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BASE-METAL MINERALIZATION IN ALKALINE PYROCLASTICS — THE REGENSTEIN VENT, SOUTH WEST AFRICA

by

C. A. M. FERREIRA, R. E. JACOB and J. S. MARSH

ABSTRACT

Geochemical analysis of soil samples taken from the area underlain by the Regenstein alkaline diatreme indicated potential areas for Pb-Zn-Ag mineralization, and these were subsequently proved by drilling. The pipelike body, emplaced into quartzites of the Damara Supergroup, consists of lithic and volcanic breccias. The breccias have been intruded, first by phonolite dykes, and then by numerous bodies of alkaline mafic and ultramafic rocks. The final phases of volcanic activity are represented by hydrothermal alteration of the pipe-filling and by Pb-Zn-Ag mineralization. The mineralization occurs in the form of fine disseminations and irregular replacements and as thin veinlets of open-space filling type along fracture zones in the volcanic breccia. The nature of the mineralization indicates that it was emplaced under epithermal-mesothermal conditions and the deposits exhibit considerable similarities to those of Cripple Creek, Colorado.

CONTENTS

I. INTRODUCTION

The Regenstein vent is one of several alkaline volcanic bodies occurring in the Auas Mountains south of Windhoek, South West Africa. During a regional stream-sediment geochemical survey conducted by geologists of Falconbridge Explorations Limited, possible base-metal mineralization associated with the Regenstein vent was indicated and this was subsequently confirmed by detailed soil sampling, geochemical analysis and diamond-drilling. The association of base metal sulphide mineralization with an alkaline rock suite of the type found at Regenstein is not a common one, and this paper is intended to draw attention to this.

II. GEOLOGY OF THE REGENSTEIN VENT

The Regenstein vent is situated near the southern margin of the Khomas Trough, a structural entity of the Pan-African Damara orogenic belt. The vent is emplaced into quartzites of the Auas Formation of the Khomas Subgroup, which is a subdivision of the Swakop Group, itself a part of the Damara Supergroup (Fig. 1). The localization of the body and its northern satellite was structurally controlled. The surrounding area is extensively faulted and the vents are situated along one of these displacements, namely the Aretaragas fault. These faults developed during the Damaran Orogeny (Guj, 1967; Hälbich, 1970) but have remained active over a long period. In fact, movement along the Aretaragas fault has occurred subsequent to lithification of the alkaline breccias (Hälbich, 1970).

The presence of alkaline volcanic bodies (Fig. 1) in the vicinity of Windhoek and Rehoboth is known through the reconnaissance mapping and descriptions of Kaiser (1911), Rimann (1914), Rennie (1926) and Gevers (1933). Of these authors, only Gevers discussed the vent and its rock types in any detail. During the present investigation the vent and its northern satellite were mapped in detail and extensive use was made of borehole cores to obtain information on the relationships between the different rock types and their petrography (Fig. 2).

As noted by Gevers (1933) the dominant materials filling the vent are somewhat friable, coarse pyroclastics — a feature responsible for the low relief of much of the area underlain by the vent. The pyroclastics are intruded by felsic dykes of phonolitic composition, and by a large plug and numerous irregular bodies of mafic and ultramafic alkaline rocks.

All the rock types associated with the vent are characterized by a high degree of alteration, with the mafic rocks being the least affected. Although this alteration has destroyed many of the original anhydrous minerals of the igneous rocks, their original textures are still well preserved. Secondary carbonate is ubiquitous in all rocks and appears to be directly related to the sulphide mineralization in the vent. The alteration and the presence of carbonate persists even in the deepest levels intersected by the boreholes (240 metres below surface).

A. Petrography

1. Pyroclastic Rocks

Two types of pyroclastic rock have been distinguished during the field mapping and in the borehole cores. Both types are composed of angular fragments ranging in size from 2 mm to 0,5 metre and can therefore be termed *lapilli breccias* or *breccias* (MacDonald, 1972, pp. 130–131). One type is composed of both accessory (older volcanic) and accidental (country rock) fragments (MacDonald, pp. 123–124), and is hereafter referred to as the *lithic breccia.* The other type is composed entirely of accessory and possibly essential (from magma of same eruption) fragments

