GEOLOGICAL CHARACTERISTICS OF IRON OXIDE-COPPER-GOLD (IOCG) TYPE MINERALISATION IN THE WESTERN BUSHVELD COMPLEX.

By

John Paul Hunt

A dissertation in fulfilment of the requirements for the degree of

MSc in Geology

University of the Witwatersrand

2005

ABSTRACT

The occurrence of large, massive iron oxide deposits throughout the Bushveld Complex, South Africa, and its associated roof-rocks is well known. The style of mineralisation and the associated alteration exhibits many characteristics of iron oxide-copper-gold (IOCG) type deposits. The contained mineralisation is dominated by iron oxide and fluorite and is accompanied by a diverse polymetallic association, with anomalous fluorite, copper, gold, barite, uranium and LREE.

The Ruigtepoort orebody, located in the western Bushveld Complex, is such an example and is surrounded by some 20 smaller occurrences in the upper stratigraphic portions of the Bushveld Complex, all displaying strong structural control. These IOCG bodies occur as narrow veins, hydrothermal breccias, subhorizontal sheets, or as pipe-like intrusions usually utilising pre-existing structures. Set in red Nebo granite, the mineralised core consists of severely chloritised rock that is haloed by progressively less-altered granite. The alteration passes from the chlorite core to more hematite-phyllosilicate-dominated alteration, to sericite-illite-dominated alteration; followed by the relatively fresh country granite. These alteration haloes dissipate rapidly away from the body over only a few metres. Sodic-calcic alteration described in other IOCG is not locally observed. Extensive zones of barren feldspar-destructive alteration exist, including K-metasomatism, sericitisation and silicification. Multiple alteration episodes appear to have occurred, resulting in extensive overprinting and a very complex paragenesis.

The primary mineral assemblage consists of Fe-chlorite, fluorite, quartz, hematite, and specularite, with accessory pyrite and chalcopyrite. Multiple generations of hematite, quartz, fluorite and chlorite are also observed. At other localities, the assemblage is dominated by magnetite-actinolite-britholite. Significantly enriched concentrations of Au (2 g/t), Cu (0,45 wt%), Ba, Y and LREE are encountered in the small, mineralised core.

A fluid mixing model is proposed characterised by an initial highly-saline, sulphur-poor magmatic fluid which mixed with a lower temperature oxidised, surficial fluid. Structure was probably a significant factor in determining the initial distribution of hydrothermal centres and the overall morphology of the entire system. Subsequently, continuous brecciation, alteration, mineral precipitation and fault activity helped develop the hydrothermal centres into a complex array of variably mineralised, lenticular, pipe-like and irregularly shaped breccia bodies.

DECLARATION

This dissertation is my own unaided work, conducted under the supervision of Prof. Laurence J. Robb. It is being submitted for the degree of Masters of Science in Geology at the University of the Witwatersrand, and has not been previously submitted for any degree or examination at any other university.

John Paul Hunt

ACKNOWLEDGEMENTS

Sincere thanks to Laurence Robb for guidance and support over the duration of this degree, and criticisms and review of this manuscript.

I am grateful to the following people for assisting in discussions, review and the collection of data:

- Judith Kinnaird and Paul Nex for invaluable discussions on the interpretation of the geochemical and petrographical data;
- Rudi Boer for getting me started me on this path by initiating the project;
- Economic Geology Research Institute, Wits, for always keeping the door open and always making a desk available;
- RTX Africa and Ben Joubert for logistical support during the first year of field work and for access to datasets and resources;
- George Sethibelo for tirelessly walking each day whilst mapping;
- Richard Bodkin for reviewing the entire manuscript in spite of not being able to ‘speak’ geology and for pushing me to finish;
- Louis Venter for reviewing the entire manuscript and for questioning everything;
- Martin Klausen for divulging the secrets of fluorine;
- Lynette Greyling for administrative support and coffee breaks;
- ACMS, Jhb, for allowing me to digitally draft my entire map, in spite of my never copying it to disk to use;
- John and Graciela Hunt, and my sisters for never letting me give up and never giving up on me;
- Richard Bodkin, Peter Auret, Chris Pefanis, Kristel Birkholtz, and Chris Volbrecht for standing beside me through it all.

