly grouped into dominant northeast- and less northwest-striking vein systems, although a few strike north or east. The observed outcropping veins in the Lucas/Atlas and South Bachelor areas strike dominantly northeast subparallel to the strike of the foliation of the metamorphic host rocks, but the dips differ and cut foliation of metamorphic rocks and pegmatite dikes. Thus the mineralization post-dates development of the prominent northeast-trending foliation. It was not possible to follow vein structures over long distances on the surface thus it is not clear whether they could be offset by the Bachelor Gulch fault. Maximum depths of the veins are not known but depth of mining indicate that some veins are continuous for 220 meters.

These veins and veinlets generally occupy tension fractures and display features like unfilled open space, and vugs or quartz grew not vertically to, but enclosing an angle with the vein border. This reflects low depth emplacement at relatively low pressures and shallow crustal levels (i.e. 2–5 km).

Veins vary in thickness from some centimeters to 20 centimeters. Vein structures can occupy up to 3 meters wide zones of quartz stringers (observed in South Bachelor). The veins occur as tabular bodies, and stringers in fractures and less dominating as lenses. Contacts between vein and wallrock tend to be frozen. The veins are generally post-tectonic and not deformed. The closest major fault zone is the northwest-trending left-lateral strike-slip fault at Bachelor Gulch which transects the southern part of the VCMD.

Superimposed textures such as later carbonate brecciation and fracture fillings are common and indicate multistage hydrothermal activity during repeated reactivation of earlier vein structures (see fig. 36 in appendix 4).

Alteration

Altered wallrocks contain an early pervasively propylitized assemblage with sericitized feldspars (replacement of plagioclase by albite, sericite and carbonate), and partly alteration of mafic minerals like biotite to chlorite. Characteristically mineralized veins have selvages of pink K-feldspar as the following alteration stage (potassic alteration, figs. 38 and 42 in appendix 4), though in some areas pervasive disseminated potassic alteration has been observed. Rarely, euhedral K-spar crystals grew into the quartz vein perpendicularly to the rim. Sulfidization which was carrying the gold occurred together with silification in the main mineralization stage. The latest stage is marked by barren carbonate alteration filling open space in the quartz vein vugs. By observing selected cores, mineralization appears to be linked to or generally associated with potassic alteration.

The shape of the alteration halo is more or less tabular (like the vein system) and usually does not exceed more than 1-3 m on either side of the vein system (see appendix 3).

Supergene weathering generally extends to depth of 30 to 80 meters (BARNARD, 1993), and the

majority of productive veins produced only from the enriched oxidized zone.

Geophysical signature

Interpretations of aeromagnetic anomaly data and results from magneto-telluric soundings were used to study buried structure and lithology of the VCMD, southwestern Montana.

High magnetic susceptibility occurred especially east of Alder Gulch and can be linked to magnetite bearing „granitic“ gneiss (Aggm) and west of the Alder Gulch, where magnetite bearing ultramafic rocks are exposed (see M.Sc. thesis of M. Karg). It should be noted especially that altered magnetic rocks of granitic modal composition show no susceptibility in the vicinity of quartz veins but do often show wide areas of iron oxide staining on joints. Close to veins, iron-staining on joints has been observed.

Conductivity anomalies are associated with Kearsarge and Easton/Pacific shear zones and associated mineralizations.

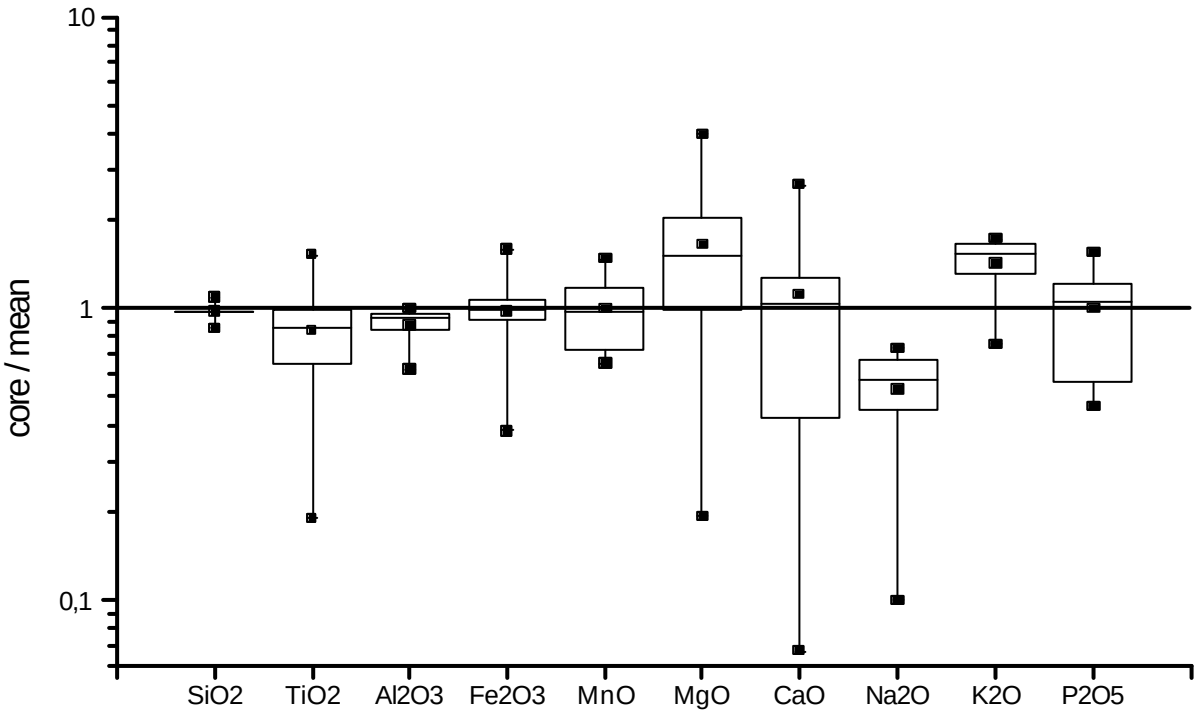
Geochemical signature

Geochemical results were used to determine variation and changes in major and trace element compositions accompanying mineralization with respect to unaltered host rocks. Chemical changes in host rocks that occurred during hydrothermal alteration were determined by whole-rock analyses of samples which form a composite profile representative of the alteration (see appendix 5). Samples consist of altered wallrock without vein material taken from cores which have been described in appendix 3 compared to means of unaltered hornblende-free Archean metamorphic rocks of the Lucas/Atlas and South Bachelor areas, VCMD. Sulfur content, which has been measured as SO_3, is not shown in figure 26 for it generally was introduced during alteration.

Alteration patterns indicate metasomatic fluid-rock interactions during ore formation especially for potassium, sodium, and calcium contents, which are primarily bound in feldspars (fig. 26).

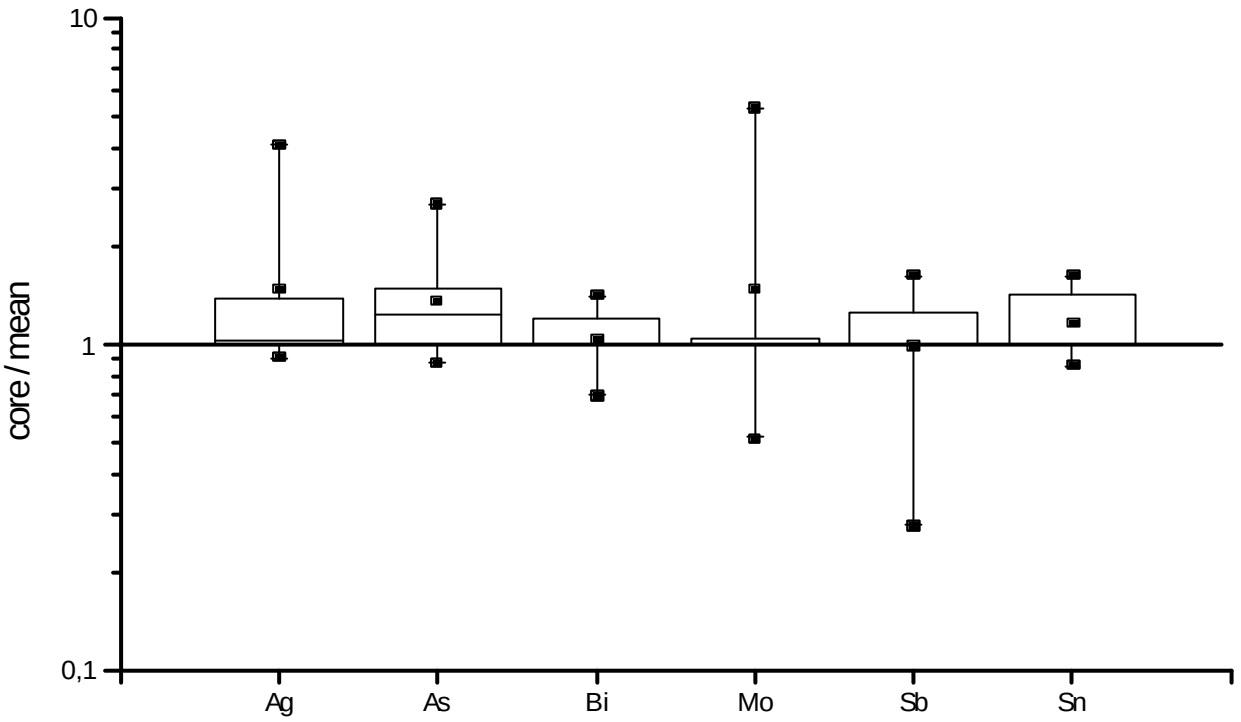
Potassium has been introduced into the system during alteration by formation of secondary K-spars. The same can be assumed for magnesium which may have been for formation of carbonates in the late stage alteration, which are possibly partly dolomitic. Calcium and sodium appear to be liberated mainly due to sericitization, whereas silica, titanium, aluminum, iron, and phosphor do not show large mobilization effects. The pH of the first fluids was probably acidic due to observed chloritization, sericitization, and secondary K-spar formation) and changed later to alkalic carbonate forming conditions.

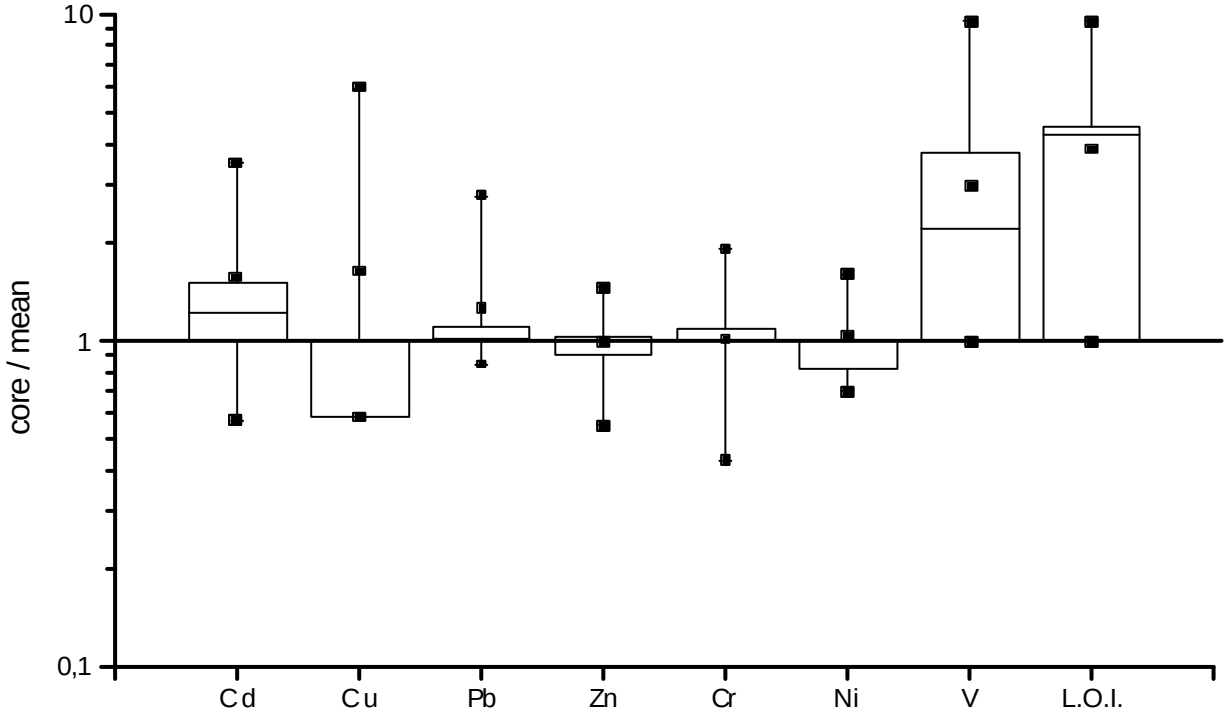
Fig. 26: Box plot showing geochemical expressions of alteration in the Lucas/Atlas and South Bachelor areas, VCMD, based on main elements, compared to the mean of unaltered hornblende-free Archean metamorphic rocks.



Generally, alteration is expressed geochemically by showing higher L.O.I. (loss on ignition) values with respect to unaltered host rocks (see fig. 27). Figures 27 and 28 show as well mobilization trends of trace elements, especially elements which are considered to be best path finder elements for mother lode deposits, such as arsenic, antimony and some base metals. Alteration caused remarkable increases in silver, arsenic, bismuth, and vanadium concentrations, and smaller increases in antimony, cadmium and tin, whereas lead, zinc, chromium, and nickel values remain almost unchanged. Molybdenum minimum and maximum values in cores vary extremely, and copper shows mainly lower values compared to the mean composition of hornblende-free host rocks.

Figs. 27 and 28: Box plots showing geochemical expressions of alteration in the Lucas/Atlas and South Bachelor areas, VCMD, based on trace elements, compared to the mean of unaltered hornblende-free Archean metamorphic rocks.





Estimated economic potential

The estimated primary gold and silver reserves of all the Hanover Gold holdings within the district are about 5 million ounces of gold and 2,5-8 million ounces of silver, respectively (STEININGER, 1997; HENRICKSEN, 1997). It must be stressed that this is based mostly on geological inference, and no proven reserves have been indicated up to now. Therefore it is risky to speculate on the total number of ounces of gold to be discovered in any one deposit, or district. The proof will be in future drilling.

Drilling in the Lucas/Atlas and South Bachelor areas has identified several intercepts that vary in width from 20 to 95 feet, with grades in the 0.030 to 0.136 opt Au range. These mineralized drill hole intervals are spread along a strike length of at least 1,000 feet and a width of 500 feet. The Lucas/Atlas and South Bachelor zone, defined by surface exposures and very widely spaced drilling, suggests a potential of approximately 20 m.t. which is likely to average 0.055 opt. This is based on variable pit depths ranging from 250-500 feet which yields an estimated strip ratio of 6.4:1 (HANOVER GOLD, 1998b).

DESBOROUGH (1971) reported finess' of placer gold grains in Alder Gulch ranging from 500 to 900, but generally to be in the range of 700 to 850 which is broadly similar to other Archean lode gold deposits.

Cyanide leach tests either by coarse crushing and heap leaching, or milling and agitated leaching were run on twenty pulp samples selected by Kennecott from the South Bachelor, Atlas, and Lucas zones. The samples from these zones included oxide, sulfide, and mixed oxide/sulfide ores, ranging in grade from 0.013 opt Au up to 0.271 opt Au. Recoveries from these sample tests ranged from 57% to 150% with an overall average recovery of 96%, which possibly is indicating a nugget effect. Hanover Gold proposed open pit mining and a gravity processing system followed by carbon-in-leach milling to be effective and efficient methods for extracting the resource (HANOVER GOLD, 1998b).

Environmental considerations

One of the most favorable aspects found with these ore types in the VCMD is their low acid generating potential due to generally low sulfide content and carbonate content which possibly buffers heavy metal release. Water pH is consequently maintained near neutral. In waters of near-neutral pH, most metals have low solubilities and are not easily transported from the deposits. Acid mine drainage is a serious concern today because acid mine drainage problems severely impact permitting and operations.

The proposed open-pit mine would produce gold from low-grade ore using cyanide heap-leach techniques whereby the ore pile is sprayed with water containing cyanide, which dissolves the gold grains. Though low acidic and metal-rich drainage from the site would be expected, leakage of cyanide-bearing solutions from the heap-leach pad could occur and represents thereby a significant concern to monitor this site.

Considering historic significance of the VCMD and earlier use of mercury for gold extraction, no contamination within tailings could be found after HENRICKSEN (1997).

5.5. Timing and genesis of mineralization in the VCMD

The genesis and age question of quartz-sulfide-precious metal vein systems in the VCMD has not been resolved yet. Previous writers mostly expressed ideas based on magmatic-hydrothermal theories and relation of the veins to one or more postulated, but unexposed intrusive centers. The following discussion will describe previous interpretations considering the source of the gold, the timing of mineralization by discussing the transportation mechanisms (linked to regional tectono-thermal events), as well as depositional systems or traps for precious metals.

Previous interpretations

a) Late Archean age:

Some features within the VCMD can be compared to those found in Archean greenstone-sedimentary belts elsewhere as most major lode gold deposits formed at 2.7 Ga. A number of deposits in amphibolite-grade rocks have been interpreted recently as synmetamorphic, including many in Western Australia and in the Superior province of Canada (GROVES and PHILLIPS, 1987). Timing interpretations of deposits in upper amphibolite and granulite facies host rocks vary widely. Examples include Hemlo, Ontario and Golden Mile mine in Western Australia, where gold introduction has been interpreted as pre-, syn-, and postamphibolite grade (SMITH, 1996).

Prograde metamorphism with increasing temperatures and pressures involves dehydration and decarbonation reactions which release H_2O or CO_2 from rocks. This can be a powerful source of fluid-generation which may leach gold from the surrounding metasedimentary and metavolcanic rocks. Gold-bearing fluids may be channeled within ductile

shear zones or redeposited in structurally favorable sites like saddle quartz reefs or lithological traps, e.g. iron formations (HAACK and ZIMMERMANN, 1996).

Considering the volcano-sedimentary nature of host rock protoliths in the VCMD, they might have been the source for gold not only in this model. Originally, gold and sulfides of volcanic-exhalative origin might have been syngenetically deposited and subsequently redistributed and concentrated to ores in favorable structures. This could have happened still in Archean time, although this model can be used as a first enrichment of gold for the other later proposed models or as additional processes for further gold enrichment.

Contradicting to this Archean-age model, shear zones in the VCMD are not ductile and no observation of saddle reefs has been made. Mineralization clearly post-dates the first two ductile tectonic events (2.7-2.9 Ga and 1.6-1.9 Ga). Moreover, widespread mineralizations occur not just within ductile shear zones. Usually iron-formations in the VCMD, are found to be not mineralized. Additionally, vein and alteration mineral assemblages compared to the metamorphic grade of the host rocks should reveal high temperature assemblages (pyrrhotite, chalcopyrite, and potassic alteration) which is only true for the alteration style in the Lucas/Atlas and South Bachelor areas and generally not for ore mineralogy. The occurrence of mineralizations within Proterozoic host rocks in the Highland Mountains and in the Late Cretaceous Tobacco Root Batholith is another aspect which contradicts this assumption of Archean age mineralization.

b) Middle Proterozoic age:

Due to the previously mentioned observation that mineralizations are younger than the first ductile deformational event, development of shear zones and tensile quartz veins could be related to the second large tectono-thermal event in southwestern Montana, which is broadly coeval to opening of the Middle Proterozoic Belt Basin and which affected the nearby Ruby Range by formation of talk deposits around 1.8 Ga (personal communication, MOGK, 1998).

Pegmatite ages of 1.6 Ga measured by COLE (1983) support the influence of this tectono-thermal event within the VCMD. Pegmatites show almost uniformly northwest-trending like other Proterozoic features, e.g. mafic dikes which were observed by WOODEN, et al. (1978) in southwestern Montana.

However, the striking direction of these features indicate another stress regime which can not be responsible for the same features of northeast-trending quartz veins. The Belt basin opened initially in northwest-southeast direction, quartz veins in the Lucas/Atlas and South Bachelor areas are dominantly oriented northeast. This favors different structural settings for mineralization than present in Middle Proterozoic time. Moreover, the clearly discordant nature of mineralized quartz veins and brittle shear zones are still contradicting emplacement in this time, when the metamorphic rocks were below the ductile-brittle transition and developed ductile folds in the second deformational event. Although, it is still possible that the ductile-brittle transition occurred slightly after this second ductile deformation in Middle Proterozoic time.

c) Sinium age:

Mineralization along brittle shear zones could be related to first, possibly northwest-trending uplifts of metamorphic core complexes in southwest Montana which occurred in Late Proterozoic (Sinium) time as has been mentioned earlier in the structural and metamorphic chronology section. This uplift may have used pre-defined Precambrian structures which enabled large fluid flux along major strike-slip faults, which may have been induced by thrust tectonics to the west. They might have produced the favorable structures for gold deposition.

The observation of overall brittle structural features along northwest-trending strike-slip faults, horsetail structures, brecciation and even open space filling would support this model.

EIMON (1997) reported gold mineralizations being intercepted by drillholes in Paleozoic limestone, shale, and dolomite at Goodrich Gulch in the southern part of the district. This would contradict Sinium age models for the mineralization in the VCMD, although a pre-enrichment of precious metals may have occurred.

d) Laramide age intrusion-related models:

The common classical model assumes that both, gold and heat that mobilized metal-bearing fluids, derived from country rocks or granitic intrusions which are often spatially related to this type of deposit (BOYLE, 1979). Such an intrusion might be the Tobacco Root Batholith around which many precious metal mining districts are located. In areas where no igneous activity can be recognized, plutons are assumed at shallow depths below the deposits. The model encompasses a geothermal convection cell (driven by igneous heat source) that circulates a large volume of hydrothermal fluids. The water in these fluids (as documented in some deposits) is dominantly or entirely meteoric. Episodic boiling of

these fluids in the upper, near-surface portion of the convection cell is thought to be responsible for metal deposition. Precious metals are deposited at and above the boiling level, whereas base-metals are deposited at and below it. Reported temperatures of precious metal deposition vary from mesothermal (200-400°C) to epithermal conditions (100°-300°C).

The VCMD is located furthest of this intrusion (approximately 20 km to the nearest exposure) and thus it is speculative whether this batholith could have influenced the mineralization. A large intrusion has neither been found nor fully proved yet in the VCMD.

The other districts within the Tobacco Root base- and precious metal region, especially the Pony and Norris mining districts, lie close to or within such a large batholithic intrusion which would support the idea of a direct influence or close relationship to the timing, transport, depositional mechanism, and possibly to a source for gold. Some metal and mineral zoning with respect to the Tobacco Root Batholith concerning the districts has been reported which would support a close genetic relationship. Moreover some of the prominent deposits in southwestern Montana like Butte and Golden Sunlight are clearly Laramide in age based on radiometric dating. VITALIANO, et al. (1979) observed that Cretaceous pegmatites related to the Tobacco Root Batholith contain sulfide minerals, whereas Precambrian pegmatites lack sulfides. This would support a Late Cretaceous and not Archean mobilization of the precious metals. A possible satellite stock of the Tobacco Root Batholith may be taken into account if the observed aplite/alaskite stock located close to the Easton/Pacific mines (the so called „Browns Gulch Stock“) would be considered as a possible pegmatitic top region of a deeper-seated intrusion based on observations of graphic granite, and perthitic K-spars. It is medium to coarse grained, with porphyritic texture. K-spar phenocrysts range from several centimeters up to 0.15 m in length. Many xenoliths of gneissic rock are present within this stock. Based on drilling, EIMON (1997) identified a post-Paleozoic granitic intrusive complex underlying upper Alder Gulch (e.g. the so called „Garrison Igneous Complex“) that appears to have affected, or been affected by, structural and mineralizing relationships in the area. This could be favored by the reported metal zoning which indicates a probable heat source in the southern part of the VCMD because of observed 1:1 Ag/Au ratios. More distant Ag/Au ratios would be higher like the ratios observed in the Easton/Pacific area (>50:1). LOCKWOOD (1990) proposed that fluid mixing occurred based on fluid inclusion studies, which would support this model, too.

e) Tertiary age:

Finally, mineralization in the VCMD may be attributed to localization of meteoric hydrothermal fluids in tensional quartz veins by Tertiary (Middle Eocene to Miocene) extensional faults, possibly during detachment fault propagation.

This is partly supported by directions of main quartz veins which strike northeast in Lucas/Atlas and South Bachelor areas and is parallel to the general extensional basins to the east and west.

Different striking directions of other veins, especially in the Easton/Pacific area, and presence of high-grade ore shoots within northwest-striking shear and breccia zones are contradicting this possibility. Andesite plugs observed by MARVIN and DOBSON (1979), which crosscut mineralization in U.S. Grant and El Fleeda mines, suggest that at least some of the mineralization is older than Eocene.

5.6. Proposed genetic model and discussion

None of the proposed models are adequate enough to explain all of the existing data and a number of different processes and events may have operated in different parts of the district over geologic time. The following model for the Lucas/Atlas and South Bachelor mineralization within the VCMD considers field examinations by the author, geophysical surveys, geochemical survey results, re-logging of core and chip samples, data compilation, and petrographic and metallographic studies.

Shallow crustal-level emplacement of the deposit is indicated by several observations:

- presence of dominant brittle ore-hosting structures (e.g. discordant quartz veins and brittle northwest-trending shear zones)
- the presence of several stages of hydrothermal activity that resulted in multiply brecciated ore and gangue, and
- the abundance of open-space filling textures

Lower formation depths led to lower lithostatic or hydrostatic pressures, higher permeabilities, and the enhanced availability of surface water reservoirs.

Structurally, mineralization in the VCMD can be assigned to the second uplift of metamorphic core complexes in southwestern Montana due to complex interaction of paired fault systems between thrust belt structures and northwest-trending left-lateral strike-slip faults and development of positive flower structures during Laramide crustal shortening. This may have been accompanied by unexposed coeval intrusions similar to the Tobacco Root Batholith although they are not necessarily needed to explain

mineralizations for some mineralized shear zones in the Tobacco Root Mountains are clearly post-intrusive. Veins could have been emplaced in an en echelon array between major left-lateral strike-slip faults as subsidiary shear fractures and Riedel shears which developed at a small angle (roughly 10-20°) synthetic to the main strike-slip fault. This proposal can be seen on the following map view of an idealized left-lateral strike slip system (fig. 29).

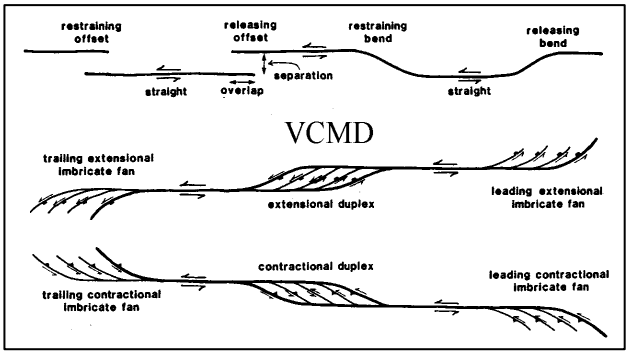


Fig. 29: Map view of an idealized left-lateral strike-slip system (modified after TWISS and MOORES, 1992).

It is necessary to state, that, depending on fault geometry, both extensional and contractional duplexes can occur along a single strike-slip fault. Brittle horsetail structures and imbricated extensional or collosional duplexes, as described by WOODWARD (1993) for the Pony district, have not been indicated without doubt within the Lucas/Atlas and South Bachelor areas of the VCMD due to limited outcrop and high coverage but can be inferred from mapping results. The more curvilinear shape of vein trends in Easton/Pacific areas could be interpreted as trailing extensional imbricate fans. Tertiary extensional tectonics are considered just to be modifiers of earlier Laramide age structures. This is left to confirmation by new mapping with the new model.

Volcano-sedimentary rocks may be considered as the primary source of gold, especially if the Alder Gulch represents a contact zone of volcanic to sedimentary rocks and the Kearsarge shear zone is paralleling it. Thus, gold and sulfides may be of volcanic-exhalative origin similar to the Pyrite Belt in Spain and Portugal where exhalative submarine mineralizations mark the top of tuffaceous rocks suites (GRIMES and KROPSCHOT, 1998). Precious metals might have been syngenetically deposited at this contact and subsequently redistributed and concentrated to ores in favorable structures.

Gold is transported most efficiently as a bisulfide complex in most epithermal environments as experimental works supports (THIERSCH, et al., 1997). Gold-chloride complexes generally predominate only at temperatures above 300°C, or under unusually H_2S-poor and chloride-rich conditions. In contrast to gold, silver forms stable complexes with both bisulfide and chloride ligands under epithermal conditions. However, at the low temperature conditions which LOCKWOOD (1990) observed by fluid inclusion studies and illite/smectite ratios at the Easton/Pacific mines, bisulfide complexes should dominate in the VCMD.

Hydrothermal fluids of dominantly meteoric origin were heated, leached metals from the country rocks, were channeled along faults to higher levels, and subsequently deposited gold and silver as a result of boiling and replacement. This was initially accompanied by pervasive propylitization which was followed by selective potassic alteration on selvages and partly by pervasive disseminated potassic alteration which has been observed. Rarely, euhedral K-spar crystals grew into the quartz vein perpendicularly to the rim. Sulfidization carrying gold occurred together with silification in the main mineralization stage. Adiabatic boiling induced a rapid drop in temperature, causing quartz supersaturation and precipitation of quartz and pyrite with enclosed gold.. The latest alteration stage is marked by barren carbonate alteration filling open space in the quartz vein vugs. The shape of the alteration halo is more or less tabular (like the vein system) and usually is not greater than 1-3 m on either side of the vein system.

It is necessary to resolve the problem of the vicinity of high-temperature potassic alteration in the Lucas/Atlas and South Bachelor areas to low-temperature argillic alteration in the Easton/Pacific area (see fig. 30).

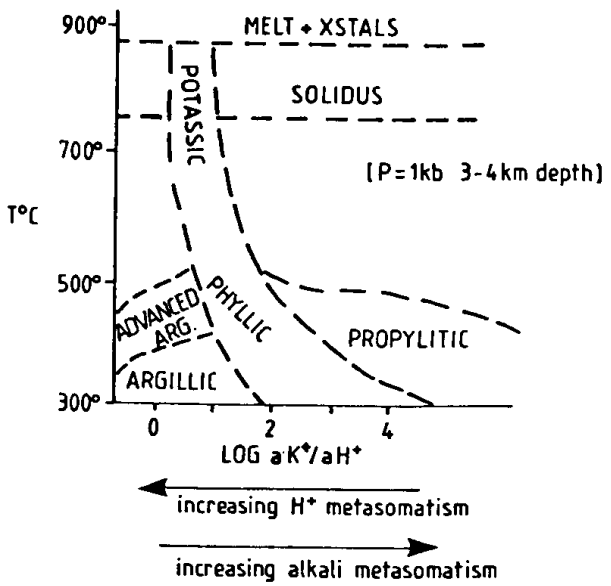


Fig. 30: Scheme of idealized evolutionary alteration sequence, alteration as a function of temperature, K^+ and H^+ activities (after GUILBERT and PARK., 1986).

