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GEOLOGY, GEOCHEMISTRY, AND TECTONO-METALLOGENIC EVOLUTION OF
NEOPROTEROZOIC GOLD DEPOSITS IN THE KADUBU AREA,
KIVU, DEMOCRATIC REPUBLIC OF CONGO.

PART 3 - 4

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Doctor of Philosophy in Science.

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PART III.- MINERALIZATION.

CHAPTER 11.- INTRODUCTION .

11.1.- GENERAL STATEMENT.

The investigation of the genesis and evolution of gold and base metal mineralization in the Kadubu area will be undertaken along three broad, interdependent fronts:

- *.- detailed studies of the mineral deposits and their geological settings ;
- *.- laboratory studies (petrography, geochemistry, SEM, Ion microprobe), fluids inclusions studies utilizing Raman spectrometry and Radiogenic & Stable isotope studies of ore and gangue minerals ;
- *.- studies of natural active geothermal systems in the study area.

11.2.- LINEAMENT TECTONICS OF KADUBU ORE DEPOSITS.

11.2.1.- GENERAL ASPECTS.

The concept of the lineament-ore relationship has been well documented and successfully applied to the search for new deposits around the world. (O'Driscoll, 1981).Conspicuous continental geomorphic lineaments represent pervasive crustal trends of great dimensions and antiquity and these megalineaments have been regarded as basement discontinuities along which metallogenic processes have operated. (O'Driscoll, 1981).

The lineament-ore philosophy has been further defined by the observation that transcontinental ore-bearing lineaments are parallel to, and in some instances coextensive with, conspicuous bathymetric lineaments in the floors of adjacent oceans, pointing to the presence of a world system of lineaments corresponding to spirals on the globe (O'Driscoll, 1981, O'Driscoll, 1990).

Woodall (1984) stressed that major continental lineaments which represent deep crustal or mantle fractures can localize centres of deep structural plumbing, can tap heat as well as metal and can be expected to be “ activity centres “ over long periods of time. Thus they have the potential to localize the giant deposits through preparing environments for ore formation.

11.2.2.- REGIONAL LINEAMENT SYSTEMS.

The most conspicuous regional lineaments in the Kadubu area is represented by a system of NNW and EW trending features. More localized lineaments with others directions are also present (Fig.III.1) .

The major lineaments are interpreted to pre-date their presently associated supracrustal rocks, and to have set up the precursory conditions of thermal energy, source materials and movements for developing the initial metallogenic environment for both syngenetic and epigenetic ore deposits.

11.2.3.- THE LINEAMENT -ORE RELATION.

On a continental scale, the lineament - ore relationship is well revealed by GIF image 600x750 pixels, and the topography map of East Africa derived from 30 arc second DEM, which clearly indicate megalineaments crossing and intersecting within the continent as indicated by arrows and defining major structural corridors.(Fig.III.1, Fig.II.3).

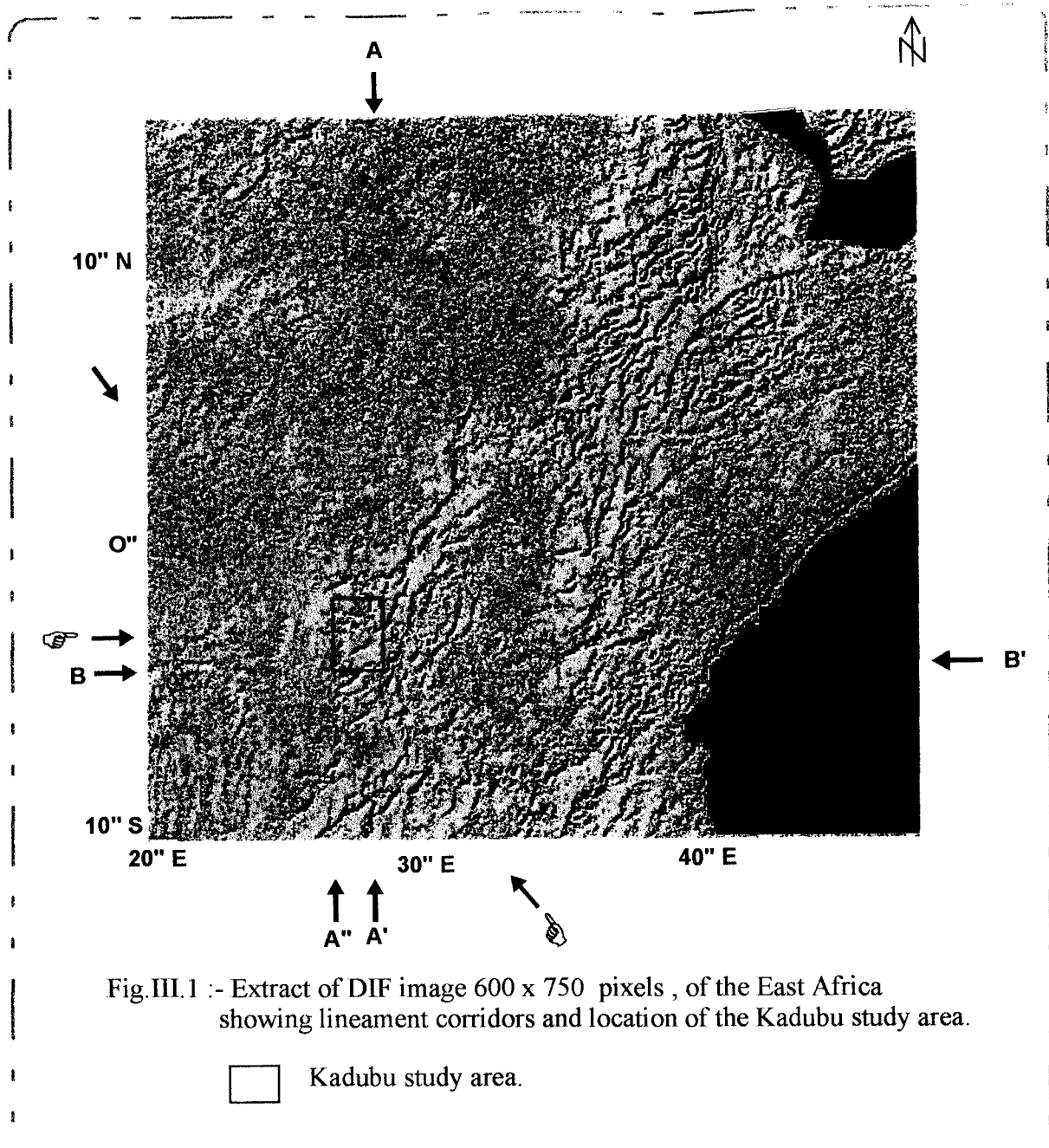
Three major trends of megalineaments are visible; a N-S lineament, an E-W lineament, and a NW lineament, traceable for thousands of kilometres. The northerly (A – A') is deflected to the left (west) where it is intersected by the E-W (B – B') lineament. (Fig.III.1).

The relation of the Kadubu ore field to these megalineaments is show in Fig.II. 3.

At prospect scale, the Kadubu ore field is located at the intersection of these lineaments and exhibit a lineament-ore signature (Fig.II.6, Fig.7). The Kadubu ore field is aligned in a NW direction, intersecting the EW corridor partner.

At ore scale, the position of gold and tin deposits in the corridor is also related to other minor lineaments which cross through the same area.

The additional relationship of the Kadubu ore field to the northwest and east-west lineaments seen in Fig.III.1 is also readily observable in the geological and structural maps in Fig.II.7 and Fig. II.16; as well as in enhanced magnetic map of this study area (Fig.II.6).



11.2.4.- SUMMARY.

A study of lineament - ore relation show that the Kadubu gold - bearing deposits is in relation to the prominent NW and EW corridors intersection readily visible in the Landsat image, aeromagnetic image and DIF image of the relevant study area.

The intersection of the northwesterly and eastwesterly lineaments could have a metallogenic significance.

CHAPTER 12.- THE TWANGIZA GOLD DEPOSIT.

12.1.- INTRODUCTION.

The Twangiza gold deposit is located in the Kadubu area (Fig.II.7; Fig.II.16; Fig.III.2). No previous integrated and detailed studies have been done on this deposit.

The aim has been to elucidate the genesis and evolution of the Twangiza gold and base-metal mineralization and to define its geological setting.

The approach has been to conduct a detailed and integrated geologic, petrographic, fluid-inclusion, geochronology as well as geochemical studies (chemical analyses, stable and radiogenic isotopes) of the vein system and host rocks in order to characterize the hydrothermal fluids and identify ore-depositional processes.

Chemical mass transfer and metasomatic reaction modeling were used to decipher the process of fluid -rock interaction and the results were related to the mineral assemblages and geochemical signatures found in the deposit.

12.2.- LOCATION OF THE DEPOSIT .

The Twangiza deposit is located on latitude 2°52' South, and longitude 28°44' East, at an altitude of 2,250m a.m.s.l . The area is covered by short savannah type shrub with thicker vegetation in the valleys.

The main deposit follows an anticlinal axis (crest) and occupies a high hill situated at the head of the Twangiza river, itself a tributary of Mwana and Kadubu rivers.

(Fig. II.16 ; Fig. III.2 ; Fig. III.3).

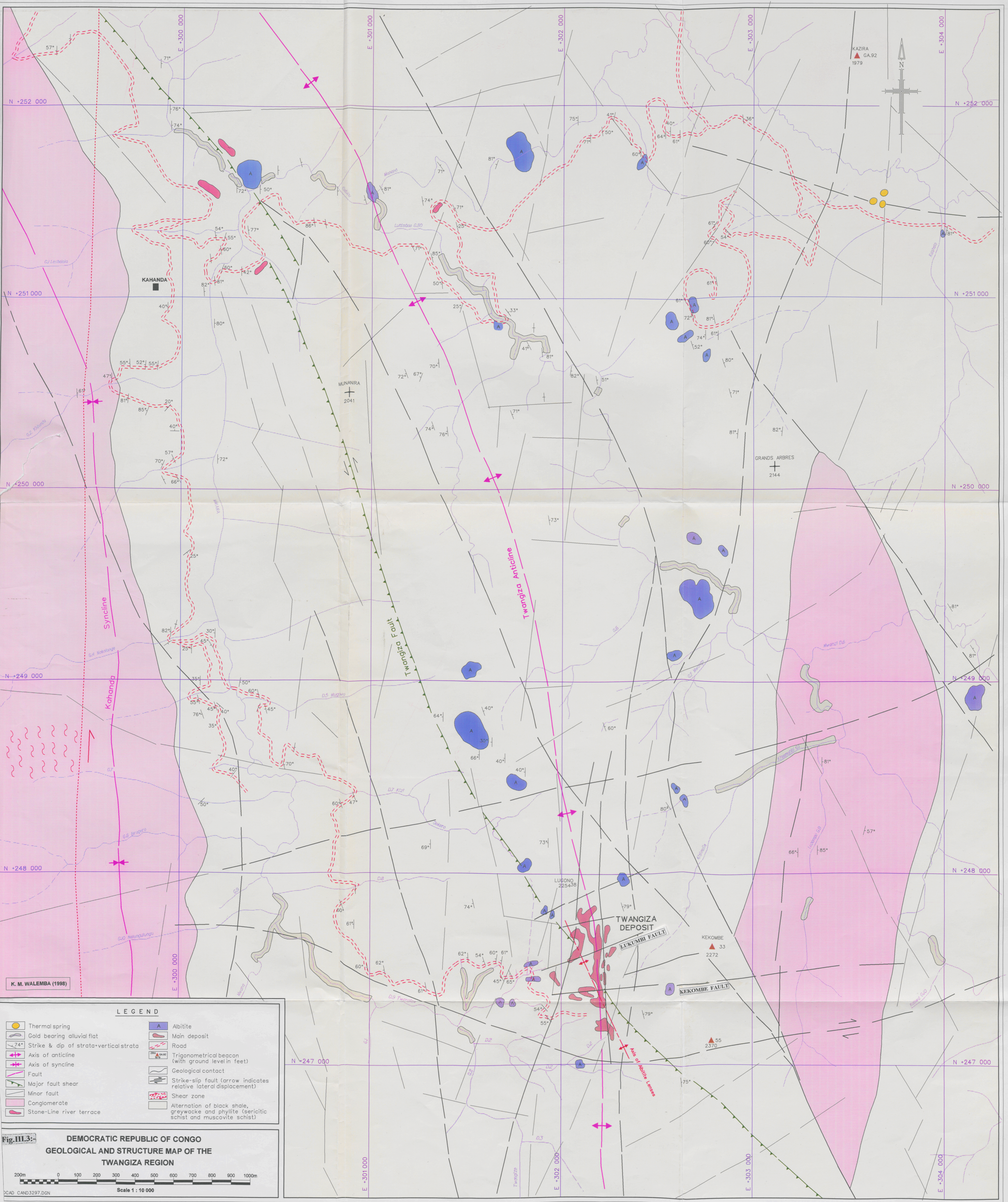
12.3.- EXPLORATION HISTORY.

From the discovery of the primary deposit, in 1957 until 1966, intermittent exploration was carried out by Cobelmin (Sominki) and was confined to the oxidation zone between the 2220m and 2100m levels. (Fig.III.4).

The ore body described below, has been explored over 700m of strike and partly over a vertical depth of 120m underground.

Fig.III.2: Twangiza gold deposit showing trenches and adits.





- LEGEND**
- | | |
|--|--|
| Thermal spring | Albite |
| Gold bearing alluvial flat | Main deposit |
| Strike & dip of strata-vertical strata | Road |
| Axis of anticline | Trigonometrical beacon (with ground level in feet) |
| Axis of syncline | Geological contact |
| Fault | Strike-slip fault (arrow indicates relative lateral displacement) |
| Major fault shear | Shear zone |
| Minor fault | Alternation of black shale, greywacke and phyllite (sericitic schist and muscovite schist) |
| Conglomerate | |
| Stone-Line river terrace | |

Fig.III.4:- Twangiza gold deposit showing trenches and adits (continued).



Charter investigated the deposit from 1974 to 1976 in order to confirm ore reserve estimates by Cobelmin and to establish the presence of an extension of the deposit along 800m of strike. Banro (1997-1998) undertook a drilling program along 800m of strike and up to 650m deep. Some petrographic-geochemical case studies were performed by: Sorotchonsky,(1952); Safianikof,(1972); Charter ,(1974-1976); Banro ,(1997-1998).

12.3.1.- COBELMIN.

- *.- *Trenching* : Cobelmin excavated 9,000 metres of trenches across the strike of the deposit
- *.- *Pitting* : No pitting was done by Cobelmin.
- *.- *Underground exploration* : Cobelmin drove 11,000m of adits. These were spaced at 20m excavated at 7 levels horizontally and vertically from the 2220m to the 2100m level. The top of the hill stands at 2250m a.m.s.l. Adits were interconnected by drives or crosscuts in areas of high grades. Some adit walls were geologically mapped.
- *.- *Soil sampling* : Trenches and adits were sampled at two metres intervals along both walls of the adits and on one wall of the trenches . The whole wall was scraped bottom to top for the two metres length. Gold content for more than 15,000 samples was determined by Cobelmin's fire assay laboratory.

12.3.2.- CHARTER (1974-1976) .

- *.- *Surface exploration* : An area of 7 sq km was investigated to the northeast of the main deposit. A soil sampling grid was set out at 25m intervals on lines 100m apart and 88 pits totalling 658m were dug. 7 adits were driven into the hillside. A small numbers of cuttings were made into the hillside.
- *.- *Underground exploration* : Charter re-logged and re-sampled three adits in the main deposit [G6/2100 ; G18/2130 and G9/2220] and their results returned an average of 8% higher gold grades than the Sominki results.

*.- *Metallurgical sampling* : A 10 tonne bulk sample was collected for metallurgical testing in Ashford's Atomic Absorption laboratory. Metallurgical testwork has shown that the gold in the upper levels is amenable to recovery by conventional amalgamation and cyanidation after fine grinding. From 12 million tonnes, with a conventional flowsheet and mill feed grades of either 4.23g/t or 3.44g/t, gold recoveries would be 90.5% and 88.5% respectively, resulting in a gold production of 160,000 oz (4,977 kg) p.a and 128,000 oz (3,976 kg) p.a respectively.

12.3.3- BANRO (1997-1998)

*.- *Sampling* : 12,100m of 16 adits have been re-sampled and mapped from level 2100 to level 2220

*.- *Drilling* : A program of deep diamond drilling was undertaken to further test the deposit in depth and to increase ore reserves. 9,122m of diamond drilling, up to 650m deep, in 20 holes was undertaken along the 800m long zone of mineralization and located narrow zones of high-grade mineralization, up to 200 g/t .

12.3.4- ORE RESERVES.

Ore reserves for the explored oxidation zone of the main deposit are estimated by Cobelmin – Charter, as follows :

- + 3 gm/tonne cut-off - 4.1 m tonnes at 5.2 gm/tonne.
- + 2 gm/tonne cut-off - 4.4 m tonnes at 5.0 gm/tonne.
- + 1 gm/tonne cut-off - 6.8 m tonnes at 3.8 gm/tonne.

This drilling program confirmed the geological interpretation and allowed inferred resources to be increased. The increased estimated resource by Banro is 104,600,000 tonnes grading 2.12 g/t Au equivalent to 7,127,915 ounces of gold resource .

The mineralized zone remains open along strike and in depth, and suggests the possibility of a considerable extension of ore reserves.

12.4.- GOLD MINERALIZATION.

12.4.1.- REGIONAL SETTING AND DEPOSIT-SCALE GEOLOGY.

