Structural, Stratigraphic and Temporal Constraints of Gold Mineralization in the Bigar Hill Deposit, Timok Region, Serbia

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the degree of	Master of Science	
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ABSTRACT

The Timok Magmatic Complex (TMC) is a well-endowed mineral district in Serbia that hosts world-class Cu-Au porphyry (Majdanpek, Veliki Krivelj, Borska Reka) and high-sulfidation deposits (Bor, Čukaru Peki). Recent exploration activities on the northwestern margin of the TMC have led to the discovery of the Bigar Hill sediment-hosted disseminated gold deposit (SHDG). It represents a previously unrecognized style of gold mineralization within the TMC and the Cretaceous metallogenic province of the western Tethyan orogenic belt - although they share many characteristics with the Carlin-type and distal disseminated gold deposits of Nevada, US.

Gold distribution at Bigar Hill and associated hydrothermal mineralogical, geochemical and stable isotope alteration features were examined to reconstruct the structural and stratigraphic controls on hydrothermal fluid flow.

The Bigar Hill stratigraphy encompasses Late Jurassic to Early Cretaceous limestone unconformably overlain by a calcareous clastic sedimentary sequence (unit S1). Late Cretaceous volcanic detritus-rich sandstone package (unit S2) unconformably overlies unit S1. Primary sparry carbonate cement, mainly ferroan calcite is characteristic features of both S1 and S2 units. Marl lies conformably over the S2 unit, and the andesitic sill intruded it.

Gold mineralization is principally stratabound, located along two stratigraphic contacts. The contact zone between units S1 and S2 is a major mineralized horizon. The other mineralized corridor lies along the unconformable contact between limestone and the S1 siliciclastic rocks. Acidic hydrothermal fluids likely exploited the enhanced porosity and permeability of preserved weathering crusts, brecciated zones, and karst along the unconformities, further creating secondary porosity by dissolving host rock carbonate cement. Although stratigraphic features are considered highly influential on the spatial distribution of ore, the regional structural framework and syn-mineralization faults reactivations are thought to be necessary to allow mineralizing fluids to permeate favorable stratigraphic horizons. A 3D spatial analysis of stratigraphic contacts and changes in the thickness of sedimentary packages suggests that the controls of the ore body geometry are previously unrecognized sub-vertical structures that channeled upwelling metal-bearing fluids. Fluids then spread laterally along the contact zones between the sedimentary packages. Two recognized structural trends, NW and NE match the major gold mineralization trends.

LAY SUMMARY

Bigar Hill is sediment-hosted disseminated gold deposit located on the margin of the Cretaceous magmatic province of the Tethyan orogenic belt; it represents the previously unclassified style of mineralization in the region explored for porphyry and epithermal deposits. Main objectives of this thesis are to establish geological features and critical processes necessary for gold deposition and to determine the timing of the key geological events relevant to the formation of the deposit. An ideal combination of structural and stratigraphic features provided favorable conditions for the circulation of Au-bearing hydrothermal fluids, their interaction with sedimentary rocks and finally gold precipitation. The most favorable mineralization host rocks were the Cretaceous calcareous sedimentary units with reactive iron, primarily permeable and porous, disturbed by processes of weathering, erosion, karstification, and structural deformations that additionally decreased rock competence. Geochronological analysis indicates that deposit-scale hydrothermal and magmatic activities were largely contemporaneous processes during the Late Cretaceous.

PREFACE

This MSc. thesis is defined and coordinated by Dr. Craig Hart and Dr. Aleksandar Mišković, within the Western Tethyan Metallogeny Project. The location of the research area is in Eastern Serbia, at the Bigar Hill deposit, discovered by Avala Resources Ltd. in 2011. Avala Resource Ltd. provided logistical assistance during the two field seasons (summer 2013, 2014), as well as the drilling and lithogeochemical database for use in this study. The sampling, observations, analyses, and interpretations were performed by Jelena Živanović unless otherwise noted. The geological map of the Bigar Hill and northwestern Timok Magmatic Complex (shown in figures 2.5, 2.6, 4.1, 5.2, 5.4, and 6.1) is based on geological mapping and data collection performed by the geologists from Avala Resources. The completion of the thesis included contributions from thesis supervisor Dr. Craig Hart, and the committee members, Dr. Kenneth Hickey and Dr. Andreas Beinlich.

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LIST OF ABBREVIATIONS

AAS = Atomic Absorption Spectrometry ABTS = Apuseni-Banat-Timok-Srednogorie magmatic-metallogenic belt BBX = Basal breccia sub-unit, part of the S1 unit ca = Calcite cy = Clay minerals f ca = Ferroan calcite g/t = Grams per tonne hb = Hornblende IB = Siltstone/mudstone interbedded sub-unit, part of the S1 unit il = Illite ICP-MS = Inductively Coupled Plasma Mass Spectroscopy JLS = Late Jurassic limestone unit KLS = Early Cretaceous limestone unit LA-ICP-MS = Laser Ablation Inductively Coupled Mass Spectroscopy Ma = Millions of years MDRU = Mineral Deposit Research Unit mu = Muscovite PCIGR = Pacific Center for Isotopic and Geochemical Research at the University of British Columbia Pk = Plagioclase ppb = Parts per billion ppm = Parts per million py = Pyrite qz = Quartz RC = Reverse Circulation (drilling) S1 = Early Cretaceous carbonate siliciclastic unit

S2 = Late Cretaceous volcanic detritus-rich, carbonate, siliciclastic unit

- SHDG = sediment-hosted disseminated gold
- si = Silica
- SMR = Late Cretaceous marl unit
- SWIR = Short-Wave Infrared Spectroscopy
- TMC = Timok Magmatic Complex
- TSG = The Spectral Geologist© interpretative software
- UBC = University of British Columbia
- VOL = Late Cretaceous andesite sill
- VPDB = Versus Peedee Belemnite (international standard for carbon isotope)
- VSMOW = Versus Standard Mean Ocean Water (international standard for oxygen isotopes)
- XRF = X-ray Fluorescence
- δ = Ratio of the heavy isotope (¹³C or ¹⁸O) vs. the light isotope (¹²C or ¹⁶O)

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To Míkí

1.1 Rationale for Study

Sediment-hosted disseminated gold (SHDG) deposits are hydrothermal replacement bodies that typically form in calcareous rock sequences typical of passive continental margins. The passive margin basin geometries were shaped by continental rifting and long-lived, deep crustal structures. These structures controlled sedimentation and deformation as well as localization of calc-alkaline magmatism, and most SHDG deposits are structurally and stratigraphically controlled (Hofstra and Cline, 2000; Cline et al., 2005). SHDG deposit host rocks are mostly reactive and permeable sedimentary rocks, including limestone, dolomite, and calcareous siliciclastic rocks (i.e., Bagby and Berger, 1985; Sillitoe and Bonham, 1990; Berger et al., 2014). Hydrothermal host rock alteration can be variable and visually subtle, but is dominated by carbonate dissolution with clay formation, sulfidization and silicification (Li and Peters, 1998; Hofstra and Cline, 2000; Cline et al., 2005). Gold mineralization is frequently termed "invisible gold" since it occurs as structurally bound Au⁺¹ or as sub-micron native gold in pyrite or arsenic-rich pyrite (Radtke et al. 1980; Muntean et al., 2011).

Such deposits were mined during the first half of the 20th century but it was only after the discovery of the Carlin deposit in Nevada in the early 1960s that SHDG deposits were recognized as economically significant and became subject of academic research interest (Li and Peters, 1998; Muntean et al., 2004; Berger et al., 2014). Since 1961, over 100 geologically similar deposits have been discovered in the Great Basin physiographic province of the southwestern U.S. (Muntean et al. 2004). With gold production, reserves, and resources amounting more than 6,000 tons, SHDG deposits of northern Nevada represent the second largest Au concentration globally (Muntean et al., 2011; Ressel and Henry, 2006; Frimmel, 2008). Mining of these systems dominates gold production in the U.S. and accounts for 6% of the annual global production (Cline et al., 2005; Frimmel, 2008; Muntean et al., 2011). As such, SHDG deposits are economically significant, but their value has mostly been exploited in technologically-advanced mining districts and the emerging regions remain underexplored and undeveloped.

Beyond Nevada, SHDG deposits are suggested to occur in western and southwestern China (Shuiyndong, Lannigou, Nibao, Zimudang etc.), Indonesia (Mesel, Lobongan Alason), Iran (Zarshurian, Agd), Malaysia (Bau), South Korea (Taebaegsan), Peru (Purisma Conception, Cajabamba), Chile (El-Hueso, Potrerillos, Jeronimo), Canada (Racla, Brewery), Spain (Salamon, Sant Bernat), Russia (Aldan, Zdiha etc.) and Macedonia (Alšar) (Daglioglu, 1996; Berger, 2014; Feebrey, 2014; Hofstra, 2015). SHDG deposits have been recognized and discovered in Serbia at Bigar Hill, Korkan and Kraku Pešter in 2010 (Avala Resources Ltd, 2013; Knaak at all., 2016). These deposits and their recognition as SHDG systems represent an opportunity to reconsider significant potential from deposits that were previously considered uneconomical. These Serbian deposits share many classic features with SHDG deposits of Nevada which are crucial for delineating geological processes and features that were critical for gold deposition.

The SHDG deposits of Serbia occur on the margin of the Timok Magmatic Complex (TMC), which is wellknown for its world-class porphyry and epithermal Cu-Au deposits. Calcareous siliciclastic rocks rich in volcanic detritus, transitional calcareous sandstone to sandy limestone, basal breccia overlying the limestone unit, and Cretaceous limestone with high organic and clastic contents all host mineralization. Deposition of sub-µm sized gold accompanies pyrite formation and an association with low-temperature metals such as Tl, Hg, Sb, and Te. Mineralization forms with subtle hydrothermal host rock alteration, including carbonate dissolution, illite ± smectite, and kaolinite alteration, and local silicification.

Bigar Hill is a gold deposit in the advanced stage of exploration. Since 2010, a significant amount of geological and geochemical data has been collected. These data enabled a general understanding of the deposit stratigraphy as well as the mineralization distribution within particular stratigraphic units. However, the exact controls on gold deposition remained unexplained. The lack of a clear understanding of the deposit structural setting made it difficult to determine feeder faults and the other structures that acted as conduits for hydrothermal fluids. The compositional variations and textural characteristics of the sedimentary host rocks that controlled gold deposition were not analyzed in details. Also, an unequivocal genetic link between mineralization and surrounding magmatic activities was not established. Listed unknowns will be addressed in this thesis.

The significance of structural and stratigraphic controls on gold mineralization at Bigar Hill will be evaluated through the application of geological mapping, core logging, major, minor and trace element geochemistry, stable isotope geochemistry, petrography, short-wave spectroscopy, and 3D structural modeling. New geochronological data will be obtained for the Bigar Hill host rocks and nearby magmatic intrusions to directly and indirectly constrain the timing of mineralization. Lastly, a new Bigar Hill genetic model will be constructed in the context of new bracketing ages on regional magmatic, sedimentary and hydrothermal events.

1.2 Overview of Sediment-hosted Disseminated Gold Deposits

In order to appreciate the significance of SHDG and its importance within this thesis, an overview of this deposit type is provided. Several classifications of SHDG deposits have been established based on their geological and geochemical characteristics. The most typical division is based on genetic links with shallow plutonic complexes and porphyry systems (Tosdal, 1998; Johnston and Ressel, 2004; Cline et al., 2005). In this classification, there are two subsets of the SHDG deposits: (1) Carlin-type and (2) Carlin-like or distal disseminated (Hofstra and Christensen, 2002; Cline et al., 2005; Theodore, 1998). Although the two subsets share many physicochemical characteristics, Carlin-type deposits lack the genetic link with igneous activity, whereas distal Carlin-like disseminated deposits are linked chemically, spatially and temporally with magmatism (Cline et al., 2005; Ressel, 2015) (Figure 1.1).



Figure 1.1: Diagrammatic model of Carlin-type and distal disseminated deposits (modified from Setijadji, 2002; Sillitoe and Humbolt, 1990; Peters et al., 2004).

1.2.1 Carlin-type Deposits in the Great Basin

Carlin-type deposits derive their name from the first deposit of its type, the "Carlin deposit," discovered in 1961 in northeastern Nevada. Since then, many geologically similar deposits have been discovered in the Great Basin province - primarily in Nevada but also in adjacent southern Idaho and western Utah (Cline and Hofstra, 2000; Berger et al., 2014). The Carlin deposit (s.s.) has become the type example of a genetic class of previously undocumented, sediment-hosted, hydrothermal gold deposits. The majority of the Great Basin Carlin-type deposits are aligned along three regionally-significant structural lineaments, known as the Carlin, Battle Mountain-Eureka, and Getchell trends, and the Jerritt Canyon and Alligator Ridge districts (Muntean et al. 2004; Berger et al. 2014) (Figure 1.2).



Figure 1.2: Hill-shaded digital elevation model of northern Nevada with the locations of mineral belts and districts, Carlin-type gold deposits (circles), and other significant deposits (crosses). Upper right box shows the northern Carlin trend with the principal Carlin-type deposits (Hofstra, 2002 and the references therein).

1.2.1.1 Magmatic History

Several stages of magmatic activity accompanied regional deformations. Paleozoic basaltic volcanism was deposited within the allochthon of the Roberts Mountains thrust but was not associated with the Carlin trend and its deposits. According to Ressel and Henry (2006), magmatic episodes affecting the rocks of the Carlin trend occurred in the Late Jurassic, Cretaceous, Eocene, and Miocene. Subduction-related magmatism prevailed from the Late Jurassic through the Cretaceous to Late Eocene. Jurassic magmatism produced diorite to granodiorite, rhyolite and lamprophyre intrusions and associated volcanic rocks, while Cretaceous intrusions were primarily granitic. After a gap in magmatic activity during Paleocene, magmatism resumed in the Eocene with calc-alkaline volcanism and shallow intrusions. Eocene magmatism occurred contemporaneously and in response to Farallon plate subduction and the initiation of crustal extension. Rift-related bimodal basalt-rhyolite lavas extruded during the Miocene (Cline et al., 2005).

The Jurassic intrusions have spatial relation with gold mineralization. However, Eocene intrusions have both spatial and temporal association with the majority of the Carlin-type gold deposits. Cretaceous and Miocene intrusions are not associated with gold mineralization (Ressel and Henry, 2006).

1.2.1.2 Deposit-hosting Sedimentary Units

Paleozoic sedimentary rocks of north-central Nevada include three main sequences: (1) autochthonous, "lower plate" Silurian to Devonian continental margin carbonate facies; (2) allochthonous, "upper plate" Ordovician deep-water terrigenous clastic rocks; and (3) Late Mississippian to Early Permian overlap sequence located east of the Roberts Mountains allochthon (Teal and Jackson, 1997; Yigit et al. 2003).

Autochthonous sequence hosts the majority of Carlin-type deposits (Teal and Jackson, 1997; Hofstra and Cline, 2000). This sequence encompasses three deposit-hosting formations: (i) Roberts Mountains; (ii) Popovich; and (iii) Rodeo Creek (Teal and Jackson, 1997). The Silurian-Devonian Roberts Mountains formation consists of medium- to thin-bedded, laminated, silty limestone and dolomitic siltstone. Stratigraphically higher sections exhibit relatively high permeability, which created a favorable environment for gold mineralization and host the Carlin, Betze, West Leeville, Pete, Screamer, Deep Post, and Goldbug-Post deposits. The Devonian Popovich formation is highly variable with sharp vertical and lateral facies changes, from thin-bedded silty limestone and micrite to massive, fossiliferous, sparry limestone. The Popovich formation hosts the Betze-Post, Genesis-Blue Star, Gold Quarry, Griffen, Rodeo, Deep Star, Bootstrap-Capstone and Dee-Storm deposits. The Late Devonian Rodeo Creek unit represents the upper transitional zone immediately beneath the Roberts Mountains allochthon. Occurrences typical of this unit have abrupt lateral and vertical facies changes, thick sequences of debris flow and synsedimentary slumping. The rocks comprise calcareous siltstone, siliceous mudstone, and chert. The upper part of Gold Quarry and Upper Betze-Post deposits are hosted in Rodeo Creek siltstone (Teal and Jackson, 1997; Emsbo et al., 2003).

Low-permeable, fine-grained siliciclastic rocks within the Roberts Mountains allochthon form a regional aquitard and lack any significant Carlin-type mineralization (Cline et al., 2005; Teal and Jackson, 1997).

1.2.1.3 Mineralization Controls and Fluid Characteristics

Deposition of passive margin sedimentary sequences and the pre-Eocene deformation events established the pre-mineralization architecture for the Nevada SHDG deposits and created a favorable environment for the hydrothermal fluid circulation and deposition of disseminated gold. The majority of the Carlin-type deposits are adjacent to steeply-dipping faults through reactive and permeable mid-Paleozoic carbonate rocks (Teal and Jackson, 1997; Cline et al., 2005; Hickey et al., 2014). However, feeder structures of some Carlin-type deposits were low-angle thrusts, focusing lateral fluid flow underneath and up into the ore zone (e.g., Pipeline gold deposit) (Hickey et al., 2014).

Multi-phase fluid inclusion data and geologic reconstructions suggest that Carlin-type deposits formed a few kilometers below the paleo-surface. Ore fluids where characterized by low temperature (~180-240°C), low salinity (mostly <6 wt.% NaCl equivalent), moderate acidity (pH~4), CO₂ content <4 mol%, CH₄ content <0.4 mol%, and H₂S content ($10^{-1} - 10^{-2}$ mol%) which were sufficient to transport Au and other metals as bisulfide-complexes (Cline et al., 2005; Muntean et al., 2011). Carlin host rock alteration is usually subtle and varies with the size of the hydrothermal system, host rock composition, and permeability. Visible alteration halo extents may be exceeded by larger zones showing an isotopic modification of the limestone host rocks and these indicate fluid circulation on the km-scale (Barker et al., 2013). Visible alteration is manifested as carbonate dissolution, clay alteration of primary silicate minerals and local silicification, particularly proximal to structural conduits (Teal and Jackson, 1997). Sulfidation of reactive iron in host rocks is the primary mineralization process. Sulfur from the fluid reacts with the reduced iron to form pyrite and destabilize aqueous Au-bisulfide complexes. Pyrite is an efficient scavenger of Au by adsorbing Au¹⁺ onto its negatively charged surfaces from AuHS⁰ complexes in acidic fluids that are under-saturated in native Au (Muntean, 2015). Elevated concentrations of As, Sb,

Hg, Tl, ±Te occur along with gold in pyrite, the Au/Ag ratio is generally >1, and base metal abundances are very low (Radtke et al. 1980; Hofstra and Cline, 2000; Muntean et al., 2011). Rb-Sr dating of rare Hgsulfosalt – galkhaite provided the only direct age of mineralization, indicating an age of 40-39 Ma (Arehart et al., 2003).

Although considerable effort has been made to integrate geological, geochemical and isotopic data, a full understanding and a widely accepted genetic model of Carlin-type deposits have yet to be established (Hofstra and Cline, 2000). In particular, the sources of fluids, metals and heat-driving hydrothermal convection systems remain debated (Arehart, 1996; Ressel and Henry, 2006). Two end-member models determining the origin of gold in Carlin-type deposits include (1) magmatic-hydrothermal models, which suggest a magmatic origin of Au, and (2) amagmatic models favoring Au mobilization from the crust by meteoric and metamorphic waters (Muntean et al., 2011).

1.2.2 Distal Disseminated Gold Deposits

Distal disseminated Au deposits share many features with Carlin-type deposits. They formed in the same regional tectonic and depositional environment of the continental margin, within carbonate and clastic sedimentary host rocks (Cox and Singer, 1990). For both types, structurally and stratigraphically controlled mineralization is disseminated and associated with the weakly developed hydrothermal host rock alteration. Distal disseminated deposits have higher Ag and base metal concentrations than Carlin-type deposits, but lower concentrations of Au, and are thought to form from fluids of higher temperature and salinity (Cline et al., 2005). The main distinction from Carlin-type deposits is their genetic and spatial relation to magmatic intrusions (Theodore, 1998; Tosdal, 1998), porphyry, skarn, polymetallic veins, and polymetallic replacement deposits (Cox and Singer, 1990). The distal disseminated deposits of north-central Nevada are proximal to Jurassic, Cretaceous and mid-Tertiary granitoid bodies and exhibit isotopic signatures that indicate formation from magmatic fluids (Hofstra, 1997; Hofstra and Cline, 2000). The most economically essential deposits (e.g., Lone Tree, Marigold) are located in the Battle Mountain-Eureka trend and are proximal to a cluster of established and inferred porphyry Cu-Mo systems of Late Eocene age (Hofstra and Cline, 2000).

1.3 Thesis Objectives

The Bigar Hill SHDG deposit represents a thrilling opportunity to study a previously unrecognized and unclassified mineralization style in the Timok Magmatic Complex (TMC) and wider in the Cretaceous metallogenic province of the western sector of the Tethyan orogenic belt. A full characterization of the

deposit is challenging due to the lack of surficial manifestation of faults, the heterogeneity of the sedimentary units, and their mineralogical and physicochemical features. Of particular importance are the geological features and processes that facilitated the formation of economically significant gold mineralization, i.e., what structures facilitated primary hydrothermal fluid flow, and what stratigraphic features favor gold deposition? As well, new geochronological data can define the relative sequence of magmatic and hydrothermal events at Bigar Hill that can constrain the timing of the sources of thermal energy, gold, and fluids? How does this deposit compare to the classic Carlin-type and disseminated gold models in a global context?

To address these questions, the central thesis objectives are to:

- (1) Establish the structural and stratigraphic controls on gold deposition formation;
- (2) Identify the critical processes that facilitated gold deposition;
- (3) Determine the timing of the key magmatic and hydrothermal events;
- (4) Develop a refined Bigar Hill deposit model.

The objectives were reached through the application of several methods.

- (1) Core logging, petrography including carbonate staining, geochemical and stable isotope data were used to define stratigraphic features that controlled the deposition and distribution of gold. The approach to establishing structural controls was through the observations of the 3D spatial distribution of lithology data recorded by core logging. Geochemical and stable isotopic data were used for further support and enabled a better understanding of the timing of structural events.
- (2) Core logging, petrography, short-wave infrared spectroscopy, and C-O isotopic data provided the basis for the identification of chemical processes that led to the deposition of gold.
- (3) The timing of the major geological events relevant to the formation of the Bigar Hill deposit was deciphered by the use of data from two geochronological techniques. U-Pb zircon technique provided the age of the major magmatic events spatially or genetically linked to the ore formation as well as the indirect age of the main sedimentary host rocks. K-Ar dating of illite was used to determine the age of hydrothermal activity and the indirect age of mineralization.
- (4) The refined geological model of the Bigar Hill deposit was built as a synthesis of all available data and observations and as such can be compared with the SHDG deposit model.

1.4 Methodology

1.4.1 Core Logging

A database of rock lithology, alteration observations, mineralization, vein properties, weathering characteristics, and structural features for 87 diamond drill holes was obtained from the Avala Resources Ltd., from their previous work at the deposit. Fifteen drill holes located along the NW-SE deposit cross-section were selected for further analysis. Characteristics of siliciclastic rocks such as grain size, composition, and distribution of clasts and cement were recorded in details. The previous classification of sedimentary units was refined into sub-facies according to their composition and grain-size. These steps helped to determine the importance of rock features for fluid transport and gold mineralization. Sample locations and descriptions are listed in Appendix A.

1.4.2 Petrography

Sixty samples were petrographically analyzed under transmitted and reflected light. The selection of 52 samples collected at the Bigar Hill represents mineralized and barren examples of all significant sedimentary and volcanic units. Eight samples are from the barren Korkan West and Korkan South prospects, collected from the same stratigraphy as in the case of the Bigar Hill deposit. The petrographic analysis focused on determining texture, mineral assemblage, and alteration, and in the case of siliciclastic rocks, also fabric characteristics (homogeneity, packing, porosity, clast orientation), grain size, grain shape, textural maturity, matrix, and cement composition.

The carbonate staining method enabled the identification and discrimination of carbonate minerals in calcareous siliciclastic sedimentary rocks from the Bigar Hill. Staining was applied on 27 samples from the S1 and S2 clastic units. The alizarin red (sodium alizarine sulfonate C₁₄O₂H₅(OH)₂SO₃) - potassium ferri-cyanide (K₃[Fe(CN)₆]) composite test allowed the distinction of ferroan carbonates. Non-ferroan dolomite, siderite, and magnesite do not stain, while calcite and aragonite become pink to scarlet red. Ferroan calcite stains dark purple to royal blue and ferroan dolomite stains pale to turquoise blue and blue. Before staining, samples were etched in diluted HCl for 5 seconds and then thoroughly washed with distilled water. The samples were then placed in the staining solution, prepared as a mixture of 250 ml of 2% HCl and 2 g of each alizarin red and potassium ferricyanide. After 2 minutes, the stained samples were removed from the solution, washed with distilled water and air dried (Hitzman, 1999). This procedure was conducted at the Mineral Deposit Research Unit (MDRU, UBC) laboratory under the fume hood.

1.4.3 Lithogeochemistry

Avala Resources Ltd provided lithogeochemistry data for approximately 50,000 samples from 87 diamond and 333 reverse circulations (RC) drill holes used in this thesis. Samples were prepared and analyzed at the SGS facility in Bor, Serbia. Gold concentration analysis was performed by conventional fire assay, with an atomic absorption spectrometry (AAS) finish. Silver and trace metal analyses were performed using a 0.3 g charge, aqua regia digestion, and AAS or inductively coupled plasma mass spectrometry (ICP-MS). Gold, silver, and sulfur analyses were performed on one-meter intervals of the split core or RC chip samples, while the remaining element suite analyses were done on five-meter composite samples. The 5 m composite samples were not available from all drill holes. One in twenty samples represented internationally-certified standard material, covering the grade range, along with blank and duplicate analyses.

An additional 59 samples were analyzed to constrain mineralization and alteration on a scale larger than that covered by samples contained in the Avala Recourses database. These samples were prepared at UBC and processed by Acme Analytical Laboratories Ltd, Vancouver, using the total whole rock characterization package. Major and trace elements were digested using a lithium borate fusion and analyzed by X-ray fluorescence (XRF) and ICP-MS, respectively. Base and precious metals were digested in aqua regia and analyzed by ICP-MS. Additionally, gold concentrations were determined by fire assay with the detection limit of 30 ppb. Total carbon and sulfur were determined using a LECO elemental analyzer and direct combustion and non-dispersive infrared detection of CO₂ and SO₂ gas. Data quality control included five duplicates and five internal standards with known chemical composition. Lithogeochemical data for analyzed samples are listed in Appendix B.

1.4.4 Short-wave Infrared Spectroscopy (SWIR)

Short-wave infrared spectra were collected from 250 core samples from volcanic and siliciclastic rocks to determine the presence and distribution of clay and carbonate minerals. The reflectance spectra resulting from the absorption of characteristic wavelengths due to sub-molecular vibrations during bending and stretching of molecular bonds in minerals were obtained using the TerraSpec[®] analytical spectral device (ASD Inc.). Spectra were processed both automatically by the interpretative software The Spectral Geologist© (TSG) and manually with the SPECMIN[™], comparing obtained spectra with the extensive library examples. Spectral analysis was conducted at MDRU laboratory.

1.4.5 Carbon and Oxygen Isotopic Analysis

Carbonate oxygen and carbon isotope ratios of the host rocks to mineralization changed due to isotope exchange between the host rock and alteration fluid. This method was used to delineate hydrothermal fluid flow pathways within the Bigar Hill system. For that purpose, 629 samples from sedimentary carbonate rocks (marl, sandstone, sandy limestone, siltstone, breccia, and limestone) collected at 5 m intervals from 22 diamond and RC drill holes that comprise an E-W section that crosses the Bigar Hill mineralization and also from the surrounding barren area. The amount of carbonate material used in the analysis ranged from 17 to 100 mg depending on carbonate concentration. Sample powders were obtained by a hand-drilling homogeneous rock or carbonate cement using a handheld Dremel tool or by crushing the RC chips. The sample powder was placed in glass vials, sealed with rubber septa. Approximately 0.2 ml of 85% H₃PO₄ was injected into each vial and left to react at 70°C for at least one hour in a heated aluminum block. Further processing of the samples and measurement of C and O isotope composition of CO₂ gas produced from the acidification of carbonate minerals was carried out using Los Gatos Research (LGR) CCIA-43r-EP carbon-dioxide isotope off-axis integrated cavity output laser spectrometer (OA-ICOS) instrument at MDRU. The sample vial connected with the instrument inlet via a series of Swagelok compression fittings, stainless steel tubing, and a cold glass trap. The measured volume fractions of several isotopologues of CO₂ (¹²C¹⁶O¹⁶O, ¹³C¹⁶O¹⁶O, and ¹²C¹⁶O¹⁸O) were converted to the conventional δ notation ($\delta^{13}C_{VPDB}$ and $\delta^{18}O_{VSMOW}$) (Beinlich et al. 2017). Instrumental drift was monitored on an hourly basis and corrected using the 2000 ppm CO₂ gas sample of constant isotopic composition. Each analytical session commenced and ended with at least three UBC in-house reference materials (BN13, Sigma, BDH). These reference materials were also run after at least the 8th to 10th unknown for quality control and to establish the analytical reproducibility of known values.

1.4.6 Geochronology

Six samples were collected for U-Pb zircon geochronology analysis by laser ablation ICP-MS (LA-ICP-MS). These included samples from volcanic detritus-rich sandstone, andesite, and diorite from the Bigar Hill, two samples from the nearby Au and Cu-Au porphyry Čoka Rakita and Crna Reka deposits, and one sample from the Crna Reka monzonite. LA-ICP-MS U/Pb age determinations were conducted at the Pacific Center for Isotopic and Geochemical Research (PCIGR) at UBC. Zircon grains from the samples were isolated using standard heavy mineral separation processes, then hand-picked under a binocular and embedded in epoxy resin. Puck were then ground, polished, cleaned with HNO₃, and carbon coated. Several grains of the Plešovice and Temora zircon standards of known age were also mounted together

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with the unknowns. Cathodoluminescence (CL) imagery preceded the zircon analysis to identify inherited cores, inclusions, and physical defects (Kolb et al., 2012). Analyses were performed using a New Wave UP-213 laser ablation system and a ThermoFinnigan Element2 single collector, doublefocusing, magnetic sector ICP-MS. The laser operated along approximately 100 µm long line scans at a beam width of 25 µm and 20 Hz repetition rate. Each analytical sequence commenced and ended with the measurement of at least three zircon standards, which were also analyzed after every five unknowns. The resulting signals were analyzed using lolite[™], an application extension of the Igor Pro[™] software. Corrections for mass and elemental fractionation were made by bracketing analyses of unknown grains with replicate analyses of both Plešovice and Temora zircon standards. Data reduction was performed using MS Excel add-in Isoplot.

K-Ar dating of hydrothermal illite was performed to constrain the age of hydrothermal alteration and gold mineralization. Clay minerals were separated from six drill core samples collected from intensively altered and highly mineralized volcanic detritus-rich sandstone and andesite from Bigar Hill. Sample preparation and K-Ar dating were carried out at the Institute of Nuclear Research at the Hungarian Academy of Science (ATOMKI). In order to avoid contamination, the <2 μ m fraction was separated from each sample according to the standard clay separation procedure. The <5 μ m and <10 μ m fractions were also separated from 2 andesitic samples to test the effect of grain size on the radiometric age. The effect of the rock host minerals was tested by dating the whole rock samples. The purity of the separated clay fraction was checked with X-ray powder diffraction at the Mineralogical Department of the Eötvös Loránd University, Budapest, using a Philips PW 1710 diffractometer with CuKα radiation at 45 kV and 35 mA. For the calculation of the K/Ar age, it was necessary to determine the concentrations of 40 K and radiogenic ⁴⁰Ar. For ⁴⁰K measurement, approximately 0.05 g of finely-grounded samples were digested in HF, HNO₃, and H₂SO₄ and finally dissolved in 0.2 M HCl. Potassium was determined by flame photometry with a Na buffer and Li internal standard using Sherwood M420 type flame photometer. For ⁴⁰Ar, approximately 0.8 g of whole-rock sample and 0.2 g of mineral fraction were preheated for about 24 h at 150–180°C in a vacuum. Argon was extracted under ultra-high vacuum conditions by RF induction heating and fusion of rock samples in Mo crucibles. The extraction line was linked directly to a mass spectrometer using in-static mode. Argon isotope ratios were measured by a ³⁸Ar isotope dilution mass spectrometric method, previously calibrated with atmospheric argon and international rock standards (Pécskay and Benkó, 2015).

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1.5 Thesis Organization

This thesis includes seven chapters. Chapter 1 is an introductory explanation of the rationale and objectives of this thesis. This chapter also provides an overview of sediment-hosted disseminated gold deposits, their characteristics and classification, and a literature review of Carlin-type and distal disseminated gold systems. The first part of chapter 2 focuses on the regional geological background, geodynamic setting and metallogeny of southeastern Europe, particularly the Cretaceous magmatic belt and Timok Magmatic Complex. The second part of chapter 2 focuses on the geology of the Bigar Hill deposit and provides an overview of the host rocks stratigraphy. It also addresses critical processes that facilitated the ore formation such as hydrothermal alteration, and gold deposition. Chapter 3 provides a hypothesis on the structural and stratigraphic factors that may have controlled the precipitation of the significant economic concentrations of gold. Chapter 4 evaluates the applicability of stable carbon and oxygen isotopes as an exploration tool. Generally, deviations in C and O isotopic composition are observable in a broader area than visible alteration and other geochemical indicators. Isotopic shifts were used to establish the extent of the fluid interaction with carbonate rock, to differentiate pervasive from structurally controlled alteration and to delineate fluid flow pathways. Chapter 5 provides a geochronological overview of the collected data on the magmatic and hydrothermal events in the Bigar Hill region and explores possible links between gold mineralization and nearby magmatic activity. Chapter 6 represents a synthesis of the obtained results and observations, giving the interpretation of the main topics set out in this study. Chapter 7 outlines the main conclusions and proposes an outlook on future applications of the obtained knowledge to future exploration and suggestions for future work.

CHAPTER 2 – GEOLOGY, HYDROTHERMAL ALTERATION, AND MINERALIZATION OF THE BIGAR HILL GOLD DEPOSIT

2.1 Introduction

The Bigar Hill is sediment-hosted disseminated gold (SHDG) deposit discovered in 2010 within the exploration license of Avala Resources Ltd in Serbia. The Bigar Hill is emplaced on the northwestern margin of the Timok Magmatic Complex (TMC) which had previously been known only for its porphyry and epithermal Cu-Au deposits (Figure 2.1). Therefore, the discovery of the Bigar Hill has wide range implications because this SHDG deposit represents a previously unrecognized genetic type within the TMC. Indicated mineral resources of Bigar Hill are 1.48 Moz Au at an average grade of 1.19 g/t (Avala Resources Ltd., 2014).

The Bigar Hill mineralization is characterized by micron to submicron scale gold within pyrite disseminated in carbonate-rich sedimentary and less in sub-volcanic rocks. The main controls of gold precipitation and its distribution are both structural and stratigraphic. The primary porosity and permeability of the host rocks as well as the secondary porosity and permeability caused by faulting, weathering or erosion were critical in the formation of the deposit. These features controlled the ore fluid flow and its interaction with reactive iron-bearing rocks. Weakly acidic gold-bearing fluids caused carbonate dissolution, clay and local silica alteration of the host rocks and reacted with liberated iron that led to the deposition of pyrite with gold (Cline et al., 2005). Within the stratigraphic sequence, only two calcareous siliciclastic S1 and S2 units had characteristics that made them the overall favorable mineralization host rocks. Particularly important were the two depositional contact zones with high secondary porosity and permeability, one between the S1 and S2 units, and the other between the S1 unit and the underlying limestone. Other rock units had a somewhat limited capacity for hosting mineralization either due to the unfavorable composition or low porosity and permeability.

This chapter will provide the review of the regional geology, geodynamic and metallogeny. Afterward, the focus will be on the Bigar Hill stratigraphy through the detailed description of the rock units as well as critical processes – alterations that were crucial for the gold deposition. The characterization of the rocks and hydrothermal alterations is based on the core logging, petrographic observations and whole rock and trace element geochemistry.

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Figure 2.1: Simplified geologic map of the Timok Magmatic Complex with the most significant ore deposits including the Bigar Hill.

2.2 Regional Geology

The Bigar Hill deposit is hosted primarily in Cretaceous strata of the westernmost component of the Tethyan orogenic belt (Figure 2.2) that spans from the western Mediterranean via the Alps and Balkan Peninsula through Turkey and the Caucasus, and into south-central Iran, Afghanistan, Pakistan, the Himalayas, and Indochina (Janković, 1997; Zimmerman et al., 2008). The Tethyan orogenic belt formed during the closure of the Tethyan Ocean in Mesozoic and Cenozoic. The arcuate, double-verging orogenic system includes temporally and spatially distinct Cretaceous and Tertiary magmatic provinces (Neubauer, 2002). The belt hosts numerous small to world-class porphyry Cu±Mo±Au and related Au±Cu epithermal and base metal deposits. Richards (2015) linked Mesozoic deposits with the subduction of the oceanic lithosphere and suggested that the majority of Tertiary deposits formed during or after the continental collision.



Figure 2.2: Simplified map of magmatic provinces within the western section of the Tethyan orogenic belt including the locations of the significant base and precious metal deposits. The red line contour shows the Timok Magmatic Complex. (Modified from MDRU, Jenkins, 2017).
2.2.1 Tectonic Evolution and Metallogeny of the Apuseni-Banat-Timok-Srednogorie Belt

The Late Cretaceous magmatic province of the western Tethyan belt is named Apuseni-Banat-Timok-Srednogorie belt (ABTS) (Figure 2.2). It represents one of the European most productive ore provinces and is well-known for its mining activities since pre-Roman times (Ciobanu et al., 2002; von Quadt et al., 2002; Drew, 2005; Chamberfort and Moritz; 2006; Richards 2015). Despite the gaps in the exposure of magmatic rocks and irregularly clustered ore deposits, the L-shaped ABTS belt is largely continuous for 1,500 km and has a width of 30 to 70 km (von Quadt et al., 2002). It extends through southeastern Europe, running southward from the North Apuseni Mountains and the Banat region in Romania to Timok area in Serbia and then eastward through the Srednogorie zone in Bulgaria where the Panagyurishte is the central metallogenic district (Ciobanu et al., 2002; von Quadt et al., 2002; Zimmerman et al., 2008). The belt continues through Turkey further to the east.

The ABTS was formed from the interaction of multiple micro-plates that were between the African and Eurasian plates during the closure of the Tethyan Ocean (Neugebauer et al., 2001; Heinrich and Neubauer, 2003). A divergence of Africa and Eurasia terminated in the Early Jurassic. Continental fragments (such as Dacia, Tisza, and Rhodopian micro-plates) migrated northwards and interacted with the Moesian platform – a promontory of the stable Eurasian plate (Zimmerman et al., 2008; Schmid et al., 2008, Kolb et al., 2012) (Figure 2.3). During the Late Cretaceous, continual continent convergence initiated the closure of the Vardar Ocean (a branch of the former Tethys Ocean) by subducting the oceanic slab beneath the Dacia micro-plate (Drew, 2005; Zimmerman et al., 2008; Kolb et al., 2012).

Several geodynamic models have been proposed to explain the formation and evolution of the Cretaceous magmatic and metallogenic belt, including slab roll back as the most accepted model (Zimmerman et al., 2005; Kolb et al., 2012). The model implies a gradual steepening of the north-dipping subduction slab resulting in an inversion from compressional to extensional tectonic regimes (Kolb et al., 2012). Subducting slab dehydration triggered the melt generation, which was enhanced by asthenosphere upwelling (Neubauer, 2002; Lips et al., 2004). Extension of the upper crust allowed melt access to high crustal levels, ultimately leading to widespread calc-alkaline magmatism and formation of the ABTS magmatic belt (Kolb et al., 2012). Subduction ceased in the region at the very beginning of the Cenozoic but continued in the Aegean region and Alps.

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Figure 2.3: Generalized tectonic element map of the Balkan Peninsula with the location of the TMC (modified from Schmid et al., 2008).

The ABTS belt hosts numerous hydrothermal metal deposits in eastern Serbia, the Southern Carpathians in Romania, and the Panagyurishte zone in Bulgaria. Porphyry and high-sulfidation deposits are in the central segments of the belt in southernmost Banat, Serbia, and northwestern Bulgaria. These deposits are copper dominated but also represent significant gold resources. Anomalous molybdenum is registered, though generally in small quantities (Janković, 1997; Ciobanu et al., 2002). Some porphyry deposits contain notable PGE abundances (Zimmerman et al. 2008). Major Cu-Au deposits are Rosia

Montana in Romania, Majdanpek, Veliki Krivelj, and Bor in Serbia, Elatsite and Chelopech in Bulgaria (Figure 2.2). Re-Os molybdenite ages constrain the timing of mineralization in the Apuseni-Banat, Timok, and Panagyrishte districts to 83-72 Ma, 88-80 Ma, and 92-87 Ma respectively (Ciobanu et al., 2002; Zimmerman et al., 2008). The data indicates an increasing mineralization age from the northwestern to the southeastern part of the ABTS belt. Sediment-hosted gold deposits discovered in Serbia in 2010 at the northwestern margin of the TMC are a previously unrecognized genetic type within the ABTS.

2.2.2 Geology and Tectonic Setting of the Timok Magmatic Complex

The Late Cretaceous magmatism in the Serbian part of the ABTS belt occurred along the TMC. The northerly-oriented, elongated, lozenge-shaped TMC is about 85 km x 25 km and is one of the most prolific mining areas in Europe. Volcanic rocks dominate the TMC. They are intercalated with the Late Cretaceous, calcareous sedimentary, volcaniclastic and epiclastic rocks (Banješević, 2006, 2010), and are intruded by numerous dikes, sills and large plutons emplaced mainly at shallow crustal levels (Figure 2.1).

The TMC is formed on the edge of the Moesian platform, on Proterozoic to Early Cretaceous continental crust of Dacia micro-plate (Figure 2.3). Basement rocks of the TMC comprise Proterozoic gneiss, amphibolite, greenschist, gabbro, metasediments, and Paleozoic schist, phyllite, and metasediments. (Dimitrijević et al., 1970; Banješević, 2006). Due to the late Paleozoic terrain uplift caused by Variscan orogeny, deposition of Triassic sedimentary rocks was sparse and had a local character (Dimitrijević et al., 1976). Transgressive basal conglomerate unit marked the beginning of the continuous carbonate sequence sedimentation in Late Jurassic and Early Cretaceous (Doger to Aptian). Approximately 800 m of limestone, dolomite and transitional varieties were deposited within the carbonate platform environment. Early, Austrian stage of the Alpine orogeny led to regression of sea level and cessation of carbonate precipitation. During the short hiatus in sedimentation, carbonate rocks were exposed to karstification processes. Further evolution of the area took place during middle Cretaceous (Albian-Cenomanian) in the environment with the frequent sea-level oscillations. Calcareous clastic rocks deposited during that time included conglomerate and breccia, sandstone, siltstone, mudstone, and sandy limestone (Banješević, 2006, 2010; Dimitrijević et al., 1976). The next break in sedimentation was caused by the Laramide phase of the Alpine orogeny. After the hiatus, Late Cretaceous, Turonian-Senonian, clastic sedimentary cycle commenced during which sequences of sandstone and conglomerate and younger marl and marly limestone were produced. Igneous activity in the TMC was synchronous with the Late Cretaceous sedimentation. TMC classically includes three successive phases

spanning over 30 Ma (Drovenik et al., 1960; Dimitrijević et al., 1976; Janković et al., 2002). However, new interpretations proposed only two phases (Milovanović et al., 2005; Banješević, 2010). Phase I rocks deposited in the eastern TMC during the Late Turonian to Santonian (von Quadt et al., 2002; Clark and Urllich, 2004), and resulted in shallow-marine hornblende \pm biotite \pm pyroxene and esite ("Timocites") to trachyandesite (Clark and Ullrich, 2004; Milovanović et al., 2005; Banješević, 2010) that built to form large stratovolcanoes dominated by volcaniclastic rocks. Sub-volcanic to hypabyssal diorite and quartzdiorite were emplaced simultaneously, resulting in skarn and hornfels alteration of the country rocks. Intrusion was emplaced and have associated porphyry and epithermal-style mineralization (e.g., Bor and Veliki Krivelj Cu-Au deposits) (Zimmerman et al., 2008). Phase II commenced during the Campanian in the central and western TMC and was synchronous with the cessation of phase I in the east (Banješević, 2010). Phase II and esite-basalt and minor and esite magmatism are more voluminous and widespread than phase I. Phase II first occurred in the sub-aquatic environment and was followed with sub-areal activity (Banješević, 2005; Milovanović et al., 2005; Banješević, 2010). Phase II included Middle Campanian monzonite, monzodiorite, diorite, granodiorite, quartz-diorite and their porphyritic varieties. The most substantial intrusion - Potaj Čuka monzonite outcrops on over $\sim 20 \text{ km}^2$. Adjacent sedimentary country rocks are thermally altered to form skarn, hornfels, and marble (Milovanović et al., 2005). Several Cu-(Au) porphyry and epithermal deposits formed during this stage (e.g., Lipa, Čoka Kuruga, Valja Strž). Igneous activity in the TMC terminated with the emplacement of small, shallow latite dikes and sills in the western part of the complex (Banješević 2010, Zimmerman et al., 2008).

Igneous rocks of the TMC dominantly have a calc-alkaline composition (Ciobanu et al., 2002; Janković et al. 2002; Kolb et al., 2012). Geochronological data suggests that Late Cretaceous magmatic activity in the TMC lasted for approximately 13 million years, from 90 Ma to 77 Ma, with a magmatic front moving from east to west, approaching the subduction zone (Banješević, 2001; Ciobanu et al., 2002; von Quadt et al., 2002; Clark and Ullrich, 2004; Kolb et al., 2012; Tosdal, 2012). Termination of Timok igneous activity in the Late Campanian corresponds with Laramide phase of Alpine orogeny. Carbonate reef sedimentation in the central and southern parts of the TMC and coarse-grained, regressive clastic deposition in the eastern parts followed. The gradual uplifting of the area led to a complete cessation of continual marine sedimentation by the end of the Cretaceous (Banješević, 2006). The youngest rocks within the TMC area are lacustrine and localized shallow-marine Tertiary and terrigenous Quaternary sediments (Dimitrijević et al., 1976).

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Formation of the TMC and its subsequent modification into present-day elongate lozenge-shape are the consequences of a complex tectonic evolution and multiple compressional and extensional deformation episodes. Proterozoic to Early Paleozoic basement rocks underwent Late Paleozoic Variscan orogeny deformation during which deep-seated N- and NNW-trending faults such as Bor-Brestovac-Tupižnica, Todorova Reka, and Blagojev Kamen-Rudaria faults were initiated. These structures were repeatedly reactivated during the Late Mesozoic Alpine orogeny (Knaak et al., 2014).

Tectonic evolution of the TMC is subject to different interpretations including formation in the extensional or transtensional regime associated with the subduction slab roll back (Zimmerman et al., 2008; Kolb et al., 2012). The lozenge-shaped geometry of the TMC, as well as the presence of the arcparallel faults across the complex, suggest a model where the crustal-scale dextral transtention and the opening of the pull-apart basin are the main controls of the TMC emplacement (Drew, 2005; Knaak et al., 2016). The orientation of the porphyry clusters and the Potaj Čuka monzonite within TMC indicates the importance of the intermittent reactivations of the Paleozoic basement structures (Knaak et al., 2014). Furthermore, fault reactivation facilitated the infiltration of hydrothermal mineralization fluids into the Mesozoic sedimentary rocks. The TMC obtained its present-day shape in the Tertiary due to post-collisional escape tectonics accommodated by oroclinal bending of the Dacia block around the tip of the Moesian platform (Schmid et al., 2008; Knaak et al., 2014), and the segment containing TMC rotated ~30° clockwise. The rotation caused a dextral displacement more than 100 km along major strike-slip fault systems, East Serbo-Macedonian on the west and Timok and Cerna on the east (Knaak et al., 2016). During late phase oroclinal bending in the Early Miocene, orogen-parallel extension produced E-W striking normal faults. Such structures played a significant role in the preservation of the Bigar Hill deposit, within the graben. A simplified tectonic map of the TMC is shown in Figure 2.4.



Figure 2.4: Simplified tectonic map of the TMC with the position of mineral deposits and major deposits trends (modified from Knaak et al., 2016).

2.2.3 Metallogeny of the TMC

Prospecting for gold and copper in the region date back to the Bronze Age. In Roman times, people mined gold from placer deposits as well as from primary quartz veins down to 20 to 30 m deep in underground adits. Modern exploration and mining have been successful in this region for over 100 years (Janković et al., 2002).

Four temporally and spatially distinct metallogenic trends within the TMC distinguished based on the mineralization type include from east to west: (1) Bor-Veliki Krivelj-Majdanpek Cu-Au porphyry, high-sulfidation trend; (2) Kuruga high-sulfidation Cu-Au trend; (3) Western porphyry trend; and (4) sediment-hosted disseminated gold trend on the northwestern margin of the TMC (Knaak et al., 2016). The fourth sector constitutes a newly recognized mineralization type in Serbia (Figure 2.4).

