The Springfontein Prospect:

A Case study of a Tertiary Age Epithermal
Hot Spring Deposit in the Eastern Cape

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Springfontein Prospect.

Abstract.

The Springfontein Prospect is a Tertiary aged epithermal Hot Spring deposit that was investigated for precious metal mineralisation. It is located some 14 kilometres due west of East London (Cape Province), within Beaufort Group sediments and Karoo dolerite. Prior to the work described in this case study, the location was known for it's abundant plant fossils and barite mineralisation.

A gossan sample collected near the main barite vein returned 1,07 g/t Au and 26,6 g/t Ag. Remote sensing studies of the site revealed a set of north-south lineaments paralleling the barite vein system. Geophysical surveys confirmed this orientation and revealed an extensive alteration system underlying the prominent sinter terrace. A detailed soil geochemical survey returned elevated values in the classical epithermal gold mineralisation element suite (Hg, Tl, As, Bi, Sb, Te, Mo, Ba and Pb - Bonham, 1986). Trenching of geochemical anomalies revealed zones of intense argillic alteration and vein stockworks). Four percussion and three diamond drill holes intersected a 'feeder-fissure' system of veins, alteration and brecciation, but failed to repeat gold levels seen at surface. Mineralogical and petrographic studies of the cores determined temperatures of formation of important indicator minerals (e.g. adularia and zeolites). Litho-geochemical work revealed mercury (and thallium) to be most elevated in the feeder systems. Stratigraphic and paleontological observations determined that the Springfontein Tertiary deposit was clearly different to the other siliceous (silcrete) units that crop out in the Eastern Cape region.

A number of distinguished visitors to the prospect, with epithermal deposit experience, confirmed that the characteristics and dimensions of the system is within those of mineralised deposits elsewhere. A brief review of current epithermal models are presented. The conceptual geological model for the Springfontein prospect evolved through the exploration programme. The final consensus is that it best fits Bonham's (1986) alkalic model and the Tertiary epithermal event was sustained by rifting associated with the break-up of Gondwanaland.

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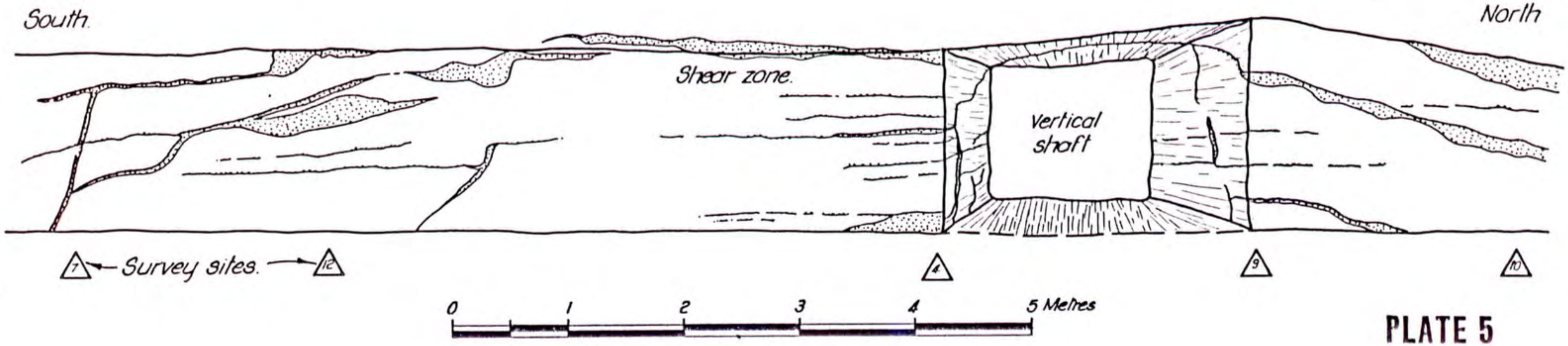

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1. Introduction.

The discovery and investigation of a Tertiary age Hot Spring Epithermal Event at the Springfontein Prospect in the Eastern Cape has been an unique and gratifying experience. Not only are occurrences of this type very rare in the South African Geological framework (especially within that part of the country) but the tectonic setting proposed for the model is unusual in a world context. It is this singularity that has prompted the writer to present the Springfontein Prospect as a case study, with a fair amount of detail into the exploration procedures and thought processes that went into the investigation.

In the regional geological context, the Springfontein location was already known for the rich accumulation of Tertiary age fossil plants as well as having been mined for barite. Recognition that these plants had been entrapped in a classical hot spring sinter terrace and that the barite was part of an epithermal event were some of the fruits of the exploration programme, mounted in mid 1984 by the writer, for the Anglo American Corporation of South Africa.

This dissertation attempts to set the background for the tectonic setting with a review of the regional geology and structure, siting by way of evidence for Tertiary volcanism, the findings of off-shore dredging samples of the Alphard Bank. The local geology is described detailing the outcrop and alteration features at Springfontein (including observations of the barite and gossan mineralisation and how they tie-in to the epithermal system). Evidence of characteristic epithermal mineralogy, element assemblages and alteration zoning is demonstrated, together with the corresponding exploration methodology that was applied (including soil, trench and borehole results).

A brief review of current classifications of Epithermal Precious Metal models and the problem of slotting the Springfontein Prospect into them is presented. Major concerns during the exploration of the prospect were to ascertain the orientation of the feeder fissure system, detect the level of boiling (generally the site of precious metal accumulation) and interpret the zonation. The fact that no economic mineralisation was intersected at the Springfontein Project does not detract from its status as a very interesting geologic phenomena.

2. Geology.

2.1. Regional Geology.

2.1.1. Preamble.

The regional geology is based on mapping by E.D.Mountain and published by the Geological Survey in 1974, as the 1:125 000 scale East London sheet (see figure 1). The region is predomi- nantly underlain by Beaufort Group sediments and intruded by Karoo dolerite dykes and sills.

The Beaufort sediments and the dolerite have been planed off by a surface that uniformly drops (an average of 18,6m/1 km) towards the sea, and undoubtedly represents the remains of an ancient marine platform (Mountain, 1946). Only minor remnants of Cretaceous marine limestone (Needs Camp and Killarney) and Tertiary deposits (Springfontein/Fort Grey) occupy topographic highs. Quaternary to Recent dune sands occur along the coastal strip. These vary from consolidated dunes inland to recent beach sands along the coast.

At face value this region is unremarkable both geologically and economically. "East London has received scant attention in geological literature, its chief claim to fame being in connection with the Needs Camp limestone deposits and the silicified plant remains at Fort Grey where barytes has *recently* been mined" (Mountain, 1946).

2.1.2 Beaufort Sediments.

Dark fine-grained siltstones and reddish mudstones of the Adelaide Subgroup underlie most of the region (figure 1). The fossil reptiles (dicynodonts) suggest the Endothiodon zone of the lower Beaufort series (Mountain, 1946). The horizontally laminated mudstones, wave and current rippled siltstones and thin discontinuous sandstone units represent a shallow lacustrine facies. A thickness of 990m was measured in the Soekor drill hole on Springfontein (Land, 1984).

Smaller areas of Tarkastad Subgroup rocks are preserved in fault-controlled blocks and synclines. The lower, Katberg Sandstone beds, represent a proximal, mixed load dominated, fluvial facies. A fully developed vertical succession consists of basal conglomerate followed by cross and planar bedded sandstone and siltstone. Channel patterns are braided and dominated by transverse bars.

An upper unit, the Burgesdorp Formation, consists of thick brown to red mudstones with minor blue, green-grey bands, probably flood plain deposits (Tankard et al, 1982).

The east-west trending Beaufort Basin trough-axis represents a northward shift from Ecca deposition. Fine-grained, varicolour- ed sediments are characteristic and vertibrate remains record a progression toward an increasing terrestrial environment. A succession of coarse, regressive wedges developed in response to orogenic pulses in the south and tapered northwards into a shrin- king Ecca sea (the Katberg Sandstone). Progressively drier climates prevailed during the closing phases of Karoo sediment- ation. Broad alluvial flats gave way to eolian dune fields, playa lakes, and ephemeral streams. Finally vast outpourings of basaltic and rhyolitic lavas heralded the end of Karoo deposition and the close of the Gondwana era (Tankard et al.,1982).

2.1.3. Intrusive Dolerites.

The dolerite intrusions belong to two distinct types, inclined sheets (sills) with wide outcrops and shallow dip, and relatively narrow and steeply dipping dykes (Mountain, 1946). Both types intrude the Beaufort sediments and occupy some 14% of the land surface (Figure 1).

The dolerite **sills** are fairly uniformly coarse-grained with a typical ophitic texture. Mountain (1946), distinguished two groups in the immediate vicinity of East London, those trending east-west and the others following the current coast line (ENE - WSW), both having northerly dips (200 to 300). In this early work he makes two very interesting observations:

i) Near the southern margin of the *Hood Point* dolerite sheet he observed two pale veins of granitised sediment or granophyre. One about 7,5 cm thick and roughly at right angles to the shore line (130 metres from the margin), the other about 30 cm wide parallel to the shore at 500 metres distance. Microscopically they consisted of a relatively coarse-grained intergrowth of quartz and feldspar with an appreciable quantity of bright green hornblende and chlorite.[1]

ii) The sheets crop out in relatively small isolated areas but at some locations the intruded sediments show signs of a high degree of metamorphism. Some of the feldspathic sandstone is appreciably granitised, whereas calcareous nodules have been typically altered to lime-silicate hornfels with hessonite garnet.[2]

Dolerite **dykes** are intruded along a dominant linear trend at 070° with subordinate trends of 340° and north-south. The dykes at 070° are the most common and persistent (up to 110 kms strike length) and are probably intruded along major faults, to which they are parallel. The dykes are all vertical to sub-

vertical in attitude and taper inland. They often display glomeroporphyrytic texture and only show minimal metamorphic effects on the intruded sediments.

2.1.4 Cretaceous.

Cretaceous lithologies are only sparsely represented in this region. The thickest and most extensive Cretaceous and Tertiary sequences in southern Africa lie offshore (under the continental shelf, slope and rise, and in the adjacent ocean basins). Locally only remnants of sedimentary cover along the edge of the buoyant Transkei Swell, mark high points in the Upper Cretaceous transgression (Dingle et al.,1983).

[1] Mountain relates that these veins were previously described as syenite, which were also shown to be more extensive at the northern end of the outcrop. Even then (1946) the exposure had been covered over by development, and no evidence of the veins has been observed.

[2] The sediment/dolerite contact at the Springfontein prospect has been extensively recrystalized and mapped as a 'hornfels' unit.

At Needs Camp, in the *lower quarry*[3] some 341m above sea-level, a small patch of fossil bearing chalky limestone occurs on the dolerite. The polyzoans and anthozoans, echinoids, brachiopods and lamellibranchs dating the formation as upper Cretaceous (Mountain, 1946). At Killarney (figure 1) some 6 kms to the east, flat-lying sandstones and marine limestone beds occupy a topographic high on the dolerite sill. Microfossil identification also dates these rocks as Cretaceous (Land,1984).

A relatively extensive outcrop of similar lithofacies in cliffs on the SW side of the Igoda River estuary has a basal sequence (3m thick) of white pebbly sands and conglomerate (resting on Beaufort Sediments) overlain by up to 20m of sandy limestones.

The inland projection of the surface, on which the Igoda lithologies are deposited, to the Lower Needs Camp rocks, gives a height well in excess (~600m) of the height at which the outcrop occurs, suggesting that there has been flexing of the present coastal region since Upper Cretaceous times (Dingle et al.,1983). The main depositories of marine sedimentation in the Cenozoic Era coincide with those of the Mesozoic Era and record several transgressive cycles which correlate with eustatic fluctuations. Depositional history was complicated locally by seaward tilting and epeirogenic uplift (Tankard et al.,1982).

2.1.5 Tertiary.

There is an even greater paucity of Tertiary lithologies in the region than those of the Cretaceous. Mountain (1974) described two **'silcrete'** occurrences, Mpetu Kop (on the Kei Mouth Road) and Springfontein (16 km west of East London on the Needs Camp road). The Mpetu Kop occurrence is very small, capping a 5m diameter hill (520 m elevation). It rests on sandstone and resembles silcrete of the Grahamstown District. The sporadic silcrete remnants of the Southern Cape are characterised by their ferrugenous siliceous 'cap rock' overlying extensively leached 'pallid zones' (the product of a 'deep weathering' phenomena). Although the patchy occurrences are recorded at differing elevations, it is possible to plot them on a 'curved' Tertiary surface extending from the Southern Cape as far north as Kentani Hill in the Transkei[4] (T.Partridge, 1985 personal communication). Silcrete is an 'absolute accumulation', introduced by the lateral movement of discharge from groundwater in areas of desilication and deposited by precipitation and crystallization induced by evapotranspiration. Although silcrete commonly supports stunted, xerophytic vegetation comprising low bush and sparse grassland over a thin soil cover, they generally sustain very little vegetation (Andrew, 1978).

[3] Note the **Upper or Western quarry,** only stratigraphically 17 metres higher, is dated by its fossils as Early Eocene and described in the Tertiary section below.

[4] Northward of the Transkei Swell the prevailing tropical Tertiary climate gave rise to the development of 'ferricrete' horizons rather than silcretes.

Considering their genesis involving desilicification and leaching of bases and the above observations on their vegetation environment, one would not expect silcretes to be particularly rich in fossils. A number of important factors distinguish the **Springfontein** occurrence from the rest of the Southern Cape silcretes: (i) the abundant Tertiary fossil plant remains; (ii) the intimate relationship to the barite veins; (iii) the lack of an extensive 'pallid zone' and (iv) its elevation does not coincide with the general Tertiary paleosurface, as do the rest of the silcretes. In his earlier work, Mountain (1946) suggested that the Springfontein occurrence must have had some hydrothermal origin and cannot be regarded as comparable in origin with the other silcrete occurrences of the Southern Cape. It is the objective of this dissertation to show that this occurrence has its origins in a Tertiary age epithermal event, therefore most of the above factors are dealt with in detail in the later sections.

The silcrete outcrops occur inland of the coastal limestones at altitudes above 300m. The silcretes are therefore regarded as of terrestrial origin whereas the limestones are clearly marine. Consequently the line between them is regarded as the limit of advance of the sea in post-Karoo times (Mountain, 1974). The *Upper* Needs Camp limestone has been worked for many years and is a National Monument. The deposit is about 400 m across with a total recorded thickness of about 8 metres. The lower part consists of pebbly and sandy, fine calcarenites and the upper part coarse calcarenites which become flaggy towards the top. The rocks are generally hard, recrystallized and yellowish grey in colour. Large *Perna* valves are a conspicuous constituent of the rock at outcrop. In thin sections the rock is a skeletal grainstone rich in molluscs, cirripeds, polyzoa and coralline algae cemented by microspar. The ranges of the Tertiary nannofossils indicates an Eocene (probably Lower Eocene) age (Dingle et al.,1983).

With continental separation in the Cretaceous, shallow seas expanded, thus increasing shoreline length and the influence of marine conditions. The southern Cape and Zululand alluvial facies were deposited by fluvial processes with moderately high runoff and humid conditions. This is supported by a diverse and abundant fossil flora. Off-shore a stratigraphic hiatus generally separates Lower and Upper Eocene rocks, the later Oligocene hiatus is even more pronounced. The episodic nature of oceanic ridge activity is fundamental in explaining this coastal stratigraphy. Sporadic volcanic activity persisted into the Tertiary. Aegerine-augite trachytes and related plugs of the Alphard Bank on the southern continental shelf have been dated at 58 $\mp$ 2 Ma (Dingle and Gentle, K-Ar 1972 in Tankard et al, 1982). Also included within this Alphard Bank igneous province are the olivine melilitite pipes in the Heidelberg region. Oligocene volcanic activity is further evidenced by 38 Ma olivine melilitite plugs in Namaqualand, and the 36 to 38 Ma Klinghardt phonolites of Namibia (Tankard et al.,1982).

2.1.6 Structure.

In the greater part of the mapped area the Beaufort sediments dip at shallow angles to the north. South of Springfontein, dips of up to 40^0S are measured. Springfontein, therefore lies near the northern limit of the Cape Fold Belt folding. East London is located near the axis of a broad anticline where the beds are consequently not highly disturbed (Mountain, 1946).

The majority of faults mapped are normal faults which strike east-west with downthrows predominantly to the south. They are hinged at the western end and are thought to be related to the Natal Monocline. There is no single case of a dolerite intrusion being demonstrably later than any fault. Consequently it has been assumed in mapping that all faulting is later than all Karoo dolerite. Faulting probably continued into the Middle Cretaceous (Mountain, 1974).

Although no structural features appear unique to epithermal deposits, regional structures are thought to play a role in localising igneous activity that supplies the energy to drive hydrothermal systems. On a more local scale, ground preparation through fracturing is important to produce not only the permeability necessary for solution migration but also open spaces for mineral precipitation (Romberger, 1985).

2.2 Local Geology.

At Springfontein the highest topographic level (>220 metres above mean sea level) consist of sinter type Tertiary deposits. These erosional remnants of a hot-spring, form two north-south striking siliceous siltstone-chalcedony capped hills which are separated by a 200 metre wide valley (see Figure 2). The western hill is called 'Soekor Hill' after the 1969 hole drilled by Soekor to a depth of 4557 metres (borehole SP1/69). This hill consists mainly of a fossil-bearing "silcrete" and has less chalcedony and veining than 'Beacon Hill' described below. The eastern hill is divided into two parts by a saddle, thus referred to as Beacon Hill South and Beacon Hill North (a trig beacon stands on top of Beacon Hill South). Beacon Hill South has the greatest thickness of chalcedony but less surface pyrite than Beacon Hill North.

The majority of the area is underlain by dolerite, which forms a prominent erosion surface just below the sinter rocks (~200 metres a.m.s.l.). The dolerite is part of a large sill with an east-west strike extent of 38 kilometres and is thought to dip northwards under the Buffalo River. The Soekor borehole intersected 197,51 metres of dolerite (see figure 20) beneath what Soekor described as 17 metres of siliceous breccia. On the southern part of the property, and in the deeply incised rivers, the dolerite crops out as a hard, crystalline, medium grained fresh rock, but at the southern contact of the sinters it is soft and highly altered, with feldspars altered to argillic clays.

The next erosion surface (~160 metres a.m.s.l.) roughly delineates the occurrence of the 'hornfels' mapped rocks. These are most noticeable in two ridges trending northwards from Beacon Hill North. The saddle between the north and south hills coincides with the northern contact of the dolerite sill and the Beaufort sediments, such that the sinter of Beacon Hill North overlies sediments and those of Beacon Hill South overlie dolerite. The albite-epidote hornfels is believed to be a contact metamorphic effect of the dolerite intrusion on Beaufort sediments. It crops out as a hard, very fine grained, dark grey, siliceous unit, which has a brown weathered rim (skin) similar in appearance to the dolerite itself.

The lowest erosion surface (<160 metres a.m.s.l.) is underlain by gently dipping light green shales and siltstones of the Beaufort group. These are generally highly fractured and poorly exposed.

East-west grid lines were cut at 100 metre intervals across the property. The north-south (10 000) base line was laid out from the beacon (see Figure A1). The area is densely vegetated with thick soil cover, limited outcrop and virtually no visible lithological contacts. Grid line traverses over the sinter hills averaged 28% outcrop, and considerably less away from the hills. The resistant nature of the chalcedony results in scree and float being found at great distances from their origin.

An attempt was made during mapping to differentiate the sinter rocks into various units. However, considering the amorphous nature of modern day geyserites and hot spring mud-pool deposits, these distinctions are not as clear-cut on the ground as they may appear on the map (Figure 2). Most sinter types grade into one another and no obvious contacts are present. Throughout the sinter, original opal has been transformed to chalcedony (Sillitoe, 1986). The sinter terrace appears to be intercalated with silicified siltstone rich in plant remains, many of them in positions of growth. Sillitoe (1986) suggested that it appeared to represent input of fluvial sediment into parts of the sinter apron.

The most distinctive and abundant rock type is the "Fossil-silcrete" of Soekor Hill. This unit commonly comprises a fine grained, light pink to grey rock with a siliceous matrix containing fossil plant fragments which vary in both size and abundance according to location (see Plate 2). It is also the only unit common to both the Beacon and Soekor Hills. The fossils from Soekor Hill were the subject of a comprehensive 1934 paper by Prof. R.S.Adamson in the Annals of the South African Museum Vol.31. He describes the majority of fragmented remains as woody stems and roots identified with Podocarpus, some gymnosperms which resemble Widdringtonia and Gleichenia ferns. He considers the silcrete as representing a solidified soil: the fossils being part of a land flora, and the rocks of Tertiary age.[5]

'Derivatives' of the *fossil-silcrete* are:-

(i) The **chert** unit mapped on Soekor Hill which forms the resistant rim of the hill, is usually hard and glassy, exhibiting a conchoidal fracture. A white matrix is common with, in some cases, minute (~1mm) fossil plant fragments.

[5] Several specimens of the Springfontein fossil plant material were forwarded to Anton Scholtz at Stellenbosch University during the latter part of 1984. In conjunction with colleagues at Bloemfontein, age-dating of the pollens confirmed a Tertiary age, but this work was not pursued or documented to my knowledge - R.L.N.

(ii) The silcrete breccia, consisting of coarse (~1-3cm) angular fragments of fine grained pink and brown silcrete - usually devoid of fossils.

(iii) The sugar breccia - a small localized outcrop on the top of the southern end of Soekor Hill. This appears to be a re-worked fossil-silcrete which is soft, bright orange and has the appearance of a badly made brick. This unit has an abundance of fragmented fossil remains and through a hand lens, the rounded matrix grains appear recemented by chalcedonic material.

The crests of the Beacon Hills are an amorphous mass of layered, vuggy, crystalline, white and grey chalcedony. At the trig beacon this unit has the morphology suggestive of a 60m diameter shallow basin or vent plunging westwards. Rimming this unit on the South Hill is a unit mapped as **'dark sinter'** - a vuggy, light, low density grey to black skeletal rock with rhombohedral boxworks (equivalent to the 'sponge' rock at Borealis?).

Apart from the layered chalcedony on top of the hills, and the large portion of 'fossil-silcrete', the rest of Beacon Hill (North and South) consists of an indistinct unit mapped as 'chalcedony breccia'. This unit is generally lumpy in outcrop, contains open vugs, is usually bright red and yellow (gossany), appears less siliceous than the layered version, and seems to contain more pyrite.

All the above units are complicated by **intrusive** chalcedony and barite veins. These are commonly zoned with minor black and red banding and cross cut the sinter, dolerite and sediments. In the siltstones, narrow silicified selvages border the veins. The dolerite with chalcedony veining is more strongly weathered than that not carrying veins. Poor outcrop and widely dispersed talus slopes make structural observations difficult at Springfontein. Dip estimates of the Beaufort sediments are possible in the underground workings (section 3.1.1. below) and these conform with the gentle dips (4° to 12° North) of the regional observations. Geophysical interpretations (section 4.2.1. below) suggest that the sinters are terminated in the south by a major east-west fault, and that the Beaufort Sediments are preserved in a graben-type structure within the dolerite (Nichols, 1985).

The classical epithermal deposit alteration and oxidation features are not particularly evident in outcrop at Springfontein apart from the localised development of white clay at the southern termination of the sinter. These features are however very prevalent in the trenches and boreholes and are thus described later (section 3.2.4 below).

3 Case History

3.1 Mineralisation.

3.1.1 The Barite Workings.

The barite at Springfontein was sporadically mined up to the Second World War and used by the East London paint industry. Records indicate that 50 to 60 tons per month were mined in 1944 with reserves estimated at 33 000 tons (Land, 1984). The mineralisation has been described as follows:" two main veins as much as 20 feet apart in places but coalesce in other places to form a single vein of 27 inches". Also that:" these veins strike 600 feet *east-west* (sic) and dip 45° South". Development proved over 300 feet of strike extent down to a depth of 60 feet. They describe the quality as good but hand cobbing was necessary to discard the discoloured (iron oxide film) barite near surface (Braber, 1976).

The orientation of the barite veins quoted in these references is incorrect as field observations, and the orientation of the underground cross-cut and stope show that the strike of the main vein is almost true north-south with a 65° dip to the east. The workings (see Figure 3) consists of an open pit (11,8 x 18,2 and 6 metres deep); a 13 metre underground adit with an approximately 25 metres deep 45° (E) stope; a 14 metre deep vertical shaft and a few prospect trenches, all of which are situated on the northern end of Beacon Hill (grid reference 11650/10125 on figure 2).

Table 3.1.1. : OPEN PIT ANALYSES.

(1 - 4 South wall: 5 - 9 North wall)

No.	Description	Au	Hg	Ba*	As	Sb	Sn	WO_3	F
		by AA(all ppb)			*by XRFME(ppm)*				
1	1m thick main barite vein	30	3210	8,6%	518	506	469	228	7,7%
2	weathered light grey sandstone	5	440	1723	6	17	1	11	-0,1%
3	ditto	10	360	4558	13	15	2	15	0,0
4	30cm barite vein	15	2210	8,8%	577	551	516	264	7,6%
5	weathered white mudstone	5	80	5987	12	14	1	10	-0,7%
6	20cm chalcedony vein	25	900	4,4%	128	142	86	54	1,7%
7	35cm barite/chalcedony vein	<5	120	9,1%	593	595	556	287	9,6%
8	60cm chalcedony vein	25	3920	5,4%	187	191	128	78	2,1%
9	light grey silty sandstone	5	100	3925	11	16	6	15	-0,1%

*NOTE: All Ba results exceed calibration and thus probably enhance the As, W, Sb, Sn and F results. No silver greater than 0,5 g/t registered for the O.P or U.G. samples.

The open pit gives the best exposure of the main barite vein in its south wall (Plate 4) where it varies in thickness from 30 centimetres to 1,2 metres. Nine grab samples (O.P.1 to O.P.9) where collected from the pit, the highest Au value (30 ppb) coming from the main barite vein itself.

The barite occurs as coarse, inter-locking, bladed crystals in cross-cutting veins and narrow sills in fine grained weathered Beaufort sediments in the pit. Subsequent to mining activities - both the open pit and the underground stope have served as a dumping site for refuse and carcasses, making access unpleasant and hazardous. At the base of the south wall of the pit there is an unexplored incline of approximately 10 metres depth in the direction of the stope.

The underground workings (Figure 4) are located 30 metres south of the open pit. Seventeen continuous groove samples (UM1 - UM17) were taken from the southern wall of the east-west oriented adit (note samples 9 to 13 were taken from the roof of the cross-cut situated between the adit entrance and the vertical shaft). Because of the dangerous condition of the stope, no attempt to map or sample it was made. The highest gold value (UM4 at 55 ppb Au) comes from the sample adjacent to a secondary barite vein in the adit. Figure 5 shows some of the analytical results of these samples (gold and mercury {ppb} by atomic absorption and the balance by XRFME{ppm}). The main barite vein is represented as sample number 12 in the roof of the cross-cut. This vein occurs again on surface at the east edge of the vertical shaft.

The Beaufort sediments in the underground workings are well jointed, fractured, fine to very fine grained, light yellow brown, silty sandstones. The chalcedony/barite veins intrude vertically up joint planes as well as into the bedding planes (10° to 12° west), at irregular intervals (see plate 5). The veins often have a thin (1 - 3cm) silicified selvage. Only very minor sulphides are present in the workings (Nichols, 1985).

3.1.2 The Gossans.

Three locations of pyrite-rich (~50%) gossanous material are present on Beacon Hill North. Sample 83BLR1 collected by B.N.Land in 1983, near the old barite prospect trench (grid location 11385/10055), initiated the interest at Springfontein because of its elevated gold and silver values (Table 3.1.2, No.1.). The second gossan is located in another old east-west oriented prospect trench, made by the barite workers, at grid point 11228/ 10075 (sample number 84RNR8 No.4 in table). The third site was uncovered during bulldozing operations for the first drill site at 11400/10150, and is represented by the top 40cm core sample number 14/1015/1 (No.6 in table).

<u>Table 3.1.2.: Gossan Sample Analyses.</u>

No.	Grid Location	Au	Ag	Ba	Sb	Sn	Te	As	Hg
		ppb	g/t	ppm	ppm	ppm	ppm	ppm	ppm
1	11385/10055	1070	26,6	1151	–	52	39	–	ND
2	11380/10050	265	3,6	755	–	10	19	–	ND
3	11375/10060	700	12,0	1595	38	446	42	12	43
4	11228/10075	2000	4,3	556	39	5	13	197	30
5	11230/10070	90	1,8	958	56	2	16	141	11
6	11400/10150	300*	20,5*	4,8%	204	134	273	364	62

*Au and Ag by FIRE assay.

R.Corrans (1985, personal communication) suggested that the large amount of pyrite might be a function of the abundance of liberated Fe (acid sulphate leaching from ferromagnesian minerals in the country rocks) which was available for reaction with H_2S in the hot spring system. Further that the Au values of the gossans are merely traces which escaped boiling/precipitation at depth, and thus high pyrite areas will not necessarily correlate with Au content (Nichols, 1985).

Petrographic studies of the Springfontein gossan material showed that very fine-grained (ranging from ±0,006 mm to submicron sizes) particles of pale (admixed with silver or mercury?) native gold particles were invariably enclosed in pyrite. Shattered pyrite grains constituted approximately 68 per cent of the sample with interstitial chalcedony making up the rest of the sample. Small to trace amounts of marcasite, arsenopyrite and pyrrhotite accompany the pyrite and minor quantities of a turbid, highly siliceous, clayey component are occasionally associated with the chalcedony. Boshoff (1985) concluded that the peculiar subspherical deformation structures displayed by the gossan are the result of igneous-hydrothermal processes and that the dynamic deformation was most likely produced by a sudden change of the confining pressure and drastic increase in volatiles (i.e. boiling), during emplacement of the pyrite-bearing veins. This is an important observation, since in many deposits, the boiling interval is associated with the zone of most intense mineralisation (Cole and Drummond, 1986).

3.2 Applied Exploration.

3.2.1 Geophysical Surveys.

Although not well documented for this type of occurrence at that time, various geophysical surveys were instituted for the Springfontein Project with some rewarding results. These surveys were conducted largely as an aid to mapping and structural interpretation, since the physical parameters of the mineralisation itself do not offer any specific geophysical response.

3.2.1.1. Magnetic Survey.

The Government Aeromagnetic survey displays a complex linear east-west pattern over Springfontein. This reflects the regional east-west structure and is probably strongly influenced by the major (east-west striking) dolerite sill. Some features of this survey are: a linear magnetic high centers over the gossan pit (at the northern end of Beacon Hill); a magnetic low lobe protrudes from the west as far as the Trig beacon (at the southern end of Beacon Hill).

The ground magnetic survey, conducted on the 100 x 25 metre grid (Figure 6), reflects the lows around the Trig beacon but imparts a strong north-south, linear magnetic high pattern, flanking Beacon Hill. Simplifying the pattern by selecting the values greater than 300 nT, we see that the north-west magnetic high coincides with the postulated dolerite/hornfels contact, whereas the north-easterly magnetic high follows the hornfels/ Beaufort sediments contact. The westernmost high forms a sinuous pattern down the center of Soekor Hill. Using values less than 50 nT, a prominent magnetic low follows the creek between Soekor and Beacon Hills and another N-S low occurs about 100 metres east of the barite workings, flanked on either side by highs.[6]

[6] A soil and stream sediment mercury geochemical signature coincides with this magnetic anomaly.

In his interpretation of the magnetic data (Figure 7), Geophysicist L.Antoine, suggests that it represents a horst and graben-type topography of the underlying dolerite sill. The magnetic highs represent dolerite highs and the lows the down thrown blocks, or highly altered zones. Noting that the N-S fence just west of the trig beacon runs over the crests of Beacon Hill North and South, this would place the sinter on top of a graben (or altered zone) with dolerite horsts on either side, whereas the Soekor sinter is located on a horst. This fundamental difference in 'basement' morphology could be an explanation for the lithological differences between the two hills and the lack of veining observed on Soekor Hill. Antione also interprets a number of faults from the magnetic data, the southern E-W fault coincides fairly well with the abrupt termination of the sinters in that area. The postulated NE-SW fault correlates with the northern end of the sinters and the N-S faults with the river valleys at Springfontein (Nichols, 1985).

3.2.1.2. Electrical Survey.

During September 1984 an orientation Induced Polarisation (I.P.) survey was conducted over the sinter hills and the barite workings at Springfontein. Initially the dipole-diplole method was used which produced an anomalous zone in the northern 'barite workings' area and a broad high polarized zone trending N-S over Beacon Hill (Figure 8). L.Antoine decided that the gradient array method would be more useful at Springfontein, and using the two longest E-W cut lines of the grid (10800 and 11700) for transmission electrodes, found a marked N-S oriented polarised zone along the eastern flank of Beacon Hill, with a more resistive zone to the west. A follow-up survey using the gradient array method, but locating the transmission electrodes on the 10 000 N-S base line (i.e. sending the current along the strike of the anomaly). This technique gave a stronger contrast anomaly and in addition the center of the anomaly is displaced approximately 100 metres west (i.e. to the west side of Beacon Hill). The author's 'layman' interpretation of this phenomenon is that:

(i) The polarized anomaly is the N-S striking pyritic/argillic alteration zone seen in the boreholes (section 3.2.4 below).
(ii) This zone is believed to be dipping east at about 60°(based largely on the orientation of the barite vein in the underground workings).
(iii) When using the transmitting electrodes on lines 10800 and 11700 (i.e. E-W), they were further apart than when oriented N-S and therefore intersected the argillic zone at greater depth.
(iv) By locating the transmitting electrodes on the 10 000 line (i.e. N-S), they are closer together, and thus detect the argillic zone at a shallower depth (near surface), and therefore confirm the orientation of the zone (point (ii) above).

The geophysical surveys confirm the steep north-south oriented structure and on reflection, move the emphasis away from the sinter outcrop towards the north. Where indications of more intense geochemical and geophysical activity suggest larger fractures (and permeablity structures?) in the vicinity of the old barite workings.

3.2.2 Remote Sensing.

An interpretation of Landsat image (Figure 9) P181R83 (A.Jack 1984 personal communication) showed that although the main structural trends are either sub-parallel to the coast or east-west, especially north of the Kei River, there is a zone between East London and the Bridle Drift Dam of north trending lineaments. These north-south lineaments may control the distribution of the Tertiary age deposits at Springfontein and any mineralisation associated with them.