TABLE OF CONTENTS

1. Introduction and Research Overview

2. Geological Setting

3. Local Geology of the Study Area

4. Silicate & Opaque Mineral Petrography

6. Fe-F (Cu-Au-REE) Mineralisation in the Bushveld Granites

7. Discussion on Aspects of Mineralisation of the Bushveld Granites

List of Figures

List of Tables

List of Plates

Plate 3.1. a) Flat, outcrop-poor weathered surface of Bushveld granites in the north, central and eastern portions of the area. b) Low hills and outcrops, often wooded, of the southern and western portions of the area. Fracture related depressions and drainage features tend to be more prominent. c) Rounded-boulder granite outcrop of the southern portion of the area, usually well-vegetated. d) Typical dull-pink perthitic Nebo granite from Blokspruit 157JQ; Sample #ID 11120. e) Grey hornblende-rich Nebo granite representing least differentiated material. Sharp contact with aplitic (Klipkloof) phase. From Paalkraal 556KQ. f) Porphyritic variety Nebo granite from Ruigtepoort 162JQ; Sample #ID 11141.

Plate 3.2. a) Weathered surface of Nebo and Klipkloof granites. Coarse quartz grains in the Nebo granite weather prominently forming a rough, pitted surface; by contrast, the Klipkloof is smooth and even. b) Outcrop of Bobbejaankop granite with characteristic quartz chains weathering prominently. c) Red Nebo granite common throughout the area. The mafic phase is dominantly biotite, which is commonly chloritised. From Blokspruit 157JQ; Sample #ID 11103. d) Bobbejaankop variety Nebo granite from type-locality in the eastern Bushveld e) Klipkloof variety Nebo granite from Ruigtepoort 162JQ.

Plate 3.3. a) Spherulitic rhyolite with greenish nodules from Slipfontein 551KQ; Sample #ID 11194. b) Heavily weathered spherulitic rhyolite from Blokspruit 157JQ; Sample #ID 11153. c) Typical fine-grained red pseudogranophyre from Ruigtepoort 162JQ; Sample #ID 11070. d) Purplish-brown Rooiberg agglomerate from Elandslaagte 154JQ; Sample #ID 11076. e) Yellowish-brown silicified Rooiberg agglomerate with rhyolitic shards, from Elandslaagte 154JQ; Sample #ID 11202.

Plate 3.4. a) Clean, highly-recrystallised meta-quartzitic xenolith consisting of up to 99 % quartz from Elandslaagte 154JQ; Sample #ID 11146. b) Finely-laminated, hematite-rich sediment. c) Massive, fine-grained leptite from Ruigtepoort 162JQ. d) Iron oxide-rich grit of possible Karoo age, from Ruigtepoort 162JQ; Sample #ID 11081.

Plate 3.5. a) Exaggerated reddening of Bobbejaankop granite due to K-metasomatism from Blokspruit 157JQ. K-feldspar grains appear to be annealing. Sample #ID 11105. b) Episyenitic granite where quartz comprises less than 10 % of the rock from Ruigtepoort 162JQ. Sample #ID 11177. c) Myrialitic episyenite with hematite cavity fill and anomalous metal contents from Blokspruit 157JQ. d) Sericitised fine-grained granite from Elandslaagte 154JQ. Sample #ID 11060. e) Intensely sericitised fine-grained granite from Elandslaagte 154JQ. Sample #ID 11201. f) Silicified-sericitised medium-grained granite from Elandslaagte 154JQ with yellow-green colouration. Sample #ID 11145.