2.2.3.1 Bor - Veliki Krivelj – Majdanpek Cu-Au Porphyry, High-Sulfidation Trend

The easternmost trend comprises several porphyry deposits, including the world-class Majdanpek, Veliki Krivelj, Borska Reka and Cerovo deposits as well as the recently discovered Čukaru Peki deposit. Some porphyry deposits occur with massive sulfide ores, e.g., Bor and Čukaru Peki deposits. Mineralization is typically hosted by hydrothermally-altered coherent and volcaniclastic hornblende-biotite andesite that have been intruded by porphyritic dikes of granodioritic, quartz-dioritic to dioritic composition (Janković, 1990; Koželj, 1999). The porphyry ore bodies consist of stockwork, stockwork-disseminated and disseminated sulfide mineralization. The mineral paragenesis comprises pyrite and chalcopyrite as dominant sulfide phases. Molybdenite is a minor phase, sporadically containing anomalously high Re concentrations (up to 3,000 ppm in Majdanpek). The copper grade of most of the deposits is up to 0.8% Cu. Gold occurs in pyrite and chalcopyrite, with typical grades of <0.25 ppm. Molybdenum grade is usually <150 ppm (Janković, 1990). Massive sulfide ore in telescoping porphyry deposits is mainly composed of chalcocite, covellite, and enargite with 3-6% Cu and 1-3 ppm Au.

Zimmerman et al. (2008) constrained the mineralization ages of these deposits to 87.9 - 83.4 Ma, using Re-Os molybdenite technique. The mineralization age at the easternmost Veliki Krivelj deposit is the oldest (87.9 ± 0.5 Ma), while the Majdanpek mineralization is the youngest (83.8 ± 0.5 to 83.4 ± 0.5 Ma). The mineralization age at Bor is between 86.2 ± 0.5 and 85.9 ± 0.4 Ma. The mineralization ages coincide with the end phase of Late Turonian-Santonian magmatic activity (phase I) of the TMC.

2.2.3.2 Kuruga High-Sulfidation Cu-Au Trend

The Kuruga high-sulfidation Cu-Au trend of the TMC includes the economically important Čoka Kuruga, and Lipa deposits. Deposits formed within hydrothermally-altered hornblende-phyric andesite. Mineralization occurs as massive, stockwork, disseminated, transitional stockwork-disseminated, local veins and veinlets (Janković, 1990). Pyrite is the most abundant mineral in these epithermal deposits, while enargite is the primary source of copper (Koželj, 1999). Gold is a significant ore constituent and is present in pyrite, copper-bearing sulfides, barite or quartz. The diorite porphyry beneath the Čoka Kuruga deposit has a U-Pb zircon age of 83.6 ± 0.4 Ma (Tosdal, 2012), consistent with the second magmatic phase of the TMC (phase II).

2.2.3.3 Western Porphyry Trend

The western porphyry trend is at the western end of the TMC and contains Au and Cu-Au deposits and occurrences along the northeastern, eastern and southern edges of the Potaj Čuka monzonite pluton. The most significant porphyry deposits are Valja Strž, Dumitru Potok, Kraku Riđi, Crna Reka (all Cu-Au deposits) and Čoka Rakita (the only Au-only bearing system). Dikes and sills associated with the deposits have mainly dioritic but also quartz-dioritic and granodioritic compositions and intrude andesite and andesitic agglomerates, breccia and epiclastic rocks of phase II. Mineralization has low to moderate Cu-Au or Au grades and occurs in quartz and quartz-pyrite stockwork veins. Pyrite and chalcopyrite are the major sulfide minerals, while molybdenite, bornite, galena, and sphalerite are present in the less significant quantities. Au occurs with pyrite and chalcopyrite; its grade is higher where these minerals form dense stockwork systems, particularly within the potassic core. In the Au-only deposit, gold is associated with pyrite and alloyed with silver (Avala Resources Ltd., 2010-2014).

2.2.3.4 The Sediment-hosted Disseminated Gold Trend

The westernmost mineralization trend is located on the NW margin of the TMC and contains three Au deposits: Bigar Hill, Korkan, and Kraku Pešter. The Bigar Hill deposit is positioned north of the Potaj Čuka pluton at the margin of the thermal contact aureole. The Korkan deposit is located farther north from Bigar Hill, and the Kraku Pešter deposit is within the thermal aureole of the Potaj Čuka monzonite pluton at the northwestern tip of the intrusion. Au mineralization at the Bigar Hill and Korkan deposits are dominantly in the Cretaceous sedimentary sequence. At the Kraku Pešter deposit, mineralization is in brittle deformed rocks composed of sulfidized fault breccia formed in both thermally metamorphosed sedimentary rocks and monzonite (Avala Resources, 2014). Late Cretaceous magmatic features, including porphyry Cu-Au deposit clusters (Kraku Riđi, Dumitru Potok, Čoka Rakita, Valja Strž) occur in proximity to SHDG deposits, a few kilometers to the east within the TMC (Figure 2.5). Geologic map of the Bigar Hill area is shown in Figure 2.6.

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Figure 2.5: Geologic map of the NW part of the TMC, with the position of the SHDG deposits (Bigar Hill, Korkan and Kraku Pešter), adjacent porphyry Cu-Au deposits (Kraku Riđi, Dumitru Potok, Čoka Rakita, Valja Strž) and Potaj Čuka monzonite pluton. Geolines from Avala Resources, 2012.



Figure 2.6: Geologic map of the Bigar Hill area with the locations of drill holes sampled for this study, including the holes from non-mineralized prospects Korkan West and Korkan South (inset, right). Grey line outlines 0.5 ppm Au mineralization shell. Geolines from Avala Resources, 2012.

2.3 Host Rock Lithology and Stratigraphic Sequence

Rock descriptions for the Bigar Hill lithostratigraphy are based on drill core logging, petrographic studies on selected thin sections and geochemical data. The stratigraphic column of the lithologies for the Bigar Hill area is in Figure 2.7. The main rock units are described in details below.

2.3.1 Paleozoic Metamorphic Rocks (MPH)

The Paleozoic crystalline basement is the oldest unit (Dimitrijević et al., 1970). Basement occurs immediately west and southwest of Bigar Hill and does not outcrop, but several drill holes intersected it. The unit is truncated in the east by steeply-dipping, normal faults, that juxtapose the unit against younger, Jurassic limestone. The depth of the transgressional basement and limestone contact is uncertain but must be >300 m. The unit consists of Paleozoic phyllites and subordinate meta-sedimentary sequence composed of sandstone, shale, and conglomerate. When fresh, phyllite is

dominantly grey to black, locally green, but in the weathering conditions it obtained tan or red color. Main components are fine-grained mica minerals, quartz, feldspar, and chlorite. Phyllite is foliated with the parallel, flat or wavy alignment of muscovite or sericite.



Figure 2.7: Stratigraphic column of the Bigar Hill deposit area.



Figure 2.8: Bigar Hill lithologic units: (a) Jurassic (Tithonian) limestone; (b) Early Cretaceous "dirty" limestone with black chert; (c) Basal breccia with limestone fragments and very fine-grained groundmass rich in pyrite or oxidized; (d) Alternation of siltstone/mudstone with fine-grained sandstone; (e) S1 carbonate sandstone with stylolite seams parallel or perpendicular to bedding; (f) S2 volcanic detritus-rich sandstone to granulite; (g) Marl with laminas of organic matter; (h) Hornblende-plagioclase phyric andesite intruded as sill in marl.

2.3.2 Late Jurassic Limestone (JLS)

The Late Jurassic carbonate sequence has a large areal extent but does not outcrop within the deposit domain. However, the carbonate sequence has an erosional exposure to the north and south of the deposit which is buried along E- trending faults. Drill holes indicate the thickness of the unit to be >300 m. Except for tectonic contact with older basement unit, registered in the southwestern part of the deposit, the character of the depositional contact between the two units is uncertain. Regionally, the deposition of carbonate sequence was preceded by transgressive sedimentation of basal conglomerate

and sandstone (Dimitrijević et al., 1970; Banješević, 2006). The Late Jurassic sequence encompasses the Oxford-Kimmeridgian and Tithonian carbonate rocks whose age is defined paleontologically (Dimitrijević et al., 1970; 1976). Due to their compositional and textural similarities as well as the negligible importance as mineralization host rocks these two units are grouped and studied together. The Oxfordian-Kimmeridgian carbonate rocks dominantly contain micritic limestone, and subordinately dolomite and limestone-dolomite. Rocks are grey to pink, with chert nodules of similar color. The conformably overlying Tithonian unit is dominantly composed of massive or bedded reef limestone that varies from white, light gray, yellow to pink (Figure 2.8a). Limestone with coarse-grained sparite cement dominates over the fine-grained micritic-cemented limestone. Depending on the different components such as carbonate fragments (intraclasts), fossils or pellets, the Tithonian limestone occurs as intrasparite, intrabiosparite, pelsparite and pelbiosparite (Folk, 1959; Vasić, 2012). X-ray powder diffraction indicates that the Tithonian limestone is pure, with CaCO₃ content from 97-100% (Vasić, 2012). Non-carbonate constituents include clay minerals and organic matter. Non-carbonate components, as well as terrigenous quartz, pyrite or Fe-hydroxides, are present in stylolite seams, which are characteristic of these rocks.

2.3.3 Early Cretaceous Limestone (KLS)

The Early Cretaceous limestone underlies the Bigar Hill deposit and extends regionally. The unit is up to 100 m thick and lies unconformably on top of Jurassic carbonate rocks. Regionally, the KLS contains Valangian-Hauterivian and Barremian-Aptian limestones dated by fossil fauna (Dimitrijević et al., 1970; 1976). The older, Valanginian-Hauterivian or "dirty" limestone comprises bedded, black to grey limestone (Figure 2.8b). Micritic limestone dominates, such as biomicrite and intrabiomicrite, while dolomite has a minor abundance. Layers rich in organic and very fine-grained clastic material are black and very prominent, several centimeters to several tens of meters thick. CaCO₃ content in limestone ranges from 70-97% (Vasić, 2012). Geochemical differences between the Jurassic and Cretaceous limestone is in figure 2.9. Chert concretions and nodules are black, dark gray or brown, ranges from cm to dm size, and are characteristic features of this unit. Stylolite seams contain organic matter, clay or very fine-grained pyrite. A younger Barremian-Aptian limestone is a significant component of the Early Cretaceous carbonate sequence in the wider TMC region forming several hundred-meter-thick packages (Dimitrijević, 1976), however it occurs only in the eastern part of the Bigar Hill and is otherwise eroded, or present as fragments in the overlying breccia from the younger, clastic S1 unit. Barremian-Aptian

limestone is grey to light grey, massive to bedded, and highly stylolitized. It contains sparite varieties such as intrabiosparite and biosparite.

Both Jurassic and Cretaceous limestone were exposed to karstification. Dissolution primarily affected their respective upper unconformities or developed along fault and fracture zones or bedding planes. Karstification process increases porosity and permeability of the otherwise compact limestones with tightly packed components.



Figure 2.9: Background values for major and immobile elements in non-altered JLS (215 samples) and KLS (466 samples) with Au<0.01ppm; Avala Resources data set.

2.3.4 Carbonate-siliciclastic unit (S1)

The carbonate-siliciclastic unit, informally named the S1, is a basal clastic sequence continuously deposited within the Bigar Hill area. It is up to 200 m thick. The S1 was deposited unconformably on the limestone and commenced with the Albian transgression. The Albian age of the unit is determined paleontologically (Dimitrijević, 1976). The S1 outcrops in the western area of the deposit. This unit is divided into three sub-units: (1) *basal breccia (BBX)*, (2) *siltstone to mudstone member (IB)*, and dominant (3) *calcareous sandstone to sandy limestone member (S1)*.

Basal breccia (BBX) forms the base of the Albian S1 sequence. Breccia is laterally discontinuous and is not present along the entire basal contact with the underlying limestone. The thickness of this sub-unit varies from a few meters to approximately 50 meters. It is the thickest in the central part of the deposit, and it is not formed in the northwestern part. The breccia is heterogeneous and poorly sorted, includes both matrix- and clast-dominated facies (Figure 2.8c). It comprises fragments of the bioclastic Barremian-Aptian limestone and, to a lesser extent, of the older, Valenginian-Hauterivian limestone, with quartz and other metamorphic rock-derived pebbles (e.g., schists, gneiss) embedded in a carbonate cement. Limestone clasts have a wide variation in size, from mm-scale pebbles to decimeter-scale cobbles and boulders which are primarily angular or weakly rounded. Well-rounded quartzite pebbles of various size originate from the crystalline basement. The breccia matrix is heterogeneous and highly variable in both grain-size and composition. It includes fine- to very coarse-grained sandy, as well as sandy-gravel to gravel or silt fraction.

Interbedded siltstone to mudstone member (IB) lies unconformably on top of the KLS, BBX, or in the form of a laterally-variable, discontinuous lens within or below the S1 sandstone. Thickness ranges from a few centimeters to 30 meters, irregularly distributed within the deposit stratigraphy. The IB sub-unit is not developed in the northwestern part of the deposit stratigraphy and generally is very thin in the northern area. The stratigraphic transition to the upper S1 sandstone member is gradational, with decreasing silty and increasing sandy fraction. The most abundant lithologies are black, laminated siltstone or mudstone that alternate with fine- to medium-grained calcareous sandstone (Figure 2.8d). Breccia bodies with limestone fragments in siltstone matrix occur locally. The IB member is composed of terrigenous quartz grains and phyllosilicate minerals, predominantly sericite and muscovite, with lesser biotite and chlorite. Phyllosilicate laths are sub-parallel with the lamination planes. Coarser interbeds contain more carbonate cement than siltstone or mudstone; organic matter and diagenetic pyrite are abundant in fine-grained interbeds. Diagenetic pyrite occurs either as individual grains or as several mm-scale accumulations. The IB member was locally affected by the soft sediment deformations.

The *S1 calcareous sandstone-sandy limestone* is the most abundant member within the S1 sequence, laterally continuous but with variable thickness, ranging from 30 to 150 m going from southeast to northwest. The S1 sub-unit lies unconformably over the Cretaceous limestone, basal breccia (BBX) or has a gradational transition to IB lenses. The rocks vary from well bedded to locally cross-bedded sandy limestone, to calcareous sandstone (Figure 2.8e). The main constituents are: terrigenous material including quartz and other fragments of metamorphic rocks, white mica, also carbonate components -

limestone fragments and carbonate fossils. Detrital material is cemented by calcite, or to a lesser extent by dolomite. Terrigenous components vary in granulometry from fine- to medium-grained size. Coarsegrained clastic material occurs locally. Stylolites are a notable feature of the S1 sub-unit, and in addition to pyrite, also contains clay, organic matter, or iron hydroxides. They occur as seams that are (sub-) parallel to bedding planes and likely formed under lithostatic pressure dissolution. They also occur oblique to the bedding planes and likely formed during deformation related stress (Vasić, 2012).

2.3.5 Carbonate and volcanic detritus-rich siliciclastic unit (S2)

The volcanic detritus-rich, calcareous siliciclastic unit, informally named S2, has a continual distribution within the Bigar Hill stratigraphic sequence. Unit S2 is 15 to 70 m thick sequence deposited unconformably on the erosional surface of the S1. The S2 outcrops in the western area of the deposit. The Late Cretaceous age of the unit is indirectly determined by U-Pb dating of detrital zircons done for this study. The S2 unit is composed of reddish, green or light grey, bedded, coarse- to medium-grained sandstone. The conglomerate occurs locally as basal beds up to 5 meters thick (Figure 2.8f). Sandstone and conglomerate typically comprise dominant quartz, detrital volcanic fragments of andesite and its groundmass or phenocrysts (plagioclase and hornblende), limestone fragments, hematite, and subordinate fragments of quartzite, schists, re-deposited S2 sandstone or detrital phyllosilicates (muscovite, clay minerals). Detrital magnetite is locally concentrated in the form of the thin laminae. Cement is mainly composed of calcite or, rarely of dolomite. Detrital pyrite is present within the carbonate cement. Chapter 3 provides a more detailed characterization of the S1 and S2 sandstones.

2.3.6 Marl (SMR)

Marl (SMR) conformably overlies S2 unit or alternates with it within the transitional zone. The overall unit thickness ranges from a few meters to 150 m. Sub-volcanic andesitic sill intruded and caused weak thermal alteration on marl. In the central and partly eastern area of the deposit, marl above the andesite is eroded. Santonian age of the unit is defined by paleontological data (Dimitrijević et al., 1970; 1976; Vasić, 2012). Marl is finely-laminated, light grey, light green, or red with laminations differing in color, thickness, and composition. The main constituents are terrigenous or calcareous (Figure 2.8g). Terrigenous components are part of clayey, silty or very fine-grained sandy fraction. Quartz is the most abundant constituent of the sandy fraction while volcanic and metamorphic rock fragments or minerals (i.e., plagioclase) are represented to a lesser degree. Phyllosilicate minerals, particularly white mica abundance is notable; their general orientation is (sub-) parallel to the lamination planes. Carbonate materials are with debris and carbonate cement. X-ray diffraction results indicate that CaCO₃ content varies from 35 to 65% (Vasić, 2012).

2.3.7 Andesite (VOL)

Andesitic sill (VOL) is a sub-volcanic intrusion that cuts the marl unit. Sill intruded towards west within the eastern section of the deposit. Andesite is exposed over the area of \sim 300 x 100 m at the top of the Bigar Hill, due to the erosion of marl. Locally, in the southeastern section, lower intrusive contact is with the S2 unit. Andesite is dark grey to grey-green, medium-grained, and porphyritic, with amphibole (hornblende) \geq intermediate plagioclase (andesine) phenocrysts (Figure 2.8h). Accessory minerals include quartz (up to 2%), apatite, zircon, Fe-Ti oxide, and Fe-sulfide. Andesite contains veins of calcite, or rarely gypsum or zeolite.

2.3.8 Other Intrusive and accompanying Metamorphic Rocks

Several, few meters wide diorite dikes (GDI) cut the deeper parts of limestone, below the deposit. The dikes occur along the NW and NE trends. The dikes are typically strongly clay altered. Locally, the host rocks are altered to marble (MLS) or calc-silicate rocks (MSC) due to the thermal or metasomatic impact of the small dikes. Kraku Riđi, Čoka Rakita, and Dumitru Potok swarms of hornblende-plagioclase-phyric diorite porphyry are proximal to the deposit, located 1-5 km to the east or southeast (Figure 2.5). Porphyry clusters are aligned along NW to N trends (Knaak et al., 2012).

2.4 Hydrothermal Alteration

Circulating hydrothermal fluids introduced chemical, thermodynamic and physical changes to the host rocks that resulted in the degradation of primary minerals, the formation of new alteration minerals and the deposition of gold. Unlike high-temperature hydrothermal deposits, alteration haloes around the low-temperature Bigar Hill deposit are subtle, often coinciding with the gold mineralization. Dominant types of host rock alteration at the Bigar Hill include carbonate dissolution which results in decarbonatization, silica addition (silicification), clay alteration of primary silicate minerals, and sulfidation which accompanied gold deposition.

2.4.1 Carbonate Dissolution

Carbonate dissolution or decarbonatization is a typical alteration feature of Carlin-type deposits (e.g., Radtke et al., 1972; Stenger et al., 1998; Cail and Cline, 2001). It is a process of partial to complete dissolution and redistribution of the host rock carbonate components, primarily calcite cement, by acidic fluids. Fluid acidity, temperature and the degree of fluid-rock interaction control the extent of alteration (Cline et al., 2005). Carbonate dissolution causes a wall rock volume decrease and the formation of secondary porosity and permeability that leads to the secondary enrichment of insoluble minerals such as quartz, clay minerals, and organic matter.

Drill core samples subjected to hydrochloric acid reaction tests, along with petrographic analyses, indicate that the most intensive calcite dissolution affected rocks at the immediate contact of the S1 and S2 sedimentary units (Figure 2.10). Dissolved carbonate material was redistributed and precipitated in fractures within and around the primary zone of intensive alteration. Calcite veins appear in stockworks or as individual veins, with thickness up to several tens of cm, and increase towards the mineralization. Decarbonatization occurs with the extensive hydrothermal pyrite deposition in high-grade gold zones. Carbonate dissolution zones also, to a various degree, contain the products of clay alteration and silicification.



Figure 2.10: Carbonate dissolution in mineralized rocks: (a) hand sample with complete carbonate cement removal from the S1 sandstone, showing secondary porosity; this sample also exhibits silica addition; (b) hand sample of the S2 sandstone that underwent complete carbonate dissolution, with quartz grain framework and hydrothermal pyrite remaining; (c) transmitted light photomicrograph of completely dissolved sparry calcite cement, with quartz (qz) and clay minerals (cy) remaining in S1 sandstone; (d) partially dissolved sparry calcite cement (ca) of basal breccia (outlined with a green line).

2.4.2 Silicification

Silica addition (silicification) is a typical but not ubiquitous alteration feature of the low-temperature SHDG deposits. In Carlin-type deposits it is manifested as jasperoid or fine-grained, drusy quartz lining vugs; ore-stage quartz veins are relatively uncommon (Cline et al. 2005).



Figure 2.11: Silica replacement: (a) and (b) hand sample and the transmitted light photomicrograph showing the replacement of carbonate cement or fragments with microcrystalline silica (si cement) in sandstone from the S1/S2 contact zone; (c) and (d) hand sample and the transmitted light photomicrograph of cryptocrystalline silica spatially associated with clay minerals (cy) and pyrite (py) in completely decarbonatized S2 sandstone.

At the Bigar Hill, low-intensity silicification is spatially discontinuous and not observed outside of the high-grade gold zones. Silica addition was challenging to identify microscopically due to the prominence of other primary quartz minerals, quartzite fragments and diagenetic silica occurrences in sedimentary host rocks. Some of the non-hydrothermal silica occurrences that complicated the identification of silicification include chalcedony in the kidney-shaped or irregular form within microfossil chambers, also chalcedony irregularly present within carbonate cement. Their origin is assumed to be organogenic or diagenetic (Vasić, 2012). Silicification related to hydrothermal alteration includes cryptocrystalline

quartz replacing calcite cement or carbonate fragments such as fossils, limestone or carbonate mud clasts (Figure 2.11). In intensely altered rocks, hydrothermal silica co-exists with other alteration minerals as a fill in secondary pores created by carbonate dissolution. In these highly mineralized zones, very fine-grained silica intergrows with hydrothermal illite and pyrite. Quartz veins are uncommon at the Bigar Hill.

2.4.3 Clay Alteration

The interaction between circulating hydrothermal fluids and the alumino-silicate minerals in Bigar Hill host rocks produced a clay minerals assemblage. This argillic alteration is typical in the andesitic sill, diorite dikes, or in volcanic detritus-rich S2 siliciclastic rocks (Figure 2.12). In the andesite, the degree of clay alteration depends on the cohesion and permeability of the rocks. Pervasive clay alteration is limited to zones of secondary permeability along fault and fracture zones. Clay alteration in calcareous S1 sediments and limestone is low due to rare primary alumino-silicate minerals.



Figure 2.12: Clay alteration of alumino-silicate minerals: (a) and (b) hand sample and the transmitted light photomicrograph of clay alteration (cy) in andesite with relicts of plagioclase (pk); (c) and (d) hand sample and the transmitted light photomicrograph of clay alteration (cy) in S2 sandstone, showing a visibly altered volcanic fragment with remnant hornblende (hb) and plagioclase (pk).

2.4.3.1 Clay Identification

Clay minerals were identified using short-wave infrared spectroscopy (SWIR) on 302 drill-core samples (Appendix C). Samples were collected from Bigar Hill and also from the non-mineralized Korkan West and Korkan South prospects, which are located near Bigar Hill and share the same stratigraphy. Drill hole collars for analyzed samples are shown in Figure 2.6. Barren prospects were also sampled to establish the background clay mineralogy (i.e., clays that have not resulted from hydrothermal alteration). Samples are collected from each lithologic unit and in the case of the Bigar Hill from both nonmineralized and mineralized rocks.

SWIR spectra reveal that illite is the dominant clay species at the Bigar Hill. Other clays, in various proportions, include kaolinite and montmorillonite, with infrequent dickite, nacrite, halloysite, and palygorskite. The main clay species in non-mineralized samples (<0.1 g/t Au) from Bigar Hill are illite, kaolinite, and montmorillonite. In mineralized samples (>0.1 g.t Au), illite dominates, with or without minor kaolinite (Figure 2.13). Montmorillonite is present in samples with low grade (0.1 – 1 g/t Au) but is absent in highly mineralized samples (>1 g/t Au). Detrital muscovite or sericite occurs in non- or weakly altered siliciclastic rocks. Samples from the Korkan West and Korkan South prospects contain montmorillonite, illite+montmorillonite and illite. At these prospects, the montmorillonite proportion is higher overall than at Bigar Hill. Other minerals such as kaolinite, palygorskite or muscovite are sparse and isolated.



Figure 2.13: General element ratio diagram indicates the correlation of gold mineralization with illite alteration; Correlation is based on approximately 4,000 samples from the S2 unit and andesite; Avala Resources data set.

2.4.3.2 Illite Crystallinity as a Mineralization Vectoring Parameter

Hydrothermally-formed clay minerals and their variable characteristics reflect changes in the alteration system of the host rocks. For example, the progression from smectite (montmorillonite) to illite-smectite and illite is generally attributed to increasing temperature (Hofstra and Cline, 2000) because illite crystallinity is higher temperature-dependent (Ji, Browne, 2000). Illite can thus be used as a vector towards mineralization by indicating pathways of higher temperature fluid movement. The illite crystallinity index is defined as a ratio of the depths of 2200 nm and 1900 nm absorption features in the mineral SWIR spectra, as calculated using The Spectral Geologist© (TSG) interpretative software on data obtained with the TerraSpec[®] analytical spectral device.

The crystallinity index for illite from the Korkan West and Korkan South prospects is relatively low, up to 0.6. Illite from the Bigar Hill exhibits a wide range of index values, from 0.1 up to 2.2. In non-mineralized samples (<0.1 g/t Au) crystallinity index varies from 0.1 to 2.2 and in mineralized samples (>0.1 g/t Au) it ranges from 0.3 to 2.2.

Although the increase in crystallinity index with gold mineralization is subtle, it shows higher values in relation to non-mineralized prospects (Figures 2.14 and 2.15). The link between the increasing illite crystallinity index with gold grades emphasizes the hydrothermal origin of illite and its formation as an alteration product of feldspar, muscovite or montmorillonite. However, particularly in clastic rocks, illite could also be the product of supergene or diagenetic processes or could have a detrital origin (Ruiz Cruz, 2006). The highest crystallinity index values (>2) might be related to high-temperature hydrothermal processes and the increasing illite crystallinity with increasing temperature (Gharrabi et al., 1998). However, the more extreme high index values are likely associated with detrital muscovite or illite-muscovite transition varieties likely originating from the Proterozoic metamorphic complex that, in addition to limestone and andesite rocks, is the main protolith for clastic rock units.



Figure 2.14: Box plots representation of the illite crystallinity index ranges depending on the gold grade.



Figure 2.15: Box plots of illite crystallinity and gold grade ranges in samples from drill holes from the Bigar Hill ore and distal, non-mineralized zone, and distal, non-mineralized Korkan West and Korkan South areas. Drill hole locations are shown in Figure 2.6.

2.4.4 Sulfidation and Gold Mineralization

Pyrite is the dominant sulfide mineral in the deposit. Pyrite occurs in the form of individual grains, from 1 mm to couple of μ m in diameter, to aggregates disseminated throughout host rock. Pyrite morphology varies from euhedral to anhedral, often porous or framboidal. Pre-ore pyrite is coarse-grained, of brassy

color and is mostly in the S2 sandstone. Fine-grained diagenetic pyrite is in organic-rich stratigraphic units, such as marl or mudstone.



Figure 2.16: Photomicrographs of pyrite morphology in mineralized rocks: (a) pyrite replacing hornblende in altered andesite; (b) pyrite associated with clay (illite?) alteration in the S2 sandstone; (c) pyrite disseminated in the S2 sandstone, replacing altered volcanic fragments; (d) distribution of pyrite of different grain sizes in decarbonatized S1 sandstone; (e) pyrite formed on the calcite from the S1 sandstone cement; (f) abundant pyrite in the fine-grained BBX breccia matrix.

Pyrite is abundant in mineralized zones, but its µm size and dark sooty color make it difficult to recognize it in hand samples. In highly mineralized domains, sulfide minerals are typically concentrated

with hydrothermal illite in secondary pore spaces that formed through carbonate dissolution. Thin sections show pyrite replacing sparry calcite or dolomite cement, Fe-bearing alumino-silicates such as hornblende (and its alteration product – chlorite), microfossils and carbonate mud fragments. Pyrite also occurs in stylolites, fractures, and micro-fractures in structurally deformed zones (Figure 2.16). Rarely, pyrite occurs within calcite veins.

Sulfidation reaction is the major mineralization mechanism (Hofstra and Cline 2000; Cline et al., 2005). Gold is "invisible," and present as structurally bound Au¹⁺ in the lattice of pyrite. Also, gold occurs as sub-µm to 50 µm inclusions within pyrite crystals, mainly as native gold, or rarely as electrum, kustellite or calaverite (Pačevski, 2012). In surficial weathering oxidized conditions, gold is in goethite formed on pyrite. Distribution of gold in pyrite and its oxide is shown in Figure 2.17. At Bigar Hill gold is part of the low-temperature metal assemblage which includes Sb, Tl, Hg, Te and As, similar to most Carlin-type deposits (e.g., Stenger et al., 1998; Hofstra and Cline, 2000; Muntean et al., 2011). There is a moderate correlation between Au and Se, Ag and W. Elements enriched with gold do not form economically interesting concentrations or minerals but represent trace level pathfinder elements.



Figure 2.17: Scatter plot of Fe vs. S from the Bigar Hill samples with Au content > 1ppm. Samples with gold hosted by pyrite are plotted near the x=y line (1 to 1 ratio corresponds to the ratio of Fe and S in pyrite). Samples with gold hosted by goethite are aligned along the y=0 line. Avala Resources data set.

2.4.4.1 Metal distribution on the Bigar Hill

The spatial distribution of gold, its correlation with the other pathfinder elements, and their distribution within Bigar Hill was evaluated using data from the geochemical database from Avala Resources Ltd. The database comprises data for approximately 50,000 1 m samples from 87 diamond and 125 reverse circulations (RC) drill holes. Gold and sulfur concentrations were obtained from 1 m samples while 52 additional elements were analyzed on 5 m samples of the split core or RC chip samples. Samples were digested by aqua regia and analyzed by fire assay with atomic absorption spectrometry finish for gold grade determination, or by atomic absorption or inductively coupled plasma mass spectrometry for the other elements. Chapter 1 provided a detailed overview of the analytical process (Section 1.5.3).

The distribution of gold within the Bigar Hill deposit is complex; it occurs in all lithological environments in various quantities. However, gold is concentrated principally along two contact zones within the Cretaceous sedimentary rock sequence. The major mineralized horizon extends laterally along the contact between the S1 and overlying S2 unit, outcropping along the western part of the deposit and dipping towards the east. A discontinuous, lower gold-bearing horizon occurs along the unconformable contact between the Cretaceous (or Jurassic) limestone and overlying S1 calcareous siliciclastic unit, mainly where there is basal breccia in the S1 or karst features in limestone. Minor gold precipitation also occurs along steeply-dipping fault and fracture zones that cut through the deposit. Structurallycontrolled mineralization is in the otherwise barren andesite. Stylolite fractures in limestone and calcareous clastic rocks of the S1 are also favorable locations for gold concentration. Siltstone and mudstone from the IB sub-unit are generally poor host rocks, with sparse mineralization only in fault zones. Similarly, the marl, which is considered to be an aquiclude, may represent a "cap-rock" to the hydrothermal system and thus a poor mineralization host. Examples of mineralized rocks are shown in Figure 2.18, and geological cross-section illustrating the distribution of gold mineralization is shown in Figure 2.19.

At Bigar Hill, gold occurs along the two orthogonal mineralized trends, NW and NE (in map view). In cross-section, however, gold is not well distributed vertically across the section and is absent from some lithologic units. The highest grades in andesite are in the SE part of the deposit, along the NW-trend. Mineralization in marl and S2 extends along the NE direction, while the S1 unit host gold along both trends. Gold in limestone is primarily concentrated at the intersection of two trends, as well as in the SE part of the Bigar Hill.

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Figure 2.18: Mineralized rocks from the Bigar Hill deposit (samples from drill core): (a) "Dirty" Cretaceous limestone, with fractures filled with secondary calcite; (b) Karst formed on the top of the Cretaceous limestone, with secondary porosity resulting from the carbonate dissolution; (c) Basal breccia with pyrite rich fine-grained matrix; (d) Decarbonatized S1 sandstone; (e) S2 coarse-grained clastic rock, located just above the contact with the S1; exposed to carbonate dissolution, clay alteration and sulfidation; (f) Strongly clay altered S2 sandstone, with visible pyrite nests; (g) Strongly decarbonatized and oxidized S2 sandstone; (h) Strongly clay altered andesite with pyrite accumulations.

Trace metals are also concentrated along NW and NE trends. Prominent NW alignment of increased values of Bi, W, Pb, Zn, In, Cd, Se, Te occurs in limestone. In the upper, clastic units, the NE trend has elevated values of the low-temperature elemental association As, Hg, Tl, Sb, Te. In volcanic rocks,

anomalous concentrations of As, Sb, Te, and Ag occur with gold mineralization in the SE part of the NW trend.



Figure 2.19: NW-SE geological cross-section through the Bigar Hill deposit, with the 0.4 grade shell outline in black line.

CHAPTER 3 – STRATIGRAPHIC AND STRUCTURAL CONTROLS ON THE BIGAR HILL GOLD MINERALIZATION

3.1 Introduction

Gold mineralization distribution at Bigar Hill emphasizes the likely combined influences of structural and stratigraphic features. The geological architecture of the area encompasses:

(1) Carbonate sedimentary sequence, with domains of physical and chemical characteristics that favorably facilitated gold deposition, such as increased porosity and permeability, as well as high carbonate content and sufficient concentrations of reactive iron. These features enabled circulation of gold-bearing hydrothermal fluids and reactions between fluids and the host rocks;

(2) Structural framework with intersecting fault planes of varying significance, including first-order feeder faults that channeled Au-bearing fluids from the source region; second-order faults that provided pathways for fluids infiltration to favorable horizons; and post-mineral faults that changed the shape of the ore body.

3.2 Stratigraphic Control on Gold Distribution

The composition, textural characteristics of the gold-hosting rock units, and their depositional contact zones with each other all represent stratigraphic features that control the spatial distribution of gold mineralization. A detailed review of these features is provided below.

3.2.1 Petrographic Characterization of the S1 Sub-Unit and S2 Unit

The erosional contact zone between S1 and S2 units hosts the most continuous gold-bearing zone and also hosts the highest gold grades. Petrography of these units evaluated their textural and structural features and composition.

3.2.1.1 Sub-Unit S1 Characterization

The composition of the S1 sub-unit ranges from sandy limestone to carbonate sandstone. The constituents of these rocks are: (1) terrigenous clasts such as: quartz (5-75% of the rock), metamorphic lithoclasts, dominantly quartzite with lesser schists and gneiss (up to 5%), muscovite (up to 10% in finer-grained rocks); (2) allochemical clasts (up to 50% of the sediment), including bioclasts (remains of whole

or fragmented calcareous fossils such as algae, bryozoans, bivalves, foraminifera) and intraclasts (lumps of carbonate mud); and (3) carbonate cement, usually composed of very fine to very coarse-grained sparry calcite, seldom of dolomite; in a hydrothermally-altered rock, carbonate cement is dissolved, locally replaced with silica.

Sorting of clastic material in sandstone varies from poor to moderate. Terrigenous clasts have a wide range of shapes (dominantly spherical to sub-prismoidal) and different degree of roundness (usually sub-angular to sub-rounded). Clastic components are mainly medium to fine-grained (0.125 to 0.5 mm). Influxes of coarse-grained material produced relatively frequent but thin layers, up to several centimeters. Gravel and pebble-sized grains are sparse. Although sediments of different grain size alternate, the overall grain size in these rocks generally increase up section.

Depending on the abundance of terrigenous and carbonate material, sedimentary facies are classified as bio- to intra-biosparite and calcareous sandstone (Figure 3.1). Rocks with >50% of terrigenous components are sandstones, and >50% of calcite defines limestone. If the content of the sandy component is >10%, limestone is sandy. Visual identification of these lithotypes is a difficult task, but according to microscopic analysis, clastic varieties generally occur in the lower part of the S1 sub-unit. Samples from this part of the sub-unit contain below 35% of calcite and correspond to calcareous sandstone. In the samples from the upper part, calcite content exceeds 65% of calcite, which determines these rocks as sandy limestone (Vasić, 2012). Stylolite seams are abundant in the sandy limestone.



Figure 3.1: Lithotypes of the S1 clastic sub-unit: (a) carbonate sandstone with dominant quartz and terrigenous detritus and subordinate carbonate cement; (b) sandy limestone (intrabiosparite) with principal carbonate components, microfossils, carbonate mud lumps, and calcite cement; quartz in this facies is subordinate.

3.2.1.2 Unit S2 Characterization

The S2 unit is composed of conglomerate, sandstone-conglomerate transitional rocks, and sandstone which is predominant lithotype and represents approximately 90% of the unit (Figure 3.2). Sandstone composition is variable and, depending on the ratio of mineral or rock fragments, quartz and rock matrix, sub-litharenite, volcanic and plagioclase litharenite lithotypes are differentiated. Main forming constituents are: (1) terrigenous clasts: quartz (5-75% of the rock), fragments of andesite (5-60%), fragments of phenocrysts – plagioclase and hornblende (1-30%), metamorphic lithoclasts of quartzite, rarely schists or gneiss (up to 10%), re-deposited S2 sandstone and limestone fragments (up to 5%); detrital phyllosilicates – muscovite, sericite (up to 3%); magnetite; hematite; (2) allochemical clasts: bio-and intraclasts, similar as in a case of the S1 unit, but less abundant (up to 10%); (3) carbonate cement, less abundant than in S1 unit; mainly composed of very fine to very coarse-grained sparry calcite or rarely dolomite. In hydrothermally-altered rocks, carbonate cement is dissolved and locally replaced with silica.

Sorting of clastic material in the unit is poor to moderate. Similar to the S1 unit, terrigenous clasts are mainly spherical or sub-prismoidal and sub-angular to sub-rounded. The S2 sandstone has variable grain-size but is principally medium to coarse-grained. Grain size decreases up section. A conglomerate of the same composition as sandstone formed beds up to 5 m thick, mainly in the lower parts of the unit. Quartz and volcanic detritus are the major constituents. Quartz and carbonate material is dominant in the lower levels of the unit, while volcanic material prevails in the upper horizons. The transition between them is gradual.



Figure 3.2: Lithotypes of the S2 clastic unit: (a) litharenite with visibly altered phenocrysts of hornblende and plagioclase and minor calcite cement; (b) sub-litharenite from the lower level of the unit, with dominant quartz and carbonate cement, and subordinate volcanic detrital clasts.

3.2.2 Petrographic Analysis of Iron Precipitation

Combined alizarin red and potassium ferri-cyanide carbonate staining methods are used to determine the presence and distribution of the iron required to precipitate hydrothermal pyrite in calcareous clastic rocks by identifying the iron-bearing carbonates. The carbonate staining procedure is described in Chapter 1. Twenty-seven mineralized and non-mineralized slab samples from the S2 and S1 sandstone, and breccia from the Bigar Hill were stained to differentiate between calcite (red to pink), ferroan calcite (purple to royal blue) and ferroan dolomite (pale to turquoise blue). Staining affected cement, carbonate fragments and veins in sandstone and breccia (Figure 3.3). Slab surfaces mainly obtained uniform color, but different colorations also affected the various carbonate components – cement, clasts or veins.



Figure 3.3: Carbonate staining of rock slabs to identify iron-bearing carbonate minerals: (a) Ferroan calcite is the dominant component in mineralized S1 sandstone; (b) Ferroan calcite (f ca) is most abundant carbonate component in mineralized S1 sandstone, also minor calcite (ca) and dolomite (do) fragments; (c) Ferroan calcite (f ca) builds breccia cement; clasts are non-stained, most likely of dolomite composition, cut with calcite veins; (d) Mineralized breccia with calcite fragments cemented by ferroan carbonate.

All three types of stained rocks show the variability in the composition of carbonate components. Cement generally has a uniform character, whether it is composed of calcite, ferroan calcite or rarely ferroan dolomite. Clasts are of diverse composition, non-related with the composition of rock cement. Spatially close occurrences of fragments of all carbonate varieties are not uncommon. Carbonate veins are dominantly composed of calcite or rarely of ferroan calcite. Distribution of stained components indicates that the S1 sandstone contains more carbonate than the S2 sandstone which is richer in terrigenous components.

Mineralized rocks contain ferroan calcite or, rarely, dolomite. Both ferroan calcite and dolomite were also observed together with non-ferroan calcite. Non-mineralized rocks mostly contain non-ferroan calcite, or rarely, ferroan calcite.



Figure 3.4: Isocon diagram represents the mass transfer of components during the fluid-rock interaction. The diagram includes the samples from all the Bigar Hill lithologic units.

Study of mass transfer between non-altered and mineralized rocks during the fluid-rock interaction has been conducted using the data set from 59 samples processed by the total whole rock characterization. Isocon diagram (Gresens, 1967; Grant, 1986; Hofstra and Cline, 2000) was defined by immobile elements Zr, Hf, Nb, and Ti and it indicates that the iron is also an immobile component in the Bigar Hill stratigraphic units and its concentration remained the same during the fluid-rock interaction. Isocon diagram that represents the ratio of non-altered (Au<0.01 ppm) and mineralized rocks (Au>0.1 ppm) for all the stratigraphic units and andesite sill is in Figure 3.4. Isocon diagrams for mass transfer in limestone, andesite, S1, and S2 units are in Appendix D.

In the units where the iron is an immobile component, carbonate staining confirmed that the ferroan carbonates are the source of reactive iron necessary for hydrothermal sulfidation and associated gold precipitation. To determine the spatial distribution of facies with different iron content in carbonates, more systematic analysis is required.

3.2.3 Enhanced Weathering along Depositional Contacts

Within the lower auriferous horizon between limestone and overlying clastic units, gold mineralization occurs in basal breccia of the S1 unit, and in karstified zones near limestone upper unconformity. Breccia and karst features are only locally developed. Karst features in the upper limestone are variable and include favorable high porosity and permeability gold-hosting features such as collapse breccia, limestone dissolution features, and sinkholes that are filled with reactive clastic material.

The S2/S1 contact is unconformable as indicated by the S1 paleosurface weathering and erosion where rocks were fractured, brecciated and re-deposited. Physical weathering is evident in the deformed or broken laminae in not fully consolidated fine-grained clastic rocks.

Chemical weathering and the formation of an intermittent, red iron-weathering crust on the surface of the S1 is sporadic. Rare occurrences of hematite-rich, altered sandstone are developed to a depth of a few meters. The intermittent presence of the iron-rich crust likely reflects erosion and further transport, particularly since hematite fragments that may represent eroded and re-deposited crust are present in the overlying S2 unit. Combined chemical and physical weathering processes acting upon the S1 surface likely created a favorable zone for the circulation of hydrothermal fluids and gold precipitation by reducing rock stability and increasing porosity and permeability.

In contrast, oxidation along the S1/S2 contact zone in the western part of the deposit is linked to postmineralization weathering process. Iron-hydroxide formed in the reaction of meteoric water and atmospheric oxygen with Fe²⁺ from hydrothermal pyrite. Oxidation is pervasive, affecting the entire rock or is restricted to the fractures. Intense oxidation affected the part of the deposit where the S1/S2 contact was near the surface, where it was not covered with thick sequences of marl and andesitic sill.

3.3 Structural Control on Gold Distribution

On the heavily-vegetated surface in the Bigar Hill region, the identification of faults is difficult. Recognized and inferred faults, based on the data from the drill core, have N or E orientations and were observed on the deposit margins. However, the overall structural setting was uncertain. A new structural model was constructed from 2D and 3D spatial analysis of stratigraphic information from the extensive diamond and RC drilling data sets. Stratigraphic contacts, their orientations, and changes in unit thickness and the differing elevations of sedimentary unit contacts were the primary data sources for the model.

Stratigraphic information from the drill holes were integrated into a series of stacked sections (Figure 3.5). Since the general dip direction of the sedimentary rocks within the deposit was to the east, and thus most drill hole azimuths are to the west, stacked sections were made in the E-W direction. The distance between parallel sections ranged from 20 to 40 m. Following the 2D analyses, stacked section observations were incorporated into a Leapfrog[®] 3D model as guides for defining structural blocks.

Tracing the changes in thickness and orientation of contact surfaces between the lithologic units was applicable only to the sedimentary units. Importantly, processes and features apart from faulting that could change unit thicknesses were also considered. For example, the shape of a unit's lower bedding plane could depend on the shape of the upper surface of the underlying rock unit that may differ from the horizontal due to weathering or erosion. As well, primary depositional features and location within a depositional basin could also affect sedimentary unit thickness. Changes in thickness or orientation were used as the indicators of structural discontinuities if they could be traced with lateral continuity and through several sedimentary units. All fault indicators were observed in the drill core to confidently incorporate them into the model.

The most prominent changes in the elevation of the Jurassic limestone paleo-surface occur along Etrending, graben-forming faults, along which the entire block hosting the deposit dropped down. On the eastern edge of the deposit area, in a northerly direction, the dip of limestone and the overlying clastic units becomes significantly steeper (~40°) compared to the dip of sedimentary units in the west. This dip change occurs along a previously inferred fault on the margins of the deposit. Within the deposit area, calcareous clastic units had variable thicknesses, elevation, and bedding-plane orientations over short distances, but the magnitude of the dip changes was minor.

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Basal breccia from the S1 unit is not laterally continuous in the deposit area, varying considerably across short intervals. The thickest breccia (up to 50 m) occurs in the central part of the deposit. A less prominent breccia zones, with a thickness <30 m, occurs in the southeastern part of the deposit area, and as NE-elongated zone across the deposit. In the northwestern deposit area, breccia is thin (up to a few meters) or is not developed.

The S1 sub-unit is up to 150 m thick but highly variable. The most prominent feature is the NE-trending break in thickness that decreases from up to 150 m in the northwestern to approximately 30 m in the southeastern part of the deposit. Within the northwestern deposit area, there are numerous subtle changes in the upper surface dip. The elevation of the S1/S2 contact decreases towards NW. Changes in the S2 thickness are opposite to the S1 thickness changes. In the northwestern area of the deposit, the S2 unit is the thinnest, up to a few meters, thickening up to 70 m towards the southeast. Marl is completely, and the S2 unit is partly eroded in the western part of the deposit. Changes in marl's thickness are obscured by the intrusion of the andesitic sill.

Discontinuities in the thicknesses of sedimentary units and the position of their contact surfaces are traced across several additional faults. Newly inferred structures have four orientations: WNW (faults F1 and F3), NE (faults F4, F5, and F6), NNW (fault F2), and E (fault F12). The new fault network interpretation at Bigar Hill with labeled faults is shown in Figure 3.6.



Figure 3.5: Phases in building the 3D structural model using the 2D cross-sections across the deposit: (a) Observations of the changes in thickness and orientation of the stratigraphic units on 2D crosssections, and definition of structural blocks; (b) Inferring a fault network by connecting them in successive cross-sections; (c) Implementation of 2D observations in the 3D model (cross-section exported from the 3D Leapfrog model); (d) Refining the interpretation further in a 3D model (crosssection exported into 2D).



Figure 3.6: Bigar Hill block model with the newly developed structural framework. All the faults are labeled with F1-F12. Structures inferred during this study are inferred in several common orientations, including (1) WNW (F1, F3); (2) NE (F4, F5, and F6); (3) NNW (F2); and (4) E (F12).

CHAPTER 4 – DECIPHERING FLUID FLOW THROUGH THE APPLICATION OF OXYGEN AND CARBON STABLE ISOTOPES

4.1 Introduction

Interactions between carbonate-bearing sedimentary rocks and percolating hydrothermal fluids can lead to mineral replacements and isotope exchange reactions. Thus, hydrothermally-altered rocks may have distinct stable isotope ratios compared to their pristine precursor rocks. The shift in stable isotope ratios of the altered rocks proceeds through to carbonate recrystallization and the formation of additional carbonate veins. Stable isotope alteration of the host rocks to hydrothermal ore deposits has been widely documented in Carlin-type, carbonate replacement, Mississippi Valley-type and skarn deposits (Barker et al., 2013; Vaughan, 2013; Arehart and Donelick, 2006; Levresse et al., 2004; Shanks, 2014).

Carbonate minerals and limestone are relatively rich in the ¹⁸O isotope (high δ^{18} O) compared to most natural fluids (low δ^{18} O) (Stenger et al., 1998; White, 2015). Consequently, the hydrothermal alteration is mostly accompanied by depletion of the rock in ¹⁸O that results in distinct alteration zones characterized by low δ^{18} O values (Stenger et al., 1998; Hickey et al., 2014). The shift to lower δ^{18} O values is typically more pronounced along fluid flow paths that have experienced higher fluid flux and pervasive alteration (Arehart and Donelick, 2006).

In contrast, the carbon isotope composition is generally less affected by fluid-rock interaction due to the much lower carbon (CO₂ and CH₄) concentration of hydrothermal fluids compared to volumetrically more significant carbonate-bearing clastic sedimentary and limestone of rock-buffered system. The complexity of the stable isotope systematics increases with the presence of organic carbon and low alteration temperature which results in strong fluid-solid fractionation and potentially non-equilibrium effects that can yield both apparent depletion and enrichment in ¹³C (Barker et al. 2013; Beinlich et al., 2017; Arehart and Donelick, 2006).

Depending on the amount of fluid involved in ore deposition, ¹⁸O isotope alteration (depletion) halos can develop on scales of up to several kilometers from the ore body. These altered depletion zones can be larger than zones of visible alteration and other geochemical haloes and thus can be used as an exploration tool for hydrothermal deposits. This method may be complementary to other, more traditional approaches such as pathfinder element and geophysical studies (Barker et al., 2013). The

stable isotope data can be used to delineate fluid flow pathways, establish the extent of its interactions with carbonate host rocks, and to discriminate structurally-controlled from pervasive alteration.