The continental margins of southern Africa are attributed to differing styles of fragmentation, the East and West being divergent and the South and South-East transform in nature. The continental edge off SE South Africa is narrow, precipitous and straight, and follows the trace of one of the longest (ca.1 300 km) continental margin offsets in the world: the Agulhas Fracture Zone (Dingle et al.,1983). Whilst on a mega-scale this transform separation appears straight and smooth, on a local scale one would expect some irregularities in its morphology (particularly as it crosses lithologies of varying crystallinity and competence). The north-south lineaments referred to above are thought to represent orthogonal and oblique peripheral faults to the main shear trend of the continental separation. These 'torn-edges' could conceivably be relatively deep-seated fractures, particularly if propagated along pre-existing weak spots, thus providing the plumbing for abyssal hot fluids that drove the hydrothermal event.

Another observation from this early interpretation (which pre-dated the current technologies in clay and iron band manipulations of TM spectral data) was that the sinter hills could be pinpointed by a distinctive pale 'orange' tone on the false- colour image. It was initially thought that this was due to the reflective properties of either the siliceous capping or the marked argillic alteration. However subsequent ground checking of similar toned occurrences in the region, revealed a universal occurrence at these locations (and the Springfontein site) of a broad leafed 'milk-weed' that grew in particular abundance and was not lithologicaly specific at all. Neither the regional geochemical programmes nor the remote sensing/aerial photograph studies at the time ever located another similar 'Springfontein' occurrence in the region. With the latest knowledge and technologies in the remote sensing field, a second study of the region could prove worth while using the clay band formula's to highlight the associated argillic alteration. The Springfontein occurrence is shown (geophysically) to be cut off at the south by a major fault and terminates in the north at the (fault directed)[7] Buffalo river. An extension of the occurrence might conceivably exist displaced some distance laterally along either of these faults.

Quite coincidently, almost due northwards, across the Buffalo River, stone is quarried for the building industry. Here they excavate a particularly silicified type of Beaufort sandstone, which although showing pervasive siliceous alteration, when investigated was found the be geochemically barren of any other elements.

3.2.3 Geochemistry.

[7] The terminal portion of the Buffalo River in East London is renowned as one of the longest, straight, navigable sections of river in the world.

In terms of impact, the classical 'bulls-eye' zonation of geochemical elements in the soils, is second only to the impressive sinter outcrop at Springfontein (see figures 10 & 11). An important factor in the soil distribution patterns is that the mercury continues northwards, whereas the barium centers on the old workings (Figure 29). Many of the other elements also peak and show concentric zoning in this location, at the northern end of Beacon Hill.

The geochemical soil sampling programme on the prospect was designed after a fairly detailed orientation study.[8] Findings of the study indicated that the greatest contrast anomalies were obtained from B-horizon samples (10 to 45 cms depth) that were sieved to a relatively coarse (+10 to -35 mesh) sieve size. The samples were collected from a close-spaced (25m centers) surveyed grid over the entire strike of the sinter hills and proportionally wider spaced (50m to 200m centers) in the surrounding areas (effectively covering the whole optioned property).

All analyses were conducted at the Anglo American Research Laboratories in Johannesburg. The samples were analysed by atomic absorption methods for gold, arsenic and mercury (cold vapour technique) as well as by the 36 element X-Ray Fluorescence facility (XRFME). Extreme care in sample handling and preparation was exercised in an attempt to overcome some of the problems inherent in gold sampling (i.e. nylon mesh and large bulk samples, etc.). The elemental response of more than 20 elements and/or element ratios were plotted and contoured for the soils (Nichols, 1985). Detailed geochemical interpretation was further enhanced by the fact that stream sediment, surface rock and borehole cores were also analysed by these same methods allowing direct lithogeochemical correlations (compare Figure 12 with 13a and b). Analysis by the XRFME method is problematic, since spectral overlap of some elements can mask the response of others. At a location such as Springfontein the barium and strontium levels often exceed the calibration levels of the instrument and tend to enhance U & Rb, and depress As, Ni, Ta, Pb, Th, Cu and Zn (F.Baumgartner AARL, personal communication, 1984). This is particularly evident when using the method for rock analysis, since the calibration is routinely designed for a soil matrix. This partly accounts for the negative values registered for some elements. Notwithstanding the forgoing the package is extremely useful and relatively cheap.

The geochemical recognition criteria for epithermal deposits are well documented. The

[8] This orientation study is described in some detail in Appendix I.

ubiquitous gold suite of associated trace elements, arsenic, mercury and antimony, is an important indicator of gold mineralised rock. Extremely high values for these elements are not necessary to define a favorable area. Instead, it is sufficient that the suite of indicator elements is present. Also jasperoidal[9] breccia and jasperoid veins generally occur near ore, even when they themselves may not carry high gold values (Bagby and Berger, 1988). In their modeling of the geochemical aspects of sediment-hosted, disseminated precious-metal deposits, these author's quote the following general trace element ranges: As from 100 to 1000 ppm; Hg from 0,2 to about 30 ppm; Sb from 5 to 200 ppm and Barium from 30 to about 1000 ppm. The Springfontein values (see next section) fall comfortably within these estimates (Figures 13 a and b).

The distribution of the trace-element patterns are related to the physico-chemical processes that occur during the hydrothermal system. The system-wide trace-element patterns observed in ore deposits represent the summation of a multiplicity of processes that are related to the time and space history of the geothermal system, the variations in the fluid chemistry of the system, the chemistry of the host rocks, and the physical nature of the heat source and the hydrothermal system including fracturing, permeability and brecciation (Silberman and Berger,1988). Mercury is common in practically all types of hypogene gold deposits, especially in those of younger Tertiary age. Mercury minerals are invariably late and commonly associated with stibnite and arsenic minerals (orpiment and realgar). Deposits rich in sulphosalts are generally enriched (>5ppm) in mercury (Boyle, 1979).

The geological mapping and soil geochemical results from Springfontein are consistent with an epithermal hot spring type model with associated gold mineralisation. The sub-surface feeder fissures for the mineralising system were most well defined by mercury in soils (see Figure 14), supported by elements As, Sb, Bi and Mg (depressed). At least three major north-south trending zones where postulated (see overlay) from the data for further investigation by drilling. Other elements from the XRFME data proved useful in establishing the geological boundaries in areas of poor outcrop (particularly Ni and $TiO2/Zr$ for dolerite; Bi for distinguishing hornfels from sediments - Nichols, 1985).

3.2.4 Drilling and trenching.

The final and most expensive exploration phases at the Springfontein prospect comprised 588 metres of trenching (0,6 to 3,00 m depth); 740 metres of percussion drilling (in 5 holes varying from 100 to 200m inclined depth) and 1450 metres of diamond core drilling (in three inclined holes). Both the trenching and percussion drilling programmes, were conducted to establish structural orientations of the feeder fissure zones, in preparation for the deep diamond drilling.

[9] These authors classify sediment-hosted gold deposits from the Carlin-type to Jasperiodal end members. Their definition of jasperiods as i) composed predominantly of silica, which in most places as in the form of aphanitic to fine-grained quartz, and ii) jasperoids form by replacement of the enclosing rock.

3.2.4.1 Stratigraphic Drilling.

Initially two stratigraphic diamond core holes were drilled (14/1015 and 9/1035 see locations on Figure 2) and completed by February 1985. The former was drilled at grid point 11400/10150 on the eastern flank of Beacon Hill North, some 90 metres northeast of the main gossan (GOP on Figure 2). The rationale for this site was based on the strongly polarized unit indicated by the initial IP survey, the high arsenic values in the soils at the north end of the hill, as well as its proximity to the only gold value known at the time (i.e. 1,07 g/t Au at GOP).

On levelling the site for the rig with the bulldozer, some gossan rubble was unearthed, thought at first to be downslope talus from the original gossan site. However, the first 40 centimetres of core consisted of pyrite-rich, vuggy, weathered gossan assaying 0,30 g/t Au; 20,5 g/t Ag and 62 ppm Hg. Subsequent interpretation showed that this gossan was the sub-surface expression of the easternmost mercury 'linear' (Hg trend 1 on the overlay).

Core recovery at the top of the hole was very poor and the hole intersected 20,50 metres of oxidized, flat lying (60°-75° to core axis) bedded Beaufort siltstones with numerous chalcedony, barite and gossanous veins (Figure 17). A 50cm breccia zone of coarse angular fragments occurs at the base of the sediments. The top of the dolerite sill at 20,50 metres had a 2,50 metre zone which was highly oxidized with completely argillised but angular feldspar laths.

The dolerite sill largely consists of fine to medium- grained, green-grey, crystalline, well consolidated rock with sporadic intrusive chalcedonic and calcite veins. The base of the sill at 283,48 metres has a 98 centimetre 'chill' zone of ultra fine crystals. The hole terminated at 296,13 metres in sediments.

The identified target zones of the hole were:

(i) The pyrite rich intensely argillised alteration zones. These consisted of poorly consolidated, medium grain white/yellow rock (where feldspars had altered to soft clay minerals). The zones typically have up to 5% pyrite and appear to be advanced argillic alteration haloes (selvages) to intrusive veins. The zones vary in width from 0,5 to 23,30 metres, occur sporadically throughout the hole and have diffuse contacts. They are best emphasized geochemicaly by high Hg and S and low Mg. The major argillic alteration zone from 49,60 metres had at its center a 1,67 metre thick massive chalcedonic breccia vein with open vugs and abundant pyrite. Apart from the gossan at the top of the hole, the highest gold result (0,12 g/t Au) occurred just above this breccia vein along with silver values up to 3,25 g/t Ag.

(ii) Intrusive veins and breccia zones, most of which have accessory pyrite. The composition of most of the veins was either chalcedonic or calcitic with increasing calcite/manganese veins towards the base of the hole.

The second borehole, 9/1015, was located 500 metres south of the first and was designed to test the lateral zonation of the alteration intersected in the first hole. The units intersected were very similar to 14/1015, the hole collared in dolerite and went into Beaufort sediments at 251,25 metres (Figure 19). There was a 55cm chill zone at the contact and the hornfels unit (5,05 metres thick) was slightly thinner than that in the first hole (7,88 metres). Borehole 9/1015 also intersected a number of pyrite rich alteration zones and intrusive chalcedonic and calcitic veins. Two major alteration zones with thick vuggy chalcedonic veins were intersected at 118,85 and 146,80 metres separated by 11,5 metres of hard crystalline (fresh) dolerite (Nichols, 1985).

Since structure, particularly fracture analysis, provides the main clue to flow patterns in fossil systems (Heneley, 1985), great attention was paid to the orientations of the veining and fractures in the cores. However because of the intense alteration and poor rock consolidation the contractors were unable to provide oriented cores, and observations were limited to measuring the angle between the long axis of the core to the different features. Computations of the two maximum angles were plotted against the surveyed borehole trace. This left one with a 'best' case of a vertical system or 'worst' case where the system dipped west.

3.2.4.2 Trenching Programme.

The above drilling confirmed the N-S strike of the system interpreted from the remote sensing, geophysics and soil geochemistry. However, the angles of the veins intersected in these borehole cores, the orientation interpreted from Gradient Array IP survey cross-sections (Figure 15) and the structures observed in the old barite workings (section 3.1.1 above), gave conflicting orientations of the dip of the system. Mineralogical work on the cores established temperatures of formation in alteration minerals, suggesting that they where still above the typical boiling bonanza zone (Appendix II). The trenching programme was undertaken (to resolve the orientation dilemma), in preparation of siting a deep diamond drill hole to intersect the 'bonanza' zone.

Four trenches (Figure 2) were cut into the soil to bedrock, varying in depth from 60 cms in the north (over Beaufort sediments) to greater than 3,00 metres in the south (over dolerite). Some 182 continuous bedrock groove samples (ranging from 1,50 metres to 5,00 metres in length) were cut from the base of the trenches. Each trench, starting in the north and working southwards, is described in the following paragraphs.

(i) The northernmost **116 Trench** is located along the 11600 E-W traverse between grid points 1000 and 10140 (Figure 2). The eastern end of the trench is 33 metres south of the mouth of the old underground adit. The trench was located to traverse across a large soil mercury anomaly, with two stations greater than 1000 ppb Hg.

Beaufort sandstones and siltstones were exposed within 80 cms of soil depth. Very few alteration (clay) zones were apparent, but several intrusive veins were exposed, particularly at the eastern end of the trench, coinciding with the large barite veins of the old workings further to the north (Figure 16) Orientations of these veins indicate a NE-SW strike and predominantly easterly dip (~60°). Apart from the 45 three metre groove samples of the trench base, 21 vein samples were also collected for analysis.

Very high mercury levels (up to 35 ppm) were returned from the central 40 metres of the trench, whereas the soil sampling anomaly occurred at the western end of the traverse. This displacement is probably due to down slope creep. The highest mercury samples have almost coincidental gold and silver peaks (also Ba and As), which can be related to intrusive veins and associated narrow alteration zones. The most anomalous vein sample (No: 10050,3) of 290 ppb Au; 6,1 g/t Ag and 110 **ppm** Hg, shows very little correlation with its companion groove sample (No: 10051) which returned only 35 ppb Au; <0,5 g/t Ag and 1920 **ppb** Hg. The major barite occurrence in the eastern end of the trench shows elevated Hg and As but low precious metal response (Figure 16). Of interest is that this eastern zone corresponds to the high resistivity IP zone, whereas the area west of the mercury highs, coincides with a low resistivity zone. The whole trench covers a generally low magnetic zone, unfortunately not reaching the spectacular high/low couple located 125 metres east on traverse 11600 (Figure 6).

(ii) **Trench B.T** is located on the northern flank of Beacon Hill, and trends NE-SW along the surface trace of borehole 14/1015, towards the discovery gossan site (GOP on Figure 2). The initial 43 metres of trenching exposed the Beaufort Group sediments through about 1 metre of soil cover. The trench was designed to expose alteration zones at surface discovered in the borehole, from 49 to 73 metres (assuming a 65^0 East dipping system, i.e. the underground observation).

The 22 continuous groove samples (B.T.) comprised mainly slightly altered siltstones and sandstones. Only the north- easternmost 11 metres contained chalcedony/barite veining, clay alteration and gossanous fragments. These 6 (NE end) samples (varying from 1 to 2 metre lengths) returned extremely high mercury (maximum 230 **ppm**), elevated silver (maximum 19 g/t); gold (0,28 g/t); arsenic (553 ppm) and barium (3,6%). The high Hg levels are attributed to very fine red needles of cinnabar identified within gossan fragments.

The trench was deepened (~2 metres) and extended 30 metres eastwards towards the borehole collar, from which 14 samples (B.T.D.) were collected (see Figure 17). The over-lapping 5 samples failed to repeat the initially high values, but the deeper material consisted more of clay (alteration) material than gossan. Two gossanous chalcedony breccia zones closer to the borehole collar returned elevated values: mercury (max: 57,5 ppm) silver (11 g/t); gold (0,17 g/t); arsenic (960 ppm) and barium (7,3%).

It is possible (on Figure 17) to relate the borehole alteration zones to surface clay zones, particularly using the mercury levels. In the borehole, the major argillic alteration zones are separated by a massive chalcedony breccia vein. By tying the latter to a similar vari-coloured gossany chalcedony breccia (approximately mid-trench) on surface, one derives an almost vertical orientation (880E for the feeder fissure system. Ignoring the surface gossan in the borehole, it is also possible to postulate an increase in Au and Ag levels with depth and a decrease in Hg with depth, implying a subtle mineral zoning consistent with epithermal gold mineralisation models.

(iii) The **111 Trench** comprises 69 metres of shallow trenching along the 11100 traverse, conducted to locate the surface expression of the feeder fissure system, based on a somewhat simplistic interpretation by the writer, of the IP data (see section 4.2.1.2 above). Although not deep enough, material at the suspected IP peak comprised extremely weathered, clayey 'fossil-silcrete'(see Figure 18).

One of the 23 samples (3 metre groove lengths) returned the highest gold value (2,7 g/t Au) from Springfontein. This sample consisted largely of silcrete breccia and dark sinter, intruded by chalcedony veins. Percussion borehole P2 was later drilled to a depth of 150 metres to investigate the mineralisation beneath the trench.

Below the top metre of weathered sinter, the hole intersected increasingly less weathered dolerite to 13 metres. At this point a 6 metre zone of clay and chalcedony was intersected, followed by fresh dolerite to the end of the hole. This break in the dolerite is interpreted as representing a fault, and the sample of the chalcedony-rich material returned the highest gold value (95 ppb) in the hole. Tying these two samples of "high" gold in both the borehole and trench, gives an orientation of 55° to the east! This observation is supported by the mercury results, where the adjacent borehole sample (No:10) is the highest (12 ppm Hg) and ties to the highest in the trench (No:19 with 5140 ppb Hg) adjacent to the trench gold high.

A steeper orientation (~71°E) is possible by tying the surface gold sample (No:20) with a 5 metre alteration zone in the borehole at 25 metres (40 ppb Au). A similar orientation (~75°E) arises by tying the 'extreme weathering" zone on surface with a deeper borehole alteration zone (5 metres at 67 metres). An almost vertical (87° to 88°E) tie-up was interpreted by tying trench sample number 15 (2,0 g/t Ag and 4,5 ppm Hg) to the lower (67 metre) borehole alteration zone.

(iv) The **109 Trench,** 305 metres along the 10900 traverse was designed to: **firstly** locate the surface expression of the alteration intersected in diamond drill hole 9/1015; and **secondly** to investigate the two prominent soil mercury trends on the western flank of Beacon Hill South (see figure 2 and the overlay). The depth of the trench varied from 40 cms over outcrop to as much as 3,65 metres in clay zones. In the valley between the two sinter hills, the soil profile exceeds 3 metres and hence no bedrock was intersected, but boulder fragments indicate that the zone is underlain by dolerite.

The easternmost 21 metres of this trench uncovered extremely weathered clay. Two samples (85 RNR 72 and 73) of the clay were petrographically studied (Appendix II), and identified as hydrothermally altered dolerite. Of particular interest is the description of 85 RNR 73 (closest to the sinter contact) which F.Boshoff (AARL) described as "a dolerite which has been hydrothermally brecciated and subsequently argillised and silicified". This ties in very well with the magnetic interpretation of a fault along the eastern flank of Beacon Hill (also see the description of percussion hole P3 below). The predominant clay mineral identified in these samples was montmorillonite and the characteristic epithermal zeolite mineral, mordenite, was positively identified by XRD analysis. This surface clay zone is correlated to the major argillic alteration zones intersected from 124 to 162 metres in borehole 9/1015. The eastern end of the surface clay zone could not be determined due to the proximity of the pineapple fields. The western end, being a fault contact between the sinter/dolerite, ties in with the base of the borehole intersection to give an orientation of 86°E (see figure 19).

The 78 groove samples from the trench floor were generally 5 metres long, but were reduced in places to 1 metre lengths, to accommodate narrow geological variances. Apart from the eastern clay zone the major discovery of this trench was a 5 metre gossan exposed on the western flank of Beacon Hill. Analysis of the samples returned a number of high mercury zones and some elevated gold in the gossan (765 ppb Au). One interpretation of the geochemical pattern from the trench samples, is that of rising mineralised fluids unable to penetrate the siliceous sinter cap, travelling horizontally to the edges giving leakage anomalies at the periphery. This holds for the southern part of Beacon Hill, but both the North Hill and Soekor Hill have geochemical trends right over the crests. The writer prefers the interpretation that although the sinter caps do, to some extent, inhibit fluid flow, the geochemical responses reflect the surface expression of sub-vertical feeder fissure zones, particularly the slightly east of north linearity of some of the soil anomalies (tying in with orientations of veins in the northern trench).

In summary, the trenching exercise did, in fact, reveal orientations close to vertical for the epithermal system. These observations however, were only convincing in hindsight, after later substantiating evidence from both the percussion drilling and the deep hole. The trenching also uncovered the gold mineralisation of 2,7 g/t Au in Trench 111, the gossan (765 ppb Au) in the 109 Trench and revealed cinnabar crystals (230 ppm Hg) in the B.T.Trench (Nichols, 1986).

3.2.4.3 Percussion Drilling Programme.

The zones of interest uncovered by the trenching exercise were invariably very weathered, a product of the alteration associated with the hydrothermal system. Consequently no structural observations could be made from the clay zones, to confirm the orientation of the system in preparation for a costly deep hole investigation. To this end a five hole percussion drilling exercise of 740 metres was undertaken to confirm the vein system's orientation, as well as to investigate mineralisation discovered by trenching. Of the five holes, P2 has been adequately described above (Section 3.2.4.2 [iii]) and the last hole, P5 served as the pilot section of the deep core hole.

The percussion chips were collected and logged on a metre sample interval. 190 composite (three metre length) samples for the first four holes were analysed by AA for gold and mercury **only**. The final hole P5 intersected only fresh dolerite (as planned) and was not analysed. All holes were inclined at 60° to the west along E-W section lines. In all cases the holes drooped (i.e. steepened) below 100 metres. The following table summarizes the programme:

Hole	**Total**	**No.**	**Alt.intersection**				**Peak**	**Analysis**			
No.	**Depth**	**Samp**	**From**	**To**	**Thick**	**VD**	**Au**	**Thick**	**VD**	**Hg**	**Thick**
P1	150	53	34	50	19	10.4	345	3	13.0	14	1.0
P2	150	54	19	26	8	14.7	95	2	16.4	12	3.0
P3	140	47	53	78	29	7.8	140	3	54.5	8	3.0
P4	100	36	-	-	-	14.7	15	2	10.4	9	2.0
P5	200	-	-	-	-	-	-	-	-	-	-

Where: VD is Vertical Depth in metres.
Thick is intersection thickness in metres. Au values in ppb. Hg values in ppm.

(i) **P1 and P3**

Both holes are located on the southern part of Beacon Hill, along traverse 10900. Mercury trench anomalies (labeled a to f), up to 35 ppm, were plotted with a sub-vertical attitude (parallel to the interpreted fault of borehole 9/1015) on Figure 18. The first percussion hole P1 was designed to investigate the exposed trench gossan and mercury anomalies 'a' to 'c'. The upper 30 metres of P1 consisted of sinter rocks and clay zones which gave the highest Au (345 ppb) and Hg (14 ppm) results of the hole. This zone, between 11 and 18 metres contained abundant chalcedony veining, pyrite and gossan fragments. A second mercury high (11 ppm) was returned from the sinter sample at the contact with the dolerite. From 30 metres to the end of the hole at 150 metres, the hole continued in dolerite with a pyritic alteration zone from 39 to 47 metres (with mercury levels 4-5 ppm). A second mixed zone of kaolinized dolerite and sericitic dolerite occurs from 125 to 130 metres (1,5 to 2,0 ppm Hg). No direct correlation between the trench mercury anomalies and the borehole mercury trace is made. The gossan zone probably ties in with the borehole 'high' gold as part of the layered chalcedony sinter cap.

Borehole P3 located 65 metres east of P1, is almost central between P1 and core hole 9/1015 and thus covers the vertical gap of information between P1 collar and 9/1015 base. This hole confirms the presence of the fault flanking the eastern side of Beacon Hill by intersecting 28 metres of sinter rocks (whereas the trench revealed dolerite at 5,20 metres east of the borehole collar). Once again the sinter section samples provided the only elevated gold (9 metres at 130 ppb Au) and high mercury (2,0 to 7,5 ppm). The rest of the hole to 140 metres is dolerite. A six metre argillic alteration zone occurs at 31 metres, which could be tied horizontally to the alteration of P1 and a 3,6 metre alteration zone at 23 metres depth in core hole 9/1015. However, the major (pyritic) argillic alteration zone (29 metres thick) occurs between 61 and 90 metres in P3. By relating this major zone with P1, the trend continues westwards to the gossan outcrop of the trench, and eastwards to the major alteration zones in 9/1015, from 112 metres depth. Thus from the data at this stage it was possible that the orientation of the system was 0400-0600 *or* horizontal *or* almost vertical!

(ii) **P4**

At least 3 major N-S high Hg lineaments were identified from the soil geochemistry (use overlay on Figure 14), the largest and most continuous being No.3 on the western side of Beacon Hill. As all the drilling to that stage was related to Hg Trends 1 and 2, percussion borehole P4 was designed to investigate No.3. Unfortunately access to the >1 km strike of this trend is very limited due to topography and in the north the anomaly is displaced off the sinter onto Beaufort sediments. The only accessible location for a drill rig (without extensive bull-dozing) was on the N-S baseline (10000) on traverse 11200.

The 100 metre hole is summarised in the following table. No gold values greater than 15 ppb were returned for any of the units

From	To	Thick	Hg(max)	Description:
0	21	21	9,9	Sinter rocks - pyritic chalcedony giving highest values.
21	45	24	6,5	Beaufort siltstones and sandstones the basal sample high.
45	63	18	1-2	Pyritic crystalline hornfels.
63	100	37	0,1-2,0	Dolerite, fresh no visible alteration.

Where: Depth and thickness of units in metres.
Hg peaks in ppm.

Surface mapping of traverse 11200 did not locate any sediments between the hornfels unit and the sinter rocks, but the down slope creep of the resistant siliceous sinter scree material probably masks the outcrop. According to the borehole Hg trace, the basal sandstone accounts for mercury anomaly No.3. However, the aforementioned slope creep seems a more plausible source for the anomaly from the high mercury levels in the sinter rocks.

(iii) **P5.**

Having established from the mineralogical evidence (Appendix II) the need for investigating the feeder fissure zones at deeper (higher temperature) levels, the deep hole was sited on the 10900 traverse at the 10350 station. Inclined at 60^0 due west this hole would intersect the alteration seen in core hole 9/1015 (collared 200 metres west) at approximately 500 metres depth (optimum boiling level).

In corroboration of the estimates the 200 metres of percussion 'pilot' drilling intersected only a monotonous sequence of fresh (unaltered) dolerite, and was therefore not submitted for any analyses. However, as a budget consideration, piloting through this 'overburden' by percussion drilling proved unsatisfactory, as the hole deviated steadily to the north and steepened rapidly from 100 metres depth (Nichols,1986). This then resulted in a costly wedging exercise to get the hole back on track.

3.2.4.4 Deep Diamond Drill Hole (P5) 9/1035.

(i) Lithologies.

The borehole collared in dolerite and intersected Beaufort sediments at 207,30 metres, with a 65 centimetre ultra fine 'chill' zone above a 49 centimetre hornfels zone at the contact.
A 3,13 metre intersection of (pyritic) argillic alteration/ breccia zone at 201,27 metres and a 27 centimetre calcite vein breccia at 204,73 metres, occur just above the dolerite/sediment contact. Thin section study of this material (Appendix II) describes the brecciated dolerite with mainly zeolite veins of low temperature geothermal alteration and some sedimentary clasts, within the hydrothermal breccia. Although much of the brecciation seen in the cores, did not involve substantial displacement of clasts, some of the breccias exhibit evidence for multiple episodes of hydraulic fracturing and mixing (presumably during ascent) of clasts. Fine-grained clastic sediments which underwent veining and brecciation were altered to yellowish-green illite and/or mixed layer illite-smectite (Sillitoe, 1987).

The sediments to the end of hole at 870,17 metres comprised 51% siltstone; 28% sandstone; 10% shale bands and 11% breccia/ alteration zones (see Figure 20). An 18,47 metre zone of highly altered sandstone and brecciated shales occurs between 590,25 and 608,72 metres. The major 31,75 metre silicified quartz stockwork breccia zone was intersected from 774,18 to 805,93 metres with a smaller 5,03 metre breccia at 824,35 metres.

(ii) Vein Study.

During the core logging exercise, considerable detail of composition, thickness and attitude of the intrusive veins was recorded. As discussed earlier (stratigraphic drilling above), with unoriented cores it is possible to get a number of attitudes for the veins. In keeping with the earlier interpretation, the maximum case (where ~30^0 angles to the long axis of the core) give rise to sub-vertical orientations for most veins, a similar plot is represented in parallel traces to the core inclination on Figure 20. Study of the vein distributions reveal:

(a) a dramatic increase in the number of veins with depth, particularly between 700 and 800 metres;

(b) that there are more calcitic veins than quartz veins, which, in turn outnumber the 'other' vein types (mostly zeolites);

(c) that by far the majority of all vein types plot around 30^0 (i.e. vertical);

(d) that there exists a subtle trend of steeper veins (i.e. 0 - 40^0) with increasing depth;

(e) that there is an almost cyclical distribution with depth for the various vein compositions. These composition domains are also plotted on Figure 20.

Similar plots were constructed for the previous core holes giving the following statistics:

Borehole Number	**Number of veins**	**Metres of core examined**	**Calcite**	**Quartz**	**Other**
14/1015	213	296	44%	40%	16%
9/1015	294	284	68%	20%	12%
9/1035	1059	670	37%	34%	29%

Thin section study of zeolite veins (Appendix II) at 433 metres identified relatively high temperature laumontite and adularia[10] at 435 metres. These high temperature assemblages indicate the proximity at this depth to the target boiling level (Nichols, 1986).

[10] Adularia was also identified in borehole 9/1015.

3.3 Results.

Despite the fact that no economic mineralisation has been intersected at the Springfontein Prospect, a fascinating example of a Tertiary age epithermal event has been shown to exist there. Each of the various philosophies and techniques applied in the exploration programme have added to the **dynamic** conceptual model with their *results*.

The remote sensing techniques displayed an anomalous zone of north-south lineaments in the region (and clay band prediction formulas might conceivably high-light the argillic alteration?). The geological observations (mapping, trenching and borehole logging) identified the typical epithermal model features of the sinter terrace, intrusive vein relationships, multiple hydraulic brecciation and alteration zoning. Detailed structural interpretation from varied sources eventually established a sub-vertical attitude for the system. On Figure 21 the 18 metre alteration zone of (P5) 9/1035 at 590,25 metre depth ties almost vertically (88°E) with the lower alteration of 9/1015 and the surface fault zone in the 109 Trench. Similarly (P5) 9/1035's major breccia zone at 774,18 metres ties vertically with the 29 metre thick alteration zone intersected between 61 and 90 metres in percussion hole P3[11] (Nichols, 1986). Other major geological observation results were the location of the gossans (which initiated the prospect in the first place) and the fossil identifications (which give the Tertiary age).

Both the geophysical and geochemical surveys furnished important results for the model. The electrical methods responded to the clay alteration zones, the ground magnetics confirmed the north-south linearity of the systems (Figure 22) and located the important faults, giving explanation to the preservation of the sediments within a horst-graben topography of the dolerite, as well as assisting in the orientation predictions of the feeder fissure zones.[12]

Figure 22 shows the Isomagnetic Contours superimposed onto the colour image of the soil mercury response. The sympathetic patterns show a number of features: the fault termination in the south; the strong N-S linearity; a general swing eastwards in the far north of both the magnetics but particularly the mercury. Other geochemical elements high-lighted the classical alteration zones, lithological boundaries and subtle metal zoning in the system. The following table lists the peak assay results from Springfontein, values that are clearly atypical for ordinary Karroo terrain.

Sample Type	**Au** *g/t*	**Ag** *g/t*	**Hg** *ppm*	**Ba** *ppm*	**As** *ppm*	**Cu** *ppm*	**Pb** *ppm*	**Zn** *ppm*
SOILS	15*	ND	2940*	62674	164	85	154	97
TRENCH	2,7	19,0	230	84176	960	206	283	97
*Thick***	*3,0*	*2,5*	*2,0*	*2,0*	*2,0*	*2,0*	*2,0*	*2,0*
CORE	0,20	5,10	14	17979	189	226	320	9700
*Thick***	*1,00*	*1,00*	*0,45*	*0,55*	*0,96*	*1,00*	*1,00*	*1,00*
VD	*168*	*152*	*36*	*157*	*76*	*545*	*545*	*545*

Where: * is ppb.

** Sample interval (thickness) in metres. VD Vertical Depth in metres. ND Not determined.

[11] A problem with this tie-line is that no evidence was visible in the bottom of 9/1015 of this alteration. However, since it was not possible to survey the hole (due to caving), it possibly steepened out of the path of this trend (as most of the other borehole surveys have shown).

[12] L. Antione predicted the major breccia zone of 9/1035 within 5 metres (at an intersection depth of 775m!).

Most soil samples returned gold and silver values below the detection limit (AAGEOPM 5ppb Au and 0,5 g/t Ag). Only 6,5% of the samples returned values of 10 ppb Au and 1,4% a value of 15 ppb. This low tenure of precious metal geochemistry need not necessarily be viewed as a negative factor, it could reflect a well-sealed system which had little escape of volatiles.[13] The concentric zoning of some of the elements has been displayed in Figures 10 & 11. The statistical distribution of the XRFME soil geochemistry is displayed in Figure 23, where the upper portion shows trace elements in ppm (note Ba and Sr had to be scaled down for graphing) and the major elements shown in the lower portion of the diagram.

Similar plots (Figures 24 and 25) are produced for the trench and core XRFME data. Although the actual levels of the elements are different[14] for the various sample materials, the overall patterns are strikingly similar. All the 'traditional' epithermal elements are seen to be elevated (i.e. Hg, Sb, As, Ba, Te, Si, Ca and Fe) but also Bi, Se and F are higher than the normal regional response. A limited amount of samples were submitted for thallium analyses, an often quoted epithermal indicator element. Thallium contained in crustal rocks is usually well below the 1 ppm level. In the Springfontein samples Tl shows a sympathetic relationship with Hg, and the highest values coincide roughly with the intervals from which the highest gold and silver values were recorded (in borehole 14/1015). Thallium is notably more abundant than gold, silver or mercury in these Springfontein samples (F.Boshoff, #7, 1985). Values exceeding 20 ppm Tl were displayed (compared to about 5 ppm Hg) in his figure 4 (see Appendix II).

Finally a consideration of the results contributed to the conceptual model by mineralogical and petrographic techniques (largely undertaken by F. Boshoff at A.A.R.L). Apart from distinguishing and identifying the classical epithermal alteration assemblages, strong guidelines on proximity to the boiling zone were forthcoming from temperature domain interpretations of these minerals. Textural details studied revealed not only multiple boiling and brecciation features but also sub-microscopic gold particles, free as well as within pyrite. As to the conceptual models themselves, they are presented in the discussion section (below). The dynamic nature of the models is evinced by the evolvement from an initial location on the 1:1,000,000 Mineral Occurrences Map of South Africa showing barite[15] - to a barite occurrence with a gossan - the recognition of the siliceous outcrop as a sinter terrace, and finally, the 'Hot Spring' epithermal target changing to the 'Open Vein Bonanza' target after the stratigraphic drilling. Many minds contributed to the development in textbook DPC (data- process-criteria) modeling, with the only omission being the lack of 'tons and grade' data to estimate an ore body.

[13] Many of the earlier publications refer to the 'barren' sinter, implying that virtually all precious metals precipitate at the boiling zone leaving only pure silica to precipitate at surface.

[14] There appears a degree fo surface enrichment in the higher trench (Figure 24) compared to the 'deeper' core results.

[15] Which caught the attention of B.N. Land after a tour of the Gamsberg Prospect and it's barite workings.

