

https://dspace.org/

The Uis pegmatites: morphology, mineralisation and distribution, with an emphasis on the V1 and V2 intrusions

Marais, Timothy

2019-02

https://hdl.handle.net/10539/29646

Marais, Timothy. (2019). The Uis pegmatites :morphology, mineralisation and distribution, with an emphasis on the V1 and V2 intrusions. University of the Witwatersrand, https://hdl.handle.net/10539/29646

Downloaded from a DSpace repository. https://dspace.org/



The Uis pegmatites: morphology, mineralisation and distribution, with an emphasis on the V1 and V2 intrusions

By

Timothy Marais

0710901M

A research report submitted to the Faculty of Science, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Science.

February 2019

Declaration

I declare that this report is my own, unaided work. It is being submitted for the partial fulfilment of the requirements for the Degree of Master of Science at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other university

_____

Timothy Marais

25 February 2019

Abstract

The Damara Orogen represents a typical Wilson Cycle initiating with extension through and culmination in a collisional environment. The geological units comprise a significant Pan-African age succession of metasedimentary and metavolcanic lithologies with various associated granitic and granodioritic magmatic bodies. The pegmatites of the Damara belt, the trending branch of the Damara Orogen, represent the final phase of orogeny and magmatism, with mineralised pegmatites (Sn, Ta, Nb, Li, Be and W) exclusively forming in a post-tectonic environment.

The Cape Cross-Uis pegmatite belt lies within the Northern Zone of the Damara Belt and runs northeast form Cape Cross to Uis. This belt is known to contain granitic pegmatites commonly enriched in Sn, Ta, Nb, Li and Be and contains 3 distinct pegmatite swarms, the Strathmore, Karlowa and Uis swarm. Each of the pegmatite swarms predominantly contain a pegmatite type with the Uis swarm primarily comprising Sn-Ta-Nb type pegmatites.

The Uis swarm covers and area of approximately 650km^2, AfriTin Mining owns a Mining License within this area which includes the historic Uis Tin Mine. An excess of 180 pegmatites were delineated proximal to the historic Uis mine, of these proximal pegmatites nine have been documented in detail. Additionally, ten of the existing excavations within the mine area have been mapped and described in detail.

Acknowledgement

Firstly, I would like to thank Prof. Judith Kinnaird and Prof. Paul Nex who never gave up on me, even though I thought I had. They provided strength and wisdom when I needed it most.

I am grateful to Anthony Viljoen and Fortune Mojapelo of VMIC and the THRIP fun for providing the funds to and granting me this opportunity to further my education.

Most importantly I would like to acknowledge my wife, Tiffany Marais, who was my girlfriend when this journey started. You have provided me with love and support I needed.

Table of Contents

CHAPTER 1. 5
Introduction 5
Overview 5
Geological Background 5
The Uis swarm 8
CHAPTER 2. 10
Research and Methodology 10
High Resolution Satellite Image 10
Elevation Model 11
CHAPTER 3. 12
Regional pegmatite clusters of the Uis Mine area 12
Overview 12
Desktop Study 14
Eastern Cluster 14
Southern Cluster 17
Western Cluster 22
Additional Observations 23
CHAPTER 4. 25
Mapping of the existing Uis Mine pits 25
Northern Cluster 27
Central Cluster 33
CHAPTER 5. 41
V1 and V2 Detailed Geological and Structural Mapping 41
V1/V2 Extension 41
V1/V2 Pegmatite Pit 44
Pegmatite Contact Characteristics 44
Interpretation 46
CHAPTER 6. 47
Geological Model of the V1 and V2 Pegmatites 47
CHAPTER 7. 52
Economic Potential of the Uis Pegmatite Swarm 52
CHAPTER 8. 55
Conclusion 55

REFERENCES. 56

List of Figures:

Figure 1: A map of the Damara and Kaoko Belts showing the various zones and pegmatite belts within the Damara Belt (After Miller, 2008; modified from Fuchsloch et al., 2018a) 6
Figure 2: Summarised geological map of the Cape Cross-Uis and Nainais-Kahero pegmatite belts, otherwise known as the Northern and Central Tin belts respectively. The image shows the three mining licences that Afritin Mining owns, known as Uis (ML 142), Tsaurob (ML129) and Nainais (ML133). 8
Figure 3: Geological map of the Uis area showing the location of the mining license areas ML 134, ML129 with an overlay of the satellite stereopair in the Uis area. 9
Figure 4: Examples of the satellite stereo pair acquired by AfriTin Mining. A) the digital elevation model of the area using colour contrasts to show changes in elevation. Green shades represent high elevations whereas purple areas are low elevations. B) A normalised difference vegetation index (false colour composite) over the area covered by the satellite image. Light areas indicate and enhance the presence of green leaf vegetation largely distributed along streams and gullies. 11
Figure 5: Images of the pegmatite clusters over the satellite stereo pair. The left image shows the subdivision of clusters and historical mine area and the location of the pilot plant. 13
Figure 6: The southern section of the Eastern Cluster showing the V series of pegmatites. Pegmatites 91V2, 91V8, V4 and V12E are described in more detail. 14
Figure 7: Outcrop photographs of pegmatites within the Eastern Cluster. A) A metre-scale schist xenolith in the V4 pegmatite which has been tourmalinised. B) An underground adit within the V4 pegmatite that traverses horizontally into the pegmatite body to the schist contact in the east. 16
Figure 8: The northern portion of the Southern Cluster showing the location and extent of the W series pegmatites at surface. 18
Figure 9: The southern portion of the Southern Cluster showing the location and surface exposure W series pegmatites. 18
Figure 10: Representative macroscopic images of pegmatites in the Southern Cluster. A) Sample displaying well-defined mineralogical banding where cassiterite is restricted to the central recrystallised alteration zone, flanked by brown Fe-Mn oxide minerals on either side. B) Fine-grained albitised zone consisting of 95% plagioclase with abundant fine-grained accessory cassiterite and apatite. C) Coarse-grained cassiterite occurring within a primary magmatic zone of pegmatite. D) Coarse-grained, cassiterite-bearing greisenised zone. 20
Figure 11: Angled satellite image from Google Earth displaying the morphology of the W2 pegmatite, with a vertical exaggeration of one. 21
Figure 12: Field photographs of the pegmatites in the Southern Cluster. A) The W17 pegmatite which appears thinner on the geological maps in the northeast due to topography. B, C) Outcropping W17 pegmatite on either side of the riverbed. 22
Figure 13: The southern portion of the Western Cluster showing the A series of pegmatites. Some of the mapped intrusions display significant strike extent with minimal thickness 23
Figure 14: Outcrop photographs of the regional pegmatites in the Uis area. A) Highly abundant cassiterite occurring in a recrystallised quartz zone. B) An outcrop photograph showing the varying thickness of pegmatites with depth, where at surface the pegmatite is several centimetres wide compared to the meter-scale pegmatite at depth. C) A 2m deep artisanal excavation along the strike

of a sigmoid-shaped pegmatite intrusion into schist. D) Characteristics of pegmatite that bifurcate joining at depth to form a larger overall pegmatite intrusion. 24
Figure 15: Map indicating structurally controlled en-echelon sigmoidal pegmatites and the outline of pit rims in relation to mined and unmined pegmatites. (Created by AfriTin Mining, 2017) 26
Figure 16: An example of a complex pegmatite intrusion with xenoliths of schist within the main pegmatite body (P6 Pegmatite). 27
Figure 17: Surface images of the K3 and K5 pegmatites A) an image of the K3 pegmatite from the base of the pit B) an overview of the K5 Pegmatite from the northern edge of the excavation, the base of the pit has filled with surface water 28
Figure 18: Geological map produced of the K7 and K7.1 pegmatites 29
Figure 19: A schematic diagram (not to scale) of the K7 pit showing dimensions of the pegmatite and the greisen layer. The pegmatite in the image is shown in pink and the greisenised zone in-between the red lines. 30
Figure 20: Surface images from the K7 pegmatite area A) K7 pegmatite and pit. B) Undulating greisenised zone of K7 (red outline) with large cassiterite grains (yellow rectangles) visible in the pit wall. C) Continuation of the K7 greisenised zone along strike visible in a small excavation 50m along strike from the pit wall. D) image of the K7.1 pegmatite and pit 31
Figure 21: Cassiterite in close association with a coarse quartz grains in the K10 pegmatite 32
Figure 22: Image of the K8 pegmatite, steeply dipping to the north, exposed in the pit sidewall. 33
Figure 23: Surface images taken from the hanging wall of the excavations A) SW view of the P5 pegmatite and pit, showing the pegmatite outcrop on the pit highwall, with a thin layer of waste schist above it. B) View east of the P6 Pegmatite, dipping towards the northwest. C) View west of the P6 Pegmatite, showing the dip of the pegmatite. D) A Mn-enriched layer above a tin mineralised greisen layer within the P6 pegmatite. 34
Figure 24: Geological map of P6 produced during the Norther and Central Cluster mapping programme. 35
Figure 25: The V1 and V2 pegmatites. A) An along-strike view of the V2 pegmatite looking SW, showing the sharp contact between pegmatite and the hanging wall and relatively shallow NW dip. B) A large, irregular shaped grain of cassiterite. C) A greisenised zone, where tin mineralisation is associated with secondary Mn-rich staining. 36
Figure 26: Geological map of the V1/V2 pit produced during the current programme 37
Figure 27: Geological map of the V5/V12 pit. 38
Figure 28: The V5 and V12 pegmatites. A) View of the V5 pegmatite looking SE. B) Pegmatite veins of the V5 pegmatite on the left and right which intersect roughly in the centre of this working near the road, forming a much larger single body. C) View of the V12 pegmatite looking east from the base of the pit. D) View SW of the V12 Pegmatite along the southern pit wall. E) Patchy greisenisation showing significant quantities of coarse cassiterite. F) Layered greisenisation above a zone associated with secondary Mn oxides, showing secondary albitisation (pale white laths below sunglasses) 40
Figure 29: Images and map of the V1/V2 area A) A geological map of the V1/V2 pegmatite. Outlined in red is the unmined, surface extension of the V2 pegmatite. B) Footwall contact of the V2 extension with dark fine-grained biotite phyllite where the person in the image is standing. The pegmatite body occupies the top portion of the photograph. C) A fresh surface of the V2 pegmatite extension showing high-grade greisen-style tin mineralisation similar to the mineralisation in the historical mine. 42
Figure 30: Detailed geological map of the V1 and V2 pegmatites showing the location of dip and strike measurements recorded. 43

Figure 31: Overview photos of the V2 pegmatite. A) An approximate outline of the V2 pegmatite looking towards the SW and showing the approximate dip of the pegmatite at various angles illustrated by red arrowed lines. B) A photo showing the main pit wall in the V2 pegmatite (left). This image shows the complex relationship between the pegmatite and it hanging wall. 45
Figure 32: Various outcrop photographs of the V1 pegmatite showing approximate dip in red arrowed lines. A) The SW extension of the V1 pegmatite showing a schist xenolith within the pegmatite. B) A portion of the V1 pegmatite where the previous mining operations exposed the footwall schist. The pegmatite in this image dips towards the viewer. C) A small-scale example of how the pegmatites may be displaced by joints at the contact with schists. 46
Figure 33: Cross section of the V2 pegmatite, recovered as part of the historic Uis data. 48
Figure 34: Historic drill data projected in Leapfrog Geo. A) all of the validated drill holes in the dataset with pegmatite intersections displayed as red. B) the digital terrain model and detailed geological mapping, blue, incorporated with the drill hole data. 49
Figure 35: Models of the V1 and V2 pegmatites. A) wireframes generated from the intersections in the drill holes extended to the mapped surface outcrop. B) Same image as 35, A with the surface model removed. C) rotated view of the generated model and incorporated drill holes looking down dip. D) Same as Image 25, C, with the historic drill holes removed. 50
Figure 36: Two cross-sections located 200m apart displaying the modelled tin grade profiles and digitised drill hole data 51

CHAPTER 1.

Introduction

Overview

AfriTin Mining's flagship project the Uis Tin Mine, Namibia, is located within the company's mining license ML134, which covers an area of approximately 200km^2. At its peak of mining, the Uis Tin Mine was the largest hard-rock tin mine in the world. The Uis Pegmatite Swarm consists of a central pegmatite field with more than 120 cassiterite-bearing (and lesser tantalite) mineralised pegmatites, and a peripheral field with approximately 25 pegmatites (Diehl, 1993). The Uis pegmatites delineate the northeastern limit of the Cape Cross-Uis pegmatite belt. This belt is well-known to be anomalous in mainly Sn, Ta and Li as it also contains other historic mines such as the Petalite and Strathmore deposits (Diehl, 1993).

Numerous investigations have been conducted by AfriTin within the ML 134 license area with the aim of furthering the understanding of the pegmatites present. This report serves as a compilation of the various work streams that have been completed over the previous 3 years.

Geological Background

The Damara Belt

The Damara Belt comprises the northeast-trending branch of the Damara Orogen, Namibia, and extends from Swakopmund, near the Atlantic coast, inland towards Botswana (Fig. 1; Keller, 1999). The belt is Pan-African in age and represents a typical Wilson Cycle of extension, spreading, rupture, plate reversal, subduction and collision (Martin and Porada, 1977; Gray et al., 2006; Milani et al., 2015). The Damara Supergroup is comprised of metasedimentary and metavolcanic lithologies and has been divided into various tectono-stratigraphic zones based on major structural boundaries, magmatic and stratigraphic horizons (Miller, 2008; Fig. 1). The volcanic units within the Damara Supergroup indicate an active orogenic period ca. 750 to 500 Ma.

During the later collisional stages of the orogen, syn- to post-tectonically, voluminous granodioritic, granitic and then pegmatitic magma was produced which gave rise to the igneous provinces that can presently be observed within the Damara Belt (Kinnaird and Nex, 2007; Longridge, 2012). The D_3 (third deformation event) is linked to the magma forming event that occurred in the syn- to post-tectonic environment, this event is likely to have produced the numerous granitic lithologies observable today (Longridge, 2012). The final phase of magmatism within the orogenic cycle is represented by the granitic pegmatites of the Damara belt. These pegmatites have been grouped into northeast-trending pegmatite belts that occur within the various tectono-stratigraphic zones (Fig. 1; Richards, 1986; Diehl, 1993; Ashworth, 2013; Fuchsloch et al., 2018*a*).

The pegmatites of the Damara Belt are suggested to have emplaced during syn and post orogenic environments and appear to be petrologically related to the voluminous granitic bodies of the Damara Belt (Richards, 1986; Wagener, 1989). However, some authors suggest that the pegmatites are exclusively post tectonic and unrelated to the granitic intrusions (Kinnaird and Nex, 2007; Ashworth, 2013; Fuchsloch et al., 2018*b*). Most authors agree that economically mineralised pegmatites, in terms of Sn, Ta, Nb, Li, Be and W exclusively formed in a post-tectonic environment and represent significantly more evolved magmatic systems when compared to the initial barren pegmatites.

The pegmatites of the Damara Belt are present in a variety of intrusive forms, including plugs, stockworks, sheeted dykes and lenses occasionally appearing sigmoidal in shape or as *en echelon* vein sets. The size of these intrusion varies significantly from thin cm-scale to hundreds of meters in length with widths exceeding 50m in some of the larger intrusions.

Primary mineralisation is generally controlled by pegmatite type, which can be summarised into 4 general groups: 1) Li-Be-bearing, 2) Sn-bearing, 3) tourmaline-bearing, 4) U-bearing pegmatites (Ashworth, 2013). These groups are not restricted to specific belts and are not mutually exclusive as a pegmatite may have significant concentrations of the primary group elements but may also contain appreciable elemental concentrations from the other groups. For example, Sn-bearing pegmatites of the Cape Cross-Uis pegmatite belt may also contain substantial amounts of Li. Tourmaline-bearing pegmatites may be host to concentrations of gem quality tourmaline, whereas U-bearing pegmatites, also known as sheeted leucogranites, mainly occur in the Rössing area.

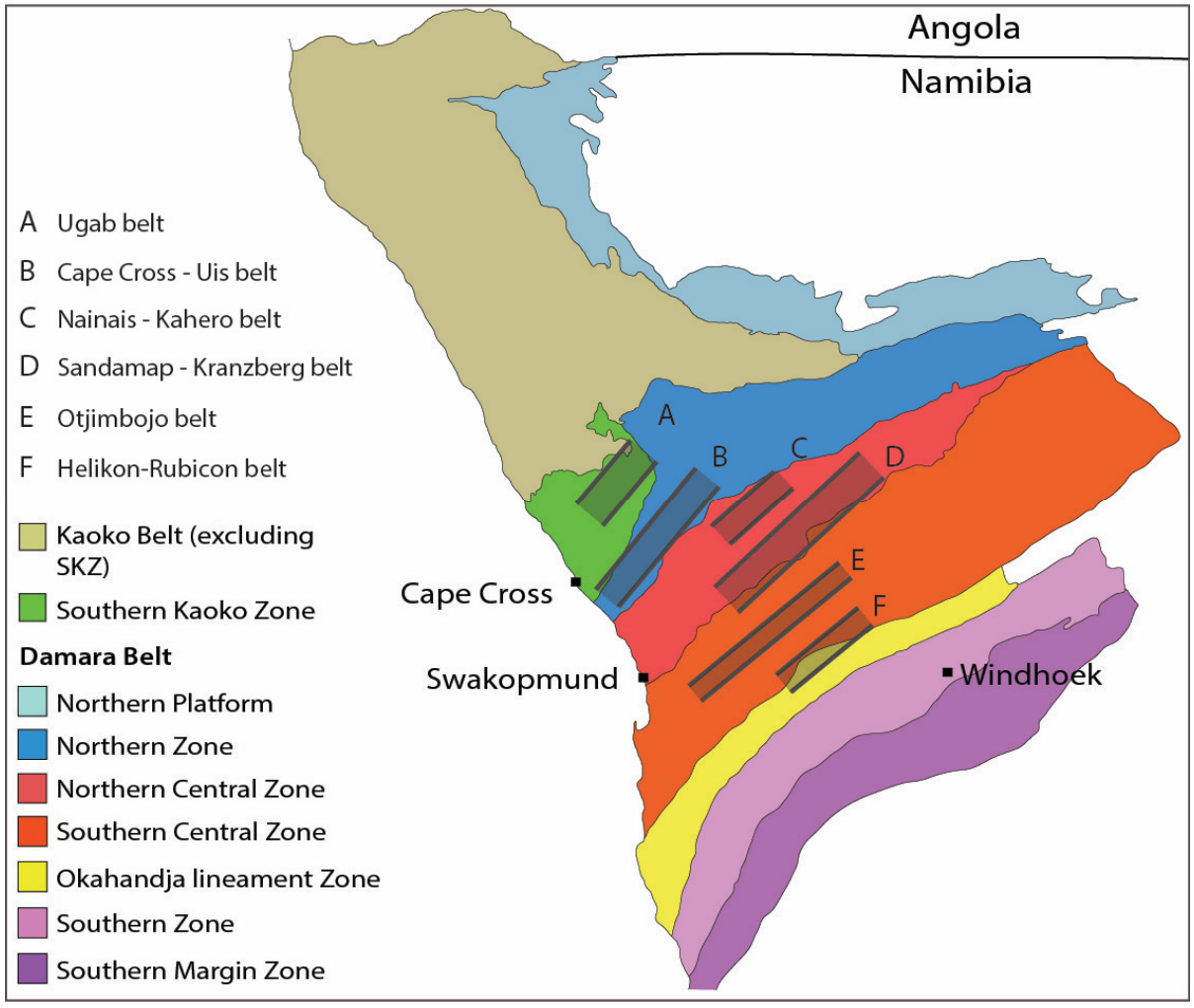


Figure 1: A map of the Damara and Kaoko Belts showing the various zones and pegmatite belts within the Damara Belt (After Miller, 2008; modified from Fuchsloch et al., 2018a)

The Cape Cross-Uis pegmatite belt

The Cape Cross-Uis pegmatite belt (CUPB), also known as the northern tin belt, occurs within the Northern Zone as defined by Miller (2008). This belt extends from Cape Cross in a northeasterly direction to the town of Uis. The Northern Zone is bound by the Autseib fault from the Northern Central Zone, to the south, which hosts the Nainais-Kahero pegmatite belt (NKPB), also known as the central tin belt (Fig. 1, 2). AfriTin Mining Limited, controls three mining licences within the area. ML 134 (Uis) and ML 129 (Tsaurob) are located within the northeastern portion of the CUPB whereas ML133 (Nainais) occurs in the NKPB (Fig. 2).

Table 1: Summarised stratigraphy of the Damara Supergroup (Modified from the Geological map of Namibia, sheet 2114, Omaruru, 1997)

Southern Kaoko Zone/Northern Zone				
Age	**Group**	**Formation**	**Intrusive Unit**	**Lithology**
510-480 Ma			Sorris Sorris Granite	Granite (red, post-tectonic, medium- to fine-grained mezogranite)
600-545 Ma			Salem- type Granite	Granite (post-tectonic, medium- to coarse-grained, porphyritic, Bi-rich)
748-600 Ma	Zerrissene Group	Amis River		Meta-greywacke and meta-pelite (phyllite), minor carbonate and quartz-wacke
		Gemsbok River		Marble and pelite (phyllite) turbiditic-hemipelagic
		Brak River		Meta-greywacke and pelite (phyllite) with dropstones
		Brandberg West		Marble and pelite (phyllite) turbiditic-hemipelagic
		Zebraputs		Meta-greywacke and pelite (phyllite)
850-748 Ma	Naawpoort	Summas		Ignimbrite (alkaline, K-rich), minor porphyritic (Qtz-Feld) lava and meta-rhyolite

The CUPB hosts a variety of pegmatites containing various degrees of mineralisation, ranging from barren to significant. The pegmatites are either intragranitic, within Red, Grey or Salem-type granites or metasediment-hosted, intruding biotite schists ± retrogressed cordierite porphyroblasts of the Amis River Formation (Fig. 2; Zerrissene Group) (Swart, 1992). The pegmatites of the CUPB are of the LCT (Lithium-Caesium-Tantalum) family. Fuchsloch et al. (2018*a*) subdivided the pegmatites into three distinct types based on mineralisation, host rock and chemical affinity. The three types are as follows: 1) metasediment-hosted, Sn-Nb-Ta-bearing, unzoned pegmatites, 2) metasediment-hosted, Li-Sn-Ta-Nb-Be-bearing complexly mineralogically zoned pegmatites and 3) intragranitic, garnet-tourmaline, crudely zoned pegmatites.

Combining the pegmatite groups defined by Ashworth (2013) with the types defined by Fuchsloch et al. (2018*a*) it could be surmised that granite-hosted pegmatites in the Damara Orogen tend to contain anomalous amounts of tourmaline and garnet while metasediment-hosted pegmatites tend to be anomalous in Sn, Ta, Nb, Li and Be. The degrees of enrichment would be dependent on the initial concentrations of the parent material, if the parent material contained Li, Ta, Nb and Be but was deficient in Sn, the resulting partial melt would be enriched in Li, Ta, Nb and Be but not contain anomalous Sn, assuming no assimilation from country rocks occurs.

Three distinct pegmatite swarms have been identified within the CUPB, the Strathmore, Karlowa and Uis swarms from southwest to northeast respectively. The pegmatite types defined by Fuchsloch et al. (2018*a*) are not restricted to a specific swarm, although the Uis swarm appears to primarily contain pegmatites that would fall within the Sn-Ta-Nb type pegmatites whereas the Strathmore swarm includes mostly the mineralogically zoned Li-Sn-Ta-Nb-Be type pegmatites. Although not listed within the name, the Ta-Nb-Sn type pegmatites also may include abundant Li-bearing phases which have been observed by a variety of authors (Richards, 1986; SRK 1989; Diehl, 1993: Ashworth, 2013).

The pegmatites of the CUPB are granitic in composition, containing abundant quartz, orthoclase, muscovite and albite. Minor mineralogy includes tourmaline, garnet, apatite, microcline and beryl. Li-bearing phases include petalite, spodumene, lepidolite, eucryptite, cookeite and amblygonite. Sn is present in the form of cassiterite whereas Ta-Nb-oxides occur as columbite-group minerals (CGM), tapiolite with minor wodginite and ixolite (Fuchsloch et al. 2018*a*). The CUPB is known for its abundant Sn mineralisation and various authors debate its origin within the pegmatites. Some argue that Sn was sourced from host rocks, either via direct assimilation of the porphyroblastic schists known as knotenschiefer, or that Sn was remobilised from knotenschiefer by late-stage hydrothermal circulatory fluids and preferentially concentrated in pegmatites (Richards, 1986; Wagener, 1989; Diehl, 1993). However, Fuchsloch et al. (2018*a, b*) found no direct evidence of assimilation based on geochemistry and field observations. They observed that the pegmatites lack the geochemical markers, in both tourmaline and whole rock chemistry, that would be indicative of contamination.