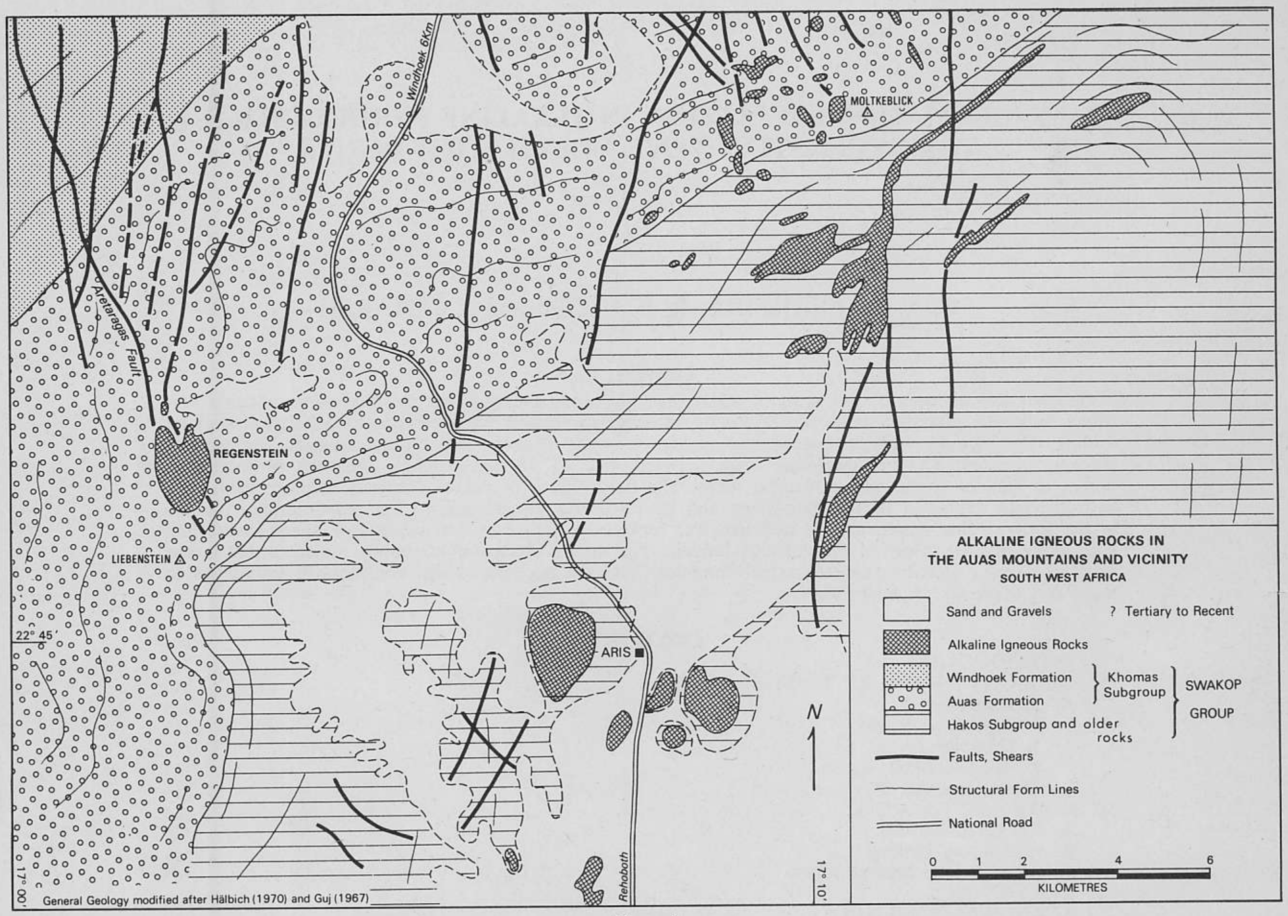

Figure 1

Simplified geological map of an area south of Windhoek showing the distribution of alkaline igneous rocks. The general geology has been modified after Hälbich (1970) and Guj (1967).

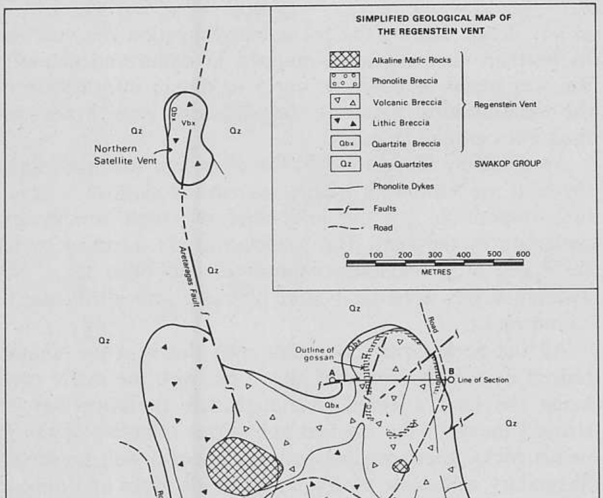

Figure 2

Simplified geological map of the Regenstein vent.