This study utilizes the results of ¹⁸O and ¹³C isotopic analyses of the carbonate-bearing rocks from the Bigar Hill deposit to delineate pathways of hydrothermal fluid flow, primarily along (sub-) vertical upflow zones through high-angle faults, but also laterally along stratigraphically-controlled high porosity and permeability zones. Additionally, the results will be tested against the inferred location of subvertical faults that have been established using the 3D deposit model.

4.2 Methodology

Six hundred and six samples from 19 drill holes were collected for stable oxygen and carbon isotope footprint analysis. Samples comprise all of the calcareous stratigraphic units (limestone, S1 – basal breccia, sandstone and mudstone, S2 – sandstone, marl). Drill holes were sampled along a ~1100 m long E-W section in the southern part of the Bigar Hill deposit (bounded by northing coordinates 4898157 and 4898187 (WGS 84/ UTM Zone 34N), that transects inferred faults F1, F2, F4, and F5. The location of the analyzed drill holes is in Figure 4.1. Samples were collected after every 5 m interval and included both reverse circulation (RC) chips and pieces of diamond drill core. Samples were collected from the carbonate rock matrix, avoiding calcite veins, to investigate the intensity of wall rock isotope alteration. Twenty additional samples from three drill holes from Korkan West and Korkan South prospects, from the northwest and north of Bigar Hill were also analyzed. Rock units of the Korkan prospects are identical to those of the Bigar Hill but are considered to be relatively unaltered and were therefore collected to establish local δ^{18} O and δ^{13} C isotope background values.

The stable oxygen and carbon isotope dataset were complemented with the corresponding gold and trace element data in order to delineate hydrothermal fluid pathways and to constrain the role of structural permeability on mineralization. The gold and sulfur dataset is from 1 m samples, and trace element data are from 5 m composite samples that were obtained from Avala Resources Ltd. Gold values were available for all the analyzed drill holes, while trace element data were available only for 9 of 22 drill holes. Additional whole rock chemical analysis was carried out on 11 samples in order to determine trace element background concentrations of the least-altered rocks. The complete δ^{18} O and δ^{13} C dataset along with corresponding gold and trace element values are listed in Appendix E.1.



Figure 4.1: Locations of the sampled Bigar Hill drill holes (bounded by northing coordinates 4898157 and 4898187); The upper right box shows the locations of sampled Korkan West and Korkan South drill holes; Structures scrutinized in this study are labeled with F mark. Geolines from Avala Resources, 2012.

4.3 Results

4.3.1 C and O Stable Isotopes

4.3.1.1 Global and Local Background Values

Stable isotope ratios of the Bigar Hill carbonate rocks are compared to the global background values for Jurassic and Cretaceous carbonate-bearing sedimentary rocks as compiled from the global Phanerozoic marine carbonate rocks database (Veizer et al., 1999), and to the local background values established from least-altered Korkan West and Korkan South prospects samples. Global background δ^{13} C values for the Jurassic limestone range from 5‰ to -1.5‰ VPDB, δ^{18} O background values range between 33.5‰ and 26.8‰ VSMOW (95% of all data, Veizer et al., 1999). The global background in Cretaceous δ^{13} C values ranges between 5.5‰ and -1.5‰ VPDB, and $\delta^{18}O_{VSMOW}$ ranges from 32.5‰ to 26.8‰ (95% of all data, Veizer et al., 1999).

Table 4.1: Compilation of δ^{13} C and δ^{18} O global and local background values, and values from the Bigar Hill for each rock unit

			Global Jurassic and						
			Cretaceous marine		Local background		Values from		
		Lithology	carbonate	background	va	values		the Bigar Hill	
			(Veizer et al., 1999)						
			δ ¹³ C (‰)	δ ¹⁸ Ο (‰)	δ ¹³ C (‰)	δ ¹⁸ Ο (‰)	δ ¹³ C (‰)	δ ¹⁸ Ο (‰)	
Jurassic limestone		5 to -1.5	33.5 to 26.8	2.4 to 1.9	27.1 to 26.6	3.2 to -1.7	27.8 to 14.7		
	Lim	nestone			2.2	25.4	3.7 to -4.6	28.4 to 8.9	
sn		Basal breccia		32.5 to 26.8 1.5 t 2.9 t			3.2 to -5.9	25.2 to 12.6	
ceol	S1	Siltstone/mudstone	5.5 to -1.5		1.5 to 1	25.3 to 24.2	2.8 to -3.9	23.6 to 11.8	
Cretao		Carbonate sandstone			2.9 to 2	29.6 to 25.9	3.6 to -2.3	29.1 to 12.9	
	S2	carbonate clastic rocks			4.2 to 1.5	29 to 24.5	3.6 to -3.5	25.6 to 13.8	
	Ma	rl			3.7 to 1.2	27.1 to 25.1	4.3 to -1.0	26.0 to 14.5	

Carbonate rocks from Korkan West and Korkan South prospect define a local stable isotope background. The samples lack visible evidence of hydrothermal alteration and contain negligible concentrations of gold. Twenty samples from three drill holes: KWDD005, KWDD008, and KODD028 represent all of the stratigraphic units. The range of average isotope values of all units is from 4.2‰ to – 1.0‰ for δ^{13} C, and 29.6‰ to 24.2‰ for δ^{18} O. δ^{13} C values are consistent with the global range of Jurassic and Cretaceous marine carbonate, while δ^{18} O is offset to somewhat lower values. The difference between the global and the local δ^{18} O background may be caused by weak hydrothermal alteration of the Korkan rocks, or reflect local primary seawater carbonate deposition from fluids that were isotopically different from global Jurassic and Cretaceous seawater. All background values for the different stratigraphic units are summarized in Table 4.1.



Figure 4.2: Plot of δ^{18} O vs. δ^{13} C for samples from all carbonate-bearing stratigraphic units, altered and least-altered, in relation to Global Phanerozoic marine carbonate background (Veizer et al., 1999) and local background ranges.

4.3.1.2 Stable Isotope Values of the Bigar Hill Deposit

Oxygen isotope ratios of 606 samples from the Bigar Hill range from 29.1‰ to 8.9‰ and 98% of the data are within a narrower range from 28‰ to 12‰. Approximately 3% of the samples are consistent with the range defined by global Jurassic to Cretaceous marine limestone (Veizer et al. 1999), and 13% of the samples are in the range of the local background values. δ^{13} C values of all samples range between 4.3‰ and -5.9‰. The majority of samples have a somewhat restricted range in δ^{13} C between 3.5‰ and -3.0‰. Unlike the oxygen isotope ratios, most δ^{13} C values are consistent with the global marine carbonate background, and 93% of samples fall within that interval. Approximately 60% of the samples are consistent with the local δ^{13} C background (Figure 4.2). δ^{18} O and δ^{13} C values are moderately correlated (correlation coefficient R = 0.62). δ^{18} O depletion is frequently accompanied by δ^{13} C depletion but not with the same intensity. Even though δ^{13} C values are dispersed in the narrower range, their

variations are more erratic than in a case of oxygen. The range in isotope ratios of all stratigraphic units are summarized in Table 4.1 and presented as box plots in Figure 4.3.



Figure 4.3: Box plot representation of the ranges of δ^{18} O and δ^{13} C for each stratigraphic unit, including all samples, altered to least-altered from Bigar Hill.

Box plots provide information on the interquartile range (range between 25th and 75th percentiles) that defines the size of the box, and median and mean values, as well as whisker values (1.5 times the interquartile range), outliers (up to 3 times the length of the box) and far outliers. The median and mean δ^{18} O values provide the most obvious indication for compositional differences between the different stratigraphic units. The median represents the average value for all the samples, fresh to altered, and reflects the various proportion of various samples in each unit. The δ^{18} O median for the S1 sub-unit equals ~22.4‰ and is close to the local background and higher than that of all other stratigraphic units. The overall range in δ^{18} O of the S1 sub-unit is from 29.1‰ to 12.9‰. Marl (SMR), S2 and Jurassic limestone (JLS) have median δ^{18} O values between 20.5‰ and 19.0‰. IB mudstone, basal breccia (BBX) and Cretaceous limestone have the lowest median values ranging between 16.9‰ and 16.1‰. The IB sub-unit is characterized by relatively low variability, δ^{18} O = 19.8 – 11.8‰ (up to 23.6‰ including outliers), the basal breccia has the interquartile range of 21.5‰ to 14‰, while the KLS has the overall highest variability δ^{18} O = 25.3‰ – 8.9‰ (up to 28.4‰ including outliers). Values of δ^{13} C exhibit less variability than δ^{18} O. The SMR and S1 have the highest median δ^{13} C values of 1.6‰ and 1.8‰ respectively. The S2, KLS and JLS units have median δ^{13} C values in the range of 1.2‰ to 0.9‰. The lowest values are present in the BBX and IB sub-units with δ^{13} C = 0.5‰ and -0.8‰, respectively. These two sub-units are characterized by the broadest interquartile ranges, from 1.3‰ to -0.8‰ in BBX, and from 0.9‰ to -2.1‰ in IB. The different carbon and oxygen isotope ratios in the different (sub-) units may be the result of variable lithologic composition.

According to Hofstra and Cline (2000), higher δ^{18} O and δ^{13} C values are typical of ordinary marine limestone while the lower values are characteristic of calcite in calcareous shales. Low isotopic values in the IB sub-unit, which is composed of mudstone to siltstone with variable amounts of organic matter, are partially caused by the typically low δ^{13} C values of organic carbon (Ohmoto, 1986; Arehart and Donelick, 2006). The same reason may apply to the BBX sub-unit, which partially contains mudstone as a matrix. In addition to rock composition, isotopic variability could reflect the intensity of alteration (Stenger et al., 1998).

4.3.2 Gold and Trace Elements Distribution

Cross-sections show the spatial distribution of δ^{18} O and δ^{13} C values and their spatial relationships to the Bigar Hill mineralization (0.4 ppm Au grade shell) and stratigraphic units (Figure 4.4). For the following discussion and correlation with Au grades, ranges in δ^{18} O values are grouped into: (1) within the range of the global background values; (2) slightly depleted (>22‰); (3) moderately depleted (22‰ – 15‰); (4) strongly depleted (<15‰); and (5) very strongly depleted (<10‰).

Gold and sulfur concentration data from 1 m core sample intervals are available for all 22 drill holes used in this study, while trace metals concentration integrating over core lengths of 5 m were obtained for nine drill holes. Correlation analysis shows that gold best correlates with Sb, Tl, Hg, As and Te. The correlation matrix for gold, trace metals, and oxygen and carbon isotope ratios is presented in Table 4.2.



Figure 4.4: Cross-sections are showing the spatial distribution of δ^{18} O (top section) and δ^{13} C (bottom section) values and their spatial relation with stratigraphic units, and the gold mineralization (0.4 ppm Au grade shell outlined with purple line). The position of the cross-section is shown on the map in Figure 4.1.

	δ ¹⁸ Ο (‰)	δ ¹³ C (‰)	Au (ppm)	As (ppm)	Sb (ppm)	Hg (ppm)	TI (ppm)	Te (ppm)	Se (ppm)	Ag (ppm)
δ ¹⁸ Ο (‰)	1	0.62	-0.32	-0.34	-0.45	-0.43	-0.41	-0.44	-0.36	-0.11
δ ¹³ C (‰)	0.62	1	-0.2	-0.24	-0.3	-0.25	-0.21	-0.2	-0.15	-0.064
Au (ppm)	-0.32	-0.2	1	0.69	0.73	0.7	0.72	0.6	0.54	0.33
As (ppm)	-0.34	-0.24	0.69	1	0.77	0.69	0.83	0.75	0.58	0.3
Sb (ppm)	-0.45	-0.3	0.73	0.77	1	0.73	0.79	0.65	0.62	0.25
Hg (ppm)	-0.43	-0.25	0.7	0.69	0.73	1	0.77	0.66	0.6	0.26
Tl (ppm)	-0.41	-0.21	0.72	0.83	0.79	0.77	1	0.74	0.62	0.37
Te (ppm)	-0.44	-0.2	0.6	0.75	0.65	0.66	0.74	1	0.63	0.41
Se (ppm)	-0.36	-0.15	0.54	0.58	0.62	0.6	0.62	0.63	1	0.34
Ag (ppm)	-0.11	-0.064	0.33	0.3	0.25	0.26	0.37	0.41	0.34	1
Pb (ppm)	-0.29	-0.16	0.21	0.27	0.27	0.23	0.3	0.34	0.34	0.39
Cu (ppm)	-0.22	-0.11	-0.012	0.22	0.043	-0.032	0.19	0.34	0.22	0.26
W (ppm)	-0.24	-0.16	0.27	0.26	0.33	0.42	0.27	0.28	0.32	0.058
Bi (ppm)	-0.11	-0.12	0.14	0.27	0.082	-0.016	0.23	0.31	0.14	0.34
Mn (ppm)	-0.57	-0.31	0.51	0.32	0.5	0.52	0.5	0.49	0.44	0.37
Mg (ppm)	-0.47	-0.25	0.08	0.069	0.16	0.17	0.23	0.19	0.21	0.23
S (%)	-0.37	-0.32	0.6	0.77	0.68	0.59	0.68	0.67	0.5	0.42

Table 4.2: Spearman correlation matrix for O and C isotopes, gold and selected trace elements

Association of gold with As, Sb, Hg, Tl, and Te is one of the characteristic features of Carlin-type gold deposits indicating their transport and deposition from the same mineralizing fluid (Bagby and Berger, 1985; Hofstra and Cline, 2000; Hickey et al. 2014). This low-temperature element association, along with the oxygen and carbon isotopes was therefore used to constrain hydrothermal flow along zones of structural permeability and within favorable stratigraphic units. Correlation coefficients (R) for the concentration of gold and low-temperature trace elements range between 0.6 and 0.74. Cross-sections showing the spatial distribution of Sb, Tl, Hg and As concentrations are in Figure 4.5.



Figure 4.5: Cross-sections showing the spatial distribution of Sb, Tl, Hg and As values and their relation with stratigraphic units, and the gold mineralization (0.4 ppm Au grade shell outlined with purple line). The position of the cross-section is shown on the map in Figure 4.1.



Figure 4.5 (Cont.)

Local background concentrations of gold and trace elements are established using the lithogeochemical dataset for the Korkan West and Korkan South prospects. Gold grades in all the assayed samples (n = 10) are below the detection limit (Au <0.01 ppm). In further work, these values were replaced by half of the limit of detection values. Tl concentrations are mainly below the detection limit (Tl <0.1 ppm); only two

samples had concentrations of 0.2 ppm. Hg ranges from the detection limit (Hg <0.01 ppm) to 0.03 ppm, Sb values vary between the detection limit (<0.1 ppm) and 0.8 ppm. Arsenic shows the highest variability, ranging between the detection limit (As <0.5 ppm) and 33.8 ppm.

4.3.3 Correlation between Isotope Ratios and Metal Concentrations

Values of δ^{18} O and δ^{13} C were correlated against all of the analyzed element concentrations. A positive correlation exists only for δ^{18} O and δ^{13} C (R = 0.62) indicating that isotopic depletion generally applies to both δ^{18} O and δ^{13} C, and that metal concentrations are elevated in zones of isotopic depletion. δ^{18} O have the strongest inverse correlation with manganese (R = -0.57). Depletion of isotope values lacks a strong correlation with gold mineralization; their correlation coefficients are R = -0.32 and R = -0.2 for oxygen or carbon versus gold respectively. Values of δ^{18} O exhibit slightly stronger correlations with Sb (R = -0.45), Te (R = -0.44), Hg (R = -0.43), Tl (R = -0.41) and As (R = -0.35). Carbon isotope ratios have a weaker correlation with trace element concentrations, ranging from -0.2 (vs. Tl) to -0.3 (vs. Sb) (Figure 4.6).

It is important to emphasize that the samples for different types of analyses were collected on a different scale, with different amount of material. Gold analyses were performed on the 1 m interval drill core or crushed RC chips. Trace element concentrations were analyzed from the 5 m composite samples. On the other hand, isotope analyses involved significantly smaller amounts of material (17 mg to 100 mg), obtained by spot drilling of selected areas of selected rock core pieces or by crushing of RC chips from the 1 m interval. Due to the discrepancy in the sample size, isotope depletion may not precisely match gold and trace elements enrichment on the sample scale. For this reason, trends of isotope depletion and metal enrichment should be the point of interest (Ahmed, 2010; Arehart and Donelick, 2006).



Figure 4.6: XY plot of δ^{18} O vs. δ^{13} C for samples taken from all the carbonate-bearing stratigraphic units, color-coded by Au (top plot), Sb (bottom plot), Hg (next page top plot) and Tl (next page bottom plot) concentrations from the appropriate intervals.



Figure 4.6 (Cont.)

4.4 Stable isotope ratios, metal concentrations, and zones of increased permeability

Depletion of stable isotopic ratios can be linked to zones of gold mineralization and the inferred location of hydrothermal fluid flow paths, in particular, proximity to inferred faults F1, F2, F4, and F5. Depths of inferred intersections of drill holes with F1, F2, F4, and F5 faults, as well as with confirmed faults (F7, F8, and F9) are shown in Table 4.3. Spatial representation of stable isotopic ratios in drill holes along the A-B cross-section is shown as box plots in Figure 4.7. From the west to the east, the ore zone spans between drill holes BHRC222 and BHRC283. The proximal ore zone is intersected with drill holes BHRC159 to BHRC221 in the west, and BHDD076 in the east, while the holes BHDD058 and BHDD053 are considered distal to the ore zone. Median and mean δ^{18} O values exhibit a continuous decrease from the westernmost drill hole (BHRC159) towards drill hole BHRC297 that is located within the ore body and contains the highest gold grade. Median values range from 23.5‰ in the west to 15.0‰ in the ore zone. A distinct decrease of median δ^{18} O values from 20.7‰ to 18.8‰ occurs between drill holes BHRC221 and BHRC222 and correlates with an increase in gold grade from the detection limit to 1.65 ppm in BHRC222. The strongest depletion of δ^{18} O, with median values below 20‰, is observed between drill holes BHRC222 and BHRC046. δ^{18} O increases strongly between BHRC046 and the neighboring hole BHDD068 from 15.9‰ to 20.3‰. Towards the east, oxygen isotopic values irregularly increase and show a sudden drop in drill hole BHRC283, which has been crosscut by the F7 fault. Gold values are significantly higher within the ore zone bounded by F4 and F7 faults. Within the ore zone, the gold grades are variable, with median values ranging between the detection limit and up to 0.41 ppm (in BHRC297). The highest gold grade of 4.97 ppm recorded in BHRC297, occurs along with the most intensive strongest oxygen depletion. Outside the ore zone, gold median values do not exceed 0.01 ppm in most drill holes; however, easternmost holes contain outliers up to 1.05 ppm Au.

	BHRC	BHRC	BHRC	BHRC	BHRC	BHDD	BHRC	BHRC	BHDD	BHRC	BHDD	BHDD
	159	143	222	105	229	056	297	130	084	283	076	058
F1								92	302			
F2				41	124	206	262					
F4			34	134								
F5	65											
F7										30	306	
F8												335
F9	65	144										

Table 4.3: Downhole depth (m) of the intersections of holes with inferred and established faults (F1-F9)



Figure 4.7: Spatial representation of stable isotopic and gold ratios in drill holes along the A-B cross-section is shown as box plots. Box plots are formed based on the δ^{18} O, δ^{13} C and Au values from all the analyzed samples within respective drill holes.

Even though carbon isotope ratios show less per mill variation than oxygen isotope ratios (median 2.24‰ to 0.11‰) both show consistent trends of depletion. Drill hole BHRC130, located in the central part of the ore zone, exhibits the lowest median and mean δ^{13} C values (0.11‰ and -0.29‰) and the lowest individual value (-5.91‰). The spatial variability of oxygen isotopes in each stratigraphic unit in drill holes along the A-B cross section is shown in Appendix E.2.

4.4.1 Spatial relation between isotope ratios, metal concentrations, tectonic and stratigraphic features

The presented data show that changes in oxygen isotope ratios and the correlation with metal concentrations have greater per mill shift than for carbon isotope ratios. Therefore, oxygen isotope ratios are the most sensitive proxy for hydrothermal fluid/host rock interaction.

Variations in δ^{18} O and metal concentration in the drill holes and their spatial relationship with the observed and inferred faults, as well as stratigraphic zones of increased porosity are apparent along a W-E trending transect. The transect encompasses the distal zone in the east (intersected with BHDD053 and BHDD058), proximal zone (BHRC159 to BHRC221 in the west and BHDD076 in the east) and the ore zone of the Bigar Hill deposit (between BHRC222 and BHRC283).

Distal zone

• The easternmost drill holes BHDD058, and BHDD053 are located outside of the ore zone and show generally high δ^{18} O values, with rare moderately-depleted δ^{18} O values, especially in narrow intervals in S1, S2 and marl units. These depletion zones may reflect the distal flow of the hydrothermal fluid without mineralization. The inferred intersection of fault F8 with the BHDD058 is coupled with isotopic depletion of the S2 clastic rocks.

Proximal zone

• The westernmost drill hole BHRC159 intersected rocks with high δ^{18} O values that are mostly >22‰, i.e., only slightly depleted relative to the global and local background values. The only significant deviation to lower δ^{18} O values occurs in the non-mineralized IB mudstone rock, directly above the contact with limestone. Although this deviation to lower δ^{18} O values may be a feature related to the mudstone's lower background values, it matches spatially with the intersection of inferred fault F5 and established fault F9, which might represent a preferred pathway for hydrothermal fluids even in the absence of mineralization. Oxygen values are lower in the S2 unit than in S1, and there is a slight decrease of isotopic values on the contact of these two units.

- Adjacent drill holes to the east (BHRC143, BHRC147, and BHRC221) show low gold grades that oscillate between the detection limit and 0.06 ppm. Zones of oxygen isotopic depletion correlate with zones of increased gold values even though individual gold concentration peaks are generally not associated with isotopic lows. The S2 unit and marl underwent moderate depletion (22% 16%), while δ^{18} O values of the S1 unit are within the global background range. Oxygen isotopic depletion in drill hole BHRC221 may be the consequence of hydrothermal fluids circulation through the fault F4 which is assumed to intersect the stratigraphy in the vicinity of the hole. The contact zone between S1 and S2 in BHRC147 and BHRC221 shows only subtle depletion in δ^{18} O.
- BHDD076 is located in the proximal zone, east from the deposit. Its oxygen values are highly variable, ranging from 27.9 to 14.8‰. Oxygen ratios in the S1 unit approach background values. Strong depletion is recorded at the contact of marl and S2 and within the S2. Increased gold and trace elements show a weak correlation with isotope depletion. Depletion in the breccia zone matches with the inferred intersection with the fault F7.

Ore zone

- The westernmost drill hole in the ore zone BHRC222 is moderately to strongly depleted in ¹⁸O ($\delta^{18}O$ <22‰) relative to the local and global background. The most depleted interval is associated with the basal breccia limestone contact and fractured limestone at a deeper level and coincides with the gold grades of up to 1.6 ppm. The inferred intersection with the fault F4 does not have any notable O isotope depletion, but only a slight decrease in marl.
- The next drill hole to the east, BHRC105 shows highly variable values of δ^{18} O, ranging from 22.7‰ to 14.5‰. The most robust depletion is in marl (14.5‰) and basal breccia (14.9‰). Strong depletion in the marl coincides with its contact zone with the andesitic sill in the vicinity of F2 and F4 faults, while moderate depletion in the S2 unit matches the projected intersection depth of the F4 fault. Mineralization is absent in both zones. However, elevated concentrations of gold (up to 6.6 ppm) and trace elements in the S1 unit correlate with moderate δ^{18} O depletion.
- δ^{18} O is moderately to strongly depleted in hole BHRC229. Strong δ^{18} O depletion is recorded in a broad zone around the S1/S2 contact (~25 m), while gold enrichment occurs in the narrow contact interval. Strong depletion in the S2 occurs at the projected depth of intersection with the F2 fault.
- Drill hole BHDD056 shows highly variable δ^{18} O values that are well-correlated with gold and trace element increased concentrations. ¹⁸O depletion zones are spatially consistent with the contact zone of S2 and andesite units, as well as S1 and S2 units, the basal breccia, and a few intervals in

limestone. Intersection with the F2 fault in basal breccia had a significant decrease in δ^{18} O and increase in gold and associated metals.

• Rocks from the drill hole BHRC297 mostly have strong ¹⁸O depletions. The lowest value (δ^{18} O = 8.9‰) appears at the intersection of the F2 fault with limestone where the gold grade is up to 2.5 ppm. The strong O depletion affected the S1 unit more than the upper S2 unit. The S1 also contains higher gold grades.

5.1 Introduction

Although there are geochronological constraints for several deposits and prospects in the TMC region, dates presented here are the first to constrain Bigar Hill geology and mineralizing processes. Constraining the age of host rock sedimentation and local igneous and associated hydrothermal activities provides insight into the timing and evolution of ore genesis at Bigar Hill. However, dating sediment-hosted disseminated gold mineralization remains a scientific challenge (Hofstra, 1999; Hofstra and Cline, 2000). Absolute dating is hindered by the very fine-grained nature of the mineralization while the limitations of indirect dating lie in a small number of datable materials that are co-genetic with gold (Hofstra and Cline, 2000; Arehart, 2003).

Numerous age dates from Carlin-type deposits in the Great Basin region of the US, obtained by different isotopic dating techniques, provided highly variable results. Rb-Sr dating of galkhaite [(Cs,TI)(Hg,Cu,Zn)₆(As,Sb)₄S₁₂] provides the only direct age of mineralization. This sulfosalt is recognized in only a few locations in Nevada (Getchell, Rodeo, Carlin, SSX), and rarely worldwide. At the Getchell and Rodeo deposits, mineral associations and detailed observations of its occurrence, distribution, and chemistry indicate that galkhaite is part of the Au stage mineralization (Arehart, 2003). Several other techniques for direct or indirect dating have had limited success. Some of those techniques include: Re-Os dating on realgar, orpiment, and pyrite; Sm-Nd dating on fluorite; Rb-Sr on sphalerite; U-Th-Pb techniques on various minerals (post-ore calcite, apatite, and late ore-stage pyrite); and K-Ar or ⁴⁰Ar-³⁹Ar on sericite, biotite, feldspar, alunite (Hofstra and Cline, 2000; Arehart, 2003).

At Bigar Hill, the K-Ar ages of hydrothermal illite are considered to best represent the timing of gold mineralization. Moderate to strong clay alteration developed during mineralization in the andesite and S2 clastic rocks and formed widespread but fine-grained illite. The K-Ar dating technique was chosen over the ⁴⁰Ar-³⁹Ar method because the very fine-grained illite would likely suffer recoil effects during irradiation which makes meaningful dates difficult or impossible to interpret (Lovera et al., 1989; Foland et al., 1992). To further constrain the understanding of the timing of mineralization, a U-Pb dating study of magmatic and sedimentary rocks was designed to better indicate the timing of igneous activity in the

northwestern Timok area, thus further constraining the timing of hydrothermal activity associated with gold mineralization of the Bigar Hill deposit.

5.1.1 Geochronology of the TMC

Previous geochronology of the igneous events within the broader TMC provided K-Ar, Ar-Ar and U-Pb ages of volcanic and plutonic rocks. The Re-Os molybdenite dating technique provided the age of the porphyry mineralization. The age data of magmatic and hydrothermal activities was constrained to a period of approximately 13 million years, from 90 to 77 Ma (von Quadt et al., 2002; Clark and Ullrich, 2004; Banješević, 2001, 2010; Tosdal, 2012), showing a general younging of magmatism from east to west. A summary of the known radiometric dates of plutonism, volcanism, and mineralization in eastern and central Timok is provided in Table 5.1.

Locality	Lithology/ Mineralization	Fraction	Isotopic System	Interpreted Age (Ma)	Reference
Veliki	Andesite	Amphibole	K-Ar	91.0 ± 4.0	Janković et al. (1981)
Krivelj	Andesite	Zircon	U-Pb	86.29 ± 0.3 to 86.17 ± 0.2	von Quadt et al. (2002)
	Diorite	Zircon	U-Pb	86.6 ± 0.6	von Quadt et al. (2002)
	Mineralization	Molybdenite	Re-Os	87.88 ± 0.5	Zimmerman et al. (2008)
Bor	Andesite	Amphibole	K-Ar	89.7 ± 3.6 to 89.6 ± 3.6	Banješević et al. (2001)
	Andesite	Biotite	Ar-Ar	89.0 ± 0.6	Clark and Ullrich (2004)
	Mineralization	Molybdenite	Re-Os	86.24 ± 0.5 to 85.94 ± 0.4	Zimmerman et al. (2008)
Majdanpek	Andesite	Biotite	Ar-Ar	84.0 ± 0.4 to 83.6 ± 0.5	Clark and Ullrich (2004)
	Andesite	Zircon	U-Pb	82.73 ± 0.5	von Quadt et al. (2002)
	Diorite	Zircon	U-Pb	83.1 ± 0.1	von Quadt et al. (2002)
	Mineralization	Molybdenite	Re-Os	83.77 ± 0.5 to 83.37 ± 0.5	Zimmerman et al. (2008)
Dumitru Potok	Mineralization	Molybdenite	Re-Os	80.82 ± 0.5 to 80.69 ± 0.4	Zimmerman et al. (2008)

Table 5.1: Summary of age dates of magmatic and hydrothermal activity in eastern and central TMC. Localities are shown in Figure 2.1 and Figure 5.2.

In the northwestern portion of the TMC, results from SHRIMP-RG ion microprobe analyses on U-Pb in zircons from the diorite porphyry stocks and dikes indicated that magmatism spanned about 5-6 million years (Tosdal, 2012). The Dumitru Potok and Valja Strž porphyry Cu-Au systems, located 2 km and 5 km SE of Bigar Hill, formed roughly contemporaneously, before 82.5 - 81.3 Ma. A late, poorly mineralized diorite porphyry from the Kraku Riđi Cu-Au system, located immediately east of Bigar Hill, has been dated at 80.6 \pm 0.6 Ma. The emplacement of the Potaj Čuka monzonite pluton, south of Bigar Hill, is interpreted to have occurred at 79.9 \pm 0.5 Ma, after the intrusion of porphyry systems (Table 5.2).

Locality	Lithology/ Mineralization	Fraction	Isotopic System	Interpreted Age (Ma)	Reference
Čoka Kuruga	Diorite	Zircon	U-Pb	83.6 ± 0.5	Tosdal (2012)
Valja Strž	Diorite	Zircon	U-Pb	82.5 ± 0.6	Tosdal (2012)
	Diorite	Zircon	U-Pb	81.3 ± 0.7	Tosdal (2012)
Dumitru Potok	Diorite	Zircon	U-Pb	82.0 ± 0.6	Tosdal (2012)
	Diorite	Zircon	U-Pb	81.4 ± 0.4	Tosdal (2012)
Kraku Riđi	Diorite	Zircon	U-Pb	80.6 ± 0.6	Tosdal (2012)
Kraku Pešter	Monzonite	Zircon	U-Pb	79.9 ± 0.5	Tosdal (2012)
Valja Strž South	Monzonite	Zircon	U-Pb	78.5 ± 1.3	Tosdal (2012)

Table 5.2: Summary of the U-Pb SHRIMP-RG ages of the intrusive rocks from the west-central TMC. Localities are shown in Figure 5.2.

5.2 Methodology

5.2.1 U-Pb Zircon Dating

Six samples were selected for U-Pb dating with the intention to establish the age of local sedimentary and igneous processes and to indirectly constrain the timing of hydrothermal activity at the Bigar Hill. Samples were collected from the Bigar Hill S2 sandstone, andesite, and diorite, but also from the adjacent intrusions which could provide a better understanding of the broader magmatic-hydrothermal activities. Samples and rationale include:

- A sample from a propylitic-altered andesitic sill at Bigar Hill (14JZBH285) was collected to indirectly provide the maximum age of the gold mineralization since the andesite is the youngest gold-bearing unit within the deposit (Figure 5.1a);
- (2) Non-mineralized, plagioclase-hornblende-phyric diorite (sample 14JZBH286) intruded into andesite on the eastern margin of the deposit was sampled to constrain the minimum age on the andesite. This sample also indirectly constrains the maximum age of mineralization (Figure 5.1b);
- (3) Diorite from the Čoka Rakita Au-porphyry prospect (sample 14JZRA001), is located 3 km SE from the Bigar Hill. It is essential to constrain the age of this porphyry, as it may have been a source of fluids, heat or gold for the SHDG deposit (Figure 5.1c);
- (4) Coarse-grained, K-feldspar-plagioclase-biotite monzonite (14JZCR002) from Crna Reka (see a sample (5) for rationale);
- (5) Porphyritic, plagioclase-hornblende diorite (14JZCR003) from Crna Reka, along with sample (4), was analyzed to distinguish the timing of these two intrusions in the broader temporal framework of the

Bigar Hill deposit evolution, and to test the assumption that diorite is younger than the Potaj Čuka monzonite batholith, as suggested by the cross-cutting relationship and soil geochemical data (Figure 5.1d, e); and

(6) S2 volcanic detritus-rich sandstone (14JZBH302) was sampled for detrital zircon dating. The sample provides a maximum age for the deposition of the S2 unit by providing an age on the volcanic protolith that was eroded and redeposited as S2, one of the key gold-hosting units.

Locations of selected samples and the results of U-Pb analyses are shown in Figure 5.2, along with the previous geochronology data for comparison.



Figure 5.1: Photographs of rocks sampled for U-Pb zircon dating: (a) 14JZBH285, a propylitic-altered andesitic sill from the Bigar Hill; (b) 14JZBH286, plagioclase-hornblende phyric diorite intruded in andesite from east of the Bigar Hill; (c) 14JZRA001, diorite from the Čoka Rakita Au-porphyry system; (d) 14JZCR003, plagioclase-hornblende diorite from the Crna Reka prospect; (e) 14JZCR002 - Coarse-grained K feldspar-plagioclase-biotite monzonite from the Crna Reka prospect; (f) S2 volcaniclastic-derived carbonate sandstone.



Figure 5.2: West and Central TMC geology with the location of the samples collected for U-Pb dating, and the obtained ages. Also, the locations of the previously obtained ages (Tosdal, 2012) shown using different symbols. Geolines from Avala Resources, 2012.

5.2.2 K-Ar Illite Dating

Illite ages can be a proxy for mineralization ages, based on the assumption that illite formed during and from the same hydrothermal process that led to coupled gold and pyrite precipitation.



Figure 5.3: Photographs of samples collected for K-Ar illite dating: (a-c) 14JZBH295, 14JZBH298, 14JZBH299 are intensively illite-altered and mineralized S2 sandstone; (d-f) 14JZBH292, 14JZBH294, 14JZBH296 are illite-altered and sulfidized andesite.

Six samples from moderately to highly mineralized and strongly to moderately clay-altered S2 sandstone (14JZBH295, 14JZBH298, 14JZBH299) and andesite (14JZBH292, 14JZBH294, 14JZBH296) were selected. Photographs of the sampled rocks are shown in Figure 5.3, and their locations in the Bigar Hill drill holes are shown in Figure 5.4. SWIR spectral analysis using the TerraSpec[®] (ADS, Inc.) enabled the identification of illite in the rock samples. Identified minerals are listed in Appendix C. Gold grades in the andesite samples are from 1.5 to 7.4 ppm, and illite is the only mineral identified by spectral analysis. In sandstone samples, gold grades are somewhat lower, from 0.5 to 2.05 ppm. All three samples contain illite, but 14JZBH295 also has kaolinite, and 14JZBH299 has kaolinite and muscovite. The petrographic study confirmed the intergrowth of illite and gold-bearing pyrite (Figure 5.5). In the andesite, clay alteration destroyed original rock texture and replaced primary minerals. Only rare occurrences of plagioclase phenocrysts relicts remained. Pyrite is formed after the primary femic minerals (hornblende or chlorite) and is disseminated as fine-grained anhedral crystalline masses or rarely occurs in veins. In the S2

sandstone, clay altered volcanic detritus material intimately intergrows with partially to intensively dissolved calcite cement. Anhedral pyrite is disseminated in the rock mass.

Two illite fractions, <2 µm and <5 µm, were separated and analyzed. The <2 µm fraction is separated to avoid contamination by rock-forming minerals. The <5 µm fraction provides a measure of the effect of a grain-size on the radiometric age; it was collected from three samples (andesite samples 14JZBH294, 14JZBH296, and S2 sample 14JZBH298). Additional age dating of the whole rock samples tests the influence of rock-forming minerals on the age (Pécskay and Benkó, 2015).

Before analysis, illite purity was quantified using X-ray diffraction (XRD) on powdered illite. The XRD analysis also registered small quantities of illite/smectite, smectite, quartz, chlorite and kaolinite and traces of calcite, dolomite, and gypsum (Pécskay and Benkó, 2015). XRD analysis results are presented in Appendix F.



Figure 5.4: Locations of sandstone and andesite samples collected for K-Ar illite dating from the Bigar Hill drill holes. Geolines from Avala Resources, 2012.



Figure 5.5: Photomicrographs of highly mineralized samples (transmitted light, X-polar, left; reflected light, right) collected for illite dating illustrate the association between gold-bearing pyrite and illite: (a-b) S2 sandstone sample 14JZBH295, with illite (il) replacing volcanic detritus, minor quartz (qz) and calcite cement (ca); and (c-d) andesite sample 14JZBH296, with moderately disseminated pyrite (py) in illite dominant groundmass.

5.3 Results and Interpretation

5.3.1 U-Pb zircon ages and interpretation

Results of U-Pb analyses are presented in Table 5.3. Results and interpretation of individual samples include:

- (1) Andesite sample 14JZBH285 yielded no zircons, so the rock age remained undefined;
- (2) Nineteen zircons from diorite sample 14JZBH286 were analyzed. Seventeen zircons yielded a mean age of 80.16 ± 0.77 Ma with an MSWD of 0.51 (Figure 5.6a). Two crystals yielded significantly older ages (approx. 570-540 Ma) and were excluded from magmatic activity interpretations. These were assumed to be zircons from Paleozoic basement rocks xenocrysts incorporated into the diorite during the intrusion. The 80.16 ± 0.77 Ma mean age is interpreted as the minimum age of the host

andesite. Because this unit is the youngest gold bearing unit of the deposit, this age also provides a bounding maximum age on mineralization.

- (3) The plagioclase-hornblende-phyric diorite (sample 14JZRA001) from the Rakita Au-porphyry system did not yield any zircons.
- (4) The monzonite sample (14JZCR002) provided six zircons. One crystal exhibited poor analytical quality and was excluded; the remaining five zircon crystals yielded an average age of 80.0 ± 1.2 Ma with the MSWD of 1.4.
- (5) Eleven zircons from the porphyritic diorite sample 14JZCR003 yielded an average age of 77.66 ± 0.75 Ma with slightly elevated MSWD of 2.0 (Figure 5.6b, c). These data confirm the assumption that the porphyritic diorite is younger than the monzonite batholith and raise the possibility of a genetic link between intrusion and the Kraku Pešter deposit.
- (6) Detrital zircons separated from S2 sandstone sample 14JZBH302 exhibit typical zoning and melt inclusions. Seventeen zircons yielded a well-distributed range of ages between 93.3 ± 3.1 Ma to 87.5 ± 3.1 Ma (Figure 5.6d, e). This age distribution indicates that the zircons derived from weathering of various igneous protoliths before deposition in the S2 clastic sequence. Without the constraints on Late Cretaceous erosion rates and duration of local sediment transport and storage, it can only be concluded that the S2 sequence is younger than the zircons and older than the marls whose age is paleontologically determined to be Santonian (Dimitrijević et al., 1970; 1976; Vasić, 2012) from 86.3 to 83.6 Ma (Cohen et al., 2013).

Sample	Lithology	U-Pb Interpreted Age (Ma)	Hole ID	From (m)	To (m)	Locality
14JZBH286	Diorite	80.16 ± 0.77	BHDD081	53.8	58.5	Bigar Hill
14JZBH302	S2 Sandstone	93.3 to 87.5 ± 3.1	BHDD084	151.6	160.7	Bigar Hill
14JZCR002	Monzonite	80.0 ± 1.2	CRDD005	395.4	399.6	Crna Reka
14JZCR003	Diorite	77.66 ± 0.75	CRDD005	408.1	416.6	Crna Reka
14JZBH285	Andesite	No zircons	BHDD083	38.0	41.4	Bigar Hill
14JZRA001	Diorite	No zircons	RADD001	231.4	235.9	Rakita

Table 5.3: Summary of the U-Pb LA-ICP-MS ages from this study with the location of samples in dril
holes. Collar locations and orientations of the drill holes are in Appendix G.



Figure 5.6: U-Pb Concordia plots showing data for zircons separated from samples (a) 14JZBH286; (b) 14JZCR002; (c) 14JZCR003 and (d) 14JZBH302; and (e) probability density plot for detrital zircon ages from the sample 14JZBH302.

5.3.2 K-Ar illite age

Age of the <2 μ m illite fraction from the andesitic sample 14JZBH292 is 79.55 ± 2.95 Ma and coincides with the whole rock age for that sample. The ⁴⁰Ar_{rad} (%) for illite separate is relatively low, indicating that the rock is not entirely altered. Therefore, the measured radiometric age of the whole rock most likely approximates the real age of the andesite. Given the relatively pure character of <2 μ m fraction, with a trace amount of illite/smectite and chlorite, it is assumed that this sample also provides the age of the alteration (Pécskay and Benkó, 2015).

Ages for <2 μ m and <5 μ m fractions of andesite sample 14JZBH294 do not coincide. The age of the <2 μ m is 81.90 ± 2.62 Ma, while the age of the <5 μ m fraction is 77.68 ± 2.59 Ma, which agrees with radiometric age of the whole rock (78.24 ± 3.41 Ma). The finer-grained fraction contains less K (5.13%) than the <5 μ m fraction (5.4%). A similar discrepancy occurs in andesite sample 14JZBH296, where the <2 μ m fraction yields an anomalously old radiometric age of 89.65 ± 3.28 Ma, whereas the age of the <5 μ m fraction is considerably younger, at 75.31 ± 2.93 Ma. Also, the smaller fraction has lower K content (4.5%) compared with the coarser one (5.3%). In both samples, the <2 μ m fraction contains higher amounts of smectite and lower K content relative to the coarser fraction. The K loss is assumed to be related to the formation of smectite that retains Ar but no K (Pécskay and Benkó, 2015). For that reason, further interpretation used the radiometric age of the <5 μ m fraction.

Age of the <2 μ m illite fraction of the 14JZBH295 sandstone sample is 78.79 ± 2.49 Ma which is consistent with the age obtained for 14JZBH298 sandstone sample. Ages for fractions <2 and <5 μ m of the 14JZBH298 are 78.86 ± 2.82 Ma and 80.42 ± 2.87 Ma, respectively, although they overlap within the error ranges. Both fractions are characterized with relatively homogeneous composition, with dominant illite and low smectite abundance, indicating that the mineralogy has not affected the radiometric age.

Sample 14JZBH299 from the S2 sandstone yielded an anomalously old radiometric age of 96.96 \pm 3.6 Ma. Even though the <2 µm fraction is dominantly illite, there is contamination with detrital mica which is identified by spectral analysis. Muscovite is preserved either in weakly altered parts of the sample or remobilized and deposited in the fracture system after the mineralization process. This age is older than the oldest known magmatic phase in the TMC.

Based on the selected K-Ar ages, the average age of 79 Ma with an average error of 2.78 Ma is a reasonable estimate for the age of the mineralization. A summary of the K-Ar radiometric age results is provided in Table 5.4. A summary of the TMC and the Bigar Hill geochronology is shown in Figure 5.7.

Sample ID	Lithology	Dated fraction	K (%)	⁴⁰ Ar _{rad} (ccSTP/g)	⁴⁰ Ar _{rad} (%)	K/Ar age (Ma)	Hole ID	From	То
14JZBH292	Andosito	w.r. 010.25	2.682	8.5245×10 ⁻⁶	63.2	79.96 ± 2.63	BHDD033	100.0	117.4
14JZBHZ92	Andesite	illite <2µm	5.532	1.7490×10 ⁻⁵	47.3	79.55 ± 2.95	BHDD032	100.0	
		w.r. 010.25	2.745	8.5322×10 ⁻⁶	35.5	78.24 ± 3.41		136.1	142.0
14JZBH294	Andesite	illite <2µm	5.130	1.6709×10 ⁻⁵	70.2	81.90 ± 2.62	BHDD017		
		illite <5µm	5.399	1.6659×10⁻⁵	60.7	77.68 ± 2.59			
	Andesite	w.r. 010.25	2.788	8.9206×10 ⁻⁶	54.9	80.49 ± 2.78		51.6	64.8
14JZBH296		illite <2µm	4.511	1.6083×10 ⁻⁵	48.3	89.65 ± 3.28	BHDD083		
		illite <5µm	5.254	1.5707×10 ⁻⁵	42.8	75.31 ± 2.93			
14JZBH295	Sandstone	illite <2µm	5.137	1.6083×10 ⁻⁵	72.1	78.79 ± 2.49	BHDD084	192.5	202.0
1417011200	Sandstone	illite <2µm	4.791	1.5315×10 ⁻⁵	50.8	80.42 ± 2.87		211.0	212.8
14J28H298	Sandstone	illite <5µm	4.806	1.5059×10 ⁻⁵	50.8	78.86 ± 2.82	впрроз	211.0	
14JZBH299	Sandstone	illite <2µm	4.631	1.7932×10 ⁻⁵	46.9	96.96 ± 3.60	BHDD085	192.0	195.0

Table 5.4: The results of the K-Ar analyses, for two illite fractions (<2 µm and <5 µm) and the whole rock samples (w.r.) with the location of samples in drill holes. Collar locations and orientations of the drill holes are in Appendix G.



Figure 5.7: Summary of the geochronology of the magmatic, sedimentary and mineralization in the TMC, with an emphasis on the Bigar Hill deposit (compiled from Janković et al., 1981; Banješević et al., 2001; von Quadt et al., 2002; Clark and Ullrich, 2004; Zimmerman et al., 2008; Tosdal, 2012; this study).

6.1 Depositional Environment and Alteration of the Gold-Hosting Sedimentary Package

Deposition of the sedimentary package hosting the Bigar Hill mineralization took place from Late Jurassic until Late Cretaceous time. Several stratigraphic units, interpreted from surficial mapping and drill hole logs, were deposited during that time: Late Jurassic (Oxfordian-Kimmeridgian and Tithonian) limestone (JLS), Early Cretaceous (Valanginian-Hautrivian and Barremian-Aptian) limestone (KLS), calcareous siliciclastic rocks of Albian age (S1), Late Cretaceous volcanic detritus-rich calcareous siliciclastic rocks (S2), and Santonian marl (SMR). Deposition of the sedimentary package was episodic, with several notable unconformities recorded between JLS and KLS, KLS and S1, S1 and S2, that span up to several million years.

Regionally, in the western margin of the TMC, the sedimentary package was deposited transgressively over the paleorelief composed of the Paleozoic crystalline basement rocks (Dimitrijević et al., 1970).

The limestone sequence of the Bigar Hill sedimentary package is part of the carbonate platform that developed during the Late Jurassic and Early Cretaceous (Grubić and Jankičević, 1973). The limestone sequence encompasses four carbonate facies of different ages: Oxfordian-Kimmeridgian micritic limestone and dolomite, Tithonian bioclastic and oolitic limestone, Valanginian-Hauterivian "dirty" micritic limestone and Barremian-Aptian bioclastic limestone. Each of the carbonate units exhibits textural differences that indicate distinct depositional environments. Reef limestone is formed on the peripheral parts of the platform, while micritic limestone is deposited in the deeper parts, contains chert concretions characteristic of a deep-marine environment (Vasić, 2012). Over time, primary sedimentary features in the limestone sequence were altered to a varying extent by tectonic activities, karstification, pressure dissolution, and thermal and chemical alteration related to localized intrusions and percolating fluids. Fault and fracture zones, karst features, brecciation, stylolite seams, skarn alteration, recrystallization, or silicification are regular features in the preserved rocks. The chemical and mineralogical composition of the Jurassic platform carbonate sequence is generally homogeneous with negligible input of non-carbonate material.

In contrast, the Valanginian-Hauterivian "dirty" limestone contains variable proportions of organic or clastic matter, and consequently, its chemical composition differs from the other limestone facies. This
limestone facies contains higher background values of lithophile and siderophile elements (e.g., K, Rb, Cs, Be, Mg, Sr, Fe, Sc, Cr, Al). Elevated iron content makes this limestone facies more reactive in contact with acidic gold-bearing fluids than the other limestone facies.

The Cretaceous limestone is not laterally-continuous in the deposit area due to the tectonic complexity of the area and variable erosion rates for discrete structural blocks. Organic material-rich black limestone facies of the Valangian-Hauterivian limestone has a variable thickness over the deposit area, from a few to several tens of meters. The Barremian-Aptian limestone is only sporadically observed in the eastern part of the Bigar Hill area, even though it is a large regional unit. However, clasts of this limestone facies represent one of the dominant components of the overlying basal breccia of the S1 unit. Abundant evidence for exposed surface weathering of the carbonate platform during regressive cycles includes collapsed sinkholes and caves, fissure enlargement due to preferential dissolution along fracture system, the formation of terra rossa, laminated clastic rocks infilling caves, and fissures. Karstification has most strongly developed on the surface and sub-surficial part of Tithonian and black Valanginian-Hauterivian limestone, particularly along NW- and NE-oriented fault and fracture systems.

Deposition of the sedimentary package S1 started in the Albian, following the Austrian deformation phase of the Alpine orogeny (Knaak et al., 2016). The unit S1 is heterogeneous, composed of various calcareous siliciclastic rocks. The basal breccia (BBX) is present at the lower levels of the S1 unit, lying unconformably over the limestone. The distribution of the breccia is not continuous and displays frequent, abrupt variations in thickness. In the northwestern part of the deposit area, the breccia is thin or not developed (potentially eroded); in the central part of the deposit, it reaches up to 50 m, preferentially in the zone of intersection of NW- and NE-faults. This poorly-sorted breccia contains limestone fragments and quartz pebbles in silty to very coarse-grained matrix cemented by calcite or Fecalcite. Variability in breccia composition, textural characteristics and its spatial distribution implies a complex genesis from several processes. Partly, the basal breccia formed during regional tectonic activity and represents fault scarp-derived deposits that are characterized by large angular dropstone clasts. Other sections appear to preserve debris flow deposits of terrestrial alluvium mixing with coarse limestone fragments derived from eroding shorelines (Vasić, 2012; Knaak et al., 2016) or intense karst activity at the surface of the underlying limestone.