4 Theoretical Models.

4.1 Epithermal Systems.

An epithermal ore deposit can be defined as a relatively near-surface deposit formed in a hydrothermal system under low to moderate pressure and a temperature range below about 300oC (Barrett, 1985).[16] The all-encompassing simplicity of this statement becomes increasingly attractive, when one delves into the multitude of definitions and classifications that have been published on epithermal type occurrences, since their recognition as such in the late 50's.

Early workers (Berger and Eimon, 1982; Rossiter, 1984) subdived the category into descriptive or genetic subsets based on their form, mineralogy, alteration assemblages, host rock and depth and mode of formation (viz: hot spring or open vein or [Carlin] disseminated replacement type precious metal deposits). The major characteristics of this type of classification are listed in Table 4.1a (and shown in Figures 26 and 27).

Rossiter (1984) suggests the essential criteria for the formation of these deposits are:

1) a heat source to drive a hydrothermal system in a continental environment;
2) high permeability structures (usually faults and fractures) through which relatively unrestricted circulation of meteoric hydrothermal water can occur; and
3) a relatively inactive tectonic/volcanic period during which a substantial hydrothermal system can develop.

Numerous workers have shown that epithermal ore deposits and geothermal systems have similar alteration mineralogy, temperatures, fluid compositions, stable isotope patterns and geochemical associations. Some have suggested that the ore deposits are essentially fossil geothermal systems often with common characteristic features such as the siliceous sinter and hydrothermal explosion breccias. Also the hydrothermal fluids in most systems are predominantly meteoric in origin and dilute, with NaCl of 0,5 to 5 wt.% (Silberman and Berger, 1988). Calculations show that many volumes of a boiling fluid passing through a given volume of rock are required, in order for ore grades in the mineralised boiling zone to reach levels typical (0.1 to 1.0 oz/ton) of most epithermal deposits (Cole and Drummond, 1986). All of which indicate that 1) above could be modified to a continental margin setting.

However, a direct or indirect magmatic origin of the gold in Western Pacific Gold deposits is preferred by Sillitoe (1988), to currently popular models that invoke leaching of trace elements of Au (say < 4 ppb) from immense volumes of disparate rock types subjected to subaerial or submarine geothermal circulation. He concedes that many epithermal deposits (especially large ones) may require hypogene upgrading of magmatic hydrothermal ores or proto-ores containing 0,1 to 1,5 ppm Au during overprinting by meteoric convection cells.

[16] In Silberman and Berger, 1988.

Table 4.1a *Epithermal Classifications.*

	Hot Spring Type	Open Vein Type	Disseminated Replacement Type
DEPTH OF FORMATION	At or near surface 0 to 500m	Below the Hot Spring Type 200 to 1500m	From surface 0 to 500m
TEMP OF FORMATION	100°C to 300°C	150°C to 300°C (average 240°C)	100°C to 300°C (main ore stage 175-200°C)
HOST ROCK	No genetic role - variable	mainly andesites/dacites and rhyolites	Predominantly carbonaceous carbonate rock
ASSOC FAULTS/FRACTURES	Complex, small and numerous	Near vertical, substantial, relatively few	Near vertical
ORE ELEMENTS	Au, Ag, As, Sb, Hg, Tl	Au, Ag, Te, Pb, Zn, Cu	Au, As, Sb, Hg, Tl
ORE TEXTURES	hydrotheaal brecciation and stockworks	Open space filling, crustification, colloform banding hydrothermal brecciation.	No visible difference between ore and fresh unmineralised host rock.
SULPHIDES	Pyrite + arsenopyrite	Pyrite,galena,sphalerite chalcopyrite	Pyrite + arsenopyrite
ABUNDANCE	Low	High	Low
ELEMENT ZONATION	(Top) Hg,Tl,As,Sb (Btm) Au, Ag	(Top)As,Sb,Hg to Au,Ag,Te (Btm) Pb, Zn, Cu	None apparent
VEIN MINERALS	Quartz,calcite,adularia ± Fluorite and barite	Quartz,calcite,adularia Chlorite ±Fluorite,barite	Calcite, barite, quartz
NATURE MIN'Z'N	stratiform,disseminated, stockwork and minor veins in and just below a siliceous sinter capping.	cross-cutting veins and and minor breccias. Min'z'n in ore shoots.	stratiform(tabular) disseminated replacement bodies.
HYDROTHERMAL ALTERATION	Propylitization, silicification, adularisation, argillization,	Propylitization, silicification, adularisation, argillization, albitization	Decarbonisation, silicification, argillization, intro. of hydrocarbons
GRADE TONNAGE	Low Large	High Moderate	Low Large
MINING	Open cast	Selective underground	Open cast

The timing of ore deposition, at or near the end of volcanism, suggests that only when a magmatic system has waned can an ore-bearing hydrothermal system maintain itself long enough and at the appropriate temperatures to form an economically significant deposit (Heald et al, 1987). Hydrothermal activity in epithermal ore deposits (geothermal systems and porphyry copper deposits) lasts between about 0,5 to greater than 2,5 million years with an average on the order of 1.25 m.y. The mineralising episodes may, in fact, be short-lived, but occur within a much longer framework of volcanic evolution and hydrothermal activity (Silberman and Berger, 1988).

Most authors of recent papers propose multiple models for the general epithermal class of deposits (Silberman and Berger, 1988). As is their wont, some authors concentrate solely on particular aspects or subsets or even localities in their classification schemes for epithermal deposits. Heald et al, (1987) concentrate on those deposits hosted primarily by Tertiary volcanic rocks and suggest that the acid-sulphate-type and the adularia-sericite-type deposits form in two separate geothermal environments distinguished primarily by the proximity of the ore deposit to the heat source which drive the system. The main features of their classification are shown in Table 4.1b.[17] However, instead of being separate entities, the adularia- sericite and alunite-kaolinite models may be viewed as end members, and their variants are primarily related more to the depth of cogenetic plutons rather than to significant differences in their petrochemistry or tectonic setting (Heneley, 1990). There is a growing awareness that epithermal systems often occur in the volcanic settings above porphyry mineralisations, many authors (Sillitoe 1988, Bonham Jr 1986 and others) suggest genetic links between these systems (particularly in subduction tectonic environments).

[17] The characteristics described by Bagby and Berger (1988), of Disseminated Replacement deposits is also appended to this table. Although essentially similar to Rossiter's data in Table 4.1a, it adds some interesting factors.

Table 4.1b

Epithermal Classifications.

	adularia-sericite-type	acid-sulfate-type	Disseminated Replacement
HOST ROCKS	Not a controlling factor variable hosts	Preferentially volcanic rocks particularly rhyodacitic (=qtz latite) domes commonly porphyritic	carbonaceous, silty dolomites or calcareous siltstones and clays
MINERALOGY	No enargite or bismuthinite Sericitic alteration dominant Sometimes kaolinite Adularia often selenides Mn gangue present often chlorite Cu poor	Enargite + pyrite + covellite Extensive hypogene alunite Major hypogene kaolinite No adularia or selenides Mn minerals rare Chlorite rare Cu rich - high base metals	Pyrite ± cinnabar, stibnite, arsenopyrite, fluorite, barite, calcite various thallium and arsenic sulfides
GEOLOGIC SETTTING	high above and offsett from deep seated heat source surficial waters mix with deep heated saline fluids in a latteral flow of neutral - weak acidic, alkali waters	root zones of volcanic domes acid waters and residual magmatic volatiles	Tertiary centres (zones of weakness?)
TECTONIC	Settings similar for both at subduction zones at Plate Boundaries		unknown influence - various?
STRUCTURE	both complex - typically several generations of faults/fractures in two or more directions.		High-angle normal and/or strike slip faults invariably present
ALTERATION	Silicified near vein Sericitic borders	Advanced Argillic associated with ore zones	Hypogene = decalcification, silicification, argillization, oxidation.
AGE/Relation	Removed (>1 m.y.) to the formation of host rocks	Close (<0,5 m.y.) to emplacement of host rocks (i.e. there's a genetic relationship).	spread in age, pre-Tertiary tend to be eroded.
SIZE	both have lateral extent of ore (1-200km^2) far exceeding the vertical extent		Range 2,5 - 200MT Grades 0,3-0,05 oz/t
Vertical Range	up to 1000m	<500m	<500m
ANALOGS	Creede (Colorado) Round Mountain (Nevada)	Goldfield (Nevada) Red Mountain (Colorado)	Carlin (Nevada) Preble (")
GENERAL NOTES	more abundant both have AU and AG subtypes *(after Heald, Foley and Hayba, 1987)*	less abundant	gold particles are submicroscopic Trace-element association: Au, As, Sb, Hg and Tl + W, Te, Se, Cd and F *(after Bagby and Berger, 1988)*

In his work, Bonham (1986), introduces an important third category for volcanic-hosted epithermal precious metal deposits. That of the gold-telluride-fluorite deposits associated with alkalic rocks. His low-sulfur (correlates closely with the adularia-sericite type); high-sulfur (essentially acid-sulfate type) and alkalic features are shown in Table 4.1c (and Figures 28 A, B and C). He also suggests that since precious metal deposits formed in a hot spring environment can occur in any of these three deposit categories, he does not consider hot springs as a separate deposit category, but rather as a sub-type. It is possible to sub-divide the low sulfur model into three main general groupings:i) high gold, low total base metals (e.g. Round Mountain) ii) high silver, low total base metals (e.g. Tonopah) and iii) high gold and silver, abundant base metals (e.g. Waihi, New Zealand).

Other known deposits have been classified according to their Ag/Au ratios (Cole and Drummond, 1986). Penteleyev (1985) suggests that the models stressing the intimate Caldera relationships and those relating epithermal ores with felsic volcanic rocks have been overemphasised. Epithermal ores occur in all rock types, particularly those that sustain large open- fracture systems over extended periods of time during hydrothermal activity. In general, permeability is an important controlling factor in mineralisation and alteration, often it is the product of intrusive volcanic activity, which not only provides the heat source to drive the hydrothermal systems, but is important in ground preparation prior to the system.

For virtually all models, the general zonation of As, Sb, Hg, B, Tl, and Au tend to be concentrated in the upper parts of the systems and decrease with depth, whereas base metals, Cu, Pb, Zn, and other elements Bi, Se, Te, Co, appear to be precipitated at greater depth in higher temperature zones (Silberman and Berger, 1988). The best trace-element guides to gold mineralisation in alkaline rock systems are Au at the ppb level followed by Te (Mutschler et al., 1985). Overprinting and complexities due to tectonic movements or solution processes (e.g. self-sealing) only add interest to what is, geologically, a relatively simple ore formation process.

Table 4.1c

Epithermal Classifications.

	Low Sulfur	High Sulfur *(Enargite)*	Alkalic *(Au-telluride-fluorite)*
HOST ROCK	calc-alkalic or alkali-calcic Andesite/dacite/rhyodacite rhyolite	calc-alkalic Andesite/dacite/rhyodacite invariably porphyrytic	syenites/trachytes/phonolites shoshonitic volcanic rocks
ANOM ELEMENTS	Mo/W/F/Nb/Sn	abundant Pyrite	Ag/As/Bi/Hg/La/Mo/Nb/Pb/Sb/ Te/Tl/U/V
FLUID CHARACTER	Low salinity (0-5% NaCl equivalent) Variable CO2+CH4 near neutral to alkaline	Med-hi salinity (5-24%NaCl equivalent) High H2S content acidic	low salinity (~5%NaCl equivalent) CO2 saturated neutral to alkaline
TEXTURES	Open space filling,colloform banding, crustiform and comb	open space breccias,multiple episodic qtz veins	Veins, sheeted zones and hyrdrualic breccias
ORE MINERALS	As/Sb/Hg sulfides/electrum/ Ag sulfides and sulfosalts Ag selenides/base metal sulfides	Hg+Sb sulfides/enargite-luzonite tennantite-tetrahedite/covellite native Au/Ag sulfides and sulfo- salts/bismuthinite/base metal sulfides and tellurides	Ag-Au tellurides/electrum Au-pyrite/As/Hg+Sb sulfides base metal sulfides including molybdenum/cinnabar/stibnite
ALTERATION			
in/adj veins	qtz/adularia/calcite/dolo- mite/Mn carbonates/minor fluorite and baryte	Avanced ARGILLIC	qtz/fluorite/calcite/dolomite roscoelite/adularia
marginal	kaolinite/illite/sericite chlorite/smectite/albite/ calcite/zeolite/± epidote	qtz/alunite/kaolinite/baryte/ zunyite/diaspore/pyrophylite	albite/chlorite/carbonate/ sericite/smectite/zeolite/ illite
ANALOGS	Hasbrouck/Sulfur (Nevada) Round Mountain (") Gold Hill (")	Lepanto (Phillipines) El Indio (Chile) Red Mountain(Arizona) Frieda River(P.N.Guinea)	Cripple Creek (Colorado) Kirkland Lake (Ontario)

(after H.F.Bonham,Jr 1986)

4.2 Discussion.

Springfontein with it's classic sinter is clearly a hot spring deposit but has characteristics that transgress many of the models described above. Epithermal ore deposits occur in a continuum of types and geological settings, and in terms of the geochemical processes responsible for mineralisation there may be little difference between the typical vein and disseminated deposits (Romberger, 1985).

In the main, geothermal systems can be regarded as large-scale, uncontrolled, open-ended natural experiments in which there usually remain several unknown variables - such as the duration of the thermal activity or the composition of the fluid before it enters the system (Browne, 1978). Although the compositions vary widely, the major dissolved components of most precious-metal systems are Na, K, Ca, Mg, Cl, silica, carbonate, sulfate, sulfide and methane. Metals typically comprise only a minor portion of the dissolved content of the fluid (Cole and Drummond, 1986). In effect, locating the system constitutes the easiest step in the exploration of epithermal bodies (although in the South African geological panorama they are indeed rare events), the more difficult step is defining within the system the specific niche occupied by the minor (but sought after) metal components.

In most models the boiling of the fluids is sited as the mechanism for gold precipitation (although systems are described where gold exists and there is little or no boiling evidence).
Evidence for boiling has been shown at Springfontein, although most of the borehole intersections appear only proximal to a boiling level. In epithermal systems the mineralogy grades to lower temperature assemblages away from the fissures (Silberman and Berger, 1988). The vertical zonation of elements, mineralogy and alteration features is well documented for the various epithermal models, however, most schematic (two dimensional cross-sections) do not adequately portray the three dimensional characteristics and variations that are present in the actual systems (Silberman and Berger, 1988). It is the writer's conviction that the boreholes were laterally displaced from the centre of the hydrothermal system (which would be in the vicinity of the barite workings or even further north).

Factors that influenced the location of the deep hole (9/1035) were:

(i) *The southern Beacon Hill displays the thickest preserved sequence of sinter material (Nichols, 1986).* The inference at the time was that the thickest sinter would overlay the center of the system, however, what is present is an erosional remnant and thicker materials could well have been removed.[18] Secondly, in many instances the sinter terrace is developed laterally displaced (up to several kilometres) from the feeder zone, dependent on hydraulic flow regimes (Pirajno, 1986).

(ii) *Mineralogical studies of the stratigraphic holes indicated that the southern hole (9/1015) was in a higher temperature regime than the northern hole (14/1015). A higher temperature regime than both listed above was optimally sought, and it was thus decided to opt for the southern or 'higher temperature' area for the location of borehole 9/1035 (Nichols, 1986).* However, in retrospect, the higher temperature assemblage is probably simply due to the deeper intersection (~126 metres) in the southern hole.

[18] Mountain (1953) pondered the origin of abundant agate pebbles on the coast. He also describes a gravel bed of agates on the Buffalo River a couple of kilometres downstream from Springfontein.

(iii) *The most likely conduit to host economic scale mineralisation, was seen to be represented by the fault at the eastern end of section 100900 (Nichols, 1986).* Where premise this still holds, but the N-S fault is present in the north as well (if not more so near the barite workings).

(iv) *With boreholes 9/1015, P1, P3 and the 109 Trench, most of the exploration effort had taken place on traverse 10900, therefore more knowledge of this part of the system existed than anywhere else (Nichols, 1986).* Where this knowledge enabled the remarkable prediction and intersection of the system at considerable depth, it did tend to keep all the 'eggs' in one basket and disregard the strong geophysical, geochemical and geological (more surface pyrite and intrusive veining) features at the northern end of Beacon Hill.

A certain lack of complexity is present at Springfontein, possibly because of the less involved tectonic setting (compared to the subduction settings of the Pacific Rim deposits or the accreted terrain environment of the North American bodies). For example the paleo-surface is preserved (captured fossils in the silica cap), a fairly finite alteration zone (as defined by the drilling to 800m depth), and despite the petrological signs of multiple boiling and brecciation (as evidence of overprinting), the 'bulls eye' geochemical distribution in the soils is relatively straight forward. An important factor of the geochemical distribution is high-lighted in Figure 29. Here the mercury image (in colour) is overlain by the barium contours. Despite the fact that the computer contour plotting is somewhat un-forgiving (with regard to the wider spaced samples), it clearly shows that the mercury signature extends northwards, past the old workings on which the barium naturally peaks. This suggests that the feeder zones (which the Hg emphasizes) continue at least as far as the wide spaced sampling programme extended (i.e. about 1,5 kms from the deep borehole).

Negative aspects (apart from the lack of intersected economic mineralisation) of the Springfontein Prospect that have to be explained include:

(i) the nebulous tectonic setting, which apart from the Landsat imagery lineaments representing rifting, have little supportive evidence.

(ii) the missing heat source, however there are many occurrences world wide without proven sources.

(iii) the fact that despite a regional exploration effort, the Springfontein prospect appears to be a solitary event, and most (but not all) known occurrences tend to cluster along trends (e.g. the Carlin Belt) or districts (e.g. Taupo New Zealand). Boyle (1979) describes an interesting post-Triassic (probably Tertiary?) gold-quartz vein and stockwork occurrence in Malagasy,[19] near Andavakorena, in a hot spring area. The mineralisation of these deposits is essentially quartz, dolomite, calcite, barite, chalcopyrite, galena, sphalerite, pyrite, marcasite and native gold.

[19] Perhaps one could make a case for a third position for Madagascar in the plate tectonic evolution of the Indian ocean?

5.1 Summary

Exploration for gold in South Africa during the mid 1980's was almost a national pastime. Depressed base metal markets coupled with the high gold prices had most mining companies rechanneling exploration funds into gold prospecting. Concern was already being expressed about the dwindling resources of the Witwatersrand mines, and South Africa (producer of more than 40% share of the non communist world gold production) was the metallogenetic province to find more reserves. The selection of a prospect just outside East London, in the Eastern Cape was, however, more than a little bit surprising.

Just prior and during this period, gold production in the United States (and Australia) was increasing markedly. Most of the increased production being attributed to **redefined** gold districts housing 'epithermal deposits'. New technologies and better understanding of these mineralisation models was giving new life to old prospects and leading to the discovery of new ones. Perhaps because of the 'new' economic backing or the fact that many of the districts were close at hand, a surfeit of publications on epithermal deposits were written. Mineralisation models evolved rapidly and a number of different classification schemes have been put forward for this type of precious metal occurrence. Unfortunately ambiguities are common in the efforts to differentiate what are essentially continuums or possibly subtypes. The fundamental concept is one of circulating (hot) fluids (plausibly driven by a magmatic source) leaching metals out of (not necessarily high background) country rocks for a sufficient period (geological time) until some circumstance (external or internal) causes a change in conditions (chemical, temperature or pressure) such that the fluid borne metals precipitate - essentially the process that can be observed in active geothermal fields.

A useful classification based on the host rock, form, mineralogy, alteration assemblage and depth and mode of formation is that which divides epithermal deposits into the Hot Spring, Open Vein and Disseminated Replacement types (Rossiter, 1984). The latter is essentially sediment hosted and can be further subdivided into the Carlin type (carbonate replacement) and the Jasperoidal Type (silicification). Deposits occurring within volcanic hosts are commonly classified as acid-sulfate or adularia-sericite types differentiation basically arising from the proximity to the magmatic source (which has causative effects in the resulting alteration and mineralogy formed).

For instance in an acid-sulfate system the significant development of kaolinite results from acid conditions near the vein (boiling, H_2S, etc.,), whereas the kaolinite alteration seen in adularia-sericite type deposits forms in a different environment, distal from the vein at low temperature under less acid conditions (Heald et al, 1987). Bonham Jr (1986) introduced a further alkalic classification that encompasses magmatism other than calc-alkaline. In general epithermal deposits have specific element assemblages and alteration features, and their occurrence at high crustal levels distinguishes them from other mineralising systems. The Springfontein Prospect, near East London, conforms to the criteria of an epithermal hot spring model, but occurs in a sedimentary environment. Consideration of it's mineralogy, alteration assemblage and tectonic setting favour it as being yet another variety of the alkalic model. This report attempts to prove this heritage.

5.2 Conclusions.

The approximately 2 year period of intermittent exploration effort at the Springfontein prospect progressed from initial reconnaissance sampling of a known barite occurrence, through ordered standard exploration methodology, to the siting of a deep (870,17 metre) borehole. The exercise incorporated most of the geological disciplines available to a large exploration company and accumulated a substantial database in support of a viable conceptual geological model.

No economic mineralisation was discovered on the prospect but a relatively unique geological occurrence in the South African context was described and investigated. This in a region of the country (Eastern Cape) that is not particularly well endowed with locations of particular geological significance. The Tertiary aged epithermal event at Springfontein is characterized by:

A well developed (fossil plant bearing) sinter terrace.
intrusive barite, chalcedony and calcite veins.
typical epithermal element assemblage including Hg, Tl, As, Ba, Te, Sn, Sb and F,
gossans with elevated gold and silver levels (as well as the elements listed above),
a prominent N-S fracture system (as evident from remote sensing techniques and geophysical surveys).
distinctive geophysical responses (electrical and magnetometry),
extensive associated alteration zones (revealed by geochemical, geophysical evidence and intersected by both trenching and drilling activities),
multiple boiling and brecciation features (mapped as surface textures and evident in petrographic studies),
abundant pyrite and locations with cinnabar crystals (seen in trenches and borehole cores).

The only feasible tectonic setting available in this region would be one of rifting (presumably related to the late stages of break-up of Gondwanaland). An association between rifting, or extensional tectonism, and alkaline magmatism has long been recognised (Mutschler et al.,1985). The closest evidence for volcanism relates to dredged samples of the Alphard Bank (Dingle et al, 1983) but little or no such work has been conducted off the coast from Springfontein. Of the visitors to the prospect who have seen other epithermal systems elsewhere in the world, most felt that the dimensions of the sinter terrace at Springfontein are comparable to a producing system. In addition it is probable that the system has been eroded and was once larger anyway. Pirajno (1986) favored an alkalic model for the system based on the mineralogy, geochemistry, alteration style and rank. This is supported by the tectonic setting and the recognition of adularia in the cores.

Sillitoe (1986) concluded that the Springfontein system is deficient in precious metals either because it is amagmatic or, alternatively, because it is only weakly developed. If it was anywhere mineralised he would have expected higher gold values (say 0,5 to 1 ppm) in the holes already drilled. Boshoff (1986) sited the low temperatures of formation of the zeolite minerals in the cores, suggesting that the system did not propagate long enough to precipitate precious metals. Other workers denigrate the occurrence as either not having gold in the system in the first place, of being too small for economic potential or of representing simply a typical Karoo 'sweat' phenomena related to the dolerite. It is this writer's contention that the Springfontein prospect does in fact represent an epithermal gold occurrence. The facts that low gold values were detected far below the dolerite (Figure 20) and that Pirajno (1986) has identified evidence of fluidization in the sediments (below the sill) distances the event from the dolerite, as does the entrapment of Tertiary aged plants within sinter rocks. In addition the intense geochemical signature and metal levels of the gossans, the pronounced geophysical response and larger fractures in the north of the prospect, still hold potential for the discovery of economic mineralisation.

5.3 Acknowledgments.

I take this opportunity to express my appreciation to the Anglo American Corporation of South Africa, New Mining Business Division for both entrusting me with the exploration of the Springfontein Prospect and assisting me to attend the Exploration Geology Masters Course at Rhodes University. Particularly extreme gratitude is expressed to the late Dr.G.L.Coetzee for permission to use the Springfontein data for this University project. Also to his successor, R.Corrans, for honoring that permission and encouraging me to complete the task. A special vote of thanks to the then Regional Manager, P.D.Danchin for assigning the project to me in the first place and all the encouragement and assistance during my work there. I am also beholden to Dr.B.H.King and J.D.Wilson (past and current Regional Manager's) for their patience and forbearance for 'their' time I have invested in the completion of this project.

Many of my colleagues at Anglo American contributed to the investigation of Springfontein, particularly Luc Antoine with his geophysical interpretations, Frans Boshoff for all the petrographic studies, Brian Griffin draughted the original maps from my technicolour scribblings and Thierry Burvenich assisted me with some of my software problems.

I would also like to thank the staff of the Geology Department of Rhodes University, particularly Professor Pirajno and Clyde Mallinson, for revitalising my geological education. A special vote of thanks to my family for their support, with apologies to my wife Cherry and daughter Caron whose time was severely neglected in favour of the project. Finally a tribute to my fellow students who despite their youth kept me on my toes and provided long hours of fruitful discussion.

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7.1 Appendix I.

Springfontein Prospect Soil Geochemical Orientation Study.

Prior to embarking on the soil sampling of the grid at Springfontein a detailed soil orientation programme was undertaken. This primarily because the prospect was the first area to be sampled in the Eastern Cape Region by the corporation and one could not expect sampling criteria established for the drier Northern Cape soil programmes to apply.In addition the target was markedly different from those prospected for before. Locally, it was realised that the distinctive topography of the region (that of deeply incised rivers) and the dense vegetation of these drainages could have an effect on element distribution patterns.

The Springfontein orientation study comprised:

(i) Seven major pits - sampling 3 or 4 levels of the soil profile above the major rock types and mineralisations for different topographic slopes.

(ii) Six minor pits- sampling only two levels of the lesser developed soil profiles on the sinter hills for different slopes.

(iii) Six anthills - one for each sinter hill and one for each rock type.

(iv) Twenty one large bulk stream sediment samples collected from the four northward draining streams on either side of the two sinter capped hills at Springfontein. Samples were collected across[1] the stream bed at approximately 200 metre intervals.

Very large samples were collected, 20 kilograms from the different levels of the orientation pits and 5 kilograms in the stream sediment samples. The samples were passed through a nest of sieves[2] and each size fraction analysed by atomic absorption methods for Au; Ag; Hg and Li as well as by the 36 element XRFME (x-ray fluorescence) package.

[1] This approach, avoiding bank contamination, is deemed to give a more standardised result than, for example sampling only 'trap-sites'. Traversing the whole stream bed collects both fines in the back water sections as well as the coarse thalwag material.

[2] Constructed of plastic sewage pipes and nylon mesh to prevent contamination.

Locations of the pits and sampling sites are shown on the attached orthophoto figure[3] (Figure A1). Some of the analytical result are depicted on Figure A2, which represents the various data on 3 axes:

(i) x axis - the elemental level on a 1 to 10 scale in ppb or ppm as indicated.

(ii) y axis - the fraction size (A-E)[4] with coarsest fraction on the left and finest on the right.

(iii) z axis - depicting the depth level where the various samples were taken and a pictorial representation of the soil profiles.

Similar plots were constructed for all the pits and most of the elements in the original study, with a detailed evaluation of the distribution for each element and some ratios of elements.

In summary the soil orientation study showed very conclusive results - both the second level sample (essentially the B soil horizon) and the coarsest sample fraction (+10 mesh) consistently gave the highest contrast anomalies. These criteria were then applied in the grid soil sampling. Silver and lithium were dropped from the analyses schedule after their poor response, leaving gold and mercury by atomic absorption and XRFME (mainly for Ba and As). In the literature both K/Na and Rb/Sr ratios (as well as Thallium analysis) are said to peak in the sinter zones of Hot Spring type deposits. For this reason they were plotted and included. The stream sediment orientation study was not as conclusive as the soil orientation study. Similarly however, greater contrast anomalies report from the coarser fractions. For the regional stream sediment survey purposes it was decided to combine the A and B fractions for general analysis (i.e. ~-5 to +35 mesh). The study indicated that stream sediment sampling is sensitive enough to locate mineralisation as found at Springfontein. It also directed some attention away from the sinters, emphasizing the need for a full soil sampling programme to cover unlikely areas where no surface geology or outcrop exists (Nichols, 1985).

[3] This figure is also convenient to study in conjunction with the notes of the local geology in the main body of the report, since it displays the various erosion surfaces (topography) clearly.

[4] Where A is +10 mesh, B is -10 to +35 mesh; C is -35 to +80 mesh; D is -80 to +200 mesh and E is -200 mesh.

7.2 Appendix II.

Petrographic Studies.

Similarities between the various deposits appear when studied at the hand specimen or microscope scale. These observations are important in developing a genetic model (Romberger, 1985). For epithermal bodies many established features (e.g. the close association of Au and pyrite, or the suggestion that the presence of adularia is indicative of boiling in the system) can only be verified by petrographic studies. On the Springfontein Prospect the majority of these studies were undertaken at the Anglo American Research Laboratory by Frans Boshoff. His studies and interpretations contributing much to the understanding of the hydrothermal system that operated at Springfontein, his summary report (No.5 dated 5 August 1986) is attached as the main body of this appendix.

Other important observations by Boshoff include the identification of very fine-grained (<0,006 mm) pale native gold enclosed in pyrite[1]; the presence of mordenite in the hydrothermally brecciated, silicified and argillized dolerite[2], the comparison of thallium to mercury values in 14/1015[3]; the identification of adularia in the borehole cores. Major emphasis in the petrographical work has been placed on temperatures of mineral formation, the distribution of zeolites is strongly temperature dependent, but several minerals, including pyrite, calcite and chlorite form readily at both low and high temperatures (Browne, 1978).

In the cores the alteration zones and permeability textures have received most attention. The parent rock influences hydrothermal alteration mainly through the control of permeability by texture and porosity (Browne, 1978). Fluidization channels are characterised by comminution of the immature greywacke rock, resulting in rotated rounded fragments embedded in a very fine fluidised matrix. These are barely recognizable by the naked eye, but quite clear under the microscope. Fluidisation is characteristic of gas discharge at high pressure. Epidote grains are present within the fluidisation channels as well as chalcedony, pyrite, and locally barite. Textural relationships indicate sequences of : sericite-opaline silica (± Fe oxide) - hydraulic fracturing and sinter silica I-deposition of carbonate + zeolite-sinter silica II, and sulphides- chalcedonic silica-opaline silica-barite-carbonate (bladed calcite). These sequences and/or paragenesis, all indicate repeated boiling episodes. The presence of abundant carbonate in the system on the other hand is indicative of CO_2 loss to vapor phases during boiling (Pirajno, 1986).

The petrographic work played a major role in the interpretation of the epithermal nature of the Springfontein system and the following pages summarise these findings.

[1] In his 1984 report on the gossan sample GOR-1.

[2] His 1985 study of trench 109 clay material.

[3] Report No. 7 dated 27/6/85.

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ANGLO AMERICAN RESEARCH LABORATORIES

AARL PROJECT NO. R/85/195 REPORT NO. 5

PETROLOGICAL RESEARCH FOR NMB EXPLORATION

GEOLOGICAL DEPT. REFERENCE NOS. GB/85/0752, GB/86/0817

GEOLOGY LABORATORY REFERENCE NOS. M/85/436, M/86/532

EVALUATION OF THE SPRINGFONTEIN PROSPECT BASED ON HYDROTHERMAL ALTERATION FEATURES

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KEYWORDS: Cristoballite, dolerite, epithermal, hydraulic-breccia, hydrothermal-alteration, sinter, Springfontein, zeolite, QD3327 BB.

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SUMMARY

The Springfontein prospect is a typical hot springs occurrence as indicated by the presence of siliceous sinter, the type of hydrothermal alteration present, hydraulic breccias, etc. The majority of springs type deposits are not mineralized and these are usually not enriched in precious metals at surface, whereas mineralized members are invariably anomalous at surface. At Springfontein, precious metal values, although small and sparsely distributed, are present and the occurrence therefore does require detailed examination.

Hydrothermal vein assemblages contained in drillcore samples are all of low temperature origin and characteristic of the upper, precious metal poor, levels of most hot spring deposits. Their temperatures of formation do not exceed 170°C and are for the most part considerably lower, even at depths in excess of 800 m. Precious metals are deposited at temperatures between 200 and 250°C above a boiling zone, and at depths of 150 to 500 m, in the majority of mineralized deposits of this kind.

The absence of any significant mineralization at Springfontein is probably due to the low temperature of the geothermal system, the consequently poor leaching capabilities of the solutions and/or short duration of leaching prior to extrusion of the hydrothermal solutions.

However, the possibility cannot be excluded that mineralization does occur below the dolerite in the northern part of the occurrence. Vertical alteration zonation is better developed in the latter locality, large fracture zones appear to be more common and the magnetic, I.P. resistivity, and geochemical signature is higher.

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PETROLOGICAL RESEARCH FOR NMB EXPLORATION

GEOLOGICAL DEPT. REFERENCE NOS. GB/85/0752, GB/86/0817

GEOLOGY LABORATORY REFERENCE NOS. M/85/436, M/86/532

EVALUATION OF THE SPRINGFONTEIN PROSPECT BASED ON HYDROTHERMAL ALTERATION FEATURES

1.0 INTRODUCTION

This report consists of:

a) The results of a petrographic study carried out on twenty rock samples from the third deep borehole (9/1035) drilled at Springfontein. These samples were taken from a core intersection extending from 236 to 862 m, during a field visit to the area. All the samples contain vein mineralization, believed to be representative of the various types of veins, and are located in Beaufort sediments occurring below the dolerite sill. Their petrographic properties are summarized in Table 1 and variations of the vein mineralogy with depth are listed in Table 2.

b) The mineralogical composition of samples from borehole 9/1015 are as given in Table 3. They consist of six samples collected on site in addition to the twenty referred to above, and ten samples previously submitted to the laboratory.

c) A general overview of the occurrence based on petrographic and mineralogical properties. The composition of veins in borehole 14/1015, as described in AARL Report Project No. R/83/109, Report No. 7, are reproduced in Table 4 for comparative purposes. Photomicrographs illustrating the petrographic features of the veins accompany this report.

2.0 VEIN MINERALOGY OF DRILLCORE SAMPLES

2.1 Borehole 9/1035 (deflection)

The bulk of the samples examined are from the lower half of this ± 200 to 860 m intersection, the object being to identify the possible presence of relatively high temperature epithermal assemblages. Results, however, indicate low temperature assemblages (Tables 1 and 2) with the exception of Sample A1 (862 m) and dolerite related veins in the upper part.

