



Gold mineralization at the Blue Rock Deposit, Gadzema Greenstone Belt:
Implications on genesis and exploration for orogenic gold mineralization
within Archaean Greenstone Belts of Zimbabwe.

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DECLARATION

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ABSTRACT

The Blue Rock gold deposit was re-discovered by African Consolidated Resources (ACR) in 2007, over a defunct historical gold mine at Blue Rock, during a regional geochemical soil sampling program, within the Gadzema Greenstone Belt (GGB), in Central Zimbabwe.

Most significant orogenic gold deposits within this belt occur as BIF- and quartz vein hosted orebodies. But unlike them, gold mineralization at Blue Rock is associated with felsite and quartz porphyry rocks. The GGB is a northern extension of the Midlands Greenstone Belt (MGB), where the common occurrence of mineralized felsites, in close association with major gold reefs within numerous gold mines is well documented. But no significant effort was directed towards their understanding or exploration in the past. They were never considered viable exploration targets for significant economic gold deposits, until recently. More attention was instead focused on high-grade BIF and quartz vein hosted gold, that dominate most orebodies exploited by numerous mines within the belt.

At Blue Rock, ACR defined a significant JORC compliant felsite-hosted gold resource of close to a million ounces, which represents a brand new attractive open-pit mining opportunity. But the successful exploration for such type of mineralization, whose footprint is so different from the common ones previously mined within the GGB, no doubt, calls for a good understanding of this type of mineralization. Which makes felsite-hosted gold mineralization a prime candidate for research, based on a deposit whose discovery and development, I was fortunate to be part of during the past few years.

In this contribution, the genesis, localization and economic significance of felsite-hosted gold mineralization is investigated, using the gold deposit at Blue Rock as a case study. The deposit could be understood best through the Mineral Systems Approach, used in this study to interrogate alternative ideas about its genesis using published information and deposit-scale exploratory data.

Results from the synthesis of published information on the evolution of Archaean Greenstone Belts and genesis of their host orogenic gold deposits, are consistent with models that view orogenic terrains as having formed through horizontal accretion in modern-day like subduction-accretion systems, at continental margins, where orogenic gold deposition occurred via processes that could be explained quite simply, through a universal orogenic gold mineral systems model. According to this model, orogenic gold deposits are believed to have formed from near neutral fluids containing dissolved gold, generated directly from the devolatilization of a subducted oceanic slab together with its overlying gold-bearing sulphide-rich sedimentary package, or indirectly through fluid released from a mantle lithosphere that was originally metasomatized and fertilized during an earlier subduction event. The fluid migrated up-dip from the mantle to crustal levels, through advection or seismic pumping along lithosphere- to crustal-scale fault zones, to form orogenic gold deposits within lower order structures.

If these models are all accurate, then the GGB formed through subduction-related east-directed horizontal accretion at the continental margins of the Sebakwe Proto-Craton (SPC), and the genesis of felsite-hosted gold mineralization at Blue Rock could be explained eloquently through a universal orogenic gold model, in which mantle derived auriferous fluids were localised within lower order structures associated with felsites during the late stages of terrain accretion.

Evidence from surface mapping and 3D modelling of exploratory drilling data, conducted during this research, strongly support the argument that the felsite hosted gold mineralization at Blue Rock, is neither unique nor accidental. It is just but, a simple product of the conjunction of favourable geological factors, no different to those that birthed typical GGB orogenic gold mineralization hosted within sheared sulphidic BIFs and quartz vein reefs. They all share the same geodynamic setting, fertility, preservation and regional architectural factors reminiscent of accretionary orogenic settings, albeit with differences in local architecture, variably controlled by geochemical and rheological properties of the different local host rocks.

At deposit scale, the felsites occur as small dykes and sills emplaced along pre-existing structural zones of weakness. Gold mineralization is structurally controlled and associated mostly with brittle-ductile shears.

During deformation, rheological contrast played a significant role in the selective failure of the more competent felsite rocks, resulting in the creation of permeability channels that allowed fluid migration. The more brittle and competent felsites acted as rigid bodies, that localised strain along their contacts with the surrounding less competent ductile mafic schists which acted as a relatively less permeable fluid cap rock.

The irregular felsite contact zones with surrounding mafic schist caused a significant variation in the orientation of local principal maximum stress relative to the internally imposed regional stress, causing anomalously low minimum stress zones at deposit scale. Gold deposition occurred within low minimum stress structural traps dominated by sheared felsite contacts and their fractured interiors as well as triple junctions formed by complex structural geometries created by multiple felsite intrusions.

The felsite hosted gold at Blue Rock can therefore be recognized as an orogenic gold mineral system archetype, for which an occurrence model is proposed. Understanding this type of mineralization is key for developing a robust exploration strategy - one that could be applied in a predictive capacity in exploration, to locate new economic gold deposits especially within well-endowed mature orogenic terrains, where exploration risk could be minimized by leveraging on new forward-thinking initiatives like Artificial Intelligence (AI) to re-analyze data from previous mining and exploration, allowing for a faster route to a return on investment.

In a world of diminishing natural resources, the potential for previously ignored gold mineralization like the one at Blue Rock, becomes very significant. The prophetic words of Foster (1984), writing in Gold '82, therefore remain true and relevant to our time, that; "... the way ahead for successful gold exploration is to search for new deposits not commonly recognized – in auriferous muds, disseminations in carbonate rocks, porphyries, and in felsic intrusive and extrusive volcanics...".

Key Words: felsite; Quartz porphyry; orogenic gold; mineral system; exploration; shear zone.

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I am extremely grateful to my family for their continuous encouragement, unfailing love and support, without whom this journey would not have been possible.

DEDICATION

This research is dedicated to:

- My parents and family – your continuous love and encouragement, moulded a resilient man. We are all strong or we wouldn't be here.
- My children - Shaun, Tanya, Keith and Jacques – you are not alone.

TABLE OF CONTENTS

DECLARATION	ii
ABSTRACT	iii
ACKNOWLEDGEMENTS.....	v
DEDICATION	vi
TABLE OF CONTENTS.....	vii
CHAPTER 1. INTRODUCTION.....	13
1.1. GENERAL INTRODUCTION	13
1.2. HISTORICAL BACKGROUND	14
1.2.1.Exploration and Mining	14
1.2.2.Geological Studies	15
1.3. RESEARCH MOTIVATION.....	17
1.4. PROBLEM STATEMENT	18
1.5. RESEARCH OBJECTIVES.....	18
1.6. METHODOLOGY	18
CHAPTER 2. HISTORICAL WORK.....	20
2.1. INTRODUCTION.....	20
2.2. EXPLORATION AND MINING HISTORY.....	21
2.3. RECENT EXPLORATION	22
2.3.1.Geochemical Sampling.....	22
2.3.2.Airborne Geophysics	23
2.3.2.1. Magnetic Survey	24
2.3.2.2. Radiometric Survey.....	24
2.3.3.Geological Mapping.....	27
2.3.4.Resource Drilling	27
2.3.5.Gold Mineralization.....	28
CHAPTER 3. THE ARCHAEO OROGENIC GOLD MINERAL SYSTEM MODEL.....	30
3.1. INTRODUCTION.....	30
3.2. OROGENIC GOLD DEPOSIT MODELS	30
3.3. DISCREDITED HISTORICAL MODELS	31
3.4. SUITABILITY OF CRUSTAL METAMORPHIC MODELS.....	31
3.5. TOWARDS A UNIVERSAL OROGENIC GOLD MODEL.....	33
3.6. A COHERENT MINERAL SYSTEMS APPROACH FOR OROGENIC GOLD.....	33
3.6.1.Geodynamic Setting	34
3.6.2.Fertility	35
3.6.3.Architecture	37
3.6.4.Preservation	38
3.7. MINERAL SYSTEMS APPLICATION TO EXPLORATION	39
CHAPTER 4. GEODYNAMIC SETTING AND ARCHAEO GREENSTONE BELT EVOLUTION	41
4.1. TOWARDS A UNIVERSAL MODEL FOR ARCHAEO ZIMBABWEAN GREENSTONES	41
4.2. VERTICAL ACCRETION.....	41

4.3. HORIZONTAL ACCRETION	42
4.4. A MODEL FOR THE GADZEMA GREENSTONE BELT.....	45
4.5. MINERALIZATION.....	46
CHAPTER 5. LOCAL GEOLOGY – THE GADZEMA GREENSTONE BELT	47
5.1. HISTORICAL WORK	47
5.1.1.GGB Geological Outline	48
5.1.2.Major Lithologies	48
5.1.2.1. Banded Iron Formation (BIF).....	48
5.1.2.2. Serpentine.....	49
5.1.2.3. Mafic Schist	49
5.1.2.4. Dolerite	49
5.1.2.5. Quartz Vein	49
5.1.2.6. Felsites and Quartz Porphyries	49
5.1.2.7. Granite	50
5.1.3.Structural Geological Framework	50
5.1.3.1. D1 (Ductile Deformation).....	50
5.1.3.2. D2 (Deformation of D1 Structures).....	51
5.1.3.3. Granite Emplacement	51
5.1.3.4. D3 (Brittle-Ductile Deformation)	51
5.1.4.Gold Belt Scale Mineralization.....	51
5.1.4.1. General	51
5.1.4.2. Lithological Association.....	51
5.1.4.3. Structural Association	52
5.2. RECENT SURFACE GEOLOGICAL MAPPING.....	53
5.2.1.Gadzema Greenstone Belt Geology	53
5.2.1.1. Regional Surface Occurrence of Felsites	53
5.2.1.2. 3D Geological Model of Regional Geology	56
5.2.2.Deposit-Scale Geology.....	57
5.2.2.1. Deposit Scale Surface Occurrence of Felsites	57
5.2.2.2. 3D Model of Felsites at Gold Deposit Scale	60
5.2.3.Deposit Scale Mineralization	62
CHAPTER 6. MINERALIZATION.....	63
6.1. GENERAL INTRODUCTION	63
6.2. FERTILITY ASSESSMENT.....	63
6.2.1.Endowment	63
6.2.2.Zipf Analysis.....	64
6.3. EXPLORATORY DATA ANALYSIS (EDA).....	66
6.3.1.Statistical Data Analysis	67
6.3.1.1. Histogram	67
6.3.1.2. Table of Statistics.....	68
6.3.1.3. Box Plot	69

6.3.1.4. Correlation Plots	69
6.4. NUMERICAL DATA MODELLING	72
6.4.1. Methodology.....	72
6.4.2. Results	72
6.5. RESOURCE MODELLING	75
6.5.1. Domainining	75
6.5.2. Ordinary Kriging	77
CHAPTER 7. DATA SYNTHESIS AND DISCUSSION.....	83
CHAPTER 8. PROPOSED OCCURRENCE AND EXPLORATION MODELS.....	88
8.1. INTRODUCTION.....	88
8.2. GEODYNAMIC SETTING.....	88
8.3. FERTILITY	89
8.4. ARCHITECTURE.....	90
8.4.1. Regional Architecture	90
8.4.2. Deposit-Scale Architecture	93
8.5. PRESERVATION.....	95
CHAPTER 9. CONCLUSIONS AND RECOMMENDATIONS	96
CHAPTER 10. REFERENCES	97

TABLE OF FIGURES

Figure 1: Location of the gold deposit at Blue Rock on a regional geology map, covering the Gadzema Greenstone Belt.	13
Figure 2: Blue Rock Project locality, showing the relative location of the Orange Farm, Blue Rock, RedHat and Berks Prospects on Regional Geology Map	20
Figure 3: Geochemical Soil Sampling map showing location of the geochemical anomaly that was followed up by excavation work which led to the initial re-discovery of the gold deposit at Blue Rock.	23
Figure 4: Airborne Magnetic Survey covering the GGB, showing highly magnetic lithologies (Red - e.g. BIF), other moderately conductive greenstone lithologies (Yellow - Orange) and Mafic Schist (Blue) in a background of largely non-conductive granitic (Green) Biri Granite rocks, on a Sun shaded, Reduced to Pole, First Vertical Derivative (RTP_1VD_SUN) image.	25
Figure 5: Airborne Radiometric Survey conducted over the GGB, showing high total radiometric count (TOT) (Red – Orange – Yellow) consistent with Felsic lithologies like felsite and granite, against other low total radiometric count (Blue – Green) non-felsic lithologies - mainly greenstone lithologies and cover.	26
Figure 6: Convergent margin-orogenic gold model showing the range of tectonic settings permissible for orogenic gold systems with a consistent Geodynamic environment. From Groves et al. (2022).	30
Figure 7: Schematic representation of (i) Invalid shallow crustal meteoric or metamorphic models and granulitization - and (ii) non-unifying magmatic-hydrothermal, ore- fluid source models for orogenic gold deposits. From Groves and Santosh (2016).	31
Figure 8: Schematic representation of generally accepted supracrustal metamorphic ore- fluid source models for orogenic gold deposits. From Groves and Santosh (2016).	32
Figure 9: Critical mineral system, with emphasis on orogenic gold. From McCuaig and Hronsky (2014).	34

Figure 10: Schematic representation of subduction-based model for ore-fluid source for orogenic gold deposits globally by direct subduction. From Groves et al. (2020b).....	34
Figure 11: Schematic representation of subduction-based model for ore-fluid source for orogenic gold deposits globally involving a mantle that was metasomatized and fertilized from a previous subduction event. From Yang et al. (2021).	35
Figure 12: Schematic representation of a self-organising orogenic gold mineral system showing alternate fertility sources that have the same basic architecture parameters. From Groves et al., (2020a).....	36
Figure 13: Schematic diagrams showing repetitive structural architecture at fluid sinks or traps for orogenic gold systems: (a) major jogs on crustal-scale- and subsidiary faults/shear zones cut by corridors of accommodation faults; (b) “locked up” thrust anticlinal folds; (c) irregular contacts on faulted margins of granite intrusions; (d) triple- and quadruple-point granite intrusion architecture. From Groves et al. (2020).	38
Figure 14: Active plate tectonic system showing subduction of oceanic lithosphere, devolatilization and partial melting of mantle wedge to create arc magmatism. From Kusky et al. (2018).	43
Figure 15: Cross Section showing (a) Ocean Plate Stratigraphy development and (b) Subduction-Accretionary processes that form orogenic terrains. From Kusky et al. (2018).	44
Figure 16: Geodynamic synthesis of the Zimbabwean Craton showing Western Succession Subduction System [4] which was responsible for the formation of Upper Greenstones, which include the Gadzema Greenstone Belt. Modified from Jelsma et al. (2021).	45
Figure 17: Regional geology of the Gadzema Greenstone Belt, showing the location of the Blue Rock Project.	47
Figure 18: Recent surface geological mapping conducted by the Author, covering the whole Gadzema Greenstone Belt, soon after the re-discovery of the Blue Rock deposit. Geological Cross Section lines ‘A-B’, ‘C-D’ and ‘E-F’ are presented as Fig. 19.	54
Figure 19: Geological Cross Sections (“A-B”, “C-D” & “E-F”) for three traverse lines on surface geology map (Fig. 18) over the Blue Rock gold deposit.	55
Figure 20: Shallow small-scale open cast mining exposure (Picture A) at the new Blue Rock deposit, mining felsite orebodies that are intrusive into mafic schist (SCH) rocks. Ore consists of sheared, faulted felsite (FEL) hosting a stock-work of mineralized (Min) quartz veins (QTZ) (Picture B).	56
Figure 21: 3D Model of the Gadzema Greenstone Belt, showing Regional Geology mapped by the Author, including Structural Interpretation by Dirks and Mikhailov (1988).	56
Figure 22: Detailed Surface Geological Mapping of the Blue Rock Deposit done by the Author at 1: 2 500, showing the distribution of host geological domains (Felsites, Bif, Quartz Vein and Mafic Schists).	58
Figure 23: Hand-Drawn 2D Geological Cross Section 7,999,400N for the gold deposit at Blue Rock (Example 1).	59
Figure 24: Hand-Drawn 2D Geological Cross Section 7,999,440N for the gold deposit at Blue Rock (Example 2).	59
Figure 25: 3D Visualisation of Geological data and information for the gold deposit at Blue Rock (covering the Berks Prospect Part of the Project) used to model deposit scale geology in Leapfrog Geo.	60
Figure 26: 3D Geological Model of the gold deposit at Blue Rock, done from a combination of surface mapping, geological cross sections and downhole drilling geology data.	61
Figure 27: Berks Prospect part of 3D Geology Model constructed from surface mapping, geological cross sections and resource drill holes, showing thin interbedded BIF horizons, intrusive felsites and quartz porphyries associated with the bulk of gold mineralisation at the gold deposit at Blue Rock.	61

Figure 28: (2 nd View) Berks Prospect part of 3D Geology Model constructed from surface mapping, geological cross sections and resource drill holes, showing thin interbedded BIF horizons, intrusive felsites and quartz porphyries associated with the bulk of gold mineralisation at the gold deposit at Blue Rock.....	62
Figure 29: Zipf Analysis Chart, showing Gadzema Greenstone Belt Gold Endowment (Rank plotted against Gold Deposit Size).	66
Figure 30: Length-Weighted Histogram Plot of gold assay values for the gold deposit at Blue Rock.....	68
Figure 31: Box Plot analysis showing gold assay values for different lithologies. Quartz Vein (YELLOW) is the most mineralized lithology, followed by Felsite (RED), then Felsic Schist (PINK) and Granitic Felsite (ORANGE). Overburden is thin cover usually not exceeding 1m below surface on most boreholes. Serpentinite (PURPLE) and Mafic Schist are the least mineralized.....	69
Figure 32: Correlation Log Plot for Boreholes BRDD001 & BRR043.....	70
Figure 33: Correlation Log Plot for Boreholes BRR036 & BRR038.....	71
Figure 34: 3D Numerical Grade Model of Gold Values for the Blue Rock Gold Deposit, done in Leapfrog Geo. 72	
Figure 35: A typical mineralised Section showing a high-grade core of structurally controlled gold mineralization dipping steeply towards the east.	73
Figure 36: Felsite/Quartz Porphyry Ore Body showing mineralised mafic schist footwall and hanging walls.	74
Figure 37: Cross-Section 7,999,400N from Numerical Au Grade Model of the gold deposit at Blue Rock.....	74
Figure 38: Berks Numerical Model on geology showing gold mineralization occurring on fractured interiors of felsites and their sheared margins.	75
Figure 39: Domaining done manually and using Numerical Model results and Geology in Leapfrog Geo.	76
Figure 40: Six (6) Mineralization Domains created for Resource Estimation.	76
Figure 41: Resource Model estimated at an assay cut-off grade of 0.5 g/t Au, for the gold deposit at Blue Rock, showing the full range of average Au grade blocks.	77
Figure 42: Resource Estimation Model of the gold deposit at Blue Rock, showing resource block average grades above 0.2 g/t Au.	77
Figure 43: Resource Estimation Model of the gold deposit at Blue Rock, showing resource block average grades above 0.5 g/t Au.	78
Figure 44: Resource Estimation Model of the gold deposit at Blue Rock, showing resource block grades above 0.5 g/t Au plotted on local deposit scale geology.....	78
Figure 45: Composite 3D Model (with surface geology map) of the gold deposit at Blue Rock, showing Au Resource Estimation on geology.	79
Figure 46: A Composite 3D Model (with cross sections) of the gold deposit at Blue Rock, showing Au Resource Estimation on a 3D Geological Model.	79
Figure 47: Representative Slice (7,999,400N) extracted from composite resource grades-on-geology model, showing resource blocks within felsite interiors and contacts associated with quartz veins and structures.	80
Figure 48: Example of typical Section (Section 7,999,400N) from the 3D Resource Estimation Model, showing gold mineralization associated with felsites, faults and associated quartz veins.....	80
Figure 49: Resource Estimation on Plan showing spatial distribution of high-grade blocks corresponding to permeable fluid conduits and good structural traps along NNW oriented lower order structures.....	81

Figure 50: Top-of-Resource Estimation model or Plan showing the spatial distribution of high-grade gold blocks on surface geology, which reveal gold mineralization trends associated with structures that possibly controlled felsite emplacement and gold localization.....	82
Figure 51: Geodynamic setting of the GGB. Hypothesized from Jelsma et al. (2021), Kusky et al. (2018) and Groves et al. (2022), for Zimbabwean Western Succession Orogenic Terrains, thought to have formed through an east-directed subduction-related horizontal accretion at the margins of the Sebakwe Proto Craton, where fluids were generated through devolatilization and rose to surface to form gold deposits within lower order structures formed during accretion and deformation.	89
Figure 52: Illustrative sketch of a regional geological section through the GGB geodynamic model. Conceived from the regional geology of the GGB (consolidated in Fig. 51) and drawn using concepts adapted from constructions of Western Succession Greenstone Belts (e.g. the Shamva-Bindura Greenstone Belt - Dirks and Jelsma, 1997).....	91
Figure 53: Schematic model for the sequence of the felsite hosted gold mineralization at Blue Rock relative to historical BIF hosted and quartz vein reefs, during the tectonic evolution of the GGB.....	92
Figure 54: Gold deposit at Blue Rock showing numerically modelled gold values hosted by felsites and quartz porphyries at the Berks prospect.	93
Figure 55: Gold deposit at Blue Rock showing structurally controlled resource estimated gold mineralization hosted within felsite fractured interiors, sheared margins and complex geometric structural trap sites.	94

LIST OF TABLES

Table 1: Blue Rock Deposit Mineral Resources by Project. Summarised from Johnson (2012).....	29
Table 2: Historical Gold Production Figures (up to 1990) for major gold deposits within the Gadzema Greenstone Belt (Extracted from Bartholomew, 1990).	64
Table 3: Zipf Analysis values based on existing major deposits including Blue Rock gold mine.	65
Table 4: Blue Rock Deposit Gold Assay Table of Statistics.....	68

CHAPTER 1. INTRODUCTION

1.1. GENERAL INTRODUCTION

Zimbabwe has been a major producer of gold for many years (Bartholomew, 1990). Gold is produced from numerous Archaean orogenic gold belts, including the Gadzema Greenstone Belt (GGB) (Fig. 1). The GGB in central Zimbabwe, is located within the northern part of the Midlands Greenstone Belt (MGB) - the country's largest and historically the most productive greenstone belt (Campbell and Pietfield, 1994; Wiles, 1957; Bartholomew, 1990). Most of the gold produced from the GGB has come from BIF hosted orebodies at the Giant (17.47t Au), New-Found-Out (0.66t Au), Elvington (0.57t Au) and the RedHat (0.5t Au) mines, as well as from subordinate quartz vein reefs like Blue Rock (0.24t Au) and Water Lily (0.12t Au) mines (Bartholomew, 1990). But all these deposits are now nearly depleted, with all the major mines having closed or simply put under care-and-maintenance.

Efforts to find new gold deposits within the GGB have been ongoing for several years, mostly through relatively low-

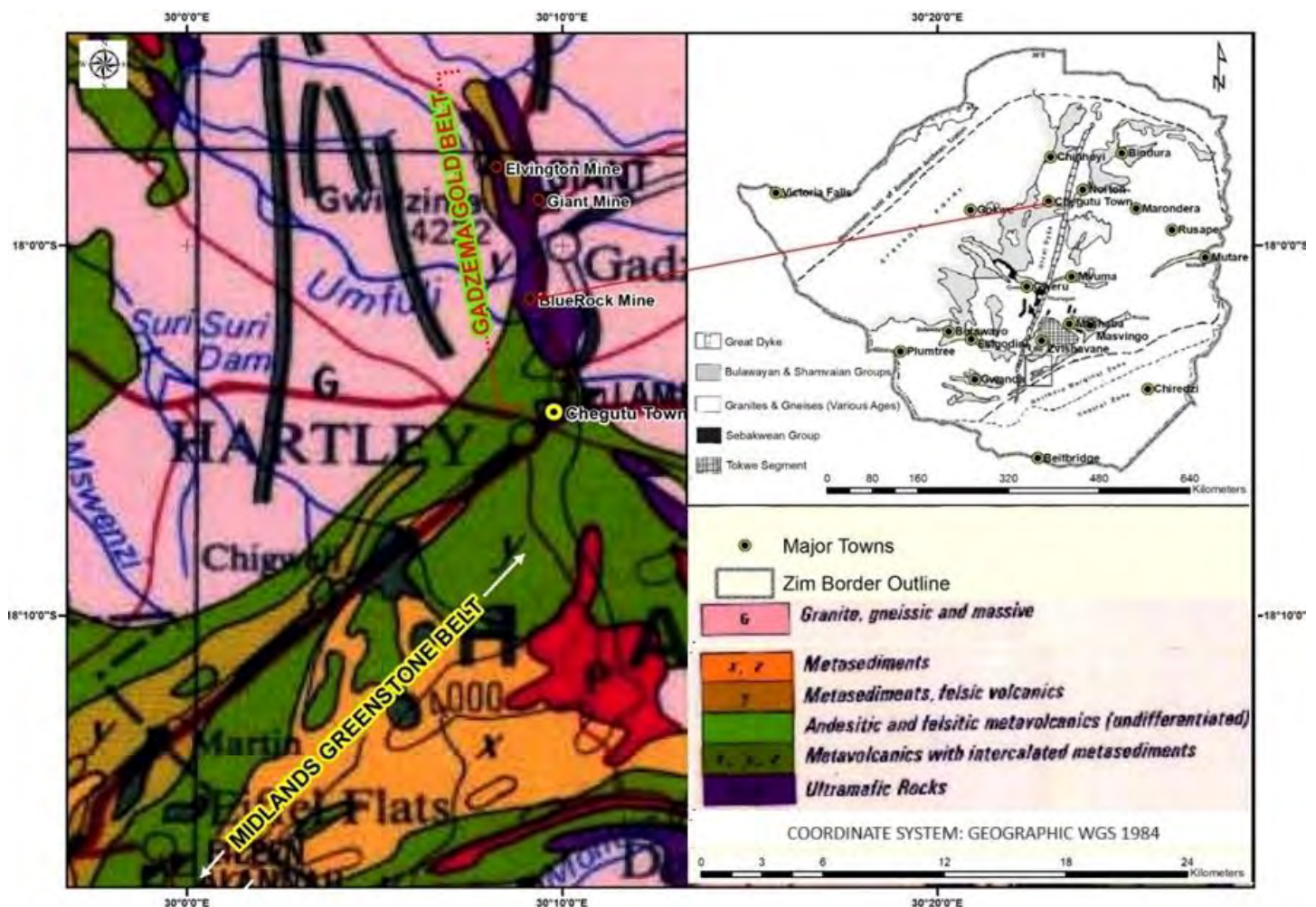


Figure 1: Location of the gold deposit at Blue Rock on a regional geology map, covering the Gadzema Greenstone Belt.

risk brownfields exploration targeted around historically productive gold mines. Success in this regard has been reported on several projects, including around the Giant mine, where discoveries of new additional resources have recently been made. Most of the new resources discovered have taken the form of low-grade mineralized halos around richer ore bodies (now mined-out) previously exploited by early mining.

Within the southern part of the GGB however, efforts to find new gold deposits have led to the discovery of a 'new' type of gold mineralization, different to the ones previously exploited by historical mining. In this type of mineralization, gold is mainly hosted within 'felsite' and 'quartz porphyry' rocks.

The term felsite is not well defined in modern literature but, has historically been used by southern African geologists as a field term to refer to fine-grained, light-coloured igneous rocks that typically require petrographic examination or geochemical analysis for precise identification. Good examples of such rocks are the acid volcanics of the Rooiberg Group in the Republic of South Africa, but since the 1980s, these rocks have been given their proper names (e.g. dacites, rhyolites, etc.). In this study the term 'felsite' will be used for variably sheared, small, dyke-like, fine-grained igneous intrusives associated with the new gold mineralisation at the Blue Rock gold deposit, whilst the term 'quartz porphyry' is used to refer to minor felsic to intermediate intrusions with porphyritic texture as is common practice in other Zimbabwean greenstone belts.

The Blue Rock gold deposit was re-discovered, by the Alternative Investment Market (AIM) listed African Consolidated Resources (ACR) in 2007, during a regional geochemical soil sampling program over the now defunct Blue Rock gold mine. The new deposit is located some six (6) kilometres north of Chegutu town, about 100 km west southwest of the capital Harare (18° 04' 34" S, 30° 09' 05" E).

Ongoing exploration by ACR at Blue Rock has so far defined a shallow JORC (Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves) compliant resource of close to a million ounces Au, at an average gold content of about 1 g/t, and a cut-off grade of 0.5 g/t.

Encouraged by the prevailing higher global gold prices, there is no doubt that this new discovery represents a viable open-cast mining opportunity, which could one day soon economically exploit low grade ores at much lower cut-off grades than those previously mined within the same gold camp.

Besides exploratory drilling done to develop this deposit by ACR, very little is known about the true nature and potential of the gold mineralization at the gold deposit at Blue Rock. This study therefore seeks to characterize the Blue Rock deposit. This is done using the Mineral Systems Approach using all available regional data, together with a thorough analysis of exploratory data generated during the development of this deposit to its present form. In this research, I would like to start a discussion regarding the genesis and economic significance of felsites in hosting economic orogenic gold deposits in Archaean terrains, using the Blue Rock deposit as a case study.

1.2. HISTORICAL BACKGROUND

1.2.1. Exploration and Mining

The GGB has historically been a major gold producing terrain in Zimbabwe. Exploration for gold began with the discovery of ancient gold workings on the banks of the Umfuli river by an elephant hunter, Henry Hartley in 1865, (Mann, 1871; Thackeray, 1938). This initial find led to the subsequent discovery of the Umfuli Gold Fields a year later, in 1866 by Carl Mauch (Anhaeusser, 1976). Since then, exploration within the GGB has been conducted by various mining companies. From 1891 onwards, numerous prospectors worked in the area, and several major mines were discovered and developed. The most significant of these discoveries are the Giant, Elvington, Newfound Out, RedHat, Waterlily and the Blue Rock mines.

The Giant mine was operational until 1981, by which time it had produced about 17,500 kg of gold at an average grade of about 8.2 g/t Au (Dirks and Mikhailov, 1998). The main production stage at Giant occurred between 1906 and 1916, after which the mine collapsed, pinching the reef at depth, which led to the halting of further production. Renewed activity at a small scale occurred during the 30's and 50's.

The Elvington mine and the adjacent Lone Star tenements are amongst the oldest recorded peggings in Zimbabwe. They were initially developed by De Beers Consolidated Mines in 1903, before being taken over by the Lone Star Mining Company in 1904, but then closed in 1906, after producing about 270.2kg gold (Phaup and Dobell, 1938). From 1922 to 1927, the mine was developed by the Newfound Out Syndicate, and from then on it changed hands between

different mining companies, before it was picked up by Lonrho and the Zimbabwe Mining Development Corporation (ZMDC). The ZMDC and Lonrho worked together through a joint venture partnership (JV) until 1986 when the ZMDC conducted detailed exploration to re-develop the Elvington mine. The mine was reopened and operated until the suspension of operations in 2003, after the collapse of one of its main shafts (Machiki, 2017).

Most recent exploration over the GGB however, has been limited to brownfields exploration around historical mines like the Elvington mine by the ZMDC. During the most recent past, the Giant mine was explored by Cambrian Resources and later by Prospecting Ventures, before it was taken over by ACR (current owners of the Giant mine). ACR explored most of the GGB including areas around the Giant mine, and in 2007 discovered a new felsic hosted gold deposit over the historical Blue Rock mine, and this new deposit is the subject of this research.

1.2.2. Geological Studies

The geology of the GGB, which hosts the gold deposit at Blue Rock, was mapped and studied by various academics and explorers since the late 1860s. Soon after the initial gold discovery within the GGB, several quartz veins and reefs were identified and mapped by Thomas Baines in 1869, through the numerous traverses he conducted covering the whole area (Carruthers and Arnold, 1995). Jameson and Selous in 1880, also worked in the area and gave general descriptions of the lithologies they had visited. Since then, almost all the gold deposits found within the GGB have been developments of existing and largely abandoned small-scale ancient workings targeted by the ancients prior to European colonization during the 1890's, (Campbell and Pitfield, 1994).

The first significant regional mapping effort, however, came from MacGregor in 1925 who described the GGB as a northern peninsula of the much larger Midlands Greenstone Belt, made up of mafic schists, banded Iron formations (BIF) and serpentinites, surrounded by great volumes of younger intrusive granitic rocks that have produced the folding and metamorphism observed in the "ancient" gold belt rocks (Phaup and Dobell, 1938).

MacGregor's work was followed by that of Phaup and Dobell (1938), who outlined the geology of the whole belt in better detail. Phaup and Dobell (1938) used detailed mine level data from mostly three major gold mines namely, the Newfound Out, Elvington and Giant mines, to improve the geological understanding of the GGB, including its host gold mineralization. Their mapping also identified metasediments in addition to lithologies previously mapped by MacGregor and others.

Another regional mapping effort came from Wiles (1957), who in addition to mapping the GGB, covered a portion of the larger MGB, south of the GGB, as well as the area to the east, which includes the Great Dyke.

More recent mapping and geological studies were conducted by Mutambara (1991), Fisher (1992) and Chisi (1994), although the scope of their work was, for the most part, only limited to deposit-scale investigations on gold mineralization at the Elvington and Lone Star mines. All their studies concluded that gold mineralization at the Elvington mine was epigenetic, and hosted within second order shears, associated mostly with banded iron formations. The host banded iron formations dip steeply (65 – 80 degrees) towards the east. Mineralization occurs mostly as sulphidic replacements of magnetite in BIF and impregnations of sulphide minerals in quartz veins that crosscut the BIFs. Mutambara (1991), Fisher (1992) and Chisi (1994), all attributed the source of gold mineralization within the GGB to hydrothermal fluids related to the emplacement of the Biri granite intrusion. Such a model is consistent with magmatic-hydrothermal models traditionally supported by vertical accretion models for granite-greenstone terrain evolution. But vertical accretion models are now losing popularity, in favour of horizontal accretion models. Based on studies in numerous Archaean gold terrains world-wide, the genesis of most Archaean gold belts in Zimbabwe could be explained best through horizontal accretion. Hydrothermal-magmatic models are also losing their relevance, and the main arguments against them will be discussed in better detail in Section 3.3, of this dissertation.

Campbell and Pitfield (1994), did a more comprehensive evaluation of the extent and significance of structural controls on Archaean gold mineralization in Zimbabwe, following the work of Colvine et. al (1984 & 1988) in Canada and that of Groves (1982) and Groves et al., (1984; 1985) in Australia, who recognized strong structural controls on Archaean orogenic gold deposits.

Campbell and Pitfield (1994)'s work was a craton-wide effort, which covered regional and mine-scale structural controls of gold mineralization for all Archaean greenstone belts within the whole of Zimbabwe including the GGB. The MGB to which the GGB is a part, was used as a case example and covered in better detail to produce a structural-based exploration strategy. A strategy where structural patterns and lithological hosts associated with gold within known existing deposits could be used in a regional context in a predictive capacity in exploration, to identify regional exploration targets. As for the GGB, a prospective major shear/deformation zone that follows the western margins of the belt was recognized as a high priority target, where shear-and BIF-hosted mineralization could be targeted.

In 1998, a GGB-wide, exploration-focused, comprehensive structural evaluation of gold occurrences around the Giant mine was conducted by Dirks and Mikhailov (1998): unpublished work, accessed by the author from ACR company records provided by the previous owners of the Giant mine (Cambrian Resources and Prospecting Ventures). Although this work was in many ways a follow-up to that of Campbell and Pietfield (1994), it managed to confirm, through mapping, the earlier regional structural targets of Campbell and Pietfield (1994), as well as to generate new ones mainly associated with quartz vein and highly deformed BIF units.

The work of Dirks and Mikhailov (1998), for good reason, emphasized the distribution of prospective BIF units. Most of the major mines within the GGB are hosted within sheared BIF – an important structural-lithological association for economic gold deposits within the GGB, also identified by Mutambara (1991), Fisher (1992), Chisi (1994) and Campbell and Pietfield (1994). Dirks and Mikhailov (1998)'s work zoomed in on earlier regional targeting by Campbell and Pietfield (1994), and used lineament analysis in GIS, to unravel the structural controls of gold mineralization for the whole GGB terrain.

Unlike previous studies, which relied on a simple “layer-cake” stratigraphic model for geological interpretation (e.g. Wilson, 1979; Wilson et al., 1995), the work of Dirks and Mikhailov (1998) used a new alternative geological understanding on the evolution of Zimbabwean greenstone belts like the GGB, which involves horizontal accretion to account for the development of a large number of shear zones, that typically parallel compositional layering or cut stratigraphic layering at low angles. Dirks and Jelsma (1998) interpreted these layer parallel shear zones as having accommodated the westward tectonic stacking of thrust sheets during horizontal accretion of Archaean Zimbabwean greenstone terrains.

When Dirks and Mikhailov (1998) mapped the GGB, they identified the same layer parallel thrusts as important structures associated with intensely mineralized tectonically thinned, boudinaged and folded BIF lenses, most of which form the most significant deposits like the Elvington, New-Found-Out and Giant mines. This interpretation has very important implications on resource exploration along extensions of known BIF hosted deposits of this type. For instance, where the BIF lenses are not faulted, there are presumed to have been thinned out by tectonic shearing or ductile deformation during D1 and are therefore of limited horizontal and vertical extent – an important proposition to consider for any future efforts to follow-up the Giant mine ore body from where it pinched out leading to mine closure in 1973 (Fisher, 1992).

Just like Campbell and Pietfield (1994), the mapping of Dirks and Mikhailov (1998) emphasized the identification of gold mineralization (exposed in historically productive mines and workings) and its spatial relationship to host lithologies (mineralized deformed BIFs and quartz veins), and structural elements (e.g. folds, secondary shears and later faulting of regional significance), which acted both as fluid movement conduits, as well as depositional sites. In

the end, this work produced for the first time, a robust exploration model for the GGB, to predict undiscovered gold targets that could be resolved through direct detection exploration methods.

But all the studies done over the GGB up to this point, had mostly been limited to data and information available from existing mines and workings, on the two recognized predominant styles of mineralization, which are in order of frequency of occurrence and significance: (a) sulphidic impregnations in BIF, which form almost all the large deposits within this belt e.g. the Giant, Elvington and NewFound-Out mines; and (b) quartz vein reefs, mainly limited to small deposits such as the Blue Rock and the Water Lilly mines.

Although the work of Dirks and Mikhailov (1998) on the GGB could be viewed as representing the earliest application of the mineral systems approach using GIS, it emphasised on known BIF and quartz vein hosted gold mineralization targets, but not the existence of significant felsic hosted targets such as the new gold deposit at Blue Rock, which would be found within the same terrain a few years later.

In this study I present for the first time, work done to develop and characterise the felsic-hosted gold deposit at Blue Rock, which bears on the above discussion.

1.3. RESEARCH MOTIVATION

In selecting a topic to study, I chose to characterize gold mineralization at Blue Rock, within the GGB, in central Zimbabwe, for several reasons, which include:

- (i) The fact that my first involvement with exploration at ACR, was concerned with gold exploration. During this period, I found the numerous, and often divergent views on gold deposit genesis (also reflected in their classification and terminology) from the enormous volumes of literature quite intriguing. Which set me on a journey to look for a best-fit model amongst many, to adequately account for a brand-new gold deposit we had just discovered at Blue Rock. Such a model, I imagined, would not only help carry us through the process of cost effective and efficient resource development of the new discovery by direct detection methods, but also equip us with the necessary knowledge to predict where to find more similar deposits elsewhere.
- (ii) After the gold deposit discovery at Blue Rock, during my coursework studies at Rhodes University (RU), I was fortunate to get introduced to the world of mineral systems by Professor “Jock” Harmer, which took on a whole new magnitude of importance in mineral exploration, especially for gold, where the numerous models and views often divergent and parallel exist and need to be reconciled through some form of a unified concept or approach. Such effort would allow researchers and explorers like me to cut through the noise of difficulties, usually encountered from the application of isolated exploration approaches, often developed from genetic models defined at localized deposit scales on already discovered known deposits.
- (iii) A personal perception that most of the targeting and resource development strategies currently being employed in gold exploration in Zimbabwe have not fully embraced the mineral systems approach. Consequently, they may not be sufficient to overcome current and future exploration challenges, as they remain focused on developing localized models that are only applicable to already found deposits. Very often they have limited capabilities to predict where to find the next new unknowns, characterised by progressively smaller and less familiar footprints compared to the larger and common deposits already found. Such models remain limited in directing the collection of new data and information as well as the integration of existing datasets, critical for robust conceptual multi-scale targeting to generate high profile targets that could yield brand new deposits to replenish diminishing gold reserves.
- (iv) It is hoped that this contribution will serve some useful function – to motivate more informed discussions to further the understanding of felsite hosted deposits, the use of the mineral systems approach for holistic

multi-scale conceptual approaches for orogenic gold targeting, and efficient exploration for gold deposits in both existing and new search spaces.

1.4. PROBLEM STATEMENT

Unlike the original Blue Rock gold mine which exploited two high grade (10.3 g/t Au), north-south striking, quartz reefs that dip at about 64° towards the east, together with associated low-grade mineralised sulphidic BIFs (Bartholomew, 1990), which characterise most economic deposits within the GGB, the recently discovered gold mineralization at Blue Rock is not spatially related to BIFs or mafic schists. Instead, the gold is largely hosted within sheared and faulted felsite and quartz-porphyry rocks that dip steeply towards the east.

Despite the common association of similar mineralized felsic intrusive rocks with gold reefs in numerous mines throughout the MGB (Macgregor, 1951; Emmons, 1937), these rocks have until recently, been considered too small, of low grade, and uneconomic to be considered significant prospective gold exploration targets. As a result, no extensive prospecting or research efforts were directed towards their understanding. More focus was instead given to the traditional higher-grade BIF and quartz vein hosted gold targets.

The initial discovery of the gold deposit at Blue Rock might have been made with no sound geological understanding critical to its discovery, but an improved understanding of the same would be critical for exploration, to uncover the next generation of hidden targets – look-alikes along strike extensions as well unknowns in completely new search spaces, in similar geodynamic settings.

The main purpose of this study is to characterise the gold deposit at Blue Rock using results from ongoing exploration, and then use the outcome in the context of an updated understanding of orogenic gold mineral systems, to formulate a robust, integrated process-based predictive model that could be used to find more similar deposits.

1.5. RESEARCH OBJECTIVES

This study aims to characterise the gold deposit at Blue Rock using the mineral systems approach, to present the geodynamic setting, endowment, architecture and preservation factors, key to the localisation of this deposit.

Specific objectives of this study are to; (a) characterize the newly discovered gold deposit through a synthesis of relevant published literature, analysis of available data collected during the discovery and resource development of the deposit, and thereafter, use the resultant understanding to; (b) devise an occurrence model for the genesis of the mineral system and the deposit, which would then be used to; (c) develop an exploration strategy or model that could be used for multi-scale conceptual targeting, in a predictive capacity, to lower geological risk, by defining high priority domains or high interest exploration targets for the successful search for similar deposits.

1.6. METHODOLOGY

Unlike previous studies done by others (e.g. Mutambara, 1991; Fisher, 1992; Chisi, 1994), which were focused only on localized deposit-scale studies of the Elvington mine deposit, this study is not limited to a local study of the gold deposit at Blue Rock. Although gold deposits in Zimbabwe are known to be fractal, i.e. scale invariant (Blenkinsop, 1995), studies based on localized small deposits are arguably heavily weighted towards the application of analytical techniques, the majority of which produce complex genetic models at a micro scale, that are often inappropriately applied to the deposit or district scale, with very little relevance and application to global mineral exploration, (Groves et al., 2022).

In this study, therefore I refer to available geological information that describe all the critical geological parameters which together variably controlled the genesis, localisation and preservation of gold mineralization at the gold deposit at Blue Rock, at all relevant scales from geodynamic through regional to deposit scales.

According to Wyborn et al. (1994), this is what constitutes a mineral system concept (**CHAPTER 3**). It is my hope that using such an approach for this research, would allow for a more holistic context, - one that recognizes the felsite-hosted gold deposit at Blue Rock, as just but a smaller part of a much larger gold mineral system, whose genesis and development was no doubt, a product of critical processes that operated at different scales and times.

The mineral systems approach calls for a multi-scale exploration concept, which allows for changes in significance of targeting elements and their mappable proxies for key mineralizing processes as a function of the scale at which they operate. It also allows for consideration to be taken on the availability of relevant geological data (McCuaig et al., 2010), to develop a more robust multi-scale targeting concept.

In this study, a general global model for orogenic gold deposits is used as the basis to discuss and synthesize all the available relevant data and information published by others as well as exploration data generated from ongoing exploration work at the gold deposit, most of which was conducted by the author while consulting for ACR (**CHAPTER 2**).

At geodynamic scale, the study looks at processes which influenced the genesis of host greenstone belt rocks (**CHAPTER 4**) together with inherent fertility parameters responsible for the generation of auriferous fluids within the mantle, together with their movement through architectural transcrustal faults which acted as conduits for auriferous fluids from the mantle to upper crustal levels, where they were localised and preserved.

After that, regional (GGB) and deposit (Blue Rock) scale factors which influenced local architecture that was key to the localisation of the gold within lower order structures within upper crustal levels are dealt with in **CHAPTER 5**. This is done through a rigorous analysis of available data using geostatistical techniques as well as 3D modelling using both numerical and resource modelling algorithms to reveal the possible controls on the localisation and preservation of gold mineralization (**CHAPTER 6**).

Results from this study are then synthesized (**CHAPTER 7**) and consolidated into an occurrence model (**CHAPTER 8**) by identifying possible key processes that led to ore formation. These can be represented as mappable critical geological proxies, which could be useful vectors for locating similar undiscovered deposits elsewhere, for which an exploration model is proposed.

CHAPTER 2. HISTORICAL WORK

2.1. INTRODUCTION

This chapter deals with the exploration and mining history of the gold deposit at Blue Rock, which covers the Blue Rock, Berks, Red Hat and Orange Farm prospects (Fig. 2), and discusses more recent exploration work conducted by ACR.

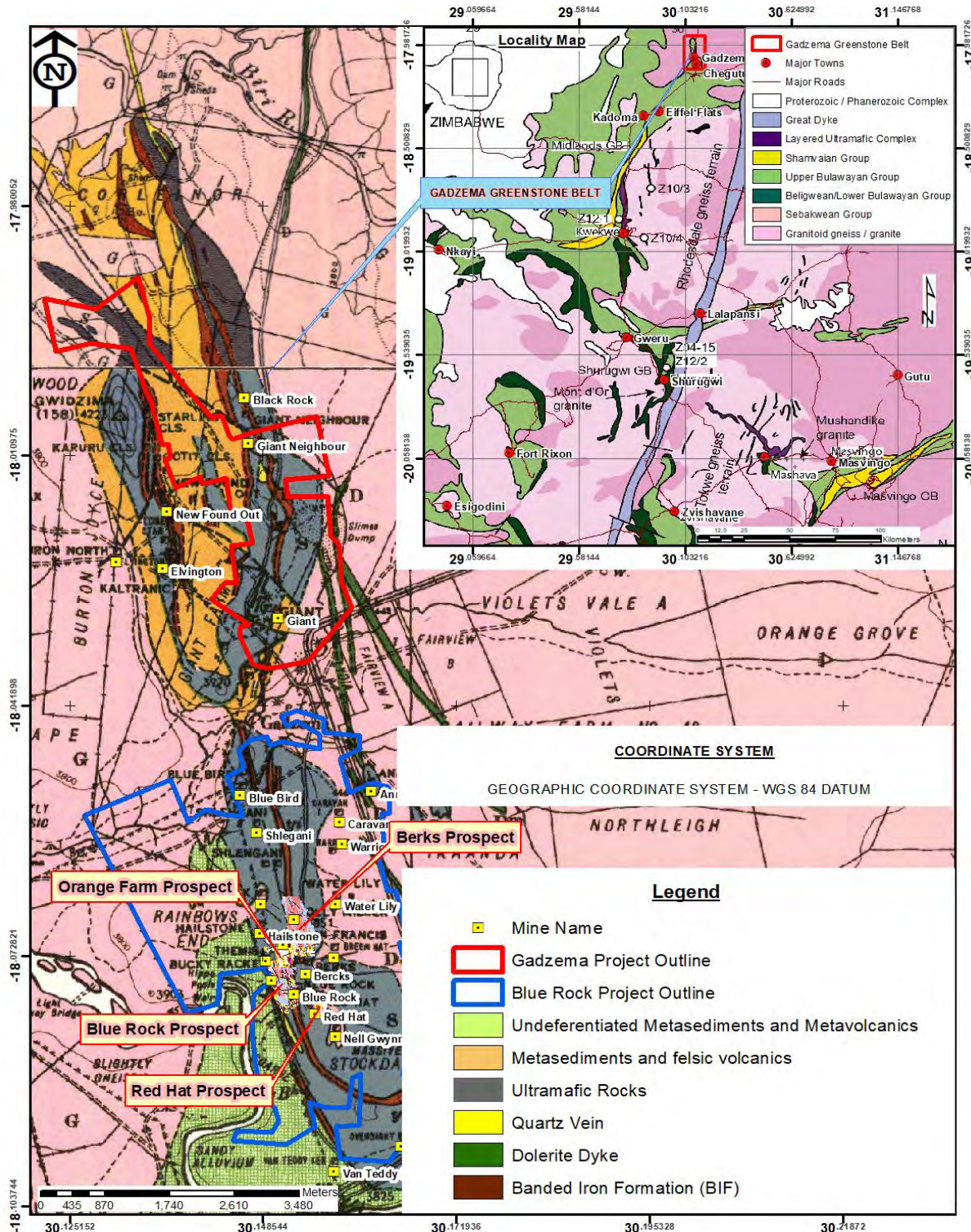


Figure 2: Blue Rock Project locality, showing the relative location of the Orange Farm, Blue Rock, RedHat and Berks Prospects on Regional Geology Map

The discovery of the gold deposit at Blue Rock was made over the now defunct historical Blue Rock gold mine, but subsequent exploration through resource drilling was later expanded to cover vendor JV ground, on which the Orange Farm to the north, the Berks mine in the east and the RedHat mine to the south, are located.

