

THE VERGENOEG FAYALITE IRON OXIDE FLUORITE DEPOSIT, SOUTH AFRICA: SOME NEW ASPECTS.

Petrus J Fourie

Vergenoeg Mining Company (Pty) Ltd.
Private Bag X202
Pienaars River 0420
Republic of South Africa
e-mail: vergenoeg@yebo.co.za

Abstract - Felsic rocks of the Rooiberg Group, which constitutes the roof of the Bushveld Complex, host the discordant volcanic pipe and associated surrounding pyroclastic and sedimentary rocks, called the Vergenoeg suite. The volcanic pipe is situated at the crossing of strong aerial photo and magnetic lineaments, about in the centre of the four lobes of the Bushveld Complex in the Republic of South Africa.

The Vergenoeg suite constitutes of an uppermost stratiform sedimentary unit, followed by fragmental conformably stratified hematite and hematite-fluorite units. This is followed by a breccia agglomerate and then a basal unit of ignimbrites. A discordant volcanic pipe completes the suite. The Vergenoeg volcanic pipe has a vertical funnel-like shape. At the surface this is about 900 m in diameter, tapering sharply in depth to where it is still open-ended at more than 650 m. Horizontal zoning exists in the pipe, with a hematite-fluorite or gossan cap at surface, followed by a deeper zone of unoxidised magnetite-fluorite, then a magnetite-fayalite transition zone and finally a fayalite zone at the deepest levels. Fluorite, siderite and pyrite veins, dykes and lenses are present throughout all the zones. Contacts between zones are gradual but are sharp with the felsic host rock. Felsite breccias, cemented by fluorite, siderite and pyrite are found at depths. Although iron oxide, fluorite and fayalite assemblages constitute 90% of the mineral content, accessory siderite, iron-sulphides and Rare Earth Elements (REE) are common. The occurrence of most base metals, and in certain areas uranium and thorium, are anomalous. Fluorite and iron oxides are present in variable quantities throughout the pipe but fluorite decreases with depth, with resultant increases in iron oxides and fayalite. Fluorite occurs in a massive as well as disseminated form. The fluorite ore body is essentially up to a depth of 360 m with a resource estimate of 174 mt at 28.1% CaF₂. The iron resource is in the order of 195 mt at 42% Fe.

Petrogenetically, this rock suite relates to the felsic rocks of the Bushveld Complex, which are regarded as the source of mineralisation. This is in accordance with the family of iron oxide copper-gold type deposits, which are mostly related to granites. Other features that Vergenoeg has in common with the related deposits are massive iron oxide mineralisation, often associated with breccias, and anomalous sulphides and REE mineralisation. Hydrothermal alterations are also distinctive.

The major hypotheses regarding the origin of the Vergenoeg suite is firstly separation of an immiscible liquid from a magma cell, and secondly, magmatic hydrothermal alterations, both related to the felsic rocks of the Bushveld Complex. Mineralised breccias, agglomerates and ignimbrites further suggest violent explosive volcanism.

Introduction

Vergenoeg Mining Company (Pty) Limited (Vergenoeg) is a company that mines and processes fluorite ore to produce acid grade fluorite concentrate for sale into the export markets. Vergenoeg is owned by both Metorex Limited (70%) and the Spanish company, Minerales Y Productos Derivados SA (Minersa) (30%). Metorex is a highly successful medium sized South African mining company listed on the South African and London stock exchanges.

Minersa is a leading European fluorite producer and consumer. Both are diversified in various mining and chemical sectors.

Vergenoeg is located on the remainder of the farm Kromdraai 209 JR, approximately 65 km north of Pretoria, in the Northern Province of the Republic of South Africa (Fig. 1). The mine is fully self-contained, with housing, the processing plant, workshops, laboratory, clinic and other amenities situated on the mine property.

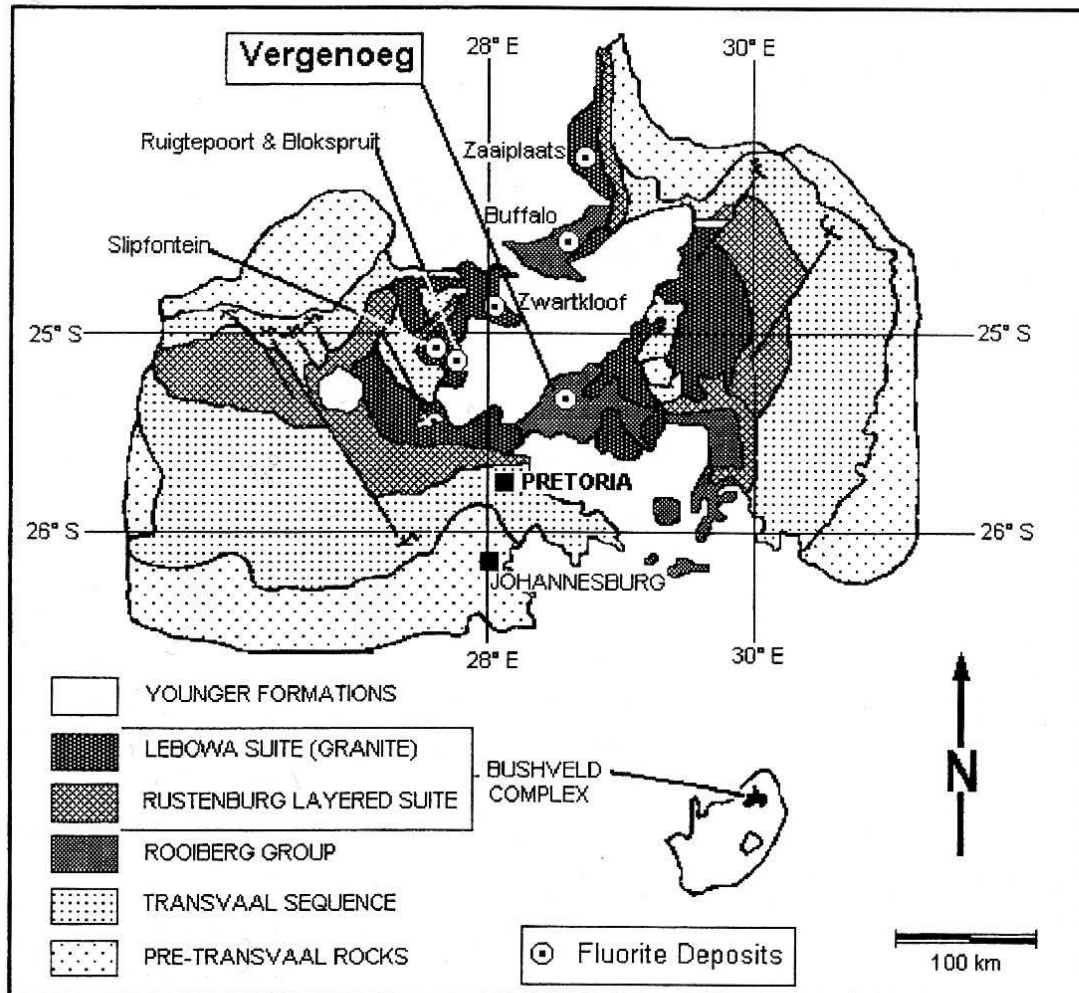


Figure 1. Location and regional geological setting of Vergenoeg in relation to the Bushveld Complex and other fluorite deposits in South Africa. (modified from Borrok et al., 1998).