Mineral deposits in the VCMD can be assigned to bridge the artificial boundary between epithermal and mesothermal deposits. It can be assumed that probably minor fault blocks have been popped-up to higher elevations like the Lucas/Atlas and South Bachelor areas or that Tertiary extension led to greater subsidence of the Greenhorn Range in its western part where the Easton/Pacific mines are located. It is possible that both mechanisms occurred as can bee seen on the previously described figure 20 in the structure section. Alternatively, potassic alteration dominating mineralization in the Lucas/Atlas and South Bachelor areas could be interpreted on a district-wide scale as an early stage epi- to mesothermal, higher temperature mineralization which was overlain by epithermal, lower temperature mineralization within the Easton/Pacific veins associated with argillic alteration. This would imply a telescoped structure as has been proposed by MARCOUX and JÉBRAK (1999) for the Butte district. On the other hand, twofold basement uplift may have introduced an early (Sinian time) mesothermal mineralization, which has been overprinted by later (Laramian time) association.

Additionally, proposed mixed fluid sources in the Easton/Pacific mines (LOCKWOOD, 1990) indicate that some fluid may have been derived from unexposed intrusions and may have contributed to the source and transport mechanism of mineralization.

The following figure 31 shows a cartoon cross section of Creede type epithermal vein deposit, where the approximate position of the Lucas/Atlas and South Bachelor areas, VCMD has been inserted.

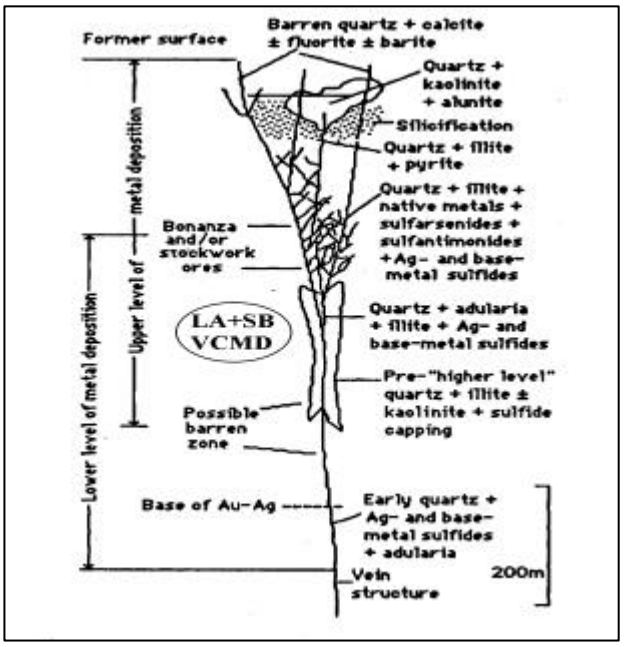


Fig. 31: Cartoon cross section of typical Creede-type epithermal vein deposit; inserted approximate position of the Lucas/Atlas and South Bachelor areas, VCMD, southwestern Montana (modified after COX and SINGER, 1992).

Comparison

Other cratons of similar ages with known gold deposits are the Australian Yilgarn Craton and the Canadian Superior Province. They usually exhibit mineralized shear zones within greenstone associations or intrusions of granitic to syenitic compositions (GROVES and PHILLIPS, 1987).

For the mineralization in the VCMD is not related to Archean or Proterozoic tectonics, but to uplifts of cordilleran metamorphic core complexes and related structures, it can be best compared to Basin and Range mineralization style in Nevada and Arizona. Similar tectonics have been assumed by NIELSEN (1979) for porphyry-copper emplacement along major north-west-trending faults during Laramide uplift.

Proposed further studies

Some features which were observed or discovered allow to get a better understanding of the geology and mineralization processes in this area. Much more work has to be done to improve the genetic model proposed here and those by different other authors. It would be interesting to look in the whole VCMD or even the Greenhorn Range if the proposed geologic model is suitable to explain all litho-structural features. Detailed stable and radiogenic isotopic studies have not been as widely applied in the VCMD as they have been in the other Archean rocks in southwest Montana (e.g. Beartooth Mountains). Future studies of oxygen, sulfur, and lead isotope may provide valuable clues about the source of some ore constituents. To determine the age relationship of mineralization and deformation, the sheared gneisses in the Kearsarge shear zone should be sampled for $^{40}K/^{40}Ar$ dating on sericite at the Kearsarge mine.

5.7. Why gold ?

Geochemistry of gold

Gold's average cosmic concentration is 5.3 ppb, and the Clarke value, which represents average concentration in the earth's crust, is 3.5 ppb (BOYLE, 1979). Concentrations within different rock types are highly variable and selected samples are presented in the following compilation (table 1, next page).

Firstly it should be noted that gold concentrations vary widely in all rock suites. Gold content in igneous rocks is highest in acidic (0.1-2,900 ppb) and to a smaller amount in basic rocks (0.1-680 ppb). Lowest concentrations are associated with lam-

prophyres (0.7-2.0 ppb) and alkali-rich rocks (0.1-13.5 ppb). This is contradicting general assumptions (for example GROOVES and PHILLIPS, 1987) that mafic rocks are enriched in gold relative to acidic rocks.

In sedimentary rocks, fine clastics are enriched in gold (0.1-800 ppb) especially when they carry sulfides like black shales do (2.5-2,100 ppb). This observation respects the favored lithogeochemical trap for gold (reduced and organic carbon-rich rocks). Evaporates carry 0.5-85.0 ppb gold in average, which is similar to limestones (0.2-88.9 ppb). High values are associated with gypsum, anhydrite. The highest gold concentrations, however, are found in unconsolidated sediments (0.3-2,500 ppb), indicating that significant mobilization occurs during compaction and diagenesis of sedimentary rocks.

Metamorphic rocks represent approximately concentration ranges of their protoliths. Therefore, highest values can be found in schists (0.1-3,700 ppb), quartzites (0.2-1,150 ppb), and gneisses (0.2-300 ppb). Elevated concentrations are secondarily associated with high fluid fluxes, for example due to intrusions (hornfels: 0.3-300 ppb).

rock types	Au range (ppb)
all igneous rocks	0.1-2,900
ultrabasic rocks	0.2-780
lamprophyres	0.7-2.0
basic rocks	0.1-680
intermediate rocks	0.1-350
acidic rocks	0.1-2,900
alkali-rich rocks	0.1-13.5
all sedimentary rocks	0.1-2,500
unconsolidated sediments, oceans	0.3-2,500
coarse clastic rocks (sandstones, arkoses)	0.2-430
fine clastic rocks (shale, siltstone)	0.1-800
sulfidic black shale	2.5-2,100
tuffs	0.5-112
limestone, dolostone	0.2-88.9
evaporates	0.5-85.0
chert	5.0-40.0
all metamorphic rocks	0.1-3,700
quartzites	0.2-1,150
meta-argillites (slates, phyllites)	0.9-15.0
gneisses, granulites	0.2-300
amphibolites, greenstones	0.1-100
schists	0.1-3,700
marble	0.2-100
hornfels	0.3-300
eclogites	0.8-40.0
skarns	7.6-22.0

Tab. 1: Gold contents of different rock types (taken from BOYLE, 1979).

Gold economy

World mine production of gold was about 2,330 tons in 1999, a drop of 5.3 % in comparison to 1998. The U.S.A. hold second position producing 340 tons of gold (14.6 %), following South Africa (450 tons or 19.3 %; USGS, 2000, fig. 32).

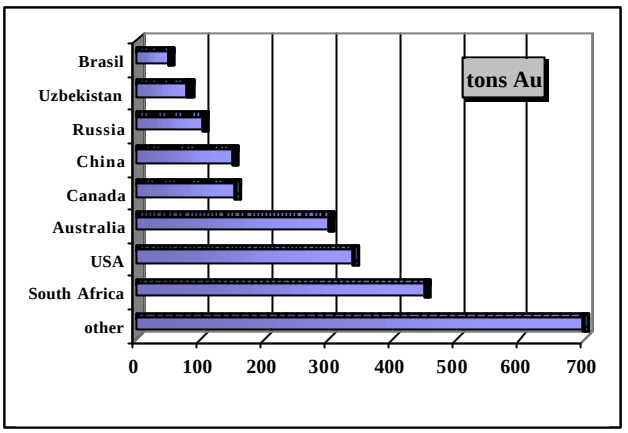


Fig. 32: World gold production in tons of selected states (data taken from USGS, 2000).

Only a fraction, about 4%, of the annually world gold production in 1999 has been used industrially (e.g. for electronics, figure 33). The majority of demand (79%) is represented by jewelry fabrication and arts. Only about 10% are investment operations, whereas 4% of gold went into dental uses. Future uses of gold may be in medical attention, for example in retarding prostate cancer and ovarian cancer which can be treated with colloidal gold.

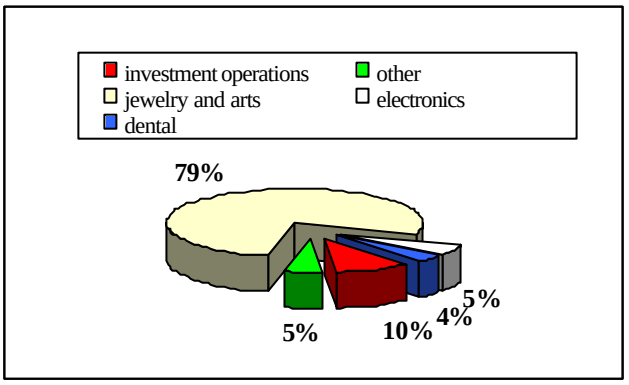


Fig. 33: Estimated uses of world gold production in 1999 (after USGS, 2000).

Total world gold resources are estimated at 100,000 tons, of which 15-20% is byproduct potential resource. South Africa possesses about one-half of all world resources, whereas Brazil and the U.S.A. have about 9% each (USGS, 2000).

Of an estimated 128,000 tons of all gold ever mined historically during approximately 6000 years, about 15% is thought to have been lost, used in dissipative industrial applications. Of the remaining 108,000 t which are still available, an estimated 34,000 t are stockpiled by central banks and about 74,000 t is privately held as coin and jewelry.

Initially, backing of national currencies by gold has been legislatory. After the American and other national banks of industrialized countries left this system in 1974, value generation and backing is

oriented on commodities and goods. The official stock hold is more than 13 times the annual production of the world's mines; if sold, these reserves could satisfy gold demand for more than 8 years (current demand is approximately 4,000 tons per year; USGS, 2000). The following table 2 shows gold reserves in main central banks in 1997.

Country	Tons	% of GDP*
U.S.A.	8138	1.2
Germany	2960	1.5
Switzerland	2590	11.2
France	2546	2.0
Italy	2074	2.0
Netherlands	1081	3.3
Japan	754	0.2
Great Britain	573	0.5
Belgium	476	2.0
Austria	334	1.8

Tab. 2: Gold reserves in main central banks in 1997. *GDP: gross domestic product (taken from BAUCHAU, 2000).

Recently, gold market has been struck by planned and executed gold sales by main European and the Australian central banks. Moreover, the International Monetary Fund (IMF) planned to fund its debt release initiative for "Highly Indebted Poor Countries" (HIPC) by selling or reevaluating its gold stock which generated additional negative sentiment in the gold markets and thus on world gold exploration expenditures. It sold its gold to HIPC countries and accepted it immediately back for payment of an obligation due that same day. IMF took advantage of the difference between the value of gold on its books and the much higher market price. The cash is then invested and the interest is used to support the HIPC initiative (AMERICAN METAL MARKET, 2000).

These actions led to a significant drop of the gold price due to oversaturation of the gold market. The following figure 34 shows the rapid fall of the price of gold since 1996 where it reached US$ 400/oz.

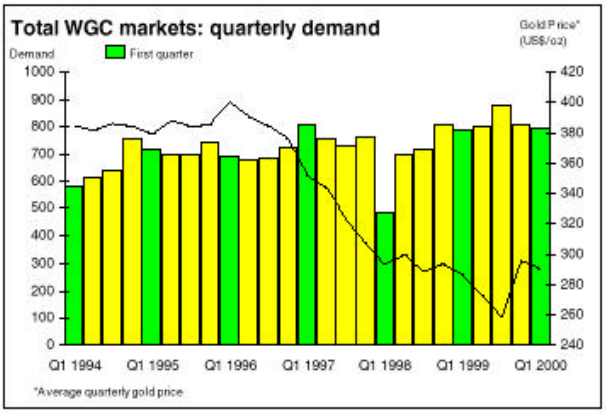


Fig. 34: Quarterly gold demand and trends of gold price from 1994-2000 (WORLD GOLD COUNCIL, 2000).

Gold encountered its lowest price for twenty years (US$ 253/oz) in September 1999. As a result, high-cost underground operations had been struck (particularly in South Africa). End of 1999, a group of mainly European central banks announced that future gold sales would be restricted to only small quantities (the so-called "Washington agreement"). This immediately propelled the price 25% higher (US$ 326/oz). Since then prices fell back to levels around US$ 270-290 (BAUCHAU, 2000).

The price of gold is unnaturally depressed, when looking at steady growth of demand, as can be seen on the same figure 34. World gold demand rose steadily from 1994 to 2000 from approximately 600 t/quarter to 800 t/quarter with the exception of the first quarter in the year 1998. This strong demand growth has basically been driven by rising demand in India, Pakistan, and Turkey, where major jewelry markets are located (WORLD GOLD COUNCIL, 2000).

Future mid-term gold prices will highly rely on selling policy of central banks and IMF. As some of the developing countries, which the IMF is keen to disencumber, are major gold producing countries, these sales will possibly be spread over several years. Besides this impact on gold prices, steady growth of demand will generate higher prices, after currently sold gold has been bought up. Demand will be rising especially for central bank investment operations constitute only for 10% of uses, whereby growth in Asia and the Middle East will be major future gold markets due to economic rebound, growing population and traditionally high valuation of gold investment and jewelry. Moreover, gold jewelry sold in the Middle East and Asia is usually made of very pure gold, whereas that marketed in America and Europe is usually alloyed and sold more as an adornment.

The possibility of rising prices is indicated additionally by a gap which between world's future gold supply and its demand and may thereby create gold shortages. This is fairly obvious from the following figure 35.

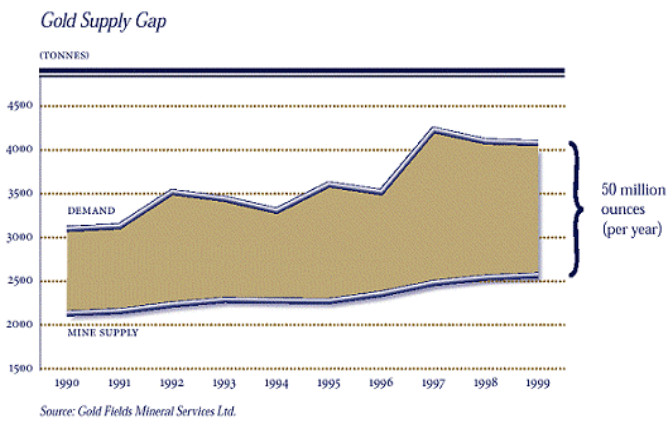


Fig. 35: Gold supply gap (taken from GOLD FIELDS MINERAL SERVICES LTD., 1999).

It should be considered that in developing countries and traditional cultures gold provide economic security. The recent devaluation of Asian currencies has reinforced their faith in gold. The gold jewelry market, at least in the West, is relatively mature. The significance of gold as reserve for federal banks will slightly diminish in the future, though gold could be kept as an alternative for foreign exchange payments and thus to diversify in order to minimize risks.

Moreover, gold has some major advantages when compared to other mineral commodities:

- absence of a market barrier: The market will buy any quantity of gold from a miner on the basis of an official assay, whether it is a small-scale miner or large mining company. This contrasts considerably with other commodities like zinc from small mines.
- generation of added value: Gold generates a much higher relative added value in the country of origin for several mining and refining stages can be done locally without sending concentrates to smelters elsewhere. This is very important for developing countries.
- shorter lead times: Gold mines are sooner in production than base metal mines, statistically, especially in industrial countries (WELLMER, 1994).

Environmental considerations

Gold mining has some major disadvantages which cannot be ignored, in addition to general impacts of mining.

Cyanides are used for leaching fine-grained gold ores and mercury for amalgamation in the final processing stage. These substances are potential hazards as they are toxic to humans and animals. Cyanide and mercury ions form more stable complexes with hemoglobin in blood compared to oxygen which ties up respiration.

On January 30, 2000, an overflow containing cyanide occurred along a tailings dam at the Aurul gold plant at Baia Mare, northwestern Romania, after exceptionally heavy rain and snow melt. The incident contaminated rivers in Hungary and Yugoslavia, fishes have been killed, and water supplies had to be shut down (WASHINGTON POST, 2000). In 1993 the Summitville gold mine in Colorado was abandoned by Galactic Resources, leaving the mine site uncleaned. In 1997, the Zortman-Landusky gold mine in Montana was abandoned by Pegasus Gold Corporation after cyanide spills and was not cleaned-up after declaration of bankruptcy (YOUNG, 2000).

The State of Montana banned the use of cyanide for any new or expanding gold or silver open-pit mines using heap-leaching or vat-leaching techniques. The ban was a result of the voters' approval of Initiative 137, which won by a 53% to 47% margin in November, 1998.

Mining, by it's nature, poses a risk to society. If a society chooses to enjoy the benefits of mining, then it should be willing to bear the responsibility if something goes wrong. Risk can be mitigated by strict governmental regulation. Technologies to deal with these toxic substances in processing gold ore in an environmentally safe way are available and widely used by many plants in Canada, the U.S.A. and Australia, even on a small prospector scale (WELLMER, 1994). Shifting local risks of mining to other, less developed countries, withdraws potential public control, as could be seen in Romania this year.

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flocation, type of outcrop	lithology, alterations	tectonic measurements	remarks
1: adit outcrop dimensions: 10x20 m	**Agg:** granitic gneiss; fine-grained; fresh colour: reddish gray; weathered: light brown; composition: K-spar 35-50%, quartz 30%, plagioclase 20-30%, biotite 0-5%; chloritic alteration; silicified breccia.	**foliation:** 297/86 **joints:** 344/40, 55/40, 205/85 slickenslides parallel to foliation	sample of breccia
2: exposure outcrop dimensions: 15x15 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; weathered: medium-gray to light brown; composition: plagioclase 40-45%, quartz 30%, K-spar 10%, biotite 10%, garnet 5-10% (red, mm-1cm-size); migmatitic (striatic, concordant; composition: plagioclase-quartz-K-spar); folds in m-dm-size; **Aam**-lenses (cm-dm-size) within this unit.	**foliations:** 302/68, 128/75, 127/80, 302/68, 128/75 **fold axises:** 10/30 (antiform), 23/25 (synform) **joints:** 87/40, 320/30, 216/54 (ac)	sample
3: exposure outcrop dimensions: 15x10 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; weathered: dark gray to light brown; composition: plagioclase 30-35%, quartz 30%, K-spar 20-25%, biotite 10%, garnet 5% (red, mm-size); migmatitic (striatic, concordant and granitic in composition).	**foliations:** 122/84, 303/65 **joints:** 88/45, 23/80, 329/40	sample
4: exposure outcrop dimensions: 10x10 m	**Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray-brown; weathered: light brown; composition: plagioclase 40%, quartz 30%, K-spar 20%, biotite 5%, garnet 5% (rot, mm-size); migmatitic (leucosome 10-15% consisting of K-spar, quartz, +/- plagioclase, +/- garnet).	**foliation:** 300/90 **joints:** 17/59, 212/62, 81/26	sample
5: road cut outcrop dimensions: 15x2 m	**Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 30-50%, quartz 30-40%, K-spar 10%, biotite 5-10%; garnet 5-10% (red, mm-3cm-size); highly migmatitic (striatic leucosome up to 20% consisting of K-spar, quartz, plagioclase).	**foliation:** 306/60 **joints:** 112/45, 43/45, 216/56	-
6: prospect/adit outcrop dimensions: 15x10 m	**Atg:** tonalitic gneiss; fine-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 35-45%, quartz 30%, K-spar 15-20%, biotite 5-10%; garnet 0-5% (red, mm-size); chloritic alteration; two discordant pegmatites (Peg): 1) 30-40 cm; coarse- to very-coarse-grained, composition: K-spar, quartz, plagioclase, +/- biotite; 2) 5-10 cm; coarse-grained, composition: K-spar, quartz, plagioclase, +/- biotite.	**foliation:** 317/60 **contact Peg 1:** 2/45 **contact Peg 2:** 46/58	sample
7: road cut outcrop dimensions: 3x10 m	tonalitic gneiss **(Atg)** at contact to granitic gneiss **(Agg)**: **Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 30-45%, quartz 30%, K-spar 25-30%, biotite 0-5%; garnet 0-5% (red, mm-size); highly migmatitic (leucosome up to 30% consisting of K-spar, quartz, and plagioclase). **Agg:** granitic gneiss; medium-grained; fresh colour: reddish gray; weathered: light brown; composition: K-spar 30-35%, quartz 35%, plagioclase 30%, biotite 0-5%; two discordant pegmatites (Peg): 1) 2 cm; coarse-grained, composition: K-spar, quartz, plagioclase, +/- biotite; 2) 10 cm; coarse-grained, composition: K-spar, quartz, plagioclase, +/- biotite.	**foliations:** 290/75, 110/80 **contact Peg 1:** 220/75 **contact Peg 2:** 70/75 **joints:** 16/70, 218/55, 295/45, 94/30	-

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
8: road cut outcrop dimensions: 10x2 m	**Agg:** granitic gneiss; medium-grained; fresh colour: reddish gray; weathered: light brown; composition: K-spar 30-40%, quartz 30%, plagioclase 30%, biotite 0-5%, garnet 0-5% (red, mm-size); K-spar around quartz stringers.	**foliation:** 294/85 **joints:** 60/55, 344/75, 245/62	-
9: road cut outcrop dimensions: 4x2 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 50-55%, plagioclase 30%, quartz 10%, garnet 5-10% (red, mm-size).	**foliation:** 124/85 **joints:** 28/16, 224/60, 120/44	-
10: road cut outcrop dimensions: 10x2 m	**Agg:** granitic gneiss; medium-grained; fresh colour: reddish white; weathered: light brown, ochre; composition: K-spar 35-45%, quartz 30%, plagioclase 20-30%, biotite 5%.	**foliation:** 124/70 **joints:** 198/80, 273/60, 342/75	-
11: road cut outcrop dimensions: 20x3 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 40%, quartz 30%, K-spar 20%, biotite 5%; garnet 5% (red, mm-size); highly migmatitic (striatic leucosome up to 40 % consisting of K-spar, quartz, and plagioclase); discordant pegmatite (Peg): 30 cm, consisting of K-spar, quartz, plagioclase, +/- biotite; quartz veins with sulfides in hand specimen (float).	**foliation:** 307/76 **joints:** 54/78, 100/25, 206/88	samples of quartz veins
12: road cut outcrop dimensions: 10x2 m	**Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 40-50%, quartz 35%, K-spar 15%, biotite 0-5%; garnet 0-5% (red, mm-size); migmatitic (striatic; leucosome 5-10% consisting of K-spar, quartz, plagioclase, biotite); discordant pegmatite **(Peg)**: 1 m; zoned: medium-grained and granitic in composition at contact; coarse grained in center.	**foliation:** 306/82 **contact Peg:** 350/46 **joints:** 195/64, 50/62, 227/52	sample
14: road cut outcrop dimensions: 50x2-3 m	**Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 40-50%, quartz 30%, K-spar 15-20%, biotite 5%, garnet 0-5% (rot, mm-1cm-size); highly migmatitic (leucosome 10-30% consisting of K-spar, quartz, +/- plagioclase, +/- garnet); selective and disseminated K-spar alteration; **Aam**-lenses (cm-dm-size) within this unit; discordant pegmatite (Peg): 5-6 cm in diameter; composition: K-spar, quartz, +/-plagioclase.	**foliation:** 304/78 **contact Peg:** 34/60 **isoclinal folds:** 220/14 (synform), 34/12 (antiform) **joints:** 231/31, 241/76, 1/35	sample
16: road cut outcrop dimensions: 10x2 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 50-55%, plagioclase 25-30%, quartz 10%, garnet 5-10% (red, mm-size), biotite 0-5%; migmatitic (nebulitic), leucosome consists of plagioclase and quartz, +/- garnet.	**foliations:** 166/46, 155/55, 168/57 **joints:** 96/85, 170/75, 50/74, 314/20	biotite rare, in 10 cm wide bands, retrogressed ? sample
17: road cut outcrop dimensions: 2x2 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; highly weathered: light brown; composition: plagioclase 50%, quartz 30%, K-spar 15%, biotite 5%, garnet 1-2% (red, mm-1cm-size); layers in cm-scale.	**foliations:** 127/60, 145/35 **joints:** 270/70, 344/60	sample
18: road cut outcrop dimensions: 20x3-4 m	**Aum:** ultramafic assemblage; fine-grained; fresh colour: black; weathered: dark brown; massive; composition: ?	**joints:** 270/75, 80/70, 340/75	sample

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
19: road cut outcrop dimensions: 15x3 m	**Atg:** tonalitic gneiss; fine-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 50-60%, quartz 30%, K-spar 5-10%, biotite 5-10%, no garnet; migmatitic (striatic, coarse grained, granitic in composition); concordant pegmatites (K-spar-quartz-biotite); highly potassic altered on joints, rarely within the tonalitic gneiss.	**foliations:** 142/66, 142/70 **joints:** 262/70, 18/52	sample
20: exposure outcrop dimensions: 15x4 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 35-60%, plagioclase 25-30%, quartz 10-20%, garnet 5-15% (red, mm-1cm-size); migmatitic (nebulitic), leucosome (10-20%) consists of plagioclase and quartz, +/- garnet. two discordant pegmatites **(Peg)**: 1) 3 m in diameter; coarse grained and complexly zoned; composition: K-spar, quartz, plagioclase, biotite in cm-2dm-size. 2) 1,5 m in diameter; coarse grained; composition: K-spar, quartz, plagioclase, biotite in cm-size.	**foliations:** 132/70, 124/70, 132/60 **joints:** 66/74, 45/86, 260/69 **Peg contact 1):** 346/48 **Peg contact 2):** 230/85	sample
21: road cut outcrop dimensions: 30x4 m	**Atg:** tonalitic gneiss; fine- to medium-grained; compositional layering; fresh colour: light gray; highly weathered: light brown; composition: plagioclase 40-50%, quartz 20-30%, K-spar 10%, biotite 10-15%, garnet 0-5% (red, mm-size); migmatitic (striatic, coarse grained, granitic in composition).	**foliations:** 133/86, 188/42, 160/75 **joints:** 240/30, 50/82, 354/74	sample
22: road cut outcrop dimensions: 50x3-5 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 50-60%, plagioclase 30%, quartz 10-20%, no garnet.	**foliations:** 101/51, 130/62, 122/50 **joints:** 19/76, 240/68, 336/62	sample
23: road cut outcrop dimensions: 3x5 m	**Atg:** tonalitic gneiss; medium-grained; compositional layering; fresh colour: light gray; weathered: yellowish brown; composition: plagioclase 40-50%, quartz 30%, K-spar 10%, biotite 5-10%, garnet 5-10% (red, mm-1cm-size).	**foliations:** 137/54, 144/60 **joints:** 4/85, 292/66, 90/62	-
24: road cut outcrop dimensions: 10x4 m	**Atg:** 2-3 m tonalitic gneiss within **Aam**; medium-grained; compositional layering; fresh colour: light gray; weathered: light brown; composition: plagioclase 40-50%, quartz 25-30%, K-spar 10-15%, biotite 10%, garnet 5% (red, mm-size); migmatitic (striatic, coarse grained, granitic in composition).	**foliation:** 140/46 **joints:** 260/80, 270/75, 22/81	sample
25: road cut outcrop dimensions: 10x2 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; highly weathered: dark brown; composition: hornblende 50-60%, plagioclase 20-25%, quartz 10%, garnet 10-15% (red, mm-1cm-size); leucosome 10-30%, then very garnet-rich (20-30% of leucosome); discordant pegmatite, coarse-grained (5 cm), K-spar, plagioclase, quartz, biotite.	**foliation:** 98/74 **joints:** 30/76, 309/75 **Peg contact:** 31/44	sample
26: exposure outcrop dimensions: 15x15 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; weathered: yellowish gray; composition: plagioclase 30-40%, quartz 30%, K-spar 20-25%, biotite 5-10%, garnet 5-15% (red, mm-size); strongly migmatitic (20-30% leucosome; striatic, coarse grained, granitic in composition).	**foliation:** 304/80 **joints:** 247/85, 206/42, 97/30	sample