(MacDonald, p. 123), and is termed the *volcanic breccia.*

The lithic breccia is located in the southern and western parts of the vent whereas the volcanic breccia is confined to the north-eastern corner of the vent (Fig. 2). The two breccias may also be distinguished by other characteristics. The volcanic breccia shows a greater degree of sorting than the lithic breccia, it is more resistant to erosion, and thus forms topographically prominent hills whereas the lithic breccia is easily weathered and underlies the areas of low relief. The base-metal mineralization is also confined to the volcanic breccia, whose weathered surfaces display a heavy, black, manganese oxide staining. The barren lithic breccia is devoid of manganese oxide staining.

Individual mineral and lithic clasts in the breccias are packed tightly together and cemented by fine-grained material which is a mixture of clay minerals and carbonate. Accidental clasts include quartzite, quartz-muscovite schist, and quartz-biotite schist. Accessory clasts comprise various fine-grained felsic rocks (trachytes and phonolites with porphyritic textures), and also fragments of lapilli breccia, suggesting that more than one episode of explosive activity has been responsible for the vent formation. The fragments of felsic rock are in many instances very similar to the phonolite dykes that intrude the breccias. All the clasts are highly altered.

A thin, discontinuous envelope of quartzite breccia is commonly found along the contact of the volcanic and lithic breccias with the surrounding country rock. The volcanic breccia/quartzite breccia contact was intersected by several boreholes and in all cases the contact is sharp although occasional quartzite fragments are found in the volcanic breccia as the contact is approached. This indicates that the quartzite breccia was generated by *in situ* fragmentation with little explosive dispersal of the fragments. Sorting in the quartzite breccia is poor and individual fragments range in size to large blocks 0,5 metre and greater in diameter. Clasts are tightly packed and well cemented. A mixture of carbonate and pyrite forms irregular blebs and veinlets infiltrated between the clasts.

2. *Phonolite Dykes*

These felsic dykes are highly altered in surface exposures and fresh specimens could not be obtained even from borehole intersections. In outcrop the phonolite is cream coloured and weathering has invariably accentuated the porphyritic textures and flow structures in the fine-grained groundmass. The phenocryst phases are sanidine (which is dominant) and a feldspathoid which is completely pseudomorphed by fibrous or micaceous alteration products. The groundmass is strongly altered and contains abundant secondary carbonate. The texture of the groundmass may be trachytic or bostonitic.

3. *Alkaline Mafic Rocks*

These rocks crop out on a prominent conical hill in the north-western part of the vent. A smaller subsidiary plug occurs near the eastern edge of the vent. Several small irregular bodies of mafic rock were intersected by the boreholes. These mafic rocks are heterogeneous and are characterized by the assemblages clinopyroxene + feldspathoid and clinopyroxene + feldspathoid + alkali feldspar. Gevers (1933) described these rocks in considerable detail but his descriptions could not be reconciled completely with specimens examined in this study.

The heterogeneous nature of the mafic rocks can be seen in exposures of the main intrusive plug. On weathered surfaces numerous "xenoliths" of a medium-grained mafic rock can be seen enclosed in a fine-grained porphyritic matrix. The medium-grained "xenoliths" are mineralogically very similar to ijolites. They have a hypidiomorphic-granular texture and grain size averages 0,4 to 0,6 mm. Subhedral pale green clinopyroxene is the dominant mafic mineral and may compose up to 60 per cent of the rock. Dolomite-serpentine-opaque oxide aggregates are pseudomorphs after sparsely scattered olivine grains. Accessory mafic minerals include one or more of biotite, garnet, apatite and an Fe-Ti oxide. Nepheline and analcite are the major feldspathoids, but nosean and hauyne may also occur. In some specimens trace amounts of altered alkali feldspar appear to be present but this could not be confirmed.

Fine-grained porphyritic material of variable composition is host to the ijolite "xenoliths". Two petrographic types can be distinguished on the basis of the presence or absence of biotite as a phenocryst or microphenocryst phase, although it has not been possible to recognize the relationship between the two types.

Representatives of the first type (without biotite), are similar to nephelinites. They are strongly porphyritic and contain phenocrysts of euhedral, zoned, diopsidic augite accompanied by less abundant dolomite + opaque oxide pseudomorphs after olivine. Microphenocryst phases are Fe-Ti oxides and minor apatite. The groundmass is fine-grained and altered and contains considerable amounts of secondary carbonate. No certain identification of groundmass phases could be made but clinopyroxene, nepheline and small amounts of alkali feldspar appear to be present.

Representatives of the second type consist of zoned phenocrysts of augite and biotite, pseudomorphs after olivine, and occasionally small amounts of brown amphibole set in a groundmass with a greater proportion of felsic material than the nephelinites. Both alkali feldspar and nepheline appear to be present but alteration and abundant secondary carbonate frustrate positive identification of the felsic phases. The accessory minerals are apatite and Fe-Ti oxides. The rocks are best described as mafic phonolites.