Black, laminated, very fine-grained clastic rocks (IB) is another facies deposited within the S1 unit. The main constituent of the IB sub-unit is clastic detritus with low carbonate components. The abundance of clay and silt-size fraction, along with clay minerals contributed to the low porosity and permeability of

the rock. The IB mudstone and siltstone have a pronounced spatial variability, not formed in the northwestern part of the deposit area, and with scatter occurrences in the northern area. The IB overlies basal breccia or Cretaceous limestone, or it can appear in the form of the lenses within the S1 sandstone. Mudstone/siltstone upper boundary with the S1 clastic rocks is transitional, and it extends up section to a few tens of meters.

The S1 sub-unit sensu stricto represents the dominant part of the S1 unit. Unlike the basal breccia and IB, the S1 shows lateral continuity. However, its thickness is variable, exceeding 100 m in the northwestern part of the deposit. Deposition of the S1 and IB sub-units is interpreted to have been contemporaneous, as products of a continuous process in transitional and marine environments, where they developed laterally adjacent to each other. Based on changes in the thickness of the unit, the possible direction of detrital material transport is from the northwest. However, the precise detritus movements are difficult to ascertain due to the structural complexity of the area. The S1 sub-unit is composed of the transitional varieties from calcareous sandstone to sandy limestone. Its principal constituents are detrital material originating from the metamorphic complex, and carbonate components, which are partly clastic, but mainly form a rock cement. Cement is composed of sparry calcite to iron-bearing calcite. Clastic-rich varieties are typical for the lower parts of the sub-unit, while the carbonate-rich facies are more abundant in the upper horizons. One of the pronounced textural characteristics of the rocks is the abundant occurrence of stylolite fractures, preferentially developed in the carbonate-rich facies.

Before the deposition of the overlying S2 unit, the surface of the S1 was exposed to weathering and erosion, in some cases to a depth of several meters. Rocks were fractured, brecciated, likely transported and re-deposited. Chemical weathering did not appear to be widespread – red iron crusts resulting from chemical weathering occurs sporadically. Disruptions of the rock coherency by the weathering and erosion increased primary porosity and permeability, making the S1/S2 contact zone favorable environment for subsequent hydrothermal fluid circulation.

The overlying volcanic detritus-rich, calcareous siliciclastic S2 unit is compositionally complex, with distinct vertical variations from carbonate-rich at the bottom to volcaniclastics dominated at the top. In both cases, calcite or iron-bearing calcite cemented the detrital material. The thickness of the unit is relatively constant, except in the northwestern part of the deposit where it decreases due to erosion of its upper levels. The source of the volcanic detritus in the S2 and direction of this material transport is not unequivocally established. However, the ages of the detrital zircons in the S2 (93.3 \pm 3.1 Ma – 87.5 \pm

3.1 Ma) coincide with the age of the oldest magmatic rocks in TMC, and therefore it is assumed that the protolithic sources of the S2 are in the east of the deposit.

Marl lies conformably over the S2 unit. Their contact is transitional, with the alternation of sandstone and marlstone for a few meters in the contact zone. The ratio of the clastic and carbonate components in marl is variable. Clay and white mica minerals have a significant share in the detrital material. These minerals along with the other very fine-grained components result in marl having a low porosity and permeability. In the area of the Bigar Hill, marl is intruded by a Late Cretaceous andesite sub-volcanic sill. In their contact zone, weak contact thermal metamorphic alteration affected the marl.

The Bigar Hill calcareous sedimentary sequence is heterogeneous, comprising rocks of different composition, grain size, and textural features, characterized by rapid lateral facies and thickness changes. Lithofacies exhibit a variable potential for fluid circulation and gold mineralization. The basal breccia, S1, and S2 sandstones are the most favorable environments for gold deposition, particularly their contact zones (BBX/limestone, and S1/S2).

6.2 Structural Control on Mineralizing Fluids

Stratigraphy exerts substantial control over the spatial distribution of mineralization. However, deposition of gold was primarily conditioned by structures that enhanced local permeability and porosity in the host rocks. The resulting pathways allowed gold-bearing fluids to reach horizons favorable for deposition.

A regional structural network formed through a series of tectonic events since the Paleozoic Era. Late Paleozoic Variscan orogeny produced N- and NW-oriented faults (present-day orientation). Weak extension dominated during the Late Jurassic to Early Cretaceous. Subsequent mid-Cretaceous Austrian compressional phase of the Alpine orogeny re-activated the old NW-oriented basement structures and formed a series of NE-oriented faults (Schmidt et al., 2008; Knaak et al., 2016). Intermittent extensional and compressional phases continued throughout the Late Cretaceous accompanied by arc magmatism and subsequent hydrothermal activities. During the transition to the Cenozoic Era, the region underwent the Laramide deformational phase of the Alpine orogeny. Significant deformation occurred along normal, reverse and strike-slip faults during oroclinal bending in the Oligocene and Miocene. The extension during the Miocene caused E-W normal faulting, forming grabens and half-grabens (Schmidt et al., 2008; Knaak et al., 2016 and the references therein; Shaw and Johnston, 2012). In the broader Bigar Hill region, N- to NW- trending structures are evident in the orientation of the large Potaj Čuka monzonite pluton (south of the Bigar Hill), and also in the alignment of porphyry clusters (east of the deposit). Anomalously high gold and chalcophile pathfinder elements in soils also align with these trends (Knaak et al., 2014). Narrow, elongated anomaly zones are particularly well-developed east of the Bigar Hill, over the porphyry clusters and volcanic complex, and also south of the deposit, in soils developed over limestone (Figure 6.1). The surface manifestations of the NE-oriented structures are evident as aligned sinkholes in the limestone karst, particularly north of the Bigar Hill. E-trending structures are also inferred from karst features, but to a lesser extent. This E-W structural trend is most apparent in the orientation of the horst-and-graben systems. Bigar Hill is bounded by parallel E-W faults, which ultimately preserved the mineralization from the erosional processes in the down-dropped graben.

Although the main regional structures are well-understood, detailed field mapping and core logging did not provide a clear understanding of the Bigar Hill structural framework. In addition to the E-trending structures, several N-trending faults were identified before this study. However, the presence of highly fractured rocks, notable facies changes, and NW- and NE-trending orientations of gold distribution suggested a more complex structural network. To visualize this framework, a 3D model was developed using lithologic information logged from the Bigar Hill diamond and reverse circulation drill holes (Figure 3.6). During the modeling process, special attention was given to the rapid facies changes (i.e., bed thickness and spatial orientation). Matching orientations and bed thicknesses provided a reconstruction of the original morphology of the sedimentary units. Comparing that model with the current lithologic information suggests that a series of faults have broken and reoriented the host rocks into discrete, fault-bounded blocks. The orientations of the newly defined faults are WNW to NW, NE, and E. The WNW- and NE-trending faults generally coincide with the gold mineralization trends.

The distribution of accompanying trace elements also supports the orientations of the inferred faults. At the local scale of the Bigar Hill deposit, elements exhibit both horizontal and vertical zoning along differently oriented trends. Geochemical anomalies of Bi, W, Pb, Zn, In, Cd, Se, Te can be traced along the NW-trend in limestone, decreasing towards the northwest. At higher stratigraphic levels, the dominant trace element assemblage is different, reflecting precipitation from low-temperature fluids. This assemblage includes Au, As, Sb, Tl, Hg, Te, and Ag (Figure 6.2). In the S1 unit, the trace elements are evenly distributed along both NW- and NE-trends, while in the upper S2 unit, they occur along the NE-trend.



Figure 6.1: Pathfinder metal associations from soil (defined using the weighted sums technique) over the geological map of the northwestern Timok magmatic complex (modified from Knaak et al., 2016).



Figure 6.2: Trace elements distribution in (a) limestone, along NW-trend, and (b) all the units above the limestone, along NE-trend; Avala Resources data set.

Trace element zoning suggests that the mineralizing hydrothermal fluids arrived from the southeast, first utilizing the NW-trending fault zone at its deeper levels. At the intersection with the NE-trending structures, fluids partly utilized these new corridors, while generally moving upward into the stratigraphically higher, clastic sedimentary units. The NW and NE faults served as first and second order fluid corridors to favorable gold-hosting horizons in the sedimentary package. The sequence of events indicates that these structural trends formed before mineralization. Details of structural controls at the scale of mineralization are discussed further in section 6.3.

The role of the E- and N-oriented structures as the fluid corridors is not clear. There is no continuity in either gold or trace element distribution along these faults, but several anomalous zones near their

intersections with the primary fluid pathways suggest that they could also be pre-mineralizing structures, re-activated by subsequent tectonic activity.

6.3 Deposit Formation – Favorable Host Environments, Critical Processes, Hydrothermal Alteration, and Metal Association

6.3.1 Gold-hosting Environments

Gold enrichments are present in all lithologic units, to variable extents. Fault and fracture zones represent one of the two main loci for the ore deposition. These structurally disturbed zones represent environments with increased permeability and porosity contrary to the undisturbed surrounding rocks and therefore provide important pathways for gold-bearing fluids. Gold mineralization deposited in marl or andesite is entirely structurally controlled, as the porosity and permeability of the undisturbed rocks are generally very low and gold-bearing fluids cannot infiltrate these rocks from fractures (Yoo et al., 2013). Similarly, the limestone is generally impermeable, however, beside fault and fracture zones, specific rock disturbances such as stylolites or karst modifications or particularly reactive clastic infill, can produce a local increase in porosity and permeability.

The S1 and S2 clastic units represent the most favorable host rocks, where in addition to structural factors, their stratigraphic features play a significant role in controlling the spatial distribution of fluid flow and gold deposition. During a hiatus in sedimentation, weathering and erosional processes affected the surfaces of the limestone and the S1. Limestone/S1 and S1/S2 contacts, as disturbed zones, enabled lateral spreading of the fluids. These clastic units have higher permeability relative to the other units, specifically the S1 and S2 sandstone and conglomerate, and particularly the basal breccia sub-unit developed at the bottom of the S1 unit. Acidic fluids in the contact zones infiltrated the pores of the surrounding rocks and dissolved calcite cement, creating secondary porosity. Gold-bearing fluids infiltrated several tens of meters from the contact zones, utilizing pore space in sandstone, conglomerate, breccia, stylolites and karst features in limestone. In the S1 upper horizons and S2 lower horizons, carbonate material that dominates over the clastic detritus was exposed to dissolution. Schematic model of the formation and modifications of the Bigar Hill deposit are shown in Figure 6.3.









Figure 6.3: Schematic diagrams of the formation and modification of the Bigar Hill deposit (not to scale): (a) Formation of the sedimentary package and its structural modification, karstification and formation of the weathering crust; (b) Magmatic activity affecting the sedimentary package – diorite intrusion in the vicinity of the deposit and andesite sub-volcanic sill intrusion within the deposit; (c) hydrothermal activity within the Bigar Hill region, porphyry deposit formation in the vicinity of the deposit within Bigar Hill; (d) burial of the deposit along graben forming faults.

The iron content required for sulfidation varied in different hosting units, in the Cretaceous limestone from 0.1 to 0.4%, in the S1 from 0.6 to 1.3%, and in the S2 unit from 2 to 3.5% (all ranges are interquartile). Iron in the host rocks originated from multiple sources. In the S1 unit and Cretaceous limestone, iron mainly derived from the iron-bearing carbonates. In the S2 unit, major iron-bearing minerals are hematite, magnetite, ferromagnesian minerals from the volcanic detritus, and Fe-carbonates. It is assumed that the major source of iron for the mineralization process derived from carbonates that are easily dissolved by acidic fluids.

6.3.2 Hydrothermal Alteration

Hydrothermal fluid-rock interactions result in chemical alteration of both interacting agents. The pervasiveness and intensity of alteration vary depending upon volume, composition and thermodynamic changes of the circulating fluids, including temperature, pH and Eh changes, but also upon host rocks composition, and its mechanical properties including permeability and porosity (Teal and Jackson, 1985). Four main rock alteration types include carbonate dissolution, clay alteration, silica addition, and sulfidation. Decarbonatization is the result of the reactions of acidic fluids with calcite mainly from the cement of the clastic host rocks. The most intensive effects of dissolution, with the removal of all the carbonate components, develop locally at the S1/S2 contact, affecting the narrow zones of few meters.

To a lesser degree, decarbonatization effects are noticed to affect the calcite cement in the basal breccia, and also in the fracture zones of "dirty" Cretaceous limestone. In all the cases, the alteration is accompanying by gold enrichment, indicating the intensive fluid-rock interactions.

Hydrothermal silica replacement of calcite cement and carbonate fragments is sparse and of low intensity, noted only in the areas with strong carbonate dissolution and high gold grades. The absence of intensive silicification indicates the relatively low temperature of ore formation since silica precipitation is significantly reduced below ~180°C, and diminishes with further cooling, while gold precipitation may continue (Hofstra and Cline, 2000; Emsbo et al., 2003; Cline et al., 2005).

Clay alteration has the most substantial impact on the rocks containing alumino-silicate minerals, such as andesite, or volcanic detritus-rich clastic rocks of the S2. Due to the low porosity of andesite, clay alteration was confined in the fault zones, where fluids were able to flow and interact with the rock. Illite is the dominant clay species, identified using the SWIR analysis, while kaolinite and montmorillonite form to a lesser degree. Dickite, nacrite, halloysite are sparsely identified by SWIR (Appendix C).

During the interaction between hydrothermal fluids and host rocks, along with the dissolution of carbonates and clay alteration of silicates, the iron released from these, and any other reactive Febearing minerals, reacted with sulfur ions from the fluids, precipitating pyrite (Hofstra and Cline, 2000). Ferroan carbonates, dominantly calcite, and dolomite to a lesser degree, are the main iron source in the sedimentary rocks. Less soluble alumino-silicate minerals, hornblende, and chlorite, present in the volcanic detritus-rich S2 clastic rocks and magmatic rocks are the alternative providers of iron. The sulfidation process results in coupled precipitation of iron sulfides with gold. The assumption is that the transport and deposition of gold of the Bigar Hill deposit generally had a similar mechanism as in the Carlin-type deposits. In moderately acidic, H₂S-rich fluids, gold was transported as AuHS⁰ or Au(HS)₂⁻¹ complexes (Hofstra and Cline, 2000; Emsbo et al., 1999). The interaction with calcareous rocks and the dissolution of carbonate minerals caused the neutralization of the acidic fluids. Increasing pH values of the fluids would destabilize the Au-bisulfide complexes, and result in sulfidation of reactive iron released from the Fe-bearing minerals. Liberated gold ions would linger near the newly formed pyrite, and eventually get structurally bound in the sulfide crystal lattice (Hofstra and Cline, 2000; Cline et al., 2005). Except for gold, ore-stage pyrite contains increased content of Sb, Tl, As, Hg and Te. These elements are typical for the low-temperature metal association, and exhibit high correlation with gold.

6.4 Exploration Tools for Hydrothermal Gold Deposits

6.4.1 Hydrothermal Alteration

The alteration minerals are closely related to the increase in gold grades, and generally, do not extend beyond the mineralization zone. The effects of decarbonatization and silicification are visible only in zones affected by the intensive fluid flow, with high gold grades, and thus have a limited application as an exploration tool that can help to establish vectors towards the mineralization.

The distribution of clay species and illite crystallization index were considered as the exploration indicators of ore proximity, particularly since clay mineralogy may indicate specific conditions during the fluid-rock interactions. The transition from smectite (montmorillonite) to illite suggests an increase in temperature (Hofstra and Cline, 2000), or similarly, the transition from kaolinite to its polytypes dickite and nacrite (Ruiz Cruz, 2006). Halloysite is an indicator for lower temperature (<60-75°C) solutions and a higher pH environment, whereas kaolinite forms in more acidic conditions (Drews-Armitage et al., 1996). Illite is a widely distributed clay mineral, present in both hydrothermally altered, and non-altered rocks. Unlike illite, montmorillonite is characteristic for non-altered rocks, and its content decreases with the intensity of the fluid-rock interaction. Kaolinite is not as abundant as illite, but it appears in both non-altered and mineralized rocks. Dickite, nacrite, and halloysite occur only sporadically, and it was not possible to establish zonation indicating the direction of the temperature gradient.

The other parameter used in this study, illite crystallinity, was defined as a ratio of depths of 2200 nm and 1900 nm absorption features. This parameter is temperature dependent, its value rising with the temperature. Thus illite crystallinity could potentially be used to establish vectors of the thermal influence of hydrothermal fluids. However, this parameter did not prove to be a robust indicator of clay mineral formation temperature, and therefore cannot be employed to establish the temperature gradient in the hydrothermal system. The parameter could be roughly used to separate the areas not exposed to hydrothermal activities from the areas with weak to intensive fluid circulation. The reason for the limited benefit of using illite crystallinity is the presence in the same place of different genetic types of illite with different formational temperature. The other reason could be analytical, caused by the interference of absorption spectra from the different minerals present in a sample.

6.4.2 Oxygen and Carbon Stable Isotopes

During the percolation of the hydrothermal fluids through the carbonate-bearing sedimentary package, changes of oxygen and carbon isotopic composition affected both the rocks and the fluid system. Rocks

interacting with fluids show depletion in both δ^{18} O and δ^{13} C values. Oxygen isotope ratios shift from the background values of 29.6-24.2‰ to the altered values of 8.9‰. Carbon shows a slightly lower degree of change, altering from 4.2-1.2‰ in fresh to -4.6‰ in mineralized rocks. When establishing the extent of isotopic depletion, it was essential to consider different background signatures appropriate to different carbonate units. Lower background values of both δ^{18} O and δ^{13} C (25.3-24.2‰ and 1.5-1‰ respectively) are noted in organic matter rich mudstone, while in the other sedimentary units these values are variable but higher. Isotopic depletion has a weak correlation with gold enrichment, while the correlation with gold accompanying trace elements (Hg, Tl, Sb, As, Te) is somewhat stronger. Even though changes in δ^{18} O and δ^{13} C do not correlate strongly with the distribution of gold mineralization, they clearly outline the domains around the feeder and main fluid conduit structures and highly porous and permeable discontinuities in sedimentary rocks. To a limited extent, isotopic shifts enable the identification of the inferred (sub-) vertical faults, as the zones with noticeable oxygen/carbon depletion. The halo formed during the isotopic exchange extends over a few hundred meters around mineralization, and it is broader than the distribution of alteration minerals or trace elements that formed during the same processes and generally coincided with the gold distribution (Figure 6.4).



Figure 6.4: Distribution of δ^{18} O (grid data), As (downhole data), and illite crystallinity (point data) and their spatial relationship with gold, and structural and stratigraphic controls.

The broader distribution of isotopic alteration can be effectively utilized in exploration. If accurate background values are established for the particular carbonate-bearing sedimentary rocks, tracking the changes in the isotopic composition can be a useful tool in vectoring towards blind deposits at depth or identifying structurally or stratigraphically controlled fluid pathways.

6.5 Temporal Constraints on Geological Processes Relevant to the Bigar Hill Deposit Formation

To fully characterize the mechanism of the Bigar Hill deposit formation, it is crucial to establish the chronology of relevant sedimentary, magmatic and hydrothermal events. The geochronology data helps not only to understand better the processes that preceded or enabled the gold deposition but also to put those processes into the perspective of the deposit-forming activities in the TMC and the broader Cretaceous Carpathian-Balkanian belt.

The ages of the stratigraphic units were defined mainly by characteristic fossils and superposition relationships. The age of the S2 unit was established indirectly using U-Pb geochronology on detrital zircons. The window of 93.3 ± 3.1 Ma to 87.5 ± 3.1 Ma defines the age range of igneous protolith rocks and indirectly suggest the maximum age of the clastic rocks. Taken together, these data constrain the period of regional sedimentary deposition between the Late Jurassic to Late Cretaceous. During that period sedimentation was not continuous, and the breaks between deposition of major stratigraphic units lasted for several millions of years. The rocks were subsequently exposed to weathering and erosional processes, resulting in increased porosity and permeability, and local iron enrichment, thus forming the favorable horizons along which the gold-bearing fluids were flowing into the sedimentary rocks.

Determining the age of the gold mineralization proves to be a complex task. The very fine-grained character of mineralization, as well as the paucity of datable or separable minerals with a clear genetic association with gold, represent the main difficulties. Due to the inability to establish the direct age of the Bigar Hill disseminated mineralization, the K-Ar technique has been applied on illite that formed during hydrothermal alteration. Previous petrographic studies suggest a spatial relationship of illite and gold-bearing pyrite. Therefore, illites were separated from the intensively altered and highly mineralized S2 sandstone and andesite. Dating identified the ages for the illite formation at approximately 79 ± 3 Ma, excluding two older samples which are considered to partially represent detrital illite. The Campanian age of the dated clay minerals suggests that the hydrothermal activity within the

sedimentary package was largely contemporaneous with the Late Cretaceous magmatic activity in the northwestern TMC. Another approach used to indirectly determine the age of mineralization includes dating an andesite sill from the Bigar Hill and a younger diorite from the eastern margin of the deposit using the U-Pb in zircon technique. The idea of dating andesite sill was to establish the maximum age of the gold mineralization given that this is the youngest gold-bearing lithology unit, but the sample yield no zircons or any other datable mineral. However, the age of the plagioclase-hornblende porphyritic diorite that intruded the andesite sill is determined to be 80.2 ± 0.8 Ma, indirectly constraining the minimum age of the sill and the maximum age of the ore-forming processes. This age matches within the error with the K-Ar age of illite, thus increasing the credibility to the interpretational Campanian age of mineralization.

Previous U-Pb zircon dating of the intrusive rocks in the northwestern part of the TMC (Tosdal, 2012), was conducted with the goal to establish the time frame of the magmatic activity, indicating a period of 2–6 million years from 82.5 \pm 0.6 to 78.5 \pm 2.0 Ma. Although temporal and spatial associations exist between the ore deposit and local diorite intrusions, their genetic link remains unproven. However, the geochemical footprint established by soil data, and the zonal distribution of chalcophile metals ranging from the high temperature assemblage (Cu, Mo, Au), intermediate (Pb, Zn, Ag, Au) to the low temperature assemblage (Au, As, Sb, Hg, Tl, Te) suggest a potential genetic relationship between the Bigar Hill mineralization and the Čoka Rakita gold porphyry system to the southeast (Figure 5.2 and Figure 6.1). The age of large Potaj Čuka monzonite batholith positioned south of Bigar Hill was determined to be between 80.0 \pm 1.2 to 79.9 \pm 0.5 Ma, but because its spatial and temporal relationship with the SHDG is unclear, a genetic link is not well-established. However, the impact of this sizeable magmatic body should not be neglected, at least as a thermal driver for the circulation of surface fluids and potentially as a source of gold-bearing magmatic-hydrothermal fluids.

6.6 Deposit Model

A proposed metallogenic model suggests that the SHDG mineralization represents the distal extension of the porphyry Au system (Knaak et al., 2016). In that model, the porphyry system is considered to be a source of metal and heat. The origin of hydrothermal fluids, either from magmatic or meteoric water, remained unconstrained. "The perfect storm" of structural and stratigraphic features has provided favorable conditions for the circulation of gold-bearing fluids, their interaction with the sedimentary rocks, and ultimately gold precipitation. NW-oriented faults are recognized as the feeder structures that channeled fluids from the source towards the favorable stratigraphy. NE structures had a role in

increasing the permeability of sedimentary rocks that opened additional pathways for fluid flow. Within such structurally prepared, heterogeneous sedimentary package, its units had a different significance for fluid flow and the associated gold mineralization. Calcareous units with reactive iron, primarily permeable and porous, disturbed by processes like weathering, erosion, karstification, pressure dissolution and structural events that further increased permeability and porosity, proved to be the most favorable host rocks. For all these reasons, the S1 and S2 units, particularly the contact zones between S1 and S2, and also S1 (basal breccia) and the Cretaceous limestone served as the main mineralization hosts.

The continental margin thick sequence of reactive calcareous sedimentary rocks, structurally modified by intermittent extensional and compressional deformation phases represents the ideal pre-mineral architecture that favored the deposition of the Bigar Hill gold mineralization, but also Carlin-type deposits. Apart from the stratigraphic and structural gold controls, Bigar Hill shares many key characteristics of the ore-forming processes with Carlin-type deposits, such as hydrothermal alteration, gold deposition mechanism, and the accompanied trace metals. In interaction with acidic fluids, calcareous host rocks were exposed to decarbonatization and silicification. Magmatic rocks that were part of the host rock package were exposed to argillization with illite and kaolinite as dominant minerals. Gold is hosted in pyrite or in its oxides. Trace metals associated with gold are As, Sb, Te, Tl, and Hg. Orefluids utilized the pathways within zones of increased permeability. However, genetic and spatial relation to magmatic intrusions, porphyry, skarn, and polymetallic replacement deposits classifies the Bigar Hill as the distal disseminated gold deposit (Figure 6.5). Its gold grade is relatively low compared to Carlin-type deposits. However, gold deposition from higher-temperature fluids (>250°C) and higher concentrations of silver and base metals that are typical for distal disseminated deposits but not for the Bigar Hill. Based on the characteristics that the Bigar Hill shares with the Carlin-type and distal disseminated gold deposits it can be defined as the transition between these two genetic types of gold mineralization.



Figure 6.5: Simplified NW long section across the Bigar Hill, Bigar and Čoka Rakita, showing the spatial distribution of different magmatic-hydrothermal mineralization types.

CHAPTER 7 – CONCLUSION, EXPLORATION IMPLICATIONS, AND RECOMMENDATIONS FOR FUTURE WORK

7.1. Conclusion

The Bigar Hill is a sediment-hosted disseminated gold deposit hosted in calcareous rocks. The mineralization-hosting sedimentary package unconformably overlies metamorphic basement and is composed of a Late Jurassic and Early Cretaceous carbonate platform limestone sequence and Early to Late Cretaceous calcareous clastic rocks. The limestone sequence includes geochemically pure Jurassic limestone and "dirty" Cretaceous limestone with variably abundant organic and clastic components. The clastic sequence contains several calcareous units: (1) S1 siliciclastic unit, dominantly composed of sandstone to sandy limestone, but also mudstone and siltstone (IB sub-unit) and basal breccia (BBX), (2) S2 volcanic detritus-rich sandstone and conglomerate, and (3) marl. The youngest lithology is a sub-volcanic andesite sill that intruded the marls. All of the lithology units host gold enrichment in variable grades, mainly depending on their structural and stratigraphic features.

The NW-trending, high-angle, long-lived fault system acted as a primary gold-bearing fluid corridor. Its increased permeability and porosity compared to the structurally-undisturbed country rock facilitated transportation of metals-bearing fluids from deeper sources. NE-trending faults are second-order structures that additionally increased permeability. These fault systems also enabled infiltration and subsequent lateral spreading of the gold-bearing fluids into favorable mineralization horizons. The locations of these faults are constrained by 3D modeling, by visualizing changes in thickness and by the orientations of the stratigraphic units. The distribution of gold and associated trace metals corroborates the presence of the main structural trends. The zonation of the trace metals supports the hierarchy of differently oriented faults in channeling fluid flow, where the high and moderate temperature fluids deposited elevated Bi, W, Pb, Zn, In, Cd, Se, Te along the NW-trend in the lower stratigraphic units (limestone), while the low-temperature assemblage with elevated As, Sb, Tl, Hg, Te, and Ag followed the NE-trend in the upper, clastic units.

Gold-bearing acidic fluid flow along (sub-) vertical faults and fracture zones infiltrated sedimentary units laterally along zones of internal structural heterogeneity. The main discontinuities include unconformities between sedimentary units, comprising weathering crust, the karstification of former surfaces, and breccia bodies. Stylolites are another feature characteristic of the calcareous rocks that are

frequently utilized by fluids. In these conduits, acidic fluids would infiltrate surrounding rocks and react with carbonates, dissolving the calcite cement or carbonate fragments and creating secondary porosity and permeability.

Gold precipitation occurs during the sulfidation that results from the reaction of sulfur in the hydrothermal fluids with iron in the host rocks, which destabilizes aqueous Au-bisulfide complexes (Muntean, 2016). Ferroan carbonates are the main iron-bearing minerals in the sedimentary sequence, while hornblende or chlorite represent the iron source in magmatic rocks or volcanic detritus-rich S2 clastic rocks. The highest gold concentrations occur along the S1/S2 and basal breccia/Cretaceous limestone contacts. Patchy and relatively low concentrations of gold precipitated along the karstified contact between Jurassic and Cretaceous limestone. Structurally-controlled mineralization, of relatively high importance but restricted distribution occurs in the fracture zones in the Cretaceous limestone and andesitic sill.

The interaction between host rocks and low-temperature, acidic fluids caused compositional changes in both the rock and the fluid and eventually led to gold deposition. Carbonate dissolution, silica addition and clay alteration of silicate minerals are the most prominent consequences of hydrothermal alteration. The most intensive decarbonatization affected the S1 and S2 units, from their contact zone towards the undisturbed rocks. Pervasive clay alteration was the strongest in the fault/fracture zones in the andesite, but also affected the volcanic detritus of the S2 clastic rocks. The primary product of the clay alteration is illite and to a lesser extent kaolinite and montmorillonite. Silica addition occurs locally and is usually related to highly mineralized zones, where microcrystalline silica replaced calcite cement or carbonate fragments. The described alteration changes do not develop a substantial footprint which exceeds the domain of ore, as is often the case for higher temperature ore systems, but mainly coincide with the distribution of gold.

The interaction of hydrothermal fluids with carbonate minerals results in changes in their oxygen and carbon isotopic composition. Stable isotope depletions occur further away from the mineralization and visible host rock alteration (e.g., decarbonatization), and also from the distribution of specific pathfinder elements such as Hg, Tl, Sb, As, Te. Zones of low stable isotope ratios outline the zones exposed to percolation of hydrothermal fluids.

Previous U-Pb zircon age dating suggests that magmatism in the west and central TMC spanned about six million years during the Late Cretaceous (83.6-77.7 Ma). Diorite and monzonite ages generally fit into

the existing hypothesis of the westward younging of magmatism in the TMC. Available age data indicates that the Potaj Čuka monzonite batholith, although spatially associated, is generally younger than diorite intrusions, except in the cases of Valja Strž and Crna Reka porphyritic diorite whose emplacement happen after the monzonite pluton. The age of one of the main Bigar Hill gold hosting lithologies – the S2 sandstone, is constrained by U-Pb dating of detrital zircons which covers the period from 93.3 to 87.5 ± 3.1 Ma, thus also constraining the age of the sandstone's protolith. Since the erosion rate of the magmatic protolith and the transport distance and duration are unknown, it can only be inferred that the S2 sandstone is younger than the dated zircons. Hydrothermal illite is used as a proxy for gold mineralization and is dated with the K-Ar technique at ca. 79 Ma. The radiometric ages of illite and zircons of the western TMC indicate that deposit-scale hydrothermal and magmatic activities were largely contemporaneous during the Late Cretaceous and that illite formation closely followed zircon crystallization.

7.2 Exploration Implications and Recommendations for Future Work

The Bigar Hill distal disseminated gold deposit is a recent discovery of a previously unrecognized type of mineralization on the flanks of the TMC and the broader Cretaceous arc region. This study has contributed to a better understanding of the geological features and critical processes necessary for the formation of the deposit. The collected data set is significant and informative; it enabled the genetic type of the deposit to be established and evaluated against its global counterparts and also helped to establish targeting criteria for further exploration. Significant exploration implications that can be applied not only on the sedimentary package around the TMC but globally, are represented below:

- Distal disseminated deposits exhibit spatial, chemical and temporal links with related porphyry deposits (e.g., Theodore, 1998; Hofstra and Cline, 2000, Johnston and Ressel, 2004). Exploration for this deposit type should involve the targeting of sedimentary rocks in the vicinity of felsic to intermediate calc-alkaline magmatic centers. The genetic link between the magmatic metal and/or heat source and low-temperature mineralization can be established based on the distribution of pathfinder trace metals, from the high-temperature assemblage of Cu, Mo, Au, through moderate Pb, Zn, Ag, towards low-temperature elements such as Au, As, Tl, Hg, Sb, Te.
- Gold mineralization is present in all of the Bigar Hill lithologic units, including the sub-volcanic andesite sill. However, the main mineralization host rocks are carbonate-bearing sedimentary rocks. Gold exhibited a different susceptibility to the lithologic varieties within the sedimentary carbonate package, with lowest gold content in marls, variable concentrations in limestone, and

highest in siliciclastic S1 and S2 units. The conclusion may be that exploration efforts should focus on carbonate-rich targets, mainly calcareous siliciclastic rocks.

- The structural network represents a first-order control on the spatial location of the
 mineralization. Therefore, understanding of the area's structural framework is crucial for
 exploration. It is important to identify significant faults that have gone through several stages of
 activation and connected the metal source and trap zone. Second order structures that
 channeled fluids further into the host stratigraphy are equally essential to identify. These
 include smaller faults that created additional porosity and permeability of the rocks.
- Within calcareous sedimentary units, mineralization lies along the contacts of limestone and S1, or S1 and S2. These contact zones have been modified by surface weathering and erosion (karstification), thus producing preferential pathways for the mineralization fluids. Focusing on contact zones narrows the target zone within the sedimentary package.
- A better understanding of the alteration product assemblages, including clay minerals, could enable their successful use as exploration vectors in low-temperature hydrothermal systems. SWIR spectroscopy carried out in this study elucidated the spatial distribution of clay minerals and allowed calculation of the illite crystallinity index as the ratio of the depth of AIOH and water adsorption features. However, identification of illite crystallinity zonation patterns is hampered by the presence of different genetic varieties of illite that are indistinct from one another by SWIR spectroscopy (hydrothermal, diagenetic, or detrital). Further study on various clay characteristics such as chemical composition, textural features (size, morphology), polytypism, Kübler illite crystallinity index or formation temperature could help establish vectors to mineralization.
- Variations in δ^{18} O and δ^{13} C values in carbonate host rocks acted as a tool to identify isotopic alteration and to delineate hydrothermal fluid flow pathways within the deposit. Oxygen and carbon isotope ratios have proven useful for identifying hydrothermally altered lithologies that did not develop visible secondary mineral assemblages. The extent of stable isotope alteration is larger than that of gold and other recognized pathfinder elements. Recent advances in analytical techniques have simplified the measurement procedure and increased the sample throughput rate at reduced analytical cost (Barker et al., 2013; Beinlich et al., 2017). Therefore, tracking the changes in δ^{18} O and δ^{13} C constitutes a powerful tool in mineral exploration for carbonatehosted gold deposits, and complements traditional geochemical and geophysical surveys.

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Hole ID	Sample ID	Easting	Northing	UTM Zone	Elevation/Depth (m)	Sample Description	Lithology Unit	Thin Section	Carbonate Staining
BHDD083	13JZBH001	570704	4898132	UTM(WGS84)34N	785/-50.35	Propylitic altered andesitic sill	VOL		
BHDD083	13JZBH002	570704	4898132	UTM(WGS84)34N	785/-62.25	Clay altered andesite with pyrite disseminations	VOL	+	
BHDD083	13JZBH003	570704	4898132	UTM(WGS84)34N	785/-71.8	Propylitic altered andesitic sill	VOL	+	
BHDD083	13JZBH004	570704	4898132	UTM(WGS84)34N	785/-77.6	Weakly clay altered andesite	VOL		
BHDD083	13JZBH005	570704	4898132	UTM(WGS84)34N	785/-89	Propylitic altered andesitic sill	VOL	+	
BHDD084	13JZBH006	570652	4898169	UTM(WGS84)34N	785/-172.95	Green sandstone with dominant volcanic detritus	S2	+	
BHDD084	13JZBH007	570652	4898169	UTM(WGS84)34N	785/-173.6	Gray, partially decarbonatized sandstone, with disseminate pyrite	S2	+	
BHDD084	13JZBH008	570652	4898169	UTM(WGS84)34N	785/-175.6	Gray, partially decarbonatized sandstone, with disseminate pyrite	S2	+	+
BHDD084	13JZBH009	570652	4898169	UTM(WGS84)34N	785/-191.62	Gray sandstone with pyrite disseminated and in veins	S2		
BHDD084	13JZBH010	570652	4898169	UTM(WGS84)34N	785/-200.52	Transition from non-altered to visibly decarbonatized sandstone	S2		
BHDD084	13JZBH011	570652	4898169	UTM(WGS84)34N	785/-201.2	Sandstone decarbonatized, clay altered and sulfidized with 8 ppm Au	S2		
BHDD084	13JZBH012	570652	4898169	UTM(WGS84)34N	785/-202.3	Sulfidized sandstone	S1		
BHDD084	13JZBH013	570652	4898169	UTM(WGS84)34N	785/-207.6	Carbonate sandstone with stylolites	\$1	+	+
BHDD084	13JZBH014	570652	4898169	UTM(WGS84)34N	785/-219.8	Alternation of sandstone with thin laminas of mudstone	S1		
BHDD084	13JZBH015	570652	4898169	UTM(WGS84)34N	785/-245.37	Alternation of siltstone, fine-grained sandstone, and diagenetic pyrite	IB		
BHDD084	13JZBH016	570652	4898169	UTM(WGS84)34N	785/-250.4	Sulfidized, dolomitized breccia	BBX	+	+
BHDD084	13JZBH017	570697	4898213	UTM(WGS84)34N	775/-94.85	Clay altered, sulfidized andesite	VOL		
BHDD085	13JZBH018	570697	4898213	UTM(WGS84)34N	775/-95.65	Chlorite, epidote altered andesite	VOL		
BHDD085	13JZBH019	570697	4898213	UTM(WGS84)34N	775/-110.33	Chlorite, epidote altered andesite	VOL		
BHDD085	13JZBH020	570697	4898213	UTM(WGS84)34N	775/-161	Hematite rich gravelite	S2		

Hole ID	Sample ID	Easting	Northing	UTM Zone	Elevation/Depth (m)	Sample Description	Lithology Unit	Thin Section	Carbonate Staining
BHDD085	13JZBH021	570697	4898213	UTM(WGS84)34N	775/-167.65	gray, sulfidized sandstone with abundant volcanic detritus	S2	+	
BHDD085	13JZBH022	570697	4898213	UTM(WGS84)34N	775/-190.45	Alternation of sandy and gravelite clastic material	S2		+
BHDD085	13JZBH023	570697	4898213	UTM(WGS84)34N	775/-193.55	Conglomerate, volcanic material rich	S2		
BHDD085	13JZBH024	570697	4898213	UTM(WGS84)34N	775/-194.73	Strongly carbonate dissolved and silicified sandstone	S1	+	
BHDD085	13JZBH025	570697	4898213	UTM(WGS84)34N	775/-195.2	Strongly carbonate dissolved and silicified sandstone with 3.42 ppm Au	S1		
BHDD085	13JZBH026	570697	4898213	UTM(WGS84)34N	775/-196.35	Brecciated, clay altered sandstone	S1		
BHDD085	13JZBH027	570697	4898213	UTM(WGS84)34N	775/-209.6	Oxidized, brecciated sandstone	S1		
BHDD085	13JZBH028	570697	4898213	UTM(WGS84)34N	775/-258.55	Basal breccia, with sulfidized fine- grained matrix	BBX		
BHDD086	13JZBH029	570431	4898382	UTM(WGS84)34N	723/-17.45	Skarn altered marl from the contact with andesite	SMR		
BHDD086	13JZBH030	570431	4898382	UTM(WGS84)34N	723/-53.5	Laminated marl	SMR		
BHDD086	13JZBH031	570431	4898382	UTM(WGS84)34N	723/-60.9	Fine-grained sandstone with disseminated diagenetic pyrite	S2	+	+
BHDD086	13JZBH032	570431	4898382	UTM(WGS84)34N	723/-67.6	Coarse-grained sandstone with abundant volcanic material	S2		
BHDD086	13JZBH033	570431	4898382	UTM(WGS84)34N	723/-74.4	Fine-grained sandstone with disseminated pyrite	S2	+	
BHDD086	13JZBH034	570431	4898382	UTM(WGS84)34N	723/-82.35	Contact between non-altered and decarbonatized sandstone	S2	+	+
BHDD086	13JZBH035	570431	4898382	UTM(WGS84)34N	723/-84.6	Strongly oxidized and brecciated sandstone	S1		
BHDD086	13JZBH036	570431	4898382	UTM(WGS84)34N	723/-90.2	Sandstone exposed to carbonate dissolution	S1		
BHDD086	13JZBH037	570431	4898382	UTM(WGS84)34N	723/-103.6	Partially oxidized, decarbonatized sandstone	S1		
BHDD086	13JZBH038	570431	4898382	UTM(WGS84)34N	723/-125	Sandy limestone	S1		
BHDD086	13JZBH039	570431	4898382	UTM(WGS84)34N	723/-144.45	Laminated mudstone/siltstone	IB		
BHDD086	13JZBH040	570431	4898382	UTM(WGS84)34N	723/-176.55	Faulted breccia-conglomerate	BBX		

Hole ID	Sample ID	Easting	Northing	UTM Zone	Elevation/Depth (m)	Sample Description	Lithology Unit	Thin Section	Carbonate Staining
BHDD087	13JZBH041	570521	4898327	UTM(WGS84)34N	761/-30	Chlorite, epidote altered andesite	VOL		
BHDD087	13JZBH042	570521	4898327	UTM(WGS84)34N	761/-45.8	Clay altered andesite	VOL		
BHDD087	13JZBH043	570521	4898327	UTM(WGS84)34N	761/-54	Strongly clay and carbonate altered andesite	VOL		
BHDD087	13JZBH044	570521	4898327	UTM(WGS84)34N	761/-56	Clay altered andesite	VOL		
BHDD087	13JZBH045	570521	4898327	UTM(WGS84)34N	761/-94.55	Carbonate veins in andesite	VOL		
BHDD087	13JZBH046	570521	4898327	UTM(WGS84)34N	761/-95.15	Chlorite, epidote altered andesite	VOL		
BHDD087	13JZBH047	570521	4898327	UTM(WGS84)34N	761/-122.9	Coarse-grained sandstone with abundant volcanic material	S2		+
BHDD087	13JZBH048	570521	4898327	UTM(WGS84)34N	761/-141.37	Dark, volcanic material rich sandstone	S2		
BHDD087	13JZBH049	570521	4898327	UTM(WGS84)34N	761/-150.7	Green, fine-grained sandstone	S2		
BHDD087	13JZBH050	570521	4898327	UTM(WGS84)34N	761/-151.7	Decarbonatized and clay-altered sandstone	S2		
BHDD087	13JZBH051	570521	4898327	UTM(WGS84)34N	761/-152.1	Decarbonatized and clay-altered sandstone	S2	+	+
BHDD087	13JZBH052	570521	4898327	UTM(WGS84)34N	761/-156.6	Greenish, decarbonatized sandstone	S2		
BHDD087	13JZBH053	570521	4898327	UTM(WGS84)34N	761/-158.2	Faulted sandstone	S2		
BHDD087	13JZBH054	570521	4898327	UTM(WGS84)34N	761/-163.1	Strongly decarbonitized sandstone with sooty pyrite	S2	+	
BHDD087	13JZBH055	570521	4898327	UTM(WGS84)34N	761/-166.65	Strongly decarbonitized sandstone with sooty pyrite with 9.7 ppm Au	S2		
BHDD087	13JZBH056	570521	4898327	UTM(WGS84)34N	761/-168.75	Brecciated sandy limestone	S1		
BHDD087	13JZBH057	570521	4898327	UTM(WGS84)34N	761/-170.3	Partially oxidized, brecciated sandstone	S1		
BHDD087	13JZBH058	570521	4898327	UTM(WGS84)34N	761/-175.63	Sandy limestone	S1		
BHDD087	13JZBH059	570521	4898327	UTM(WGS84)34N	761/-191.3	Carbonate sandstone	S1		
BHDD087	13JZBH060	570521	4898327	UTM(WGS84)34N	761/-209.25	Polymictic breccia, with pyrite in fine- grained matrix	BBX		
BHDD026	13JZBH061	570220	4898565	UTM(WGS84)34N	685/-13.55	Green, volcanic material rich sandstone	S2	+	

Hole ID	Sample ID	Easting	Northing	UTM Zone	Elevation/Depth (m)	Sample Description	Lithology Unit	Thin Section	Carbonate Staining
BHDD026	13JZBH062	570220	4898565	UTM(WGS84)34N	685/-19.15	Contact between oxidized and non- oxidized sandstone	S2		
BHDD026	13JZBH063	570220	4898565	UTM(WGS84)34N	685/-23.85	Oxidized, clay altered sandstone from the fault zone	S2		
BHDD026	13JZBH064	570220	4898565	UTM(WGS84)34N	685/-34.8	Strongly oxidized, decarbonatized sandstone	S2		
BHDD026	13JZBH065	570220	4898565	UTM(WGS84)34N	685/-48.7	Skarn altered sandstone	S1		
BHDD026	13JZBH066	570220	4898565	UTM(WGS84)34N	685/-58.15	Contact between oxidized zone in conglomerate and fresh in sandstone	S1		
BHDD026	13JZBH067	570220	4898565	UTM(WGS84)34N	685/-75.8	Brecciated, skarn altered sandstone	S1		
BHDD026	13JZBH068	570220	4898565	UTM(WGS84)34N	685/-80.2	Sandstone with pyrite disseminations	S1		
BHDD026	13JZBH069	570220	4898565	UTM(WGS84)34N	685/-82.25	Brecciated, skarn altered sandstone	S1		+
BHDD026	13JZBH070	570220	4898565	UTM(WGS84)34N	685/-101	Brecciated sandstone with fine-grained matrix	S1		
BHDD026	13JZBH071	570220	4898565	UTM(WGS84)34N	685/-157.6	Carbonate sandstone	S1		
BHDD020	13JZBH072	570373	4898559	UTM(WGS84)34N	691/-6.1	Oxidized, strongly decarbonatized granulite	S2		
BHDD020	13JZBH073	570373	4898559	UTM(WGS84)34N	691/-13.5	Oxidized, fine-grained sandstone rich in volcanic material	S2		
BHDD020	13JZBH074	570373	4898559	UTM(WGS84)34N	691/-16.7	Strongly oxidized sandstone, decalcified, with 10.66 ppm Au	S2		
BHDD020	13JZBH075	570373	4898559	UTM(WGS84)34N	691/-16.85	From the same interval, less oxidized sandstone	S2		
BHDD020	13JZBH076	570373	4898559	UTM(WGS84)34N	691/-17.9	Weakly oxidized, brecciated sandstone	S2		
BHDD020	13JZBH077	570373	4898559	UTM(WGS84)34N	691/-21.85	Weakly oxidized sandstone	S2		
BHDD020	13JZBH078	570373	4898559	UTM(WGS84)34N	691/-22.9	Strongly oxidized, decarbonatized sandstone	S2		
BHDD020	13JZBH079	570373	4898559	UTM(WGS84)34N	691/-24.05	Strongly oxidized, brecciated, decarbonatized sandstone	S2		
BHDD020	13JZBH080	570373	4898559	UTM(WGS84)34N	691/-30.95	Brecciated sandstone with oxide infill in stylolites	S1		
BHDD020	13JZBH081	570373	4898559	UTM(WGS84)34N	691/-36.4	Dacarbonatized, sulfidized sandstone	S1		

Hole ID	Sample ID	Easting	Northing	UTM Zone	Elevation/Depth (m)	Sample Description	Lithology Unit	Thin Section	Carbonate Staining
BHDD020	13JZBH082	570373	4898559	UTM(WGS84)34N	691/-51	Brecciated sandy limestone	S1		
BHDD020	13JZBH083	570373	4898559	UTM(WGS84)34N	691/-124.35	Carbonate sandstone with finer- grained laminas	S1		
BHDD020	13JZBH084	570373	4898559	UTM(WGS84)34N	691/-153.9	Oxidation front in carbonate sandstone	S1	+	
BHDD020	13JZBH085	570373	4898559	UTM(WGS84)34N	691/-185.15	Breccia with oxidized sandy matrix and limestone clasts	BBX		
BHDD020	13JZBH086	570373	4898559	UTM(WGS84)34N	691/-196.3	Oxidized sandstone breccia matrix	BBX		
BHDD020	13JZBH087	570373	4898559	UTM(WGS84)34N	691/-197.85	Breccia with oxidized granulite size matrix	BBX		
BHDD004	13JZBH088	570364	4898444	UTM(WGS84)34N	701/-17.8	Green, hematite clasts rich sandstone	S2	+	
BHDD004	13JZBH089	570364	4898444	UTM(WGS84)34N	701/-20.9	Clay altered sandstone with disseminated pyrite	S2	+	
BHDD004	13JZBH090	570364	4898444	UTM(WGS84)34N	701/-37.5	Strongly decarbonitized conglomerate- sandstone	S2	+	
BHDD004	13JZBH091	570364	4898444	UTM(WGS84)34N	701/-49.3	Fine-grained, skarn altered sandstone	S1	+	+
BHDD004	13JZBH092	570364	4898444	UTM(WGS84)34N	701/-49.7	Clastite with zones of different alteration	S1		
BHDD004	13JZBH093	570364	4898444	UTM(WGS84)34N	701/-63.3	Brecciated, dolomitized sandstone	S1		
BHDD004	13JZBH094	570364	4898444	UTM(WGS84)34N	701/-69.5	Oxidized, brecciated sandstone	S1		
BHDD004	13JZBH095	570364	4898444	UTM(WGS84)34N	701/-81.7	Brecciated sandy limestone	S1		
BHDD004	13JZBH096	570364	4898444	UTM(WGS84)34N	701/-89.35	Brecciated, partially decarbonatized sandstone	S1		
BHDD004	13JZBH097	570364	4898444	UTM(WGS84)34N	701/-125.25	Laminated mudstone-siltstone	IB		
BHDD004	13JZBH098	570364	4898444	UTM(WGS84)34N	701/-135.45	Breccia, partially decarbonatized	BBX		
BHDD004	13JZBH099	570364	4898444	UTM(WGS84)34N	701/-137	Breccia with partially oxidized and sulfidized matrix and 4.66 ppm Au	BBX		
BHDD004	13JZBH100	570364	4898444	UTM(WGS84)34N	701/-147	Breccia-conglomerate with sandy matrix	BBX		
BHDD004	13JZBH101	570364	4898444	UTM(WGS84)34N	701/-195.8	Gray Cretaceous limestone, fractured, with calcite veins	KLS		