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
27: road cut outcrop dimensions: 3x3 m	transition from **Aam** to **Atg**: **Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 50-60%, plagioclase 30%, quartz 10-20%, no garnet. **Atg:** tonalitic gneiss; medium-grained; compositional layering; fresh colour: light gray; weathered: light brown; composition: plagioclase 40%, quartz 30%, K-spar 10%, biotite 10-15%, garnet 5-10% (red, mm-size); garnet-rich especially at contact to **Aam**.	**foliation:** 154/40 **joints:** 57/88, 337/42	Atg sample
28: road cut outcrop dimensions: 2x2 m	**Atg:** tonalitic gneiss; fine- to medium-grained; compositional layering; fresh colour: light gray; weathered: yellowish gray; composition: plagioclase 40-50%, quartz 30%, K-spar 10%, biotite 5-10%, garnet 5-10% (red, mm-size).	**foliations:** 168/35, 166/55 **joints:** 273/85, 308/25, 268/40	sample
30: road cut outcrop dimensions: 20x2 m	**Atg:** tonalitic gneiss; fine-grained; compositional layering; fresh colour: light gray; weathered: yellowish gray; composition: plagioclase 45-55%, quartz 30%, K-spar 10%, biotite 5-10%, garnet 0-5% (red, mm-size).	**fold axises:** 36/31, 52/29 (antiforms) **foliations:** 154/45, 312/70, 132/36, 312/85 **joints:** 277/60, 77/67, 274/68 **faults:** 90/61 (direction ?)	sample
31: road cut outcrop dimensions: 8x2 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 40%, plagioclase 40%, quartz 10%, garnet 10% (red, mm-size).	**foliation:** 108/45 **joints:** 61/74, 321/40	sample
32: road cut outcrop dimensions: 4x2 m	**Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray; weathered: yellowish gray; composition: plagioclase 40-50%, quartz 30%, K-spar 10-20%, biotite 10%, no garnet; migmatitic (10% leucosome; striatic, coarse grained, granitic in composition).	**foliations:** 284/80, 129/70 **joints:** 200/80, 198/19	sample
33: road cut outcrop dimensions: 10x3 m	**Agg:** granitic gneiss; fine- to medium-grained; fresh colour: reddish gray; weathered: light (tan) yellow-brown; composition: K-spar 40%, quartz 30%, plagioclase 20%, biotite 5%, garnet 5% (red, mm-size); K-spar alteration on joints.	**foliation:** 134/76 **joints:** 253/68, 28/23, 273/35	sample
34: road cut outcrop dimensions: 10x3 m	**Agg:** granitic gneiss; fine- to medium-grained; fresh colour: reddish gray; weathered: light (tan) yellow-brown; composition: K-spar 40%, quartz 30%, plagioclase 20%, biotite 5%, garnet 5% (red, mm-size). discordant pegmatite **(Peg)**: 1) 1 m in diameter; coarse grained and massive; composition: K-spar, quartz, plagioclase, biotite in cm-size.	**foliation:** 306/86 **joints:** 218/70, 50/66 **fault:** 80/37 (sinistral) **Peg contact:** 341/86	-
35: road cut outcrop dimensions: 4x3 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 20-25%, plagioclase 20%, quartz 20%, garnet 15-20% (pink !, mm-size).	**foliation:** 286/76 **joints:** 192/85, 15/45	sample
36: road cut outcrop dimensions: 8x2-3 m	**Agg:** granitic gneiss; fine- to medium-grained; fresh colour: reddish gray; weathered: light (tan) yellow-brown; composition: K-spar 40%, quartz 30%, plagioclase 20%, biotite 5%, garnet 5% (red, mm-size).	**foliation:** 315/82 **joints:** 8/10, 212/85, 208/40	-

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
38: road cut outcrop dimensions: 40x3 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; highly weathered: dark brown; composition: hornblende 40%, plagioclase 30%, quartz 20%, garnet 10% (red, mm-2cm-size).	**fold axis:** 26/35 (antiform) **foliation:** 286/82 **joints:** 8/10, 212/85, 208/40	sample
39: road cut outcrop dimensions: 10x3 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; highly weathered: dark brown; composition: hornblende 40%, plagioclase 30%, quartz 20%, garnet 10% (red, mm-2cm-size). two discordant pegmatites **(Peg)** which are crossing eachother without displacement: 1) 50 cm in diameter; coarse grained to very coarse grained; composition: K-spar, quartz, plagioclase, biotite. 2) 20 cm in diameter; coarse grained; composition: K-spar, quartz, plagioclase, biotite.	**Peg contact 1):** 54/24 **Peg contact 2):** 344/50	-
40: road cut outcrop dimensions: 8x4 m	**Aggm:** granitic gneiss, magnetic; fine-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 45-50%, quartz 30%, plagioclase 20%, biotite 0-5%, magnetite ~1%.	**foliations:** 121/84, 278/75 **joints:** 198/76, 40/45, 188/71, 62/25	sample
41: road cut outcrop dimensions: 15x5 m	**Agg:** granitic gneiss; fine- to medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 30-40%, quartz 35-40%, plagioclase 20-30%, biotite 0-5%.	**foliation:** 119/80 **joints:** 172/55, 310/83, 282/65, 336/67	sample
45: road cut outcrop dimensions: 30x5 m	**Agg:** granitic gneiss; medium-grained; fresh colour: reddish gray; weathered: light (tan) brown; composition: K-spar 40-50%, quartz 30%, plagioclase 20-25%, biotite 0-5%. discordant pegmatite **(Peg)**: 5 cm; medium- to coarse-grained; composition: quartz-K-spar-plagioclase-biotite).	**foliation:** 310/75 **contact Peg:** 18/32 **joints:** 221/70, 74/45, 6/25	sample
46: road cut outcrop dimensions: 20x3-4 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 40-50%, quartz 30-35%, K-spar 5-10%, biotite 10%, garnet 5% (red, mm-1cm-size).	**foliations:** 297/75, 132/80 **fold axis:** 29/10 (antiform) **joints:** 209/82 (ac)	-
47: road cut outcrop dimensions: 30x3-5 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 40-50%, quartz 30-35%, K-spar 5-10%, biotite 10%, garnet 5% (red, mm-1cm-size).	**foliation:** 125/75 **joints:** 308/25, 227/26, 247/65, 218/25	sample
49: road cut outcrop dimensions: 20x3 m	**Agg:** granitic gneiss; medium-grained; fresh colour: reddish white; weathered: light (tan) yellow-brown; composition: K-spar 45%, quartz 30%, plagioclase 30%, biotite 5%.	**foliation:** 312/80 **joints:** 240/70, 212/85, 91/25 **fault:** 308/86	sample
50: road cut outcrop dimensions: 40x3-4 m	**Agg:** granitic gneiss; medium-grained; fresh colour: reddish gray; weathered: light (tan) brown; composition: K-spar 40%, quartz 25-30%, plagioclase 20-30%, biotite 0-5%.	**fold axis:** 21/17 (antiform) **foliations:** 300/55, 127/80 **joints:** 197/54, 184/88, 190/25	sample
51: road cut outcrop dimensions: 10x3 m	**Agg:** granitic gneiss; medium-grained; fresh colour: reddish white; weathered: light (tan) yellow-brown; composition: K-spar 45%, quartz 30%, plagioclase 30%, biotite 5%.	**fault:** 110/88	-

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
52: road cut outcrop dimensions: 40x3 m	**Agg:** granitic gneiss; medium-grained; fresh colour: reddish white; weathered: light (tan) yellow-brown; composition: K-spar 45%, quartz 30%, plagioclase 30%, biotite 5%.	**foliation:** 300/84 **fault:** 110/86	-
53: road cut outcrop dimensions: 10x3 m	**Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 40-50%, quartz 30%, K-spar 10-15%, biotite 5-10%, garnet 5% (red, mm-size).	**foliation:** 116/88 **joints:** 224/68, 176/72, 188/16, 332/56	sample
54: road cut outcrop dimensions: 20x2 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 50%, quartz 30%, K-spar 5-10%, biotite 5%, garnet 5% (red, mm-size).	**foliation:** 148/70 **joints:** 59/86, 10/56, 42/62, 36/46	sample
55: road cut outcrop dimensions: 10x2 m	**Agg:** granitic gneiss; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 40%, quartz 30%, plagioclase 25%, biotite 5%.	**foliation:** 294/78 **joints:** 186/44, 188/75, 186/40, 97/54	sample
56: road cut outcrop dimensions: 40x4 m	**Agg:** granitic gneiss; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 50%, quartz 30%, plagioclase 15-20%, biotite 0-5%. discordant pegmatite (Peg): 5 cm, medium- to coarse-grained; composition: K-spar, quartz, plagioclase; dragged foliation during emplacement (dextral)	**contact Peg:** 350/32 **foliation:** 130/85 **joints:** 240/40, 46/35, 77/50, 248/84	sample
58: adit outcrop dimensions: 15x10 m	**Atg:** tonalitic gneiss; fine-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 40-50%, quartz 35%, K-spar 10-15%, biotite 5%, garnet 0-5% (rot, mm-size).	**foliation:** 112/52 **joints:** 230/76, 7/52, 332/70	sample
59: exposure outcrop dimensions: 10x20 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 35-40%, quartz 30%, plagioclase 20%, biotite 10%, garnet 0-5% (red, mm-size), magnetite ~1%.	**foliation:** 313/60 **joints:** 100/84, 281/18, 297/74, 191/55	sample
60: exposure outcrop dimensions: 10x20 m	**Agg:** granitic gneiss; medium-grained; fresh colour: reddish-pinkish white; weathered: light brown; composition: K-spar 30%, quartz 30%, plagioclase 30%, biotite 10%.	**foliation:** 313/55 **joints:** 98/59, 91/80, 209/71	sample
61: prospect outcrop dimensions: 15x10 m	contact **Aggm** to **Aam**: **Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 35-45%, quartz 30%, plagioclase 25-30%, biotite 0-5%, magnetite ~1%; quartz veins with sulfides parallel to foliation in hand specimen. **Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 60-70%, plagioclase 10-20%, quartz 10%, biotite 10%.	**foliation:** 297/81 **joints:** 260/88, 199/70, 58/68	sample, sample H1
63: road cut outcrop dimensions: 4x3 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; highly weathered: dark brown; composition: hornblende 60-70%, plagioclase 10-20%, quartz 15%, garnet 5% (red, mm-size); migmatitic (nebulitic), leucosome (10-15%) consists of plagioclase and quartz, +/- garnet.	**foliation:** 120/30 **joint:** 336/55	sample

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
64: exposure outcrop dimensions: 2x2 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: grayish brown; composition: hornblende 55-60%, plagioclase 20%, quartz 10%, biotite 0-5%; garnet 10% (red, mm-1cm-size); leucosome 10%, then very garnet-rich (20% of leucosome).	**foliation:** 289/85 **joints:** 193/70, 90/32	sample
65: exposure outcrop dimensions: 8x6 m	**Atg:** tonalitic gneiss; medium-grained; compositional layering; fresh colour: medium gray; weathered: light gray; composition: plagioclase 50%, quartz 30%, K-spar 10%, biotite 10%, garnet 5% (red, mm-size).	**foliation:** 118/83 **joints:** 226/45, 210/82	sample
66: road cut outcrop dimensions: 1x2 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; highly weathered: dark brown; composition: hornblende 60%, plagioclase 10%, quartz 10%, no garnet.	**foliation:** 120/88 **joints:** 260/28, 16/86	sample
67: road cut outcrop dimensions: 6x2 m	**Agg:** granitic gneiss; medium-grained; fresh colour: reddish medium-gray; weathered: light (tan) brown; composition: K-spar 40-50%, quartz 30%, plagioclase 10-20%, biotite 10%.	**foliation:** 324/64 **joints:** 195/60, 243/51, 38/41	sample
68: road cut outcrop dimensions: 6x2 m	**Agg:** granitic gneiss; medium-grained; fresh colour: reddish medium-gray; weathered: light (tan) brown; composition: K-spar 45-55%, quartz 30%, plagioclase 10-20%, biotite 5-10%, garnet 0-5% (red, mm-size).	**foliation:** 326/76 **joints:** 69/45, 244/42, 172/47	-
69: exposure outcrop dimensions: 20x20 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 35-40%, quartz 30%, plagioclase 25-30%, magnetite 5%, virtually no other phase in hand specimen.	**foliation:** 310/51 **joints:** 129/86, 233/36, 244/36, 24/60	sample
70: exposure outcrop dimensions: 10x10 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 35-40%, quartz 30%, plagioclase 25-30%, magnetite 5%, virtually no other phase in hand specimen.	**foliation:** 130/70 **joints:** 220/32, 20/61	sample
71: road cut outcrop dimensions: 30x4 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white-gray; weathered: light (tan) brown; composition: K-spar 35-45%, quartz 30%, plagioclase 25-30%, biotite 5%; K-spar alteration as spots.	**foliation:** 334/56 **joints:** 232/74, 221/60, 150/58	sample
72: road cut outcrop dimensions: 8x2 m	**Agg:** granitic gneiss; fine-grained; fresh colour: reddish white; weathered: light (tan) yellowish brown; composition: K-spar 35-40%, quartz 30%, plagioclase 25-30%, biotite 5%.	**foliation:** 123/88 **joints:** 241/60, 44/32, 139/44	sample
73: road cut outcrop dimensions: 4x2 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; weathered: yellowish middle-gray; composition: plagioclase 40-50%, quartz 30%, K-spar 15%, biotite 5-10%, garnet 0-5% (red, mm-size).	small open folds (dm-m-scale) **fold axises:** 50/25, 32/25, 35/10 (antiforms); 52/34, 36/26 (synforms) **foliations:** 124/85, 320/65 **joints:** 271/34, 221/71, 240/40, 338/42	sample
74: road cut outcrop dimensions: 20x2 m	**Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray; slacky weathered: brownish gray; composition: plagioclase 40-45%, quartz 30%, K-spar 20%, biotite 5-10%, no garnet.	**foliation:** 160/79 **joints:** 266/42, 358/62, 25/40	sample

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
75: road cut outcrop dimensions: 30x3 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 35-40%, quartz 30%, plagioclase 25-30%, magnetite 5%, virtually no other phase in hand specimen.	**foliation:** 110/84 **joints:** 348/34, 355/46, 112/88	sample
76: road cut outcrop dimensions: 25x2-3 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light (tan) yellowish brown; composition: K-spar 45-55%, quartz 30%, plagioclase 15%, biotite 0-5%, weak magnetic.	**foliation:** 268/86 **joints:** 183/32, 243/70, 46/44	sample
78: road cut outcrop dimensions: 20x2 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 35-40%, quartz 30%, plagioclase 25-30%, magnetite 5%, virtually no other phase in hand specimen.	**foliation:** 322/81 **joints:** 121/88, 335/44, 230/64	sample
79: road cut outcrop dimensions: 10x2 m	**Atg:** tonalitic gneiss; fine-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 40-50%, quartz 30%, K-spar 10%, biotite 10-15%, garnet 0-5% (red, mm-size).	**foliation:** 233/24	sample
81: road cut outcrop dimensions: 8x2 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; fine- to medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 40-45%, plagioclase 40%, quartz 10%, garnet 5% (red, mm-1cm-size); migmatitic (nebulitic), leucosome consists of plagioclase, quartz, and garnet (10%).	**foliation:** 296/73 **joints:** 149/40, 40/71	sample
82: road cut outcrop dimensions: 20x2-3 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light (tan) brown; foliation weak, visible in medium-grained parts; composition: K-spar 45-50%, quartz 35%, plagioclase 10%, biotite 0-5%, magnetite 2-3% (?), garnet (red, ~1mm).	**foliation:** 308/56 **joints:** 334/80, 4/20, 234/60, 190/56, 192/56	sample
83: road cut outcrop dimensions: 20x3 m	**Agg:** granitic gneiss; fine- to medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 45%, quartz 30%, plagioclase 20%, biotite 5%.	**foliations:** 300/72 **joints:** 318/68, 355/74, 172/44	sample
85: road cut outcrop dimensions: 15x2 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; fine-grained; fresh colour: black; weathered: dark brown; almost no foliation; composition: hornblende 50-60%, plagioclase 30-40%, quartz 10%, no garnet.	**foliation:** (120/55) **joints:** 228/55, 112/50, 324/46	sample
86: road cut outcrop dimensions: 40x2 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: tan, light brown; composition: K-spar 35%, quartz 30%, plagioclase 25%, biotite 5%, magnetite 3% (?).	**foliation:** 320/62 **joints:** 240/35, 142/62, 252/68, 42/25	sample
87: road cut outcrop dimensions: 3x2 m	**Tv:** mafic dike, float; very fine grained, aphanitic; mineralogy ?	-	sample
88: road cut outcrop dimensions: 3x1 m	**Tv:** mafic dike, float; very fine grained, aphanitic; mineralogy ?	-	sample
89: road cut outcrop dimensions: 3x1 m	**Tv:** mafic dike, float; very fine grained, aphanitic; mineralogy ?	-	sample

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
90: road cut outcrop dimensions: 10x2 m	**Tv:** mafic dike; very fine grained, aphanitic; mineralogy ?	-	sample
91: road cut outcrop dimensions: 10x2 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: medium-gray; weathered: light brown; composition: hornblende 30%, plagioclase 30%, quartz 20%, biotite 10%; garnet 10% (red, mm-1cm-size).	**foliation:** 97/70 **joints:** 356/30, 202/85, 64/33	sample
92: road cut outcrop dimensions: 20x2 m	**Agg:** granitic gneiss; fine-grained; fresh colour: reddish white; weathered: reddish (tan) brown; composition: K-spar 35%, quartz 30%, plagioclase 30%, biotite 5%.	**foliation:** 301/46 **joints:** 96/54, 191/85, 270/85	sample
93: adit outcrop dimensions: 3x3 m	**Aggm:** granitic gneiss, magnetic; fine-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 40%, quartz 30%, plagioclase 20%, biotite 5%, magnetite 5%.	**foliation:** 98/67 **joints:** 84/46, 25/52, 224/37 **faults:** 98/67, 107/60 (slickenslides)	sample
94: adit outcrop dimensions: 20x40 m	contact **Aam** to **Aggm**: **Aam:** hornblende-plagioclase gneiss and amphibolite; fine- to medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 50%, plagioclase 30%, quartz 15%, biotite 5%. **Aggm:** granitic gneiss, magnetic; fine-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 40-45%, quartz 30%, plagioclase 20%, biotite 5%, magnetite 0-5%.	**foliations:** 310/65, 120/60 **joints:** 16/23, 218/80, 190/70, 325/14 **faults:** 126/80, 218/68, 96/55	samples
95: road cut outcrop dimensions: 15x2 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish gray; weathered: light (tan) gray; composition: K-spar 40-45%, quartz 30%, plagioclase 20%, biotite 5%, magnetite 0-5%.	**foliations:** 104/80, 115/85 **joints:** 71/36, 266/85, 202/75	sample
96: road cut outcrop dimensions: 10x2 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) gray; composition: K-spar 30-40%, quartz 30%, plagioclase 20%, biotite 10-15%, magnetite 0-5%.	**foliation:** 292/50 **joints:** 140/85, 2/88, 84/70	sample
97: road cut outcrop dimensions: 10x2 m	**Agg:** granitic gneiss; fine-grained; fresh colour: yellowish white; weathered: yellowish (tan) brown; composition: K-spar 30-40%, quartz 30%, plagioclase 30%, biotite 0-5%; garnet 0-5% (red, mm-size).	**foliation:** 302/69 **joints:** 38/56, 191/50, 39/50	-
98: road cut outcrop dimensions: 20x2 m	**Tv:** mafic dike, 6 m in diameter; very fine grained, aphanitic; mineralogy ?	-	sample
99: adit outcrop dimensions: 20x4-5 m	exposed contact **Aggm** to **Tv**: **Tv:** mafic dike; very fine grained, aphanitic; mineralogy ? **Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) gray; composition: K-spar 35%, quartz 30%, plagioclase 30%, biotite 5%, magnetite ~1%.	**foliation:** 294/40 **joints:** 42/85, 110/60, 300/88, 128/20, 0/50, 112/80, 52/80, 311/36, 250/55	samples
100: road cut outcrop dimensions: 10x2 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; fine- to medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 40-60%, plagioclase 20-30%, quartz 10%, garnet 10-15% (red, mm- to cm-size), biotite 0-5%; migmatitic (nebulitic), leucosome (mm- to 1 cm-range) consists of plagioclase and quartz, +/- garnet.	**foliations:** 148/58, 138/86 **joints:** 84/68, 254/56, 240/90, 241/80, 54/74 **faults:** 62/50, 270/51	faults aligned with chlorite and biotite; sample

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
101: road cut outcrop dimensions: 8x2 m	**Atg** with **Aam**: **Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 50%, quartz 30%, K-spar 15%, biotite 5%, garnet 1-2% (red, mm-size); especially quartz- and plagioclase-rich layers are medium- to coarse-grained, and contain 4-5% garnet. **Aam:** hornblende-plagioclase gneiss and amphibolite; fine- to medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 60%, plagioclase 20%, quartz 10%, garnet 10% (red, mm-size).	**Atg:** **foliations:** 314/70, 304/68 **joints:** 62/85, 2/74, 8/88 **Aam:** **foliations:** 350/56 **joints:** 250/68, 206/30, 253/70	samples
102: road cut outcrop dimensions: 8x2 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 60%, plagioclase 20%, quartz 15%, garnet 5% (red, mm-size); migmatitic (nebulitic), leucosome consists of plagioclase and quartz, +/- garnet.	**foliations:** 148/60, 142/80 **joints:** 256/52, 81/82, 261/42, 280/30 **fault:** 60/32 (sinistral)	sample
103: adit/prospect outcrop dimensions: 20x10 m	see detailed sketch map in appendix x: contact **Atg** to **Aam** with dolomitic marble incorporated within a shear zone which is almost parallel to foliation: **Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray to white; weathered: light brown; composition: plagioclase 30%, quartz 50%, K-spar 10%, biotite 5%, garnet 5% (red, mm-size). **Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; highly weathered: dark brown; composition: hornblende 45-55%, plagioclase 25-30%, quartz 10%, biotite 5%; garnet 5-10% (red, mm-1cm-size).	**foliations:** 78/40, 80/18, 110/30, 108/35, 90/60, 81/35, 80/55 **contact Peg:** 48/75	sample of trondhejmitic Atg
104: exposure outcrop dimensions: 2x3 m	**Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light yellowish gray; weathered: light (tan) brown; composition: plagioclase 40%, quartz 30%, K-spar 15%, biotite 15%, no garnet.	**foliations:** 43/36, 48/32 **joints:** 295/74, 196/68, 122/71	sample
105: exposure outcrop dimensions: 4x2 m	**Atg:** tonalitic gneiss; fine-grained; fresh colour: light gray; weathered: light (tan) brown; composition: plagioclase 40-45%, quartz 30%, K-spar 15-20%, biotite 0-5%, garnet 0-5% (red, mm-size).	**foliations:** 110/30, 70/10 **joints:** 315/79, 202/53, 70/85	sample
106: exposure outcrop dimensions: 6x4 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 45-55%, plagioclase 25-30%, quartz 10%, biotite 5%; garnet 5-10% (red, mm-1cm-size); migmatitic (nebulitic), leucosome (10-15%) consists of plagioclase, quartz, and garnet.	**foliation:** 93/56 **joints:** 192/80, 297/43	sample
107: exposure outcrop dimensions: 15x5 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 45-55%, plagioclase 25-30%, quartz 10%, biotite 5%; garnet 5-10% (red, mm-1cm-size); migmatitic (nebulitic), leucosome (10-20%) consists of plagioclase, quartz, and garnet.	**foliation:** 105/71 **joints:** 46/86, 4/89; 308/25	sample

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
108: exposure outcrop dimensions: 4x4 m	**Aum:** ultramafic assemblage; fine-grained; fresh colour: black; weathered: dark brown; massive; composition: ?	**joints:** 44/85, 302/20; 115/80	sample
109: exposure outcrop dimensions: 6x6 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; fine- to medium-grained; fresh colour: black; weathered: brownish black; composition: hornblende 45-55%, plagioclase 30-35%, quartz 10%, garnet 5-10% (mm-size); migmatitic (nebulitic; leucosome 10% consisiting of plagioclase, quartz, +/- garnet).	**foliation:** 108/52 **joints:** 218/80, 340/70, 263/32	sample
110: exposure outcrop dimensions: 8x8 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: brownish black; composition: hornblende 30-45%, plagioclase 30%, quartz 15-20%, biotite 0-5%, garnet 10-15% (mm-size); some parts much richer in quartz and garnet than described.	**foliation:** 118/85 **joints:** 287/74, 220/70, 191/64, 193/2	sample
111: exposure outcrop dimensions: 6x6 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: brownish black; composition: hornblende 35-40%, plagioclase 35-40%, quartz 10%, biotite 0-5%, garnet 0-10% (mm-size).	**foliation:** 120/80 **joints:** 9/86, 223/76, 232/25	sample
112: adit outcrop dimensions: 6x2 m	**Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray; highly weathered: light brown; composition: plagioclase 40-50%, quartz 30-35%, K-spar 10%, biotite 5-10%; garnet 5% (red, mm-size).	**foliation:** 105/46 **joints:** 28/84, 298/50, 120/81	-
113: exposure outcrop dimensions: 2x2 m	**Atg:** tonalitic gneiss; fine-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 50-60%, quartz 30%, K-spar 5-10%, biotite 5-10%, no garnet; migmatitic (striatic, coarse grained, granitic in composition).	**foliation:** 133/64 **joints:** 308/70, 4/60, 262/64	sample
114: exposure outcrop dimensions: 10x3 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 35-60%, plagioclase 25-30%, quartz 10-20%, garnet 5-15% (red, mm-1cm-size); migmatitic (nebulitic), leucosome (10-20%) consists of plagioclase and quartz, +/- garnet.	**foliations:** 118/71, 162/30 **joints:** 30/71, 344/65	sample
115: exposure outcrop dimensions: 2x2 m	**Atg:** tonalitic gneiss; fine-grained; fresh colour: light gray; weathered: medium-gray, light tan; composition: plagioclase 50%, quartz 30%, K-spar 10%, biotite 5%, garnet 5% (red, mm-size).	**foliation:** 126/58 **joints:** 248/89, 340/80	sample
116: exposure outcrop dimensions: 4x4 m	**Atg:** tonalitic gneiss; fine- to medium-grained; compositional layering; fresh colour: light gray; weathered: medium-gray; composition: plagioclase 40-50%, quartz 30%, K-spar 10-20%, biotite 10%; migmatitic (leucosome granitic in composition).	**foliations:** 107/28, 123/38, 109/39, 112/58 **joints:** 246/86, 334/84	sample
117: exposure outcrop dimensions: 4x3 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 40-55%, plagioclase 20-30%, quartz 10%, biotite 0-5%; garnet 10-15% (red, mm-1cm-size); migmatitic (nebulitic), leucosome (up to 30%) consists of plagioclase, quartz, and garnet.	**foliation:** 102/65 **joints:** 316/42, 210/72	sample

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
118: exposure outcrop dimensions: 15x10 m	**Atg:** tonalitic gneiss; fine-grained; fresh colour: light gray; weathered: yellowish gray, light tan; composition: plagioclase 50%, quartz 30%, K-spar 10-15%, biotite 5%, garnet 0-5% (red, mm-size).	**foliation:** 114/44 **joints:** 273/38, 347/73, 31/85	sample
119: exposure outcrop dimensions: 2x4 m	**Atg:** tonalitic gneiss; fine-grained; fresh colour: light gray; weathered: yellowish gray, light tan; composition: plagioclase 30%, quartz 30%, K-spar 30%, biotite 10%; K-spar alteration.	**foliation:** 120/45 **joints:** 282/41, 257/68, 348/62	sample
120: exposure outcrop dimensions: 2x2 m	**Agg:** granitic gneiss; fine-grained; fresh colour: yellowish gray; weathered: light (tan) brown; composition: K-spar 40-50%, quartz 30%, plagioclase 15-20%, biotite 5%, garnet 0-5% (red, mm-size).	**foliation:** 306/66 **joints:** 239/45, 171/36, 106/61	sample
121: exposure outcrop dimensions: 10x10 m	**Agg:** granitic gneiss; fine-grained; fresh colour: light gray; weathered: light reddish (tan) brown; composition: K-spar 30%, quartz 30%, plagioclase 30%, biotite 5%, garnet 5% (red, mm-size).	**foliation:** 323/65 **joints:** 18/72, 192/70, 58/69, 52/20	sample
122: exposure outcrop dimensions: 4x4 m	**Agg:** granitic gneiss; medium-grained; fresh colour: light gray; weathered: reddish brown (tan); composition: K-spar 30%, quartz 30%, plagioclase 30%, biotite 5%, garnet 5% (red, mm-size).	**foliation:** 302/45 **joints:** 188/60, 210/75, 134/60, 48/46, 106/56	sample
124: exposure outcrop dimensions: 2x2 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 45-55%, plagioclase 30-40%, quartz 10%, garnet 5-10% (red, mm-size).	**foliation:** 107/70 **joints:** 241/71, 177/70; 286/30	sample
125: trench outcrop dimensions: 40x2-3 m	**Agg:** granitic gneiss; medium-grained; fresh colour: reddish white; weathered: reddish brown (tan); composition: K-spar 40-45%, quartz 30%, plagioclase 20-25%, biotite 0-5%.	**fold axises:** 199/42, 38/22 (antiforms) **foliations:** 254/46, 274/66, 113/75, 291/80 **joints:** 27/71, 20/80, 228/88, 74/47	sample
126: road cut outcrop dimensions: 30x2 m	**Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray; highly weathered: brownish medium-gray; composition: plagioclase 50%, quartz 30%, K-spar 10%, biotite 5-10%, garnet 5-10% (red, mm-1cm-size); Aam lenses within this unit not distinguished.	**foliation:** 310/72 **joints:** 198/84, 67/60	sample
127: road cut outcrop dimensions: 50x2 m	**Agg:** granitic gneiss; medium-grained; fresh colour: reddish white; weathered: reddish brown (tan); composition: K-spar 35-40%, quartz 30%, plagioclase 30%, biotite 0-5%.	**foliation:** 330/42 **joints:** 320/62, 46/65, 160/50	sample
128: road cut outcrop dimensions: 20x3 m	**Tv:** mafic dike, float; very fine grained, aphanitic; mineralogy ?	-	sample
129: road cut outcrop dimensions: 20x3 m	**Tv:** mafic dike, float; very fine grained, aphanitic; mineralogy ?	-	sample
130: trench outcrop dimensions: 30x2 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) gray; composition: K-spar 35-40%, quartz 30%, plagioclase 20-30%, biotite 5%, magnetite ~1%, very weak; highly potassic altered (red spots), quartz veins (cm-scale), concordant to foliation but steeper dipping.	**foliation:** 304/40 **quartz veins:** 300/70, 320/65 **joints:** 42/85, 110/60, 300/88, 128/20	sample; at contact to quartz veins decreasing susceptibility of the rocks