Hydrothermal/...

Hydrothermal breccias (see Fig. 8) cemented by fine grained quartz and pyrite are common below 600 m. They range from fairly coarse to fine hairline features and are in some cases accompanied by calcite. Quartz-rich veins not notably associated with brecciation features and containing pseudomorphs after baryte or remnant baryte, are developed at $\pm$ 800 m and lower down. What in handspecimen appears to be feldspar (possibly adularia) in these samples, are due to quartz aggregates of variable grain size. The deepest sample (A1) examined from this drillcore is of relatively high temperature origin as indicated by the presence of epidote, sericite and relatively coarse-grained quartz, occurring in association with calcite. It also contains small amounts of molybdenite. In view of the carbonate-rich nature of the vein and the apparent absence of dolerite at this depth it is probably of epithermal origin. No zeolites were identified below 640 m but are common higher up, particularly in the 600 to 500 m zone. Laumontite is the predominant zeolite and no mordenite (very low temp.) was observed.

High temperature dolerite related veins, similar in composition to those described from borehole 9/1015, occur at $\pm$ 400 m and higher up in the succession. Some of these contain sericite pseudomorphs after feldspar, (exhibiting rhombic cross sections characteristic of adularia), as well as chalcopyrite (Geol. Lab. Ref. M/86/085).

2.2 Borehole 14/1015

This hole intersects the dolerite sill and was terminated in sediment directly below the sill. The composition of hydrothermal vein alteration in the core is typical of veins developed in the upper parts of geothermal systems close to a sinter capping, and consists essentially of variable proportions of calcite, zeolite, silica and pyrite.

Low temperature silica polymorphs such as opalline silica, cristobalite and chalcedony predominate over the more crystalline varieties. The associated zeolites, mordenite, heulandite and laumontite, listed in increasing order of temperature of formation, exhibit vertical zonation (see Table 4). Whereas mordenite occurs virtually throughout the intersection and heulandite in samples at a depth of 56 m and deeper, laumontite was identified in only one of the samples occurring at a depth of 218 m. The absence of any poorly crystalline silica in the latter is in agreement with the indicated higher temperature of formation. Baryte was originally notably more abundant in the samples as evidenced by euhedral tabular crystals consisting of calcite and silica pseudomorphous after baryte. Pyrite accounts for the bulk of the sulphides present. Minor amounts of marcasite are occasionally intergrown with the latter, and pyrrhotite is very rare.

2.3 Borehole 9/1015

As in the previous case this hole is drilled in dolerite and was discontinued when footwall sediments were intersected. The vein mineralization differs from the former in that in addition to low temperature vein assemblages a large number of relatively high temperature veins are present.

The high/...

The high temperature veins are genetically related to the dolerite intrusion and represent late stage differentiates and hybrid contact phenomena. Quartz in these veins is fairly coarse-grained, poorly crystalline silica is absent, and chlorite, feldspar, epidote and occasionally chalcopyrite are present. The low temperature veins are comparable in composition to those intersected by borehole 14/1015 but the zeolite distribution does not exhibit depth zonation as in the latter case. Heulandite occurring in association with high temperature vein material (Table 3, Sample 7) is attributed to hydrothermal alteration during the geothermal event, as is the extensive sericitization of feldspar in these veins.

Small amounts of adularia and minor chlorite were identified in a quartz vein crosscutting sediment (Table 3, Sample 10) at the bottom of the borehole. This was initially interpreted as vein mineralization conforming to a higher temperature adularia-bearing zone occurring above and proximal to a boiling zone. The high incidence of dolerite related veins in samples subsequently collected, however indicated that it is of the same origin as the latter.

3.0 HYDROTHERMAL ALTERATION

3.1 Typical Hot Springs Deposit

In hot spring gold deposits the mineralization occurs in the upper few hundreded meters of the paleosurface as evidenced by siliceous sinter and wall rock alteration related to a palaeoground-watertable, all in close spatial and temporal proximity to ore. Hydrothermal vent breccias, in addition to peripheral stockwork zones are present in all of the mineralized deposits recognized to date. Gold is lifted into this environment above a boiling level and is precipitated with abundant quartz, pyrite and adularia, and a steeply zoned trace element suite. Pyrite-bearing veins cementing the breccias and fractures are vertically zoned from cryptocrystalline silica (often cristobalite), chalcedony, zeolite and calcite near the paleosurface, passing with depth into quartz and calcite (± baryte, fluorite), and in deeper levels to mineralized quartz, adularia, minor sericite, (± chlorite, calcite) assemblages.

Near surface alteration of the wall rocks has given rise to a relatively shallow argillic zone consisting of kaolin, pyrite and alunite, in some cases accompanied by montmorillonite and illite, underneath the sinter, and that for some distance extends locally down the vein. Below the argillic zone country rocks are altered to a fairly restricted zone of silica, illite and celadonite passing in depth to silica, sericite and adularia, enveloping the veins. Propylitic alteration (chlorite, calcite, montmorillonite, pyrite) forms a widespread outer halo around the deposit.

3.2 Springfontein

The bleached appearance of sediments occurring above the dolerite and below the sinter are due to kaolinitization, silicification, minor pyritization and illite. This alteration assemblage is in agreement with the high level argillic zone characteristic of hot springs deposits, but does not contain alunite. Hydrothermal alteration of the dolerite matrix ranges from pervasive, usually in association with extensive veining, to incipient, and is mainly a mixture of the propylitic and celadonite-silica types of alteration. The pyroxenes are the first to be altered and is replaced by calcite, pyrite, hydromica and celadonite, and the plagioclase is replaced by montmorillonite and in some cases kaolinite. Alteration of the sediments below the dolerite are less prominent. Matrix replacement by silica, sericite and/or illite, pyrite and occasionally cryptocrystalline clay, has taken place. The fine-grained nature of the sediments and the fact that it is difficult to distinguish between primary and alteration products may impede characterization of the latter. The absence of propylitization in these sediments is largely a function of their original composition.

Hydrothermal veins are quite common throughout the drillcore intersections, but are of low temperature derivation and different in composition and texture to the higher temperature veins with which the bulk of the precious metals are associated in typical hot springs deposits. They consist of variable proportions of zeolites, cryptocrystalline and/or very fine grained silica, calcite, baryte and pyrite. In Fig. 1 the vertical distribution of vein minerals at Springfontein (shaded area) are compared to those in a typical mineralized deposit. The inferred temperature regime of the former, demarcated in stippled lines, has an upper level of approximately 170°C. Precious metal deposition in most hot springs deposits, however, has taken place in the 200 to 250°C temperature range and is accompanied by adularia. Small amounts of adularia in quartz veins were identified in a few of the core samples but are regarded to be of similar origin as the earlier high temperature veins produced by the dolerite. The lowermost sample examined from drillhole 9/1035 is anomalous. This vein occurs in excess of 500 m below the dolerite sill but, does contain epidote, primary sericite and molybdenite and formed at temperatures close to 200°C.

4.0 GENERAL

Hydrothermal veins at Springfontein are a combination of typical hydraulic breccias, occurring down to at least 800 m, and open space fracture fillings not accompanied by wall rock inclusions. Evidence of multiple injection exists, especially at higher levels, and fluidization has taken place as indicated by breccia in dolerite containing sedimentary fragments. No coarse vent breccias have apparently been encountered suggesting that no violent eruption occurred close to surface or that they have been eroded away. It is uncertain to what extent the "sinter breccias" consist of detrital inclusions or eruption fragments. Veins associated with localized shearing, and alteration along fault breccia indicate that the ascent of the solutions were partly controlled by older zones of structural deformation.

It is/...

It is currently the consensus that hydrothermal eruptions are triggered by an external event such as heat flux from a magmatic intrusion or seismically induced activity. The heat source during the pre-existing geothermal system is usually also an intrusion, but may be a fault zone which generates heat by friction, or a pile of glassy clastic rocks which generates heat by exothermic hydration reactions. No apparent heat source has been established at Springfontein. The existence of hydraulic breccias strongly suggest that the hydrothermal activity cannot be solely attributed to an elevated geothermal gradient, and the possibility does exist that deep seated magmatism which gave rise to dolerite intrusion, is the heat source.

No magmatic intrusions or significant hydrothermal alteration was observed in percussion chips examined from the Soekor borehole (15,000 ft) drilled on the southern sinter hill. Rock chips containing quartz veining at 6 570 ft do however have an anomalous gold content. It is interesting to note that in some sinter deposits, particularly those containing anomalous mercury, petroleum and hydrocarbon gases occur as inclusions in silica. Whether this feature had any bearing on the siting of this borehole is not known.

In most hot springs gold deposits the bulk of the mineralization occurs between 150 and 400 m below the sinter, but in a few cases is located in the sinter or directly below the sinter capping. This is probably a function of the level at which boiling takes place and the extent to which the system is vapour or solution dominated. Evidence gained from hot springs deposit indicate that boiling and consequent loss of H_2S and CO_2, is the primary mechanism responsible for gold precipitation. Boiling causes cooling, oxidation, an increase in solution pH and a decrease in the activity of reduced sulphur, all mechanisms for gold precipitation. According to recent literature most workers in this field are of the opinion that the gold is transported as a hydrosulphide complex, like $Au(HS)_2^-$, in epithermal ore solutions. Boiling producing H_2S vapour will thus be a most effective process for gold deposition. The only gold observed in polished section from Springfontein occurs as very fine inclusions in pyrite, suggesting that it was transported as a sulphide complex. In cases where no boiling or boiling close to surface takes place gold is precipitated close to the paleo-surface.

The apparent paucity of precious metals at Springfontein can be due to the following possibilities:

a) The geothermal system was not enriched in gold as a result of the nature of the source rocks, no effective leaching of gold on account of the low temperature of the circulating solutions, or insufficient period of leaching prior to hydrothermal eruption.

b) Precious metal mineralization took place, but was not intersected by drilling. No effective boiling took place at depth and the gold was precipitated from solutions discharging at surface or close to surface. In this case mineralized zones occurring close to the vent have subsequently been eroded. Alternatively, mineralization does occur at depth and possibly north of the deep boreholes, 9/1035 and the Soekor hole.

It seems/...

It seems highly unlikely that mineralization took place within the silica capping or in the shallow argillic zone, as indicated by the poor geochemical values obtained from surface and trench samples. The most plausible explanation for the lack of gold mineralization is that the geothermal system was deficient in gold. This is probably mainly on account of the poor gold content of the source rock sediments and relatively short duration of the geothermal cell, as hydraulic breccias extending to deep levels (borehole 9/1035) suggest that boiling did occur.

The hydrothermal alteration in boreholes 9/1015 and 14/1015 are both very low temperature, but vertical zonation of the veins is best developed in the borehole 14/1015, north of the former. R.L. Nichols has also found that a stronger geochemical trend, and higher magnetic and I.P. resistivity zone exists off the northern end of Beacon Hill. The possibility of higher temperature vein assemblages occurring below the dolerite in this locality has not been established.

5.0 CONCLUSIONS

No doubt exists that the Springfontein prospect represents a fossil hot spring occurrence as indicated by the presence of siliceous sinter, hydraulic breccias, the type of hydrothermal wall rock and vein alteration, geochemical signature, etc.

Hydrothermal vein assemblages are of low temperature origin and typical of the upper, precious metal poor, levels of most hot spring deposits. They consist mainly of poorly crystalline silica, various zeolites, calcite and pyrite, and extend to the deepest levels intersected by the boreholes. High temperature veins are present, but these occur mainly within or close to dolerite and are siliceous differentiates produced by the latter.

Temperatures of formation inferred by the vein minerals do not exceed 170°C, and for the most part are considerably lower. In the majority of mineralized deposits of this kind precious metals are precipitated above a boiling zone at temperatures between 200 and 250°C, at depths between 150 and 500 m, and adularia is almost invariably a major gangue constituent. However, in a small number of deposits gold is precipitated close to the paleosurface and at temperatures as low as 140°C, as a result of boiling close to surface.

Based on present knowledge, the absence of any significant mineralization revealed by exploration is due to the apparent low temperature of the geothermal system, the consequently poor leaching capabilities of the solutions and possibly relatively short duration of leaching prior to extrusions of the hydrothermal solutions. However, it is important to note that widespread hydraulic brecciation is evident in deeper levels of borehole 9/1035. This strongly suggests that boiling of the system took place and that precipitation of precious metals, if present, would have taken place above the focus of boiling.

It is extremely unlikely that any notable mineralization occurs close to surface in silicic and argillic zones. Contaminated surface waters would have given rise to a more extensive gold anomaly throughout the surface expression than is the case. Also, the bulk of any gold in solution, transported mainly as a hydrosulphide complex in these types of deposits, would be precipitated at depth due to the development of H_2S during boiling. The possibility of mineralization below the northern sinter at depths in excess of ± 350 m, although not promising, does exist. Hydrothermal alteration and depth zonation is somewhat more common and better developed in borehole 14/1015, the baryte occurrence is indicative of a large fracture zone, and magnetic and I.P. resistivity is also higher in the northern zone.

INVESTIGATED AND REPORTED BY:

F. Boshoff

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FB/ln

TABLE 1

MINERALOGICAL COMPOSITION OF VEINS AND NATURE OF HOST ROCK IN SAMPLES FROM BOREHOLE 9/1035

Sample No. depth (m)	Description	Vein mineralogy (%)
A20 236,0	Partly brecciated sericite-rich mudstone cemented by vein quartz, sericitized feldspar laths and minor, unevenly distributed chlorite, epidote and sphene.	quartz (f.mx to mg)-50, feldspar-12, chlorite-5, epidote-3, sphene-1, sphene-1, calcite-t.
A19 279,0	Biotite-rich siltstone, containing notably angular grains of quartz and feldspar, is veined by fairly coarse calcite exhibiting zonal structures and containing fine inclusions of subhedral pyrite.	calcite-11, pyrite-t, marcasite-tt.
A18 397,5	Chlorite-bearing, coarse siltstone containing typical vein quartz accompanied by partly sericitized feldspar, minor chlorite and epidote. Occasional monomineralic feldspar veinlets are present.	quartz (c.mx to mg)-28, feldspar-6, chlorite-3, epidote-1.
A17 411,5	Chlorite-bearing fine feldspathic sandstone veined by zeolite and interstitial clayey-chloritic mineral. Fine pyrite veinlets replace the zeolite along cleavage planes.	laumontite-17, clayey-chloritic-10, calcite-2, pyrite-1, marcasite-t.
A14 511,9	Medium-to-coarse-grained siltstone containing notably sericitized feldspar, is veined by zeolite.	laumontite-8.
A16 532,5	Locally sheared and partly brecciated coarse siltstone cemented by zeolite showing dynamic deformation. Small disseminated euhedra and veinlets of pyrite are associated with the zeolite.	laumontite-50, pyrite-2.
A15 564,8	Protocataclastic fine siltstone cemented and veined by zeolite.	laumontite-25.
A13 568,1	Fine silicified siltstone is crosscut by zeolite veins, in some cases containing a peripheral zone of fine quartz. Pyrite occurs mainly along cleavage fractures in the zeolite.	laumontite-15, quartz (f.mx)-4, pyrite-2.

A12 / ...

Sample No. depth (m)	Description	Vein mineralogy (%)
A12 599,7	Partly brecciated, somewhat sheared, medium-to coarse-grained siltstone. It is highly sericitized in parts, shows matrix silicification and possibly argillation.	quartz (f.mx)-3, calcite-4, pyrite-1 clay?-2, laumontite-t.
A11 600,9	Similar to A12.	laumontite-10, calcite-4, quartz (f.mc)-2,
A10 634,8	As above	calcite-23, pyrite-5, marcasite-1, quartz (f.mx)-2.
A9 637,9	Mudstone containing thin quartz, calcite, pyrite pyrite veinlets and carbonate, clay, pyrite, phosphate? concretion	quartz (f.mx)-2, calcite-1, pyrite-1.
A8 220,0	Pyritized, fine feldspathic sandstone containing fine to coarse microcrystalline quartz veins partly rimmed by an outer cryptocrystalline quartz zone. Disseminated pyrite crystals in the quartz contain rare marcasite.	quartz (crx to c.mx)-20, pyrite-2, calcite-1, marcasite-t.
A7 756,7	Brecciated mudstone, sericite-rich, cemented by relatively coarse calcite, minor quartz and pyrite. Matrix silicification evident in the host adjacent to the veins.	calcite-28, quartz (f.mc)-6, pyrite-2, marcasite-t.
A6 793,8	Somewhat silicified, pyritized and brecciated mudstone containing quartz, calcite veins. The quartz ranges from cryptocrystalline to typical euhedral, coarse microcrystalline, and encloses rare pyrite grains. The calcite is pseudomorphous after baryte and contains replacement remnants of the latter.	quartz (crx to c.mx)-20, calcite-7, baryte-t, pyrite-1.
A5 804,3	Protocataclastic, silicified fine feldspathic sandstone containing porous quartz vein and calcite pseudomorphous after baryte. Some of the quartz is turbid due to very fine "clayey" inclusions. The sediment is enriched in pyrite adjacent to the vein contact.	quartz (crx to c.mx)-30, calcite-5, baryte-t, pyrite-t.

A4 / ...

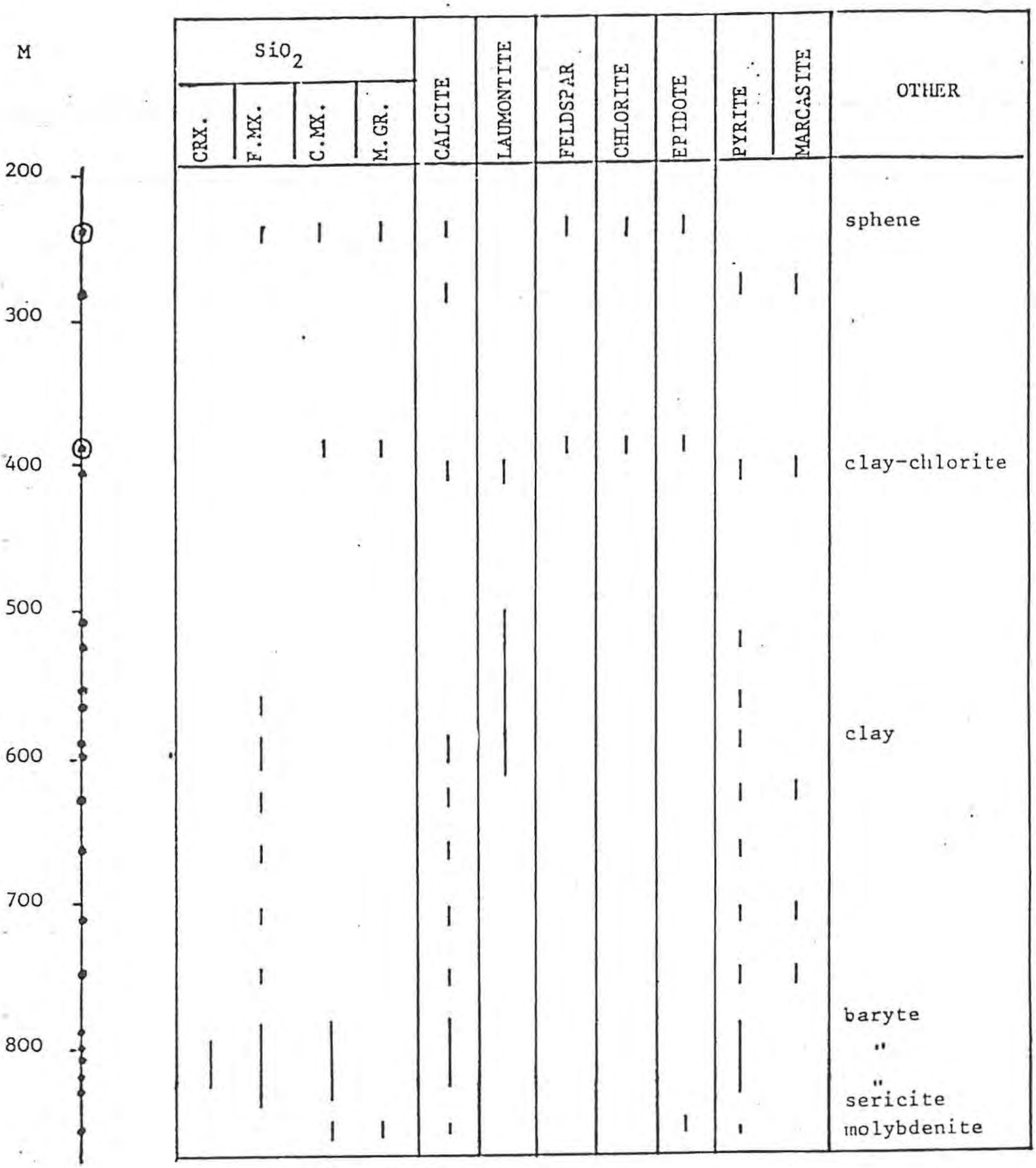
Sample No. depth (m)	Description	Vein mineralogy (%)
A4 808,6	Protocataclastic, silicified mudstone with vein quartz accompanied by calcite (not pseudomorphous after baryte) and occasionally epidote and pyrite.	quartz (f.mx to c.mx)-15, calcite-5, epidote-1, pyrite-t.
A3 825,7	Silicified, medium to coarse siltstone with composite quartz veining. Individual quartz veins constituting the latter are crypto-crystalline, fine or coarse microcrystalline. Small elongate crystals of baryte occur in the quartz	quartz (crx to c.mx)-20, baryte-1, pyrite-t,
A2 827,8	Silicified, pyritized mudstone veined by quartz and pyrite.	quartz (f.mx to c.mx)-6, pyrite-6, marcasite-t.
A1 862,1	Fine feldspathic sandstone containing minor epidote and veined by coarse calcite enclosing relatively coarse, euhedral quartz crystals and minor spherulitic sericite (not derived from feldspar). Small flakes of molybdenite are present in the calcite close to the contact zone with the sediment	calcite-17, quartz (c.mx to m.gr)-4, epidote-2, sericite-1, molybdenite-t.

Abbreviations denote the following:

crx. - cryptocrystalline (0,05 mm)
f.mx - fine microcrystalline
c.mx - coarse microcrystalline
m.g - medium-grained (1,0 mm)

TABLE 2

VEIN MINERALOGY - DEPTH ZONATION (9/1035)



ABBREVIATIONS DENOTE :

CRX. - Cryptocrystalline. F.MX. - Fine microcrystalline.
C.MX. - Coarse microcrystalline. M.GR. - Medium-grained.

⊙ These veins are probably due to dolerite intrusion.

TABLE 3

VEIN MINERALOGY BOREHOLE 9/1015

		SiO_2											
SAMPLE	M	CRISTOB.	CHALCED.	CRYPTO.X.	MICRO.X.	MED. GR.	CALCITE	MORDENITE	HEULANDITE	FELDSPAR	CHLORITE	PYRITE	OTHER
1	24,4						|		|			|	
2	56,7				|	|				|	|		
C7	125,4	|	|	|	|		|	|				|	
3	128,7							|					
4	143,8					|	|				|	|	
C6	154,9	|	|	|			|	|				|	laumontite baryte
5	156,2		|	|				|				|	
C5	159,1	|					|					|	
6	160,3						|					|	
7	207,3				|	|	|		|		|		
C3	217,7		|		|		|	|				|	
8	241,9						|					|	
9	250,6				|					|		|	
C2	257,8				|	|					|		epidote sericite
C1	274,7				|	|	|				|		epidote
10	275,1				|	|				|			epidote garnet
													chalcopyrite in C2

ABBREVIATIONS DENOTE:

CRISTOB. - cristoballite   CHALCED. - chalcedony   CRYPTO.X. - cryptocrystalline
MICRO.X. - microcrystalline   MED. GR. - medium-grained
Veins in samples 2, 4, 7, 9, 10, C1 and C2 are probably produced by the dolerite.

TABLE 4

VEIN MINERALIZATION BOREHOLE 14/1015

			ZEOLITE			SILICA							
			Mord.	Heu.	Lau.	Cris.	Cha.	Cryp.	Mqz.	Ba	Cc	Py	Ct
SED.	1.	2	2				2	3	1			3	
	2.	22					3	2				2	
DOLERITE	3.	41	1					4			3	2	
	4.	56	2	2		1	2	3			4		
	5.	60	2	2		2	3		2	2	3	3	
	6.	64	2			2	4	1		2	3	2	
	7.	68	2			1	1	3	2		4		
	8.	78											
	9.	89					2	4			1	2	
	10.	95	2			2		4				2	
	12.	153	1					3			4	2	
	13.	168	2	2		3	2	2		3	2	2	
	23.	177					1	2	2		3		
	14.	191	3			2		2	2		1	3	
	15.	204	2			2		3		1	4	2	
	16.	212	1				1	2			4	2	
	17.	218		1	3				2		4	2	2
	18.	229						2			4	3	
	19.	233	3	3			2				4	2	
	20.	251	2	2							4	3	
	22.	260					2	2			4	2	
SED	24.	295						3	2		3	2	

Abbreviations denote the following:

Mord. - mordenite
Heu. - heulandite
Lau- - laumentite

Chris - cristoballite
Cha - chalcedony
Cryp - cryptocrystalline
M.Qqz - micro-crystalline

Ba - baryte
Cc - calcite
Py - pyrite
Ct - chlorite

4 - Predominant. 3 - Major 2 - Minor 1 - Small amounts

TABLE 5

SPRINGFONTEIN - VEIN MINERALOGY

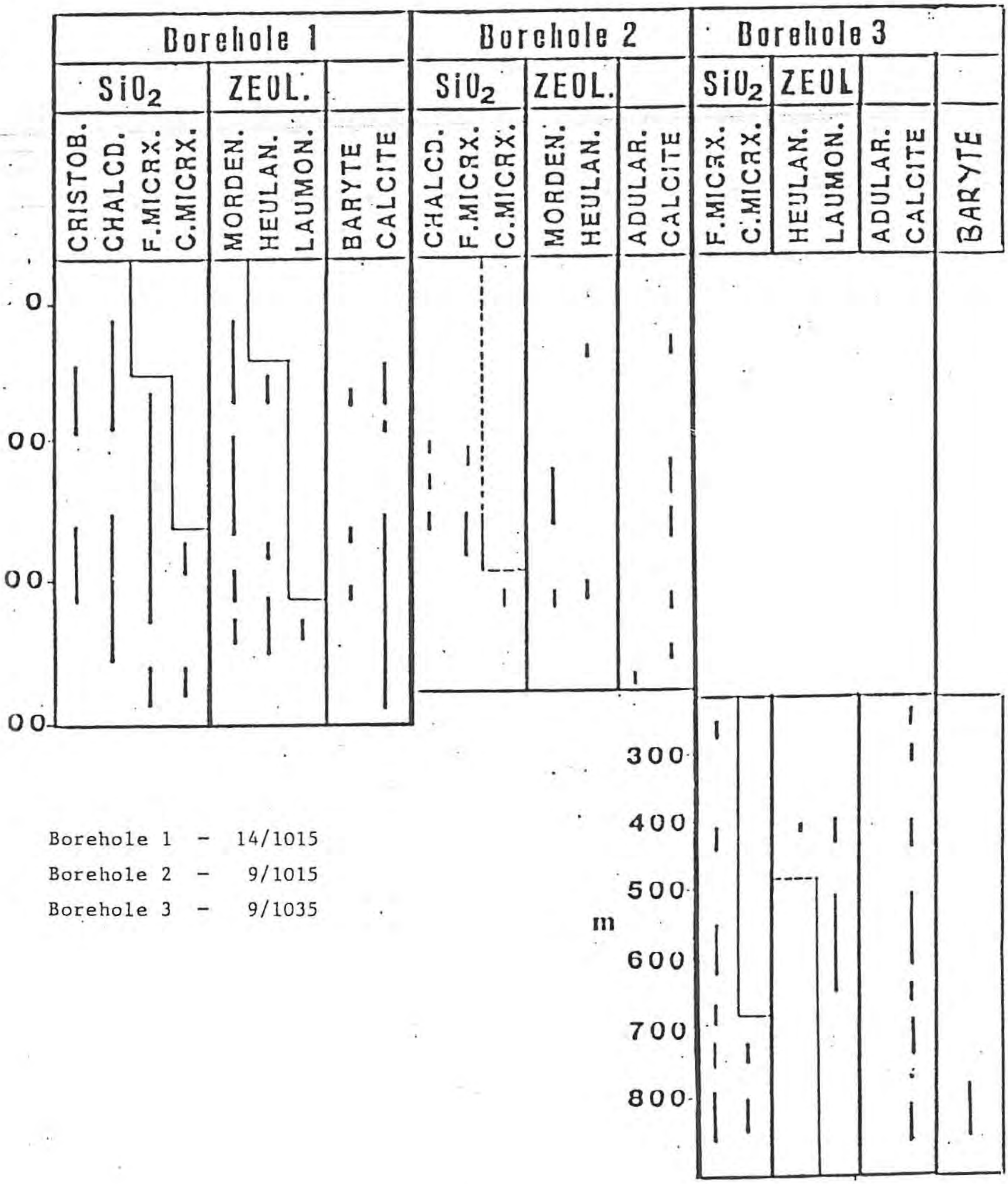
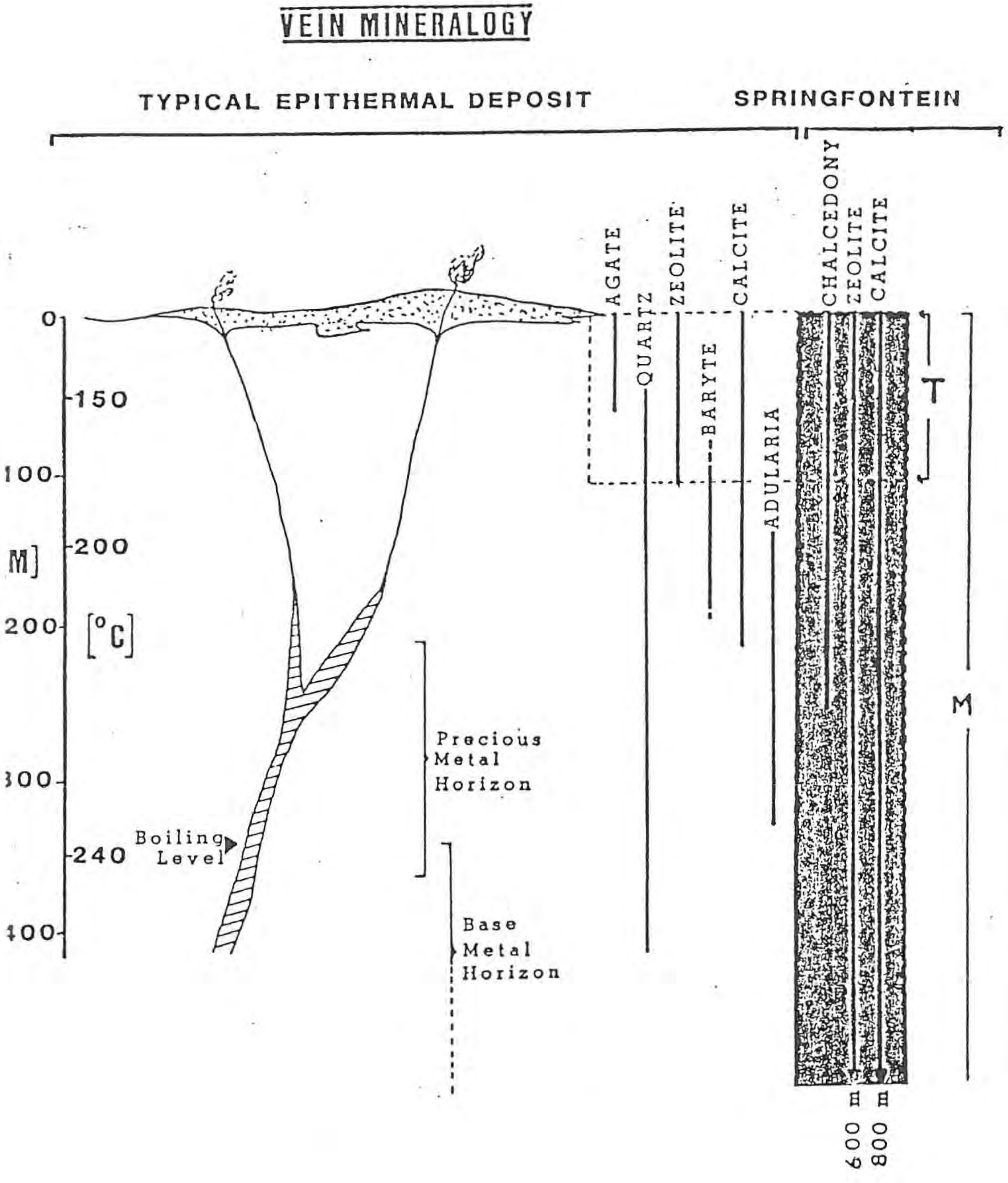


FIGURE 1


VEIN MINERALOGY
TYPICAL EPITHERMAL DEPOSIT
SPRINGFONTEIN
AGATE
QUARTZ
ZEOLITE
BARYTE
CALCITE
ADULARIA
CHALCEDONY
ZEOLITE
CALCITE
0
150
100
200
M]
200
[°C]
300
240
400
Boiling Level
Precious Metal Horizon
Base Metal Horizon
T
M
600 m
800 m

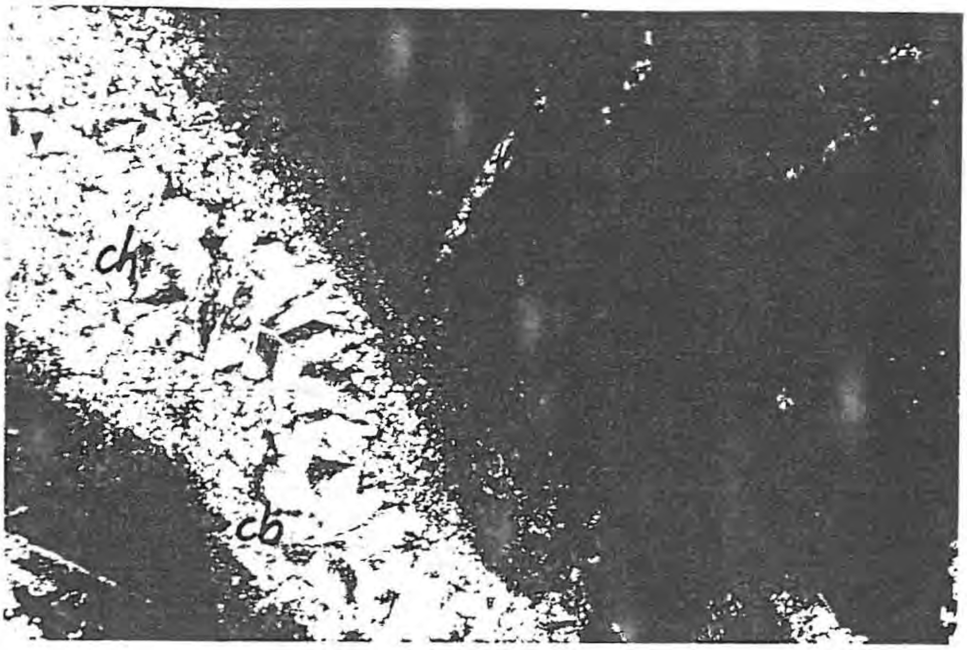


Fig. 1. Vein Mineralization.