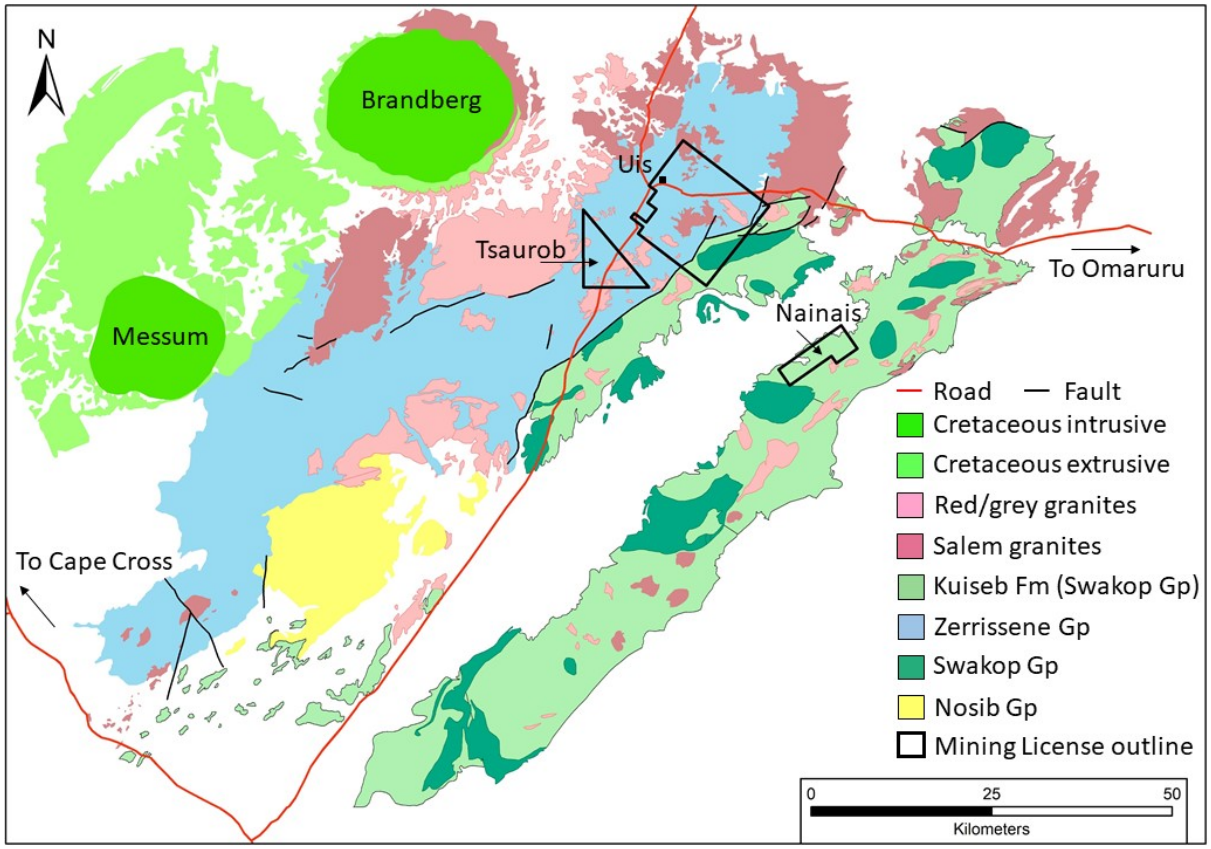


Figure 2: Summarised geological map of the Cape Cross-Uis and Nainais-Kahero pegmatite belts, otherwise known as the Northern and Central Tin belts respectively. The image shows the three mining licences that Afritin Mining owns, known as Uis (ML 142), Tsaurob (ML129) and Nainais (ML133).

The Uis swarm

The Uis pegmatite Swarm covers an area of approximately 650km^2 and contains in the order of several hundred individual pegmatite intrusions outcropping at surface compared to the Strathmore and Karlowa swarms where many pegmatites are buried by desert sands (Fig. 3). Both intragranitic and metasedimentary rock-hosted pegmatites occur within the Uis swarm. Highly Sn- and Ta-mineralised pegmatites appear to be restricted to the metasedimentary hosts (Richards, 1986).

Sn, Ta and Nb mineralisation in the Uis swarm is either associated with primary magma crystallisation or alteration zones known as greisens and saccharoidal aplitic albitised units. Whole-rock geochemistry and the mineral chemistry of cassiterite and CGM, indicate that these elements preferentially separated into late-stage pegmatite derived fluids (Fuchsloch et al. 2018*a, b*). These late stage fluids resulted in internal alteration of the pegmatites forming greisens and albitised zones. These zones generally appear as sporadic patches within the pegmatite but have also been observed as continuous zones within a single intrusion.

In addition to the known Sn and Ta mineralisation within the Uis swarm, Li-minerals have also been identified in the form of lepidolite, petalite and eucryptite but have not been quantified as of yet (Diehl, 1993; Ashworth, 2013; Fuchsloch et al., 2018*a*). Apatite appears to be abundant within the Uis swarm and is generally associated with primary crystallised cassiterite. Tourmaline is less abundant in the Uis pegmatites, however, tourmaline does also occur within the metasedimentary rocks surrounding the pegmatites.

The mining licence ML134, the focus of this study, is approximately 200 km^2 in size and falls entirely within the Uis swarm containing Sn-Nb-Ta type pegmatites (Fig. 3). A portion of the mining licence was originally mined as a large-scale tin mine by ICSOR from ca. 1959 to 1991. The pegmatites in this area are granitic in composition and are primarily homogeneous intrusions that do not appear to contain any distinct zones of specific mineral assemblages (Richards, 1986). Some pegmatites have been observed to show distinguishable zones of alteration appearing within the intrusion as bands or lenses. This report documents a number of field observations regarding the Uis pegmatites their emplacement, mineralisation and composition.

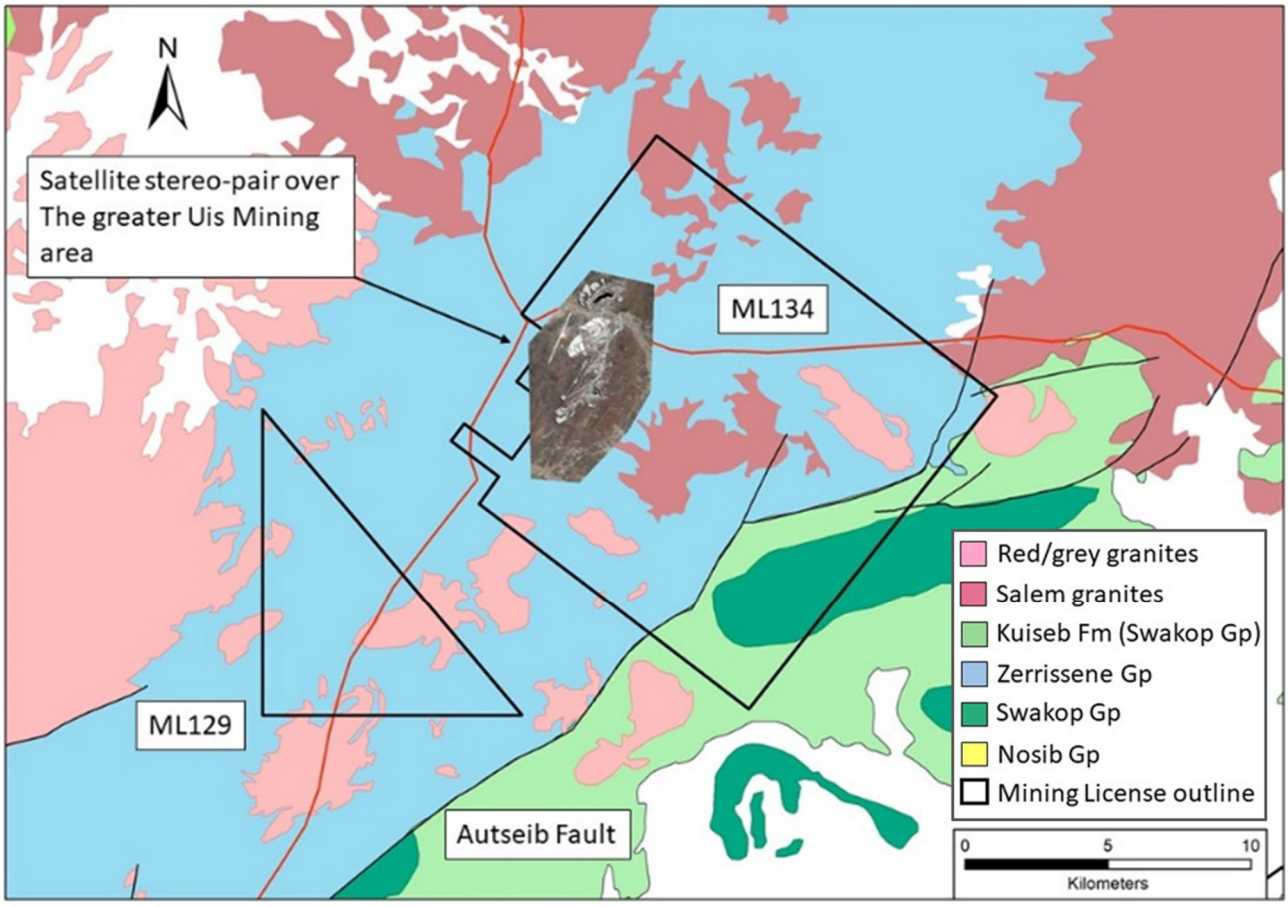


Figure 3: Geological map of the Uis area showing the location of the mining license areas ML 134, ML129 with an overlay of the satellite stereopair in the Uis area.

CHAPTER 2.

Research and Methodology

A number of field programmes have been completed within the area of the AfriTin mining license (ML 134). The main objective of these programmes is to aid in the understanding of the Uis pegmatite swarm in general and specific mineralised pegmatites, which may be of economic significance. Each programme focused on deriving a deeper understanding of the pegmatite emplacement, morphology, mineral composition and economic potential. The reports generated by AfriTin resulting from these work programmes have been summarised in this report. The author was part of the team that produced all of the reports including the field work. In addition, the author added and updated the information in the reports with subsequent observations that were made during additional field visits. The reports utilised and their contributing authors are as follows:

Table 2: Summary of the reports utilised that were generated by AfriTin and utilised in this thesis.

Title	**Contributing Authors**	**Year of Investigation**
Initial site evaluation of the Uis Mine	Longridge and Marais,	2016
Geological mapping and delineation of the historical Uis Mine pits	Longridge, Marais and Fuchsloch	2017
Detailed geological mapping and 3-D modelling of the V2 and V1 pegmatites, Uis Tin Mine	Fuchsloch and Marais	2018
Geological mapping of the peripheral pegmatites to the Uis Mine within mining license 134	Fuchsloch and Marais	2018
Liberation study on a tin-bearing pegmatite sample	FT Geolabs	
Uis Mine dense media separation (DMS) test report	Trueground Consulting	2017

In addition to the above reports AfriTin acquired a significant portion of the historic mine data. The raw information was digitised and utilised in the generation of a 3-D model, the generation of the model was completed with the assistance of B&S Consulting.

High Resolution Satellite Image

In January 2018, a satellite stereo pair of images was acquired over the greater Uis area encompassing the historic Uis mine and surrounds (Fig. 28). The image was used as the base for further exploration and mine planning. The satellite stereo pair obtained consists of two overlapping images taken from different angles and allows for the change in elevation over the area to be calculated. Following the acquisition of the stereo pair, a differential GPS survey was conducted to generate 12 control points within the area. These points were used to geo-reference the image with a high degree of accuracy. The combination of the control points and stereo pair allowed for the generation of a digital elevation model.

From the stereo pair, two individual high-resolution images were produced over the area of interest. Both images have a 50cm pixel size for RGB and 1m pixel size for near infrared. This image makes it possible to geologically map the area with a high degree of accuracy. At this resolution, individual

40cm thick pegmatite veins are visible in pit walls and in outcrop on the image. This imagery allowed for the production of detailed geological maps of both the historically exploited and unexploited pegmatites.

Elevation Model

A high precision digital elevation model is essential when generating 3-D geological models as an accurate elevation of outcrop, both within and surrounding the pits, as well as structural readings such as dip and strike are important in being able to depict the pegmatite intrusion in three dimensions. This also applies to the mapping, when large changes in elevation are present in areas such as the pit faces which extend to a height of up to 30m in some areas.

Additional Uses

The satellite stereo pair contains a near infrared band in the spectrum. This band allows for a normalised difference vegetation index (NDVI) to be created which highlights the total density of green leaf vegetation in the analysed area at the time the image was produced (Fig. 4 A). This has allowed for the establishment of an environmental baseline prior to any significant development of mining and this will be used as a reference for an assessment of the impact of future developments. In addition, the NDVI allows for an environmental study and monitoring of the vegetation cover. This information will be utilised for environmental compliance that is required for any mining activity. The vegetation index may also prove useful in hydrogeology, as it could be utilised as an aid in the siting of suitable boreholes to be drilled for water for the pilot production plant.

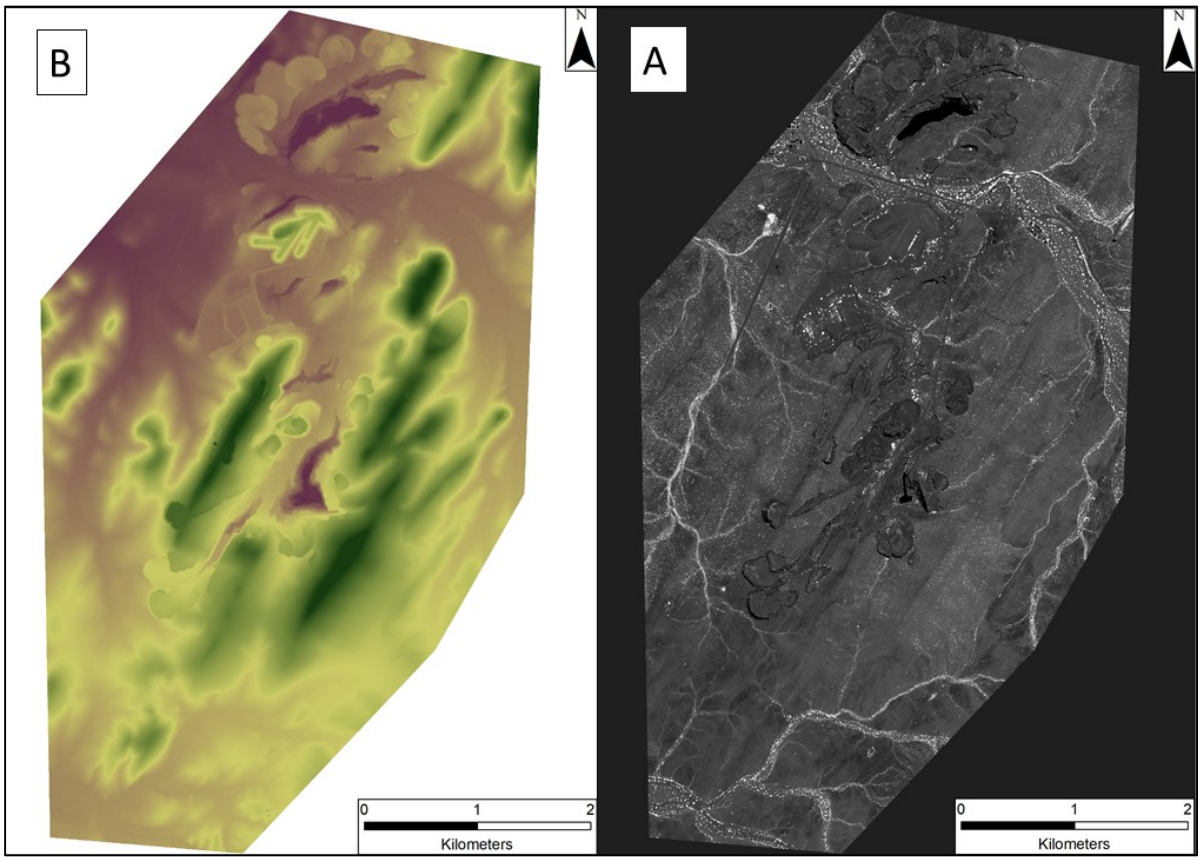


Figure 4: Examples of the satellite stereo pair acquired by AfriTin Mining. A) the digital elevation model of the area using colour contrasts to show changes in elevation. Green shades represent high elevations whereas purple areas are low elevations. B) A normalised difference vegetation index (false colour composite) over the area covered by the satellite image. Light areas indicate and enhance the presence of green leaf vegetation largely distributed along streams and gullies.

CHAPTER 3.

Regional pegmatite clusters of the Uis Mine area

Overview

A regional geological mapping programme was undertaken to the southeast and west of the existing Uis pits. The primary objective of this exercise was to identify large pegmatites with significant cassiterite or CGM minerals that might potentially be of economic interest. Additional information gained about the characteristics of the pegmatite emplacement and mineral composition will be utilised in future exploration activities. Due to the nature of these ore bodies potentially widening at depth, all of the outcropping pegmatites were mapped with mineral characteristics and structural information being recorded wherever possible.

The area covered by this programme was constrained to within a 5km radius of the planned processing plant location and excluded pegmatites that occur within granite. Initial observations indicated that granite-hosted pegmatites do not appear to contain potentially economic concentrations of cassiterite or CGMs.

A high definition stereo-pair of satellite images was utilised for this programme as part of the planning and mapping phases. The area covered by the mapping programme was subdivided into 3 separate sections (Fig. 5) with the historically mined area in the centre. The sections were roughly delineated by clusters of pegmatites identified on the satellite imagery. In addition to the planning phase, the high-resolution satellite imagery was utilised during the field programme as geological and structural data obtained on site was recorded directly onto hard copies of the satellite image. The information gathered during the field visits was scanned and digitised once the field work had been completed.

Due to the history of tin production in the area, a number of the mapped pegmatites displayed evidence of historic working by artisanal miners. In some instances, the workings extended over the majority of the outcropping pegmatite. The presence of artisanal workings has been used as an indication of significant Sn and/or Ta bearing minerals.

The majority of the pegmatites mapped during this programme shared a number of similar characteristics that can be attributed to the Uis pegmatite swarm as a whole. These characteristics are as follows:

1) A general northeast strike with variable dip angles to the northwest,
2) A sigmoidal- or lens-like morphology,
3) A granitic composition consisting of a homogeneous patchwork of coarse-grained feldspar with minor quartz and muscovite as rock-forming minerals,
4) Low to high degrees of mineralisation in terms of cassiterite (95% of the mapped pegmatite contained visible cassiterite at surface), and,
5) Greisenisation and albitisation alteration present to various degrees

As the pegmatites were the primary focus of the programme, minimal information was gathered about the host lithologies. The main host lithologies in the Uis area have been identified as schists and quartzites. Some authors (Richards, 1986; Diehl, 1993) have hypothesised that highly mineralised pegmatites are particularly associated with the knotenschiefer host rock (cordierite, porphyroblastic schists). Subsequently the host lithology of each mapped pegmatite was recorded with an emphasis placed on the presence of retrograded porphyroblasts/knots.

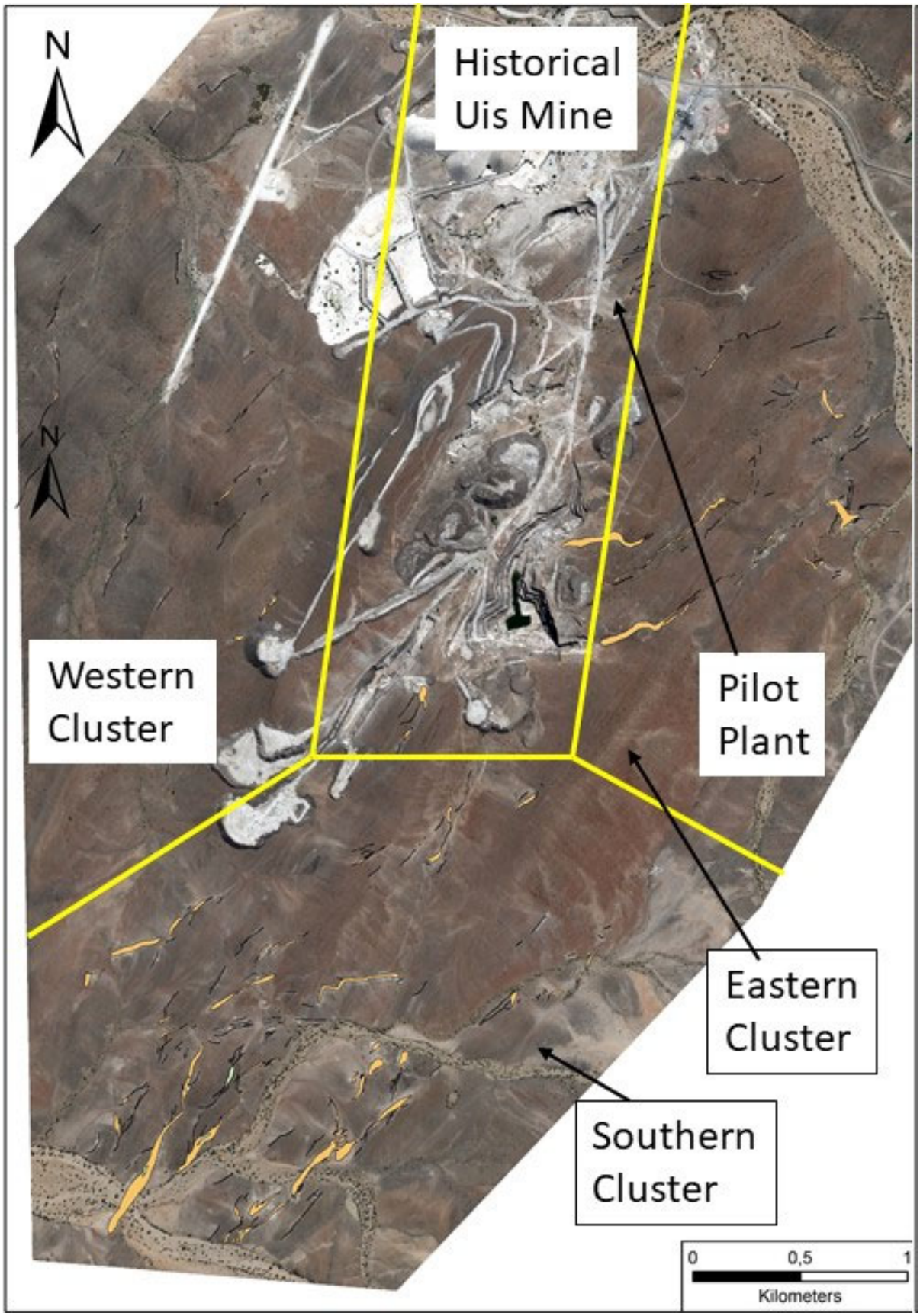


Figure 5: Images of the pegmatite clusters over the satellite stereo pair. The left image shows the subdivision of clusters and historical mine area and the location of the pilot plant.

Desktop Study

Initial identification of the pegmatites was undertaken during a desktop study utilising high-resolution satellite imagery and historic maps produced by Iscor. Where possible the name of each mapped pegmatite was continued from preceding reports, appendices and diagrams.

Following the desktop study, a mapping programme was executed. The outcropping areas of each pegmatite was recorded with the use of a GPS. Where possible, structural measurements of the intrusive body, characteristics of the host rock and mineralogical composition with the presence of greisenisation, alteration and ore minerals were recorded. The mapped pegmatite bodies are indicated in the figures below however, only the ones considered to have some potential to be economically viable in the future will be discussed in detail.

Eastern Cluster

The Eastern Cluster includes multiple pegmatite intrusions that have varying shape, size, mineralogy, and mineralisation (Fig. 6). The Eastern Cluster contains four larger pegmatite bodies (91V2, V4, V12E and 91V8) in terms of size and observed mineralisation/ artisanal workings.