Apart from the ijolite the mafic rocks are host to a varied xenolith/xenocryst suite which includes rounded xenocrysts of alkali feldspar (possibly anorthoclase), unzoned diopside, and olivine and xenoliths of wehrlite, gabbro, syenite, pyroxenite and anorthosite. Xenolith suites can give important information on the origin and evolution of their host rocks, but this requires detailed studies beyond the scope of the present investigation.

B. The Age of the Regenstein Vent

The Regenstein vent has always been correlated with the other post-Damara alkaline bodies to the south and east; the dykes and sheets in the vicinity of Moltkeblick, the breccia vent at Gochenganas and the phonolites at Aris and Geelkopf near Rehoboth. One of us (J. S. M.) has recently started a re-investigation of these rocks and has found that the phonolites near Geelkopf and in the immediate vicinity of Aris are eroded tholoids which have been erupted on to a land surface not very different from that of the present day. Also the phonolites are very fresh. In contrast, the Gochenganas and Regenstein vents are completely different in character and the present outcrops represent much deeper levels of a volcanic conduit system. In addition the felsic rocks and breccias are characterized by intense alteration of the constituent minerals.

This suggests that the Regenstein–Gochenganas–Moltkeblick suite of rocks is older than the Aris–Geelkopf phonolites. Currently there are no radiometric ages for any of these occurrences but one of these suites may be Eocene in age since alkaline volcanism of Eocene–Oligocene age is widespread in southern Africa, e.g. Klinghardt phonolites, Namaqualand nephelinite-melilitite pipes (see Moore, 1976). However, Gevers (1942) has suggested a Cretaceous age for Regenstein, and Hälbich (1970) argues for a pre late-Jurassic age. These estimates are obtained from arguments relating the alkaline volcanics to the geomorphology of the area, particularly to the pronounced erosion surfaces.

A minimum age for the Regenstein vent could be obtained from a knowledge of the age of the small intermontane surface lying to the north-east of the vent. Unconsolidated sediments on this surface overlie part of the northern vent/country rock contact. However, the age of the surface and its sedimentary cover are not well established. The surface has an altitude of 2 000 metres and is possibly a remnant of the extensive 1 920 metres peneplanation of the Windhoek Highlands (Mabbutt, 1955). Both Gevers (1942) and Hälbich (1970) consider the peneplain to be Late Cretaceous in age. However, Martin (personal communication to R. E. J.) suggests an Early Tertiary age for the surface. Until an age for the small surface or a reliable correlation with the Khomas Highland peneplain is established, the minimum age for the Regenstein vent must remain in doubt.

III. ECONOMIC GEOLOGY

A. Soil Geochemistry

Routine stream-sediment sampling of the Regenstein Grant area indicated Pb-Zn anomalies up to 15 times background levels and indicated that the Regenstein vent was the source. Subsequent investigation involved soil sampling, on a 50 metre grid pattern, of an area measuring 3 by 2 km. The soil samples were collected at a depth of 15 cm and the minus 80 mesh fraction was analysed.

Ninety samples were analysed for the following elements as part of an orientation survey: Ag, Pb, Zn, Cd, Sr, Ba, Co, Ni, Hg, Cu, V, As, Mo and Bi. No anomalous concentrations of Hg, Cu, V, As, Mo and Bi were detected. The remaining samples (about 600 in number) were analysed for Pb, Zn, Ag, Cd, Ba, Sr, Cu and Hg.

Cu and Hg values vary insignificantly but the spatial dis-

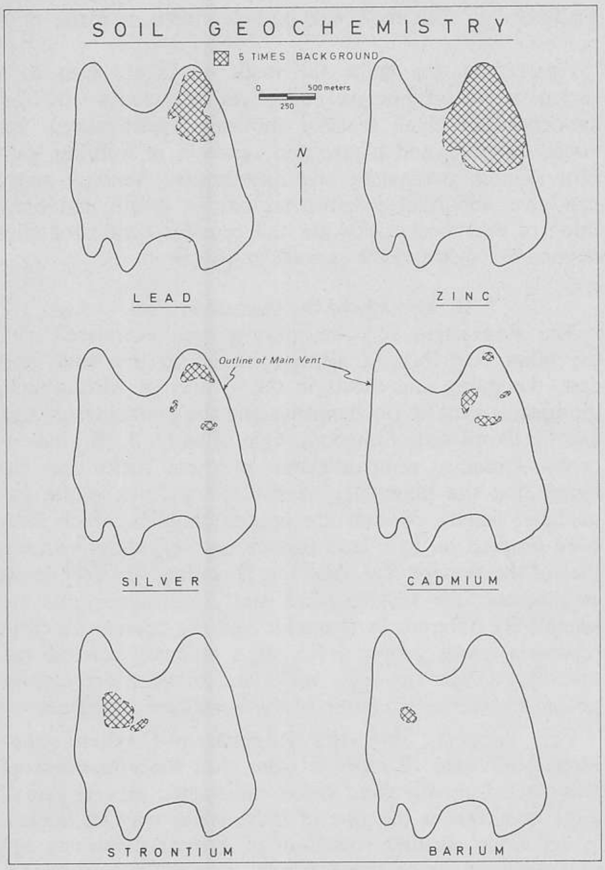

Figure 3
Geochemical soil anomalies over the Regenstein vent.

tribution of other anomalies proved interesting (compare Figs. 2 and 3).