Mining is by means of conventional opencast methods while processing is by means of crushing, milling, a flotation circuit and final filtration. Processing is at a rate of about 500 000 tons of hematite-fluorite ore per annum at a feed grade of 38% CaF_2 . This results in the production of close to 120 000 tons of acid grade fluorite concentrate per annum. Various improvements are currently underway to optimise the performance of the mine, which will result in an increase in the recoveries as well as the quality of the final product.

The deposit ranks as one of the largest single fluorite deposits in the world. The ore resource is currently defined as indicated, and constitutes, at a cut off grade of 10%, in excess of 174 mt at 28.1% CaF_2 . At the present rate of production, mining will continue for a number of centuries. The Iron resource is in the order of 195 mt at 42% Fe (ISCOR, 1999).

Fluorite and iron oxide mineralisation in this area was first reported by Wagner (1928). Glathaar (1956) re-mapped the area and discovered more fluorite and iron deposits at that time. He described the pyroclastic rocks, fluorite and iron mineralisation and proposed a lithological order in the area. The mining of fluorite only commenced in 1956 when Vergenoeg Mining Company was formed. Initially there was selective mining of some of the massive fluorite bodies

in the greater ore body, producing metallurgical grade fluorite. Behr (1964) then did a geological survey of the area and a detailed description of the iron deposits for the Dunswart Iron and Steel Works.

During 1973 to 1974, De Bruijn (1974) mapped the area and named the pyroclastic suite in the area as the Rust de Winter pyroclastic suite. SACS (The South African Committee for Stratigraphy, 1980) and Walraven (1981) defined the associated sediments of the pyroclastics as the Rust de Winter Formation, omitting the pyroclastic rocks. Crocker (1985), for obvious reasons, introduced then the informal name of the Vergenoeg rock suite, encompassing the volcanic pipe, all the pyroclastics rocks, associated hematite-fluorite ores and the sedimentary rocks.

Crocker (1979, 1985 and 1988) investigated and then described the Vergenoeg rock assemblages and associated ore deposits extensively in various publications. These are currently recognised as the authoritative publications on fluorite deposits in South Africa. At the same time, a few diamond boreholes were drilled by the then Geological Survey of South Africa. One borehole (No. V6), sited at the deepest point indicated by a gravity survey, entered a diabase dyke at 612 m and was stopped at a depth of 730m, still in the dyke. This borehole was also radiometrically logged during 1982 and a confidential report produced by

Anderson and Roets (1983), both from the then Nuclear Development Corporation of South Africa. Palmer (1979) conducted a detailed gravity and self-potential survey across the northern flank of the Vergenoeg ore body. This was followed by an extended gravity survey by Stettler and Stigter (1980) across the entire volcanic pipe, and subsequent delineation of the pipe and ore body.

The deposits were examined by several concerns with a view to recovering the iron minerals, and during 1980 to 1982 some 200 000 tons of hematite ore was mined.

In the period from 1956 up to 1996 some 246 exploratory percussion holes was drilled by Vergenoeg Mining Company while The Iron and Steel Corporation of South Africa (ISCOR) completed a drilling program on the massive hematite deposits during 1982, and then conducted a comprehensive exploration program in the area during 1994 to 1999. This included about 50 diamond boreholes and 8 percussion boreholes in and around the Vergenoeg ore bodies. Some applicable but non-confidential information from ISCOR appears in this paper.

Regional Setting

General

The discordant Vergenoeg volcanic pipe and associated pyroclastic and sedimentary rocks are hosted by the massive red rhyolites of the Selonsrivier Formation of the Rooiberg Group. The pipe is situated centrally between the four lobes of the world renowned Bushveld Complex, Republic of South Africa (Fig. 1).

The Rooiberg Group consists of porphyritic amygdaloidal and rhyolitic lavas and includes part of the lower Damwal

Formation and the involved upper Selonsrivier Formation. U-Pb analyses of zircons indicate an age of 2.06 Ga for Rooiberg volcanism (Walraven and Hattingh, 1993). The Bushveld Complex consists of the mafic Rustenburg Layered Suite and the felsic and later Lebowa Suite, both of which were injected into the Rooiberg Group and other surrounding rock suites, the ages of which are 2.058 to 2.049 Ga and 2.01 to 1.67 Ga respectively (Borrok et al. 1998).

The Wilgerivier Formation of the Waterberg Group, which consists of a thick sequence of red to red-brown clastic sediments, lies to the east of Vergenoeg. An intercalated rhyolite flow within the Wilgerivier Formation has been dated as 1.790 ± 0.070 Ga (Crocker, 1985). It is generally believed that the Vergenoeg deposits are older than this and were once covered by the Waterberg Group. The age of the Vergenoeg suite is estimated at 1.950 Ga.

Structural Geology

The Bushveld Complex is crossed by faults (i.e. Steelpoort fault) and strong lineaments of varying ages. Strong parallel lineaments, faults and fracture zones, both local and regional with no obvious displacements, are common near Vergenoeg (Fig. 2). These lineaments display dominantly north-westerly and to a lesser extent, north-easterly trends. The Vergenoeg volcanic pipe (ore body) is situated at the crossing of two strong lineaments and the location might have been controlled by such structures.

The Vergenoeg volcanic pipe is clearly recognisable on both regional aero magnetic and regional airborne radiometric surveys performed by various concerns, some of which are confidential. Exceptional large anomalies are present over the ore body. This was also mentioned and described in more detail by Crocker (1985) and Palmer (1979).