Transmitted light.
Crossed nicols.
Photolength 2,6 mm

Cristoballite (cb) grading into an intergrowth of cryptocrystalline silica and cristoballite (qcb) occurs interstitially to elongate crystals of calcite and quartz (p) pseudomorphous after baryte. Fibrous chalcedony (ch) is present on the left.

Fig. 2. Vein Mineralization

Transmitted light.
Crossed nicols.
Photolength 2,6 mm.

Baryte crystals (b) partly replaced by quartz, calcite and mordenite are contained in a fine matrix of quartz (q) accompanied by minor fibrous mordenite.

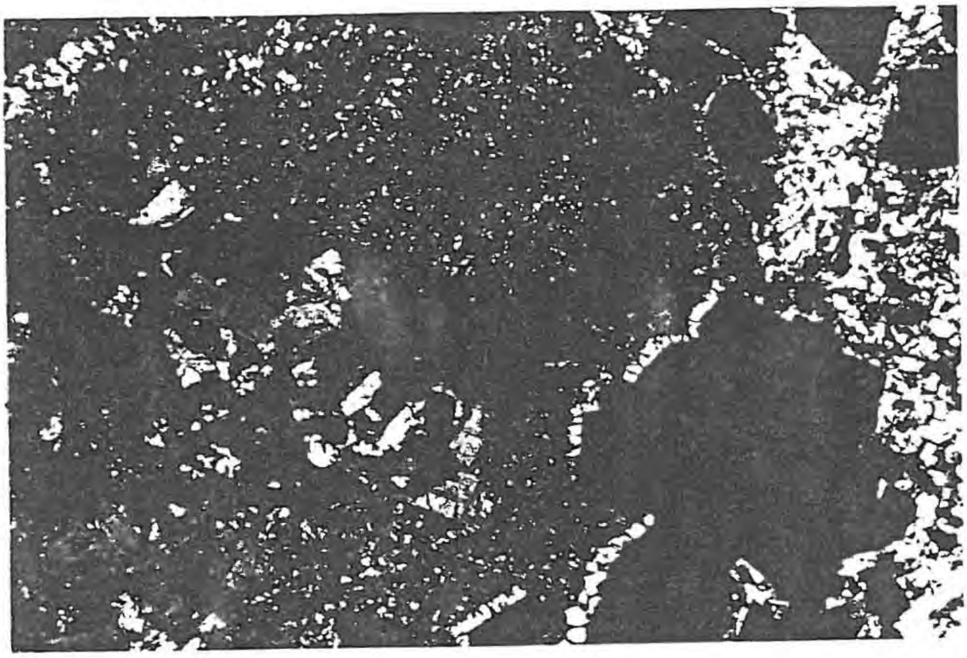


Fig. 3. Vein Mineralization

Transmitted light.
Crossed nicols.
Photolength 2,6 mm.

Fig. 4. Vein Mineralization

Transmitted light.
Uncrossed nicols.
Photolength 2,6 mm.

Euhedral pyrite (black) occurs in a matrix of nearly cryptocrystalline quartz extensively replaced by fibrous mordenite-quartz intergrowths (mq), fine-grained quartz (q) and laumontite (l).

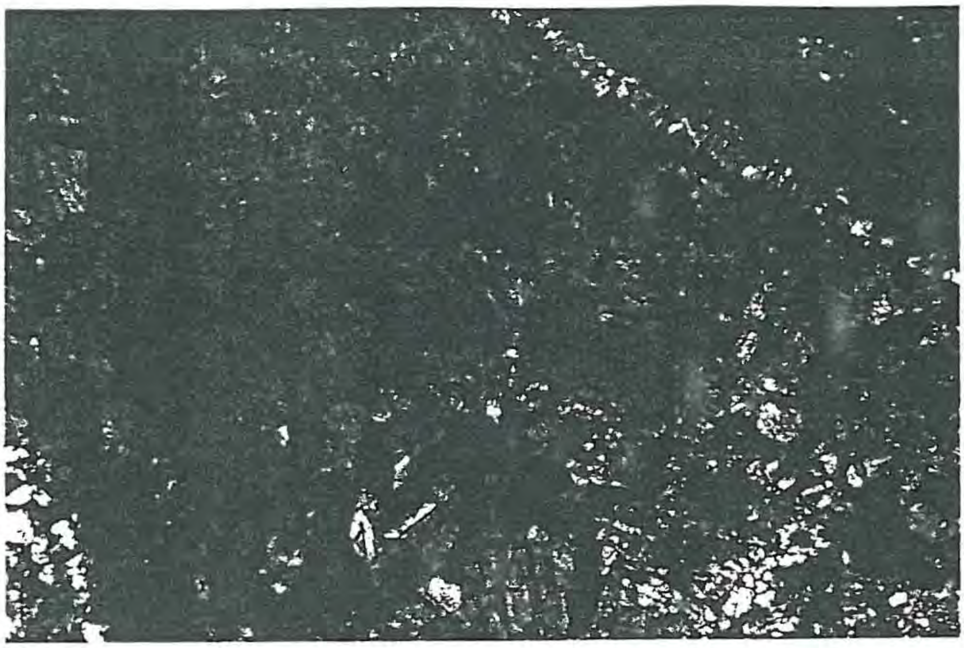


Fig. 5. Vein Mineralization

Transmitted light.
Crossed nicols.
Photolength 2,6 mm.

Massive laumontite (l) rimmed by fine-grained quartz (q) veining sediment (s).

Fig. 6. Vein Mineralization & Wallrock Alteration

Transmitted light.
Crossed nicols.
Photolength 2,6 mm.

Baryte crystals (b), turbid and partly replaced by calcite are contained in a fine, porous aggregate of quartz accompanied by interstitial calcite (c). Brown discoloured, finer grained areas in the quartz are probably recrystallized cristoballite. The sediment has undergone matrix silicification and argillic alteration.

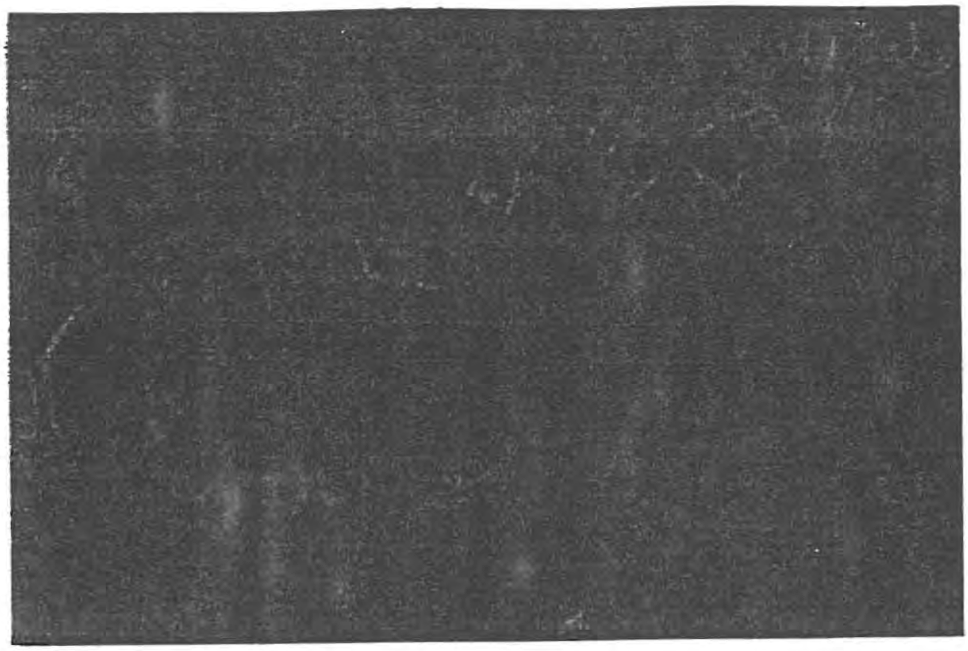


Fig. 7. Vein Mineralization

Incident light.
Uncrossed nicols.
Photolength 0,7 mm.

Molybdenite (m) is contained in a matrix consisting of calcite and minor sericite.

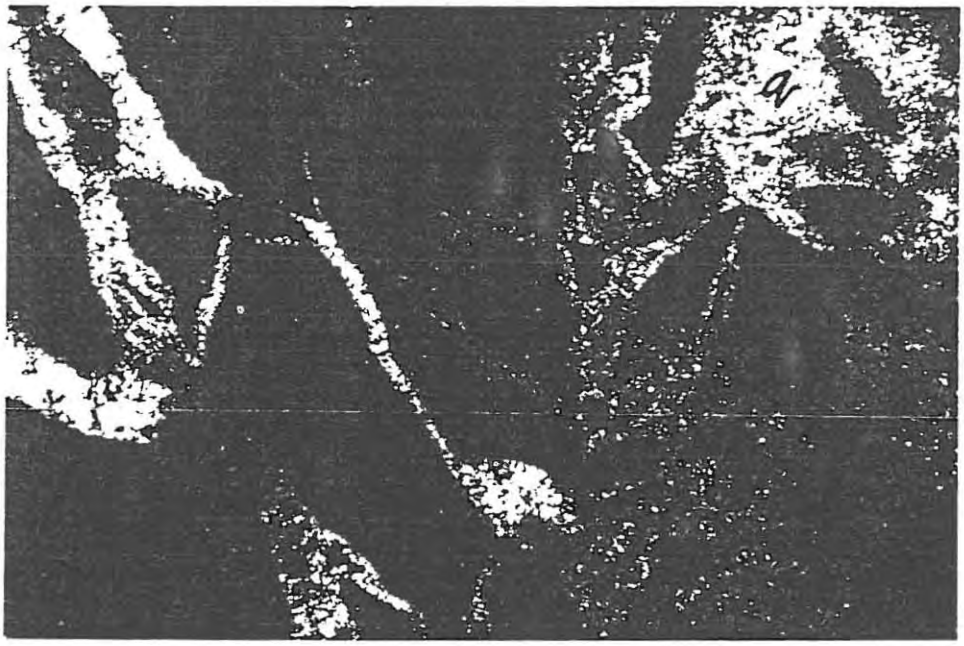


Fig. 8. Vein Mineralization & Wallrock Alteration

Transmitted light.
Crossed nicols.
Photolength 2,6 mm.

Brecciated, sericitic mudstone (s) exhibiting matrix silicification and cementing by fine-grained quartz (q) and pyrite (black).

Fig. 9. Vein Mineralization

Transmitted light.
Crossed nicols.
Photolength 2,6 mm.

Relatively high temperature vein (dolerite related) consisting of fairly coarse quartz, sericitized feldspar (f), epidote (e) and chlorite (ct).

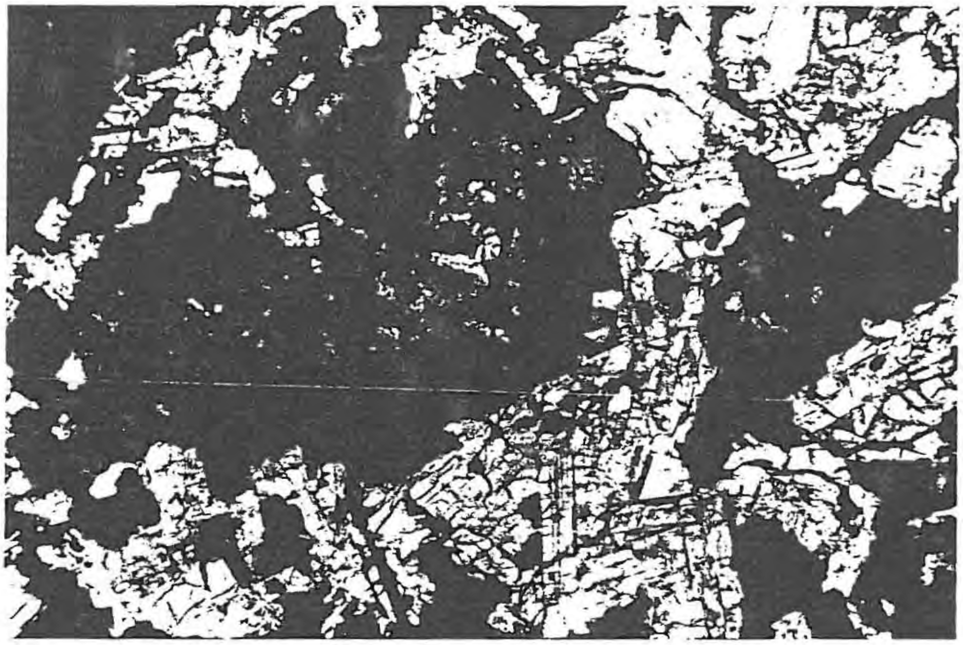


Fig. 10. Wallrock Alteration

Transmitted light.
Uncrossed nicols.
Photolength 1,3 mm.

Pyroxene in dolerite is extensively replaced by pyrite and celadonite type mineral (dark brown).

Fig. 11. Wallrock Alteration

Transmitted light.
Crossed nicols.
Photolength 1,3 mm.

Dolerite consisting of calcite (multicoloured) pseudomorphous after pyroxene and plagioclase laths showing incipient argillic alteration.

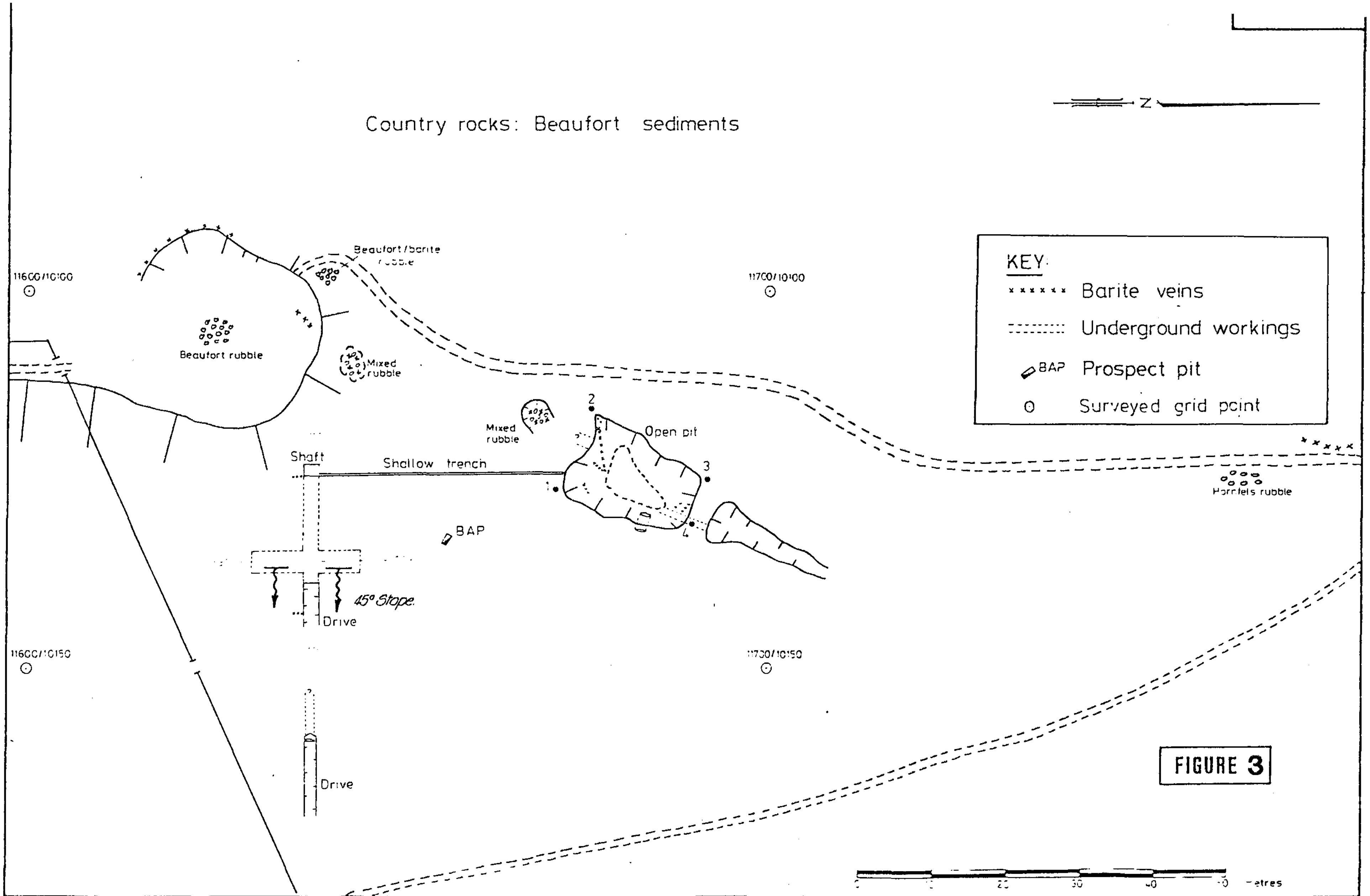


FIGURE 3

GEOLOGY BY		ANGLO AMERICAN PROSPECTING SERVICES (PTY) LTD.	DATE	
DRAWN BY	T.A Barnard	SPRINGFONTEIN PROJECT	REPORT	13/173/ff/85/117
REVISED BY			SCALE	
PLAN REGISTER No. 11182.3.(X)	FILE	Diagram showing open pit and underground barite workings	MAP REF	

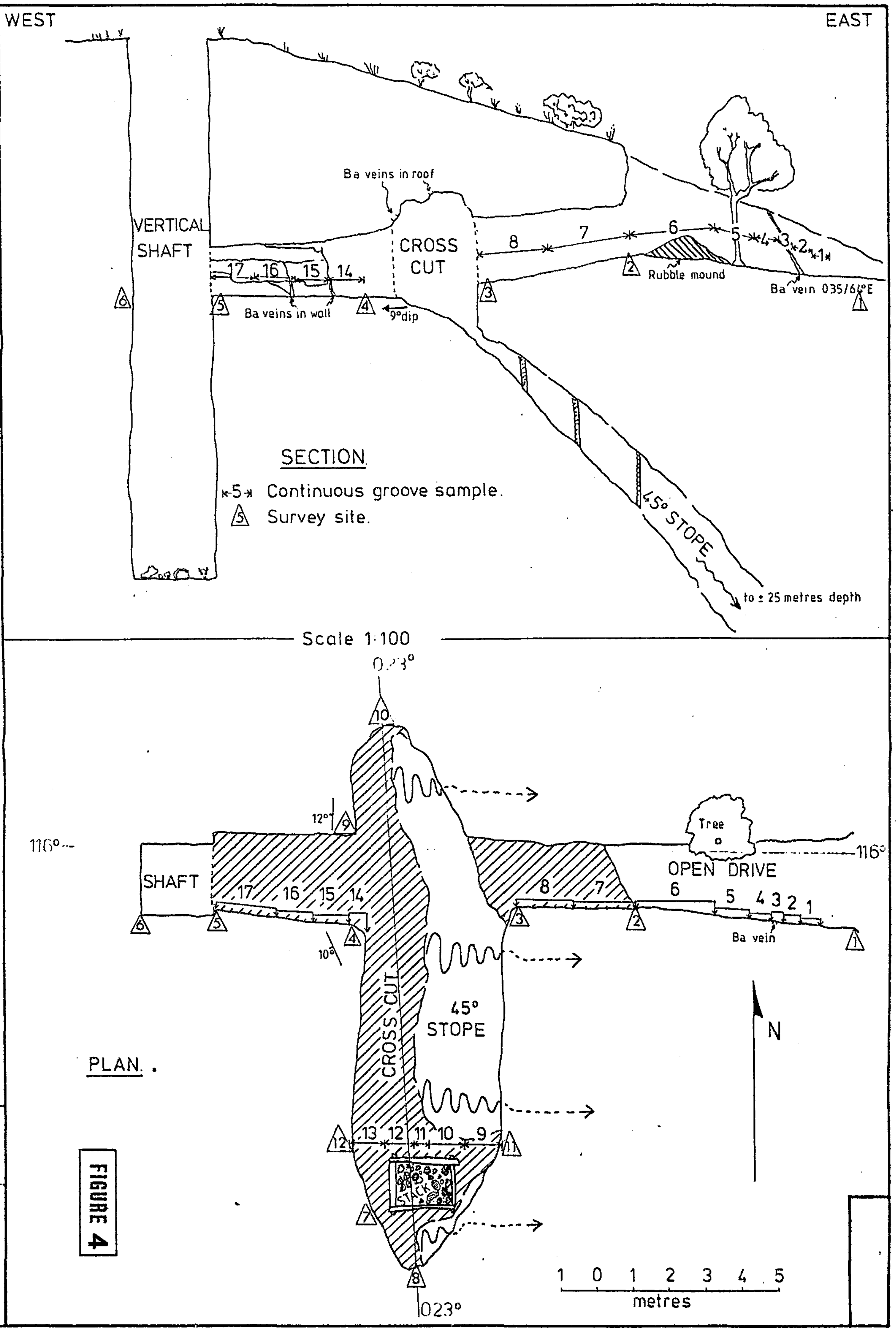


FIGURE 4

ANGLO AMERICAN PROSPECTING SERVICES (PTY) LTD.

SPRINGFONTEIN PROJECT.

Diagram of the underground workings showing the groove sampling.

GEOLOGY BY	R L Nichols	JULY 84
DRAWN BY	R.L.Nichols	JULY 84
REVISED BY		
PLAN REGISTER No.	X10056.3	FILE

DATE	
REPORT	13/173/ff/85/117
SCALE	1:100
MAP REF.	

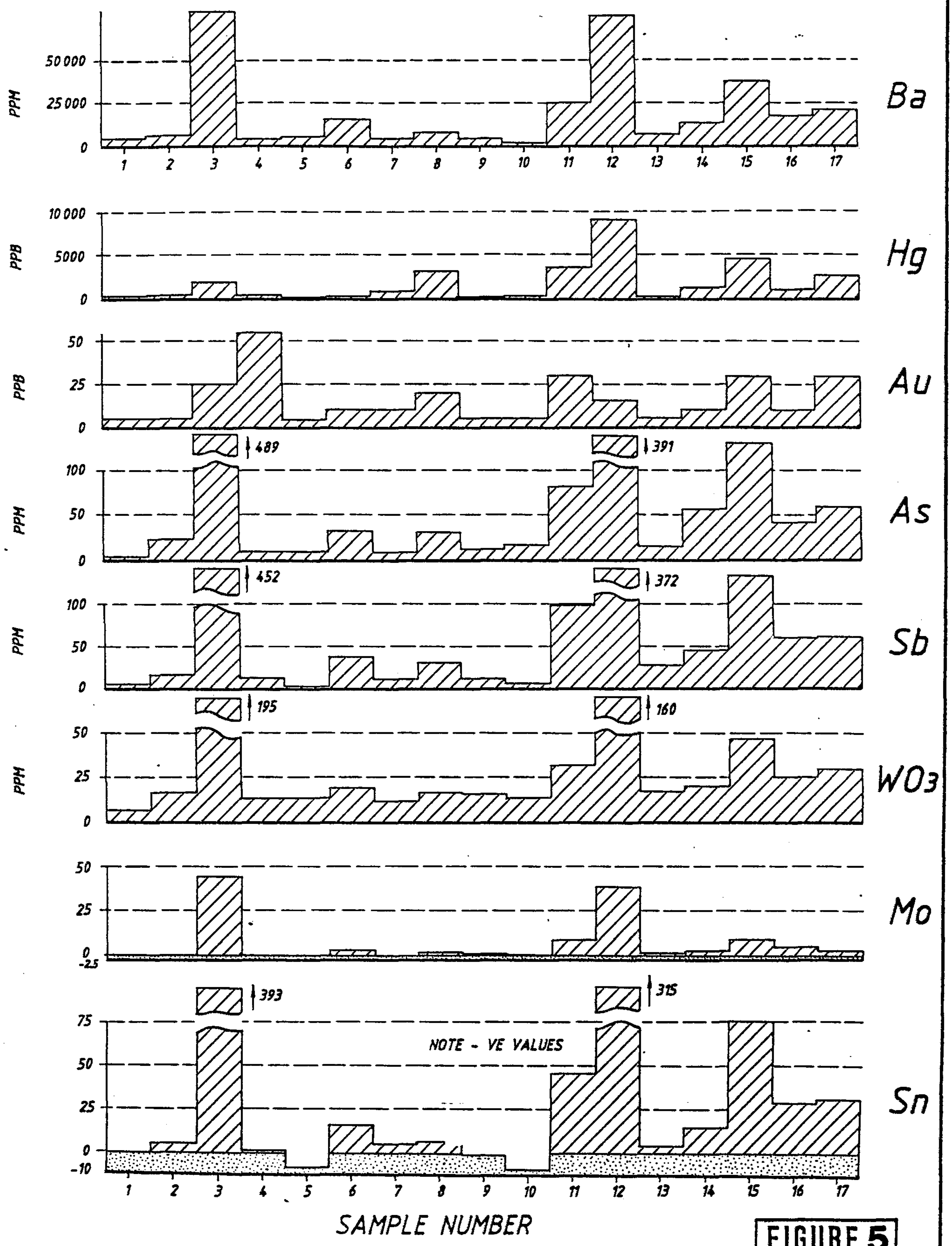


FIGURE 5

GEOLOGY BY	R.L.N	ANGLO AMERICAN PROSPECTING SERVICES (PTY.) LTD.	DATE	12 FEBRUARY 85
DRAWN BY	B.T.G.	BARITE WORKINGS - UNDERGROUND ROCK SAMPLE ANALYSIS OXRLN84/3	REPORT	13/173/11/85/117
REG.No.			SCALE	
FILE	X11209.2		MAP REF.	3327BB

WB 1049

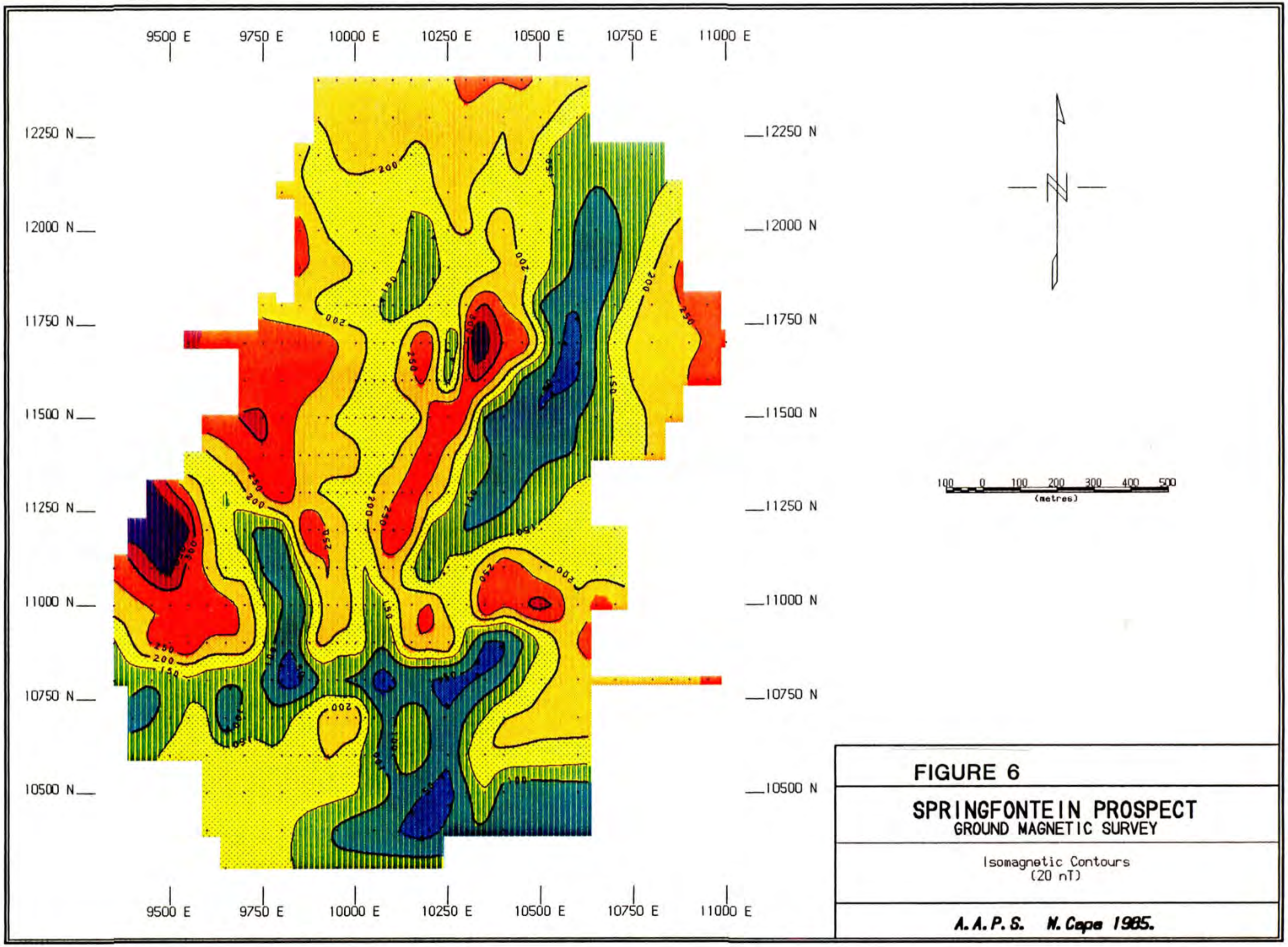


FIGURE 6

SPRINGFONTEIN PROSPECT
GROUND MAGNETIC SURVEY

Isomagnetic Contours
(20 nT)

A.A.P.S. N. Cape 1985.