Hole ID	Sample ID	Easting	Northing	UTM Zone	Elevation/Depth (m)	Sample Description	Lithology Unit	Thin Section	Carbonate Staining
BHDD005	13JZBH102	570533	4898412	UTM(WGS84)34N	747/-9.2	Oxidized , thermally altered marl at the contact with andesite	SMR		
BHDD005	13JZBH103	570533	4898412	UTM(WGS84)34N	747/-18.25	Strongly clay altered, and partially oxidized andesite from the fault zone	VOL		
BHDD005	13JZBH104	570533	4898412	UTM(WGS84)34N	747/-45.92	Thermally altered marl	SMR		
BHDD005	13JZBH105	570533	4898412	UTM(WGS84)34N	747/-106.6	Conglomerate-sandstone transition, rich in volcanic material	S2		
BHDD005	13JZBH106	570533	4898412	UTM(WGS84)34N	747/-126.45	Green-reddish sandstone rich in volcanic detritus	S2	+	
BHDD005	13JZBH107	570533	4898412	UTM(WGS84)34N	747/-131	Light gray to gray sandstone with diagenetic pyrite	S2	+	
BHDD005	13JZBH108	570533	4898412	UTM(WGS84)34N	747/-139.2	Partially oxidized carbonate sandstone	S1		
BHDD005	13JZBH109	570533	4898412	UTM(WGS84)34N	747/-144.5	Brecciated sandstone filled with calcite	S1		
BHDD005	13JZBH110	570533	4898412	UTM(WGS84)34N	747/-158.7	Brecciated sandstone with finer- grained material between clasts	S1	+	
BHDD005	13JZBH111	570533	4898412	UTM(WGS84)34N	747/-163.55	Bedded sandstone with disseminated pyrite	S1		
BHDD005	13JZBH112	570533	4898412	UTM(WGS84)34N	747/-175.15	Siltstone-mudstone alternation with diagenetic pyrite	IB		
BHDD005	13JZBH113	570533	4898412	UTM(WGS84)34N	747/-185	Breccia-conglomerate with sandy matrix, with disseminated pyrite	BBX		
BHDD005	13JZBH114	570533	4898412	UTM(WGS84)34N	747/-197.9	Sandy matrix of the polymictic breccia	BBX		
BHDD041	13JZBH115	570221	4898488	UTM(WGS84)34N	686/-11.8	Oxidation front in coarse-grained sandstone	S2		
BHDD041	13JZBH116	570221	4898488	UTM(WGS84)34N	686/-15.8	Fractured sandy limestone, with calcite veins	S1		
BHDD041	13JZBH117	570221	4898488	UTM(WGS84)34N	686/-45.2	Thermally altered sandstone	S1		
BHDD041	13JZBH118	570221	4898488	UTM(WGS84)34N	686/-55.6	Sandstone with pyrite filled stylolites	S1		+
BHDD041	13JZBH119	570221	4898488	UTM(WGS84)34N	686/-57	Skarn altered sandstone	S1		
BHDD041	13JZBH120	570221	4898488	UTM(WGS84)34N	686/-79.1	Skarn altered sandstone	S1		
BHDD041	13JZBH121	570221	4898488	UTM(WGS84)34N	686/-100.85	Calcite-pyrite veins in carbonate sandstone	S1		

Hole ID	Sample ID	Easting	Northing	UTM Zone	Elevation/Depth (m)	Sample Description	Lithology Unit	Thin Section	Carbonate Staining
BHDD041	13JZBH122	570221	4898488	UTM(WGS84)34N	686/-123.3	Sandstone-skarn altered siltstone contact	S1		
BHDD041	13JZBH123	570221	4898488	UTM(WGS84)34N	686/-134.45	Breccia with pyrite filled stylolite	BBX		
BHDD007	13JZBH124	570534	4898248	UTM(WGS84)34N	776/-157.6	Conglomerate with re-deposited S2 sandstone	S2		
BHDD007	13JZBH125	570534	4898248	UTM(WGS84)34N	776/-180	Contact of green and light gray sandstone	S2		
BHDD007	13JZBH126	570534	4898248	UTM(WGS84)34N	776/-180.45	Sandstone oxidized along laminas	S2	+	
BHDD007	13JZBH127	570534	4898248	UTM(WGS84)34N	776/-181.65	Clay altered, sulfidized sandstone	S2		
BHDD007	13JZBH128	570534	4898248	UTM(WGS84)34N	776/-185.4	Oxidized, brecciated sandstone	S1		
BHDD007	13JZBH129	570534	4898248	UTM(WGS84)34N	776/-190.95	Brecciated sandstone, with calcite infill	S1		+
BHDD007	13JZBH130	570534	4898248	UTM(WGS84)34N	776/-193.2	Contact of sandy limestone with stylolites and finer-grained fraction	S1	+	
BHDD007	13JZBH131	570534	4898248	UTM(WGS84)34N	776/-233.35	Brecciated sandstone with pyrite matrix infill and 12.08 ppm Au	BBX		
BHDD068	13JZBH132	570761	4898166	UTM(WGS84)34N	769/-40.9	Strongly clay altered andesite with pyrite nests and calcite-pyrite veins	VOL		
BHDD068	13JZBH133	570761	4898166	UTM(WGS84)34N	769/-48.2	Clay, pyrite altered andesite	VOL	+	
BHDD068	13JZBH134	570761	4898166	UTM(WGS84)34N	769/-49.8	Chlorite, clay altered andesite	VOL		
BHDD068	13JZBH135	570761	4898166	UTM(WGS84)34N	769/-136	Brecciated marl	SMR		
BHDD068	13JZBH136	570761	4898166	UTM(WGS84)34N	769/-136.6	Laminated marl	SMR		
BHDD068	13JZBH137	570761	4898166	UTM(WGS84)34N	769/-153.55	Dark green, volcanic material rich sandstone	S2		
BHDD068	13JZBH138	570761	4898166	UTM(WGS84)34N	769/-160.6	Clay altered sandstone with pyrite concentrations along lamination	S2		
BHDD068	13JZBH139	570761	4898166	UTM(WGS84)34N	769/-173.45	Clay and pyrite altered sandstone	S2	+	
BHDD068	13JZBH140	570761	4898166	UTM(WGS84)34N	769/-174.35	Coarse-grained sandstone with abundant volcanic material	S2		
BHDD068	13JZBH141	570761	4898166	UTM(WGS84)34N	769/-187.6	Reddish sandstone with pyrite disseminations	S2	+	

Hole ID	Sample ID	Easting	Northing	UTM Zone	Elevation/Depth (m)	Sample Description	Lithology Unit	Thin Section	Carbonate Staining
BHDD068	13JZBH142	570761	4898166	UTM(WGS84)34N	769/-211.6	Sandy limestone	S1	+	+
BHDD068	13JZBH143	570761	4898166	UTM(WGS84)34N	769/-214.6	Sandy limestone alternating with finer clastic fractions	S1	+	
BHDD017	13JZBH144	570854	4898097	UTM(WGS84)34N	742/-14	Skarn altered marl at the contact with andesite	SMR		
BHDD017	13JZBH145	570854	4898097	UTM(WGS84)34N	742/-17.2	Tuffaceous marl	SMR		
BHDD017	13JZBH146	570854	4898097	UTM(WGS84)34N	742/-34.5	Clay alteration front in andesite	VOL		
BHDD017	13JZBH147	570854	4898097	UTM(WGS84)34N	742/-39.9	Propylitic altered andesitic sill	VOL		
BHDD017	13JZBH148	570854	4898097	UTM(WGS84)34N	742/-49.1	Enclaves within andesite	VOL		
BHDD017	13JZBH149	570854	4898097	UTM(WGS84)34N	742/-147.3	Transition between S2 sandstone and marl	SMR		
BHDD017	13JZBH150	570854	4898097	UTM(WGS84)34N	742/-164.45	Coarse-grained reddish sandstone with abundant volcanic material	S2		
BHDD017	13JZBH151	570854	4898097	UTM(WGS84)34N	742/-182.45	Contact of reddish and greenish sandstone	S2	+	
BHDD017	13JZBH152	570854	4898097	UTM(WGS84)34N	742/-192.85	Clay altered gray sandstone with pyrite disseminations	S2		
BHDD017	13JZBH153	570854	4898097	UTM(WGS84)34N	742/-194.45	Altered conglomerate with pyrite rich matrix	S2		
BHDD017	13JZBH154	570854	4898097	UTM(WGS84)34N	742/-195.5	Strongly decarbonatized, vuggy clastite with 4.33 ppm Au	S1	+	+
BHDD017	13JZBH155	570854	4898097	UTM(WGS84)34N	742/-197.55	Brecciated sandstone with 4.97 ppm Au	S1		
BHDD017	13JZBH156	570854	4898097	UTM(WGS84)34N	742/-210	Sandy limestone with stylolite	S1	+	+
BHDD017	13JZBH157	570854	4898097	UTM(WGS84)34N	742/-224.6	Carbonate siliciclastic rock	S1	+	
BHDD017	13JZBH158	570854	4898097	UTM(WGS84)34N	742/-236.38	Carbonate siliciclastics alternating with finer fraction	S1	+	
BHDD017	13JZBH159	570854	4898097	UTM(WGS84)34N	742/-241.2	Coarser influx in S1 sandstone	S1		+
BHDD017	13JZBH160	570854	4898097	UTM(WGS84)34N	742/-244.3	Laminated siltstone	IB		
KWDD008	13JZBH161	568862	4900428	UTM(WGS84)34N	737/45.5	Very coarse-grained, non-altered sandstone	S2		
Hole ID	Sample ID	Easting	Northing	UTM Zone	Elevation/Depth (m)	Sample Description	Lithology Unit	Thin Section	Carbonate Staining
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KWDD005	13JZBH162	568862	4900428	UTM(WGS84)34N	737/44.6	Coarse red sandstone	S2		
KWDD008	13JZBH163	569494	4899763	UTM(WGS84)34N	739/31.95	Coarse red sandstone	S2		
KWDD005	13JZBH164	569494	4899763	UTM(WGS84)34N	739/32	Red-dark green coarse-grained non- altered sandstone	S2		
BHDD067	13JZBH165	570927	4898011	UTM(WGS84)34N	724/-32.15	Laminated gray marl	SMR		
BHDD067	13JZBH166	570927	4898011	UTM(WGS84)34N	724/-36.2	Volcanic material rich marl	SMR		
BHDD067	13JZBH167	570927	4898011	UTM(WGS84)34N	724/-115.15	Epidote-chlorite altered andesite	VOL		
BHDD067	13JZBH168	570927	4898011	UTM(WGS84)34N	724/-213.85	Gray sandstone with pyrite disseminated	S2		
BHDD067	13JZBH169	570927	4898011	UTM(WGS84)34N	724/-214.75	Clay altered and sulfidized, brecciated sandstone	S2	+	+
BHDD067	13JZBH170	570927	4898011	UTM(WGS84)34N	724/-219.5	Grey, sulfidized sandstone	S2		
BHDD067	13JZBH171	570927	4898011	UTM(WGS84)34N	724/-223.75	Strongly clay altered sandstone, with pyrite laminas	S2		
BHDD067	13JZBH172	570927	4898011	UTM(WGS84)34N	724/-235.3	Clastic dominated sandstone	S1		+
BHDD067	13JZBH173	570927	4898011	UTM(WGS84)34N	724/-243	Fault breccia with pyrite rich fine- grained matrix and 3.47 ppm Au	BBX		
BHDD067	13JZBH174	570927	4898011	UTM(WGS84)34N	724/-244.5	Polymictic breccia with pyrite rich matrix	BBX		
BHDD063	13JZBH175	570925	4898075	UTM(WGS84)34N	718/-195.1	Strongly clay altered and sulfidized andesite	VOL		
BHDD063	13JZBH176	570925	4898075	UTM(WGS84)34N	718/-197.45	Light gray sandstone	S2	+	+
BHDD063	13JZBH177	570925	4898075	UTM(WGS84)34N	718/-212.47	Sulfidized gray sandstone	S2		
BHDD063	13JZBH178	570925	4898075	UTM(WGS84)34N	718/-215.95	Contact of conglomerate and fine- grained sandstone	S2		+
BHDD063	13JZBH179	570925	4898075	UTM(WGS84)34N	718/-217.45	Alternation of fine-grained sandstone with silty/muddy fraction	S1	+	
BHDD063	13JZBH180	570925	4898075	UTM(WGS84)34N	718/-217.8	Sandy limestone with stylolites	S1	+	+
BHDD063	13JZBH181	570925	4898075	UTM(WGS84)34N	718/-233.9	Fine-grained, sulfidized sandstone	S1		
BHDD063	13JZBH182	570925	4898075	UTM(WGS84)34N	718/-248.8	Clastic rich sandstone	S1		

Hole ID	Sample ID	Easting	Northing	UTM Zone	Elevation/Depth (m)	Sample Description	Lithology Unit	Thin Section	Carbonate Staining
BHDD063	13JZBH183	570925	4898075	UTM(WGS84)34N	718/-256	Mudstone with calcite veins	IB		
BHDD057	13JZBH184	570864	4898154	UTM(WGS84)34N	734/-3.5	Partially oxidized marl	SMR		
BHDD057	13JZBH185	570864	4898154	UTM(WGS84)34N	734/-19.5	Laminated marl	SMR		
BHDD057	13JZBH186	570864	4898154	UTM(WGS84)34N	734/-43.8	Weakly clay, chlorite altered andesite	VOL		
BHDD057	13JZBH187	570864	4898154	UTM(WGS84)34N	734/-50	Strongly clay altered andesite with calcite-pyrite veins	VOL	+	
BHDD057	13JZBH188	570864	4898154	UTM(WGS84)34N	734/-51.35	Strongly clay altered andesite from the fault gauge	VOL		
BHDD057	13JZBH189	570864	4898154	UTM(WGS84)34N	734/-120.75	Weakly clay, chlorite altered andesite	VOL		
BHDD057	13JZBH190	570864	4898154	UTM(WGS84)34N	734/-138.5	Light gray sandstone with pyrite lenses along bedding	S2		
BHDD057	13JZBH191	570864	4898154	UTM(WGS84)34N	734/-144.57	Strongly clay altered and sulfidized andesite	S2		
BHDD057	13JZBH192	570864	4898154	UTM(WGS84)34N	734/-161.85	Breccia with limestone and S2 sandstone re-deposited clasts	S2		
BHDD057	13JZBH193	570864	4898154	UTM(WGS84)34N	734/-169.2	Reddish-gray sandstone with calcite veins	S2		
BHDD057	13JZBH194	570864	4898154	UTM(WGS84)34N	734/-185.95	Green, coarse sandstone with pyrite disseminations	S2		
BHDD057	13JZBH195	570864	4898154	UTM(WGS84)34N	734/-189.65	Conglomerate-sandstone contact, clay altered and decarbonatized	S2	+	
BHDD057	13JZBH196	570864	4898154	UTM(WGS84)34N	734/-192.5	Brecciated, strongly decarbonatized sandstone with 9.65 ppm Au	S1		
BHDD057	13JZBH197	570864	4898154	UTM(WGS84)34N	734/-198.1	Sandy limestone with stylolites	S1		
BHDD057	13JZBH198	570864	4898154	UTM(WGS84)34N	734/-226.2	Fine-grained sandstone and finer fractions	S1		
BHDD057	13JZBH199	570864	4898154	UTM(WGS84)34N	734/-264.95	Laminated siltstone	IB		
BHDD057	13JZBH200	570864	4898154	UTM(WGS84)34N	734/-271.6	Siltstone from the fault gauge	IB		
BHDD057	13JZBH201	570864	4898154	UTM(WGS84)34N	734/-273.2	Breccia with fine-grained, pyrite rich BBX matrix			
BHDD057	13JZBH202	570864	4898154	UTM(WGS84)34N	734/-276.6	Gray limestone and calcite vein	KLS		

Hole ID	Sample ID	Easting	Northing	UTM Zone	Elevation/Depth (m)	Sample Description	Lithology Unit	Thin Section	Carbonate Staining
BHDD084	13JZBH206	570652	4898169	UTM(WGS84)34N	785/-186.3	Red-green, medium to coarse-grained sandstone	S2		
BHDD084	13JZBH207	570652	4898169	UTM(WGS84)34N	785/-193	Grey, medium to coarse-grained sandstone, with pyrite disseminations	S2		
BHDD084	13JZBH208	570652	4898169	UTM(WGS84)34N	785/-204.05	Light grey, fine to medium-grained sandstone, with pyrite dissemination	S2		
BHDD085	13JZBH209	570697	4898213	UTM(WGS84)34N	775/-172.73	Red-green, medium to coarse-grained sandstone	S2		
BHDD086	13JZBH210	570431	4898382	UTM(WGS84)34N	723/-47	Grey, laminated, very fine-grained marl	SMR		
BHDD086	13JZBH211	570431	4898382	UTM(WGS84)34N	723/-60.7	Light grey, medium-grained sandstone, with pyrite dissemination	S2		
BHDD086	13JZBH212	570431	4898382	UTM(WGS84)34N	723/-70.1	Green-red, medium-grained sandstone, with pyrite dissemination	S2		
BHDD005	13JZBH213	570533	4898412	UTM(WGS84)34N	747/-113.81	Green-red, coarse-grained sandstone	S2		
BHDD005	13JZBH214	570533	4898412	UTM(WGS84)34N	747/-130.69	Grey-green, medium-grained sandstone, with pyrite dissemination	S2		
BHDD068	13JZBH215	570761	4898166	UTM(WGS84)34N	769/-176.3	Green, medium-grained sandstone	S2		
BHDD068	13JZBH216	570761	4898166	UTM(WGS84)34N	769/-228.5	Light grey, stylolitized, sandy limestone	S1		
BHDD087	13JZBH217	570521	4898327	UTM(WGS84)34N	761/-133.3	Red-green, medium to fine-grained sandstone	S2		
BHDD087	13JZBH218	570521	4898327	UTM(WGS84)34N	761/-141.5	Red-green, coarse-grained sandstone, rich in volcanic material	S2		
BHDD087	13JZBH219	570521	4898327	UTM(WGS84)34N	761/-189.8	Light grey, medium to coarse-grained sandstone	S1		
BHDD007	13JZBH220	570534	4898248	UTM(WGS84)34N	776/-85.62	Green-grey, non-altered, plagioclase- hornblende-phyric andesite	VOL		
BHDD007	13JZBH221	570534	4898248	UTM(WGS84)34N	776/-176.1	Green-red, medium to coarse-grained sandstone	S2		
BHDD007	13JZBH222	570534	4898248	UTM(WGS84)34N	776/-181.55	Ochre-grey, coarse-grained sandstone with pyrite dissemination	S2		
BHDD007	13JZBH223	570534	4898248	UTM(WGS84)34N	776/-195	Light grey, fine to medium-grained, stylolitized sandstone			
BHDD007	13JZBH224	570534	4898248	UTM(WGS84)34N	776/-213.5	Light grey, medium to coarse grained, stylolitized sandstone	S1		

Hole ID	Sample ID	Easting	Northing	UTM Zone	Elevation/Depth (m)	Sample Description	Lithology Unit	Thin Section	Carbonate Staining
BHDD057	13JZBH225	570864	4898154	UTM(WGS84)34N	734/-247.15	Grey, medium to fine-grained sandstone	S1	+	
BHDD057	13JZBH226	570864	4898154	UTM(WGS84)34N	734/-203.29	Gray, sandy limestone	S1	+	+
BHDD017	13JZBH227	570854	4898097	UTM(WGS84)34N	742/-153.48	Volcanic material rich green, medium to coarse-grained sandstone	S2		
BHDD017	13JZBH228	570854	4898097	UTM(WGS84)34N	742/-182.55	Green, medium-grained sandstone	S2		
BHDD063	13JZBH229	570925	4898075	UTM(WGS84)34N	718/-218.43	Light grey, stylolitized, sandy limestone	S1		
BHDD026	13JZBH230	570220	4898565	UTM(WGS84)34N	685/-4.93	Green-grey, medium-grained sandstone	S2		
BHDD026	13JZBH231	570220	4898565	UTM(WGS84)34N	685/-113.75	Light grey, stylolitized, sandy limestone	S1		
BHDD020	13JZBH232	570373	4898559	UTM(WGS84)34N	691/-72.8	Grey, medium-grained sandstone	S1		
BHDD020	13JZBH233	570373	4898559	UTM(WGS84)34N	691/-153.96	Grey, medium-grained, sandstone	S1		
BHDD020	13JZBH234	570373	4898559	UTM(WGS84)34N	691/-167.09	Oxidation front in medium-grained sandstone	S1		
KWDD005	14JZBH235	569494	4899763	UTM(WGS84)34N	739/-6	Red laminated marl	SMR	+	
KWDD005	14JZBH236	569494	4899763	UTM(WGS84)34N	739/-16	Grey marlstone with laminas of organic material	SMR		
KWDD005	14JZBH237	569494	4899763	UTM(WGS84)34N	739/-21.5	Red, fine-grained sandstone on the basis of the marl formation	SMR		
KWDD005	14JZBH238	569494	4899763	UTM(WGS84)34N	739/-22	Gray, medium-grained sandstone, on the contact with marl	S2		
KWDD005	14JZBH239	569494	4899763	UTM(WGS84)34N	739/-45	Red to light grey sandstone with alternations of different size fractions	S2		
KWDD005	14JZBH240	569494	4899763	UTM(WGS84)34N	739/-65	Red-green sandstone, with cc.0.2 mm thick magnetite laminas	S2		
KWDD005	14JZBH241	569494	4899763	UTM(WGS84)34N	739/-100	Weakly oxidized, medium-grained sandstone	S2		
KWDD005	14JZBH242	569494	4899763	UTM(WGS84)34N	739/-108	Contact of sandstone richer in carbonate and richer in clastic detritus	S1		
KWDD005	14JZBH243	569494	4899763	UTM(WGS84)34N	739/-114	Light grey sandstone to gravelite richer in carbonate component	S1		
KWDD005	14JZBH244	569494	4899763	UTM(WGS84)34N	739/-130	Fine-grained sandstone with glauconite	S1		

Hole ID	Sample ID	Easting	Northing	UTM Zone	Elevation/Depth (m)	Sample Description	Lithology Unit	Thin Section	Carbonate Staining
KWDD005	14JZBH245	569494	4899763	UTM(WGS84)34N	739/-274	Light grey, fine to very coarse grained sandstone	S1	+	
KWDD005	14JZBH246	569494	4899763	UTM(WGS84)34N	739/-291	Fresh to partially weakly oxidized, light grey, biogenic limestone	JLS		
KWDD005	14JZBH247	569494	4899763	UTM(WGS84)34N	739/-306	Fresh, grey limestone, with pyrite filled stylolites	JLS		
KWDD008	14JZBH248	568862	4900428	UTM(WGS84)34N	737/-55.3	Alternation of coarse grained sandstone and conglomerate	S2		
KWDD008	14JZBH249	568862	4900428	UTM(WGS84)34N	737/-59.9	Weakly oxidized, red, coarse to very coarse grained sandstone	S2		
KWDD008	14JZBH250	568862	4900428	UTM(WGS84)34N	737/-60.7	Weakly oxidized sandstone with interbeds of finer grained fraction	S1		
KWDD008	14JZBH251	568862	4900428	UTM(WGS84)34N	737/-80	Weakly oxidized, coarse-grained carbonate rich sandstone	S1		
KWDD008	14JZBH252	568862	4900428	UTM(WGS84)34N	737/-81.8	Calcareous sandstone alternating with different grain sizes	S1		
KWDD008	14JZBH253	568862	4900428	UTM(WGS84)34N	737/-200.4	Interbedding of siltstone and very fine-grained sandstone	IB		
KWDD008	14JZBH254	568862	4900428	UTM(WGS84)34N	737/-241.5	Grey, medium to coarse-grained sandstone	S1		
KWDD008	14JZBH255	568862	4900428	UTM(WGS84)34N	737/-245.5	Partially oxidized, cream, fractured limestone	JLS		
KWDD008	14JZBH256	568862	4900428	UTM(WGS84)34N	737/-85.4	Fresh, poorly sorted conglomerate (clasts ranging from 0.5-10 cm)	S1		
KODD028	14JZBH257	570882	4899188	UTM(WGS84)34N	708/-120	Green, coarse-grained plag- hornblende phyric diorite	GDI		
KODD028	14JZBH258	570882	4899188	UTM(WGS84)34N	708/-174	Green, plag-hornblende phyric andesite, chlorite and epidote altered	VOL		
KODD028	14JZBH259	570882	4899188	UTM(WGS84)34N	708/-203	Light grey, very fine-grained marl, with laminas of organic material	SMR		
KODD028	14JZBH260	570882	4899188	UTM(WGS84)34N	708/-239	Dark green-grey, medium-grained sandstone, rich in volcanic material	S2	+	
KODD028	14JZBH261	570882	4899188	UTM(WGS84)34N	708/-283	Fresh, dark grey, fine-grained sandstone, near contact with S1	S2		
KODD028	14JZBH262	570882	4899188	UTM(WGS84)34N	708/-294	Light grey, coarse-grained carbonate rich, stylolitized sandstone	S1	+	
KODD028	14JZBH263	570882	4899188	UTM(WGS84)34N	708/-374	Dark grey, fine-grained sandstone interbedded with siltstone	S1		

Hole ID	Sample ID	Easting	Northing	UTM Zone	Elevation/Depth (m)	Sample Description	Lithology Unit	Thin Section	Carbonate Staining
KODD028	14JZBH264	570882	4899188	UTM(WGS84)34N	708/-444.5	Mudstone interbedded with thin layers of fine-grained sandstone	IB		
KODD028	14JZBH265	570882	4899188	UTM(WGS84)34N	708/-473.7	Dark grey, cherty limestone	KLS		
KODD028	14JZBH266	570882	4899188	UTM(WGS84)34N	708/-592.7	Light grey, biogenic limestone	JLS		
BHDD056	14JZBH267	570468	4898171	UTM(WGS84)34N	775/-151	Dark red, coarse-grained sandstone	S2		
BHDD056	14JZBH268	570468	4898171	UTM(WGS84)34N	775/-175	Light grey-green, medium grained sandstone	S2		
BHDD056	14JZBH269	570468	4898171	UTM(WGS84)34N	775/-186.5	Moderately oxidized, grey-brown sandstone from the fault zone	S2		
BHDD056	14JZBH270	570468	4898171	UTM(WGS84)34N	775/-214.5	Black siltstone with laminas of organic material	IB		
BHDD056	14JZBH271	570468	4898171	UTM(WGS84)34N	775/-216.4	Sandstone from fault zone, with 5.8 ppm Au, and carbonate removed	S1	+	+
BHDD056	14JZBH272	570468	4898171	UTM(WGS84)34N	775/-224	Fresh, light grey, limestone	KLS		
BHDD056	14JZBH273	570468	4898171	UTM(WGS84)34N	775/-260.7	Carbonate dissolution texture in karstified limestone, partially oxidized	KLS		
BHDD056	14JZBH274	570468	4898171	UTM(WGS84)34N	775/-279	Recrystallized carbonate related with karstification	KLS		
BHDD056	14JZBH275	570468	4898171	UTM(WGS84)34N	775/-373	Massive pyrite from the fault zone within limestone, weak silica addition	JLS	+	
BHDD056	14JZBH276	570468	4898171	UTM(WGS84)34N	775/-413	Dark grey-reddish, partially oxidized, fine-grained meta-sandstone	MPH		
BHDD047	14JZBH277	570599	4898502	UTM(WGS84)34N	723/-95	Fresh, grey, very fine-grained marl with blebs of organic material	SMR	+	
BHDD047	14JZBH278	570599	4898502	UTM(WGS84)34N	723/-124	Grey, partially oxidized, medium- grained sandstone	S2		
BHDD047	14JZBH279	570599	4898502	UTM(WGS84)34N	723/-126	Grey-ochre, partially oxidized, medium-grained sandstone	S2		
BHDD047	14JZBH280	570599	4898502	UTM(WGS84)34N	723/-157	Grey, partially oxidized, medium- grained sandstone	S1		
BHDD047	14JZBH281	570599	4898502	UTM(WGS84)34N	723/-263	Dark grey, cherty, stylolitized limestone	KLS		
BHDD047	14JZBH282	570599	4898502	UTM(WGS84)34N	723/-297	White, partially oxidized, biogenic limestone	JLS		

Hole ID	Sample ID	Easting	Northing	UTM Zone	Elevation/Depth (m)	Sample Description	Lithology Unit	Thin Section	Carbonate Staining
BHDD047	14JZBH283	570599	4898502	UTM(WGS84)34N	723/-216	Basal breccia from the fault, with fine- grained, sulfidized matrix	BBX	+	
BHDD047	14JZBH284	570599	4898502	UTM(WGS84)34N	723/-231	Breccia with limestone clasts and partially oxidized sandy matrix	BBX		
BHDD083	14JZBH285	570704	4898132	UTM(WGS84)34N	785/-41.4	Dark green, clay, chlorite altered andesite	VOL	+	
BHDD081	13JZBH286	571331	4898419	UTM(WGS84)34N	677/-58.5	Green-grey, coarse-grained plag- hornblende phyric diorite	GDI		
BHDD049	13JZBH287	570455	4898400	UTM(WGS84)34N	730/-103	Brecciated sandstone with calcite infill and sulfidation	S1	+	+
BHDD080	13JZBH288	571521	4898384	UTM(WGS84)34N	661/-313.5	Volcanic polymictic breccia	VOL		
BHDD021	13JZBH289	570394	4898251	UTM(WGS84)34N	749/-187	Fractured limestone with thick calcite- sulfide vein, and 5.3 ppm Au	JLS	+	
BHDD065	13JZBH290	570700	4898012	UTM(WGS84)34N	787/-197.7	Breccia with carbonate fragments and fine-grained, pyrite rich matrix	BBX		+
BHDD009	13JZBH291	570540	4898087	UTM(WGS84)34N	780/-212	Medium-grained sandstone to siltstone karst infill within KLS limestone	KLS	+	+
BHDD032	13JZBH292	570781	4897931	UTM(WGS84)34N	771/-117.4	Partially oxidized, strongly clay altered and sulfidized andesite	VOL		
BHDD010	13JZBH293	570700	4898243	UTM(WGS84)34N	771/-199	Grey to light grey, moderately oxidized, medium-grained sandstone	S2		
BHDD017	13JZBH294	570854	4898097	UTM(WGS84)34N	742/-142	Strongly clay altered and sulfidized andesite	VOL		
BHDD084	13JZBH295	570652	4898169	UTM(WGS84)34N	785/-202	Medium-grained, brecciated sandstone, decarbonatized	S2	+	
BHDD083	13JZBH296	570704	4898132	UTM(WGS84)34N	785/-64.8	Intensively clay altered andesite, with pyrite disseminations	VOL	+	
BHDD068	13JZBH297	570761	4898166	UTM(WGS84)34N	769/-169.76	Strongly clay altered sandstone, with pyrite disseminations	S2	+	
BHDD063	13JZBH298	570925	4898075	UTM(WGS84)34N	718/-212.8	Reddish , clay altered sandstone	S2		
BHDD085	13JZBH299	570697	4898213	UTM(WGS84)34N	775/-195	Sandstone with thin beds of conglomerate, partially decarbonatized	S2		
BHDD047	13JZBH300	570599	4898502	UTM(WGS84)34N	723/-130.3	Sandstone-conglomerates, clay altered, decarbonatized, with 3 ppm Au	S2	+	+

Appendix A: Samp	les fro	om the	Bigar Hill	– lo	cations,	descriptions	

Hole ID	Sample ID	Easting	Northing	UTM Zone	Elevation/Depth (m)	Sample Description	Lithology Unit	Thin Section	Carbonate Staining
BHDD068	13JZBH301	570761	4898166	UTM(WGS84)34N	769/-185.2	Green, coarse-grained sandstone, rich in volcanic material	S2		
BHDD084	13JZBH302	570652	4898169	UTM(WGS84)34N	785/-160.7	Green-red, coarse-grained sandstone	S2	+	
RADD001	14JZRA001	572785	4896010	UTM(WGS84)34N	889/-235.9	Dark grey, coarse grained plag- hornblende diorite	GDI		
CRDD002	14JZCR001	574479	4888711	UTM(WGS84)34N	812/-442.5	Grey, medium to coarse-grained plag- hornblende diorite-porphyry	GDI		
CRDD005	14JZCR002	574327	4888084	UTM(WGS84)34N	510/-399.6	Light grey, very coarse-grained plagioclase-biotite phyric monzonite	GMO		
CRDD005	14JZCR003	574327	4888084	UTM(WGS84)34N	510/-416.6	Grey, coarse-grained plag-hornblende diorite-porphyry	GDI		

Analyte	Analytical Method*	Detection Limit	13JZBH035	13JZBH076	13JZBH092	13JZBH230	13JZBH235	13JZBH238	13JZBH242	13JZBH245
Au (ppb)	FA130	1	>1000	955	>1000	15	14	6	6	5
SiO2 (%)	LF700	0.1	86	10.8	26.3	47	45.7	42.6	30.2	46.4
Al2O3 (%)	LF700	0.01	4.89	3.15	4.93	12.04	10.17	8.7	2.3	1.14
Fe2O3 (%)	LF700	0.01	2.39	1.78	3.6	3.11	5.16	1.82	0.9	0.74
CaO (%)	LF700	0.01	2.29	45.95	33.65	17.19	17.07	24.61	35.57	28.08
MgO (%)	LF700	0.01	0.06	0.15	0.14	1.7	1.42	0.7	0.56	0.34
Na2O (%)	LF700	0.01	<0.01	<0.01	<0.01	2.17	1.21	2.01	0.17	0.02
K2O (%)	LF700	0.01	0.07	<0.01	0.05	1.62	2.03	0.68	0.52	0.27
MnO (%)	LF700	0.01	0.1	0.13	0.23	0.07	0.04	0.04	0.02	0.01
TiO2 (%)	LF700	0.01	0.27	0.14	0.24	0.29	0.6	0.16	0.11	0.05
P2O5 (%)	LF700	0.01	0.13	0.15	0.08	0.13	0.07	0.11	0.07	0.07
Cr2O3 (%)	LF700	0.001	0.002	0.002	0.005	0.001	0.007	<0.001	<0.001	<0.001
Ba (%)	LF700	0.01	0.04	<0.01	<0.01	0.03	0.04	0.02	<0.01	<0.01
LOI (%)	LF700	-5.11	3.44	36.61	24.72	13.64	15.95	18.99	28.61	21.8
Cu (%)	LF700	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ni (%)	LF700	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Pb (%)	LF700	0.01	0.04	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SO3 (%)	LF700	0.002	1.02	0.07	5.808	0.497	0.04	0.022	0.356	0.853
Sr (%)	LF700	0.002	<0.002	<0.002	<0.002	0.039	0.014	0.042	<0.002	<0.002
V2O5 (%)	LF700	0.002	0.009	0.007	0.009	0.015	0.015	0.008	0.005	0.004
Zn (%)	LF700	0.001	0.027	0.004	0.004	0.003	0.006	0.002	<0.001	<0.001
Zr (%)	LF700	0.002	0.008	0.003	0.005	0.003	0.02	<0.002	0.003	<0.002
SUM (%)	LF700	0.01	100.75	99.01	99.77	99.51	99.55	100.47	99.4	99.74
TOT/C (%)	тс000	0.02	0.36	10.15	7.52	3.49	3.73	5.11	7.97	6.28

Analyte	Analytical Method*	Detection Limit	13JZBH035	13JZBH076	13JZBH092	13JZBH230	13JZBH235	13JZBH238	13JZBH242	13JZBH245
TOT/S (%)	TC000	0.02	0.4	0.05	2.9	0.24	<0.02	0.03	0.11	0.37
Ba (ppm)	LF100	1	19	8	65	270	395	187	64	25
Be (ppm)	LF100	1	<1	2	<1	1	2	2	2	<1
Co (ppm)	LF100	0.2	6.7	3.1	5.3	7.8	8.6	2.9	1.2	0.7
Cs (ppm)	LF100	0.1	0.4	0.3	0.4	4.4	3.6	0.6	1.2	1
Ga (ppm)	LF100	0.5	2.5	3.8	6.7	10.9	11.5	7.2	1.5	<0.5
Hf (ppm)	LF100	0.1	2.3	1.4	1.6	1.3	6.2	1.1	1.3	0.9
Nb (ppm)	LF100	0.1	4.5	2.7	4.3	3.1	9.7	1.7	2.1	1.1
Rb (ppm)	LF100	0.1	1.9	0.8	1.5	25.9	94.7	17.2	22.3	9.8
Sn (ppm)	LF100	1	<1	<1	<1	<1	2	<1	<1	<1
Sr (ppm)	LF100	0.5	22.3	168.9	74.7	569.5	328.2	731.1	314.7	139.8
Ta (ppm)	LF100	0.1	0.3	0.2	0.2	0.2	0.8	0.1	0.2	<0.1
Th (ppm)	LF100	0.2	3.5	2.5	3.6	2.7	9.2	1.8	1.9	0.9
U (ppm)	LF100	0.1	2.8	1	2.7	0.5	1.4	0.4	0.7	0.5
V (ppm)	LF100	8	60	42	71	91	84	45	27	19
W (ppm)	LF100	0.5	2.4	7.6	23	<0.5	1.5	<0.5	<0.5	0.5
Zr (ppm)	LF100	0.1	87	54.5	59.7	45	229.8	39.4	49.4	34.3
Y (ppm)	LF100	0.1	5.9	14	8.6	10.2	22.3	9.1	7.3	3.5
La (ppm)	LF100	0.1	10.3	14.7	11.1	13.4	26.2	10.9	10	5.5
Ce (ppm)	LF100	0.1	18.3	19	19.8	23.7	51.2	16.7	15.5	8.8
Pr (ppm)	LF100	0.02	2.32	2.78	2.26	2.76	5.71	2.01	1.94	1.01
Nd (ppm)	LF100	0.3	10.1	11.3	8.9	11.4	22.6	8.5	7.7	4.5
Sm (ppm)	LF100	0.05	1.69	2.32	1.65	2.28	4.18	1.66	1.31	0.85
Eu (ppm)	LF100	0.02	0.37	0.53	0.39	0.71	0.83	0.51	0.33	0.18

Analyte	Analytical Method*	Detection Limit	13JZBH035	13JZBH076	13JZBH092	13JZBH230	13JZBH235	13JZBH238	13JZBH242	13JZBH245
Gd (ppm)	LF100	0.05	1.51	2.27	1.48	2.16	3.96	1.63	1.4	0.7
Tb (ppm)	LF100	0.01	0.21	0.34	0.23	0.31	0.6	0.24	0.19	0.1
Dy (ppm)	LF100	0.05	1.16	2.02	1.37	1.88	3.54	1.48	1.17	0.61
Ho (ppm)	LF100	0.02	0.24	0.45	0.28	0.39	0.76	0.29	0.24	0.12
Er (ppm)	LF100	0.03	0.58	1.27	0.75	1.06	2.18	0.88	0.69	0.31
Tm (ppm)	LF100	0.01	0.1	0.2	0.11	0.17	0.35	0.12	0.09	0.05
Yb (ppm)	LF100	0.05	0.6	1.11	0.68	1	2.31	0.79	0.57	0.31
Lu (ppm)	LF100	0.01	0.1	0.18	0.12	0.15	0.37	0.12	0.1	0.04
Mo (ppm)	AQ200	0.1	0.3	1.2	0.4	0.1	<0.1	<0.1	<0.1	0.1
Cu (ppm)	AQ200	0.1	29.8	4.1	74.9	14.6	10.8	7.3	2.2	1.5
Pb (ppm)	AQ200	0.1	360.9	35.5	78.9	8.3	14.5	4.7	4.7	4.5
Zn (ppm)	AQ200	1	299	47	49	36	64	20	11	8
Ni (ppm)	AQ200	0.1	14.3	5.3	18.2	6.5	26.9	4.4	3.1	4.5
As (ppm)	AQ200	0.5	212.7	512.5	110.7	18	2.5	2.3	<0.5	33.8
Cd (ppm)	AQ200	0.1	0.6	0.3	0.4	<0.1	<0.1	<0.1	<0.1	<0.1
Sb (ppm)	AQ200	0.1	441.9	51.7	19.1	1.8	0.1	<0.1	<0.1	0.2
Bi (ppm)	AQ200	0.1	0.2	<0.1	0.4	<0.1	0.2	<0.1	<0.1	<0.1
Ag (ppm)	AQ200	0.1	11.8	1.7	9.6	<0.1	<0.1	<0.1	<0.1	<0.1
Au (ppb)	AQ200	0.5	2094	1070	4808.4	41.1	5.5	0.7	2.3	1.7
Hg (ppm)	AQ200	0.01	4	2.87	1.33	0.05	0.01	0.01	<0.01	0.01
Tl (ppm)	AQ200	0.1	5.1	4	16.2	0.2	0.2	<0.1	<0.1	<0.1
Se (ppm)	AQ200	0.5	6.6	0.8	6	<0.5	<0.5	<0.5	<0.5	<0.5
Sc (ppm)	AQ200	0.1	5.5	5.2	3.1	5.3	4.7	3.2	2.3	1.4
Te (ppm)	AQ200	0.2	5.1	5.4	1.3	<0.2	<0.2	<0.2	<0.2	<0.2

Analyte	Analytical Method*	Detection Limit	13JZBH246	13JZBH247	14JZBH257	14JZBH260	14JZBH262	14JZBH264	14JZBH265	14JZBH267
Au (ppb)	FA130	1	6	4	3	3	3	7	2	3
SiO2 (%)	LF700	0.1	0.2	5.4	52	49.3	19.7	54.9	12.5	45.2
Al2O3 (%)	LF700	0.01	0.03	0.04	18.58	12.49	1.13	17.8	0.88	7.94
Fe2O3 (%)	LF700	0.01	0.08	0.35	6.14	4.75	0.54	7.13	0.3	2.91
CaO (%)	LF700	0.01	55.56	52.28	8.71	13.59	42.71	4.28	47.75	21.34
MgO (%)	LF700	0.01	0.42	0.48	3.34	3.03	0.68	2.46	0.56	1.42
Na2O (%)	LF700	0.01	<0.01	<0.01	2.23	2.64	0.13	1.63	<0.01	1.13
K2O (%)	LF700	0.01	<0.01	<0.01	1.02	1.15	0.22	3.32	0.13	0.73
MnO (%)	LF700	0.01	<0.01	<0.01	0.12	0.12	0.04	0.05	<0.01	0.08
TiO2 (%)	LF700	0.01	<0.01	<0.01	0.5	0.43	0.05	1.01	0.04	0.25
P2O5 (%)	LF700	0.01	0.03	0.07	0.17	0.21	0.04	0.11	0.02	0.13
Cr2O3 (%)	LF700	0.001	<0.001	<0.001	0.001	<0.001	<0.001	0.016	<0.001	0.001
Ba (%)	LF700	0.01	<0.01	<0.01	0.02	0.03	<0.01	0.06	<0.01	0.03
LOI (%)	LF700	-5.11	43.74	40.76	6.84	11.84	34.02	7.47	37.9	17.53
Cu (%)	LF700	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ni (%)	LF700	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Pb (%)	LF700	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SO3 (%)	LF700	0.002	0.031	0.607	0.057	0.019	0.003	0.911	0.131	0.02
Sr (%)	LF700	0.002	<0.002	<0.002	0.05	0.084	<0.002	0.013	0.037	0.008
V2O5 (%)	LF700	0.002	<0.002	<0.002	0.03	0.022	0.004	0.026	0.002	0.01
Zn (%)	LF700	0.001	<0.001	<0.001	0.005	0.005	<0.001	0.01	<0.001	0.002
Zr (%)	LF700	0.002	<0.002	<0.002	0.005	<0.002	<0.002	0.021	<0.002	<0.002
SUM (%)	LF700	0.01	100.03	99.97	99.88	99.73	99.31	101.2	100.23	98.76
TOT/C (%)	TC000	0.02	12.29	11.66	0.12	2.63	9.67	1.67	10.74	4.68

Analyte	Analytical Method*	Detection Limit	13JZBH246	13JZBH247	14JZBH257	14JZBH260	14JZBH262	14JZBH264	14JZBH265	14JZBH267
TOT/S (%)	TC000	0.02	<0.02	0.26	<0.02	<0.02	0.04	0.61	0.06	<0.02
Ba (ppm)	LF100	1	2	3	247	359	43	553	29	353
Be (ppm)	LF100	1	<1	<1	1	1	<1	5	<1	3
Co (ppm)	LF100	0.2	<0.2	<0.2	17.4	11.1	1.7	17.8	0.9	5.7
Cs (ppm)	LF100	0.1	<0.1	<0.1	1.4	0.5	0.4	5.6	0.6	2.9
Ga (ppm)	LF100	0.5	<0.5	<0.5	15.8	12.6	<0.5	21.8	<0.5	7.4
Hf (ppm)	LF100	0.1	<0.1	<0.1	2.1	1.7	0.8	7.2	0.3	1.1
Nb (ppm)	LF100	0.1	<0.1	<0.1	4.8	2.8	1	15.6	0.7	2.1
Rb (ppm)	LF100	0.1	0.2	0.3	21.3	21.4	10.1	133.3	9.1	19.8
Sn (ppm)	LF100	1	<1	<1	<1	<1	<1	3	<1	<1
Sr (ppm)	LF100	0.5	182.4	189.4	647.7	1147.6	401.2	177.3	1132	362.7
Ta (ppm)	LF100	0.1	<0.1	<0.1	0.3	0.2	<0.1	1.1	<0.1	0.1
Th (ppm)	LF100	0.2	<0.2	<0.2	3.3	3	0.9	12.6	0.6	1.9
U (ppm)	LF100	0.1	0.3	1	1.1	0.3	1.1	3.6	1.1	0.4
V (ppm)	LF100	8	15	11	199	135	16	156	17	79
W (ppm)	LF100	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	2.2	0.6	<0.5
Zr (ppm)	LF100	0.1	0.8	0.8	79.7	59.4	33.3	264.3	9.5	39.9
Y (ppm)	LF100	0.1	0.6	0.7	13.3	16.6	4.2	35.4	1.9	12.9
La (ppm)	LF100	0.1	1.4	0.6	12.7	16.1	5.1	37.3	2.7	11.4
Ce (ppm)	LF100	0.1	0.4	0.4	24.8	31.1	7.3	76.9	3.2	17.7
Pr (ppm)	LF100	0.02	0.02	<0.02	2.91	3.69	0.95	8.83	0.36	2.42
Nd (ppm)	LF100	0.3	<0.3	<0.3	11.4	15.4	3.5	34.8	1.7	10.1
Sm (ppm)	LF100	0.05	<0.05	<0.05	2.53	3.3	0.74	6.62	0.3	2
Eu (ppm)	LF100	0.02	<0.02	<0.02	0.74	0.99	0.16	1.33	0.07	0.57

Analyte	Analytical Method*	Detection Limit	13JZBH246	13JZBH247	14JZBH257	14JZBH260	14JZBH262	14JZBH264	14JZBH265	14JZBH267
Gd (ppm)	LF100	0.05	0.06	<0.05	2.26	3.19	0.71	6.45	0.31	2.04
Tb (ppm)	LF100	0.01	<0.01	<0.01	0.39	0.52	0.11	1.04	0.05	0.31
Dy (ppm)	LF100	0.05	0.1	0.08	2.43	2.98	0.66	6.57	0.31	1.84
Ho (ppm)	LF100	0.02	<0.02	<0.02	0.54	0.66	0.13	1.3	0.07	0.41
Er (ppm)	LF100	0.03	0.05	0.04	1.54	1.77	0.38	3.91	0.22	1.17
Tm (ppm)	LF100	0.01	<0.01	<0.01	0.24	0.26	0.07	0.62	0.03	0.17
Yb (ppm)	LF100	0.05	<0.05	<0.05	1.52	1.72	0.35	3.76	0.18	1.06
Lu (ppm)	LF100	0.01	<0.01	<0.01	0.27	0.27	0.05	0.61	0.03	0.16
Mo (ppm)	AQ200	0.1	<0.1	0.2	<0.1	<0.1	<0.1	0.3	0.4	<0.1
Cu (ppm)	AQ200	0.1	0.8	1.5	36.2	23.4	2	34.1	1.6	6.9
Pb (ppm)	AQ200	0.1	1.6	1.2	2.5	6.7	2.9	17.2	1.9	5.8
Zn (ppm)	AQ200	1	4	7	29	46	8	103	8	27
Ni (ppm)	AQ200	0.1	2	3.4	3.7	6.1	3.8	48.8	6.5	4.3
As (ppm)	AQ200	0.5	2.4	6.5	1.7	2.8	1.7	9.8	1.6	1.2
Cd (ppm)	AQ200	0.1	0.2	0.3	<0.1	<0.1	<0.1	<0.1	<0.1	0.1
Sb (ppm)	AQ200	0.1	0.2	0.8	<0.1	<0.1	<0.1	0.3	0.4	0.6
Bi (ppm)	AQ200	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.4	<0.1	<0.1
Ag (ppm)	AQ200	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Au (ppb)	AQ200	0.5	<0.5	3.1	<0.5	1.3	<0.5	0.9	0.7	0.8
Hg (ppm)	AQ200	0.01	0.03	0.03	<0.01	<0.01	<0.01	0.03	0.02	0.01
Tl (ppm)	AQ200	0.1	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Se (ppm)	AQ200	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Sc (ppm)	AQ200	0.1	0.7	0.8	2.1	5.4	1.6	7.6	1.3	4.5
Te (ppm)	AQ200	0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2