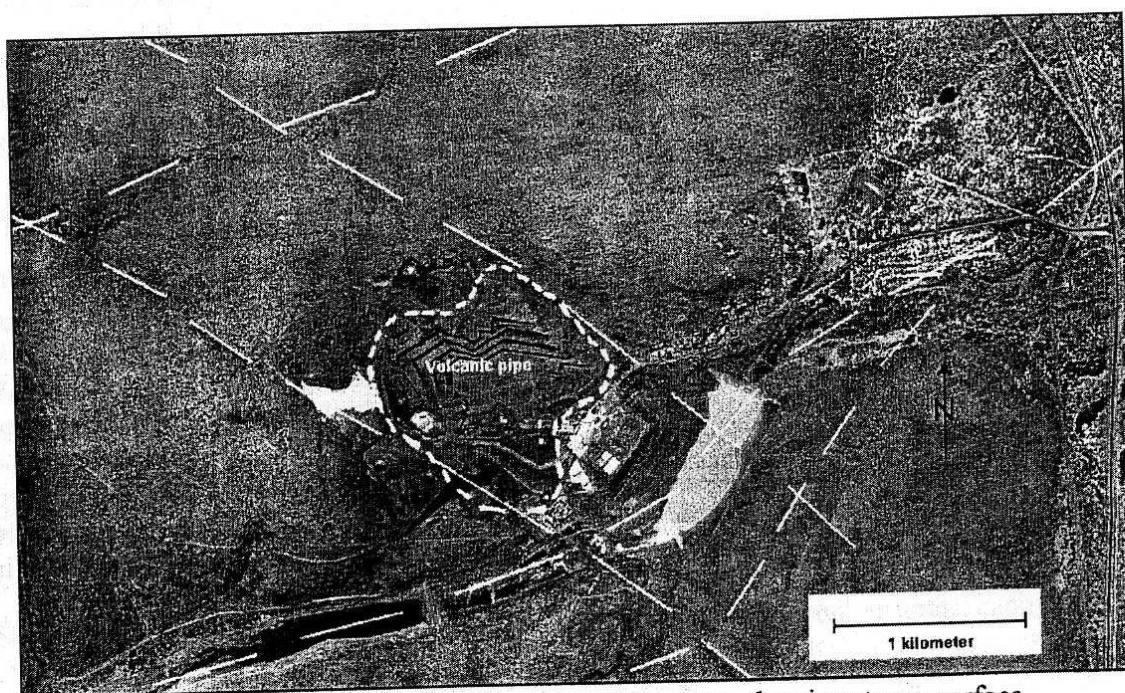


Figure 2. Aerial photograph of the Vergenoeg Mine area, showing strong surface lineaments in relation to the volcanic pipe.

Although the strong lineaments (both magnetic, radiometric and aerial photography) suggest sizeable dykes, as was also mentioned by Crocker (1985), no dykes of any kind have been recognised on the surface in the area. However, two well defined steeply dipping dyke-like bodies with the mineralogical composition similar to diabase and/or dolerite were intersected in some boreholes (Fig. 4). Both these bodies consist of plagioclase, olivine and clinopyroxene in about equal quantities with accessory biotite and opaque ore minerals. The smaller dyke cuts through all rock types in the volcanic pipe, and is obviously younger but the relationship between the diabase dyke (?) and the volcanic pipe is not yet clear. The sharp contacts, chill zones and very little alteration of the dyke suggests that it also post dates the volcanic pipe, although both these dykes are confined only to in, or immediately adjacent to the volcanic pipe. No boreholes passed entirely through the diabase, leaving in doubt the extent in depth. Drilling of the deepest hole was stopped after about 103 m into the diabase without the drill passing through the bottom contact.

Local Geology

General

The Vergenoeg rock suite is an informal name suggested by Crocker (1985) to describe the discordant vertical volcanic pipe and associated suite of volcano genetically derived pyroclastics and sedimentary rocks, which occur on the farms Kromdraai 207 JR and Naauwpoort 208 JR (Fig. 3). This rock suite is hosted by the rhyolites of the Selonsrivier Formation of the Rooiberg Group (Crocker, 1985), which are considered as the roof of the intrusive Bushveld Complex. A simplified and modified stratigraphic succession of the Vergenoeg suite, based on lithology and field relationships, and modified after Crocker (1985), is depicted in Table 1.

The relative distribution of these stratigraphic units is indicated in Fig. 3. The purpose of this paper is to concentrate on the discordant volcanic pipe and associated conformably stratified hematite and hematite-fluorite units, which form the fluorite and iron deposits.

Sedimentary unit

This alluvial unit encompasses stratiform banded iron formation and associated shale and conglomerates, occurring in particular on the farm Naauwpoort, and described by Crocker (1985) as a sedimentary outwash fan deposit. Crocker (1985) included the above in the Vergenoeg suite because they consist entirely of fragmental pyroclastic rock detritus, formed by the erosion of the pyroclastic rocks. This unit is capped by the banded iron formation and is described as the terminal phase of the Vergenoeg suite (Crocker, 1985). The banded iron formation consists of thin interbedded hematite and chert beds, displaying minor cross bedding, ripple marks, mud cracks and dewatering slump structures, and formed undoubtedly in shallow water (Crocker, 1985).

Small isolated layers and pockets of ferruginous sandstones

and conglomerates, capping some of the massive hematite bodies, occur in and near the discordant Vergenoeg volcanic pipe (Fig. 3). The sub angular to sub rounded clasts, imbedded in fine to medium sand, consists mainly of hematite (partly altered to goethite), felsite and subsidiary hematite-fluorite. Some fine grained quartz clasts, and occasional aggregates of two or three quartz grains, are present. Preservation of cubic and octahedral crystal faces in many hematite grains, although rounded at the corners, indicates primary magnetite. These rocks are viewed as erosion remnants of the Vergenoeg volcanic cone.

Hematite units

A number of small fragmental lens-shaped, concordant massive, grey and specularitic hematite bodies, interstratified with felsite and concordant hematite-fluorite bodies, occur within the pyroclastic sequence. The larger of these bodies occurs north of the volcanic pipe (Northern High Grade, Fig. 3) and contains up to 90% Fe_2O_3 , with little fluorite. Outcrops of several smaller bodies of various grades are scattered near the pipe (Fig. 3), all hosted by felsites and often accompanied by small hematite fluorite bodies and lenses, of which the relationship is not clear. A few larger massive hematite bodies are found about 3 km south of the pipe at The Nek (Fig. 3). Hematite layers, hosted by felsite and/or hematite fluorite, were also encountered in boreholes up to 30 m from the surface in and adjacent to the pipe. Crocker (1985) also described inter bedded massive black hematite sheets hosted by hematite-fluorite, in the Plattekop "froth-flow, channel lag" hematite-fluorite deposit (Fig. 3), and which he described as "tuff beds".

Hematite-fluorite unit

A number of irregular concordant hematite-fluorite sheets and small bodies are scattered around the volcanic pipe (Fig. 3). The author views these concordant bodies and lenses as spill over remnants of lava and pyroclastics. The largest of these is the Plattekop deposit, located about 1000 m south of the volcanic pipe, and this covers an area of about 800 m², is 20 m thick, and dips 10° southeast. The Plattekop deposit consists of red to greyish massive hematite containing phenocrysts of predominantly euhedral fluorite crystals. At first glance, the angularity of the euhedral fluorite crystals suggests a fragmental (breccia) texture, but the author is of the opinion that this brecciated texture is only because of the angular crystal faces of fluorite. The fluorite content is about 40%, with about 10% quartz and the balance iron oxides (mainly hematite). Bedding is present in many places caused by a concentration of fluorite crystals. The lack of expected volcanic and lava textures/structures is conspicuous.

In some boreholes near the volcanic pipe, inter layering of hematite-fluorite with felsites was observed; while in other boreholes inter layering with massive hematite occurs. Thus there is proof of an inter relationship.