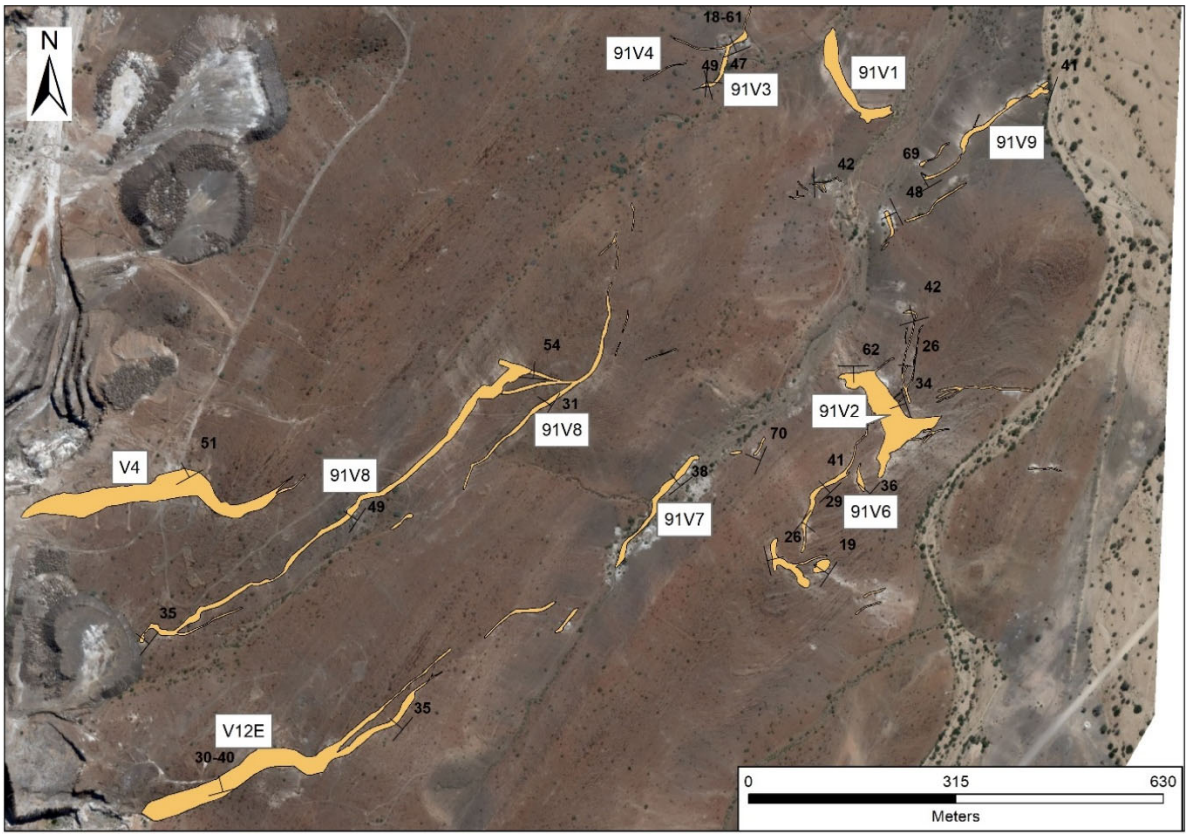


Figure 6: The southern section of the Eastern Cluster showing the V series of pegmatites. Pegmatites 91V2, 91V8, V4 and V12E are described in more detail.

Pegmatite 91V2

The 91V2 is one of the few intrusions observed to have a contrasting orientation compared to the regional NE strike and NW dip direction at variable dip angles of the majority of pegmatites in the area. The 91V2 has a NW strike and variable dip angle to the SW. Multiple subsidiary pegmatite veins associated with the larger dominant intrusion have been identified. These smaller veins are either in contact with the primary pegmatite at surface or outcrop in near proximity to the 91V2 pegmatite, all of which observe a NE strike orientation.

This pegmatite is an irregularly-shaped intrusion with a moderately linear bearing of 160° (Fig. 6). The intrusion thickens towards the SE extension, and terminates with two limbs extending to the northeast and southwest. The main pegmatite body is approximately 165m in length with an average thickness of 35m, in the southeast the thickness increases to over 50m. The subsidiary pegmatite veins around the main body average in thickness between 1-2m and are visible at surface for over a hundred meters along strike, the 91V6 pegmatite is included as one of these extensions.

The 91V2 pegmatite consists of the usual granitic Uis pegmatite mineralogy. The primary rock-forming minerals include plagioclase and orthoclase feldspar, with quartz and lesser muscovite. Visible greisenisation and sericitic alteration is present to a lesser extent. The pegmatite appears to be mineralogically unzoned with coarse-grained minerals comprising the bulk of the orebody, some of the finer-grained contacts appear to contain higher muscovite concentrations. Observed accessory minerals include apatite, black tourmaline (near contacts), cassiterite, CGM and secondary Fe-Mn-oxides.

Observed cassiterite mineralisation in this pegmatite is notably coarse-grained and associated with greisenisation. In this body the greisenisation does not appear to coincide with a reduction in cassiterite grain size and appears to be most abundant along the border zones of the orebody. Fine CGM were identified in hand samples as striated fine-grained platelets.

Pegmatite 91V8

The 91V8 pegmatite consists of two sub-parallel pegmatite intrusions connected by multiple thin pegmatite veins. The dominant intrusion occurs in the southwest, near V4, and the other thinner portion occurs toward the northeast (Fig. 6). Both intrusions strike roughly northeast, with various dip angles to the northwest. The two bodies appear to have been emplaced as an *en echelon* pair that have been connected by minor veins. The larger pegmatite body is approximately 12m across at the thickest point which pinches to 1m at the thinnest point, the strike length extends for almost 750m. The smaller of the two connected bodies reaches a maximum thickness of 2m and has a strike length of 500m.

The veins connecting the two larger pegmatite bodies strike in an east-west direction (Fig. 6). This area is also the thickest part of the dominant pegmatite body. Cassiterite mineralisation appears to be slightly more abundant in this area as well. Medium- to coarse-grained cassiterite was observed throughout both pegmatite bodies. However, the grade observed at surface appears to be lower than the average for this cluster. Greisenised zones in these intrusions were observed but appear to be sporadic and not very abundant.

Mineralogically, albite dominates the mineral assemblage whereas orthoclase is only present in minor portions, quartz and muscovite are present in equal abundances with muscovite being concentrated on the pegmatite contacts. The pegmatite is not mineralogically zoned or banded and appears to be homogenous with random patches of greisen and sericitic alteration.

Pegmatite V4

This intrusion strikes roughly east-west with variable dip angles to the north. The western section of this body is degraded due to the presence of significant mining activity that makes delineating the intrusion in this area difficult. The overall length of this sigmoid-shaped intrusion is 400m, of which the majority ranges in width between 33–40m. The width of the pegmatite at surface reduces to an average of 20-25m in the east, this subsequently thins and terminates. A historic mine adit is present in the central part of the V4 pegmatite (Fig. 7 B). The adit shows the pegmatite continues at this depth, approximately 20m below the highest point of pegmatite outcrop

The V4 pegmatite appears to be mineralogically homogeneous consisting primarily of orthoclase, plagioclase, quartz and muscovite which is typical for the Uis pegmatites. Meter-scale schist xenoliths have been observed within the pegmatite, these xenoliths contain significant amounts of tourmaline and appear bleached (Fig. 7 A). Alteration is a significant feature of the V4 pegmatite which contains significant greisens, finer-grained sericitic alteration and plagioclase replacement in the form of saccharіodal, albitised zones.

Cassiterite mineralisation was observed throughout this pegmatite and appears to be above average grade when compared to the other pegmatites in the Eastern Cluster. The V4 pegmatite is fairly anomalous as it contains a number of well-formed greisens, which in turn display a significant amount of coarse-grained cassiterite. Albitised zones were also observed in this intrusion, less frequently than the adjacent V5 pegmatite, and they appear to be enriched in cassiterite. These crystals, however, appear to be finer-grained than in the greisens. No visible CGM were observed to be present in this pegmatite, however, it is likely that they occur as finer-grained minerals within or around the cassiterite grains as is typically found in the other Uis pegmatites.

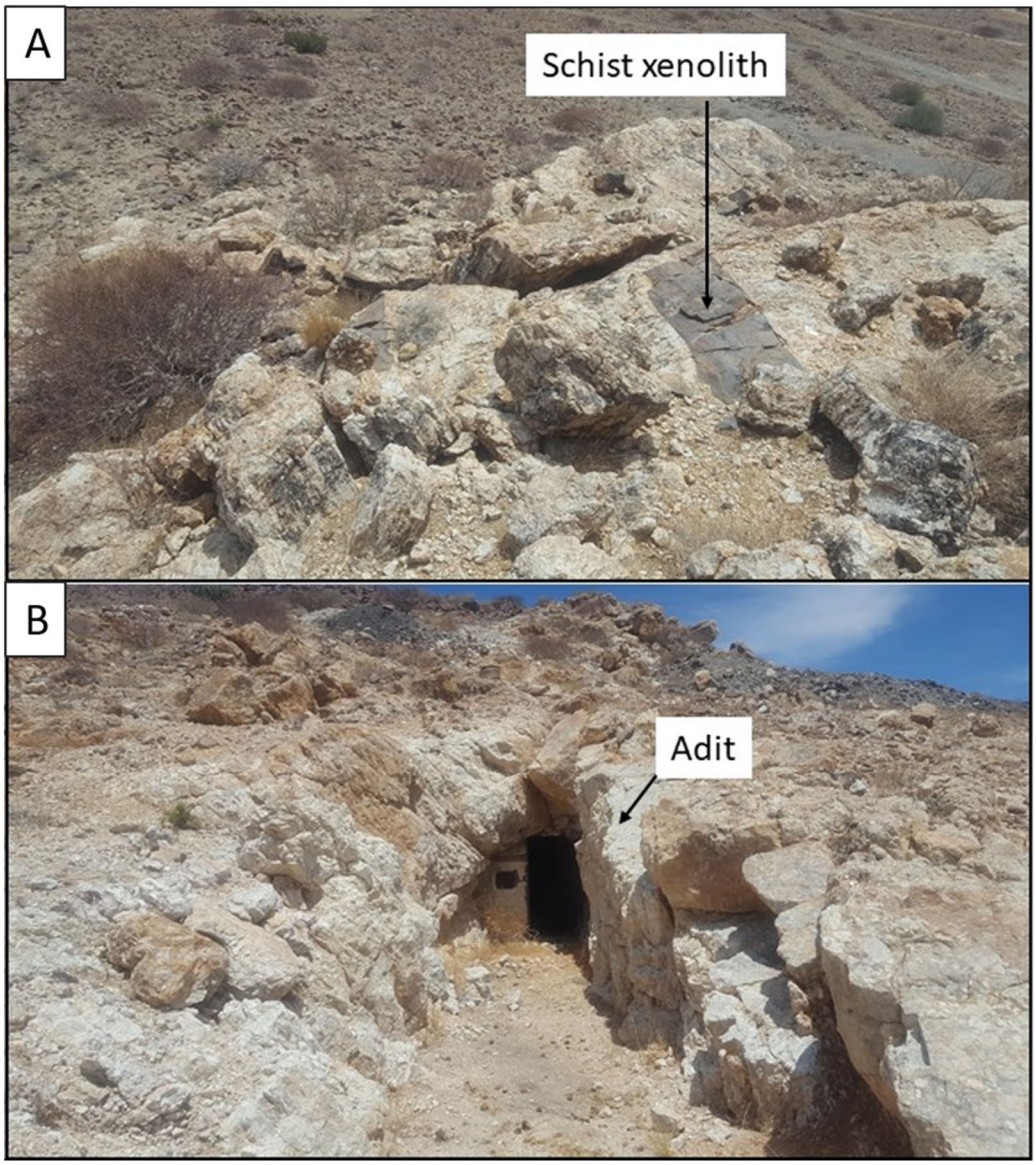


Figure 7: Outcrop photographs of pegmatites within the Eastern Cluster. A) A metre-scale schist xenolith in the V4 pegmatite which has been tourmalinised. B) An underground adit within the V4 pegmatite that traverses horizontally into the pegmatite body to the schist contact in the east.

Pegmatite V12E

The V12E pegmatite comprises the eastern portion of the overall V12 pegmatite body. The intrusion has been mapped from the edge of the V12/V5 historical pit (Fig. 6). For this programme the untouched portion of the V12 pegmatite will be discussed as the V12E pegmatite. The strike length of this pegmatite is approximately 570m with a strike of 040° and an average dip of 35° to the northwest. The pegmatite undulates providing a sigmoidal shape (this is not as a result of the topography). The intrusion bifurcates as it thins and splays into two separate pegmatites veins northeastwards.

The primary portion of this intrusion has an average width of 37m at surface over a distance of more than 350m. The pegmatite then bifurcates and thins. It should be noted that these two veins are likely to intersect at depth as the southern vein dips at a shallower 32° compared to 56° dip for the northern vein in the same direction, this can also be seen the side wall of the V12 pit.

The pegmatite is primarily constituted of orthoclase, plagioclase with quartz and minor muscovite. Fresh outcrop reveals abundant fractures filled with late-stage Fe-Mn oxide precipitates. Some areas display slight brecciation near fracture planes, indicating structural movement post emplacement of the pegmatites. Black tourmaline is present within the two subsidiary pegmatite vein extensions which form after the bifurcation and becomes less abundant toward the main body. Cassiterite was observed sporadically throughout the pegmatite, with higher concentrations being associated with partial greisenisation and sericitic alteration. The border zones of the V12E pegmatite which show marked increases in muscovite modal abundances. Apatite is regularly observed with cassiterite-bearing primary mineralised magmatic zones of this intrusion.

Southern Cluster

The Southern Cluster hosts multiple, closely spaced and large pegmatite intrusions which contain, qualitatively, significantly high grades of cassiterite mineralisation in relation to the Uis Pegmatite swarm. Academic studies indicate that Ta-Nb-oxides may be more abundant in the Southern Cluster (Fuchsloch et al., 2018).

This Cluster contains several of the intrusions with a surface width exceeding 30 m. The pegmatites in this cluster that have been described in detail are: W6, W9, W19, W2 and W17 (Fig. 8, 9). Of all the pegmatites mapped during this programme W17 represents the largest and most significant pegmatite in terms of economic potential.

A recent well-field expansion programme was conducted in the river bed located in the southern portion of this cluster (Fig. 9), several water boreholes were drilled, of which one intersected the W17 pegmatite at depth. A vertical intersection of approximately 67m of pegmatite was drilled through the pegmatite. This further confirms the economic potential of the W17 pegmatite.

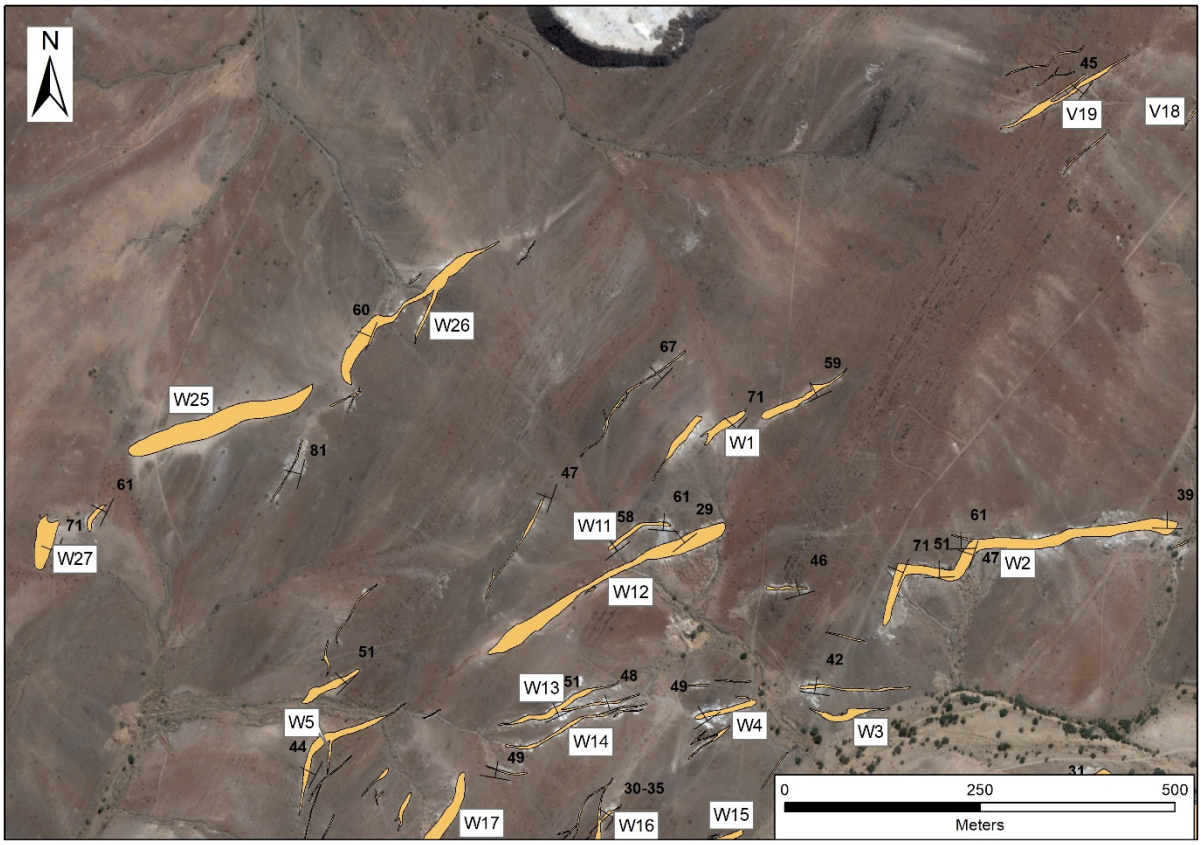


Figure 8: The northern portion of the Southern Cluster showing the location and extent of the W series pegmatites at surface.

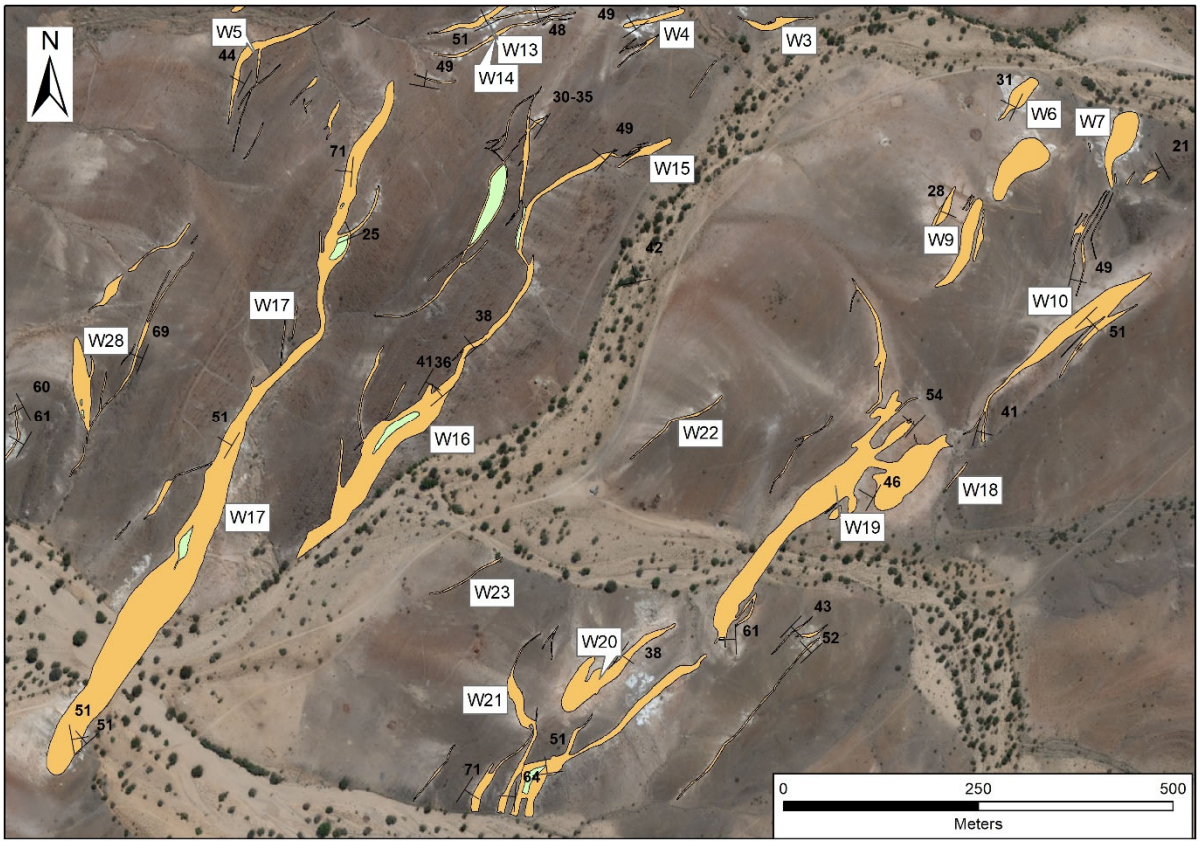


Figure 9: The southern portion of the Southern Cluster showing the location and surface exposure W series pegmatites.

Pegmatites W6 and W9

The W6 and W9 pegmatites occur in a relatively flat topographic area with a semi-consolidated sediment cover, particularly in the river bed, hampering surface mapping as the full extent of the intrusion may not always be evident. The presence of multiple exploration trenches, created by Iscor, provided additional data points and aided in understanding the full extent of these pegmatite bodies. Unfortunately, the trenches were further exploited by artisanal miners which hampered the mapping process in some areas.

Surface cover and additional rubble generated by artisanal mining activities made it difficult to confirm. Assuming a connection, the full strike length of the pegmatite body is approximately 380m with an average width between 25-30m. It is likely that this intrusion thickens with depth, as indicated by the deeper exploration trenches. This intrusion strikes roughly northeast. Establishing the dip angle of the intrusion proved problematic due to the disturbances. The dip of the upper contact is roughly 26° and the dip of the lower contact is roughly 31° both to the northwest. The two differing dip angles further support the intrusion widening at depth.

Pegmatites W6 and W9 appear to be mineralogically identical, containing abundant plagioclase, equal proportions of orthoclase and quartz and minor muscovite which becomes more abundant specifically on contact zones. The surrounding pegmatite bodies appear to be mineralogically similar, possibly indicating that they were derived from the same parental magma. Typical alteration observed in W9 and W6 pegmatites, occurs as either albitised units or greisenised zones (Fig. 10). Albitisation appears to be particularly abundant within these pegmatites whereas the dominant alteration type within the Uis area is usually greisenisation. An increase in fine- and coarse-grained cassiterite mineralisation is usually associated with both albitisation and greisenisation respectively. In addition to cassiterite, apatite is another mineral specifically associated with albitised zones in these pegmatites.

Pegmatite W19

The W19 pegmatite displays a highly irregular shape outcropping at surface, particularly in the northeastern portion of the body (Fig. 9). The southwestern section of the intrusion is almost linear in shape with a northeast strike, dipping to the northwest. The northeastern section splays into multiple veins of which one forms a large oval shaped body, the other veins form irregular-shaped extensions. The strike of these differently shaped veins is consistent with the main intrusion however the dip angle to the northwest varies considerably from 35–61°. The strike length of the main intrusion, is approximately 400m with the width varying significantly due to the undulose shape of the intrusion. The linear section of the pegmatite is roughly 25–28m wide while the irregular shaped extension in the northeast reaches almost 50m at the widest point.

The W19 pegmatite is not considered to be mineralogically zoned, but does display local mineralogical banding, especially associated with alteration or recrystallised zones, along the surface outcrop of this intrusion. These bands are typically Sn-bearing, containing abundant coarse-grained cassiterite (Fig. 910 A).

Surface outcrop to the southwest of the W19 pegmatite is minimal due to the topography and unconsolidated sediment cover and pegmatites W20 and W21 may possibly join with W19 under cover (Fig. 13). The W20 pegmatite has a southeastern dip direction compared to W21 and W19 northwestern dip direction indicating that the bodies potentially intersect at depth. These three pegmatites bodies joining at depth may possibly form a very significantly larger body.

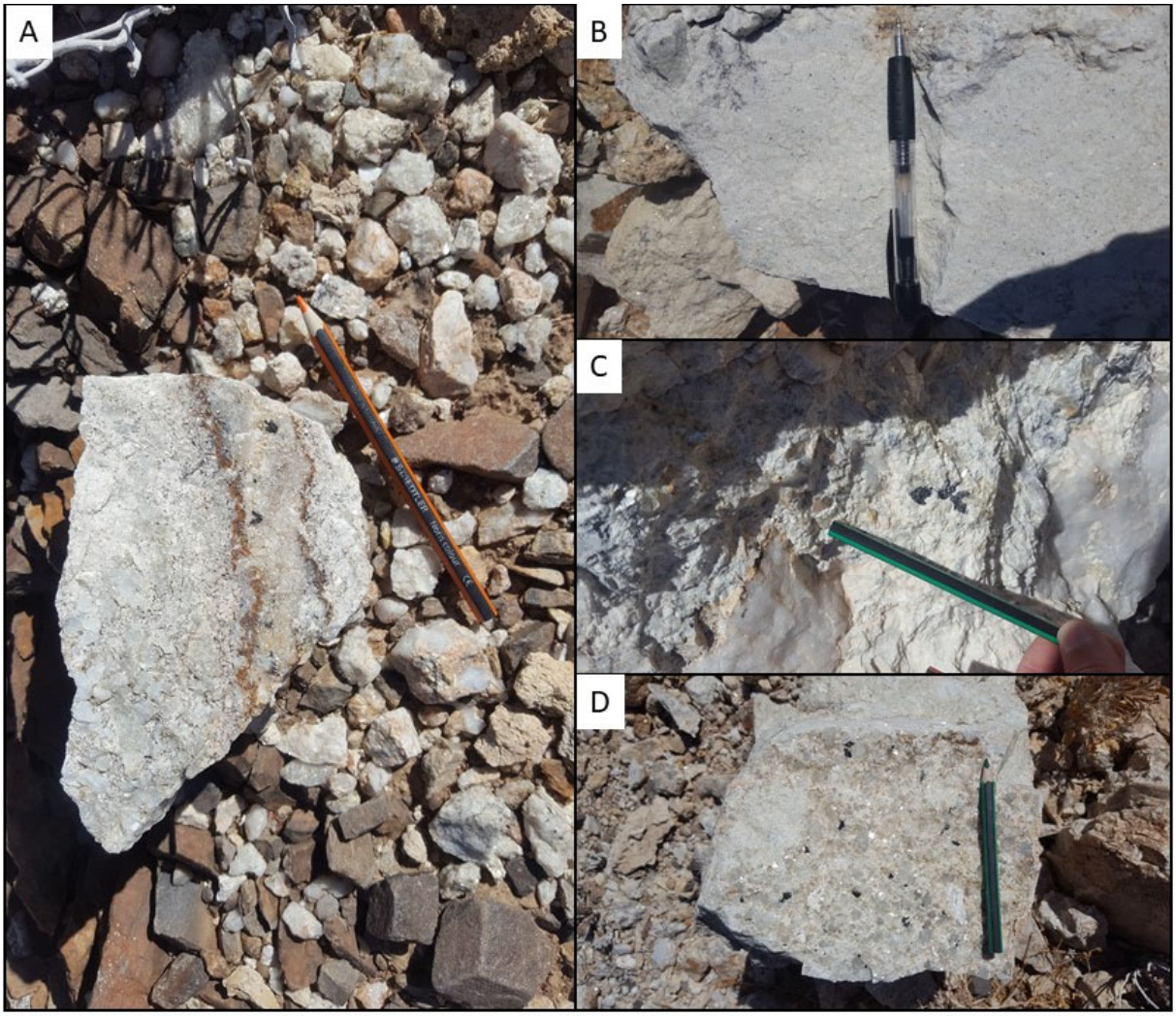


Figure 10: Representative macroscopic images of pegmatites in the Southern Cluster. A) Sample displaying well-defined mineralogical banding where cassiterite is restricted to the central recrystallised alteration zone, flanked by brown Fe-Mn oxide minerals on either side. B) Fine-grained albitised zone consisting of 95% plagioclase with abundant fine-grained accessory cassiterite and apatite. C) Coarse-grained cassiterite occurring within a primary magmatic zone of pegmatite. D) Coarse-grained, cassiterite-bearing greisenised zone.