Plate 3.6. a) Intensely hematised coarse Nebo granite from Ruigtepoort 162JQ. Sample #ID 11068. b) Intensely and pervasively chloritised medium-grained granite from Doornfontein 155JQ. Late fracture has introduced oxidised iron oxides and caused local overprinting. Sample #ID 11089. c) Alteration front between earlier sericitisation-silicification of fine-grained granite from Blokspruit 154JQ, with later hematite overprint. Hm=hematite, Ser-Sil=sericitised-silicified. Sample #ID 11187. d) Compounded alteration overprinting of early sericitisation by intense hematisation, presumably followed

by intense chloritisation; from Blokspruit 154JQ. Hm=hematite, Ser= sericitised, Chl=chloritised. Sample #ID 11122. e) Coarse granite country rock to the Ruigtepoort fluorspar mine; sample taken approximately 10 m from orebody contact. Intense hematisation developed away from the orebody and overprinted by intense chloritisation developed closer to the orebody. Hm=hematite, Chl=chloritised. Sample #ID 11067. f) Sericitised-silicified actinolite rock overprinted by gossanous hematite from Blokspruit 154JQ. Hm=hematite, Ser-Sil=sericitised-silicified.

Plate 4.1. a) Typical hypersolvus, perthitic granite comprising perthite and quartz. Accessory phases not visible in this photograph. Crossed polars x4; field of view is 2.75 mm wide; Photo ID: 11097-F. b) Typical subsolvus Klipkloof granite with plagioclase needles, indicative of super-cooling. Plane polars x10; field of view is 0.85 mm wide; Photo ID: 11212-B. c) Transsolvus granite as defined by the occurrence of both albite plagioclase and perthite. Crossed polars x4; field of view is 2.75 mm wide; Photo ID: 11103-H. d) Anhedral comagmatic perthite and quartz, with quartz completely enclosing an albite plagioclase grain. Crossed polars x10; field of view is 0.85 mm wide; Photo ID: 11193-G. e) Anhedral perthitic K-feldspar. Plane polars x10; field of view is 0.85 mm wide; Photo ID: 11194-C. f) Anhedral perthitic K-feldspar. Crossed polars x10; field of view is 0.85 mm wide; Photo ID: 11194-D.

Plate 4.2. a) Embayed and resorbed quartz grains intergrown with K-feldspar. Plane polars x4; field of view is 2.75 mm wide; Photo ID: 11121-C. b) Embayed and resorbed quartz grains intergrown with K-feldspar. Crossed polars x4; field of view is 2.75 mm wide; Photo ID: 11049-M. c) Biotite-quartz symplectite. Plane polars x4; field of view is 2.75 mm wide; Photo ID: 11023-K. d) Biotite-quartz symplectite. Plane polars x4; field of view is 2.75 mm wide; Photo ID: 11034-A. e) Cluster of accessory phases including zircons, chloritised biotite, magnetite and other iron oxides. Crossed polars x20; field of view is 0.45 mm wide; Photo ID: 11067-L. f) Interstitial biotite with subsolidus hydrothermal magnetite developed along cleavage planes demonstrating the relationship between K- and Fe- metasomatism. Crossed polars x10; field of view is 0.85 mm wide; Photo ID: 11193-F.

Plate 4.3. a) Granophyric texture of typical granophyre. Crossed polars x4; field of view is 2.75 mm wide; Photo ID: 11102-A. b) Granophyric texture with no discernible nucleation point Crossed polars x4; field of view is 2.75 mm wide; Photo ID: 11102-B. c) Typical massive Rooiberg rhyolite consisting of quartz, feldspar and minor biotite. Plane polars x4; field of view is 2.75 mm wide; Photo ID: 11049-J. d) Coarse pseudogranophyre from Elandslaagte 154JQ. Fine stringy quartz-feldspar symplectic intergrowth nucleating off the side of K-feldspar grain. Crossed polars x4; field of view is 2.75 mm wide; Photo ID: 11058-A. e) Donut graphic texture of pseudogranophyre. Plane polars x10; field of view is 0.85 mm wide; Photo ID: 11213-H. f) Streaky texture of pseudogranophyre. Crossed polars x4; field of view is 2.75 mm wide; Photo ID: 11213-I.