Analyte	Analytical Method*	Detection Limit	14JZBH268	14JZBH269	14JZBH270	14JZBH271	14JZBH272	14JZBH273	14JZBH274	14JZBH275
Au (ppb)	FA130	1	72	>1000	770	>1000	12	>1000	237	654
SiO2 (%)	LF700	0.1	44.3	29.3	57.1	72.5	0.7	8.4	0.5	30.9
Al2O3 (%)	LF700	0.01	9.44	19.1	17.74	7.07	0.39	3.06	0.28	7.5
Fe2O3 (%)	LF700	0.01	2.73	8.89	6.01	8.35	0.48	2.36	2.59	19.07
CaO (%)	LF700	0.01	19.84	10.51	1.6	1.35	52.93	32.57	40.89	14.91
MgO (%)	LF700	0.01	1.7	6.45	1.78	0.74	1.61	12.5	10.46	1.02
Na2O (%)	LF700	0.01	0.09	0.06	0.14	0.02	<0.01	0.06	<0.01	0.01
K2O (%)	LF700	0.01	1.4	3.12	4.91	1.28	0.02	0.66	<0.01	0.25
MnO (%)	LF700	0.01	0.1	0.73	0.15	0.11	0.04	0.1	0.39	0.07
TiO2 (%)	LF700	0.01	0.25	0.82	0.93	0.34	0.02	0.17	0.02	0.26
P2O5 (%)	LF700	0.01	0.12	0.38	0.1	0.36	0.14	0.32	0.05	0.16
Cr2O3 (%)	LF700	0.001	<0.001	0.003	0.015	0.006	<0.001	0.002	<0.001	0.002
Ba (%)	LF700	0.01	0.02	0.09	0.14	0.02	<0.01	<0.01	0.01	<0.01
LOI (%)	LF700	-5.11	17.77	12.23	7.74	7.56	42.48	37.55	41.77	11.18
Cu (%)	LF700	0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	0.1
Ni (%)	LF700	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Pb (%)	LF700	0.01	<0.01	<0.01	<0.01	0.27	<0.01	<0.01	<0.01	<0.01
SO3 (%)	LF700	0.002	1.895	7.992	1.429	0.634	0.759	2.368	2.975	14.459
Sr (%)	LF700	0.002	<0.002	<0.002	<0.002	0.011	<0.002	<0.002	<0.002	<0.002
V2O5 (%)	LF700	0.002	0.014	0.045	0.026	0.017	0.002	0.006	<0.002	0.017
Zn (%)	LF700	0.001	0.004	0.003	0.026	0.502	<0.001	0.007	0.007	0.003
Zr (%)	LF700	0.002	0.002	0.008	0.018	0.006	<0.002	<0.002	<0.002	<0.002
SUM (%)	LF700	0.01	99.65	99.8	99.85	101.33	99.53	100.16	99.93	99.94
TOT/C (%)	тс000	0.02	4.54	2.45	0.79	0.3	11.99	11	12.21	3.56

Analyte	Analytical Method*	Detection Limit	14JZBH268	14JZBH269	14JZBH270	14JZBH271	14JZBH272	14JZBH273	14JZBH274	14JZBH275
TOT/S (%)	TC000	0.02	1.41	6.66	4.48	6.98	0.38	1.9	1.78	14.82
Ba (ppm)	LF100	1	241	1114	1523	232	11	107	113	39
Be (ppm)	LF100	1	2	2	<1	<1	1	<1	<1	<1
Co (ppm)	LF100	0.2	5	20.7	23.3	18.6	0.8	4.7	5.9	35
Cs (ppm)	LF100	0.1	4.6	18.3	13.5	4.8	0.1	3.3	0.2	2.6
Ga (ppm)	LF100	0.5	8.1	13.4	21.9	14.3	<0.5	2.6	<0.5	7.9
Hf (ppm)	LF100	0.1	1.6	3.6	6	2.6	<0.1	1.1	<0.1	0.9
Nb (ppm)	LF100	0.1	2.5	6.6	15	5.4	0.4	2.5	<0.1	1.8
Rb (ppm)	LF100	0.1	33.2	79.3	165.4	37.8	1.4	28.4	0.7	5.7
Sn (ppm)	LF100	1	<1	<1	3	2	<1	<1	<1	2
Sr (ppm)	LF100	0.5	171.2	142.7	36.5	103.2	163.6	69.9	48.8	33.6
Ta (ppm)	LF100	0.1	0.2	0.5	1	0.4	<0.1	0.2	<0.1	0.1
Th (ppm)	LF100	0.2	2.7	5	13.4	5.6	<0.2	2.1	<0.2	1.6
U (ppm)	LF100	0.1	0.5	1.9	5.5	3.5	0.4	2.8	0.8	1.7
V (ppm)	LF100	8	87	312	164	112	19	49	21	115
W (ppm)	LF100	0.5	<0.5	7.7	3.9	6.4	<0.5	1.3	0.6	3.2
Zr (ppm)	LF100	0.1	55.7	138.2	217	93.5	4	39.4	3.8	36.5
Y (ppm)	LF100	0.1	9.5	18.8	35.7	9.2	2.6	10.8	3.8	8.9
La (ppm)	LF100	0.1	11.1	18	39.8	13	2.1	8.5	2.5	7.2
Ce (ppm)	LF100	0.1	19.4	36.1	86.1	21.6	2.1	14.6	2.9	13.7
Pr (ppm)	LF100	0.02	2.43	4.66	9.52	2.52	0.27	1.79	0.29	1.68
Nd (ppm)	LF100	0.3	10	19.5	36.1	9.4	1.3	7.2	1.4	7.5
Sm (ppm)	LF100	0.05	2.1	4.17	7.3	2.51	0.23	1.48	0.31	1.49
Eu (ppm)	LF100	0.02	0.67	0.6	1.06	0.58	0.06	0.31	0.08	0.55

Analyte	Analytical Method*	Detection Limit	14JZBH268	14JZBH269	14JZBH270	14JZBH271	14JZBH272	14JZBH273	14JZBH274	14JZBH275
Gd (ppm)	LF100	0.05	1.93	3.89	6.7	2.4	0.25	1.55	0.42	1.52
Tb (ppm)	LF100	0.01	0.3	0.6	1.09	0.32	0.05	0.26	0.06	0.25
Dy (ppm)	LF100	0.05	1.85	3.47	6.45	1.55	0.31	1.56	0.43	1.4
Ho (ppm)	LF100	0.02	0.34	0.73	1.36	0.31	0.07	0.35	0.1	0.31
Er (ppm)	LF100	0.03	1	2.14	3.85	0.88	0.21	0.89	0.31	0.9
Tm (ppm)	LF100	0.01	0.15	0.31	0.56	0.14	0.03	0.12	0.05	0.12
Yb (ppm)	LF100	0.05	0.98	2.04	3.56	1.02	0.14	0.83	0.3	0.84
Lu (ppm)	LF100	0.01	0.14	0.3	0.55	0.18	0.02	0.12	0.04	0.13
Mo (ppm)	AQ200	0.1	0.2	0.4	1.4	5.7	0.3	2.7	1.9	6.6
Cu (ppm)	AQ200	0.1	12.7	34.4	48	192.8	4.3	14.3	12.7	1044.7
Pb (ppm)	AQ200	0.1	5.6	87.1	28.1	2816.8	3.2	10.9	11.1	38.8
Zn (ppm)	AQ200	1	41	55	284	5320	14	76	59	44
Ni (ppm)	AQ200	0.1	5.1	18.1	61.6	53.1	2.6	17.3	15.8	19.5
As (ppm)	AQ200	0.5	155.7	431.3	242.3	452.9	18.3	152.8	156.8	926.4
Cd (ppm)	AQ200	0.1	0.1	0.4	0.6	44.4	0.4	0.9	0.9	1
Sb (ppm)	AQ200	0.1	1.3	34.8	14.1	111.7	1.8	25	17.6	4
Bi (ppm)	AQ200	0.1	<0.1	<0.1	0.5	30.5	<0.1	0.1	<0.1	2.4
Ag (ppm)	AQ200	0.1	0.2	>100.0	3.3	33.4	0.3	0.4	1.7	0.7
Au (ppb)	AQ200	0.5	71	1524	160	9167.7	15.7	980	181	608.7
Hg (ppm)	AQ200	0.01	0.17	1.2	2.21	50.54	0.15	6.24	1.73	1.36
Tl (ppm)	AQ200	0.1	0.3	10.2	4.5	16.3	0.1	9.9	2.7	0.8
Se (ppm)	AQ200	0.5	0.7	13.9	2.5	9.9	<0.5	4.5	4.1	7.2
Sc (ppm)	AQ200	0.1	4.9	8.4	3.2	0.7	1.3	2.7	1.5	4
Te (ppm)	AQ200	0.2	0.5	4.9	2.6	6.8	<0.2	1.4	1	1.5

Analyte	Analytical Method*	Detection Limit	14JZBH276	14JZBH277	14JZBH279	14JZBH282	14JZBH285	14JZBH295	14JZBH296	14JZBH301	14JZBH302
Au (ppb)	FA130	1	16	7	232	3	3	917	12	4	3
SiO2 (%)	LF700	0.1	62.2	43	62.3	0.2	54	51.5	51.9	43.2	44.5
Al2O3 (%)	LF700	0.01	17.37	10.04	9.77	0.06	16.89	9.17	16.06	11.72	7.8
Fe2O3 (%)	LF700	0.01	7.96	4.3	3.99	0.07	7.06	4.69	6	4.66	2.9
CaO (%)	LF700	0.01	0.57	19.47	9.25	55.49	5.99	13.72	5.7	17.67	22.77
MgO (%)	LF700	0.01	0.76	1.67	0.2	0.3	3.51	1.32	2.91	2.12	1.16
Na2O (%)	LF700	0.01	0.62	0.12	<0.01	<0.01	3.73	0.05	0.26	0.15	0.78
K2O (%)	LF700	0.01	2.67	2.02	0.61	<0.01	1.36	1.94	3.61	2.16	1.16
MnO (%)	LF700	0.01	0.06	0.06	0.04	0.01	0.12	0.18	0.2	0.11	0.07
TiO2 (%)	LF700	0.01	1.39	0.52	0.3	<0.01	0.6	0.41	0.58	0.4	0.25
P2O5 (%)	LF700	0.01	0.15	0.12	0.2	<0.01	0.16	0.23	0.15	0.14	0.13
Cr2O3 (%)	LF700	0.001	0.022	0.007	0.001	<0.001	<0.001	0.003	0.003	<0.001	<0.001
Ba (%)	LF700	0.01	0.06	0.04	<0.01	<0.01	0.02	<0.01	0.02	0.01	<0.01
LOI (%)	LF700	-5.11	7.07	17.83	9.7	43.4	7.53	11.24	9.39	16.81	18.97
Cu (%)	LF700	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ni (%)	LF700	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Pb (%)	LF700	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SO3 (%)	LF700	0.002	0.044	0.081	3.326	0.014	0.019	5.277	3.958	0.02	0.014
Sr (%)	LF700	0.002	0.01	0.006	<0.002	<0.002	0.038	<0.002	<0.002	<0.002	<0.002
V2O5 (%)	LF700	0.002	0.04	0.013	0.019	<0.002	0.037	0.022	0.033	0.022	0.012
Zn (%)	LF700	0.001	0.009	0.005	0.007	<0.001	0.005	0.007	0.004	0.003	0.003
Zr (%)	LF700	0.002	0.021	0.014	<0.002	<0.002	0.002	0.005	0.003	0.002	<0.002
SUM (%)	LF700	0.01	101.01	99.32	99.67	99.53	101.08	99.73	100.77	99.21	100.53
TOT/C (%)	TC000	0.02	0.97	4.51	2.02	12.36	1.17	3.33	2.15	3.88	4.9

Appendix B: Lithogeochemical data

Analyte	Analytical Method*	Detection Limit	14JZBH276	14JZBH277	14JZBH279	14JZBH282	14JZBH285	14JZBH295	14JZBH296	14JZBH301	14JZBH302
TOT/S (%)	TC000	0.02	0.56	0.05	2.87	<0.02	<0.02	3.58	3	0.03	<0.02
Ba (ppm)	LF100	1	588	427	40	5	220	80	69	116	116
Be (ppm)	LF100	1	4	3	2	<1	<1	<1	2	<1	2
Co (ppm)	LF100	0.2	22.7	8.3	8.2	<0.2	19.8	9.4	18.1	9.6	5
Cs (ppm)	LF100	0.1	7.6	5.8	2.5	<0.1	2.5	8.5	8.7	8.5	4.8
Ga (ppm)	LF100	0.5	19.7	11.8	9	<0.5	14.4	9.7	14.7	11.8	6.7
Hf (ppm)	LF100	0.1	6.3	4	1.3	<0.1	1.7	1.8	1.7	1.7	1.1
Nb (ppm)	LF100	0.1	10.1	8.4	2.3	<0.1	3.7	3.3	3.8	3.1	2.3
Rb (ppm)	LF100	0.1	81.8	84.8	17.3	0.3	43.8	43.8	101	50.6	27.5
Sn (ppm)	LF100	1	3	2	<1	<1	<1	<1	<1	<1	<1
Sr (ppm)	LF100	0.5	70.2	337	53.4	94.6	455.1	81.1	96.6	157.4	175.8
Ta (ppm)	LF100	0.1	0.7	0.5	0.2	<0.1	0.3	0.2	0.3	0.2	0.1
Th (ppm)	LF100	0.2	5.8	7.7	1.9	<0.2	2.8	2.3	2.7	2.9	1.7
U (ppm)	LF100	0.1	2.3	2.3	1	0.4	0.6	0.7	0.9	0.5	0.5
V (ppm)	LF100	8	242	93	122	<8	227	151	209	142	75
W (ppm)	LF100	0.5	1	1.6	2.2	<0.5	<0.5	1.2	1.5	<0.5	<0.5
Zr (ppm)	LF100	0.1	247.2	148.3	43.9	0.8	66.6	57.3	62.4	59.4	39.3
Y (ppm)	LF100	0.1	36.4	20.6	10.5	0.8	14.2	12.6	14.4	12.5	10.4
La (ppm)	LF100	0.1	24.3	23.8	11.8	0.9	11.2	12.4	10.5	12.9	9.7
Ce (ppm)	LF100	0.1	53.1	48.6	22.4	0.6	22.9	25.1	20.4	22.5	15.1
Pr (ppm)	LF100	0.02	6.26	5.34	2.7	<0.02	2.69	3.18	2.62	2.95	2.2
Nd (ppm)	LF100	0.3	25	21.3	11.5	<0.3	10.7	13.3	10.7	11.9	9
Sm (ppm)	LF100	0.05	5.76	4.08	2.34	0.06	2.38	2.73	2.35	2.39	1.86
Eu (ppm)	LF100	0.02	1.5	0.85	0.6	0.02	0.75	0.67	0.73	0.76	0.56

Appendix B: Lithogeochemical data

Analyte	Analytical Method*	Detection Limit	14JZBH276	14JZBH277	14JZBH279	14JZBH282	14JZBH285	14JZBH295	14JZBH296	14JZBH301	14JZBH302
Gd (ppm)	LF100	0.05	6.1	3.74	2.24	0.1	2.64	2.52	2.41	2.32	1.88
Tb (ppm)	LF100	0.01	1.03	0.62	0.33	0.01	0.41	0.38	0.39	0.34	0.28
Dy (ppm)	LF100	0.05	6.52	3.39	1.89	0.07	2.65	2.17	2.42	2.02	1.66
Ho (ppm)	LF100	0.02	1.44	0.74	0.36	<0.02	0.55	0.42	0.5	0.4	0.34
Er (ppm)	LF100	0.03	4.11	2.12	1.04	0.06	1.66	1.26	1.45	1.25	0.92
Tm (ppm)	LF100	0.01	0.63	0.31	0.16	<0.01	0.23	0.19	0.21	0.18	0.14
Yb (ppm)	LF100	0.05	4.01	2.07	1.03	<0.05	1.51	1.27	1.44	1.14	0.85
Lu (ppm)	LF100	0.01	0.63	0.33	0.14	<0.01	0.24	0.19	0.22	0.19	0.13
Mo (ppm)	AQ200	0.1	0.2	<0.1	0.2	<0.1	<0.1	0.5	0.3	<0.1	<0.1
Cu (ppm)	AQ200	0.1	9.4	22.7	31.8	0.9	28.7	16.8	42.8	8.8	2.2
Pb (ppm)	AQ200	0.1	3.2	8.6	11.3	0.3	1.5	10.2	4.1	3.2	4
Zn (ppm)	AQ200	1	87	64	84	8	59	75	47	32	24
Ni (ppm)	AQ200	0.1	50.9	29	8.9	2	14.3	7	12	5	3
As (ppm)	AQ200	0.5	12.3	2.6	326.7	2	2.7	235.4	446.9	5.2	3.4
Cd (ppm)	AQ200	0.1	<0.1	<0.1	<0.1	0.1	<0.1	0.2	<0.1	<0.1	<0.1
Sb (ppm)	AQ200	0.1	0.6	0.1	10.6	0.5	0.4	4	15	7.2	0.8
Bi (ppm)	AQ200	0.1	<0.1	0.2	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1
Ag (ppm)	AQ200	0.1	<0.1	<0.1	0.4	<0.1	<0.1	1.2	0.2	<0.1	<0.1
Au (ppb)	AQ200	0.5	12.4	1.6	239.2	1.5	<0.5	974.1	12.5	2.7	2.4
Hg (ppm)	AQ200	0.01	0.15	0.01	1.42	0.02	0.01	0.5	0.04	0.02	<0.01
Tl (ppm)	AQ200	0.1	<0.1	<0.1	6.5	<0.1	<0.1	1.5	0.8	<0.1	<0.1
Se (ppm)	AQ200	0.5	<0.5	<0.5	1.1	<0.5	<0.5	1.6	<0.5	<0.5	<0.5
Sc (ppm)	AQ200	0.1	6.1	4.6	5.5	0.7	11.9	6.6	14.6	4.2	3.1
Te (ppm)	AQ200	0.2	<0.2	<0.2	2.4	<0.2	<0.2	1.1	<0.2	<0.2	<0.2

Appendix B: Lithogeochemical data

Analyte	Analytical Method*	Detection Limit	13JZBH014	13JZBH030	13JZBH032	13JZBH033	13JZBH041	13JZBH050	13JZBH071	13JZBH083	13JZBH106
Au (ppb)	FA130	0.5	21.6	9	11.1	7.2	4.2	2.6	11.9	0.7	2
SiO2 (%)	LF700	0.10	49.10	46.90	51.40	45.50	54.40	49.20	35.50	57.70	49.00
Al2O3 (%)	LF700	0.01	3.17	10.46	17.21	15.16	17.55	16.31	1.41	4.72	13.71
Fe2O3 (%)	LF700	0.01	1.12	4.14	6.39	6.61	7.48	6.54	0.65	1.31	3.87
CaO (%)	LF700	0.01	24.10	17.28	7.86	11.74	5.11	8.67	33.96	18.03	13.59
MgO (%)	LF700	0.01	0.72	1.69	3.10	1.56	4.20	1.09	0.42	0.43	2.54
Na2O (%)	LF700	0.01	0.01	0.61	3.05	0.42	4.79	0.35	0.01	0.02	1.83
K2O (%)	LF700	0.01	0.76	2.07	1.17	1.28	1.66	1.06	0.25	1.19	1.82
MnO (%)	LF700	0.01	0.05	0.05	0.13	0.15	0.13	0.09	0.02	0.01	0.08
TiO2 (%)	LF700	0.01	0.21	0.57	0.67	0.68	0.63	0.79	0.09	0.31	0.33
P2O5 (%)	LF700	0.01	0.04	0.09	0.19	0.16	0.17	0.20	0.06	0.06	0.13
Cr2O3 (%)	LF700	0.001	0.01	0.01	<0.001	<0.001	0.01	<0.001	<0.001	<0.001	<0.001
LOI (%)	LF700	-5.11	19.60	15.91	8.22	10.09	3.84	11.76	26.92	14.76	13.41
SO3 (%)	LF700	0.002	1.08	0.29	0.21	6.99	0.03	3.41	0.53	1.11	0.09
V2O5 (%)	LF700	0.002	0.01	0.02	0.03	0.03	0.04	0.04	<0.002	0.01	0.02
Total (%)	LF700	0.01	99.96	100.09	99.64	100.38	100.04	99.51	99.82	99.66	100.42
TOT/C (%)	TC000	0.02	5.50	3.93	1.31	2.79	0.15	1.94	7.54	4.08	2.73
TOT/S (%)	TC000	0.02	0.80	0.11	0.03	4.58	0.01	4.21	0.22	0.83	0.01
Ba (%)	LF700	0.01	0.01	0.04	0.14	0.05	0.02	0.03	0.01	0.02	0.03
Cu (%)	LF700	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02
Ni (%)	LF700	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Pb (%)	LF700	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02
Sr (%)	LF700	0.002	0.02	0.04	0.07	0.03	0.07	0.03	0.02	0.02	0.05

Appendix B: Lithogeochemical data

Analyte	Analytical Method*	Detection Limit	13JZBH014	13JZBH030	13JZBH032	13JZBH033	13JZBH041	13JZBH050	13JZBH071	13JZBH083	13JZBH106
Zn (%)	LF700	0.001	<0.001	0.01	0.01	0.01	<0.001	0.01	<0.001	<0.001	0.01
Zr (%)	LF700	0.002	0.01	0.02	0.01	0.01	<0.002	0.01	<0.002	0.01	<0.002
Ba (ppm)	LF100	1	148	457	1407	589	304	270	62	172	285
Be (ppm)	LF100	1	0.5	3	0.5	3	0.5	0.5	0.5	0.5	2
Co (ppm)	LF100	0.2	2.2	10.8	13.5	13.6	20.5	13.1	0.9	3.6	6.9
Cs (ppm)	LF100	0.1	2.9	4	7	7.2	9.8	6.1	1	7.1	7.8
Ga (ppm)	LF100	0.5	2.7	14	17.4	17.3	15.6	17.8	1.1	6.5	11.5
Hf (ppm)	LF100	0.1	2	5	2.4	2.6	1.7	2.9	1.4	3.5	1.3
Nb (ppm)	LF100	0.1	3.1	7.9	4.5	4.3	3.2	5	1.2	4.7	3
Rb (ppm)	LF100	0.1	20.5	88.8	23.1	27.3	45.7	26.2	9.8	42.9	33.6
Sn (ppm)	LF100	1	0.5	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Sr (ppm)	LF100	0.5	190.4	438.5	649.9	236.6	646.4	224.9	254.9	208.1	472.1
Ta (ppm)	LF100	0.1	0.3	0.7	0.4	0.3	0.2	0.3	0.2	0.3	0.2
Th (ppm)	LF100	0.2	2.7	9.4	3.4	2.8	2.6	3	1.4	4.3	2.9
U (ppm)	LF100	0.1	0.8	1.8	0.8	0.4	0.7	0.7	0.6	1.2	0.7
W (ppm)	LF100	0.5	0.6	1.2	0.25	0.25	0.25	1.1	0.25	1.1	0.25
V (ppm)	LF100	8	28	89	212	208	226	218	15	41	113
Zr (ppm)	LF100	0.1	70	153.5	84.7	108.5	60.8	111.4	56.6	122.2	46
Y (ppm)	LF100	0.1	7.1	20.5	17.2	16	14.1	15.8	4.8	11.9	10.4
La (ppm)	LF100	0.1	8.9	23.2	16.5	10.9	10.5	13.2	8.9	16.1	13.1
Ce (ppm)	LF100	0.1	22.1	51.5	33.3	32.2	24.5	28.3	17.3	27.6	23.6
Pr (ppm)	LF100	0.02	2.56	5.88	4.55	4.24	2.85	3.75	2.01	3.39	3.04
Nd (ppm)	LF100	0.3	9.5	21.4	20.8	18	11.5	16.9	7.1	12.4	12.3

Appendix B: Lithogeochemical data

Analyte	Analytical Method*	Detection Limit	13JZBH014	13JZBH030	13JZBH032	13JZBH033	13JZBH041	13JZBH050	13JZBH071	13JZBH083	13JZBH106
Sm (ppm)	LF100	0.05	1.64	3.97	4.27	3.6	2.63	3.59	1.11	2.41	2.27
Eu (ppm)	LF100	0.02	0.33	0.84	1.23	1.1	0.75	1.01	0.29	0.51	0.67
Gd (ppm)	LF100	0.05	1.41	4.09	3.57	3.51	2.75	3.01	0.94	1.84	2.15
Tb (ppm)	LF100	0.01	0.24	0.59	0.57	0.5	0.42	0.46	0.14	0.33	0.34
Dy (ppm)	LF100	0.05	1.28	4.11	3.12	3	2.34	2.45	0.86	1.85	1.82
Ho (ppm)	LF100	0.02	0.26	0.87	0.72	0.67	0.57	0.61	0.14	0.37	0.41
Er (ppm)	LF100	0.03	0.8	2.42	2.05	1.93	1.5	1.54	0.44	1.03	0.98
Tm (ppm)	LF100	0.01	0.1	0.3	0.23	0.22	0.22	0.28	0.07	0.17	0.15
Yb (ppm)	LF100	0.05	0.79	2.03	1.87	1.47	1.38	1.65	0.4	0.93	0.9
Lu (ppm)	LF100	0.01	0.12	0.33	0.31	0.23	0.23	0.24	0.06	0.14	0.14
Mo (ppm)	AQ200	0.1	0.2	0.05	0.05	0.05	0.2	0.05	0.1	0.1	0.05
Cu (ppm)	AQ200	0.1	9.5	20.5	6	21.3	67.8	28.3	2.1	10.3	221
Pb (ppm)	AQ200	0.1	4.8	7.6	3	6.7	1	7.5	2.9	5.6	2.3
Zn (ppm)	AQ200	1	16	54	48	68	29	59	8	22	33
Ni (ppm)	AQ200	0.1	4.7	27.6	3.4	4.9	10.2	4.7	1.9	10	4.4
As (ppm)	AQ200	0.5	44.3	4.2	0.8	217.9	2	50.7	59.9	18.3	2.9
Cd (ppm)	AQ200	0.1	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Sb (ppm)	AQ200	0.1	1.7	0.05	0.05	1.1	0.05	1.2	0.8	2.5	3.6
Bi (ppm)	AQ200	0.1	0.05	0.2	0.05	0.05	0.05	0.1	0.05	0.05	0.05
Ag (ppm)	AQ200	0.1	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.1
Hg (ppm)	AQ200	0.01	0.09	0.005	0.005	0.11	0.005	0.33	0.01	0.02	0.005
Tl (ppm)	AQ200	0.1	0.1	0.05	0.05	0.3	0.05	0.9	0.05	0.05	0.05
Se (ppm)	AQ200	0.5	0.5	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25

Appendix B: Lithogeochemical data

Analyte	Analytical Method*	Detection Limit	13JZBH111	13JZBH118	13JZBH125	13JZBH133	13JZBH136	13JZBH140	13JZBH142	13JZBH143	13JZBH147
Au (ppb)	FA130	0.5	4	1861.1	62.3	302.3	9.1	9.4	511.9	7	11.2
SiO2 (%)	LF700	0.10	47.30	1.80	36.10	52.40	33.50	43.60	12.80	31.60	53.40
Al2O3 (%)	LF700	0.01	2.02	1.02	5.18	16.78	9.77	10.45	0.59	1.60	17.09
Fe2O3 (%)	LF700	0.01	1.02	0.77	2.46	5.94	5.88	4.61	0.58	0.52	7.13
CaO (%)	LF700	0.01	26.22	36.55	28.75	6.53	16.89	18.24	47.62	36.50	7.30
MgO (%)	LF700	0.01	0.48	14.74	1.67	2.86	7.27	0.72	0.47	0.57	3.97
Na2O (%)	LF700	0.01	0.01	0.01	0.01	0.21	0.05	0.09	0.01	0.01	2.50
K2O (%)	LF700	0.01	0.48	0.01	0.58	3.34	2.20	2.52	0.11	0.37	1.32
MnO (%)	LF700	0.01	0.02	0.46	0.12	0.15	0.09	0.17	0.05	0.03	0.11
TiO2 (%)	LF700	0.01	0.15	0.05	0.24	0.60	0.52	0.31	0.03	0.14	0.59
P2O5 (%)	LF700	0.01	0.03	0.05	0.15	0.16	0.07	0.16	0.03	0.03	0.15
Cr2O3 (%)	LF700	0.001	0.01	<0.001	0.01	0.01	0.01	<0.001	0.01	<0.001	<0.001
LOI (%)	LF700	-5.11	20.34	43.38	23.58	8.98	23.55	13.76	37.23	28.74	6.80
SO3 (%)	LF700	0.002	1.55	1.03	1.13	2.24	0.37	4.96	0.64	0.55	0.06
V2O5 (%)	LF700	0.002	<0.002	0.01	0.01	0.04	0.02	0.02	<0.002	<0.002	0.04
Total (%)	LF700	0.01	99.63	99.87	99.99	100.23	100.18	99.62	100.17	100.66	100.46
TOT/C (%)	TC000	0.02	5.93	12.30	6.32	1.47	6.17	4.07	10.50	8.08	1.03
TOT/S (%)	TC000	0.02	0.61	0.57	0.78	2.73	0.10	3.15	0.22	0.23	0.01
Ba (%)	LF700	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.02
Cu (%)	LF700	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Ni (%)	LF700	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Pb (%)	LF700	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Sr (%)	LF700	0.002	0.03	0.01	0.02	0.03	0.03	0.02	0.03	0.04	0.04

Appendix B: Lithogeochemical data

Analyte	Analytical Method*	Detection Limit	13JZBH111	13JZBH118	13JZBH125	13JZBH133	13JZBH136	13JZBH140	13JZBH142	13JZBH143	13JZBH147
Zn (%)	LF700	0.001	<0.001	<0.001	<0.001	<0.001	0.01	<0.001	<0.001	<0.001	0.01
Zr (%)	LF700	0.002	0.01	<0.002	<0.002	<0.002	0.02	<0.002	<0.002	0.01	<0.002
Ba (ppm)	LF100	1	101	4	85	96	141	98	17	69	132
Be (ppm)	LF100	1	0.5	0.5	2	2	5	0.5	0.5	0.5	3
Co (ppm)	LF100	0.2	1.1	1	6	23.2	8.3	8.4	1	0.6	21.4
Cs (ppm)	LF100	0.1	1.5	1	4	5.6	3.6	11.1	0.3	1	4.5
Ga (ppm)	LF100	0.5	2.1	0.25	5.3	14.2	12	9.6	0.6	1	16.1
Hf (ppm)	LF100	0.1	1.6	1.2	1.3	1.7	4.1	1.5	0.4	1.4	1.7
Nb (ppm)	LF100	0.1	2.6	0.9	1.8	3.8	7.7	2.1	0.2	1.9	3.7
Rb (ppm)	LF100	0.1	18.7	0.6	16.6	85.1	75.8	54.8	5.3	13.1	48.4
Sn (ppm)	LF100	1	0.5	0.5	0.5	0.5	1	0.5	0.5	0.5	0.5
Sr (ppm)	LF100	0.5	196.6	75.2	153.3	162.6	320.3	129.3	330.5	369.2	377.2
Ta (ppm)	LF100	0.1	0.2	0.05	0.3	0.2	0.6	0.3	0.05	0.2	0.3
Th (ppm)	LF100	0.2	1.7	1.1	1.2	2.9	8.2	2.4	0.5	1.5	2.9
U (ppm)	LF100	0.1	0.6	0.8	0.4	1.1	1.6	0.5	0.7	0.7	0.9
W (ppm)	LF100	0.5	0.25	0.8	0.25	2	1.5	1.6	0.25	0.25	0.25
V (ppm)	LF100	8	24	29	83	213	85	104	13	18	215
Zr (ppm)	LF100	0.1	60.6	30.8	47.3	63.5	155.4	47.3	19.4	53.5	68.5
Y (ppm)	LF100	0.1	6.4	8.5	12.2	13.1	23.1	11.6	5.4	6.7	13.9
La (ppm)	LF100	0.1	8.3	7.6	11.6	10.2	21.3	13.1	4.2	7.7	11
Ce (ppm)	LF100	0.1	14.5	11.9	21.6	21.4	44.5	24.6	6.2	12.8	22.4
Pr (ppm)	LF100	0.02	1.62	1.58	2.98	2.56	5.53	3.16	0.87	1.59	2.69
Nd (ppm)	LF100	0.3	6.3	6.9	12.4	10.2	22.1	12.9	4.2	6.3	11

Appendix B: Lithogeochemical data

Analyte	Analytical Method*	Detection Limit	13JZBH111	13JZBH118	13JZBH125	13JZBH133	13JZBH136	13JZBH140	13JZBH142	13JZBH143	13JZBH147
Sm (ppm)	LF100	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Eu (ppm)	LF100	0.02	<0.02	<0.02	<0.02	<0.02	0.02	<0.02	<0.02	<0.02	<0.02
Gd (ppm)	LF100	0.05	101	4	85	96	141	98	17	69	132
Tb (ppm)	LF100	0.01	0.5	0.5	2	2	5	0.5	0.5	0.5	3
Dy (ppm)	LF100	0.05	1.1	1	6	23.2	8.3	8.4	1	0.6	21.4
Ho (ppm)	LF100	0.02	1.5	1	4	5.6	3.6	11.1	0.3	1	4.5
Er (ppm)	LF100	0.03	2.1	0.25	5.3	14.2	12	9.6	0.6	1	16.1
Tm (ppm)	LF100	0.01	1.6	1.2	1.3	1.7	4.1	1.5	0.4	1.4	1.7
Yb (ppm)	LF100	0.05	2.6	0.9	1.8	3.8	7.7	2.1	0.2	1.9	3.7
Lu (ppm)	LF100	0.01	18.7	0.6	16.6	85.1	75.8	54.8	5.3	13.1	48.4
Mo (ppm)	AQ200	0.1	0.5	0.5	0.5	0.5	1	0.5	0.5	0.5	0.5
Cu (ppm)	AQ200	0.1	196.6	75.2	153.3	162.6	320.3	129.3	330.5	369.2	377.2
Pb (ppm)	AQ200	0.1	0.2	0.05	0.3	0.2	0.6	0.3	0.05	0.2	0.3
Zn (ppm)	AQ200	1	1.7	1.1	1.2	2.9	8.2	2.4	0.5	1.5	2.9
Ni (ppm)	AQ200	0.1	0.6	0.8	0.4	1.1	1.6	0.5	0.7	0.7	0.9
As (ppm)	AQ200	0.5	0.25	0.8	0.25	2	1.5	1.6	0.25	0.25	0.25
Cd (ppm)	AQ200	0.1	24	29	83	213	85	104	13	18	215
Sb (ppm)	AQ200	0.1	60.6	30.8	47.3	63.5	155.4	47.3	19.4	53.5	68.5
Bi (ppm)	AQ200	0.1	6.4	8.5	12.2	13.1	23.1	11.6	5.4	6.7	13.9
Ag (ppm)	AQ200	0.1	8.3	7.6	11.6	10.2	21.3	13.1	4.2	7.7	11
Hg (ppm)	AQ200	0.01	14.5	11.9	21.6	21.4	44.5	24.6	6.2	12.8	22.4
Tl (ppm)	AQ200	0.1	1.62	1.58	2.98	2.56	5.53	3.16	0.87	1.59	2.69
Se (ppm)	AQ200	0.5	6.3	6.9	12.4	10.2	22.1	12.9	4.2	6.3	11

Appendix B: Lithogeochemical data

Analyte	Analytical Method*	Detection Limit	13JZBH156	13JZBH165	13JZBH167	13JZBH176	13JZBH181	13JZBH185	13JZBH190	13JZBH197
Au (ppb)	FA130	0.5	9.1	1.3	2.2	0.7	1.5	0.8	2.2	0.25
SiO2 (%)	LF700	0.10	15.20	39.30	54.10	27.20	14.60	52.00	30.40	9.30
Al2O3 (%)	LF700	0.01	0.63	9.53	16.99	3.68	0.75	11.37	4.61	0.44
Fe2O3 (%)	LF700	0.01	0.50	4.15	7.02	1.38	0.71	5.15	1.57	0.69
CaO (%)	LF700	0.01	46.32	23.42	6.38	36.47	45.90	8.37	33.76	49.69
MgO (%)	LF700	0.01	0.38	5.39	4.12	0.76	0.57	5.88	0.79	0.41
Na2O (%)	LF700	0.01	0.01	1.47	3.35	0.04	0.01	2.04	0.06	0.01
K2O (%)	LF700	0.01	0.11	2.17	1.38	0.62	0.15	2.04	0.74	0.07
MnO (%)	LF700	0.01	0.03	0.09	0.13	0.06	0.03	0.13	0.07	0.03
TiO2 (%)	LF700	0.01	0.03	0.51	0.58	0.21	0.05	0.60	0.24	0.02
P2O5 (%)	LF700	0.01	0.03	0.10	0.15	0.07	0.03	0.08	0.08	0.02
Cr2O3 (%)	LF700	0.001	<0.001	0.01	<0.001	<0.001	<0.001	0.01	<0.001	<0.001
LOI (%)	LF700	-5.11	36.44	13.94	6.04	29.02	36.21	13.05	26.81	38.44
SO3 (%)	LF700	0.002	0.33	0.06	0.09	0.53	0.79	0.05	0.87	1.01
V2O5 (%)	LF700	0.002	<0.002	0.02	0.04	0.01	<0.002	0.02	0.01	<0.002
Total (%)	LF700	0.01	100.01	100.15	100.37	100.04	99.80	100.79	100.01	100.13
TOT/C (%)	TC000	0.02	10.20	3.57	0.65	7.97	10.10	3.02	7.33	10.90
TOT/S (%)	тс000	0.02	0.14	0.01	0.04	0.09	0.27	0.01	0.40	0.32
Ba (%)	LF700	0.01	0.01	0.06	0.02	0.01	0.01	0.04	0.01	0.01
Cu (%)	LF700	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Ni (%)	LF700	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Pb (%)	LF700	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Sr (%)	LF700	0.002	0.03	0.06	0.05	0.02	0.03	0.04	0.02	0.03

Analyte	Analytical Method*	Detection Limit	13JZBH156	13JZBH165	13JZBH167	13JZBH176	13JZBH181	13JZBH185	13JZBH190	13JZBH197
Zn (%)	LF700	0.001	<0.001	0.01	0.01	<0.001	<0.001	<0.001	<0.001	<0.001
Zr (%)	LF700	0.002	<0.002	0.01	<0.002	<0.002	<0.002	0.02	<0.002	<0.002
Ba (ppm)	LF100	1	23	525	160	94	21	399	78	19
Be (ppm)	LF100	1	0.5	2	2	0.5	0.5	0.5	2	0.5
Co (ppm)	LF100	0.2	0.7	10.2	19.2	2.5	0.7	13.3	2.9	0.6
Cs (ppm)	LF100	0.1	0.2	0.6	2.3	2.3	0.5	2.1	1.4	0.2
Ga (ppm)	LF100	0.5	0.25	12	14.6	3.2	0.25	14.5	4.8	0.25
Hf (ppm)	LF100	0.1	0.4	3.2	1.8	1.5	0.6	5.4	1.4	0.2
Nb (ppm)	LF100	0.1	0.05	7.3	3.4	1.5	0.4	9.3	2.3	0.05
Rb (ppm)	LF100	0.1	5.4	74.1	44.1	19.8	6.6	67.9	21.6	4.2
Sn (ppm)	LF100	1	0.5	1	0.5	0.5	0.5	3	0.5	0.5
Sr (ppm)	LF100	0.5	328.4	638.9	428.2	121.3	365	373.6	189.6	295.8
Ta (ppm)	LF100	0.1	0.05	0.5	0.3	0.05	0.05	0.7	0.2	0.05
Th (ppm)	LF100	0.2	0.5	8	3	1.8	0.8	9.6	2	0.3
U (ppm)	LF100	0.1	0.5	1.8	0.8	1.1	0.8	2.4	0.8	0.7
W (ppm)	LF100	0.5	0.25	0.7	0.25	0.25	0.25	1.9	0.6	0.25
V (ppm)	LF100	8	9	94	196	32	12	102	45	4
Zr (ppm)	LF100	0.1	20.3	129.5	69.9	53.2	33.8	203.5	58.7	12.5
Y (ppm)	LF100	0.1	3.5	19.3	14.1	8.8	4.7	18	9.7	3
La (ppm)	LF100	0.1	4.3	23.1	10.7	10.2	5.9	25.6	9	3.2
Ce (ppm)	LF100	0.1	5.6	42.1	22	16.9	7.8	50.3	15.8	4.5
Pr (ppm)	LF100	0.02	0.84	5.35	2.7	2.13	1.11	6.45	2.05	0.6
Nd (ppm)	LF100	0.3	3.9	22.4	11.6	8.2	4.9	25.9	8.9	2.4

Analyte	Analytical Method*	Detection Limit	13JZBH156	13JZBH165	13JZBH167	13JZBH176	13JZBH181	13JZBH185	13JZBH190	13JZBH197
Sm (ppm)	LF100	0.05	0.64	4.59	2.32	1.41	0.89	5.05	1.85	0.44
Eu (ppm)	LF100	0.02	0.13	0.95	0.7	0.33	0.2	0.83	0.39	0.09
Gd (ppm)	LF100	0.05	0.62	3.64	2.62	1.54	0.76	3.79	1.54	0.43
Tb (ppm)	LF100	0.01	0.08	0.56	0.39	0.23	0.14	0.64	0.24	0.08
Dy (ppm)	LF100	0.05	0.55	3.18	2.74	1.51	0.73	3.55	1.38	0.43
Ho (ppm)	LF100	0.02	0.13	0.64	0.6	0.27	0.14	0.67	0.28	0.09
Er (ppm)	LF100	0.03	0.29	2.11	1.5	0.77	0.34	1.82	0.72	0.26
Tm (ppm)	LF100	0.01	0.03	0.28	0.22	0.12	0.05	0.28	0.12	0.03
Yb (ppm)	LF100	0.05	0.22	1.64	1.4	0.65	0.38	1.97	0.74	0.18
Lu (ppm)	LF100	0.01	0.04	0.24	0.22	0.11	0.05	0.3	0.12	0.03
Mo (ppm)	AQ200	0.1	0.2	0.05	0.2	0.1	0.05	0.2	0.5	0.3
Cu (ppm)	AQ200	0.1	1.1	8.3	67	2.4	2.1	1.2	4.4	1
Pb (ppm)	AQ200	0.1	1.7	4.8	1.2	2.4	1.8	3.9	3.8	1.8
Zn (ppm)	AQ200	1	3	20	49	14	6	119	19	3
Ni (ppm)	AQ200	0.1	0.5	10.7	10.5	2.9	2.5	33.4	4.5	3.1
As (ppm)	AQ200	0.5	14.9	1.9	1.4	1.9	26.1	1.5	30.2	5.6
Cd (ppm)	AQ200	0.1	0.05	0.05	0.05	0.05	0.05	0.2	0.05	0.05
Sb (ppm)	AQ200	0.1	0.7	0.05	0.05	0.05	1.1	0.05	0.6	0.5
Bi (ppm)	AQ200	0.1	0.05	0.05	0.05	0.2	0.05	0.05	0.05	0.05
Ag (ppm)	AQ200	0.1	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Hg (ppm)	AQ200	0.01	0.03	0.005	0.005	0.005	0.01	0.005	0.005	0.01
Tl (ppm)	AQ200	0.1	0.1	0.05	0.05	0.05	0.1	0.05	0.05	0.05
Se (ppm)	AQ200	0.5	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25

Sample ID	Litho. Unit	Mineral 1	Mineral 2	Mineral 3	w2200 (nm)*	Hqd 2200*	Width 2200*	Hqd 1900*	Sericite Crysta- llinity
13JZBH001	VOL	Illite			2196.04	0.27	31.81	0.34	0.78
13JZBH002	VOL	Illite			2197.76	0.33	34.39	0.37	0.89
13JZBH003	VOL	Illite			2197.05	0.18	32.14	0.23	0.78
13JZBH004	VOL	Illite			2196.73	0.20	33.18	0.27	0.72
13JZBH005	VOL	Montmo- rillonite	Illite		2218.58	0.05	30.85	0.17	0.31
13JZBH006	S2	Dickite	Kaolinite	Illite	2207.40	0.11	29.73	0.04	2.70
13JZBH007	S2	Illite			2198.78	0.06	32.59	0.07	0.79
13JZBH008	S2	Illite			2195.47	0.09	32.04	0.11	0.74
13JZBH009	S2	Illite			2197.97	0.11	33.69	0.12	0.91
13JZBH010	S2	Illite	Kaolinite		2205.36	0.14	33.08	0.11	1.21
13JZBH010a	S2	Illite	Kaolinite		2207.69	0.20	31.01	0.12	1.75
13JZBH011	S2	Kaolinite	Illite	Muscovite	2208.20	0.14	28.10	0.07	2.01
13JZBH011a	S2	Kaolinite	Illite		2207.77	0.09	29.52	0.08	1.20
13JZBH012	S1	Kaolinite							
13JZBH013	S1	Illite			2203.77	0.04	28.42	0.05	0.86
13JZBH014	S1	Illite			2198.33	0.05	31.38	0.06	0.86
13JZBH015	IB	Illite	Muscovite		2202.74	0.08	28.94	0.06	1.34
13JZBH017	VOL	Illite			2194.13	0.22	32.20	0.28	0.78
13JZBH018	VOL	Illite			2197.44	0.08	32.31	0.14	0.62
13JZBH020	S2	Illite	Kaolinite		2203.01	0.07	32.80	0.12	0.63
13JZBH021	S2	Illite			2194.42	0.24	33.07	0.26	0.93
13JZBH021a	S2	Illite	Kaolinite		2206.88	0.17	31.70	0.25	0.67
13JZBH023	S2	Illite			2204.10	0.14	33.79	0.12	1.12
13JZBH024	S1	Illite	Muscovite		2206.19	0.20	30.60	0.13	1.50
13JZBH024a	S1	Illite			2203.25	0.12	31.43	0.15	0.79
13JZBH025	S1	Illite			2201.35	0.13	31.12	0.09	1.42
13JZBH025a	S1	Illite	Kaolinite		2200.07	0.13	28.99	0.11	1.15
13JZBH027	S1	Illite			2205.89	0.15	30.77	0.10	1.58
13JZBH028	BBX	Illite			2202.49	0.11	33.01	0.14	0.80
13JZBH029	SMR	Illite			2210.75	0.07	34.10	0.11	0.68
13JZBH030	SMR	Illite			2207.28	0.11	31.00	0.08	1.42
13JZBH031	S2	Illite			2202.71	0.10	29.78	0.09	1.14
13JZBH032	S2	Illite			2208.51	0.10	25.20	0.19	0.55
13JZBH033	S2	Illite	Kaolinite		2207.29	0.28	33.56	0.23	1.18
13JZBH034	S2	Illite			2197.40	0.11	32.16	0.12	0.98
13JZBH035	S1	Kaolinite							
13JZBH036	S1	Kaolinite							

Appendix C: SWIR data, identified phyllosilicate minerals, and their spectral features

Sample ID	Litho. Unit	Mineral 1	Mineral 2	Mineral 3	w2200 (nm)*	Hqd 2200*	Width 2200*	Hqd 1900*	Sericite Crysta- Ilinity
13JZBH037	S1	Illite			2202.53	0.08	32.40	0.08	0.94
13JZBH039	IB	Illite			2210.46	0.06	31.35	0.07	0.89
13JZBH040	BBX	Illite	Kaolinite		2208.35	0.13	25.38	0.20	0.66
13JZBH041	VOL	Montmo- rillonite			2210.62	0.04	25.30	0.23	0.16
13JZBH042	VOL	Nacrite	Kaolinite						
13JZBH043	VOL	Kaolinite	Nacrite						
13JZBH044	VOL	Illite	Kaolinite		2208.14	0.31	26.71	0.43	0.71
13JZBH045	VOL	Kaolinite							
13JZBH046	VOL	Illite	Montmo- rillonite	Kaolinite	2208.52	0.09	27.96	0.23	0.36
13JZBH047	S2	Illite			2208.65	0.06	24.64	0.06	1.05
13JZBH049	S2	Illite	Kaolinite		2208.22	0.28	28.45	0.26	1.11
13JZBH050	S2	Kaolinite	Illite		2208.38	0.16	31.01	0.18	0.92
13JZBH051	S2	Illite			2185.70	0.11	28.17	0.19	0.57
13JZBH052	S2	Illite			2207.76	0.09	30.06	0.08	1.07
13JZBH053	S2	Illite			2207.82	0.07	33.06	0.09	0.78
13JZBH054	S2	Muscovite	Dickite	Illite	2206.53	0.09	29.43	0.07	1.37
13JZBH054a	S2	Illite	Muscovite		2207.89	0.07	27.33	0.04	1.72
13JZBH055	S2	Illite	Nacrite		2209.04	0.05	25.70	0.04	1.34
13JZBH059	S1	Illite			2200.62	0.04	28.84	0.09	0.51
13JZBH061	S2	Illite			2206.75	0.14	31.93	0.27	0.51
13JZBH062	S2	Kaolinite	Illite		2207.58	0.16	33.07	0.26	0.64
13JZBH063	S2	Kaolinite	Illite		2190.62	0.22	35.74	0.41	0.54
13JZBH064	S2	Kaolinite	Illite		2208.43	0.12	28.01	0.12	1.00
13JZBH066	S1	Kaolinite							
13JZBH072	S2	Kaolinite	Illite		2208.56	0.20	26.72	0.13	1.55
13JZBH073	S2	Kaolinite							
13JZBH074	S2	Kaolinite							
13JZBH075	S2	Kaolinite							
13JZBH076	S2	Kaolinite							
13JZBH077	S2	Kaolinite							
13JZBH078	S2	Kaolinite							
13JZBH079	S2	Kaolinite							
13JZBH083	S1	Illite			2205.51	0.06	29.15	0.06	1.07
13JZBH084	S1	Illite			2208.36	0.08	27.97	0.11	0.69
13JZBH085	BBX	Illite			2192.15	0.15	33.76	0.27	0.54
13JZBH086	BBX	Illite			2194.90	0.15	35.18	0.25	0.60