Borrok et al. (1998) mentioned the thickness of this conformable stratified unit as approximately 10 m near the

Stratigraphic units	Maximum thickness (metres)	Constituent rock type	Structural and textural properties	
Wilgerivier Formation		Sandstone and conglomerate	Once covered the Vergenoeg suite	Waterberg Group
Sedimentary unit	10	Ferruginous conglomerates, grits, banded iron formations and chert.	Rounded hematite, felsitic and fluorite clasts in ferruginous matrix, cross bedding, ripple marks and mud cracks in places	Vergenoeg Suite
Conformably stratified hematite fluorite and hematite units	20		Hematite and fluorite	
Breccia agglomerate unit	40	Predominantly felsic and rhyolitic pyroclasts in hematite matrix	Fines enriched and fines depleted facies	
Ignimbrites	60	Predominantly felsic tuffs, ferruginous in places	White, black and multi coloured glassy tuffs	
Discordant volcanic pipe (Vergenoeg volcanic pipe)	Deeper than 650 meter	Hematite-fluorite, Magnetite-fluorite, Magnetite-fayalite- and fayalite zones	Horizontally zoned, including sideritic, fluoritic and pyritic zones	
Selonsrivier Formation	3000 to 5000	Felsites	Massive and flow-banded	Rooiberg Group

Table 1. Stratigraphic succession of the Vergenoeg suite showing the different rock units (modified from Crocker, 1985).

volcanic pipe to approximately 3 m some 750 m south of the pipe. In contrast, thin layers of this unit were observed in borehole core near the pipe.

Breccia agglomerate unit

Layers of extrusive volcanic breccia and agglomerate, interlayered with tuff, occur on most of the higher hills immediately adjacent to the volcanic pipe (Fig. 3). Crocker (1985) described this unit as the top of the volcanogenetic pyroclastic suite, but the author is of the opinion that this unit pre-dates most of the fluorite rich units. Volcanic breccias and agglomerate lenses, hosted by felsite, and

overlain by hematite and hematite-fluorite layers, were observed in various boreholes.

These undifferentiated breccias and agglomerates consist of predominantly felsic clasts, angular to well rounded in a matrix of fine ferruginous and hematite tuff. Felsic clasts cemented by felsic tuffs, were also observed in some places. The proportion of clasts to matrix may vary, but the clasts are generally matrix supported. The sizes of clasts ranges from <1 mm to 50 cm. Clasts are usually strongly zoned because of reaction with the matrix. The matrix consists of angular felsic fragments <0.2 mm in size down to <0.02 mm and massive hematite. Accessory quartz, quartz

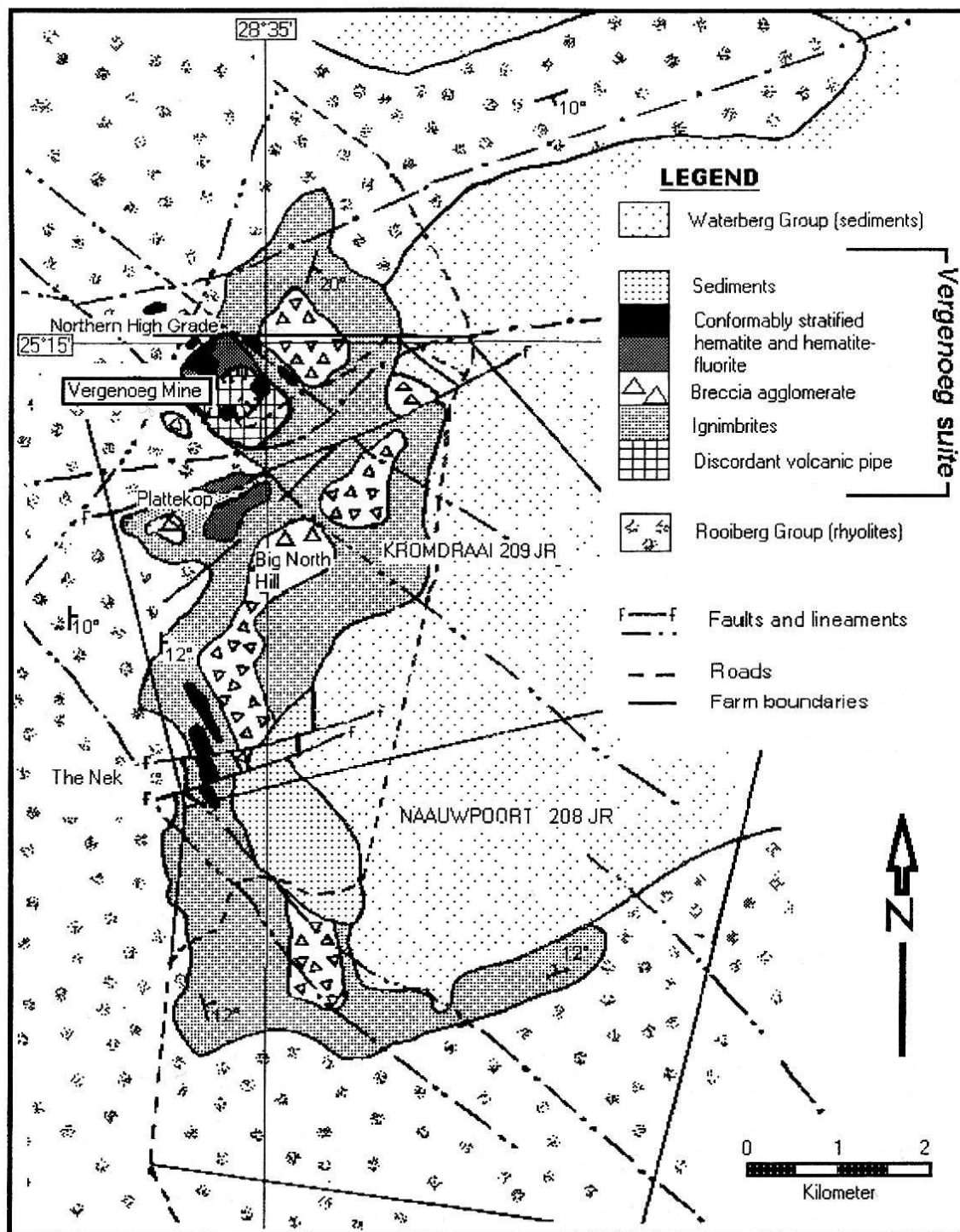


Figure 3. Distribution of the lithological units of the Vergenoeg suite (modified from Crocker, 1985).

aggregates, and amphibole are also present.

The thickness of this unit may be up to 40 m and areas with high iron content can be classified as low-grade siliceous iron ore (Crocker, 1985).

Ignimbrite unit

This unit forms the basal part (Fig. 3) and consists of siliceous fines depleted welded agglomerate, varying laterally into a facies-equivalent, fines-enriched tuff. This rock forms white outcrops above the brown flow-banded Selonsrivier Formation rhyolites (Crocker, 1985) and are generally refer to as felsites.