Plate 4.4. a) Spotted texture of pseudogranophyre. Crossed polars x10; field of view is 0.85 mm wide; Photo ID: 11213-E. b) Agglomerate groundmass composed of chalcedonic quartz and sericite. Plane polars x4; field of view is 2.75 mm wide; Photo ID: 11076-E. c) Agglomerate groundmass composed of

chalcedonic quartz and sericite. Crossed polars x4; field of view is 2.75 mm wide; Photo ID: 11076-F. d) Fine needles, altered and obscured by ferrohydroxides, in agglomerate possibly indicative of supercooling. Plane polars x4; field of view is 2.75 mm wide; Photo ID: 11088-A. e) Angular fragment in agglomerate with relict faces of feldspar crystal; completely altered. Plane polars x4; field of view is 2.75 mm wide; Photo ID: 11076-A. f) Subhedral lathlike fragments in agglomerate, presumably feldspar crystals, completely obscured by hematite and other ferrohydroxides. Plane polars x10; field of view is 0.85 mm wide; Photo ID: 11076-G.

Plate 4.5. a) Quartzitic xenolith near granite roof principally composed of mosaic textured quartz, with iron oxides along grain boundaries and microfractures. Plane polars x4; field of view is 2.75 mm wide; Photo ID: 11072-A. b) Quartzitic xenolith near granite roof principally composed of mosaic textured quartz, with iron oxides along grain boundaries and microfractures. Crossed polars x4; field of view is 2.75 mm wide; Photo ID: 11072-B. c) Annealed quartz of sedimentary xenolith. Minor phases include sericite and iron oxides. Plane polars x4; field of view is 2.75 mm wide; Photo ID: 11150-A.

Plate 4.6. a) Fresh yellowish-green ferroactinolite. Plane polars x4; field of view is 2.75 mm wide; Photo ID: 11091-A. b) Colourless to pale green, unaltered actinolite with rounded oxide grains. The brownish phase along grain margins and in fractures may be nontronite. Plane polars x4; field of view is 2.75 mm wide; Photo ID: 11139-D. c) Pervasive chloritisation alteration front over actinolite. Plane polars x4; field of view is 2.75 mm wide; Photo ID: 11139-C. d) Hematite replacement of actinolite. Plane polars x4; field of view is 2.75 mm wide; Photo ID: 11139-F. e) Silica-hematite pseudomorph after actinolite. Plane polars x4; field of view is 2.75 mm wide; Photo ID: 11046-A. f) Yellowish brown Y-britholite. Plane polars x4; field of view is 2.75 mm wide; Photo ID: 11091-E.

Plate 4.7. a) Euhedral magnetite in quartz partially oxidised to hematite. Mt=magnetite, Hm=hematite. Reflected light x50; field of view is 0.16 mm; Photo ID: 11194-N. b) Gossanous iron oxide of hematite with relict magnetite. Mt=magnetite, Hm=hematite. Reflected light x80; field of view is 0.10 mm; Photo ID: 11079-A. c) Specularite flakes from Ruigtepoort contact granite. Reflected light with Plane polars x4; field of view is 2.75 mm; Photo ID: 11067-Q. d) Quartz-hematite vein demonstrating multiple episodes of quartz growth. Plane polars x4; field of view is 2.75 mm; Photo ID: 11074-J. e) Hematite gossan. Rhombic forms may be indicative of primary siderite-magnetite in ore. Reflected light x4; field of view is 2.75 mm; Photo ID: 11055-A. f) Hematite gossan from Elandslaagte 154JQ with pyrite in cores of gossan lattice. Py=pyrite, Hm=hematite. Reflected light x4; field of view is 2.75 mm; Photo ID: 11074-E.