The mineralized zone has an irregular outline and has been exposed and traced over a strike length of 700m, in a north-south direction; the width is very variable and ranges from 100m to 200m. This mineralized zone is open along strike and in depth. Along strike, pitting at 200m, 500m and 800m, north of the deposit, has encountered gold mineralization in fractured black shale and albitite. Possible extensions along strike following a watershed over 4km north, is suggesting by the distribution of alluvial gold. During the course of this study, albitite rock with sulphide mineralization was discovered 6km, east of the Twangiza deposit within the Mwanza stream, a tributary of the Lulimbowe river (Fig.I.7; Fig.III.3).

Diamond drilling has intersected sulphide mineralization at a depth of 650m deep, and has defined the base of the oxidation zone. Drilling has increased the gold resource and has indicated an inferred resource in at depth

The known oxide and sulphide orebodies remain open ended in all directions and in depth .

12.4.2.- STRUCTURAL STYLE AND DEPOSIT ARCHITECTURE.

The structural control of the Twangiza deposit can be considered on both a regional and local scales. Both are important because of the necessity to recognize features controlling gold mineralization and the plumbing systems that transmitted the mineralizing solutions.

12.4.2.1.- REGIONAL CONTROLS ON DEPOSIT LOCALIZATION.

The Twangiza area is situated on the intersection of three major structures, the Twangiza shear-fault (N-S), the Kekombe shear-fault (NE-SW), and the Lukumbi (E-W) fault suggesting that increased permeability associated with faulting was one of the significant ore controls.

The Twangiza shear-fault follows, more or less the Twangiza anticlinal axis and is presumed to have served as feeder systems for the mineralization.

The shear zone forms a subsidiary structure to the Twangiza fault; which is a high-angle reverse fault. (Fig.II.16; Fig.III.3). This location is related to the approximately east-west far field (σ_1) stress vector of the late Pan African compression.

On a deposit-scale, flexures in shear-fault zones and the interplay of the geometry and rheology of the enclosed albitite and black shale lithologies has controlled mineralization.

It could be suggested that the Twangiza high-angle reverse fault began as a major normal - slip growth fault which reacted as a reverse fault with a minor strike-slip component. The development of the gold-quartz-vein systems appears to be related to this last phase of reactivation, postdating albitite alkaline magmatic activity within the Twangiza region.

12.4.2.2.- CONTROLS ON DEPOSIT-SCALE STRUCTURE.

The deposit itself is exposed by erosion on a steep slope and the gold mineralization zone follows the NNW-SSE ($\sim 10^\circ$ W) trending Twangiza anticlinal axis, with steep dips ($\sim 80^\circ$) to the east and pitch to the south.

The Twangiza anticline is moderately tight, and inclined to the west, with the west limb dipping more steeply (70° - 75°) than the eastern limb. Associated parasitic folds, with N25 $^\circ$ W trending axis, southeastward dipping axial plane ($\sim 36^\circ$ SE), occur in the hinge zone of the anticline in particular. This parasitic, subisoclinal folding caused thickening and repetition of the orebody.

All albitite lenses outcropping within and/or close to Twangiza deposit are associated with this deposit. Axis of albitite lenses follows Twangiza anticline axis.

Three major fault zones have been identified in and/or close to the deposit: Twangiza fault zone (up to 6.5m wide, N 35 $^\circ$ W/ $\sim 60^\circ$ SW), Kekombe fault zone (up to 3m wide, N 70 $^\circ$ W / 60 $^\circ$ S) and Lukumbi fault zone (up to 4m wide, E-W / 87 $^\circ$ S). (Fig.III.3). Infilling vein materials of the Twangiza reverse-fault are mainly randomly oriented quartz breccia, quartz veins and clay minerals.

The Kekombe fault is composed mainly of quartz fragments, limonite and brown clay materials, while the Lukumbi fault is made up of quartz veins.

Twangiza fault and anticlinal axis are parallel until they converge slightly and cross at the Twangiza deposit. This 'intersection' is obviously an important control to be stressed. Saddle reefs are associated with both the Twangiza anticline and fault. Thus, it is possible that these faults have been formed after "locking" of the folds (Twangiza anticline) in response to a change in deformation from a ductile to brittle regime during the one progressive deformation. The association of saddle reefs with the Twangiza reverse fault suggests also that the saddle reefs could represent the variation of the fault reefs and thus syntectonic.

12.4.2.2.1.- LITHOSTRATIGRAPHY.

The host to the gold mineralization is the black shale units (up to 1000m thick) with interbedded siltstone (up to 60cm thick) and arkosic sandstone grading to greywacke (up to 1m thick) in which albitite lenses have been emplaced.

From bottom to top, the detailed lithostratigraphy within the deposit is as follows :

Black shale, Siltstone, and Greywacke .

12.4.2.2.1.1- BLACK SHALE .

Black shale is a fine-grained, graphitic argillaceous rock, finely interlaminated grading to slaty cleavage, black to dark in colour, sometimes indurated with varying amount of organic matter. Abundant medium to coarse grained, euhedral to subhedral pyrite and arsenopyrite occur as disseminated grains and as veinlets. Towards the contact of the bedding parallel sulphide vein, there is a definite increase in carbonate "calcifying-out". (KW 448A ; Fig.III.6).

Hydrothermally altered black shale (KW 622 A, Fig.III.7) is hard, massive, brittle, firmly indurated, with amorphous carbonaceous matter and without fissility or slaty cleavage. Abundant sulphide minerals (pyrite & arsenopyrite) occur as fine-grained disseminations with some specks scattered through the rock. A brown staining of hydrous oxides is found within the fissures and interbeds.

Combined intense hydrothermal alterations and weathering of graphitic black shale gives a discoloured, bleached, grey to brown shale; sometimes ferruginous, with oxidation of sulphide and leaching of carbonaceous materials.

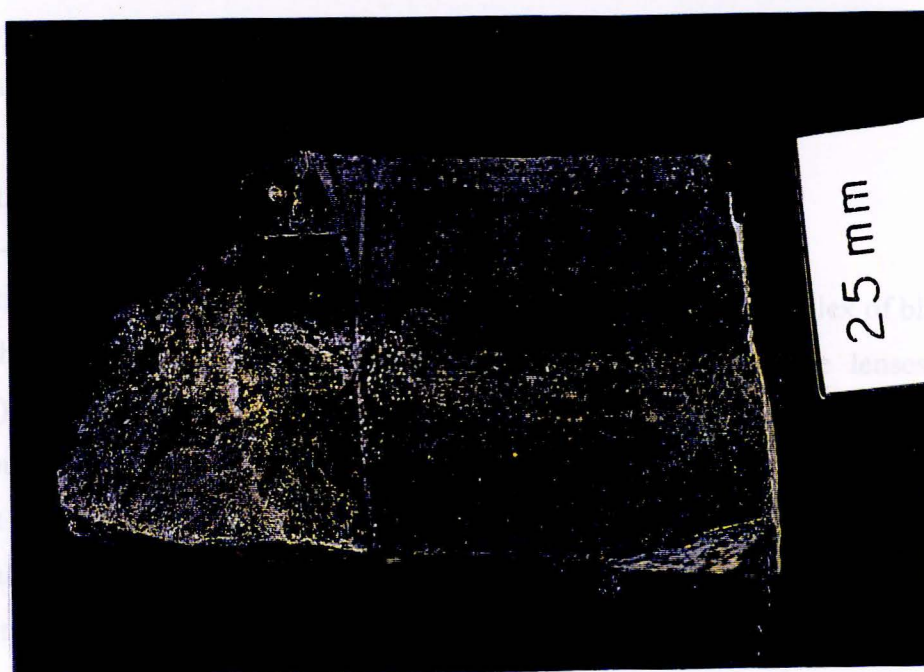
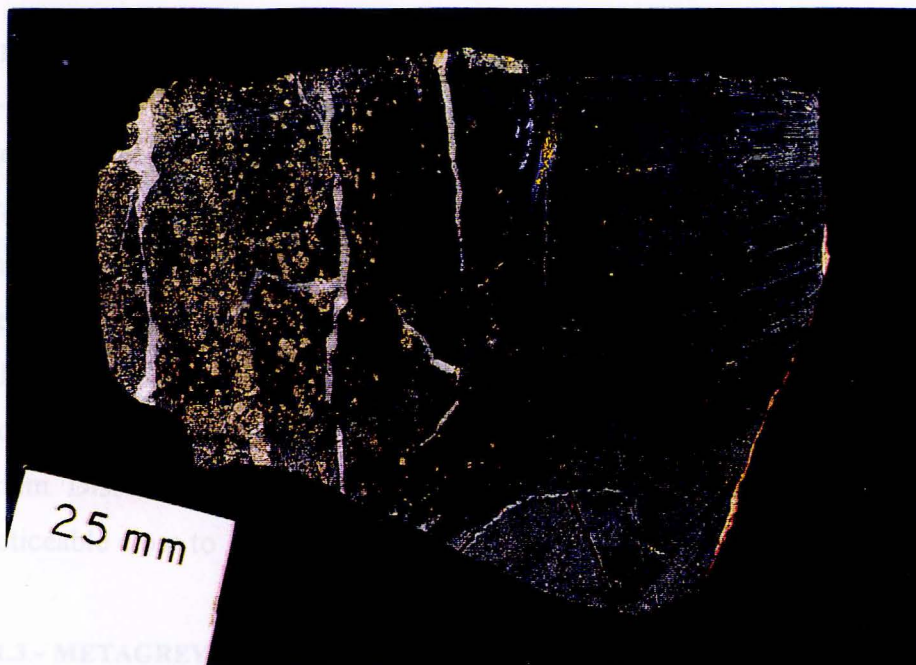


Fig.III.6:- - Black shale sample with " calciting -out ".

Fig.III.7:- - Hydrothermally altered black shale.

12.4.2.2.1.2. - SILTSTONE.

Siltstone occurs as graded beds, up to 50cm thick, with a greyish color, hard, with silt sized grains materials and no visible fissility (Fig.III.8). The rock, interbedded within the black shale, consists of quartz wacke containing mainly quartz, sericite, and epidote in the lower few centimetre and grades upward through quartz wacke to very fine-grained soft shale (mudstone) at the top. The rock is sometimes silicified, sandy or clay-rich, fractured, brecciated or bleached depending on the proximity of a faulted zone and /or vein system. Disseminated sulphide mineralization (pyrite and arsenopyrite) is present and is noticeable close to sulphide veins .

12.4.2.2.1.3. - METAGREYWACKE.

Metagreywacke, is a light grey to whitish in color, spotted with pyrite and arsenopyrite. It grades into arkosic sandstone (Fig.III.9).

12.4.2.2.1.4. - ALBITITE.

The albitite rock has been described above and occurs within the complex of black shale unit in the very axial zone of the Twangiza anticline. Three main albitite lenses (A₁, A₂ and A₃), with 150 to 350m length and up to 15m thick, have been mapped in the underground and a few other occurrences have been observed in outcrop north and northeast of the Twangiza deposit. The lenses are concordant with the bedding of the black shale unit and are folded in the same way.

The albitite rock exhibits a metasomatic zoning with three distinct zones being recognized, based on the sequence of mineralogical changes, textural petrography and color with increasing distance from the inner zone of albitite.

All three albitite rocks result from metasomatism and occupy the same position in the sequence of structural development of the Twangiza region.

The following Table III.1 gives the change in mineralogy within the different zones of the albitite rock. (Fig. III.10).

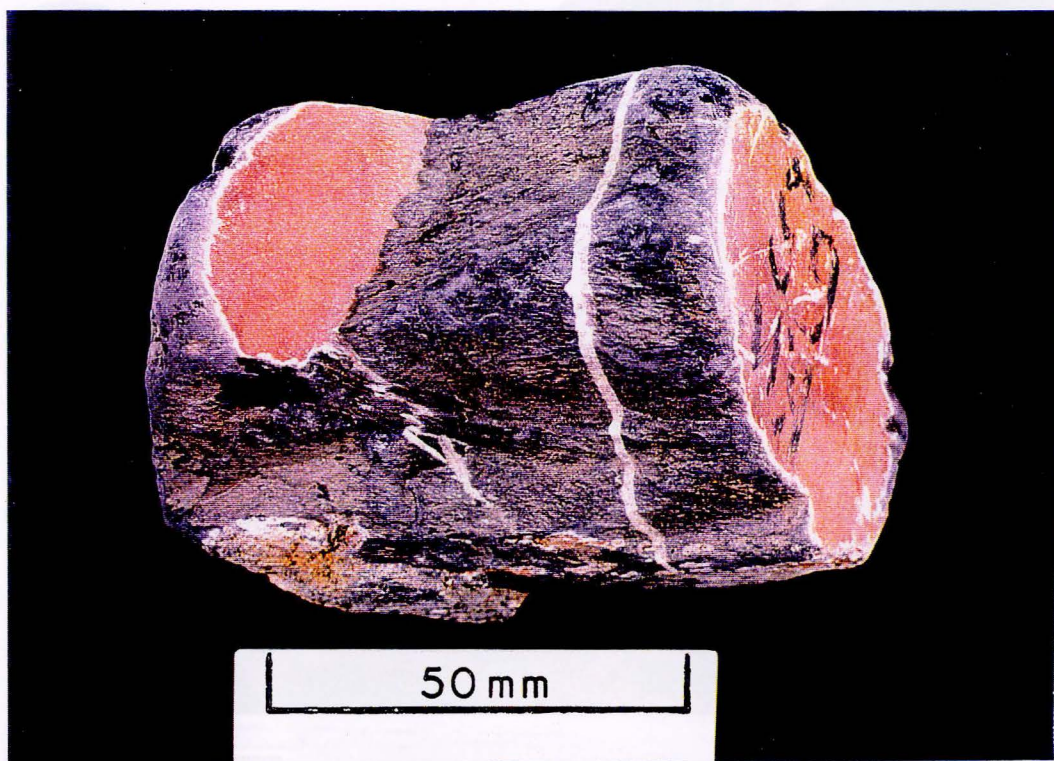


Fig.III.8:- - Siltstone hand specimen .



Fig.III.9:- - Metagreywacke outcrop. Twangiza gold deposit.

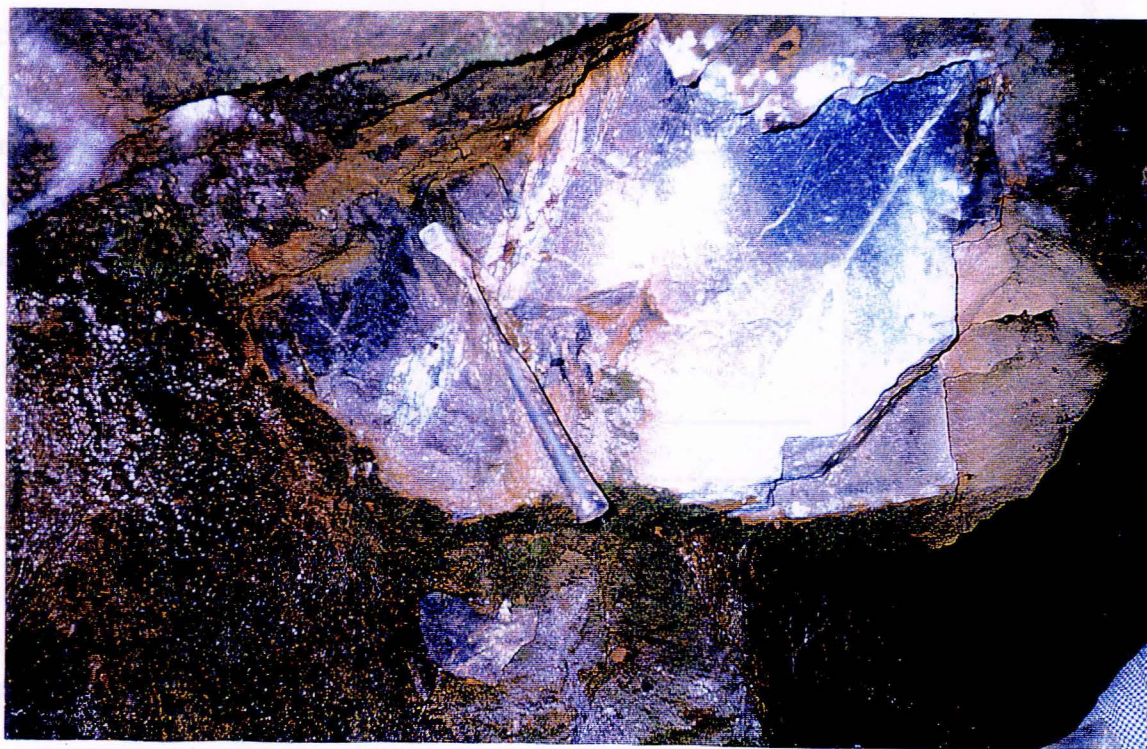


Fig.III.10:- - Albitite outcrop. Twangiza gold deposit.

Table III.1: Metasomatic zoning within albitite rock.

Minerology	Inner Zone. Samples KW 618B & KW 620 A	Medium Zone. Samples KW 618E & KW 618E7	Outer Zone Samples KW 1A & KW 1B
Colour	Dark green	Grey whitish	Green
Rock classification	Ultramafic to Mafic	Ultramafic to Felsic	Mafic
Fresh Rock:			
Clinochlore			
Dolomite			
Albite			
Quartz			
Magnesite			
Muscovite			
Epidote			
Magnesiohornblende			
Microcline			
Maganocalcite			
Weathered rock :			
Kaolinite			
Muscovite			
Quartz			
Goethite			
Rutile			
Albite			

12.4.2.2.2.- STRUCTURAL CONTROL.

Twangiza deposit exhibit three clear structural controls of gold mineralization :

12.4.2.2.2.1.- FOLDING.

Mineralization occurs as classic concordant saddle reefs on the flanks of the Twangiza anticline near the Twangiza high -angle reverse fault, along 5kms length. Structural traps related to folding and faulting control the mineralization. The Saddle reef mineralization is frequently located at an interface between two black shale beds (interbeds) or between a thick black shale and an arkosic sandstone unit (Fig.III.11a ,Fig.III.11b).