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
131: trench outcrop dimensions: 30x2 m	**Tv:** mafic dike, at least 4 m in diameter; very fine grained, aphanitic; mineralogy ?	**joints:** 151/76, 292/85, 223/76	sample
132: trench outcrop dimensions: 50x1 m	**Tv:** mafic dike, float; very fine grained, aphanitic; mineralogy ?	-	sample
133: trench outcrop dimensions: 35x2 m	**Tv:** mafic dike, float; very fine grained, aphanitic; mineralogy ?	-	sample
134: adit outcrop dimensions: 20x12 m	contact **Aam** to **Atg**: **Aam:** hornblende-plagioclase gneiss and amphibolite; medium- to coarse-grained; fresh colour: black; weathered: dark brown; composition: hornblende 40%, plagioclase 30%, quartz 10%, biotite 15%, garnet 5% (red, mm-size). **Atg:** tonalitic gneiss; medium-grained; fresh colour: reddish white; weathered: reddish brown (tan); composition: plagioclase 30%, quartz 30%, K-spar 30%, biotite 5%, garnet 5% (red, mm-size). discordant pegmatite **(Peg)**: 20-50 cm; coarse-grained; not zoned, composition: quartz-K-spar-plagioclase-biotite).	**foliations:** 310/71, 310/80 **fold axis:** 8/30 (antiform) **Peg contact:** 24/46 **fault:** 24/45 (chloritized) **joints:** 224/88, 284/48, 136/64, 227/72, 174/46, 121/65	samples
135: road cut outcrop dimensions: 20x2 m	**Aggm:** granitic gneiss, magnetic; fine-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 40-45%, quartz 30%, plagioclase 20%, biotite 5%, magnetite 0-5%.	**foliation:** 318/55 **joints:** 80/64, 228/38, 96/54, 168/64	sample
136: road cut outcrop dimensions: 2x2 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; two different types: a) medium-grained; fresh colour: black; highly weathered: dark brown; composition: hornblende 50%, plagioclase 30%, quartz 10%, biotite 10%. b) medium-grained; fresh colour: medium-gray; highly weathered: grayish brown; composition: hornblende 20-30%, plagioclase 50-60%, quartz 10%, biotite 10%.	**foliation:** 326/44 **joints:** 28/54, 129/74	-
137: road cut outcrop dimensions: 2x2 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: grayish white; weathered: light brown; composition: plagioclase 40%, quartz 30%, K-spar 10-15%, biotite 10%, garnet 10-15% (red, mm-size).	**foliation:** 299/83 (exposure ?) **joint:** 39/66	sample
138: road cut outcrop dimensions: 10x4 m	**Tv:** mafic dike, float; very fine grained, aphanitic; mineralogy ?	-	sample
139: road cut outcrop dimensions: 8x4 m	**Tv:** mafic dike, float; very fine grained, aphanitic; mineralogy ?	-	sample
140: float measured altitude: 2340 m	**Tv:** mafic dike, float; very fine grained, aphanitic; mineralogy ?	-	sample
141: float measured altitude: 2340 m	**Tv:** mafic dike, float; very fine grained, aphanitic; mineralogy ?	-	sample
142: road cut outcrop dimensions: 2-3x2 m	**Tv:** mafic dike, 2-3 m in diameter; very fine grained, aphanitic; mineralogy ?	-	sample

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
143: road cut outcrop dimensions: 10x2 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 50%, quartz 30%, plagioclase 15-20%, biotite 5%, magnetite ~1%.	**foliation:** 307/55 **joints:** 236/85, 128/55, 305/65	sample
144: road cut outcrop dimensions: 10x2-3 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: grayish white; weathered: light brown; composition: plagioclase 40-50%, quartz 30%, K-spar 10%, biotite 5-15%, garnet 0-5% (red, mm-1cm-size); selective K-spar alteration and on joints.	**foliation:** 304/80 **joints:** 300/55, 350/68, 127/58	sample
145: road cut outcrop dimensions: 8x2 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: gray; weathered: light brown; composition: plagioclase 40-50%, quartz 30%, K-spar 10-15%, biotite 5-10%, garnet 5% (red, mm-1cm-size).	**foliation:** 290/69 **joints:** 290/50, 137/66, 40/55, 335/44	sample
146: road cut outcrop dimensions: 20x2 m	**Agg:** granitic gneiss; medium-grained; fresh colour: reddish white; weathered: light (tan) yellow-brown; composition: K-spar 45%, quartz 30%, plagioclase 30%, biotite 5%.	**foliation:** 280/72 **joints:** 123/58, 173/60, 18/88	sample
147: road cut outcrop dimensions: 20x3 m	**Tv:** mafic dike, float over 15 m in diameter; very fine grained, aphanitic; mineralogy ?	-	sample
148: road cut outcrop dimensions: 8x2 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 40-45%, quartz 30%, plagioclase 20%, biotite 5%, magnetite 0-5%.	**foliation:** 319/52 **joints:** 210/85, 90/70, 172/52	sample
149: road cut outcrop dimensions: 8x2 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 40-45%, quartz 30%, plagioclase 20%, biotite 5%, magnetite 0-5%; weak migmatitic (leucosome striatic, medium to coarse grained, generally granitic in composition).	**foliation:** 299/55 **joints:** 40/54, 130/76, 218/70	sample
150: prospect outcrop dimensions: 2x2 m	**Agg:** granitic gneiss; medium-grained; fresh colour: reddish white; highly weathered: light (tan) yellow-brown; composition: K-spar 50%, quartz 30%, plagioclase 15%, biotite 5%; strongly K-spar and chloritic altered; quartz veins subparallel to foliation.	**foliation:** 304/80 **joints:** 78/86, 27/70, 102/78, 328/62	sample
151: road cut outcrop dimensions: 10x2 m	**Tv:** mafic dike, float; very fine grained, aphanitic; mineralogy ?	-	sample
152: road cut outcrop dimensions: 50x3-4 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 40-50%, quartz 30%, K-spar 15%, biotite 5-10%, garnet 0-5% (red, mm-size).	**foliations:** 142/65, 306/72 **fold axis:** 33/28 (antiform) **joints:** 234/44, 295/34, 14/48	sample
153: exposure outcrop dimensions: 10x20 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 40-50%, plagioclase 20%, quartz 20%, biotite 5-10%, garnet 5-10% (red, mm-1cm-size); migmatitic (nebulitic; leucosome (10-20%) consisting of plagioclase and quartz).	**foliation:** 161/30 **joints:** 12/40, 41/80, 315/40	sample

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
154: exposure outcrop dimensions: 10x20 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 40-50%, plagioclase 20%, quartz 20%, biotite 5-10%, garnet 5-10% (red, mm-1cm-size); migmatitic (nebulitic; leucosome (10-20%) consisting of plagioclase and quartz).	**foliation:** 136/42 **joints:** 281/80, 111/85, 185/47, 280/80	sample
155: road cut outcrop dimensions: 10x10 m	**Agg:** granitic gneiss; fine- to medium-grained; fresh colour: reddish white; weathered: light (tan) brown, ochre; composition: K-spar 35-45%, quartz 30%, plagioclase 25-30%, biotite 0-5%.	**foliation:** 139/30 **joints:** 337/58, 215/84, 13/49	sample
156: road cut outcrop dimensions: 2x2 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 50-60%, plagioclase 15-20%, quartz 15-20%, biotite 5%, garnet 5% (red, mm-size); migmatitic (nebulitic; leucosome (5-10%) consisting of plagioclase and quartz).	**foliation:** 150/68 **joints:** 302/52, 81/88, 5/30	sample
157: road cut outcrop dimensions: 10x10 m	**Agg:** granitic gneiss; fine- to medium-grained; fresh colour: reddish white; weathered: light (tan) brown, ochre; composition: K-spar 35-40%, quartz 30%, plagioclase 30%, biotite 0-5%.	**foliation:** 112/82 **joints:** 344/52, 40/10, 217/37	sample
158: road cut outcrop dimensions: 10x10 m	**Agg:** granitic gneiss; fine- to medium-grained; fresh colour: reddish white; weathered: medium (tan) brown; composition: K-spar 30-35%, quartz 30%, plagioclase 30%, biotite 5-10%.	**foliation:** 295/75 **joints:** 352/50, 189/24, 86/54	sample
159: road cut outcrop dimensions: 10x10 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; weathered: light yellowish brown; composition: plagioclase 40-50%, quartz 30%, K-spar 5-10%, biotite 10%, garnet 5-10% (red, mm-size); strong compositional layering.	**foliation:** 288/88 **joints:** 358/68, 212/52, 16/45	sample
160: exposure outcrop dimensions: 15x3-4 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; weathered: light to medium-brown; composition: plagioclase 35-45%, quartz 30%, K-spar 10-15%, biotite 10%, garnet 5-10% (red, mm-1cm-size).	**foliation:** 113/85 **joints:** 231/45, 27/50, 226/40	sample
161: exposure outcrop dimensions: 10x10 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; weathered: light to medium-brown; composition: plagioclase 35-45%, quartz 30%, K-spar 10-15%, biotite 10%, garnet 5-10% (red, mm-1cm-size).	**foliation:** 129/88 **joints:** 188/45, 106/24, 14/76	sample
162: exposure outcrop dimensions: 5x3-4 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 30-40%, plagioclase 20%, quartz 20%, garnet 15-20% (red, mm-1cm-size), biotite 5-10%; migmatitic (nebulitic).	**foliation:** 276/79 **joints:** 358/40, 191/26, 13/57	sample
163: exposure outcrop dimensions: 30x6-8 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; weathered: light to medium-brown; composition: plagioclase 35-45%, quartz 30%, K-spar 10-15%, biotite 10%, garnet 5-10% (red, mm-1cm-size).	**foliations:** 290/63, 300/88 **joints:** 209/65, 60/88, 236/52	sample

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
164: exposure outcrop dimensions: 30x6 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; weathered: light brown (tan); composition: plagioclase 35-45%, quartz 30%, K-spar 15-20%, biotite 5-10%, garnet 5% (red, mm-size).	**foliation:** 294/76 **joints:** 17/86, 229/42, 19/2	sample
165: exposure outcrop dimensions: 25x10 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 45-55%, plagioclase 20%, quartz 20%, garnet 5-10% (red, mm-1cm-size), biotite 0-5%; migmatitic (nebulitic; leucosome 10%; composition: plagioclase and quartz).	**foliation:** 290/88 **joints:** 163/56, 5/60, 106/25	sample
166: exposure outcrop dimensions: 25x4-5 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; weathered: medium-brown; composition: plagioclase 40-50%, quartz 30%, K-spar 15-25%, biotite 5%.	**foliation:** 104/85 **joints:** 200/80, 18/50, 292/40	sample
167: exposure outcrop dimensions: 10x10 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; weathered: light yellowish brown; composition: plagioclase 35%, quartz 30%, K-spar 30%, biotite 5%, garnet 0-5% (red, mm-size).	**foliation:** 282/85 **joints:** 351/28, 226/40, 112/28	sample
168: road cut outcrop dimensions: 10x10 m	**Agg:** granitic gneiss; fine- to medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 40-50%, quartz 30%, plagioclase 15-25%, biotite 0-5%; **Aam**-lenses within this unit.	**foliation:** 318/55 **joints:** 59/80, 273/70, 38/40, 149/56	sample
169: exposure outcrop dimensions: 10x8 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; weathered: light yellowish brown; composition: plagioclase 40%, quartz 30%, K-spar 15%, biotite 10%, garnet 5% (red, mm-size).	**foliation:** 163/58 **joints:** 226/45, 10/39, 110/58, 162/54, 154/50, 220/58	sample
170: road cut outcrop dimensions: 15x2 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 40-45%, quartz 30%, plagioclase 25-30%, biotite 0-5%, magnetite ~1%.	**foliation:** 307/64 **joints:** 80/77, 174/62, 231/85, 110/52	sample
171: exposure outcrop dimensions: 20x3 m	**Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray; weathered: light yellowish brown; composition: plagioclase 30-35%, quartz 30%, K-spar 30%, biotite 5-10%.	**foliation:** 317/54 **joints:** 126/76, 57/52, 204/45	sample
172: exposure outcrop dimensions: 25x5 m	**Agg:** granitic gneiss; medium-grained; fresh colour: reddish white; weathered: light (tan) yellowish brown; composition: K-spar 30-35%, quartz 30%, plagioclase 30%, biotite 5-10%.	**foliation:** 308/43 **joints:** 349/62, 342/85, 112/70, 133/45	sample
173: exposure outcrop dimensions: 5x5 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 30-35%, quartz 30%, plagioclase 30%, biotite 5-10%, magnetite ~1%.	**foliation:** 322/58 **joints:** 136/82, 202/50, 52/34 **fault:** 113/56	sample
174: road cut outcrop dimensions: 10x2 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 40-50%, plagioclase 20%, quartz 20%, garnet 5-10% (red, mm-1cm-size), biotite 5-10%; highly migmatitic (nebulitic; leucosome 20-30%; composition: plagioclase, quartz, biotite); 10-20 cm tonalitic lenses within this unit.	**foliations:** 178/85, 345/74, 347/82 **joints:** 90/56, 281/12, 255/21	sample

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
175: road cut outcrop dimensions: 20x2-3 m	contact **Atg** to **Aam**: **Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 45-55%, quartz 30%, K-spar 10-15%, biotite 5-10%. **Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: brown; composition: hornblende 45-55%, plagioclase 20%, quartz 15-20%, biotite 5-10%; garnet 5% (red, mm-size); migmatitic (nebulitic; leucosome 10-20%; composition: plagioclase, quartz).	**foliations:** 306/85, 132/82 **joints:** 258/32, 1/55, 290/55	sample
176: road cut outcrop dimensions: 20x3 m	pinching out of **Aam** within **Atg**: **Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: brown; composition: hornblende 45-55%, plagioclase 20%, quartz 15-20%, biotite 5-10%; garnet 5% (red, mm-size); migmatitic (nebulitic; leucosome 10-20%; composition: plagioclase, quartz). **Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray; weathered: light yellowish brown; composition: plagioclase 50%, quartz 30%, K-spar 10-15%, biotite 5%, garnet 0-5% (red, mm-size).	**foliation:** 131/45 **joints:** 18/85, 230/55, 338/65	sample
177: road cut outcrop dimensions: 10x2 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: brown; composition: hornblende 40-50%, plagioclase 20-25%, quartz 15-20%, biotite 10%; garnet 5% (red, mm-1cm-size); migmatitic (nebulitic; leucosome 10%; composition: plagioclase, quartz, +/-garnet).	**foliation:** 302/69 **joints:** 219/71, 24/50, 2/64	-
178: road cut outcrop dimensions: 10x2 m	**Tv:** mafic dike, float; very fine grained, aphanitic; mineralogy ?	-	-
179: road cut outcrop dimensions: 10x3 m	**Agg:** granitic gneiss; fine- to medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 35-45%, quartz 30%, plagioclase 25-30%, biotite 0-5%.	**foliation:** 58/50 !? (really exposed ?) **joints:** 269/33, 354/58, 185/80	sample
180: road cut outcrop dimensions: 4x2 m	**Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 50-55%, quartz 30%, K-spar 10-15%, biotite 5%.	**foliation:** 121/21 **joints:** 264/74, 347/52, 220/69	sample
181: road cut outcrop dimensions: 40x3 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: brown; composition: hornblende 40-55%, plagioclase 25-30%, quartz 10-15%, biotite 5%; garnet 5-10% (red, mm-1cm-size); discordant pegmatite **(Peg)**: 2 m in diameter; coarse to very coarse grained, simple (not zoned); composition: K-spar, quartz, plagioclase, biotite.	**foliation:** 102/43 **contact Peg:** 6/70 **joints:** 296/85, 196/80, 299/85	sample
182: road cut outcrop dimensions: 20x2 m	**Atg:** tonalitic gneiss; fine-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 40-55%, quartz 30-35%, K-spar 10%, biotite 0-5%.	**foliation:** 127/35 **joints:** 288/50, 18/85, 52/80	sample

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
183: road cut outcrop dimensions: 7x2-3 m	**Atg:** tonalitic gneiss; fine-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 40-55%, quartz 30-35%, K-spar 10%, biotite 0-5%.	**foliation:** 250/26 **joints:** 169/76, 254/70, 314/76	-
184: road cut outcrop dimensions: 30x2 m	**Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 40-50%, quartz 30%, K-spar 10%, biotite 5-10%, garnet 0-10% (red, mm-1cm-size).	**foliation:** 114/30 **joints:** 3/71, 276/68, 329/60, 13/72	sample
185: road cut outcrop dimensions: 30x2-3 m	contact **Atg** to **Aam**: **Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; highly weathered: dark brown; composition: hornblende 40-55%, plagioclase 15%, quartz 15-20%, biotite 10-15%; garnet 5-10% (red, mm-1cm-size). **Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 35-40%, quartz 30%, K-spar 15%, biotite 10%, garnet 5-10% (red, mm-size).	**foliation:** 114/45 **joints:** 260/45, 273/85, 16/61	sample
186: road cut outcrop dimensions: 8x2 m	**Agg:** granitic gneiss; fine-grained; fresh colour: reddish white; weathered: light (tan) brown, ochre; composition: K-spar 35-45%, quartz 30%, plagioclase 25-30%, biotite 0-5%.	**foliation:** 115/38 **joints:** 263/60, 246/62, 340/55, 188/68	sample
187: road cut outcrop dimensions: 30x2 m	**Agg:** granitic gneiss; medium-grained; fresh colour: reddish white; weathered: light (tan) brown, ochre; composition: K-spar 35-45%, quartz 30%, plagioclase 25-30%, biotite 0-5%; K-spar alteration on joints.	**foliation:** 297/86 **joints:** 30/64, 109/44, 71/65	sample
188: road cut outcrop dimensions: 50x2-4 m	**Agg:** granitic gneiss; medium-grained; fresh colour: reddish white; weathered: light (tan) brown, ochre; composition: K-spar 35-45%, quartz 30%, plagioclase 25-30%, biotite 0-5%; concordant pegmatites.	**foliation:** 293/88 **joints:** 265/74, 10/40, 18/60, 149/69	-
189: exposure outcrop dimensions: 15x10 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: brown; composition: hornblende 45-50%, plagioclase 25-30%, quartz 15-20%, biotite 0-5%; garnet 10% (red, mm-size); leucosome 0-5% (nebulitic, plagioclase, quartz, +/- garnet); discordant pegmatite **(Peg)**: 1 m in diameter: coarse- to very coarse-grained; composition: K-spar, quartz, plagioclase, biotite).	**foliation:** 312/58 **joints:** 202/68, 111/60, 352/40 **contact Peg:** 64/64	sample
190: prospect outcrop dimensions: 10x10 m	contact **Aggm** to **Aam**: **Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 35-45%, quartz 30%, plagioclase 25-30%, biotite 0-5%, magnetite ~1%; quartz veins with sulfides parallel to foliation in hand specimen. **Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 60-70%, plagioclase 10-20%, quartz 10%, biotite 10%.	**foliation:** 297/47 **joints:** 57/62, 272/86, 48/86, 74/75	-

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
191: road cut outcrop dimensions: 30x2-3 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 35-40%, quartz 30%, plagioclase 30%, biotite 0-5%, magnetite ~1%.	**foliation:** 304/45 **joints:** 54/82, 119/70, 79/45	sample
192: road cut/prospect outcrop dimensions: 10x10 m	**Agg:** granitic gneiss; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 40-45%, quartz 30%, plagioclase 30%, biotite 0-5%; quartz veins parallel to foliation within float.	**foliation:** 125/65 **joints:** 355/46, 55/68, 307/25	sample
193: road cut outcrop dimensions: 30x2-4 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light (tan) yellowish brown; composition: K-spar 35-45%, quartz 30%, plagioclase 25-30%, biotite 0-5%, magnetite 1-2%.	**foliations:** 140/85, 130/78 **joints:** 246/70, 93/50, 68/35, 312/45	sample
194: road cut/prospect outcrop dimensions: 30x4-5 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) yellowish brown; composition: K-spar 40%, quartz 30%, plagioclase 25-30%, biotite 0-5%, magnetite ~1%.	**foliation:** 309/46 **joints:** 62/86, 27/58, 189/82, 142/75	sample
195: road cut outcrop dimensions: 15x3 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 40-50%, quartz 30%, plagioclase 20-25%, biotite 0-5%, magnetite ~1%.	**foliation:** 312/50 **joints:** 210/50, 157/76, 97/60	sample
196: road cut outcrop dimensions: 3x2 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 40-50%, quartz 30%, plagioclase 20-25%, biotite 0-5%, magnetite ~1%.	**foliation:** 319/47 **joints:** 188/84, 160/52, 171/29, 122/85	sample
197: exposure outcrop dimensions: 15x10 m	**Atg:** tonalitic gneiss; medium-grained; compositional layering; fresh colour: light gray; weathered: light brown to medium-gray; composition: plagioclase 30-40%, quartz 30%, K-spar 25%, biotite 5%, garnet 0-5% (red, mm-1cm-size), hornblende 0-5%; apparently more K-spar because of more leucosome (up to 30%, composition: K-spar, quartz, plagioclase, +/- biotite); **Aam**-lens, 1,5-5 m within this unit.	**foliation:** 307/50 **joints:** 264/31, 165/68, 145/86, 78/79	sample
198: exposure outcrop dimensions: 10x2 m	**Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 30-40%, quartz 30%, K-spar 30%, biotite 0-5%, garnet 0-5% (red, mm-1cm-size); highly migmatitic like in outcrop 197.	**foliation:** 276/44 **joints:** 82/52, 47/44, 178/36	sample
199: exposure outcrop dimensions: 2x2 m	**Atg:** tonalitic gneiss; fine-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 50-55%, quartz 30%, K-spar 10%, biotite 5%, garnet 0-5% (red, mm-size).	**foliation:** 280/75 **joints:** 32/34, 32/58, 114/54	sample
200: road cut outcrop dimensions: 30x4-5 m	**Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 35-50%, quartz 30%, K-spar 20-25%, biotite 0-5%, garnet 0-5% (red, mm-size); highly migmatitic (granitic in composition).	**foliation:** 112/70 **joints:** 317/45, 204/70, 156/70	sample

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
201: exposure outcrop dimensions: 2x2 m	contact **Atg** to **Aam-** lenses: **Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 40%, quartz 30%, K-spar 20%, biotite 10%. **Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 30%, plagioclase 30%, quartz 20%, garnet 10% (red, mm-1cm-size), biotite 10%; leucosome up to 30%.	**foliation:** not measurable **joints:** 76/88, 172/54, 43/38, 307/90	samples
202: exposure outcrop dimensions: 10x60 m	**Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 35-40%, quartz 30%, K-spar 10%, biotite 10%, garnet 10-15% (rot, mm-2cm-size); migmatitic (leucosome 5-10%; composition: K-spar-quartz-plagioclase); **Aam**-lenses within this unit.	**foliation:** 310/56 **joints:** 134/69, 150/70, 8/70, 111/28	sample
203: exposure outcrop dimensions: 20x40 m	**Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 35-40%, quartz 30%, K-spar 20%, biotite 10%, garnet 0-5% (rot, mm-size); migmatitic (leucosome up to 30 %; composition: K-spar-quartz-plagioclase).	**foliation:** 305/38 **joints:** 82/83, 26/68, 123/76	sample
204: exposure outcrop dimensions: 30x20 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 50-55%, quartz 30%, plagioclase 15%, biotite 0-5%, magnetite ~1%.	**foliation:** 300/45 **joints:** 81/82, 12/82, 199/64	sample
205: exposure outcrop dimensions: 10x4-5 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 40-45%, quartz 30%, K-spar 15-20%, biotite 5%, garnet 5% (rot, mm-size).	**foliation:** 318/43 **joints:** 208/78, 347/12, 110/70	-
206: exposure outcrop dimensions: 10x2 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 35-45%, quartz 30%, plagioclase 20-25%, biotite 5-10%, magnetite ~1%.	**foliation:** 310/58 **joints:** 120/78, 52/70, 231/54	-
207: exposure outcrop dimensions: 10x2 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 45-50%, quartz 30%, plagioclase 20%, biotite 0-5%, magnetite ~1%.	**foliation:** 340/82 **joints:** 245/84, 80/58, 252/60	sample
208: road cut outcrop dimensions: 40x2-3 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 40-50%, quartz 30-35%, plagioclase 20%, biotite 0-5%, magnetite ~1%.	**foliation:** 303/68 **joints:** 53/80, 348/53, 168/40, 132/14	sample
209: road cut outcrop dimensions: 20x2 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 45-50%, quartz 30%, plagioclase 20%, biotite 0-5%, magnetite ~1%.	**foliation:** 330/63 **joints:** 261/58, 226/75, 137/58	sample
210: road cut outcrop dimensions: 20x2 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 45-50%, quartz 30%, plagioclase 20%, biotite 0-5%, magnetite ~1%; chloritic and K-spar alteration; small quartz veins.	**foliation:** 304/80 **joints:** 40/77, 167/51, 88/75	sample

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
211: road cut outcrop dimensions: 20x2 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 40-45%, quartz 30%, plagioclase 20%, biotite 5-10%, magnetite ~1%; green amphiboles on joints.	**foliation:** 302/88 **joints:** 26/60, 109/46, 201/75	sample
212: road cut outcrop dimensions: 20x2 m	**Aggm:** granitic gneiss, magnetic; fine-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 35-40%, quartz 30%, plagioclase 30%, biotite 0-5%, magnetite ~1%.	**foliation:** 308/65 **joints:** 180/84, 122/44, 34/86	sample
213: road cut outcrop dimensions: 10x2 m	**Aggm:** granitic gneiss, magnetic; fine-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 30-45%, quartz 30-40%, plagioclase 20%, biotite 5-10%, magnetite ~1%.	**foliation:** 140/65 **joints:** 260/75, 40/10, 32/84	sample
214: road cut outcrop dimensions: 10x2 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 35-45%, quartz 30-35%, plagioclase 20%, biotite 5-10%, magnetite ~1%; magnetite ligned almost horizontally.	**foliation:** 300/54 **joints:** 90/51, 199/80, 107/40 **magnetite lineament:** 30/4	sample
215: road cut outcrop dimensions: 30x2 m	**Agg:** granitic gneiss; fine- to medium-grained; fresh colour: reddish gray; weathered: light (tan) yellow-brown; composition: K-spar 35%, quartz 30%, plagioclase 30%, biotite 5%.	**foliation:** 318/50 **joints:** 235/87, 130/40, 38/70	sample
216: road cut outcrop dimensions: 30x2 m	**Aggm:** granitic gneiss, magnetic; fine-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 35-40%, quartz 30%, plagioclase 30%, biotite 0-5%, magnetite ~1%.	**foliation:** 298/62 **joints:** 210/60, 115/16, 99/45	-
217: road cut outcrop dimensions: 20x2 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 40-45%, quartz 35%, plagioclase 20%, biotite 0-5%, magnetite ~1%.	**foliation:** 292/55 **joints:** 32/82, 138/35, 352/50	-
218: exposure outcrop dimensions: 2x3 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 45-55%, quartz 30%, plagioclase 15-20%, biotite 0-5%, magnetite ~1-2%.	**foliation:** 303/78 **joints:** 202/55, 219/80, 160/58, 98/35	sample
219: exposure outcrop dimensions: 10x15 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 30-35%, quartz 30%, plagioclase 30%, biotite 5-10%, magnetite ~1%.	**foliation:** 304/74 **joints:** 42/72, 176/44, 48/42, 192/90	sample
220: exposure outcrop dimensions: 15x15 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 45-50%, quartz 30%, plagioclase 20%, biotite 0-5%, magnetite ~1%.	**foliation:** 308/88 **joints:** 15/59, 82/39, 149/50	sample
221: exposure outcrop dimensions: 15x10 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 40-45%, quartz 30%, plagioclase 20%, biotite 5-10%, magnetite ~1% (weaker close to quartz veins within float).	**foliation:** 293/54 **joints:** 4/90, 162/62, 25/10	sample
222: trench outcrop dimensions: 10x4 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light brown, ochre; composition: K-spar 40%, quartz 40%, plagioclase 15%, biotite 5%, magnetite <1%.	**foliation:** 320/80 **joints:** 213/74, 129/64, 14/40	sample

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
223: exposure outcrop dimensions: 2x3 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 40-45%, quartz 30%, plagioclase 20%, biotite 5-10%, magnetite ~1%; highly migmatitic (leucosome up to 20%; K-spar, quartz, plagioclase).	**foliation:** 302/55 **joints:** 222/65, 16/85, 112/70	sample
224: exposure outcrop dimensions: 10x15 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 35-40%, quartz 30%, plagioclase 30%, biotite 0-5%, magnetite ~1%.	**foliation:** 316/50 **joints:** 220/40, 36/50, 98/86	-
225: exposure outcrop dimensions: 35x15 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 40-45%, quartz 35%, plagioclase 20%, biotite 0-5%, magnetite ~1%.	**foliation:** 304/63 **joints:** 17/75, 23/4, 128/58	sample
226: exposure outcrop dimensions: 2x3 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 35-40%, quartz 30%, plagioclase 30%, biotite 0-5%, magnetite ~1%.	**foliation:** 290/42 **joints:** 335/64, 122/75, 332/86	sample
227: exposure outcrop dimensions: 2x3 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 50-60%, quartz 20-25%, plagioclase 20%, biotite 0-5%, magnetite ~1%; strong K-spar alteration.	**foliation:** 304/46 **joints:** 200/58, 133/75, 33/75	sample
228: exposure and adit outcrop dimensions: 10x4 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 50-60%, quartz 20-25%, plagioclase 20%, biotite 0-5%, magnetite ~1%; strong K-spar and chloritic alteration; quartz veins parallel to foliation but vertical in hand specimen.	**foliations:** 304/80, 282/75 **joints:** 312/32, 221/60, 130/74	sample
229: exposure outcrop dimensions: 3x3 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; fine- to medium-grained; fresh colour: black; weathered: brownish black; composition: hornblende 30%, plagioclase 50%, quartz 15%.	**foliation:** 302/55 **joints:** 179/85, 127/68, 61/79	sample
231: exposure outcrop dimensions: 2x2 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 30-35%, quartz 35%, plagioclase 30%, biotite 0-5%, magnetite ~1%.	**foliation:** 330/70 **joints:** 242/30, 125/84, 52/60	sample
232: prospect outcrop dimensions: 10x6 m	**Aggm:** granitic gneiss, magnetic; fine-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 40-50%, quartz 30%, plagioclase 20-25%, biotite 0-5%, magnetite ~1%; quartz veins (2-3 cm), strong K-spar alteration.	**foliation:** 334/35 **joints:** 59/50, 10/57, 154/52 **quartz veins:** 311/86, 109/60	sample
233: exposure outcrop dimensions: 3x5 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 40-50%, quartz 35%, plagioclase 10-15%, biotite 5-10%, magnetite ~1%; quartz veins (cm in diameter).	**foliation:** 321/52 **joints:** 30/76, 102/85, 69/60 **quartz veins:** 333/82	sample
234: exposure outcrop dimensions: 4x2 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 30-35%, quartz 35%, plagioclase 30%, biotite 0-5%, magnetite ~1%.	**foliation:** 314/53 **joints:** 149/45, 82/45, 44/69	sample