Vergenoeg Volcanic Pipe

Size, shape and contacts

The Vergenoeg volcanic pipe was formed about 1.950 Ga years ago when a violent gas-vapour volcanic eruption occurred. Crocker (1985) genetically relates this volcanic pipe to the granites of the Bushveld Complex, in particular the Bobbejaankop granite (Fig. 1), despite its absence in the immediate vicinity of the pipe. The iron oxide fluorite ore body itself occupies the volcanic vent and has a vertical funnel-like shape, about 900 m in diameter at surface, tapering sharply in depth, but is still open-ended at about

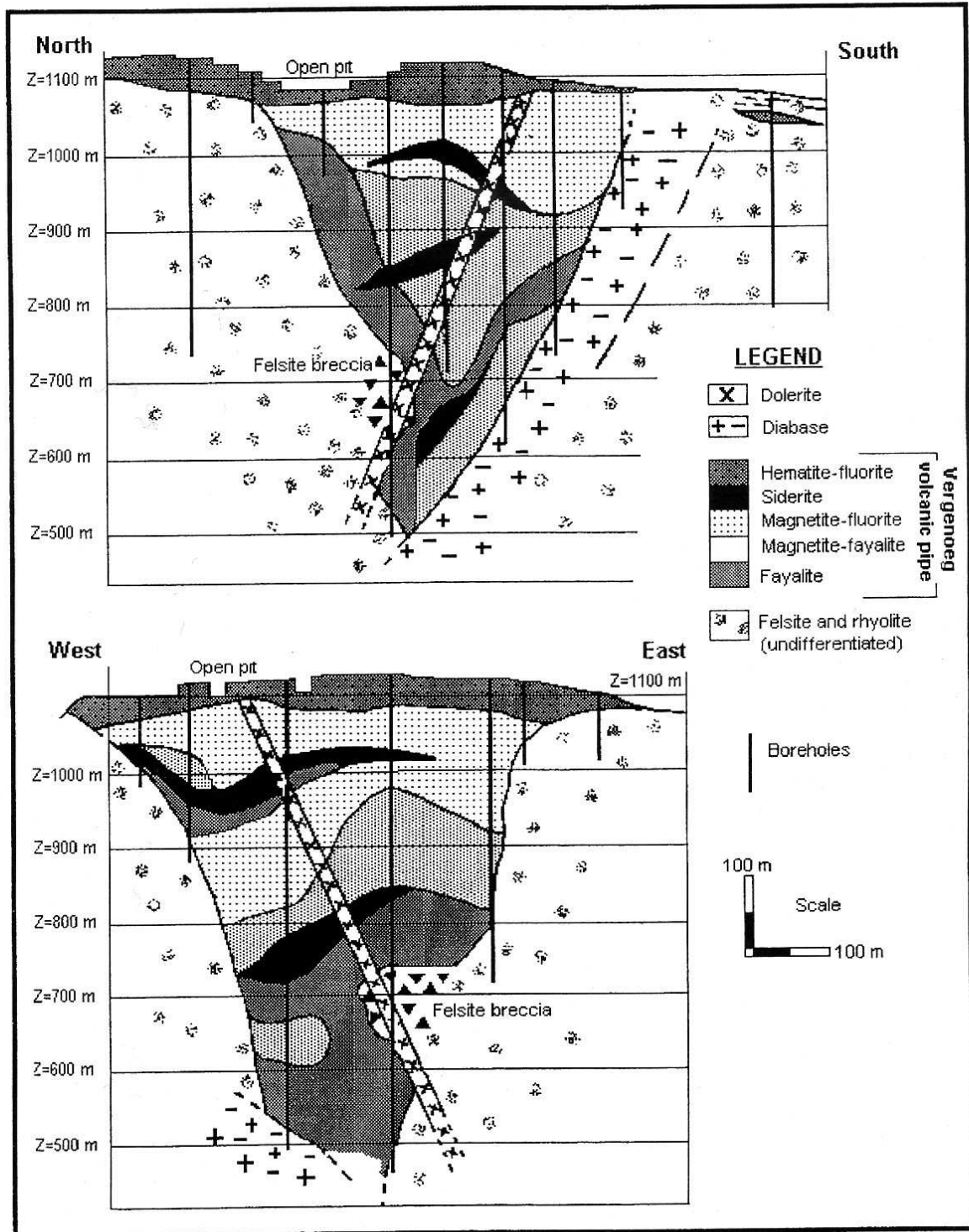


Figure 4. Cross sections through the Vergenoeg volcanic pipe showing the different lithological units and horizontal zoning.

650 m, which is the depth of the deepest borehole (Fig. 4). On the surface, a fragmental hematite-fluorite spill over cap, resting on felsites and ignimbrites, completes the pipe. Rooiberg rhyolites, which form the host rock, and stratiform bodies of basal felsite, ignimbrites, breccia agglomerates and tuffs surround this vertical discordant body.

Contacts between the ferruginous volcanic pipe and surrounding felsic wall rocks are generally sharp. Alterations to the adjacent felsitic rocks are surprisingly small. Iron oxide (hematite) veins and stringers in the wall rock with resultant slight reddish brown staining and discoloration across the contacts are common. Felsite

breccias, cemented by fluorite, siderite and a pyritic matrix were observed at depth in some of the boreholes (Fig. 4).

The shape of the ore body was defined by geophysical methods, in particular a gravity survey, surface mapping and borehole information.

Mineralisation

Although hematite-fluorite, magnetite-fluorite and magnetite-fayalite assemblages make up over 90% of the mineralogical composition, more than 40 separate minerals have been identified, of which most are iron oxides and

hydroxides. Accessory minerals are apatite, monazite, xenotime, and iron and copper-sulphide minerals. Patchy weathered zones with limonitic minerals (i.e. goethite) are common, particularly near the water table. Purple fluorite with higher phosphate contents indicates the presence of monazite, xenotime and fluorocerite, with resultant anomalies in uranium, thorium and rare earth elements.

Borrok et al. (1998) distinguished between two stages of mineralisation. The early-stage minerals are interpreted to represent the primary assemblages that made up the pipe when it formed, and later alteration minerals that represent secondary assemblages, which formed by alteration of the primary assemblages. These secondary alteration minerals comprise about 80 % of the total minerals while magnetite comprises about 40 % of this assemblage at Vergenoeg. Borrok et al. (1998) further distinguished between an early secondary and a late secondary assemblage. The primary assemblage dominates the lower part of the pipe and the secondary (alteration) assemblages dominate the upper part of the pipe. Suggested primary assemblage minerals are fayalite, ilmenite, titanium magnetite, fluorite and REE minerals. Main secondary assemblage minerals are magnetite, titanium magnetite, siderite, quartz, apatite, sulphides, and REE minerals. Hematite is a late alteration product. Although not all of these minerals have been recognised by the author, the premise by Borrok et al. (1998) is generally confirmed by field relationships and observations of borehole core in the pipe.

Fluorite is present in variable quantities throughout the pipe but the content decreases with depth, with a resultant increase in the iron content (mainly magnetite and fayalite). Fluorite occurs in both massive and disseminated form. The fluorite ore body is essentially up to a depth of approximately 360 m, although mineralisation is present in uneconomic quantities deeper down. Irregular vertical bodies of exceptionally high concentrations of massive fluorite, (and which were selectively mined as metallurgical grade fluorite in the past), is present in the open pit. Vertical transgressive fluorite dykes and veins (some being more than 1 m in width) roughly radiate from these massive fluorite bodies. Fluorite is not restricted to the pipe alone, but sometimes occurs as veins and pods in the adjacent wall rock of felsites. In this case, the fluorite then forms (together with siderite, pyrite, accessory magnetite and base metal sulphides) the matrix in brecciated felsites and rhyolites.