Pegmatite W2

The W2 pegmatite is an uncommonly shaped intrusion and presents a unique structural control (Fig. 9). The body is divided into eastern and western sections, where the eastern section has intruded in a similar fashion to the other pegmatites in the area and has an east-west strike dipping to the north at 39°. The western section displays three consecutive sharp bends. The strike of the intrusion changes significantly, initially the strike is first toward the south, then west and then south again with the angles of the bends being approximately 100° (Fig. 11).



Figure 11: Angled satellite image from Google Earth displaying the morphology of the W2 pegmatite, with a vertical exaggeration of one.

It appears that the W2 pegmatite intruded along joint sets which are approximately 120°/60°. This would facilitate the dramatic strike and morphology changes over short distances. Furthermore, the W2 pegmatite has one of the most consistent thicknesses and is approximately 11m wide over the majority of the 470m strike length. The majority of the pegmatites in the area display a sigmoidal shape with the ends pinching out. This is not observed in the W2 pegmatite, further supporting emplacement along a conjugate pair of fractures.

The mineralogy of the W2 pegmatite remains fairly consistent with the other Uis pegmatites, however, a lower abundance of orthoclase and quartz was observed with plagioclase clearly dominating the mineralogical composition. Muscovite is mostly concentrated on the margins of the body and within greisenised zones. Significant cassiterite mineralisation was observed throughout this pegmatite with the majority of the grains being coarse. Significant artisanal workings were also noted.

Pegmatite W17

The W17 pegmatite is the largest pegmatite within the Southern Cluster and is comparable to the large pegmatites historically mined by ISCOR (pegmatites V1, V2, V12, V5, K3 and K5). The W17 intrusion extends over a strike length of 1km at surface in a northeastern direction (Fig. 9). The primary pegmatite body can be separated into three portions, the largest of these is the southwestern section which has an average width of 35m over a length of 600m at surface (Fig. 11 B, C). The thinner central section an average thickness of 3-7m over a 200m strike length and the northeastern section is slightly thicker than the central section averaging a 12m width over a 200m of strike (Fig. 11 A).

The W17 pegmatite has minor associated intrusions proximal to the primary W17 intrusion, which bifurcate or splay from the dominant intrusion with various dip angles and strike directions. This is an indication of the large magma volume associated with a pegmatite of this size. Xenoliths have been incorporated into the W17 pegmatite and vary in size from several meters up to 20m in the northern section. The water borehole drilled in the southern section of this pegmatite intersected approx. 67m of pegmatite without any schist inclusions as xenoliths.

This unzoned pegmatite is of a homogeneous texture and is mineralogically dominated by orthoclase and plagioclase with minor quartz and muscovite. The accessory mineralogy consists of monazite, cassiterite, CGM, tapiolite, wodginite, apatite, zircon and multiple varieties of tourmaline. Fuchsloch et al. (2018*a*) studied this pegmatite in detail, specifically in terms of whole rock chemistry, CGM,

cassiterite chemistry, and tourmaline chemistry. Alteration is also present in the form of greisenisation and albitisation, the latter occurring in less abundance. Local mineralogical banding has been identified occasionally throughout the pegmatite, similar to Pegmatite W19 (Fig. 12 A).

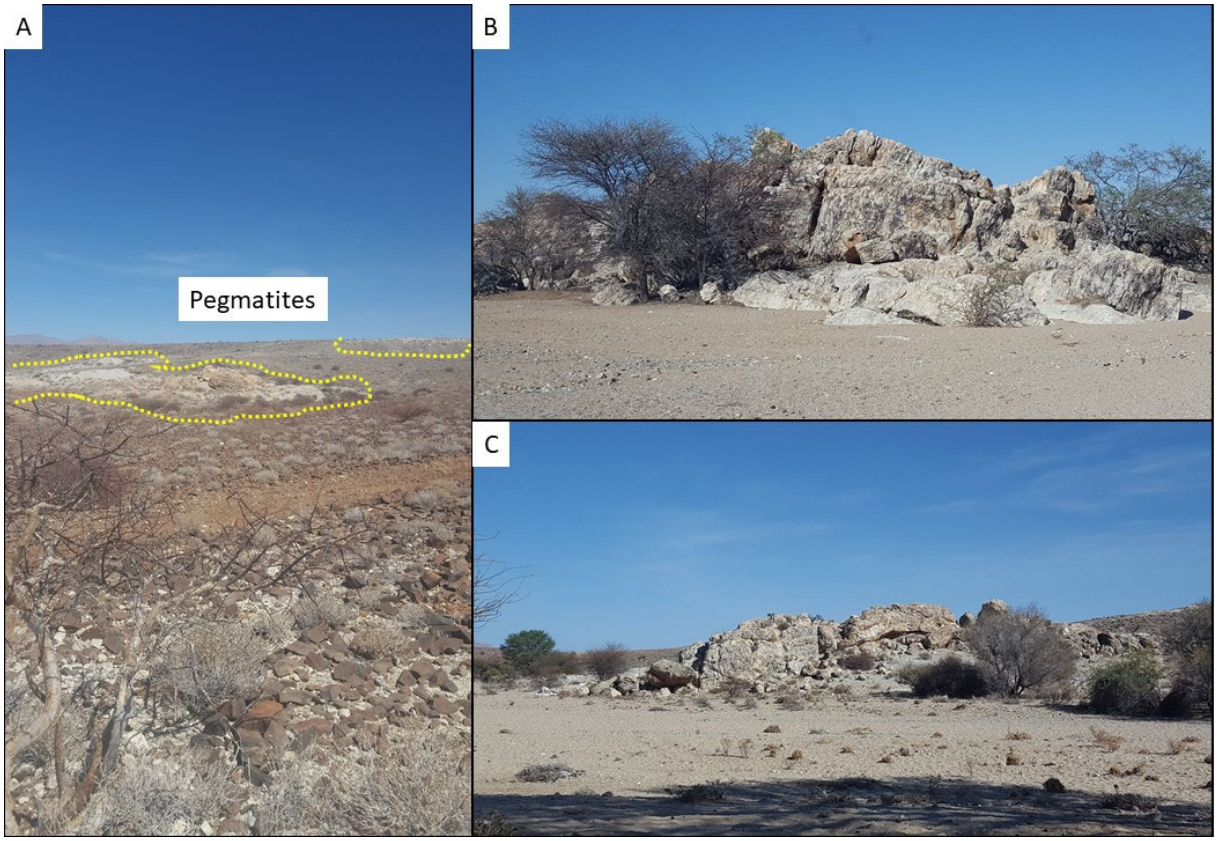


Figure 12: Field photographs of the pegmatites in the Southern Cluster. A) The W17 pegmatite which appears thinner on the geological maps in the northeast due to topography. B, C) Outcropping W17 pegmatite on either side of the riverbed.

Cassiterite mineralisation occurs in the classic Uis style, being predominantly associated with greisenisation. However, fine-grained cassiterite has also been observed in the albitised zones. The W17 pegmatite is anomalous in terms of CGM occurrence and abundance. Fuchsloch et al. (2018*a*) found that CGM occur more abundantly in the Southern Cluster compared to the historically mined Uis pegmatites. The grain size of CGM is significantly larger in the W17 pegmatite compared to the historically mined Uis pegmatites where CGM generally occur as smaller inclusions within cassiterite (Fuchsloch et al., 2018*a*).

Western Cluster

Geological mapping within the Western Cluster in the current investigation found no pegmatites that would warrant detailed description as none of the mapped pegmatites are significant in terms of thickness (Fig. 13). Several pegmatites within the Western Cluster extend over 500m in length, however, their thickness does not exceed 3-4m and are, in most cases, only 2m thick, and as a result these pegmatites are not presently considered to be of economic interest. However, mineralisation in these pegmatites may still be high compared to other Uis pegmatites, as observed during the mapping programme.

The pegmatites of the Western Cluster generally follow a northeasterly strike and dip steeply to the northwest. The morphology is similar to that of the pegmatites in the greater Uis area, being mostly linear lens-shaped intrusions that pinch at either end. No intrusions within the Western Cluster show irregular or variable morphologies worth noting.

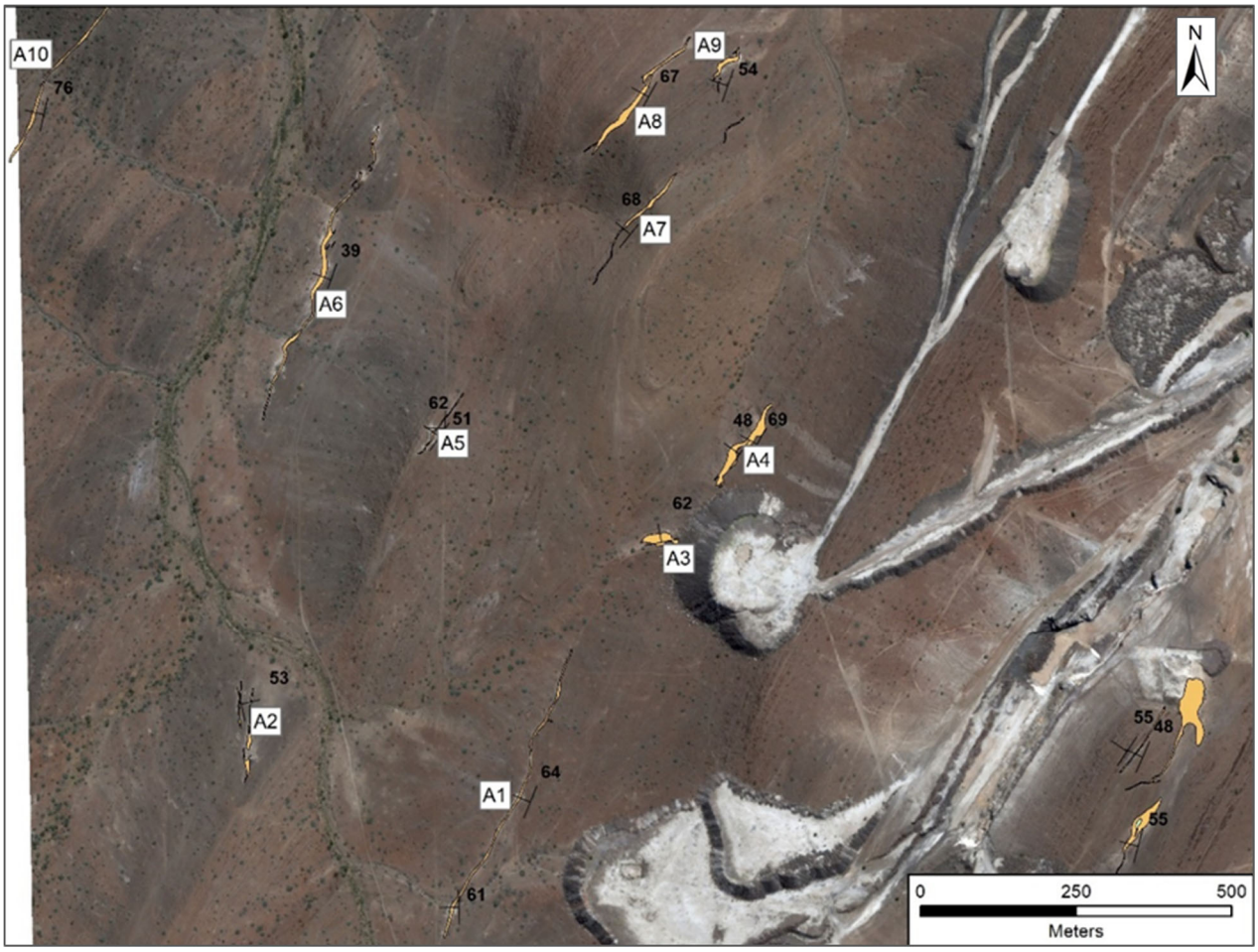


Figure 13: The southern portion of the Western Cluster showing the A series of pegmatites. Some of the mapped intrusions display significant strike extent with minimal thickness

The Western Cluster pegmatites are mineralogically similar to the other clusters and historically mined areas, these pegmatites consist of homogeneous patchworks of orthoclase, plagioclase and quartz with minor primary muscovite. Observed accessory minerals include apatite, cassiterite, CGM, garnet and tourmaline. Alteration is typically displayed in the form of greisenisation with minor sericitic alteration and albitisation observed.

Cassiterite mineralisation abundances vary within the pegmatites of the Western Cluster with some of the intrusions containing significantly high grades. Visual tin mineralisation is abundant in alteration zones and primarily occurs as coarse-grained cassiterite in greisens. Magmatic cassiterite also occurs, but is limited in abundance and is generally coarse-grained.

Additional Observations

Additional observations made during this programme may yield some insight into the characteristics of the Uis Pegmatites. Figure 14 contains four images which individually display a useful characteristic of the Uis pegmatites. These can be used to aid in a better understanding of these intrusion at depth and the nature of the mineralisation contained within.

Cassiterite has been deposited during multiple phases of the magma crystallisation. Magmatically deposited cassiterite grains occur as coarse grains situated between orthoclase, plagioclase and quartz crystals, with minor muscovite occasionally observed alongside the cassiterite grains. Cassiterite

occurs more abundantly as coarse grains in localised greisens and finer grains in albitised zones (Fig. 14 A).

Surface exposure of the pegmatite veins are not necessarily representative of the extent at depth. A small outcrop at surface may be linked to a much larger body at depth. Figure 14B is an extreme example of this, where a small vein is visible at surface but expands into a much larger unit at depth within a relatively small distance.

The majority of the pegmatites appear to be sigmoidal in shape indicating the presence of far field stresses at the time of emplacement. The competency of the host lithologies should be further investigated to deduce if some lithological units were preferentially intruded due to the competency contrast of the layers. The schists would have preferentially deformed over the quartzite layers, this may have resulted in the schist being preferentially intruded (Fig. 14 C).

Pegmatite bifurcations occur along strike as noted for V12E, they may also occur down dip (Fig. 14 D). Smaller parallel veins at surface may join at depth to form a significantly larger intrusion. As a result, smaller veins in close proximity to larger pegmatites may join at depth. This would enhance the economic potential of the bodies that are considered to be marginal at surface due to insufficient width.



Figure 14: Outcrop photographs of the regional pegmatites in the Uis area. A) Highly abundant cassiterite occurring in a recrystallised quartz zone. B) An outcrop photograph showing the varying thickness of pegmatites with depth, where at surface the pegmatite is several centimetres wide compared to the meter-scale pegmatite at depth. C) A 2m deep artisanal excavation along the strike of a sigmoid-shaped pegmatite intrusion into schist. D) Characteristics of pegmatite that bifurcate joining at depth to form a larger overall pegmatite intrusion.

CHAPTER 4.

Mapping of the existing Uis Mine pits

A detailed geological mapping programme was undertaken within the existing accessible Uis Mine open pits, which comprise the Central and Northern Clusters. These clusters are the most extensively and consistently mineralised group of pegmatites within the larger Uis pegmatite swarm. Sixteen discrete pegmatites were mined from a number of open pits, by Iscor until 1991. This chapter specifically refers to the pegmatites previously exploited by mining operations.

The outcropping areas were mapped using GPS coordinates, satellite images and graph paper. Structural measurements were recorded where possible and the mineralogical composition of each pegmatite was noted. The generated data was subsequently georeferenced and digitised. In order to avoid any confusion, the pegmatites within the project area are referred to according to the nomenclature used by Iscor (Fig. 15). The K3, K5, K7, K7.1, K8 and K10 pegmatites are located north of the Omaruru-Uis Road, these pegmatites collectively form the Northern Cluster. Pegmatites south of the road include the P4, P5, P6, V1, V2, V9, V10, V13, V5 and V12 pegmatites which collectively form the Central Cluster. Only a few smaller, unmined, pegmatites remain within these clusters. These have been deemed to be of little economic importance at this stage and have not been investigated in any detail.

These pegmatites have a generally northeasterly to easterly strike, and dip between 30° and 70° towards the northwest, cross-cutting the host biotite schist, quartzite and gneiss of the isoclinally folded Amis River Formation, of the Damara Supergroup. The host rocks generally dip towards the southeast. The pegmatite emplacement appears to be controlled by sinistral, S-shaped *en-echelon* fractures or sigmoid structures possibly associated with regional north-northeast south-southwest striking half-graben faults. The emplaced pegmatites appear to have curvilinear surface shapes.

The structural complexity of the pegmatites within the host rocks appears to be related to intrusion size, with larger pegmatite bodies containing xenoliths of the schist host rock and bifurcation of the pegmatite occurring within the host rock. Xenoliths and bifurcations are usually orientated perpendicular to schist foliation (Fig. 16). The larger pegmatite bodies pinch out along strike or splay out into multiple smaller pegmatite veins, intruding in an overall sigmoidal surface outcrop pattern

The Northern and Central Clusters are indicative of the ‘typical’ Uis pegmatites. The major minerals are primarily orthoclase, plagioclase, quartz and muscovite, in typical order of abundance. Numerous accessory minerals, including cassiterite, CGM, garnet, tourmaline, apatite, beryl and various Li-minerals (petalite, amblygonite and cookeite) have been observed in hand sample. The grain sizes varying from a few mm to decimetres, with cassiterite crystals varying from fine-grained (< 1mm) to coarse (> 5cm) in size and are assumed to have a fairly consistent average tin grade. Greisenisation and albitisation occur as patchy networks, of varying sizes, within most pegmatites and show little continuity, these patches are generally associated with higher-grade tin mineralisation.

Each of the Northern and Central Cluster pegmatites is discussed separately below (Fig. 15).

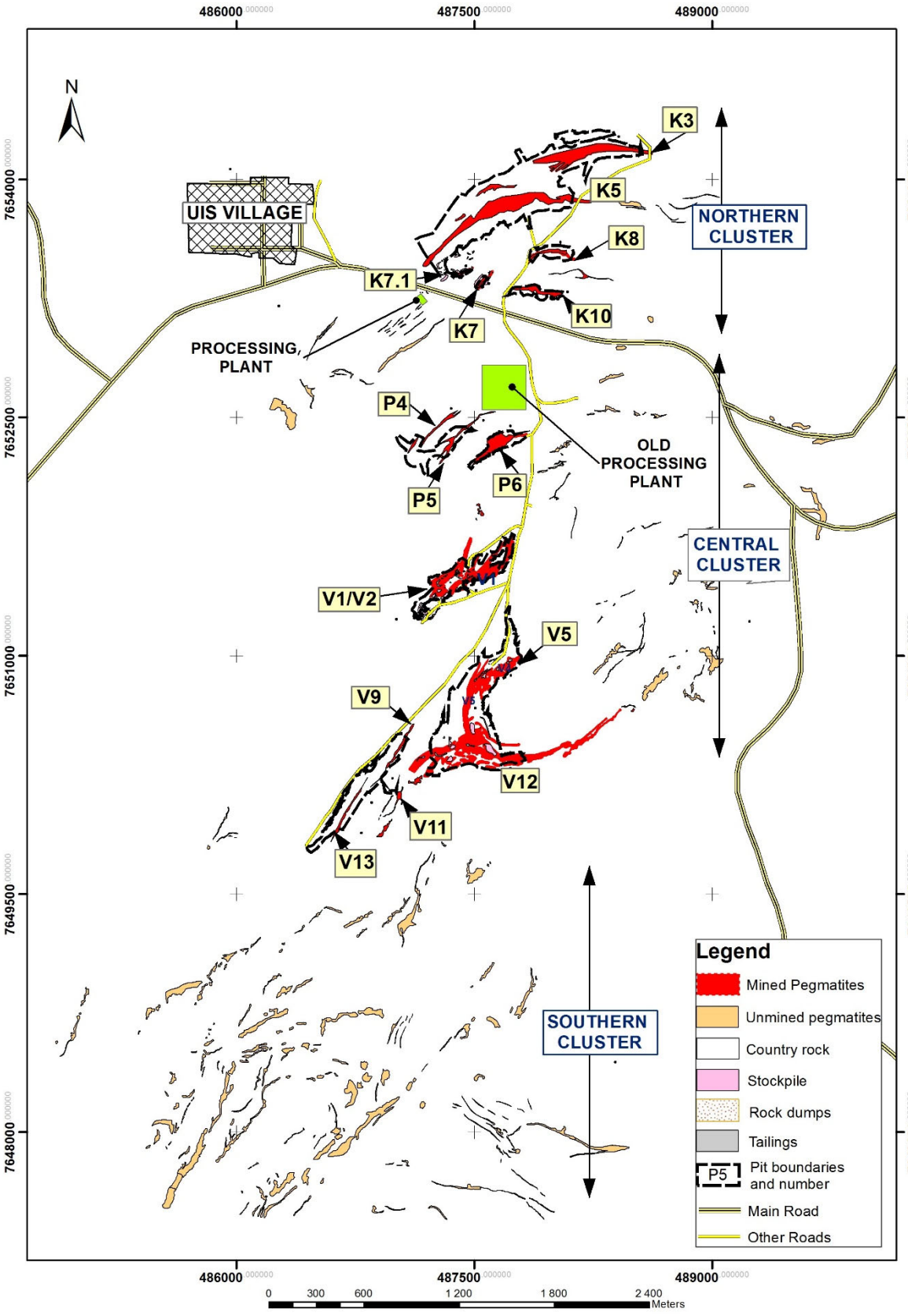


Figure 15: Map indicating structurally controlled en-echelon sigmoidal pegmatites and the outline of pit rims in relation to mined and unmined pegmatites. (Created by AfriTin Mining, 2017)



Figure 16: An example of a complex pegmatite intrusion with xenoliths of schist within the main pegmatite body (P6 Pegmatite).

Northern Cluster

K3 Pegmatite

The K3 Pegmatite is the most northerly pegmatite of the Uis Pegmatite swarm and lies in the northeast portion of the area (Fig. 15). This pegmatite has a surface width of up to 17m in the centre which thins to the east, the average dip of this intrusion is 60° to the north-northwest. The strike of the body is east-northeast and extends over a distance of 1km (Fig. 17 A)

The mineral assemblage of this pegmatite is consistent with the general Uis composition however the orthoclase crystals have acquired a pink tinge, possibly from the addition of Fe, provided by the assimilation of some country rock or hydrothermal alteration causing Fe to come out of the crystal lattice. Coarse cassiterite grains were observed in the base of the pit, however they were sparse. Few greisen patches were observed in this pegmatite, the visible patches were relatively small (<1m) for an intrusion of this magnitude.