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
235: exposure outcrop dimensions: 35x25 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 45-55%, quartz 25-30%, plagioclase 15-20%, biotite 5%, magnetite ~1%; dm-size **Aam**-lenses within this unit.	**foliation:** 318/70 **joints:** 300/80, 199/68, 22/30	sample
236: exposure outcrop dimensions: 30x20 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 30-35%, quartz 30%, plagioclase 30%, biotite 5-10%, magnetite ~1%; dm-size **Aam**-lenses within this unit.	**foliation:** 306/48 **joints:** 357/57	sample
237: exposure outcrop dimensions: 10x10 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 40-45%, quartz 35%, plagioclase 15-20%, biotite 5%, magnetite ~1%.	**foliation:** 308/40 **joints:** 133/52, 133/70, 28/85	sample
238: exposure outcrop dimensions: 10x8 m	**Aggm:** granitic gneiss, magnetic; fine-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 45-50%, quartz 30%, plagioclase 20%, biotite 0-5%, magnetite ~1%.	**foliation:** 302/47 **joints:** 143/85, 120/85, 39/88, 350/32	sample
239: exposure outcrop dimensions: 12x4 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 50%, quartz 30%, plagioclase 15%, biotite 5%, magnetite <1%.	**foliation:** 311/63 **joints:** 226/83, 181/60, 343/32	-
240: exposure outcrop dimensions: 30x30 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 50-55%, quartz 30%, plagioclase 15%, biotite 0-5%, magnetite ~1%; dm-size **Aam**-lenses within this unit; discordant pegmatite: 40 cm; very coarse grained; composition: K-spar, quartz, plagioclase).	**foliation:** 306/68 **joints:** 173/70, 124/64, 85/52 **contact Peg:** 67/78	sample
241: exposure outcrop dimensions: 3x2 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 50-55%, quartz 30%, plagioclase 10%, biotite 5-10%, magnetite ~1%; dm-size **Aam**-lenses within this unit.	**foliation:** 313/60 **joints:** 53/86, 295/15, 141/84	-
242: exposure outcrop dimensions: 6x2 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 40-45%, quartz 35%, plagioclase 20%, biotite 0-5%, magnetite ~1%; garnet <1% (red, mm-size).	**foliation:** 306/62 **joints:** 27/34, 220/90, 130/75	-
243: exposure outcrop dimensions: 2x4 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 40-45%, quartz 35%, plagioclase 20%, biotite 0-5%, magnetite ~1%; garnet <1% (red, mm-size).	**foliation:** 328/52 **joints:** 141/79, 17/19, 221/44	-
244: exposure outcrop dimensions: 3x2 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; fine-grained; fresh colour: black; weathered: brownish black; composition: hornblende 60%, plagioclase 30%, quartz 10%; strong K-spar alteration.	**foliation:** 313/67 **joints:** 320/38, 242/52, 19/28	sample

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
245: exposure outcrop dimensions: 4x2 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 35%, quartz 30%, plagioclase 30%, biotite 5%, magnetite <1%; garnet <1% (red, mm-size).	**foliation:** 330/58 **joints:** 123/55, 11/46, 213/74	sample
246: exposure outcrop dimensions: 2x2 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 50-55%, quartz 30-35%, plagioclase 15-20%, biotite 0-5%, magnetite <1%; garnet 0-2 % (red, mm-size).	**foliation:** 291/55 **joints:** 153/54, 343/30, 221/74	sample
247: exposure outcrop dimensions: 8x10 m	**Aggm:** granitic gneiss, magnetic; fine-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 45-55%, quartz 30-35%, plagioclase 15%, biotite 0-5%, magnetite <1%; garnet <1% (red, mm-size).	**foliation:** 307/50 **joints:** 205/48, 115/80, 43/50	sample
248: exposure outcrop dimensions: 8x8 m	**Aggm:** granitic gneiss, magnetic; fine-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 35-50%, quartz 30-35%, plagioclase 20-25%, biotite 0-5%, magnetite <1%; garnet <1% (red, mm-size).	**foliation:** 310/47 **joints:** 185/84, 162/90, 32/82, 263/69	sample
249: exposure outcrop dimensions: 2x2 m	**Agg:** granitic gneiss; fine- to medium-grained; fresh colour: reddish gray; weathered: light (tan) brown; composition: K-spar 50%, quartz 40%, plagioclase 10%, biotite <1%.	**foliations:** 128/80, 314/75 **fold axis:** 212/15 (antiform) **joints:** 41/80 (ac), 109/0	-
250: exposure outcrop dimensions: 35x15 m	**Atg:** tonalitic gneiss; fine-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 40-45%, quartz 30%, K-spar 15%, biotite 5-10%; garnet 5% (red, mm-1cm-size); highly migmatitic (striatic, leucosome 5-10% consisiting of K-spar, quartz, plagioclase, +/- garnet).	**foliation:** 303/52 **joints:** 126/74, 181/84, 112/65, 120/68	sample
251: exposure outcrop dimensions: 35x10 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 30-45%, quartz 30%, K-spar 25%, biotite 0-5%; garnet 0-10% (red, mm-1cm-size); highly migmatitic (striatic, leucosome 5-10% consisiting of K-spar, plagioclase, +/- garnet).	**foliation:** 296/33 **joints:** 273/86, 198/66, 144/55	sample
252: exposure outcrop dimensions: 15x4 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; fine- to medium-grained; fresh colour: black; weathered: brownish black; composition: hornblende 70%, plagioclase 20%, quartz 10%; no leucosome; discordant pegmatite **(Peg)**: 20 cm, coarse-grained; composition: quartz, K-spar, plagioclase).	**foliation:** 312/63 **contact Peg:** 85/44 **joints:** 143/75, 229/50, 84/28	sample
253: exposure outcrop dimensions: 2x2 m	**Atg:** tonalitic gneiss; fine-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 30-50%, quartz 30%, K-spar 20-30%, biotite 0-5%; garnet 0-5% (red, mm-size); highly migmatitic (striatic, leucosome 10-30% consisiting of K-spar, quartz, plagioclase, +/- garnet).	**foliation:** 302/26 **joints:** 127/80, 227/88, 300/85	sample
254: exposure outcrop dimensions: 2x2 m	**Atg:** tonalitic gneiss; fine-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 30-40%, quartz 30%, K-spar 30%, biotite 0-5%; garnet 0-5% (red, mm-2cm-size); highly migmatitic (striatic, leucosome 30% consisiting of K-spar, quartz, plagioclase, +/- garnet).	**foliation:** 300/50 **joints:** 211/64, 109/52, 132/73	-

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
255: exposure outcrop dimensions: 15x15 m	**Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 30-40%, quartz 30%, K-spar 30%, biotite 0-5%; garnet 0-5% (red, mm-2cm-size); highly migmatitic (striatic, leucosome 30% consisiting of K-spar, quartz, plagioclase, +/- garnet).	**foliation:** 311/62 **joints:** 128/84, 193/60, 4/76	sample
256: road cut outcrop dimensions: 2x3 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 35-45%, quartz 30%, K-spar 25%, biotite 0-5%; garnet 0-5% (red, mm-size).	**foliation:** 142/85 **joints:** 220/42, 158/22, 32/65	-
257: road cut outcrop dimensions: 10x8 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 60%, plagioclase 20%, quartz 10%, garnet 10% (red, mm-2cm-size); migmatitic (nebulitic leucosome 10% consisting (plagioclase and quartz); discordant pegmatite (Peg): 30 cm; coarse grained (quartz, plagioclase, K-spar).	**foliation:** 137/50 **contact Peg:** 21/38 **joints:** 188/88, 221/74, 4/21	-
258: exposure outcrop dimensions: 10x10 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light reddish gray; weathered: light brown; composition: plagioclase 40-45%, quartz 30%, K-spar 20%, biotite 5%; garnet 0-5% (red, mm-size); Augen-texture of K-spars.	**foliation:** 120/70 **joints:** 190/85, 240/20, 274/80, 210/80	-
259: exposure outcrop dimensions: 3x2 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 45-55%, plagioclase 30%, quartz 10-15%, garnet 5-10% (red, mm-1cm-size); migmatitic (striatic leucosome 10% consisting (plagioclase and quartz).	**foliation:** 148/64 **joints:** 40/85, 275/34, 48/82	-
260: exposure outcrop dimensions: 4x2 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 45-55%, plagioclase 35%, quartz 10-15%, garnet 0-5% (red, mm-size).	**foliation:** 124/50 **joints:** 57/55, 97/70, 286/81, 182/88	-
261: prospect outcrop dimensions: 2x2 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 40-45%, quartz 30%, K-spar 10%, biotite 10%; garnet 5-10% (red, mm-1cm-size).	**foliation:** 113/30 **joints:** 17/89, 298/56, 62/82	-
263: exposure outcrop dimensions: 10x10 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 45-60%, quartz 30%, K-spar 10-15%, biotite 0-5%; garnet 0-5% (red, mm-size); **Aam**-lenses dm in diameter within this unit.	**foliations:** 309/52, 318/86 **joints:** 220/56, 155/65, 65/40	-
264: prospect outcrop dimensions: 6x4 m	**Aggm:** granitic gneiss, magnetic in contact to **Tv** (mafic dike; mineralogy ?); fine-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 35-40%, quartz 30%, plagioclase 30%, biotite 0-5%, magnetite <1%.	**foliation:** 135/80 **joints:** 44/65, 287/58, 287/30	sample
265: road cut outcrop dimensions: 10x3 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 40-50%, quartz 40%, K-spar 10%, biotite 0-5%; garnet 0-5% (red, mm-size).	**foliation:** 132/45 **joints:** 50/87, 305/65, 238/72, 240/62	sample

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
266: exposure outcrop dimensions: 3x3 m	**Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 30-40%, quartz 30%, K-spar 30%, biotite 0-5%; garnet 0-5% (red, mm-2cm-size); highly migmatitic (striatic, leucosome 30% consisiting of K-spar, quartz, plagioclase, +/- garnet).	**foliation:** 308/36 **joints:** 223/68, 124/90, 64/72	-
267: exposure outcrop dimensions: 3x3 m	**Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 35-45%, quartz 30%, K-spar 20%, biotite 5-10%; garnet 0-5% (red, mm-1cm-size); highly migmatitic (striatic, leucosome 10-20% consisiting of K-spar, quartz, plagioclase, +/- garnet).	**foliation:** 310/42 **joints:** 169/85, 306/76, 219/65	-
268: exposure outcrop dimensions: 4x8 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: brownish black; composition: hornblende 30-50%, plagioclase 25-30%, quartz 10%, biotite 10-20%, garnet 5-10% (mm-3cm-size); discordant pegmatite **(Peg)**: 20-30 cm; coarse grained; composition: quartz, K-spar, plagioclase.	**foliation:** 305/56 **contact Peg:** 71/38 **joints:** 215/85, 160/74, 260/41	samples
269: exposure outcrop dimensions: 8x10 m	**Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 30-35%, quartz 30%, K-spar 20-25%, biotite 10%; garnet 5% (red, mm-size).	**foliations:** 298/55, 306/50 **joints:** 223/86, 47/28, 10/35	sample
270: exposure outcrop dimensions: 3x2 m	**Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 40-45%, quartz 30%, K-spar 15%, biotite 5-10%; garnet 5% (red, mm-size).	**foliation:** 299/45 **joints:** 160/88, 84/65, 23/82	sample
271: road cut outcrop dimensions: 3x2 m	**Tv:** mafic dike, float; very fine grained, aphanitic; mineralogy ?	-	sample
272: exposure outcrop dimensions: 10x10 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 35-45%, plagioclase 40%, quartz 10%, garnet 5-10% (red, mm-size), biotite 0-5%; migmatitic (leucosome up to 30% consisting of plagioclase, quartz, garnet).	**foliation:** 298/85 **joints:** 30/58, 198/80, 194/44	sample
273: exposure outcrop dimensions: 6x10 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 40-50%, plagioclase 35%, quartz 10%, garnet 5-10% (red, mm-size), biotite 0-5%.	**foliation:** 292/88 **joints:** 223/76, 232/43, 204/54	-
274: exposure outcrop dimensions: 6x10 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 35-40%, plagioclase 40%, quartz 10-15%, garnet 10% (red, mm-size).	**foliation:** 285/74 **joints:** 340/86, 110/39, 25/35	-
275: exposure outcrop dimensions: 30x15 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 40-45%, plagioclase 35%, quartz 10%, garnet 10-15% (red, mm-size).	**foliation:** 290/80 **joints:** 32/56, 323/80, 83/42	sample
276: exposure outcrop dimensions: 3x4 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 50%, plagioclase 30%, quartz 10%, garnet 10% (red, mm-size).	**foliation:** 70/30	sample

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
277: exposure outcrop dimensions: 30x10 m	**Agg:** granitic gneiss; fine- to medium-grained; fresh colour: reddish gray; weathered: light (tan) yellow-brown; composition: K-spar 40-50%, quartz 30%, plagioclase 20%, biotite 0-5%, garnet 0-5% (red, mm-size).	**foliation:** 294/70 **joints:** 330/84, 220/73 (ac), 184/48, 184/24	sample
278: exposure outcrop dimensions: 10x10 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 30-35%, quartz 30%, K-spar 30%, biotite 5%; garnet 0-5% (red, mm-1cm-size); highly migmatized (leucosome 20-30% consisiting of K-spar, quartz, plagioclase).	**foliation:** 298/78 **joints:** 126/15, 79/30, 34/81	sample
279: exposure outcrop dimensions: 10x10 m	**Agg:** granitic gneiss; fine- to medium-grained; fresh colour: reddish gray; weathered: light (tan) yellow-brown; composition: K-spar 35-40%, quartz 30%, plagioclase 30%, biotite 0-5%.	**foliation:** 298/78 **joints:** 126/15, 79/30, 34/81	sample
280: exposure and prospect outcrop dimensions: 4x6 m	**Agg:** granitic gneiss; fine-grained; fresh colour: reddish gray; weathered: light (tan) yellow-brown; composition: K-spar 45-50%, quartz 30%, plagioclase 20%, biotite 0-5%.	**foliation:** 302/65 **joints:** 48/55, 217/63, 258/57	-
281: trench outcrop dimensions: 4x4 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) yellowish brown; composition: K-spar 35%, quartz 30%, plagioclase 30%, biotite 5%, magnetite <1%.	**foliations:** 320/80, 125/75 **joints:** 188/88, 100/25, 202/81	-
282: exposure outcrop dimensions: 4x3 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 35%, quartz 30%, plagioclase 30%, biotite 5%, magnetite <1%.	**foliation:** 304/64 **joints:** 222/55, 220/50, 68/30	sample
283: trench outcrop dimensions: 3x3 m	**Agg:** granitic gneiss; fine-grained; fresh colour: reddish gray; weathered: light (tan) brown; composition: K-spar 35-40%, quartz 30%, plagioclase 30%, biotite 0-5%; potassic alteration.	**foliation:** 318/86 **joints:** 63/86, 36/65, 158/48	sample
285: exposure outcrop dimensions: 4x3 m	**Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 30-45%, quartz 30%, K-spar 25-30%, biotite 0-5%; garnet 0-5% (red, mm-size).	**foliation:** 202/62 **joints:** 288/36, 280/50, 37/36	sample
286: road cut outcrop dimensions: 15x4 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 35-40%, quartz 30%, plagioclase 30%, biotite 0-5%, magnetite <1%; potassic alteration on rims of quartz veins in hand specimen (float).	**foliation:** 300/62 **joints:** 328/66, 70/52, 212/40	sample
287: exposure outcrop dimensions: 1x3 m	**Agg:** granitic gneiss; fine- to medium-grained; fresh colour: reddish gray; weathered: light (tan) brown; composition: K-spar 50%, quartz 30%, plagioclase 15-20%, biotite 0-5%; potassic alteration.	**foliation:** 120/85 **joints:** 23/70, 41/55, 352/72, 50/63	sample
288: road cut outcrop dimensions: 2x2 m	**Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 35-45%, quartz 30%, K-spar 20-25%, biotite 5%; garnet 0-5% (red, mm-size); chloritic and potassic alteration.	**foliation:** 304/61 **joints:** 192/60, 167/85, 30/64	-

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
289: adit outcrop dimensions: 30x4 m	**Agg:** granitic gneiss; fine- to medium-grained; fresh colour: reddish gray; weathered: light (tan) brown; composition: K-spar 45-50%, quartz 35%, plagioclase 15%, biotite 0-5%; potassic alteration; quartz veins 5-20 cm in diameter and quartz stringers.	**quartz veins:** 126/72 **joints:** 50/65, 110/72, 235/70	sample
290: exposure outcrop dimensions: 2x2 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 40-50%, quartz 30%, plagioclase 20-25%, biotite 0-5%, magnetite <1%.	**foliation:** 318/69 **joints:** 228/85, 133/56, 196/52	-
291: exposure outcrop dimensions: 2x2 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 45-50%, quartz 30%, plagioclase 20%, biotite 0-5%, magnetite <1%.	**foliation:** 120/89 **joints:** 162/72, 327/34, 200/67, 26/65	-
292: exposure outcrop dimensions: 3x3 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 35-50%, quartz 30%, plagioclase 20-30%, biotite 0-5%, magnetite <1%.	**foliation:** 322/60	-
293: exposure outcrop dimensions: 2x2 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 50-55%, plagioclase 30-35%, quartz 10-15%, garnet 5-10% (red, mm-size).	**foliation:** 292/78 **joints:** 352/45, 136/20, 200/62	sample
294: road cut outcrop dimensions: 10x2 m	**Agg:** granitic gneiss; medium-grained; fresh colour: reddish gray; weathered: light (tan) brown; composition: K-spar 45%, quartz 35%, plagioclase 15%, biotite 5%.	**foliation:** 300/83 **joints:** 96/62, 30/86, 96/37	sample
295: road cut outcrop dimensions: 15x2 m	**Agg:** granitic gneiss; fine- to medium-grained; fresh colour: reddish gray; weathered: light (tan) brown; composition: K-spar 45-55%, quartz 30-35%, plagioclase 15%, biotite 0-5%.	**foliation:** 300/85 **joints:** 220/80, 150/47, 306/15	-
296: road cut outcrop dimensions: 8x2 m	**Agg:** granitic gneiss; medium-grained; fresh colour: reddish gray; weathered: light (tan) brown; composition: K-spar 30-35%, quartz 35%, plagioclase 30%, biotite 0-5%, garnet <1% (red, mm-size).	**foliation:** 300/65 **joints:** 114/75, 30/68, 215/30	sample
297: road cut outcrop dimensions: 6x2 m	**Agg:** granitic gneiss; fine- to medium-grained; fresh colour: reddish gray; weathered: light (tan) brown; composition: K-spar 30-35%, quartz 35%, plagioclase 25-30%, biotite 5%.	**foliation:** 302/38 **joints:** 195/72, 95/74, 100/65	-
298: adit outcrop dimensions: 3x3 m	**Agg:** granitic gneiss; medium-grained; fresh colour: reddish gray; weathered: light (tan) brown; composition: K-spar 35-40%, quartz 30%, plagioclase 30%, biotite 0-5%.	**foliation:** 112/86 **joints:** 213/64 (ac), 9/40, 37/32	-
299: road cut outcrop dimensions: 3x2 m	**Agg:** granitic gneiss; fine- to medium-grained; fresh colour: reddish gray; weathered: light (tan) brown; composition: K-spar 35%, quartz 30%, plagioclase 30%, biotite 5%.	**foliation:** 141/68 **joints:** 273/55, 19/76, 346/32	sample
300: road cut outcrop dimensions: 10x10 m	**Atg:** tonalitic gneiss; fine-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 30-40%, quartz 30%, K-spar 25-30%, biotite 5%; garnet 0-5% (red, mm-size); migmatitic (leucosome 15 % consisting of K-spar, quartz, and plagioclase); discordant pegmatite (Peg): 25 cm; coarse grained; composition: K-spar, quartz, plagioclase, and biotite.	**foliation:** 148/43 **contact Peg:** 207/86 **joints:** 31/81, 301/21, 30/74, 177/64	sample

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
301: road cut outcrop dimensions: 2x1 m	**Agg:** granitic gneiss; medium-grained; fresh colour: reddish gray; weathered: light (tan) brown; composition: K-spar 35-40%, quartz 30%, plagioclase 30%, biotite 0-5%.	**foliation:** 321/75 **joints:** 112/81, 255/34, 208/48	-
302: prospect outcrop dimensions: 4x3 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 30-55%, quartz 30%, K-spar 5-10%, biotite 5-10%; garnet 5-20% (red, mm-1cm-size).	**foliation:** 290/72 **joints:** 13/85, 129/46, 90/46, 17/78	sample
303: exposure outcrop dimensions: 15x3 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 40-45%, quartz 35%, plagioclase 20%, biotite 0-5%, magnetite <1%.	**foliation:** 312/72 **joints:** 30/38, 212/58, 44/44	-
304: exposure outcrop dimensions: 15x10 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 40-50%, quartz 30%, plagioclase 20%, biotite 0-5%, garnet 0-5% (red, mm-size), magnetite <1%.	**foliation:** 301/72 **joints:** 177/58, 83/60, 219/70	sample
305: adit outcrop dimensions: 3x2 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 35-40%, quartz 30%, plagioclase 30%, biotite 0-5%, magnetite <1%.	**foliation:** 307/83 **joints:** 242/89, 237/70, 49/30	-
306: exposure outcrop dimensions: 3x3 m	**Agg:** granitic gneiss; medium-grained; fresh colour: reddish gray; weathered: light brown; composition: K-spar 30-35%, quartz 30%, plagioclase 30%, biotite 5-10%.	**foliation:** 308/80 **joints:** 18/88, 63/75, 190/41	sample
307: exposure outcrop dimensions: 2x3 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 30-35%, quartz 30%, plagioclase 30%, biotite 5%, garnet 0-5% (red, mm-size), magnetite <1%; isoclinally folded.	**foliation:** 322/70 **joints:** 246/62, 114/40, 110/42	sample
308: exposure outcrop dimensions: 2x2 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 30-40%, quartz 30%, plagioclase 20%, biotite 0-5%, garnet 0-5% (red, mm-size), magnetite <1%.	**foliation:** 293/50 **joints:** 221/85, 20/64, 206/30	-
309: adit/prospect outcrop dimensions: 2x2 m	**Agg:** granitic gneiss; medium-grained; fresh colour: reddish gray; weathered: light brown, ochre; composition: K-spar 45-50%, quartz 30%, plagioclase 20%, biotite 0-5%; potassic and chloritic alteration.	**joints:** 147/28, 120/62, 187/70	sample
311: exposure outcrop dimensions: 2x2 m	**Agg:** granitic gneiss within **Aggm**; medium-grained; fresh colour: reddish gray; weathered: light brown, ochre; composition: K-spar 45-55%, quartz 20-25%, plagioclase 15%, biotite 10-15%; potassic and chloritic alteration +/- sulfides; 3-6 cm discordant quartz veins.	**foliation:** 303/78 **quartz veins:** 246/65, 358/56 **joints:** 188/42, 45/52, 185/44	-
313: prospect outcrop dimensions: 2x2 m	**Agg:** granitic gneiss; fine-grained; fresh colour: reddish gray; weathered: light brown, ochre; composition: K-spar 30-60%, quartz 30-40%, plagioclase 10-25%, biotite 0-5%.	**foliation:** 136/45 **joints:** 310/81, 55/85, 98/58	sample

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
314: exposure outcrop dimensions: 2x2 m	**Agg:** granitic gneiss; medium-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 35-45%, quartz 35%, plagioclase 20-25%, biotite 0-5%.	**foliation:** 281/58 **joints:** 81/25, 37/28, 187/70	-
315: exposure outcrop dimensions: 4x3 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 30%, quartz 30%, K-spar 25-30%, biotite 0-5%; garnet 5-10% (red, mm-size); partly highly migmatitic (leucosome up to 30% consisiting of K-spar, quartz, plagioclase).	**foliation:** 309/55 **joints:** 80/44, 35/50, 190/25	-
316: exposure outcrop dimensions: 4x4 m	**Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 45-50%, quartz 30-35%, K-spar 10%, biotite 0-5%; garnet 5% (red, mm-1cm-size); **Aam**-lenses (10x5 cm within this unit).	**foliation:** 300/52 **joints:** 140/40, 42/86, 51/75	-
317: exposure outcrop dimensions: 4x4 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 30-45%, quartz 30-35%, K-spar 25%, biotite 0-5%; garnet 0-5% (red, mm-size).	**foliation:** 290/37 **joints:** 281/87, 216/83, 233/70	-
319: exposure outcrop dimensions: 6x4 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 65%, plagioclase 20%, quartz 10%, garnet 5% (red, mm-size); discordant pegmatite **(Peg):** 15 cm in diameter; coarse- to very coarse-grained; composition: quartz, K-spar, +/- plagioclase.	**foliation:** 135/50 **contact Peg:** 78/58 **joints:** 56/36, 227/85, 210/70	-
320: exposure outcrop dimensions: 15x15 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 60%, plagioclase 25%, quartz 10%, garnet 5% (red, mm-size).	**foliations:** 134/78, 293/88 (synform) **joints:** 220/75, 212/65	sample
321: exposure outcrop dimensions: 10x10 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 50-60%, plagioclase 30%, quartz 10%, garnet 0-10% (red, mm-size); migmatitic (nebulitic; leucosome 5-10% consisiting of plagioclase, quartz, and garnet).	**foliation:** 295/75 **joints:** 236/66, 128/45, 16/18	-
322: exposure outcrop dimensions: 4x10 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 35-50%, quartz 30%, plagioclase 20-30%, biotite 0-5%, magnetite <1%.	**foliation:** 321/77 **joints:** 213/62, 304/39, 43/90	-
324: exposure outcrop dimensions: 8x10 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 35-40%, quartz 30%, plagioclase 30%, biotite 0-5%, magnetite <1%.	**foliations:** 30/50, 70/35 (antiform) **joints:** 100/87, 60/62, 342/84	sample
325: exposure outcrop dimensions: 4x6 m	**Aggm:** granitic gneiss, magnetic; variations to **Agg**; fine- to medium-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 35-40%, quartz 30%, plagioclase 30%, biotite 0-5%, magnetite <1%; dm-scale Aam-lenses within this unit; discordant quartz veins: mm-scale; close to the veins no magnetic susceptibility measureable.	**foliations:** 10/62, 197/86, 337/70 (anticline) **quartz veins:** 332/79, 285/81, 167/76 **joints:** 72/86, 120/47, 100/77, 276/47	-

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
326: exposure outcrop dimensions: 6x8 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 30-40%, quartz 30%, plagioclase 30-35%, biotite 0-5%, magnetite <1%.	**foliation:** 60/68 **joints:** 290/62, 157/88, 176/80	-
327: exposure outcrop dimensions: 2x2 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 35-40%, quartz 30%, plagioclase 30%, biotite 0-5%, magnetite <1%.	**foliation:** 33/41 **joints:** 200/68, 147/55, 284/86	sample
328: exposure outcrop dimensions: 3x6 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 35-40%, quartz 30%, plagioclase 30%, biotite 0-5%, magnetite <1%.	**foliation:** 2/21 **joints:** 16/78, 84/70, 185/78	-
329: exposure outcrop dimensions: 2x2 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 40-50%, quartz 30%, plagioclase 20-25%, biotite 0-5%, magnetite <1%.	**foliation:** 0/68 **joints:** 17/55, 35/70, 291/60	sample
330: prospect outcrop dimensions: 6x2 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 35-40%, quartz 30%, plagioclase 30%, biotite 0-5%, magnetite <1%.	**foliation:** 307/54 **joints:** 186/78, 128/82, 19/51	-
331: road cut outcrop dimensions: 10x2 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 30-35%, quartz 35%, plagioclase 30%, biotite 0-5%, magnetite <1%; discordant quartz veins: mm-cm in diameter.	**foliation:** 307/24 **quartz veins:** 308/85 **joints:** 296/80, 148/72, 38/80	sample
332: road cut outcrop dimensions: 2x2 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 30-35%, quartz 35%, plagioclase 30%, biotite 0-5%, magnetite <1%.	**foliation:** 290/79 **joints:** 197/65, 150/32, 6/62	-
333: exposure outcrop dimensions: 3x3 m	**Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 50-55%, quartz 30%, K-spar 5-10%, biotite 5%; garnet 5% (red, mm-1cm-size).	**foliation:** 322/41 **joints:** 111/86, 114/33, 353/69, 210/76	sample
334: road cut outcrop dimensions: 2x2 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 45-50%, quartz 30%, plagioclase 20%, biotite 0-5%, magnetite <1%.	**foliation:** 300/45 **joints:** 62/65, 112/58, 163/71	sample
335: exposure outcrop dimensions: 3x10 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 35-40%, quartz 30%, plagioclase 30%, biotite 5%, magnetite <1%.	**foliation:** 310/50 **joints:** 220/85, 83/46, 310/76	-
337: exposure outcrop dimensions: 8x4 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 50-55%, quartz 30%, plagioclase 15%, biotite 0-5%, magnetite <1%.	**foliation:** 290/51 **joints:** 217/70 (ac), 120/58, 168/17	-
338: exposure outcrop dimensions: 2x2 m	**Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 40-55%, quartz 30%, K-spar 15-20%, biotite 0-5%; garnet 0-5% (red, mm-2cm-size).	**foliation:** 300/70 **joints:** 217/80, 18/18, 112/42	-

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
339: exposure outcrop dimensions: 2x2 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 45-50%, quartz 30%, plagioclase 20%, biotite 0-5%, magnetite <1%.	**foliation:** 302/58 **joints:** 195/84, 150/58, 21/41	-
340: exposure outcrop dimensions: 2x2 m	**Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 40-50%, quartz 30-35%, K-spar 10-15%, biotite 5%; garnet 5% (red, mm-size).	**foliations:** 291/35, 282/12 (antiform) **fold axis:** 210/10 (antiform) **isoclinal fold:** 208/15 **joints:** 22/70, 286/80, 97/85	-
341: exposure outcrop dimensions: 2x2 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light reddish gray; weathered: light brown; composition: plagioclase 30-35%, quartz 30%, K-spar 25%, biotite 5%; garnet 5-10% (red, mm-size); highly migmatitic (leucosome up to 40% consisting of K-spar, quartz, plagioclase).	**foliation:** 276/42 **joints:** 48/40, 40/80, 213/72	-
342: exposure outcrop dimensions: 3x2 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 40%, quartz 30%, K-spar 20%, biotite 5%; garnet 5% (red, mm-size).	**foliation:** 293/72 **joints:** 16/40, 145/75, 147/75	-
343: float	**Tv:** mafic dike, float; very fine grained, aphanitic; mineralogy ?	-	sample
344: float	**Tv:** mafic dike, float; very fine grained, aphanitic; mineralogy ?	-	sample
345: float	**Tv:** mafic dike, float; very fine grained, aphanitic; mineralogy ?	-	sample
346: exposure outcrop dimensions: 2x3 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 55-65%, plagioclase 20%, quartz 10-15%, garnet 5-10% (red, mm-size).	**foliation:** 145/60 **joints:** 100/82, 346/40, 50/88	-
347: road cut outcrop dimensions: 2x2 m	**Atg:** tonalitic gneiss; fine-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 40-50%, quartz 40%, K-spar 10%, biotite 0-5%; garnet 0-5% (red, mm-size).	**foliation:** 130/25 **joints:** 315/85, 243/75	-
348: float	**Tv:** mafic dike, float; very fine grained, aphanitic; mineralogy ?	-	sample
349: exposure outcrop dimensions: 8x6 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 60-65%, plagioclase 20%, quartz 10%, garnet 5-10% (red, mm-size).	**foliation:** 114/85	-
352: road cut outcrop dimensions: 2x2 m	**Agg:** granitic gneiss; fine-grained; fresh colour: reddish gray; weathered: light brown; composition: K-spar 40-45%, quartz 35%, plagioclase 20%, biotite 0-5%.	**foliations:** 290/50, 320/45 **joints:** 237/85, 180/42	-
353: exposure outcrop dimensions: 6x8 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 35-50%, quartz 30%, plagioclase 20-30%, biotite 0-5%, magnetite <1%; discordant quartz veins, mm-size in diameter.	**foliation:** 317/70 **quartz veins:** 310/88 **joints:** 290/88, 22/80, 60/45	-