Plate 4.8. a) Hematite gossan. Primary fluorite still contained in some partitions. Hm=hematite, Fl=fluorite. Reflected light x20; field of view is 0.45 mm; Photo ID: 11055-A. b) Multiple growth phases of quartz associated to hematite ores. Plane polars x10; field of view is 0.85 mm; Photo ID: 11143-F. c) Quartz growth terminating in triple junction with hematite in final pore space. Qtz=quartz. Plane polars x4; field of view is 2.75 mm; Photo ID: 11055-H. d) Octahedral growth planes in high temperature fluorite. Plane polars x20; field of

view is 0.45 mm; Photo ID: 11068-G. e) Pseudomorphed quartz after actinolite needles with fine inclusions of hematite. Matrix is quartz. Plane polars x4; field of view is 2.75 mm; Photo ID: 11037-F. f) Pseudomorphed hematite after actinolite with crystalline quartz matrix. Plane polars x4; field of view is 2.75 mm; Photo ID: 11037-C.

Plate 4.9. a) Pseudomorphed quartz after actinolite needles with larger aggregates of hematite. Plane polars x4; field of view is 2.75 mm; Photo ID: 11017-F. b) Chloritised granite with iron oxides developed within perthite and along grain boundaries. Plane polars x10; field of view is 0.85 mm; Photo ID: 11008-P. c) Iron oxides occurring as veins and stringers in actinolite rock. Plane polars x4; field of view is 2.75 mm; Photo ID: 11056-A. d) Granite breccia with hematite fill. Plane polars x4; field of view is 2.75 mm; Photo ID: 11149-B.

Plate 4.10. a) Chlorite-specularite-fluorite ore of Ruigtepoort Mine with fragmented pyrite grains and bright red iron oxides. Reflected with Plane polars x10; field of view is 0.85 mm; Photo ID: 11001-ZG. b) Chlorite and ferrohydroxides after actinolite in radiating growths. Plane polars x20; field of view is 0.45 mm; Photo ID: 11611-D. c) Chlorite groundmass with fluorite and minor sulphides. Black spots are radiation damage around thorium-rich minerals. Reflected with Plane polars x4; field of view is 2.75 mm; Photo ID: 11001-R. d) Iron oxide staining within the chlorite groundmass. Euhedral pyrite grain in bottom field of view with small pyrite grains above. Reflected with Plane polars x80; field of view is 0.10 mm; Photo ID: 11001-ZC. e) Heavily-pitted, euhedral pyrite crystal with pyritohedral habit; predates fluorite and chlorite. Reflected with Plane polars x4; field of view is 2.75 mm; Photo ID: 11001-E. f) Pyritohedral pyrite with chalcopyrite core and small angular fluorite inclusion. Fine exsolution-type lamellae unidentified. Reflected with Plane polars x4; field of view is 2.75 mm; Photo ID: 11001-X.

Plate 4.11. a) Inclusions in pyrite of earlier-formed ore phases magnetite. Reflected x40; field of view is 0.20 mm; Photo ID: 11160-T. b) Inclusions in pyrite of earlier-formed ore phase, possibly ilmenite. Reflected x80; field of view is 0.10 mm; Photo ID: 11160-J. c) Sub-euhedral pyrite enclosed by later-formed fluorite. Reflected with Plane polars x4; field of view is 2.75 mm; Photo ID: 11001-G. d) Pyrite with flame-like chalcopyrite in chlorite-iron oxide groundmass. Reflected with Plane polars x80; field of view is 0.10 mm; Photo ID: 11001-ZF. e) Chalcopyrite with reddish brown alteration/exsolution in pyrite. Reflected with Plane polars x20; field of view is 0.45 mm; Photo ID: 11001-U. f) Fine chalcopyrite and pyrite fragments in coarse fluorite. Reflected with Plane polars x10; field of view is 0.85 mm; Photo ID: 11002-C.