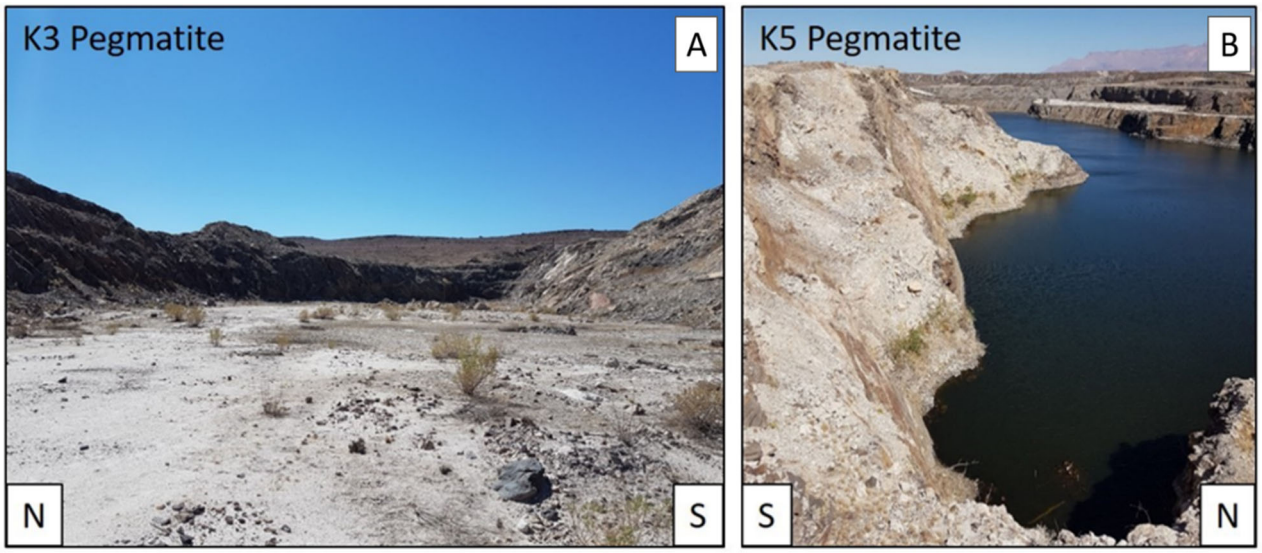


Figure 17: Surface images of the K3 and K5 pegmatites A) an image of the K3 pegmatite from the base of the pit B) an overview of the K5 Pegmatite from the northern edge of the excavation, the base of the pit has filled with surface water.

K5 Pegmatite

The K5 Pegmatite was historically one of the more important pegmatites at Uis and the pit is the largest in the area. The K5 has an arcuate shape, and extends at surface for over 1km, striking northeast to east-northeast (Fig. 17 B). The width of the main outcropping pegmatite is up to 30m at surface with an average dip of 60° north-northwest. In addition to the main intrusion a small pegmatite is visible in the hanging wall and is thought to join with the main body at depth.

The majority of the pit floor is covered by water, however there is some outcropping pegmatite visible in the southwestern portion of the pit. The observed mineralogy here comprises primarily of orthoclase, plagioclase, quartz and minor muscovite. Coarse-grained cassiterite and apatite grains were observed sporadically over the outcrop. This southwestern portion of the K5 pegmatite contains multiple schist xenoliths, some of which appear to have been metasomatised to varying degrees. Some of the crystal boundaries in the pegmatite adjacent to the xenoliths display a pinkish tinge.

K7 Pegmatite

The K7 is a smaller pegmatite, dipping north-northwest at roughly 30°. This pegmatite was emplaced perpendicular to the fabric of the host schist which dips at 44° to the southeast. The pegmatite is exposed in an old mining excavation with fresh exposure visible along the base and in the northern high wall of the pit. The surface exposure has a relatively short strike length of approximately 200m northeast-southwest and is approximately 15m wide (Fig. 18, 19). The old mining excavation is approximately rectangular in shape with a maximum depth of 5–7m from surface. The K7 pegmatite differs from the other pegmatites as it has a positive relief and has been excavated to ground level (Fig. 20 A).

The pegmatite is well exposed at surface and although it is not zoned, it contains a continuous greisen layer with visible cassiterite (Fig. 20 B), indicating higher grade tin mineralisation that is sub-parallel to the pegmatite contacts. This greisen layer occurs approximately 30cm below the hanging wall contact (Fig. 20 B) and can be traced over the entire length of the exposed pegmatite body in the pit; it is also present in another small excavation 55m along strike from the northern pit high wall, suggesting continuity (Fig. 20 C). The greisen layer averages approximately 40cm in width and is roughly parallel to the pegmatite contacts, the greisen undulates and its thickness varies (Fig 20 B, C) but remains present along strike, this is the only observed continuous greisen layer observed in the

Uis pegmatite swarm. The cassiterite in the greisen layer is present as coarse subhedral crystals. The modal abundance of cassiterite in the greisenised layer is significantly higher than the average observed in the K7 pegmatite.

A second greisen layer was observed near the footwall contact of the pegmatite. This layer is not as continuous as the first layer. The second layer displayed a saccharoidal texture and is an albitised unit with mostly fine grained cassiterite (< 2mm grains) observed. This layer is poorly preserved as it has been extensively exploited by artisanal miners and coarser cassiterite grains may have been preferentially removed from this unit during mining.

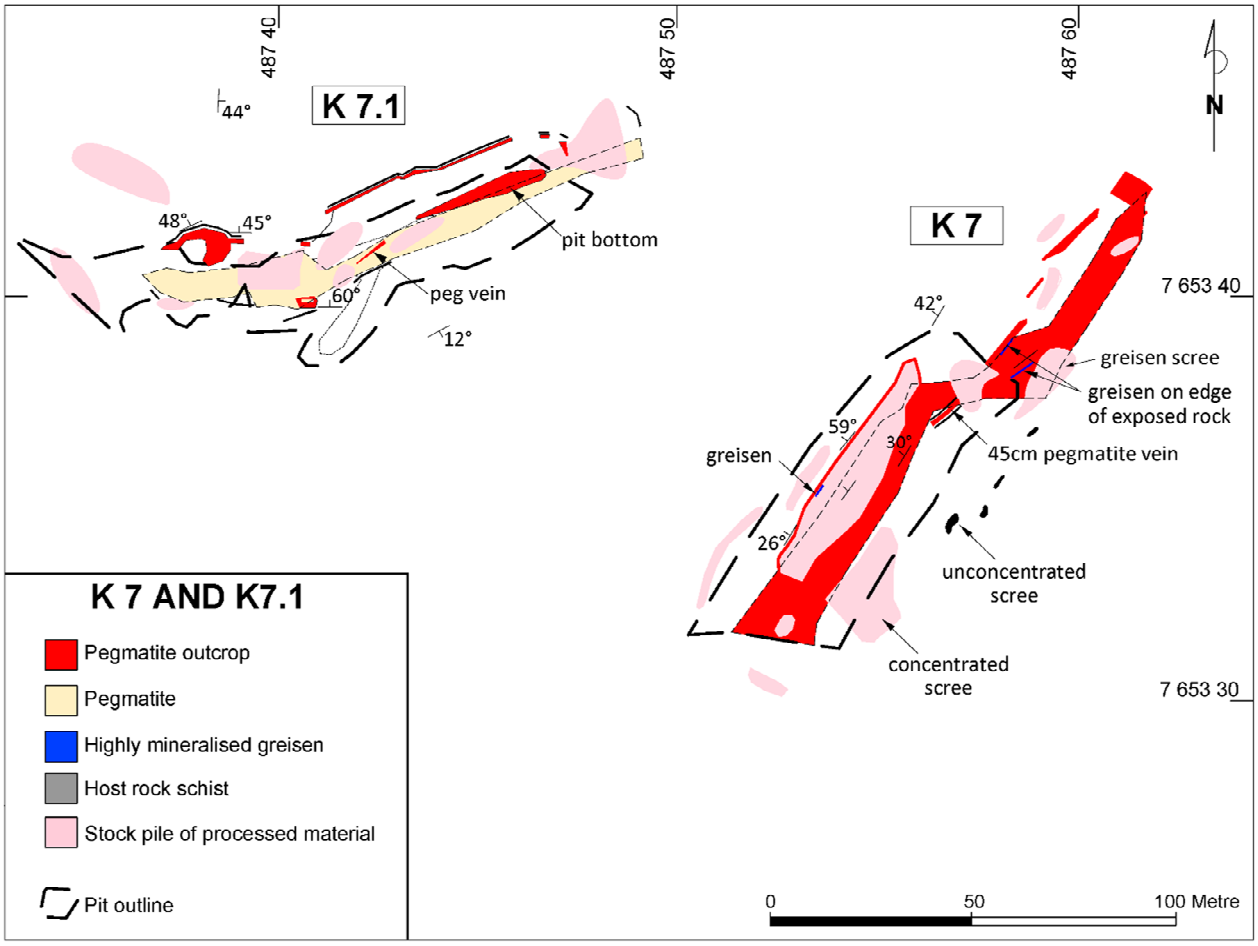


Figure 18: Geological map produced of the K7 and K7.1 pegmatites

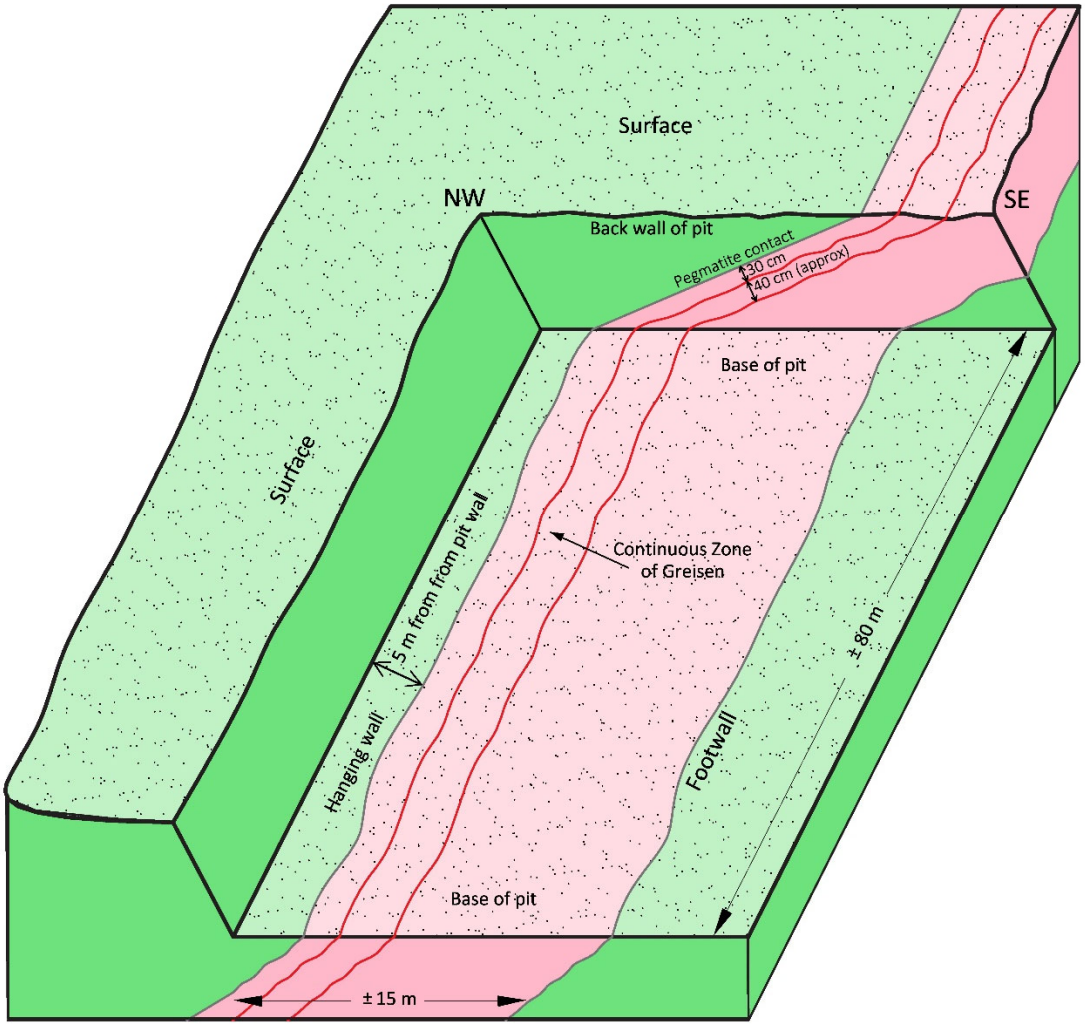


Figure 19: A schematic diagram (not to scale) of the K7 pit showing dimensions of the pegmatite and the greisen layer. The pegmatite in the image is shown in pink and the greisenised zone in-between the red lines.

K7.1 Pegmatite

The K7.1 pegmatite lies approximately 70m northwest of the K7 pegmatite. The K7.1 pegmatite appears to be smaller and of a lower tin grade than the K7 Pegmatite, and similarly dips northwest at 30° (Fig. 20 B). It is a fairly small pegmatite with a northeast strike extension of approximately 150m and an average width of 5m (Fig. 18). It appears to be sigmoidal in shape and shows no complex interfingering within the schist host rock.

The K7.1 pegmatite has been partially excavated down to 2m and it appears to be low grade in terms of mineralisation compared to other pegmatite bodies described in this report. No clear greisenisation is visible however sporadic muscovite and quartz rich areas were observed.

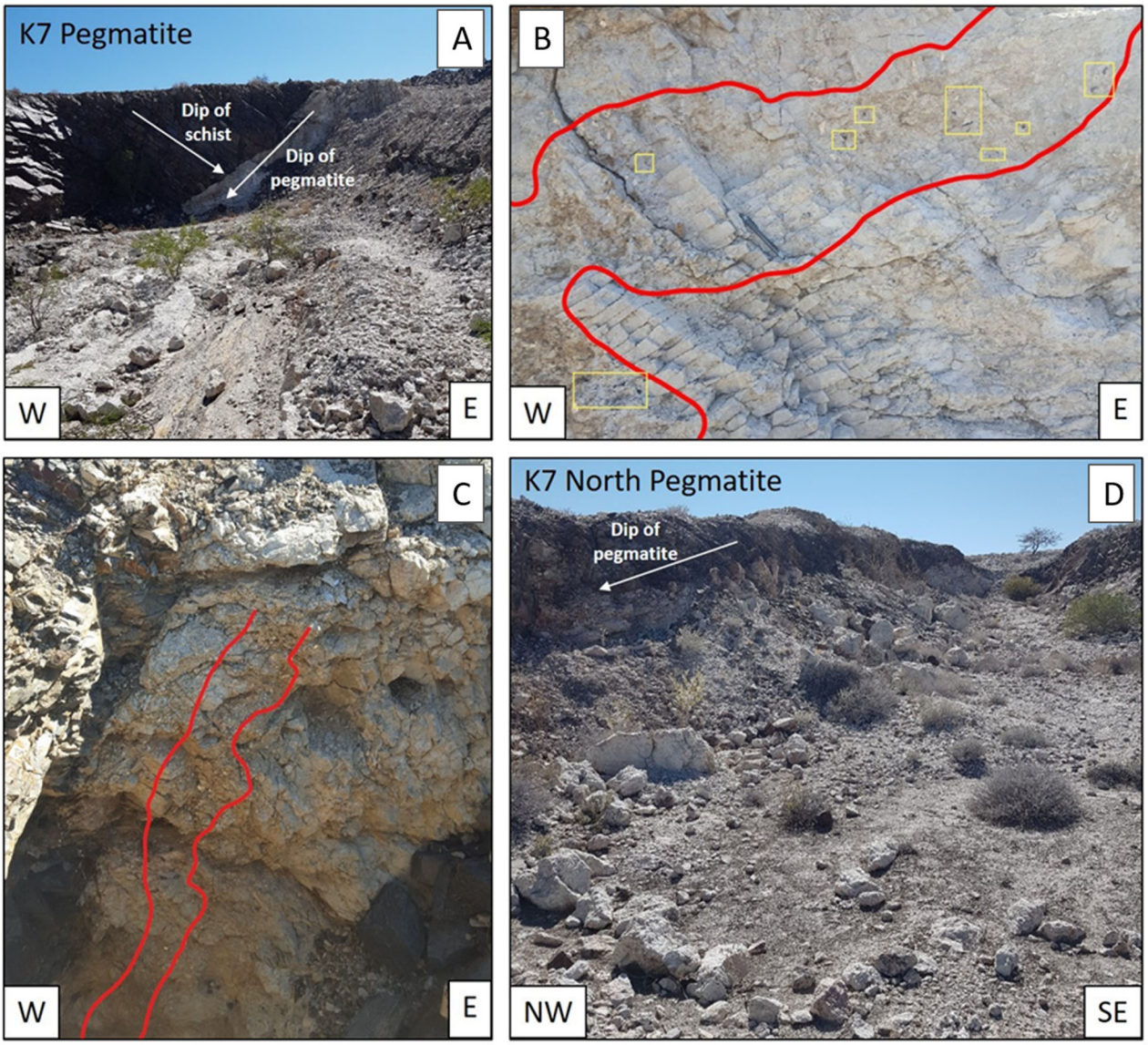


Figure 20: Surface images from the K7 pegmatite area A) K7 pegmatite and pit. B) Undulating greisenised zone of K7 (red outline) with large cassiterite grains (yellow rectangles) visible in the pit wall. C) Continuation of the K7 greisenised zone along strike visible in a small excavation 50m along strike from the pit wall. D) image of the K7.1 pegmatite and pit

K10 Pegmatite

K10 is a moderately sized pegmatite that strikes to the east for approximately 300m. The average width is roughly 18m at surface, and dips 60° north. Historical mining followed the strike of the pegmatite eastwards.

K10 appears as two main pegmatite bodies that are difficult to distinguish along the surface of the pit floor. It is probable that the pegmatite was emplaced as two *en echelon* intrusions, linked by thinner veins which dip to the south, no visible tin mineralisation was identified in the smaller connecting veins.

The tin mineralisation in the K10 pegmatite appears to be low grade based on the general lack of significant greisenised material. While some areas do contain well-developed greisen zones, these zones are not common nor extensive. Cassiterite in the K10 pegmatite is observed to occur in close association with large (≤ 10cm) quartz grains (Fig. 21). Whilst these large quartz grains are present in other pegmatites, the association of cassiterite with these grains is uncommon in the Uis pegmatites.



Figure 21: Cassiterite in close association with a coarse quartz grains in the K10 pegmatite

K8 Pegmatite

K8 is a moderately sized intrusion (relative to the other pegmatites exploited in the area) which extends for approximately 300m along surface with an east to east-southeast strike, the width is approximately 15m and it dips roughly 60° to the north (**Error! Reference source not found.**Fig. 22).

The pegmatite outcrop is limited to the (eastern) highwall of the pit (Fig. 22), with only sporadic pegmatite outcrop visible along the pit floor due to cover by waste material that has been washed into the excavations. Surface exposure continues for another 50m behind the highwall. No interfingering with host schists was observed for this pegmatite. Due to the poor exposure, the in-situ tin mineralisation is difficult to evaluate, subsequently no greisenisation was observed in situ however it was present in surface scree within the excavated area.



Figure 22: Image of the K8 pegmatite, steeply dipping to the north, exposed in the pit sidewall.

Central Cluster

P4 and P5 Pegmatites (P4/P5 Pit)

The P4 and P5 pegmatites delineate the northwestern edge of the Central Cluster and were mined together from a single pit (Fig. 15). The P4 pegmatite is the more westerly pegmatite body, and forms the western highwall of the P4/P5 pit over a distance of approximately 200m with an average dip of 30° north northwest. Neither pegmatite body was mapped in detail during the current field investigation owing to the outcrop only being present along the pit face and it could not be identified in the pit floor. The P5 pegmatite strikes at 040° to the northeast and dips to the northwest. An 8m thick exposure is visible along the pit wall over a distance of roughly 300m (Fig. 23 A).

The pegmatite wall face shows highly mineralised areas with higher grade greisenised patches randomly scattered along the surface exposure. The SRK (1989) report indicates that the P4 and P5 contain above average Sn grades of 0.136 and 0.135 respectively however the average grain size is much finer resulting in significantly reduced recoveries of cassiterite during processing.

P6 Pegmatite

The P6 intrusion is one of the larger pegmatite bodies in the historically mined Uis area that has been mapped during the current investigation. The P6 pegmatite is approximately 12m thick and extends along an east-west strike for 250m at surface. This pegmatite dips to the west, with the dip angle steepening from 20° in the west to 55° in the east. The P6 pegmatite has undergone a moderate amount of excavation with at least three benches visible in a northern highwall (the total height of the northern high wall is approximately 30m) (Fig. 23 B).

The P6 Pegmatite contains an estimated grade of 0.155 % Sn (SRK, 1989) this infers that this pegmatite is one of the highest-grade intrusions in the Uis mining district (of the historically mined pegmatites).

A continuous greisen layer, approximately 1m thick, containing coarse-grained cassiterite crystals (>10 mm) is visible along the south western pit side wall. This greisen layer can be traced for 25m before coming to an abrupt end. A zone of secondary manganese precipitation is present immediately above the greisen layer and is present over the entire extent (Fig. 23 D).

A large schist xenolith is present in the middle of the pit (Fig. 24). At first glance it appears to be the footwall of the pegmatite however upon closer inspection it becomes evident that the pegmatite has bifurcated around the xenolith and joined again on the other side (Fig. 23 B, C). Multiple lensoidal xenoliths are present near the hanging- and footwall of the P6 pegmatite, the general shape of these smaller xenoliths appears to be similar to the overall shape of the hosting intrusion (Fig. 23 B).

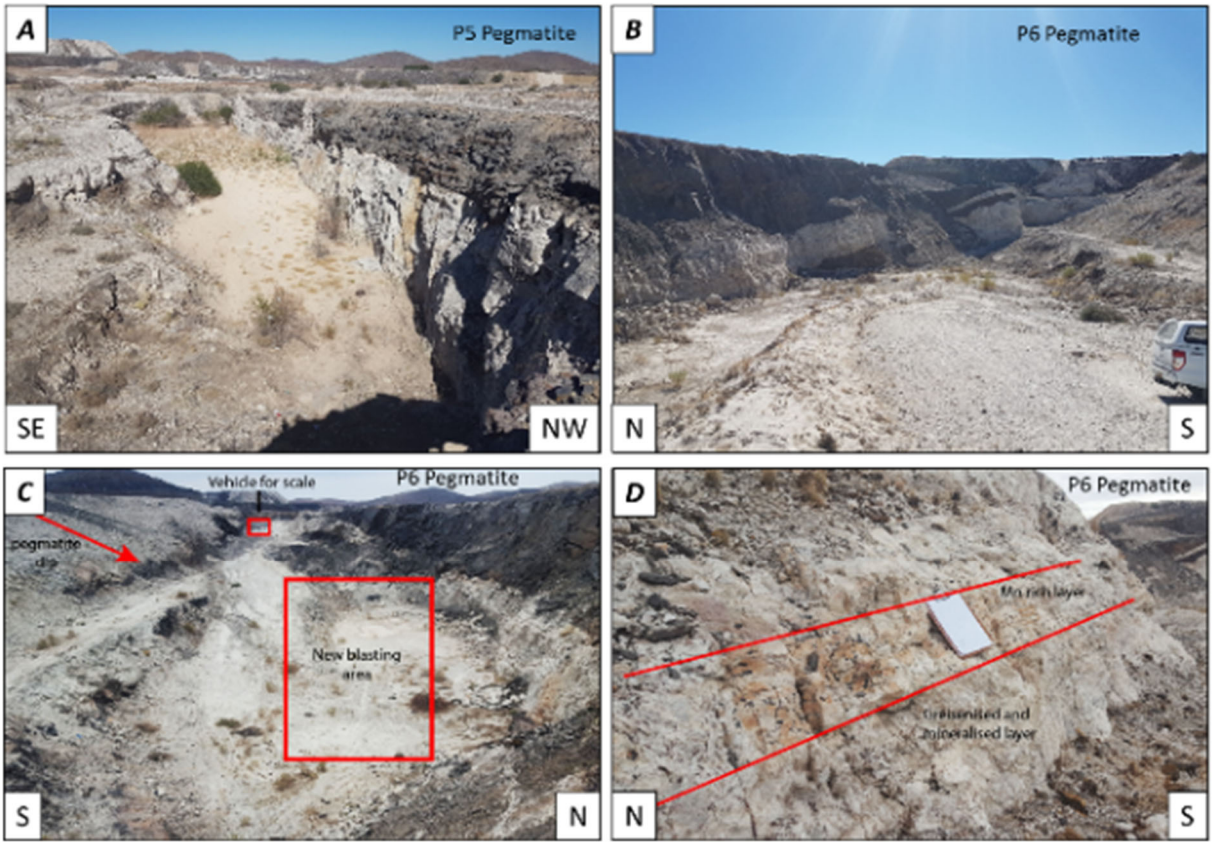


Figure 23: Surface images taken from the hanging wall of the excavations A) SW view of the P5 pegmatite and pit, showing the pegmatite outcrop on the pit highwall, with a thin layer of waste schist above it. B) View east of the P6 Pegmatite, dipping towards the northwest. C) View west of the P6 Pegmatite, showing the dip of the pegmatite. D) A Mn-enriched layer above a tin mineralised greisen layer within the P6 pegmatite.