This late observation suggests that competency contrasts during folding also provided the major control on saddle reef formation. The formation of these reefs probably postdate folding. It is likely that folding influenced ore fluid migration and gold deposition. The exact number of reefs and depth dimensions remain to be determined.

12.4.2.2.2.2.- FAULTING.

The size and geometry of the orebody is controlled by the N- S striking Twangiza high-angle reverse fault, which is interpreted as the main fluid pathway (Fig. III.3). It is likely that faulting also played an important role in the formation of the saddle reefs and fracturing associated with parasitic (?) flexures may have played an important role in localizing mineralization.

In the adits, several individual brittle- ductile shear zones, with associated sulphides, can be traced for significant distances along the deposit, but none are major structures. (Fig.III 11a ; Fig.III.11b).

12.4.2.2.2.3.- LITHOLOGICAL.

In addition to folding and shear-faulting, the loci of gold deposition in the Twangiza deposit, is controlled, or influenced by lithology and rock geochemistry .

Mineralization is strongly controlled by structure and geochemistry of the host rock black shale unit and albitite at different scales.

Fig.III.11a : - Saddle reef mineralization at an interface between two black shale beds.

Fig.III.11b : - Saddle reef mineralization at an interface between two black shale beds.

Fig.III.12 : - Brittle-ductile shear zone within black shale.



A number of quartz-veins, fault-breccia veins and veinlets are contained within the brecciated, folded and altered black shale and/or albitite rocks.

At the hanging wall of the albitite lenses, on either side of the contact, albitite and/or black shale are strongly disturbed and often brecciated and/or altered. The black shale and arkosic sandstone show signs of shearing, veining, brecciation, faulting and of chemical alteration. Fissures, cracks and decollement are noticeable in a zone of tension. (Fig.III.12; Fig.III.13; Fig.III.14).

Metamorphic minerals include sericite, chlorite, and muscovite indicating a greenschist facies.

12.4.2.3.- DISTRIBUTION OF GOLD AND CONTROLS ON ORE SHOOT FORMATION.

12.4.2.3.1- DISTRIBUTION OF GOLD .

The regional gold background for the ore is 2 ppb Au, as indicated by an experimental soil sampling programme amplify.

The gold content is extremely variable and the average of gold grade increases from 4.6 gm/tonne on the 2200m level to 5.6 gm/tonne on the 2100m; the lowest level investigated by underground workings, and up to 200 gm/t at 400m depth. There is thus an increase in grade with depth.

There is a strong spatial association of gold mineralization with albitite outcrops.

The higher Au-grade (> 10 gm/tonne) tend to be localized, either in the proximity of the albitite –black shale host rock interface contact or closely associated with fault-breccia along a fault zone. High gold contents also occurs on the flank of an anticlinal zone and closely associated with sulphide veins (saddle reef system).

Beyond this structural domain, the grade falls progressively as is evidenced by the gold distribution grade shown on cross-sections (Fig.III.15) and by hand coloured underground geological mapping showing gold value distribution on various levels (Not included).



Fig.III.13:- - Shearing and veining within black shale.

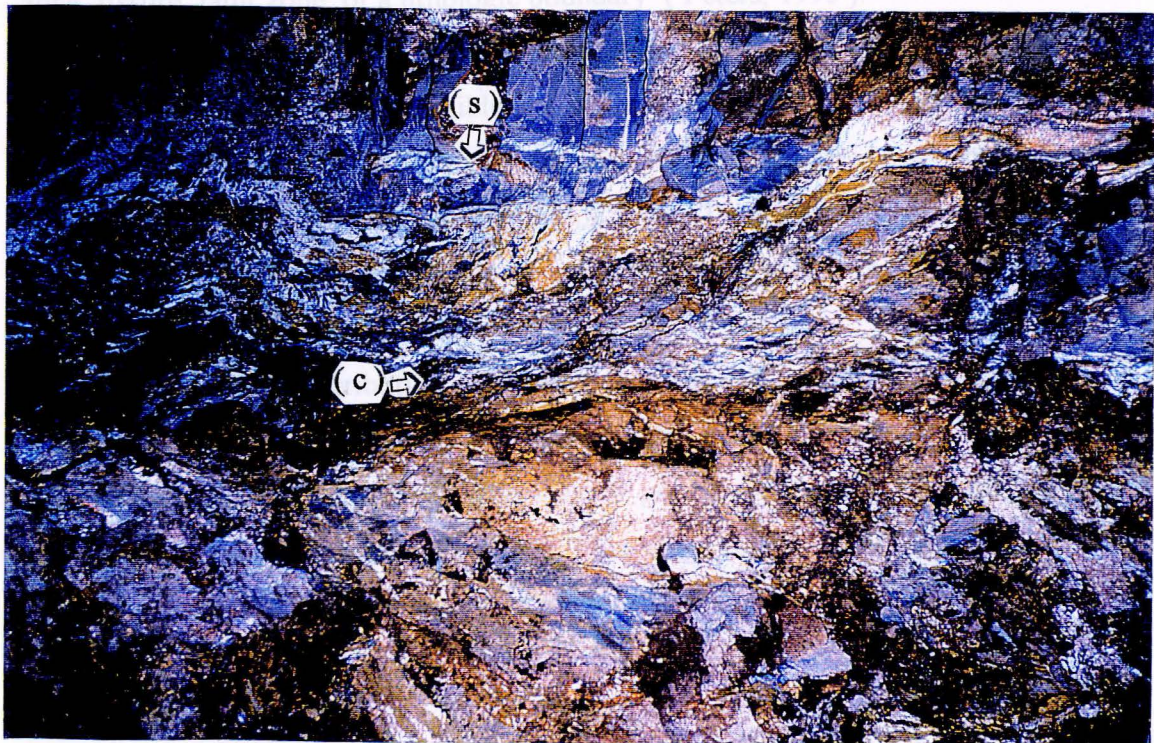


Fig.III.14:- . Shear zone in black shale .; rotation of (S) fabric towards (C) in centre zone.

Gold associated with pyrite and arsenopyrite forms disseminations or occurs in quartz / sulphide veins in a stockwork in the albitite lenses and in the adjoining black shale and arkosic sandstone.

The relation between gold values and structural and stratigraphic features is shown in cross section (Fig.III.15).

These different plots suggest that major structural features (particularly the Twangiza high-angle reverse fault) provided important pathways for mineralizing solutions but that large amounts of gold were deposited away from the structures in favorable stratigraphic intervals. Ore-bearing and more or less barren stratigraphic horizons in this deposit have undergone the same amount of folding, suggesting that fracturing and related permeability enhancement were not the only factors controlling the distribution of gold.

12.4.2.3.2.- ORE SHOOT FORMATION.

Ore shoots in fault/vein system take the form of discrete hypogene mineralization usually hosted within a planar structure which has acted as a conduit for the ore fluid. These structures are commonly referred to as a channel, surface, or lode which may be a shear zone, fissure, fault zone, or a lithologic boundary (Peters, 1993).

The shape and geometry of possible ore shoots for Twangiza deposit is not yet well constrained. More data are needed to characterise these features. Preliminary data however indicates that the gold distribution in the Twangiza deposit takes two forms. Classic saddle reefs with high grade material and fault reefs with associated spur veins. (splays) . (Fig.III.16; Fig.III .17) .

Fig.III.16 shows the distribution of ore shoots relative to the geometry of the deposit on level 2100. A strong relationship between the plunge of the Twangiza fold and the ore shoots is evident (Fig. III.15). The general geometry of the ore shoot comprises a feeder zone controlled by the Twangiza high-angle reverse fault, and an upper, brittle, stratiform black shale unit , acting as a reactive lithology.

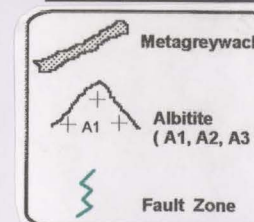
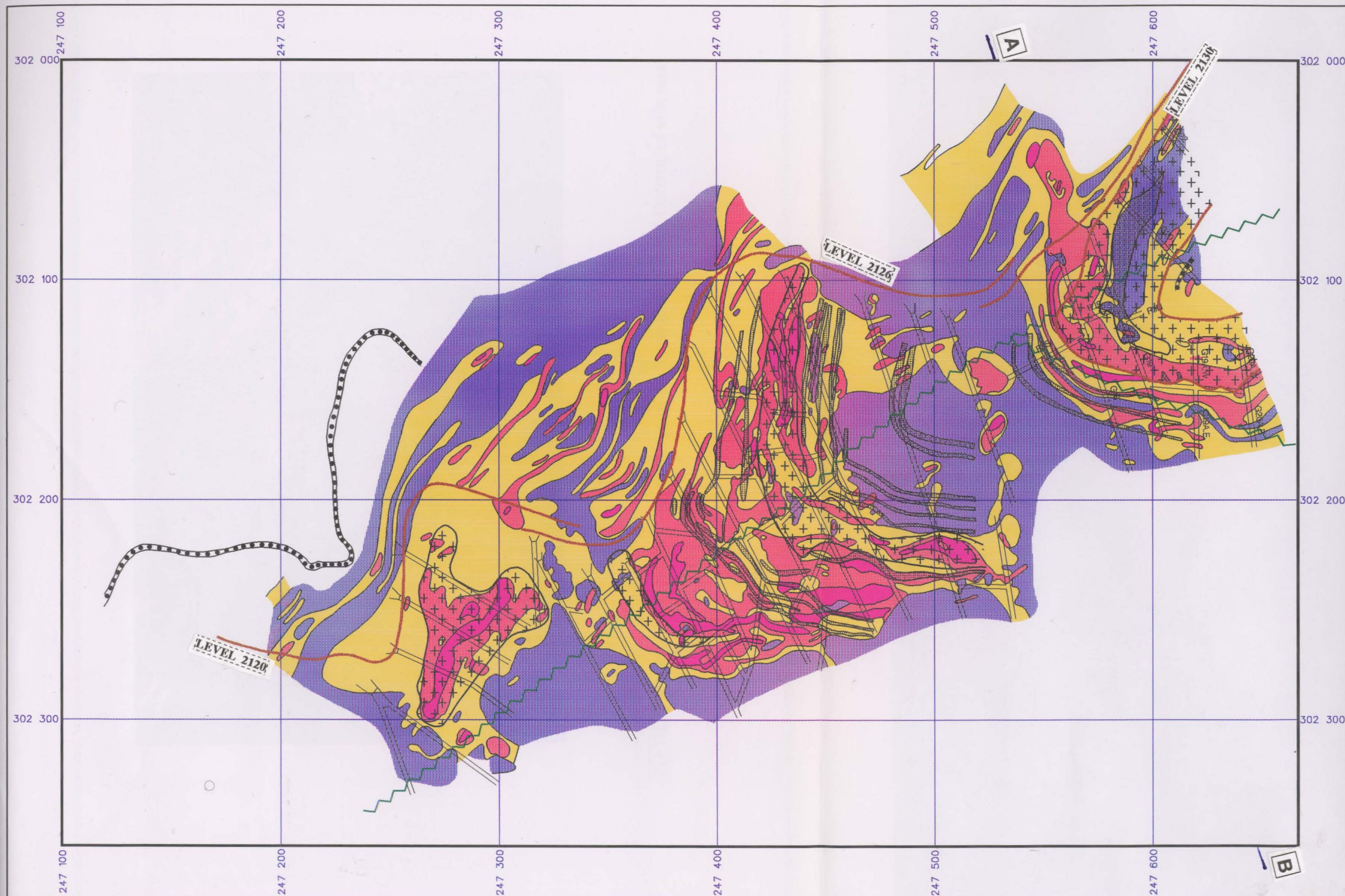
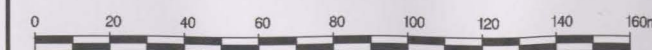


Fig. III.16:

DEMOCRATIC REPUBLIC OF CONGO
GEOLOGY - LEVEL 2120, 2126, 2130
TWANGIZA GOLD DEPOSIT
(K.M. WALEMBA, 1998)



NOVEMBER 1998

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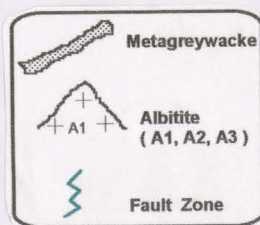
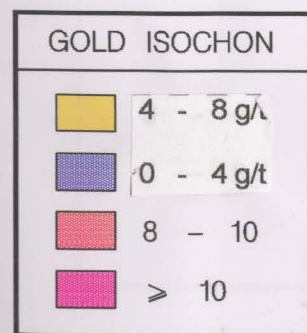
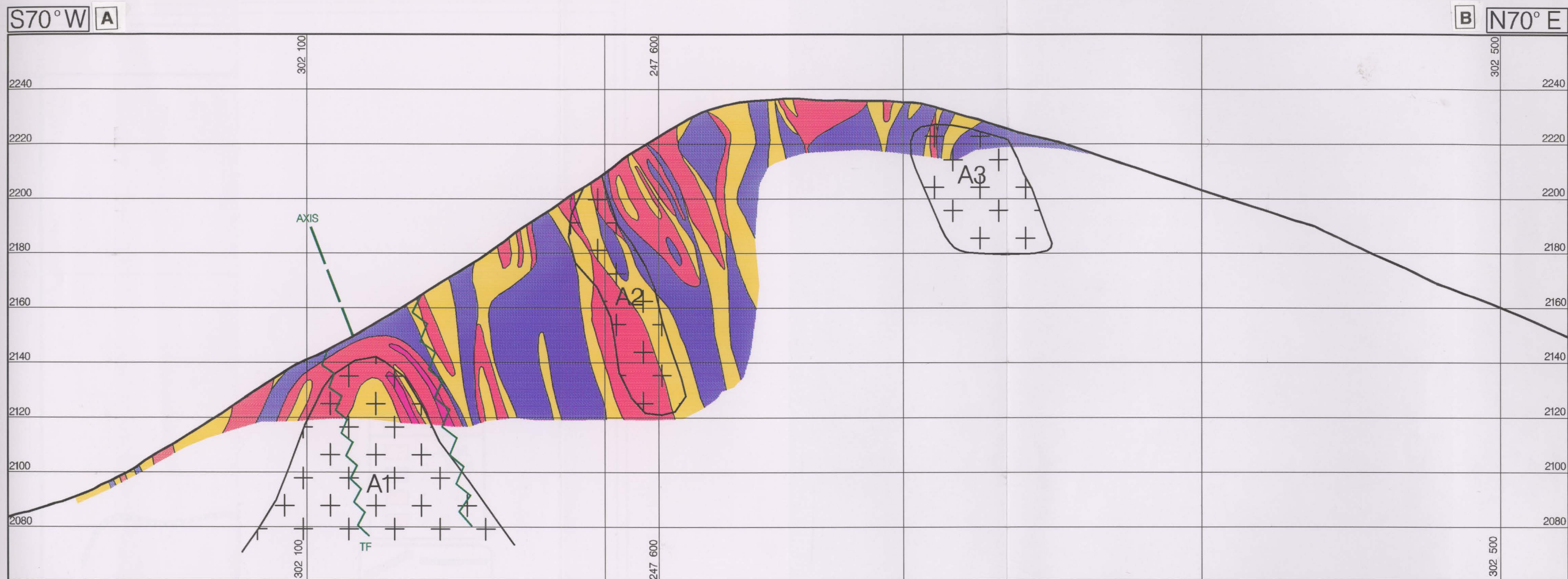
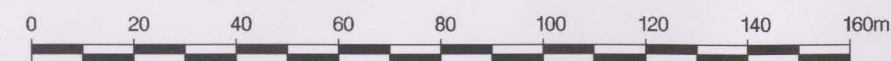


Fig. III.15:

DEMOCRATIC REPUBLIC OF CONGO
 CROSS-SECTION ALONG G18 / LEVEL 2130
 TWANGIZA GOLD DEPOSIT
 (K.M. WALEMBA, 1998)



NOVEMBER 1998

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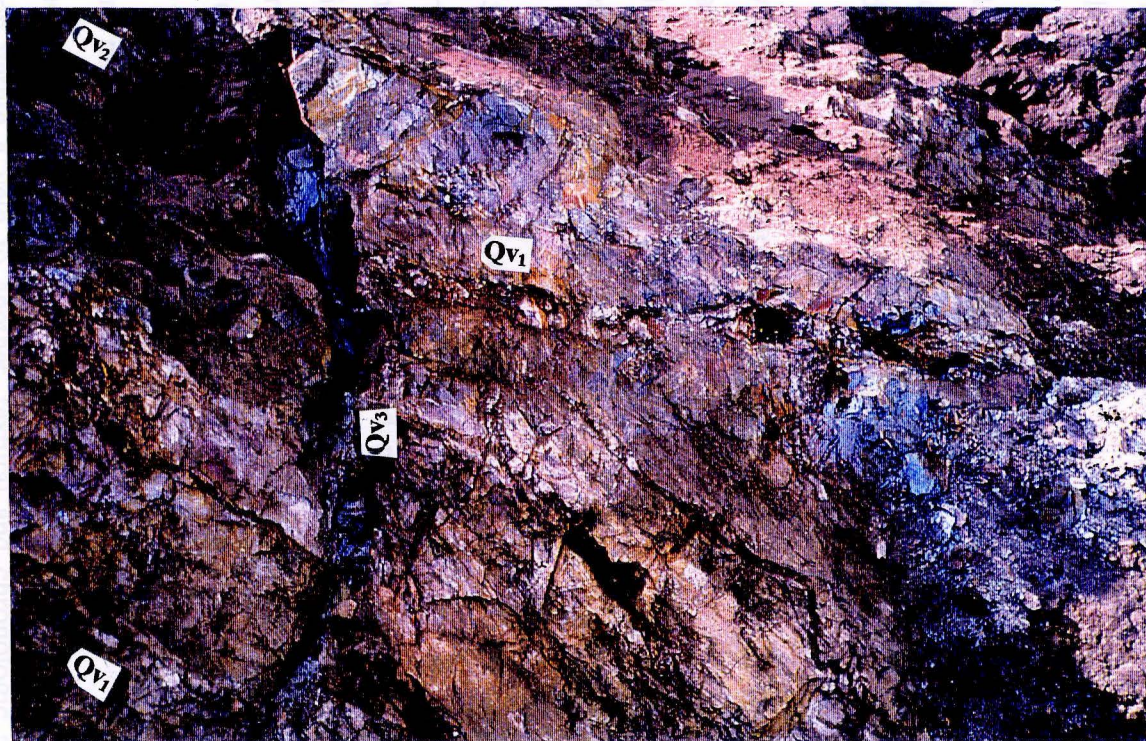


Fig.III.17:- - Fault reef and spur vein outcrops of the Twangiza deposit. [Outcrop of vein sets QV₁; QV₂; QV₃].