Plate 4.12. a) Multiple growth quartz of sinter. Plane polars x4; field of view is 2.75 mm; Photo ID: 11159-E. b) Mosaic textured epithermal quartz. Crossed polars x4; field of view is 2.75 mm; Photo ID: 11159-D. c) Highly-pitted and fractured pyrite grain. Reflected light x4; field of view is 2.75 mm; Photo ID: 11159-A. d) Highly-fragmented arsenopyrite and pyrite. Reflected light x4; field of view is 2.75 mm; Photo ID: 11159-B. e) Gold grain in quartz 0.01 mm (10 µ) in size. Reflected light x80; field of view is 0.10 mm; Photo ID: 11160-ZT. f) Multiple gold grains in quartz approximately 0.015 mm (15 µ) in length. Reflected light x80; field of view is 0.10 mm; Photo ID: 11001-Y.

Plate 4.13. a) Tightly packed metaquartzitic rock with interstitial hematite. Small quartz grains included in larger grains (centre left) evidence for recrystallisation. Qtz=quartz, Hm=hematite. Crossed polars x4; field of view is 2.75 mm; Photo ID: 11150-D. b) Quartzitic xenolith where 40-50 % of field of view is replacement hematite. Plane polars x4; field of view is 2.75 mm; Photo ID: 11087-C. c) Specularitic hematite replacement in sedimentary xenolith. Reflected light x4; field of view is 2.75 mm; Photo ID: 11150-E. d) High-relief rare earth mineral bastnaesite. Qtz=quartz, FeOx=iron oxide, Bast=bastnaesite. Plane polars x20; field of view is 0.45 mm; Photo ID: 11087-E. e) Sericite clot in sedimentary xenolith. Plane polars x4; field of view is 2.75 mm; Photo ID: 11150-F. f) High birefringence of sericite clot in sedimentary xenolith. Crossed polars x4; field of view is 2.75 mm; Photo ID: 11150-G.

Plate 4.14. a) Deuterically altered, reddened K-feldspar with interstitial symplectic biotite. Plane polars x4; field of view is 2.75 mm; Photo ID: 11023-G. b) Deuteric chloritised symplectic biotite. Plane polars x4; field of view is 2.75 mm; Photo ID: 11023-I. c) Microclinisation of albite feldspar. Crossed polars x4; field of view is 2.75 mm; Photo ID: 11120-D. d) Microclinisation of granite; new K-feldspar growth at the expense of quartz. Plane polars x4; field of view is 2.75 mm; Photo ID: 11004-J. e) Microclinisation of granite; new K-feldspar growth at the expense of quartz. Plane polars x4; field of view is 2.75 mm; Photo ID: 11177-B. f) Growth of secondary biotite related to K-metasomatism; growing at expense of pre-existing feldspar. Crossed polars x4; field of view is 2.75 mm; Photo ID: 11120-H.

Plate 4.15. a) Sericite replacement of perthite K-feldspar. Crossed polars x4; field of view is 2.75 mm; Photo ID: 11125-B. b) Sericitisation of K-feldspar; quartz grains unaffected. Crossed polars x10; field of view is 0.85 mm; Photo ID: 11115-A. c) Near-complete replacement of K-feldspar in intensely altered zone. Crossed polars x4; field of view is 2.75 mm; Photo ID: 11078-D. d) Intensely sericitised K-feldspar exhibiting primary crystal habit; associated quartz and hematite. Crossed polars x4; field of view is 2.75 mm; Photo ID: 11201-E. e) Intensely sericitised granite; biotite replaced by muscovite with magnetite symplectic banding still apparent. Plane polars x10; field of view is 0.85 mm; Photo ID: 11111-D. f) Intense muscovite replacement of feldspars with associated iron oxides, possibly liberated from feldspar with alteration. Crossed polars x4; field of view is 2.75 mm; Photo ID: 11078-F.