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
354: road cut outcrop dimensions: 10x2 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 35-40%, quartz 30%, plagioclase 30%, biotite 0-5%, magnetite <1%.	**foliation:** 300/75 **joints:** 17/70, 0/30, 228/30	-
355: road cut outcrop dimensions: 20x2 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 30-40%, quartz 30%, plagioclase 25%, biotite 5-10%, garnet 0-5% (red, mm-size), magnetite <1%.	**foliation:** 293/70 **joints:** 167/55, 10/55, 13/60	-
356: road cut outcrop dimensions: 25x5 m	contact **Atg** to **Aggm**: **Atg:** tonalitic gneiss; fine-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 30-40%, quartz 30%, K-spar 25%, biotite 5-10%; garnet 0-5% (red, mm-size). **Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 35-40%, quartz 30%, plagioclase 30%, biotite 0-5%, magnetite <1%.	**foliations:** 310/74, 290/80 **joints:** 63/62, 113/40, 105/38	-
357: exposure outcrop dimensions: 15x8 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 40-45%, quartz 30%, plagioclase 20%, biotite 5%, garnet 0-5% (red, mm-size), magnetite <1%.	**foliation:** 110/85 **joints:** 260/40, 18/86, 121/30	-
358: exposure outcrop dimensions: 35x20 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 35-40%, quartz 30%, plagioclase 30%, biotite 0-5%, magnetite <1%.	**foliation:** 304/82 **joints:** 206/62, 34/55, 123/60	-
359: exposure outcrop dimensions: 10x20 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 35-40%, quartz 30%, plagioclase 30%, biotite 0-5%, magnetite <1%.	**foliation:** 296/78 **joints:** 235/72, 28/57, 188/52	-
360: exposure outcrop dimensions: 10x20 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 35-40%, quartz 30%, plagioclase 30%, biotite 0-5%, magnetite <1%.	**foliation:** 301/67 **joints:** 45/76, 210/88	-
361: exposure outcrop dimensions: 30x20 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 50-60%, quartz 30%, plagioclase 10-15%, biotite 0-5%, magnetite <1%.	**foliation:** 320/70 **joints:** 75/55, 211/65, 269/65	-
363: prospect outcrop dimensions: 10x6 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 35-50%, quartz 30%, plagioclase 20-25%, biotite 0-10%, magnetite <1%; discordant quartz veins, sulfidic, mm-size.	**foliations:** 320/45, 298/62 (indicating an antiform) **quartz veins:** 110/68 **joints:** 218/75, 236/25, 16/38	-
364: adit outcrop dimensions: 10x20 m	**Agg:** granitic gneiss; fine- to medium-grained; fresh colour: reddish gray; weathered: light brown, ochre; composition: K-spar 45-55%, quartz 35%, plagioclase 10-15%, biotite 0-5%.	**foliation:** 320/75 **joints:** 250/65, 218/88, 25/88	-

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
365: exposure outcrop dimensions: 20x10 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 35-40%, quartz 30%, plagioclase 30%, biotite 0-5%, magnetite <1%.	**foliation:** 138/85 **joints:** 42/54, 222/38, 108/54	-
366: exposure outcrop dimensions: 30x20 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 45-50%, quartz 35%, plagioclase 15%, biotite 0-5%, magnetite <1%.	**foliation:** 310/56 **joints:** 88/58, 210/48, 272/87	-
367: exposure outcrop dimensions: 30x15 m	**Aggm:** granitic gneiss, magnetic; fine-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 40-50%, quartz 30%, plagioclase 20%, biotite 0-10%, magnetite <1%.	**foliation:** 310/60 **joints:** 221/70, 104/80, 168/27	-
368: exposure outcrop dimensions: 10x10 m	**Aggm:** granitic gneiss, magnetic; medium-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 45-50%, quartz 35%, plagioclase 15%, biotite 0-5%, magnetite <1%.	**foliation:** 310/54 **joints:** 230/90, 125/70, 167/66	-
369: exposure outcrop dimensions: 12x8 m	**Aggm:** granitic gneiss, magnetic; fine-grained; fresh colour: reddish white; weathered: light brown; composition: K-spar 40-45%, quartz 35%, plagioclase 20%, biotite 0-5%, magnetite <1%.	**foliation:** 310/60 **joints:** 37/60, 137/60, 112/62	-
370: exposure outcrop dimensions: 5x2 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 50%, plagioclase 30%, quartz 10%, garnet 10% (red, mm-1cm-size); migmatitic (nebulitic leucosome up to 15% consisting of plagioclase, quartz, +/-garnet.	**foliation:** 314/78 **joints:** 43/86, 214/21, 183/85	-
371: exposure outcrop dimensions: 10x10 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 30-55%, quartz 30%, K-spar 10-30%, biotite 5%; garnet 0-5% (red, mm-size); migmatitic (striatic leucosome up to 15% consisting of K-spar, quartz, plagioclase).	**foliation:** 300/70 **joints:** 16/72, 190/10, 200/70	-
372: exposure outcrop dimensions: 20x20 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 35-60%, quartz 35-45%, K-spar 0-10%, biotite 5%; garnet 0-5% (red, mm-1cm-size).	**foliation:** 305/74 **joints:** 22/80, 355/65, 350/78	-
373: exposure outcrop dimensions: 10x10 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 30-40%, quartz 30%, K-spar 20-30%, biotite 5%; garnet 5% (red, mm-size); migmatitic (striatic leucosome up to 20% consisting of K-spar, quartz, plagioclase, +/-garnet).	**foliation:** 300/74 **joints:** 57/65, 202/38, 76/30	-
375: exposure outcrop dimensions: 15x30 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray, reddish white; weathered: light brown; composition: plagioclase 30-50%, quartz 30-40%, K-spar 10-20%, biotite 5%; garnet 5% (red, mm-size); migmatitic (striatic leucosome up to 30% consisting of K-spar, quartz, plagioclase, +/-garnet).	**foliation:** 312/60 **joints:** 112/55, 172/45, 50/60	-
376: trench outcrop dimensions: 30x2 m	**Agg:** granitic gneiss; fine- to medium-grained; fresh colour: reddish gray; weathered: light brown, ochre; composition: K-spar 30-40%, quartz 30%, plagioclase 30%, biotite 0-5%, garnet 0-5% (red, mm-size).	**foliation:** 312/85 **joints:** 260/35, 210/50, 335/68	-

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

location, type of outcrop	lithology, alterations	tectonic measurements	remarks
377: exposure outcrop dimensions: 5x5 m	**Atg:** tonalitic gneiss; medium-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 35-40%, quartz 30-35%, K-spar 20%, biotite 5%; garnet 5% (red, mm-size).	**foliation:** 298/88 **joints:** 7/60, 38/85, 72/52, 153/30	-
378: exposure outcrop dimensions: 10x10 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: dark brown; composition: hornblende 50-65%, plagioclase 20-30%, quartz 10%, garnet 5-10% (red, mm-1cm-size); migmatitic (nebulitic leucosome up to 20% consisting of plagioclase, quartz, +/-garnet.	**foliation:** 292/84 **joints:** 212/80, 236/10, 7/32	-
379: exposure outcrop dimensions: 5x5 m	**Atg:** tonalitic gneiss; fine-grained; fresh colour: light gray; weathered: light brown; composition: plagioclase 40-50%, quartz 30%, K-spar 20%, biotite 0-5%; garnet 0-5% (red, mm-size); potassic alteration.	**foliation:** 114/75 **joints:** 1/68, 221/21, 177/80	-
380: exposure outcrop dimensions: 10x8 m	**Atg:** tonalitic gneiss; fine- to medium-grained; fresh colour: light reddish gray; weathered: light brown; composition: plagioclase 30-35%, quartz 30%, K-spar 30%, biotite 5%; garnet 0-5% (red, mm-size); migmatitic (striatic leucosome up to 30% consisting of K-spar, quartz, plagioclase).	**foliation:** 300/88 **joints:** 28/80, 30/22, 177/20	-
381: exposure outcrop dimensions: 6x4 m	**Atg:** tonalitic gneiss; medium- to fine-grained; fresh colour: light reddish gray; weathered: light brown; composition: plagioclase 30-35%, quartz 30%, K-spar 30%, biotite 5%; garnet 0-5% (red, mm-size); migmatitic (striatic leucosome up to 30% consisting of K-spar, quartz, plagioclase).	**foliation:** 108/79 **joints:** 40/79, 130/16	-
395: exposure outcrop dimensions: 45x15 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 35-40%, quartz 30%, plagioclase 30%, biotite 0-5%, magnetite <1%.	**foliation:** 300/55 **joints:** 106/81, 118/36, 122/50	-
396: exposure outcrop dimensions: 15x10 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 35-40%, quartz 30%, plagioclase 30%, biotite 0-5%, magnetite <1%; potassic alteration; discordant pegmatite **(Peg)**: 4 cm; coarse-grained; composition: K-spar, quartz, plagioclase, +/- biotite.	**foliation:** 304/48 **contact Peg:** 61/40 **joints:** 61/40, 178/85, 110/68	-
397: adit outcrop dimensions: 4x2 m	**Agg:** granitic gneiss; fine- to medium-grained; fresh colour: reddish gray; weathered: light brown, ochre; composition: K-spar 45-50%, quartz 30%, plagioclase 20%, biotite 0-5%; quartz veins, mm-cm-size in diameter accompagnied with potassic alteration.	**foliation:** 304/89 **quartz veins:** 90/74 **joints:** 240/83, 28/50	-
398: adit outcrop dimensions: 20x10 m	**Aggm:** granitic gneiss, magnetic; fine- to medium-grained; fresh colour: reddish white; weathered: light (tan) brown; composition: K-spar 35-50%, quartz 30%, plagioclase 20-30%, biotite 0-5%, magnetite <1%; quartz veins, mm-cm-size in diameter accompagnied with potassic and chloritic alteration.	**foliation:** 308/65 **quartz veins:** 296/88 **joints:** 38/68, 222/56, 133/58	-
399: exposure outcrop dimensions: 20x10 m	**Aam:** hornblende-plagioclase gneiss and amphibolite; medium-grained; fresh colour: black; weathered: brown; composition: hornblende 45-65%, plagio-clase 20-25%, quartz 10-15%, garnet 5-15% (red, mm-1cm-size); migmatitic (nebulitic leucosome up to 30% consisting of plagioclase, quartz, +/-garnet.	**foliation:** 307/65 **joints:** 36/83, 135/35, 350/10	-

Appendix 1: Description of outcrops in Lucas/Atlas and South Bachelor areas, VCMD.

sample no.	depth [ft]	lithology	alteration
CD-352	16 – 21	**Aggm:** medium- to fine-grained; pink; K-spar 40-50%; quartz 35%; plagioclase 10-20%; biotite 5%	-
CD-353	12 – 17	**Aggm:** medium- to fine-grained; pink; K-spar 40-50%; quartz 35%; plagioclase 10-20%; biotite 5%	K-spar
CD-354	17 – 22	**Aggm:** medium- to fine-grained; pink; K-spar 40-50%; quartz 35%; plagioclase 10-20%; biotite 5%	-
CD-355	12 – 17	**Aggm:** medium- to fine-grained; pink; K-spar 40-50%; quartz 35%; plagioclase 10-20%; biotite 5%	K-spar
CD-356	17 – 22	**Aggm:** medium- to fine-grained; pink; K-spar 40-50%; quartz 35%; plagioclase 10-20%; biotite 5%	K-spar
CD-357	17 – 22	**Aggm:** medium- to fine-grained; pink; K-spar 40-50%; quartz 35%; plagioclase 10-20%; biotite 5%	K-spar
CD-358	14 – 19	**Aggm:** medium- to fine-grained; pink; K-spar 40-50%; quartz 35%; plagioclase 10-20%; biotite 5%	K-spar
CD-359	17 – 22	**Aggm:** medium- to fine-grained; pink; K-spar 40-50%; quartz 35%; plagioclase 10-20%; biotite 5%	K-spar
CD-360	17 – 22	**Aggm:** medium- to fine-grained; pink; K-spar 40-50%; quartz 35%; plagioclase 10-20%; biotite 5%	K-spar, weaker
CD-361	17 - 22	**Aggm:** medium- to fine-grained; pink; K-spar 40-50%; quartz 35%; plagioclase 10-20%; biotite 5%	-
CD-362	17 – 22	**Aggm:** medium- to fine-grained; pink; K-spar 40-50%; quartz 35%; plagioclase 10-20%; biotite 5%	K-spar
CD-363	17 – 22	**Aggm:** medium- to fine-grained; pink; K-spar 40-50%; quartz 35%; plagioclase 10-20%; biotite 5%	K-spar
CD-364	17 – 22	**Aggm:** medium- to fine-grained; pink; K-spar 40-50%; quartz 35%; plagioclase 10-20%; biotite 5%; with **Aam**-chips	K-spar
CD-365	17 – 22	**Aggm:** medium- to fine-grained; pink; K-spar 40-50%; quartz 35%; plagioclase 10-20%; biotite 5%; with **Aam**- and **Atg**-chips	-
CD-366	17 – 22	**Aggm:** medium- to fine-grained; pink; K-spar 40-50%; quartz 35%; plagioclase 10-20%; biotite 5%; with **Aam**-chips	K-spar, weaker
CD-367	17 – 22	**Aggm:** medium- to fine-grained; pink; K-spar 40-50%; quartz 35%; plagioclase 10-20%; biotite 5%	K-spar, weaker
CD-368	17 – 22	**Aggm:** medium- to fine-grained; pink; K-spar 40-50%; quartz 35%; plagioclase 10-20%; biotite 5%; with **Aam**-chips	-
CD-369	17 – 22	**Atg:** medium-grained; gray; plagioclase 40-50%; quartz 30%; K-spar 10-15%; biotite 5-10%; garnet, red, 5%	-
CD-370	17 – 22	**Atg:** medium-grained; gray; plagioclase 40-50 %; quartz 30 %; K-spar 10-15%; biotite 5-10%; garnet, red, 5%	-
CD-371	17 – 22	**Aggm:** medium-grained; pink; K-spar 45-50%; quartz 35%; plagioclase 10-15%; biotite 5%	K-spar
CD-372	-	large void → no sample	-
CD-373	-	large void → no sample	-
CD-374	-	large void → no sample	-
CD-375	17 – 22	**Aam:** medium-grained; black; hornblende 55%; plagioclase 30%; quartz 10%; garnet, red, 5%	K-spar
CD-376	17 – 22	**Aam:** medium-grained; black; hornblende 55%; Plagioclase 30%; quartz 10%; garnet, red, 5%	-
CD-377	17 – 22	**Agg:** medium-grained; pink to white; K-spar 55%, quartz 30%, plagioclase 10%, biotite 5%	K-spar, weak chloritic
CD-378	-	void → no sample	-
CD-379	-	void → no sample	-
CD-380	12 – 17	**Atg:** fine-grained; gray; plagioclase 40-45%; quartz 30%; K-spar 20%; biotite 5-10%; garnet, red, <1%	K-spar, weaker
CD-381	12 – 17	**Atg:** medium-grained; gray; plagioclase 45%; quartz 40%; K-spar 10%; biotite 5%; garnet: - ; with **Aggm**-(magnetite-bearing)-chips	-
CD-382	-	void → no sample	-
CD-383	-	void → no sample	-
CD-384	14 – 19	**Atg:** fine- to medium-grained; gray to pink; plagioclase 35%; quartz 30%; K-spar 30%; biotite 5%; garnet: - ; possibly **Atg** with a lot of leucosome or **Agg**	K-spar

Appendix 2: Relogging of RC-chipsamples in Lucas/Atlas and South Bachelor areas, VCMD (***spacing*:** 20 ft).

sample no.	depth [ft]	lithology	alteration
CD-385	17 – 22	**Atg:** medium-grained; gray; plagioclase 40-45%; quartz 35-40%; K-spar 10%; biotite 5%; garnet, red, 5%	-
CD-386	17 – 22	**Peg:** grain-size ?, K-spar of 2 cm in size; pink, otherwise only K-spar / quartz / plagioclase / biotite and muscovite !	-
CD-387	17 – 22	**Atg:** medium- to fine-grained; gray; plagioclase 35%; quartz 40%; K-spar 15%; biotite 5%; garnet, red, 5%	-
CD-388	-	water @ 10‘-17‘, still in gravel, no sample	-
CD-389	-	water @ 12‘-17‘, still in gravel, no sample	-
CD-390	-	water, no sample	-
CD-391	6 – 11	**Atg:** medium-grained; gray to pinkish-gray; plagioclase 35%; quartz 30%; K-spar 30%; biotite 5%; garnet: - ; possibly higher leucosome content	chloritic, weak
CD-392	7 – 12	**Atg:** trondhejmitic; medium-grained; gray; plagioclase 30-35%; quartz 45-50%; K-spar 10%; biotite 5%; garnet, red, 5%	-
CD-393	6 – 11	**Atg:** trondhejmitic; medium-grained; gray; plagioclase 30-35%; quartz 45-50%; K-spar 10%; biotite 5%; garnet, red, 5%	-
CD-394	6 – 11	**Atg:** trondhejmitic; medium-grained; gray; plagioclase 30-35%; quartz 45-50%; K-spar 10%; biotite 5%; garnet, red, 5%	-
CD-395	5 – 10	**Aggm:** fine- to medium-grained; pink; K-spar 55%; quartz 30%; plagioclase 10%; biotite 5%	chloritic, weak
CD-396	7 – 12	**Agg:** fine- to medium-grained; pink; K-spar 50%; quartz 30%; plagioclase 15%; biotite 5%	-
CD-397	7 – 12	**Agg:** fine- to medium-grained; pink; K-spar 50%; quartz 30%; plagioclase 15%; biotite 5%	-
CD-398	7 – 12	**Agg:** fine- to medium-grained; pink; K-spar 50%; quartz 30%; plagioclase 15%; biotite 5%	-
CD-399	3 – 8	**Agg:** fine- to medium-grained; pink; K-spar 50%; quartz 30%; plagioclase 15%; biotite 5%	-
CD-400	3 – 8	**Atg:** medium-grained; gray; plagioclase 40-50%; quartz 30%; K-spar 5%; biotite 10-15%; garnet, red, 5-10%	-
CD-401	3 – 8	**Atg:** medium-grained; gray; plagioclase 40-50%; quartz 30%; K-spar 5%; biotite 10-15%; garnet, red, 5-10%	-
CD-402	4 – 9	**Atg:** medium-grained; gray; plagioclase 40-50%; quartz 30%; K-spar 5%; biotite 10-15%; garnet, red, 5-10%	-
CD-403	5 – 10	**Atg:** medium-grained; gray; plagioclase 40-50%; quartz 30%; K-spar 5%; biotite 10-15%; garnet, red, 5-10%	-
CD-404	6 – 11	**Atg:** medium-grained; gray to pinkish-gray; plagioclase 25-40%; quartz 30%; K-spar 20-30%; biotite 5-10%; garnet, red, 5%	-
CD-405	5 – 10	**Atg:** medium-grained; gray to pinkish-gray; plagioclase 25-40%; quartz 30%; K-spar 20-30%; biotite 5-10%; garnet, red, 5%	-
CD-406	5 – 10	**Agg:** medium-grained; pink; K-spar 45-55%; quartz 30%; plagioclase 10-20%; biotite 5%	-
CD-407	5 – 10	**Agg:** medium-grained; pink; K-spar 45-55%; quartz 30%; plagioclase 10-20%; biotite 5%	-
CD-408	7 – 12	**Atg:** medium- to fine-grained; gray; plagioclase 30-40%; quartz 40%; K-spar 10-15%; biotite 5-10%; garnet, red, 5%	K-spar, weak
CD-409	7 – 12	**Atg:** medium- to fine-grained; gray; plagioclase 30-40%; quartz 40%; K-spar 10-15%; biotite 5-10%; garnet, red, 5%	K-spar
CD-410	7 – 12	**Atg:** medium- to fine-grained; gray; plagioclase 30-40%; quartz 40%; K-spar 10-15%; biotite 5-10%; garnet, red, 5%	K-spar
CD-411	7 – 12	**Aggm:** fine-grained; pink; K-spar 55%; quartz 30%; plagioclase 10%; biotite 5%	-
CD-412	5 – 10	**Aggm:** fine-grained; pink; K-spar 55%; quartz 30%; plagioclase 10%; biotite 5%	chloritic
CD-413	5 – 10	**Aam:** medium-grained; black; hornblende 55-70%; plagioclase 10-20%; quartz 10%; biotite 5-10%; garnet, red, 5%	-
CD-414	5 – 10	**Atg:** medium-grained; gray; plagioclase 50%; quartz 30%; K-spar 10%; biotite 5%; garnet, red, 5%	-
CD-415	2 – 7	**Aggm:** fine-grained; pinkish-gray; K-spar 45%; quartz 40%; plagioclase 10%; biotite 5%	K-spar
CD-416	2 – 7	**Aggm:** fine-grained; pinkish-gray; K-spar 45%; quartz 40%; plagioclase 10%; biotite 5%	K-spar

Appendix 2: Relogging of RC-chipsamples in Lucas/Atlas and South Bachelor areas, VCMD (***spacing*:** 20 ft).

sample no.	depth [ft]	lithology	alteration
CD-417	1 – 6	**Aggm:** fine-grained; pinkish-gray; K-spar 45%; quartz 40%; plagioclase 10%; biotite 5%	K-spar
CD-418	5 – 10	**Atg:** fine- to medium-grained; pinkish-gray; plagioclase 40%; quartz 30%; K-spar 20%; biotite 5%; garnet, red, 5%	-
CD-419	5 – 10	**Atg:** fine- to medium-grained; pinkish-gray; plagioclase 40%; quartz 30%; K-spar 20%; biotite 5%; garnet, red, 5%	chloritic
CD-420	5 – 10	**Atg:** fine- to medium-grained; pinkish-gray; plagioclase 40%; quartz 30%; K-spar 20%; biotite 5%; garnet, red, 5%	-
CD-421	5 – 10	**Agg:** medium-grained; pink; K-spar 35%; quartz 30%; plagioclase 30%; biotite 5%	-
CD-422	5 – 10	**Aggm:** fine- to medium-grained; pink; K-spar 45%; quartz 30%; plagioclase 20%; biotite 5%	-
CD-423	5 – 10	**Agg:** fine- to medium-grained; pink; K-spar 45%; quartz 30%; plagioclase 20%; biotite 5%	-
CD-424	5 – 10	**Aggm:** fine- to medium-grained; pink; K-spar 45%; quartz 30%; plagioclase 20%; biotite 5%	-
CD-425	5 – 10	**Agg:** fine- to medium-grained; pink; K-spar 45%; quartz 30%; plagioclase 20%; biotite 5%	-
CD-426	7 - 12	**Agg:** fine- to medium-grained; pink; K-spar 45%; quartz 30%; plagioclase 20%; biotite 5%	-
CD-427	7 – 12	**Agg:** fine- to medium-grained; pink; K-spar 45%; quartz 30%; plagioclase 20%; biotite 5%	-
CD-428	7 – 12	**Agg:** fine- to medium-grained; pink; K-spar 45%; quartz 30%; plagioclase 20%; biotite 5%	-
CD-429	7 – 12	**Agg:** fine- to medium-grained; pink; K-spar 45%; quartz 30%; plagioclase 20%; biotite 5%	-
CD-430	7 – 12	**Aggm:** fine- to medium-grained; pink; K-spar 45%; quartz 30%; plagioclase 20%; biotite 5%	-
CD-431	7 – 12	**Agg:** fine- to medium-grained; pink; K-spar 45%; quartz 30%; plagioclase 20%; biotite 5%	-
CD-432	7 – 12	**Atg:** medium-grained; gray; plagioclase 45-50%; quartz 30%; K-spar 10-15%; biotite 5%; garnet, red, 5%	K-spar, weak
CD-433	3 – 8	**Atg:** medium-grained; gray; plagioclase 45-50%; quartz 30%; K-spar 10-15%; biotite 5%; garnet, red, 5%	-
CD-434	4 – 9	**Atg:** medium-grained; gray; plagioclase 45-50%; quartz 30%; K-spar 10-15%; biotite 5%; garnet, red, 5%	-
CD-435	4 – 9	**Atg:** medium-grained; gray; plagioclase 45-50%; quartz 30%; K-spar 10-15%; biotite 5%; garnet, red, 5%	-
CD-436	4 – 9	**Atg:** medium-grained; gray; plagioclase 45-50%; quartz 30%; K-spar 10-15%; biotite 5%; garnet, red, 5%	-
CD-437	4 – 9	**Atg:** trondhejmitic; medium-grained; gray; plagioclase 25-35%; quartz 50%; K-spar 5-10%; biotite 5-10%; garnet, red, 5%	-
CD-438	1 – 6	**Atg:** trondhejmitic; medium-grained; gray; plagioclase 25-45%; quartz 50%; K-spar 5-10%; biotite 5-10%; garnet, red, 5%	-
CD-439	4 – 9	**Atg:** medium-grained; gray; plagioclase 35-45%; quartz 30%; K-spar 10%; biotite 10-15%; garnet, red, 5-10%	-
CD-440	4 – 9	**Atg:** medium-grained; gray; plagioclase 35-45%; quartz 30%; K-spar 10%; biotite 10-15%; garnet, red, 5-10%	-
CD-441	4 – 9	**Agg:** fine- to medium-grained; pink to white; K-spar 45%; quartz 30%; plagioclase 20%; biotite 5%	K-spar
CD-442	4 – 9	**Agg:** fine- to medium-grained; pink to white; K-spar 45%; quartz 30%; plagioclase 20%; biotite 5%	K-spar
CD-443	4 – 9	**Agg:** fine- to medium-grained; pink to white; K-spar 45%; quartz 30%; plagioclase 20%; biotite 5%	K-spar
CD-444	4 – 9	**Atg:** medium- to fine-grained; gray to white; plagioclase 35-45%; quartz 45%; K-spar 5-10%; biotite 5-10%; garnet: -	-
CD-445	5 – 10	**Atg:** medium- to fine-grained; gray to white; plagioclase 35-45%; quartz 45%; K-spar 5-10%; biotite 5-10%; garnet: -	-
CD-446	5 – 10	**Atg:** medium- to fine-grained; gray to white; plagioclase 35-45%; quartz 45%; K-spar 5-10%; biotite 5-10%; garnet: -	-

Appendix 2: Relogging of RC-chipsamples in Lucas/Atlas and South Bachelor areas, VCMD (***spacing*:** 20 ft).

sample no.	depth [ft]	lithology	alteration
CD-447	5 – 10	**Atg:** medium- to fine-grained; gray to white; plagioclase 35-45%; quartz 45%; K-spar 5-10%; biotite 5-10%; garnet: -	-
CD-448	5 – 10	**Atg:** medium- to fine-grained; gray; plagioclase 45-55%; quartz 30%; K-spar 5-10%; biotite 5-10%; garnet, red, 5%	-
CD-449	5 – 10	**Atg:** medium- to fine-grained; gray; plagioclase 40-50%; quartz 35%; K-spar 5-10%; biotite 5-10%; garnet, red, 5%	-
CD-450	5 – 10	**Atg:** fine-grained; gray; plagioclase 35-50%; quartz 30%; K-spar 10-20%; biotite 10-15%; garnet: - ; possibly containing more leucosome	-
CD-451	5 – 10	**Atg:** fine-grained; gray to white; plagioclase 40-45%; quartz 35%; K-spar 15%; biotite 5-10%; garnet: -	-
CD-452	6 – 11	**Agg:** fine- to medium-grained; pink; K-spar 50%; quartz 30%; plagioclase 15%; biotite 5%	K-spar
CD-453	7 – 12	**Aggm:** fine-grained; pink; K-spar 35%; quartz 30%; plagioclase 30%; biotite 5%	K-spar
CD-454	7 – 12	**Aggm:** fine-grained; pink; K-spar 35%; quartz 30%; plagioclase 30%; biotite 5%	-
CD-455	7 – 12	**Aggm:** fine-grained; pink; K-spar 35%; quartz 30%; plagioclase 30%; biotite 5%	-
CD-456	7 – 12	**Aggm:** fine-grained; pink; K-spar 35%; quartz 30%; plagioclase 30%; biotite 5%	-
CD-457	7 – 12	**Aggm:** fine-grained; pink; K-spar 35%; quartz 30%; plagioclase 30%; biotite 5%	-
CD-458	7 – 12	**Aggm:** fine-grained; pink; K-spar 35%; quartz 30%; plagioclase 30%; biotite 5%	-
CD-459	7 – 12	**Aggm:** fine-grained; pink; K-spar 35%; quartz 30%; plagioclase 30%; biotite 5%	-
CD-460	7 – 12	**Aggm:** fine-grained; pink; K-spar 35%; quartz 30%; plagioclase 30%; biotite 5%	-
CD-461	7 – 12	**Atg:** fine- to medium-grained; gray; plagioclase 45%; quartz 35%; K-spar 15%; biotite 5%; garnet: -	-
CD-462	7 – 12	**Atg:** fine- to medium-grained; gray; plagioclase 45%; quartz 35%; K-spar 15%; biotite 5%; garnet: -	-
CD-463	7 – 12	**Atg:** fine- to medium-grained; gray; plagioclase 45%; quartz 35%; K-spar 15%; biotite 5%; garnet: -	K-spar
CD-464	7 – 12	**Aggm:** fine-grained; pinkish-white; K-spar 30-35%; quartz 30-35%; plagioclase 30%; biotite 5%	-
CD-465	7 – 12	**Aggm:** fine-grained; pinkish-white; K-spar 30-35%; quartz 30-35%; plagioclase 30%; biotite 5%	K-spar
CD-466	4 – 9	**Aggm:** fine-grained; pinkish-white; K-spar 30-35%; quartz 30-35%; plagioclase 30%; biotite 5%	K-spar
CD-467	4 – 9	**Aggm:** fine-grained; pinkish-white; K-spar 30-35%; quartz 30-35%; plagioclase 30%; biotite 5%	K-spar, weaker
CD-468	4 – 9	**Aggm:** fine-grained; pinkish-white; K-spar 30-35%; quartz 30-35%; plagioclase 30%; biotite 5%	-
CD-469	4 – 9	**Aggm:** fine-grained; pinkish-white; K-spar 30-35%; quartz 30-35%; plagioclase 30%; biotite 5%	K-spar, weaker
CD-470	4 – 9	**Aggm:** fine-grained; pinkish-white; K-spar 30-35%; quartz 30-35%; plagioclase 30%; biotite 5%	K-spar
CD-471	3 – 8	**Aggm:** fine-grained; pinkish-white; K-spar 30-35%; quartz 30-35%; plagioclase 30%; biotite 5%	-
CD-472	2 – 7	**Aggm:** fine-grained; pinkish-white; K-spar 30-35%; quartz 30-35%; plagioclase 30%; biotite 5%	-
CD-473	2 – 7	**Aggm:** fine-grained; pinkish-white; K-spar 30-35%; quartz 30-35%; plagioclase 30%; biotite 5%	-
CD-474	2 – 7	**Aggm:** fine-grained; pink; K-spar 45-50%; quartz 30%; plagioclase 15-20%; biotite 5%	-
CD-475	5 – 10	**Aggm:** fine-grained; pink; K-spar 45-50%; quartz 30%; plagioclase 15-20%; biotite 5%	-
CD-476	5 – 10	**Aggm:** fine-grained; pink; K-spar 45-50%; quartz 30%; plagioclase 15-20%; biotite 5%	K-spar
CD-477	7 – 12	**Aggm:** fine-grained; pinkish-white; K-spar 30-35%; quartz 30-35%; plagioclase 30%; biotite 5%	-
CD-478	7 – 12	**Aggm:** fine-grained; pinkish-white; K-spar 30-35%; quartz 30-35%; plagioclase 30%; biotite 5%	-
CD-479	7 – 12	**Agg:** fine- to medium-grained; pink; K-spar 50%; quartz 30%; plagioclase 15%; biotite 5%	K-spar
CD-480	6 – 11	**Aggm:** fine- to medium-grained; pink; K-spar 45%; quartz 30%; plagioclase 20%; biotite 5%	-