Appendix C. Swin data, identified phyliosificate finiterals, and their spectral reature

Sample ID	Litho. Unit	Mineral 1	Mineral 2	w2200 (nm)*	Hqd 2200*	Width 2200*	Hqd 1900*	Sericite Crysta- Ilinity
13JZBH087	BBX	Kaolinite						
13JZBH088	S2	Montmorillonite		2208.25	0.06	25.63	0.25	0.23
13JZBH089	S2	Illite		2206.18	0.15	32.15	0.37	0.42
13JZBH090	S2	Illite		2195.95	0.09	32.65	0.13	0.74
13JZBH092	S1	Kaolinite						
13JZBH093	S1	Kaolinite						
13JZBH094	S1	Kaolinite	Dickite					
13JZBH095	S1	Illite		2204.66	0.09	30.22	0.12	0.74
13JZBH097	IB	Illite		2192.30	0.18	33.57	0.24	0.74
13JZBH099	BBX	Illite		2186.33	0.04	26.28	0.09	0.42
13JZBH100	BBX	Illite		2188.00	0.07	30.43	0.14	0.52
13JZBH103	VOL	Montmorillonite	Nacrite	2204.15	0.31	31.17	0.34	0.91
13JZBH104	SMR	Montmorillonite		2227.90	0.01	26.43	0.24	0.04
13JZBH105	S2	Illite	Montmorillonite	2208.23	0.09	27.02	0.24	0.38
13JZBH106	S2	Montmorillonite	Halloysite	2208.66	0.12	23.77	0.25	0.52
13JZBH107	S2	Kaolinite						
13JZBH108	S1	Illite		2205.62	0.06	29.97	0.08	0.71
13JZBH109	S1	Illite		2205.20	0.06	29.63	0.08	0.83
13JZBH110	S1	Illite		2203.41	0.10	30.77	0.13	0.82
13JZBH112	IB	Kaolinite						
13JZBH113	BBX	Illite	Kaolinite	2207.70	0.07	28.79	0.06	1.16
13JZBH113a	BBX	Illite	Kaolinite	2208.57	0.06	27.76	0.04	1.55
13JZBH114	BBX	Illite		2208.69	0.20	27.40	0.32	0.62
13JZBH115	S2	Illite		2200.51	0.22	34.63	0.27	0.84
13JZBH116	S1	Illite	Montmorillonite	2208.32	0.05	32.21	0.12	0.42
13JZBH117	S1	Montmorillonite		2208.87	0.03	25.73	0.20	0.14
13JZBH124	S2	Illite		2209.31	0.06	29.55	0.15	0.41
13JZBH125	S2	Illite		2207.80	0.09	29.00	0.17	0.57
13JZBH126	S2	Illite		2192.21	0.07	30.45	0.10	0.73
13JZBH127	S2	Illite		2195.70	0.18	32.27	0.26	0.69
13JZBH132	VOL	Illite		2196.57	0.29	33.98	0.39	0.75
13JZBH133	VOL	Illite		2197.23	0.25	32.74	0.29	0.86
13JZBH134	VOL	Illite		2194.08	0.18	32.71	0.26	0.72
13JZBH135	SMR	Illite		2199.80	0.11	29.82	0.13	0.81
13JZBH136	SMR	Illite		2199.19	0.12	31.90	0.12	1.04
13JZBH138	S2	Illite		2196.81	0.27	33.94	0.36	0.75
13JZBH139	S2	Illite		2200.15	0.19	33.19	0.23	0.83

Appendix C. Swirk data, identified phyliosilicate fillinerals, and their spectral reature

Sample ID	Litho. Unit	Mineral 1	Mineral 2	w2200 (nm)*	Hqd 2200*	Width 2200*	Hqd 1900*	Sericite Crysta- Ilinity
13JZBH140	S2	Illite		2200.74	0.21	34.41	0.25	0.85
13JZBH141	S2	Montmorillonite		2208.87	0.03	25.73	0.12	0.26
13JZBH144	SMR	Illite		2199.32	0.22	33.23	0.27	0.82
13JZBH145	SMR	Illite		2198.88	0.15	27.90	0.22	0.69
13JZBH146	VOL	Illite		2196.49	0.19	34.66	0.20	0.95
13JZBH147	VOL	Illite		2204.71	0.13	32.19	0.15	0.89
13JZBH148	VOL	Montmorillonite		2207.35	0.03	23.17	0.18	0.16
13JZBH149	SMR	Illite		2208.85	0.17	31.83	0.23	0.71
13JZBH151	S2	Montmorillonite		2209.30	0.11	23.93	0.26	0.43
13JZBH152	S2	Kaolinite						
13JZBH153	S2	Illite		2204.69	0.06	28.81	0.11	0.56
13JZBH154	S1	Muscovite	Illite	2205.75	0.10	30.66	0.12	0.83
13JZBH159	S1	Illite		2204.39	0.04	27.62	0.06	0.74
13JZBH160	IB	Illite		2203.59	0.10	26.77	0.11	0.93
13JZBH161	S2	Illite		2206.84	0.14	31.63	0.31	0.43
13JZBH163	S2	Montmorillonite	Palygorskite	2214.28	0.05	28.32	0.24	0.20
13JZBH167	VOL	Illite	Montmorillonite	2208.78	0.09	21.67	0.19	0.48
13JZBH168	S2	Illite		2201.73	0.11	32.02	0.08	1.41
13JZBH170	S2	Illite		2202.43	0.07	30.73	0.10	0.71
13JZBH170a	S2	Illite		2203.25	0.14	31.11	0.10	1.39
13JZBH171	S2	Illite		2194.16	0.25	32.59	0.28	0.89
13JZBH172	S1	Illite		2199.64	0.12	32.58	0.09	1.35
13JZBH173	BBX	Illite		2210.24	0.06	30.82	0.05	1.19
13JZBH174	BBX	Illite	Montmorillonite	2208.29	0.04	27.41	0.06	0.69
13JZBH175	VOL	Illite		2206.12	0.22	32.52	0.29	0.76
13JZBH176	S2	Illite		2207.71	0.13	28.83	0.16	0.79
13JZBH177	S2	Illite		2197.34	0.11	33.04	0.12	0.93
13JZBH178	S2	Kaolinite						
13JZBH179	S1	Illite		2203.25	0.09	30.85	0.13	0.71
13JZBH182	S1	Illite	Muscovite	2199.66	0.07	29.39	0.13	0.58
13JZBH184	SMR	Illite		2208.00	0.09	29.27	0.15	0.61
13JZBH185	SMR	Illite		2206.63	0.18	30.74	0.23	0.80
13JZBH186	VOL	Illite		2195.66	0.11	33.32	0.17	0.69
13JZBH187	VOL	Illite		2194.48	0.31	33.49	0.43	0.72
13JZBH188	VOL	Illite		2202.58	0.09	34.82	0.19	0.50
13JZBH188a	VOL	Illite		2202.14	0.25	35.23	0.32	0.79
13JZBH189	VOL	Montmorillonite		2207.17	0.06	26.45	0.30	0.19

	Appendix C: SWIR d	lata, identified	ohyl	losilicate	minerals,	and	their	spectral	features
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Sample ID	Litho. Unit	Mineral 1	Mineral 2	Mineral 3	w2200 (nm)*	Hqd 2200*	Width 2200*	Hqd 1900*	Sericite Crysta- llinity
13JZBH190	S2	Illite			2197.62	0.11	33.07	0.14	0.74
13JZBH191	S2	Illite			2199.85	0.14	33.24	0.16	0.85
13JZBH192	S2	Illite	Montmo- rillonite	Halloysite	2206.37	0.08	26.05	0.15	0.52
13JZBH193	S2	Montmo- rillonite	Illite		2208.08	0.10	27.14	0.20	0.53
13JZBH194	S2	Kaolinite							
13JZBH195	S2	Illite	Muscovite		2202.07	0.10	30.70	0.12	0.87
13JZBH195a	S2	Illite			2200.81	0.07	31.35	0.13	0.61
13JZBH199	IB	Muscovite	Illite		2204.19	0.10	28.03	0.12	0.83
13JZBH200	IB	Illite			2208.31	0.05	29.00	0.02	2.03
13JZBH206	S2	Illite			2199.20	0.08	32.28	0.13	0.65
13JZBH207	S2	Illite			2198.71	0.15	34.49	0.16	0.92
13JZBH208	S2	Illite			2202.35	0.05	32.83	0.07	0.71
13JZBH208a	S2	Illite			2203.40	0.16	33.46	0.14	1.10
13JZBH210	SMR	Illite			2202.55	0.06	30.78	0.04	1.35
13JZBH211	S2	Illite			2200.92	0.10	32.82	0.11	0.85
13JZBH212	S2	Illite	Montmo- rillonite		2208.16	0.08	27.01	0.18	0.42
13JZBH213	S2	Illite			2209.14	0.06	24.77	0.09	0.60
13JZBH214	S2	Illite			2193.80	0.08	33.01	0.13	0.57
13JZBH215	S2	Illite			2200.92	0.25	33.95	0.39	0.64
13JZBH218	S2	Illite	Montmo- rillonite		2206.66	0.12	26.71	0.20	0.59
13JZBH221	S2	Montmo- rillonite			2208.51	0.03	26.66	0.10	0.32
13JZBH222	S2	Illite			2195.92	0.20	33.39	0.29	0.69
13JZBH225	S1	Illite			2201.66	0.06	31.36	0.03	2.14
13JZBH225a	S1	Illite			2204.01	0.06	29.79	0.07	0.80
13JZBH226	S1	Illite	Kaolinite	Dickite	2209.30	0.05	31.27	0.05	1.15
13JZBH227	S2	Illite	Halloysite		2205.33	0.16	30.99	0.18	0.91
13JZBH228	S2	Kaolinite	Montmo- rillonite	Illite	2208.90	0.10	24.14	0.15	0.64
13JZBH228a	S2	Kaolinite	Montmo- rillonite	Illite	2208.71	0.19	25.16	0.41	0.46
13JZBH230	S2	Illite			2207.05	0.13	29.92	0.28	0.49
13JZBH232	S1	Illite			2209.79	0.04	28.56	0.06	0.60
13JZBH233	S1	Illite			2205.29	0.06	29.69	0.10	0.61
13JZBH234	S1	Illite			2200.27	0.06	30.14	0.13	0.46
14JZBH235	SMR	Illite			2203.06	0.08	31.30	0.14	0.54
14JZBH236	SMR	Illite			2202.48	0.06	30.06	0.11	0.53

Sample ID	Litho. Unit	Mineral 1	Mineral 2	Mineral 3	w2200 (nm)*	Hqd 2200*	Width 2200*	Hqd 1900*	Sericite Crysta- Ilinity
14JZBH237	SMR	Illite			2203.90	0.04	29.68	0.11	0.35
14JZBH237a	SMR	Illite			2204.00	0.06	29.41	0.10	0.62
14JZBH238	S2	Montmo- rillonite	Palygorskite		2212.46	0.07	31.19	0.27	0.24
14JZBH239	S2	Montmo- rillonite			2217.86	0.04	31.53	0.10	0.37
14JZBH240	S2	Montmo- rillonite	Palygorskite		2215.42	0.04	28.60	0.25	0.17
14JZBH241	S2	Montmo- rillonite			2208.73	0.05	26.23	0.16	0.30
14JZBH242	S1	Illite	Montmo- rillonite		2208.59	0.06	29.53	0.17	0.35
14JZBH243	S1	Montmo- rillonite			2208.30	0.03	26.76	0.07	0.40
14JZBH244	S1	Montmo- rillonite			2208.85	0.04	23.91	0.18	0.20
14JZBH245	S1	Illite			2208.73	0.05	25.93	0.09	0.48
14JZBH248	S2	Montmo- rillonite			2209.81	0.07	25.40	0.34	0.21
14JZBH249	S2	Montmo- rillonite			2208.88	0.06	24.61	0.21	0.28
14JZBH250	S1	Montmo- rillonite			2208.81	0.05	23.19	0.19	0.27
14JZBH251	S1	Montmo- rillonite			2210.53	0.06	28.55	0.30	0.18
14JZBH252	S1	Montmo- rillonite	Illite		2208.44	0.09	26.45	0.30	0.30
14JZBH253	IB	Illite	Montmo- rillonite		2203.05	0.04	28.80	0.09	0.39
14JZBH254	S1	Kaolinite	Illite		2208.28	0.04	21.75	0.06	0.66
14JZBH259	SMR	Muscovite	Illite		2206.41	0.07	32.47	0.07	1.02
14JZBH260	S2	Illite			2214.37	0.06	27.99	0.15	0.36
14JZBH261	S2	Illite	Montmo- rillonite		2209.43	0.05	32.68	0.11	0.46
14JZBH262	S1	Illite			2208.10	0.04	32.82	0.08	0.52
14JZBH264	IB	Illite			2201.71	0.04	32.37	0.02	1.54
14JZBH267	S2	Illite			2205.14	0.10	30.16	0.16	0.64
14JZBH268	S2	Illite			2192.04	0.07	31.79	0.11	0.65
14JZBH268a	S2	Illite			2196.89	0.11	32.45	0.13	0.78
14JZBH269	S2	Illite			2201.96	0.07	32.41	0.11	0.64
14JZBH269a	S2	Illite			2203.67	0.13	32.75	0.09	1.36
14JZBH270	IB	Illite	Muscovite		2206.14	0.05	27.48	0.03	1.63
14JZBH270a	S2	Illite	Kaolinite		2205.81	0.06	29.26	0.03	2.11
14JZBH271	S1	Illite	Kaolinite	Muscovite	2206.21	0.06	30.46	0.07	0.88

Sample ID	Litho. Unit	Mineral 1	Mineral 2	Mineral 3	w2200 (nm)*	Hqd 2200*	Width 2200*	Hqd 1900*	Sericite Crysta- llinity
14JZBH273	KLS	Illite			2208.12	0.04	31.65	0.06	0.71
14JZBH277	SMR	Illite	Muscovite		2208.46	0.09	27.23	0.06	1.51
14JZBH278	S2	Kaolinite							
14JZBH279	S2	Kaolinite							
14JZBH283	BBX	Illite			2198.01	0.05	32.26	0.09	0.57
14JZBH284	BBX	Illite	Kaolinite		2208.34	0.20	29.05	0.16	1.29
14JZBH285	VOL	Illite			2207.35	0.08	27.99	0.15	0.53
14JZBH286	GDI	Illite			2200.87	0.02	26.68	0.16	0.14
14JZBH287	S1	Kaolinite							
14JZBH288	VOL	Illite		Montmo- rillonite	2195.86	0.23	32.54	0.27	0.88
14JZBH290	BBX	Illite	Dickite		2207.83	0.07	26.96	0.04	1.45
14JZBH291	KLS	Illite			2208.89	0.07	25.73	0.07	0.96
14JZBH292	VOL	Illite			2197.67	0.31	34.38	0.36	0.85
14JZBH293	S2	Kaolinite	Illite		2208.66	0.29	27.74	0.13	2.22
14JZBH294	VOL	Illite			2195.91	0.20	33.39	0.24	0.84
14JZBH295	S2	Illite	Kaolinite		2204.28	0.14	33.34	0.13	1.08
14JZBH295a	S2	Illite	Kaolinite		2207.71	0.14	30.47	0.09	1.46
14JZBH296	VOL	Illite			2197.63	0.28	34.30	0.35	0.82
14JZBH297	S2	Illite			2197.76	0.25	33.79	0.30	0.85
14JZBH298	S2	Illite			2197.96	0.18	33.57	0.20	0.88
14JZBH299	S2	Illite	Muscovite	Kaolinite	2203.01	0.13	31.25	0.12	1.07
14JZBH299a	S2	Illite	Kaolinite		2204.61	0.11	30.50	0.07	1.47
14JZBH300	S2	Kaolinite							
14JZBH301	S2	Illite			2208.02	0.06	27.28	0.12	0.47
14JZBH302	S2	Illite			2198.41	0.06	30.72	0.12	0.55

Appendix C: SWIR data, identified phyllosilicate minerals, and their spectral features








	Comple ID	From	Та	Stratigraphic	Lithology	δ13C	δ18Ο	Au	As	Sb	TI	Те	Hg
HOLE ID	Sample ID	FIOIII	10	Unit	Litilology	(VPDB)	(VPDB)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
BHDD053	01-53	460	461	SMR	Marl	3.69	20.35	0.006	6.8	0.44	0.08	0.13	0.02
BHDD053	02-53	465	466	SMR	Marl	1.70	19.75	0.018	17.5	1.89	0.12	0.025	0.04
BHDD053	03-53	470	471	SMR	Marl	2.55	21.64	0.009	22.2	3.22	0.12	0.07	0.03
BHDD053	04-53	475	476	SMR	Marl	1.84	22.14	0.005	4.2	0.51	0.08	0.025	0.02
BHDD053	05-53	480	481	SMR	Marl	1.15	18.95	0.005	2.7	0.32	0.1	0.06	0.005
BHDD053	06-53	485	486	S2	Sandstone	1.67	19.22	0.005	0.5	0.47	0.05	0.07	0.005
BHDD053	07-53	490	491	S2	Sandstone	-0.88	17.31	0.005	0.5	1.32	0.05	0.025	0.02
BHDD053	08-53	495	496	S2	Fault	-0.46	17.09	0.047	16.8	1.06	0.09	0.15	0.02
BHDD053	09-53	500	501	S2	Breccia	0.13	17.16	0.051	72.5	4.97	0.1	0.1	0.04
BHDD053	10-53	505	506	S2	Sandstone	1.39	19.08	0.163	162	4.17	0.08	0.39	0.03
BHDD053	11-53	510	511	S2	Sandstone	2.58	21.31	0.008	0.5	0.55	0.02	0.025	0.03
BHDD053	12-53	515	516	S2	Sandstone	2.02	20.41	0.006	2	0.5	0.01	0.025	0.005
BHDD053	13-53	520	521	S2	Sandstone	2.27	22.42	0.005	56.7	1.62	0.03	0.025	0.04
BHDD053	14-53	525	526	S2	Sandstone	2.53	23.12	0.005	5.9	0.61	0.01	0.025	0.005
BHDD053	15-53	530	531	S2	Sandstone	2.39	24.89	0.01	24.8	0.86	0.05	0.025	0.005
BHDD053	16-53	535	536	S1	Sandstone	1.99	25.31	0.01	22.1	1	0.03	0.025	0.03
BHDD053	17-53	540	541	S1	Sandstone	0.69	24.61	0.005	8	0.71	0.03	0.025	0.01
BHDD053	18-53	545	546	S1	Sandstone	2.32	27.66	0.005	5.9	0.62	0.02	0.025	0.005
BHDD053	19-53	550	551	S1	Sandstone	2.73	29.17	0.005	5.3	0.4	0.01	0.025	0.005
BHDD053	20-53	555	556	S1	Sandstone	2.49	27.36	0.005	4.3	0.42	0.01	0.06	0.005
BHDD053	21-53	560	561	S1	Sandstone	1.13	25.25	0.01	17.7	0.87	0.04	0.025	0.03
BHDD053	22-53	565	566	S1	Sandstone	0.81	17.39	0.032	15.8	0.9	0.03	0.025	0.03
BHDD053	23-53	570.1	570.9	S1	Sandstone	1.71	21.10	0.005	15.8	0.9	0.03	0.025	0.03
BHDD056	24-56	132	133	SMR	Marl	-1.03	15.00	0.06	27.6	0.79	0.08	0.3	0.03
BHDD056	25-56	137	138	S2	Sandstone	-0.48	15.04	0.005	1.4	0.56	0.08	0.025	0.005
BHDD056	26-56	142	143	S2	Sandstone	-0.92	15.38	0.008	61.5	5.14	0.34	0.07	0.06
BHDD056	27-56	147	148	S2	Sandstone	0.31	18.68	0.008	25.4	1.66	0.13	0.11	0.005
BHDD056	28-56	152	153	S2	Conglomerate	2.25	18.74	0.008	3.7	0.75	0.1	0.13	0.005
BHDD056	29-56	157	158	S2	Conglomerate	1.92	18.06	0.012	5.8	1.46	0.17	0.09	0.005
BHDD056	30-56	162	163	S2	Sandstone	2.52	18.32	0.04	147	7.1	0.43	1.19	0.03
BHDD056	31-56	167	168	S2	Sandstone	-1.04	13.88	0.032	82.4	5.94	0.34	0.36	0.06
BHDD056	31-56a	167	168	S2	Vein	-0.99	19.58						
BHDD056	32-56	172	173	S2	Sandstone	2.17	16.88	0.074	129	5.42	0.61	0.68	0.19
BHDD056	33-56	177	178	S2	Sandstone	1.07	15.76	0.252	173	16.3	1.59	1.32	1.01
BHDD056	34-56	182	183	S2	Sandstone	-0.25	14.93	0.306	249	25.4	3.48	1.8	0.61
BHDD056	35-56	187	188	S2	Sandstone	1.17	17.16	0.474	240	73.4	4.8	2.4	2.24
BHDD056	36-56	192	193	S1	Sandstone	-0.81	15.44	0.464	69	18	2.16	1.35	1.16

Appendix E.1: Carbon and oxygen isotope data from Bigar Hill, Korkan West, and Korkan South rocks

Drill Llolo	Comple ID	From	Та	Stratigraphic	Lithology	δ13C	δ180	Au	As	Sb	TI	Те	Hg
	Sample ID	From	10	Unit	Lithology	(VPDB)	(VPDB)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
BHDD056	37-56	197	198	S1	Sandstone	2.35	21.74	0.796	137	16.9	2.52	1.8	1.34
BHDD056	38-56	202	203	S1	Mudstone	0.20	16.99	0.432	310	25.3	2.66	2.26	1.18
BHDD056	39-56	207	208	BBX	Mudstone	-1.59	12.77	0.028	349	21.6	1.38	0.58	0.19
BHDD056	40-56	212	213	IB	Mudstone	-0.78	15.10	3.62	240	99.2	5.6	3.94	9.43
BHDD056	41-56	217	218	KLS	Vein	0.86	14.03						
BHDD056	42-56	222	223	KLS	Limestone	1.72	17.76	0.006	16	1.6	0.17	0.13	0.21
BHDD056	43-56	227	228	KLS	Limestone	2.02	18.27	0.044	47.8	4.67	0.67	0.42	0.18
BHDD056	44-56	232	233	KLS	Limestone	2.35	18.88	0.015	28.4	3.15	0.48	0.29	0.19
BHDD056	45-56	237	238	KLS	Limestone	0.26	16.93	0.124	57.1	11.9	1.61	0.68	1.01
BHDD056	46-56	242	243	KLS	Limestone	0.39	17.68	0.198	53.4	12.3	1.81	0.41	1.47
BHDD056	47-56	247	248	KLS	Limestone	0.45	15.89	0.104	77.5	33.2	0.9	0.62	0.69
BHDD056	48-56	252	253	KLS	Limestone	0.26	12.11	0.096	42.5	7.37	0.76	0.59	0.58
BHDD056	49-56	257	258	KLS	Limestone	1.23	18.01	0.416	78.7	21.2	2.79	0.76	1.95
BHDD056	50-56	262	263	KLS	Limestone	1.66	21.15	0.486	102	26	2.68	0.81	1.76
BHDD056	51-56	267	268	KLS	Limestone	1.75	14.71	0.306	88.9	17.5	2.22	0.65	1.25
BHDD056	52-56	272	273	KLS	Limestone	1.36	13.87	0.2	67.4	15.5	1	0.75	1.17
BHDD056	53-56	277	278	KLS	Limestone	0.53	14.52	0.154	64	26.7	1.44	0.99	0.97
BHDD056	54-56	282	283	KLS	Limestone	1.04	16.64	0.144	147	36.4	2.78	1.81	0.93
BHDD056	55-56	287	288	KLS	Limestone	1.85	26.21	0.036	72.5	8.77	1.04	0.58	0.43
BHDD056	56-56	292	293	JLS	Limestone	2.43	23.91	0.011	18.8	2.32	0.32	0.14	0.37
BHDD056	57-56	297	298	JLS	Limestone	2.19	25.38	0.011	18.7	4.79	0.25	0.06	0.45
BHDD056	58-56	302	303	JLS	Limestone	1.00	25.75	0.007	6.5	3.22	0.05	0.025	0.21
BHDD056	59-56	307	308	JLS	Limestone	2.41	24.35	0.023	14.5	2.27	0.15	0.025	0.11
BHDD056	60-56	312	313	JLS	Limestone	2.33	15.59	0.088	17.2	2.68	0.35	0.11	0.53
BHDD056	61-56	317	318	JLS	Limestone	1.52	15.51	0.074	27.3	4.49	0.48	0.2	1.04
BHDD056	62-56	322	323	JLS	Limestone	1.31	14.74	0.04	22.1	2.55	0.35	0.23	0.38
BHDD057	63-57	244	245	S1	Sandstone	2.92	22.04	0.26	94.1	2.81	0.35	0.44	0.26
BHDD057	64-57	249	250	S1	Sandstone	2.87	21.57	0.12	77	2.06	0.24	0.23	0.15
BHDD057	65-57	254	255	S1	Sandstone	1.52	22.08	0.093	70.8	2.38	0.23	0.18	0.11
BHDD057	66-57	259	260	IB	Sandstone	0.78	16.60	0.005	6.1	0.84	0.07	0.025	0.06
BHDD057	67-57	264	265	IB	Mudstone	1.85	16.31	0.047	59.9	4.82	0.13	0.5	0.09
BHDD057	68-57	269	270	IB	Mudstone	1.19	16.19	0.122	219	6.01	0.34	0.51	0.19
BHDD057	69-57	274	275	KLS	Fault	1.28	19.39	0.504	362	10.6	0.9	1.18	1.12
BHDD057	70-57	279	280	KLS	Limestone	1.61	23.98	0.404	21.8	3.61	0.28	0.15	0.44
BHDD057	71-57	284	285	KLS	Limestone	1.01	17.80	0.13	5.2	0.91	0.08	0.025	0.07
BHDD057	72-57	289	290	KLS	Limestone	1.57	16.77	0.04	2.8	1.1	0.02	0.025	0.08

Appendix E.1: Carbon and oxygen isotope data from Bigar Hill, Korkan West, and Korkan South rocks

Drill Llala	CompleID	From	Та	Stratigraphic	Lithology	δ13C	δ18Ο	Au	As	Sb	TI	Те	Hg
Drill Hole	Sample ID	From	10	Unit	Lithology	(VPDB)	(VPDB)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
BHDD057	73-57	294	295	KLS	Limestone	1.00	15.31	0.022	3.3	1.98	0.03	0.025	0.07
BHDD057	74-57	299	300	KLS	Limestone	0.87	21.60	0.205	6.4	1.3	0.05	0.025	0.11
BHDD057	75-57	304	305	KLS	Limestone	2.43	25.21	0.278	6.5	1.23	0.1	0.025	0.09
BHDD057	76-57	309	310	KLS	Limestone	2.81	26.71	0.336	15.1	1.13	0.09	0.025	0.09
BHDD057	77-57	314	315	KLS	Limestone	2.33	24.09	0.212	12.6	1.21	0.08	0.06	0.05
BHDD057	78-57	319	320	KLS	Limestone	2.35	24.93	0.038	31.5	2.48	0.29	0.08	0.2
BHDD058	79-58	280	281	SMR	Marl	4.33	20.00	0.02	1.9	0.28	0.1	0.13	0.04
BHDD058	80-58	285	286	SMR	Marl	2.37	19.73	0.01	1.2	0.21	0.07	0.11	0.02
BHDD058	81-58	290	291	SMR	Marl	2.25	21.67	0.011	1.6	0.98	0.08	0.17	0.005
BHDD058	82-58	295.2	296.2	SMR	Marl	1.91	22.61	0.008	5.4	0.32	0.09	0.19	0.01
BHDD058	83-58	300	301	SMR	Marl	1.75	23.15	0.006	3.1	0.25	0.08	0.11	0.005
BHDD058	84-58	305	306	SMR	Marl	3.26	24.21	0.007	3.9	0.25	0.07	0.06	0.005
BHDD058	85-58	310	311	SMR	Marl	1.72	23.46	0.008	19.8	0.67	0.07	0.06	0.05
BHDD058	86-58	315	316	SMR	Marl	3.26	24.61	0.007	3.6	0.18	0.06	0.13	0.02
BHDD058	87-58	320	321	SMR	Marl	2.60	24.11	0.007	5.5	0.33	0.05	0.15	0.08
BHDD058	88-58	325	326	SMR	Marl	4.34	25.70	0.007	0.5	0.1	0.07	0.025	0.005
BHDD058	89-58	330	331	SMR	Marl	3.32	25.18	0.007	8	0.28	0.1	0.18	0.02
BHDD058	90-58	335	336	SMR	Marl	4.10	25.98	0.008	4.2	0.2	0.06	0.025	0.005
BHDD058	91-58	340	341	SMR	Fault	2.78	24.21	0.007	4.5	0.28	0.05	0.06	0.04
BHDD058	92-58	345	346	SMR	Sandstone	3.14	26.00	0.006	3	0.18	0.03	0.025	0.005
BHDD058	93-58	350	351	SMR	Sandstone	1.82	21.98	0.008	7	0.22	0.05	0.05	0.03
BHDD058	94-58	355	356	SMR	Marl	1.62	22.37	0.007	8.6	0.17	0.09	0.025	0.02
BHDD058	95-58	360	361	SMR	Marl	1.72	22.80	0.006	8.3	0.12	0.1	0.09	0.02
BHDD058	96-58	365	366	SMR	Marl	2.72	22.68	0.005	10.3	0.12	0.1	0.11	0.05
BHDD058	97-58	370	371	SMR	Sandstone	3.28	22.57	0.009	10.6	0.35	0.1	0.21	0.02
BHDD058	98-58	375	376	S2	Sandstone	1.06	24.04	0.005	4.5	0.21	0.01	0.09	0.005
BHDD058	99-58	380	381	S2	Conglomerate	1.42	23.04	0.006	6	0.32	0.05	0.025	0.01
BHDD058	100-58	385	386	S2	Conglomerate	2.74	21.86	0.005	2.6	0.17	0.04	0.025	0.04
BHDD058	101-58	390	391	S2	Sandstone	1.78	20.17	0.009	6.5	0.21	0.03	0.09	0.02
BHDD058	102-58	395	396	S2	Sandstone	0.32	17.71	0.008	3.3	0.23	0.05	0.025	0.03
BHDD058	103-58	400	401	S2	Sandstone	1.11	18.93	0.008	1.9	0.1	0.05	0.06	0.005
BHDD058	104-58	405	406	S2	Sandstone	1.59	20.47	0.008	1.2	0.06	0.02	0.09	0.005
BHDD058	105-58	410	411	S2	Sandstone	1.23	18.03	0.006	1.4	0.1	0.01	0.05	0.005
BHDD058	106-58	415	416	S2	Sandstone	2.80	23.21	0.005	2	0.11	0.01	0.025	0.005
BHDD058	107-58	420	421	S2	Sandstone	1.97	22.71	0.005	2.4	0.24	0.01	0.09	0.005
BHDD058	108-58	425	426	S2	Sandstone	3.09	25.38	0.007	1.3	0.19	0.01	0.025	0.01

Appendix E.1: Carbon and oxygen isotope data from Bigar Hill, Korkan West, and Korkan South rocks

Drill Hole	Comple ID	From	То	Stratigraphic	Lithology	δ13C	δ18Ο	Au	As	Sb	TI	Те	Hg
Drill Hole	Sample ID	FIOIII	10	Unit	Lithology	(VPDB)	(VPDB)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
BHDD058	109-58	430	431	S2	Sandstone	3.57	24.60	0.008	3.7	0.1	0.04	0.025	0.005
BHDD058	110-58	435	436	S1	Sandstone	1.72	25.95	0.008	6.8	0.21	0.04	0.025	0.005
BHDD058	111-58	440	441	S1	Sandstone	1.52	23.46	0.01	4.6	0.18	0.04	0.05	0.005
BHDD058	112-58	445	446	S1	Sandstone	2.82	26.71	0.008	3.4	0.22	0.04	0.025	0.005
BHDD058	113-58	450	451	S1	Sandstone	1.43	26.58	0.009	3.4	0.3	0.03	0.025	0.005
BHDD058	114-58	455	456	S1	Sandstone	1.58	27.24	0.008	13.7	0.69	0.1	0.025	0.005
BHDD058	115-58	460	461	S1	Sandstone	1.85	27.57	0.006	3.8	0.24	0.03	0.025	0.005
BHDD058	116-58	465	466	S1	Sandstone	0.74	21.30	0.01	7.6	0.23	0.03	0.025	0.005
BHDD058	117-58	470	471	S1	Sandstone	2.03	26.65	0.008	74.8	0.86	0.04	0.65	0.005
BHDD058	118-58	475	476	S1	Sandstone	0.77	24.10	0.006	3.8	0.19	0.02	0.025	0.005
BHDD058	119-58	480	481	S1	Sandstone	0.65	23.21	0.009	3.3	0.15	0.02	0.025	0.02
BHDD058	120-58	485	486	S1	Sandstone	2.34	24.00	0.007	4.6	0.25	0.03	0.025	0.005
BHDD058	121-58	490	491	S1	Sandstone	2.29	23.87	0.009	2.6	0.27	0.03	0.025	0.005
BHDD058	122-58	495	496	S1	Sandstone	1.53	27.23	0.009	1.1	0.23	0.02	0.025	0.005
BHDD058	123-58	500	500.7	S1	Sandstone	1.22	23.96	0.006	1.1	0.23	0.02		
BHDD058	124-58	505	506	S1	Sandstone	2.62	22.71	0.007	6.5	0.26	0.03	0.025	0.005
BHDD058	125-58	510	511	S1	Sandstone	1.55	21.35	0.006	18.7	0.71	0.04	0.13	0.005
BHDD058	126-58	515	516	S1	Sandstone	2.10	22.37	0.006	3.6	0.15	0.02	0.025	0.005
BHDD058	127-58	520	521	S1	Sandstone	1.32	21.40	0.006	5.1	0.66	0.04	0.025	0.005
BHDD058	128-58	525	526	S1	Sandstone	1.65	21.00	0.007	6.5	0.91	0.04	0.05	0.06
BHDD058	129-58	530	531	S1	Sandstone	0.90	19.82	0.01	6.6	0.83	0.05	0.025	0.03
BHDD058	130-58	535	536	S1	Sandstone	2.63	19.83	0.005	5.4	0.44	0.05	0.08	0.02
BHDD058	131-58	540	541	S1	Sandstone	2.30	21.28	0.005	5.5	0.3	0.04	0.05	0.005
BHDD058	132-58	545	546	IB	Sandstone	0.79	19.76	0.013	31	2.51	0.08	0.025	0.005
BHDD058	133-58	550	551	BBX	Breccia	1.04	18.05	0.448	282	3.99	0.07	0.66	0.005
BHDD058	134-58	555	556	BBX	Breccia	2.52	24.01	0.011	18.7	0.93	0.07	0.025	0.005
BHDD058	135-58	560	561	BBX	Breccia	2.75	23.92	0.006	3.1	0.32	0.03	0.025	0.005
BHDD058	136-58	565	566	KLS	Limestone	1.72	24.60	0.022	5.2	1.21	0.05	0.025	0.07
BHDD058	137-58	570	571	KLS	Limestone	1.41	17.29	0.02	3	1.17	0.02	0.06	0.06
BHDD058	138-58	575	576	KLS	Limestone	1.66	22.92	0.024	1.9	1.48	0.01	0.025	0.005
BHDD068	139-68	160	161	S2	Sandstone	0.36	17.42	0.483	335	20.6	0.22	1.85	0.06
BHDD068	140-68	165	166	S2	Conglomerate	3.06	19.75	0.783	3134	38.9	0.86	5.37	0.18
BHDD068	141-68	170	170.9	S2	Sandstone	2.22	21.63	3.613	27.1	16.6	0.21	0.07	0.03
BHDD068	142-68	175	176	S2	Sandstone	1.82	19.59	0.022	5.4	2.97	0.06	0.025	0.005
BHDD068	143-68	180	181	S2	Sandstone	0.83	19.29	0.005	413	26.7	19.9	4.28	2.54
BHDD068	144-68	185	186	S2	Sandstone	1.77	18.48	2.192	626	59.4	39.8	13.7	6.05

Appendix E.1: Carbon and oxygen isotope data from Bigar Hill, Korkan West, and Korkan South rocks

Drill Llala	Commission	Fuere	Та	Stratigraphic	Litheless	δ13C	δ18Ο	Au	As	Sb	TI	Те	Hg
Drill Hole	Sample ID	FIOIII	10	Unit	Lithology	(VPDB)	(VPDB)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
BHDD068	145-68	190	191	S2	Sandstone	1.23	19.33	3.458	142	24.4	6.69	1.45	1.07
BHDD068	146-68	195	196	S1	Sandstone	-1.04	13.30	3.202	144	25.3	6.8	1.63	1.18
BHDD068	147-68	200	201	S1	Sandstone	2.72	23.62	1.29	16.6	2.77	0.68	0.09	0.02
BHDD068	148-68	205	206	S1	Sandstone	2.12	24.76	0.492	16.1	1.58	0.41	0.07	0.03
BHDD068	149-68	210	211	S1	Sandstone	1.74	24.13	0.862	20.2	2.2	0.47	0.09	0.05
BHDD068	150-68	215	216	S1	Sandstone	2.05	22.38	0.354	16.6	1.94	0.3	0.025	0.03
BHDD068	151-68	220	221	S1	Sandstone	1.55	22.91	0.42	22.3	1.69	0.29	0.025	0.08
BHDD068	152-68	225	226	S1	Sandstone	1.98	22.74	0.126	21.8	1.56	0.28	0.025	0.005
BHDD068	153-68	230	231	S1	Sandstone	1.48	23.32	0.172	17.8	1.83	0.22	0.08	0.02
BHDD068	154-68	235	236	S1	Sandstone	2.01	23.08	0.132	32.1	2.5	0.4	0.025	0.12
BHDD068	155-68	240	241	S1	Sandstone	1.44	20.32	0.166	47.4	2.4	0.36	0.24	0.15
BHDD068	156-68	245	246	S1	Sandstone	1.52	18.74	0.276	64.3	2.7	0.35	0.11	0.13
BHDD068	157-68	250	251	S1	Sandstone	0.72	25.26	0.009	29.8	0.88	0.1	0.025	0.005
BHDD068	158-68	255	256	IB	Breccia	0.09	16.63	0.011	66.1	1.18	0.13	0.22	0.05
BHDD068	159-68	260	261	IB	Breccia	2.81	23.58	0.038	52	1.5	0.07	0.09	0.02
BHDD068	160-68	265	266	IB	Mudstone	-1.50	15.62	0.019	94.1	3.06	0.14	0.24	0.02
BHDD068	162-68	275	276	IB	Mudstone	-2.34	14.54	0.42	221	28.5	1.57	0.53	0.66
BHDD068	163-68	280	281	KLS	Limestone	0.15	17.06	0.558	58.8	107	0.72	0.13	5.41
BHDD068	164-68	285	286	KLS	Limestone	0.29	16.07	0.086	12.4	3.35	0.13	0.025	0.03
BHDD068	165-68	290	291	KLS	Limestone	1.36	17.49	0.232	18	32.6	0.52	0.12	1.05
BHDD068	166-68	295	296	KLS	Limestone	0.91	22.33	0.572	13.8	3.34	0.2	0.025	0.36
BHDD068	167-68	300	301	KLS	Limestone	-0.05	17.29	0.256	16.4	2.64	0.16	0.08	0.18
BHDD068	168-68	305	306	KLS	Limestone	1.64	22.56	1.062	15.3	4.23	0.3	0.24	0.41
BHDD068	169-68	310	311	KLS	Limestone	0.85	23.26	1.4	18.4	3.93	0.4	0.18	0.43
BHDD068	170-68	315	316	KLS	Limestone	1.49	25.77	0.164	24.2	2.46	0.32	0.14	0.24
BHDD068	171-68	320	321	KLS	Limestone	1.92	18.10	0.234	107	8.49	1.16	0.53	0.67
BHDD068	172-68	325	326	JLS	Limestone	0.67	18.24	0.226	5.8	0.69	0.08	0.06	0.01
BHDD068	173-68	330	331	JLS	Limestone	-0.97	15.45	0.308	11.6	1.96	0.09	0.11	0.06
BHDD068	174-68	335	336	JLS	Limestone	-0.01	15.22	0.476	21.7	3.59	0.15	0.07	0.68
BHDD068	175-68	340	341	JLS	Limestone	0.39	15.52	0.436	5.8	1.5	0.06	0.08	0.12
BHDD068	176-68	345	346	JLS	Limestone	0.85	20.96	0.088	7.3	1.53	0.05	0.025	0.11
BHDD068	177-68	350	351	JLS	Limestone	0.42	22.06	0.012	26.6	2.2	0.14	0.025	0.1
BHDD068	178-68	355	356	JLS	Limestone	0.48	21.51	0.01	7.6	0.78	0.04	0.025	0.06
BHDD068	179-68	360	361	JLS	Limestone	0.86	24.12	0.016	5.9	0.59	0.05	0.025	0.04
BHDD068	180-68	365	366	JLS	Limestone	1.22	22.24	0.012	9.8	1.64	0.09	0.025	0.15
BHDD068	181-68	370	371	JLS	Limestone	0.90	19.67	0.018	9.4	0.94	0.09	0.08	0.13

Appendix E.1: Carbon and oxygen isotope data from Bigar Hill, Korkan West, and Korkan South rocks

Drill Llala	Commite ID	Fuere	Та	Stratigraphic	Lithelese	δ13C	δ18Ο	Au	As	Sb	TI	Те	Hg
Drill Hole	Sample ID	FIOIII	10	Unit	Lithology	(VPDB)	(VPDB)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
BHDD068	182-68	375	376	JLS	Limestone	0.92	20.14	0.064	16.8	2.41	0.1	0.06	0.12
BHDD068	183-68	380	381	JLS	Limestone	0.53	23.82	0.028	3.3	0.69	0.09	0.06	0.06
BHDD068	184-68	385	386	JLS	Limestone	0.49	24.05	0.054	6	0.59	0.06	0.025	0.01
BHDD068	185-68	390	391	JLS	Limestone	0.44	20.40	0.013	8.2	0.97	0.07	0.025	0.005
BHDD068	186-68	395	396	JLS	Limestone	0.18	15.90	0.008	2.1	0.84	0.04	0.025	0.11
BHDD068	187-68	400	401	JLS	Limestone	0.36	20.06	0.041	5.1	0.92	0.09	0.06	0.14
BHDD076	188-76	195	196	SMR	Marl	0.77	14.84	0.005	1.7	0.22	0.03	0.025	0.005
BHDD076	189-76	200	201	S2	Sandstone	1.17	20.89	0.005	1.3	0.24	0.04	0.05	0.04
BHDD076	190-76	205	206	S2	Sandstone	2.38	20.14	0.006	0.5	0.14	0.04	0.025	0.01
BHDD076	191-76	210	211	S2	Sandstone	1.11	15.28	0.006	0.5	0.14	0.03	0.025	0.02
BHDD076	192-76	215	216	S2	Sandstone	-2.70	15.24	0.006	3.9	0.16	0.04	0.05	0.005
BHDD076	193-76	220	221	S2	Sandstone	2.16	20.41	0.005	1.1	0.14	0.01	0.06	0.03
BHDD076	194-76	225	226	S2	Sandstone	1.66	20.75	0.005	0.5	0.1	0.01	0.06	0.03
BHDD076	195-76	230	231	S2	Sandstone	1.24	19.51	0.006	1.1	0.09	0.01	0.025	0.005
BHDD076	196-76	235	236	S2	Sandstone	2.97	20.17	0.006	1.8	0.09	0.01	0.07	0.02
BHDD076	197-76	240	241	S1	Sandstone	2.12	21.31	0.079	52.8	2.02	0.22	0.13	0.09
BHDD076	198-76	245	246	S1	Sandstone	1.52	22.19	0.006	10.5	0.5	0.07	0.08	0.03
BHDD076	199-76	250	251	S1	Sandstone	2.21	26.58	0.005	8.3	0.45	0.06	0.025	0.02
BHDD076	200-76	255	256	S1	Sandstone	2.51	26.10	0.005	5.1	0.43	0.05	0.025	0.01
BHDD076	201-76	260	261	S1	Sandstone	2.46	27.63	0.006	7	0.59	0.09	0.025	0.01
BHDD076	202-76	265	266	S1	Sandstone	2.45	27.87	0.01	9.1	0.79	0.16	0.05	0.08
BHDD076	203-76	270	271	S1	Sandstone	2.04	26.31	0.011	7.5	0.69	0.09	0.025	0.02
BHDD076	204-76	275	276	S1	Sandstone	1.90	22.00	0.005	6	0.77	0.08	0.025	0.02
BHDD076	205-76	280	281	S1	Sandstone	2.32	22.62	0.235	64.9	1.86	0.42	0.17	0.03
BHDD076	206-76	285	286	S1	Sandstone	2.00	22.78	0.006	4.7	0.59	0.05	0.06	0.01
BHDD076	207-76	290	291	S1	Sandstone	1.51	22.42	0.009	7.1	0.77	0.09	0.21	0.04
BHDD076	208-76	295	296	S1	Sandstone	1.85	22.32	0.006	6.9	0.49	0.1	0.025	0.03
BHDD076	209-76	300	301	S1	Sandstone	2.12	20.80	0.012	7.2	0.49	0.03	0.025	0.02
BHDD076	210-76	305	306	S1	Sandstone	0.88	18.27	0.008	4.5	0.21	0.08	0.025	0.05
BHDD076	211-76	310	311	IB	Mudstone	-1.50	18.47	0.006	9.9	0.38	0.12	0.025	0.09
BHDD076	212-76	315	316	BBX	Breccia	1.97	22.34	0.005	13	0.36	0.12	0.025	0.01
BHDD076	213-76	320	321	BBX	Conglomerate	0.18	18.14	0.005	27.6	0.96	0.16	0.025	0.03
BHDD076	214-76	325	326	BBX	Breccia	3.20	22.91	0.019	28	1.5	0.16	0.025	0.02
BHDD076	215-76	330	331	KLS	Limestone	2.21	22.70	0.042	12.6	1.91	0.15	0.025	0.08
BHDD076	216-76	335	336	KLS	Limestone	1.90	22.42	0.066	3.5	1.2	0.05	0.025	0.05
BHDD076	218-76	345	346	KLS	Limestone	1.37	23.14	0.076	4.8	2.02	0.07	0.025	0.09

Appendix E.1: Carbon and oxygen isotope data from Bigar Hill, Korkan West, and Korkan South rocks

Drill Llolo	Comple ID	From	То	Stratigraphic	Lithology	δ13C	δ18Ο	Au	As	Sb	Tİ	Те	Hg
Drill Hole	Sample ID	FIOIII	10	Unit	Lithology	(VPDB)	(VPDB)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
BHDD076	219-76	350	351	KLS	Limestone	2.55	24.86	0.02	12.2	1.05	0.29	0.025	0.05
BHDD076	219-76a	350	351	KLS	Vein	2.37	17.72						
BHDD076	220-76	355	356	KLS	Limestone	2.74	23.01	0.19	19.6	2.75	0.24	0.025	0.07
BHDD076	221-76	360	361	JLS	Limestone	0.79	20.36	0.015	1	0.6	0.03	0.025	0.02
BHDD076	222-76	365	366	JLS	Limestone	1.10	20.28	0.021	10.8	0.99	0.05	0.025	0.07
BHDD076	223-76	370	371	JLS	Limestone	1.75	18.70	0.015	1.7	0.74	0.01	0.025	0.05
BHDD076	224-76	375	376	JLS	Limestone	1.68	18.03	0.015	2.1	1.13	0.03	0.025	0.04
BHDD076	225-76	380	381	JLS	Limestone	0.70	19.62	0.011	0.5	0.78	0.02	0.025	0.04
BHDD076	226-76	385	386	JLS	Limestone	0.15	20.03	0.017	2.6	1.19	0.05	0.025	0.04
BHDD076	227-76	390	391	JLS	Limestone	0.73	19.43	0.024	2.2	0.89	0.02	0.025	0.06
BHDD076	228-76	395	396	JLS	Limestone	1.39	19.90	0.01	2.4	0.95	0.03	0.025	0.03
BHDD076	229-76	400	401	JLS	Limestone	2.34	24.89	0.006	2.4	0.64	0.03	0.025	0.02
BHDD076	230-76	405	406	JLS	Limestone	1.24	22.19	0.007	1.9	0.67	0.02	0.025	0.03
BHDD076	231-76	410	411	JLS	Limestone	-1.73	21.56	0.007	7.9	3.13	0.03	0.025	0.04
BHDD076	232-76	415	416	JLS	Limestone	-1.11	22.32	0.006	13.9	6.15	0.05	0.07	0.1
BHDD076	233-76	420	421	JLS	Limestone	0.92	21.29	0.006	4	1.9	0.03	0.025	0.03
BHDD076	234-76	425	426	JLS	Limestone	1.24	20.51	0.007	1	0.93	0.01	0.025	0.01
BHDD076	235-76	430	431	JLS	Limestone	1.33	20.96	0.006	1.8	0.86	0.02	0.025	0.02
BHDD084	236-84	120	121	SMR	Marl	-0.20	14.84	0.006	4.5	1.25	0.08	0.025	0.005
BHDD084	237-84	125	126	SMR	Marl	0.73	16.37	0.005					
BHDD084	238-84	130	131	SMR	Marl	0.15	15.83	0.012	4.2	0.94	0.07	0.025	0.01
BHDD084	239-84	135	136	S2	Sandstone	0.58	19.35	0.005	1.3	1.88	0.07	0.07	0.02
BHDD084	240-84	140	141	S2	Sandstone	1.84	19.24	0.005	0.5	1.97	0.08	0.025	0.02
BHDD084	241-84	145	146	S2	Sandstone	1.02	17.88	0.005	3.2	3.22	0.07	0.05	0.02
BHDD084	242-84	150	151	S2	Sandstone	-0.39	15.88	0.005	3.7	1.48	0.05	0.1	0.02
BHDD084	243-84	155	156	S2	Sandstone	0.79	17.53	0.008	6	1.88	0.05	0.12	0.03
BHDD084	244-84	160	161	S2	Conglomerate	2.24	18.85	0.012	8.5	1.31	0.05	0.025	0.01
BHDD084	245-84	165	166	S2	Conglomerate	0.94	18.90	0.017	39.1	2.89	0.09	0.1	0.1
BHDD084	246-84	170	171	S2	Sandstone	1.21	17.32	0.598	289	7.17	0.39	1.02	0.42
BHDD084	247-84	175	176	S2	Sandstone	-2.96	15.85	0.237	118	3.79	0.17	0.37	0.2
BHDD084	248-84	180	181	S2	Sandstone	0.58	19.03	0.005	6.3	0.62	0.1	0.025	0.01
BHDD084	249-84	185	186	S2	Sandstone	0.39	16.40	0.005	27.3	3.26	0.21	0.025	0.03
BHDD084	250-84	190	191	S2	Sandstone	-0.80	16.37	0.528	318	10.2	0.7	0.84	0.07
BHDD084	251-84	195	196	S2	Sandstone	0.14	15.03	1.656	262	13.1	1.58	1.55	0.3
BHDD084	252-84	200	201	S2	Sandstone	-2.86	14.20	1.926	112	16	3.95	1.52	4.42
BHDD084	253-84	205	206	S1	Sandstone	1.53	20.79	0.144	22.9	2.57	0.59	0.15	0.12