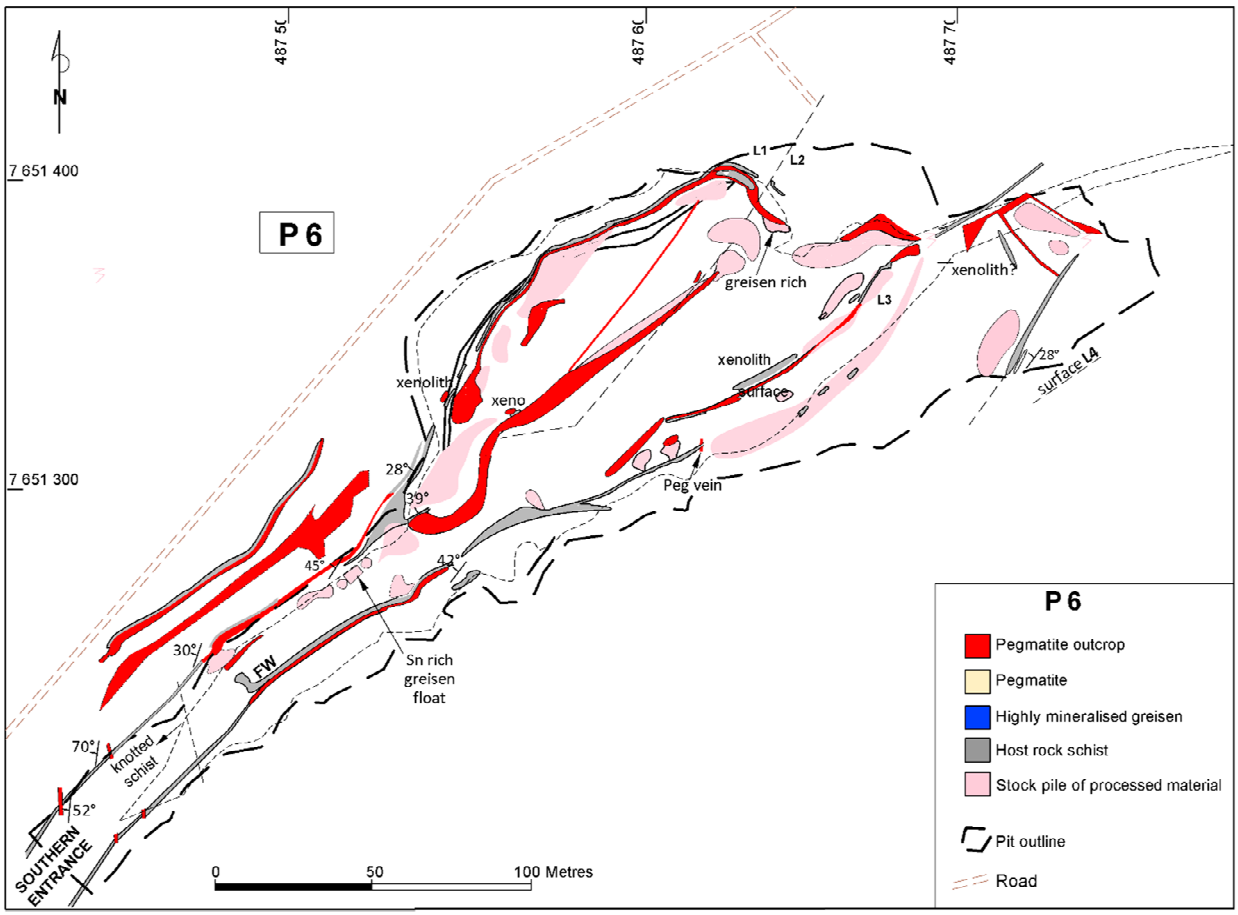


Figure 24: Geological map of P6 produced during the Norther and Central Cluster mapping programme.

V1 and V2 Pegmatites (V1/V2 Pit)

The V1 and V2 pegmatites are both exposed in the V1/V2 pit, and represent two of the largest pegmatites in the Uis pegmatite swarm. The V1 pegmatite is exposed in the northeast of the pit, and the V2 in the northwest; both pegmatites converge near the centre of the pit. The V1 pegmatite extends for 600m along a northeast-southwest strike, dipping at 50° to the northwest, with an estimated thickness of 20 to 30m to the west the V1 pegmatite is exposed in close proximity to the V2 pegmatite. The V2 pegmatite dips at 30-40° to the northwest and has a northeasterly strike in excess of 650m. Both pegmatite bodies are cross-cutting schist which dips to the southeast (Fig. 26).

The V2 pegmatite is 9m wide in the east, but thickens to >60m towards the southwest, along the north western highwall of the pit. The V2 Pegmatite, is exposed along the entire northwest pit face and outcrops along the pit floor (Fig. 25 A). The combined strike length of the V1 and V2 pegmatites extends over 1.4km, and appears to consistently reach thicknesses greater than 20m for the majority of the outcropping length.

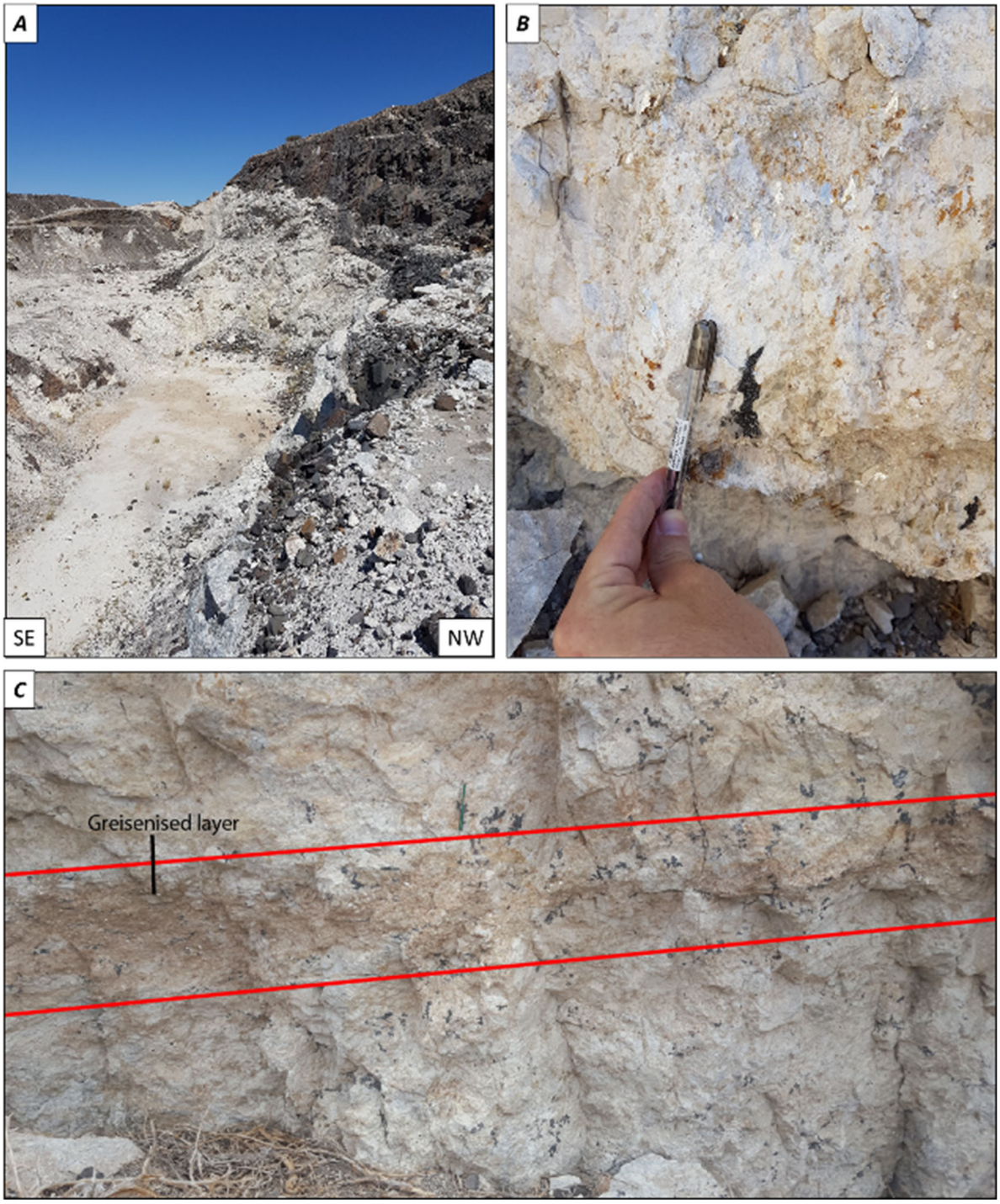


Figure 25: The V1 and V2 pegmatites. A) An along-strike view of the V2 pegmatite looking SW, showing the sharp contact between pegmatite and the hanging wall and relatively shallow NW dip. B) A large, irregular shaped grain of cassiterite. C) A greisenised zone, where tin mineralisation is associated with secondary Mn-rich staining.

The V1 and V2 pegmatites have only been partially exploited as the V1 pegmatite has been mined down a single 10m bench, the V2 pegmatite has undergone more extensive mining with a small portion being excavated to a depth of 20m in the southwestern most portion of the pit (Fig. 25 A). Due to topographic influence, multiple bench levels intersect in a complex manner. The southwest portion of these old workings is the most complex and consists of different bench heights and intersections.

Higher grade patches of greisen and albitisation alteration, with extremely coarse cassiterite, are present throughout both pegmatites. The texture of the higher-grade mineralisation often has an equigranular, saccharoidal texture. In some areas a secondary Mn oxide precipitate appears to become more prevalent around these alteration zones (Fig. 25 C)

The V1 and V2 pegmatites are the most structurally complex of the mapped pegmatites. They appear to be composed of multiple northeast-southwest striking pegmatites which have coalesced to form two large pegmatites containing large xenoliths of schist. The main pit has been developed around the V2 pegmatite as it appears to be the larger of the 2 bodies at surface. *Additional information on the V1 and V2 pegmatite is provided in subsequent chapters of this report.*

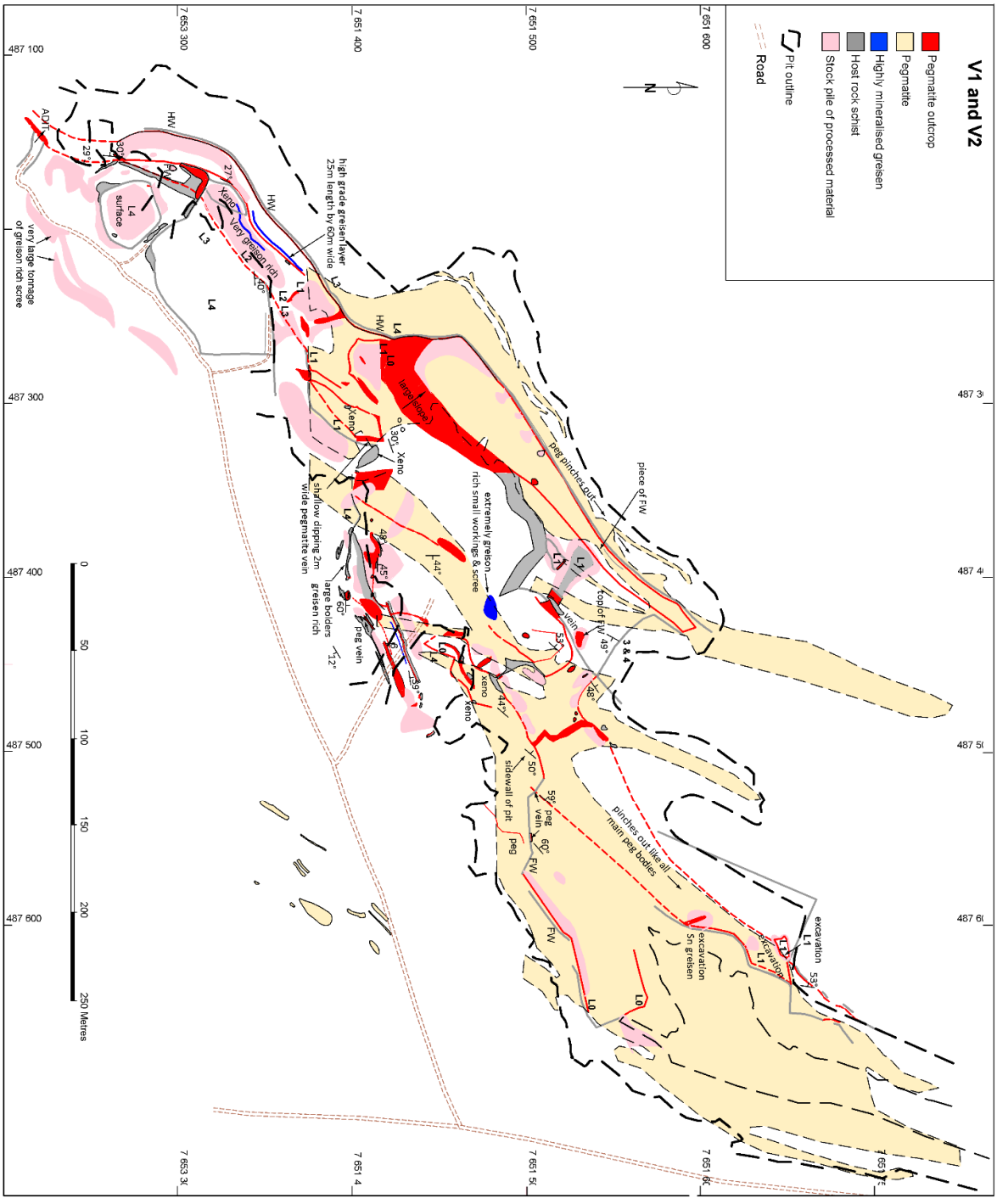


Figure 26: Geological map of the V1/V2 pit produced during the current programme

V5 and V12 Pegmatites (V5/V12 Pit)

The northern V5 pegmatite forms a sigmoidal arc with the strike changing from northeast-southwest to east-southeast west-northwest. To the east of the pit, the pegmatite extends for at least 250m, and dips to the northwest or north at 50°, with a width ranging between 15m and 25m.

The southern portion of the pit contains the large, east-west striking V12 pegmatite. The V12 pegmatite strikes east-west along strike for approximately 1km, with at least 500m extending eastwards beyond the current eastern pit edge (this becomes the V12E pegmatite). The V12 pegmatite dips at 45° to the north and is approximately 28m wide along the floor of the pit. The V5 and V12 pegmatites intersect in the deepest portion of the pit, where the southernmost extension of the V5 pegmatite intersects the centre of the V12 pegmatite. This forms the shape of an inverted "T" in plan view (Fig. 27). The southern edge of the pit sidewall forms a dip slope that approximates the footwall contact of the pegmatite.

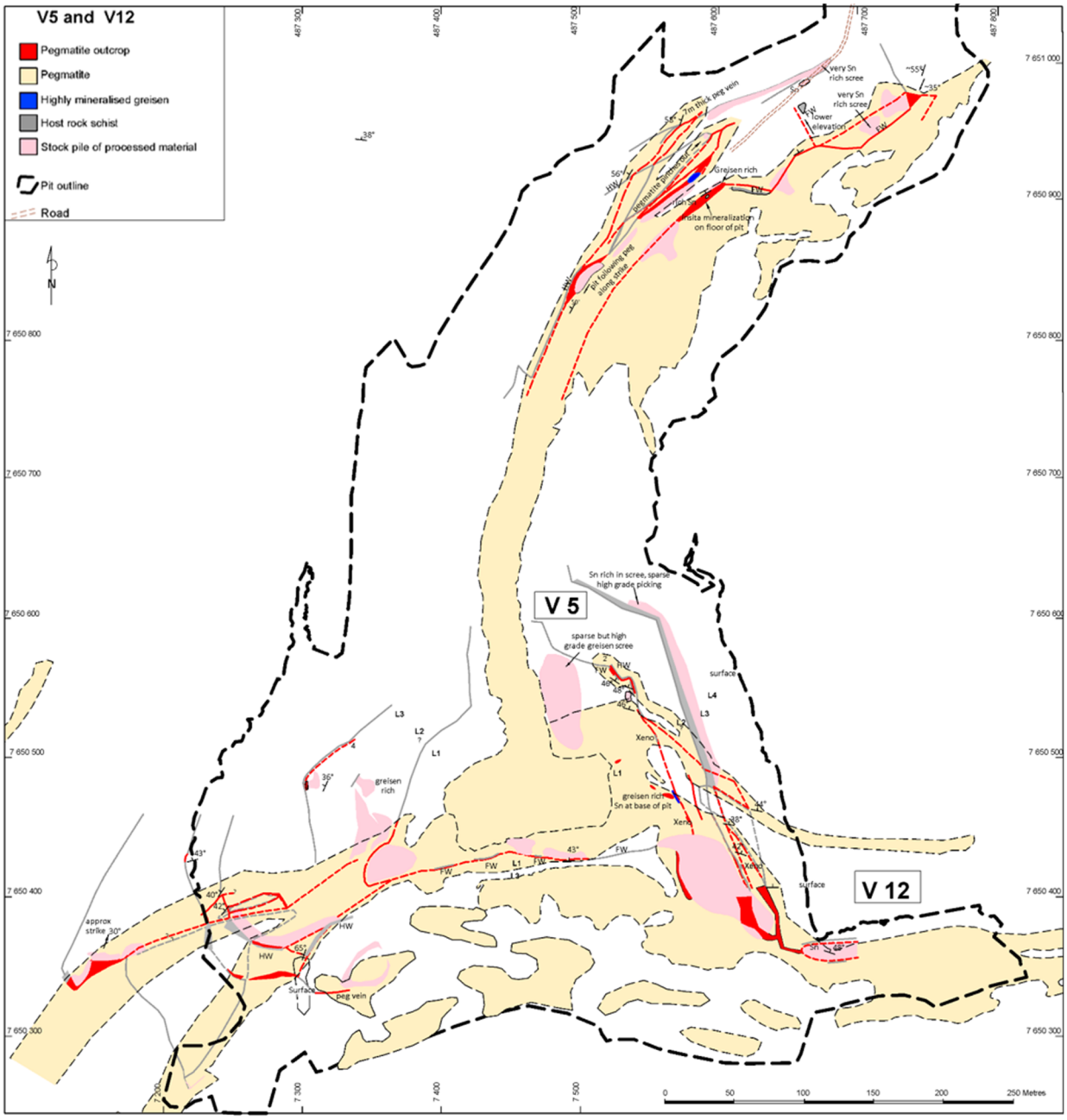


Figure 27: Geological map of the V5/V12 pit.

The V5 pegmatite and a portion of the V12 pegmatite have been extensively mined down to depths of >40m (Fig. 28 A, B, and C). The intersection of the V5 and V12 pegmatites occurs in the deepest, water-filled, portion of the pit (Fig. 28 C). Although this area is the largest mined area, these pegmatites are the second largest of the Uis pegmatites (after V1 and V2) mapped during the current programme. The V5 and V12 pegmatites display the typical complex nature of intrusion commonly associated with the larger pegmatites at Uis. In the northeastern portion of the workings, near the main pit entrance, two moderately sized pegmatite veins occur with strikes of approximately 035°, steeply dipping to the northwest. The veins are clearly visible in the side wall of the pit (Fig. 28 B) and become significantly smaller as they approach the surface. One of the veins pinches out before reaching the original surface level. These veins are convergent with the main V5 intrusion at depth, once they join with the main V5 intrusion the width of the body increases substantially.

The second major pegmatite exposure (V12) occurs in the southern portion of the old pit. This pegmatite has an approximate strike of 100° and dips steeply to the north. The pegmatite contains numerous xenoliths of schist host rock as a result of the inter-fingering, splaying and coalescing of the pegmatite veins, the main intrusion bifurcates as it approaches the surface and would originally have been interpreted as two separate pegmatite bodies at surface (Fig 28 C). Recent mapping shows that tin mineralisation appears to dominantly occur near the intersection of the V5 and V12 pegmatites. This is also where the pit reached its greatest depth and where mining was still active when the operations were stopped (SRK, 1989).

High-grade mineralisation is associated with greisenisation, with both patchy and continuous greisenised zones enriched in cassiterite (Fig. 28 E). Continuous greisenised zones do not extend over the entire length of the pegmatite body, but pinch out and reappear at various points along strike. Lenses of the greisenised zones appear to be associated with albitisation of the feldspars as seen in Figure 28, F.

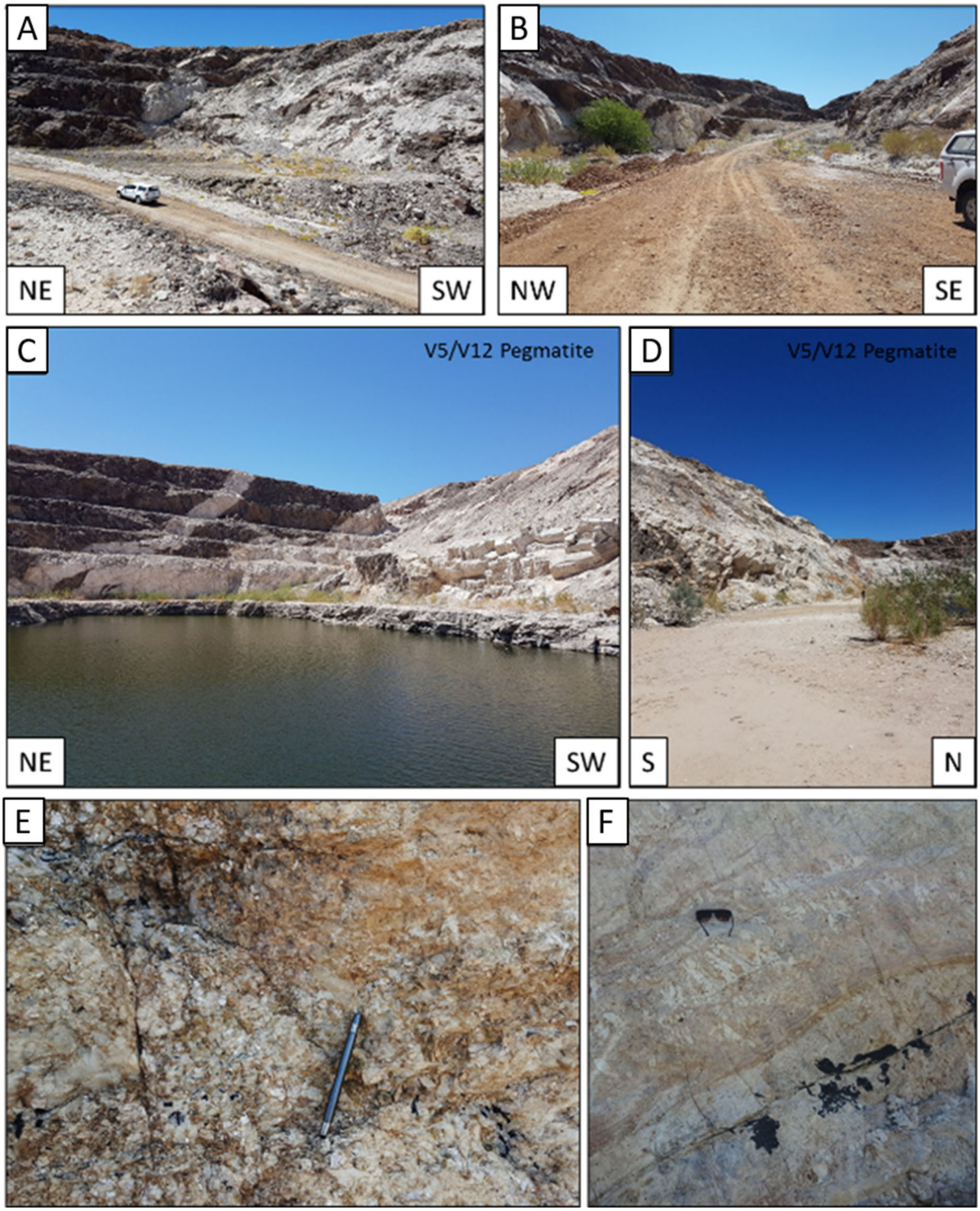


Figure 28: The V5 and V12 pegmatites. A) View of the V5 pegmatite looking SE. B) Pegmatite veins of the V5 pegmatite on the left and right which intersect roughly in the centre of this working near the road, forming a much larger single body. C) View of the V12 pegmatite looking east from the base of the pit. D) View SW of the V12 Pegmatite along the southern pit wall. E) Patchy greisenisation showing significant quantities of coarse cassiterite. F) Layered greisenisation above a zone associated with secondary Mn oxides, showing secondary albitisation (pale white laths below sunglasses)

CHAPTER 5.

V1 and V2 Detailed Geological and Structural Mapping

Previous field programmes identified the V1 and V2 pegmatites as the primary exploration target for the area. These two intrusions comprise the largest mineralised intrusions, of which half the surface extent remains untouched by mining activities. Furthermore, these two bodies contain 42 Mt. of the total 74 Mt. of ore as reported by SRK (1989). With the V1 and V2 pegmatites potentially comprising more than 50% of the known minable ore in the area, all efforts were focussed on establishing a modern mineral resource code compliant resource (Table 3).

The V1 and V2 pegmatites were geologically mapped in detail between January and February 2018. The methodology used to map the pegmatites involved using a handheld GPS, printed images of the acquired satellite imagery, field observations and interpretation, and the use of compass clinometer to establish strike directions and dip angles. The mapping was completed at a 1:500 scale. All contacts between pegmatites and host rocks were recorded on the satellite imagery utilising the handheld GPS for verification of position. In addition, photographs were taken of outcrops and pit wall faces to aid in detailed geological mapping and subsequent geological modelling and interpretation.

Strike and dip direction measurements were recorded where possible, by measuring planar features within individual pegmatite bodies which gave a reliable indication of orientation. Both hanging wall and footwall measurements were also recorded where possible, with access to the hanging wall proving difficult in a number of areas due to steep and inaccessible pit faces. The structural readings and contact positions were utilised to model below surface extensions of the geology.