Crackle brecciated fluorite bodies are present in certain areas. The texture is typical cataclastic, consisting of large angular crystals of fluorite in a matrix of finer grained fluorite, siderite, pyrite, quartz, reddish brown goethite and limonite with relict hematite. This breccia gives the appearance of having formed by the intrusion of a coarsely crystalline mass of fluorite with very little fluid and a resultant grinding of grains against each other as the mass moved.

Siderite is common in all rock types and at all depths, occurring mainly as veinlets and stringers cutting through all other older rocks. Large lateral bodies, 20 m thick and

up to 200 m in length, occur at varying depths mainly in the centre of the pipe (Fig. 4). Siderite forms the main mineral (up to about 90%) in the lateral bodies with accessory fluorite, hematite, magnetite and quartz.

Magnetite is present in variable proportions throughout the pipe. Borrok et al. (1998) identified mainly magnetite, ilmenite and titanium magnetite in the deeper part of the Vergenoeg pipe. This was substantiated with Electron Microprobe Analysis. Borrok et al. (1998) described ilmenite as primary, and magnetite and titanium magnetite as secondary replacement mineral assemblages. The author did not observe ilmenite or titanium magnetite.

A plug like body of massive magnetite, surrounded by a mixed zone of pyrite and fluorite, occurs centrally in the pipe (Fig. 3). This body is also associated with a crackle breccia fluorite zone, although it is unsure if the fluorite crackle breccia encircles the magnetite. The vertical extent of this plug unknown.

Hematite is present in the upper part of the pipe, particularly in the first about 50 m from the surface where it was formed, together with goethite, as an oxidation replacement product of the deeper-seated magnetite, fayalite, pyrite, siderite and other minerals.

Goethite is present in the first 50 m from the surface, and particularly in and along fracture zones and cavities in the pipe. In certain areas, particularly in weathered areas and near the water table, goethite and yellow limonitic iron hydroxides, together with fluorite, form the dominant minerals. Goethite occurs in a massive form as the groundmass for iron oxides and as coarse grained concentrically banded radial spheroidal masses. The mineral is also very common as inclusions in fluorite and along cleavage plains and in intergranular spaces.

Fayalite occurs mainly at lower levels and forms the deepest zone of the volcanic pipe (Fig. 4). Both primary and secondary fayalite is present (ISCOR, 1999 and Borrok et al., 1998). Fayalite is described in more detail with the lithology of the zones in the pipe.

Pyrite and pyrrhotite are the commonest sulphide minerals and may account for up to 60 % of the volume of some rocks assemblages. Pyrite has been observed in various boreholes and there is a distinct concentration of pyrite in the northeastern part of the pipe. Pyrite mineralisation across the contact into the wallrock of rhyolites and felsites is common. A felsite breccia with a matrix of fluorite, siderite and pyrite with accessory magnetite, was observed in two boreholes adjacent to the pipe. Pyrite is also present in felsite intersected by a borehole some 1000 m away from the pipe. Borrok et al. (1998) described all sulphide minerals as mainly late alteration products, concentrated in the higher levels of the pipe. The exception is pyrrhotite, which is considered part of the primary minerals. Other sulphide minerals that were identified are arsenopyrite, chalcopyrite, galena, molybdenite, and sphalerite. Borrok et al. (1998) mentioned löllingite and other unidentified and possible new minerals, while sulphide minerals like bornite, covellite, chalcocite, marcasite, pentlandite and

tetrahedrite were identified by Kleyenstüber et al. (1998).

Other minerals of interest identified by Kleyenstüber et al. (1998) are azurite, cryptomelane, diopside, hollandite, gearsutite ($\text{CaAl}(\text{OH})\text{F}_4 \cdot \text{H}_2\text{O}$), maghemite and lepidocrocite. Crocker (1979) mentioned cassiterite.

REE, in appreciable amounts, are associated with rare earth minerals such as monazite and xenotime, occurring throughout the volcanic pipe and in some pyroclastic rocks. The main elements in decreasing order are Y, La, Ce and Nd with anomalous values of Th and U in purple fluorite. Purple fluorite is concentrated in the extreme north-eastern area of the volcanic pipe.

Lithology

Zoning

The vertical volcanic pipe is roughly horizontally zoned (Fig. 4). It consists essentially of an uppermost-oxidised hematite-fluorite (gossan) zone from surface down to a depth of approximately 50-70 m. It caps a deeper-seated unoxidised magnetite-fluorite zone, which extends to about 250 m. This zone gradually changes in depth to magnetite-fayalite and then to fayalite with accessory magnetite and fluorite (ISCOR, 1999).

The contacts between the different zones are mainly gradual and uneven, except for the siderite and fluorite dikes and plugs with sharp contacts. Contacts of all lithological units with the felsic rocks are sharp.

Siderite zones

Various transgressive and crosscutting lens-shaped bodies and veins of siderite are present (Fig. 4). These bodies occur at different depths in the volcanic pipe but they appear to be concentrated in the central areas.

Siderite mainly forms a coarse mosaic aggregate of anhedral to subhedral crystalline grains, with occasional aggregates of finer grained granular siderite. The colour is predominantly greyish but occasional grains are brown, probably due to limonitic alteration. Fluorite occurs as anhedral grains, partly interstitially to the siderite mineral crystal, and partly as coarse elongated crystals. The larger crystals contain many inclusions of siderite and arsenopyrite, pyrite, hematite and goethite, although these ore minerals also occur in other forms. Arsenopyrite is well formed, commonly rhombic and grains are clustered. Hematite occurs as thin planar infill veinlets between siderite grains, and sometimes altered to goethite/limonite. Pyrite occurs as accumulations of fine, euhedral grains, which form larger masses, and are intergrown with siderite. Quartz occurs mainly as small aggregates of fine-grained, anhedral crystals amongst the siderite grains. Aggregates of randomly orientated acicular crystals of amphibole, sometimes completely replaced by limonite, occur in places.

Hematite-fluorite zone

This unit forms a gossan at the surface and has originated from the oxidation and hydration of magnetite, iron sulphides and siderite, to hematite and goethite. The thickness of this zone is relative constant compared to the other zones, although it is slightly better developed in the

east and central areas of the pipe. The rock type consists mainly of hematite and fluorite, goethite and fluorite and with accessory magnetite, clay minerals, siderite and quartz. Typically, the gossan has a porous colloidal-botryoidal texture. Cavities in the rock with reniform and stalactitic forms, and box work textures of goethite are numerous. Fluorite is generally well preserved but some times displays a friable sugary texture with a purple colour, particular near these cavities. Overgrowing of crystals is also noticeable. These cavities and textures are typical of leaching and alteration due to hydration and dehydration by meteoric water. It seems that these cavities and textures are more or less concentrated along the present water table, but a palaeo water table might also have played a role. The fluorite content of this rock is about 40% and the iron oxides are in the order of 50%. Fluorite occurs in both massive and disseminated form, where it occupies the pore spaces between the iron oxide grains. Conformable hematite-fluorite lenses, hosted by felsite are present, particular south of the volcanic pipe (Fig. 4).