Historical mining over the original Blue Rock, Red Hat and Berks mines was covered by Wiles (1957), whilst production data were compiled by Bartholomew (1990).

Prior to the work done by ACR, there is scant published literature on modern exploration and mining, except for just six (6) Reverse Circulation (RC) holes drilled around old workings at the original Blue Rock gold mine tenements, as reported by Cambrian Resources in unpublished internal company reports and memorandums.

2.2. EXPLORATION AND MINING HISTORY

Ancient exploration and mining at the Blue Rock gold tenements, dates to 1892, when the ground was originally pegged as Claim No. 629 by T.J. Byne, who later ceded it to the Zambezia Exploring Company Ltd. The mine is reported to have produced 237kg of gold at 10.3 g/t Au, up to 1990 from two (2) small, fractured blue and white, glassy quartz reefs, which dip steeply at about 64 degrees towards the east (Bartholomew, 1990). The quartz reefs are hosted in hornblende-biotite schists, adjacent to a N-S striking BIF, that contains a low-grade gold-bearing jaspillite, which was also mined during the time the old Blue Rock mine was still operational. Gold mineralization is mainly associated with pyrite, which occurs with subordinate chalcopyrite and galena.

The Berks claims were originally pegged much earlier in 1890, on an existing extensive line of ancient workings (Wiles, 1957). The claims are reported to have been worked by several companies including the Dwarf Gold Mining Company (1909 – 1912), the G.P. Syndicate (1913), the New-Dwarf Gold Limited (from 1913), and the Parthenon Syndicate (1926 – 1930). The orebodies consist of a mineralized quartz reef running next to a BIF unit, both of which were mined simultaneously.

The Red Hat mine located south of the old Blue Rock mine, was initially operated as an open cast operation (Wiles, 1957). The mine is reported to have exploited a strongly deformed fault-bound BIF orebody which produced 500.50kg at 12 g/t Au up to 1990 (Bartholomew, 1990). The deformed BIF orebody strikes roughly NS and is dominated by pyrite as the major sulphide mineralization associated phase.

From the years that followed historical mining, until Cambrian Resources took over Giant mine to the north, there is no record of any significant mining or exploration known to have occurred over the Blue Rock, Berks and RedHat claims, other than very small-scale operations, through un-mechanized shallow mining and reprocessing of tailings from previous mining.

When Cambrian Resources took over the Giant mine, it commissioned a regional geophysical survey in 1996, which was conducted by High-Sense Geophysics Ltd, covering the whole GGB. The objective of the survey was to provide high resolution magnetic mapping suited for anomaly definition, detailed structural evaluation and lithological mapping. An internal company report for the Gadzema JV between Cambrian Resources and Prospecting Ventures, dated 1998, reports on several highly prospective geophysical/geological targets to have been generated from this survey, although no prospective targets are reported to have been followed up over any of the areas covered by the Blue Rock prospect. Most of the work done by Cambrian Resources was in the form of brownfields exploration conducted between June 1996 and June 1999. The work was mostly limited to RC drilling around the Giant mine to the north, although the company also drilled 6 RC holes (308m) over the Blue Rock project to test the mineralized haloes around old workings from historical mining. Drilling over Blue Rock gave a best result of only 1.3 g/t over 7m beneath the old Blue Rock mine workings, but no follow-up work was ever conducted by Cambrian Resources.

The last effort covering the Blue Rock area before the ground was taken over by ACR, was a belt-wide mapping and structural interpretation effort by Dirks and Mikhailov (1998). Dirks and Mikhailov (1998) produced an exploration model

which prioritized targets interpreted to have a structural-lithological association signature like known existing major deposits. The study targeted mainly the deformed BIFs similar to those that host major gold deposits within the belt (e.g. Elvington, Giant and New-Found-Out deposits) as well as, Quartz vein hosted gold mineralization associated with shears and faults of regional significance (e.g. Blue Rock and Water Lily), but no new discovery was made from the follow-up work that ensued, until the discovery of a “new” different type of mineralization hosted within felsite and quartz porphyry rocks, by ACR around the old Blue Rock mine.

The new gold deposit was discovered in 2007 by ACR during a regional geochemical soil sampling survey. All the work that led to the discovery and subsequent development of this deposit is presented and discussed below.

2.3. RECENT EXPLORATION

The most recent exploration work over Blue Rock was conducted by ACR - a project, I was fortunate to lead from initial gold deposit discovery to subsequent resource development. Work conducted over this project included, a regional airborne geophysical survey, detailed surface geological mapping, regional soil geochemistry, percussion drilling, reverse circulation and diamond core drilling. A summary of the work done over this deposit is presented below, to shed light on the different mineralization proxies and exploration strategies that were useful not only for discovering the deposit, but for the subsequent resource development phase as well.

2.3.1. Geochemical Sampling

Exploration over the GGB by ACR, took the form of a brownfields program centred over two major historical mines, the Giant mine in the north and the Blue Rock mine to the south, after which the two respective projects, Giant and Blue Rock explored by ACR, were conveniently named. This report covers the Blue Rock project which hosts the new gold discovery at Blue Rock. Exploration work by ACR started off with a regional geochemical soil sampling program, which covered the entire ground over the GGB held by ACR at the time. Soil sampling was conducted along E-W lines normal to the general N-S trending regional geological fabric and known mineralized lithological-structural domain trends. Sampling was conducted from the B-horizon, on a 100m line x 20m sample spacing grid and yielded a total of 6,074 soil samples. All the samples were screened and homogenized at a field camp in the town of Chegutu, before they were shipped to a SANAS- accredited laboratory named Antec located in the town of Kwekwe, Zimbabwe, for processing using aqua-regia digest with Atomic Absorption Spectrum (AAS) finish analytical methods. Results from the sampling defined two major anomalies, one around the Giant mine and the second one in the south, centred around the historical Blue Rock gold mine, from which the new gold deposit was later discovered (Fig. 3).

The gold deposit at Blue Rock was discovered after follow-up excavations and drilling to resolve the regional soil geochemical anomaly. Both the excavation and drilling revealed that gold mineralization was not hosted within traditional BIFs or quartz vein gold hosts. Instead, the new gold mineralization was associated with sheared felsite intrusive rocks. This early discovery led to subsequent work to probe the strike and down-dip extensions through regional geophysics, surface mapping and resource drilling, in what would define the new gold deposit to its current form, as presented below.

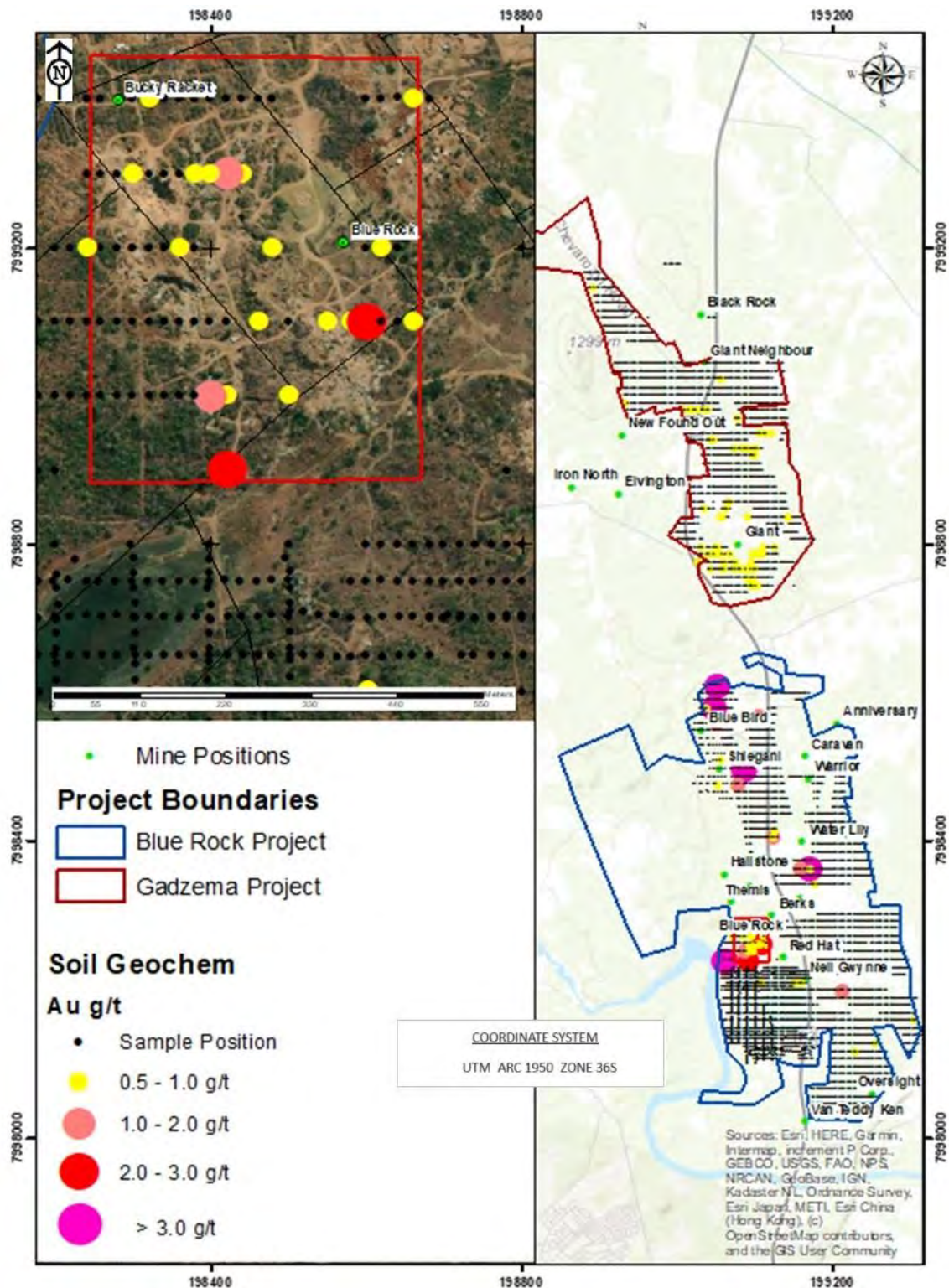


Figure 3: Geochemical Soil Sampling map showing location of the geochemical anomaly that was followed up by excavation work which led to the initial re-discovery of the gold deposit at Blue Rock.

2.3.2. Airborne Geophysics

An airborne geophysical survey was flown covering the whole GGB, including the Blue Rock prospect, to optimise geological and structural mapping of felsite rocks and associated structural sites capable of hosting Blue Rock-type felsite-hosted gold mineralization beyond the initial discovery site.

The airborne survey was designed to simultaneously collect both magnetic and radiometric data. This combination of survey techniques is optimum for the rapid discrimination and mapping of major lithological and structural associations that host all known gold mineralization types within the GGB.

The survey was conducted during November 2008 by ACR, using a Jabiru aircraft, whilst data processing was done soon after completion of the survey by Baigent Geosciences Pty Ltd. Surveying was conducted at a flight line separation of 50 meters and a tie-line separation of 500 meters.

2.3.2.1. Magnetic Survey

During the airborne survey, magnetic data were acquired using a Geometrics G822 Caesium Vapour instrument, at a 10 Hz, (Approx. 5.5 metres) sampling interval, and a resolution of 0.01 nT.

The survey helped to; (a) map out magnetic lithologies (serpentinites and BIF) against the less magnetic lithologies of the greenstone belt and to (b) delineate the relatively less magnetic greenstone belt lithologies from the surrounding non-magnetic younger Biri granite rocks. Interpretations from the magnetic survey (Fig. 4) were also used during regional surface geological mapping.

2.3.2.2. Radiometric Survey

Radiometric data were acquired using a Radiation Solutions RS 500 spectrometer at 1.0 Seconds (approx. 35 metres) sampling interval.

Interpretation of the radiometric survey data was done to enable a better understanding of the possible geometry and extent of the felsic intrusive rocks, as well as to assist in identifying broad target areas of interest for follow-up with direct detection exploration methods.

Results from primarily geological interpretation of radiometric data (Fig. 5), confirmed the potential for Blue Rock gold mineralization-type extensions along deposit strike. And these results were then integrated with new surface geological mapping conducted over the whole GGB.

The radiometric survey was useful in mapping out areas with felsite and quartz-porphyrries, previously not mapped in any detail from all known historical mapping efforts by Phaup and Dobell (1938), Wiles (1957), Mutambara (1991) and Dirks and Mikhailov (1998).

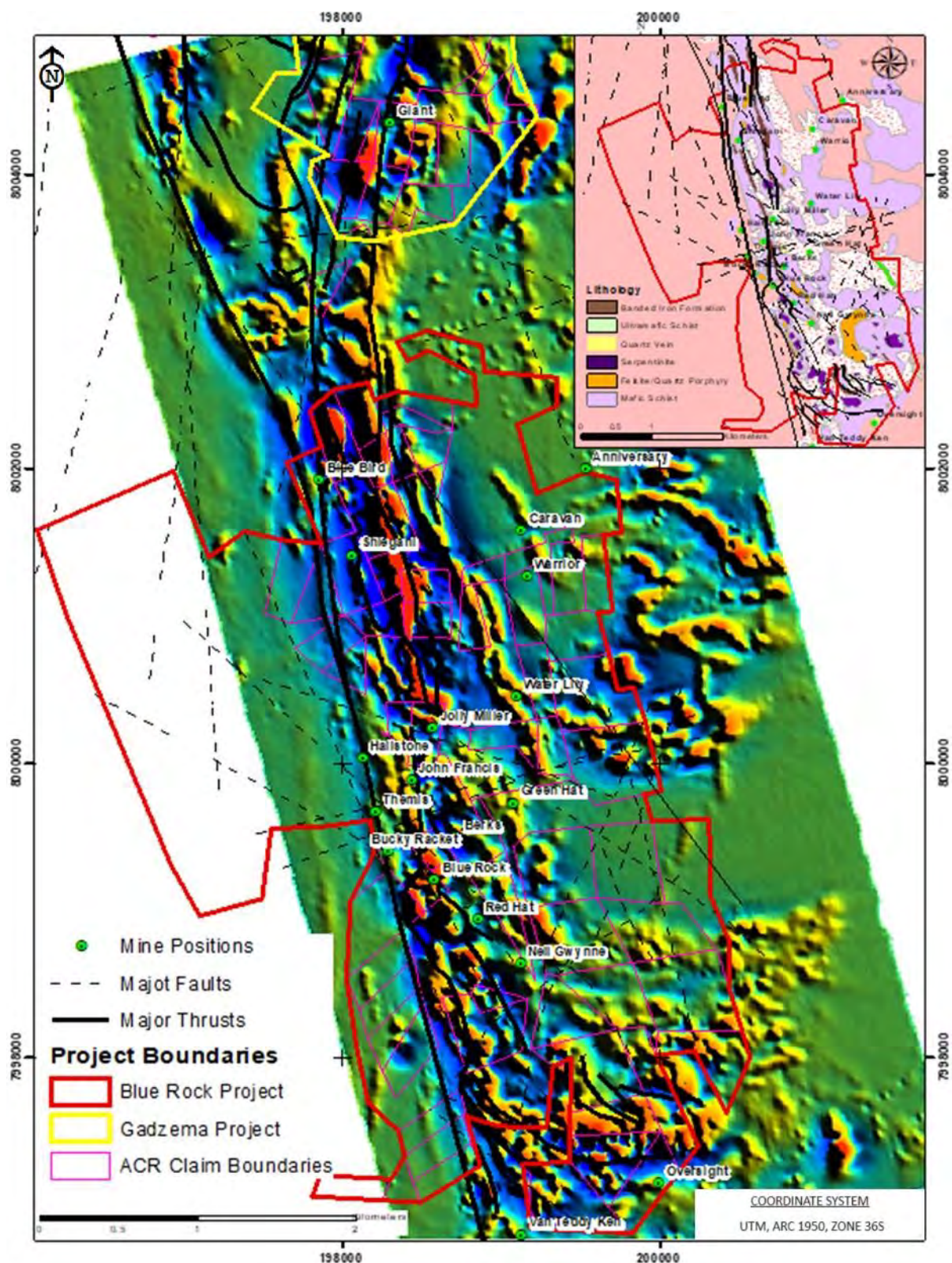


Figure 4: Airborne Magnetic Survey covering the GGB, showing highly magnetic lithologies (Red - e.g. BIF), other moderately conductive greenstone lithologies (Yellow - Orange) and Mafic Schist (Blue) in a background of largely non-conductive granitic (Green) Biri Granite rocks, on a Sun shaded, Reduced to Pole, First Vertical Derivative (RTP_1VD_SUN) image.

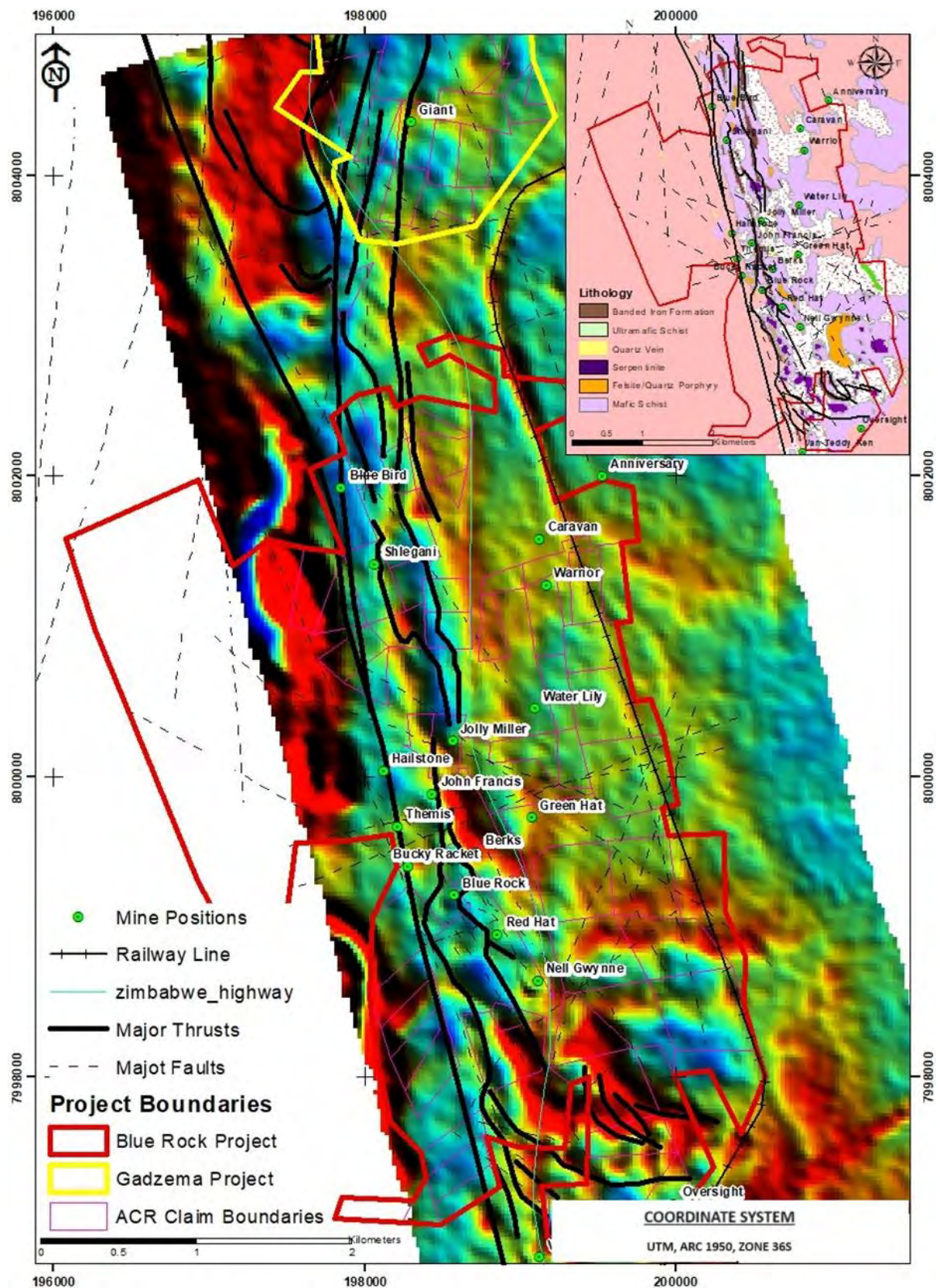


Figure 5: Airborne Radiometric Survey conducted over the GGB, showing high total radiometric count (TOT) (Red – Orange – Yellow) consistent with Felsic lithologies like felsite and granite, against other low total radiometric count (Blue – Green) non-felsic lithologies - mainly greenstone lithologies and cover.

The radiometric survey defined two main linear narrow zones of high total radiometric count interpreted as felsite zones trending NNW. This is consistent with regional surface geological mapping, and the anomalous zones were targeted for further work. One of the zones starts off at the old Blue Rock mine and stretches northwards, whilst the second one with an even stronger signature, located to the east and running subparallel to the first one, starts off at the RedHat prospect in the south and passes through Berks, extending northwards towards Shlegani. The survey also showed up smaller other poorly defined areas of potential, as well as mapped the Biri granite, which flanks the GGB on its western margin.

2.3.3. Geological Mapping

Field mapping of the Blue Rock mining claims commenced after the initial discovery of the new gold deposit at Blue Rock. The mapping was an effort to complement previous work by others, with a detailed exploration-focused one, which recognized the presence of mineralised felsites and quartz porphyry rocks, previously not mapped by others. During this phase the felsite hosted gold mineralization was being prioritised and considered an important target with potential to host a substantial gold deposit.

The mapping was a belt-wide effort, conducted by the author at a scale of 1: 25,000, covering the whole GGB from Mupfure River in the south, up to the Musengezi River in the north.

Surface mapping was conducted after the generation of geochemical sampling anomalies and the acquisition of new higher resolution airborne geophysical data. The new geophysical data enabled better interpretation of the geology and structure of the ground covered by the licence areas and would assist exploration through deposit scale targeting.

The mapping entailed the ground-proofing and mapping of small scale mine-workings as well as outcrops (mainly BIF and quartz vein ridges, serpentinite hills and granite kopjes). The poorly exposed mafic schists and felsites which form low lying areas, were mapped through the interpretation of airborne geophysical survey data. Magnetic data were most useful in the mapping and discrimination of BIFs and greenstone belt lithologies against a less magnetic granitic background, whilst radiometric data were more useful for mapping out felsites, quartz porphyries and granites.

Unlike the mapping done by others, the author mapped out the distribution of felsite and quartz porphyry intrusives for the first time. Within the GGB, most of the felsites appear to have previously been mapped as either mafic schist or as metasediments, although they are common throughout the larger MGB (Phaup and Dobell, 1938; Wiles, 1957).

2.3.4. Resource Drilling

A resource drilling campaign was conducted at the Blue Rock prospect by ACR between 2007 and 2014. The drilling was initially focused over the original gold discovery site near the old Blue Rock mine shaft, where prospects for depth continuity of soil geochemical anomalies had been indicated by trenching and shallow Rotary Air Blast (RAB) drilling results. The programme was then extended to deeper drilling with Diamond (DD) and Reverse Circulation (RC) drilling techniques, covering the Berks, Red Hat and the Orange Farm prospects, under option-to-purchase JV agreements. The drilling achieved a total of 230 individual RC, 29 DD and RC pre-collared diamond (RD) drill-holes, adding up to a combined total of 35,508 meters.

All the holes were inclined at ~ 60 degrees towards the west, normal to the general strike of mapped felsite targets, known mineralization and regional geological fabric. Drilling targeted the NNW trending felsite bodies defined from both surface mapping and radiometric surveying. These were initially tested using shallow (up to 20m) RAB drilling, and then followed up with widely spaced (120m apart) E-W, RC drill lines with a 40m borehole spacing. The grid was later tightened with infill drilling to 40m line spacing, as guided by results from the initial wide-spaced drilling. Sampling was conducted every meter and assayed at a SANAS accredited laboratory called Antec Laboratories based in the town of Kwekwe, Central Zimbabwe. Geological logging was done in the field by the author with a support team of geologists, to allow for robust decision-making during drilling, to either terminate holes or plan stepped-back drilling of

deeper boreholes to intersect mineralization down dip. Most of the holes variously intersected gold mineralization of different widths and depths and were used for resource modelling.

2.3.5. Gold Mineralization

In order to develop a good understanding of the mineralization extent and grade continuity at Blue Rock, all the data available within the whole Blue Rock project (Blue Rock Main, Berks, RedHat and Orange Farm prospects) were reviewed by a consulting resource geologist, Johnson (2010; 2012), initially under Hellman & Schofield Pty Ltd (H & S) in 2010, and then under MPR Geological Consultants Pty Ltd (MPR) in 2012. The data included collar, survey, gold assays, geological logging and QAQC data. The database contained 230 individual reverse circulation (RC) and 29 diamond (DD) plus RC pre-collared diamond (RD) drill-holes, for a combined length of 35,508 meters. All the sampling was collapsed to 2m downhole composites, and the data were imported into Micromine to allow for 3D visualization and statistical analysis to be performed (Johnson, 2012).

According to Johnson (2012), assessment and definition of recoverable resources was estimated using the method of Multiple Indicator Kriging (MIK) with block support adjustment. MIK is a method developed during the early 1980's with a view to address some of the problems associated with estimation of resources in mineral deposits, and to provide better resource estimates compared to more traditional methods such as, ordinary kriging and inverse distance weighting.

During data analysis and resource estimation, gold mineralization and associated host felsite rocks were interpreted from geological logging data to be structurally controlled, with widespread quartz veins following the same trend. Their genesis was interpreted as representing later "liquid escapes" from the main felsic bodies or Biri granite rocks.

Resource drilling by ACR defined a resource of close to a million ounces at an average grade of 1 g/t and a cut-off grade of 0.5 g/t Au. Resource statistics for the different sub-projects for the whole gold deposit at Blue Rock are summarized in Table 1, below.

Table 1: Blue Rock Deposit Mineral Resources by Project. Summarised from Johnson (2012).

Blue Rock Mineral Resource

Cut-Off	Indicated			Inferred			Total		
	Tonnes	Grade	Ounces	Tonnes	Grade	Ounces	Tonnes	Grade	Ounces
0.5	11,753,659	0.89	335,485	13,250,285	0.87	372,698	25,003,944	0.88	708,182
1.0	3,052,712	1.43	140,097	3,104,504	1.49	149,026	6,157,216	1.46	289,122
1.5	789,624	2.10	53,293	990,263	2.13	67,763	1,779,888	2.12	121,056

Berks Mineral Resource

Cut-Off	Indicated			Inferred			Total		
	Tonnes	Grade	Ounces	Tonnes	Grade	Ounces	Tonnes	Grade	Ounces
0.5	2,750,986	0.97	85,359	985,804	1.02	32,435	3,736,789	0.98	117,794
1.0	761,803	1.68	41,257	286,412	1.85	17,067	1,048,215	1.73	58,324
1.5	286,280	2.48	22,861	126,809	2.67	10,880	413,089	2.54	33,741

Orchard Mineral Resource

Cut-Off	Indicated			Inferred			Total		
	Tonnes	Grade	Ounces	Tonnes	Grade	Ounces	Tonnes	Grade	Ounces
0.5	37,487	0.77	926	3,143,459	0.91	91,567	3,180,946	0.90	92,494
1.0	5,194	1.21	202	806,029	1.51	39,236	811,223	1.51	39,439
1.5	405	1.76	23	266,584	2.16	18,545	266,989	2.16	18,567

RedHat Mineral Resource

Cut-Off	Indicated			Inferred			Total		
	Tonnes	Grade	Ounces	Tonnes	Grade	Ounces	Tonnes	Grade	Ounces
0.5	10	0.64	0	1,310,890	0.73	30,599	1,310,899	0.73	30,600
1.0	-	-	-	139,558	1.23	5,535	139,558	1.23	5,535
1.5	-	-	-	14,368	1.78	821	14,368	1.78	821

TOTAL OUNCES @ 0.5 g/t Au Cut-Off Grade

949,070

CHAPTER 3. THE ARCHAEOAN OROGENIC GOLD MINERAL SYSTEM MODEL

3.1. INTRODUCTION

At the present stage of this study, the definitive character of the new gold deposit at Blue Rock is not fully understood and is the subject of this investigation. The deposit occurs within the Archaean GGB – an important geodynamic setting for orogenic gold mineralization. The deposit occurs within an orogenic setting, and shares important characteristics with well known, already studied BIF and quartz vein hosted orogenic gold deposits, common within the same gold belt. So, any meaningful attempts to characterize this deposit, therefore, should first invoke the orogenic gold mineral system, as the natural logical model of choice.

But how do orogenic deposits form? At present there is no single universally accepted model to explain their genesis. For this reason, any attempt to understand the possible evolution of the gold deposit at Blue Rock, should start with a discussion to unravel a universally accepted model for orogenic gold deposits. This chapter provides an up-to-date understanding on Archaean Orogenic gold mineral systems with a view to shed light on their possible evolution.

3.2. OROGENIC GOLD DEPOSIT MODELS

Orogenic deposits, also previously known by different names including, mesothermal gold deposits (Lindgren, 1933), were defined by Groves et al. (1998), as a coherent group of structurally controlled, vertically extensive, gold-only lode-gold deposits, which formed in convergent margin settings, in broad thermal equilibrium with their wall-rocks, from low salinity H₂O-CO₂ ore fluids, at crustal depths that range from 2 to 15, and arguably up to 20 km (Fig. 6).

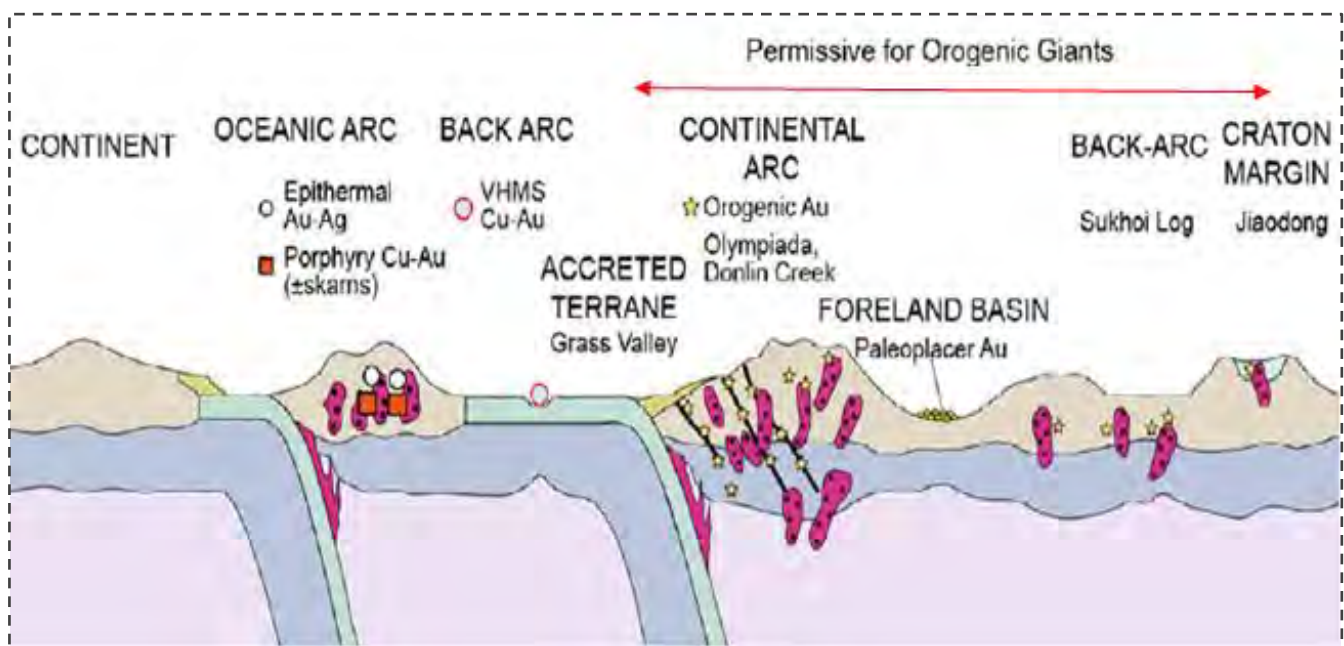


Figure 6: Convergent margin-orogenic gold model showing the range of tectonic settings permissible for orogenic gold systems with a consistent Geodynamic environment. From Groves et al. (2022).

As discussed earlier, the genesis of orogenic gold deposits is not uniformly understood. Numerous models have been put forward to explain their formation, as presented in many reviews including Kerrich (1993), Goldfarb and Groves (2015); and a heated debate about their genesis is still ongoing (Groves et al., 2020a & 2020b).

3.3. DISCREDITED HISTORICAL MODELS

Although numerous models have been put forwards to explain the genesis of orogenic gold deposits, most shallow crustal models [Fig. 7(i)], have so far proved to be less viable (Goldfarb and Groves, 2015). In a review of many such models, Goldfarb and Groves (2015), have shown that syngenetic-exhalative models can be discredited based on inconsistent field evidence, which show that orogenic deposits are structurally controlled (Colvine et. al., 1984 & 1989; Groves, 1982; Groves et al., 1984 & 1985), syn- to late-metamorphic deposits, with stratiform to strata bound BIF-hosted deposits having formed through the sulphidation of magnetite (Phillips et al., 1984). Meteoric fluid models have also been shown to be inadequate, as they are based on H and O isotope data, most of which come from the measured components of mixed primary and secondary fluid inclusions.

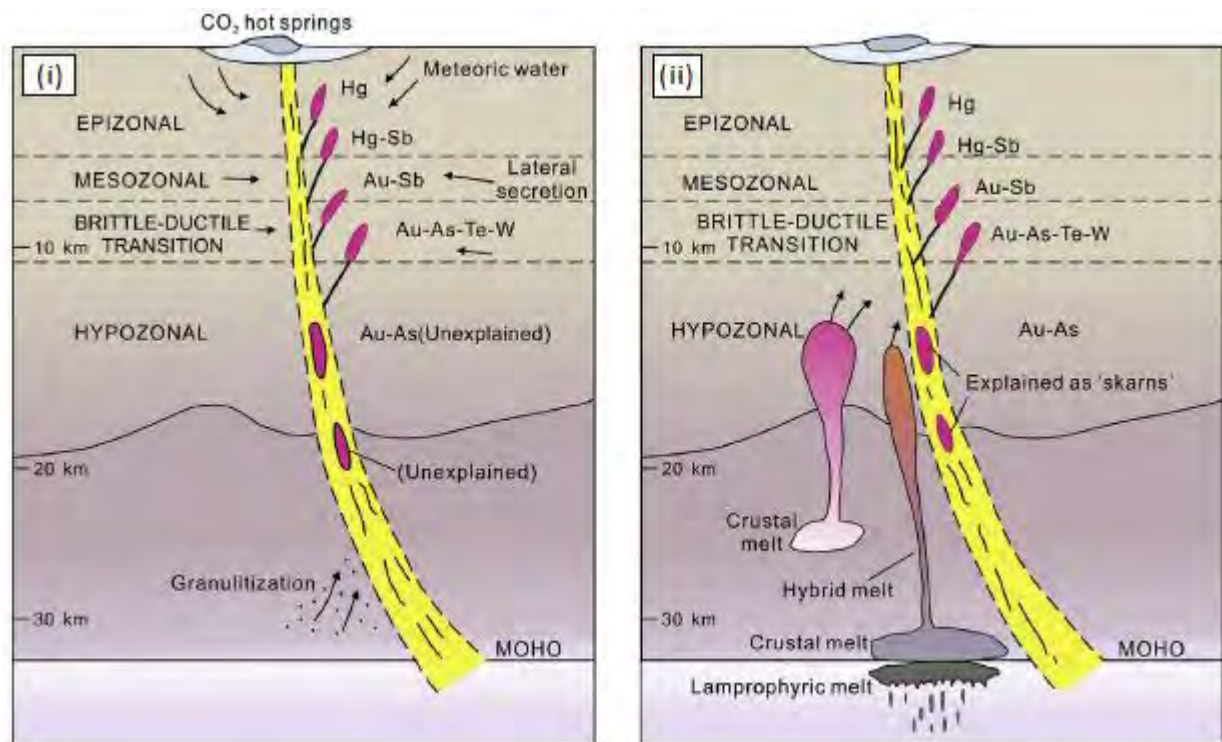


Figure 7: Schematic representation of (i) Invalid shallow crustal meteoric or metamorphic models and granulitization - and (ii) non-unifying magmatic-hydrothermal, ore- fluid source models for orogenic gold deposits. From Groves and Santosh (2016).

Early 20th century magmatic hydrothermal models [Fig. 7(ii)], historically used by many workers to explain the genesis of orogenic gold deposits in Zimbabwe, are also not viable. This is because; (a) gold deposits and the proposed fertile granites thought to have brought about the mineralization are not always of the same age (e.g. arguments by Goldfarb and Groves, 2015 – for other gold belts). Granite intrusions have been shown to be pre-syn- or post mineralization in the same terrain or (b) even absent altogether in other well-endowed gold belts, or (b) In other cases where lamprophyre and mafic intrusions are present, they are often too small to have produced the large volumes of fluids required to form economic gold deposits.

3.4. SUITABILITY OF CRUSTAL METAMORPHIC MODELS

As discussed above, magmatic-hydrothermal models cannot adequately account for the formation of individual orogenic gold deposits such as those found within the GGB, including this new gold deposit, or let alone, provide a universal global model for orogenic gold deposits (Wyman et al., 2016). This then only leaves metamorphic models (Fig. 8), as the most viable possibilities for a universal model for orogenic gold genesis (Groves et al., 2020a, Groves et al., 2022; Groves & Santosh, 2023).

Some of the versions for crustal metamorphic models, however, have been shown to be less viable. As argued by Goldfarb and Groves (2015), the lateral secretion model by Boyle (1979), for example, cannot be valid because of the limited volumes of metamorphic fluids and metals together with the unlikely dominance of lateral fluid migration. Models that also involve advection of mantle CO₂ through the lower crust to produce granulite are also invalidated by the lack of a universal association between gold and granulite.

A more plausible metamorphic model that promotes metamorphic devolatilization of largely supracrustal rocks within continental mid-crust under greenschist facies to amphibolite facies conditions, proposed by Phillips and Powell (2010) and supported by e.g. Goldfarb and Groves (2015), Groves and Santosh (2016) and many others referenced herein, is so far the most plausible model, for reasons which include:

- (i) The fact that it emphasizes on upward advection of the resultant metamorphic fluid and metals to deposit gold at higher crustal levels (Goldfarb et al., 2005).
- (ii) According to this model, the resultant mineralization would be epigenetic and therefore requires no special association with host rock units.
- (iii) The model allows for broadly late metamorphism and deformational timing of gold deposition, with studies by Ridley and Diamond (2000), supporting long and complex continental fluid pathways.
- (iv) The model calls for typical low salinity fluids which are consistent with metamorphic devolatilization of supracrustal rocks (Fyfe et al., 1978).

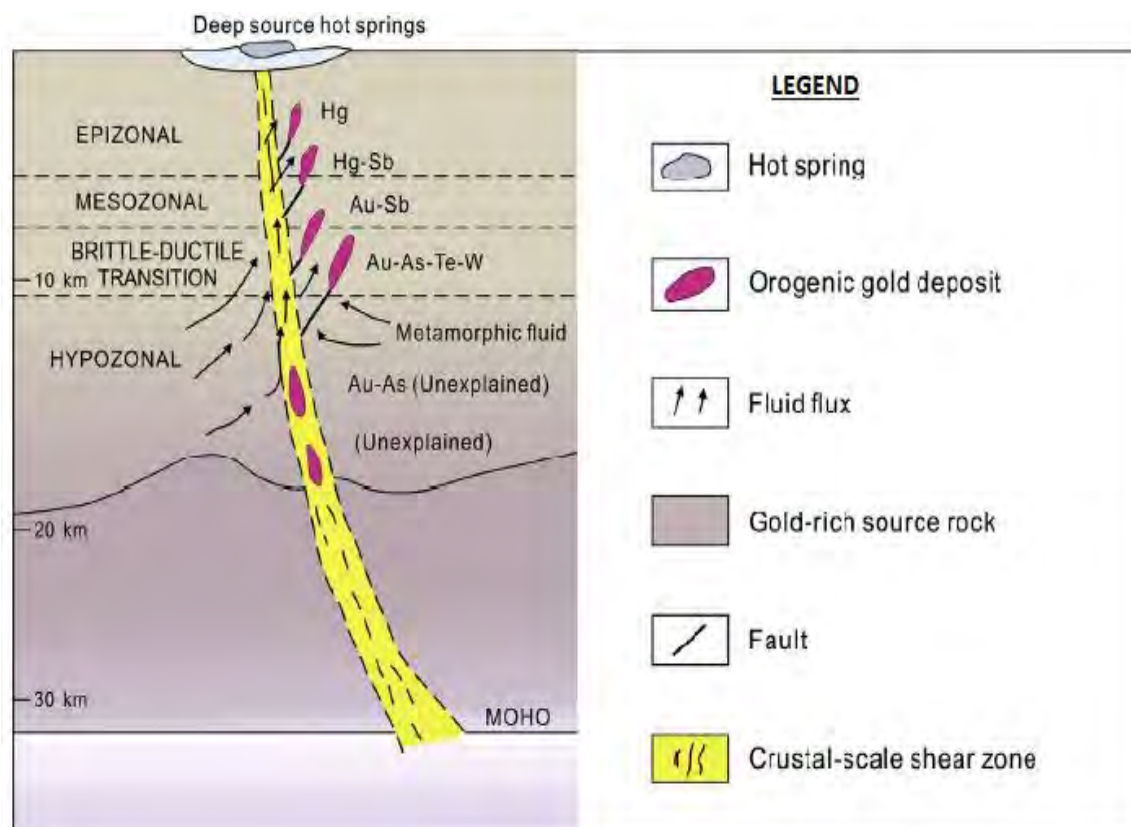


Figure 8: Schematic representation of generally accepted supracrustal metamorphic ore- fluid source models for orogenic gold deposits. From Groves and Santosh (2016).

But, despite these strengths however, the crustal metamorphic model has its own weaknesses including those which point to a fluid source much deeper than the depth of the deepest orogenic gold deposits, as pointed out by Groves et al. (2020a), which include:

- (i) The occurrence of a significant number of gold deposits known to be hosted by upper amphibolite facies domains. This suggests that they formed from a fluid source deeper than the depth of the deepest

orogenic gold deposits (15km, or possibly up to 20km), and therefore not a result of devolatilization during amphibolite facies metamorphism as per the crustal metamorphic model.

- (ii) Evidence of sulphur in auriferous fluids suggesting an origin from a deeper homogenised subcrustal source (La Flamme et al., 2018).

3.5. TOWARDS A UNIVERSAL OROGENIC GOLD MODEL

If orogenic gold deposits are indeed a single coherent group of deposits, there is therefore clearly a need to resolve the numerous different and divergent individual models, into a single integrated universal model. As argued by Wyborn et al. (1994), the mineral systems model for orogenic gold deposits should be able to represent a single coherent model that can explain the genesis of all the deposits within that group. Groves et al. (2020b; 2022) and many others, who have variously contributed towards the subject, are convinced that the key to achieving a unified model for orogenic gold deposits is by using the “mineral systems approach”.

In this study, the story about the Blue Rock gold deposit therefore, is better told through the mineral systems approach - But what is a Mineral Systems Concept?

3.6. A COHERENT MINERAL SYSTEMS APPROACH FOR OROGENIC GOLD

The mineral systems approach is the product of research into genetic models for mineral systems, which have now gradually evolved towards holistic mineral system models. The system views the mineralization process in a hierarchical manner using a multiple-scale approach from geodynamic setting through province- and district- to deposit-scale.

Although various workers have contributed towards the subject, the mineral systems concept is thought to have originally been initiated by Wyborn et al. (1994) and championed by Knox-Robinson and Wyborn (1997) as well as Hronsky & Groves (2008). However, the concept has not yet been fully embraced, although it seems to be gaining popularity as a critical tool of choice for the development of genetic models and for conceptual targeting for a variety of mineral commodities, in place of small-scale studies based on localized individual deposits. As argued by Groves et al. (2022), the downside of using traditional isolated small-scale studies, is that such studies are heavily weighted towards the application of analytical techniques, which often produce complex genetic models at a micro-scale, that are inappropriately applied to the deposit or district scale, but with very little relevance to global exploration. Such models are also known to be explanatory rather than predictive and therefore not particularly useful for targeting undiscovered deposits (Wyman et al., 2016).

Wyborn et al. (1994), described the mineral system as “all the geological factors that control the generation and preservation of mineral deposits”. In other words, all the processes involved in mobilizing ore components from their source, accumulating them in a more concentrated form, and then preserving them throughout geological history. When applied to orogenic gold, the aim of the mineral systems approach is quite simply, to provide a holistic, coherent and unified model for orogenic gold deposits of all ages. Groves et al. (2022) and others believe that the mineral systems could be used to derive holistic genetic models. In a world of diminishing mineral discoveries particularly for gold, which have significantly slowed down within the 21st century (Schodde, 2017), such models would be handy in improving exploration targeting, including for orogenic gold exploration in Zimbabwe. There is therefore no better time to use the mineral systems approach in the investigation of deposits like the new gold deposit at Blue Rock, than now. According to Wyman et al. (2016), a coherent orogenic gold mineral systems model can be viewed in terms of four critical components (Fig. 9), which are discussed here in logical order, from; (a) a Geodynamic setting with a favourable lithosphere; (b) a Fertile ore-component source, with a suitable (c) crustal Architecture, that allows fluid migration from source to a trap site, with suitable post-mineralization tectonic processes to ensure deposit (d) Preservation.

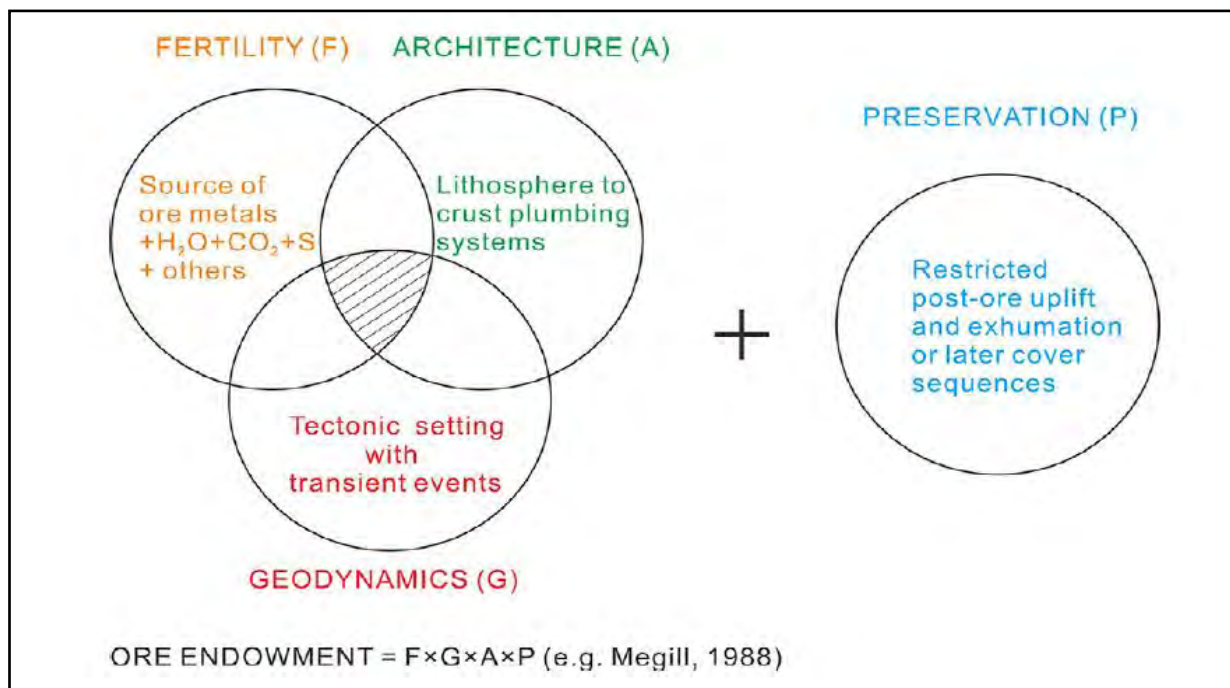


Figure 9: Critical mineral system, with emphasis on orogenic gold. From McCuaig and Hronsky (2014).

3.6.1. Geodynamic Setting

In terms of geodynamic setting, convergent margins are the most critical environments for orogenic gold deposit formation. It is widely accepted that orogenic gold deposits form in accretionary or, less commonly in collisional tectonic environments related to subduction (Fig. 10), and not in any other types of metamorphic belts (e.g. Goldfarb et al., 2005).