V1/V2 Extension

Figure 29 A and Figure 30 show the mapped extent of the important V2 and V1 pegmatites established during this programme. The unmined surface extension of the V2 pegmatite was prioritised as it was not properly covered in previous mapping exercises (Fig. 29 A).

The mapped V2 surface extension (outlined in red; Fig. 29 A) was found to extend for an additional 700m to the southwest of the southern edge of the southernmost V1/V2 pit wall. The intrusion is, therefore, substantially larger than the original programmes implied. The width of the pegmatite is greater than 20m for the first 550m from the edge of the existing workings with the last 150m of the extension tapering off and thinning until it pinches out after a bifurcation. The unmined surface extension of the V2 pegmatite shows a complex intrusion style, similar to that observed in the existing pits. The overall strike of the pegmatite body ranges between 25° and 35° with a dip ranging from 28°-42°to the NW (Fig 29 B).

Similar to the outcrop in the pit, the V2 unmined pegmatite extension contains various bifurcations and rapid changes in dip angle orientation. Two overall structural domains were observed in the extension (within the red line in Figure 29 A) where the pegmatite thins out along strike and a new pegmatite intrusion approaches and joins with the former resulting in a significantly thicker intrusion. These structural patterns could be interpreted as two *en echelon* tension gashes in close proximity, joining along strike and are likely to join at depth to form a larger, dominant, V2 pegmatite body. Structural readings of the orientations in these sigmoidal structural domains confirm that separated pegmatite veins most likely join at depth to make up the larger V2 pegmatite body.

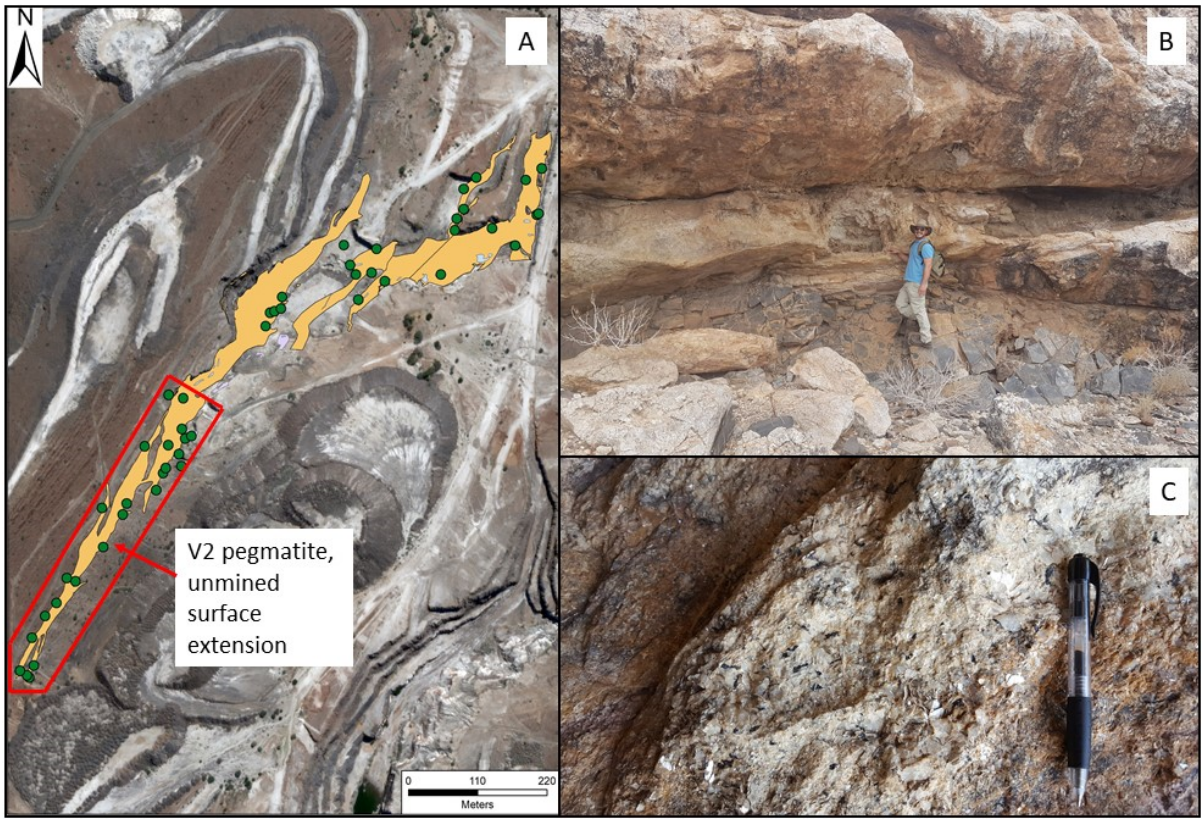


Figure 29: Images and map of the V1/V2 area A) A geological map of the V1/V2 pegmatite. Outlined in red is the unmined, surface extension of the V2 pegmatite. B) Footwall contact of the V2 extension with dark fine-grained biotite phyllite where the person in the image is standing. The pegmatite body occupies the top portion of the photograph. C) A fresh surface of the V2 pegmatite extension showing high-grade greisen-style tin mineralisation similar to the mineralisation in the historical mine.

The old Uis Mine exploration adit near the southern pit edge of the mine confirms the observations that the pegmatites are consistent and join at depth. At surface, a pair of *en-echelon* pegmatite veins occur, but within the adit at depth, the veins become a single solid body.

No changes in the mineralogical composition of the pegmatites were observed between the fresh exposure in the V2 pit face and its unmined surface extension. The unmined outcrop is significantly weathered, which hindered estimating overall modal abundances and quantifying cassiterite mineralisation. The outcropping extension is dominated by quartz, albite and perthite. Muscovite is mostly weathered away, however, fresh rock surfaces reveal large muscovite rich patches are present in the form of greisens, sericitic alteration and aplitic zones.

Field observations strongly suggest that mineralisation and grade, from a qualitative perspective, remain the same as observed within the existing V1/V2 open pit. In the weathered outcrop cassiterite was observed in similar abundances, crystal sizes and mineralisation styles, being associated with greisens and alteration zones (Fig 29 C). Even in the far SW extensions, where the V2 pegmatite begins to thin and terminate, the surface outcrop contains cassiterite mineralisation.



Figure 30: Detailed geological map of the V1 and V2 pegmatites showing the location of dip and strike measurements recorded.

V1/V2 Pegmatite Pit

As previously described, the V1 and V2 pegmatite bodies are mineralogically homogenous intrusions. They show considerable late-stage alteration associated with significant cassiterite and CGM. Greisenised zones within the pegmatite bodies occur sporadically but are locally abundant and, in some places, contain up to 1 % Sn. The average grade for the V1 and V2 pegmatites is reported to be 0.14 % Sn (SRK, 1989).

This primary purpose of this detailed mapping programme in the pits was to characterise the V1 and V2 pegmatites in terms of intrusion dimensions and contact parameters (strike, dip and dip direction). The results of this programme were utilised in the production of a three-dimensional model. The wireframes generated were limited to the surface extent delineated during this programme.

Pegmatite Contact Characteristics

In a regional sense, the V2 pegmatite may be seen as a roughly NE trending slightly arcuate lensoidal- or sigmoidal-shaped body whereas the V1 pegmatite is slightly more complicated (Fig. 30, Fig. 31 A). Figure 30 depicts that the regional strike of the V1 pegmatite is roughly ENE in the central portions of the body. However, the western extension of the V1 pegmatite splays or bifurcates into two NE trending thinner dyke-like bodies whereas the eastern extensions change strike to NNE with a similar thickness. A thinner, 5-7m thick, pegmatite vein also bifurcates from the central portion of the V1 pegmatite towards the north. The suggestion is of a tensional jog forming the ENE central sector with the NNE trending bodies.

Closer inspection of the V2 pegmatites hanging wall contacts reveals that the characteristics are undulatory. Figure 31A shows that there is roughly a 20° difference in the dip angle at the footwall (steeper) compared to the hanging wall. The central section of the image in Figure 31A shows that the dip angle also changes significantly, and that the pegmatite probably increases in thickness with depth towards the lowest level of the historical pit (red arrows). There is also a large variation in the V2 pegmatite orientation along its hanging wall (Fig. 31 B).

Chevron-like contacts are seen in Figure 31 B, this image also shows hanging wall bifurcations where thinner pegmatite veins separate from the main pegmatite body and intrude the host rock. From a three-dimensional perspective, the contacts of the pegmatite intrusions with the host rock are complex and do not follow a definable trend at the cm- to m- scale, however, the overall contact orientation is relatively regular at a regional scale (Fig. 30).

The V1 pegmatite appears to be slightly more complex in terms of its dominant regional intrusion pattern. However, this could be due to less surface exposure where outcrop is now limited primarily to the side walls of the pit. The contact characteristics are similar to the V2 pegmatite where the contacts are non-linear and show various xenoliths, undulations and steps (Fig. 32 A-C respectively). Where xenoliths are present, they may extend for several meters along strike but terminate abruptly at depth (Fig. 32 A). Undulations in the side walls are more common near the footwall contacts where previous mining activity mining has exposed footwall schists (Fig 32 B). Figure 32B also shows that cm-scale pegmatite veins are a common feature near contacts.

Figure 32 C reveals features that pertain to the nature of the pegmatite intrusion at a larger scale - abrupt changes in the strike or dip angle occur where the pegmatites seem to disappear into the footwall or hanging wall and then reappear a few meters away. These features are likely to be due to small faulted ‘steps’ along the pegmatite margins resulting in abrupt changes in dip angle and direction (Fig 32 C). This feature probably accounts for unexpected changes in orientation observed during regional geological mapping and should be viewed as minor structural anomalies at contacts. This type

of disturbance does not appear to affect the overall proportions of the dominant pegmatite or the regional trend.

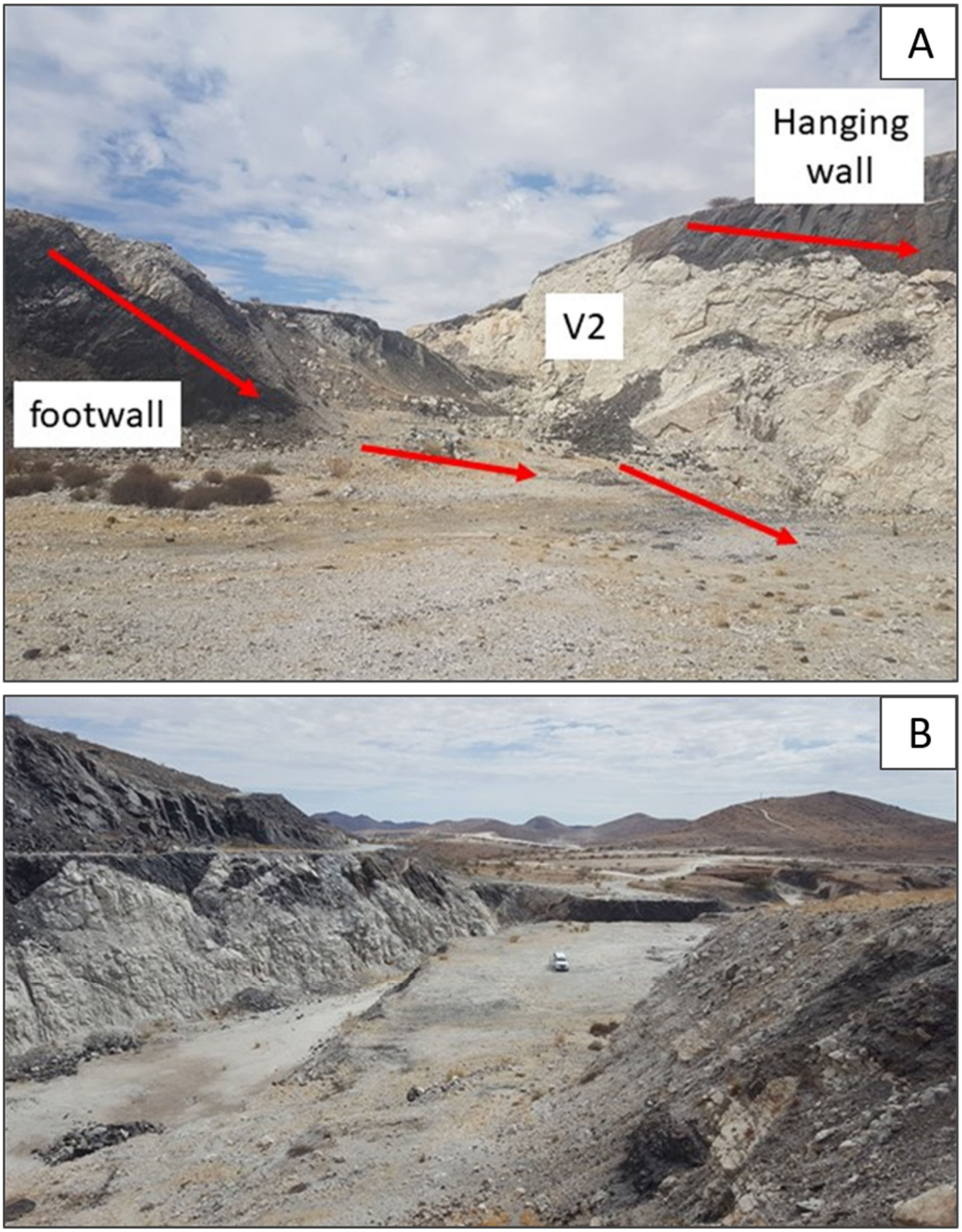


Figure 31: Overview photos of the V2 pegmatite. A) An approximate outline of the V2 pegmatite looking towards the SW and showing the approximate dip of the pegmatite at various angles illustrated by red arrowed lines. B) A photo showing the main pit wall in the V2 pegmatite (left). This image shows the complex relationship between the pegmatite and it hanging wall.

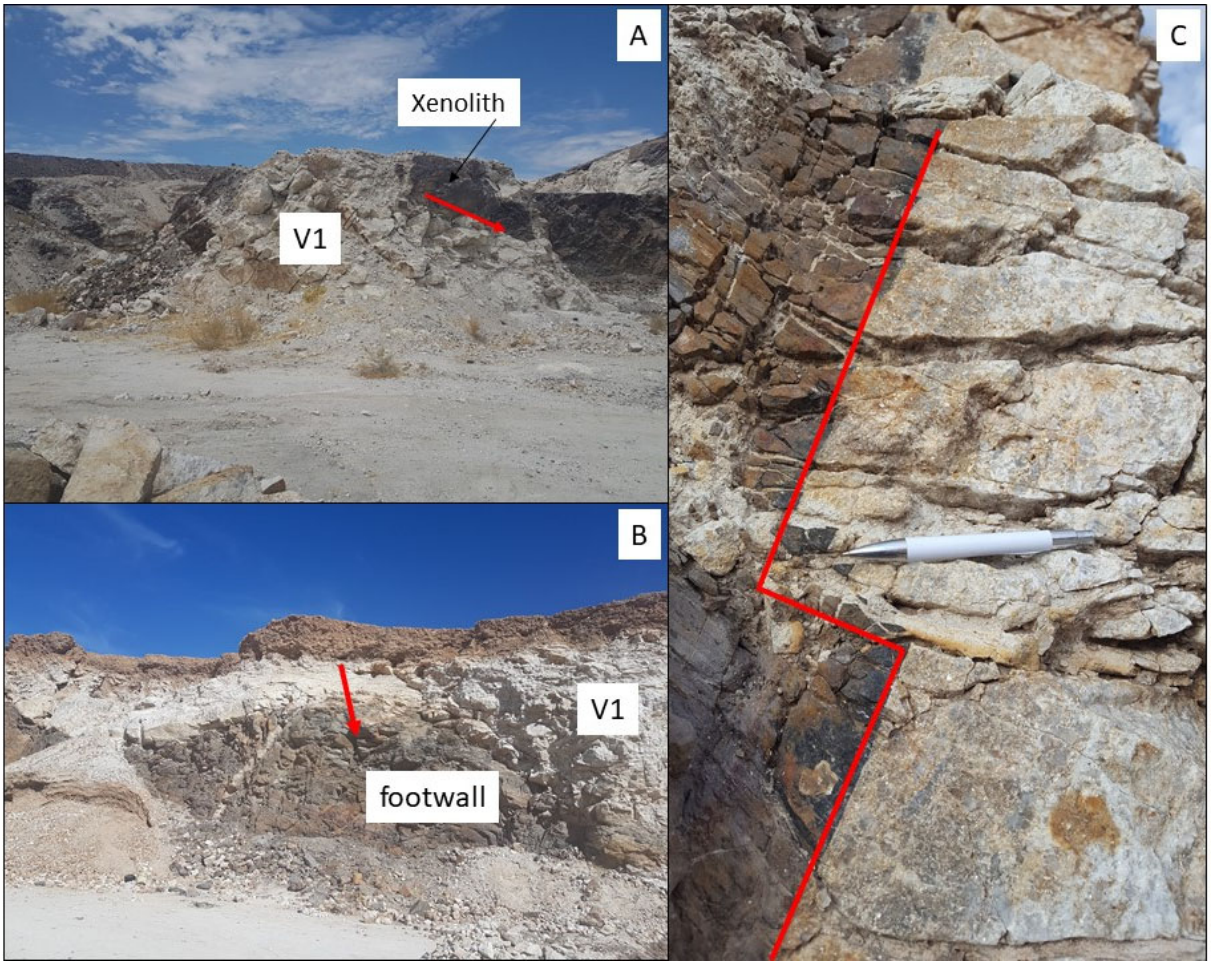


Figure 32: Various outcrop photographs of the V1 pegmatite showing approximate dip in red arrowed lines. A) The SW extension of the V1 pegmatite showing a schist xenolith within the pegmatite. B) A portion of the V1 pegmatite where the previous mining operations exposed the footwall schist. The pegmatite in this image dips towards the viewer. C) A small-scale example of how the pegmatites may be displaced by joints at the contact with schists.

Interpretation

Fluid-enriched magmas that form these bodies achieve significantly low viscosities that allow for an abrupt change in direction, bifurcation and undulation when moving through the host rock where the final setting was controlled by structural features in the schists. These intrusive characteristics are more apparent along contacts whereas the larger magmatic body intruded more along prominent structural features within the host schist. The Uis pegmatites tend to have intruded as large elongate sigmoidal and *en-echelon* tension gashes which are controlled by regional stress regimes (Fig. 30).

The general shape of an individual pegmatite body, such as the V2 pegmatite, is comparable to an ellipse, with the widest part of the pegmatite being situated near the centre of the body. From the information gathered in the field it is likely that the V2 pegmatite body increases in thickness with depth, as witnessed in pegmatites proximal to the V1 and V2 bodies. In addition, it is suspected that the V2 and V1 pegmatite bodies intersect at depth, as this has been observed in other parts of the Uis Mining area.

CHAPTER 6.

Geological Model of the V1 and V2 Pegmatites

AfriTin successfully acquired the majority of the historic Uis Mine data generated by Iscor between 1959 and 1989. This acquired information was sorted and digitised. As the company had previously identified the V1 and V2 pegmatites as the primary target for exploration and production, this resulted in information relevant to the V1 and V2 pegmatites being prioritised.

Historic information

The data acquired by AfriTin was all printed on papers ranging from A6 assay reports through to A0 maps and sections with the majority being A4 in size. To maintain the integrity of the database each page was imaged or scanned then returned to the file it came from in the exact same order, then returned to the collection. The maps and sections too large for files are stored as rolls. Each roll contained a number of large sheets comprised of maps, plans and sections of various page sizes, each sheet was scanned individually and labelled with a unique file name. Once each roll was scanned in its entirety it was returned to the archive and the next roll was examined and scanned. Care was taken wherever possible to prevent any damage to the original documents and to maintain the integrity of the original dataset.

Each of the scanned files were then digitised. Tables and results were captured in Excel while reports were either typed out and saved as text files or converted to a PDF file containing high resolution images of each cropped page. In all instances the digitised file is stored in a folder containing a copy of the original source document for verification.

Modelling

Post digitisation, information pertaining to a total of 200 exploration drill holes, over the V1 and V2 pegmatites, was identified. Of the 200 holes only 152 contained complete data sets comprising geological logs, surface coordinates, assay data and down hole surveys (A complete data set contains all of the information required for a drill hole to be plotted in relation to the surrounding holes in a three-dimensional space). In addition to the drill hole information numerous surface maps and cross sections (Fig. 33) were included in the dataset.

Only the dataset containing complete drill holes was digitally projected in 3-D space using Leapfrog Geo™ (Fig. 34 A). Four holes were found to contain irrational data (such as impossible down hole survey readings) and excluded from the database. The digital terrain model and detailed geological surface mapping was then imported to ensure the projection was correct (Fig. 34 B). Some of the historic drill holes are projected though the current surface, this is as a result of mining activities which occurred after the drill hole was complete.

The successful incorporation of this data provided confidence in the veracity of the historical data. If the data had been manufactured or was incorrect, the holes would not have projected consistently in the correct area in relation to each other, or would not have all projected to the correct surface and matched well with the surface outcrop.

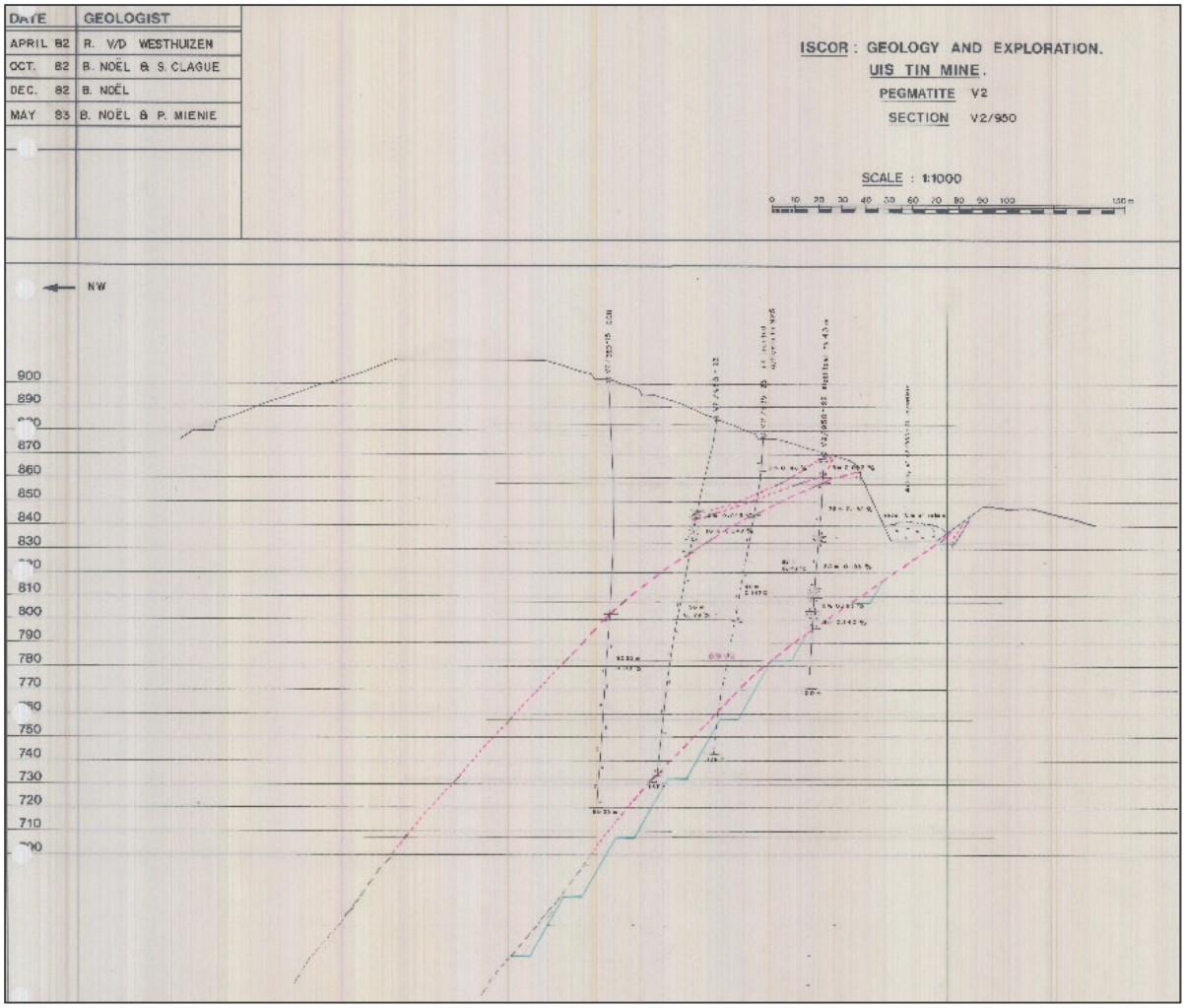


Figure 33: Cross section of the V2 pegmatite, recovered as part of the historic Uis data.