Anomalous concentrations of Ni, Co, Ba and Sr are centred over outcrops of the alkaline mafic rocks. Ba values over the prominent conical hill (p. 245) reach 1 971 ppm (more than three times background, see Fig. 3) while Sr values reach 1 335 ppm (ten times background) in the same area.

Anomalous Pb values of up to 2 100 ppm (thirty times background) were recorded over the north-eastern part of the vent (Fig. 3) with minor anomalies along the western side of the plug. Low values were recorded over the northern satellite vent.

Zn anomalies exhibit a similar pattern to Pb (Fig. 3) but indicate a wider dispersion. The maximum values recorded were 1 380 ppm (ten times background) and the anomalies are centred over outcrops of the volcanic breccia. Low-order anomalies were located along the western side of the main vent and over the northern satellite vent.

The maximum Ag-in-soil value recorded was 29 ppm and anomalous values of 3 ppm plus are centred over the volcanic breccia of the main vent (Fig. 3). However, no anomalies are present over the northern satellite vent.

Cd exhibits maximum values of 34 ppm and anomalous values of more than 10 ppm show a similar distribution to Ag anomalies (Fig. 3).

The Pb, Zn, Ag and Cd anomalies are thus coincident and outline an approximately circular area of some 500 metres in diameter over outcrops of the volcanic breccia in the north-eastern part of the main vent. The outcrops here are extensively stained by manganese and iron oxides and have a gossanous appearance in places. Representative chip samples across these outcrops assayed as follows: Cr 78 ppm, Pb 670 ppm and Zn 1 520 ppm. The coincident Pb-Zn anomaly over the northern satellite vent follows the trend of the Aretaragas fault, which crops out as a silicified, vuggy, shear zone through the centre of this vent.

After the initial soil-sampling survey the north-eastern part of the main vent and the northern vent were investigated in more detail and these areas were resampled on a 25 metre grid. The soil-geochemistry results obtained for Pb, Zn and Ag confirmed those of the previous survey and showed that these metals are concentrated in a circular pattern closely coincident with the gossanous outcrops (Fig. 2).

B. Exploratory Drilling

Based on the results of the geochemical surveys, eight diamond-drill and four percussion holes were sunk to test the anomalies in the north-eastern part of the main vent, and one diamond-drill hole tested the northern vent target area. The holes were inclined at angles of near 45 ° and were aligned either east–west or north–south.

The number of mineralized zones that were intersected varied in the holes drilled and up to three such zones were recorded in holes RG2 and RG4. However, the exploratory drilling indicated that the mineralization is uneconomic and that less than one million tonnes of mineralized material are present (see Table I).

A section along one of the boreholes, RG1, is shown in Fig. 4. Along this borehole a transition from oxide to sulphide occurs at about 70 metres. Two mineralized zones were intersected in the volcanic breccia. Assays of the first zone, over two metres true width, averaged Pb 1,08 per cent; Zn 2,85 per cent, Ag 48,6 grams per tonne; Cd 120 grams per tonne and Au 0,2 grams per tonne. A second intersection, over four metres true width, averaged Pb 3,44 per cent; Zn 0,57 per cent; Ag 48,55 grams per tonne and Cd 28 grams per tonne. Pyrite is present throughout the length of the borehole from 70 metres depth onwards and parts of the quartzite breccia are extensively mineralized with pyrite.

The borehole cores were tested with a scintillometer

TABLE I
Drilling Results — Regenstein Pb-Zn-Ag Deposit

Borehole	True width	% Pb	% Zn	g/t Ag	Comments	
RG-1	Less than 4 m (?)	3,44	0,57	48,5	Main Deposit	Diamond Drillhole
RG-2	2 m	1,29	0,23	18,5	Main Deposit	Diamond Drillhole
RG-3	1 m	0,57	2,15	49,3	Main Deposit	Diamond Drillhole
RG-4	4 m	2,37	3,55	58,7	Main Deposit	Diamond Drillhole
RG-5	2 m	1,21	0,98	42,2	N. Satellite vent	Diamond Drillhole
RG-6	All assays less than 1,25 % combined Pb + Zn				Main Deposit	Percussion Drillhole
RG-7	Abandoned in decomposed ground				Main Deposit	Percussion Drillhole
RG-8	All assays less than 0,2 % combined Pb + Zn				Main Deposit	Percussion Drillhole
RG-9	2 m	1,04,	0,51	156,5	Main Deposit	Percussion Drillhole
RG-10	2 m	1,06	0,63	9,5	Main Deposit	Diamond Drillhole
RG-11	Very little sulphide — not sampled				Main Deposit	Diamond Drillhole
RG-12	2 m	0,41	1,05	7,8	Main Deposit	Diamond Drillhole