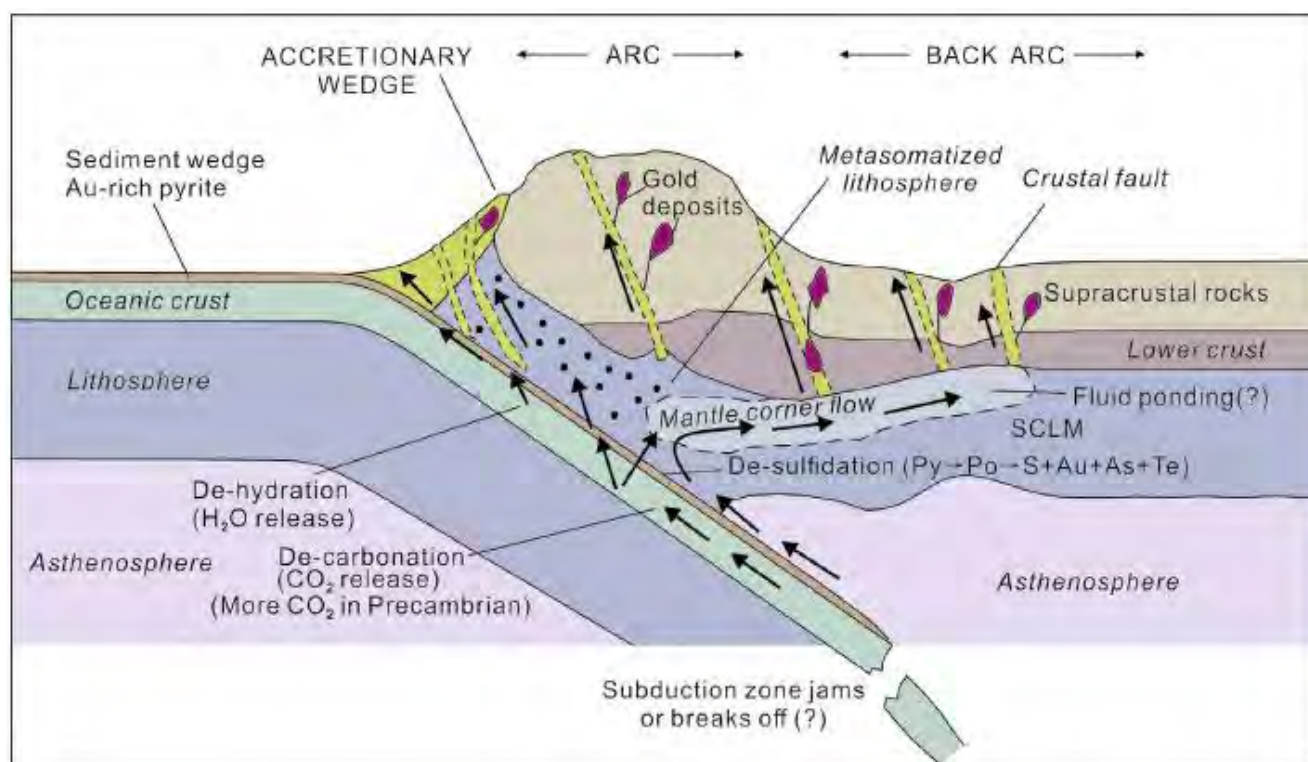


Figure 10: Schematic representation of subduction-based model for ore-fluid source for orogenic gold deposits globally by direct subduction. From Groves et al. (2020b).

This geodynamic setting is critical for direct fluid generation via the devolatilization of a subducted oceanic slab, together with its overlying sulphides-rich sedimentary package, or indirectly through fluid released from a mantle

lithosphere that was originally metasomatized and fertilized during a previous subduction event (Fig. 11), as well as its subsequent migration from the mantle to crustal levels within lithosphere- to crustal-scale fault zones, to form gold deposits.

Such a geodynamic setting can also explain the apparent late- to post-metamorphic timing of gold within host sequences precisely at the time that a change in far-field stresses occurred, which promoted a change from compression (represented by structures and metamorphic fabric observed in host rocks) to transpression or transtension (demonstrated by the geometries of orogenic gold orebodies) (Groves and Santosh, 2015). Tectonic processes responsible for the switchover from compression to transpression, have been discussed by Seno and Kirby (2014), as being a possible consequence of the cessation of subduction, possibly due to collision with a basement block or stalling of the slab during subduction, especially flat subduction (Wyman et al., 2008; Wyman and Kerrich, 2010).

3.6.2. Fertility

Based on many reviews, key among them that of Wyman et al. (2016), there is now clear evidence that the genesis of most orogenic deposits can no longer be attributed to derivation from magmatic-hydrothermal or crustal metamorphic fluid sources alone. In a coherent orogenic model, the fertility parameter is argued by Groves et al. (2022) to be represented by a sub-crustal $\text{H}_2\text{O}-\text{CO}_2$, S-bearing fluid containing dissolved Au, together with associated metals commonly found with orogenic Au, such as As, Bi, Sb, Te and W. But the exact nature of this subcrustal fluid is currently difficult to confine to only one source (Goldfarb and Groves, 2015) due to the modification of fluid by reactions along the complex and long crustal pathways it traverses on its way as it migrates towards the ultimate gold depositional site (Ridley and Diamond, 2000), where it can be found, sampled and examined.

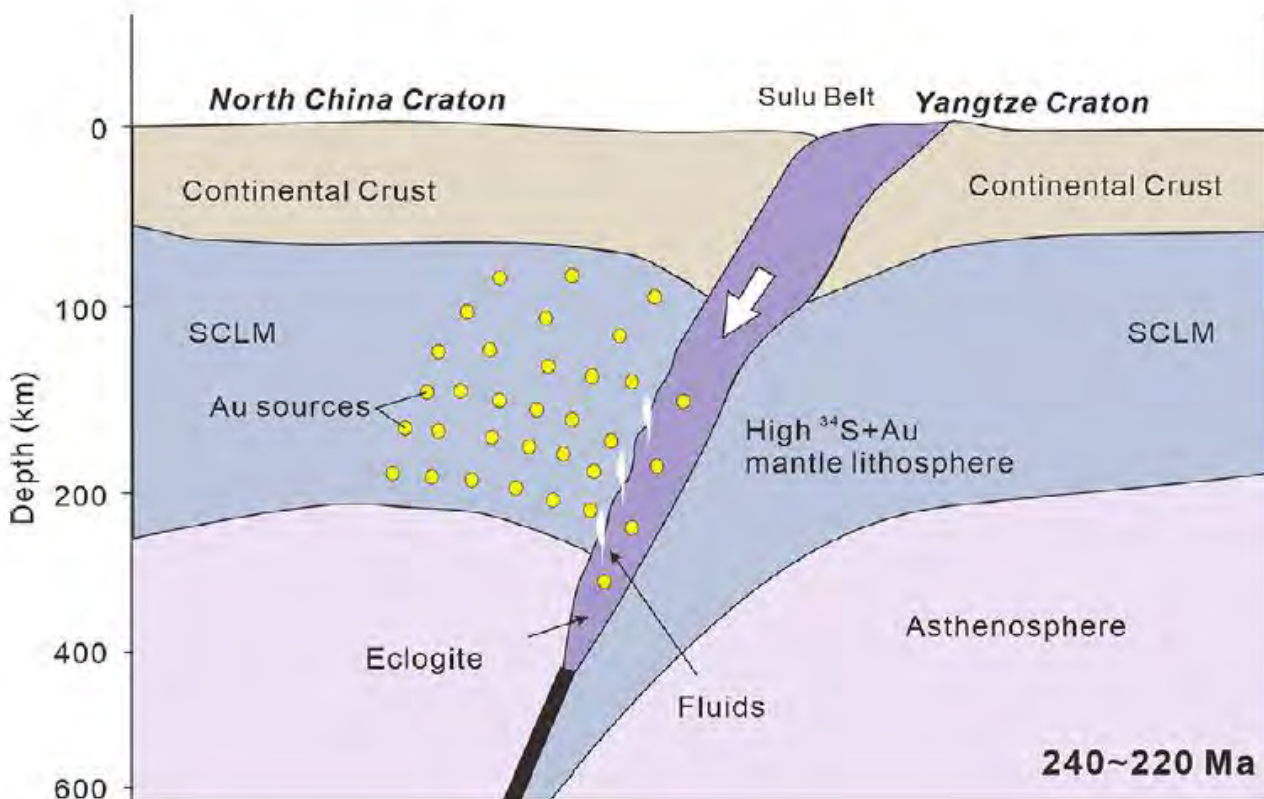


Figure 11: Schematic representation of subduction-based model for ore-fluid source for orogenic gold deposits globally involving a mantle that was metasomatized and fertilized from a previous subduction event. From Yang et al. (2021).

The nature of the original fluid, however, is almost certainly believed to have been near-neutral and reduced (Goldfarb and Groves, 2015), and the sub-crustal sources could be deduced from interpretations of tectonic timing and

geodynamic setting (Groves et al., 2022). Groves et al. (2022) believe that, if all orogenic gold deposits define a single coherent mineral system, based on their syn-mineralization and geodynamic setting, then there are only two realistic viable sub-crustal sources for this fluid. As already discussed for the geodynamic setting, one possible source would be fluid generated from the devolatilization of a subducted oceanic slab, together with its overlying sulphides-rich sedimentary package and the other one would be fluid released from a mantle lithosphere that was originally metasomatized and fertilized during a previous subduction event, particularly adjacent to craton margins (Fig. 12). In other words, Fertility is linked to subduction, so that both fertility and geodynamics are related to convergent margin tectonics (Groves et al., 2022).

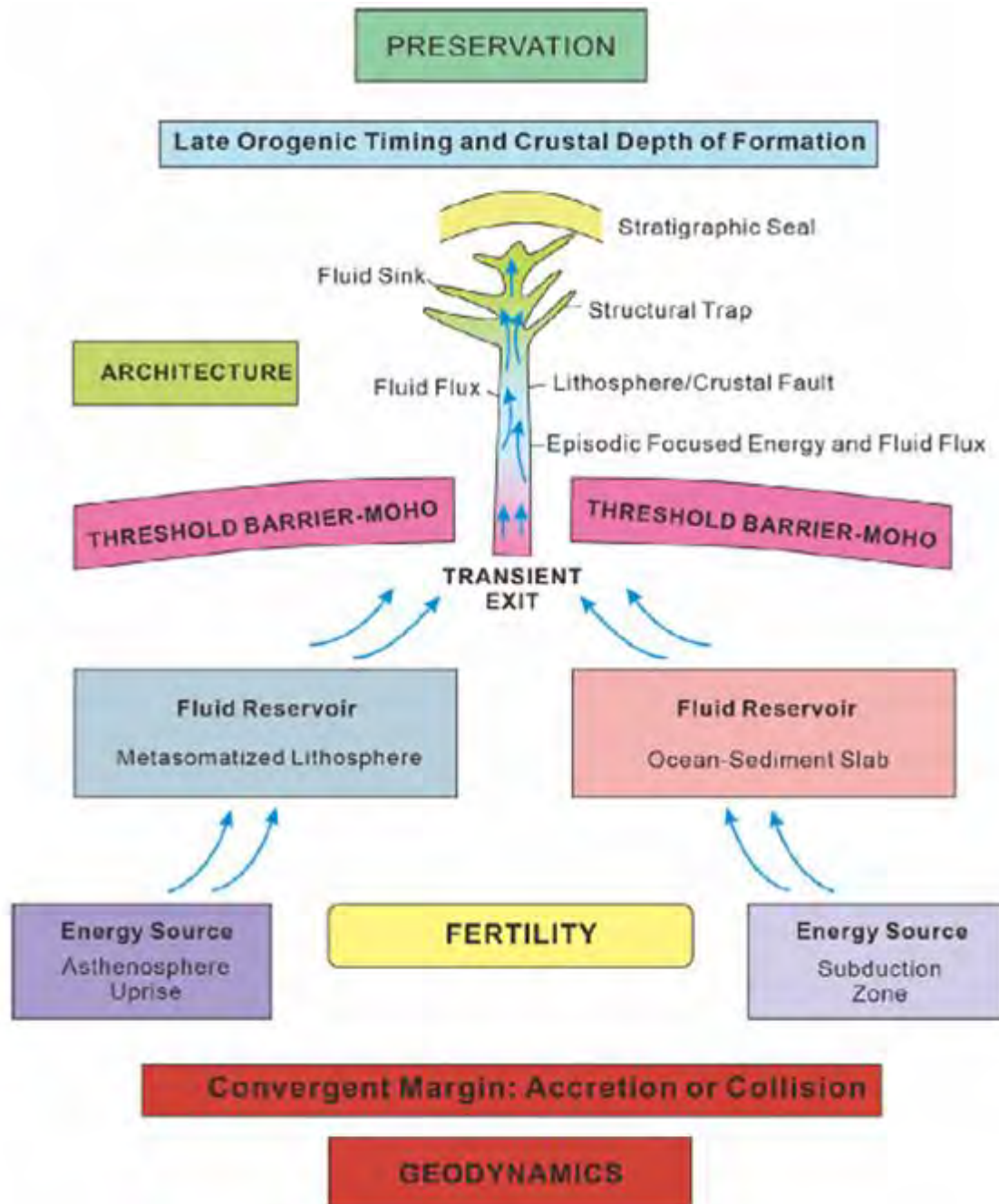


Figure 12: Schematic representation of a self-organising orogenic gold mineral system showing alternate fertility sources that have the same basic architecture parameters. From Groves et al., (2020a).

In the case of devolatilization of a subducted slab together with its overlying pyrite-bearing sediment wedge, extensive upward fluid flux is thought to occur along slab-mantle boundaries into fore-arc or accretionary terrain margins (e.g. Sibson, 2004), releasing fluids loaded with gold and related elements via the breakdown of sedimentary pyrite to pyrrhotite (Large et al., 2009). In other words, the released fluids are transported from the mantle to crustal levels

within lithosphere- to crustal-scale fault zones, with over-pressured fluids (Sibson, 2013) migrating up-dip, and eventually getting channelled into crustal-scale fault zones at higher crustal levels, to eventually form gold deposits within even shallower lower order structures (Hyndman et al., 2015).

The alternative fluid source model where auriferous fluids can be generated indirectly from the mantle lithosphere wedge that was fertilized and metasomatized by fluids derived from an earlier subduction event, was proposed by Goldfarb and Santosh (2014) and is supported by geochemical and isotopic studies by Deng et al. (2019). Key evidence to support this alternative fluid source model has come from observations from certain gold deposits including several from China (e.g. the Jiaodong deposits - Zhang et al., 2018; Wang et al., 2019), whose timing of formation is incompatible with direct derivation of fluid from the devolatilization of subduction-related sediment wedges, but have evidence of an underlying mantle-lithosphere that was metasomatized during devolatilization related to an earlier subduction event (Zhou et al., 2002; Zhao and Zhou, 2008). The subsequent migration of such fluids to crustal scale faults is thought to occur through advection or seismic pumping along crustal-scale faults (Cox, 2016).

3.6.3. Architecture

The continuity of structural architecture from the lithosphere to the crust is a requirement for a holistic orogenic gold model (McCuaig and Hronsky, 2014). Given the origin of auriferous fluids from deep-seated sources as discussed for the fertility parameter, the first-order components of the orogenic gold system architecture naturally become the primary lithosphere-crustal scale faults and shear zones. Such structures are capable of channelling and delivering a focused flux of auriferous fluids to crustal levels equivalent to the brittle-ductile transition, during seismic activity. These low-order faults are most highly endowed especially where they are intersected by high-angle accommodation structures (Groves et al., 2022; Groves & Santosh, 2023).

Lithospheric structures are commonly marked by anomalous concentrations of lamprophyre dykes or felsic-intermediate intrusions with mantle source components (Witt et al., 2013), that indicate a lithospheric connection for fluid conduits (Perring et al., 1987; Rock et al., 1989). Within the crust, fluid is further focused through injection-driven swam seismology, into lower order structures and structural traps. During deposition, favourable fluid pathways are thought to be controlled by rheological and geochemical contrasts between rock units within host sequences, producing a variety of structural host rock geometries at different scales. Common structural traps related to second-order subsidiary faults and shear zones include fractured anticlines and anti-forms (Fig. 13b), intersections between strike-extensive shear zones (e.g. at fault jogs) (Fig. 13a), irregular sheared margins of small granite or other intrusions (Fig. 13c) and triple or quadruple-point junctions between adjacent intrusions (Fig. 13d). Important chemical control traps include fractured iron-rich host rocks and carbonaceous sedimentary units (Goldfarb and Groves, 2015). These hydrothermal systems also require caps that effectively impound fluid flux within the permeable trap zone. And such traps are commonly provided by the relatively impermeable metasedimentary sequences which overlie more permeable fractured volcanic rock sequences within host greenstone belts (Groves et al., 2022; Groves & Santosh, 2023).

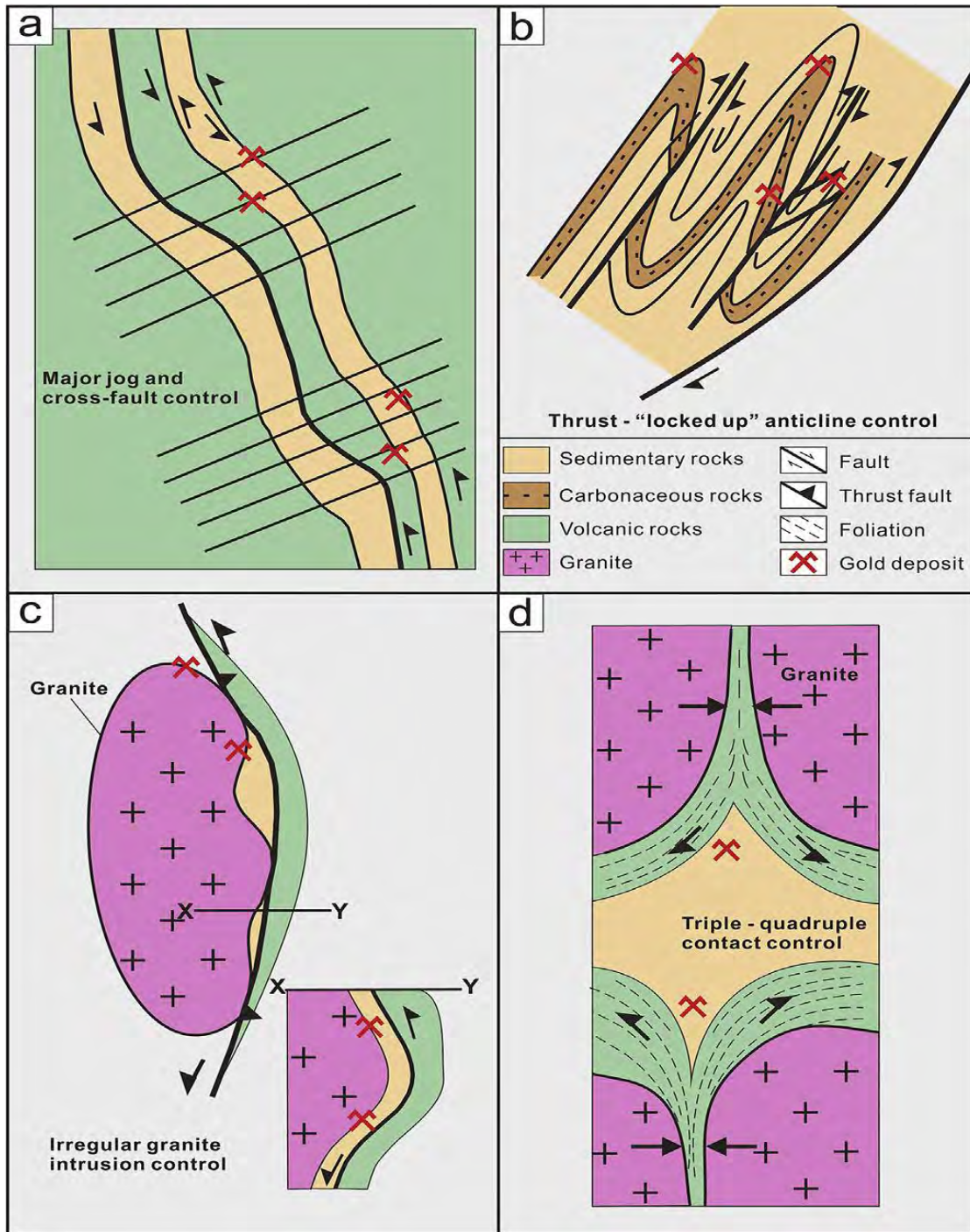


Figure 13: Schematic diagrams showing repetitive structural architecture at fluid sinks or traps for orogenic gold systems: (a) major jogs on crustal-scale- and subsidiary faults/shear zones cut by corridors of accommodation faults; (b) “locked up” thrust anticlinal folds; (c) irregular contacts on faulted margins of granite intrusions; (d) triple- and quadruple-point granite intrusion architecture. From Groves et al. (2020).

3.6.4. Preservation

Preservation is an important parameter which influences the distribution of orogenic gold through time (Groves et al., 2005). Unlike other deposits that form on or very close to surface, orogenic gold deposits mostly formed at deep crustal depths of >5km (Goldfarb et al., 2005) and may individually extend to >2km down dip or plunge (Goldfarb et al., 2001), and therefore have a good preservation potential. In addition to that, they formed late during orogenic deformation, after the major compressional phase of tectonism (Goldfarb et al., 2001), further improving their preservation potential.

3.7. MINERAL SYSTEMS APPLICATION TO EXPLORATION

In practice the application of the mineral systems concept to orogenic gold exploration and resource development, calls for the identification of mineral systems components. These can be identified through critical parameters that are recognized through geological proxies, i.e. the mappable geological, geophysical and geochemical responses to critical geological parameters that have exploration significance, as described below.

(i) Geodynamics and Fertility Parameters

Critical factors for fertility and geodynamics are related to the subduction of the oceanic slab and its overlying sedimentary wedge, which produces auriferous fluids. Subduction is linked to continental margins and as such viable exploration targeting must identify such terranes as crucial to target for orogenic gold exploration. Most of these terranes would have their fertility reflected by significant gold occurrences in areas where exploration has already produced deposits. Permissible terranes for the formation of orogenic gold deposits can also be recognized from their supracrustal sequences. For example, Archaean and Paleoproterozoic convergent margins are dominated by more mafic sequences in greenstone belts that host orogenic gold deposits, although arc-type volcanics and turbidites may also be present (Kawai et al., 2009). High thermal flux in these terranes is represented by voluminous granite batholiths and plutons that dominate these preserved convergent margin terranes. Boundaries of accretionary terranes are marked by extensive lithosphere to crustal scale faults and shear zones that extend for many kilometres and are often marked by lamprophyre and alkaline intrusions (Caroff et al., 2015). And these can be located using aeromagnetic and gravity survey techniques. Most terrane bounding faults or shear zones are normally clearly defined as lineaments on combined gravity-aeromagnetic images. Pre-competitive geophysical data, where available, would be useful for defining crustal architecture, and for locating deeper structures using edge analysis of potential field data (Groves et al., 2022; Groves & Santosh, 2023).

A combination of gravity, seismic and magneto-telluric data is good for providing 2D-3D representations of complex geometrical features over the fragmented craton margin, but in most cases aeromagnetic data could very easily map lineaments that define critical permeable zones through which auriferous fluids can migrate from deep seated sources upwards into the crust to form orogenic deposits.

(ii) Architecture

The architectural component and related critical geological parameters of exploration significance can be defined at different scales. Most of these factors have already been reviewed by Groves et al. (2018) and others, and will be presented in a logical manner below, starting from province through district to deposit scale.

At terrane scale, the architectural component is related to the geodynamic and fertility factors. The architecture parameter at this scale refers to the major permeable lithospheric-crustal structures that channel high thermal and seismic-driven fluid flux from the mantle to the upper crustal levels. These major structures are the first-order faults and shear zones commonly marked by lineaments on aeromagnetic data. First-order structures are often marked by the distribution of lamprophyres and related intrusions, whose emplacement they control. They normally show up as shallowing thrusts on seismic sections commonly used to profile them, although magneto-telluric sections have been reported to be very useful for clearly marking their vertical extents (Dentith et al., 2013). For a greater opportunity to form significant deposits, fluid focusing into very narrow permeable areas defined by very high strain, and separated by wide domains of very low strain, is key (Groves et al., 2022).

At district scale repetitive structural geometries responsible for controlling the localization of orogenic gold deposits are the most significant architectural factors to consider. These include the curvilinear segments of crustal to lithospheric-scale faults and shear zones or jogs on first-order structures (Groves et al., 2020a; 2022; 2023). Most of these are associated with anticlinal structures, and host some of the world's largest orogenic gold deposits. Along

these jogs, gold is believed to be hosted by adjacent shear zone and fault structures which pre-date mineralization. Important structures to target for exploration are therefore oblique faults that develop at areas where jogs or flexures develop. These structures can be mapped as linear structural features in aeromagnetic data. Anticlinal or antiformal structures tend to be modified by thrusts and fracture arrays, which promote focused fluid flow, resulting in gold deposition (Leader et al., 2010). Detection of these features through complex gravity and aeromagnetic techniques is difficult due to their variable signatures, but where detected, they form more robust fluid traps to target using predictive orogenic gold exploration tools at the district and deposit scales.

Additional architectural features that enhance orogenic gold deposition at deposit scale are associated with granite intrusions. Granite intrusions are a common feature of many orogenic gold provinces and where present they can be pre-, syn- or post-gold mineralization. But those that are syn- and pre-mineralization may play significant roles in the localization of gold mineralization at both regional and deposit scales. Individual rigid and more competent granite intrusions are thought to induce a significant variation in the orientation of local principal maximum stress relative to the internally imposed regional stress, causing anomalously low minimum stress zones at deposit scale, due to the variations in the geometry of intrusion contact zones, whether having sheared or complex contacts with surrounding volcano-sedimentary sequences. These zones of low minimum stress become the focus of fluid flux and therefore gold mineralization (Ridley, 1993). Where these areas of low minimum stress are formed by more than one granite intrusion, more complex structural geometries that range from triple, quadruple points etc., which enhance gold deposition are formed (Fig. 13d) (Li and Santosh, 2017).

At deposit scale, stratigraphic traps and caps are critical factors for enhanced gold deposition. Most of these however control the location of the mineralization envelope and are critical for guiding drilling and not deposit scale targeting as extensively discussed by Hronsky et al. (2020). For deposit scale targeting, rheological and chemical lithological properties play a huge role in increasing the chemical suitability of host rocks or in creating secondary permeability in the form of veins that allow auriferous fluids to be focused into a very small volume of rock. There must be pathways which allow fluid migration to the rheologically and geochemically prospective rocks, (Hronsky et al., 2020). Competency contrast between different rock types within potential host sequences is thought to play a key role in the selective failure of more competent rock units, resulting in the creation of permeability channels that allow fluid migration and fluid-rock interaction. A decrease in supralithostatic pressure to hydrostatic pressure related to hydraulic fracturing (Sibson 1992) allows for fluid immiscibility and direct gold precipitation (Loucks and Mavrogenes, 1999). As for Fe-rich rocks like BIF, dolerite and diorite rocks which do have high magnetic susceptibility, gold deposition occurs through sulphidation reactions.

During rock-fluid interaction, it would be critical to stop the fluid from escaping the hydrothermal system by way of cap rocks. Important cap rocks are usually provided by a rheological contrast between the different rock units. In such cases the more competent rock units would form the potential hosts whilst the less permeable and more ductile sediments form the fluid caps (Groves et al., 2020a; 2022; 2023).

(iii) Preservation

The exposure of orogenic gold deposits or their occurrence close to the surface is a function of erosion and exhumation. The rate at which exhumation occurs in any given terrain, is normally quantified through thermo-chronological studies, but for more practical purposes, the deduced level of erosion of existing deposits would give a good exploration guide (Groves et al., 2020a).

CHAPTER 4. GEODYNAMIC SETTING AND ARCHAEOAN GREENSTONE BELT EVOLUTION

4.1. TOWARDS A UNIVERSAL MODEL FOR ARCHAEOAN ZIMBABWEAN GREENSTONES

In this study the gold deposit at Blue Rock is investigated using the Mineral Systems Approach, looking at all the factors critical to its formation and subsequent preservation. One of the key factors to consider is the geodynamic setting, which has a bearing on the Fertility and Architecture factors, at regional scale. The new gold deposit at Blue Rock is located within the GGB, which is a part of the Zimbabwean Archaean crust.

The geodynamic setting of the gold deposit at Blue Rock, therefore, can only be described best through the evolution of the Zimbabwean Archaean crust. But there is currently no universal working model for the evolution of the Zimbabwean crust. There is therefore a need to seek a universal working model to account for the evolution of the Zimbabwean crust in order arrive at a holistic understanding of the regional controls of orogenic gold mineralization within the GGB, including the new gold deposit at Blue Rock.

The evolution of Archaean crusts worldwide is not uniformly understood. There are currently two (2) prominent schools of thought to account for their genesis. One model involves (a) Vertical Accretion of rift sequences deposited on pre-existing fragments of felsic crust, whilst the other one involves (b) Horizontal Accretion of crustal segments.

4.2. VERTICAL ACCRETION

Vertical accretion relates to magma accretion and subsequent deformation of the greenstones and their felsic basement by vertical processes which include, melt segregation from a convecting mantle, underplating and diapirism in an evolving crust. Crustal terrains around the world commonly attributed to this model include the Dharwar Craton in India (Bouhallier et al., 1993), the Pilbara Craton in Australia (Hickman, 1983), and the Zimbabwe Craton of Southern Africa (Macgregor, 1951; Ramsay, 1989; Jelsma et al., 1993).

The Zimbabwean Craton has for a long time generally been interpreted as a vertically accreted crust, in which greenstone sequences and related sediments were deposited within rifts, over a pre-existing older continental felsic basement (e.g. Bickle et al., 1975; Blenkinsop et al., 1993; Bickle et al., 1994; Shackleton, 1995; Wilson et al., 1995; Ridley et al., 1997).

Vertical accretion of the Zimbabwean Craton was first proposed by Macgregor (1951) to explain the emplacement of numerous sub-elliptical granitic batholith domes (Gregarious Batholiths), surrounded by arcuate-shaped Archaean greenstone belts. This model was supported by studies on detailed strain patterns around such batholiths, which are consistent with typical ballooning diapiric granite dome geometries e.g. the Chinamora batholith (Ramsay, 1989; Jelsma, 1993; Jelsma et al., 1993), as well as, by the recognition of several unconformities at the base of major greenstone sequences overlying older greenstones and felsic crust (Bickle et al., 1975).

The existence of such unconformities led to the possibility that, maybe continental crust was once covered by one or several inter-connected extensional basins or intra-cratonic rifts, in which cyclic distinctive autochthonous volcano-sedimentary successions or greenstone sequences were deposited, before they were disturbed by vertical diapiric processes. These basal unconformities are common in all greenstone belts in Zimbabwe, and were assumed to be continuous, and consequently used as the basis for regional country-wide lithostratigraphic correlations across much of the Zimbabwean Craton (e.g. Wilson, 1979; Wilson et al., 1995). Stratigraphic correlation across different greenstone belts employed the Chingezi Group within the Belingwe belt in the southern part of the country, as a “type” stratigraphic occurrence, for the ubiquitous Upper Bulawayan stratigraphy (Bickle and Nisbet, 199; Blenkinsop et al., 1997). This allowed different Zimbabwean greenstones to be correlated into a single Supergroup style nomenclature, in what became the famous tripartite subdivision of Zimbabwean Archaean geology. In this stratigraphic model, all Zimbabwean greenstone stratigraphy is divided into three different groups, starting with the oldest Sebakwean Group

(>3 200 Ma) at the base, followed by the Bulawayan Group (>3 200 - 2 680 Ma) and then capped by the youngest Shamvaian Group (2 670 – 2 645 Ma) at the top (Macgregor, 1951; Stagman, 1978; Wilson, 1979; Wilson et al., 1995; Jelsma et al., 2021). According to this model, GGB geology is assigned to the Upper Bulawayan Group (Campbell and Pietfield, 1994; Phaup and Dobell, 1938).

Following the recognition of numerous unconformities within almost all Zimbabwean greenstones, most contacts with angular stratigraphic relationships within Zimbabwean greenstone sequences, were interpreted as unconformities (Wilson, 1979; Wilson et al., 1995), although others occur as strongly sheared contacts. These shears have mostly been viewed as accommodation structures related to either folding (Blenkinsop et al., 1993), gravity-induced detachment zones with cover rocks sliding off the batholith domes (Stowe, 1984; Jelsma et al., 1993) or as late strike-slip shear zones (Campbell and Pietfield, 1994), believed to not have seriously affected the stratigraphy (e.g. Wilson et al., 1995).

Subsequent deformation is usually related to far-field stresses associated with the Limpopo orogeny (e.g. Treloar and Blenkinsop, 1995) or to the emplacement of granites (e.g. Jelsma et al., 1993), followed by repeated stages of strike-slip movement on conjugate sets of large-scale shear zones (Stowe, 1980; Campbell and Pietfield, 1994).

But the vertical accretion model is now losing popularity in favour of horizontal accretion, as a credible hypothesis to explain the evolution of Zimbabwean crust. This view has received support from alternative interpretations of the common shear zones widespread within many Zimbabwean greenstones (e.g. Dirks and van der Merwe, 1997; Dirks, 1997; Jelsma and Dirks, 2002). Jelsma and Dirks (2002) interpreted these layer-parallel thrusts as having formed through horizontal accretion.

4.3. HORIZONTAL ACCRETION

Horizontal accretion deals with near uniformitarian models, which involve the lateral amalgamation of mafic oceanic and felsic (island arc) crustal fragments through a subduction-accretion related process. For a long time, this was the preferred model for terrains like the Abitibi Belt in Canada (Card, 1990), the Kaapvaal Craton in South Africa (de Wit, 1982), the Yilgarn Block in Australia (Swager and Griffin, 1990; Myers, 1995), and not the Zimbabwean Craton.

But contrary to historical views, some workers including Dirks and van der Merwe (1997) and Dirks (1997), have interpreted the numerous and widespread sheared contacts within many Zimbabwean greenstone belts as silicified layer-parallel shear zones that could have significantly affected greenstone belt stratigraphy. Such views are now changing the course of geological thinking on the evolution of the Zimbabwean Archaean craton, from a predominantly vertically accreted terrain, towards a horizontally accreted one, like numerous other major Archaean terrains of the world, already discussed.

Horizontal accretion models have been popularised by Dirks and Jelsma (1998), Kusky (1998), Kusky et al. (2018), Jelsma et al. (2021), as more plausible mechanisms to account for the origin of the Zimbabwean Archaean granite-greenstone crust.

Dirks and Jelsma (1998) interpreted the common shear zones that parallel compositional layering or cut layering at low angles in many Zimbabwean greenstones, as thrusts which accommodated west-directed tectonic stacking of thrust sheets during greenstone terrain evolution. This, they believe could be explained eloquently through a horizontal accretion model, in which thrusting and tectonic stacking affected separate lithological domains (which today display different sedimentary and structural-metamorphic histories) before they were juxtaposed across steep, west-directed thrust zones. The thrusts are viewed as having formed during progressive stages in an accretionary and crustal thickening sequence, possibly associated with underplating or low-angle subduction.

Similar views are also shared by Kusky and Vearncombe (1997) and de Wit and Ashwal (1997), who believe that Archaean Zimbabwean granite-greenstone terrains are remnants of collisional tectonics. But, exactly how this process

happened, has for a long time been a very controversial topic, mainly because plate tectonics is less well understood and a modern-day like subduction process is believed by many supporters of Vertical Accretion models (e.g. Stern, 2007) as not having occurred during Archaean times.

But despite a diversity in opinion over this matter, a lot of evidence from developments during the last two decades, including studies in geology, geochronology and numerical modelling, is in support of a modern-day like plate tectonic process during the Archaean. A number of workers including Cawood et al. (2018), Kusky et al. (2018), Maruyama and Safonova (2019) and many others, now believe that plate tectonics operated on this planet during the Archaean just as it does today (Fig. 14), or at least since the formation of the oldest rocks by the Neoproterozoic (e.g. Windley et al., 2021), albeit with some differences in processes and therefore results, during earlier times of higher mantle temperature and different atmospheric conditions.

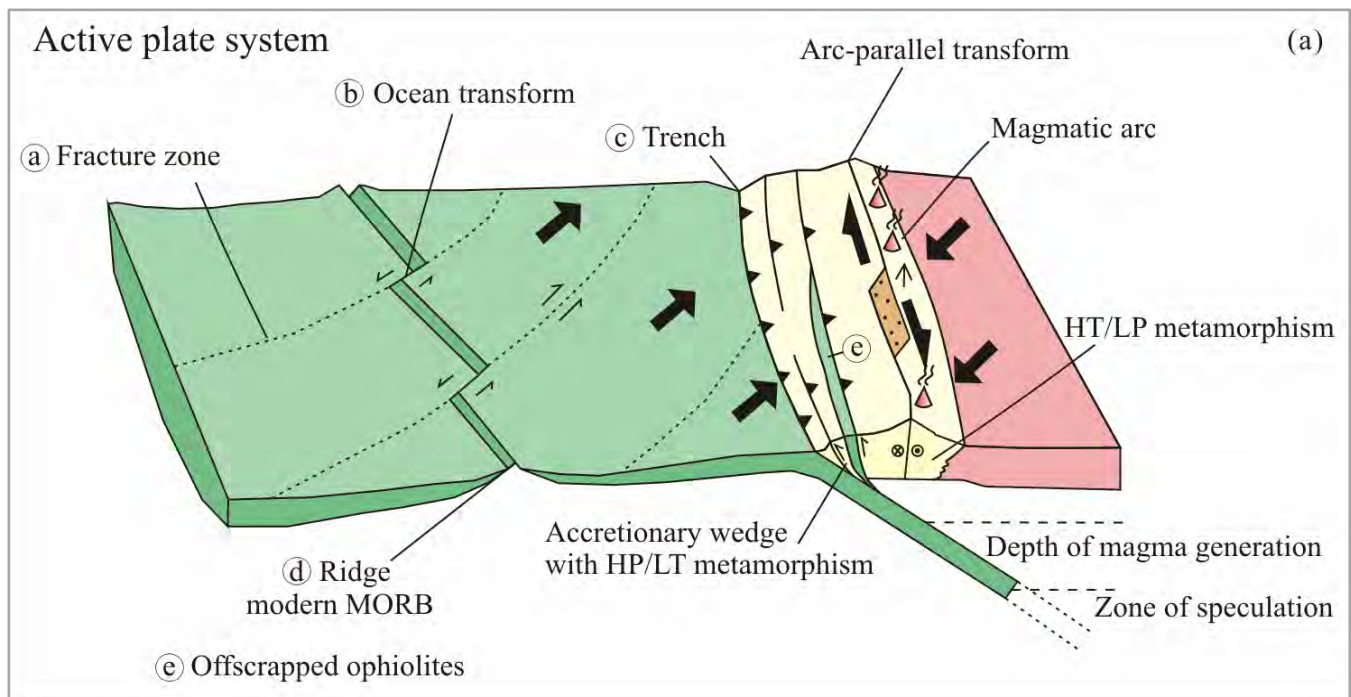


Figure 14: Active plate tectonic system showing subduction of oceanic lithosphere, devolatilization and partial melting of mantle wedge to create arc magmatism. From Kusky et al. (2018).

Examples of new developments which support the occurrence of plate tectonics during the Archaean include the recognition of the sequence of sediments which accumulated over ocean plates (OPS) within accretionary orogens since Archaean times (Kusky et al., 2013; 2019), leading to a new model for Ophiolite structure. Unlike traditional definitions, new views reveal a greater diversity in Ophiolite structure and how to recognize ancient oceanic crust (Coleman, 2012; Dilek and Furnes, 2011; Kusky, 2011), ranging from magma-poor or magma-rich types and those associated with the different subduction zone environments, to those associated with spreading centres. Ocean Plate Stratigraphy (OPS) is the sequence of sedimentary and volcanics deposited on the oceanic crust from the moment they form at a spreading centre up to the time they get incorporated into a convergent margin or accretionary prism (Kusky et al., 2013). The young plate starts off with a basal pillow lavas section of the oceanic crust, and grades upwards into deep sea sediments (cherts, and limestones to BIFs) to shallow water turbidites (shales, mudstones, sandstones and conglomerates) derived from the erosion of continental blocks (Fig. 15a).

In this model (Fig. 15b), just like in modern day tectonic processes, the oceanic crust is created at a spreading centre or mid-oceanic ridge (MOR), then experience lateral movement along strike-slip transform faults, towards deep sea trenches (which mark subduction zones), where the oceanic lithosphere along with its overlying sediments gets subducted into the mantle.

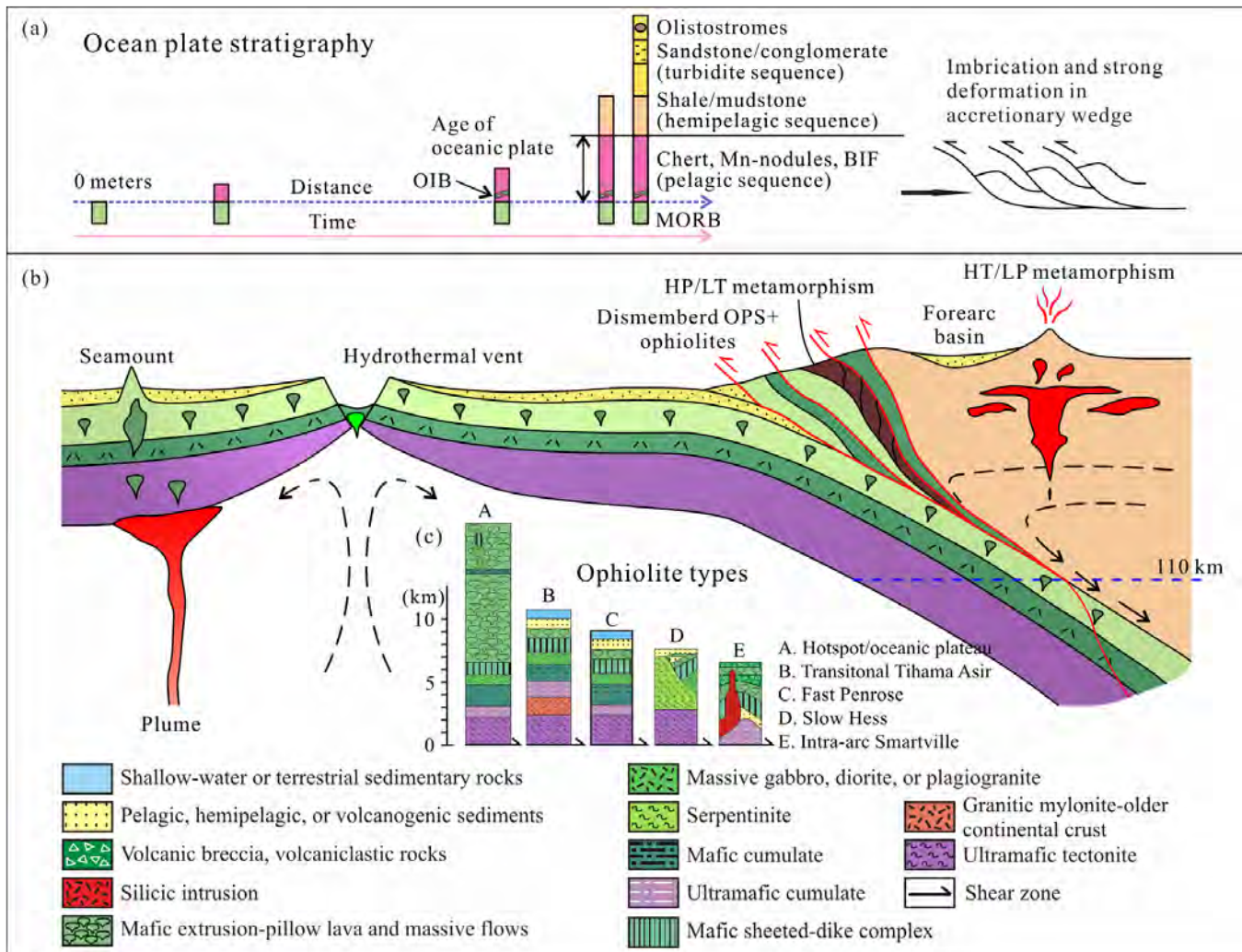


Figure 15: Cross Section showing (a) Ocean Plate Stratigraphy development and (b) Subduction-Accretionary processes that form orogenic terrains. From Kusky et al. (2018).

During subduction, small fragments of oceanic lithosphere are scraped off the subducting oceanic plates, along with overlying oceanic plate sediments (OPS) and get incorporated into an accretionary wedge, where they are imbricated and strongly deformed above the trenches at convergent margins. Some of the continental material eroded and deposited within trenches or scraped off above Benioff zones is also subducted along with the oceanic plate. During this part of the cycle, material is brought back into the mantle where it releases volatiles including water, inducing partial melting within the overlying mantle wedge. The partial melting creates magmas which rise back to the surface and erupt to form Island arcs or continental margin arcs. Thus, a distinct tectonic association typical for subduction related tectonics is formed, consisting of an accretionary prism (now preserved as Archaean orogenic belts) between the trench and the magmatic arc.

Archaean orogenic belts like the Zimbabwean greenstone belts including the GGB, are therefore ancient accretionary terrains, in which OPS provides first-order evidence for the operations of plate tectonics. More recent work on the subject to support the operations of modern day like plate tectonics and horizontal accretion for the Zimbabwean greenstones were conducted by Kusky et al. (2018) and Jelsma et al. (2021).

Jelsma et al. (2021), used more recent geochronological data from SHRIMP U-Pb zircon dating of volcanic and plutonic rocks from northern Zimbabwe and unpublished data by Wilson et al. (1995), to re-interpret the extent of the Sebakwe Proto Craton (SPC), as well as the spatial distribution and geodynamic setting of different Zimbabwean greenstone successions.

Based on marked differences in geochemistry and lithostratigraphy, the ubiquitous Upper Greenstones of the Bulawayan Supergroup, Zimbabwean greenstones are sub-divided into two spatially distinct successions, namely the "Eastern" and the "Western" Successions (Wilson, 1979) or "Type 1" and "Type 2" successions (Jelsma and Dirks, 2002) (Fig. 16). The Western or Type 2 succession is believed to have formed between (>2 745 to 26 80 Ma) in a subduction accretion system at the convergent margins of the SPC of Horstwood et al. (1999), and supported by for example, Jelsma and Dirks (2002) and McCourt et al. (2004), whilst the Eastern or Type 1 greenstone succession is believed to have formed in a 'Rift' or 'Red Sea' type environment (Blenkinsop et al., 1993; Hunter et al., 1998; Prendergast, 2004).

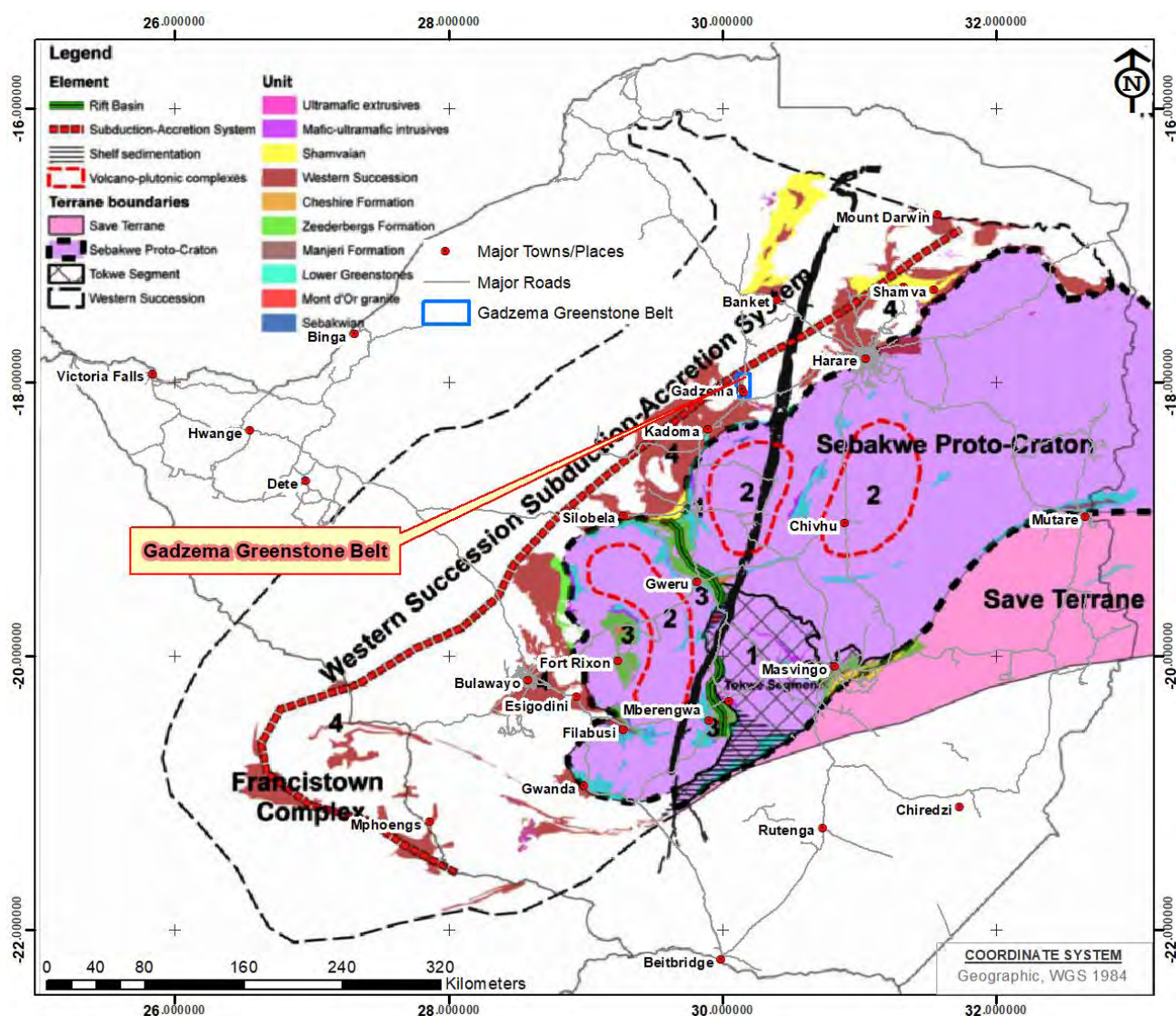


Figure 16: Geodynamic synthesis of the Zimbabwean Craton showing Western Succession Subduction System [4] which was responsible for the formation of Upper Greenstones, which include the Gadzema Greenstone Belt. Modified from Jelsma et al. (2021).