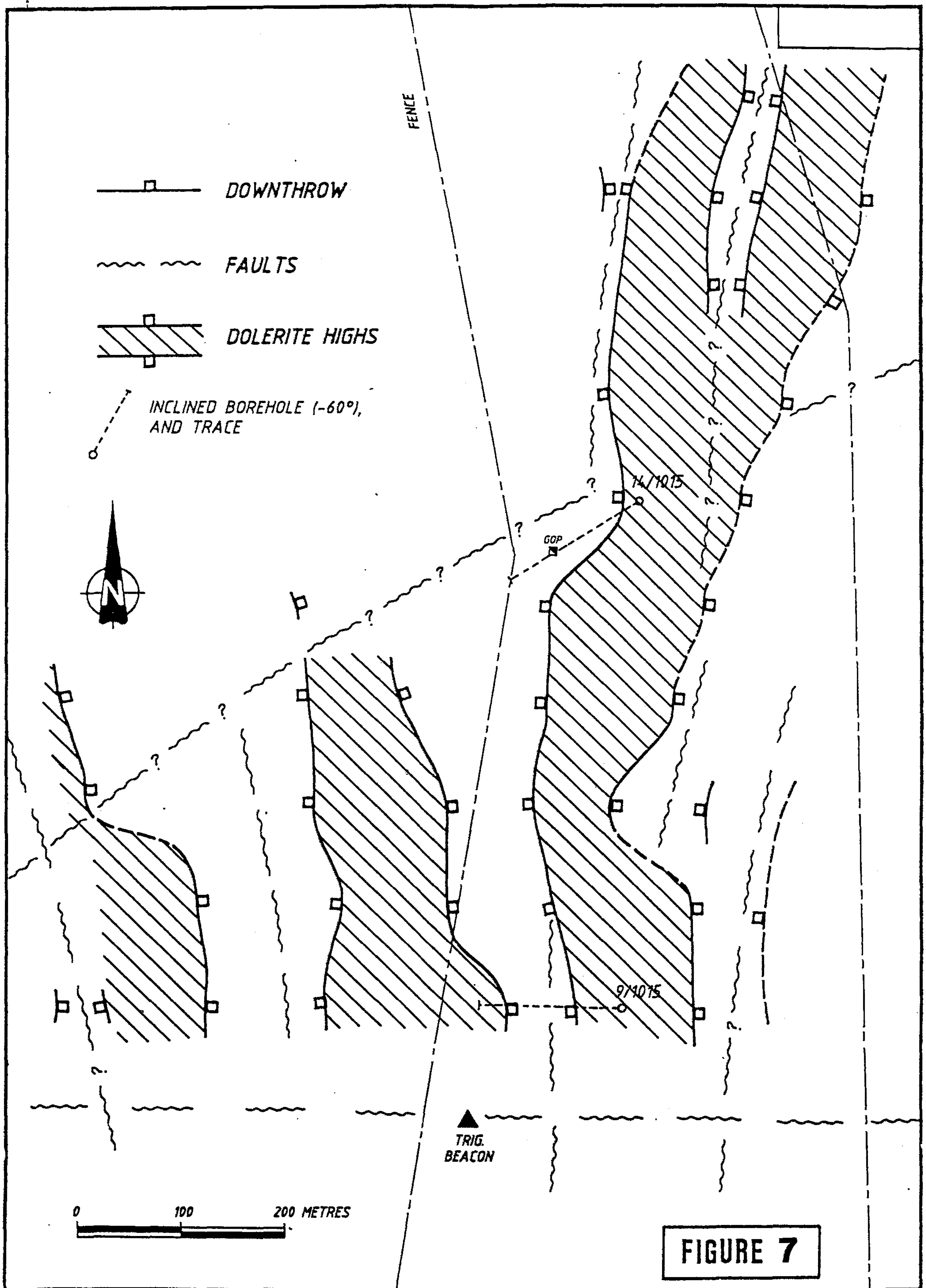


FIGURE 7

GEOLOGY BY	R.L.N.	ANGLO AMERICAN PROSPECTING SERVICES (PTY.) LTD.	DATE	19 FEBRUARY 85
DRAWN BY	B.T.G.	SPRINGFONTEIN PROSPECT	REPORT	13/173/11/85/117
REG.No.	X11198.4	MAGNETIC INTERPRETATION	SCALE	1 : 5000
FILE			MAP REF.	3327BB

WB 1049

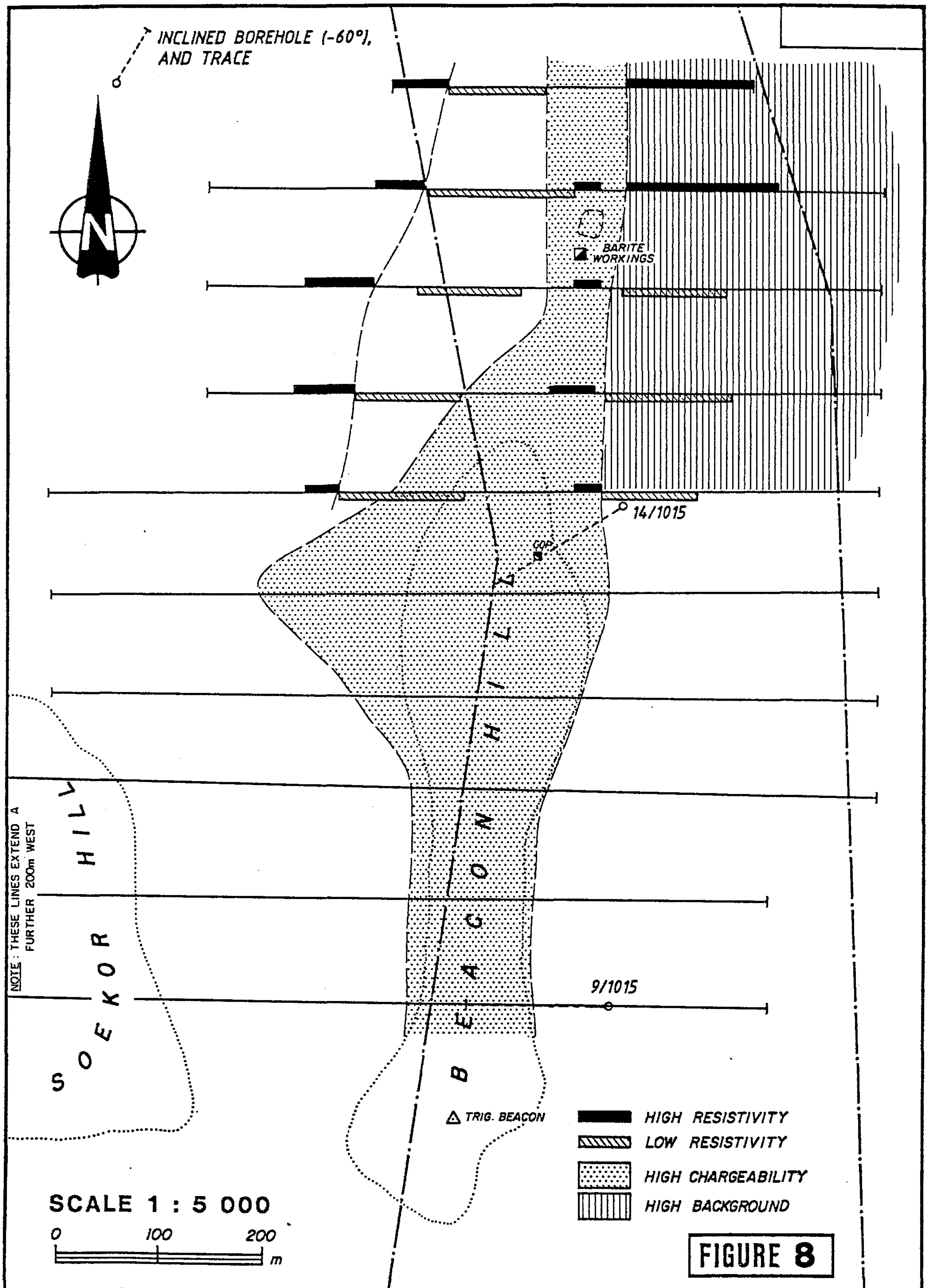


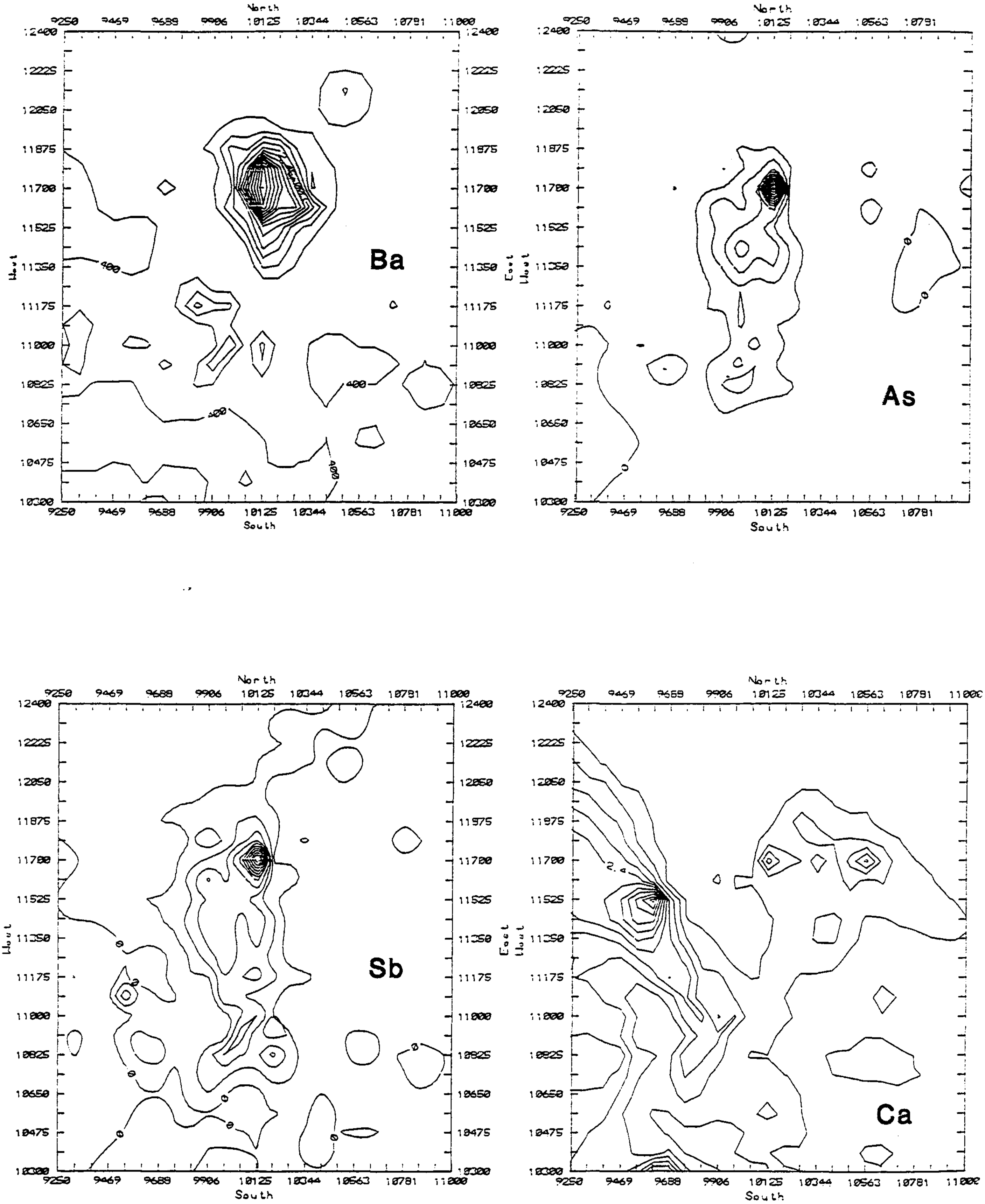
FIGURE 8

GEOLOGY BY	L.A.G.A.	ANGLO AMERICAN PROSPECTING SERVICES (PTY.) LTD.	DATE	20.02.85
DRAWN BY	P.J.E.	**SPRINGFONTEIN PROSPECT**	REPORT	13/173/11/85/117
REG.No.		**ORIENTATION DIPOLE-DIPOLE IP SURVEY**	SCALE	1:5000
FILE	X11286.4	**(50m ELECTRODE SPACING)**	MAP REF.	3227 DD

W B 1049

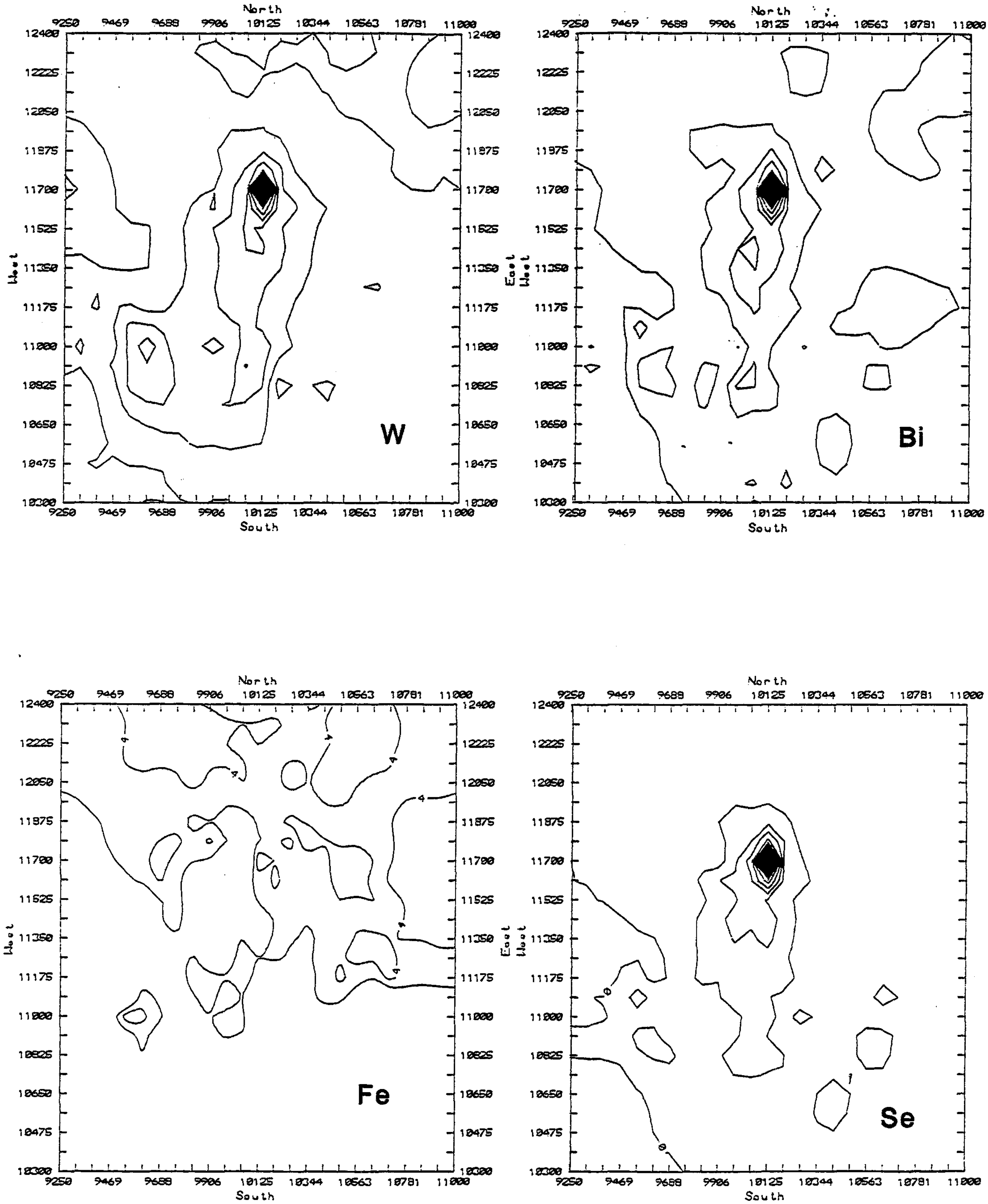
FIGURE 9


GE NAME: P181R83'NEG NS = 2513 NL = 2372 RASTER SPACING = 50.0 MICRONS
E ENHANCED FCC OF P181R83
NOV 26, 1983 PROCESSED AAC REMOTE SENSING 10KM TICK INTERVALS
Bridle Drift Dam
CT72 C S33-01/E027-57 N S33-03/E028-04 SUN EL48 AZ062 190-1165- -1- D- NASA ERTS E-1084-07265-



Springfontein Geochemical Soil Plots

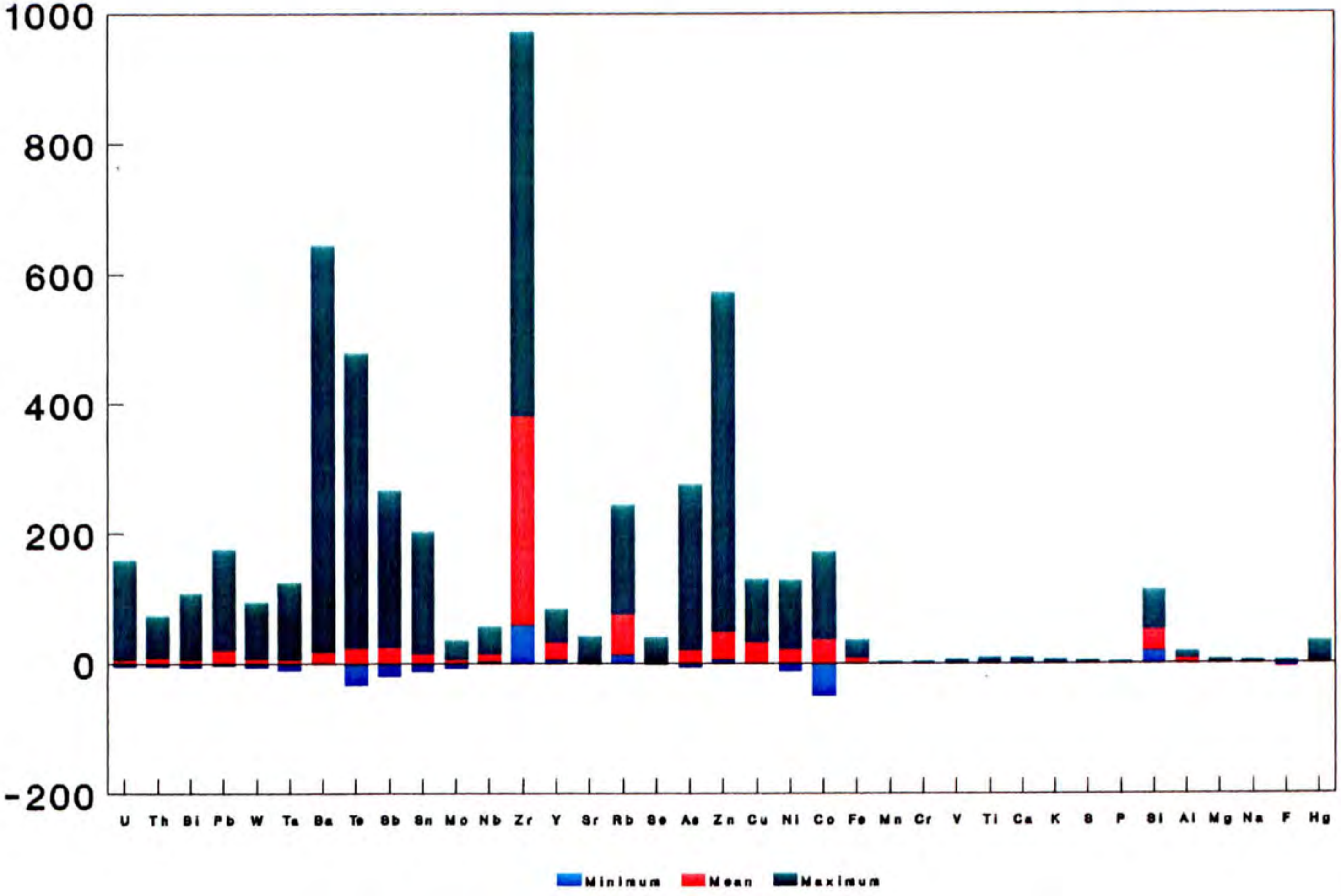
FIGURE 10



Springfontein Geochemical Soil Plots

FIGURE 11

Springfontein Soil Geochemistry.
36 element XRFME and Hg AAGEOBM data.

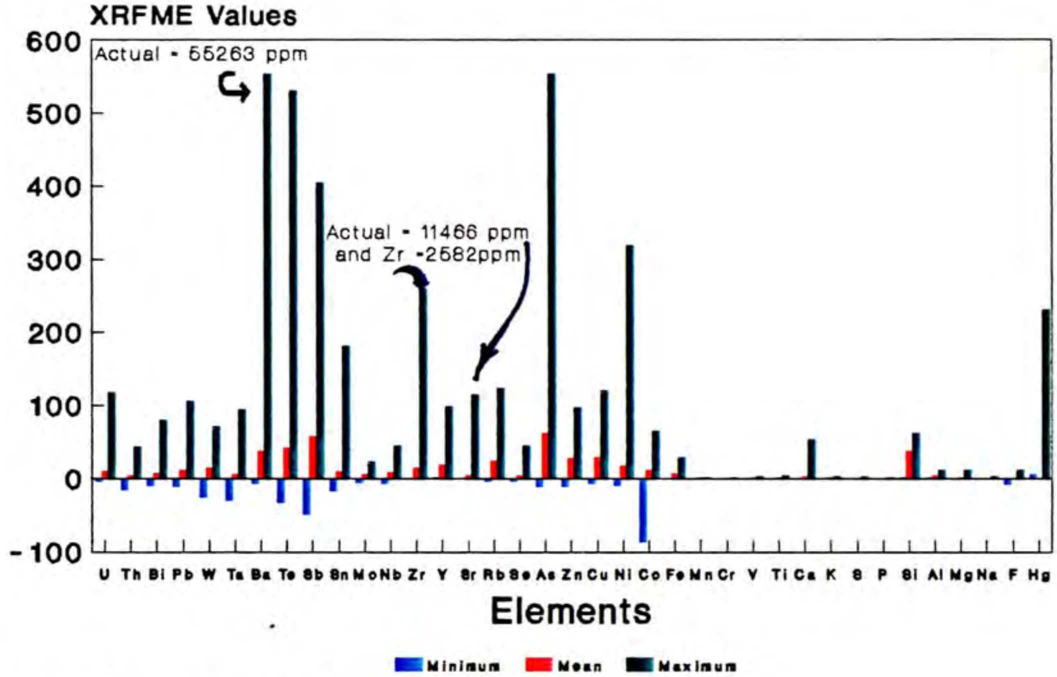


Note Ba,Sr and Hg values x 0.01.

FIGURE 12

Springfontein Trench Geochemistry.
36 element XRFME and Hg AAGEOBM data.

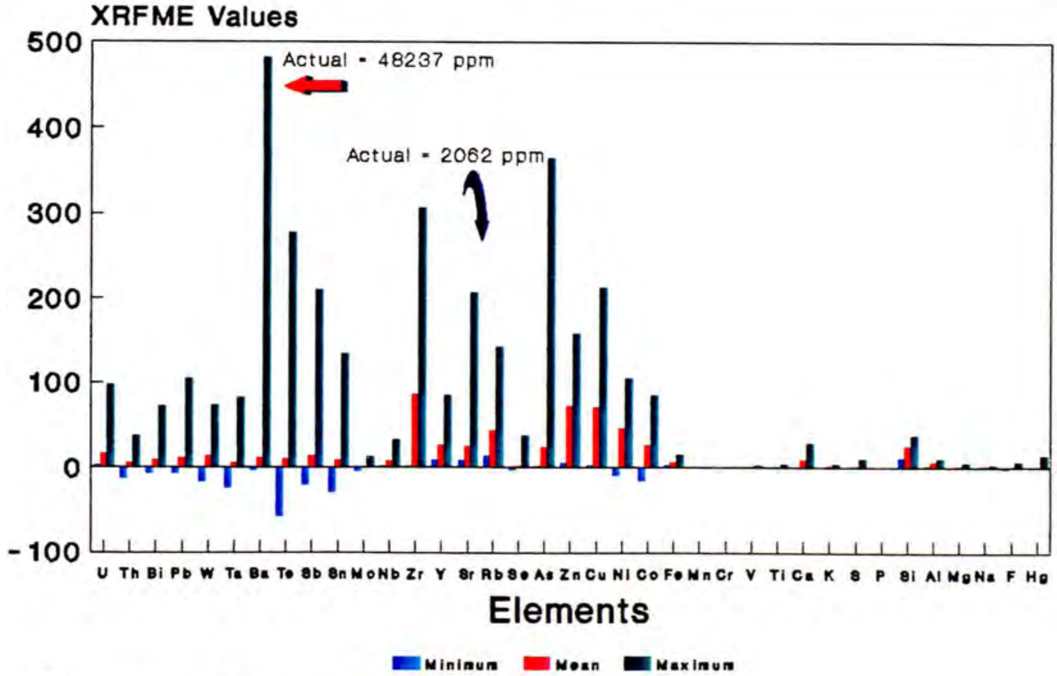
a)



Note Ba, Sr and Zr modified for graph.

Springfontein Core Geochemistry
36 element (XRFME) & Hg (AAGEOBM) data.

b)



Ba x 0.01 and Sr x 0.1 for graph.

FIGURE 13

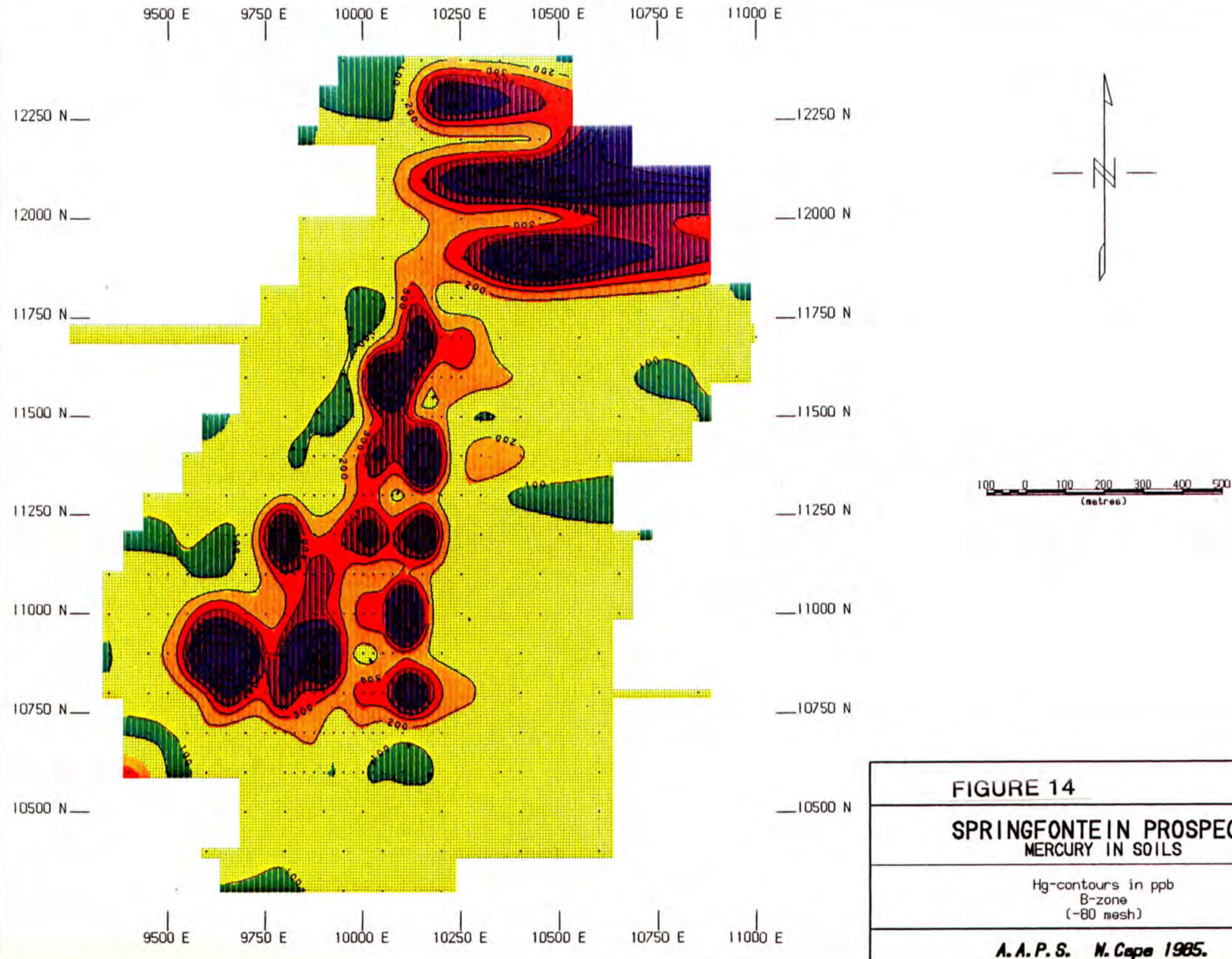
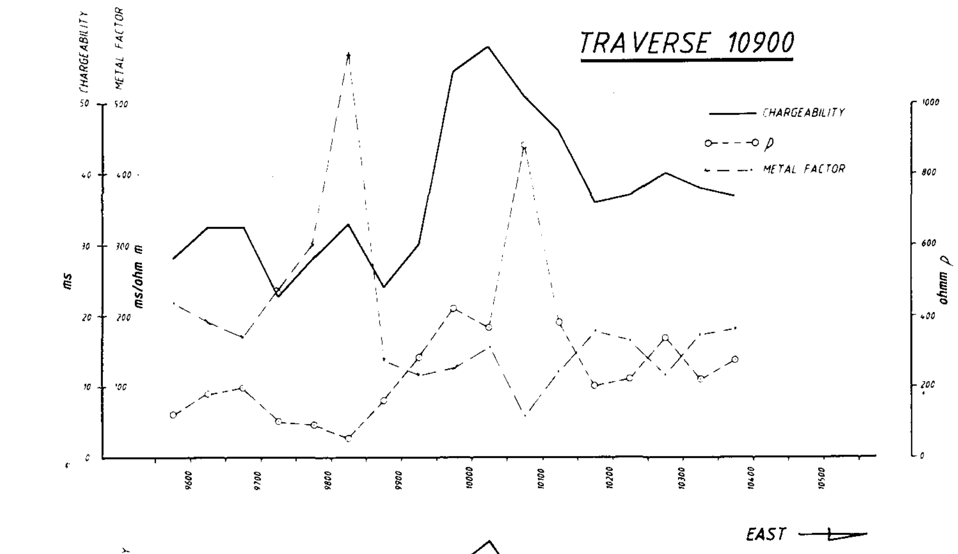


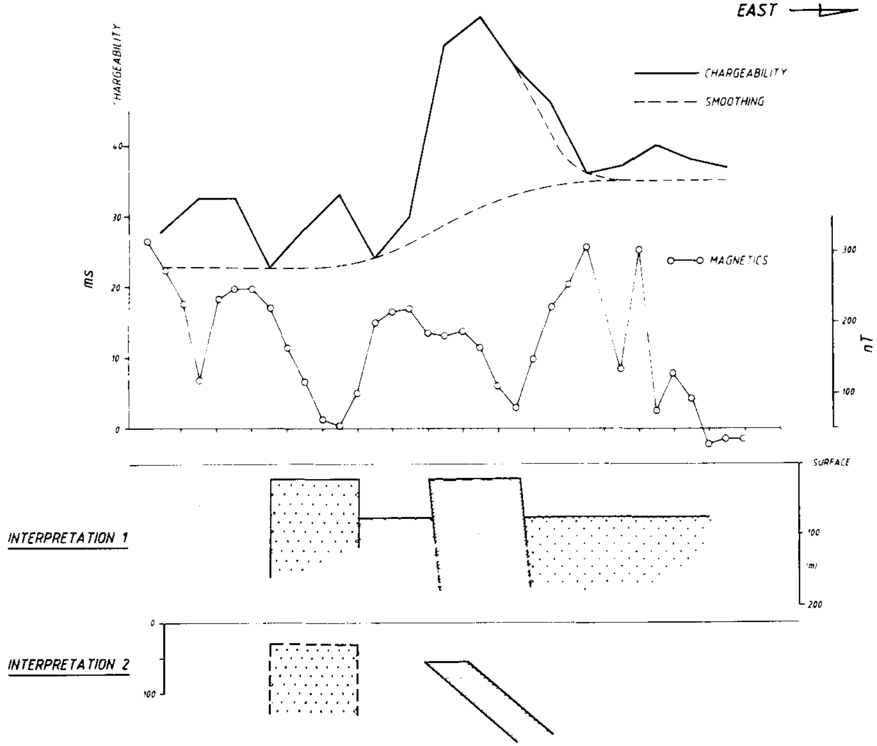
FIGURE 14

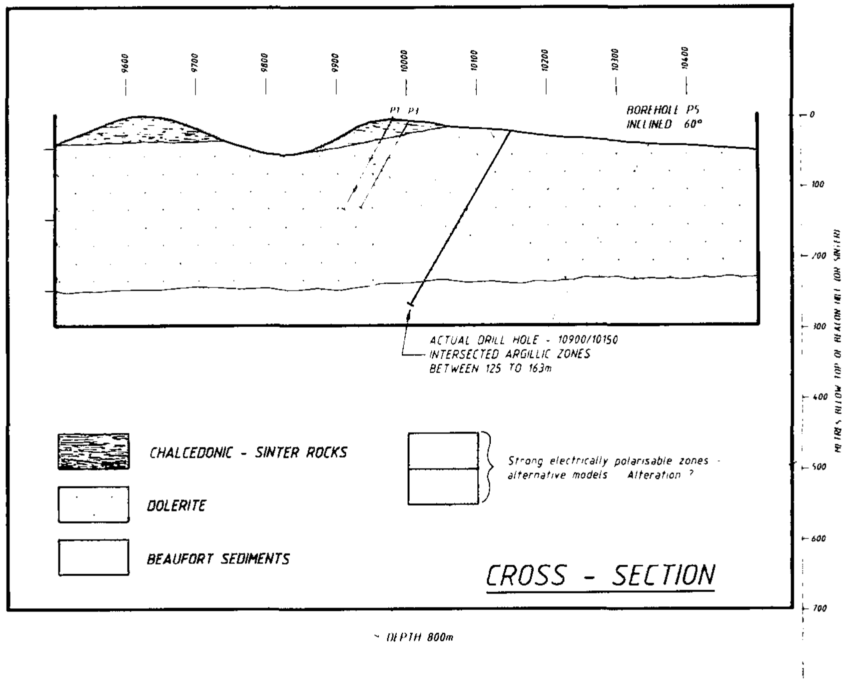
SPRINGFONTEIN PROSPECT
MERCURY IN SOILS

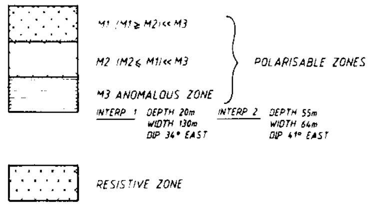
Hg-contours in ppb
B-zone
(-80 mesh)

A.A.P.S. N.Cape 1985.