Appendix E.1: Carbon and oxygen isotope data from Bigar Hill, Korkan West, and Korkan South rocks

Drill Llolo	Comple ID	From	Ta	Stratigraphic	Lithology	δ13C	δ18Ο	Au	As	Sb	TI	Те	Hg
	Sample ID	From	10	Unit	Lithology	(VPDB)	(VPDB)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
BHDD084	254-84	210	211	S1	Sandstone	1.38	20.05	0.376	17.4	2.36	0.24	0.2	0.13
BHDD084	255-84	215	216	S1	Sandstone	0.48	16.83	0.202	62.3	4.43	0.49	1.08	0.32
BHDD084	256-84	220	221	S1	Sandstone	-1.31	15.55	0.044	155	4.93	0.24	0.31	0.14
BHDD084	257-84	225	226	S1	Sandstone	1.83	19.08	0.072	68.6	4.31	0.2	0.62	0.61
BHDD084	258-84	230	231	S1	Sandstone	-0.23	16.82	0.082	504	5.35	0.18	0.87	0.04
BHDD084	259-84	235	236	IB	Mudstone	-1.61	17.43	0.019	82.4	2.02	0.16	0.06	0.02
BHDD084	260-84	240	241	IB	Mudstone	-3.12	16.06	0.008	37.1	2.79	0.25	0.07	0.04
BHDD084	261-84	245	246	IB	Breccia	-1.58	15.52	0.448	293	65.9	0.81	2.53	3.1
BHDD084	262-84	250	251	BBX	Breccia	-0.83	17.08	0.674	167	256	1.51	1.42	4.45
BHDD084	263-84	255	256	KLS	Limestone	-0.66	12.88	0.016	15.3	3.2	0.25	0.09	0.11
BHDD084	264-84	260	261	KLS	Limestone	1.76	20.52	0.016	27.6	5.07	0.77	0.2	0.3
BHDD084	265-84	265	266	KLS	Limestone	-0.48	18.16	0.006	20.9	2.81	0.3	0.12	0.14
BHDD084	266-84	270	271	KLS	Limestone	1.04	14.14	0.009	7.9	1.04	0.11	0.06	0.08
BHDD084	267-84	275	276	KLS	Limestone	0.49	13.96	0.026	9.5	1.02	0.12	0.025	0.06
BHDD084	268-84	280	281	KLS	Limestone	0.82	16.88	0.016	9.7	0.94	0.36	0.025	0.04
BHDD084	269-84	285	286	KLS	Limestone	1.10	13.97	0.012	6	0.72	0.1	0.11	0.08
BHDD084	270-84	290	291	KLS	Limestone	1.96	15.39	0.042	3.3	0.53	0.09	0.025	0.07
BHDD084	271-84	295	296	KLS	Limestone	-0.21	10.57	0.016	3.8	0.71	0.04	0.025	0.04
BHDD084	272-84	300	301	KLS	Limestone	0.87	10.96	0.044	12.2	7.45	0.17	0.17	0.33
BHDD084	273-84	305	306	KLS	Limestone	-0.75	12.13	0.162	12.1	2.81	0.23	0.64	0.17
BHDD084	273-84a	305	306	KLS	Vein	0.72	17.00						
BHDD084	274-84	310	311	KLS	Limestone	-1.76	12.10	0.406	12.4	5.49	0.54	0.75	0.45
BHDD084	275-84	315	316	KLS	Limestone	0.32	16.42	0.312	33.4	16.3	3.07	0.55	1.28
BHDD084	276-84	320	321	KLS	Limestone	1.83	14.38	0.146	17.3	6.81	1.21	0.25	0.84
BHDD084	277-84	325	326	KST	Limestone	1.37	14.03	0.122	63.6	6.17	1.5	0.59	0.73
BHDD084	278-84	330	331	JLS	Limestone	3.25	27.77	0.035	9.5	2.19	0.11	0.025	0.32
BHDD084	279-84	335	336	JLS	Limestone	2.57	20.44	0.006	5.2	0.69	0.13	0.025	0.09
BHDD084	280-84	340	341	JLS	Limestone	2.83	25.14	0.005	1.3	0.29	0.06	0.025	0.04
BHRC046	281-46R	139	140	S2	Sandstone	2.07	20.07	0.006	2.3	1.31	0.05	0.025	0.005
BHRC046	282-46R	144	145	S2	Sandstone	1.72	17.96	0.006	1.2	0.97	0.03	0.025	0.005
BHRC046	283-46R	149	150	S2	Sandstone	1.21	15.85	0.006	1.6	2.04	0.07	0.025	0.03
BHRC046	284-46R	154	155	S2	Sandstone	0.64	16.26	0.006	1.6	2.72	0.05	0.025	0.005
BHRC046	285-46R	159	160	S2	Sandstone	1.68	16.08	0.14	196	4.25	0.14	0.59	0.12
BHRC046	286-46R	164	165	S2	Sandstone	1.71	16.77	0.008	14.8	4.36	0.09	0.13	0.05
BHRC046	287-46R	169	170	S2	Sandstone	2.09	18.20	0.367	107	7.77	0.44	0.44	0.26
BHRC046	288-46R	174	175	S2	Sandstone	0.61	15.15	0.968	213	12.6	1.47	0.61	0.55

Appendix E.1: Carbon and oxygen isotope data from Bigar Hill, Korkan West, and Korkan South rocks

Drill Lala	Commissio	Frame	Ta	Stratigraphic	Litheles	δ13C	δ18Ο	Au	As	Sb	TI	Те	Hg
Drill Hole	Sample ID	From	10	Unit	Lithology	(VPDB)	(VPDB)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
BHRC046	289-46R	179	180	S2	Sandstone	0.39	17.42	0.216	137	9.31	0.67	0.34	0.13
BHRC046	290-46R	184	185	S2	Sandstone	1.10	17.78	0.212	173	8.95	2.56	0.4	0.11
BHRC046	291-46R	189	190	S2	Sandstone	1.15	16.67	0.076	101	10.4	2.42	0.39	0.09
BHRC046	292-46R	194	195	S2	Sandstone	-0.21	16.20	0.088	149	12.2	4.15	0.41	0.2
BHRC046	293-46R	199	200	S1	Sandstone	-0.51	13.61	0.292	151	69.4	0.53	1.02	0.14
BHRC046	294-46R	204	205	S1	Sandstone	-1.60	12.89	0.061	41.5	9.25	0.12	0.32	0.06
BHRC046	295-46R	209	210	S1	Sandstone	-0.53	13.60	0.106	41.1	17.9	0.38	1.8	1.01
BHRC046	296-46R	214	215	S1	Sandstone	0.14	13.13	0.013	14.9	1.79	0.1	0.11	0.03
BHRC046	297-46R	219	220	S1	Sandstone	-0.07	15.31	0.007	17.6	1.18	0.09	0.3	0.08
BHRC046	298-46R	224	225	S1	Sandstone	1.11	15.89	0.012	53.9	1.53	0.14	0.39	0.16
BHRC046	299-46R	229	230	S1	Sandstone	0.22	16.55	0.152	41.7	2.15	0.22	0.2	0.17
BHRC046	300-46R	234	235	S1	Sandstone	-1.03	16.71	0.444	42.5	3.06	0.19	0.35	0.14
BHRC046	301-46R	239	240	S1	Sandstone	0.79	19.54	0.308	43.8	2.56	0.23	0.12	0.03
BHRC046	302-46R	244	245	IB	Sandstone	-2.01	13.78	0.086	134	17.7	0.65	0.13	0.24
BHRC046	303-46R	249	250	IB	Sandstone	-0.63	14.32	0.124	491	96.7	0.88	0.48	0.13
BHRC046	304-46R	254	255	IB	Sandstone	-0.31	16.42	0.89	349	46	1.21	1.28	0.39
BHRC046	305-46R	259	260	BBX	Sandstone	-2.09	12.57	0.242	588	27.6	0.61	0.09	0.04
BHRC046	306-46R	264	265	BBX	Limestone	-1.42	13.82	0.104	272	29.9	1.57	1.12	0.83
BHRC046	307-46R	269	270	KLS	Limestone	-0.47	13.20	0.194	113	11.7	0.61	0.57	1.16
BHRC046	308-46R	274	275	KLS	Limestone	2.28	14.53	0.064	18.5	2.84	0.2	0.025	0.58
BHRC046	309-46R	279	280	KLS	Limestone	0.60	14.10	0.026	15.5	1.71	0.12	0.2	0.11
BHRC046	310-46R	284	285	KLS	Limestone	1.38	14.84	0.034	10.9	0.91	0.12	0.025	0.15
BHRC046	311-46R	289	290	KLS	Limestone	1.63	16.58	0.056	27.4	2.68	0.2	0.12	0.2
BHRC105	312-105R	71	72	SMR	Marl	0.32	14.54	0.031	8.4	0.32	0.14	0.08	0.06
BHRC105	313-105R	76	77	SMR	Marl	1.04	18.32	0.052	13.1	0.48	0.16	0.28	0.07
BHRC105	314-105R	81	82	SMR	Marl	1.36	20.57	0.01	13.5	0.24	0.08	0.09	0.03
BHRC105	315-105R	86	87	SMR	Marl	1.00	19.22	0.007	11.6	0.16	0.05	0.1	0.04
BHRC105	316-105R	91	92	SMR	Marl	0.14	17.52	0.005	6.9	0.19	0.07	0.11	0.02
BHRC105	317-105R	96	97	SMR	Marl	1.03	18.67	0.005	5.5	0.14	0.09	0.06	0.04
BHRC105	318-105R	101	102	S2	Sandstone	2.24	21.33	0.007	50.6	0.49	0.11	0.11	0.12
BHRC105	319-105R	106	107	S2	Sandstone	1.39	19.42	0.006	23.4	0.22	0.09	0.1	0.08
BHRC105	320-105R	111	112	S2	Sandstone	1.39	18.78	0.012	19.1	0.17	0.1	0.08	0.09
BHRC105	321-105R	116	117	S2	Sandstone	1.12	18.38	0.012	4.2	0.08	0.05	0.06	0.03
BHRC105	322-105R	121	122	S2	Sandstone	-1.94	16.33	0.009	4.1	0.1	0.04	0.025	0.03
BHRC105	323-105R	126	127	S2	Sandstone	-0.90	18.21	0.025	9.8	0.1	0.06	0.06	0.15
BHRC105	324-105R	131	132	S2	Sandstone	-1.52	16.45	0.019	47.7	0.23	0.17	0.09	0.34

Appendix E.1: Carbon and oxygen isotope data from Bigar Hill, Korkan West, and Korkan South rocks

Drill Holo	Sampla ID	From	То	Stratigraphic	Lithology	δ13C	δ18Ο	Au	As	Sb	TI	Те	Hg
	Sample ID	FIOIII	10	Unit	LITIOIOgy	(VPDB)	(VPDB)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
BHRC105	325-105R	136	137	S2	Sandstone	-2.19	17.06	0.01	4.5	0.11	0.06	0.025	0.02
BHRC105	326-105R	141	142	S2	Sandstone	-1.73	18.38	0.008	35.3	0.47	0.16	0.07	0.14
BHRC105	327-105R	146	147	S2	Sandstone	0.98	17.26	0.01	49.5	1.47	0.16	0.16	0.24
BHRC105	328-105R	151	152	S2	Sandstone	2.30	19.56	0.171	312	10.1	0.66	2.77	1.21
BHRC105	329-105R	156	157	S1	Sandstone	-0.40	17.39	0.49	182	9.14	1.02	5.79	2.1
BHRC105	330-105R	161	162	S1	Sandstone	3.31	21.58	0.226	83.3	6.47	0.53	1.88	0.7
BHRC105	331-105R	166	167	S1	Sandstone	1.81	21.32	0.302	120	4.91	0.58	2.25	0.74
BHRC105	332-105R	171	172	IB	Sandstone	0.54	16.96	0.688	243	8.68	1.46	5.67	1.67
BHRC105	333-105R	176	177	S1	Sandstone	1.93	19.83	0.71	180	6.89	1.29	3.99	1.05
BHRC105	334-105R	181	182	S1	Sandstone	2.40	20.03	1.116	178	10.2	1.79	4.09	1.59
BHRC105	335-105R	186	187	S1	Sandstone	3.04	22.69	1.214	141	8.38	1.54	3.93	1.55
BHRC105	336-105R	191	192	S1	Sandstone	2.94	22.01	1.546	193	10.6	2.18	7.06	2.14
BHRC105	337-105R	196	197	S1	Sandstone	1.38	16.93	6.56	537	11.3	1.82	10.8	3.13
BHRC105	338-105R	201	202	IB	Sandstone	1.05	16.58	0.75	847	8.5	0.35	5.32	2.02
BHRC105	339-105R	206	207	IB	Sandstone	1.30	15.38	0.386	576	2.76	0.25	0.94	1.34
BHRC105	340-105R	211	212	BBX	Breccia	-0.56	15.50	0.076	383	1.06	0.26	1.11	0.74
BHRC105	341-105R	216	217	BBX	Breccia	0.78	14.86	0.063	488	0.8	0.5	0.87	0.46
BHRC130	342-130R	136	137	S2	Sandstone	0.31	15.96	0.005					
BHRC130	343-130R	141	142	S2	Sandstone	1.41	15.37	0.005					
BHRC130	344-130R	146	147	S2	Sandstone	0.69	19.12	0.005					
BHRC130	345-130R	151	152	S2	Sandstone	1.57	17.47	0.005					
BHRC130	346-130R	156	157	S2	Sandstone	-0.08	15.49	0.067					
BHRC130	347-130R	161	162	S2	Sandstone	0.89	17.88	0.005					
BHRC130	348-130R	166	167	S2	Sandstone	-0.53	15.63	0.031					
BHRC130	349-130R	171	172	S2	Sandstone	1.43	17.49	0.008					
BHRC130	350-130R	176	177	S1	Sandstone	2.26	20.92	0.005					
BHRC130	351-130R	181	182	S1	Sandstone	1.74	23.48	0.028					
BHRC130	352-130R	186	187	S1	Sandstone	2.68	24.33	0.062					
BHRC130	353-130R	191	192	S1	Sandstone	1.82	19.96	0.005					
BHRC130	354-130R	196	197	S1	Sandstone	2.25	19.61	0.008					
BHRC130	355-130R	201	202	S1	Sandstone	0.69	17.50	0.048					
BHRC130	356-130R	206	207	S1	Sandstone	0.82	19.69	0.248					
BHRC130	357-130R	211	212	IB	Mudstone	-1.80	15.05	0.046					
BHRC130	358-130R	216	217	IB	Mudstone	-3.86	14.22	0.024					

Appendix E.1: Carbon and oxygen isotope data from Bigar Hill, Korkan West, and Korkan South rocks

Drill Hole	Sample ID	From	То	Stratigraphic	Lithology	δ13C	δ180	Au	As	Sb	TI	Те	Hg
	eample is			Unit		(VPDB)	(VPDB)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
BHRC130	359-130R	221	222	IB	Mudstone	-2.79	15.37	0.048					
BHRC130	360-130R	226	227	BBX	Breccia	1.34	16.79	0.072					
BHRC130	361-130R	231	232	BBX	Breccia	-5.91	19.12	1.18					
BHRC130	362-130R	236	237	KLS	Limestone	-2.31	14.53	1.274					
BHRC130	363-130R	241	242	KLS	Limestone	-0.84	14.93	0.382					
BHRC130	364-130R	246	247	KLS	Limestone	0.54	15.05	0.152					
BHRC130	365-13UK	251	252	KLS	Limestone	-2.38	15.30	0.264					
BHRC130	366-130K	256	257	KLS	Limestone	-1.35	14.42	0.126					
BHRC130	367-13UK	261	262	KLS	Limestone	-0.84	14.00	0.058					
	308-130K	200	207	KLS KLS	Limestone	-2.08	14.24	0.082					
	209-130K	271	272	KLS KLS	Limestone	-0.00	14.54	0.05					
BHRC130	370-130K	270	277	KLS	Limestone	-4.62	17.00	0.022					
BHRC130	372-130R	281	282	KLS	Limestone	-4.02	15.20	0.033					
BHRC130	372-130R	200	207	KLS	Limestone	-0.82	12.35	0.040					
BHRC130	374-130R	296	297	KLS	Limestone	1 20	10.66	0.000					
BHRC130	375-130R	301	302	KLS	Limestone	-0.89	12 45	0 294					
BHRC143	376-143R	8	9	52	Sandstone	0.57	20.17	0.011					
BHRC143	377-143R	13	14	52	Sandstone	0.13	18.89	0.007					
BHRC143	378-143R	18	19	52	Sandstone	0.13	18 51	0.015					
BHRC143	379-143R	23	24	52	Sandstone	-0.73	19.05	0.009					
BHRC143	380-143R	28	29	52	Sandstone	-0.74	19.71	0.009					
BHRC143	381-143R	33	34	52	Sandstone	0.44	19.70	0.007					
BHRC143	382-143R	38	39	52	Sandstone	1.33	21.19	0.014					
BHRC143	383-143R	43	44	52	Sandstone	1 01	21.81	0.007					
BHRC143	384-143R	48	49	S2	Sandstone	0.47	21.62	0.018					
BHRC143	385-143R	53	54	S2	Sandstone	1.09	22.01	0.012					
BHRC143	386-143R	58	59	S2	Sandstone	1.87	23.52	0.008					
BHRC143	387-143R	63	64	S1	Sandstone	1.97	25.34	0.015					
BHRC143	388-143R	68	69	S1	Sandstone	1.94	26.28	0.024					
BHRC144	388-143a	68	69	S1	Vein	1.75	23.33						
BHRC143	389-143R	73	74	S1	Sandstone	2.82	27.04	0.005					
BHRC143	390-143R	78	79	S1	Sandstone	2.80	27.57	0.006					
BHRC147	391-147R	3	4	S2	Sandstone	1.85	23.64	0.018					

Appendix E.1: Carbon and oxygen isotope data from Bigar Hill, Korkan West, and Korkan South rocks

Drill Hole	Sample ID	From	To	Stratigraphic	Lithology	δ13C	δ18Ο	Au	As	Sb	TI	Те	Hg
Drin Hole	Sumple IB	mon	10	Unit	Enthology	(VPDB)	(VPDB)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
BHRC147	392-147R	8	9	S2	Sandstone	1.57	24.67	0.031					
BHRC147	393-147R	13	14	S2	Sandstone	1.53	23.66	0.02					
BHRC147	394-147R	18	19	S2	Sandstone	1.89	20.94	0.01					
BHRC147	395-147R	23	24	S2	Sandstone	1.47	19.25	0.026					
BHRC147	396-147R	28	29	S2	Sandstone	0.76	21.68	0.007					
BHRC147	397-147R	33	34	S2	Sandstone	-0.83	19.01	0.037					
BHRC147	398-147R	38	39	S2	Sandstone	-1.07	18.80	0.009					
BHRC147	399-147R	43	44	S2	Sandstone	0.92	20.76	0.012					
BHRC147	400-147R	48	49	S2	Sandstone	-0.27	18.33	0.016					
BHRC147	401-147R	53	54	52	Sandstone	0.79	19.35	0.007					
BHRC147	402-147K	58	59	52	Sandstone	1.18	20.76	0.008					
	403-147K	03 62	04 64	52 52	Voin	3.07	21.05	0.01					
	403-147Nd	05 60	04 60	52	Veill	-0.00 2 4 2	22.17	0.011					
	404-147N	00 72	74	32 52	Sandstone	2.45	22.17	0.011					
BHRC147	405-147R	73	74	52 57	Sandstone	1.74	22.13	0.013					
BHRC147	400 147N	83	8/	52	Sandstone	0.63	22.05	0.005					
BHRC1/7	407 147R	88	29 29	52 S1	Sandstone	2.84	27.15	0.005					
	400-1470	00	0/	S1	Sandstone	2.04	27.55	0.004					
BHRC147	409-1476	33	94 00	51	Sandstone	2.75	20.70	0.001					
BHRC147	410-147R	98	99	51	Sandstone	2.81	20.40	0.021					
BHRC147	411-147R	103	104	S1	Sandstone	3.06	26.42	0.006					
BHRC147	412-147R	108	109	S1	Sandstone	2.41	26.63	0.014					
BHRC159	413-159R	8	9	S2	Sandstone	1.94	22.42	0.005					
BHRC159	414-159R	13	14	S2	Sandstone	1.86	22.31	0.006					
BHRC159	415-159R	18	19	S2	Sandstone	1.55	23.74	0.017					
BHRC159	416-159R	23	24	S2	Sandstone	1.46	22.16	0.006					
BHRC159	417-159R	28	29	S2	Sandstone	1.40	23.13	0.005					
BHRC159	418-159R	33	34	S2	Sandstone	1.14	23.47	0.005					
BHRC159	419-159R	38	39	S2	Sandstone	0.93	21.83	0.011					
BHRC159	420-159R	43	44	S2	Sandstone	1.28	23.40	0.005					
BHRC159	421-159R	48	49	S1	Sandstone	2.51	27.35	0.005					
BHRC159	422-159R	53	54	S1	Sandstone	1.88	27 30	0.016					
BHRC159	423-159R	58	59	S1	Sandstone	2.00	26.76	0.015					
	423-1351	62	55	51 C1	Sandstone	1.25	20.70	0.015					
внкс159	424-159K	63	64	21	Sanustone	1.25	20.48	0.006					

Appendix E.1: Carbon and oxygen isotope data from Bigar Hill, Korkan West, and Korkan South rocks

Drill Hole	Sample ID	From	То	Stratigraphic	Lithology	δ13C	δ18Ο	Au	As	Sb	TI	Те	Hg
DIIIIIIOIE	Sample ID	TTOIN	10	Unit	Enthology	(VPDB)	(VPDB)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
BHRC159	425-159R	68	69	S1	Sandstone	2.16	26.30	0.032					
BHRC159	426-159R	73	74	S1	Sandstone	1.48	24.49	0.008					
BHRC159	427-159R	78	79	S1	Sandstone	1.45	24.20	0.015					
BHRC159	428-159R	83	84	BBX	Sandstone	1.06	25.22	0.007					
BHRC159	429-159R	88	89	IB	Sandstone	1.69	23.11	0.005					
BHRC159	430-159R	93	94	IB	Mudstone	-2.70	18.48	0.005					
BHRC159	431-159R	98	99	IB	Mudstone	-2.28	17.77	0.005					
BHRC159	432-159R	103	104	JLS	Limestone	1.88	25.92	0.005					
BHRC159	433-159R	108	109	JLS	Limestone	1.53	21.34	0.0/1					
BHRC1/2	434-172R	148	149	S2	Sandstone	1.43	14.26	0.005					
BHRC172	435-172R	153	154	S2	Sandstone	1.88	15.12	0.006					
BHRC172	430-172K	158	159	52	Sandstone	1.89	18.64	0.005					
BHRC172	437-172R	103	104	52	Sandstone	1.93	20.43						
	438-172R	108	109	52	Sandstone	2.20	19.19	0.005					
	439-172N	170	174	52	Sandstone	2.59	20.72	0.005					
	440-172N	102	10/	52	Sandstone	0.44	10.02	0.005					
	441-172N	100	104	52 S1	Sandstone	0.44	20.05	1 672					
	442-172N	100	109	51	Sandstone	1.51	20.05	1.075					
BHRC1/2	443-172R	193	194	51	Sandstone	0.21	21.05	1.550					
BHRC1/2	444-172R	198	199	51	Sandstone	2.44	24.73	0.502					
BHRC172	445-172R	203	204	S1	Sandstone	1.17	22.12	0.064					
BHRC172	446-172R	208	209	S1	Sandstone	2.27	24.80	0.006					
BHRC172	447-172R	213	214	S1	Sandstone	-2.30	19.59	0.16					
BHRC172	448-172R	218	219	S1	Sandstone	1.52	24.46	0.024					
BHRC221	449-221R	3	4	SMR	Marl	0.80	18.95	0.005					
BHRC221	450-221R	8	9	SMR	Marl	1.28	19.28	0.005					
BHRC221	451-221R	13	14	SMR	Marl	0.39	18.60	0.005					
BHRC221	452-221R	18	19	SMR	Marl	1.77	19.81	0.005					
BHRC221	453-221R	23	24	SMR	Marl	0.87	20.07	0.005					
BHRC221	454-221R	28	29	SMR	Marl	2.08	19.95	0.005					
BHRC221	455-221R	33	34	SMR	Marl	1.57	20.22	0.005					
BHRC221	456-221R	38	39	SMR	Marl	1.32	19.87	0.005					
BHRC221	457-221R	43	44	SMR	Marl	1.05	19.32	0.005					
BHRC221	458-221R	48	49	S2	Sandstone	2.26	24.48	0.005					

Appendix E.1: Carbon and oxygen isotope data from Bigar Hill, Korkan West, and Korkan South rocks

Drill Hole	Sample ID	From	То	Stratigraphic	Lithology	δ13C	δ18Ο	Au	As	Sb	TI	Те	Hg
Drin Hole	Sample IB	TIOIII	10	Unit	Enthology	(VPDB)	(VPDB)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
BHRC221	459-221R	53	54	S2	Sandstone	1.32	22.07	0.005					
BHRC221	460-221R	58	59	S2	Sandstone	0.86	21.10	0.005					
BHRC221	461-221R	63	64	S2	Sandstone	2.32	22.60	0.005					
BHRC221	462-221R	68	69	S2	Sandstone	0.71	19.68	0.005					
BHRC221	463-221R	73	74	S2	Sandstone	-0.17	20.22	0.005					
BHRC221	464-221R	78	79	S2	Sandstone	-0.13	19.81	0.016					
BHRC221	465-221R	83	84	S2	Sandstone	0.51	18.33	0.005					
BHRC221	466-221R	88	89	S2	Sandstone	0.79	20.34	0.005					
BHRC221	467-221R	93	94	\$2	Sandstone	1.52	19.83	0.005					
BHRC221	468-221R	98	99	\$2	Sandstone	2.07	19.25	0.005					
BHRC221	469-221R	103	104	52	Sandstone	2.21	22.92	0.005					
BHRC221	470-221R	108	109	52	Sandstone	2.62	21.01	0.005					
BHRC221	4/1-221R	113	114	52	Sandstone	2.20	25.57	0.005					
BHRC221	472-221R	118	119	52	Sandstone	1.23	21.95	0.005					
	475-221R 474 221P	125	124	52	Sandstone	1.90	21.77	0.005					
	474-221R 475 221P	120	129	32 S1	Sandstone	2.45	21.10	0.005					
	475-221R 476 221P	120	120	51 S1	Sandstone	2.45	23.10	0.003					
	470-221R	142	139	51	Sandstone	2.50	24.59	0.021					
BHRC221	477-221R	143	144	51	Sandstone	1.78	20.85	0.006					
BHRC221	478-221R	148	149	51	Sandstone	2.36	27.50	0.005					
BHRC221	479-221R	153	154	S1	Sandstone	2.57	26.72	0.005					
BHRC221	480-221R	158	159	S1	Sandstone	3.56	25.97	0.005					
BHRC222	481-222R	5	6	SMR	Marl	0.61	16.31	0.005					
BHRC222	482-222R	10	11	SMR	Marl	1.26	17.21	0.005					
BHRC222	483-222R	15	16	SMR	Marl	1.52	17.17	0.005					
BHRC222	484-222R	20	21	SMR	Marl	2.06	18.84	0.005					
BHRC222	485-222R	25	26	SMR	Marl	2.31	19.75	0.005					
BHRC222	486-222R	30	31	SMR	Marl	1.12	19.16	0.005					
BHRC222	487-222R	35	36	SMR	Marl	1.07	18.86	0.005					
BHRC222	488-222R	40	41	SMR	Marl	0.58	18.48	0.016					
BHRC222	489-222R	45	46	SMR	Marl	1.28	19.45	0.005					
BHRC222	490-222R	50	51	SMR	Marl	1.07	19.60	0.005					
BHRC222	491-222R	55	56	SMR	Marl	1.59	20.01	0.005					
BHRC222	492-222R	60	61	SMR	Marl	1.42	18.80	0.005					

Appendix E.1: Carbon and oxygen isotope data from Bigar Hill, Korkan West, and Korkan South rocks

Drill Hole Sample	Sample ID	From	То	Stratigraphic	Lithology	δ13C	δ18Ο	Au	As	Sb	TI	Те	Hg
DHILLIOIE	Sample ID	FIOIII	10	Unit	Litilology	(VPDB)	(VPDB)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
BHRC222	493-222R	65	66	S2	Sandstone	1.30	20.32	0.005					
BHRC222	494-222R	70	71	S2	Sandstone	1.84	23.42	0.005					
BHRC222	495-222R	75	76	S2	Sandstone	1.90	21.26	0.005					
BHRC222	496-222R	80	81	S2	Sandstone	1.37	20.03	0.005					
BHRC222	497-222R	85	86	S2	Sandstone	2.22	19.37	0.026					
BHRC222	498-222R	90	91	S2	Sandstone	-0.68	18.16	0.005					
BHRC222	499-222R	95	96	S2	Sandstone	1.18	19.56	0.005					
BHRC222	500-222R	100	101	S2	Sandstone	-1.22	18.19	0.02					
BHRC222	501-222R	105	106	S2	Sandstone	0.40	17.44	0.005					
BHRC222	502-222R	110	111	S2	Sandstone	1.97	16.98	0.005					
BHRC222	503-222R	115	116	S2	Sandstone	1.51	21.15	0.005					
BHRC222	504-222K	120	121	52	Sandstone	1.10	18.60	0.005					
BHKC222	505-222K	125	120	52	Sandstone	1.15	21.43	0.005					
	500-222K	130	131	52	Sandstone	1.50	17.44	0.000					
	507-222R	135	1/1	52 S1	Sandstone	1.05	21.70	0.04					
BHRC222	500-222K	140	141	S1	Sandstone	2.15	21.17	0.074					
	509-222K	145	140	S1	Sandstone	2.15	22.12	0.044					
BHRC222	510-222K	150	151	51	Sandstone	1.55	23.33	0.102					
BHRCZZZ	511-222R	155	150	51	Sandstone	2.18	23.03	0.324					
BHRC222	512-222R	160	161	51	Sandstone	1.65	21.53	0.16					
BHRC222	513-222R	165	166	S1	Sandstone	1.18	18.75	0.318					
BHRC222	514-222R	170	171	S1	Sandstone	1.50	20.38	0.167					
BHRC222	515-222R	175	176	S1	Sandstone	1.04	16.98	0.182					
BHRC222	516-222R	180	181	S1	Sandstone	0.71	15.42	0.03					
BHRC222	517-222R	185	186	S1	Sandstone	0.83	14.80	0.009					
BHRC222	518-222R	190	191	S1	Sandstone	0.45	16.52	0.075					
BHRC222	519-222R	195	196	IB	Mudstone	-0.37	14.88	0.041					
BHRC222	520-222R	200	201	BBX	Breccia	-0.41	13.45	0.458					
BHRC222	521-222R	205	206	KLS	Limestone	2.53	16.99	0.04					
BHRC222	522-222R	210	211	KLS	Limestone	1.21	12.15	0.214					
BHRC222	523-222R	215	216	KLS	Limestone	0.66	15.14	0.194					
BHRC222	524-222R	220	221	KLS	Limestone	0.60	12.09	0.51					
BHRC222	525-222R	225	226	KLS	Limestone	0.68	17.28	0.4					
BHRC222	526-222R	230	231	KLS	Limestone	2.55	14.49	1.278					

Appendix E.1: Carbon and oxygen isotope data from Bigar Hill, Korkan West, and Korkan South rocks

Drill Hole	Sample ID	From	То	Stratigraphic	Lithology	δ13C	δ18Ο	Au	As	Sb	TI	Те	Hg
Drin Hole	Sample IB	TION	10	Unit	Enthology	(VPDB)	(VPDB)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
BHRC222	527-222R	235	236	KLS	Limestone	1.26	14.64	1.574					
BHRC222	528-222R	240	241	KLS	Limestone	1.33	17.41	0.078					
BHRC222	529-222R	245	246	JLS	Limestone	-0.84	21.64	0.109					
BHRC222	530-222R	250	251	JLS	Limestone	-1.59	20.41	0.006					
BHRC229	531-229R	110	111	S2	Sandstone	-2.02	15.00	0.005					
BHRC229	532-229R	115	116	S2	Sandstone	2.52	18.13	0.005					
BHRC229	533-229R	120	121	S2	Sandstone	0.24	17.56	0.022					
BHRC229	534-229R	125	126	S2	Sandstone	-1.43	16.07	0.005					
BHRC229	535-229R	130	131	S2	Sandstone	1.70	13.80	0.009					
BHRC229	536-229R	135	136	S2	Sandstone	2.09	17.11	0.005					
BHRC229	537-229R	140	141	S2	Sandstone	1.16	18.27	0.005					
BHRC229	538-229K	145	140	52	Sandstone	0.43	18.52	0.005					
BHRC229	539-229R	150	151	52	Sandstone	1.94	16.00	0.005					
	540-229R	155	150	52	Sandstone	-1.12	10.02	0.009					
	541-229R	165	101	52	Sandstone	2.57	14.04	0.009					
BHRC229	542-229N	105	171	52	Sandstone	-3.23	15.74	0.105					
BHRC220	545 225R	175	176	52 S1	Sandstone	-0.18	16 10	0.05					
BHRC220	545-229R	180	101	S1	Breccia	-0.82	1/ 28	0.012					
	545-229N	100	101		Broccia	-0.02	17.25	0.012					
	540-229K	100	100		Breecia	0.02	17.25	0.015					
BHRC229	547-229R	190	191	BBX	Breccia	0.35	15.44	0.338					
BHRC229	548-229R	195	196	BBX	Breccia	0.84	14.58	0.49					
BHRC229	549-229R	200	201	KLS	Limestone	2.49	18.62	0.029					
BHRC229	550-229R	205	206	KLS	Limestone	3.75	16.47	0.074					
BHRC229	551-229R	210	211	KLS	Limestone	2.64	14.51	0.022					
BHRC229	552-229R	215	216	KLS	Limestone	-0.66	15.80	0.039					
BHRC229	553-229R	220	221	KLS	Limestone	0.21	14.46	0.048					
BHRC229	554-229R	225	226	KLS	Limestone	1.98	18.02	0.032					
BHRC229	555-229R	230	231	KLS	Limestone	2.37	18.16	0.174					
BHRC229	556-229R	235	236	KLS	Limestone	2.27	23.93	0.142					
BHRC229	557-229R	240	241	KLS	Limestone	1.03	18.23	0.016					
BHRC229	558-229R	245	246	KLS	Limestone	2.64	11.93	0.051					
BHRC229	558-229Ra	245	246	KLS	Vein	-4.48	18.65						
BHRC229	559-229R	250	251	KLS	Limestone	1.44	15.24	0.058					

Appendix E.1: Carbon and oxygen isotope data from Bigar Hill, Korkan West, and Korkan South rocks

Drill Hole Sampl	Sample ID	From	То	Stratigraphic	Lithology	δ13C	δ18Ο	Au	As	Sb	TI	Те	Hg
DHILLIOIE	Sample ID	FIOIII	10	Unit	Lithology	(VPDB)	(VPDB)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
BHRC229	560-229R	255	256	KLS	Limestone	0.92	24.40	0.015					
BHRC229	561-229R	260	261	KLS	Limestone	2.23	28.43	0.006					
BHRC229	562-229R	265	266	KLS	Limestone	2.03	27.85	0.005					
BHRC283	563-283R	5	6	SMR	Marl	2.83	17.82	0.006					
BHRC283	564-283R	10	11	SMR	Marl	1.49	15.84	0.005					
BHRC283	565-283R	15	16	SMR	Marl	-0.88	14.83	0.006					
BHRC283	566-283R	20	21	SMR	Marl	-0.17	14.58	0.014					
BHRC283	567-283R	146	147	S2	Sandstone	-0.53	14.64	0.023					
BHRC283	568-283R	151	152	S2	Sandstone	0.57	15.36	0.027					
BHRC283	569-283R	156	157	S2	Sandstone	-1.79	13.85	0.005					
BHRC283	570-283R	161	162	S2	Sandstone	2.21	16.46	0.005					
BHRC283	571-283R	166	167	S2	Sandstone	2.69	18.92	0.005					
BHRC283	572-283R	171	172	S2	Sandstone	2.79	18.38	0.005					
BHRC283	573-283R	176	177	S2	Sandstone	2.24	19.45	0.038					
BHRC283	574-283R	181	182	S2	Sandstone	0.71	17.12	0.036					
BHRC283	575-283R	186	187	S2	Sandstone	3.31	19.82	4.618					
BHRC283	576-283R	191	192	S1	Sandstone	2.87	24.00	3.518					
BHRC283	577-283R	196	197	S1	Sandstone	2.27	22.51	0.104					
BHRC283	578-283R	201	202	S1	Sandstone	3.39	24.28	2.318					
BHRC283	579-283R	206	207	S1	Sandstone	3.14	22.69	0.126					
BHRC297	581-297R	140	141	S2	Sandstone	-3.50	15.28	0.544					
BHRC297	582-297R	145	146	S2	Sandstone	0.13	18.43	0.61					
BHRC297	583-297R	150	151	S2	Sandstone	-1.80	17.39	1.482					
BHRC297	584-297R	155	156	S2	Conglomerate	-0.48	16.07	0.474					
BHRC297	585-297R	160	161	S2	Sandstone	-0.67	15.69	0.408					
BHRC297	586-297R	165	166	S2	Conglomerate	-1.13	17.86	2.064					
BHRC297	587-297R	170	171	S1	Sandstone	2.10	18.45	3.016					
BHRC297	588-297R	175	176	S1	Sandstone	-0.05	16.04	3.056					
BHRC297	589-297R	180	181	S1	Sandstone	1.20	14.42	1.352					
BHRC297	590-297R	185	186	S1	Sandstone	-0.03	13.30	0.368					
BHRC297	591-297R	190	191	S1	Sandstone	0.67	14.27	0.134					
BHRC297	592-297R	195	196	IB	Mudstone	-0.98	12.60	0.076					
BHRC297	593-297R	200	201	IB	Mudstone	-2.72	11.76	1.516					
BHRC297	594-297R	205	206	IB	Mudstone	2.15	17.24	3.536					
BHRC297	596-297R	215	216	BBX	Breccia	-0.30	13.52	4.254					

Appendix E.1: Carbon and oxygen isotope data from Bigar Hill, Korkan West, and Korkan South rocks

Drill Hole Sample	Sample ID	From	То	Stratigraphic	Lithology	δ13C	δ18Ο	Au	As	Sb	TI	Те	Hg
DHILHOLE	Sample ID	FIOIII	10	Unit	Lithology	(VPDB)	(VPDB)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
BHRC297	597-297R	220	221	KLS	Breccia	1.30	11.46	0.44					
BHRC297	598-297R	225	226	KLS	Limestone	0.13	13.37	0.042					
BHRC297	599-297R	230	231	KLS	Limestone	1.78	13.95	0.114					
BHRC297	600-297R	235	236	KLS	Limestone	2.01	19.25	0.68					
BHRC297	601-297R	240	241	KLS	Limestone	-2.20	12.55	0.07					
BHRC297	602-297R	245	246	KLS	Limestone	1.03	15.71	0.072					
BHRC297	602-297Ra	245	246	KLS	Vein	-0.71	13.92						
BHRC297	603-297R	250	251	KLS	Limestone	1.61	14.73	0.114					
BHRC297	604-297R	255	256	KLS	Limestone	2.10	16.21	0.066					
BHRC297	605-297R	260	261	KLS	Limestone	1.44	13.06	0.088					
BHRC297	606-297R	265	266	KLS	Limestone	-1.53	8.93	1.792					
BHRC297	607-297R	270	271	KLS	Limestone	-0.13	14.33	2.544					
BHRC297	608-297R	275	276	JLS	Limestone	0.51	20.70	0.24					
BHRC297	609-297R	280	281	JLS	Limestone	1.23	18.68	0.1					
KWDD005	KW5-235	5	6	SMR	Marl	1.21	26.55	0.005					
KWDD005	KW5-236	15	16	SMR	Marl	3.69	27.19	0.005					
KWDD005	KW5-238	21	21.5	S2	Sandstone	2.66	29.01	0.005					
KWDD005	KW5-241	99	100	S2	Sandstone	2.27	27.07	0.005					
KWDD005	KW5-242	107	108	S1	Sandstone	4.23	28.71	0.005					
KWDD005	KW5-243	113	114	S1	Sandstone	2.63	28.17	0.005					
KWDD005	KW5-245	273	274	S1	Sandstone	2.95	25.91	0.005					
KWDD005	KW5-246	290	291	JLS	Limestone	1.87	28.74	0.005					
KWDD005	KW5-247	305	306	JLS	Limestone	2.39	29.60	0.005					
KWDD008	KW8-249	59	59.9	S2	Sandstone	1.59	27.67	0.005					
KWDD008	KW8-252	81	81.8	S1	Sandstone	2.11	29.60	0.005					
KWDD008	KW8-253	200	200.4	IB	Siltstone	1.51	25.26	0.005					
KWDD008	KW8-254	241	241.5	S1	Sandstone	0.99	24.23	0.005					
KWDD008	KW8-255	245	245.5	JLS	Limestone	1.65	31.07	0.005					
KODD028	KO28-259	202	203	SMR	Marl	2.61	25.15	0.005					
KODD028	KO28-260	238	239	S2	Sandstone	2.41	24.49	0.005					
KODD028	KO28-261	282	283	S2	Sandstone	2.58	26.16	0.005					
KODD028	KO28-262	293	294	S1	Sandstone	2.02	28.52	0.005					
KODD028	KO28-265	473	473.7	KLS	Limestone	2.23	25.37	0.005					
KODD028	KO28-266	592	592.7	JLS	Limestone	1.26	21.35	0.005					

Appendix E.1: Carbon and oxygen isotope data from Bigar Hill, Korkan West, and Korkan South rocks



Appendix E.2: The spatial variability of O isotope in each stratigraphic unit in drill holes along the A-B cross section

Appendix F: K-Ar Radiometric Age Dating

X-Ray Powder Diffraction Analysis

14JZBH292 and esite

Illite is the dominant mineral phase in this sample. Illite/smectite and chlorite occur in a small amount. Quartz is present in the separate in a minor amount.



14JZBH294 and esite

Discrete illite and illite/smectite are present in the sample in almost equal proportion. Chlorite, discrete smectite, quartz, and gypsum are also present in the separated <2 μ m fraction.



14JZBH296 and esite

Three different size fractions (<2 μ m; <5 μ m; and the <10 μ m) were separated and analyzed with XRPD method. There are only minor differences between the three samples. The clay minerals are illite and illite/smectite. The latter one contains approximately 10-15% smectite interstratification. The relative proportion of the pure illite in the <10 μ m fraction is a bit higher compared to the smaller size fractions. Dolomite, calcite, quartz, and chlorite occur in the <10 μ m fraction, but their amount decreases in the smaller fractions. In the <2 μ m fraction their proportion is almost negligible.



14JZBH295 sandstone

Clay minerals in this sample are discrete smectite and discrete illite. Chlorite and kaolinite are also present. Quartz and calcite occur in a minor amount.



14JZBH299 sandstone

Discrete, well-crystallized illite is dominant in the sample. Kaolinite, quartz, and calcite occur in low amount.



	-				Azimuth	Dip
Hole ID	Easting	Northing	UTM Zone	Elevation (m)	(Degrees)	(Degrees)
BHDD004	570364.5	4898443.9	UTM(WGS84)34N	700.7	270	-60
BHDD005	570533.1	4898412.4	UTM(WGS84)34N	747.4	270	-60
BHDD007	570534.4	4898247.9	UTM(WGS84)34N	775.9	270	-60
BHDD009	570540.3	4898087.1	UTM(WGS84)34N	779.8	270	-60
BHDD010	570700.4	4898243.2	UTM(WGS84)34N	771.2	270	-60
BHDD017	570854.2	4898097.4	UTM(WGS84)34N	742.1	270	-60
BHDD020	570372.5	4898558.9	UTM(WGS84)34N	691.3	270	-60
BHDD021	570394.3	4898250.5	UTM(WGS84)34N	748.6	270	-60
BHDD026	570219.6	4898565.5	UTM(WGS84)34N	685.2	270	-60
BHDD032	570781.4	4897931.3	UTM(WGS84)34N	771.4	45	-60
BHDD041	570220.8	4898488.4	UTM(WGS84)34N	686.3	270	-60
BHDD047	570598.6	4898502.3	UTM(WGS84)34N	722.6	270	-60
BHDD049	570454.7	4898400.3	UTM(WGS84)34N	729.8	270	-60
BHDD053	571503.6	4898163.3	UTM(WGS84)34N	708.8	270	-60
BHDD056	570468.3	4898171.4	UTM(WGS84)34N	774.6	270	-60
BHDD057	570863.8	4898153.9	UTM(WGS84)34N	734.0	270	-60
BHDD058	571342.3	4898160.6	UTM(WGS84)34N	702.7	270	-60
BHDD063	570925.0	4898075.2	UTM(WGS84)34N	717.9	270	-60
BHDD065	570700.4	4898012.4	UTM(WGS84)34N	787.3	270	-60
BHDD067	570926.8	4898011.0	UTM(WGS84)34N	724.5	270	-60
BHDD068	570761.0	4898165.7	UTM(WGS84)34N	769.0	270	-60
BHDD076	571003.9	4898167.4	UTM(WGS84)34N	691.1	270	-60
BHDD080	571521.3	4898384.2	UTM(WGS84)34N	660.8	270	-60
BHDD081	571331.1	4898418.7	UTM(WGS84)34N	676.8	270	-60
BHDD083	570704.0	4898132.1	UTM(WGS84)34N	784.7	80	-60
BHDD084	570652.4	4898169.4	UTM(WGS84)34N	785.3	270	-60
BHDD085	570697.5	4898213.3	UTM(WGS84)34N	774.7	270	-60
BHDD086	570430.6	4898381.7	UTM(WGS84)34N	723.5	260	-60
BHDD087	570521.1	4898327.1	UTM(WGS84)34N	761.1	270	-60
BHRC046	570691.7	4898161.1	UTM(WGS84)34N	782.1	270	-60
BHRC105	570376.4	4898172.8	UTM(WGS84)34N	751.7	270	-60
BHRC130	570579.5	4898170.9	UTM(WGS84)34N	787.4	270	-60
BHRC143	570182.0	4898172.1	UTM(WGS84)34N	684.7	275	-60
BHRC147	570225.0	4898169.1	UTM(WGS84)34N	701.7	275	-60
BHRC159	570142.7	4898168.3	UTM(WGS84)34N	666.5	275	-60
BHRC172	570815.3	4898170.8	UTM(WGS84)34N	747.8	270	-60
BHRC221	570307.1	4898171.5	UTM(WGS84)34N	732.8	273	-60
BHRC222	570339.3	4898177.0	UTM(WGS84)34N	741.3	272	-60
BHRC229	570423.8	4898170.0	UTM(WGS84)34N	765.7	270	-60
BHRC283	570895.9	4898171.0	UTM(WGS84)34N	722.9	270	-60
BHRC297	570498.7	4898168.6	UTM(WGS84)34N	779.7	270	-60
CRDD002	574478.9	4888710.6	UTM(WGS84)34N	812.1	120	-50
CRDD005	574327.4	4888083.6	UTM(WGS84)34N	743.5	135	-50
KODD028	570881.6	4899187.7	UTM(WGS84)34N	708.5	270	-60
KWDD005	569494.3	4899762.7	UTM(WGS84)34N	739.4	0	-60
KWDD008	568862.4	4900428.4	UTM(WGS84)34N	737.2	0	-60
RADD001	572784.5	4896009.7	UTM(WGS84)34N	889.4	130	-60

Appendix G: Bigar Hill, Korkan, Korkan West, Rakita, and Crna Reka drill hole collar locations and orientation data