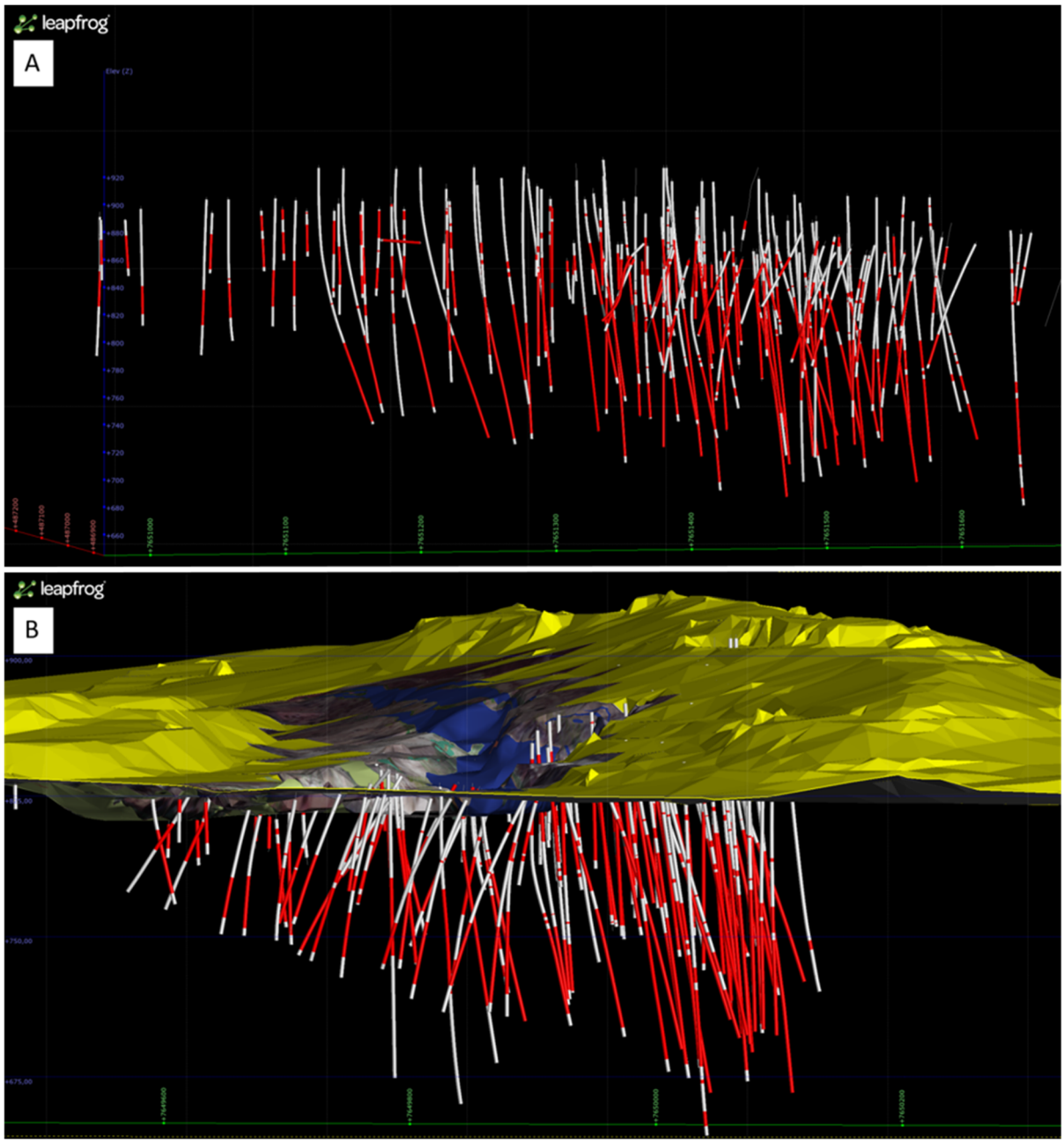


Figure 34: Historic drill data projected in Leapfrog Geo. A) all of the validated drill holes in the dataset with pegmatite intersections displayed as red. B) the digital terrain model and detailed geological mapping, blue, incorporated with the drill hole data.

The pegmatite contacts in each drill hole (depicted as the red units in Fig. 34 A, B) were then connected with digital wireframes which generated the outer shell of the pegmatite contact. This shell was then projected to the surface where it was clipped to the mapped surface outcrop. This resulted in the creation of a model showing the below surface extensions of the V1 and V2 pegmatites (Fig. 35).

The model indicates that the V1 and V2 pegmatites intersect at depth to form a single massive intrusion, similar to what can be seen in Figure 27 C. Some of the drill holes indicated that this intrusion is more than 120m thick, vertically, below surface. With the two bodies combining at depth the combined strike length of this unit is approximately 1450m along the surface.

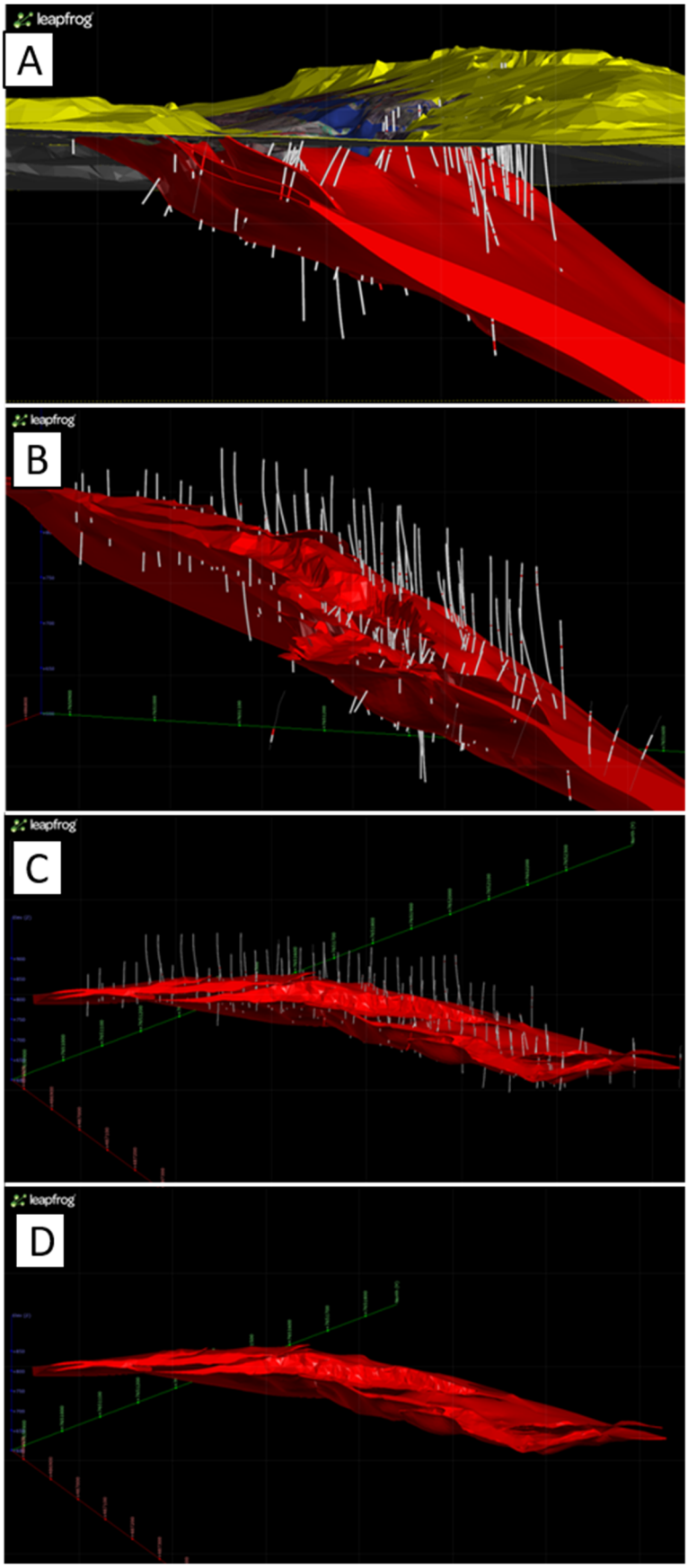


Figure 35: Models of the V1 and V2 pegmatites. A) wireframes generated from the intersections in the drill holes extended to the mapped surface outcrop. B) Same image as 35, A with the surface model removed. C) rotated view of the generated model and incorporated drill holes looking down dip. D) Same as Image 25, C, with the historic drill holes removed.

Although previous work indicates that the pegmatite bodies widen at depth a conservative approach was taken during the modelling process and the model was made to pinch as the depth increases. The pegmatite intersection in the hangingwall and footwall were not modelled in this exercise, as they are not thought to be of economic significance. The drill hole data also indicated the presence of schist xenoliths within the main pegmatite body. These were separately modelled as individual bodies that could be subtracted from the main pegmatite wireframe. A total of thirteen bodies were modelled within the main pegmatite body.

In addition to the geological information the assay data was also modelled. The assay values for each meter was plotted along the drill hole data. The data was then constrained to exclude all readings that do not fall within the modelled wireframes. The program was then able to extrapolate the expected tin grade of the pegmatite from the data present. The parameters provided for the extrapolation were to limit extrapolation to 40m from a datapoint, to preferentially favour a plane that follows the dip of the ore body and use a 30% nugget effect (rounding down the top 30 % of the assay data points) to account for the coarse grade nature of the ore body. The result of this modelling is indicated in Figure 36.

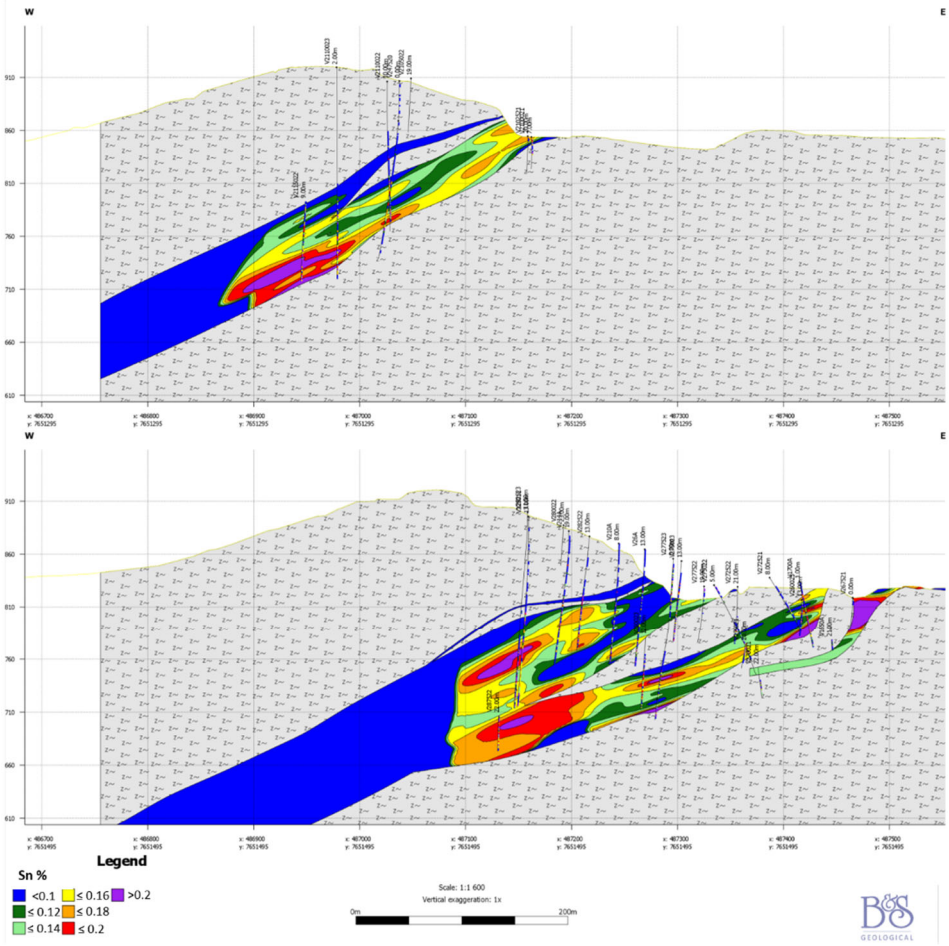


Figure 36: Two cross-sections located 200m apart displaying the modelled tin grade profiles and digitised drill hole data

The down dip extensions indicated in Figure 36 appear as low grade due to the extrapolation from a known point being limited. Any information contained in intersections that are presently above the surface model could not be incorporated, resulting in some near surface extrapolations being lower than should be expected due to missing data points.

CHAPTER 7.

Economic Potential of the Uis Pegmatite Swarm

Historic resources established for the Uis pegmatites indicate that the average grades of the pegmatites range from 0.105 – 0.155 % Sn (Table 3) with an average grade of 0.139 % Sn reported when all the of the tonnages are combined respectively (SRK, 1989). Although there are higher grade greisens found within each of the pegmatites, the average contained grade over a strike length of 4.7km varies by only 0.05 %. Removing the outliers, P6 and V4, which comprise 2.6 % of the total ore tonnage reduces the average grade variance to 0.025 % or 250 ppm. This variance occurs over a surface distance of approximately 5km.

Table 3: Grade and tonnage estimations of the Uis Mine pegmatites (SRK, 1989).

Orebody	Proven Ore (t)	Probable Ore (t)	Grade *(% Sn)*
V1/V2	7 451 960,00	34 371 130,00	0,140
V9/V10/V13	740 630,00	4 520 400,00	0,141
V4	92 210,00	717 670,00	0,105
K8	102 380,00	333 990,00	0,132
K10	130 320,00	361 020,00	0,121
V5/V12	1 119 600,00	10 213 890,00	0,126
K3	1 864 520,00	3 597 910,00	0,135
K5	2 577 540,00	4 966 960,00	0,146
P6	248 310,00	928 940,00	0,155
P4/P5	284 490,00	730 910,00	0,135
Total	**14 611 960,00**	**60 742 820,00**	

The cassiterite mineralisation appears to be relatively consistent throughout the previously mined pegmatites, with only the P4 pegmatite having been reported as finer grained, resulting in lower tin recoveries during processing (SRK, 1989). However, visual inspection of the V4 pit faces displayed significant amounts of coarse cassiterite grains along the unweathered exposure.

The relatively minor variation in tin content between the individual pegmatite bodies within this pegmatite swarm and the visual observations of each pegmatite shows that the bulk composition of these intrusive bodies is relatively similar. The mineralogical and metallurgical characteristics have been shown to have minimal variances in both the previously exploited and surrounding intrusions.

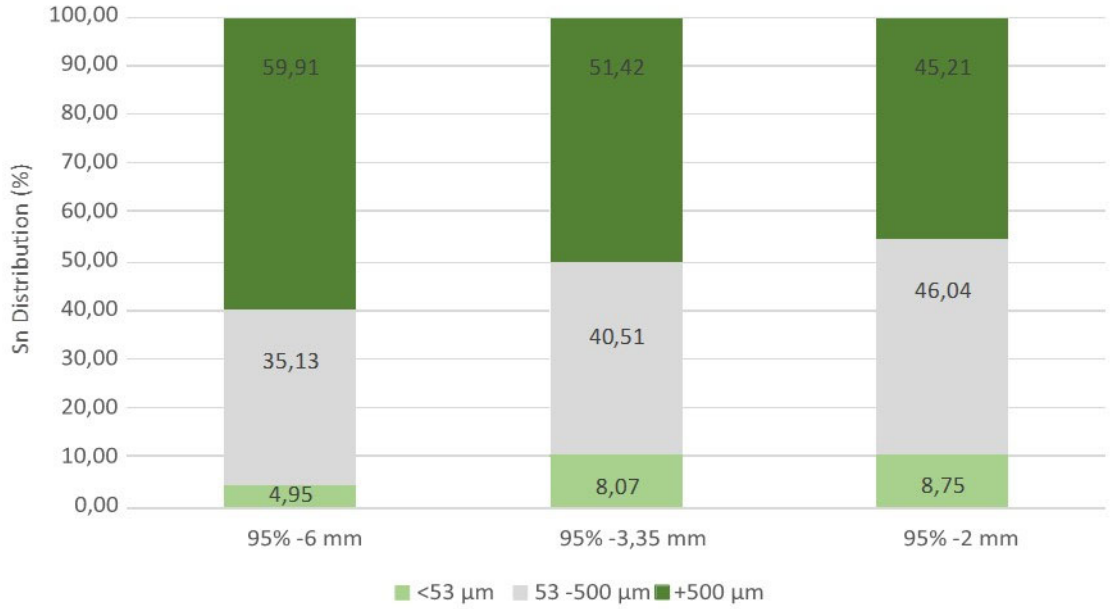
A number of bulk samples have been collected, primarily form the V1 and V2 pegmatites for liberation and concentration test work. These tests were carried out by FT Geolabs, PESCO and TrueGround Consulting. The primary objective of the test work was to define the liberation characteristics of the cassiterite grains and investigate the optimal separation densities for the respective grain sizes.

The average density of the Uis pegmatites is 2.65g/cm^3 with quartz, feldspar, muscovite comprising 98% of the bulk composition (Pirajno and Jacob, 1987). Other minerals identified are cassiterite, CGM's, apatite, beryl, calcite and cookeite.

Cassiterite Liberation

The bulk samples were passed through a primary and secondary jaw crusher then screened with 6mm, 3mm and 2mm screens respectively. Particles that did not pass through the screen were passed through the secondary crusher and screen again. The process was repeated until 95% of the total sample passed through the screen. The samples were then separated into >500µm, 500-53µm and <53µm size fractions and analysed for tin (Table 4).

Table 4: Size fraction distribution of Sn in relation to different crushing top sizes



The various crushing sizes indicated that the cassiterite grains become significantly finer as the top size reduces. This is undesirable as cassiterite recoverability becomes reduced with grain size. This data also displays the course nature of the tin mineralisation in the Uis pegmatite swarm, as 60% of the cassiterite grains remain above 500µm when crushed to 6mm.

These samples were then placed into a dense media with a density of 3.1 g/cm^3 as it would separate denser grains from the quartz, muscovite and feldspar which all have a density lower than 3.1 g/cm^3. The grains with a higher specific gravity than the dense medium which contain cassiterite are considered to contain 'liberated' cassiterite as the percentage of cassiterite within these grains is considered to be saleable. The sample crushed to 6mm indicated that 85% of the cassiterite grains were liberated, the 3mm and 2mm samples had 90% and 89% liberation respectively. These results are similar to those reported by Voges (1982).

The results of the liberation test works indicated the optimal top size range to be between 5.5mm and 4.5mm and this will provide better liberation than recorded in the 6mm tests while limiting the proportion of the material reduced to a grain size below 53µm which can be considered unrecoverable utilising conventional gravity techniques.

Cassiterite concentration

Cassiterite is primarily concentrated though basic gravity techniques due to its relatively high specific gravity and relatively stable crystal structure in normal atmospheric conditions. The Uis Tin mine historically concentrated the cassiterite ore, by utilising jigs for the coarser-grained material and spirals for the finer-grained material. Both of these simple gravity processes proved to be very effective in the recovery of cassiterite with 80% of the mineral content being recovered (Voges, 1982)

Following the liberation test work, concentration tests were carried out on similar material with the use of a small Dense Media Separation (DMS) plant. This plant utilises ferrosilicon (FeSi) powder in solution to adjust the average density of the medium that is passed through a gravity enhancing cyclone. The material that is denser than the medium passes through to the base of the cone, with lower density material floating off to a separate area.

Separation tests were carried out using multiple medium densities ranging from 2.62-3.10 g/cm^3. The lowest test density resulted in 90% of the cassiterite reporting to the sinks fraction and 43% of the CGM reporting to the sinks fraction. A decrease in the density of the dense medium results in an increase in mineral recovery and the total percentage of the sample mass that reports to the sinks fraction also increases. At a density of 2.62 g/cm^3 28% of the sample mass reports to the sinks fraction. When the average density of the dense medium is increased to 3.1g/cm^3 the percentage of the total sample that reports to the sinks fraction reduces to 0.16%. The test results indicate that a medium density of 2.65 resulted in 86% of the cassiterite reporting to the sinks fraction with 86% of the sample mass being rejected to the floats fraction. The crushing size distribution and recovery results indicate that cassiterite liberation and recovery has economic potential as the recoverability is high while processing costs remain low.

CHAPTER 8.

Conclusion

The Uis pegmatite swarm contains a significant number (>180) of Sn, Ta, and Nb bearing pegmatites covering an area of 600ha. The results of the regional mapping highlighted the extent and vast number of pegmatites within the Uis pegmatite swarm that have remained undocumented. The programme identified that a number of the larger intrusions merit further investigation for potential economic concentrations of tin, tantalum and niobium.

The pre-existing workings have been documented in detail with mineralisation recorded in all of the workings. All of the historic Uis workings are of economic interest as the historic SRK report indicates the presence of approximately 90000t of tin was still present in 1987, 3 years before mining activities ceased.

The processing and modelling of the historic information relating to the V1 and V2 pegmatites highlight the emplacement of these bodies as *en echelon* fracture sets. In addition, the data highlighted that the pegmatite bodies widen and intersect at depth enhancing the economic potential of the orebody by reducing the average stripping ratio and increasing the total tonnage.

The cassiterite mineralisation identified within the Uis pegmatites is very coarse with the majority of the grains being greater than 10mm in length. This increases the recoverability and reduces the amount of crushing required to a achieve the required liberation for efficient concentration.

The Uis tin mine was once one of the world's largest, and lowest grade, tin mines. The detailed delineation of the existing orebodies with the incorporation of the surrounding pegmatites into the resource, may result in it one again being one of the worlds largest tin mines.

REFERENCES.

Ashworth, L. 2013. Mineralised pegmatites of the Damara Belt, Namibia. Fluid inclusion and geochemical characteristics with implications of post tectonic mineralisation. Ph.D. thesis, University of the Witwatersrand, Johannesburg.

Diehl, B.T.M. 1993. Rare metal pegmatites of the Cape Cross – Uis pegmatite belt, Namibia: geology, mineralisation, rubidium-strontium characteristics and petrogenesis. *Journal of African Earth Sciences*, **17**, 167-181.

Fuchsloch, W.C., Nex, P.A.M. and Kinnaird, J.A. 2018*a*. Classification, mineralogical and geochemical variations in pegmatites of the Cape Cross – Uis pegmatite belt, Namibia. *Lithos*, **296-299**, 79-95.

Fuchsloch, W.C., Nex, P.A.M. and Kinnaird, J.A. 2018*b*. The geochemical evolution of the Nb-Ta-Sn oxides from pegmatites of the Cape Cross-Uis pegmatite belt, Namibia. *Submitted to Mineral Magazine.*

Gray, D.R., Foster, D.A., Goscombe, B., Passchier, C.W. and Trouw, R.A.J. 2006. $^{40}Ar/^{39}Ar$ thermochronology of the Pan-African Damara Orogen, Namibia, with implications for tectonothermal and geodynamic evolution. *Precambrian Research*, **150**, 49-72.

Kinnaird, J.A. and Nex, P.A.M. 2007. A review of geological controls on uranium mineralisation in sheeted leucogranites within the Damara Orogen, Namibia. Trans I.M.M. *Applied Earth Sciences*, **116(2)**, 68-85.

Longridge, L. 2012. Tectonothermal evolution of the southwestern Central Zone, Damara Belt, Namibia. Ph.D. thesis, University of the Witwatersrand, Johannesburg, 1-524.

Martin, H. and Porada, H. 1977. The intracratonic branch of the Damara Orogen in South West Africa. I. Discussion of geodynamic models. II. Discussion of relationships with the Pan-African Mobile Belt system. *Precambrian Research* **5**, 311 - 338 and 339-357.

Milani, L., Kinnaird, J.A., Lehmann, J., Naydenov, K.V., Saalmann, K., Frei, D. and Gerdes, A. 2015. Role of crustal contribution in the early stage of the Damara Orogen, Namibia: New constraints from combined U-Pb and Lu-Hf isotopes from the Goas Magmatic Complex. *Gondwana Research* **28**, 961-986.

Pirajno, F., and Jacob, R.E. 1987. Sn-W metallogeny in the Damara orogen, South West Africa/Namibia. *South African Journal of Geology* **90(3)**, 239-255.

Miller, R.McG. 2008. Neoproterozoic and early Palaeozoic rocks of the Damara Orogen. *The Geology of Namibia* **2,** 13-1 – 13-410**.**

Richards, T.E. 1986. Geological characteristics of rare-metal pegmatites of the Uis type in the Damara orogen, South West Africa/Namibia. *Mineral Deposits of Southern Africa* **2**, 1845-1862**.**

SRK. 1989. Uis Tin Mine Life-of-Mine Plan for period 1987-2063. *Report Number GC4525/1, Vol 1 of 5*.

Swart, R. 1992. The sedimentology of the Zerrissene turbidite system, Damara Orogen, Namibia. *Memoirs of the Geological Society of Namibia* **13**, 54 pp.

Voges, H.C. 1982. Heavy-medium and gravity separation at Iscor's tin-ore and iron-ore mines. *Journal of the South African Institute of Mining and Metallurgy,* 186-192.

Wagener, G.F. 1989. Systematic variation in the tin content of pegmatites in western central Namibia. *Journal of Geochemical Exploration*, **34**, 1-19.