Magnetite-fluorite zone

This mineral assemblage forms the next zone in the pipe, and extends down to about 250 m in depth. It is the best developed in the southern and particularly the western areas of the pipe (Fig. 4). The zone is not uniform and transgressive lenses and veins of siderite and relicts of hematite-fayalite and fayalite are common. There is a gradual but also irregular change from hematite to magnetite while the texture of, and relationship with fluorite stays the same. However, the overall fluorite content of this rock type gradually decreases with depth from about 32% to less than 20% at 250 m, while the fayalite content increases. This zone also accounts for the main fluorite ore resource.

Magnetite-fayalite zone

This zone forms the transition zone between the magnetite-fluorite and the fayalite zones, and it may extend to the deeper levels, particularly in the southern areas of the pipe alongside the massive diabase body. It is still unknown if there is any association, or just coincidence between the diabase and the strong development of this zone next to it.

Fayalite zone

This zone forms the deepest part of the volcanic pipe and extends to over 650 m in depth (Fig. 4), which is the depth of the deepest borehole. In the northern part of the pipe, fayalite reaches from about 70 m in depth to the deepest levels. This zone is also not uniform and is cut by transgressive siderite veins and lenses and alteration zones comprised of magnetite-fayalite and magnetite-fluorite. Borrok et al. (1998) described fayalite, together with fluorite and ilmenite as the main primary mineral assemblage, and apatite, allanite, pyrrhotite, and some rare earth minerals as accessory primary minerals. Subsequently, all other minerals are alteration products off these primary mineral assemblages.

This rock type is essentially a dunite, composed of more than 90 % olivine (fayalite) with fluorite, magnetite and amphibole as accessory minerals. Borrok et al. (1998) described fluorite, ilmenite and allanite, while Crocker et

al. (1988) described fluorite, magnetite and grunerite. Thus, the exact mineral composition of this rock type is still arguable regarding the ferromagnesian and ore minerals. Nevertheless, the author recognised fayalite, serpentine, magnetite and fluorite, with accessory grunerite, chlorite, phlogopite, siderite and limonite, but no ilmenite or allanite. Fayalite forms subhedral prismatic grains up to at least 10 mm long and is very weakly pleochroic in pale green to colourless. It is partly altered along cracks and in patches to serpentine, chlorite and magnetite. Occasionally fayalite might be completely replaced by isotropic brown bowlingite with abundant associated magnetite. Magnetite occurs as anhedral to subhedral blocky grains up to 3.5 mm in size as well as anhedral and irregular straggly grains, disseminations and laminae along thin veinlets and zones of alterations. It appears that magnetite has mainly formed as part of the alteration assemblage of fayalite. Magnetite also follows cleavages within coarse fluorite where some oxidation to hematite has occurred. In the highly altered zones where fresh fayalite was replaced by serpentine and chlorite, the magnetite becomes more massive and a coarse "myrmekitic" type texture exists between magnetite and secondary silicates. Fluorite forms subhedral to euhedral coarse-grained colourless cubic crystals and anhedral grains lying interstitially to fayalite and the magnetite crystals. It contains inclusions of anhedral grains and subhedral to euhedral crystals of magnetite. Chlorite may also occur as a rim to magnetite grains within fluorite. The only sulphide mineral observed was pyrrhotite, as coarse inclusions surrounded by magnetite.

Petrogenetic Considerations

There are three major theories regarding the origin of the Vergenoeg suite.

Firstly, Crocker (1985) sees Vergenoeg as the end member of a series of genetically related fluorite-hematite deposits which are associated with the Bushveld granites. Rapid pressure release from centripetally fractionated Bushveld magma cells, due to structural failure of the roof, led to iron-calcium-fluorine-CO₂ enrichment trends, and immiscible melts which separated from silica-sodium-rich melts. This resulted in firstly, the formation of the Bobbejaankop type granites and secondly, the iron oxide fluorite type deposits in various parts of the Bushveld Complex. Although no surface outcrops of granite is found within 20 km from Vergenoeg, Iron oxide-fluorite mineralisation, often with accessory siderite and fayalite, is found in the Bobbejaankop granites (Fig. 1).

Secondly, Borrok et al. (1998) suggest, from work done on fluid petrography and comparisons with other similar deposits, that Vergenoeg mineralisation formed from hydrothermal fluids of magmatic origin. He also relates, like Crocker (1985), the deposit to the granites of the Bushveld Complex, particularly the Bobbejaankop granite.

Thirdly, Wagner (1928) postulates on the contact metasomatic replacement of porous agglomerate and tuff via iron-laden gasses emanating from sub adjacent

Bushveld granite.

The theory of Wagner (1928) has lost support with new available information on the deposits, in particular the presence of a volcanic pipe. However, field and petrographic evidence of Vergenoeg is still not conclusive in deciding between the theory of immiscible liquid of Crocker (1985) and the magmatic hydrothermal theory of Borrok et al. (1998).

The author views the following aspects as important in postulating on the origin and the paragenesis of the Vergenoeg suite:

The Vergenoeg suite of rocks is without doubt volcanogenic. The Vergenoeg pipe is the only known volcanic vent in this area and is surrounded by the pyroclastic rock types (i.e. agglomerate, ignimbrite and tuff). The origin of these pyroclastics, typical of a volcano, is undoubtedly the Vergenoeg pipe. Field relationships, mineralogical and chemical similarities between the pipe and surrounding pyroclastic rocks (i.e. iron oxide and fluorite), and close proximity, are proof of the same petrogenesis. The inward dipping strata in the area also supports the idea of a caldera like volcanic cone.

The current position (height) of the Vergenoeg suite is not far from the stratigraphic position of the original volcanic cone. Erosion removed at the most about 1000 m of the original cone. Borrok et al. (1998) follows the same reason. Surrounding felsites and rhyolites show very little if any alteration, even in close proximity with and at the contacts of the pipe. It is concluded that these rock types are not susceptible to easy alteration by iron-calcium-fluorine-CO₂-solutions, gases and melts. In the magmatic hydrothermal theory, alterations of other rocks must occur, and remnants of some of these older rocks are preserved. No remnants of altered felsitic rocks are found at Vergenoeg. Although Borrok et al. (1998) demonstrated that hydrothermal alterations occurred in the pipe (and the author is in agreement with this), the theory does not explain the origin of the surrounding pyroclastic rocks.

Widespread distributions of pyroclastics (agglomerate, ignimbrites and tuffs) are testament to the violent explosive volcanism. The size of some pyroclasts (up to 50 cm in length) is also an indication of this. Pyroclasts in the agglomerates are mainly felsitic, originating from the rhyolites and possible from the ignimbrite, with a ferruginous matrix. The matrix formed from ferruginous volcanic ash ejected from the volcanic vent, and not from hydrothermal alterations. The lack of clear volcanic structures, flow textures and remnants of lava flows are supportive of this idea. Mineralised felsite breccias are to be found in several places deeper and adjacent to the pipe, which supports the idea of explosive volcanism.