Appendix 2: Relogging of RC-chipsamples in Lucas/Atlas and South Bachelor areas, VCMD (***spacing*:** 20 ft).

sample no.	depth [ft]	lithology	alteration
CD-481	6 – 11	**Agg:** fine- to medium-grained; pinkish-white; K-spar 45-50%; quartz 30%; plagioclase 15-20%; biotite 5%	-
CD-482	6 – 11	**Agg:** fine- to medium-grained; pinkish-white; K-spar 45-50%; quartz 30%; plagioclase 15-20%; biotite 5%	K-spar
CD-483	6 – 11	**Agg:** fine- to medium-grained; pinkish-white; K-spar 45-50%; quartz 30%; plagioclase 15-20%; biotite 5%	K-spar
CD-484	7 – 12	**Aggm:** fine- to medium-grained; pink; K-spar 45-50%; quartz 30%; plagioclase 15-20%; biotite 5%	K-spar
CD-485	1 – 6	**Aggm:** fine- to medium-grained; pink; K-spar 45-50%; quartz 30%; plagioclase 15-20%; biotite 5%	K-spar
CD-486	3 – 8	**Aggm:** fine- to medium-grained; pink; K-spar 45-50%; quartz 30%; plagioclase 15-20%; biotite 5%	K-spar
CD-487	6 – 11	**Aggm:** fine- to medium-grained; pink; K-spar 45-50%; quartz 30%; plagioclase 15-20%; biotite 5%	K-spar
CD-488	6 – 11	**Aggm:** fine- to medium-grained; pink; K-spar 45-50%; quartz 30%; plagioclase 15-20%; biotite 5%	-
CD-489	6 – 11	**Aggm:** fine- to medium-grained; pink; K-spar 45-50%; quartz 30%; plagioclase 15-20%; biotite 5%	K-spar, weaker
CD-490	7 – 12	**Aggm:** fine- to medium-grained; pink; K-spar 45-50%; quartz 30%; plagioclase 15-20%; biotite 5%	-
CD-491	6 – 11	**Aggm:** fine- to medium-grained; pink; K-spar 45-50%; quartz 30%; plagioclase 15-20%; biotite 5%	K-spar
CD-492	7 – 12	**Aggm:** fine- to medium-grained; pink; K-spar 45-50%; quartz 30%; plagioclase 15-20%; biotite 5%	K-spar
CD-493	7 – 12	**Aggm:** fine- to medium-grained; pink; K-spar 45-50%; quartz 30%; plagioclase 15-20%; biotite 5%	-
CD-494	6 – 11	**Aggm:** fine- to medium-grained; pink; K-spar 45-50%; quartz 30%; plagioclase 15-20%; biotite 5%	-
CD-495	6 – 11	**Aggm:** fine- to medium-grained; pink; K-spar 45-50%; quartz 30%; plagioclase 15-20%; biotite 5%	-
CD-496	6 – 11	**Aggm:** fine- to medium-grained; pink; K-spar 45-50%; quartz 30%; plagioclase 15-20%; biotite 5%; possibly with **Peg** (indicated by a 1,5 cm K-spar in size)	-
CD-497	6 – 11	**Aggm:** fine- to medium-grained; pink; K-spar 45-50%; quartz 30%; plagioclase 15-20%; biotite 5%; with **Aam**-chips	K-spar
CD-498	6 – 11	**Aggm:** fine- to medium-grained; pink; K-spar 45-50%; quartz 30%; plagioclase 15-20%; biotite 5%	K-spar

Appendix 2: Relogging of RC-chipsamples in Lucas/Atlas and South Bachelor areas, VCMD (***spacing*:** 20 ft).

core log: 98-1 (Roughrider Vein) **altitude:** 7390 ft **drilled:** 300 ft
type: H-core **azimuth:** 124° **dip:** 45°

depth [ft]	Au	veining	lithology	alteration	remarks
0 – 55		-	**overburden**	-	-
55 – 80		-	**Aam:** medium-grained; black; hornblende 50%; plagioclase 30%; quartz 10%; garnet 10% (red, mm-size); small amount of leucosome 0-5% (plagioclase, quartz)	-	upper part highly disrupted
80 – 85		-	missing core	-	-
85 – 90		-	**Peg:** coarse- to very coarse-grained; pinkish yellow; (K-spar, quartz, plagioclase, biotite)	-	-
90 – 93		-	**Aam:** medium-grained; black; hornblende 50%; plagioclase 30%; quartz 10%; garnet 10% (red, mm-size)	-	-
93 – 120		-	**Atg:** fine- to medium-grained; gray; plagioclase 50-65%; quartz 30%; K-spar 5-10%; biotite 0-5%; garnet 0-5 % (red, mm-size)	weak chloritic in lower part	-
120 – 145		-	**Aam:** medium-grained; black; hornblende 60%; plagioclase 15-20%; quartz 10%; garnet 10-15% (red, mm-1cm-size)	-	-
145 – 170		-	**Atg:** fine-grained; gray; plagioclase 50-60%; quartz 30%; K-spar 10%; biotite 0-5%; garnet 0-5 % (red, mm-size); small amount of leucosome 0-5% (K-spar, quartz, plagioclase)	weak chloritic in lower part	-
170 – 193		-	**Aam:** medium-grained; black; hornblende 50-55%; plagioclase 30%; quartz 10%; garnet 5-10% (red, mm-size)	-	-
193 – 220		quartz stringers	**Atg:** fine- to medium-grained; gray to pinkish gray; plagioclase 30-45%; quartz 30%; K-spar 20-30%; biotite 5-10%; garnet <1% (red, mm-size); migmatitic, leucosome 20-25% (K-spar-quartz-plagioclase)	K-spar in the lower part	-
220 – 230		quartz veins (mm)	**Atg:** fine- to medium-grained; gray to pinkish gray; plagioclase 30-45%; quartz 30%; K-spar 20-30%; biotite 5-10%; garnet <1% (red, mm-size); migmatitic, leucosome 20-25% (K-spar-quartz-plagioclase)	K-spar	-
230 – 235		quartz stringers	**Aam:** medium-grained; black; hornblende 50%; plagioclase 30-35%; quartz 10%; garnet 5-10% (red, mm-size)	K-spar	-
235 – 272		-	**Aam:** medium-grained; black; hornblende 50%; plagioclase 30-35%; quartz 10%; garnet 5-10% (red, mm-size)	chloritic in the middle part	slickenslides at 253‘ and 276‘
272 – 278		-	**Peg:** coarse- to very coarse-grained; pinkish; (K-spar, quartz, plagioclase, biotite)	-	-
278 – 284		-	**Aam:** medium-grained; black; hornblende 50%; plagioclase 30-35%; quartz 10%; garnet 5-10% (red, mm-size)	-	-
284 – 286		-	**Atg:** fine- to medium-grained; gray to pinkish gray; plagioclase 30-45%; quartz 30%; K-spar 20-30%; biotite 5-10%; garnet <1% (red, mm-size); migmatitic, leucosome 20-25% (K-spar-quartz-plagioclase)	-	-
286 – 290		-	**Aam:** medium-grained; black; hornblende 50%; plagioclase 30-35%; quartz 10%; garnet 5-10% (red, mm-size)	-	-
290 – 300		-	**shear zone:** fine-grained; greenish black; gauge	chloritic + clay	slickenslides

Appendix 3: Relogging of diamond drill cores, Lucas/Atlas and South Bachelor areas, VCMD.

core log: KS 9 (Kearsarge) **altitude:** 6988 ft **drilled:** 444 ft
type: H-core **azimuth:** 105° **dip:** 61°

depth [ft]	Au	veining	lithology	alteration	remarks
0 – 10			**overburden**	-	-
10 – 18		-	**Atg:** medium-grained; gray; plg 25-45%; qtz 30%; K-spar 10-30%; biot 10%; grt 5% (red, mm-size); migmatitic, leucosome 0-15% (K-spar-quartz-plg)	-	-
18 – 30			**shear zone:** fine-grained; greenish black; gauge	chloritic + clay	slickenslides
30 – 37		-	**Peg:** medium- to coarse-grained; pinkish (K-spar, quartz, plagioclase, biotite)	-	-
37 – 58		-	**shear zone:** fine-grained; greenish black; gauge	chloritic + clay	slickenslides
58 – 64		-	**Atg:** medium-grained; gray; plagioclase 25-45%; quartz 30%; K-spar 10-30%; biotite 10%; garnet 5% (red, mm-size); migmatitic, leucosome 0-15% (K-spar-quartz-plagioclase)	-	-
64 – 68		-	**Aam:** medium-grained; black; hornblende 60%; plagioclase 25%; quartz 10%; garnet 5% (red, mm)	-	-
68 – 70		-	**shear zone:** fine-grained; greenish black; gauge	chloritic + clay	slickenslides
70 – 72		-	**Peg:** medium- to coarse-grained; pinkish (K-spar, quartz, plagioclase, biotite)	-	-
72 – 133		-	**Aggm:** fine- to medium grained; pinkish; K-spar 45-60%; quartz 30%; plagioclase 10-20%; biotite 0-5%	disseminated chloritic, lower part on joints	-
133 – 170		-	**Atg:** medium-grained; gray; plagioclase 20-45%; quartz 30%; K-spar 10-30%; biotite 10%; garnet 5-10% (red, mm-size); migmatitic, leucosome 0-15% (K-spar-quartz-plagioclase)	chloritic at contact to Aam	-
170 – 262		-	**Aam:** medium-grained; black; hornblende 55%; plagioclase 25%; quartz 10%; garnet 10% (red, mm-1cm-size); in the lower part leucosome up to 10 % (plagioclase and quartz); lowest part fine-grained, no leucosome	upper part: chloritic; K-spar, dissemi-nated sulfides in the middle part	pink garnets in the upper part
262 – 289		-	**Atg:** fine- to medium-grained; gray; plagioclase 40-60%; quartz 30%; K-spar 0-10%; biotite 10-15%; garnet 0-5% (red, mm-size)	lowest part with saussuritized plagioclases	lowest part highly disrupted
289 – 300		-	**shear zone:** fine-grained; greenish black; gauge	chloritic + clay	slickenslides
300 – 322		-	**Agg:** medium grained; pinkish white; K-spar 50-60%; quartz 30%; plagioclase 10-15%; biotite 0-5%	chloritic and K-spar stringers in the lower part	upper part highly disrupted
322 – 368		-	**shear zone:** fine-grained; greenish black; gauge	chloritic + clay sulfides at 366‘	slickenslides, brecciated
368 – 385		-	**Aam:** medium-grained; black; hornblende 50-55%; plg 25-30%; qtz 15%; grt 5% (red, mm-size)	-	disrupted
385 – 387		-	**Peg:** coarse- to very coarse-grained; pinkish (K-spar, quartz, plagioclase, biotite)	-	-
387 – 403		-	**shear zone:** fine-grained; greenish black; gauge	chloritic + clay + K-spar	slickenslides
403 – 408		-	**Peg:** coarse- to very coarse-grained; pinkish (K-spar, quartz, plagioclase, biotite)	-	-
408 – 420		-	**Aam:** medium-grained; black; hornblende 50-60%; plagioclase 20-30%; quartz 10%; garnet 5% (red, mm-1cm-size); leucosome 0-10% (plg + qtz)	-	-
420 – 424		-	**Peg:** coarse- to very coarse-grained; pinkish (K-spar, quartz, plagioclase, biotite)	-	-
424 – 433		-	**Aam:** medium-grained; black; hornblende 50-60%; plagioclase 20-30%; quartz 10%; garnet 5% (red, mm-1cm-size); leucosome 0-10% (plg + qtz)	-	-
433 – 444		-	**Atg:** medium-grained; gray; plg 35-45%; qtz 35%; K-spar 15%; biotite 5-10%; grt 0-5% (red, mm-1cm-size); leucosome 0-10% (K-spar, qtz, plg)	upper part slightly chloritized	-

Appendix 3: Relogging of diamond drill cores, Lucas/Atlas and South Bachelor areas, VCMD.

core log: KS 11 (Lucas veins) **altitude:** 7169 ft **drilled:** 550 ft
type: H-core **azimuth:** 124° **dip:** 45°

depth [ft]	Au	veining	lithology	alteration	remarks
0 – 10		-	**overburden**	-	-
10 – 30		-	**Aggm:** fine- to medium-grained; pinkish; K-spar 45-55%; quartz 30%; plagioclase 15-20%; biotite 0-5%	-	-
30 – 85		-	**Atg:** fine- to medium-grained; gray; plagioclase 30-55%; quartz 30%; K-spar 10-20%; biotite 5-15%; garnet 0-5% (red, mm-size); leucosome 0-15% (K-spar + quartz +/- plagioclase)	chloritic and K-spar in the middle part	-
85 – 95		quartz veins (mm)	**Agg:** fine- to medium-grained; pinkish; K-spar 45-50%; quartz 30%; plagioclase 20%; biotite 0-5%	chloritic and K-spar	-
95 – 105		quartz stringers	**Agg:** fine- to medium-grained; pinkish; K-spar 45-50%; quartz 30%; plagioclase 20%; biotite 0-5%	chloritic	-
105 – 115		-	**Agg:** fine- to medium-grained; pinkish; K-spar 45-50%; quartz 30%; plagioclase 20%; biotite 0-5%	-	-
115 – 123		quartz veins (mm)	**Agg:** fine- to medium-grained; pinkish; K-spar 45-50%; quartz 30%; plagioclase 20%; biotite 0-5%	chloritic and K-spar	-
123 – 135		quartz veins (mm)	**Aggm:** fine-grained; pinkish; K-spar 40-55%; quartz 35%; plagioclase 10-20%; biotite 0-5%	chloritic and K-spar	-
135 – 140		quartz veins (mm)	**Aggm:** fine-grained; pinkish; K-spar 40-55%; quartz 35%; plagioclase 10-20%; biotite 0-5%	chloritic and K-spar	-
140 - 145		quartz veins (mm)	**Peg:** coarse-grained; pinkish (K-spar, quartz, plagioclase, biotite)	chloritic and K-spar	quartz vein at 145‘ clearly discordant to Peg
145 – 165		quartz veins (mm)	**Aggm:** fine-grained; pinkish; K-spar 40-55%; quartz 35%; plagioclase 10-20%; biotite 0-5%	chloritic and K-spar	-
165 – 200		quartz stringers	**Aggm:** fine-grained; pinkish; K-spar 40-55%; quartz 35%; plagioclase 10-20%; biotite 0-5%	chloritic and K-spar	-
200 – 252		-	**Aggm:** fine-grained; pinkish; K-spar 40-55%; quartz 35%; plagioclase 10-20%; biotite 0-5%	-	-
252 – 269		quartz veins (mm)	**Aggm:** fine-grained; pinkish; K-spar 40-55%; quartz 35%; plagioclase 10-20%; biotite 0-5%	K-spar	feet-size Pegs; not distinguished within this unit
269 – 272		-	**Aam:** fine- to medium-grained; black; hornblende 70%; plagioclase 20%; quartz 10%; garnet -	-	-
272 – 302		quartz veins (mm)	**Aggm:** fine-grained; pinkish; K-spar 40-55%; quartz 35%; plagioclase 10-20%; biotite 0-5%	K-spar, lower part chloritic	feet-size Pegs; not distinguished within this unit
302 – 304		-	**Aam:** fine- to medium-grained; black; hornblende 70%; plagioclase 20%; quartz 10%; garnet -		
304 – 310		quartz veins (mm)	**Aggm:** fine-grained; pinkish; K-spar 40-55%; quartz 35%; plagioclase 10-20%; biotite 0-5%	K-spar; sulfides within quartz veins	-
310 – 318		quartz veins (mm)	**Aggm:** fine-grained; pinkish; K-spar 40-55%; quartz 35%; plagioclase 10-20%; biotite 0-5%	K-spar	-
318 – 320		quartz veins (mm)	**Aam:** fine- to medium-grained; black; hornblende 70%; plagioclase 20%; quartz 10%; garnet -	K-spar	-
320 – 338		quartz veins (mm)	**Aggm:** fine-grained; pinkish; K-spar 40-55%; quartz 35%; plagioclase 10-20%; biotite 0-5%	K-spar	-

Appendix 3: Relogging of diamond drill cores, Lucas/Atlas and South Bachelor areas, VCMD.

depth [ft]	Au	veining	lithology	alteration	remarks
338 – 340		-	**Peg:** coarse-grained; pinkish (K-spar, quartz, plagioclase, biotite)	-	-
340 – 362		-	**Aggm:** medium-grained; pinkish; K-spar 40-55%; quartz 35%; plagioclase 10-20%; biotite 0-5%	upper part chloritic	-
362 – 381		quartz stringers	**Aggm:** medium-grained; pinkish; K-spar 40-55%; quartz 35%; plagioclase 10-20%; biotite 0-5%	K-spar	feet-size Aam; not distinguished within this unit
381 – 383		quartz veins (mm)	**Aam:** fine- to medium-grained; black; hornblende 70%; plagioclase 20%; quartz 10%; garnet -	K-spar	-
383 – 418		quartz veins (mm) and stringers	**Aggm:** medium-grained; pinkish; K-spar 40-55%; quartz 35%; plagioclase 10-20%; biotite 0-5%	K-spar	feet-size Aam; not distinguished within this unit
418 – 430		quartz veins (mm)	**Agg:** fine- to medium-grained; pinkish; K-spar 50-60%; quartz 30%; plagioclase 10-15%; biotite 0-5%	K-spar	-
430 – 460		quartz veins (mm)	**Agg:** fine- to medium-grained; pinkish; K-spar 50-60%; quartz 30%; plagioclase 10-15%; biotite 0-5%	K-spar	feet-size Aam; not distinguished within this unit; **sample KS 11-2 (444‘)**
460 – 485		quartz veins (mm)	**Aggm:** fine- to medium-grained; pinkish; K-spar 55-60%; quartz 30%; plagioclase 10%; biotite 0-5%	K-spar, sulfides in quartz veins at 458‘-461‘; lower part chloritic	slickenslides at 462‘
485 - 491		quartz veins (mm)	**Aam:** fine-grained; greenish black; mineralogy ?	K-spar, chloritic	-
491 – 500		quartz veins (mm-cm)	**Aggm:** fine- to medium-grained; pinkish; K-spar 55-60%; quartz 30%; plagioclase 10%; biotite 0-5%	K-spar	**sample KS 11-3 (491‘-492‘)**
500 – 520		quartz veins (mm)	**Aggm:** fine- to medium-grained; pinkish; K-spar 55-60%; quartz 30%; plagioclase 10%; biotite 0-5%	-	-
520 – 525		quartz veins (mm)	**Aggm:** fine- to medium-grained; pinkish; K-spar 55-60%; quartz 30%; plagioclase 10%; biotite 0-5%	K-spar, chloritic, carbonate	**sample KS 11-1 (525‘)**

Appendix 3: Relogging of diamond drill cores, Lucas/Atlas and South Bachelor areas, VCMD.

core log: KS 12 (Lucas veins) **altitude:** 7352 ft **drilled:** 593 ft
type: H-core **azimuth:** 107° **dip:** 45.7°

depth [ft]	Au	veining	lithology	alteration	remarks
0 – 20		-	**overburden**	-	-
20 – 38		-	**Aggm:** fine- to medium-grained; pinkish; K-spar 50-60%; quartz 30%; plagioclase 10-15%; biotite 0-5%	extremely weathered; Fe-staining	-
38 – 60		quartz veins (cm)	**Aggm:** fine- to medium-grained; pinkish; K-spar 50-60%; quartz 30%; plagioclase 10-15%; biotite 0-5%	K-spar around quartz veins	-
60 – 69		-	**Aam:** fine-grained; black; mineralogy ?	-	-
69 – 120		-	**Aggm:** fine- to medium-grained; pinkish; K-spar 45-60%; quartz 30%; plagioclase 10-20%; biotite 0-5%	-	-
120 – 125		quartz stringers	**Aggm:** fine- to medium-grained; pinkish; K-spar 45-60%; quartz 30%; plagioclase 10-20%; biotite 0-5%	K-spar	-
125 – 145		quartz stringers	**Aggm:** fine- to medium-grained; pinkish; K-spar 45-60%; quartz 30%; plagioclase 10-20%; biotite 0-5%	K-spar	-
145 – 152		-	**Atg:** medium-grained; gray; plagioclase 35-45%; quartz 30%; K-spar 20-30%; biotite 5%; leucosome 10-15% (K-spar + quartz + plagioclase)	-	-
152 – 196		quartz stringers middle part	**Aggm:** fine- to medium-grained; pinkish; K-spar 35-40%; quartz 30%; plagioclase 30%; biotite 0-5%	chloritic in the middle part	small Aam-lenses within this unit in the middle part
196 – 204		quartz veins (mm)	**Atg:** medium-grained; gray; plagioclase 35-45%; quartz 30%; K-spar 20-30%; biotite 5%; leucosome 10-15% (K-spar + quartz + plagioclase)	chloritic	-
204 – 220		quartz veins (mm)	**Aggm:** fine- to medium-grained; pinkish; K-spar 35-40%; quartz 30%; plagioclase 30%; biotite 0-5%	chloritic	-
220 – 235		quartz veins (mm-cm)	**Aggm:** fine- to medium-grained; pinkish; K-spar 35-40%; quartz 30%; plagioclase 30%; biotite 0-5%	K-spar, chloritic	feet-size Aam; not distinguished within this unit
325 – 245		quartz veins (mm)	**Aggm:** fine- to medium-grained; pinkish; K-spar 35-40%; quartz 30%; plagioclase 30%; biotite 0-5%	K-spar, chloritic	-
245 – 255		-	**Agg:** medium-grained; pinkish; K-spar 35-50%; quartz 30%; plagioclase 20-30%; biotite 0-5%	-	
255 – 265		quartz veins (mm-cm)	**Agg:** medium-grained; pinkish; K-spar 35-50%; quartz 30%; plagioclase 20-30%; biotite 0-5%	K-spar, chloritic	**sample KS 12-1; 263‘**
265 – 275		quartz veins (mm-cm)	**Agg:** medium-grained; pinkish; K-spar 35-50%; quartz 30%; plagioclase 20-30%; biotite 0-5%	K-spar, chloritic	**sample KS 12-2; 270‘**
275 – 285		-	**Agg:** medium-grained; pinkish; K-spar 35-50%; quartz 30%; plagioclase 20-30%; biotite 0-5%	-	-
285 – 310		quartz veins (mm-cm)	**Agg:** medium-grained; pinkish; K-spar 35-50%; quartz 30%; plagioclase 20-30%; biotite 0-5%	K-spar, chloritic	-
310 - 325		-	**Aggm:** medium-grained; pinkish; K-spar 35-60%; quartz 30%; plagioclase 10-30%; biotite 0-5%	upper part chloritic	-

Appendix 3: Relogging of diamond drill cores, Lucas/Atlas and South Bachelor areas, VCMD.

depth [ft]	Au	veining	lithology	alteration	remarks
325 – 340		quartz stringers	**Aggm:** medium-grained; pinkish; K-spar 35-60%; quartz 30%; plagioclase 10-30%; biotite 0-5%	-	-
340 – 360		quartz veins (mm)	**Agg:** medium-grained; pinkish yellow; K-spar 35-50%; quartz 30%; plagioclase 20-30%; biotite 0-5%	K-spar	-
360 – 380		quartz stringers	**Aggm:** fine- to medium-grained; pinkish; K-spar 45-60%; quartz 30%; plagioclase 10-20%; biotite 0-5%	chloritic	-
380 – 400		quartz veins (mm)	**Aggm:** fine- to medium-grained; pinkish; K-spar 45-60%; quartz 30%; plagioclase 10-20%; biotite 0-5%	K-spar, chloritic	-
400 – 415		-	**Aggm:** fine- to medium-grained; pinkish; K-spar 45-60%; quartz 30%; plagioclase 10-20%; biotite 0-5%	K-spar	-
415 – 420		-	**Aggm:** fine- to medium-grained; pinkish; K-spar 45-60%; quartz 30%; plagioclase 10-20%; biotite 0-5%	K-spar	-
420 – 425		-	**Aggm:** fine- to medium-grained; pinkish; K-spar 45-60%; quartz 30%; plagioclase 10-20%; biotite 0-5%	K-spar	-
425 – 432		-	**Aggm:** fine- to medium-grained; pinkish; K-spar 45-60%; quartz 30%; plagioclase 10-20%; biotite 0-5%	K-spar	-
432 – 434		-	**Aam:** fine- to medium-grained; black; hornblende 70%; plagioclase 20%; quartz 10%; garnet -	K-spar	-
434 - 440		-	**Aggm:** fine- to medium-grained; pinkish; K-spar 45-60%; quartz 30%; plagioclase 10-20%; biotite 0-5%	-	-
440 – 460		quartz veins (mm-cm)	**Aggm:** fine- to medium-grained; pinkish; K-spar 45-60%; quartz 30%; plagioclase 10-20%; biotite 0-5%	K-spar, carbonates	-
460 – 502		quartz stringers	**Aggm:** fine- to medium-grained; pinkish; K-spar 45-60%; quartz 30%; plagioclase 10-20%; biotite 0-5%	K-spar, chloritic	-
502 – 535		quartz veins (mm-cm)	**Aggm:** fine- to medium-grained; pinkish; K-spar 45-50%; quartz 30%; plagioclase 20%; biotite 0-5%	K-spar, chloritic	-
535 – 542		quartz veins (mm-cm)	**Aam:** fine- to medium-grained; black; hornblende 70%; plagioclase 20%; quartz 10%; garnet -	K-spar, chloritic	-
542 – 560		quartz veins (mm-cm) and stringers	**Aggm:** fine- to medium-grained; pinkish; K-spar 45-50%; quartz 30%; plagioclase 20%; biotite 0-5%	K-spar, chloritic	-
560 – 563		-	**shear zone:** fine-grained; greenish black; gauge	chloritic + clay	slickenslides
563 – 575		quartz veins (mm-cm) and stringers	**Aggm:** fine- to medium-grained; pinkish; K-spar 45-50%; quartz 30%; plagioclase 20%; biotite 0-5%	K-spar, chloritic	-
575 – 578		quartz stringers	**Aam:** fine- to medium-grained; black; hornblende 70%; plagioclase 20%; quartz 10%; garnet -	K-spar, chloritic	-
578 – 593		quartz stringers	**Aggm:** fine- to medium-grained; pinkish; K-spar 45-50%; quartz 30%; plagioclase 20%; biotite 0-5%	K-spar, chloritic	-

Appendix 3: Relogging of diamond drill cores, Lucas/Atlas and South Bachelor areas, VCMD.

core log: KS 13 (Atlas veins) **altitude:** 8030 ft **drilled:** 363 ft
type: H-core **azimuth:** 112° **dip:** 45°

depth [ft]	Au	veining	lithology	alteration	remarks
0 – 3		-	**overburden**	-	-
3 – 55		quartz stringers upper part	**Aggm:** fine- to medium-grained; pinkish-gray; K-spar 45-55%; quartz 30%; plagioclase 10-20%; biotite 5%	upper part K-spar; chloritic in the lower part	-
55 – 58		-	**Atg:** fine- to medium-grained; pinkish gray; plagioclase 35-45%; quartz 30%; K-spar 20-30%; biotite 5%; leucosome 10-15% (K-spar + quartz + plagioclase)	-	-
58 – 94		quartz stringers lower part	**Aggm:** fine- to medium-grained; pinkish; K-spar 45-55%; quartz 30%; plagioclase 10-20%; biotite 5%	chloritic in the middle and lower part; K-spar in the lower part	-
94 – 96		quartz stringers	**Aam:** fine- to medium-grained; black; hornblende 60-70%; plagioclase 20-30%; quartz 10%; garnet -	chloritic	-
96 – 120		-	**Aggm:** fine-grained; pinkish; K-spar 50-55%; quartz 30%; plagioclase 10-15%; biotite 5%	chloritic in the upper part	-
120 – 160		quartz stringers	**Aggm:** fine-grained; pinkish; K-spar 50-55%; quartz 30%; plagioclase 10-15%; biotite 5%	K-spar	
160 – 183		-	**Aggm:** fine-grained; pinkish; K-spar 50-55%; quartz 30%; plagioclase 10-15%; biotite 5%	weak K-spar	-
183 – 195		quartz stringers	**Agg:** fine- to medium-grained; pinkish; K-spar 45-50%; quartz 30%; plagioclase 20%; biotite 0-5%	K-spar	-
195 – 210		quartz veins (mm-cm)	**Agg:** fine- to medium-grained; pinkish; K-spar 45-50%; quartz 30%; plagioclase 20%; biotite 0-5%	K-spar, weak chloritic	**sample KS 13-1; 196‘**
210 - 216		quartz stringers	**Aam:** fine- to medium-grained; black; hornblende 60%; plagioclase 20-30%; quartz 10-20%; garnet -	K-spar	-
216 – 220		quartz stringers	**Agg:** fine- to medium-grained; pinkish; K-spar 45-50%; quartz 30%; plagioclase 20%; biotite 0-5%	-	-
220 – 235		quartz stringers	**Aggm:** fine- to medium-grained; pinkish; K-spar 45-55%; quartz 30%; plagioclase 15-20%; biotite 0-5%	K-spar	-
235 – 255		-	**Aggm:** fine- to medium-grained; pinkish; K-spar 45-55%; quartz 30%; plagioclase 15-20%; biotite 0-5%	-	-
255 – 265		quartz stringers	**Aggm:** fine- to medium-grained; pinkish; K-spar 45-55%; quartz 30%; plagioclase 15-20%; biotite 0-5%	K-spar	-
265 – 300		-	**Aggm:** fine- to medium-grained; pinkish; K-spar 45-55%; quartz 30%; plagioclase 15-20%; biotite 0-5%	-	-
300 – 310		quartz stringers	**Aggm:** fine- to medium-grained; pinkish; K-spar 45-55%; quartz 30%; plagioclase 15-20%; biotite 0-5%	K-spar	-
310 – 322		quartz veins (mm-cm)	**Agg:** fine- to medium-grained; pinkish white; K-spar 40-50%; quartz 30%; plagioclase 20-25%; biotite 0-5%	K-spar	**sample KS 13-2; 318‘**
322 – 335		quartz veins (mm-cm),	**Agg:** fine- to medium-grained; pinkish white; K-spar 40-50%; quartz 30%; plagioclase 20-25%; biotite 0-5%	K-spar, weak chloritic	-
335 - 363		quartz stringers upper part	**Aggm:** fine- to medium-grained; pinkish white; K-spar 40-50%; quartz 30%; plagioclase 20-25%; biotite 0-5%	upper part with K-spar	-