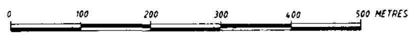
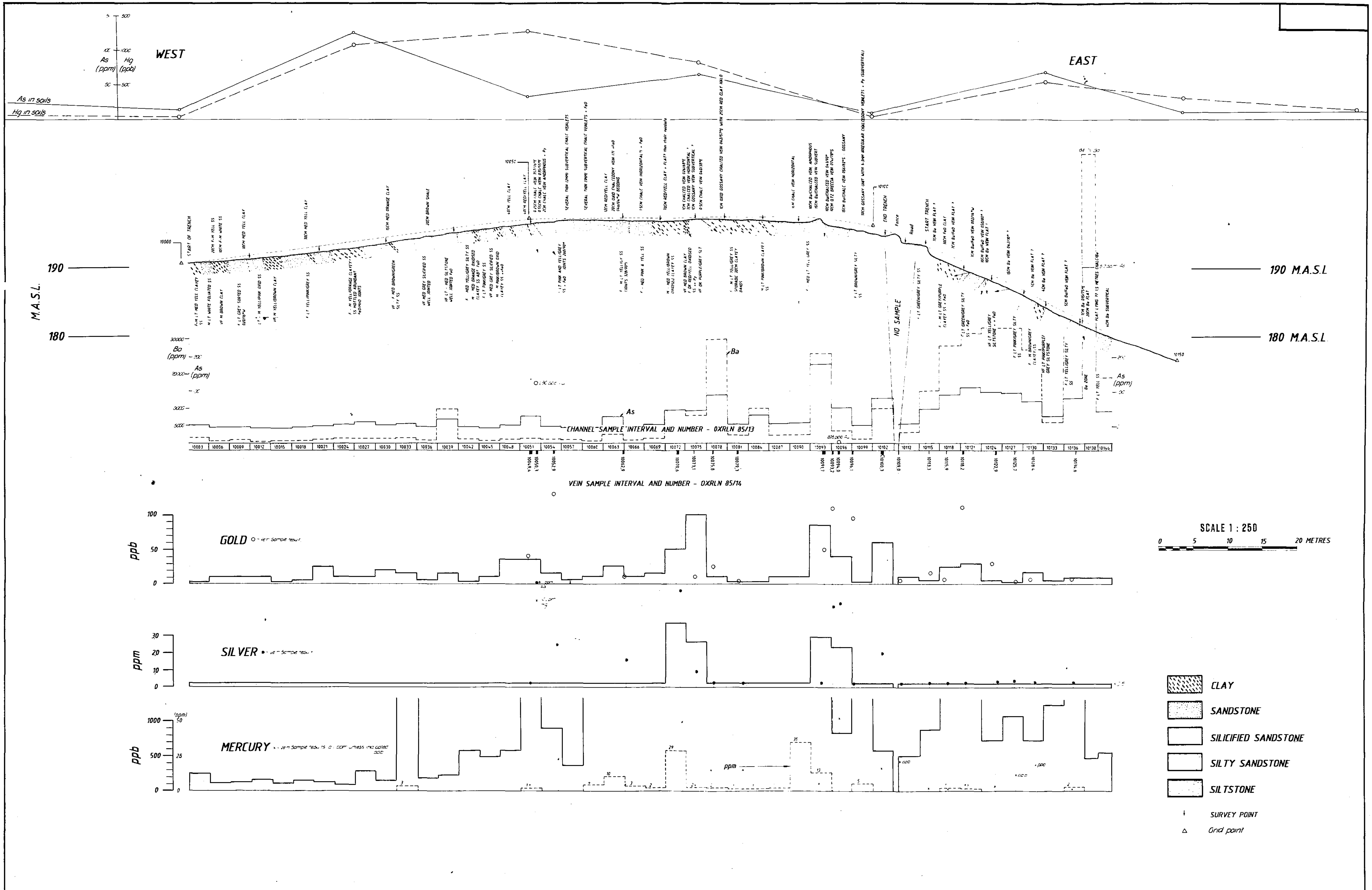


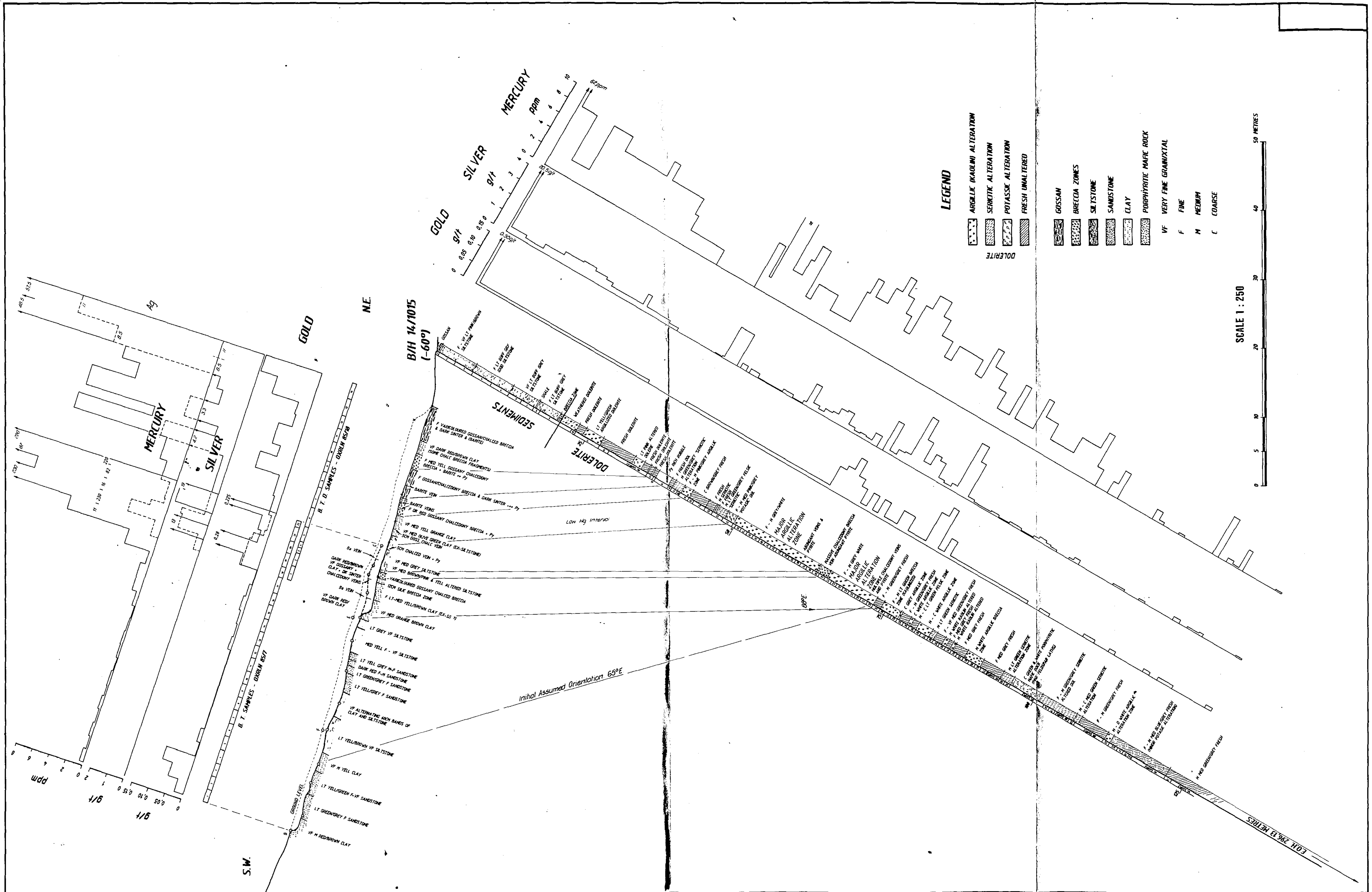
FIGURE 15

GEOLOGY BY		ANGLO AMERICAN PROSPECTING SERVICES PTY LTD	DATE
DRAWN BY		SPRINGFONTEIN PROSPECT	REPORT
REVISED BY			SCALE 1 : 5000
PLAN REGISTER No 11834 (X)	FILE	GRADIENT ARRAY I.P. SURVEY - CROSS-SECTION TRAVERSE 10900	MAP REF 3327BB



GEOLOGY BY	RL NICHOLS	ANGLO AMERICAN PROSPECTING SERVICES (PTY) LTD		DATE	18 JUNE 85
DRAWN BY	B T GRIFFIN	SPRINGFONTEIN PROSPECT		REPORT	13/173/FF/86/500
REVISED BY			FIGURE 16	SCALE	1 : 250
PLAN REGISTER No.	X12176.3,2 FILE	116 TRENCH		MAP REF.	3327BB

William Barker AA 1046



GEOLOGY BY	R.L. NICHOLS		
DRAWN BY	B.T. GRIFFIN		
REVISED BY			
PLAN REGISTER No.	X12177.3,2	FILE	

ANGLO AMERICAN PROSPECTING SERVICES (PTY) LTD.

SPRINGFONTEIN PROSPECT

B.T. TRENCH & BOREHOLE 14/1015

FIGURE 17

DATE	20 JUNE 85
REPORT	13/173/FF/86/500
SCALE	1 : 250
MAP REF.	3327BB

X12177.3,2

William Barker AA 1046

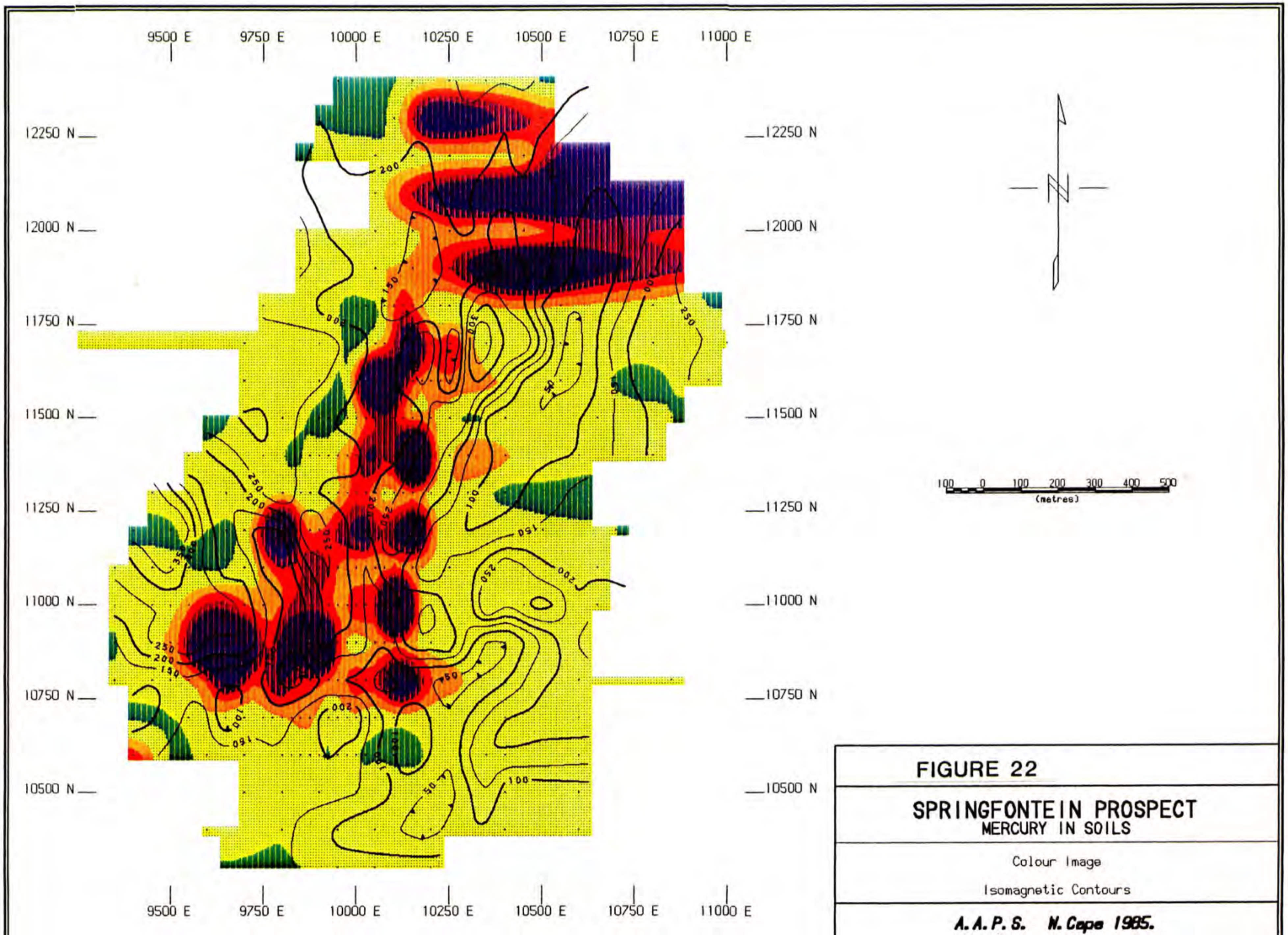


FIGURE 22

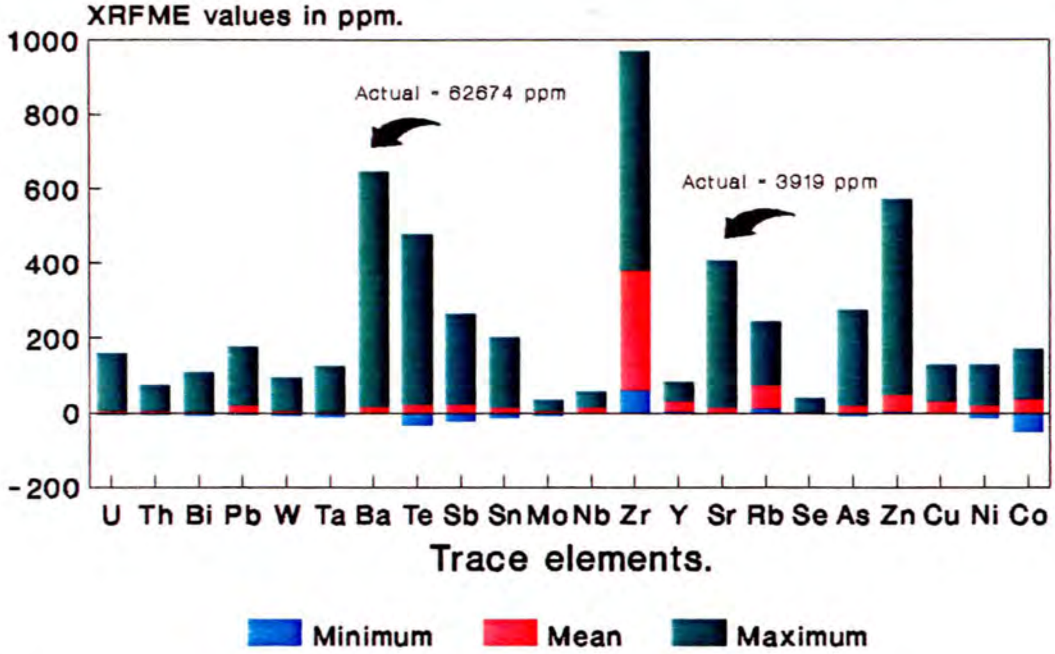
SPRINGFONTEIN PROSPECT
MERCURY IN SOILS

Colour Image

Isomagnetic Contours

A.A.P.S. N.Cape 1985.

Springfontein Soil Geochemistry.
Trace element (XRFME) data.



Note Ba and Sr values changed for graph.

Springfontein Soil Geochemistry.
Major element XRFME & Hg AAGEOBM data.

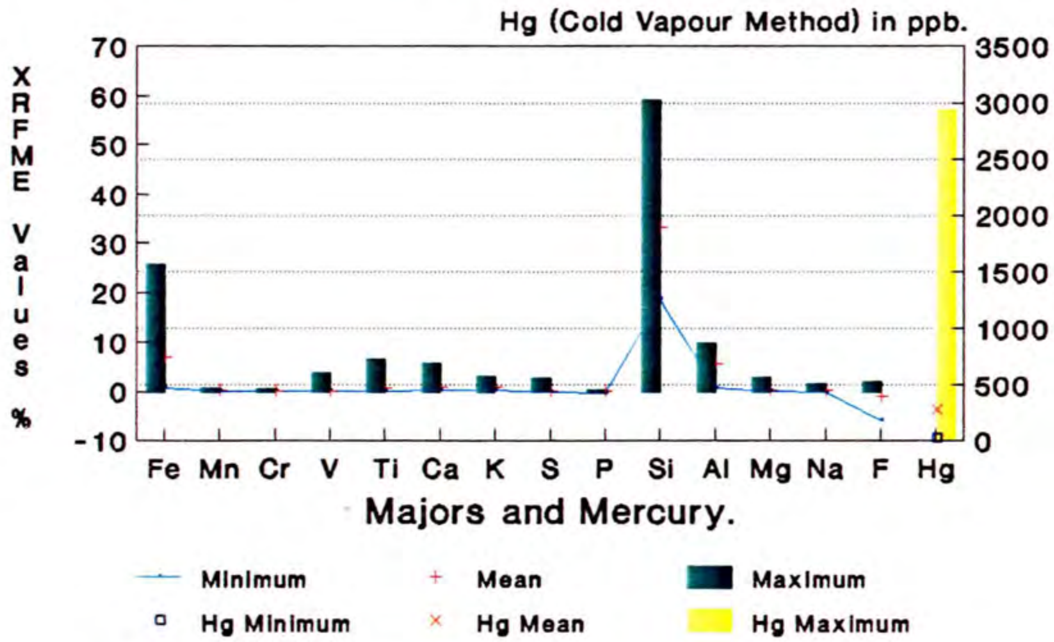
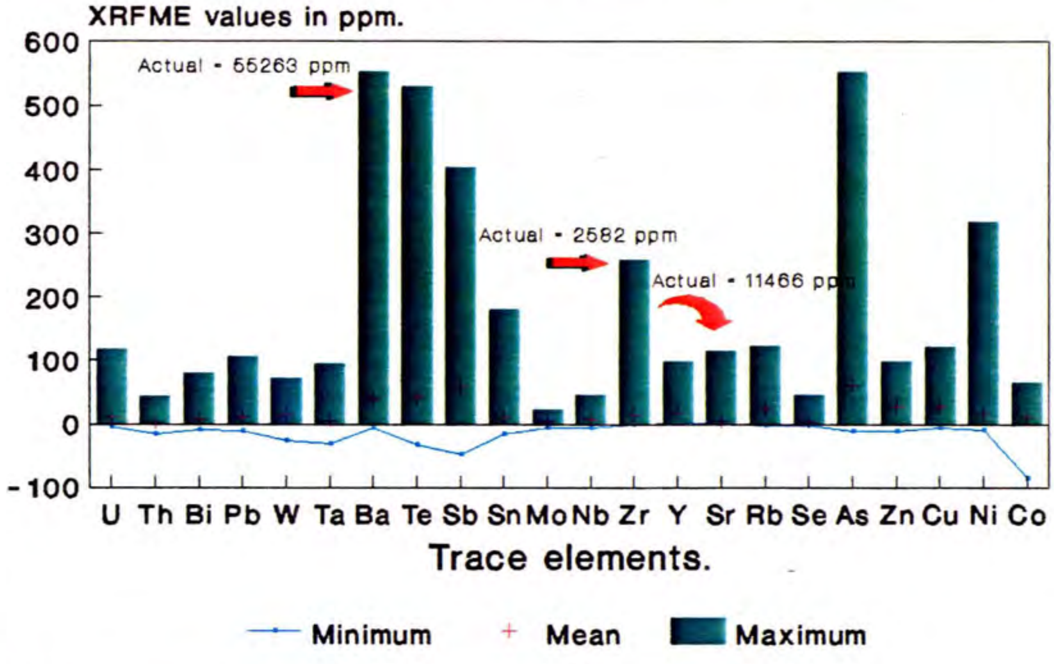


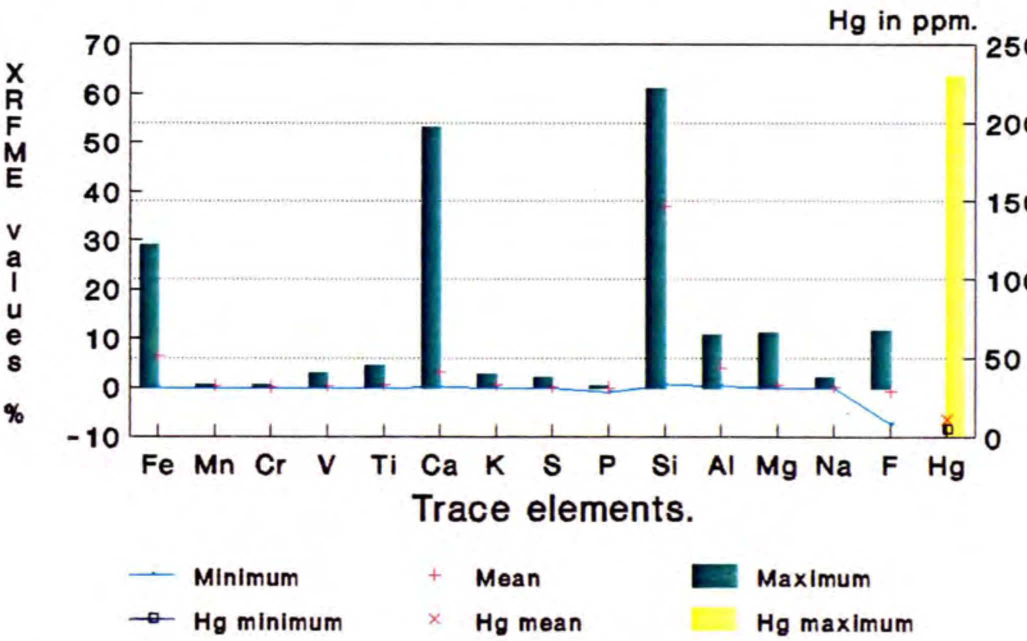
FIGURE 23

Springfontein Trench Geochemistry.
Trace element (XRFME) data.



Ba, Zr and Sr modified for graph.

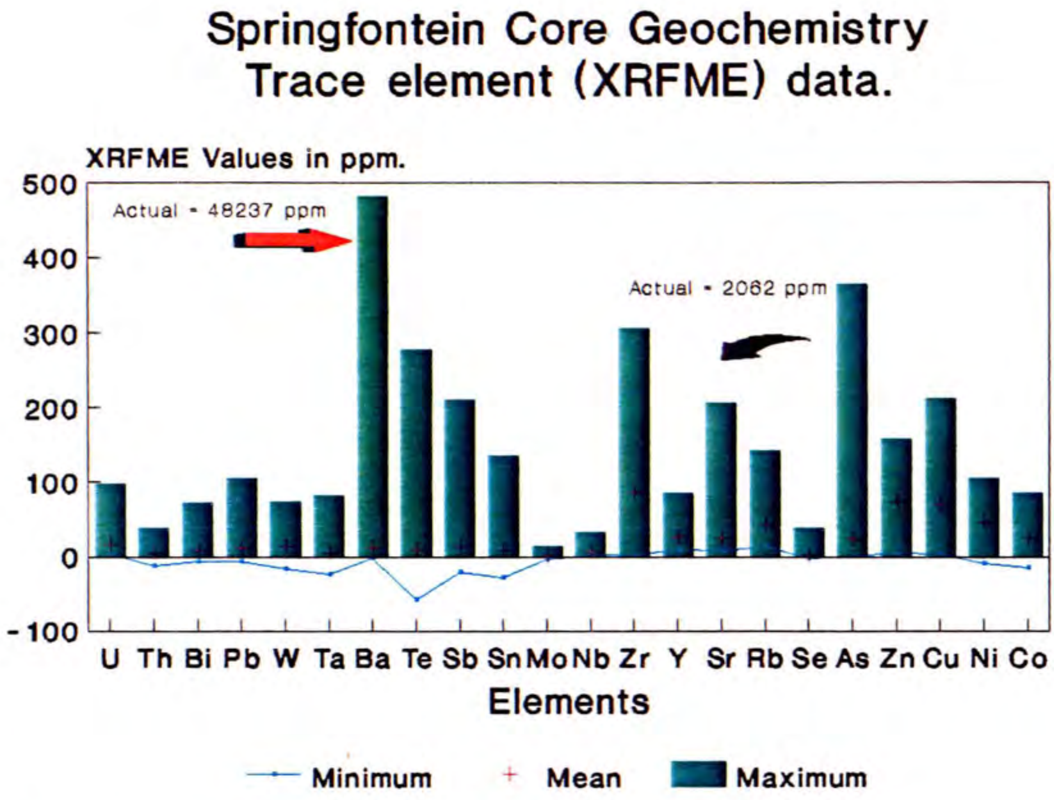
Springfontein Trench Geochemistry.
Major element (XRFME)&Hg(AAGEOBM) data.



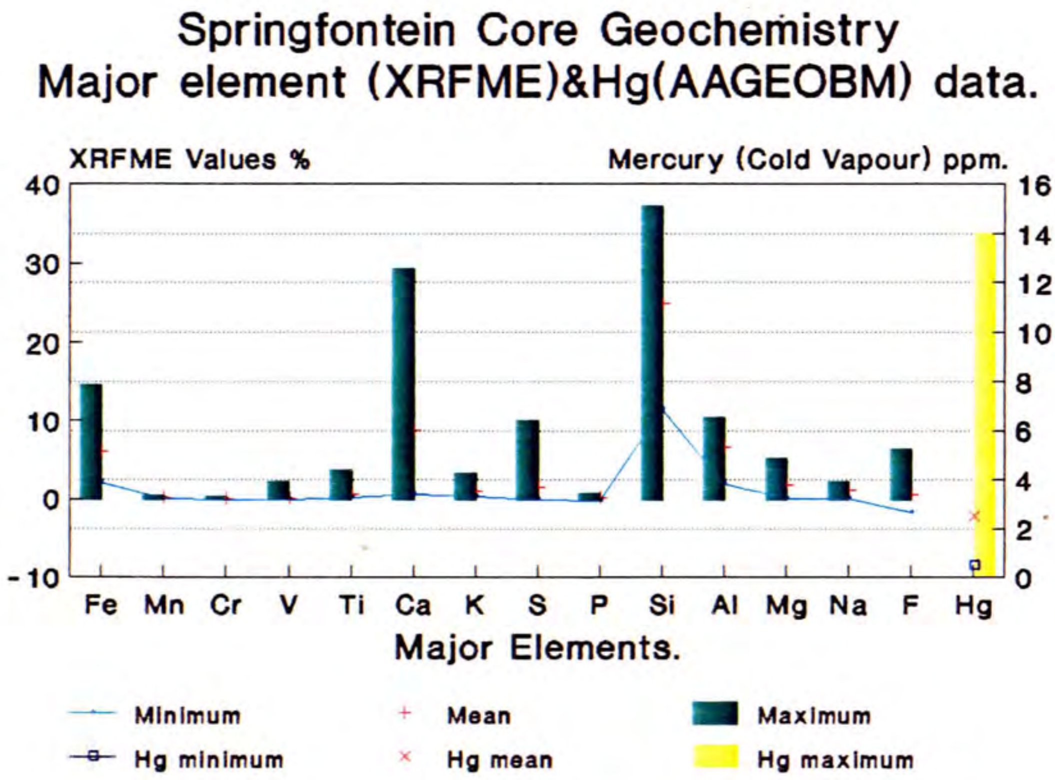
Mercury values (cold vapour) in ppm.

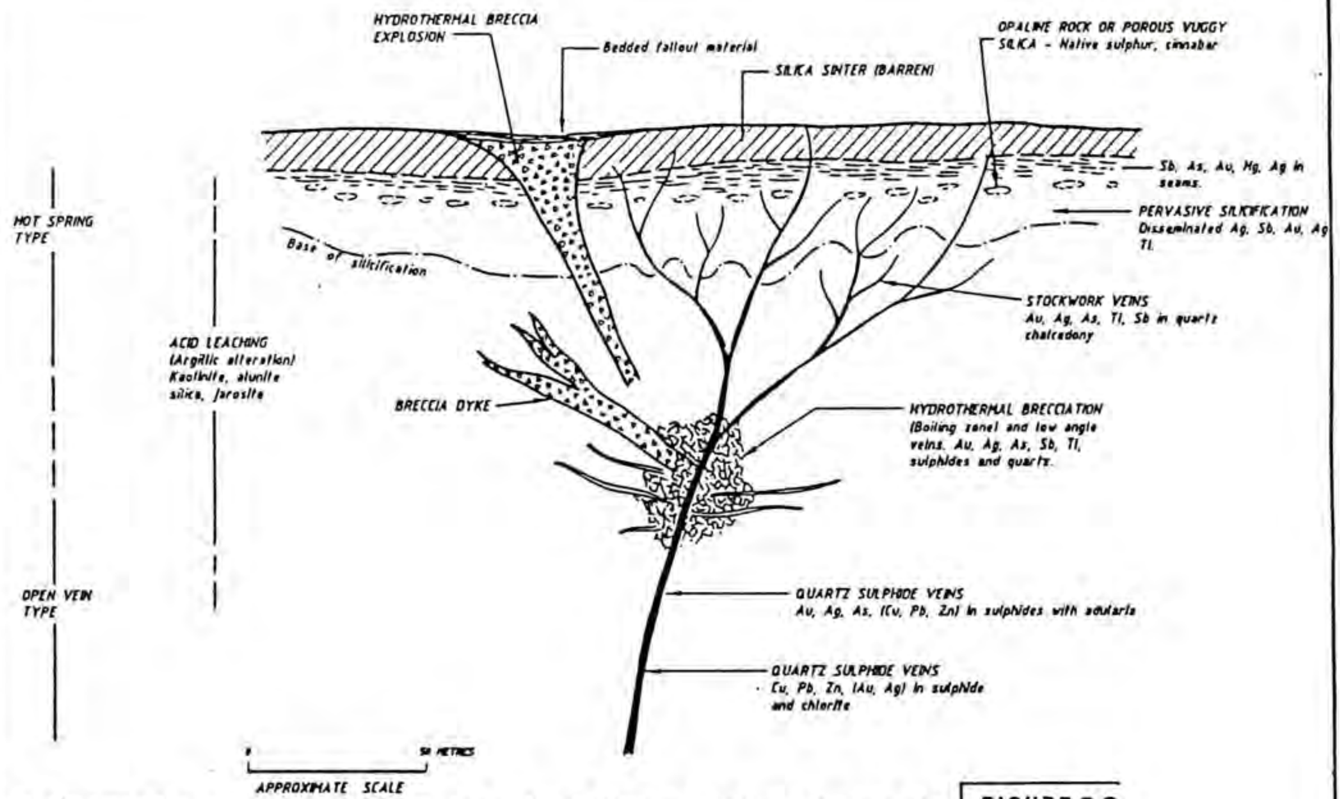
FIGURE 24

FIGURE 25



Ba and Sr modified for graph.





Schematic cross-section of a Hot Spring Type Deposit. FIGURE 26

(Modified from Berger and Eimon, 1982).

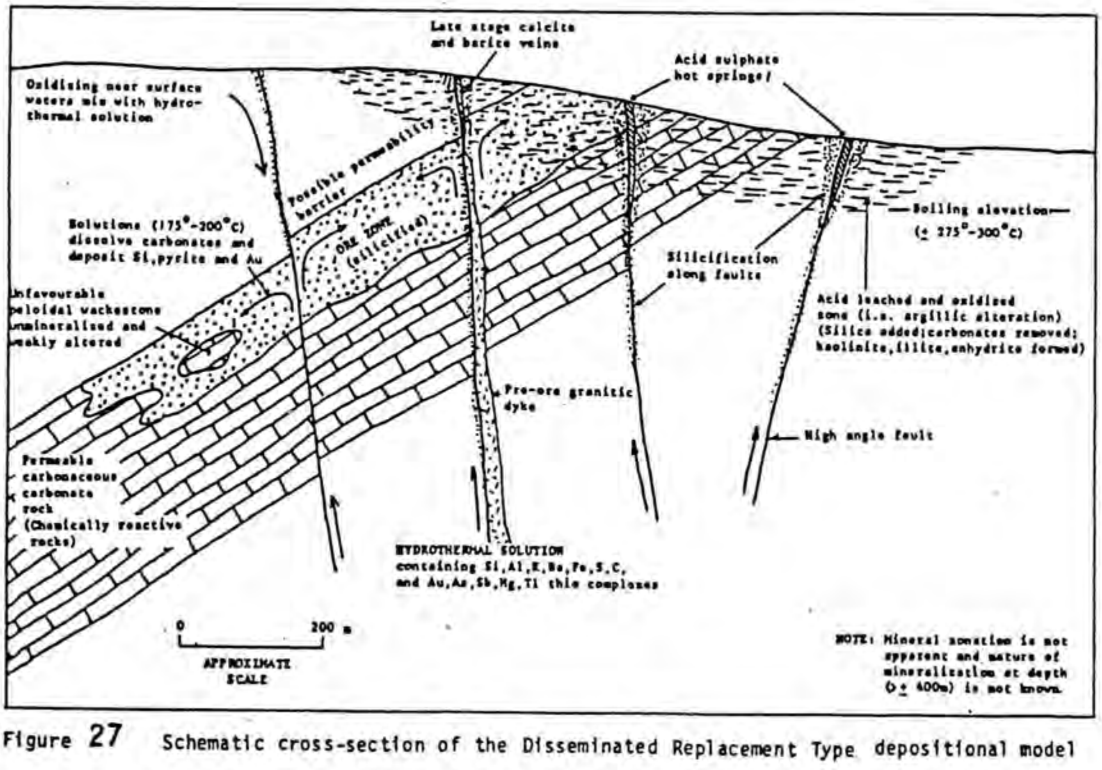


Figure 27 Schematic cross-section of the Disseminated Replacement Type depositional model

(Modified from Rossiter, 1986).

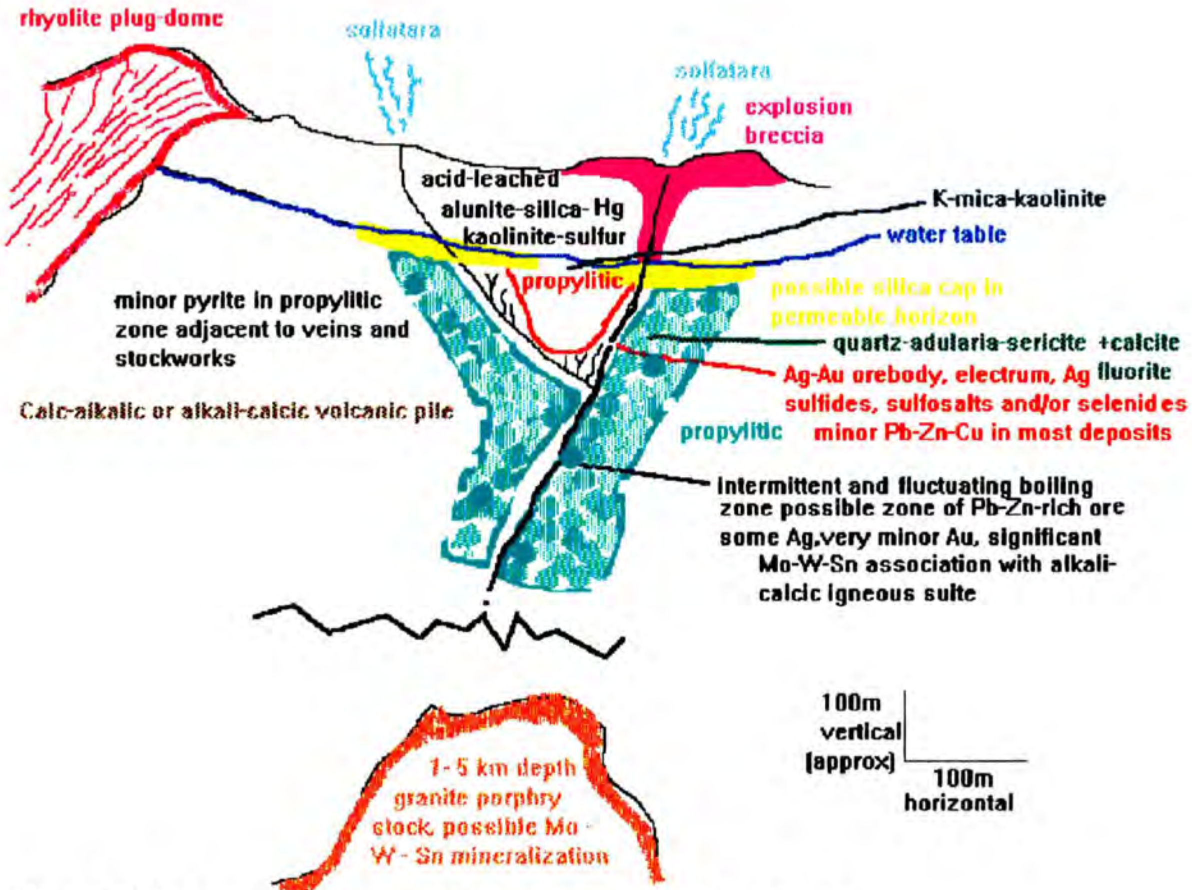


Figure 28A. Schematic cross section of low sulfur epithermal precious-metal mineralisation related to granite rhyolite magmatism (modified from BONHAM, 1986).