4.4. A MODEL FOR THE GADZEMA GREENSTONE BELT

Most of the GGB geology is assigned to the Upper Bulawayan Series (Wilson, 1979; Foster et al., 1986; Phaup & Dobell, 1938), and therefore belongs to the Western Succession of Wilson (1979) or Type 2 succession (Jelsma and

Dirks, 2002). If the proposed Horizontal accretion model for Western Succession Zimbabwean greenstones is accurate, and if a modern day-like subduction process indeed occurred during the Archaean then, the GGB could be viewed as a paleo accretionary terrain, formed between >2 745 to 2 680 Ma (Jelsma et al., 2021), through accretion during an eastward directed subduction of oceanic slab together with its overlying sediments, at the convergent margins of the SPC of Horstwood et al. (1999) (Jelsma and Dirks, 2002; McCourt et al., 2004).

4.5. MINERALIZATION

If the proposed model for the GGB is accurate, then it formed within a subduction-accretionary geodynamic setting and the genesis of its host orogenic gold deposits is therefore consistent with a universal orogenic gold model already discussed. The GGB belongs to the Western Succession group of Archaean Zimbabwe greenstones which are more endowed in terms of gold than their Eastern Succession counterparts, believed to have formed in red sea-type rift settings.

Orogenic gold mineralization within the GGB is epigenetic, and hosted by any rock type, within shear zones, fractures, brecciation zones, vein stock works or folds between deformation zones (Foster, 1985; Foster et al., 1986; Campbell and Pitfield, 1994). Such structures are associated with greenstone lithologies as well as granitoid intrusives within or proximal to the margins of greenstone belts, where semi-digested mafic inclusions and remnants are more abundant (Kalbskopf and Nutt, 2003).

CHAPTER 5. LOCAL GEOLOGY – THE GADZEMA GREENSTONE BELT

5.1. HISTORICAL WORK

The geology of the whole GGB was historically mapped in detail in part by Phaup and Dobell (1938), and by Wiles (1957) under Bulletin Numbers 34 and 44, respectively and then by Dirks and Mikhailov (1998) in an unpublished exploration-focused report. The gold deposit at Blue Rock is located within the Gadzema Greenstone Belt (Fig. 17).

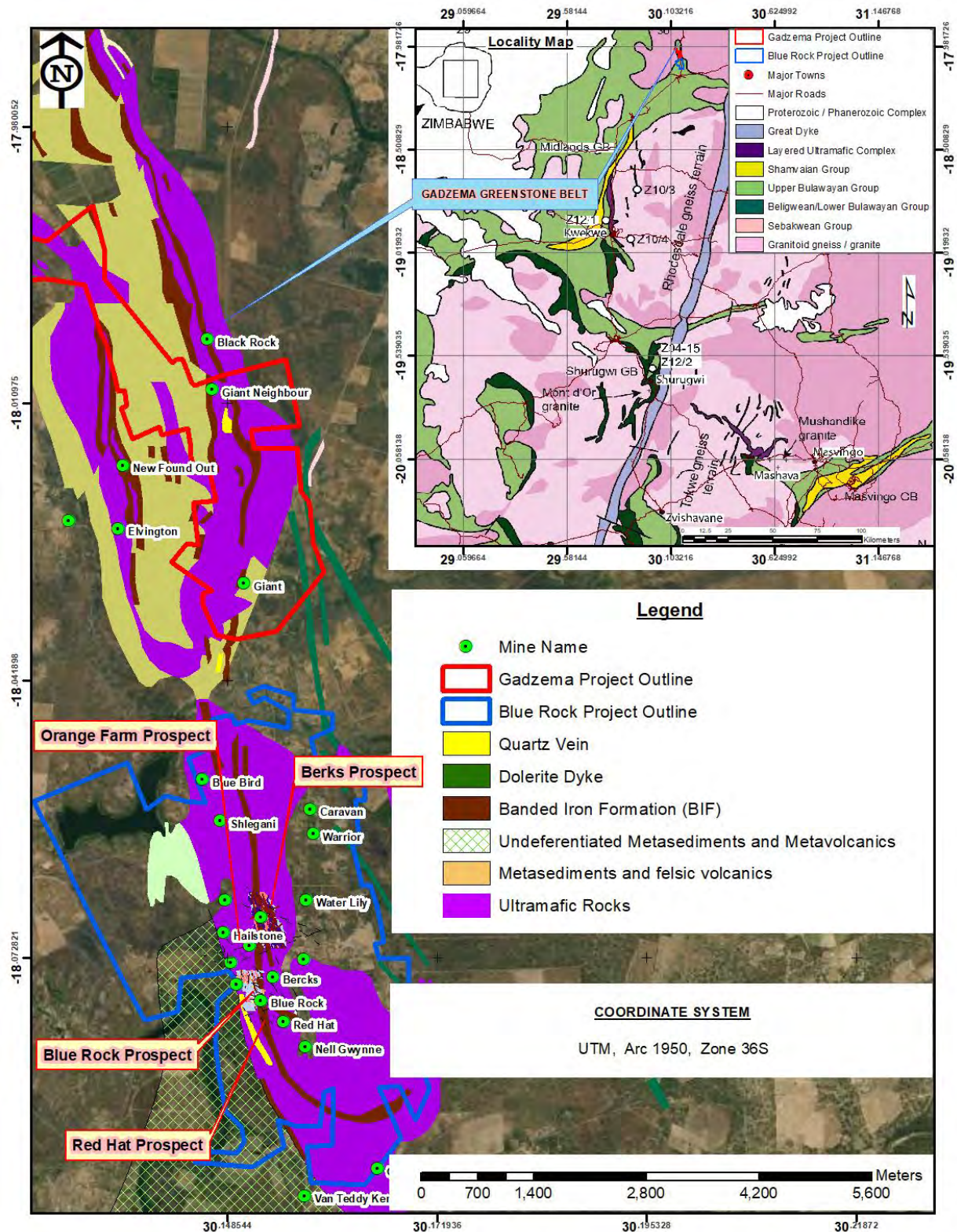


Figure 17: Regional geology of the Gadzema Greenstone Belt, showing the location of the Blue Rock Project.

The recent discovery of a gold deposit at Blue Rock led to a mapping campaign recently conducted by the author soon after the initial discovery of the deposit. The main objective of the mapping was to understand the distribution of felsites and quartz-porphyry rocks, which had just been identified as a new significant lithological association at the gold discovery.

5.1.1. GGB Geological Outline

The GGB is a narrow (approx. 8km wide x 15km long), volcano-sedimentary sequence bound on all sides by great volumes of younger granite rocks (Biri Granite), except in the south, where the belt merges with the more extensive MGB (Wiles, 1957; Wilson, 1979). The GGB strikes roughly NS in the north, but swings in the south to follow the Umfuli river towards the Great Dyke in the east, forming a synform (Wiles, 1957). Here the rocks have been overturned towards the east, and now dip steeply at between 60 degrees towards the east, to vertical.

Most of the GGB was assigned by Wilson (1979), Foster et al. (1986) and Phaup & Dobell (1938) to the Upper Greenstone Series, whilst the younger intrusive granites were assigned by Wilson et al. (1995) to the Sesombi Suite. The Upper Greenstone Series rocks are dominated by basic volcanic rocks, now metamorphosed to mafic schists, mostly talc-chlorite schist. These dominant rocks were intruded by very subordinate bodies of ultrabasic rocks which are now serpentinitized. The sequence is interbedded with BIFs and shallow water sediments consisting of mostly quartzites that occupy the central part of the synform (Wiles, 1957; Phaup and Dobell, 1938). Acid rocks consisting of mainly younger intrusive felsites, and quartz porphyry rocks were mapped recently by the author.

Dirks and Mikhailov (1998) reported minor aplite and pegmatite dyke occurrences whose intrusion, they believe, is coeval with the Biri granite, but gave no indication of their spatial distribution. Surface mapping by the author to support exploration for, and development of, the gold deposit at Blue Rock, identified numerous felsites and quartz-porphyry rocks extending NS close to the western margins of the greenstone belt, to be important gold hosts for this new type of gold mineralization previously not known to exist within the GGB. These felsites and quartz-porphyries are most likely related to the same earth magma which gave rise to the Biri granite batholith as argued for granitoid and porphyry volcanism during granite-greenstone terrain and Archaean craton development by for example, Wiles (1957).

The role of felsites and quartz-porphyries in localising this type of gold mineralization, is the scope of this study, and will be discussed in better detail in subsequent sections below.

The GGB is flanked on the western margin by a major NS trending deformation zone, which appears to be a northern continuation of the Kadoma Deformation Zone (KDZ) from the adjoining MGB in the south. Lithological contacts between the different types of volcanics and metasediments are invariably sheared and believed to have a major control on gold mineralization, that occur mostly as sulphidic replacements within BIFs as well as quartz vein reefs, hosted within second and third order structures. Detailed descriptions of the major geological formations that make up the greenstone and associated sedimentary successions are discussed below, whilst their spatial distribution is presented in Fig. 18.

5.1.2. Major Lithologies

5.1.2.1. Banded Iron Formation (BIF)

Thin layers of Banded Iron Formations are common throughout the area. The BIFs occur as NS trending and variably deformed layers interbedded within mafic schists. Two prominent parallel layers of BIF can be identified as strongly deformed, but semi-continuous bands that can be traced from the Biri river in the north to the Mupfure river in the south. The deformed BIF bands are associated with most major gold occurrences within the GGB. One of the band trends in the west passing through the Newfound Out, Elvington and Kaltranic mines, whilst the second one in the east passes through the Giant mine.

In its strongly sheared and deformed state, the BIF occurs as structural lenses or thin (<20m) discontinuous layers. Within this sheared BIF, regular compositional layering is absent. Instead, the BIF is characterized by lensoidal, discontinuous layers in which lenses of quartz and magnetite are enveloped by foliation domains, dominated by grunerite. Sulphides, generally altered to iron-oxides, are common. The strongly sheared BIF generally forms no to very little topographic expression.

In contrast, the least deformed BIF consists of a regularly layered massive rock composed of alternating 5-20cm compositional bands of quartz and magnetite. Gruneritic amphibolite forms a minor constituent of the massive BIF, although sulphides have not been observed in hand specimen. This type of BIF occurs in layers of up to 200m in thickness. It is clearly resistant to weathering and forms prominent hills above the low-lying strongly deformed BIF and mafic schists. The less-deformed BIF is generally associated with only few and generally small gold workings.

A continuum, however, exists between the massive, well-banded, magnetite-rich BIF and the sheared, poorly layered, grunerite-rich BIF. Mineralization is generally concentrated within the most intensely sheared and deformed portions of the BIF. BIF is also fractured due to a relatively higher competency contrast compared to both serpentinite and mafic schists. And the fractures are commonly filled with quartz vein or calcite, with occasional sulphides in places.

5.1.2.2. Serpentinite

Massive serpentinites form prominent topographic features. Most of them occur as undeformed lenses wrapped by all other lithologies. They locally preserve cumulate textures, but massive varieties are most common. Serpentinite occurs as trails of lenses throughout the area and most probably represent an intensely boudinaged stratigraphic horizon (Dirks and Mikhailov, 1998).

5.1.2.3. Mafic Schist

Mafic schist is the most dominant lithology within the GGB and occurs mainly as talc-chlorite schist. Talc-chlorite schists are thought to be a result of the shearing of ultramafics during deformation. They rarely outcrop and are intensely deformed, with S-C fabrics well developed within shear zones. They possess a very prominent foliation which dips steeply towards the east. Due to lack of exposure this unit is difficult to map, but its surface spatial distribution pattern can be mapped with help from Ni-Cu surface geochemistry (Dirks and Mikhailov, 1998). Mafic schists are characterised by intermediate Ni values (1000 – 1500ppm), and probably represent intensely altered and sheared komatiitic basalts.

5.1.2.4. Dolerite

Outcrops of dolerites occur to the E and SW of Giant mine. But in general, they are very rare, and the GGB seems to be crosscut by only a few of them.

5.1.2.5. Quartz Vein

Prominent quartz veins occur as boulders and outcrops of white, coarse-crystalline quartz which is common within the GGB. The Giant mine is characterized by such veins, and 2.5km N of Giant mine (near the Giant Neighbour mine), a massive quartz “blow” forms a prominent hill. In general, however the most significant quartz occurrences appear to be aligned consistent with a NS array of faults, as well as the general geological fabric of the belt. Many of the quartz veins show a close spatial association with gold workings and some of them are mineralized. In places they show pinch and swell structures parallel to the NS and NW-SE directions of extension.

5.1.2.6. Felsites and Quartz Porphyries

Felsites and quartz-porphyry rocks were mapped by the author soon after the discovery of the gold deposit at Blue Rock. They cover an area near the western edge of the GGB, described by Phaup and Dobell (1938) to contain poorly exposed rocks, presumed to be sedimentary rocks. Previous mapping by others never identified any of these felsites

despite their occurrence in other Zimbabwean Archaean gold belts, including the larger MGB to the south. A detailed investigation of these rocks is part of this research aimed at unravelling gold mineralization which appears to be associated with these rocks at the new gold deposit at Blue Rock. Detailed mapping by the author to investigate the spatial distribution of felsites and quartz porphyries, will be covered in better detail in subsequent sections below.

5.1.2.7. Granite

The Biri granite invaded the GGB on all sides except the south and has been assigned by Wilson et al. (1995) to the Sesombi Suite. It is thought to have been emplaced during the progressive D1-D2 deformation events (Dirks and Mikhailov, 1998). The granite is a medium-grained, grey granitic rock consisting typically of cloudy feldspar, quartz and biotite, and is best described as a granodiorite due to abundant oligoclase feldspar (Phaup and Dobell, 1938). Numerous small aplite and pegmatite dykes and veins that truncate the dominant D1 and D2 structures are emplaced within faults that are thought to be reactivated cracks, developed in the rock during the cooling of the granite. Where the granite is in contact with greenstones, it has caused contact metamorphism which converted the greenstone rocks to an epidiorite. The epidiorite becomes coarser as the granite is approached, and is characterized by the development of hornblende, which gets coarser towards the contact until the rock becomes an amphibolite (Wiles, 1957).

5.1.3. Structural Geological Framework

All the lithologies within the GGB are generally intensely deformed. Most of the deformation history of the GGB presented here was updated from a detailed structural evaluation effort conducted over the whole belt by Dirks and Mikhailov (1998). Dirks and Mikhailov (1998) interpreted deformation of the GGB to have occurred in three major distinct deformation events namely D1, D2 and D3, as presented below:

5.1.3.1. D1 (Ductile Deformation)

D1 deformation refers to the first ductile deformation phase believed to have occurred at amphibolite facies grade and resulted in the development of penetrative deformation structures that dominate most outcrops within the GGB. D1 structures represent the dominant deformation features in the area. It is associated with an S1 foliation, that parallels compositional layering within lithologies such as BIF. S1 is generally intensely developed, with fabric asymmetries such as S/C structures very common. A mineral lineation, L1, is generally preserved on S1 foliation surfaces. S1 and L1 are defined by amphibolite facies minerals, including hornblende in meta-andesites and grunerite in BIF. This indicates that the main stage of D1 deformation occurred at relatively high metamorphic grades of ($T > 500^{\circ}\text{C}$). At such metamorphic grades, pyrrhotite is more stable than pyrite. S1/L1 are most intensely developed within mafic schists. Serpentinities are the least deformed and occur as lenses of relatively undeformed massive and cumulate textured serpentinite usually found wrapped within the regional S1 foliation. BIF units were variably deformed during D1. The less deformed sections of BIF horizons preserve a regular compositional layering. The layering was intensely folded during several progressive folding events, with parallel fold axes that also parallel the mineral lineation. In highly deformed sections of the BIF, the primary layering is entirely transposed, sheared out and overprinted by an intense S1 foliation, mainly defined by grunerite. The foliation generally dips at 60 – 80 degrees towards the east and the NE. The D1 deformation phase resulted in intense shearing parallel to layering within BIF units, producing pinch and swell, boudinaging, isoclinal folding, transposition, shearing and attenuation of the primary BIF layers.

On a regional scale, the D1 phase is associated with several major deformation zones, the most important ones include the NNW trending deformation zone on the western margins of the GGB. A second one appears to follow a poorly exposed BIF horizon to the west of Giant mine. Dirks and Mikhailov (1998) believe these to have accommodated the tectonic stacking and duplication of greenstone belt lithologies during a west directed horizontal accretion event during greenstone belt evolution.

5.1.3.2. D2 (Deformation of D1 Structures)

The D2 deformation phase produced ductile structures that are related to folding and deformation of early penetrative (D1) deformation fabric. The dominant S1 foliation is strongly crenulated and folded. D2 folds are commonly developed in or near the boudin necks of competent layers that were boudinaged during D1. These D2 structures however can be interpreted as the late-stage geometries that developed in a continuous D1-D2 progressive deformation regime. Quartz and carbonate veins were also emplaced during the D2 phase.

5.1.3.3. Granite Emplacement

After the progressive D1-D2 events, the area was invaded by granites. These granites and associated aplite dykes, pegmatites and veins truncate the dominant D1 and D2 structures. Emplacement of the granites was associated with amphibolite facies contact metamorphic events, reflected in non-oriented amphibole growth in meta-basic lithologies and BIF.

5.1.3.4. D3 (Brittle-Ductile Deformation)

The D3 deformational phase resulted in the formation of brittle-ductile shears and related fracture zones and quartz veins. All the lithologies, including the intrusive granites are truncated by brittle-ductile shear zones. D3 shear zones are relatively narrow and usually occur along lithological boundaries that often follow D1 shears and commonly occur with thin salvages of chlorite schist. It is common to find such shear zones along the margins of BIF horizons where they are generally associated with mineralized quartz veins. The dominant shear directions trend NS and NW-SE. They are associated with NS, EW and NW trending quartz veins.

5.1.4. Gold Belt Scale Mineralization

5.1.4.1. General

As already discussed, the GGB is part of the much larger MGB belt. The MGB is Zimbabwe's largest, most endowed and productive belt in terms of gold (Wiles, 1957; Bartholomew, 1990). It hosts the highest concentration of gold mines in Zimbabwe (Foster et al., 1986; Campbell and Pitfield, 1994), which including some of the country's largest deposits e.g. the Globe and Phoenix, Dalny, Golden Valley, Gaika, Patchway, and the Cam and Motor mine, and others. The Cam and Motor mine is historically the country's largest gold mine, having produced more than 150 metric tonnes of gold (Bartholomew, 1990; Nyagumbo, 2017). Gold mineralization within the GGB is epigenetic and structurally controlled. It is associated with D1 ductile and D3 brittle ductile shears and faults, that are variably hosted by almost any of the lithologies within the GGB, as discussed below.

5.1.4.2. Lithological Association

In terms of deposit scale geology, economic gold mineralization within the GGB is mostly hosted within (i) sheared BIFs and (ii) quartz vein reefs associated with lower order structures. The recently discovered (iii) felsite hosted gold mineralization represents a third significant type of gold mineralization within the GGB, as discussed below.

(i) BIF hosted Deposits

BIF hosted deposits form most of the large economic gold deposits within the GGB. Examples include the Giant, Elvington and Newfound Out deposits. Mineralization within the BIF generally occur as sulphide-quartz impregnations hosted within discontinuous lenses of strongly deformed BIF, although mineralized veinlets are also very common. In the Lone Star/Elvington mine deposit, it was noted that a clear relationship exists between fold hinges in BIF and gold mineralization (Campbell & Pietfield, 1994). Gold mineralization is most intense along chloritic partings, especially where the BIF is strongly sheared.

Within the mineralized BIF, pyrrhotite forms the most dominant sulphide and occurs along foliation planes (Phaup and Dobell, 1938). Late unoriented pyrite cubes, overgrowing foliation are also very common

(Mutambara, 1991). Chalcopyrite and bornite staining have been recorded from several deposits, with arsenopyrite generally forming a minor phase, together with galena which has also been described in several deposits (Dirks and Mikhailov, 1998). The deposits can be described as Au-only, although appreciable amounts of silver have also been produced as a by-product from several gold mines in the past.

Mineralization is believed to have occurred through deformation induced fluid flow (Fisher, 1992), related to strain partitioning and shearing within and around the BIF. Fluid flow was clearly focused along the contacts of the BIFs and along zones of brittle failure and other dilational conduits within the more competent BIF. Channelling of mineralizing fluids within the BIF units promoted fluid-wallrock interaction in the form of sulphidation of magnetite-rich laminae, resulting in the co-precipitation of gold (Campbell and Pietfield, 1994).

(ii) Quartz Reefs

Apart from BIF, some of the mines within the area are related to relatively thin, but laterally continuous quartz veins. They may or may not be associated with BIF. The two largest recorded deposits of this type (Blue Rock and Water Lily) mined quartz vein reefs that either cut or occur close to BIF lenses.

(iii) Felsite and Quartz-Porphyry hosted Deposits

Felsite hosted gold deposits are a relatively new discovery and the third most significant lithological association within the GGB. In the past such mineralization was known to exist as an insignificant, small and low grade mineral lithological association, commonly associated with major gold reefs in numerous mines within the district. This thinking is however changing following the discovery of a new gold deposit at Blue Rock, as well as numerous others discovered in the past in several different gold belts. At present, no research has been conducted on the felsite-hosted gold deposit at Blue Rock to support the understanding of this type of gold mineralization, but efforts to characterize it in detail is the scope of this study. Recent mapping of the whole GGB dedicated to understanding the occurrence and significance of felsites in localizing gold within the GGB is presented below.

5.1.4.3. Structural Association

Gold mineralization within the GGB is structurally controlled and mainly associated with NS and NW-SE trending shears. Mineralization is believed to have occurred in two stages viz:

- (i) An early D1, ductile deformation and tectonic stacking event which resulted in the intense shearing and folding of certain BIF horizons that got mineralized. This phase is associated with pyrrhotite as the most abundant sulphide, which formed during the late syn-D1 shearing event and occurs along foliation planes within mineralized BIF horizons (Phaup and Dobell, 1938). These ductile D1 shears are associated with many gold workings. The largest and most significant of these include the Giant and Elvington mines, which occur within intensely sheared and folded portions of the BIF. Gold mineralization increases with the intensity of BIF deformation (Dirks and Mikhailov, 1989).
- (ii) A subsequent D3, brittle-ductile faulting and shearing event which resulted in a second stage of mineralization, is mainly associated with quartz veins. This second Au mineralization event was associated with pyrite during post-recrystallization. The most highly mineralized workings are cut by D3 shears. And such shears occur especially along the margins of BIF lenses, where they cut the BIF at low angles (Dirks and Mikhailov, 1998).

The most dominant brittle-ductile fault directions trend NS, EW and NW and to a lesser extent NE. They are the most significant in localizing major gold workings, although some of the major gold workings in the

southern part of the area occur on intersections of NW and NE trending lineaments of regional significance (Dirks and Mikhailov, 1998).

5.2. RECENT SURFACE GEOLOGICAL MAPPING

5.2.1. Gadzema Greenstone Belt Geology

More recent surface geological mapping of the whole GGB was conducted by the author at a scale of 1: 25 000 (Fig. 18 & 19). The main objective of the mapping was to characterise the various structural and lithological associations important for localizing significant gold deposits. Key among these are felsites and quartz-porphyry rocks, which had just been identified as representing a new significant lithological association for felsite-hosted gold mineralization at Blue Rock. But these rocks had not been mapped in any detail by historical geological studies. The mapping was conducted using a combination of walkover surveys, together with interpretations of airborne geophysics and remote sensing data.

5.2.1.1. Regional Surface Occurrence of Felsites

Surface mapping identified felsites and quartz-porphyries to be a significant constituent of the geology of the GGB, which improved the prospectivity of the belt for felsite hosted gold mineralisation.

In hand specimen (Fig. 20B), the felsites are composed of abundant quartz and feldspars mostly altered to sericite, with mica occurring as a minor phase. Some of the quartz and feldspar occur as phenocrysts set in a finer groundmass matrix of the same composition. In the field these rocks mostly form low-lying ground covered by brownish silty sand soils, except where outcrops occur within small-scale mine workings (Fig. 20A). Most of the felsites are concealed below this thin cover of soil and could only be mapped using a combination of airborne magnetic and radiometric data. On outcrop, the felsites occur as light coloured, fine to medium-grained rocks. They commonly occur as massive, well jointed rocks crosscut by numerous small faults, that have been penetrated by quartz vein stock-works especially along their sheared margins.

The felsites appear to have been emplaced parallel to the regional NNW trending geological fabric, as semi-continuous, intrusive, narrow and elongate bodies with dyke and sill-like morphologies as well as other irregular shapes. They are variably sheared in places to a banded rock with a weak schistose cleavage, that is consistent with the regional geological fabric. Occasionally the shearing is intense especially towards their margins where they are in contact with surrounding abundant older mafic schists which they intruded. The shearing has variably produced a strongly banded rock, a sericite- or felsic schist with coarse quartz grains. In places they are metamorphosed, possibly through contact metamorphism from the nearby intrusive Biri granite to a fine-grained granular rock with an aplitic texture.

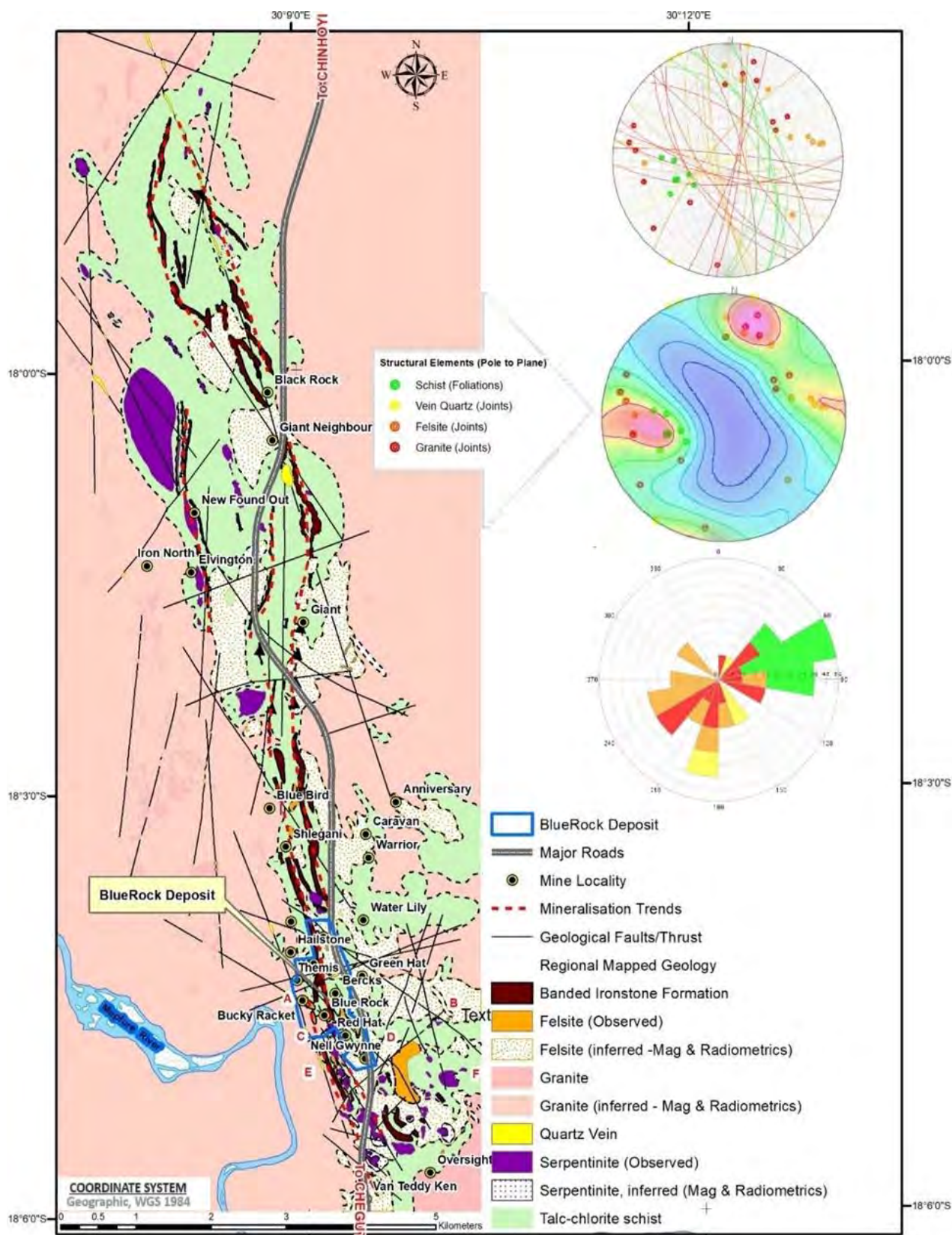


Figure 18: Recent surface geological mapping conducted by the Author, covering the whole Gadzema Greenstone Belt, soon after the re-discovery of the Blue Rock deposit. Geological Cross Section lines 'A-B', 'C-D' and 'E-F' are presented as Fig. 19.

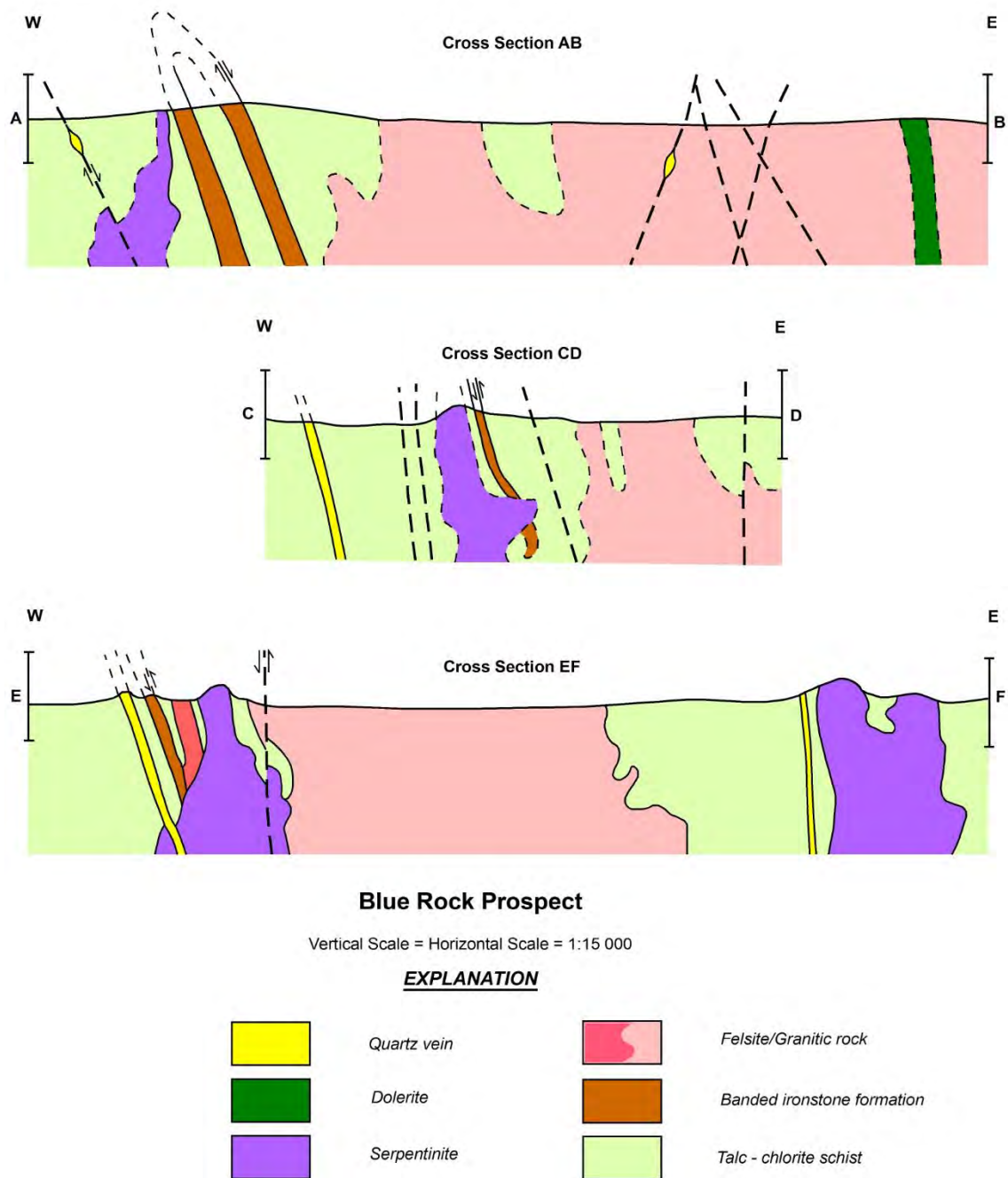


Figure 19: Geological Cross Sections ("A-B", "C-D" & "E-F") for three traverse lines on surface geology map (Fig. 18) over the Blue Rock gold deposit.

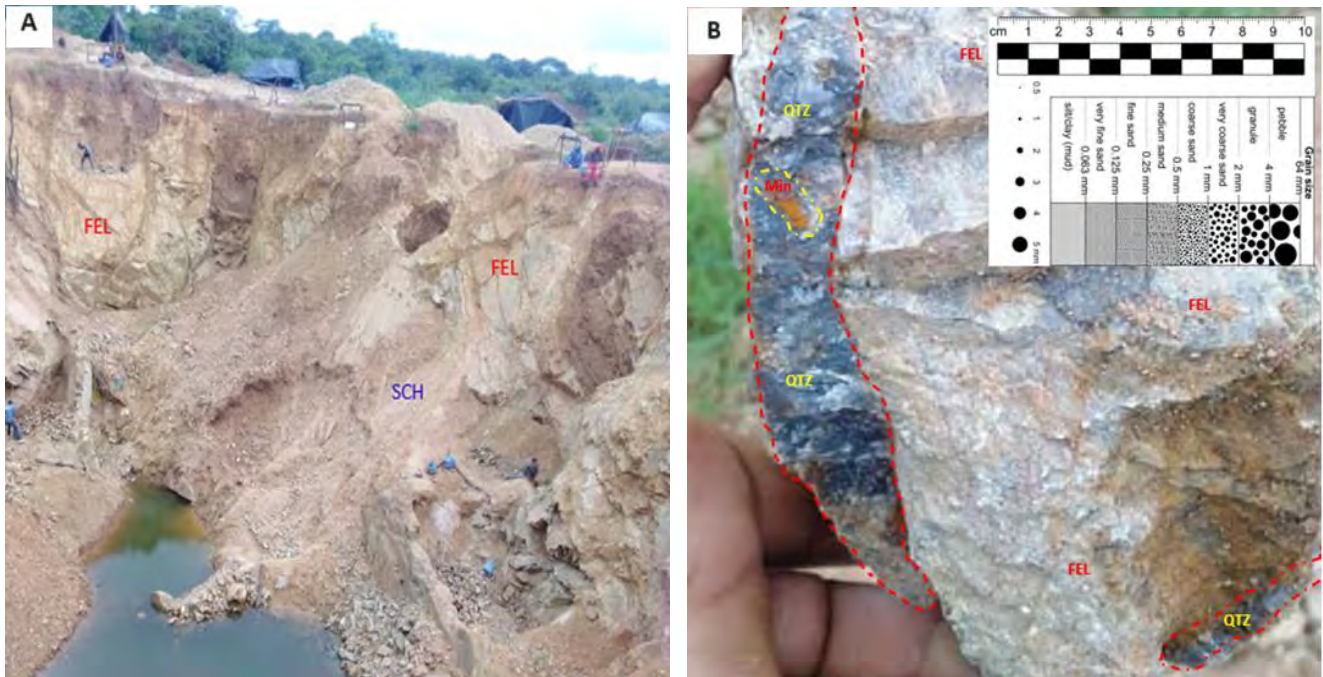


Figure 20: Shallow small-scale open cast mining exposure (Picture A) at the new Blue Rock deposit, mining felsite orebodies that are intrusive into mafic schist (SCH) rocks. Ore consists of sheared, faulted felsite (FEL) hosting a stock-work of mineralized (Min) quartz veins (QTZ) (Picture B).

5.2.1.2. 3D Geological Model of Regional Geology

At regional scale, the spatial distribution of the felsites and gold occurrences within the GGB, can be visualised best in a 3D geological model (Fig. 21), done by the Author as part of this study using surface geological mapping, related regional geology cross sections, as well as geological information for the whole GGB. The model was done to provide sufficient regional geological context, within which to model and improve the understanding of gold mineralization at the gold discovery at Blue Rock.

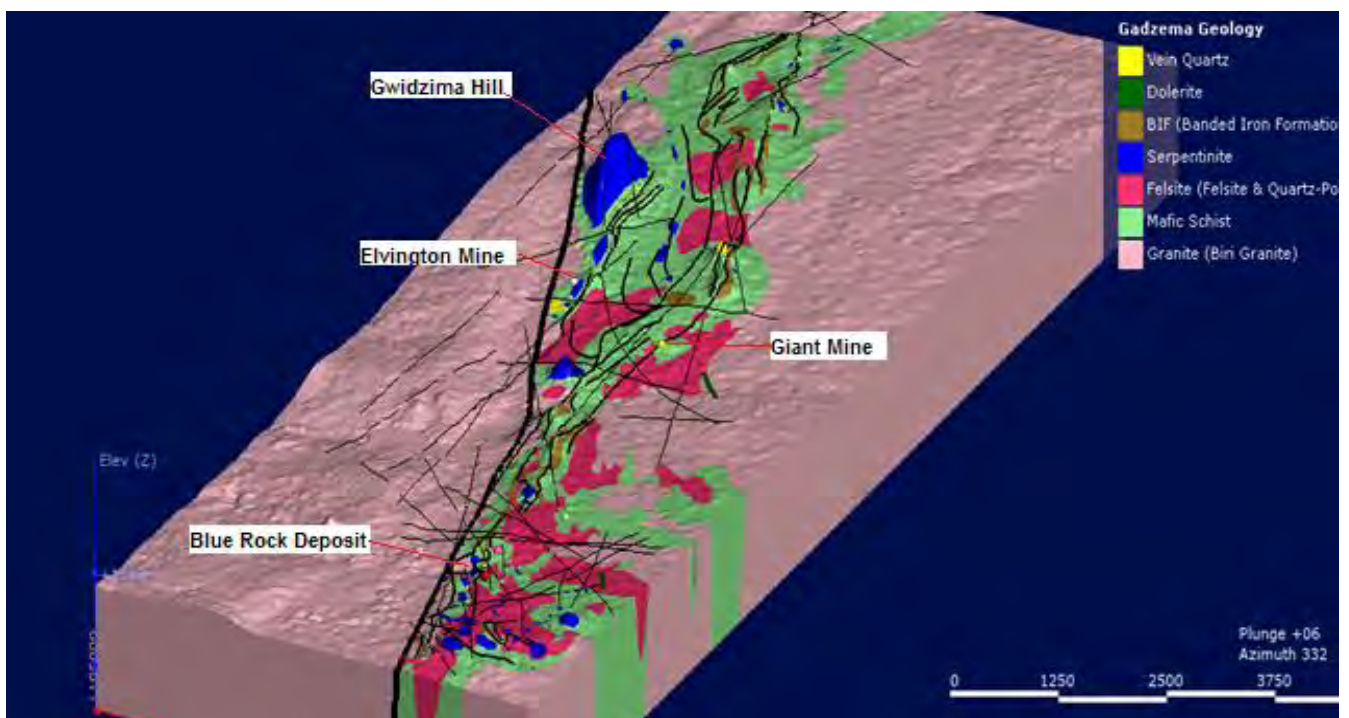


Figure 21: 3D Model of the Gadzema Greenstone Belt, showing Regional Geology mapped by the Author, including Structural Interpretation by Dirks and Mikhailov (1988).

The gold deposit at Blue Rock is located within the southern part of the GGB. The geology of the deposit at this scale is dominated by felsites in mafic schists. Gold mineralization and host felsite rocks occur near the western contact of ancient gold belt rocks with younger intrusive granite rocks to the west. The contact is defined by a major regional thrust zone flanking the belt on its western margin, which appears to be a northern continuity of the KDZ.

5.2.2. Deposit-Scale Geology

Unlike regional surface geological mapping, the main objective of deposit-scale surface geological mapping was to help understand in more detail the distribution of gold mineralization within host lithological domains and structures at deposit scale.

Results from regional surface geological mapping of the GGB, allowed for the mapping of the regional spatial distribution of the felsites, which became an important target for drill target testing of felsite-hosted gold mineralisation. At the gold deposit at Blue Rock, follow-up target testing work took the form of RAB, RC and diamond core drilling. And from this work the felsite rocks were confirmed to be the host for a “new” type of gold mineralization with potential to warrant a full-blown resource drilling campaign.

Deposit scale surface mapping (Fig. 22) initially utilized observations from small scale gold working exposures scattered all over Blue Rock, and then got refined further using resource drilling data. Such data included top-of-hole geology, done from interpretations of cross sections constructed by interpolating logged down-the-hole geology in between drill holes, for all the drilling phases (RC and DD drilling). Resource drilling boreholes were spaced at 20m borehole spacing and 40m line spacing. Geological cross sections (e.g. Fig. 23 & 24) were initially drawn by hand in the field and then re-interpreted during this study. This was done by plotting all the boreholes to produce 2D geological cross sections which were then imported into Leapfrog Geo and visualized together with borehole geology data in 3D, with a view to correlate geological domains and structural elements between different sections along the deposit or gold mineralization strike.

5.2.2.1. Deposit Scale Surface Occurrence of Felsites

A total of 42 geological cross sections were produced by the author and then used to construct a detailed deposit-scale surface geological map for the whole deposit. Detailed surface geological mapping of the deposit was done at a scale about 10 times more detailed (1: 2 500) than the one used for the regional geological mapping of the GGB.

Surface mapping at Blue Rock revealed gold deposit geology to be dominated by felsites and quartz porphyry rocks, hosted within a volcano-sedimentary sequence, consisting of mainly mafic schists, common interbedded BIF layers and serpentinites of the Upper Greenstone Series.

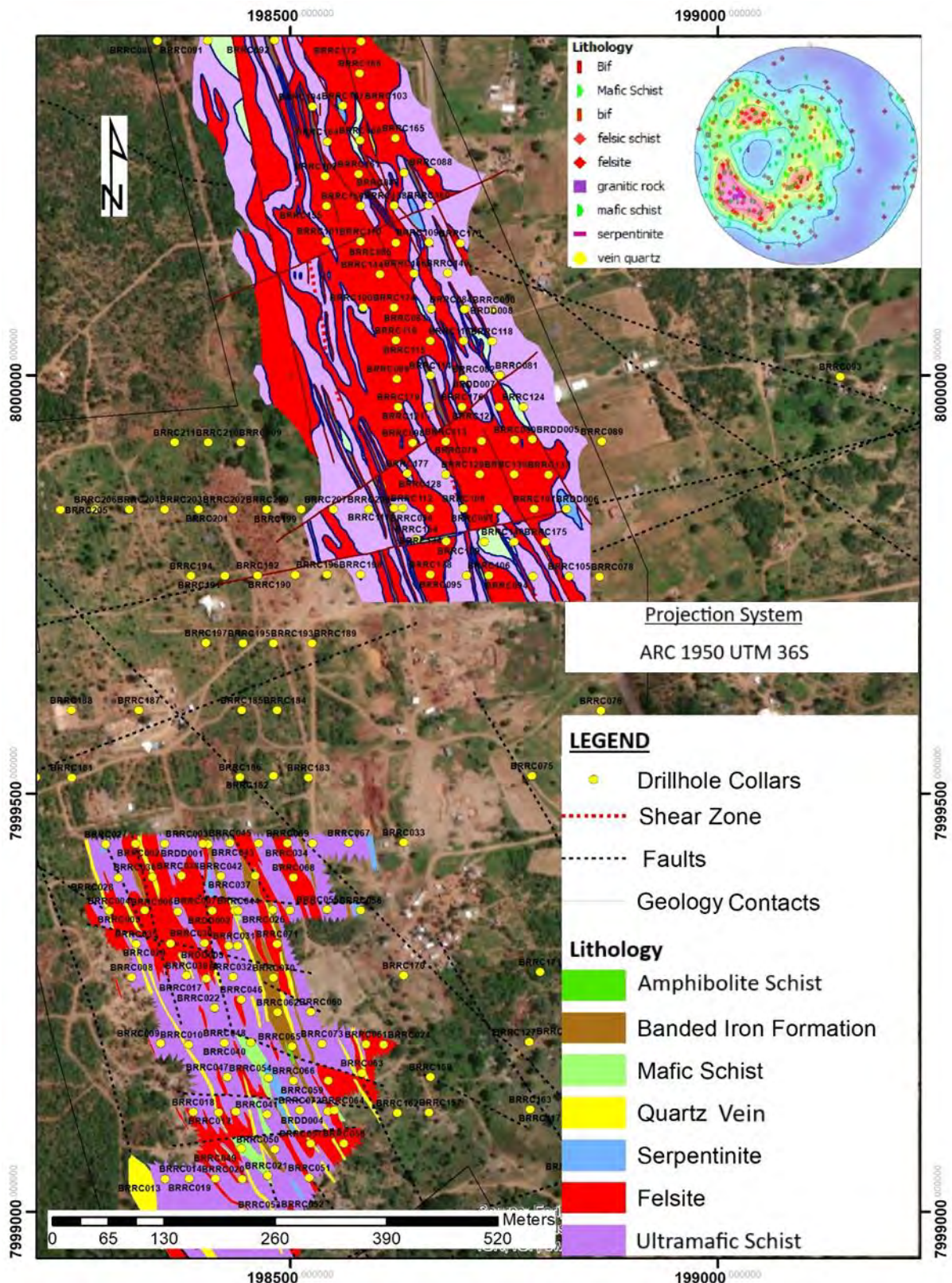


Figure 22: Detailed Surface Geological Mapping of the Blue Rock Deposit done by the Author at 1: 2 500, showing the distribution of host geological domains (Felsites, Bif, Quartz Vein and Mafic Schists).

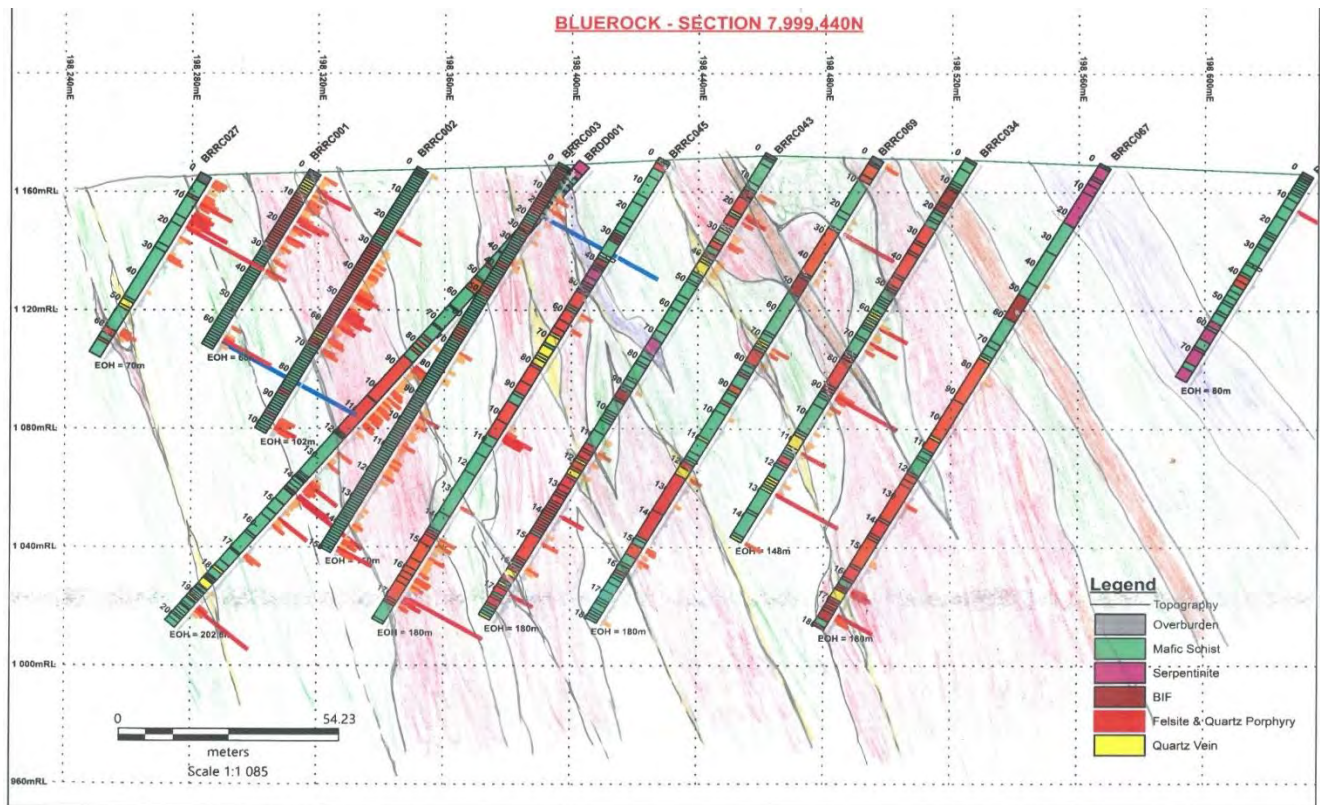


Figure 23: Hand-Drawn 2D Geological Cross Section 7,999,400N for the gold deposit at Blue Rock (Example 1).