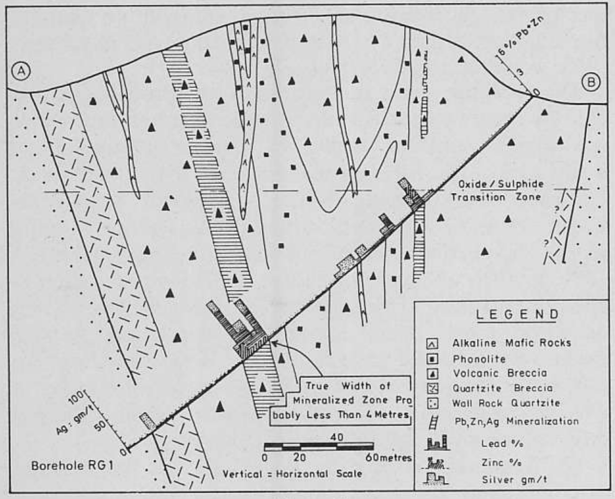

Figure 4
Schematic section through the north-eastern part of the Regenstein diatreme showing the distribution of Pb, Zn and Ag in borehole RG1.

and ultraviolet lamp but no anomalous concentrations of radioactive minerals were recorded. In addition to routine analysis of the cores for Pb, Zn and Ag, composite samples were selected for analysis of certain other elements. Au values are generally very low and vary between 0,05 and 0,5 gram per tonne while Te is uniformly low at 10 ppm. Arsenic varies between 30 and 200 ppm and Bi concentrations are invariably about 0,006 per cent. Y, Ta and Sn concentrations are each below 10 ppm while Nb varies between 40 and 120 ppm. The rare-earth elements Ce and La vary between 30 and 230 ppm, and 50 and 100 ppm respectively; these are more or less average concentrations for alkaline rocks but less than carbonatites and indicate that the Regenstein breccias do not have carbonatitic affinities.

C. Nature of the Mineralization

Very finely disseminated sulphide mineralization has been identified from cores throughout the volcanic breccia but most of it is localized along fracture zones. Within these mineralized fracture zones clasts of the volcanic breccia and dykes of phonolite have been fragmented. The sulphides are present as regular and irregular veinlets and blebs in the matrix of the breccia and along fractures in the various clasts (Figs. 5 and 6). In many instances evidence of open-space filling can be seen but examination of polished sections indicates that extensive replacement of the matrix of the volcanic breccia has also occurred. Voids are commonly present within the mineralized zones and well-formed crystal terminations project into them. It has been mentioned above that most of the rocks are strongly carbonated and this is true also of the ore zones. The sulphide veinlets are closely associated with aggregates of carbonate and sericitic, kaolinitic and alunitic material. The sulphide grains are commonly found nested in carbonate aggregates. Qualitative microprobe analysis of the carbonate showed it to be a manganese-bearing ankerite having a preponderance of iron over magnesium. The ore-mineral assemblage appears to be simple, and consists of pyrite, sphalerite galena, chalcopyrite and tetrahedrite.

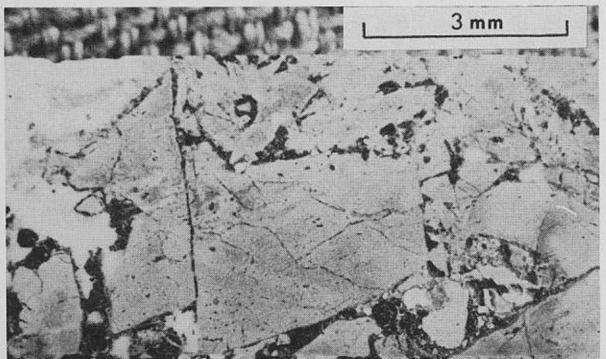

Figure 5
Section of borehole core from RG4 showing fractured clasts (grey), kaolinite (white) and sulphide mineralization (dark) mainly in the matrix but also as thin veinlets in the clasts.