Ore shoots also occur on both sides of albitite / black shale lithologic contact and within the intersection of two or more mineralized fissures. (Fig. III.16).

The black shale and its interbedded arkosic sandstone hosts up to 80 % of the ore. Some 10 % of gold within the oxidized zone is native and extremely fine-grained (less than 100 mesh).

The intersection of the two presumed mineralized conduits (the Twangiza and Kekombe faults) does not necessarily give a high gold value. (Fig. III.3 ; Fig.III.15 ; Fig. III.16).

Lithologic contacts represent zones of contrasting competency, chemistry, thermal conductance and porosity.

Low-grade disseminated sulphides (with gold) mineralization occurs within black shale, meta-sandstone and albitite. The disseminated mineralization often occurs near high-grade sulphide vein mineralization suggesting that the Twangiza deposit may have potential as a large tonnage bulk mineable gold deposit.

12.4.3.-VEIN MINERALOGY AND PARAGENESIS .

Vein minerals have been identified macroscopically, microscopically (polished thin sections), by XRD and by Ion microprobe analysis.

Four distinct vein-types are present in the Twangiza deposit: Vein set QV1, QV2, QV3, and QV4. They are hosted by a metaturbidite sequence of the Tsibangu Formation that has been metamorphosed to greenschist facies. Repeated fracturing and brecciation during mineralization produced complex vein textures.

Although the proportions of minerals may vary from one vein to another and from one ribbon within a vein to another, textural and chronologic relationships between veins (minerals) are consistent throughout the deposit.

Quartz/sulphide –vein generation is characterised by an associated alteration and paragenesis as summarized below :

12.4.3.1.- VEIN SET QV1: IRREGULAR CRACK-SEAL QUARTZ VEINS.

This vein set is characterised by anhedral coarsely granular, milky-white bucky or vuggy quartz, and dolomite comprising the bulk of the vein. Quartz commonly forms more than 90% of vein. (Fig.III.17; Fig.III.18 ; Fig.III.19; Fig.III.20; Fig.III.21).

These veins are subvertical, non concordant, non laminated with variable thickness (up to 50 cm), transect the bedding, show mutual cross -cutting relationships with albitite and black shale rocks and strike consistently north- northwest.

Pyrite and arsenopyrite occur as extremely coarse-grained porphyroblasts (up to 2 cm wide) throughout the veins, but can also form clusters, aggregates or nests. Hematite after sulphide has been observed. They occur in the black shale, arkosic sandstone and albitite.

The mineral assemblage consists of quartz, +/- pyrite, +/- arsenopyrite, +/- carbonate (ankerite, calcite, dolomite) +/- albite.

12.4.3.2.- VEIN SET QV2: FOLDED BEDDING -PARALLEL VEINS.

This is the most important vein type in the deposit. It consists of a laminated (ribbon) vein structure consisting of multiple laminae or veinlets of sulphides (pyrite and arsenopyrite) separated by millimetre -thick slivers of black shale wall-rock. There is a definite increase in carbonaceous material towards the periphery of the bedding parallel veins and the abundance and thickness of carbonaceous wall rock slivers decreases from the margins towards the center of the veins. This implies that the slivers were progressively dissolved after being incorporated into the veins. The opening of these veins was purely dilational. (Fig.III.11; Fig.III.18; Fig.III.19; Fig.III.20; Fig.III.21).

Compared to QV1, they have a relatively more uniform thickness (~ 25 cm), very high length to thickness ratios, are laterally continuous over tens to hundreds of metres and formed between bedding surfaces (where the differential movement is often considered to be sub-parallel to bedding).



Fig.III.18:- - Outcrop of vein set QV₁; QV₂; QV₃; QV₄. Twangiza deposit.

Fig.III.19:- - Outcrop of vein set QV₁; QV₂; QV₃; QV₄. Twangiza deposit.

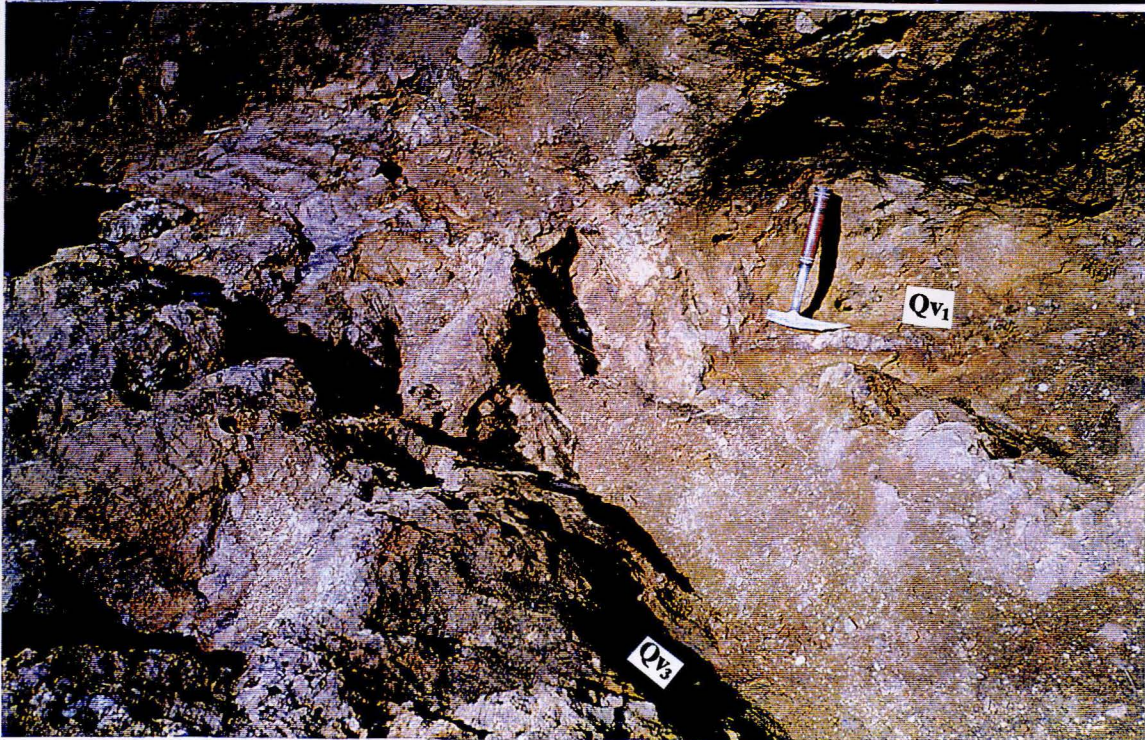
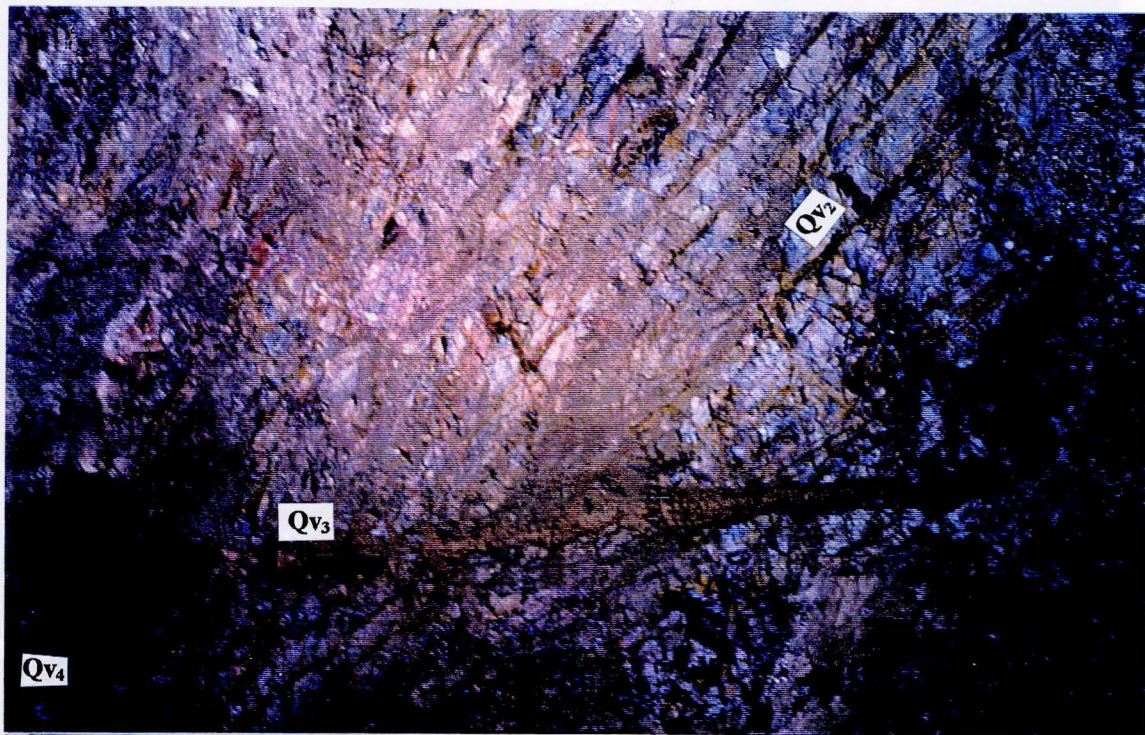
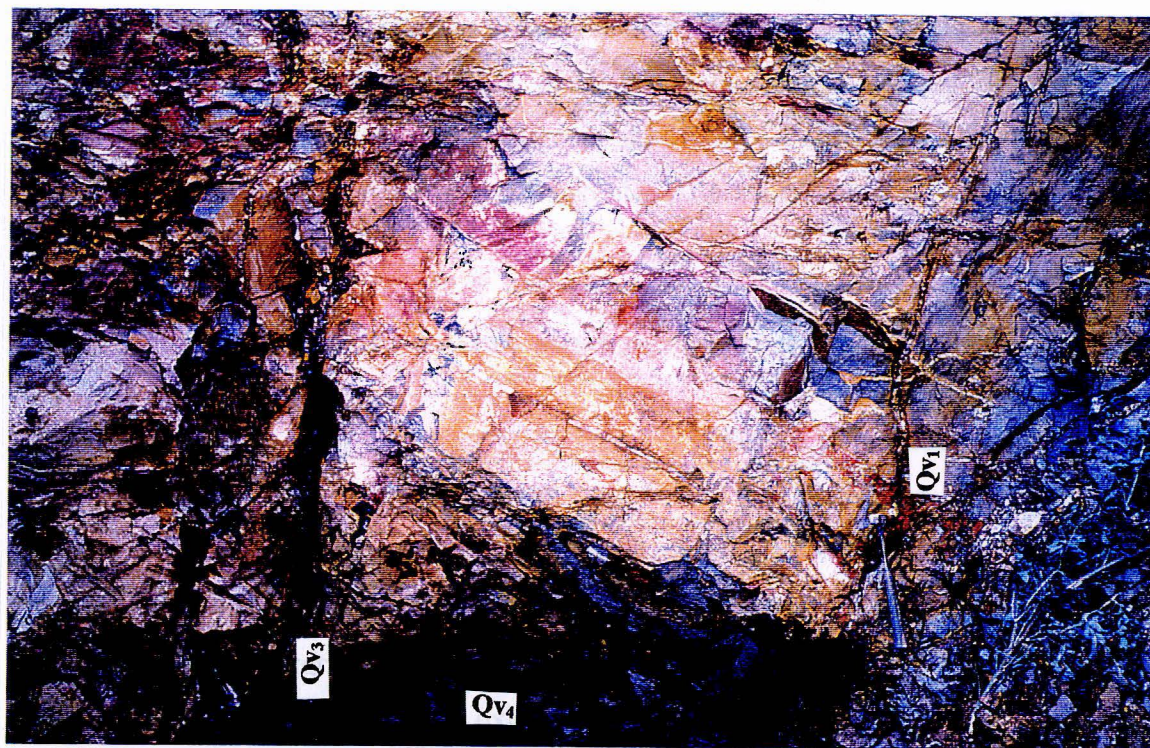


Fig.III.20:- - Outcrop of vein set QV₂ ; QV₃; QV₄. Twangiza deposit.



clusters, randomly oriented, with or without direct association with quartz-sulphide veins.

The presence of both disseminated and vein type mineralization occurring within the

same

but

Fig.III.21:- Outcrop of vein set QV₁; QV₂; QV₃; QV₄. Twangiza deposit.

Fig.III.22:- Out crop of vein set QV₄. Twangiza deposit.

These veins appear to have been developed syntectonically in horizontal compressional (and /or transpressional) regimes. These bedding parallel veins occur in saddle reefs structures within interbeds of black shale, preferably in the vicinity of albitite, or between a thick black shale and an arkosic sandstone (Fig.III.20). The main mineral assemblage is pyrite, arsenopyrite, Au, ankerite. Alteration mineral, include limonite, scorodite, +/- quartz.

12.4.3.3.- VEIN SET QV3: VUGGY FAULT-BRECCIA.

Vuggy fault-breccia veins and associated extension veins are subvertical, continuous, with a thickness of 1cm - 50cm, and length ; > 100m. (Fig.III.18; Fig. III.19; Fig.III.20; Fig.III.21).

They occur in black shale and albitite host-rocks. The mineral assemblage consists of quartz veins, clay material (aluminium silicate ; halloysite ? + allophane ?) +/- quartz fragments and +/- sulphide or iron oxide.

12.4.3.4.- VEIN SET QV4: STOCKWORK VEINING, BRECCIATION , AND/OR DISSEMINATION.

These veins occur as a network texture consisting of a mixture of vein material and silicified host rock fragments. The stockwork systems consist of mutually crosscutting sulphide/quartz vein sets and are restricted to zones of brittle deformation within particularly competent albitite rock. Stockwork formation is probably related to late brittle movement on a series of north-trending faults (Twangiza, Kekombe and Lukumbi faults) and is related to late stage secondary flexures. (Fig.III.22).

The breccia consists of interlocking fractures with centimetre -scale elliptical shapes with sulphides (weathered to iron oxide : limonite ...), wall rock and gouge fragments. Disseminated sulphides occur in the form of euhedral grains to massive, irregular clusters, randomly oriented , with or without direct association with quartz/sulphide veins. The presence of both disseminated and vein type mineralization occurring within the same deposit, in close proximity to each other, indicates significant potential for large bulk mineable deposits in the Twangiza region.

12.4.3.5.- COMPARISON WITH (META)TURBIDITE HOSTED - GOLD DEPOSITS.

Twangiza gold deposit bears many similarities with other syndeformational (meta)turbidite - hosted gold deposits, elsewhere in the world, particularly the Beding - Ballarat zone in Centrale Victoria, Australia.

These similarities are outlined by the lithology (flysch-type shales and turbiditic greywacke), by structural and geochemical controls on ore genesis, as well as the interaction of regional deformation, fault dynamics and fluid dynamics in controlling the development of quartz/sulphide vein - hosted gold deposit in Twangiza deposit.

A serie of sketches showing the different styles of structural control of mineralized veins in Twangiza gold deposit is sketched in Fig.III.23a, Fig.III.23b, and Fig.III.24a . For comparison, the structural style of mineralization at Bendigo field is portrayed in Fig.III.24b, Fig.III.24c, Fig.III.24d and Fig.III.24e.

12.4.3.6.- PARAGENESIS .

The paragenesis of the mineralized veins of the Twangiza deposit was determined in order to provide a relative temporal framework, within which absolute ages would be determined by $^{39}\text{Ar} / ^{40}\text{Ar}$ geochronology.

Fig.III.25 and Fig.III.26 schematically illustrate the lateral zonation in wall-rock alteration assemblage and paragenetic sequences for respectively black shale and albitite host rocks.

The alteration minerals listed in Fig.III.25 and Fig.III.26, form the silicate and carbonate gangue of gold ore, and generally replace the metamorphic assemblage of the principal, albitite and black shale host-rocks. (preore). Oxide minerals (limonite, jarosite, kaolinite, haematite, rutile, goethite) are present in the oxidation zone of the orebodies and locally extend to considerable depth along fractures.

These minerals are an oxidation product of the ore due to weathering. A wide variety of minor minerals, (not shown in Fig.III.25 and Fig.III.26), are temporally associated with the main gold-depositing event.