The first phase in the paragenesis of the Vergenoeg suite was the discharge of an acid phase comprising the felsic ignimbrites from the volcanic pipe. This is the bottom unit in the stratigraphic succession and was the largest, resulting in the current widespread distribution of ignimbrites (Fig. 3). The nature of this phase (i.e. ash, lava flows etc.) is not clear. A violent eruption phase followed, resulting in the

ejection of felsitic pyroclasts of different sizes from the volcanic pipe. Felsite breccias found deep down adjacent to the pipe might be remnants of this event. This violent eruption might have been the consequence of blockage of the vent by the previous viscous acid magma and lava, resulting in the build up of pressure in the top, and eventually culminating in a sudden violent eruption. Several repeated cycles of this phase occurred. Agglomerate bands and lenses in the ignimbrites, and hematite and hematite-fluorite bands in felsite and ignimbrite are indications of multi phase eruptions and cycles. A progressive increase in the iron, fluorine and CO₂ content occurred in these individual phases, eventually resulting in the discharge of ash, gas and fluids enriched in these components. Lava flow eruptions from the Vergenoeg volcanic vent were limited, indicated by the absence of definite volcanic textures and structures. These eruptions formed the current iron oxide fluorite rock assemblages outside the pipe. Iron, fluorine and the other elements were finely dispersed in all the final phases of lava flows and ash ejections, and crystallised into magnetite and fluorite. Magnetite was subsequently oxidised to hematite, resulting in the hematite-fluorite rock assemblages. Hydrothermal solutions played a major role in the alteration of mineral assemblages inside the pipe, but were unimportant outside the pipe in the rhyolitic wall rock and in conformably stratified hematite and hematite-fluorite.

Inside the pipe, iron oxide minerals, fayalite and fluorite crystallised after the final eruption, to form the primary mineral assemblages as described by Borrok et al. (1998). The final phases were the intrusion of fluorite dykes and veins, ending with the formation of siderite bodies and veins in the fading stage of the Vergenoeg volcanic event. Magmatic hydrothermal solutions, together with meteoric water, both probably strongly acidic (i.e. HF), circulated within the pipe and resulted in hydrothermal alteration to form secondary mineral assemblages. The presence of calderas in the cone of the extinct volcano is also a strong possibility. Primary minerals (i.e. fayalite, magnetite and ilmenite) changed to secondary magnetite, hematite, siderite and other minerals. Fluorite was resistant to any large-scale alterations.

Conclusions

The resemblance of the Vergenoeg fayalite iron oxide fluorite deposit with the family of iron oxide related deposits lies in a few common features. The most common feature is the massive occurrence of iron oxides (magnetite and hematite) in both the pyroclastics and the volcanic pipe. Although REE, uranium, thorium and most base metals are anomalous, copper and gold concentrations are conspicuously low in comparison. Iron-sulphides (i.e. pyrite and pyrrhotite) are also characteristic, but the presence of fayalite and particularly fluorite mineralisation is rare, although not uncommon in some other related deposits.

Mineralised breccias, agglomerates and ignimbrites, indicative of violent explosive eruptions from a volcanic

vent, are common at Vergenoeg. The majority of other iron oxide deposits includes some sort of mineralised breccias or volcanoclastic rocks, often concealed below younger rocks. Hydrothermal alterations, a distinctive feature of most of the family of iron oxide deposits, have been recognised in the Vergenoeg pipe, but not in the surrounding conformably stratified pyroclastic rocks.

Most other iron oxide deposits are related to granite or other felsic rocks. At Vergenoeg granite is absent from the surface outcrops, although felsic rocks are part of the suite of rocks. By referring to other similar iron oxide fluorite deposits in the Bushveld Complex, which all are associated with granite, it is also suggested that the Vergenoeg deposit is associated with the granites although they are not evident.

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References

- Anderson, N.J.B., & Roets, D.L., 1983 – Report on the Radiometric Borehole Logging conducted by NUCOR of Borehole VG6 on the Vergenoeg Fluorite Mine. *Restricted report by the Nuclear Development Corporation of South Africa (Pty) Ltd*, PIN-682(B/R), 8pp.
- Behr, S.H., 1966 – Geological report on the explanation of the iron ore on the farms Kromdraai 209 JR and Naauwpoort 208 JR, district Cullinan, Transvaal. *Confidential report for Dunswart Iron and Steel Works*.
- Borrok, D.M., Boer, R.H., & Essene, E. J., 1998 - The Vergenoeg Magnetite-Fluorite Deposit, South Africa: Support for a hydrothermal Model for massive iron Oxide Deposits. *Economic Geology* 93, 564–586.
- Crocker, I.T., 1979 – Metallogenic Aspects of the Bushveld Granites: Fluorite, Tin and associated Rare Metal-Carbonate Mineralisation. *Special Publication of the Geological Survey of South Africa*. 5 (1979), 275-279.
- Crocker, I.T., 1985 - Volcanogenic Fluorite-Hematite Deposits and Associated Pyroclastic Rock Suite at Vergenoeg, Bushveld Complex. *Economic Geology* 80, 1181–1200.
- Crocker, I.T., Martini, J.E., & Sohng, A.P.G., 1988 - The Fluorite deposits of the Republic of South Africa and Bophuthatswana. *South African Geological Survey Handbook*. 11, 1-172.

- De Bruijn, H., 1974 - The geology of the Bushveld Complex between Winterveld and Dennilton, northern Transvaal: Area 2528A (Pienaars River). *South African Geological Survey Unpublished Report*, 44pp.
- Glatthaar, C.E., 1956 - Die verysterde piroklaste en 'n na Waterbergse graniet, suid-oos van die dam Rust de Winter. *M. Sc. thesis, University of Pretoria*, Unpublished. 80pp.
- ISCOR Ltd., 1999 - Visitors information hand out.
- Kleyenstüber, A.S.E., & Kramlich, E.R., 1998 - A mineralogical investigation of the Vergenoeg Fluorite Mine beneficiation plant. *Confidential report, MINTEK* 1998, 161pp.
- Palmer, J.E., 1979 - A preliminary geophysical investigation of the Vergenoeg fluorite mine, Kromdraai 209 JR. *Unpublished Report Geological Survey of South Africa* 1979-0024, 10pp.
- South African Committee for Stratigraphy (SACS). 1980 - Stratigraphy of South Africa (Compiled by Kent, L. E.). Lithostratigraphy of the Republic of South Africa, South west Africa/Namibia, and the Republics of Bophuthatswana, Transkei, and Venda. *Handbook of the Geological Survey of South Africa* 8.
- Stettler, E.H., Kleywegt, R.J., & Crocker, I.T., 1993 - Geophysical delineation of the Vergenoeg Mine Fluorite-Hematite Ore-body on the farms Kromdraai and Naauwpoort. *Southern African Geophysical Review* 1, 1-20.
- Stettler, E.H., & Stigter, D., 1980 - An extended gravity survey at the Vergenoeg fluorite mine, Kromdraai 209 JR. *Geological Survey of South Africa Unpublished Report*, 1980-0230, 7pp.
- Wagner, P.A., 1928 - The iron deposits of the Union of South Africa. *South African Geological Survey Memoir* 26, 42-55.
- Walraven, F., 1981 - The stratigraphic position of the post-Rooiberg sediments at Rust de Winter. *South African Geological Survey Annals* 15, 37-41.
- Walraven, F., & Hattingh, E., 1993 - Geochronology of the Nebo granite, Bushveld Complex. *South African Journal of Geology* 96, 31-41.