Plate 4.16. a) Quartz rim developed around K-feldspar grain likely derived from sericitisation. Abundant iron oxides. Plane polars x4; field of view is 2.75 mm; Photo ID: 11014-G. b) Epithermal sinter of Ruigtepoort mine where a quartz-sulphide assemblage has wholly replaced the original chlorite ore assemblage. Crossed polars x4; field of view is 2.75 mm; Photo ID: 11159-D. c) Intensely chloritised feldspar with iron oxide staining. Plane polars x4; field of view is 2.75 mm; Photo ID: 11066-B. d) Matted chlorite fans. Plane polars x4; field of view is 2.75 mm; Photo ID: 11067-F. e) Chlorite replacing quartz. Plane polars x4; field of view is 2.75 mm; Photo ID: 11059-A. f) Chlorite alteration of ferroactinolite. Plane polars x4; field of view is 2.75 mm; Photo ID: 11139-C.

Plate 4.17. a) Hematisation of chloritised granites adjacent to Ruigtepoort mine; iron oxides distributed along fractures and between grains. Plane polars x20; field of view is 0.45 mm; Photo ID: 11066-E. b) Hematisation alteration front

consisting of fine stringer veins of hematite in fine-grained granite. Left portion of photograph unaltered assemblage. Plane polars x4; field of view is 2.75 mm; Photo ID: 11187-D. c) Iron oxides precipitated along grain boundaries in chloritised granite. Plane polars x10; field of view is 0.85 mm; Photo ID: 11008-P. d) Iron oxides precipitated along grain boundaries. Plane polars x10; field of view is 0.85 mm; Photo ID: 11008-Q. e) Hematite precipitated in a patchwork pattern in coarse Bobbejaankop granite. Plane polars x4; field of view is 2.75 mm; Photo ID: 11068-C. f) Bands of hematite in intensely sericitised feldspar; may be consequence of iron liberation during alteration. Plane polars x4; field of view is 2.75 mm; Photo ID: 11082-A.

Plate 6.1. a) Defunct Ruigtepoort Fluorite Mine 100 m long by 40 m wide; person in blue for scale. b) Contact between Bobbejaankop granite country rock and Ruigtepoort Mine ore body. The granites to the left of the contact are chlorite altered nearest the contact, grading into pervasive hematite alteration, grading to common deuterically altered granite. The contact is steeply dipping (~80°), with numerous parallel fractures, and strikes N-S. FeOx=iron oxide, Chl=chlorite. c) Chlorite rock of the Ruigtepoort ore zone, consists of chlorite, fluorite with minor sulphides and quartz; here with large euhedral fluorite and abundant sulphides. The sulphides visible in the photograph are dominated by pyrite with minor chalcopyrite; Chl=chlorite, Py=pyrite, Fl=fluorite. Sample #ID 11215. d) Chlorite rock with milky quartz and chalcopyrite in abundance, oxidised to bornite and covellite. Chl=chlorite, Cp=chalcopyrite, Bn=bornite, Cv=covellite, Qtz=quartz. e) Kaolinite and halloysite associated with the chlorite rock is likely an alteration product after actinolite. f) Vermiform quartz chains in the chlorite rock.

Plate 6.2. a) Specularitic hematite with milky quartz and occasional prismatic quartz crystals, and abundant iron oxides; Sample #ID 11013. b) Hematite-chlorite altered country granite with specularitic vein. Hm=hematite, Chl=chlorite, Spu=specularite. c) Chlorite alteration overprinting earlier hematite alteration of country granite, where the chlorite alteration exists closest to ore body. The hematite alteration will grade into fresh country rock over a few 10’s of metres; Hm=hematite, Chl=chlorite. Sample #ID 11067. d) Sectioned country granite near Ruigtepoort mine; quartz chains and deep red colour indicative of Bobbejaankop variety and suggest close proximity to intrusion roof. Chlorite developed along fine fracture in rock; Sample #ID 11089. e) Contact between altered country granite and chlorite rock ore zone. Granite altered to chlorite and sericite; Sample #ID 11004. f) Contact between chlorite rock and high-sulphidation quartz-pyrite-arsenopyrite sinter with conspicuous dividing oxidation front. Qtz=quartz, Py=pyrite.