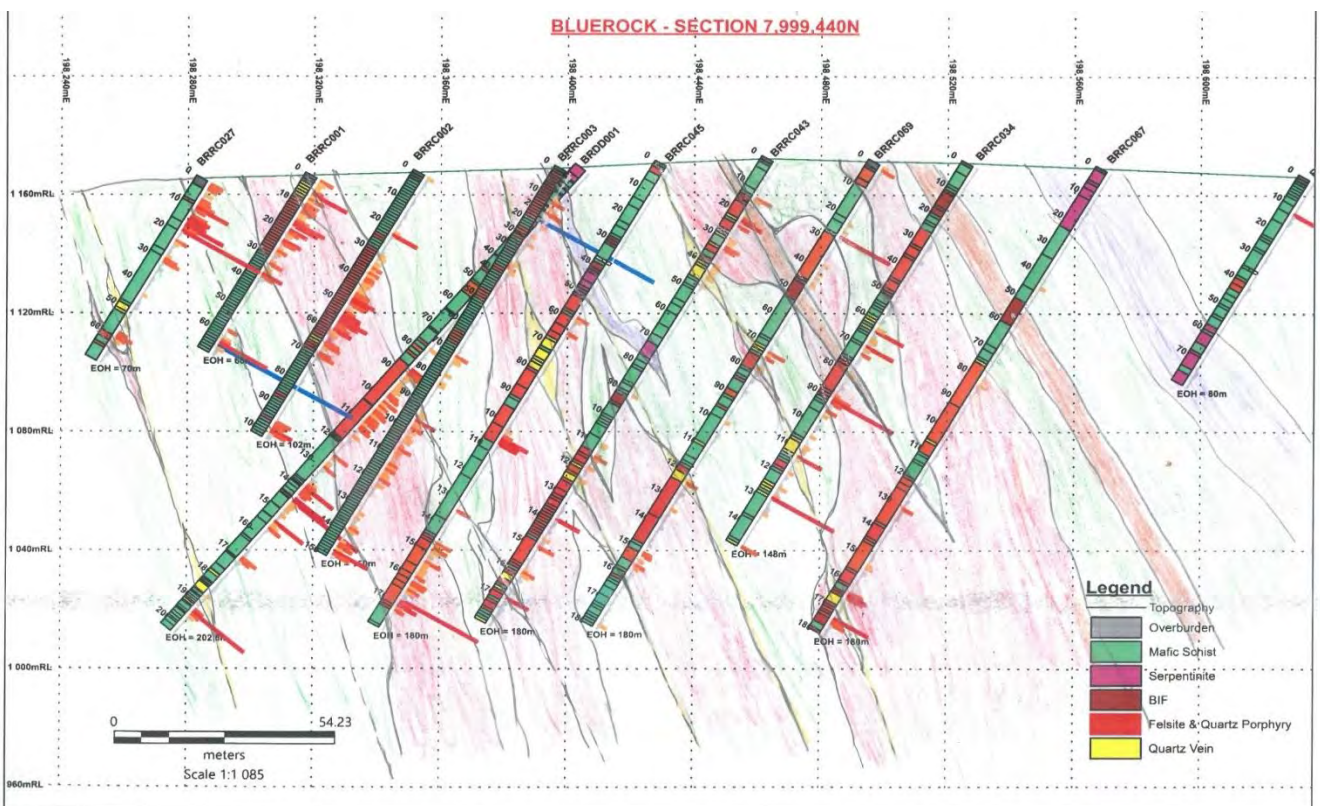


Figure 24: Hand-Drawn 2D Geological Cross Section 7,999,440N for the gold deposit at Blue Rock (Example 2).

5.2.2.2. 3D Model of Felsites at Gold Deposit Scale

All the data and results from detailed deposit scale surface geological mapping were modelled using Leapfrog Geo's powerful RBF™ engine, for better visualisation in 3D. In particular, the modelling was conducted using deposit scale surface maps, geological cross sections, as well as downhole geology logging data. To do this, lithological contacts were modelled using polylines digitized on georeferenced geological cross sections, whilst GIS lines digitised on detailed deposit-scale surface geological maps were used to model the geology and related structural elements (Fig. 25).

All the surface mapping data were integrated with downhole borehole logging data and together interpolated in 3D and then refined using the dominant regional structural trend, which variably strikes towards the NW. A total of 260 drill holes adding up to 34,500 meters and 29,400 gold assays were used. And from this, a geologically sensible 3D model of subsurface geology (Fig. 26, 27 & 28), covering the entire gold deposit was produced.

Results from the modelling show the geology of the gold deposit to be dominated by a network of felsite and quartz-porphyry intrusive rocks that dip steeply towards the east at an average of about 70 degrees, consistent with regional geology.

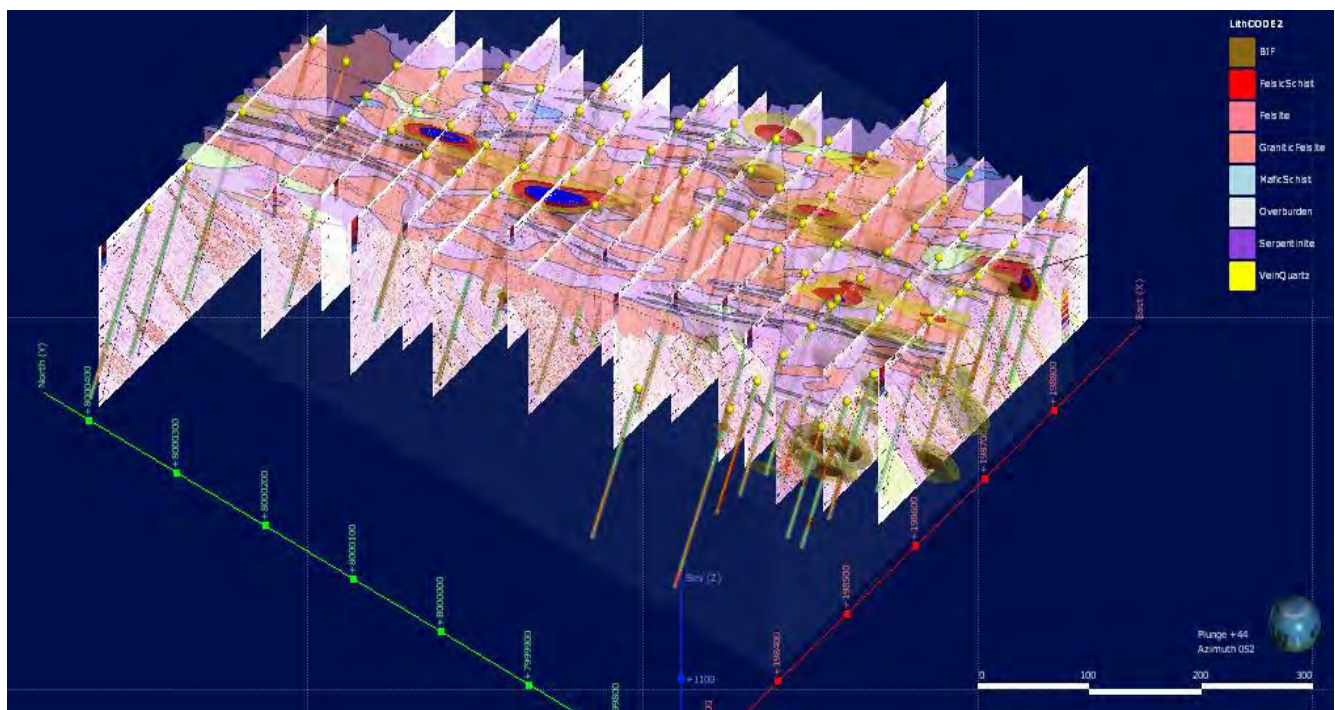


Figure 25: 3D Visualisation of Geological data and information for the gold deposit at Blue Rock (covering the Berks Prospect Part of the Project) used to model deposit scale geology in Leapfrog Geo.

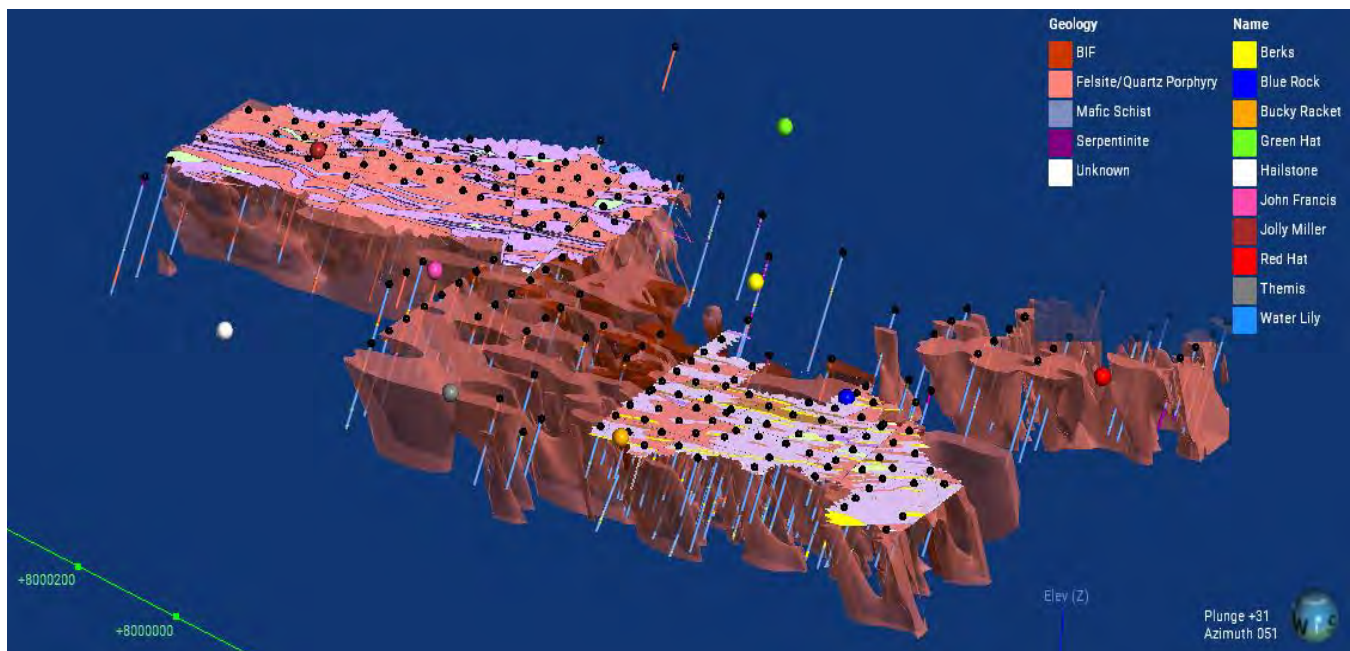


Figure 26: 3D Geological Model of the gold deposit at Blue Rock, done from a combination of surface mapping, geological cross sections and downhole drilling geology data.

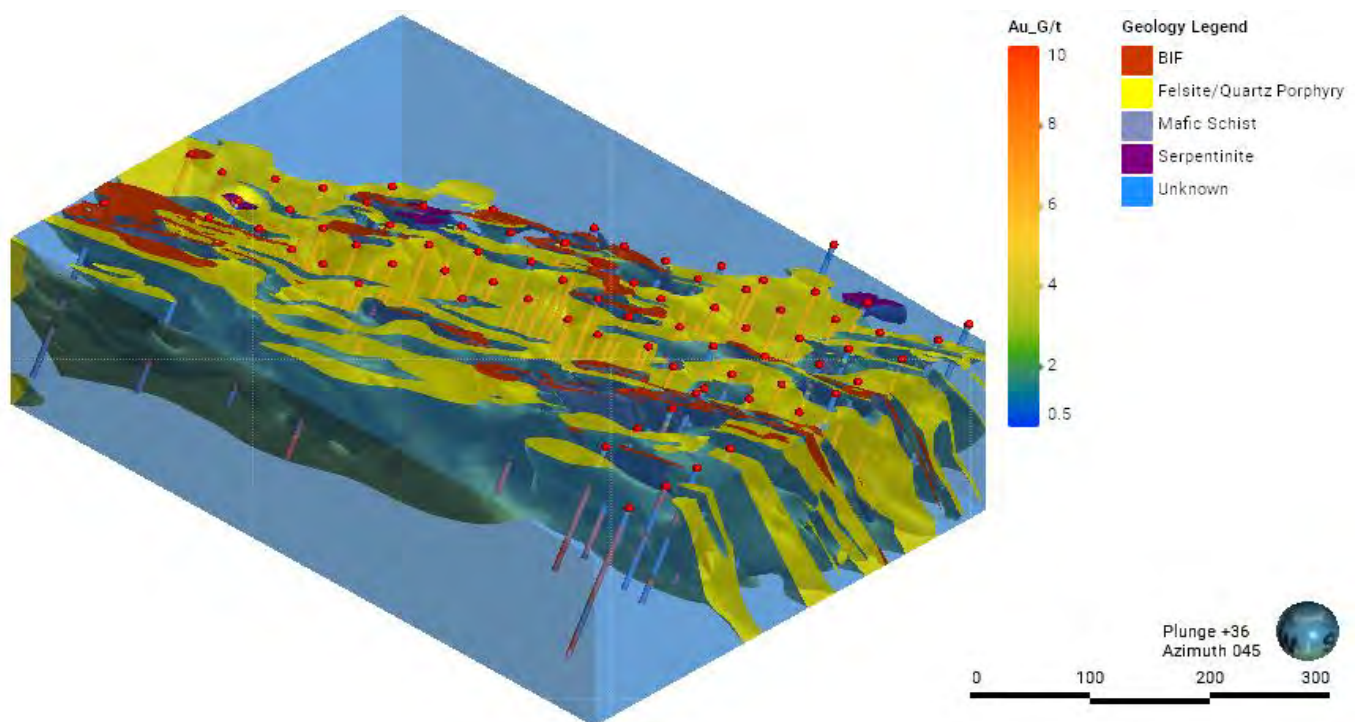


Figure 27: Berks Prospect part of 3D Geology Model constructed from surface mapping, geological cross sections and resource drill holes, showing thin interbedded BIF horizons, intrusive felsites and quartz porphyries associated with the bulk of gold mineralisation at the gold deposit at Blue Rock.

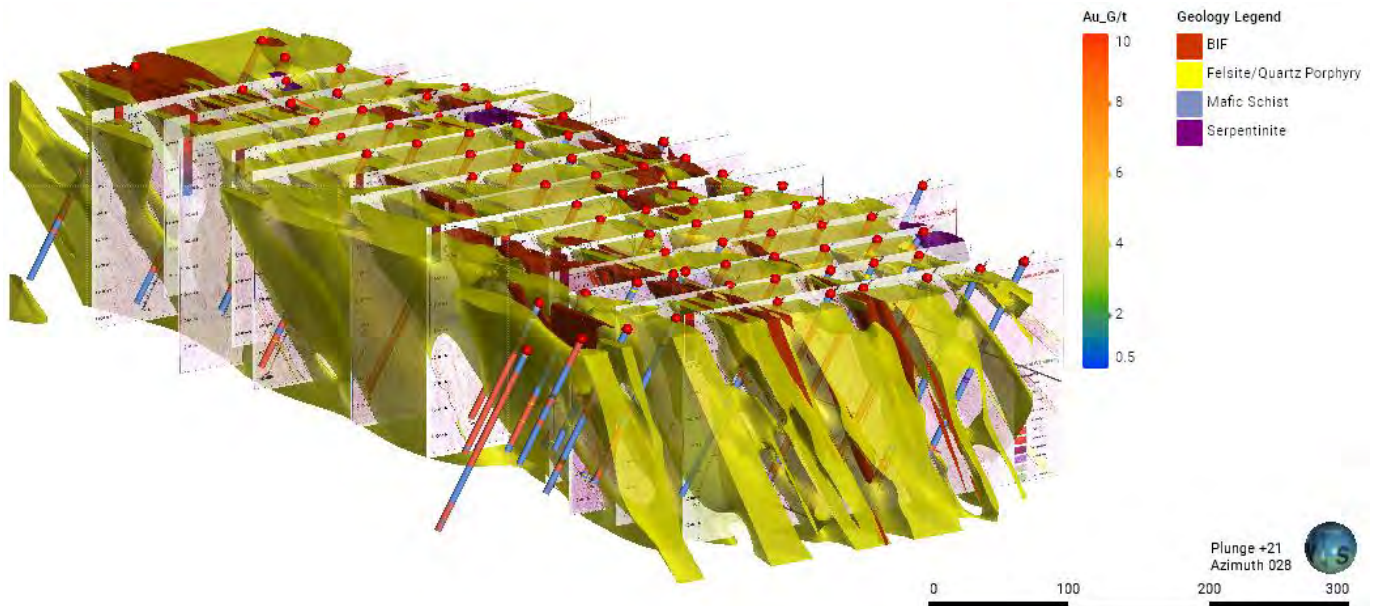


Figure 28: (2nd View) Berks Prospect part of 3D Geology Model constructed from surface mapping, geological cross sections and resource drill holes, showing thin interbedded BIF horizons, intrusive felsites and quartz porphyries associated with the bulk of gold mineralisation at the gold deposit at Blue Rock.

5.2.3. Deposit Scale Mineralization

At the gold deposit at Blue Rock, the felsites are exposed in small-scale workings currently being operated by small scale workers. Most of the workings are just shallow open cast excavations dug by hand and small diggers.

Gold mineralization is commonly associated with pyrite and occurs within numerous quartz vein stock works within joints and faults that crosscut the felsites as well as occur within their sheared margins. Mining by small workers is mostly selective and targets the mineralized stock-works of quartz veins along shears and fractures within the felsite and quartz porphyries. Grade control is done visually, with the most prospective ore consisting of strongly sheared, highly fractured and faulted rocks considered as good grade ore. The good ore is screened in the field by crushing it manually, and then hand-panning it to identify visible gold, which confirms gold mineralization in good grade ore, that is then selected for processing at a custom stamp- or ball mill to recover the gold.

CHAPTER 6. MINERALIZATION

6.1. GENERAL INTRODUCTION

This chapter seeks to characterize gold mineralisation at Blue Rock from all available data and information, using both quantitative and qualitative analytical methods.

At regional scale, the study uses endowment as a measure of the fertility factor which operated at geodynamic scale to influence the genesis, localisation and preservation of the gold deposit at Blue Rock. The study employs Zipf Law to evaluate all major historical gold occurrence data, available within production records from the numerous mines which operated in the past, scattered over the GGB.

Assessment at a local deposit-scale, however, makes use of abundant resource drilling data and information generated during drill target testing. Such data includes logged downhole geological data, and relevant gold assay results from ongoing resource drilling efforts. Analysis of data and results from drilling, was conducted using exploratory data analysis (EDS) as well as numerical and resource modelling tools available in Leapfrog Geo and Edge, to simultaneously analyse and visualize data in 3D.

Results from the analysis of gold mineralization were then integrated with geological models already discussed (CHAPTER 5) to characterise all the critical elements (including the role of felsites) that came together to form the gold mineralization which define the gold deposit at Blue Rock.

It is hoped that such information would serve a useful function to complement discussions already made on the role of geodynamic setting, fertility, architecture and preservation on gold deposits within the GGB terrain, including the one at Blue Rock.

6.2. FERTILITY ASSESSMENT

6.2.1. Endowment

As already discussed, the GGB belongs to the Western Succession, whose formation is believed to have occurred through accretion at continental margins (e.g. Kusky, 1998; Dirks and Jelsma, 1998; Dirks et al., 2002). Its fertility is marked by the occurrence of significant gold deposits including the Giant, Elvington, Newfound Out, and others. Like many other Western Succession terrains, gold potential within the GGB, is believed to average approximately 30kg/km² (Jelsma et al, 2021). But to understand the Fertility parameter for the GGB in better detail, ore endowment would be a good indicator.

Ore endowment, as defined for the holistic mineral systems concept, is the product of all critical factors responsible for ore deposit formation put together – where, “Ore Endowment = Fertility Factors x Geodynamic Factors x Architectural Factors x Preservation Factors” (Megill, 1988; Wyborn et al., 1994).

There are numerous ways of conducting a quantitative assessment of endowment. One such way involves the fractal analysis. The fractals method was used by Blenkinsop (1995), to demonstrate from detailed production and grade statistics of gold deposits, that produced more than 100kg Au, for the whole of Zimbabwe (Bartholomew, 1990), that gold deposits within the whole country are fractal and therefore scale invariant, just like most natural phenomena.

A fractal is a typical hierarchy (e.g. Batty and Longley, 1994; Chen, 2009; Frankhauser, 1998), that always follow scaling laws. Therefore, fractals can be described using power functions, and one such power function is the Zipf Law (Zipf, 1949). In this study the Zipf Law will be used to assess endowment, as a measure of fertility for the GGB, which hosts the new gold deposit at Blue Rock.

6.2.2. Zipf Analysis

The Zipf's Law was originally proposed by George Kingsley Zipf (Zipf, 1949; Florence, 1950), as a guide to statistical distributions in social studies. It is used to describe the relationship between the size and rank of discrete phenomena. Zipf's law states that the probability of an observation is inversely proportional to its rank. When applied to mineral resource populations, the law postulates most simply that, the largest deposit will be twice the size of the second, three times as great as the third, and one hundred times bigger than the hundredth, etc. In essence, the law predicts how many entities of a certain size may be left in a sequence of decreasing size assuming the largest one has already been ascertained. This implies that deposits become infinitesimally small as their number goes to infinity. When a deposit or pool size versus rank is plotted on double logarithmic paper, the law graphs as a straight line with a slope of minus one. The Y intercept, with size as the ordinate, equals that of the item designated as the first rank.

An accurate prediction of the total amount of resource material, of which only a part has been discovered and produced, is the major objective of such resource assessments. Thus, the question of how many deposits remain to be discovered, how rich would they be as individuals and what would be their total volume, must be addressed. To effectively do this, inferences from empirical or mathematical models based on analogies of Zipf's Law are generally utilized.

To estimate potential endowment for the GGB therefore, historical gold production and deposit resource estimates are required to quantitatively analyse or calculate natural and residual gold endowment.

In this study gold production statistics from major historical gold mines within the GGB (Table 2), including the original Blue Rock gold deposit (Bartholomew, 1990) were used. Almost all the major mines within the GGB are now closed and therefore no longer productive. Published historical gold production figures up to 1990, from Bartholomew (1990) as well as deposit resource estimates from exploration company records were used in this study.

Table 2: Historical Gold Production Figures (up to 1990) for major gold deposits within the Gadzema Greenstone Belt (Extracted from Bartholomew, 1990).

Major Mine	Mineralization Style	Associated Sulphide Mineralogy	X_Coordinate	Y_Coordinate	Production 1984 (Kg) – Bartholomew (1994)	Average Recovery Grade (g/t)
Blue Rock	Quartz reefs striking NS and dipping 64°E in hornblende-biotite schist.	Pyrite, Chalcopryrite, galena	18°04'30" S	30°09'00" E	236.93	10.3
Elvington	Sulphide impregnation in BIF and mineralised Quartz veined serpentinite schist striking NS and dipping 50-70°E	Pyrite, arsenopyrite, pyrrhotite	18°01'30" S	30°08'00" E	565.21	9.6
Giant	NS striking BIF with interbedded chloritic schist and sulphide rich layers	Pyrrhotite, Pyrite, arsenopyrite, Chalcopryrite	18°02'00" S	30°09'00" E	17 474.11	8.2
Iron Hat	Quartz veins striking NS and dipping 30°E in	Pyrite	18°22'00" S	30°06'30" E	126.21	7.9

	granite and BIF rubble with visible gold.					
Newfound Out	Sulphide impregnation in BIF striking NS and dipping 70°E	Pyrrhotite, Pyrite, Chalcopyrite, arsenopyrite,	18°01'00" S	30°08'00" E	655.85	11.1
Red Hat	Deformed NS striking BIF	Pyrite	18°05'00" S	30°09'30" E	500.50	12.0
Water Lily	Quartz vein dipping 500E in granite and associated with BIF	Pyrite	18°04'00" S	30°09'30" E	117.67	11.8
Totals					19676.48 #	8.4*

Results from the analysis of gold endowment of the GGB using Zipf analysis are summarised in Table 3 and presented graphically in Fig. 29, below. According to this analysis, the GGB has a total endowment potential of about 3 million Au ounces, with only about a third (1 million ounces) of that having been discovered and mined to date. The balance of about 2 million ounces, estimated from Zipf's law statistical assessment, represents residual gold endowment, which remains to be discovered from ongoing and future exploration efforts.

Table 3: Zipf Analysis values based on existing major deposits including Blue Rock gold mine.

Rank	Gold Deposit Name	Calculated Zipf (Kg)	Discovered (Kg)	Residual (Kg)
1	Giant Mine Deposit	18 000	18 000	0
2	New Blue Rock Discovery	9 000	9 000	0
3	Undiscovered	6 000	0	6 000
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
16	Elvington Mine Deposit	1 125	1 125	0
17	Undiscovered	1 059	.	1 059
18	Undiscovered	1 000	0	1 000
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
25	Undiscovered	720	0	720
26	Undiscovered	692		692
27	NewFound Out Mine Deposit	667	667	0
28	Undiscovered	643	0	643
.	.	.	.	.
.	.	.	.	.

34	Undiscovered	529	0	529
35	RedHat Mine Deposit	514	514	0
36	Undiscovered	500	0	500
.	.	.	.	.
.	.	.	.	.
74	Undiscovered	243	0	243
75	Blue Rock Mine Deposit	240	240	0
.	.	.	.	.
Totals (KGs)		88 224	29 546	88 224
Total (Ounces)		> 3 million ounces	~ 1 million ounces	>2 million ounces

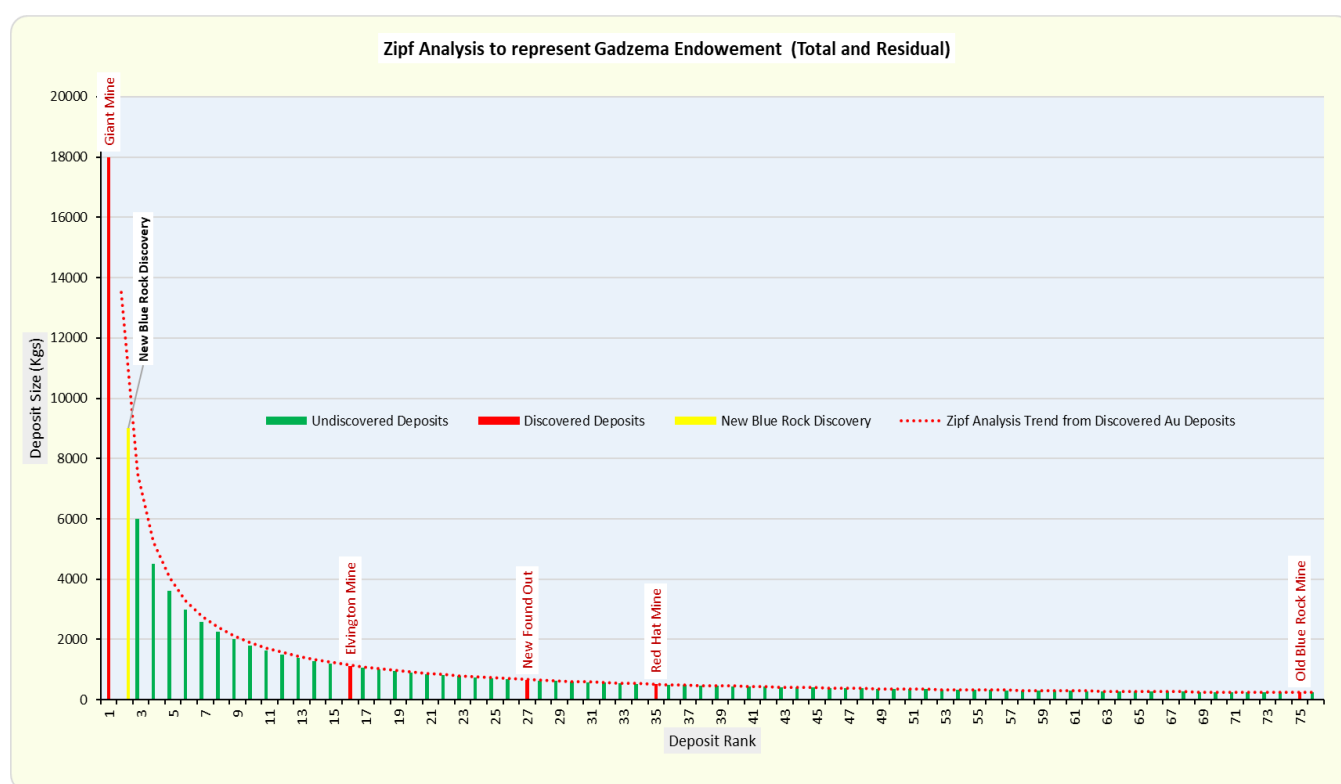


Figure 29: Zipf Analysis Chart, showing Gadzema Greenstone Belt Gold Endowment (Rank plotted against Gold Deposit Size).

The gold deposit at Blue Rock is hosted within an orogenic geodynamic setting with very good fertility, as evidenced by a very good endowment demonstrated in this study.

6.3. EXPLORATORY DATA ANALYSIS (EDA)

This section deals with the analysis of deposit-scale exploration data, conducted in this study to characterize mineralization at the gold deposit at Blue Rock. Data analysis is conducted to reveal the nature and possible controls of gold mineralization. This is done through the modelling of mineralization and subsurface geology together, with a view to interrogate the possible relationships that might exist between gold mineralization, lithology and structure. Available surface geological mapping, downhole subsurface borehole geology logging and assay data, are all used for this purpose.

6.3.1. Statistical Data Analysis

Exploratory Data Analysis (EDA) was conducted on drilling data by plotting the data on univariate, bivariate plots and graphs to quantify numeric distributions. In addition to quantifying the distribution of data, results from this analysis were used to support the analysis and modelling of geological domains from both interval and point datasets.

Analysis of numerical data consisting of gold assay results for the gold deposit at Blue Rock was done through a histogram, table of statistics, box plots and correlation logs, to display and reveal the distribution of gold assay values within the different lithological and structural domains.

- A length-weighted **Histogram** was produced for the entire undifferentiated drilling data set consisting of 260 (RC & DD) drillholes and 29,407 gold assay values from sampling done every meter (Fig. 30).
- A **Table of Statistics** (Table 4) was utilised to gain more valuable insight into the geological controls on gold mineralization, by focusing data analysis on geological unit specific statistics. This was done by simultaneously analysing both numerical (assay) and categorical (geology) data integrated together in Leapfrog Geo. To do this, a table of statistics was created from a merged table consisting of both geological logging and gold assay data.
- Further data analysis was done using a **Box Plot** to conduct statistical analysis on gold values. The objective of using a Box Plot was to characterize the different mineralized geological domains through testing for any possible spatial relationships that might exist between gold mineralization and the different lithologies sampled during resource development drilling of the gold deposit. The analysis was done by graphing gold assay values against logged borehole lithologies (Fig. 31).
- The different mineralised domains were then plotted on **Correlation Logs**, to display the different lithologies and their respective assay values within different boreholes (e.g. Fig. 32 & 33).

6.3.1.1. Histogram

When displayed on a Histogram plot, gold assays from exploration of the gold deposit at Blue Rock, display a positively skewed population, which is typical of low-grade deposits. The histogram of gold values was also used to select a cut-off grade of assay values for further statistical analysis and for numerical modelling of mineralization as discussed below.

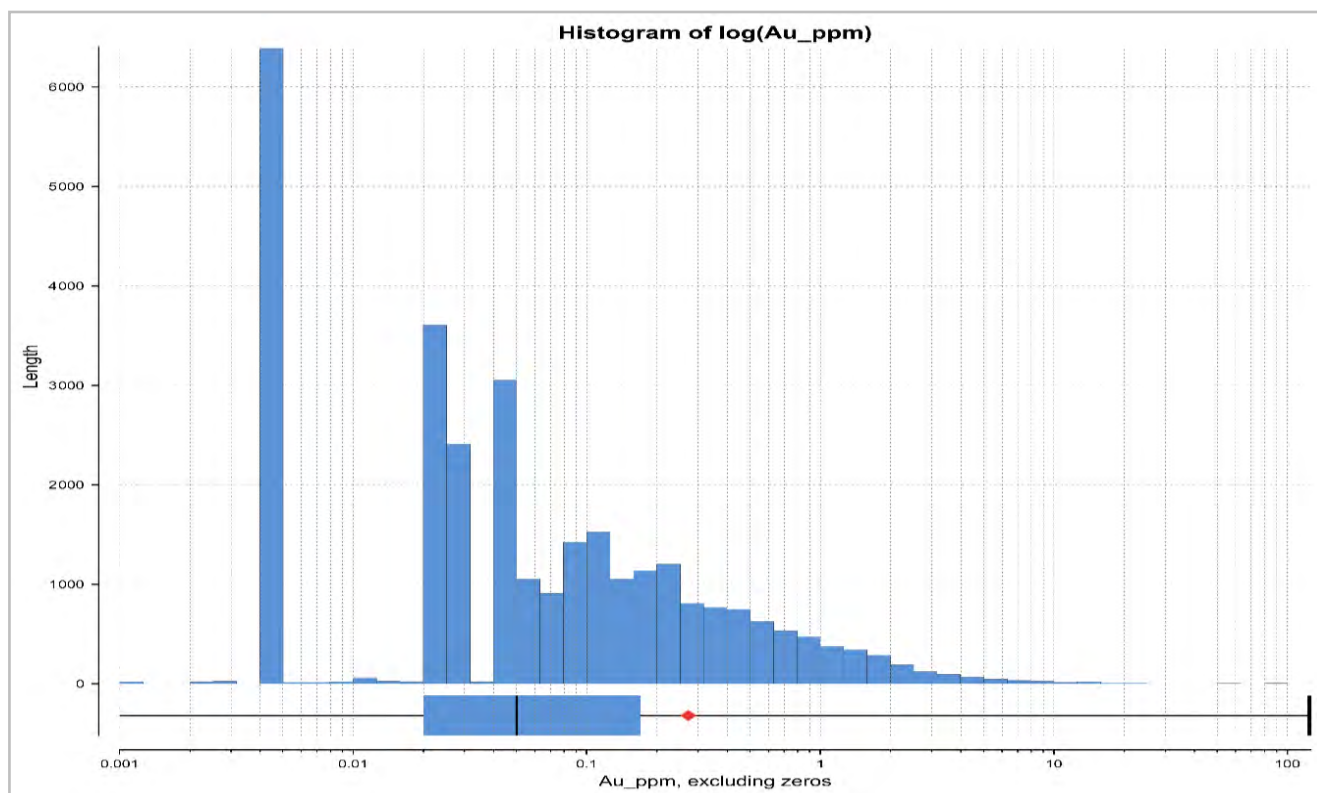


Figure 30: Length-Weighted Histogram Plot of gold assay values for the gold deposit at Blue Rock.

6.3.1.2. Table of Statistics

A table of statistic (Table 4) derived from analysing the statistical distribution of gold values within different lithological domains shows gold to be associated with almost all the lithologies (typical of epigenetic orogenic gold that require no special rock), albeit with differences in the degree of mineralization amongst the different lithological units. The bulk of the mineralization (58%) is associated with felsic intrusive and quartz porphyry rocks, which were variously logged from drill core, as felsite, felsic schists and granitic felsites, but later classified through petrographic work conducted by ACR, as felsites and quartz porphyries. The rest of the mineralization is variously hosted by different lithologies, which in order of decreasing abundance and grade, are mafic schist (29%), Quartz vein (7%), BIF (4%), and the least mineralized serpentinites (<1%). A few meters of overburden or soil cover is also mineralized, with analysed samples constituting about 2% of positive assays above a cut-off grade of 0.5 g/t Au, - a response that could serve as a useful vector during the search for this type of gold mineralization.

Name	Count	Length	Mean	Minimum	Maximum
✓  Au, g/t	3,409	3,317.0	1.78227	0.5	124.09
 BIF	116	114.5	1.76943	0.5	14.46
 FelsicSchist	312	298.5	1.87473	0.5	14.16
 Felsite	1,497	1,476.1	1.9941	0.5	124.09
 GraniticFelsite	6	6.0	0.891667	0.55	1.62
 MaficSchist	1,144	1,097.8	1.514	0.5	84.95
 Overburden	100	98.8	1.31483	0.5	15.494
 Serpentinite	10	9.8	3.152	0.65	16.26
 VeinQuartz	221	212.6	1.79344	0.5	21.06

Table 4: Blue Rock Deposit Gold Assay Table of Statistics.

6.3.1.3. Box Plot

In terms of gold grade distribution, results from data analysis using the Box Plot, show mineralization at the gold deposit at Blue Rock, to be spread across multiple lithological domains, including quartz veins although most of it is hosted within the felsites and quartz porphyry rocks (originally visually logged from drill core in the field as felsite, felsic-schist and granitic-felsite). The mineralized quartz veins occur within all the mineralized lithologies as stringers and vein stockworks. The rest of the mineralization is spread across various lithological domains as shown on the Box plot (Fig. 31).

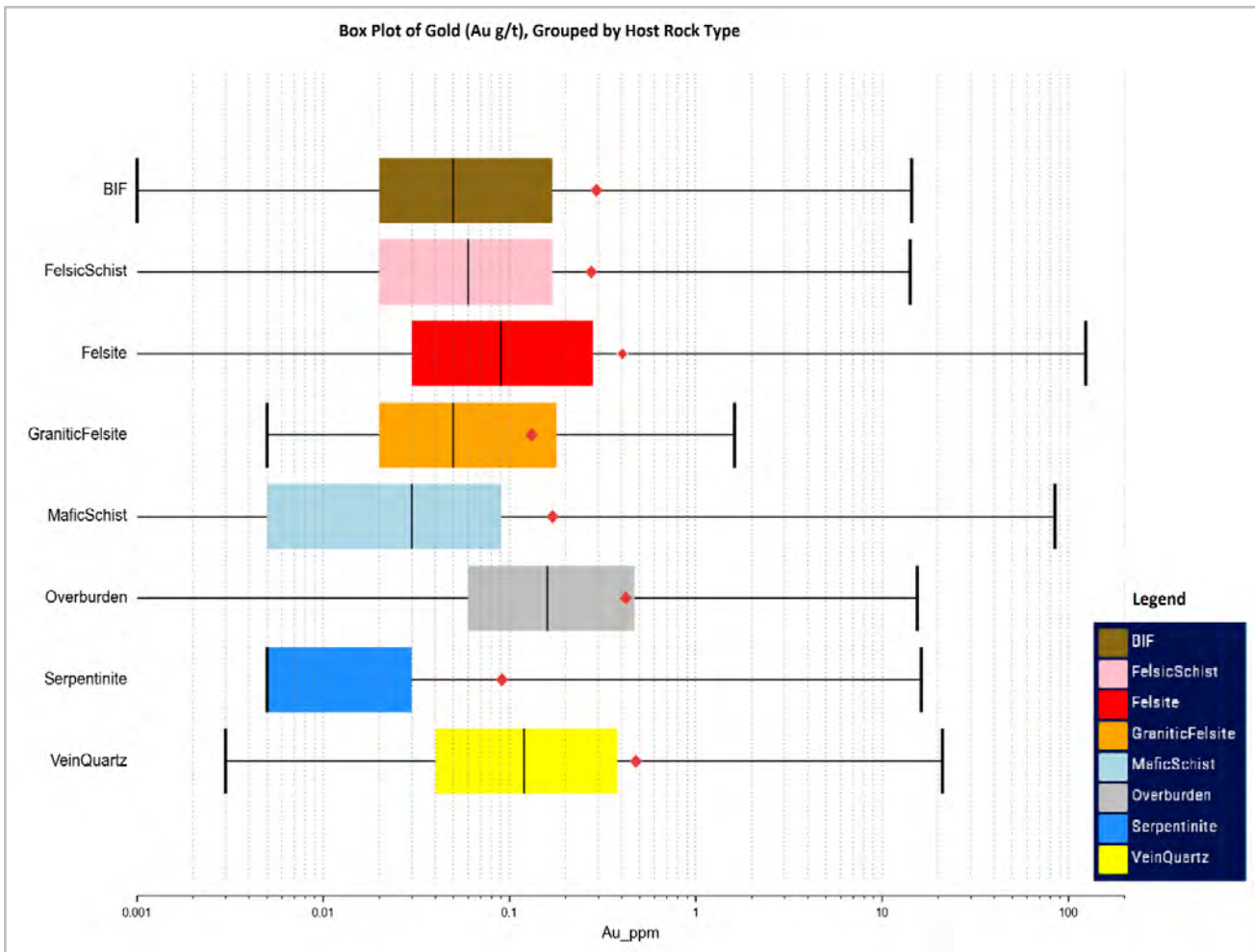


Figure 31: Box Plot analysis showing gold assay values for different lithologies. Quartz Vein (YELLOW) is the most mineralized lithology, followed by Felsite (RED), then Felsic Schist (PINK) and Granitic Felsite (ORANGE). Overburden is thin cover usually not exceeding 1m below surface on most boreholes. Serpentine (PURPLE) and Mafic Schist are the least mineralized.

6.3.1.4. Correlation Plots

In addition to statistical analysis, gold assays were plotted on correlation logs, to display the gold values together with geology as downhole data on respective boreholes, from which samples were collected, logged and analysed.

Representative correlation logs for boreholes BRDD001, BRRC036, BRRC038 and BRRC043 are presented in Fig. 32 & 33. The logs show gold mineralization to be associated mostly with felsites and quartz porphyries, with subordinate mineralization occurring within the hanging wall and footwall mafic schists and BIFs. But in almost all the cases mineralization is epigenetic and associated with structures (shears and faults) marked by quartz veins and strongly sheared domains within mineralised lithologies. The serpentinites are the least mineralized, showing no to very poor gold mineralization.

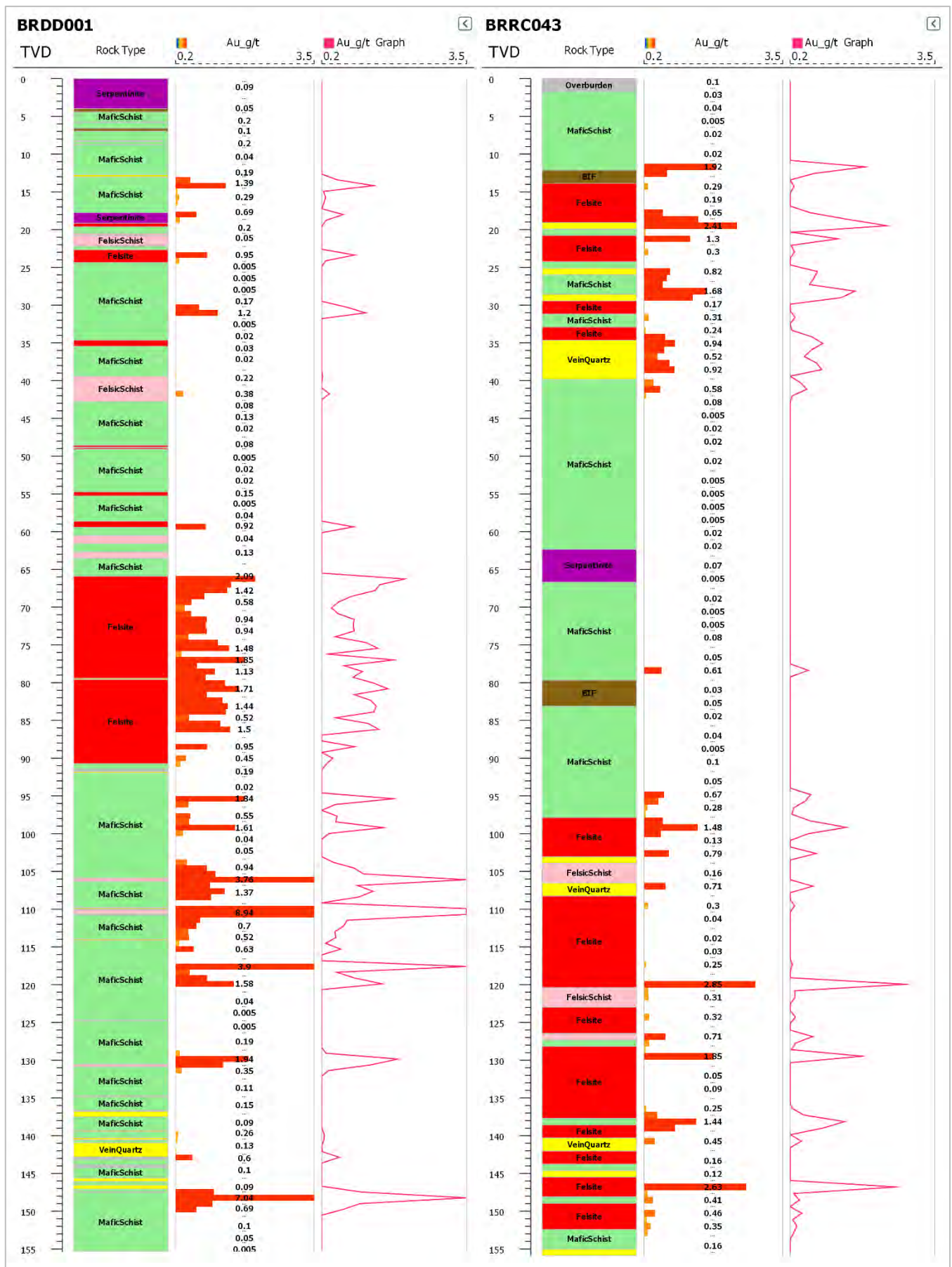
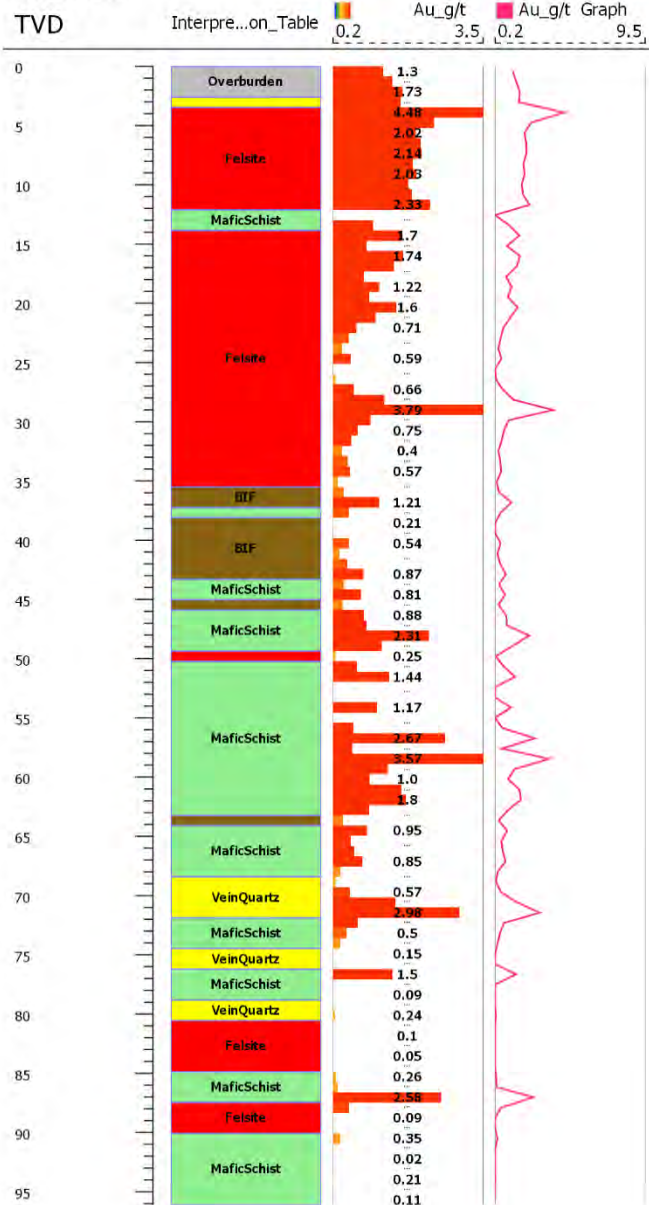


Figure 32: Correlation Log Plot for Boreholes BRDD001 & BRR043.