Appendix 3: Relogging of diamond drill cores, Lucas/Atlas and South Bachelor areas, VCMD.

core log: KS 14 (Lucas veins) **altitude:** 7617 ft **drilled:** 838 ft
type: H-core **azimuth:** 115° **dip:** 45°

depth [ft]	Au	veining	lithology	alteration	remarks
0 – 1		-	**overburden**	-	-
1 – 46		-	**Aggm:** fine- to medium-grained; pinkish; K-spar 45-50%; quartz 30%; plagioclase 20%; biotite 0-5%	weak chloritic in the lower part	-
46 – 52		-	**Aam:** fine-grained; black; hornblende 70-80%; plagioclase 15-20%; quartz 5-10%; garnet -	-	-
52 – 80		-	**Aggm:** fine- to medium-grained; pinkish; K-spar 45-50%; quartz 30%; plagioclase 15%; biotite 5-10%	-	Aam lenses (1‘-2‘) within this unit
80 – 98		-	**Agg:** fine- to medium-grained; pinkish; K-spar 50%; quartz 30%; plagioclase 15%; biotite 5%	K-spar in the lower part	2‘-3‘ Peg within this unit
98 – 118		-	**Aggm:** fine- to medium-grained; pinkish gray; K-spar 40-50%; quartz 30%; plagioclase 15-20%; biotite 5-10%	-	-
118 – 126		-	**Aam:** fine-grained; black; hornblende 55-70%; plagioclase 20-30%; quartz 10%; garnet 0-5% (red, mm) within the leucosome	-	-
126 – 152		-	**Agg:** fine- to medium-grained; pinkish gray; K-spar 35-50%; quartz 35%; plagioclase 15%; biotite 0-15%	-	-
152 – 156		-	**Peg:** coarse-grained; pinkish (K-spar, quartz, plagioclase, biotite)	-	-
156 – 180		-	**Agg:** fine- to medium-grained; pinkish gray; K-spar 35-50%; quartz 35%; plagioclase 15%; biotite 0-15%	lower part K-spar	-
180 – 196		-	**Aggm:** fine- to medium-grained; pinkish gray; K-spar 40-50%; quartz 30%; plagioclase 20%; biotite 5-10%	K-spar	-
196 – 218		-	**Agg:** fine-grained; pinkish; K-spar 45-50%; quartz 30%; plagioclase 15-20%; biotite 5%	K-spar	-
218 – 280		-	**Aggm:** fine- to medium-grained; pinkish; K-spar 45-50%; quartz 30%; plagioclase 15-20%; biotite 5%	weak K-spar + chloritic in the upper part; K-spar in lower part	-
280 – 284		-	**Aam:** fine-grained; black; hornblende 70-75%; plagioclase 20%; quartz 5-10%; garnet –	-	-
284 – 290		-	**Aggm:** fine- to medium-grained; pinkish; K-spar 35-45%; quartz 30%; plagioclase 20-30%; biotite 5%	chloritic	-
290 – 300		-	**Aggm:** fine- to medium-grained; pinkish; K-spar 35-45%; quartz 30%; plagioclase 20-30%; biotite 5%	-	-
300 – 330		-	**Aggm:** fine- to medium-grained; pinkish; K-spar 35-45%; quartz 30%; plagioclase 20-30%; biotite 5%	K-spar	Aam lenses within this unit
330 – 345		quartz veins (mm-cm) and stringers	**Aggm:** fine- to medium-grained; pinkish; K-spar 35-45%; quartz 30%; plagioclase 20-30%; biotite 5%	chloritic, K-spar	Aam lenses within this unit
345 – 367		quartz stringers	**Agg:** fine-grained; pinkish; K-spar 45%; quartz 30%; plagioclase 20%; biotite 5%	-	-
367 – 380		quartz stringers	**Agg:** fine-grained; pinkish; K-spar 45%; quartz 30%; plagioclase 20%; biotite 5%	K-spar	-

Appendix 3: Relogging of diamond drill cores, Lucas/Atlas and South Bachelor areas, VCMD.

depth [ft]	Au	veining	lithology	alteration	remarks
380 – 417		quartz veins (mm-cm) and stringers	**Agg:** fine-grained; pinkish; K-spar 45%; quartz 30%; plagioclase 20%; biotite 5%	chloritic, K-spar	**sample KS 14-2; 409‘**
417 – 442		quartz veins (mm-cm) and stringers	**Aggm:** fine- to medium-grained; pinkish; K-spar 50-55%; quartz 30%; plagioclase 10-15%; biotite 5%	strong K-spar	-
442 – 456		quartz veins (mm-cm) and stringers	**Agg:** fine- to medium-grained; pinkish; K-spar 50%; quartz 25%; plagioclase 20%; biotite 5%	strong K-spar	-
456 – 462		quartz veins (mm-cm) and stringers	**Aam:** fine-grained; black; hornblende 80%; plagioclase 15%; quartz 5%; garnet –	strong K-spar	Peg within this unit
462 – 470		quartz veins (mm-cm) and stringers	**Aggm:** fine- to medium-grained; pinkish; K-spar 35-45%; quartz 30%; plagioclase 20-30%; biotite 5%	strong K-spar, sulfides	-
470 – 475		quartz veins (mm-cm) and stringers	**Aggm:** fine- to medium-grained; pinkish; K-spar 35-45%; quartz 30%; plagioclase 20-30%; biotite 5%	K-spar	**sample KS 14-3; 471‘**
475 – 500		quartz stringers	**Aggm:** fine- to medium-grained; pinkish; K-spar 35-45%; quartz 30%; plagioclase 20-30%; biotite 5%	K-spar	-
500 – 522		-	**Aggm:** fine- to medium-grained; pinkish; K-spar 35-45%; quartz 30%; plagioclase 20-30%; biotite 5%	K-spar in the lower part	-
522 – 530		-	**Aam:** fine-grained; black; hornblende 60-70%; plagioclase 20-30%; quartz 10%; garnet –	-	several Aam lenses summarized into one unit
530 – 593		quartz stringers in the upper part	**Aggm:** fine- to medium-grained; pinkish; K-spar 30-45%; quartz 30%; plagioclase 20-30%; biotite 5-10%	K-spar in the upper part, otherwise weak chloritic and K-spar	-
593 – 598		quartz stringers	**Aam:** fine-grained; black; hornblende 65-80%; plagioclase 15-25%; quartz 5-10%; garnet –	K-spar	-
598 – 640		-	**Aggm:** fine- to medium-grained; pinkish; K-spar 35-45%; quartz 30%; plagioclase 20-30%; biotite 5%	-	-
640 – 662		weak quartz stringers	**Aggm:** fine- to medium-grained; pinkish; K-spar 35-45%; quartz 30%; plagioclase 20-30%; biotite 5%	weak K-spar	Aam lenses within this unit
662 – 670		-	**Aam:** fine-grained; black; hornblende 80%; plagioclase 15%; quartz 5%; garnet –	-	-
670 – 702		quartz stringers	**Aggm:** fine- to medium-grained; pinkish; K-spar 35-55%; quartz 25-30%; plagioclase 20-30%; biotite 5%	K-spar	Aam lenses within this unit
702 – 705		-	**Peg:** coarse-grained; pinkish (K-spar-quartz-plagioclase-biotite)	-	-

Appendix 3: Relogging of diamond drill cores, Lucas/Atlas and South Bachelor areas, VCMD.

depth [ft]	Au	veining	lithology	alteration	remarks
705 – 722		quartz stringers	**Aggm:** fine- to medium-grained; pinkish; K-spar 35-55%; quartz 25-30%; plagioclase 20-30%; biotite 5%	K-spar	Aam lenses in the lower part of this unit (several ft)
722 – 738		-	**Aggm:** fine-grained; pinkish; K-spar 50-55%; quartz 30%; plagioclase 10-15%; biotite 5%	-	-
738 – 805		quartz stringers	**Aggm:** fine-grained; pinkish; K-spar 50-55%; quartz 30%; plagioclase 10-15%; biotite 5%	K-spar, lower part chloritic	with small Aam lenses within this unit
805 – 810		quartz stringers	**Aam:** fine-grained; black; hornblende 80%; plagioclase 15%; quartz 5%; garnet –	K-spar	-
810 – 818		quartz veins (mm-cm) and stringers	**Aggm:** fine-grained; pinkish; K-spar 50-55%; quartz 30%; plagioclase 10-15%; biotite 5%	K-spar, chloritic	-
818 – 820		quartz stringers	**Peg:** medium- to coarse-grained; pinkish yellow (K-spar-quartz-plagioclase-biotite)	K-spar	-
820 – 838		quartz veins (mm-cm) and stringers	**Aggm:** fine-grained; pinkish; K-spar 30-45%; quartz 30-35%; plagioclase 20-30%; biotite 5%	K-spar, chloritic	-

Appendix 3: Relogging of diamond drill cores, Lucas/Atlas and South Bachelor areas, VCMD.

Fig. 36: Core sample KS 11-1, long edge ~ 7 cm.

Fig. 37: Sample H1, long edge ~ 7 cm.

Fig. 38: Core sample KS 14-3, long edge ~ 5 cm.

Fig. 39: Core sample KS 11-2, long edge ~ 6 cm.

Appendix 4: Photographs of cores, Lucas/Atlas and South Bachelor areas, VCMD.

Fig. 40: Core sample KS 12-1, long edge ~ 6 cm.

Fig. 41: Detail of core sample KS 14-1a, long edge ~2 cm.

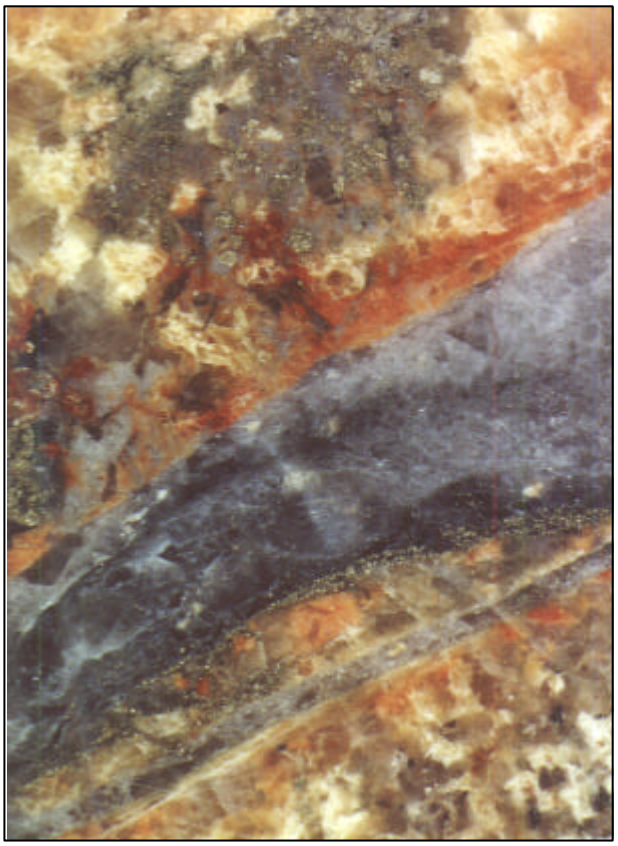

Fig. 42: Detail of core sample KS 14-3, long edge 3 cm.

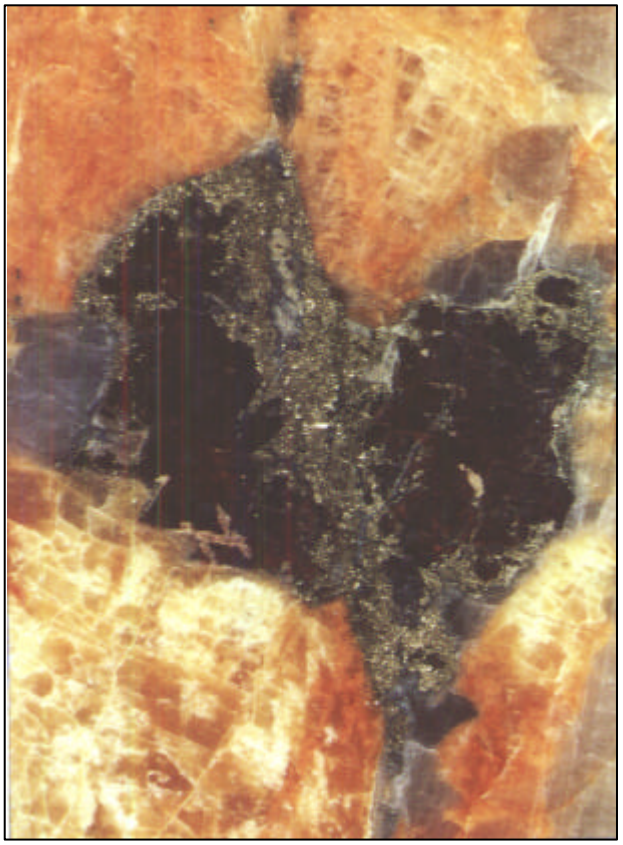

Fig. 43: Detail of core sample KS 14-1b, long edge 2 cm.

Appendix 4: Photographs of cores, Lucas/Atlas and South Bachelor areas, VCMD.

Study of Au-Ag-mineralizations in the Virginia City Mining District, Montana, U.S.A. – Pero Despotovic - Appendix 5: Major- and trace-element geochemistry.

suite	Aggm					Agg			Atg							Tv		
sample no.	**218**	**149**	**193**	**195**	**86**	**283**	**168**	**289**	**171**	**28**	**253**	**166**	**265**	**152**	**176**	**343**	**264**	**128**
									major elements (weight percent)									
SiO_2	76,77	76,45	77,15	74,96	75,03	77,02	74,36	74,54	72,34	69,92	76,75	73,46	76,37	77,06	69,59	43,09	43,80	43,45
Al_2O_3	10,62	11,24	11,03	11,89	11,20	10,68	12,12	11,20	11,56	14,44	10,67	13,58	11,90	10,24	14,82	14,30	14,15	14,68
Fe_2O_3	2,76	2,67	2,99	2,74	3,57	3,18	2,74	3,65	5,20	2,66	2,59	1,26	1,51	4,38	2,87	17,55	17,22	17,34
MnO	0,03	0,04	0,02	0,03	0,03	0,03	0,02	0,03	0,06	0,05	0,03	0,02	0,03	0,13	0,03	0,23	0,21	0,16
MgO	0,07	0,14	0,16	0,13	0,26	0,23	0,38	0,13	2,27	0,98	0,29	0,23	0,18	0,29	1,22	6,20	5,70	6,04
CaO	0,90	0,84	0,38	0,49	0,63	0,71	0,62	0,50	1,07	1,67	0,70	0,96	0,40	1,36	2,21	7,20	7,88	6,55
Na_2O	3,19	3,13	2,68	3,14	2,70	2,93	3,10	2,47	3,80	3,74	2,50	3,04	2,76	1,98	3,86	2,17	2,05	2,47
K_2O	4,19	4,68	5,32	4,67	4,63	4,60	4,88	5,23	1,34	3,95	4,49	6,22	5,02	4,94	3,05	1,85	1,72	0,76
TiO_2	0,27	0,29	0,28	0,32	0,34	0,35	0,27	0,35	0,55	0,30	0,31	0,14	0,16	0,39	0,37	3,44	3,45	3,26
P_2O_5	0,03	0,04	0,06	0,05	0,06	0,06	0,05	0,05	0,17	0,10	0,04	0,04	0,01	0,06	0,09	0,78	0,82	0,65
SO_3	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	0,20	0,07	0,02
									trace elements (ppm)									
Ag	1,6	1,7	1,9	1,4	1,4	1,9	2,0	0,6	0,8	b.d.l.	1,9	0,7	2,0	4,0	1,3	0,4	b.d.l.	b.d.l.
As	18	21	24	22	19	25	10	24	13	18	18	17	30	16	16	10	b.d.l.	1,0
Ba	1519	1247	1423	1392	1462	1621	1564	1575	511	1772	1718	1079	744	1935	1524	1007	806	924
Bi	1,1	3,4	4,1	2,3	3,1	2,7	1,3	3,1	3,8	1,8	2,0	2,1	5,1	0,4	2,0	14	10	12
Br	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Cd	2,4	0,9	4,9	3,7	1,6	1,7	1,0	2,6	2,0	0,6	2,9	b.d.l.	b.d.l.	5,3	b.d.l.	0,3	0,4	0,9
Ce	133	116	170	166	130	131	126	193	140	78	185	45	87	172	93	65	78	66
Cl	21	b.d.l.	b.d.l.	b.d.l.	12	b.d.l.	12	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	77	b.d.l.	b.d.l.	b.d.l.	103
Co	162	151	183	142	169	142	124	156	125	139	102	112	196	161	140	60	63	61
Cr	7,0	10	10	28	11	13	11	24	7,0	28	11	7,0	7,0	24	44	93	77	116
Cu	7,0	8,0	7,0	27	8,0	13	8,0	5,0	13	21	8,0	8,0	10	7,0	32	25	26	7,0
Cs	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	12	b.d.l.	4,9
F	274	341	470	607	660	544	556	726	846	385	422	350	268	414	424	1346	1392	1316
Ga	19	20	18	19	17	20	20	23	19	20	14	18	17	19	19	23	23	23
Hf	10	11	13	12	11	14	8,0	13	11	5,0	13	4,0	8,0	14	5,0	6,0	7,0	6,0
Hg	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
La	86	86	101	88	48	33	59	110	54	26	88	26	11	88	55	41	44	53
Mo	2,4	1,6	2,7	2,6	3,1	2,0	1,7	4,2	2,0	b.d.l.	2,3	1,5	3,2	1,7	1,2	1,7	1,7	0,6
Nb	12	14	18	17	16	16	11	20	19	3,0	8,0	8,0	7,0	19	4,0	24	20	18
Nd	48	38	55	66	39	41	51	66	57	22	61	18	32	65	30	39	38	32
Ni	6,0	5,3	6,0	12	8,0	9,0	6,0	9,0	6,0	21	6,0	7,0	7,0	9,0	33	49	49,0	69
Pb	16	16	17	8,0	7,0	16	21	14	15	13	22	23	11	19	11	14	11	7,0
Pr	15	15	18	16	7,0	6,7	11	20	12	7,0	16	12	7,0	17	7,0	7,0	7,0	7,0
Rb	116	129	158	112	132	106	141	165	39	93	90	177	120	116	73	86	69	56
Sb	b.d.l.	0,3	0,8	b.d.l.	1,7	1,4	1,2	0,1	2,4	1,9	0,1	2,0	1,0	2,3	3,3	b.d.l.	b.d.l.	b.d.l.
Sc	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	7,0	7,0	b.d.l.	7,0	7,0	b.d.l.	6,7	7,0	31	28	30
Se	b.d.l.	0,2	b.d.l.	0,1	b.d.l.	b.d.l.	b.d.l.	0,2	b.d.l.	b.d.l.	b.d.l.	b.d.l.	0,3	b.d.l.	0,4	1,5	0,8	1,5
Sm	9,0	6,0	9,0	12	6,0	7,0	9,0	11	12	3,0	10	3,0	6,0	14	4,0	9,0	8,0	8,0
Sn	4,2	3,6	7,6	2,7	5,2	6,5	5,0	4,7	4,3	3,9	1,5	4,9	3,5	6,9	3,9	5,2	1,9	b.d.l.
Sr	67	59	46	89	65	68	80	64	51	313	62	88	50	91	297	289	291	222
Th	22	26	38	39	24	31	28	37	28	19	27	17	14	31	16	3,0	3,0	6,0
Tl	b.d.l.	b.d.l.	0,2	0,3	1,2	b.d.l.	0,6	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
U	3,0	3,3	3,0	4,7	3,9	3,3	3,0	6,2	6,3	3,0	3,0	3,0	3,0	3,3	3	3,0	3,0	b.d.l.
V	7,0	6,7	7,0	19	12	14	12	11	14	30	8,0	7,0	7,0	21	36	308	306	347
W	1209	1146	1341	1133	1219	1144	969	1133	924	1015	787	827	1442	1299	948	101	110	105
Y	45	24	48	51	29	43	30	61	79	11	25	22	33	90	7,0	38	40	40
Zn	87	43	51	28	63	54	69	57	69	39	41	17	11	37	39	135	175	145
Zr	419	470	520	494	444	596	281	553	458	146	578	80	322	616	140	257	270	201
L.O.I.	0,19	0,37	0,55	0,89	0,74	0,74	0,66	0,72	0,91	0,62	0,35	0,31	0,46	0,09	0,75	2,43	2,56	2,65
Total	**99,46**	**100,29**	**101,10**	**99,76**	**99,65**	**101,00**	**99,62**	**99,38**	**99,63**	**98,86**	**99,16**	**99,56**	**99,14**	**101,46**	**99,26**	**99,86**	**100,02**	**98,43**

Study of Au-Ag-mineralizations in the Virginia City Mining District, Montana, U.S.A. – Pero Despotovic - Appendix 5: Major- and trace-element geochemistry.

suite	Aam							Aum		core samples								
sample no.	**320**	**174**	**175**	**268**	**293**	**38**	**114**	**108**	**18**	**KS 11-1**	**KS 11-2**	**KS 11-3**	**KS 12-1**	**KS 12-2**	**KS 13-1**	**KS 13-2**	**KS 14-2**	**KS 14-3**
									major elements (weight percent)									
SiO_2	50,62	67,11	59,77	54,77	58,96	49,65	57,91	51,47	50,99	73,21	69,17	76,91	72,91	72,95	81,18	72,71	64,56	72,43
Al_2O_3	13,66	11,85	13,94	14,73	12,12	14,67	13,35	5,15	5,29	11,08	11,74	8,29	10,91	9,96	7,30	11,93	11,01	11,32
Fe_2O_3	14,11	7,74	8,92	10,62	15,20	11,88	11,05	11,11	11,14	2,97	3,52	1,14	3,19	2,70	3,20	2,95	4,71	1,84
MnO	0,21	0,13	0,12	0,11	0,24	0,18	0,18	0,17	0,19	0,03	0,04	0,06	0,04	0,03	0,02	0,05	0,04	0,03
MgO	6,27	3,05	4,13	5,33	1,92	7,71	4,30	25,64	24,81	0,82	1,26	0,95	0,70	0,71	0,09	0,20	1,84	0,46
CaO	9,52	4,64	6,38	6,64	5,25	9,64	6,36	4,57	5,39	1,14	0,93	2,36	0,37	0,54	0,06	0,38	2,35	0,97
Na_2O	2,36	2,50	3,94	3,05	2,03	2,47	3,18	0,61	0,55	2,15	1,62	2,22	1,34	1,73	0,30	2,01	1,04	1,88
K_2O	0,80	1,05	1,30	1,50	0,52	0,65	1,43	0,06	0,06	5,36	7,60	3,38	7,42	5,87	5,95	6,87	7,76	6,98
TiO_2	1,45	0,63	0,63	0,85	1,87	0,96	0,94	0,27	0,26	0,31	0,35	0,06	0,27	0,27	0,19	0,25	0,48	0,20
P_2O_5	0,26	0,10	0,06	0,11	0,28	0,10	0,16	0,04	0,03	0,09	0,07	0,06	0,06	0,03	0,03	0,07	0,09	0,03
SO_3	0,03	b.d.l.	0,002	0,006	0,02	0,01	0,01	b.d.l.	b.d.l.	0,41	0,44	b.d.l.	0,55	1,01	b.d.l.	b.d.l.	1,08	0,62
									trace elements (ppm)									
Ag	b.d.l.	b.d.l.	b.d.l.	b.d.l.	2,0	b.d.l.	2,3	0,3	b.d.l.	6,8	2,3	1,0	2,6	1,5	5,7	4,9	1,7	2,0
As	21	21	11	2	12	b.d.l.	10	7,0	2,0	26	24	13	52	34	47	14	29	17
Ba	560	581	204	222	112	177	272	24	28	954	1167	577	1419	1146	894	1040	1372	1361
Bi	7,1	7,1	6,0	6,1	14	4,9	5,0	7,3	6,6	3,3	1,8	b.d.l.	3,1	2,6	2,5	1,2	3,6	1,8
Br	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	2,0	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Cd	2,2	2,2	b.d.l.	0,1	b.d.l.	1,2	4,4	b.d.l.	b.d.l.	7,8	8,6	1,0	3,7	1,4	3,6	5,2	3,0	3,0
Ce	29	77	16	32	45	17	31	b.d.l.	17	309	284	64	125	131	122	274	152	150
Cl	b.d.l.	b.d.l.	15	38	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	87	87
Co	140	140	109	113	177	105	118	149	130	129	98	120	113	138	214	106	129	129
Cr	77	77	83	7,0	7,0	283	34	3614	3613	20	18	17	6,9	7,0	16	17	31	17
Cu	44,0	18,0	16	5,0	59	77	35	14	b.d.l.	72	7,0	3,0	9,0	7,0	18	6,0	40	7,0
Cs	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
F	657	777	793	638	655	652	747	445	301	677	972	555	686	683	1018	736	1158	493
Ga	17	14	20	16	18	19	25	5,0	6,0	16	19	11	16	21	12	22	16	18
Hf	4,0	6,0	3,0	4,0	6,0	3,0	4,0	2,0	3,0	9,8	15	5,0	10	11	7,6	11	6,7	8,0
Hg	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
La	17	45	b.d.l.	17	17	17	22	17	17	172	137	18	79	77	46	141	86	89
Mo	b.d.l.	2,5	1,7	1,7	1,7	1,7	b.d.l.	2,0	1,7	12	b.d.l.	2,0	3,3	2,2	16	3,9	2,4	1,2
Nb	9,0	7,0	12	11	15	5,0	9,0	3,0	5,0	9,8	10	4,0	16	16	11	9,0	14	7,0
Nd	17	24	12	14	28	6,7	18	12	12	97	110	27	51	51	51	93	53	59
Ni	54,0	39	114,0	47	13	143	18	747	684	7,0	13,0	7,0	8,2	10	14	6,0	15,9	8,0
Pb	12	7,0	10	14	7,0	12	10	6,7	6,7	42	21	11,0	15	13	50	14	17	17
Pr	7,0	7,0	7,0	7,0	7,0	6,7	6,7	6,7	6,7	29	25	5,0	15	14	9,0	24	15	16
Rb	22	38	27	32	9,0	8,0	38	1,0	b.d.l.	135	171	93	173	146	119	155	142	164
Sb	b.d.l.	2,5	b.d.l.	1,6	b.d.l.	0,2	2,6	0,8	0,6	1,8	0,4	2,0	2,0	b.d.l.	4,4	1,4	0,5	2,3
Sc	47	7,0	17	30	25	38	27	19	13	b.d.l.	b.d.l.	b.d.l.	6,9	7,0	b.d.l.	b.d.l.	6,7	7,0
Se	0,3	0,9	0,1	0,9	0,6	0,5	0,9	0,6	0,5	0,1	b.d.l.	b.d.l.	b.d.l.	b.d.l.	0,3	b.d.l.	b.d.l.	b.d.l.
Sm	5,0	4,0	3,0	3,0	7,0	3,3	5,0	2,7	2,7	15	20	5,0	11	10	10	15	8,9	11
Sn	0,7	2,9	6,1	4,2	1,4	2,6	7,9	3,5	0,6	7,4	4,4	3,0	6,5	3,9	4,3	7,2	5,0	6,8
Sr	145	139	218	114	93	121	154	12	6,7	150	142	119	140	65	39	88	181	150
Th	5,0	16	b.d.l.	3,0	5,6	3,3	7,0	3,3	b.d.l.	86	101	29	28	28	29	99	37	30
Tl	b.d.l.	b.d.l.	0,2	0,4	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	1,0	b.d.l.	0,8	b.d.l.	b.d.l.	0,3	0,3	b.d.l.
U	3,0	3,0	3,0	0,8	3,4	3,3	3,3	b.d.l.	b.d.l.	9,0	14	3,0	6,2	10	8,0	4,8	13	5,5
V	307	81	128	250	147	263	190	116	119	27	56	8,0	53	33	36	56	135	31
W	398	891	539	512	1043	400	592	449	303	894	688	879	830	1001	1525	812	564	917
Y	31	33	23	24	47	23	29	6,7	6,7	60	61	16	71	50	47	43	44	27
Zn	100	60	77	108	85	84	90	64	79	49	43	7,0	69	52	33	50	43	26
Zr	141	206	90	110	228	76	136	36	42	290	497	108	400	435	273	268	275	271
L.O.I.	0,57	0,29	0,58	0,79	2,32	1,08	0,47	0,13	0,29	2,47	3,36	3,17	2,53	2,38	0,72	1,08	5,32	1,56
Total	**100,15**	**99,42**	**100,03**	**98,73**	**101,01**	**99,25**	**99,61**	**99,80**	**99,54**	**100,47**	**100,58**	**98,87**	**100,73**	**98,60**	**99,51**	**98,91**	**100,75**	**98,73**