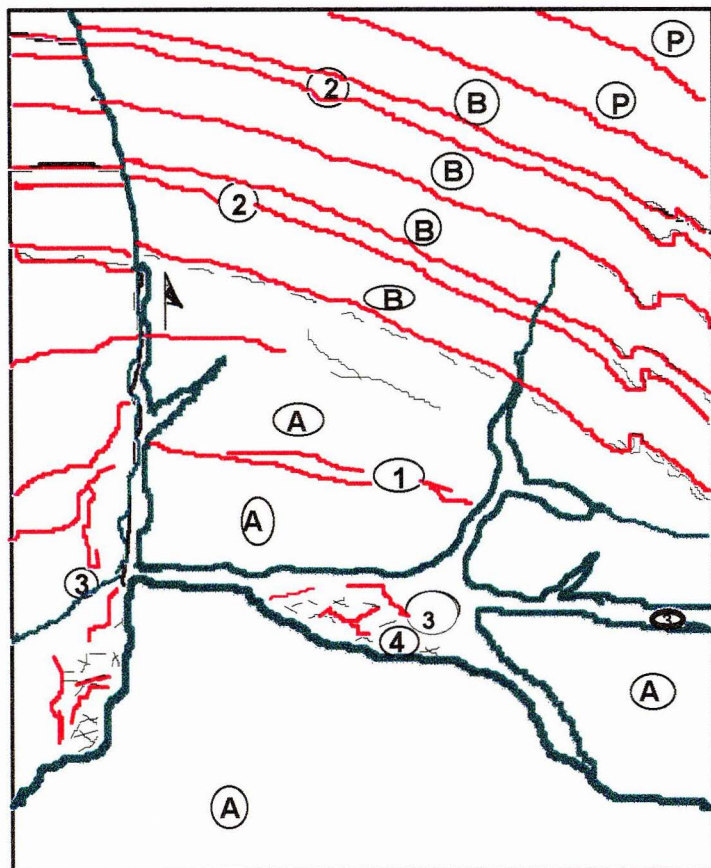
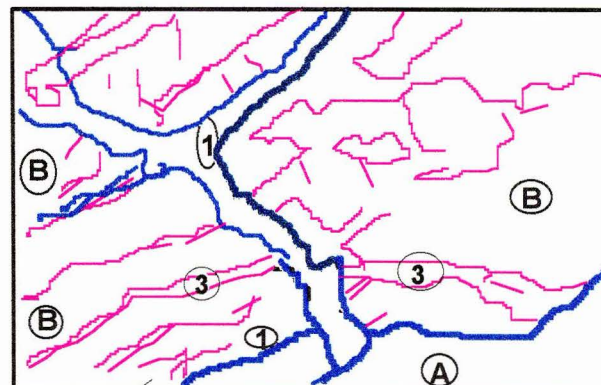


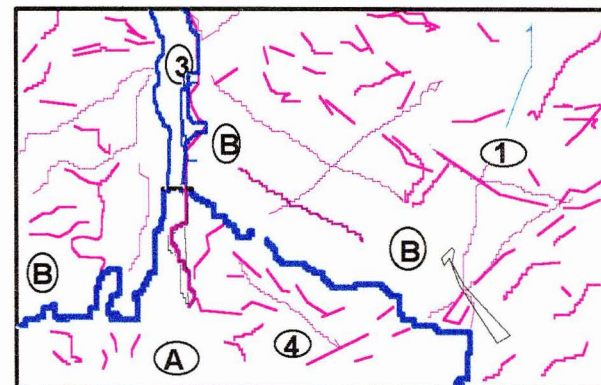
Fig.III.23a.- Sketch of main type of gold-sulphide/quartz vein systems. Twangiza gold deposit.

SYMBOLS:

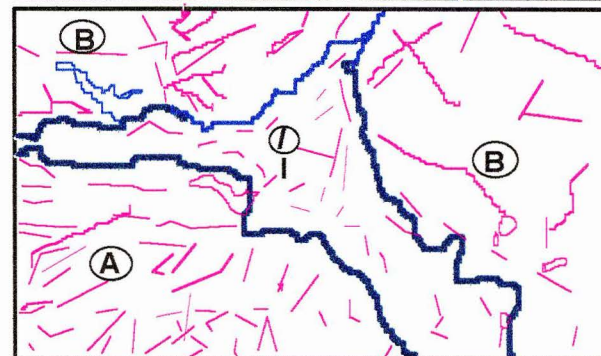
- ①.- Vein set QV1: Irregular crack-seal quartz veins.
- ②.- Vein set QV2: Folded bedding - Parallel veins.
- ③.- Vein set QV3: Vuggy fault -breccia.
- ④.- Vein set QV4: Stockwork veining , brecciation and/or dissemination.
- Ⓐ : - Albitite ; Ⓡ :- Injection.
- Ⓑ : - Black shale; Ⓟ :- Phyllite.



After
FIG.III.18



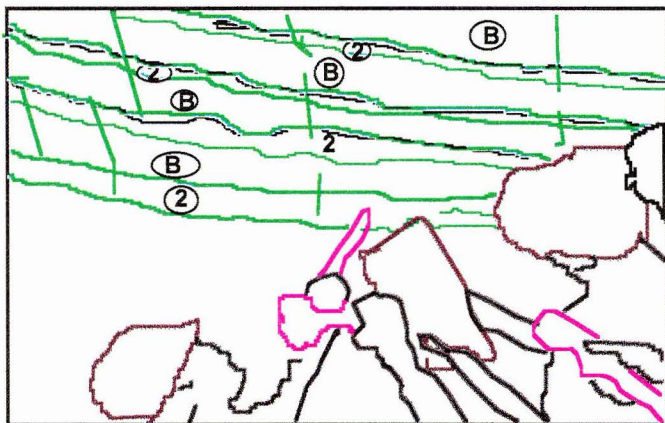
After
FIG.III.21



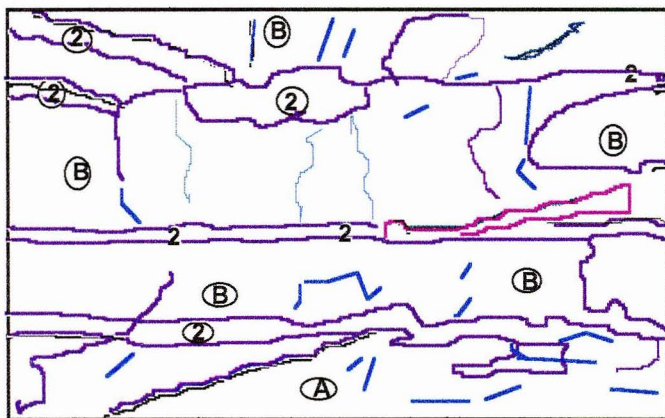
After
FIG.II.77

FIG.III.23b.- A series of sketches showing the different styles of structural control of mineralized veins. Twangiza gold deposit.

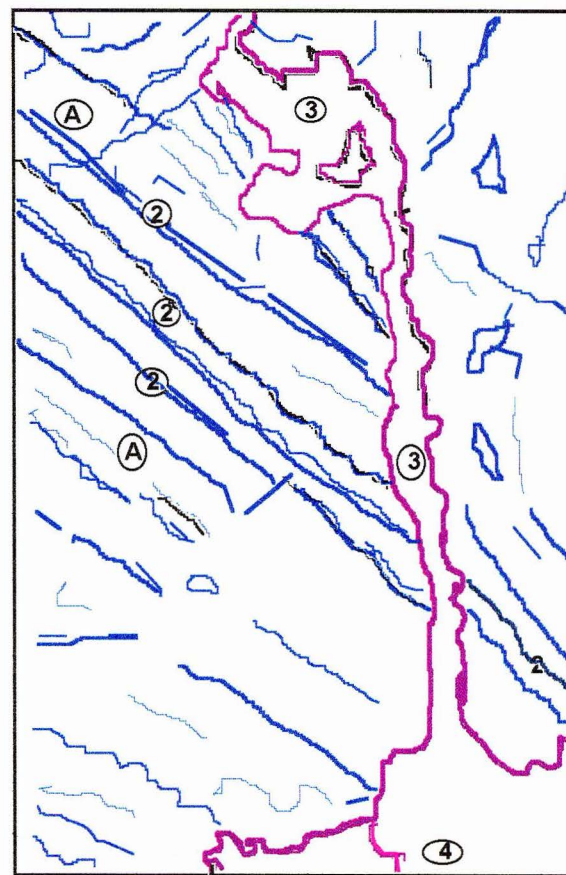
Fig.III.23b.- A series of sketches showing the different styles of structural control of mineralized veins. Twangiza gold deposit (Continues).



After
Fig.III.11a



After
Fig.III.11b



After
Fig.III.20a

SYMBOLS.

- ① - Vein set QV1: Irregular crack-seal quartz veins.
- ② - Vein set QV2: Folded bedding -Parallel veins.
- ③ - Vein set QV3: Vuggy fault - breccia .
- ④ - Vein set QV4: Stockwork veining, brecciation and/or dissemination.
- A - Albitite ; B - Black shale .

KM Walemba, 2000

Fig.III.24a :- Schematic portrayal derived from Fig.III.15&16 showing classic saddle reefs associated with Twangiza anticline and fault.

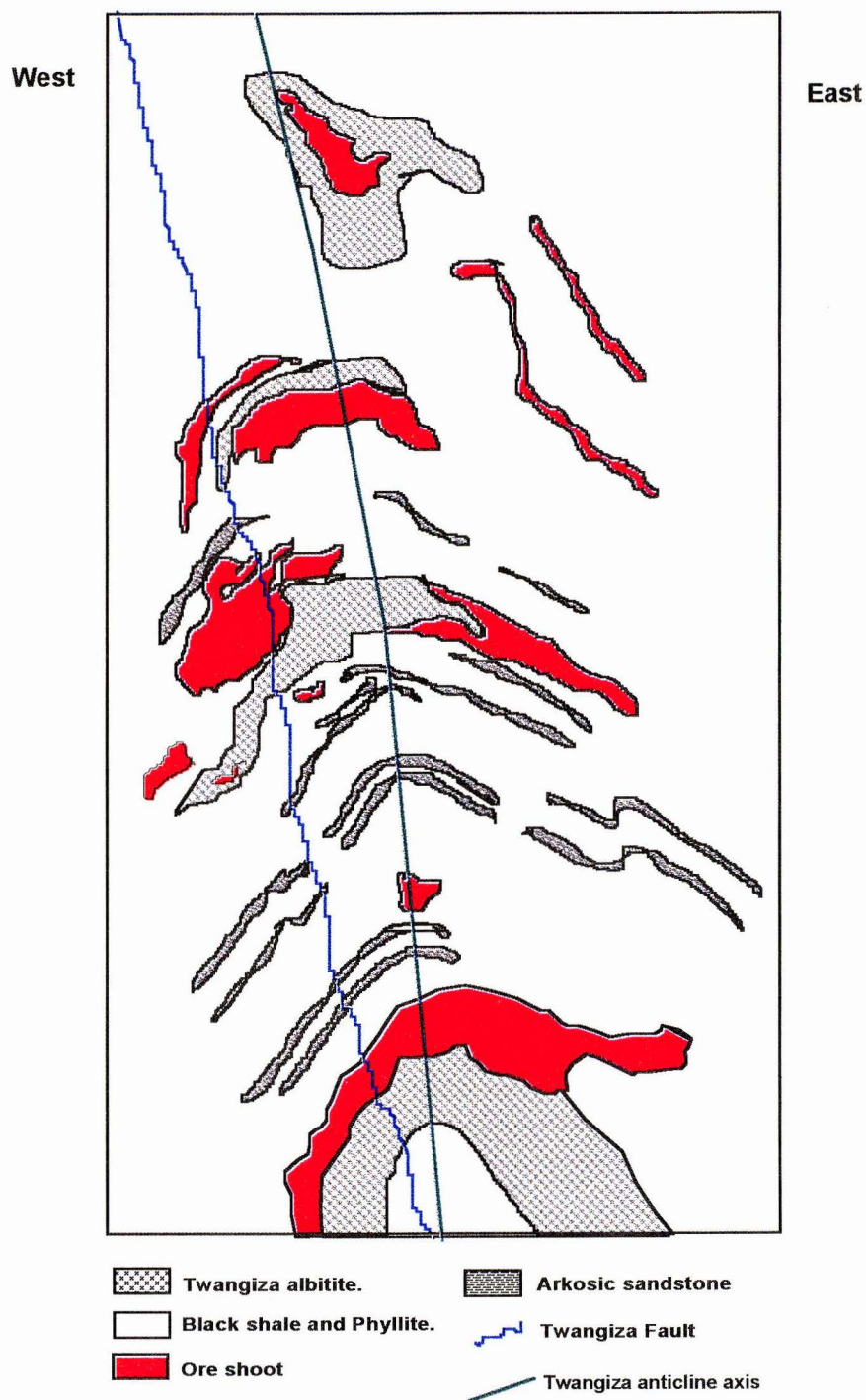


Fig.III.24:- Generalised form of saddle reefs at Bendigo.

Fig.III.24b:- Schematic fluid circulation pattern around saddle reefs and related fault-hosted deposits. Supralithostatic fluid pressures develop transiently in the stippled regions when fluid supply rate from fault feeder zones locally exceeds the rate at which fluid escapes from these areas by infiltration of low permeability wall-rocks. (B) Variation of fluid pressure with depth along profile A - B. Growth of hydraulic fractures takes place in regions of supralithostatic fluid pressure (stippled). (after Cox, F.L. et al., 1991).

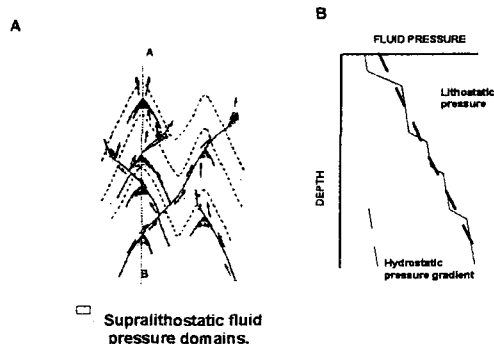
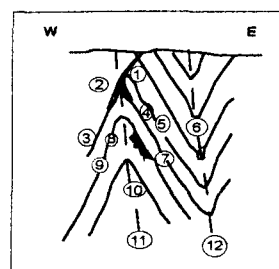


Fig.III.24d:- Types of quartz reefs, Bendigo. (Cross - section)



- | | |
|------------------|-------------------|
| ① Neck reef | ⑦ Spurs |
| ② Saddle Reef | ⑧ Cap of Reef |
| ③ Fault West leg | ⑨ Saddle Reef |
| ④ East leg | ⑩ Cap of middle |
| ⑤ Leg Reef | ⑪ Anticline style |
| ⑥ Through Reef | ⑫ Syncline style |

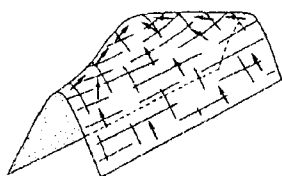


Fig.III.24C :- Schematic illustration showing how large -scale fluid migration patterns and the development of supralithostatic fluid pressure regimes at Bendigo have been controlled by the location of major culmination zones on anticlines. Major vein deposits are most abundant at , or adjacent to the culmination zones. (after Cox, T.L. et al., 1991).

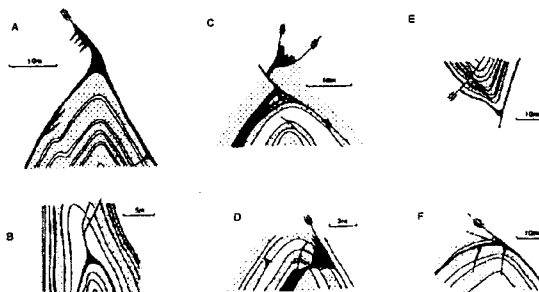


Fig.III.24a:- Examples of saddle reef gold- quartz vein systems. Bendigo goldfield . (modified after Chace, 1949 , and Thomas, 1953a). Sandstone units are stippled, quartz lodes are black. (after Cox , F. L et al, 1991).

Fig.III.25:- Wall- rock alteration assemblage and paragenesis for black shale host rock
and QV₂ vein. (This study)

<i>Mineral</i>	<i>Wall rock</i>	<i>Alteration Mineralogy</i>		<i>Vein Mineralogy</i>		
	<i>Least altered</i>	<i>Distal Zone</i>	<i>Proximal Zone</i>	<i>Stage III</i>	<i>Stage II</i>	<i>Stage I</i>
Silicates:						
Albite						
Muscovite						
Quartz						
White mica						
Clay minerals						
Carbonate:						
Dolomite						
Ankerite						
Calcite						
Phosphate:						
Chlorapatite						
Monazite						
Oxides:						
Goethite						
Rutile						
Kaolinite						
Haematite						
Limonite						
Jarosite						
Sulphides:						
Pyrite						
Arsenopyrite						
Pyrrhotite						
Native gold						

Fig.III.26:- Wall-rock alteration assemblage and paragenesis for albite host rock and
 QV₃ vein . (This study)

<i>Mineral</i>	<i>Wall rock</i>	<i>Alteration Mineralogy.</i>		<i>Vein Mineralogy.</i>		
	<i>Least altered.</i>	<i>Distal Zone.</i>	<i>Proximal Zone.</i>	<i>Stage III</i>	<i>Stage II</i>	<i>Stage I</i>
Silicates:						
Muscovite						
Clinocllore						
Hornblende						
Quartz						
Albite						
White mica						
Talc						
Epidote						
Microcline						
Chlorapatite						
Carbonates:						
Dolomite						
Ankerite						
Magnesite						
Calcite						
Oxides:						
Goethite						
Rutile						
Kaolinite						
Haematite						
Scorodite						
Sulphides:						
Pyrite						
Arsenopyrite						
Pyrrhotite						
Native Gold						

Paragenetic relationships determined through field sampling, textural relationships, (mineralogy and vein textures, combination of crosscutting relationships, composition of clasts and cementing materials), XRD and assay results indicate that gold is associated with three mineralogically distinct assemblages.

A multistage style of mineralization thought to be represented by distinct episodes of mineralization termed stage **I**, **II** and **III**, and separated by major fracturing and brecciation events has been identified :

I: a quartz +/- sulphide +/- gold stage ;

II: a sulphide + gold stage ;

III: a postore carbonate + quartz +/- sulphide +/- gold stage.

Some examples of crosscutting relationships are illustrated in Fig.III.22 and shown the different stages of mineralization.

Stage I vein mineralization related to QV₁, began with the deposition of massive milky-white bucky or vuggy quartz containing rare disseminations of pyrite and arsenopyrite (plus hematite after pyrite in sample photo KW430).