BRRC036



BRRC038

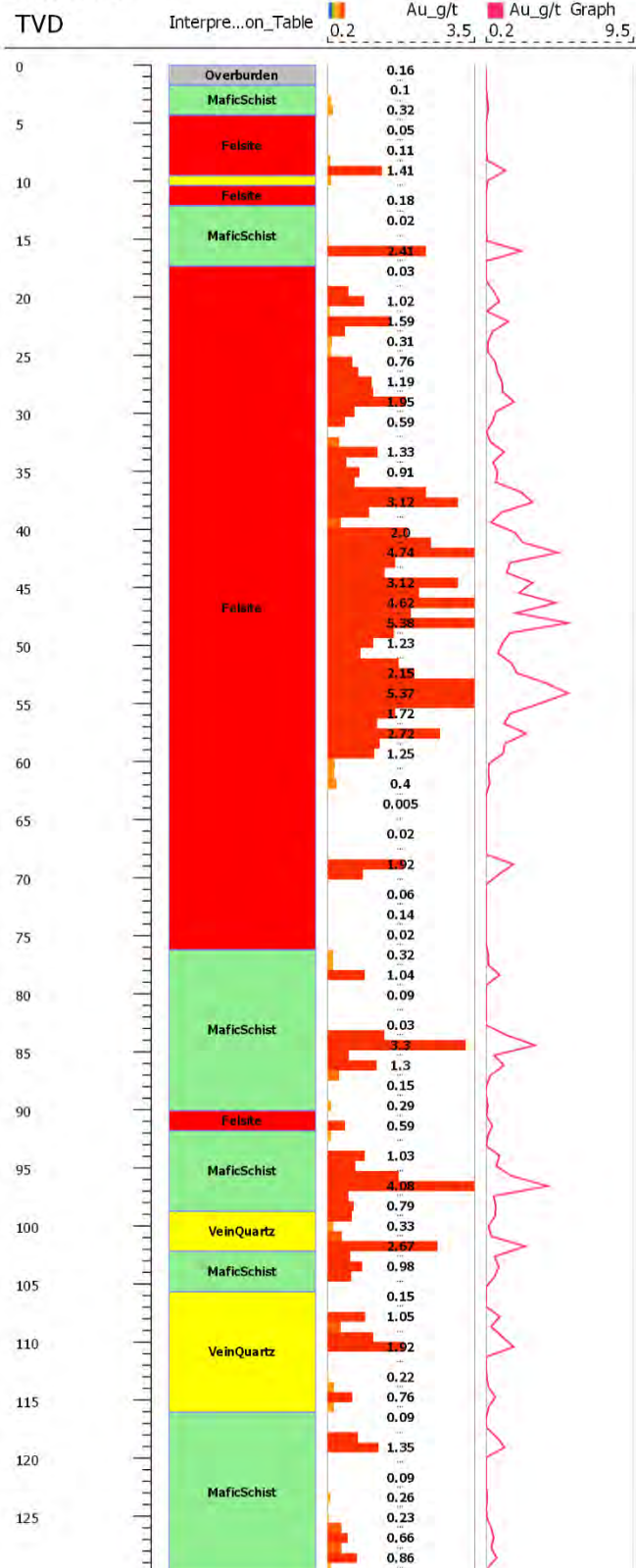


Figure 33: Correlation Log Plot for Boreholes BRRC036 & BRRC038.

6.4. NUMERICAL DATA MODELLING

6.4.1. Methodology

Numerical Modelling of gold assay data from resource drilling was conducted to understand the distribution of assay values that define gold mineralization in 3D space. The modelling was done using the indicator Radial Basis Interpolant Function (RBF) in Leapfrog Geo. The boundary for the numerical model was set to include all the four (4) prospects namely, the Blue Rock, Berks, RedHat and the Orange Farm prospects, covering the whole gold deposit at Blue Rock. Results from statistical analysis work done earlier, were used to select a cut-off grade of 0.5 g/t Au for numerical modelling of assay data. The model was optimized by selecting the spheroidal interpolant function. This function is preferable not only because it's in common use in the modelling of most metallic deposits including gold, but because it makes a lot of geological sense in terms of the size of influence known assay values exert on unknown ones during approximation. The modelling parameters were fine-tuned to specifications considered robust in describing the gold deposit at Blue Rock. Such parameters included; (a) using a structural trend consistent with regional structural and geological trends that had already been defined from the spatial location of gold workings and historical mines, as well as from structural surface mapping data and 2D geological cross sections, and (b) using three Au grade value thresholds which range from low (0.5 - 1 g/t Au), through intermediate (1 - 4 g/t Au) to high (>4 g/t Au) to produce representative model grade shells.

6.4.2. Results

Results from the numerical modelling conducted using Leapfrog's RBF interpolant function, defined two major broad sub-parallel mineralization trends – one located in the western part of the deposit and the other one in the east (Fig. 34). The more prominent western mineralization trend is flanked by a major thrust on its western margin and is richer than the one in the east. It starts off at the south-western end of the RedHat prospect and then extends northwards through the Blue Rock and Orange Farm prospects. The eastern trend on the other hand, originates around the north-eastern part of the old Red Hat mine and extends northwards through the Berks prospect.

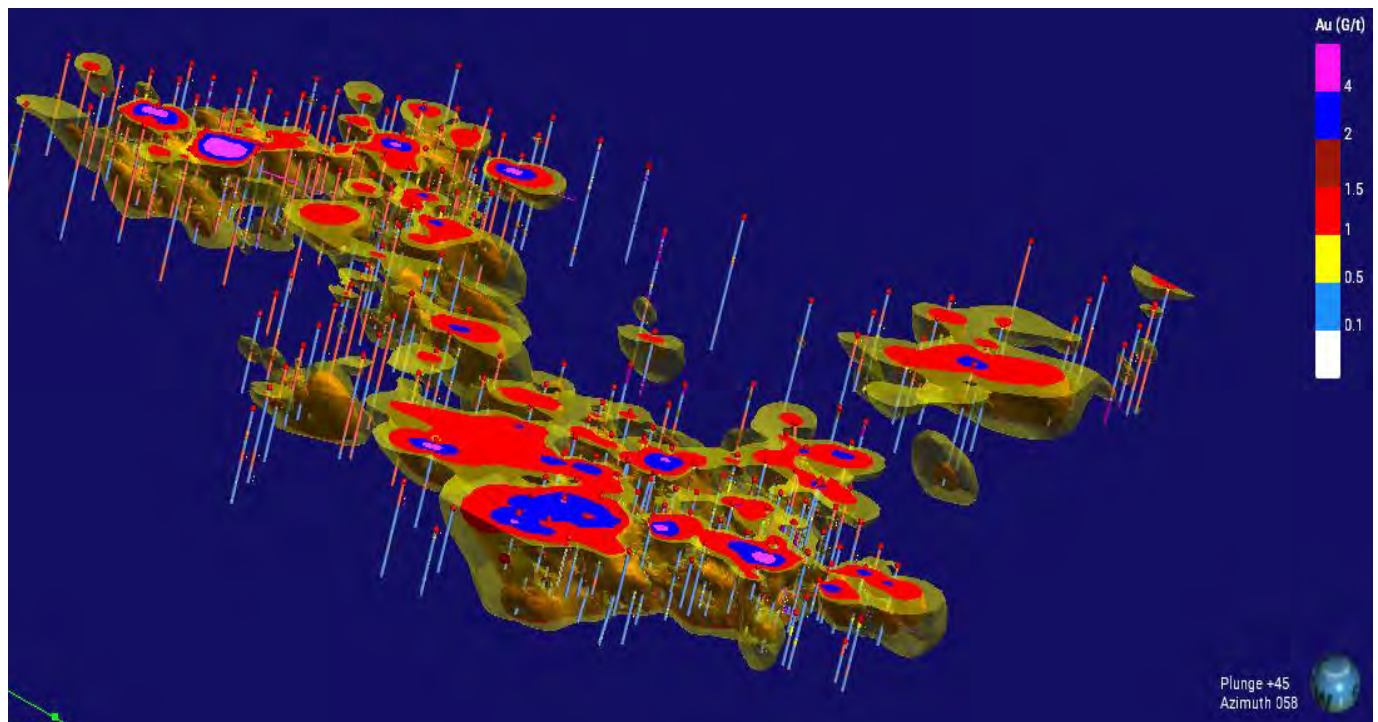


Figure 34: 3D Numerical Grade Model of Gold Values for the Blue Rock Gold Deposit, done in Leapfrog Geo.

Both mineralization trends are associated with felsite and quartz porphyry rocks and still open going north and down-dip. A detailed anatomy of the model generated from the numerical modelling of gold assay results, could be described best using slices extracted from a representative section (e.g. Fig. 35).

The section shows gold values spatially distributed and hosted within multiple lithological domains. Mineralization consists of high-grade gold domains, that occur with relatively lower grade Au haloes within their footwall and hanging walls.

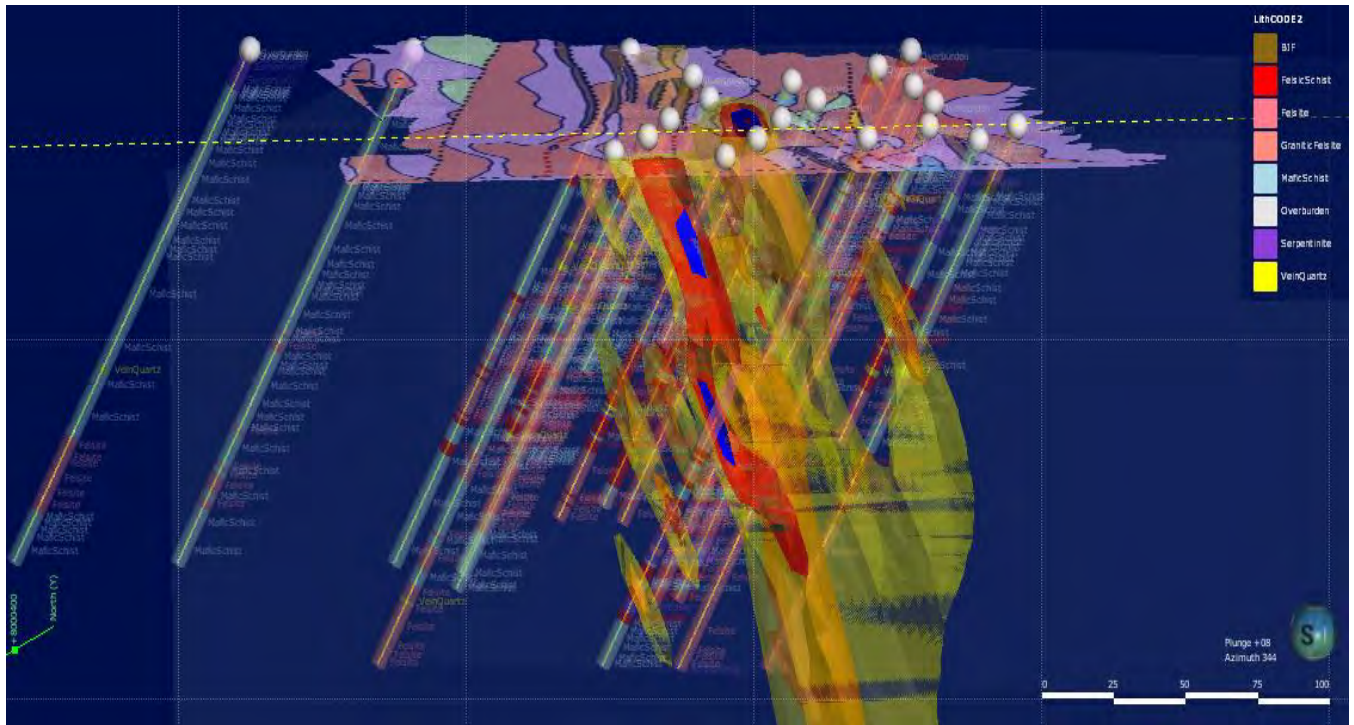


Figure 35: A typical mineralised Section showing a high-grade core of structurally controlled gold mineralization dipping steeply towards the east.

A more simplified gold grade distribution scenario of the numerical model is presented in 2D cross sections (Fig. 36 & 37) created by reducing slice information to cross sections extracted from the same profile of the numerical grade model. These cross sections show typical sub-parallel gold mineralization hosted within sheared felsite and quartz porphyry rocks, flanked by a mineralized footwall and or hanging wall of lower-grade Au, all hosted within Western Succession Upper Greenstone mafic schists and BIF rocks. They also reveal the finer details of grade distribution within the different lithological and structural domains and show the continuity of gold mineralization across drillholes down-dip.

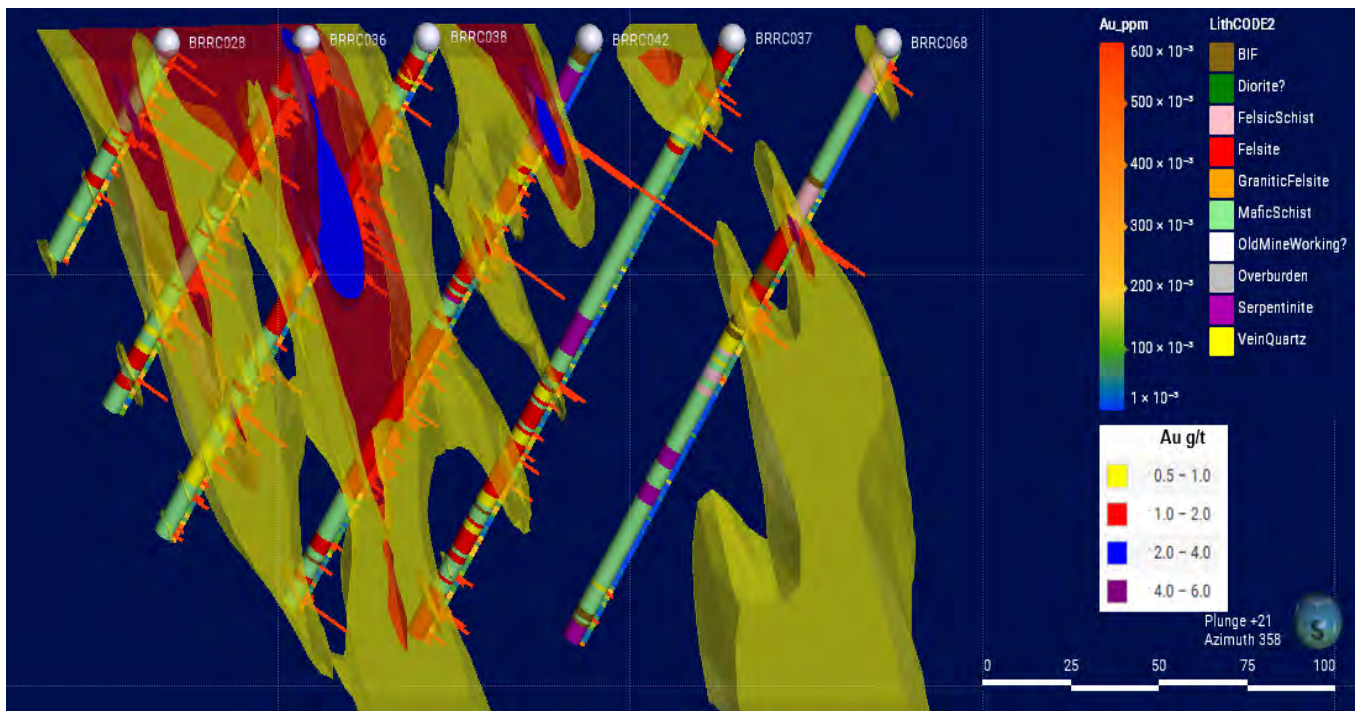


Figure 36: Felsite/Quartz Porphyry Ore Body showing mineralised mafic schist footwall and hanging walls.

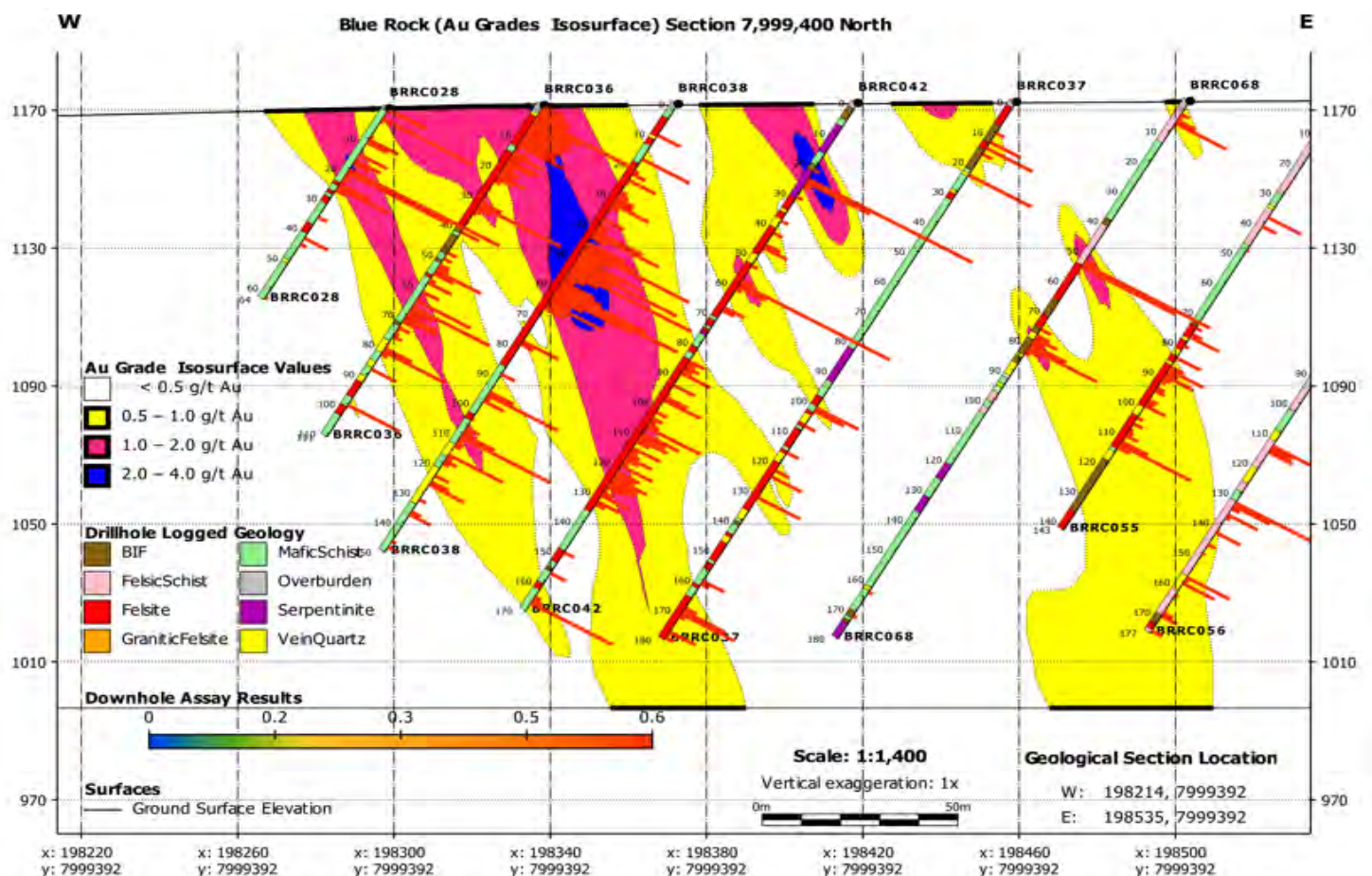


Figure 37: Cross-Section 7,999,400N from Numerical Au Grade Model of the gold deposit at Blue Rock.

A compound model generated by integrating the numerical gold grade model with the deposit-scale geological model in 3D (Fig. 38), clearly shows that although gold mineralization is hosted in almost all the lithologies, the bulk of it is associated with felsite and quartz porphyry intrusives, that dip steeply towards the east, consistent with regional stratigraphy. The good grades are hosted mostly within a stock work of quartz veins within the faults and sheared margins of felsites and quartz porphyry rocks.

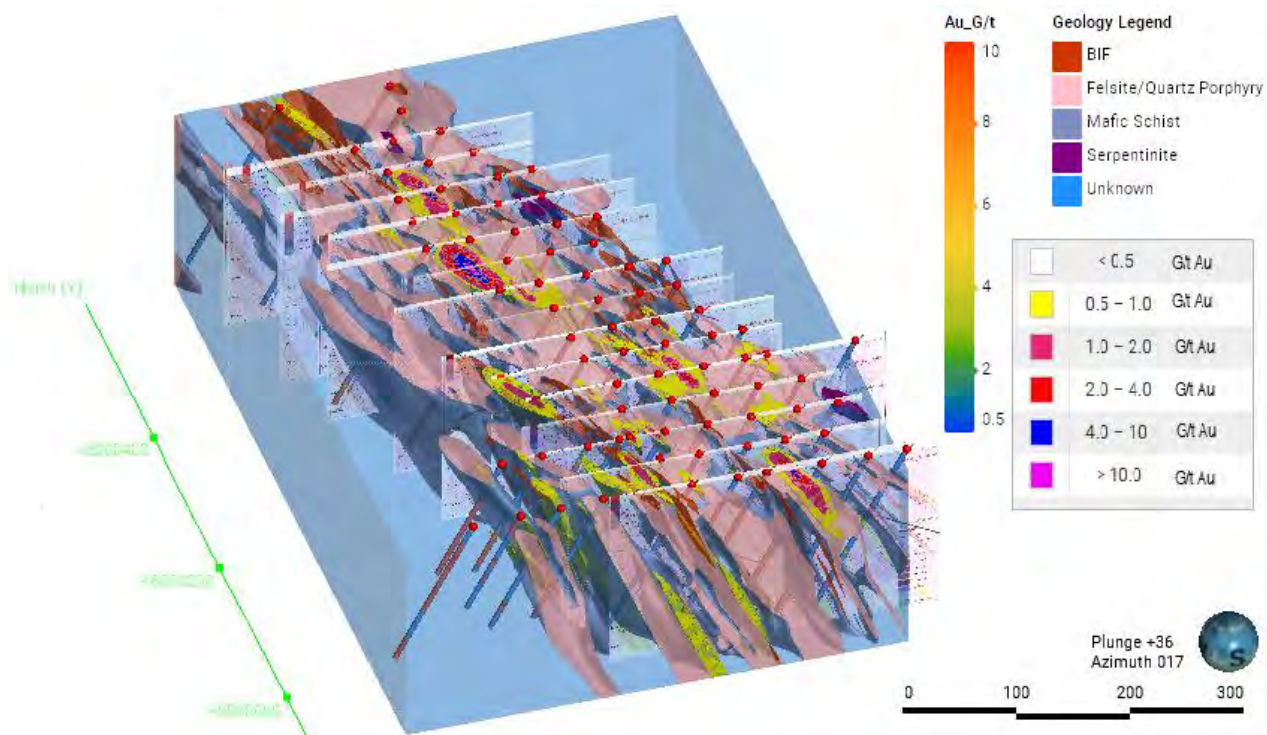


Figure 38: Berks Numerical Model on geology showing gold mineralization occurring on fractured interiors of felsites and their sheared margins.

6.5. RESOURCE MODELLING

The main objective of resource modelling was to conduct first-pass gold resource modelling for exploration, to complement numerical modelling in assessing the spatial distribution of gold mineralization within the gold deposit in 3D space – or simply put – to assess the localization of gold mineralization within host lithologies at deposit scale. Unlike numerical modelling which used more generous grade shells, and produced a generalized numerical model, resource estimation would provide a more robust means to assess the distribution of Au mineralization by estimating gold grade values for each block within the different estimation domains, using standard modelling algorithms in common use for conventional mineral resource estimation.

In this study, resource estimation was conducted using implicit modelling tools in Leapfrog Geo and Edge, taking advantage of Leapfrog's powerful 3D Radial Basis Function "Fast (RBF™)" engine's ability to interpolate downhole data by describing how it varies in three-dimensional space. Gold assay data were interpolated to produce an estimate or an interpolated value that is not known at the point of interest, but known at other points along the drill holes, where the boreholes were sampled, logged and analysed. Assay data was used for grade estimation using Ordinary Kriging methods. Ordinary Kriging is preferable because it is known to produce the best estimate for this type of deposit, with the smallest standard error, narrowest confidence interval and the most confidence or lowest risk (Bertoli et al., 2003). Estimation parameters were optimized by employing a spherical variogram, together with the testing of numerous experimental variogram parameters until the optimum one was selected. A structural trend consistent with the regional geology and domain boundaries was also used. And a cut-off grade of 0.5 Au g/t was selected for resource estimation as informed by the statistical data analysis, already discussed.

6.5.1. Domaining

The process of gold grade estimation started with domain definition. Domaining is useful for defining boundaries of mineralization zones within which the grade distribution of target minerals (in this case gold) can be quantified using established mineral resource definition methods. Although there are several methods for domain definition, in this

study the domain boundaries are established through a combination of manual interpretation, and numerical modelling using implicit modelling in Leapfrog Geo. Manual interpretation was done by inspecting the distribution of gold assay values on geology in 3D space, whilst implicit modelling made use of the numerical model created from 3D statistical modelling of gold assay values (Fig. 39). The domains were defined where gold grades appear to have a spatially coherent relationship, with a high probability of sharing a common dominant geological control.

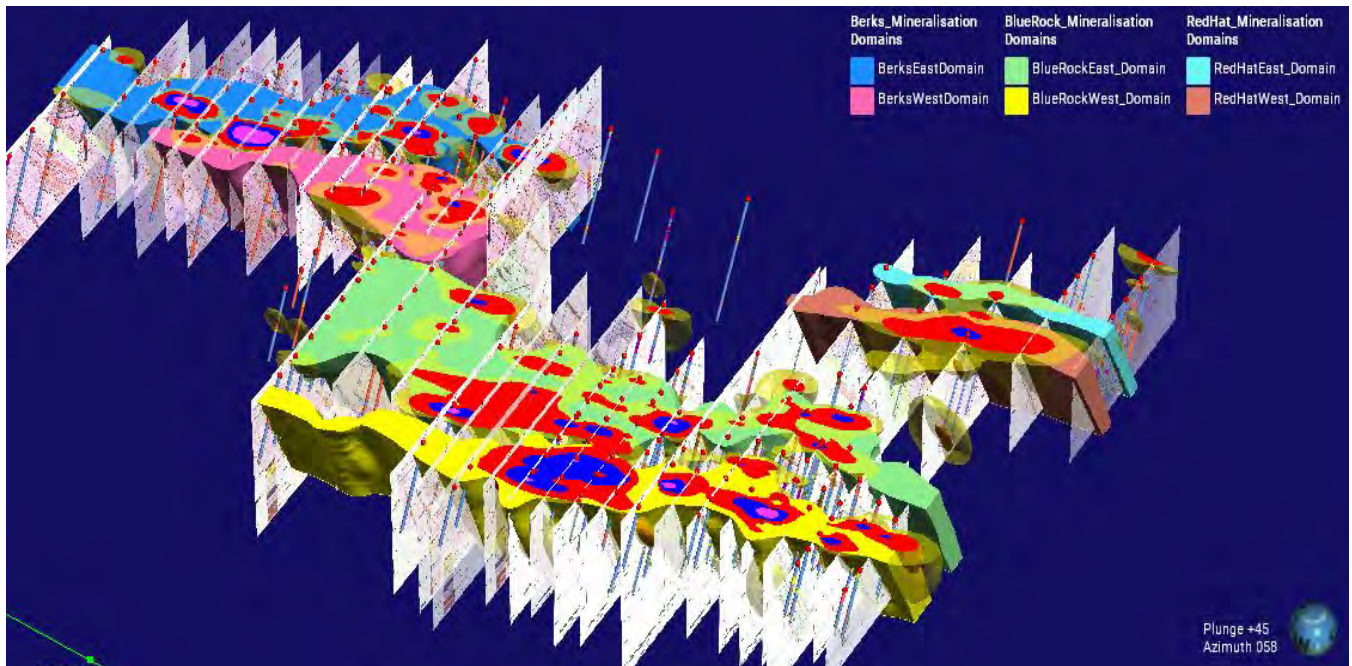


Figure 39: Domaining done manually and using Numerical Model results and Geology in Leapfrog Geo.

A total of six (6) mineralization domains (Fig. 40), were defined by the domaining process. The domains are characterized by spatially coherent Au mineralization zones associated with structural lineaments, shear zones and host felsite rocks, whose emplacement was, no doubt, structurally controlled.

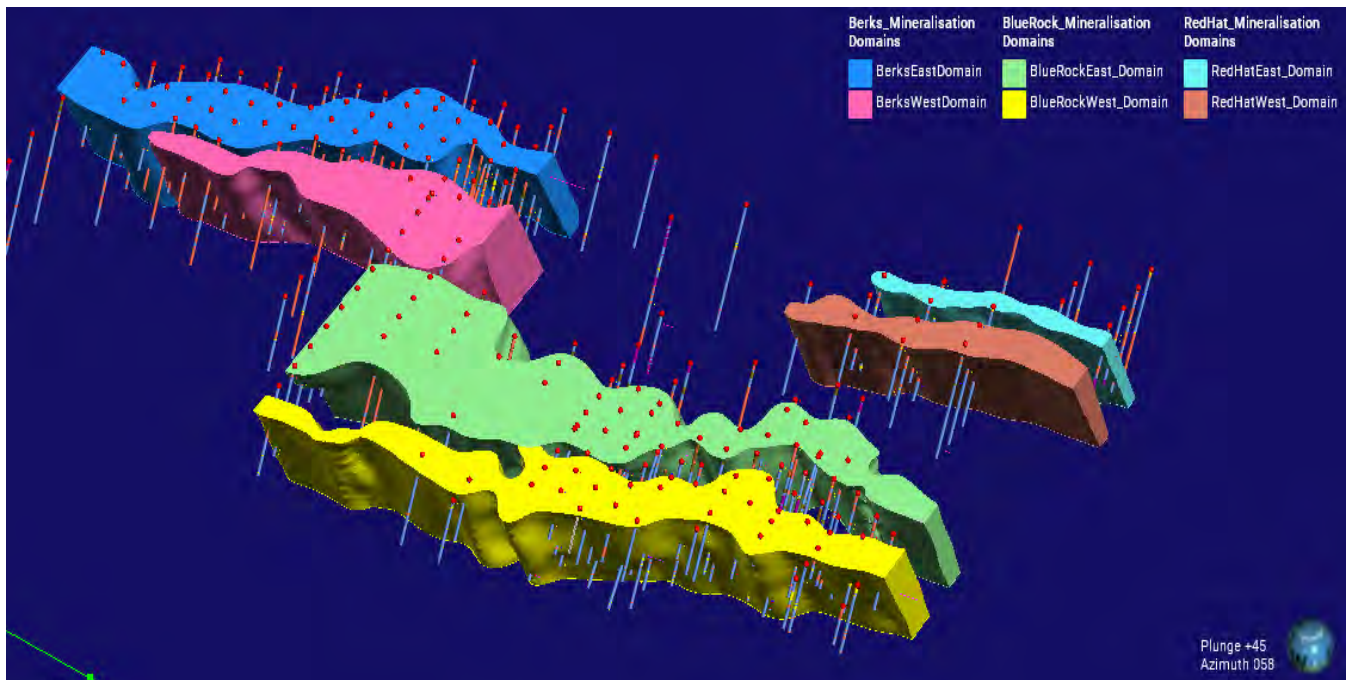


Figure 40: Six (6) Mineralization Domains created for Resource Estimation.

6.5.2. Ordinary Kriging

The six resource estimation domains generated for the gold deposit at Blue Rock, were used for grade estimation for exploration, to show the distribution of average gold assay grades within different domains using Ordinary Kriging. The estimation was done using soft domain boundaries to allow for a gradual change in average grades across domain boundaries. A cut-off grade of 0.5 g/t Au was selected and used to do the estimation for all the 6 domains at 5x5x5 meter block sizes (Fig. 41).

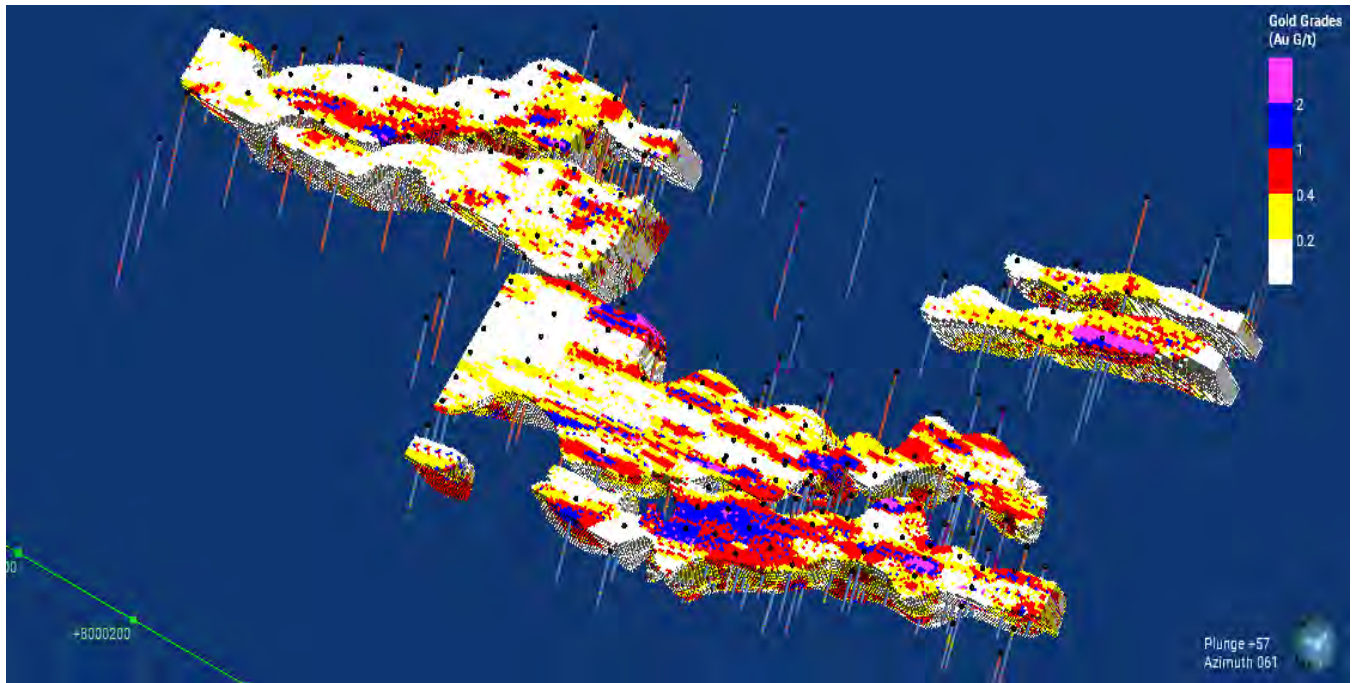


Figure 41: Resource Model estimated at an assay cut-off grade of 0.5 g/t Au, for the gold deposit at Blue Rock, showing the full range of average Au grade blocks.

The resultant resource estimation was then filtered for different average block grade cut-offs of >0.2 Au g/t (Fig. 42) and >0.5 g/t Au (Fig. 43) to show the distribution and concentration of high-grade value mineralization trends.

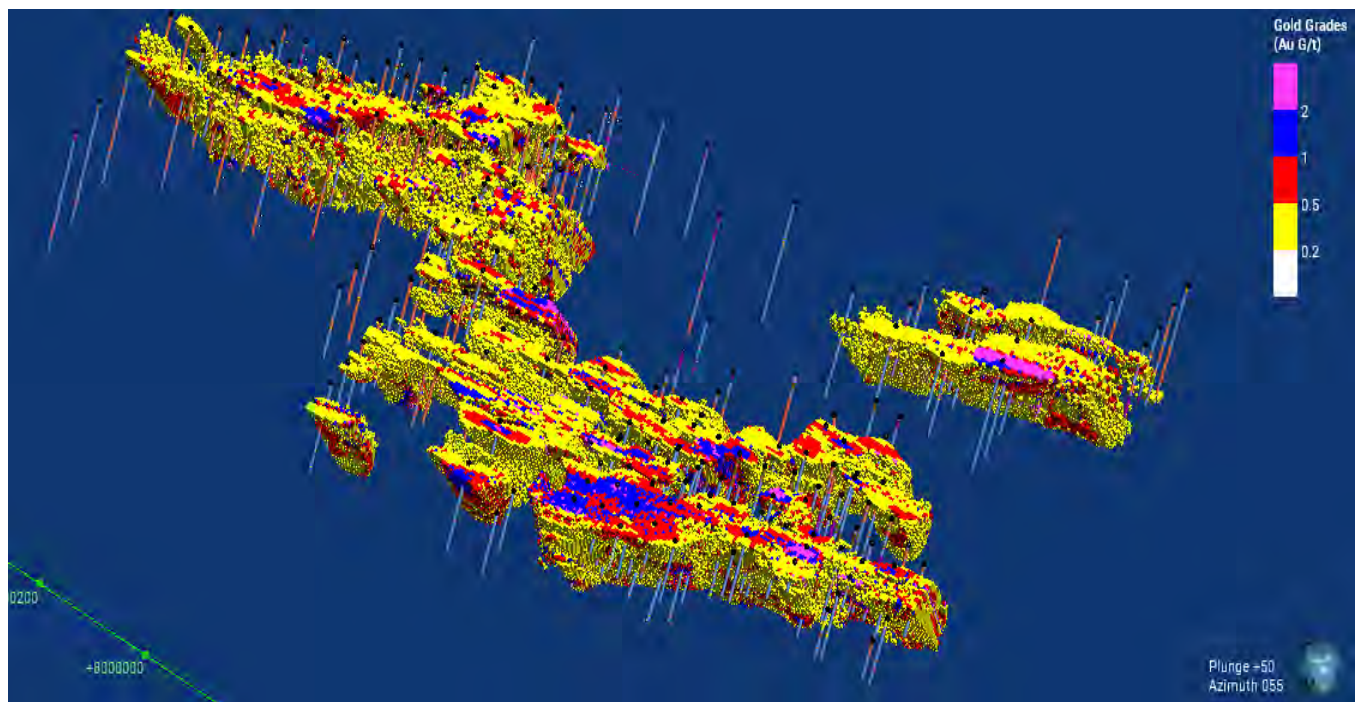


Figure 42: Resource Estimation Model of the gold deposit at Blue Rock, showing resource block average grades above 0.2 g/t Au.

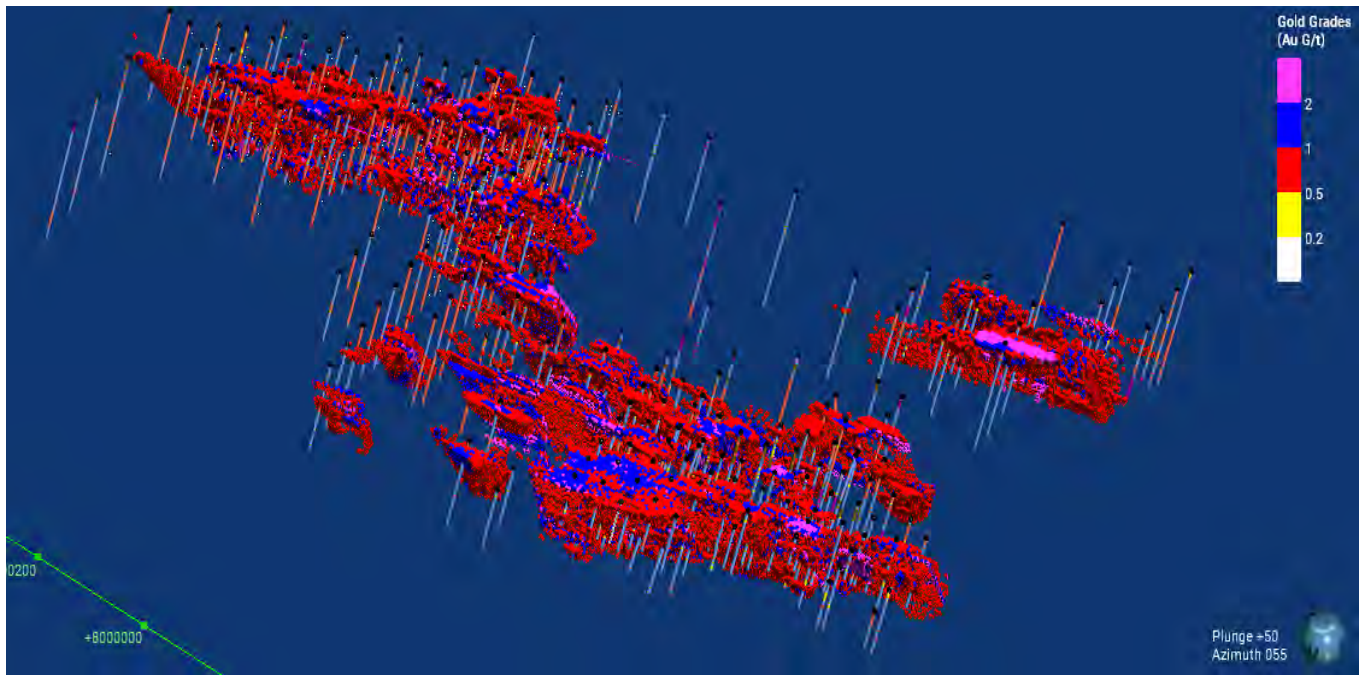


Figure 43: Resource Estimation Model of the gold deposit at Blue Rock, showing resource block average grades above 0.5 g/t Au.

Results from grade estimation were then integrated with the geological model, to produce composite models (Fig. 44, 45 & 46), that show in 3D how gold mineralization is variably localized by structural trap sites and lithological hosts within the different resource estimation domains.

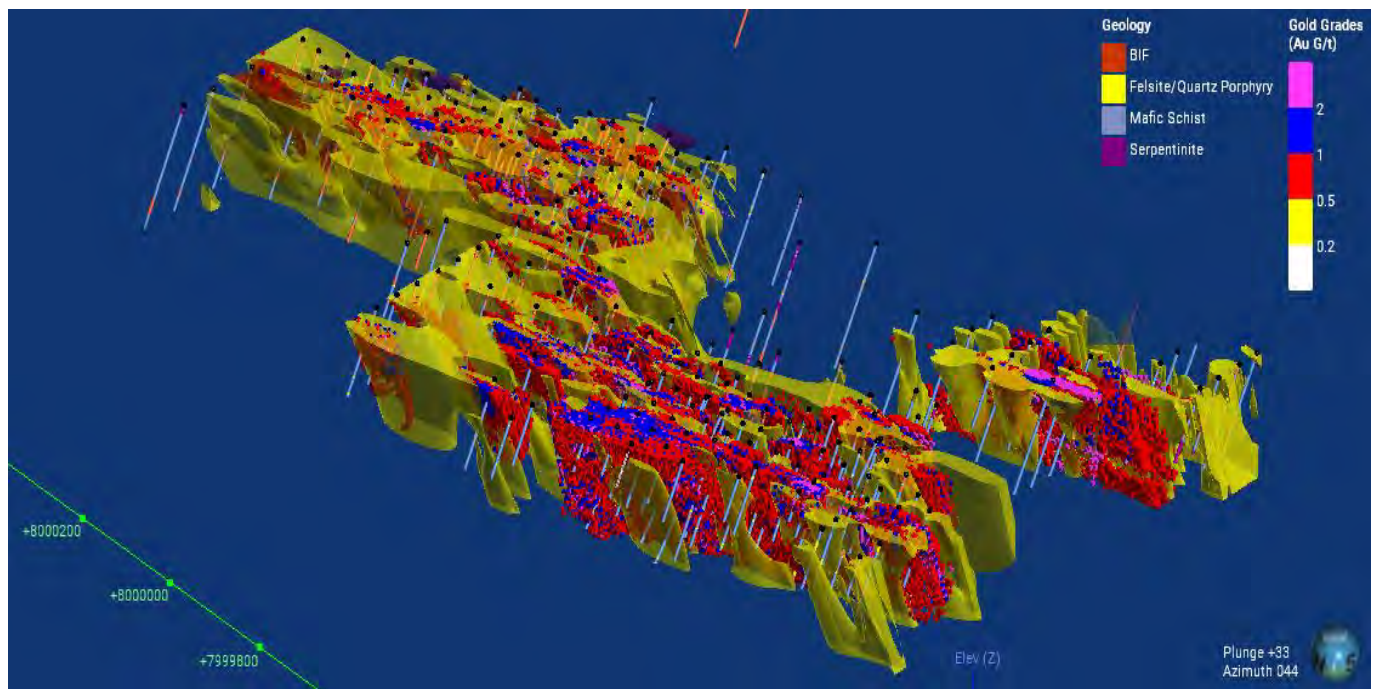


Figure 44: Resource Estimation Model of the gold deposit at Blue Rock, showing resource block grades above 0.5 g/t Au plotted on local deposit scale geology.

The composite models of estimated gold resource block grades integrated with geology, clearly show gold mineralization to be hosted within felsites and their sheared margins. The foot- and hanging walls are mostly greenstone lithologies that wrap around the sheared margins of the felsites.

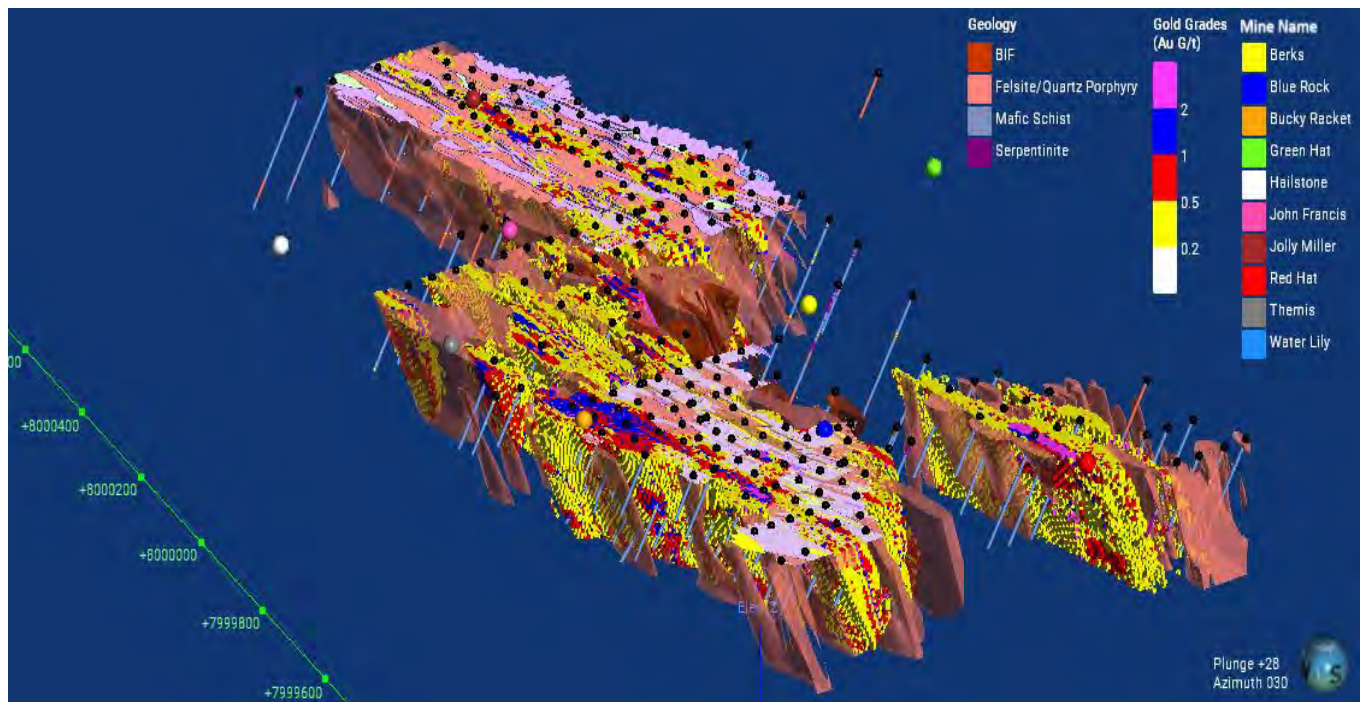


Figure 45: Composite 3D Model (with surface geology map) of the gold deposit at Blue Rock, showing Au Resource Estimation on geology.