Plate 6.3. a) Quartz-pyrite-arsenopyrite sinter. Sulphides pseudomorph after actinolite blades with milky vein quartz filling pore spaces; Qtz=quartz, Flu=fluorite, Py + Apy=pyrite + arsenopyrite Sample #ID 11159. b) Quartz-pyrite-arsenopyrite sinter. Minor late generation purple and colourless fluorite; Sample #ID 11159. c) Hand specimen of scoria-like material from Ruigtepoort mine, composed of abundant iron oxides and quartz. d) Scoria-like material in section showing gossanous hematite, limonite and other iron oxides and brecciated vein quartz fragments. FeOx=iron oxide, Hm=hematite, Qtz=quartz. e) Specularite-quartz vein in Bobbejaankop granite, near Ruigtepoort mine;

Sample #ID 11181. f) Hydrothermal granite breccia with hematite-magnetite-quartz vein fill. Granite clasts affected by sericite alteration; Sample #ID 11178.

Plate 6.4. a) Hematite-quartz-fluorite vein-fill of brecciated quartz blocks. b) Flat-lying manto-shaped orebody with pegmatite sill base. c) Sericite-epidote altered granite near mineralised aplitic dykes; Sample #ID 11015. d) Gossan of hematite quartz and minor sulphides; Sample #ID 11217. e) Brecciated vein quartz with hematite-quartz-fluorite-sulphide vein fill. f) Siderite-magnetite ore in breccia vein fill; Sample #ID 11216. g) Coarse molybdenite flakes in pegmatitic quartz.

Plate 6.5. a) Example of hematite-quartz pseudomorphed actinolite crystals with fluorite filling the residual vug. Fl=fluorite. b) Actinolite blades range in size from less than 1 cm to in excess of 10 cm. c) Actinolite rock in outcrop from the Ysterkop North prospect. d) Fresh ferroactinolite blades from Ysterkop North with pink britholite euhedral. In weathered examples the ferroactinolite may alter to lime-green nontrite and the britholite to goethite (Crocker *et al*., 2001); Act=actinolite, Brith=britholite. Sample #ID 11091. e) Mega-breccia of sub-rounded and angular granite blocks set in dissaciated ferroactinolite matrix, from Ysterkop North. f) Mega-breccia from Ysterkop North of granite blocks in ferroactinolite matrix. Field of view approximately 4 m.

Plate 6.6. a) Massive hematite with intermingled white adularia, from Blokspruit 157JQ. b) Black hematite veining in fine-grained granite episyenite, the granite taking a deep red to purplish hue; Sample #ID 11057. c) Hematite infilling pore-spaces of granite episyenite. Fe_2O_3 now accounts for 26 wt% of bulk rock; Sample #ID 11053.

Plate 6.7. a) Hydrothermal granite breccia with hematite-quartz fracture fill associated with several mineralised occurrences on Elandslaagte 154JQ; Sample #ID 11147. b) Siliceous host rock to hematite-REE mineralisation, possibly bastnaesite-bearing; from Elandslaagte 154JQ; Sample #ID 11150. c) Siliceous host rock with abundant purplish hematite and fine specularite; Sample #ID 11152. d) White, crystalline quartzitic xenolith found in association with centres of hydrothermal activity; Sample #ID 11146. e) Intensely sericite-epidote altered granite country host rock; Sample #ID 11145. f) Massive hematite-quartz veins; Sample #ID 11079.

Plate 6.8. a) Chlorite-altered granite from Doornfontein 155JQ; Sample #ID 11085. b) Breccia of gossanous hematite after amphibole and chalcedonic quartz; Sample #ID 11073. c) Intense kaolinitisation of granite country rocks in immediate vicinity to mineralisation; Sample #ID 11083. d) Hydrothermal breccia with fragments of hematite-quartz gossan and granitic rocks; Sample #ID 11203.