Stage II mineralization, related to QV₂, is the result of multiple episodes (at least three) of vein opening and filling typical of saddle and fault reef hosted mesothermal veins. (Fig. III.27) .

*.- episode 1 veins : pyrite, albite ;

*.- episode 2 veins : arsenopyrite, pyrite, albite, clinocllore ;

*.-episode 3 veins : pyrite, carbonate. (Seen in KW 617 → 448A), (Fig. III.27) .

Gold is closely associated with hydrothermally-generated arsenian pyrite and orpiment has been found in the oxidized zone.

Stage III vein mineralization, related to QV₃, represents the introduction of massive carbonates (dolomite and/or ankerite, calcite, magnesite) with whitish quartz, which fill voids created by postore faulting and brecciation. Minor pyrite and rare pyrrhotite replacing pyrite is evident with increasing depth. Carbonate -quartz veins (stage III) frequently crosscut stage II veins. (Seen in sample photo KW 618E) . (Fig.III.28) .

The paragenetic assemblages that characterize the successive stages of vein formation provide the basis for interpretation of the physicochemical conditions of gold deposition.

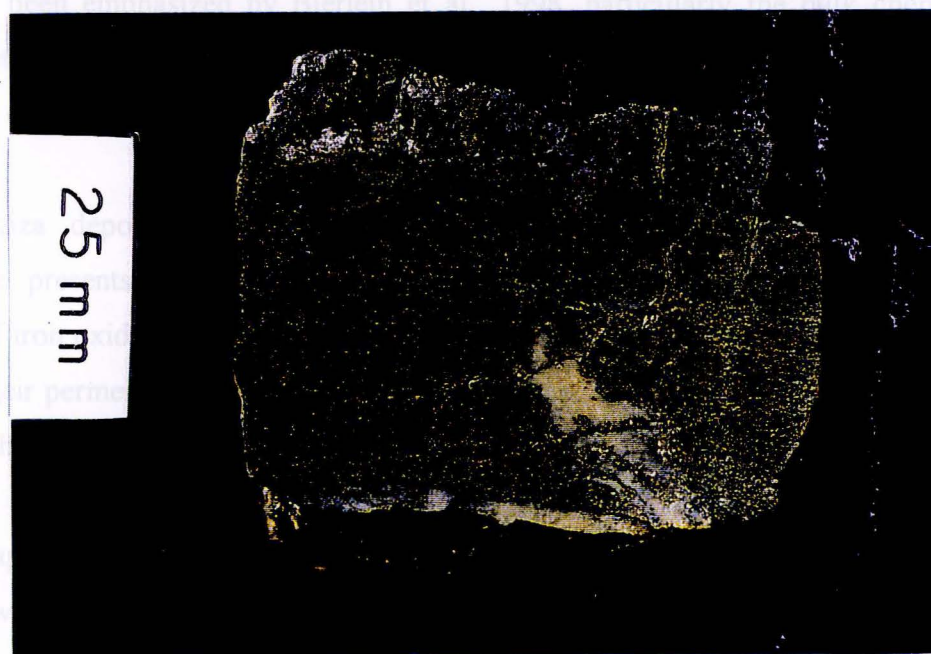


Fig.III.27:- Stage II mineralization with multiple episodes of vein opening and filling.

Fig.III.28:- - Stage III mineralization with massive carbonate.

12.4.4.- WALL-ROCK ALTERATION AND RELATIVE CHEMICAL CHANGES.

Commonly, the host rocks for hydrothermal deposits are considered important in the ore-forming process because they serve as chemical sinks for material dissolved in the mineralizing solutions and related. A study of hydrothermal alteration can therefore be an indicator of the character of the solutions associated with ore deposition.

Hydrothermal alteration due to fluid-wall rock interaction occurs by two main processes : infiltration of fluids along open fractures at different scales and diffusion of ions through static pore fluids . The permeability of the fluid conduit and the diffusion rates along grains boundaries determine which is the dominant process, with fluids infiltration into the wall rocks inferred to be the dominant process in lode gold deposits(McCuaig and Kerrich , 1994).

The dilemma of recognizing " true" wall rock alteration around turbidite-hosted gold deposits has been emphasized by Bierlein et al., 1998, particularly the bulk chemical difference between two lithologies (e.g. black shale & metagreywacke) could affect the development of wall-rock alteration.

In theTwangiza deposit, both superficial weathering alteration and hydrothermal alteration are presents. Deep weathered alteration has affected the distribution and abundance of iron oxides and sulphides, carbonate minerals, clay minerals, carbonaceous matter and their permeability and porosity of the rocks concerned . Weathering decreases with the depth and unaltered rocks appear in the 2100m level .

A leached capping or gossan is typically developed within the superficial weathered horizon and within the brecciated zones. The whole brecciated rock is rich in iron oxides, (blades and plates of limonites), and assumes a very distinctive brownish colour. Limonitization is the most intense surficial weathering alteration. Limonite alteration occurs as pseudomorphs of the earlier sulfides (pyrite and arsenopyrite) and is disseminated in the altered host-rocks or occurs as colloform masses in quartz-vein systems.

A network of intersecting blades and plates of iron oxide along fracture planes is frequently developed to form a typical box work pattern (Fig.III.29).

The most striking type of hydrothermal alteration in sulphide veins consists of a combination of arsenopyrite and pyrite porphyroblasts which occur as disseminations in wallrock haloes. Aside from these sulphides, the main alteration phases are dolomite, magnesite, ankerite, chlorite, sericite, quartz and albite.

Alteration styles represented include albitisation, sericitisation, chloritization, sulphidation, carbonatisation, and (de-) silicification .

Hydrothermal alteration in auriferous quartz -carbonate veins ,is characterized by a diffuse albitization, silicification, carbonatization, pyritization and argillaceous alteration (sericite, chlorite).

Alteration of host-rock is minor, of limited extent (4-5 cm wide) and intensity and restricted mainly to narrow zones surround and/or adjacent to major quartz/sulphide veins system and fault-breccia veins, and in which, the host-rocks are discoloured and softened. This alteration halo, is in turn fringed by an irregular zone of propylitic alteration (argillaceous alteration: halloysite + allophane), (Fig.III.30).

Relative variations for two selected chemical profiles across alteration envelopes around sulphide vein (QV₂) and quartz- carbonate -vein (QV₃) respectively from black shale and albitite rocks have been examined according to the approaches of Riverin and Hodgson (1980) .

The system (F-C-A-K) used involves CaO - K₂O - Na₂O - (FeO + MgO), in which each component represents carbonate (calcite, dolomite, ankerite), white mica, albite and chlorite, respectively. (CaO + Na₂O , being the plagioclase component). Al₂O₃ displaying the same trends as FeO and MgO , is the component common to all micas and feldspars and is not included in the system. SiO₂ is always present in excess as quartz.

The main features of metasomatic trends are shown by the unfolded F-C-A-K tetrahedron plots (Fig.III.31 and Fig. III.32) .



Fig.III.29:— Box work with iron oxide along fracture planes. Twangiza deposit

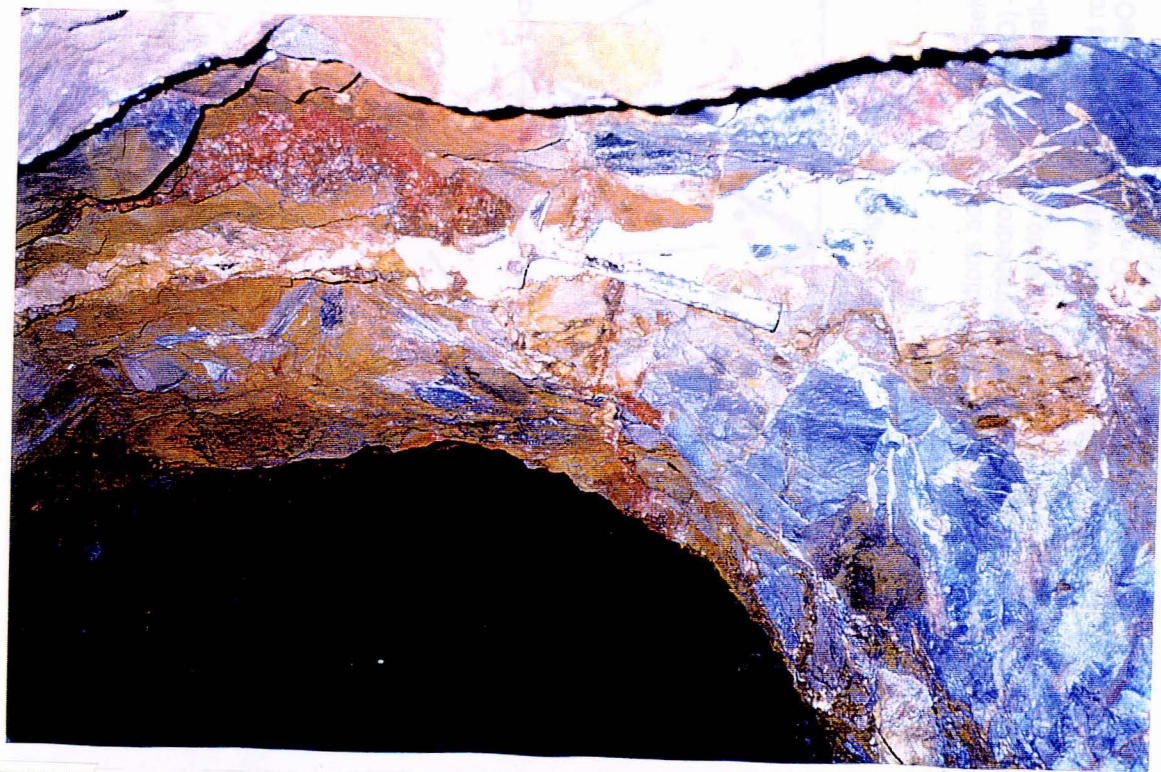


Fig.III.30: - Propylitic alteration with mid-argillaceous alteration (halloysite and allophane).
R15/ level 2130 . Twangiza deposit.

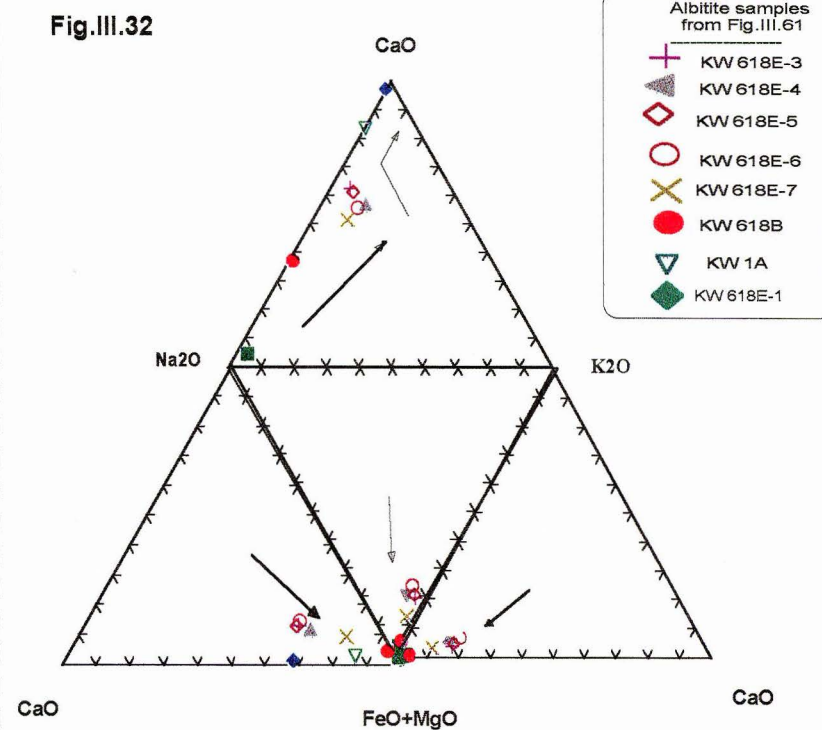
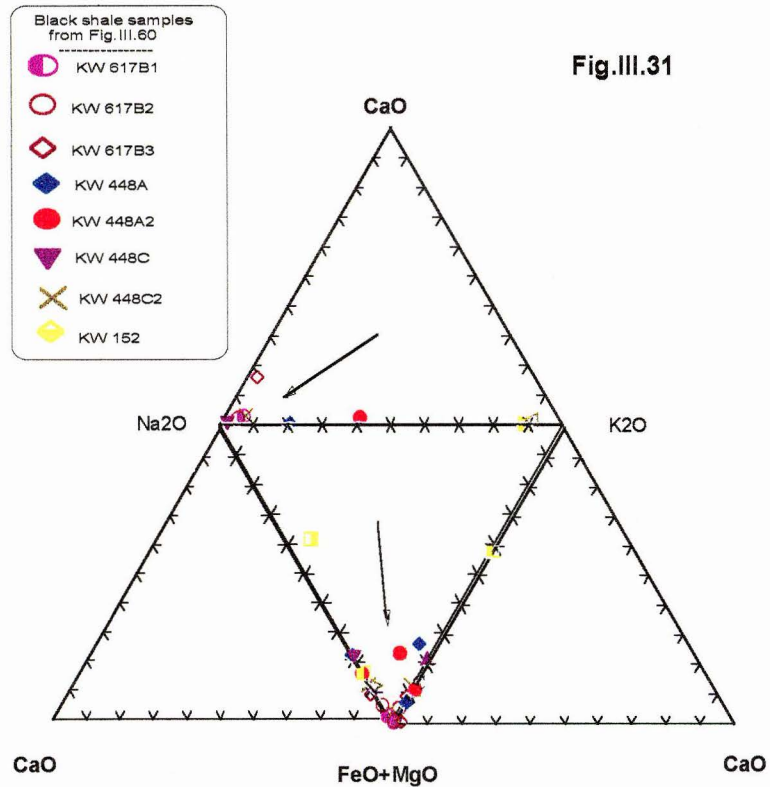


Fig.III.31:- Chemical variations across alteration selvages bordering a sulphide vein (QV2), plotted in the unfolded tetrahedron : [(FeO+MgO) - CaO- K2O - Na2O]. The arrows reflect the approximate path from unaltered to visibly altered wall-rock.

Fig.III.32:- Relative chemical variations in altered rock bordering a quartz - carbonate vein (QV3), plotted in the unfolded tetrahedron [CaO - K2O - Na2O - (FeO - +MgO)]. The arrows reflect the approximate path from unaltered to visibly altered wall-rock.

Chemical data indicate that SiO_2 , Al_2O_3 , FeO , MgO , CaO , K_2O , and Na_2O moved relative to each other during wall-rock alteration. High ($\text{FeO}+\text{MgO}$), low CaO and Na_2O , and very low K_2O are the characteristic chemical features of both profiles.

The first profile (Fig.III.31) is characterized by an abrupt increase in ($\text{FeO}+\text{MgO}$), while Na_2O increase relative to CaO at constant K_2O , plotting on the ($\text{K}_2\text{O}-\text{Na}_2\text{O}$) join. These relative chemical changes correspond to the abrupt replacement of white mica by chlorite, magnesite and Carbonate (dolomite and/or ankerite, calcite).

The second profile (Fig.III.32) is represented by an increase in ($\text{FeO}+\text{MgO}$), accompanied by an increase in CaO and Na_2O relative to K_2O , and plotting on the ($\text{Na}_2\text{O}-\text{CaO}$) join and corresponding to the introduction of chlorite, magnesite, chloroapatite albite and carbonate (dolomite, calcite, ankerite).

12.4.5.- SUPERGENE ENVIRONMENT.

Supergene acid sulfate alteration is a product of the weathering of sulfide-rich deposits. Resulting assemblages contain disordered kaolinite, halloysite, or occasionally allophane as well as iron oxide minerals, such as hematite, goethite and jarosite. Typically, the alteration occurs as topographically controlled blankets that often underlie the gossans. The alteration may occur as curtains running down structure over vertical distances up to a hundred metres or more.

12.4.6.- ORE - ELEMENT ASSOCIATION.

Bulk ore samples from the deposit show consistent major enrichments relative to the hosts albitite and black shale with respect to Au, Ag, As, and variable enrichments in Mo, Nb and, sporadically enrichments of W, Ta. Gold enrichment factors are typically of the order of 10^3 to 10^5 . Base metals (Cu, Pb, Zn, Ni, V, Cr, Co), display no consistent enrichment. No visible chalcopyrite, galena or sphalerite have been observed in the deposit.

The deposit is characterized by a very high Au/Ag ratio (10 : 1 - 35 : 1) and abundant sulphide mineralization (pyrite, arsenopyrite, pyrrhotite). The metal association comprises Au, Ag, As, Bi, Se with low concentrations of Zn, Cu, Ni, V, Nb, Pb, Cr, Co, Ta, W, Mo.

12.4.7.- SUMMARY AND DISCUSSIONS.

The Twangiza ore body has been explored over 700m of strike and partly over a vertical interval of 120m underground in the oxidation zone between the 2220m and 2100m levels. Twenty holes totalling 9,122 m were completed to a maximum vertical depth of 650m below surface outcrop, along 800m of strikes .

The deposit is exposed by erosion on a steep slope and the gold mineralization zone follows the NNW-SSE ($\sim 10^{\circ}$ W) trending Twangiza anticlinal axis, with steep dips ($\sim 80^{\circ}$) to the east and pitch to the south. The location of this deposit is typically controlled by the intersection of two regional lineament structures (NNW-SSE and E-W), the flexures in shear-fault zones on a deposit-scale, and the interplay of the geometry and rheology of the enclosed albitite and black shale lithologies. The Twangiza anticlinal is moderately tight and inclined to the west, with the west limb dipping more steeply (70° - 75°) than the eastern limb. Associated parasitic, subisoclinal folding has caused thickening and repetition of the orebody.