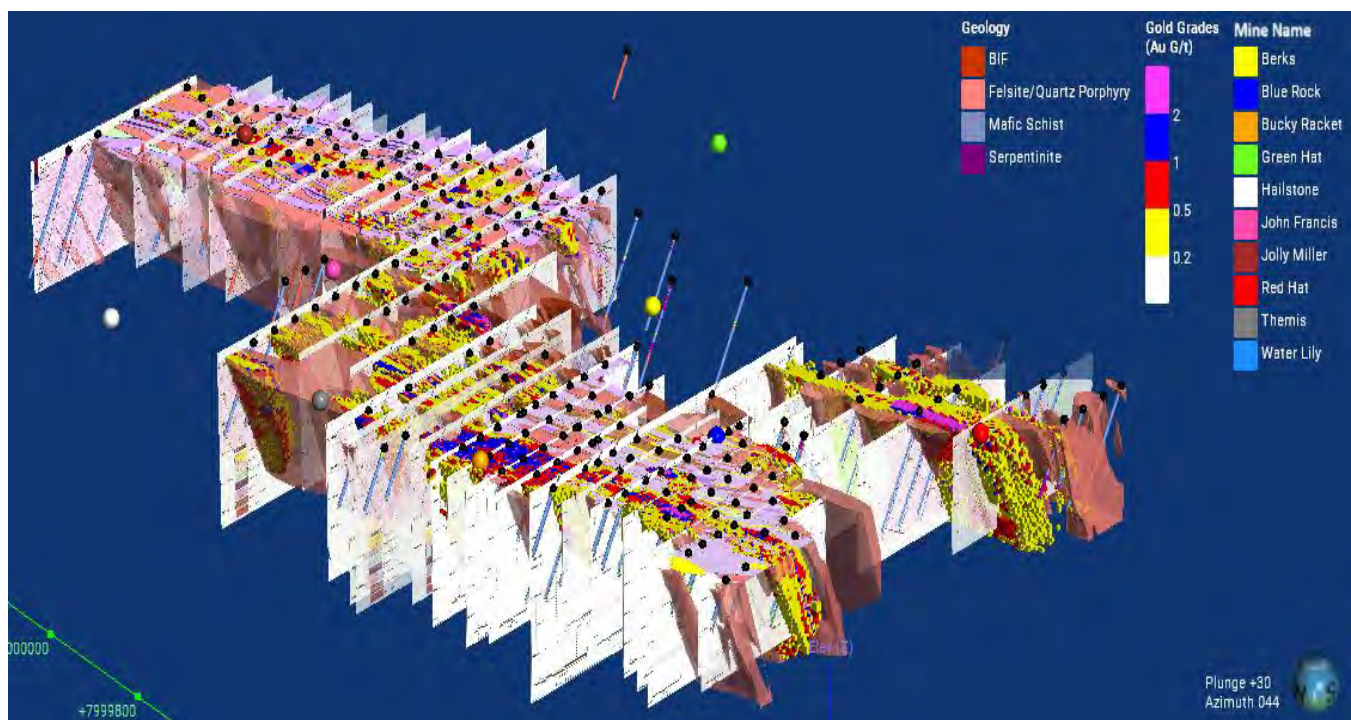


Figure 46: A Composite 3D Model (with cross sections) of the gold deposit at Blue Rock, showing Au Resource Estimation on a 3D Geological Model.

But to get a close-up view of gold mineralization at the gold deposit at Blue Rock, slices were extracted from the composite resource estimation block model to reveal finer details on gold localization within the different host rocks and trap sites. Fig. 47 is a good example of one such slice extracted from the model. The slice data were further reduced to cross sections (e.g. Fig. 48), to show the details on how the gold mineralization is associated with host rock and structures at orebody and trap site scale. Gold mineralization occurs within the felsite interiors as well as along their sheared margins with the good gold grades associated mostly with quartz vein stockworks.

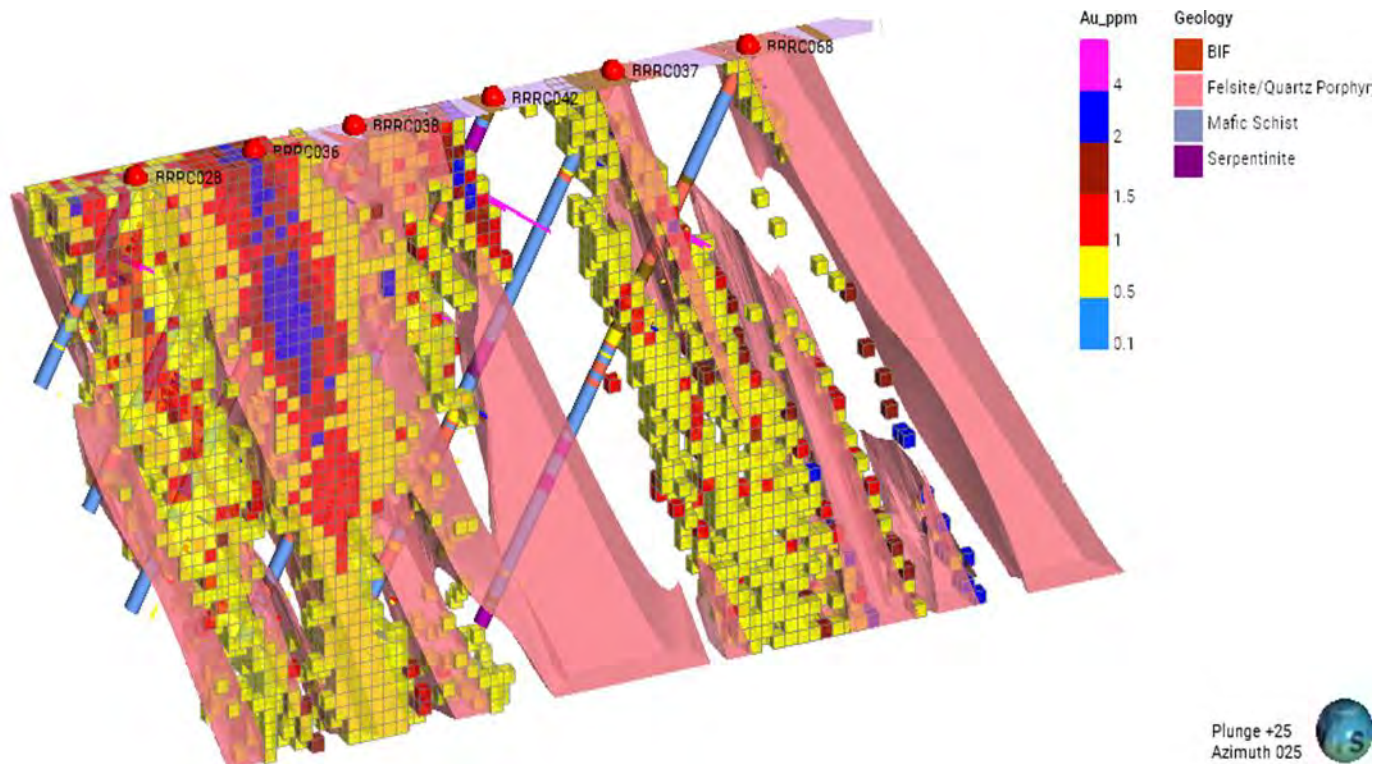


Figure 47: Representative Slice (7,999,400N) extracted from composite resource grades-on-geology model, showing resource blocks within felsite interiors and contacts associated with quartz veins and structures.

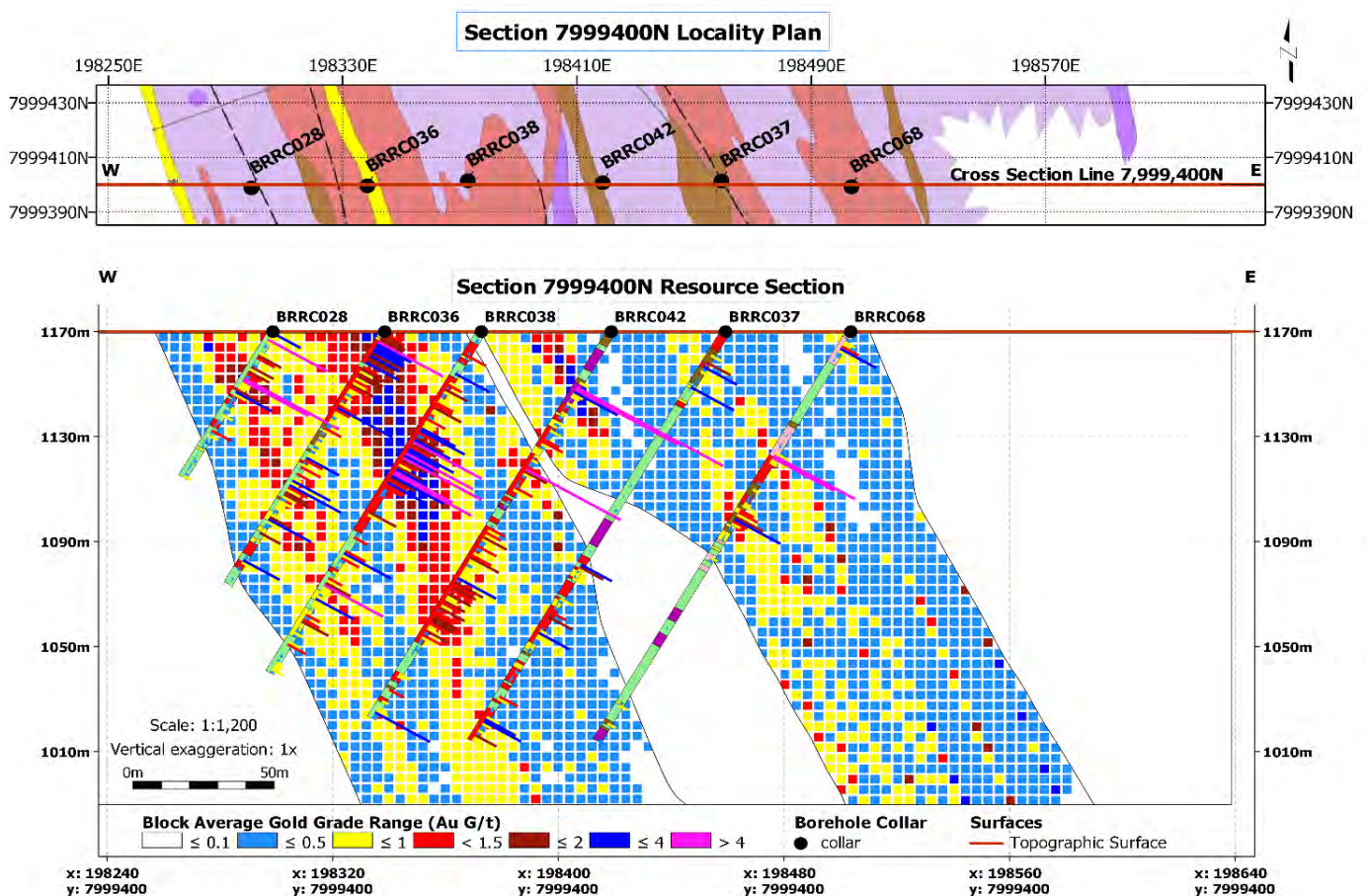


Figure 48: Example of typical Section (Section 7,999,400N) from the 3D Resource Estimation Model, showing gold mineralization associated with felsites, faults and associated quartz veins.

A summary of the spatial distribution of gold mineralization within the deposit can be represented with a plan view showing major mineralization trends is presented on Fig. 49 & 50. The plan views show the lateral continuity of high average grade resource blocks that form narrow linear domains trending parallel to the NNW-SSE regional structural trend, that appears to control both felsite intrusives as well as the gold mineralization they host.

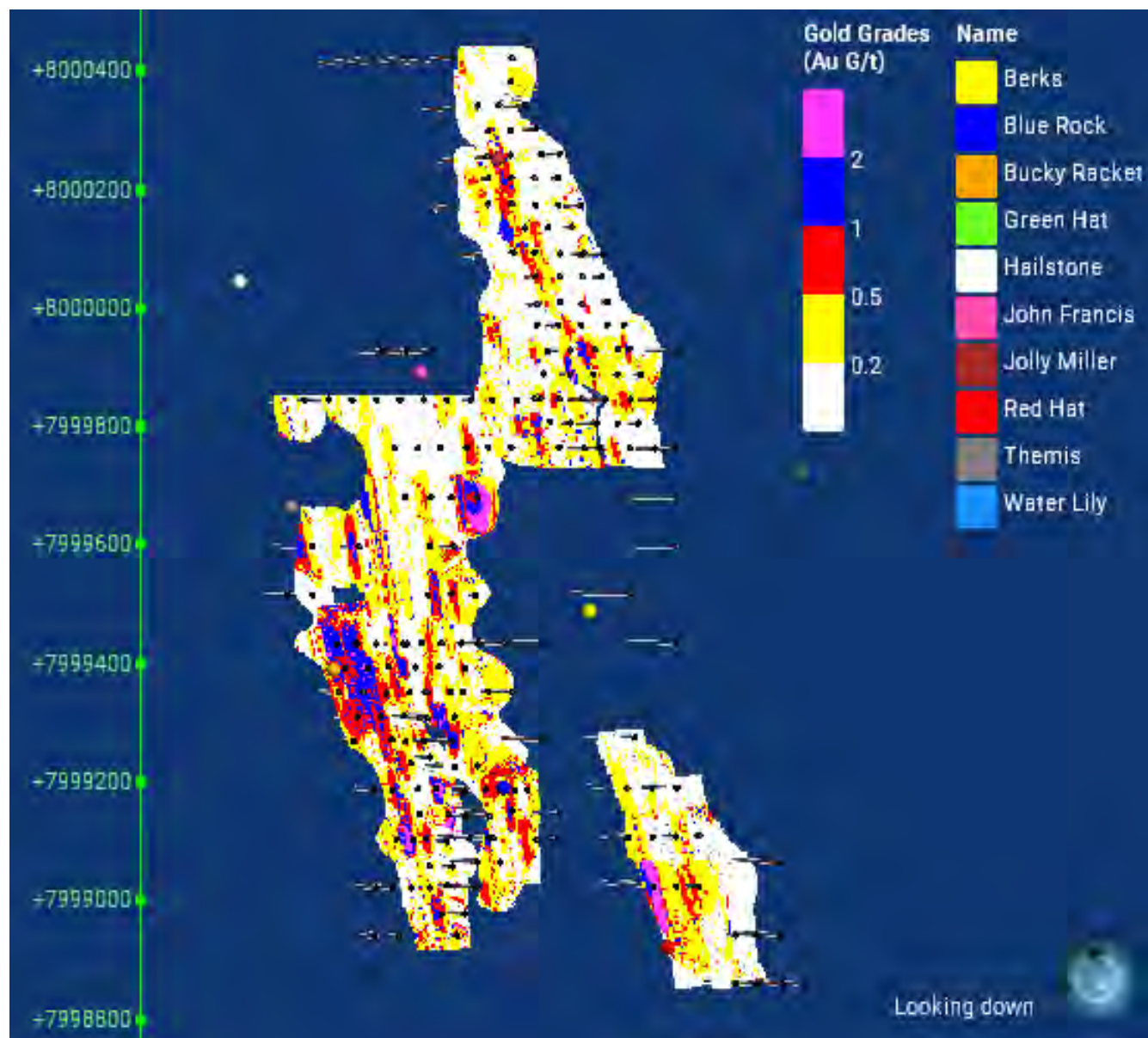


Figure 49: Resource Estimation on Plan showing spatial distribution of high-grade blocks corresponding to permeable fluid conduits and good structural traps along NNW oriented lower order structures.

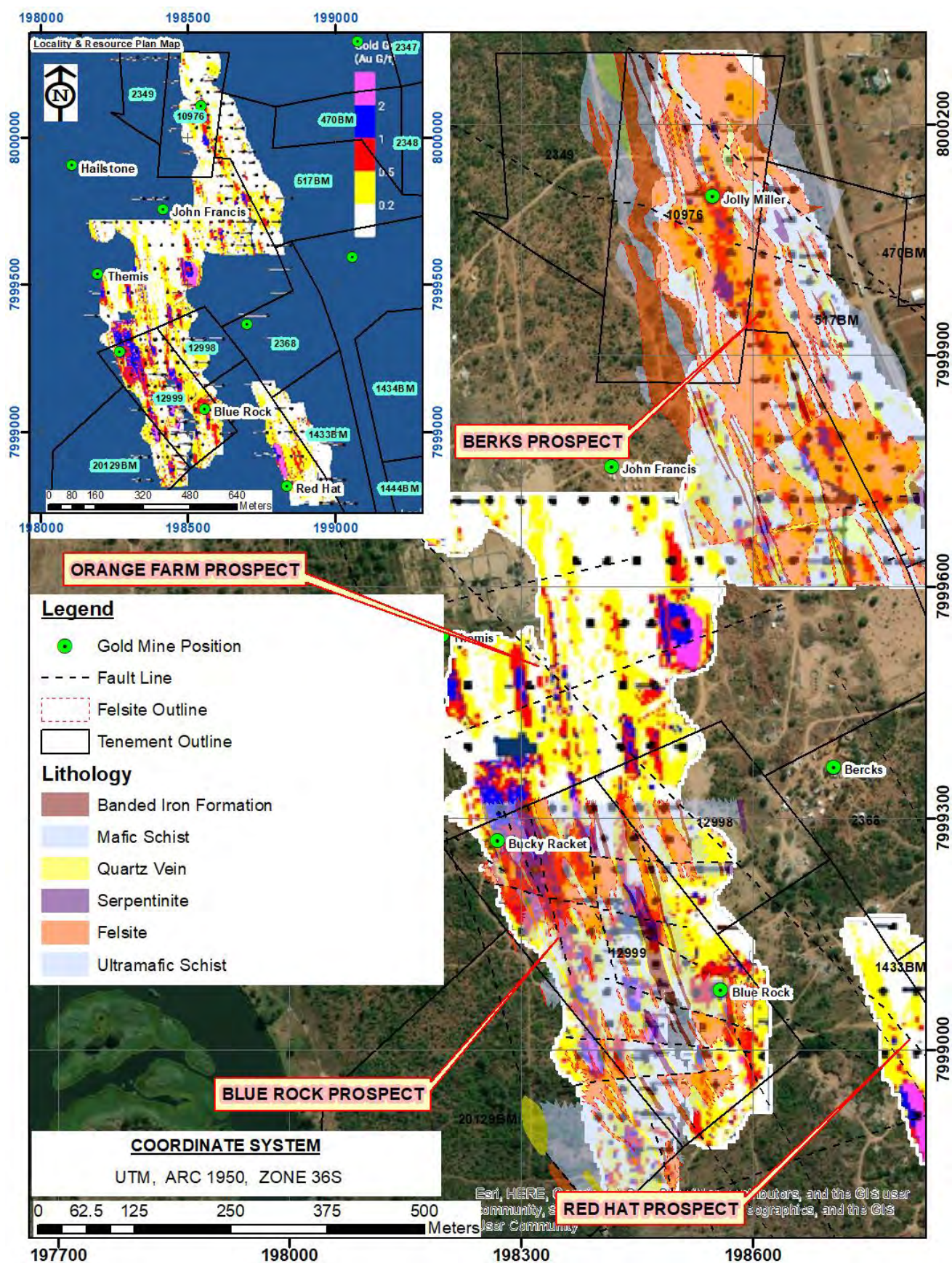


Figure 50: Top-of-Resource Estimation model or Plan showing the spatial distribution of high-grade gold blocks on surface geology, which reveal gold mineralization trends associated with structures that possibly controlled felsite emplacement and gold localization.

CHAPTER 7. DATA SYNTHESIS AND DISCUSSION

(i) Choice of Study Methodology

The gold deposit at Blue Rock is a relatively 'new' type of gold mineralization discovered within the GGB in 2007, by ACR. There are no previous studies done on it, other than just historical belt-wide mapping by Phaup & Dobell (1938) and Wiles (1957), as well as more recent work conducted during the 90s by Mutambara (1991), Fisher (1992), Chisi (1994) and later by Dirks and Mikhailov (1998).

In this study the deposit is characterized using the Mineral Systems Approach - a methodology I considered best suited for this study, to allow for the building of a holistic model for this type of deposit, contrary to commonly used traditional approaches. Traditional approaches usually focus on localized deposit-scale studies, that are most often, heavily weighted towards analytical techniques, which tend to produce complex, but less robust genetic models at a micro-scale. Such models are usually explanatory rather than predictive. They are very often inappropriately applied to deposits at regional or district scale, with very little relevance to global exploration for successfully targeting undiscovered deposits. In contrast, the mineral system approach involves looking at all the factors critical to the formation of the deposit as well as its subsequent preservation at all relevant scales. Such factors include the Geodynamic setting, Fertility, Architecture and Preservation. These factors are all inherent in the evolution of greenstone belts like the GGB, which hosts the new gold deposit, and so, a thorough understanding the evolution of the GGB is therefore critical to unravel the genesis of the gold deposit at Blue Rock.

(ii) Historical Models for the GGB Gold Deposits

The genesis of Zimbabwean greenstone belts including the GGB, is not universally understood. At present there are two schools of thought - (a) the traditional Vertical Accretion model and, (b) the Horizontal Accretion model. Vertical accretion is thought to have occurred through the deposition of sediments within rift basins over a pre-existing older continental felsic basement (MacGregor, 1951; Bickle et al., 1975; Blenkinsop et al., 1993; Bickle et al., 1994; Shackleton, 1995; Wilson et al., 1995; Ridley et al., 1997), followed by deformation, metamorphism and mineralization from younger intrusive vertically emplaced "Gregarious" batholiths (MacGregor, 1951). Support for vertical accretion include evidence from stress mapping patterns of "Gregarious" batholiths like the Chinamora Batholith (Ramsay, 1989; Jelsma, 1993; Jelsma et al., 1993).

Historical studies limited to the Elvington mine done on the GGB by Mutambara (1991), Fisher (1992) and Chisi (1994), attributed gold mineralization within the GGB to hydrothermal fluids of a magmatic origin, related to the younger surrounding Biri granite intrusion. They invoked traditional vertical accretionary models for Zimbabwean greenstone belt evolution which were acceptable at the time, to explain the origin of fluid sources for gold deposits.

But the question on whether these models are still viable to explain the genesis of gold deposits within Archaean gold belts like the new gold discovery at Blue Rock need to be addressed.

(iii) Shortcomings of Historical Models applied to the GGB and host Gold Deposits

Despite a lot of evidence in support of Vertical Accretion for Zimbabwean greenstone belts like the GGB, which hosts the new gold deposit, these models are now losing credibility. They can no longer be considered adequate for explaining the genesis of Zimbabwean greenstone belts like the GGB, including its constituent lithologies and architecture, which together were responsible for the localization of host gold deposits like the one at Blue Rock.

The biggest shortcomings of vertical accretion models in accounting for the genesis of Archaean Zimbabwean greenstones have been their failure to;

- (i) adequately account for layer parallel shears common in most Zimbabwean greenstones, which are consistent with those found in other Archaean orogenic belts of the world (e.g. the Abitibi in Canada - Card, 1990; the Kaapvaal Craton in South Africa - de Wit, 1982; and the Yilgarn Block in Australia - Swager and Griffin, 1990; Myers, 1995), whose formation are mostly attributed to horizontal accretion.
- (ii) resolve age inconsistencies of fault-bound geological units juxtaposed across steep west directed faults, recognized by such models as mere unconformities which did not significantly affect the stratigraphy.

Vertical accretion and all other historical models that fail to adequately account for the evolution of orogenic gold belts like the GGB, have additionally been questioned on their credibility to sufficiently explain the sources of fluids that formed the orogenic gold deposits hosted by the greenstone belts. For example, crustal metamorphic models, such as the lateral secretion model by Boyle (1979), have faced strong criticism for not being capable to provide a mechanism for generating large volumes of fluids required, together with the likelihood of lateral fluid migration proposed by the model. There is now clear evidence from the many reviews, including those by Wyman et al. (2016) and Goldfarb and Groves (2015), that the genesis of most orogenic gold deposits, including Zimbabwean ones, can no longer be attributed to derivation from magmatic-hydrothermal or shallow crustal metamorphic fluid sources. Key arguments that invalidate magmatic-hydrothermal models include inconsistencies in relative ages, spatial relationship and size between gold mineralization and magmatic intrusions (e.g. Goldfarb and Groves, 2015).

This therefore implies that the genesis of gold deposits within the GGB including the re-discovered deposit at Blue Rock, can no longer be attributed to derivation from magmatic-hydrothermal or to shallow crustal metamorphic fluid sources, contrary to historical studies by Mutambara (1991), Fisher (1992), Chisi (1994) and others, who attributed auriferous fluid origin for GGB orogenic gold deposits to derivation from magmatic-hydrothermal fluids related to the Biri granite.

So, are there any models available to explain the genesis of Archean gold deposits like those within the GGB, including the felsite-hosted one at Blue Rock?

(iv) Towards New Models for the Evolution of Zimbabwean Greenstones and Orogenic Gold Deposits

A call for alternative models that can sufficiently account for the genesis of GGB hosted orogenic gold deposits better than outdated historical shallow crustal metamorphic and magmatic-hydrothermal models, is therefore clearly warranted. And this has serious implications on the genesis of orogenic gold deposits in Zimbabwe including the one at Blue Rock, covered in this study.

To understand the genesis of orogenic gold deposits, including the new type of gold mineralization at Blue Rock, a thorough understanding on the evolution of Archaean Zimbabwean greenstones at geodynamic scale is not negotiable. This is because the geodynamic setting is related to the fertility, architecture and preservation factors, which together are responsible for the genesis of gold deposits within host orogenic gold terrains, as already discussed for a universal orogenic gold deposit model.

But, to achieve a universal model for orogenic gold deposits like those hosted within the GGB, Wyborn et al. (1994) and Groves et al. (2020b) proposed the use of the mineral systems concept. Using the mineral systems concept, Groves et al. (2022) has already proposed a coherent and unified model for all orogenic gold deposits, which share a common geodynamic setting, fertility, regional architecture and preservation factors.

There is therefore a need to investigate if the GGB which hosts felsite hosted gold at Blue Rock, shares all the factors common to all Archaean orogenic belts of the world, that are critical to the formation of orogenic gold deposits, which could trivially be explained through the proposed coherent unified model for all orogenic gold deposits.

(v) A Proposed Model for Zimbabwean Greenstones and the Gadzema Greenstone Belt

Most Zimbabwean greenstone belts including the GGB, are now strongly believed to be products of horizontal accretionary tectonics at convergent plate margins (e.g. Dirks and Jelsma, 1998; Kusky, 1998; Jelsma et al., 2021; Kusky et al., 2018), contrary to historical views (e.g. Macgregor, 1951) that attributed their formation to diapiric or vertical tectonics.

The GGB is dominated by Upper Greenstone Series rocks which belong to the Western Succession of Wilson (1979) or Type-2 Succession of Jelsma and Dirks (2002). Western Succession greenstones are believed to have formed from subduction related accretion at the continental margins of the SPC, as supported by new SHRIMP U-Pb zircon dating geochronological data from volcanic and plutonic rocks of northern Zimbabwe (Jelsma et al., 2021). In other words, the GGB, a part of Archaean Zimbabwean crust, is a remnant of collisional tectonics, believed to have formed through horizontal accretion during an east-directed subduction of the oceanic slab together with its overlying sediments at the continental margins of the SPC.

If this model is accurate, then GGB rocks mapped by the author as presented in this study, would represent ocean plate stratigraphic sequences, where ultramafics/mafic rocks (mafic schists and serpentinites) common throughout the GGB, would have been derived from basal pillow lavas section of the oceanic slab, with the interbedded BIF units representing deep sea sediments, which grade into shallow water turbidites, that occur as hemipelagic sandstone sediments, now metamorphosed to quartzites found mainly around the Giant mine. These sediments would have been off scraped from the oceanic plate during subduction and added to the accretionary wedge where they were imbricated, deformed and metamorphosed to form the GGB.

During imbrication, accretionary wedge sediments were not only deformed by folding, but also thrust and duplicated. The repeated stratigraphic sequences duplicated across NS striking layer parallel thrusts within the GGB could be perfect examples of accretionary stratigraphic sequences that were duplicated during such thrusting events as suggested by Dirks and Mikhailov (1998). If this is correct, then GGB lithologies represent multiple cycles of subduction-driven horizontally accreted domains now juxtaposed across steep D1 thrust contacts, along which they were accreted and thrust together to form the GGB. And if this model is accurate, then the layer parallel thrusts formed during the D1 ductile deformation, could be explained better through this model, with some of them having been reactivated during D3 deformational events. Examples of these thrusts include the major (D1) thrust flanking the GGB in the west as well as, layer parallel D1, D3 shears which cut through mafic schists, and occur on the margins of BIF layers, serpentinites and felsites.

During orogenesis, part of the oceanic plate and overlying sediments that were subducted into the mantle were devolatilized, inducing partial melting in the overlying mantle wedge and produced auriferous fluids and magmas. These magmas then rose to upper crustal levels towards the surface to form syntectonic intrusive granites in the form of the Biri granites and associated (melt escapes) or small bodies of felsites and quartz-porphyry intrusives, emplaced along thrusts as sill and dyke-like bodies that would help in localizing orogenic gold deposits within the GGB, including the gold mineralization at Blue Rock.

(vi) Geological Constraints for GGB Orogenic Gold Deposits

If the proposed horizontal accretion model for the Archaean Zimbabwean crust is accurate in describing Zimbabwean greenstones like the GGB and their geodynamic setting, and if Archaean subduction took a form similar to that experienced today as argued for by Cawood et al. (2018), Kusky et al. (2018), Maruyama and Safonova (2019), and others, then the geodynamic setting that formed the GGB supports an orogenic gold deposit formation model consistent with the universal model for orogenic gold deposits, proposed by Groves et al. (2020b 2022), where;

- The Fertility parameter responsible for orogenic gold deposits within greenstone belts like the GGB is related to the geodynamic setting, in which the orogenic belts were formed, and,
- The Architectural parameter responsible for bringing mantle generated auriferous fluids to upper crustal levels through lithospheric-crustal faults and localizing them within lower order structures to form orogenic gold deposits, is related to greenstone belt evolution and its subsequent deformation.
- The preservation factor for the resultant gold deposits is also influenced by their depth of formation and their late timing towards the end of orogenic deformation.

Results from Zipf analysis on gold endowment of the GGB, conducted during this study suggests that the GGB contains up to 3 million ounces of gold. About a third of this is held in known historical deposits including the Giant, Elvington, New-Found-Out, Blue Rock, Water Lilly, and the felsite hosted gold deposit at Blue Rock, whilst the balance of about two thirds amounting to 2 million, represent residual endowment in the form of unknown deposits still awaiting to be discovered within the belt.

Orogenic deposits within the GGB would have been localized from auriferous fluids generated from the devolatilization of a subducted oceanic slab with its overlying sulphide-rich sedimentary package (as already discussed) at the continental margins of the SPC. The auriferous fluid migrated to upper crustal levels via lithosphere- to crustal-scale fault zones to be localized in lower order structural traps to form gold deposits within the GGB, including the new gold deposit at Blue Rock.

If the universal orogenic gold model of Groves et al. (2022) is accurate in describing orogenic gold deposits within the GGB, then the formation of these deposits does not require any special rock type. Which implies that gold mineralization within the GGB is epigenetic as it was localized within almost all suitable lithological units in lower order structures, including within felsites and quartz porphyry rocks that host the gold mineralization at Blue Rock.

Major lithological associations that make up major gold deposits within the GGB, therefore include:

(i) BIF hosted deposits

- Sheared BIF hosted gold deposits make up the bulk of the major mines like the Giant, Elvington and the New-Found-Out mines.
- Gold mineralization is believed to have formed from the sulphidation of magnetite to pyrrhotite.

(ii) Quartz vein reef deposits

- Examples include the original and now defunct Blue Rock mine and the Water Lilly mines.

(iii) Felsite hosted deposits

- Represents the third significant deposit type previously not known to exist within the GGB until the recent discovery of the new gold deposit Blue Rock, which is discussed in better detail below.

(vii) Parameters for the formation of the Felsite-hosted gold deposit at Blue Rock

(a). Fluid Source

The gold deposit at Blue Rock occurs within the same geodynamic setting as other well-known orogenic gold deposits within the GGB. Gold mineralization at the deposit is structurally controlled and epigenetic. Results from Exploratory Data Analysis (EDA) of exploration data from the gold deposit, conducted using statistical analysis, Box Plot, Table of Statistics and Correlation Logs, all clearly demonstrate that the mineralization is epigenetic. It occurs within almost all lithologies (including BIF, Mafic Schist, Quartz vein and Serpentinite), although most of the gold is associated with felsites and quartz porphyries. The deposit therefore shares a common fluid source with BIF and Quartz vein hosted deposits within the belt. If the horizontal accretion model is a plausible model for explaining the genesis of the GGB (Jelsma et al., 2022), and the universal model for orogenic gold deposits by Groves et al. (2022), is also credible, then

the fluid responsible for the formation of the gold deposit at Blue Rock would have been generated from the devolatilization of a subducted oceanic slab with its overlying sulphides-rich sedimentary package, at the continental margins of the SPC, and not from the Biri granite contrary to contributions by Mutambara (1991), Fisher (1992) and Chisi (1994).

(b). Lithological Association

The gold deposit at Blue Rock most likely formed like all other major gold deposits within the GGB, albeit with differences in lithological association and grade. The deposit is associated within felsites and quartz porphyries. Evidence from field mapping and synthesis of regional historical mapping data, suggest that these host rocks formed soon after the formation of the Biri granite, from a related magma source.

Felsites occur as sills and dykes intruded along regional zones of structural weakness where they were sheared. The shearing of felsites along their margins, suggest that they were syntectonically emplaced, and then sheared before they were fractured and mineralized. Major structures that acted as auriferous fluid conduits during deposit formation at Blue Rock are discussed for the Architecture factor in better detail below.

(c). Architecture

The over-pressurized auriferous fluids would migrate up-dip from the mantle to crustal levels along slab-mantle boundaries and lithosphere- to crustal-scale fault zones and then subsequently into D1 thrusts within upper crustal levels, to reach the sheared felsites and quartz porphyry rocks within the GGB including those at Blue Rock. Shearing of the felsites appears to have been influenced by rheological or competency contrast between the more rigid and competent felsites (which deformed via brittle failure) against the more ductile surrounding mafic rocks which acted as fluid cap rocks that stopped fluids from escaping.

Results from 3D numerical analysis, resource estimation and geological modelling have shown gold mineralization at Blue Rock to be localized within lower order structures that formed zones of low minimum stress at deposit scale, focusing fluid flux as well as enhancing gold mineralization. Such areas include shears that wrap around felsite margins and faults that traverse these rocks, as well as areas of low minimum stress formed where individual felsite bodies meet to create complex structural geometries that range from triple, quadruple points, etc, which enhance gold deposition.

(d). Preservation

The gold deposit at Blue Rock was formed within the same orogenic belt as other known historical deposits associated with different host rocks including the BIF and quartz vein reefs and should therefore share the same preservation potential. The BIF and quartz vein reef hosted deposits within the GGB have been mined to depths of over 210m below ground surface.

All the factors that came together at different scales to form the gold deposit at Blue Rock will be consolidated into an occurrence model in a subsequent discussion (CHAPTER 8), from which a prospecting model for the effective exploration of felsite-hosted orogenic gold is proposed.

CHAPTER 8. PROPOSED OCCURRENCE AND EXPLORATION MODELS

8.1. INTRODUCTION

In this Chapter, a model for the genesis of gold mineralization at Blue Rock is proposed. This is done using the mineral systems concept - the preferred approach used in this study for numerous reasons already discussed. The main objective is to assess data and information on all the factors critical to the formation and subsequent preservation of felsite hosted mineralization at Blue Rock, and then map effective exploration strategies, capable of locating and developing similar types of gold deposits.

With increasing challenges in discovering new gold deposits, exploration success today depends largely on developing effective exploration strategies from a thorough understanding of a target area's geodynamic setting, fertility, structural architecture and potential deposit preservation. This approach allows for a conceptual model to be developed into a pragmatic exploration targeting tool, where all the critical parameters required to derive the identification of prospective orogenic gold provinces are recognized. But in practice however, such parameters can only get recognized through geological proxies that manifest as mappable geological, geophysical or geochemical responses to the different deposit footprint properties.

Conceptual geological targeting is required as the initial crucial step to focus exploration into the most prospective districts within potentially well-endowed terranes or provinces (Hronsky and Groves, 2008). As an important first step, this requires the establishment of superior predictive models for the type of deposit which is being sought by the exploration program. Once this has been done and viable regional targets have been established, then exploration at progressively reduced scales, can be achieved using direct detection methods to confirm and resolve selected targets into discoveries.

8.2. GEODYNAMIC SETTING

Results from the synthesis of data covering the GGB, together with evidence from surface geological mapping and 3D modelling of the same, show gold mineralization within the GGB and at the gold deposit at Blue Rock, to be epigenetic. The felsite hosted gold mineralization at Blue Rock is orogenic just like all known historical BIF and quartz vein hosted deposits within the same belt, albeit with differences in host rock type.

The genesis of these orogenic gold deposits is inherent to the same geodynamic processes that formed the GGB. The GGB is a remnant tectonic terrain formed during the Archaean at ca. >2 745 – 2 680 Ma (Jelsma et al., 2021). If modern-day style subduction commenced before or at least during the Archaean (e.g. Kusky et al., 2018), then the GGB must have evolved from subduction related processes driven by modern-day like plate tectonic processes, through horizontal accretion at the convergent margins of the SPC (Fig. 51).

At the subduction zone, the ocean plate stratigraphic sequences including overlying sediments scrapped off the oceanic plate, were accreted onto the continental margins of the SPC, along major NS trending crustal-scale thrusts and faults, preserved today as major deformation zones.

Within the GGB, the accreted fragments of oceanic crust (mainly pillow basalts) now metamorphosed to mafic schists that dominate the GGB, occur with interbedded sediments scraped off the subducting oceanic plates, which are now preserved as BIFs and sandstones metamorphosed to quartzites.

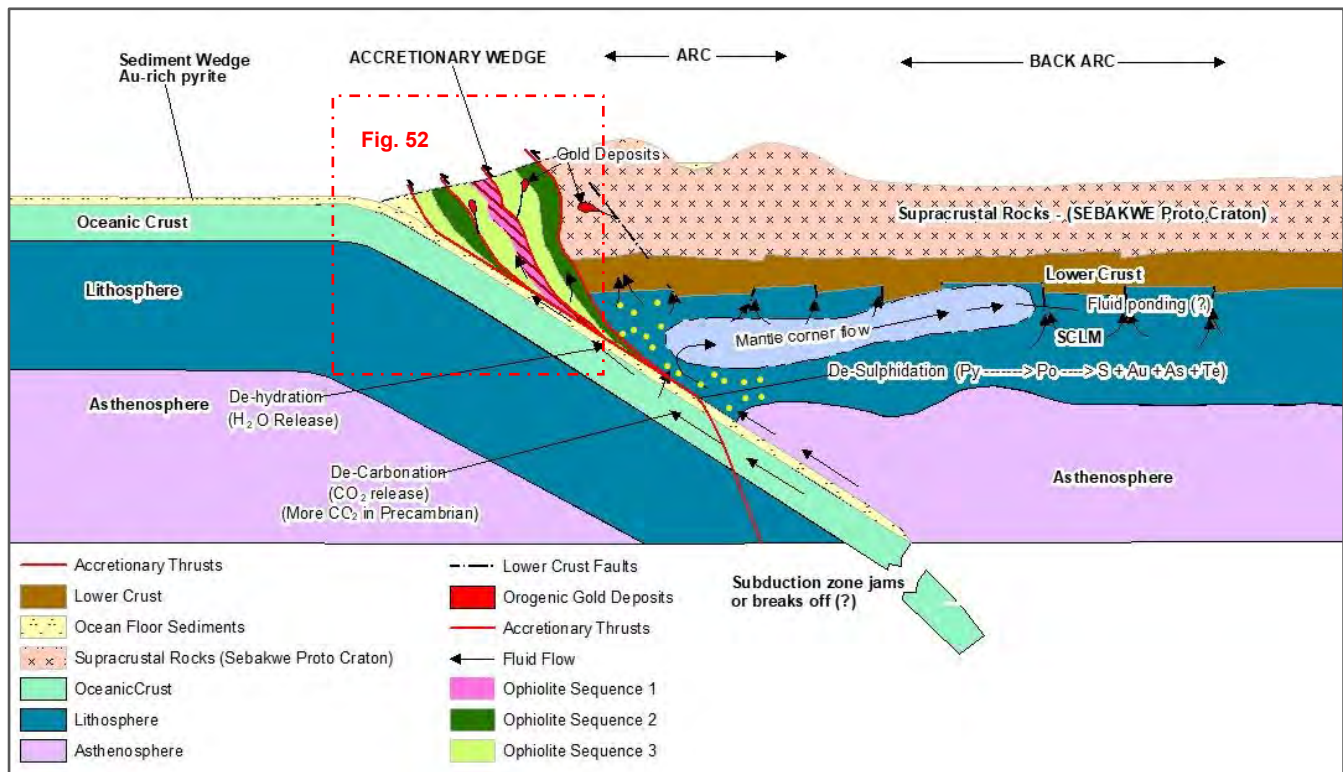


Figure 51: Geodynamic setting of the GGB. Hypothesized from Jelsma et al. (2021), Kusky et al. (2018) and Groves et al. (2022), for Zimbabwean Western Succession Orogenic Terrains, thought to have formed through an east-directed subduction-related horizontal accretion at the margins of the Sebakwe Proto Craton, where fluids were generated through devolatilization and rose to surface to form gold deposits within lower order structures formed during accretion and deformation.

The process of accretion occurred at continental margins of the SPC, where orogenic belts that host gold deposits formed, therefore all Archaean orogenic belts in Zimbabwe, are the primary exploration targets crucial to focus or target exploration for orogenic gold deposits like the one at Blue Rock.

- In other words, at geodynamic scale, these orogenic belts represent paleo-convergent margin settings, which form the ultimate global targets for orogenic gold deposits like the one at Blue Rock.
- Greenstone terrains suitable for hosting orogenic gold deposits can be identified through the recognition of diagnostic tectonic features that form at convergent margins within orogenic belts. Such features include Island or continental margin arc magmas with a distinctive geochemical signature reflecting a specific history.
- Most of these greenstone belts have already been extensively mapped, studied, explored and mined, and as a result, well documented, except of course in places where they are concealed under cover.
- In the case of those under cover, ground-penetrating geophysics would be very useful for locating and characterising them. Apart from mapping the lithology, such tools would also help unravel the structural framework of these terrains, including deep seated transcrustal lineaments of exploration significance that acted as primary conduits for bringing auriferous fluid from the mantle to upper crustal levels to form gold deposits. Examples of such gold belts in Zimbabwe include whole or parts of greenstone belts covered under the Kalahari Sands in the western parts of the country. Similar examples at global scale include the more recent orogenic belts of the Arabian-Nubian Shield, variably covered by desert sands in countries like Egypt, Sudan and Saudi Arabia.

8.3. FERTILITY

If ore fluid generation models for a universal orogenic gold model by Groves et al. (2020b) are accurate, then the fertility of the GGB which hosts the gold deposit at Blue Rock, is tied to its geodynamic setting. The GGB formed

through east directed subduction at continental margins of the SPC, as already discussed. Evidence from surface geological mapping of felsite intrusions within the GGB, supports a timing for the formation of gold mineralization at Blue Rock, to be consistent with a fluid source directly derived from the devolatilization of a subducted oceanic slab, together with its overlying sulphide-rich sedimentary package, at the continental margins of the SPC.

During subduction, the oceanic crust together with some of its overlying sediments that were not scrapped off or incorporated onto the accretionary wedge, were subducted into the mantle where they were devolatilized, inducing partial melting within the overlying mantle wedge. The resultant magmas and fluids generated from this process, rose to upper crustal levels through major deep-seated lithosphere- to crustal-scale thrusts and faults. Within upper crustal levels, the magmas formed younger intrusive granites represented for example by the Biri granites, as well as by related younger felsitic magmas now preserved as felsites and quartz-porphyrries including those at Blue Rock that were emplaced along transcrustal scale faults where they were sheared and mineralized. The felsites appear to have been intruded towards the end of the progressive D1-D2 deformation phase, soon after the emplacement of the main Biri granite. Their Intrusion was syntectonic and controlled by major NNW striking thrusts.

Auriferous fluids were generated through the breakdown of sedimentary pyrite to pyrrhotite. Although the exact nature of the fluid is uncertain, within this geodynamic setting, it is believed to be a near-neutral and reduced sub-crustal H₂O-CO₂, S-bearing fluid, containing dissolved Au together with associated metals commonly found with orogenic gold (Au), such as As, Bi, Sb, Te and W.

A measure of just how fertile this fluid was, could be represented by the numerous known gold deposits hosted with the GGB, together with possible many more awaiting to be discovered, as testified by residual endowment of the GGB, inferred in this study from Zipf's analysis. So that, the fertility of the GGB terrain is reflected in the numerous gold deposits it hosts including potential more to be discovered.

- Exploration for orogenic gold deposits should therefore prioritise targeting well-endowed orogenic terrains like the GGB, where exploration has already produced viable economic gold deposits. Orogenic terrains with a higher residual endowment where the potential to find new undiscovered resources still exist, either as extensions to existing deposits or completely new undiscovered ones, should be prioritized over equally endowed orogenic terrains with poor residual endowment.
- Exploration for Blue Rock type gold deposits (or any type of orogenic gold deposit for that matter) should therefore target fertile terrains like these, which pass the criteria for both high total gold endowment, as well as good residual endowment potential.
- Reliable gold production figures on economic gold deposits within such terrains could very easily be sourced from government mining department repositories or pre-competitive data from company reports on exploration-focused work held in the past, that could be useful for generating viable exploration targets.
- There are numerous methods and techniques in common use today for working out endowment which is a useful measure for fertility. A few of them already discussed in this study include the fractal analysis method used for example by Blenkinsop et al. (1995), to assess endowment for the MGB and most of the gold belts in Zimbabwe. And then the Zipf Law which has already been used in this study to assess the gold endowment and fertility of the GGB.

8.4. ARCHITECTURE

8.4.1. Regional Architecture

At regional scale, the architectural elements most critical to the formation of orogenic deposits like the one at Blue Rock should include all the major D1 transcrustal belt-wide thrusts, that acted as primary permeable conduits for fluids.

The most prominent of these major belt-scale structures include the northern extension of the KDZ which wraps around the western margins of the GGB, marking its contact with younger Biri granite rocks to the west.

These major regional thrusts allowed over pressurised fluids (Sibson, 2014) released during partial melting to migrate up-dip from the mantle to upper crustal levels, where gold was concentrated to eventually form structurally controlled epigenetic orogenic gold deposits like the one at Blue Rock, localized within shallower lower-order structures (Fig. 52).

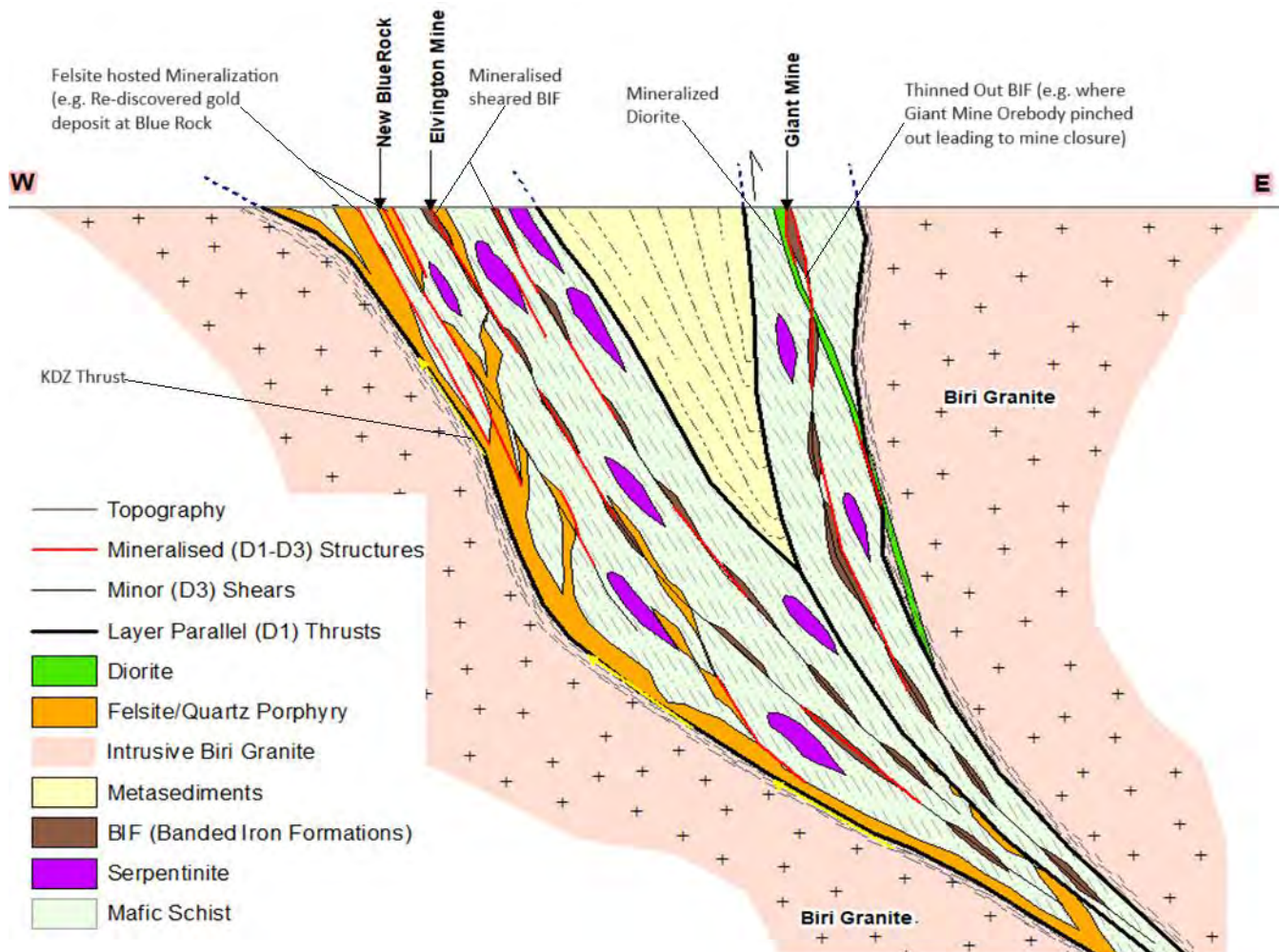


Figure 52: Illustrative sketch of a regional geological section through the GGB geodynamic model. Conceived from the regional geology of the GGB (consolidated in Fig. 51) and drawn using concepts adapted from constructions of Western Succession Greenstone Belts (e.g. the Shamva-Bindura Greenstone Belt - Dirks and Jelsma, 1997).