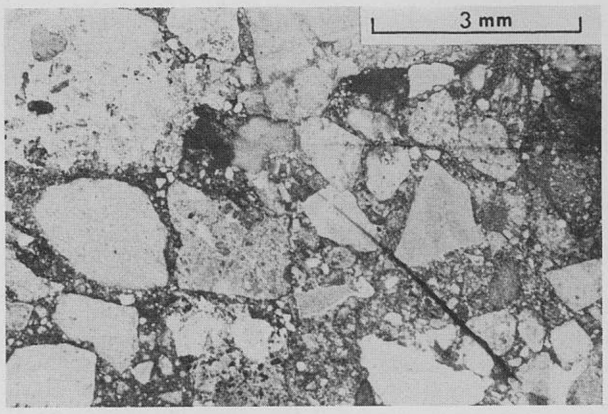

Figure 6
Section of borehole core from RG2 showing the volcanic breccia. The very dark blebs and speckling in the matrix are sulphides.

Pyrite is the most common of the sulphides and occurs as finely disseminated, euhedral and subhedral grains in the matrix of the volcanic breccia and in a number of breccia clasts. In the mineralized zones it is found as granular aggregates, and as euhedral grains exhibiting atoll texture

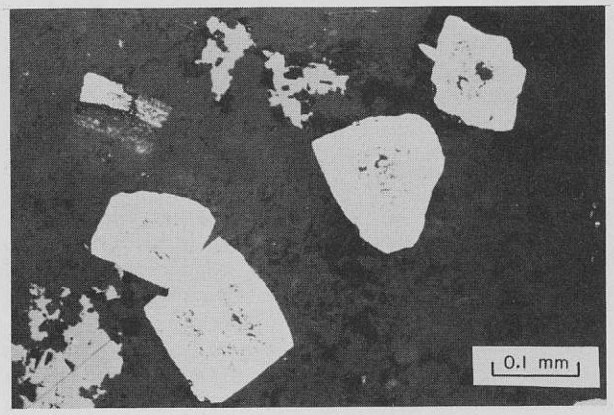

Figure 7
Subhedral pyrite grains in the matrix of the volcanic breccia showing atoll texture. The irregular grains (pale grey) are sphalerite. Reflected, plane-polarized light.

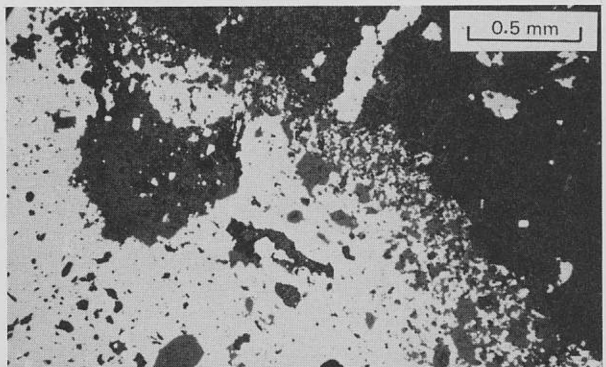

Figure 8
Sphalerite (white) replacing the volcanic breccia (dark grey) and exhibiting very irregular boundaries. Reflected, plane-polarized light.

(Fig. 7) and growth lines. In most cases euhedral pyrite grains are enclosed in aggregates of sphalerite and galena but in places pyrite grains completely enclose grains of those two minerals. In the quartzite breccia, pyrite, in association with carbonate, occurs as porous aggregates, and sphalerite and galena are found as tiny blebs and granules along the outer margins of these pyrite aggregates.

Sphalerite takes a good polish and occurs as irregular masses with very crenulate margins (Fig. 8). The sphalerite grains contain inclusions of matrix material, grains of euhedral and subhedral pyrite, and anhedral galena and chalcopyrite. Sphalerite aggregates are occasionally partially rimmed by tiny blebs of galena. Under high-power magnification the sphalerite is seen to contain very small blebs and lamellae of exsolved chalcopyrite. Electron microprobe analyses indicate that the sphalerite contains about five per cent Fe and that the cores of sphalerite grains are richer in Zn than the margins.

Galena has generally crystallized late, and surrounds and cements pyrite aggregates, but is occasionally found enclosed within both pyrite and sphalerite. It is frequently present in the form of thin veinlets. The mineral is argentiferous and electron microprobe data shows Ag to be present at about the one per cent level. Textural evidence suggests that galena and sphalerite crystallized together.

Chalcopyrite is present in very small amounts as tiny rounded blebs within sphalerite and, less commonly, within galena but is most common as minute exsolution lamellae in sphalerite.

Tetrahedrite occurs only in small amounts, generally as inclusions within galena grains. Leucoxene is also present in very minor amounts in the matrix of the volcanic breccia as lathlike, and irregular pocked grains exhibiting deep red internal reflections.

The presence of pyrite in certain clasts and in the matrix indicates that sulphide mineralization extended over a considerable period and this is supported by the varying relative ages of pyrite and galena-sphalerite.