Three major shear -fault zones have been identified in and/or close to the deposit: the Twangiza shear-fault zone (up to 6.5m wide, N 35° W/ $\sim 60^{\circ}$ SW), the Kekombe shear-fault zone (up to 3m wide, N 70° W / 60° S) and the Lukumbi shear-fault zone (up to 4m wide, E-W / 87° S).

Infilling vein material of the Twangiza reverse-fault consists mainly of randomly oriented quartz breccia, quartz veins and clay minerals. The Kekombe fault zone is composed mainly of quartz fragments, limonite and brown clay materials, while the Lukumbi fault zone is made up of quartz veins. It is possible that these faults have been formed after " locking" of the Twangiza anticline in response to a change in deformation from a ductile to brittle regime during one progressive deformational event .

It is suggested that the Twangiza high-angle reverse fault began as a major normal -slip growth fault which later reacted as a reverse fault with a minor strike-slip component. The development of the gold-quartz-vein systems appears to be related to this last phase of reactivation, postdating albitite alkaline magmatic activity within the Twangiza region.

The association of saddle reefs with the Twangiza high-angle reverse fault suggests that the saddle reefs represent a variation of the fault controlled reefs and thus postdate folding.

The hosts to gold mineralization is a black shale unit (up to 1000m thick) with interbedded siltstone beds (up to 60cm thick) and beds of arkosic sandstone grading to greywacke (up 1m to thick) in which albitite lenses are emplaced.

From the base to the top, the detailed lithostratigraphy within the deposit is as follows: Black shale, siltstone, and greywacke: These units belong to the metaturbidite sequence of the Tsibangu Formation which have been metamorphosed to greenschist facies .

The Twangiza deposit exhibits three clear structural controls of gold mineralization:

- .*- Mineralization occurs as classic concordant saddle reefs on the flanks of the Twangiza anticline (tight folding with limb and stratigraphic controls) near the Twangiza high -angle reverse fault, along 5kms length.
- *-The size and geometry of the orebody is controlled by the N- S striking Twangiza high-angle reverse fault, (fault control) which is interpreted as the main fluid pathway of the mineralizing solutions .
- *- The loci of gold deposits in the Twangiza deposit, is controlled, or influenced by a lithological factor. (lithological and geochemical control). Mineralization is controlled strongly by structure and geochemistry of the host rock black shale unit and albitite at different scales.

The high Au-grades (> 10gm/tonne) tend to be localized, either in proximity of the albitite –black shale host rock and closely associated with the fault-brecciated zone (fault reef system); or on the flank the anticlinal zone and closely associated with sulphide veins (saddle reefs system). Beyond this domain, the grade falls progressively.

Major structural features (particularly the Twangiza high-angle reverse fault) provided important pathways for mineralizing solutions but that large amounts of gold were deposited away from the structures in favorable stratigraphic intervals. Ore-bearing and more or less barren stratigraphic horizons in this deposit have undergone the same amount of folding, suggesting that fracturing and related permeability enhancement were not the only factors controlling the distribution of gold.

The shape and geometry of the ore shoot for Twangiza deposit is well constrained. However, preliminary data indicates that the gold in Twangiza takes two forms. Classic saddle reefs with high grade material and fault reefs and associated spur veins.

The general geometry of the ore shoot comprises a feeder zone controlled by the Twangiza high-angle reverse fault, and an upper, brittle, stratiform black shale unit, acting as a reactive lithology.

Four distinct vein-types are present in the Twangiza deposit : Vein set QV₁, (Irregular crack -seal quartz veins); QV₂, (folded bedding-parallel veins); QV₃, (Vuggy fault-breccia) and QV₄ (stockwork veining, brecciation, and/or dissemination).

Paragenetic relationships indicate that gold is associated with three mineralogically distinct assemblages (multistage mineralization) that is thought to represent distinct episodes of mineralization termed stage I (quartz +/- sulphide +/- gold stage), stage II (sulphide - gold stage) and stage III (postore carbonate - quartz +/- sulphide +/- gold stage) and separated by major fracturing and brecciation events.

Both superficial meteoric alteration and hydrothermal alteration are present. Deeply weathered alteration has affected the distribution and abundance of iron oxides/sulphides, carbonate minerals, clay minerals, carbonaceous matter and their permeability and porosity. The weathering decreases with the depth vertically in the lower levels and unaltered rocks appear at the 2100m level.

A leached capping, and gossan are developed within the superficial weathered horizon and within the brecciated zones. Limonitization is the most widespread surficial meteoric alteration.

The most striking type of hydrothermal alteration in sulphide veins consists of a combination of arsenopyrite and pyrite porphyroblasts which occur as disseminations in wallrock haloes. Aside from these sulphides, main alteration phases are dolomite, magnesite, ankerite, chlorite, sericite, quartz and albite. Alteration styles represented include albitisation, sericitisation, chloritization, sulphidation, carbonatisation, and (de-) silicification .

Hydrothermal alteration in auriferous quartz-carbonate veins, is characterized by a diffuse albitization, silicification, carbonatization, sulphidation, and mid argillaceous alteration (sericite, chlorite).

Alteration of host-rock is minor, of limited extent (4-5cm wide) and intensity and restricted mainly to narrow zones surrounding and/or adjacent to major quartz/sulphide veins system and fault-breccia veins, and in which, the host-rocks are discoloured and softened.

Chemical data indicate that SiO_2 , Al_2O_3 , FeO , MgO , CaO , K_2O , and Na_2O moved relative to each other during wall-rock alteration. High ($\text{FeO}+\text{MgO}$), low CaO and Na_2O , and very low K_2O are the characteristic chemical features of both profiles.

Metal association comprise Au, Ag, As, Bi, Se , and low concentrations of Zn, Cu, Ni, V, Nb, Pb, Cr, Co, Ta, W, Mo.

This drilling program confirmed the geological interpretation and allowed inferred resources to be increased to 104,600,000 tonnes grading 2.12 g/t Au, equivalent to 7,127,915 ounces of gold resource. The mineralized zone is open ended along strike and depth ,and suggests the possibility of a considerable extension of ore reserves.

The specific loci of gold-bearing shear / fault zones are along, or adjacent to, lithological contacts where there is a marked competency contrast between rock types.

According to Campell and Pitfield, (1994); the relative orientation of the principal compressive - stress axis determines the style of the deposit, and the preference of mineralization within either the more, or less competent unit, in addition to the contact zone. Where the compressive stress axis is orthogonal to the contact, mineralization tends to be concentrated in the more competent unit, but where it is oblique ,or parallel to the contact, it concentrates within the less competent unit.

In general terms, proximity to granitoid and felsic intrusions, significantly influences the spatial distribution of gold, with preferred concentrations about the margins of granitoid pluton and concentric zones about their peripheries.

In such case, the granitoid appear :

- either to act passively as rigid blocks within the slate belt, directly influencing the adjacent development and orientation, during regional deformation, of shear zones and folds;
- or , to play an active role during their forceful intrusion, by generating structures (concentric and radial shear zones and concentric folds) within expanding marginal facies and in the peripheral envelope of country rock;
- or, to generate structures during their cooling and contraction after emplacement.

Twangiza albitite rock, related to Kasika granite at depth, have played one or more of these roles.

The contrasting competency of the black shale to arkosic sandstone and /or albitite is probably a prerequisite to the brittle- ductile vein propagation.(Sibson and Scott,1996).

Chevron folds, high -angle reverse faults and spaced cleavage characterize crustal shortening above subsurface detachment in the metaturbidite succession of the Itombwe synclinorium. Inferred detachment - faulting are within the interface contact of the Itombwe supergroup and the Kibaran basement .

Subvertical extension associated with subhorizontal shortening due to folding and cleavage formation are part of the overall plane strain, coaxial deformation sequence. The deformed metaturbidite sequence is remarkable for regional -scale regularity of chevron -style folding and the development of auriferous quartz/sulphide reefs, either as saddle -reefs in the flanks zones of these chevron folds or as fault-reefs along faults that truncate the chevron folds.

Continued compression produced reverse faulting at acute angles to the maximum principal stress (plane), particularly near the apices of the anticlinal axis (e.g., Twangiza high-angle reverse fault).

In the Twangiza deposit, the stockworks are restricted to zones of brittle deformation within specific competent lithologies (e.g., contact albitite/ black shale) related to late stage secondary flexures.

The vein mineralization usually occurs within black shale interbeds. The finer-grained interbeds are often very organic rich in nature and the carbon may have acted as reductor (by forming CO_2) to the gold mineralization.

The Saddle reefs mineralization are associated with bedding -parallel veins (QV_2) and occurs at an interface between two black shale beds or between a thick black shale and an arkosic sandstone unit.

Bedding parallel veins are common in chevron - folded sequences and have been attributed to episodic hydraulic fracturing during cleavage formation but before the generation of folds (Henderson et al., 1986), gravity-controlled sedimentary detachment processes operating " at burial depths of several hundred metres or more " (Fitches et al. 1986), flexural -slip during folding (Tanner, 1989), layer-parallel simple shear prior to folding. (Tanner, 1989), pre-folding hydraulic detachment at depth (Fitches et al., 1990), hydraulic pumping either as post-cleavage " water sills " or syn-tectonic veins (Mawer 1987 ; Henderson et al, 1990); or during folding (Cosgrove., 1993 ; Ghosh et al, 1993). Anticipating to the results of microstructures studies in these bedding parallel veins, preliminary field observations and timing relationship between ore fluids production, mineralization and folding suggest that the model of their origin could be attributed to hydraulic pumping during (late stage ?) folding .

12.5.-. ORE MINERALOGY.

12.5.1.- INTRODUCTION.

Scanning electron microscopy analysis and ion-microprobe analysis have been undertaken during the course of these studies respectively at Wits (Physic Department, Electron microscope unit), and at RAU (Geology Department) in order to determine grain morphology and texture of gold, pyrite and arsenopyrite, ore mineralogy and geochemistry. The analysis have been performed for all elements.

Grain of gold, pyrite and arsenopyrite were selected by hand separation from crushed samples, hand -picked and examined under a binocular microscope and by SEM. Five grains of gold, three of pyrite, two of arsenopyrite, and one of quartz were examined by SEM, from which 29 analyses were performed.

Samples for ion-probe microanalysis were prepared as polished grains set in 25-mm-diameter blocks of epoxy (with up to 40wt % graphite added). Standard 25-mm-diameter polished thin sections were also used. All polished blocks and sections were stained with a solution of KMnO_4 in 1:1 H_2SO_4 before analysis by ion-microprobe .

The S/Se ratios in hypogene pyrites from the QV2 vein were investigated in order to provide information of the sources of sulfur, selenium, and by inference, gold in the ore fluids .

Mesothermal lode gold deposits are commonly termed " gold -only " deposits (Hodgson and MacGeehan, 1982) because of the extreme enrichment of Au relative to other metallic elements (e.g., Cu, Pb, Zn, Ag) that commonly accompany Au in other deposit-types (e.g. porphyry Cu-Au , epithermal deposits < Au-rich VMS deposits). The mesothermal lode gold deposits show a characteristic association of Au with As, W, Ag, Sb, Te, Bi and B, with generally low base-metal (Cu, Zn, Pb) and Mo contents, Au/Ag ratios averaging 5 . (e.g. Kerrich , 1983; Phillips and Groves, 1983) .

12.5.2.- MORPHOLOGY AND TEXTURE.

12.5.2.1- PYRITE.

Pyrite is the most abundant sulfide and is common to all of the mineralization types .

Typically, the Twangiza ore contain two types of pyrite, distinguished from one another by textural criteria :

*.- The medium-coarse -grained *pyrite I*; generally exhibits subhedral to anhedral forms, up to 0.5mm in diameter and occurs as relatively bright yellow, high relief cubes, striated modified cubic forms, and octahedral as well as pyritohedron and consisting of single

crystals or aggregates of a few crystals with, triple points and inclusions of other phases. (Fig.III.33; Fig.III.34). (Fig.III.33) displays an annealing texture showing equant grains of pyrite with triple junction and straight boundaries.

*.- *Pyrite 2* is more dull to brownish-yellow and has a lower polishing relief than *pyrite 1*. (Fig.III.34). Microscopically, the pyrite consists of equant grains, ranging in size from 5 to 500 μm (Fig.III.35; Fig.III.36), which are progressively more euhedral as the grains size increases.

SEM photomicrographs of pyrite grains morphologies are shown in Fig.III.37, Fig.III.38 and Fig.III.39 .

12.5.2.2.-ARSENOPYRITE.

Arsenopyrite is the most important mineral in the ores of this deposit. Arsenopyrite occurs as large euhedral to subeuhedral crystals ranging from 7 to 15 μm and from 1 to 3 mm in size. Prismatic and needle shapes are typical for the arsenopyrite crystals, which are irregularly distributed. (Fig.III.40).

Arsenopyrite is also intergrown with pyrite, occurring as inclusions in larger pyrite porphyroblasts. (Fig. III.40) .

Next to As-rich pyrite, arsenopyrite is the most important host of visible gold in nature. The association of arsenic and gold is common that the former is used as a pathfinder element for hidden gold deposits (Boyle, 1979).

12.5.2.3.- GOLD.

Generally, native gold occurs in oxidized zone as grains which vary in size from microscopic to grains which are just visible with the naked eye (200 μm). (Fig. III.41 and Fig.III.42).

Free gold is rare in sulphide zone. The gold must be submicroscopic or in solid solution in the pyrite and mostly in the arsenopyrite.

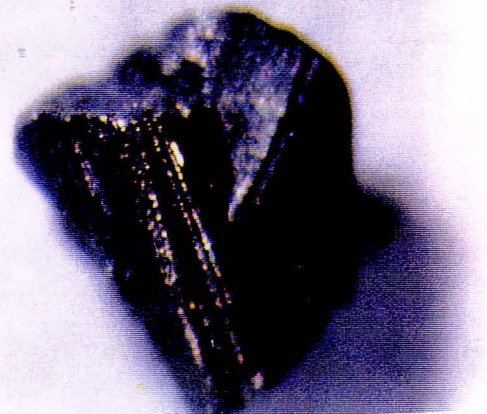


Fig.III.33:- - Equant grain of pyrite with triple junction and straight boundaries.

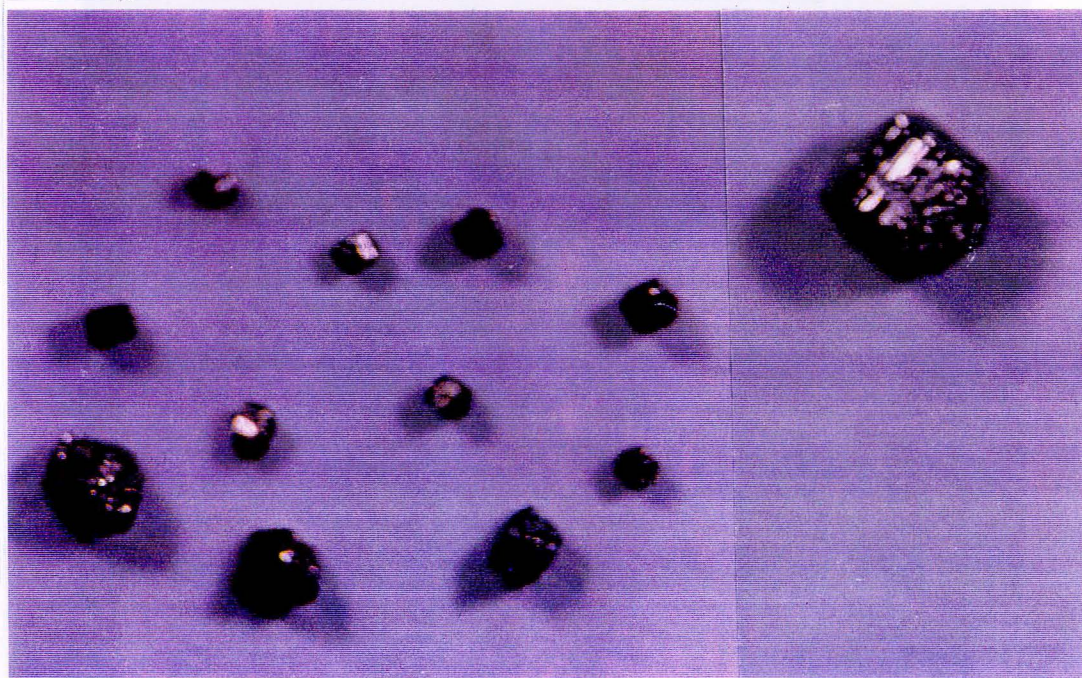


Fig.III.34:- - Pyritohedron crystals of pyrite. Some of them are striated with triple points. Twangiza gold deposit.