Lower order structures form favourable auriferous fluid pathways and structural traps where gold is localised through sudden pressure-temperature and or chemical changes. Development of these structures was controlled by rheological and geochemical contrasts between rock units within host sequences during deformation, to produce different structure, host rock geometries and lithological associations.

Within the GGB all the major gold deposits can be classified into three (3) major mineralised lithological associations (Fig. 53), which are; (a) the chemically controlled traps defined by fractured and strongly sheared iron-rich BIF hosts, (b) shear and fault hosted quartz vein lodes hosted within any lithological domain within the GGB, and (c) igneous

intrusive hosted deposits, which are associated with granite, diorite or felsite and quartz porphyries to which the felsite-hosted gold deposit at Blue Rock belongs.

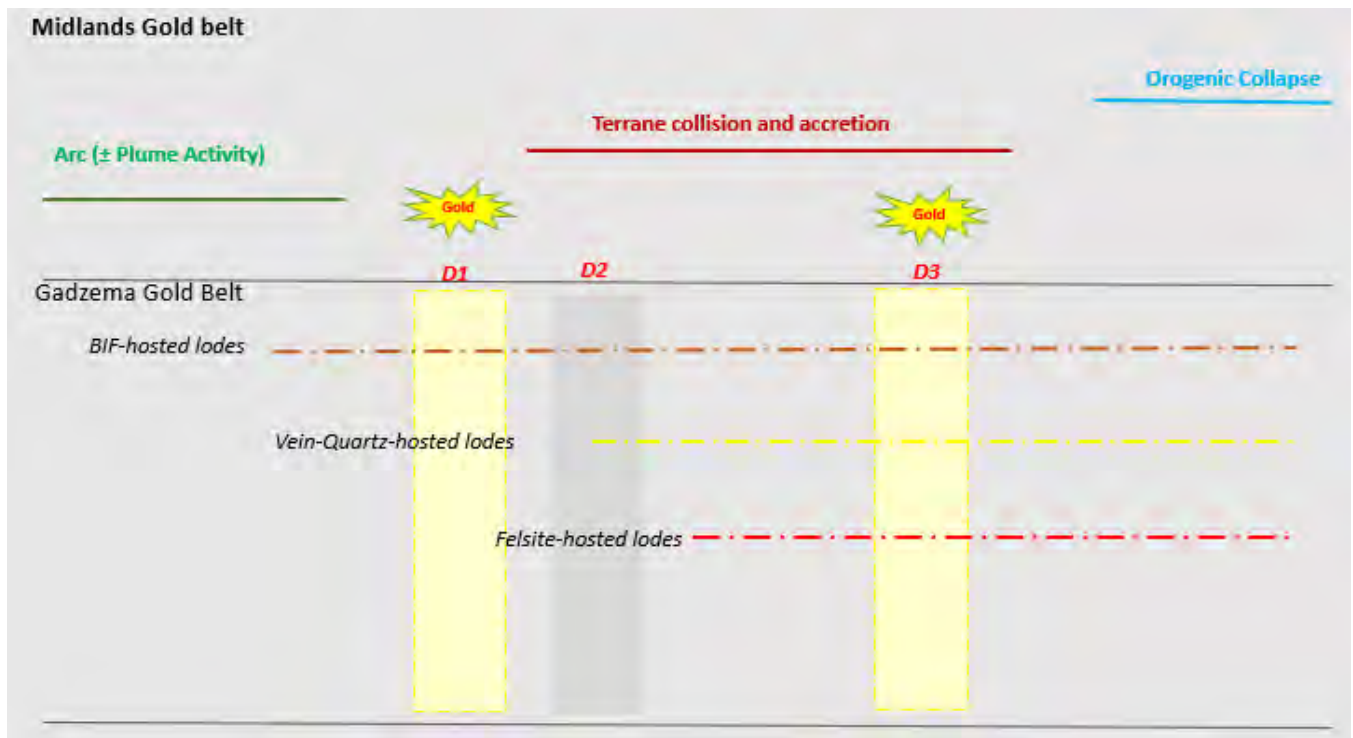


Figure 53: Schematic model for the sequence of the felsite hosted gold mineralization at Blue Rock relative to historical BIF hosted and quartz vein reefs, during the tectonic evolution of the GGB.

At regional scale, exploration for Blue Rock-type deposits;

- Should prioritise areas near first order (D1) transcrustal structures that not only acted as major fluid conduits, but also controlled the emplacement of host felsites and quartz porphyry rocks, as well as their deformation and therefore, mineralization.
- Spatial analysis in GIS (e.g. using proximity algorithms), are some of the useful techniques to employ in the ranking of target areas at different locations relative to these major transcrustal faults.
- Remote sensing is usually a great tool for elucidating the structural framework of greenstone belts and delineating high strain zones and felsic intrusions. Its use is usually advocated for, as one of the first steps useful in evaluating the gold potential of an area. Target selection can be refined by identifying favourable structural patterns and lithological associations.
- Transcrustal structures, just like those within the GGB, are commonly marked by lineaments that show up on satellite and airborne geophysical data. Aeromagnetic data would be useful in delineating faults, shears, iron-formations and granitic rocks, especially where the more conductive mafic to ultramafic rocks of the gold belt terminate against a less conductive background of surrounding younger intrusive granites. Geophysical techniques useful for profiling these structures at depth include gravity as well as magneto-tellurics.
- The nature of architectural element patterns at regional scale can also be characterised through mapping and structural evaluation of lineaments, for example, using fractals and stress mapping techniques.
- Structural evaluation can also be supported by the distribution of mines and workings of economic significance to get a better understanding of specific structures that control economic gold mineralization.
- It is these structures, their intersections, trap sites (e.g. fault jogs) and lithological associations that should be targeted for possible economic gold mineralization.

- From such work, targets are then selected and ranked for testing using direct detection exploration methods including regional geochemical sampling. Geochemical sampling can be conducted from scratch or data for the same could be sourced as pre-competitive data from company archives. Results from sampling are interpreted in the context of structural evaluation data and used to generate anomalies to test using shallow excavations and drilling to both firm them up, and to test their continuity at depth.

8.4.2. Deposit-Scale Architecture

At local scale, gold mineralization at Blue Rock is hosted within sheared felsite and quartz porphyry rocks. The felsites and quartz porphyries occur proximal to major thrusts and faults. Their intrusion and subsequent mineralization are structurally controlled. Gold mineralization is hosted as quartz vein stockworks within sheared felsites, as well as, along their irregular sheared margins and contacts with the mafic schists they intruded (Fig. 54).

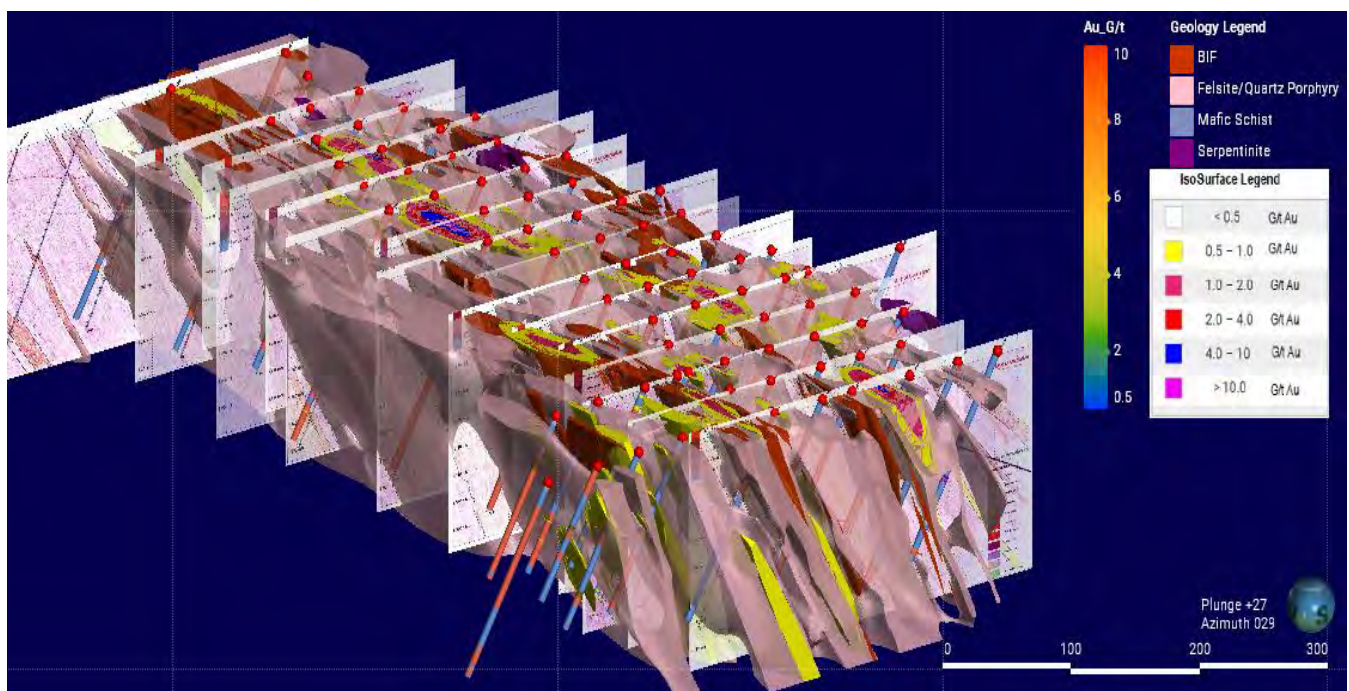


Figure 54: Gold deposit at Blue Rock showing numerically modelled gold values hosted by felsites and quartz porphyries at the Berks prospect.

Subordinate gold mineralization is also hosted by quartz veins within the hanging- and footwalls dominated by mafic schist which acted as an impermeable cap rock that confined auriferous fluids around the main mineralized fractured and permeable felsite bodies (Fig. 55).

Gold mineralization appears to be associated with re-activated D1 structures, as well as the D3 brittle-ductile shears. The mineralized felsites are cut by D3 shears, most of which dominate the margins of the felsites. The most significant shear orientations are the NS, NW-SE and EW trending. These multiple lower order shears and faults formed during the (D3) brittle-ductile deformation phase. They define local structural conduits which are not well interconnected, within very large volumes of felsites and quartz porphyry rocks. As a result, auriferous fluids were poorly focused and produced a very broad, low-grade felsite-hosted deposit next to the D1 lithospheric crustal thrust fault near the western margin of the GGB.

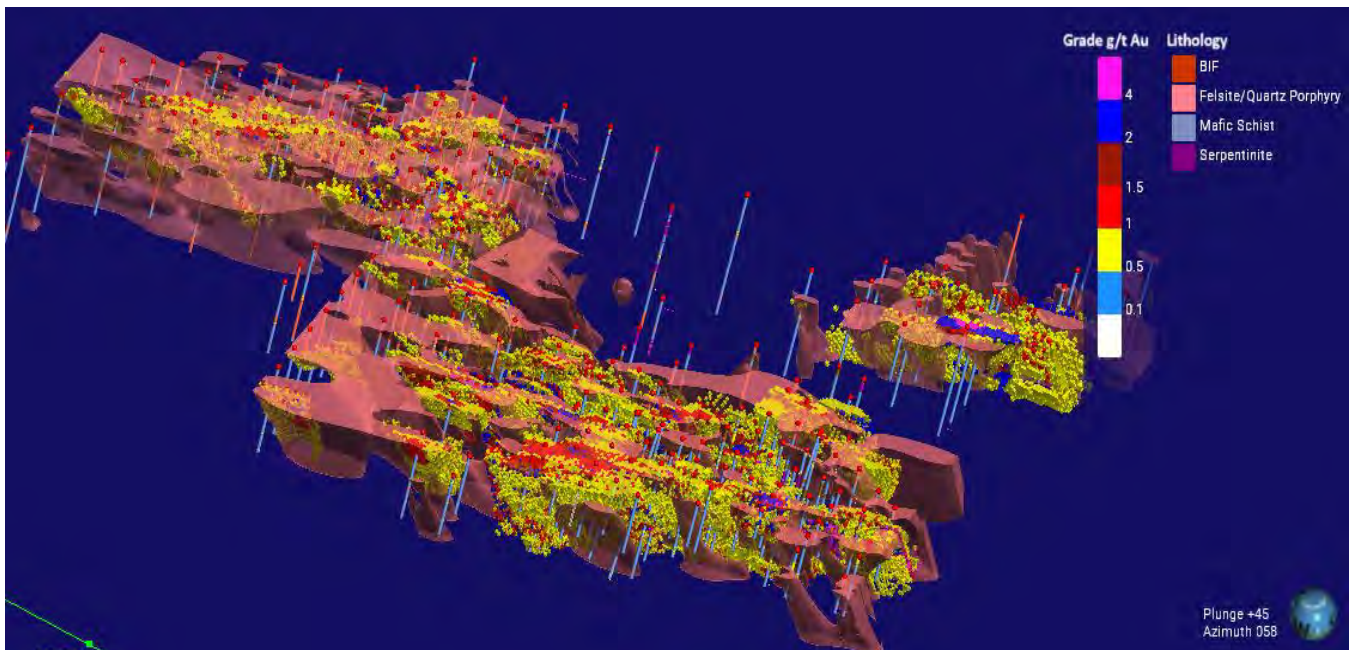


Figure 55: Gold deposit at Blue Rock showing structurally controlled resource estimated gold mineralization hosted within felsite fractured interiors, sheared margins and complex geometric structural trap sites.

The sheared margins of small felsic intrusions together with triple or quadruple-point junctions between adjacent intrusions formed trap sites, whilst mafic schists and serpentinites formed an important impermeable cap rock.

Exploration success for Blue Rock type of gold deposits therefore hinges upon developing a strong understanding of a target area's geology and structural architecture. Understanding the Architecture at this scale is useful mainly for guiding drill target testing, resource drilling and modelling.

- At deposit scale, surface geological and structural mapping would be useful for characterizing the spatial distribution of felsites together with associated structures that influenced their emplacement, subsequent deformation and mineralization. Various tools could be used to map felsites including radiometric surveys. An airborne radiometric survey like the one conducted by ACR over the GGB to help re-discover the gold deposit at Blue Rock, would provide a quick way to map out felsites against a non-radiometric background of mostly mafic-ultramafic greenstone lithologies. Additionally, site walkover surveys to map the distribution of mine workings exploiting mineralized felsites would be key.
- Exploration at this scale should target and prioritise felsites associated with structures of exploration significance. This is done through integrating geological mapping with structural evaluation maps.
- Once the geological and structural mapping is in place, shallow, low cost, scout percussion drilling (e.g. RAB), can be conducted covering the entire strike where felsites would have been identified. To minimise risk, the drilling would initially be conducted at widely spaced drill lines targeting prioritized areas of potential mineralization, selected from a combination of surface mapping, geophysical radiometric survey data interpretations, structural target evaluations, mineralization trends defined from productive mines, spatial distribution of shallow gold workings, as well as regional geochemical survey anomalies.
- Positive and anomalous gold sample results from shallow drilling would then be used to guide full-scale drilling with reverse circulation and diamond core drilling for resource evaluation.
- Results from the drilling need to be integrated and analysed to define geological models and mineral resources using cutting edge software like Leapfrog Geo and Edge used in this study, to handle 3D visualisation, mineralization domain definition, narrow vein modelling, grade continuity and dilution. This would greatly improve resource estimation by reducing errors often introduced from resource estimates done without a proper understanding of geological controls on gold grade distribution.

In addition to these tools, modern exploration techniques such as prospectivity analysis using (e.g. Bayesian Algorithms, Machine Learning and Artificial Intelligence), would find great use towards the exploration of felsite-hosted gold mineralization, by making use of the wealth of available pre-competitive data generated in mature terrains during early exploration phases that targeted higher grade BIF and Quartz vein hosted orogenic gold targets, during earlier times when low-grade felsite hosted deposits like the one at Blue Rock were still being viewed as not prospective for economic gold deposits.

8.5. PRESERVATION

The occurrence of orogenic gold deposits close to the surface is a function of erosion and exhumation, and the degree to which exhumation occurs can be measured through thermo-chronological studies. Such studies, however, are not part of the scope of this study, but for more practical purposes, the deduced level of erosion of existing deposits would give a good exploration guide (Groves et al., 2020). For a measure of preservation of the gold deposit at Blue Rock therefore, we turn to the many known orogenic gold deposits within the local GGB and the more extensive MGB.

The gold deposit at Blue Rock was drill tested to a vertical depth of at least 150m but left open ended down-dip. Gold mineralization could also be expected to continue up to at least 300m based on the maximum mined depth of the Elvington mine orebodies within the GGB, or down to at least 1500m depth, based on the maximum development depth of the Cam and Motor mine within the MGB.

Additionally, the gold mineralization appears to have been localized late during the deformation of the GGB and would therefore have good preservation potential. Such deposit occurrence attributes would be useful to consider when searching for felsite-hosted gold deposits in similar geological terrains.

CHAPTER 9. CONCLUSIONS AND RECOMMENDATIONS

This study on the gold deposit at Blue Rock provided a wealth of information critical for understanding its genesis, and to propose effective ways to successfully explore for felsite hosted mineralization. An important unlikely outcome from this study, however, has also been the recognition of a universal model for orogenic gold deposits as well as the evolution of Archaean greenstone belts like the GGB, through subduction-driven horizontal accretion at continental margins. This geodynamic setting is key for fluid generation, and for the formation of the right architecture, which was later exploited by felsite and quartz-porphyry intrusives as well as by auriferous fluids that got localized within felsites to form an extensive structurally controlled, low-grade open-pitabile gold deposit within lower order structures.

The orogenic gold mineralization at Blue Rock is epigenetic and hosted mostly within felsites, whose emplacement was structurally controlled. The felsites occur in sill and dyke-like morphologies that were syntectonically emplaced within layer parallel thrusts, formed during horizontal accretion of the GGB, at the continental margins of the SPC. Three-dimensional models of gold grades and downhole geology from the drill hole database were important tools for interpreting structural controls on gold mineralization. Gold mineralization at the deposit was controlled by brittle-ductile thrusts and faults that focused fluid flow.

Application of the mineral system to the study of the gold deposit at Blue Rock revealed that, the deposit has potential to yield more than 1 million Au ounces. At a time when new world-class deposits are increasingly becoming hard to find, even when exploration expenditure is increasing, this type of mineralization can no longer be ignored.

In this research I would like to speculate that the genesis of the gold deposit at Blue Rock was no different from those that formed major BIF and quartz vein hosted deposits within the same orogenic terrain, albeit with differences in host rock and precipitation mechanisms, and would encourage further discussion on this topic.

CHAPTER 10. REFERENCES

- Anhaeusser, C.R. (1976). The nature and distribution of Archaean gold mineralization in Southern Africa. *Minerals Sci. Engng*, pp. 46-84.
- Bartholomew, D.S. (1990). Gold deposits of Zimbabwe. *Geol. Surv. Zimbabwe, Mineral Resources Series 23*, 75pp.
- Batty, M. & Longley, P. (1994). *Fractal Cities. A Geometry of Form and Function*. Academic Press, San Diego, pp. 394.
- Bertoli, O., Job, M., Vann, J. & Dunham, S. (2003). Two dimensional geostatistical methods – theory, practice and a case study from the IA shoot nickel deposit, Leinster, Western Australia. In: *Proceedings Fifth International Mining Geology Conference*, (The Australasian Institute of Mining and Metallurgy: Melbourne), pp. 187-195.
- Bickle, M.J., Martin, A. & Nisbet, E.G. (1975). Basaltic and peridotitic komatiites and stromatolites above a basaltic unconformity in the Belingwe greenstone belt, Rhodesia. *Earth. Planet. Sci. Lett.*, **27**, pp.133-149.
- Bickle, M.J. & Nisbet, E.G. (Eds.). (1993). *The geology of the Belingwe greenstone belt* (Geological Society of Zimbabwe Special Publication 2): Rotterdam, A.A. Balkema, 239 p.
- Bickle, M.J., Nisbet, E.G. & Martin, A. (1994). Archaean greenstone belts are not oceanic crust. *Journal Geology* **102**, pp.121–138.
- Blenkinsop, T.G. (1995). Fractal Measures for Size and Spatial Distributions of Gold Mines: Economic Implications. In: Blenkinsop, T.G. & Tromp, P.L. (eds.). *Sub-Saharan Economic Geology. Special Publication Geological Society of Zimbabwe* **3**, pp. 177-186.
- Blenkinsop, T.G., Fedo C. M., Bickle M.J., Eriksson, K.A., Martin, A., Nisbet, E.G. & Wilson, J.F. (1993). Ensilic origin for the Ngezi group, Belingwe greenstone belt, Zimbabwe, *Geology* **21**, pp.1135- 1138.
- Blenkinsop, T.G., Martin, A., Jelsma, H.A. & Vinyu, M.L. (1997). The Zimbabwe Craton. In: de Wit, M.J., Ashwal, L.D. (Eds.), *Greenstone Belts*. Oxford University Press, Oxford, pp. 567–580.
- Bouhallier, H., Choukroune, P. & Ballkvre, M. (1993). Diapirism, bulk homogeneous shortening and transcurrent shearing in the Archaean Dharwar craton, the Holenarsipur area, southern India. *Precamb. Res.*, v. **63**, pp. 43-58.
- Boyle, R.W. (1979). The geochemistry of gold and its deposits. *Geol. Surv. Canada. Bull* **280**, 584 pp.
- Campbell, S.D.G. & Pitfield, P.E.J. (1994). Structural controls of gold mineralization in the Zimbabwe Craton: Exploration guidelines. *Geol. Surv. Zimbabwe, Bull.* **101**, 270 pp.
- Card, K.D. (1990). A review of the Superior Province of the Canadian Shield, a product of Archaean accretion. *Precambrian Research* **48**, pp. 99–156.
- Caroff, M., Labry, C., Le Gall, B., Authemayou, C. & Guillong, M. (2015). Petrogenesis of late Variscan high K alkali-calcic granitoids and calc-alkalic lamprophyres: the Aber/ Ildut/North-Ouessant complex, Armorican Massif, France. *Lithos* **238**, pp. 140–155.
- Carruthers, J. & Arnold, M. (1995). *The life and work of Thomas Baines*. Vlaeberg: Fernwood Press, 1995.
- Cawood, P.A., Hawkesworth, C.J., Pisarevsky, S.A., Dhuime, B., Capitanio, F.A. & Nebel, O. (2018). Geological archive of the onset of plate tectonics. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 376(2132), p. 20170405.
- Chen, Y. (2009). “A new model of urban population density indicating latent fractal structure” *International Journal of Urban Sustainable Development* 1, pp. 89–110.

- Chisi, K. (1994). Geology of the Gadzema Schist Belt; Tectonic and Structural Constraints on Gold Precipitation. Unpublished B. Sc Hons. Proj. thesis, University of Zimbabwe.
- Coleman, R.G. (2012). Ophiolites: Ancient Oceanic Lithosphere? Springer, Berlin. 229.
- Colvine, A.C. (1989). An empirical model for the formation of Archean gold deposits. Products of final cratonization of the Superior Province, Canada. In: Keays, R.R., Ramsay, W.R.H. & Groves, D.I. (Eds.). The Geology of Gold Deposits: The Perspective in 1988. Econ. Geol. Monogr., 6, pp. 37–53.
- Colvine, A.C., Andrews, A.J., Cherry, M.E., Durocher, M.E., Fyon, J.A., Lavigne, M.J., Macdonald, A.J., Marmont, S., Poulsen, K.H., Springer, J.S. & Troop, D.G. (1984). An integrated model for the origin of Archean lode-gold deposits. Ont. Geol. Surv. Open-File Rep. 5524, 98 pp.
- Colvine, A.C., Fyon, J.A., Heather, K.B., Marmont, S., Smith, P.M., & Troop, D.G. (1988). Archaean lode deposits in Ontario: Ontario Geol. Survey Misc. Paper 139, 136 p.
- Cox, S.F. (2016). Injection-driven swarm seismicity and permeability enhancement: implications for the dynamics of hydrothermal ore systems in high fluid-flux, over pressured faulting regimes: an invited paper. Econ. Geol. 111, pp. 559–588.
- Deng, J., Wang, Q.F., Santosh, M., Liu, X., Liang, Y., Yang, L.Q., Zhao, R. & Yang, L. (2019). Remobilization of metasomatized mantle lithosphere: a new model for the Jiaodong gold province, eastern China. Miner. Depos. 1–12.
- Dentith, M.D., Aitkin, A., Evans, S. & Joly, A. (2013). Regional targeting for gold and nickel deposits using crustal electrical conductivity variations determined using the magnetotelluric method. Austr. Soc. Explor. Geophys. Extend. Abstr. 124, pp. 1–4.
- de Wit, M.J. (1982). Gliding and overthrust nappe tectonics in the Barberton Greenstone Belt, J. Struct. Geol., 4, pp.117-136.
- de Wit, M.J. & Ashwal, L.D. (1997). Greenstone Belts. Oxford Monograph on Geology and Geophysics 35. Clarendon Press, Oxford. 809.
- Dilek, Y. & Furnes, H. (2011). Ophiolite Genesis and Global Tectonics: Geochemical and Tectonic Fingerprinting of Ancient Oceanic Lithosphere. Geological Society of America Bulletin, 123(3/4), pp. 387–411.
- Dirks, P.H.G.M. (1997). Accretion and stabilization of the Archaean Zimbabwe Craton (extended abstract), Netherlands Journal of Geosciences, 76, 365-368.
- Dirks, P.H.G.M. & Jelsma, H.A. (1998). Horizontal accretion and stabilization of the Zimbabwe Craton. Geology 26, 11–14.
- Dirks, P.H.G.M. & Jelsma, H.A. (2002). Crust–mantle decoupling and the growth of the Archaean Zimbabwe craton, Journal of African Earth Sciences, Volume 34, Issues 3–4, pp. 157-166.
- Dirks, P.H.G.M. & Mikhailov, A. (1998). A Structural Evaluation of the gold occurrences around Giant Mine, Gadzema Schist Belt: Internal Consulting report. African Consolidated Resources, Company Archives, (Unpublished).
- Dirks, P.H.G.M. & van der Merwe, J. (1997). Early duplexing in an Archaean greenstone sequence and its control on gold mineralization. Journal African Earth Sciences 24, 603–620.
- Emmons, W.H. (1937). Gold deposits of the world: London and New York, McGraw-Hill, Geological Magazine 74(11), pp. 525-562.
- Fisher, N.J. (1992). Deformation Induced Fluid Flow and Gold Precipitation in Banded Iron-Formation, Unpublished Ph.D. thesis, University of Southampton, U.K.

- Florence, P.S. (1950). Review of Human Behavior and the Principle of Least Effort., by G.K. Zipf. The Economic Journal, 60(240), 808–810.
- Foster, R.P. (1985). Major controls on Archean gold mineralization in Zimbabwe. Barberton Centenary Symposium. Transactions of the Geological Society of South Africa 88, 109-133.
- Foster, R.P., (ed.). (1984). Gold '82: The Geology. Geochemistry and Genesis of Gold Deposits. Proceedings of the symposium Gold '82', Special Publication No. 1. Geological Society of Zimbabwe. A. A. Balkema, Rotterdam, 753 p.
- Foster, R.P., Mann, A.G., Stowe, C.W. & Wilson, J.F. (1986). Archaean gold mineralization in Zimbabwe, in Anhaeusser, C.R. & Maske, S. (eds.). Mineral deposits of southern Africa; vol I: Johannesburg, Geol. Soc. South Africa, pp. 43-112.
- Frankhauser, P. (1998). The fractal approach. A new tool for the spatial analysis of urban agglomerations. Population: An English selection, special issue New Methodological Approaches in Social Sciences, pp. 205–240.
- Fyfe, W.S., Price, N.J. & Thompson, A.B. (1978). Fluids in the Earth's crust. Elsevier, Amsterdam, pp. 383.
- Goldfarb, R.J., Baker, T., Dube, B., Groves, D.I., Hart, C.J.R. & Gosselin, P. (2005). Distribution, character, and genesis of gold deposits in metamorphic terranes. In: Economic Geology 100th Anniversary, pp. 407–450.
- Goldfarb, R.J. & Groves, D.I. (2015). Orogenic gold: Common or evolving fluid and metal sources through time: Lithos, **233**, pp. 2–26.
- Goldfarb, R.J., Groves, D.I. & Gardoll, S. (2001). Orogenic gold and geologic time; a global synthesis. Ore Geol. Rev. 18, 1–75.
- Goldfarb, R.J. & Santosh, M. (2014). The dilemma of the Jiaodong gold deposits: are they unique? Geoscience Frontiers 5, 139-153.
- Groves, D.I. (1982). The Archaean and earliest Proterozoic evolution and metallogeny of Australia. Revista Brasileira de Geosciences **12**, pp. 135-148.
- Groves, D.I., Condie, K. C., Goldfarb, R. J., Hronsky, J. M. A., & Vielreicher, R. (2005). Secular changes in global tectonic processes and their influence on the temporal distribution of gold-bearing mineral deposits. *Economic Geology*, 100 (2), 203-224.
- Groves, D.I., Goldfarb, R.J., Gebre-Mariam, M., Hagemann, S.G. & Robert, F. (1998). Orogenic gold deposits: A proposed classification in the context of their crustal distribution and relationship to other gold deposit types: Ore Geology Reviews, v. 13, pp. 7–27.
- Groves, D.I., Phillips, G.N., Ho, S.E., Henderson, C.A., Clark, M.E. & Woad, G.M. (1984). Controls on distribution of Archaean hydrothermal gold deposits in Western Australia, 689-712. In: Foster, R.P. (ed.). Gold '82': The geology, geochemistry and genesis of gold deposits. A.A. Balkema, Rotterdam, 753 p.
- Groves, D.I., Phillips, G.N., Ho, S.E. & Houston, S.M. (1985). The nature, genesis and regional controls of gold mineralization in Archaean greenstone belts of the Western Australian Shield: a brief review. Trans. Geol. Soc. S. Afr. **88**, 135-148.
- Groves, D.I. & Santosh, M. (2016). The giant Jiaodong gold province: the key to a unified model for orogenic gold deposits? Geosci. Front **7**:409–418.
- Groves, D.I., & Santosh, M. (2023). *Mineral Systems, Earth Evolution, and Global Metallogeny*. (1 ed.) Elsevier. 251 p.
- Groves, D.I., Santosh, M., Deng, J., Wang, Q.F., Yang, L.Q. & Zhang, L. (2020b). A holistic model for the origin of orogenic gold deposits and its implications for exploration. Miner. Depos. 55, 275–292.

- Groves, D.I., Santosh, M., Goldfarb, R.J. & Zhang, L. (2018). Structural geometry of orogenic gold deposits: implications for exploration of world-class and giant deposits. *Geosci. Front.* 9, 1163–1177.
- Groves, D.I., Santosh, M., Müller, D., Zhang, L., Deng, J., Yang, L. & Wang, Q. (2022). Mineral systems: Their advantages in terms of developing holistic genetic models and for target generation in global mineral exploration, *Geosystems and Geoenvironment*, Volume 1, Issue 1, 100001.
- Groves, D.I., Santosh, M. & Zhang, L. (2020a). A scale-integrated exploration model for orogenic gold deposits based on a mineral system approach. *Geosci. Front.* 11, 719–738.
- Hickman, A.H. (1983). Geology of the Pilbara Block and its environs. *Geol. Survey W. Australia, Bull.* v. 127, pp. 268.
- Horstwood, M.S., Nesbitt, R.W., Noble, S.R. & Wilson, J.F. (1999). U-Pb zircon evidence for an extensive early Archean craton in Zimbabwe: A reassessment of the timing of craton formation, stabilization, and growth. *Geology*, 27(8), pp.707-710.
- Hronsky, J.M.A. (2020). Deposit-scale structural controls on orogenic gold deposits: an integrated, physical process-based hypothesis and practical targeting implications. *Miner. Depos.* 55, 197-216.
- Hronsky, J.M.A. & Groves, D.I. (2008). The science of targeting: definition, strategies, targeting and performance measurement. *Aust. J. Earth Sci.* 55, 3-12.
- Hunter, M.A., Bickle, M.J., Nisbet, E.G. Martin, A. & Chapman, H.J. (1998). Continental extensional setting for the Archaean Belingwe Greenstone Belt, Zimbabwe. *Geology* **26**, 883–886.
- Hyndman, R.D., McCrory, P.A., Wech, A., Kao, H. & Ague, J. (2015). Cascadia subducting plate fluids channelled to forearc mantle corner: ETS and silica deposition. *Journal of Geophysical Research. Solid Earth* **120**, 4344-4358.
- Jelsma, H. A. (1993). Granites and greenstones in Northern Zimbabwe: tectono-thermal evolution and source regions, Ph.D. Thesis, Free Univ. of Amsterdam, Netherlands, 268 pp.
- Jelsma, H.A. & Dirks, P.H.G.M. (2002). Neoarchaean tectonic evolution of the Zimbabwe Craton. *Geological Society, London, Special Publications*, 199(1), pp.183-211.
- Jelsma, H.A., Nesbitt, R.W. & Fanning, C.M. (2021). Exploring our current understanding of the geological evolution and mineral endowment of the Zimbabwe Craton. *South African Journal of Geology*, 124 (1): 279-310.
- Jelsma, H.A., van der Beek, P.A. & Vinyu, M.L. (1993). Tectonic evolution of the Bindura–Shamva greenstone belt (northern Zimbabwe): progressive deformation around diapiric batholiths. *Journal Structural Geology* 15, 163–176.
- Johnson, N. (2010). Updated resource estimation for the Blue Rock Gold Project, Zimbabwe. Unpublished Mineral Resources Estimation report by Hellman & Schofield (Pty) Ltd, for African Consolidated Resources Plc.
- Johnson, N. (2012). Updated resource estimation for the Blue Rock Gold Project, Zimbabwe. Unpublished Mineral Resources Estimation report by MPR Geological consultants (Pty) Ltd, for African Consolidated Resources Plc.
- Kalbskopf, S. & Nutt, T. (2003). Lithological contrasts and constraints on gold mineralization in granitoids in the Zimbabwe Craton: Structural controls and implications for exploration. *Economic Geology Research Institute, Circular* 370, 27 p.
- Kawai, K., Tsuchiya, T., Tsuchiya, J. & Maruyama, S. (2009). Lost primordial continents. *Gondwana Res.* 16, 581–586.

- Kerrick, R. (1989). Geodynamic setting and hydraulic regimes: shear zone hosted mesothermal gold deposits. In: Bursnall, J.T. (ed.) Mineralization and Shear zones. Geological Association of Canada Short Course Notes 6, 89–128.
- Kerrick, R. (1989). Geodynamic setting and hydraulic regimes: shear zone hosted mesothermal gold deposits. In: Bursnall, J.T. (ed.). Mineralization and Shear zones. Geological Association of Canada Short Course Notes 6: 89–128.
- Kerrick, R. (1993). Perspectives on genetic models for lode gold deposits. *Mineral. Deposita* **28**, 362–365.
- Knox-Robinson, C.M. & Wyborn, L.A.I. (1997). Towards a holistic exploration strategy: using geographic information systems as a tool to enhance exploration. *Aust. J. Earth Sci.* **44**, 453–463.
- Kusky, T.M. (1998). Tectonic Setting and Terrane Accretion of the Archean Zimbabwe Craton. *Geology*, **26**(2): 163–166.
- Kusky, T.M. (2011). Geophysical and geological tests of tectonic models of the North China Craton. *Gondwana Research*, **20**(1), 26–35.
- Kusky, T.M. & Vearncombe, J. (1997). Structure of Archean Greenstone Belts. In: de Wit, M. J. & Ashwal, L. D. (eds.). *Tectonic Evolution of Greenstone Belts*. Oxford Monograph on Geology and Geophysics. Clarendon Press, Oxford, pp. 95–128.
- Kusky, T.M., Windley, B.F. & Polat, A. (2018). Geological Evidence for the Operation of Plate Tectonics throughout the Archean: Records from Archean Paleo-Plate Boundaries. *J. Earth Sci.* **29**, 1291–1303.
- Kusky T.M., Windley, B.F., Safonova, I., Wakita, K., Wakabayashi, J., Polat, A. & Santosh M. (2013). Recognition of Ocean Plate stratigraphy in accretionary orogens through earth history: a record of 3.8 billion years of sea floor spreading, subduction, and accretion. *Gondwana Res* **24**: 501–547.
- LaFlamme, C., Jamieson, J.W., Fiorentini, M.L., The baud, N., Caruso, S. & Selvaraja, V. (2018). Investigating sulfur pathways through the lithosphere by tracing mass independent fractionation of sulfur to the Lady Bountiful orogenic gold deposit, Yilgarn Craton. *Gondwana Res.* **58**, 27–38.
- Large, R.R., Danyushevsky, L.V., Hollit, C., Maslennikov, V., Meffre, S., Gilbert, S., Bull, S., Scott, R., Emsbo, P., Thomas, H. & Foster, J. (2009). Gold and trace element zonation in pyrite using a laser imaging technique: implications for the timing of gold in orogenic and Carlin-style sediment- hosted deposits. *Economic Geology* **104**, 635-668.
- Leader, L.D., Robinson, J.A. & Wilson, C.J.L. (2010). Role of faults and folding in controlling gold mineralization at Fosterville, Victoria. *Aust. J. Earth Sci.* **57**, 259–277.
- Li, S.R. & Santosh, M. (2017). Geodynamics of heterogeneous gold mineralization in the North China Craton and its relationship to lithospheric destruction. *Gondwana Res.* **50**, 267–292.
- Lindgren, W. (1933). *Mineral Deposits*. 4th ed. McGraw Hill, New York and London, 930 pp.
- Loucks, R.R. & Mavrogenes, J.A. (1999). Gold solubility in supercritical hydrothermal brines measured in synthetic fluid inclusions. *Science* **284**, 2159–2163.
- MacGregor, A.M. (1951). Some milestones in the Precambrian of Southern Rhodesia. *Proc. Geol. Soc. S. Afr.* **54**, pp. 27-71.
- Machiki, T. (2017). ZMDC secures US\$6m for Jena Gold Mine. *The Sunday Mail* (22 October 2017).
- Mann, R.J. (1871). Account of Mr. Baines's Exploration of the Gold-bearing Region between the Limpopo and Zambesi Rivers prepared from Mr. Baines's Journals. *The Journal of the Royal Geographical Society of London*, Vol. **41** (1871), pp. 100-131.

- Maruyama, S. & Safonova, I. (2019). Orogeny and mantle dynamics: role of tectonic erosion and second continent in the mantle transition zone. Novosibirsk State University, Novosibirsk, IPC NSU, p. 208.
- McCourt, S., Kampunzu, A.B., Bagai, Z. & Armstrong, R.A. (2004). The crustal architecture of Archaean terranes in Northeastern Botswana. *South African Journal of Geology* 107, 146-158.
- McCuaig, T.C., Beresford, S. & Hronsky, J. (2010). Translating the mineral systems approach into an effective exploration targeting system. *Ore Geology Reviews* 38, pp. 128-138.
- McCuaig, T.C. & Hronsky, J.M.A. (2014). The Mineral System Concept: The Key to Exploration Targeting, Building Exploration Capability for the 21st Century. Society of Economic Geologists, Inc. Special Publication 18, pp. 153- 175.
- Megill, R.E. (1988). *Exploration Economics*: Tulsa. PennWell, p. 238.
- Mutambara, T.B. (1991). The Geology, Structure, Mineralization and Metamorphism at Elvington Mine, Chegutu. Unpublished B. Sc Hons. Proj. Thesis, University of Zimbabwe.
- Myers, J.S. (1995). The generation and assembly of an Archaean super continent: evidence from the Yilgarn craton, Western Australia. In: Coward, M.P., Ries, A.C. (Eds.), *Early Precambrian Processes*, vol. 95. Geological Society Special Publications, pp. 143–154.
- Nyagumbo, J. (2017). The Cam and Motor Gold Mine – Rio Tinto Zimbabwe: A SAIMM CONFERENCE Presentation. Cresta Lodge, Harare, Zimbabwe. 03-04 August 2017.
- Perring, C.S., Groves, D.I. & Ho, S.E. (1987). Constraints on the source of auriferous fluids for Archaean gold deposits. In: Ho, S.E., Groves, D.I. (Eds.), *Recent Advances in Understanding Precambrian Gold Deposits*, Publication 11, Geology Department and University Extension. University of Western Australia, pp. 287-306.
- Phaup, A.E. & Dobell, F.O.S. (1938). The geology of the lower Umfuli Gold Belt, Hartley and Lomagundi Districts. *Geol. Surv. S. Rhod., Bull.* 34, 150 pp.
- Phillips, G.N., Groves, D.I. & Martyn, J.E. (1984). An epigenetic origin for banded iron formation- hosted gold deposits. *Econ. Geol.* 79, 162–171.
- Phillips, G.N., Powell, R. (2010). Formation of gold deposits – a metamorphic devolatilization model. *J. Metamorph. Geol.* 28, 689-718.
- Prendergast, M.D. (2004). The Bulawayan Supergroup: a late Archaean passive margin-related large igneous province in the Zimbabwe craton. *Journal of the Geological Society, London*, 161, 431-445.
- Ramsay, J.G. (1989). Emplacement kinetics of a granite diapir: The Chinamora Batholith, Zimbabwe, *J. Struct. Geol.*, 11, 191-209.
- Ridley, J.R. (1993). The relations between mean rock stress and fluid flow in the crust: with reference to vein- and lode-style gold deposits. *Ore Geology Reviews* 8, 23-37.
- Ridley, J.R. & Diamond, L.W. (2000). Fluid chemistry of orogenic lode gold deposits and implications for genetic models. *Reviews in Economic Geology*; Vol, 13, pp. 141-162.
- Ridley, J.R., Vearncombe, J.R. & Jelsma, H.A. (1997). Relations between greenstone belts and associated granitoids, in *Greenstone Belts*, edited by de Wit, M.J., and Ashwal, L.D., Oxford Univ. Press, New York, pp. 376-397.
- Rock, N.M.S., Groves, D.I., Perring, C.S. & Golding, S.D. (1989). Gold, lamprophyres, and porphyries: what does their association mean? *Econ. Geol. Monogr.* 6, 609–625.
- Schodde, R. (2017). Long term trends in global exploration - Are we finding enough metals? In: 8th Fennoscandian Exploration and Mining Conference. Levi, Finland, pp. 1–66.

- Seno, T. & Kirby, S.H. (2014). Formation of plate boundaries: the role of mantle devolatilization. *Earth-Science Reviews* 129, 85-99.
- Shackleton, R.M. (1995). Tectonic evolution of greenstone belts, in Coward, M.P. & Ries, A.C., (eds.). *Early Precambrian processes*, Geol. SOC. Special Publication 95, pp. 53-65.
- Sibson, R.H. (1992). Implications of fault-valve behaviour for rupture nucleation and recurrence. *Tectonophysics* 211, 282-293.
- Sibson, R.H. (2004). Controls on maximum fluid overpressure defining conditions for mesozonal mineralization. *Journal of Structural Geology* 26, 1127-1136.
- Sibson, R.H. (2013). Stress switching in subduction forearcs: implications for over pressure containment and strength cycling on megathrusts. *Tectonophysics* 600, 142-152.
- Sibson, R.H. (2014). Earthquake rupturing in fluid-overpressured crust: how common? *Pure & Appl. Geophysics*, 171, 2867–2885.
- Stagman, J.G. (1978). An Outline of the Geological History of Rhodesia. Rhodesia Geological Survey Bulletin, 80.
- Stern, R.J. (2007). When and how did Plate Tectonics Begin? Theoretical and Empirical Considerations. *Chinese Science Bulletin*, 52(5): 578– 591.
- Stowe, C.W. (1980). Wrench fault tectonics in the Archaean Rhodesian Craton. *Geological Society South Africa* 83, 193–206.
- Stowe, C.W. (1984). The early Archaean Selukwe nappe, Zimbabwe, in Kroner, A. and Greiling, R., (Eds.). *Precambrian tectonics illustrated*, Nagele und Obermiller, Stuttgart, pp. 41 -56.
- Swager, C. & Griffin, T.J. (1990). An early thrust duplex in the Kalgoorlie-Kambalda greenstone belt, Eastern Goldfields Province, Western Australia, *Precambrian Research*, v. 48, pp. 63-73.
- Thackeray, R.H. (1938). Henry Hartley: African Hunter and Explorer. *Journal of the Royal African Society*, Vol. 37, No. 148, pp. 238 – 297.
- Treloar, P.J. & Blenkinsop, T.G. (1995). Archaean deformation patterns in Zimbabwe: True indicators of Tibetan-style crustal extrusion or not? in *Early Precambrian Processes*, edited by M.P. Coward and A. C. Ries, Geol. Soc. Spec. Publ., 95, 87-108.
- Wang, Q.F., Zhao, H.S., Groves, D.I., Deng, J., Zhang, Q. & Xue, S. (2019). Role of metasomatized mantle lithosphere in the genesis of the Jurassic Danba hypozonal orogenic gold deposit, western China. *Miner. Depos.*
- Wiles, J.W. (1957). The geology of the eastern portion of the Hartley Gold Belt. *Geol. Surv. Zimbabwe, Bull.* 44, 128 pp.
- Wilson, J.F. (1979). A preliminary reappraisal of the Rhodesian basement complex. In: Anhaeusser, C.R., Foster, R.P., Stretton, T. (Eds.), *A symposium on mineral deposits and transportation and deposition of metals*, vol. 5. Geological Society South Africa Special Publications, pp. 1–23.
- Wilson, J.F., Nesbitt, R.W. & Fanning, C.M. (1995). Zircon geochronology of Archaean felsic sequences in the Zimbabwe craton: a revision of greenstone stratigraphy and a model for crustal growth. In: Coward, M.P., Ries, A.C. (Eds.), *Early Precambrian processes*, vol. 95. Geological Society Special Publications, pp. 109–126.
- Windley, B.F., Kusky, T. & Polat, A. (2021). Onset of plate tectonics by the Eoarchean. *Precambrian Research*, 352, p.105980.
- Witt, W.K., Ford, A., Hanrahan, B. & Mamuse, A. (2013). Regional scale targeting for gold in the Yilgarn craton: Part 1 of the Yilgarn gold exploration targeting atlas. *Geol. Surv. West. Austr. Rep.* 125, 130.

- Wyborn, L.A.I, Heinrich, C.A & Jaques, A.L. (1994). Australian Proterozoic mineral systems: Essential ingredients and mappable criteria: Proceedings of the Australasian Institute of Mining and Metallurgy Annual Conference, Darwin, 5–9 August 1994, pp.109–115.
- Wyman, D.A., Cassidy, K.F. & Hollings, P. (2016). Orogenic gold and the mineral systems approach: resolving fact, fiction and fantasy. *Ore Geol. Rev.* 78, 322–335.
- Wyman, D.A. & Kerrich, R. (2010). Mantle plume-volcanic arc interaction: consequences for magmatism, metallogeny, and cratonization in the Abitibi and Wawa sub-provinces, Canada. *Canadian Journal of Earth Sciences* 47, 565-589.
- Wyman, D.A., O'Neill, C.O. & Ayer, J.A. (2008). Evidence for Modern-Style Subduction to 3.1 Ga: a Plateau-Adakite-Gold (Diamond) Association, Vol 440. Geological Society of America Special Publication, pp. 129 –148.
- Yang, L.Q., Deng, J., Groves, D.I., He, W.Y., Li, N. & Zhang, R.R. (2021). China's Anomalously Rich Mineral Endowment: The Critical Role of Metallogenic Factories on Craton Margins. *Geological Society of America Bulletin*.
- Zhang, L., Yang, L.Q., Groves, D.I., Liu, Y., Sun, S.C., Qi, P., Wu, S.G. & Peng, J.S. (2018). Geological and H–O–S–Pb isotopic constraints on ore genesis, Huangjindong goldfield, Jiangnan Orogen, southern China. *Ore Geol. Rev.* 99, 264–281.
- Zhao, J.H. & Zhou, M.F. (2008). Neoproterozoic adakitic plutons in the northern margin of the Yangtze block, China: partial melting of a thickened lower crust and implications for secular crustal evolution. *Lithos* 104, 231–248.
- Zhou, M.F., Yan, D.P., Kennedy, A.K., Li, Y.Q. & Ding, J. (2002). SHRIMP zircon geochronological and geochemical evidence for Neoproterozoic arc-related magmatism along the western margin of the Yangtze Block, South China. *Earth Planet. Sci. Lett.* 196, 51–67.
- Zipf, G.K. (1949). Human behaviour and the principle of least effort: An introduction to human ecology. Cambridge: Addison-Wesley Press.