IV. DISCUSSION

The nature of the fill of the Regenstein vent indicates a complex history. The oldest volcanic event is clearly the generation of the pyroclastic breccias. It has been shown (see Petrography) that the breccias contained no essential fragments, indicating that a solid mass of phonolite must have occupied the conduit system before explosive creation of the breccias. The absence of essential fragments suggests that the gas causing the explosions was not, or only to a minor extent, magmatic in origin but was derived by heating of groundwater drawn into the hot magma lying below the congealed plug. Such an origin for gases driving volcanic explosions is probably the rule rather than the exception as repeatedly emphasized by MacDonald (1972, p. 243) and McBirney (1963). The presence of different textural types and compositions (trachyte and phonolite) of igneous rock suggests that this process was repetitive, i.e. repeated clogging of the conduit by frozen magma and repeated fragmentation of the plug by explosion.

The surface expression of the vulcanism at the time of eruption is also of interest. We estimate that the present erosion level intersects the pipe no more than 400 to 500 metres below the surface at the time the vent was active. Clearly with repeated explosion a tuff cone must have been established surrounding the vent and it also seems probable that lava was extruded on to the surface as domes or short flows.

Several features of the Regenstein pipe are difficult to explain by our envisaged model. It is difficult to explain the irregular outcrop pattern of the volcanic breccia (see Fig. 2) and its lack of accidental fragments especially as it is in contact with quartzites around the northern and north-eastern edge of the vent. We could suggest several mechanisms to explain these features but with no quantitative data on fragment size and fragment type distribution these would be largely speculative.

The explosive cycle at Regenstein was probably terminated by the emplacement of the large plug and the numerous smaller intrusive bodies of alkaline ultramafic and mafic rocks. The heterogeneous nature of the mafic rocks has been noted, particularly the "fragmental" texture displayed on many weathered surfaces. This feature is similar to the "kimberlite breccia" of kimberlite pipes (Dawson, 1971, p. 192), although, of course, different rock compositions are involved. This suggests that the mafic rocks were emplaced rapidly from considerable depth (and possibly explosively) into the pyroclastic pile — a suggestion supported by the presence of numerous dense ultramafic inclusions and mafic megacrysts which would otherwise have settled under the influence of gravity.

The final intrusive event at Regenstein was the emplacement of phonolite dykes along fissures cutting the pyroclastic fill and the mafic alkaline rocks. The dykes are thin and regular and exhibit sharp, regular and chilled contacts with the breccias. This indicates that the breccias were largely lithified at the time of dyke emplacement.

Hydrothermal alteration and mineralization constituted the final phases of volcanic activity and the breccias and intrusive dykes were carbonated to varying degrees as CO_2-bearing fluids permeated along faults and fractures and through the breccias. Contemporaneous with, and following on, the alteration, deposition of the ore minerals occurred through open-space filling and replacement processes, particularly along fracture zones. The character of the breccias and their hydrothermal alteration, the presence of open spaces and the ore-mineral assemblage, are indicative of relatively low temperatures of deposition and shallow depths of mineralization and the deposits could be classed as mesothermal to epithermal.

The economically important elements generally found in alkaline igneous rocks include Nb, Ti, Zr, Al, Be, P, U, Th, Fe, Ta, Ba and the rare earths (Schröcke, 1955; Sheynmann *et al.*, 1963; Semenov, 1974). Base-metal sulphide and precious-metal mineralization is not at all common although minor concentrations of silver have been detected in ussingite veins in the Ilimaussaq intrusion in Greenland (Semenov, 1974) and an economically significant deposit of molybdenite occurs in a syenite massif at Werner Bjerge, East Greenland (Bearth, 1959). In addition, galena and sphalerite are widely distributed minor accessories in alkaline rocks and minor concentrations have been reported at Ilimaussaq (Sorensen *et al.*, 1969) and Lovozero (Vlasov *et al.*, 1966). At Regenstein, however, the mineralization is not found to be concentrated in the intrusive alkaline rocks but rather within the volcanic breccias as hydrothermal veinlets and replacements. In many respects the deposits exhibit pronounced similarities to the Cripple Creek deposits of Colorado which are also associated with alkaline rocks and breccias (Lovering and Goddard, 1950). The relationship between the mineralization and volcanic activity seems clear and the occurrence can be compared with vein deposits of volcanic–precious metal–telluride association (Stanton, 1972). According to Stanton, no systematic relation between type of mineralization and a particular lava composition has yet been recognised in ores of this class. Nevertheless, the association of base-metal sulphide mineralization and alkaline bodies remains unusual.

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C. A. M. Ferreira,
Falconbridge Explorations Limited,
P.O. Box 3847,
9100 Windhoek,
South West Africa.

Present address:
Riofinex Do Brasil,
Box 2431-ZC-00,
Rio de Janeiro 20,000,
Brazil.

R. E. Jacob and J. S. Marsh,
Department of Geology,
Rhodes University,
6140 Grahamstown.

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