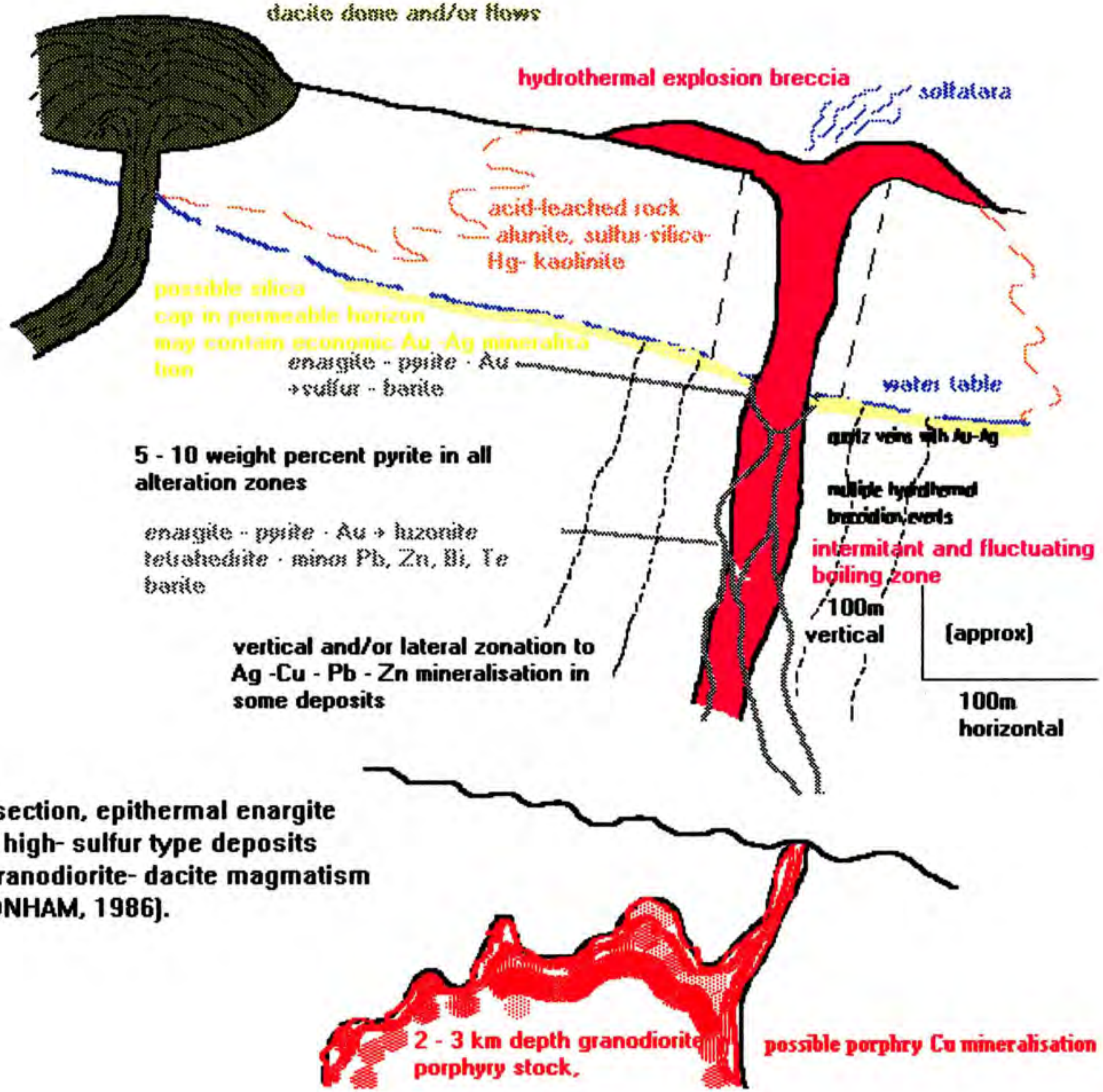


Figure 28B.

Schematic cross section, epithermal enargite precious metal or high- sulfur type deposits associated with granodiorite- dacite magmatism (modified from BONHAM, 1986).

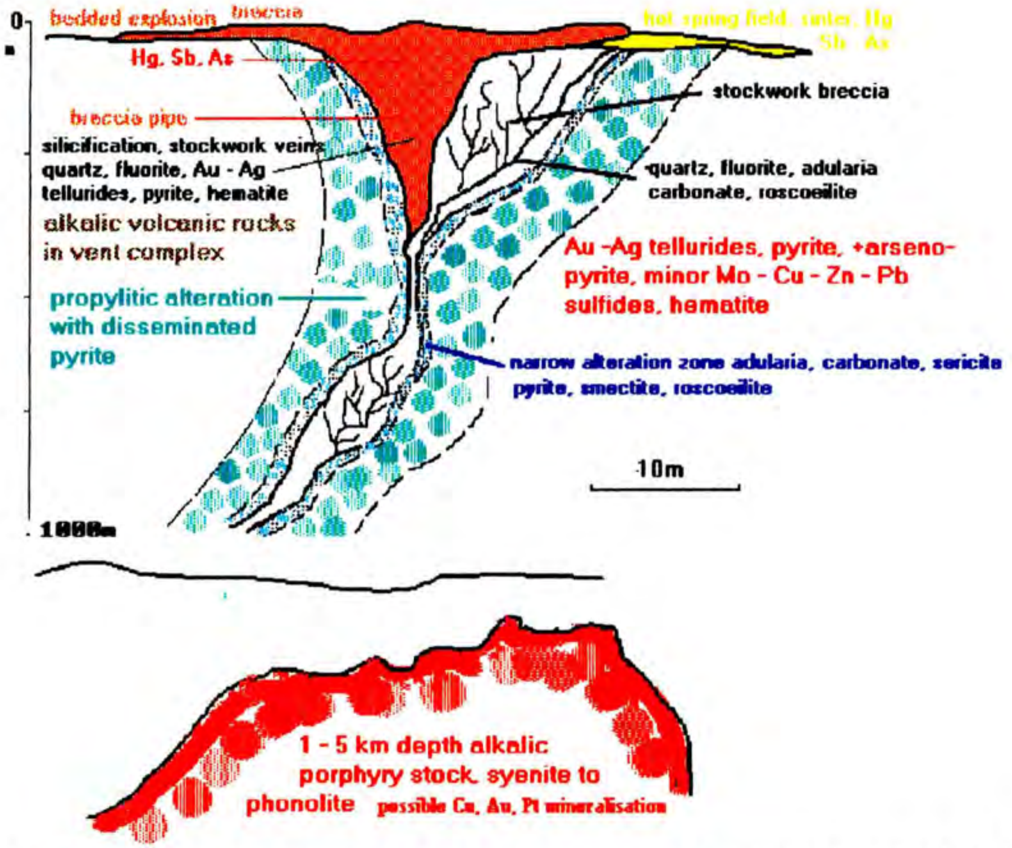


Figure 28C. Schematic model, alkalic Au - Ag deposit (modified from BONHAM, 1986).

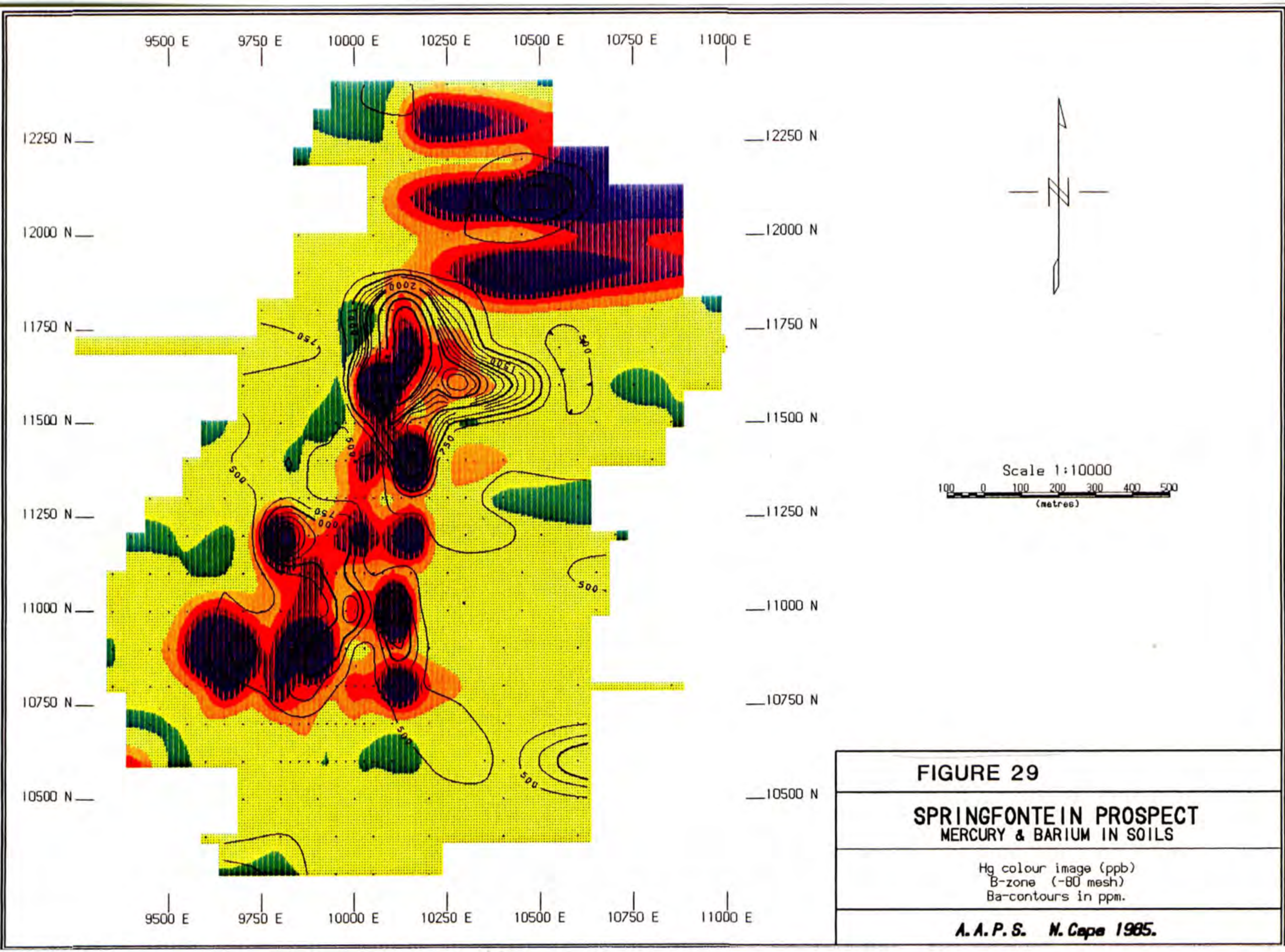


FIGURE 29

SPRINGFONTEIN PROSPECT
MERCURY & BARIUM IN SOILS

Hg colour image (ppb)
B-zone (-80 mesh)
Ba-contours in ppm.

A.A.P.S. N.Cape 1985.

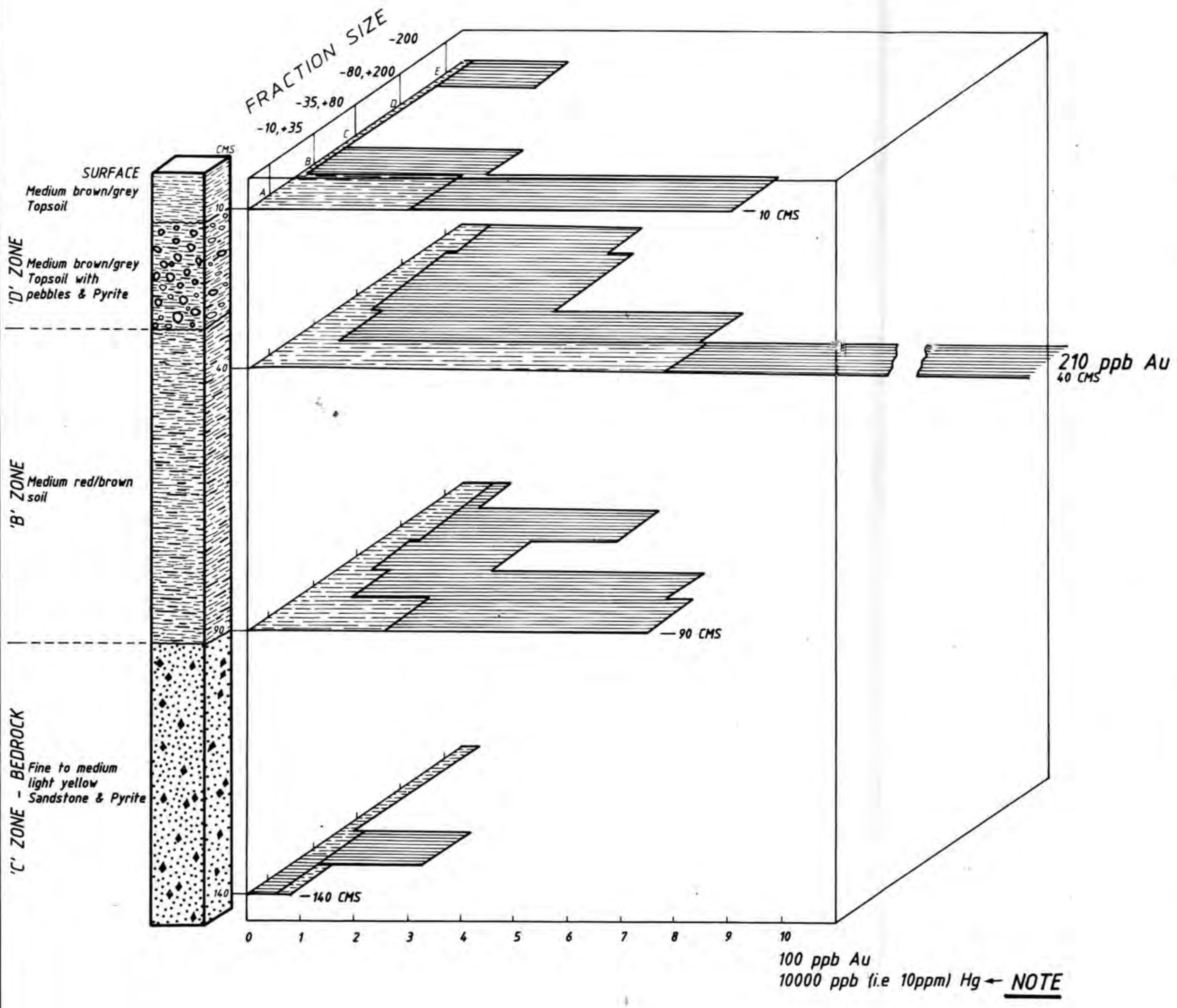
FIG. A1

GEOLOGY BY	R.L.N.	ANGLO AMERICAN PROSPECTING SERVICES (PTY.) LTD.	DATE	24.9.84
DRAWN BY	R.L.N.	SPRINGFONTEIN PROJECT	REPORT	OCT'84
REG.No.		Location plan showing stream sediment(◊3)	SCALE	1:10000
FILE	X11201.1	samples and soil orientation pits (■GOP).	MAP REF.	3227 DD

W8 1049

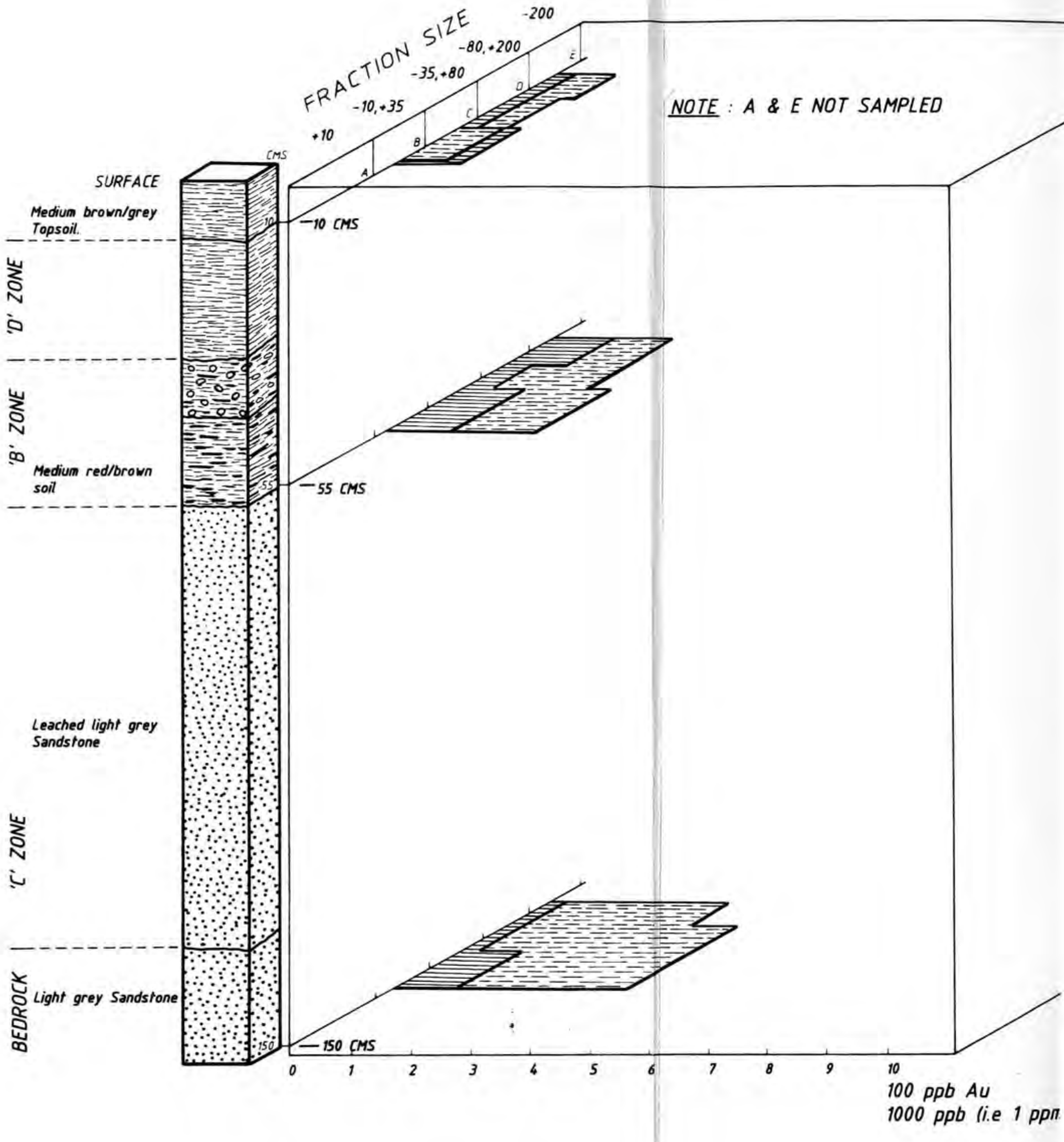
GOSSAN PIT

(Au analysed by AA)
(Hg analysed by AAGEO)



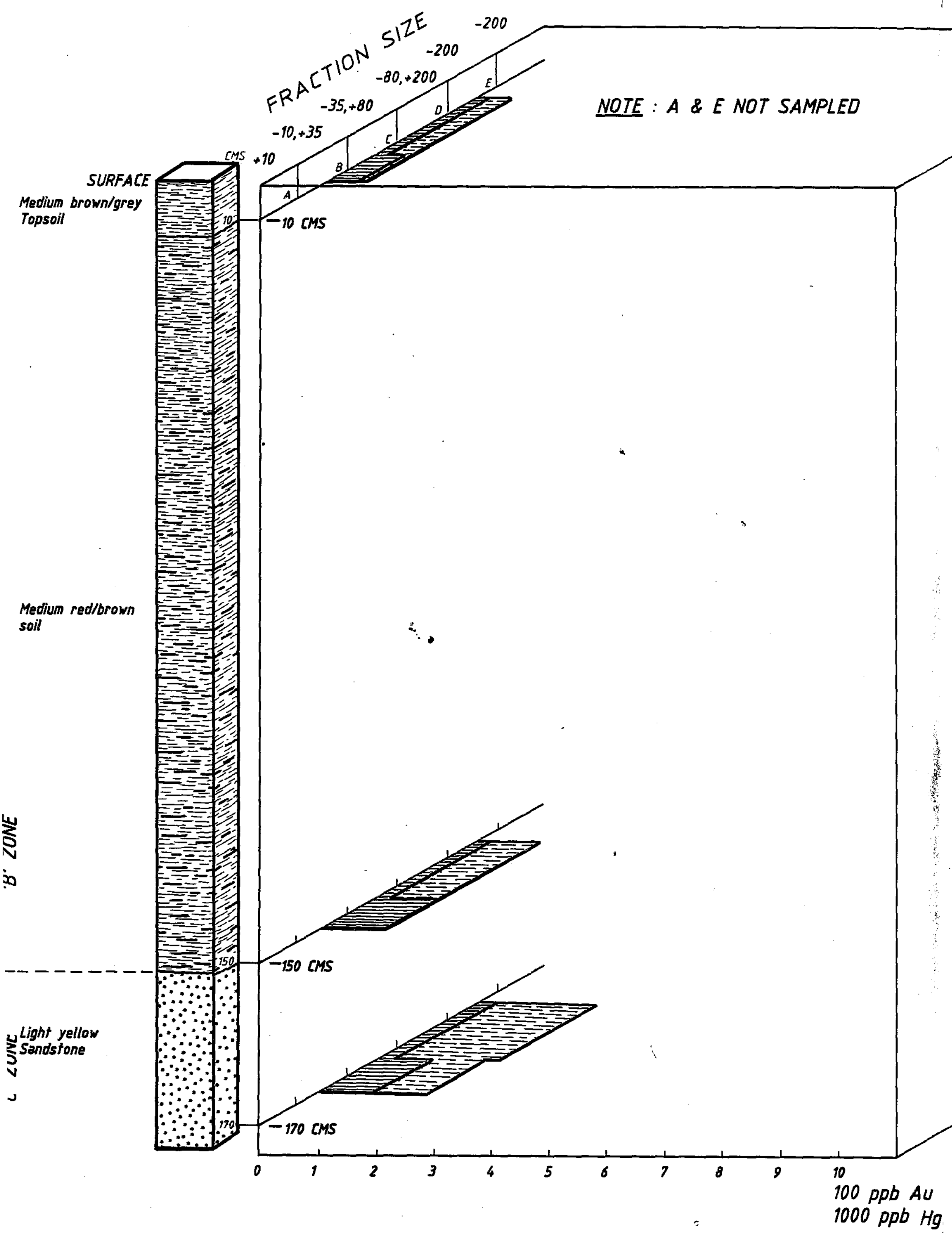
BARITE PIT

(Au analysed by AA)
(Hg analysed by AAGEO)



BEAUFORT SLOPE PIT

(Au analysed by AA)
(Hg analysed by AAGEO)



BEAUFORT TOP PIT

(Au analysed by AA)
(Hg analysed by AAGEO)

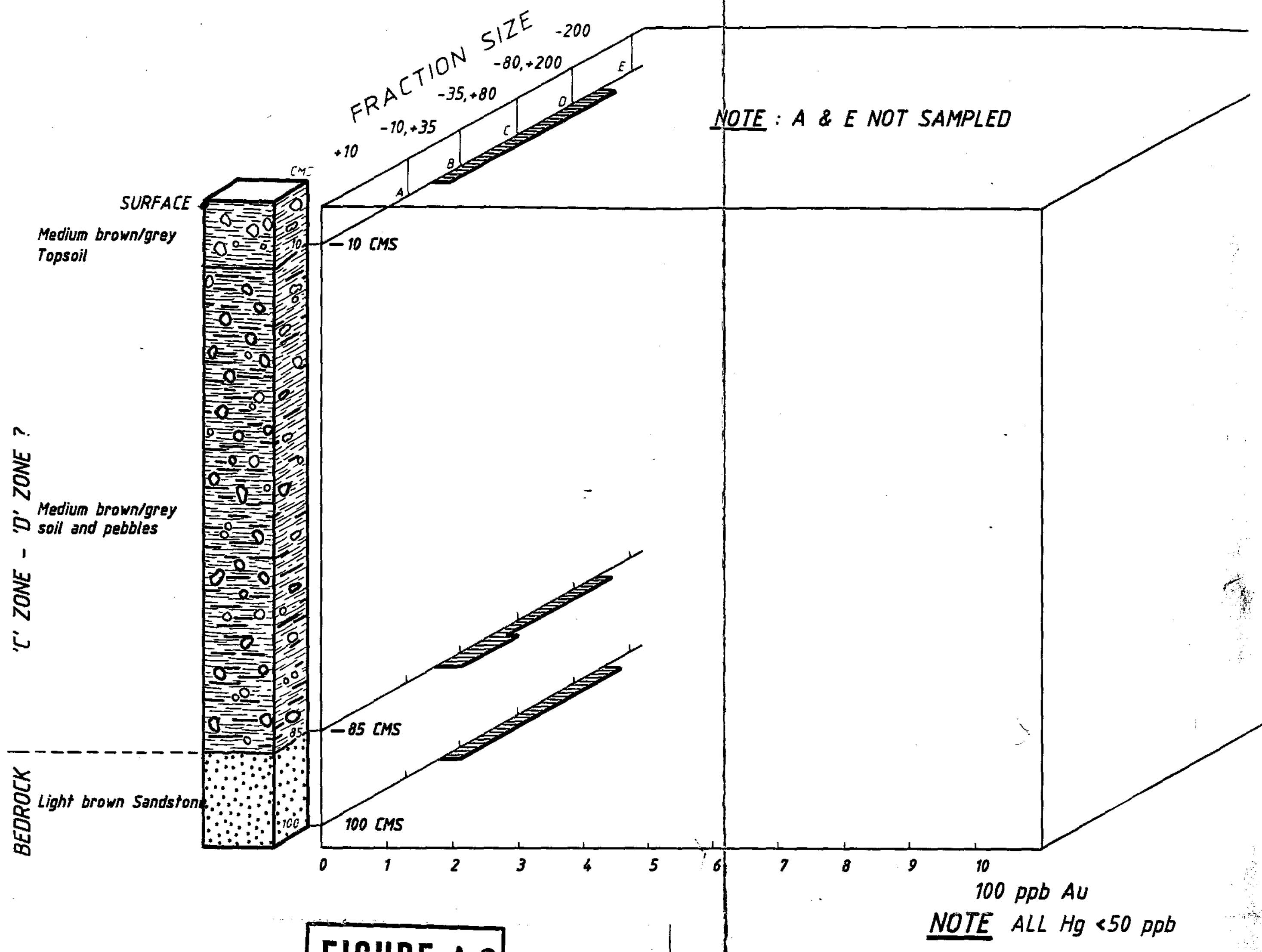
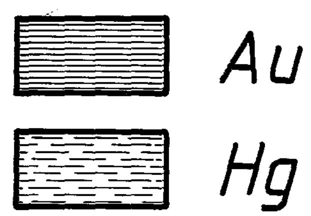


FIGURE A.2

DATE	OCTOBER 84
REPORT	13/173/ff/85/117
SCALE	1:1000
MAP REF.	3327BB

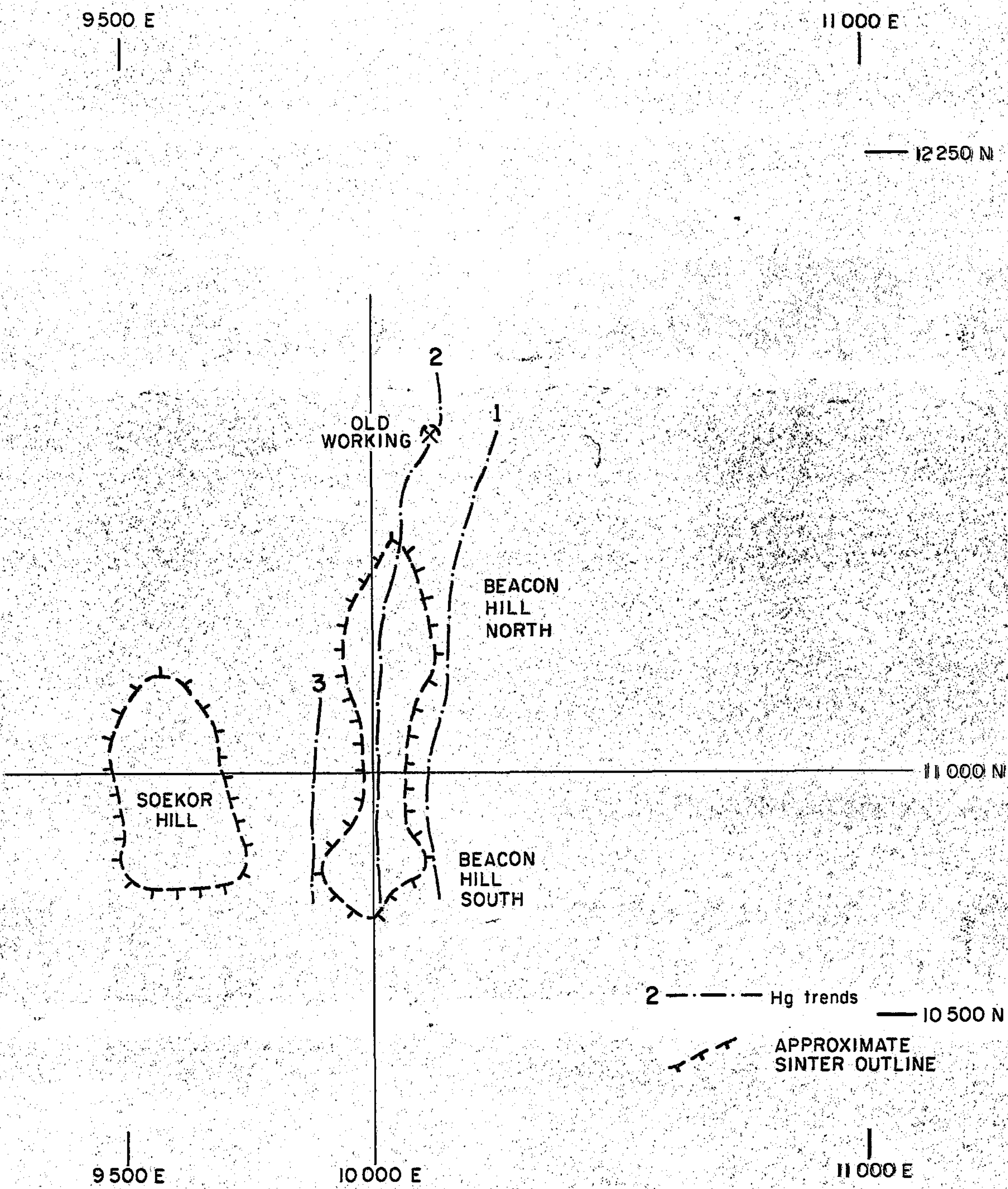


EOLOGY BY	R.L. NICHOLS
DRAWN BY	B.T.G.
ᴙEVISED BY	
	FILE

ANGLO AMERICAN PROSPECTING SERVICES (PTY) LTD.

SPRINGFONTEIN PROSPECT

SCHEMATIC DIAGRAM OF SOIL GEOCHEMICAL ORIENTATION PITS



GEOLOGY BY		ANGLO AMERICAN PROSPECTING SERVICES (PTY) LTD	DATE	
DRAWN BY		OVERLAY TO GEOSOFT PLOTS	REPORT	
REG.No.		**SPRINGFONTEIN PROSPECT**	SCALE	
FILE			MAP REF	

William Barker 89 677

227D EAST LONDON

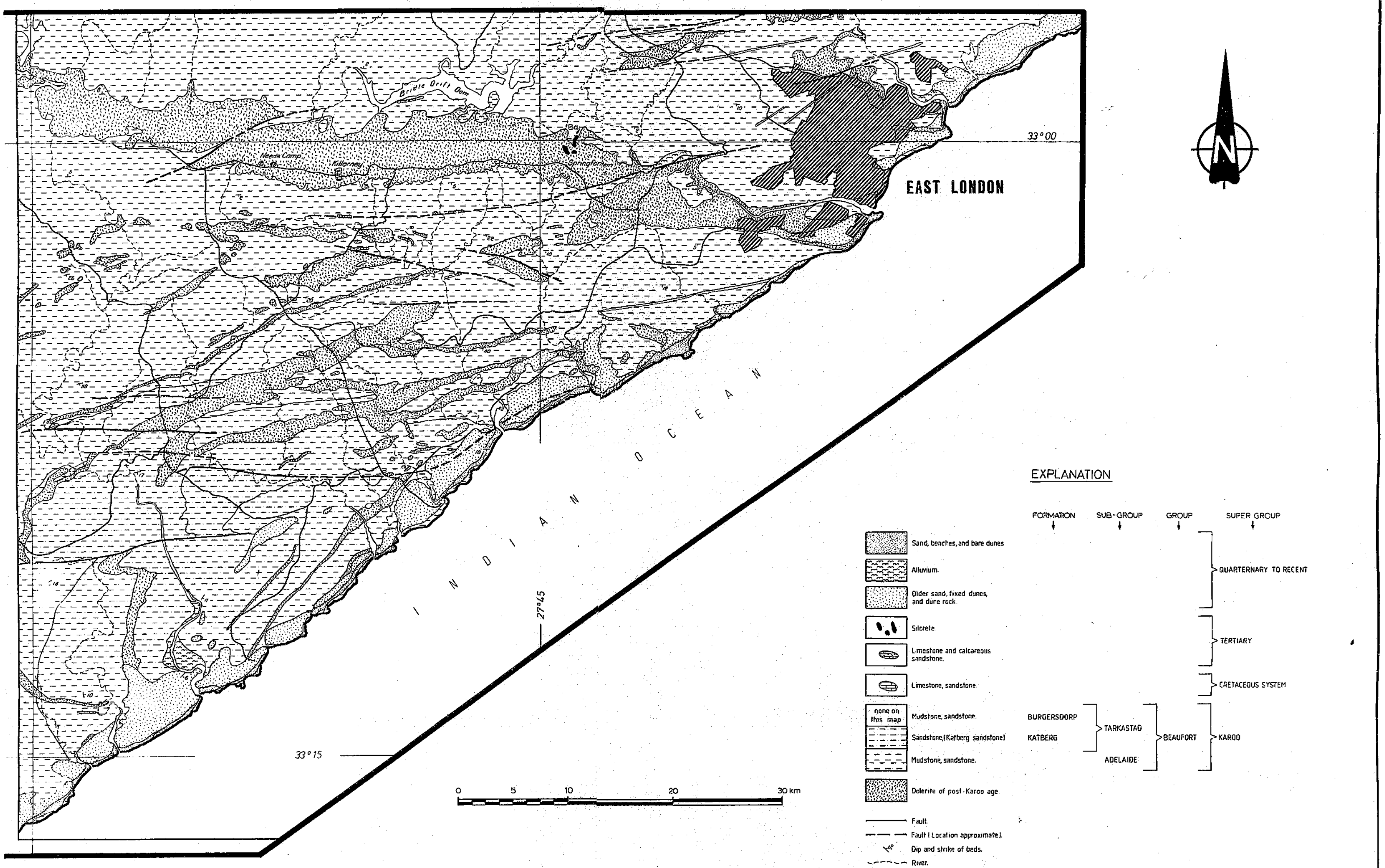


FIGURE 1

E D Mountain (1974)
B T Griffin

No. X 7471.3.

FILE

ANGLO AMERICAN PROSPECTING SERVICES (PTY) LTD.

REGIONAL GEOLOGY - SPRINGFONTEIN AREA

DATE	8 February 84
REPORT	13/173/ff/85/117