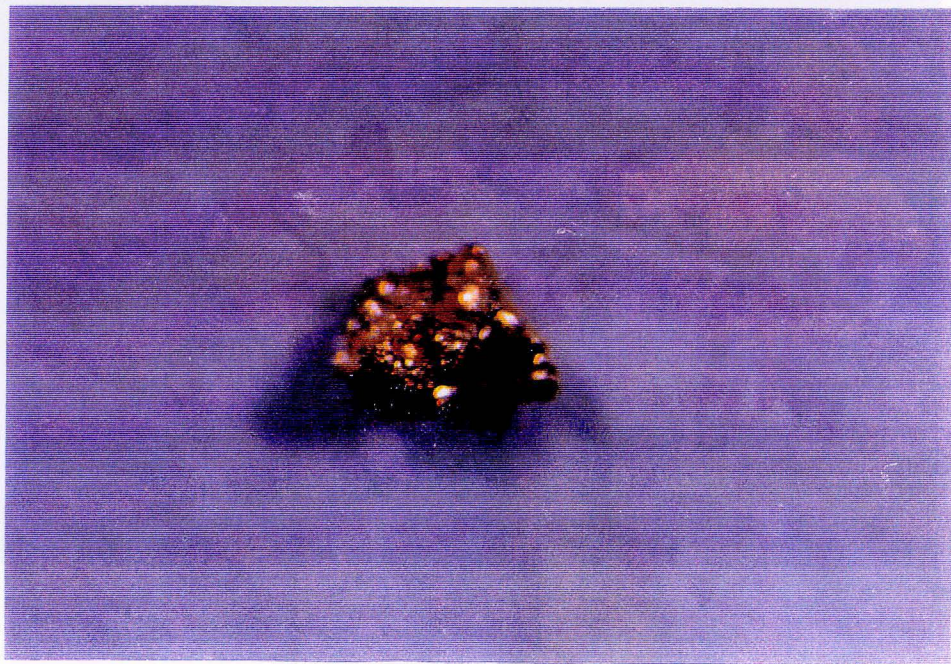
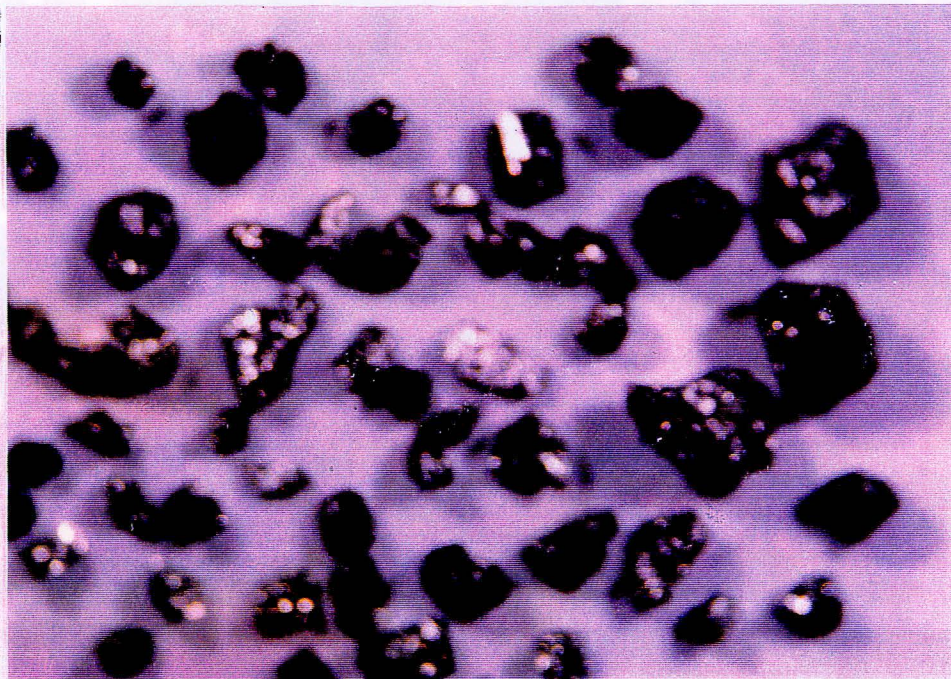


Fig. III.34:- - Pyritohedron crystals of pyrite. Some of them are striated with triple points. Twangiza gold deposit. (continues).

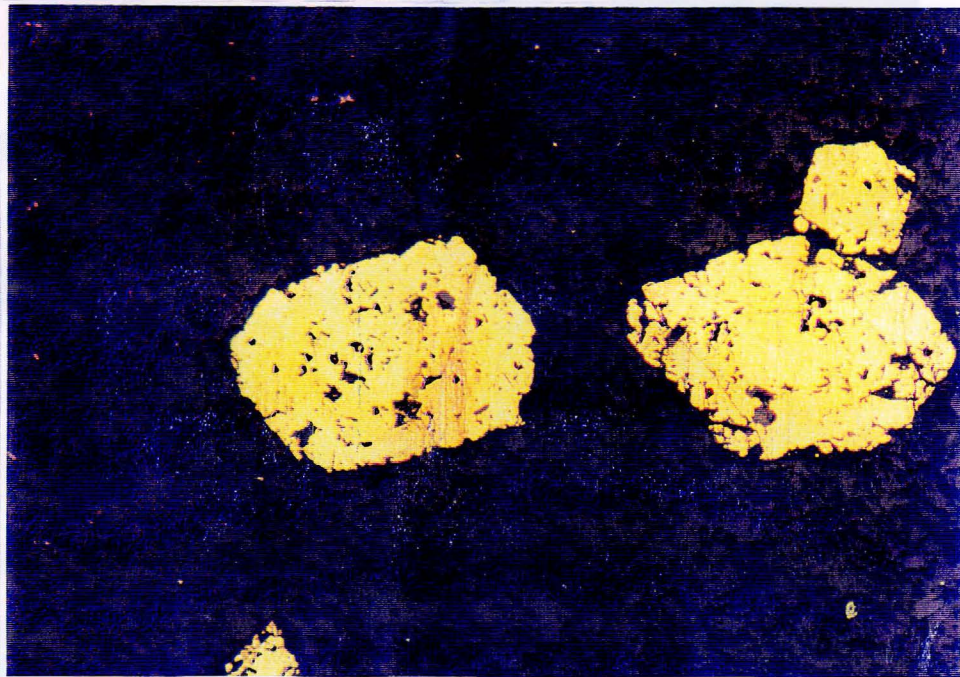
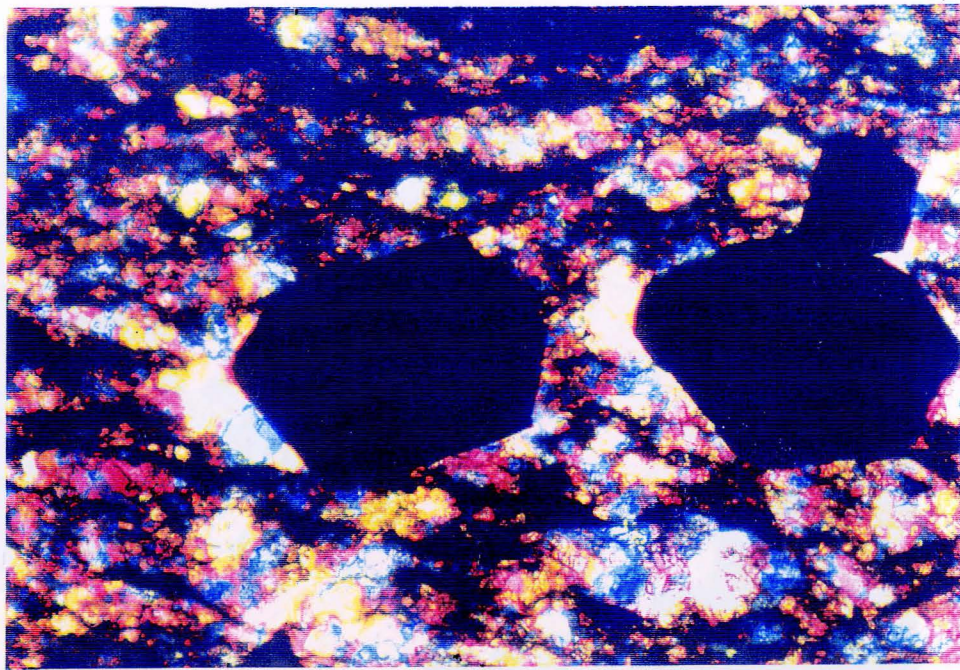


Fig.III.35:- Photomicrograph of pyrite grains from the Twangiza deposit.(TL and PL).

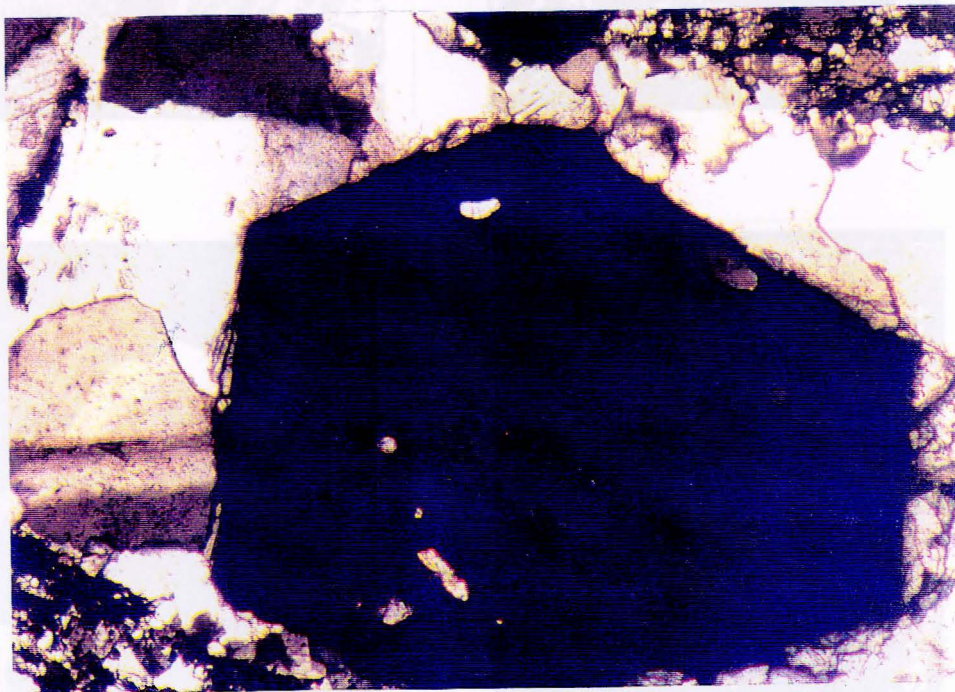
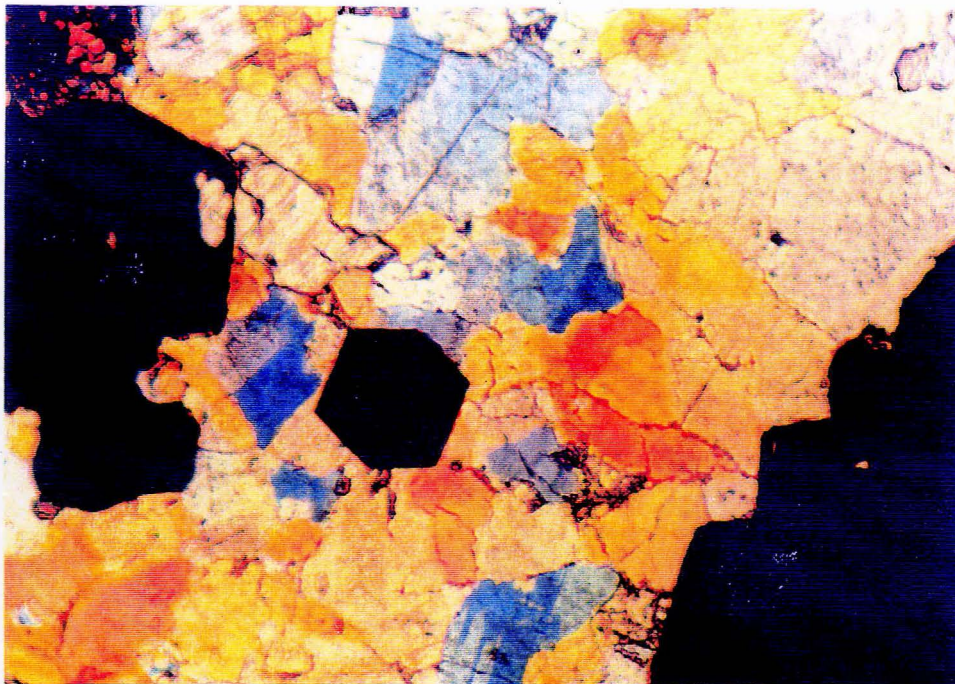


Fig.III.36:- - Photomicrograph of pyrite grains from
the Twangiza deposit.(TL and PL).

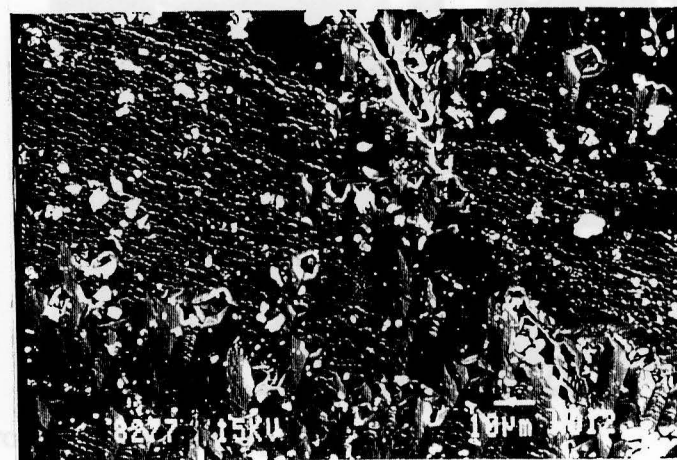
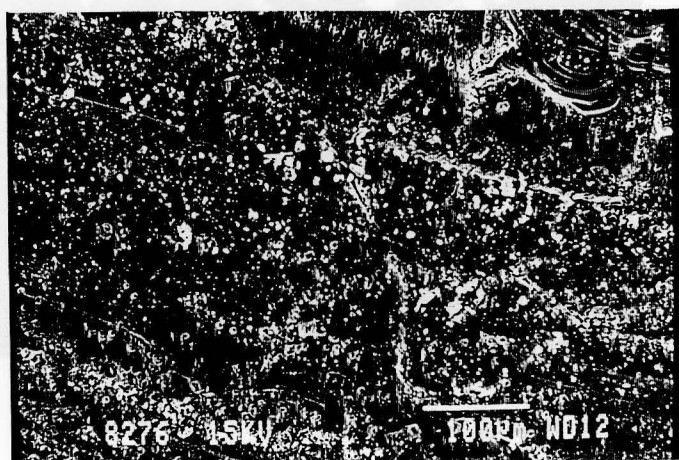
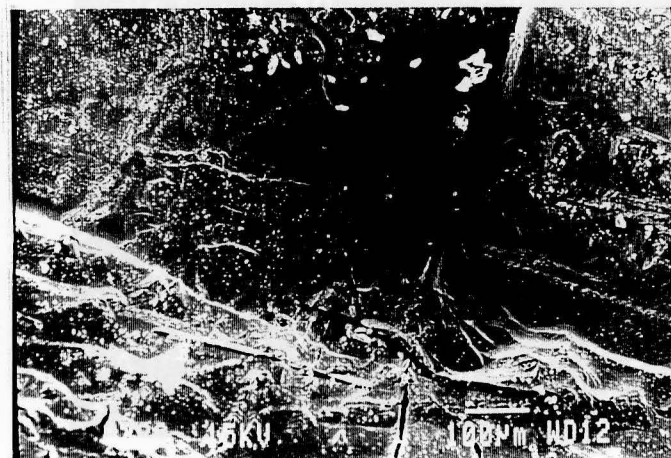
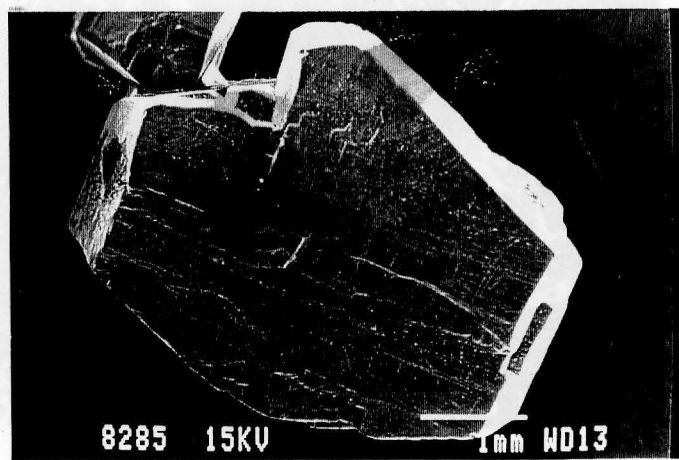


Fig.III.37:- - SEM photomicrographs of pyrite grain from the Twangiza deposit.

(Mag: x 20, x 40, x 200, x 750).

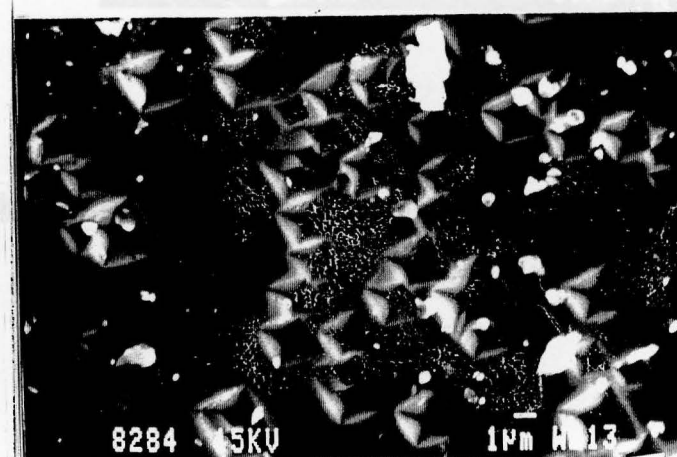
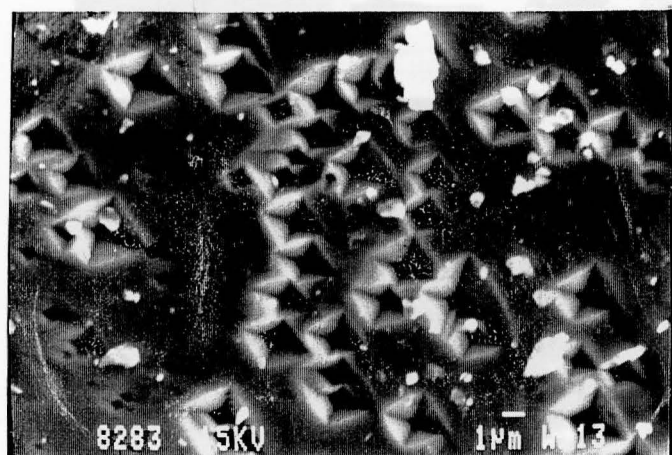
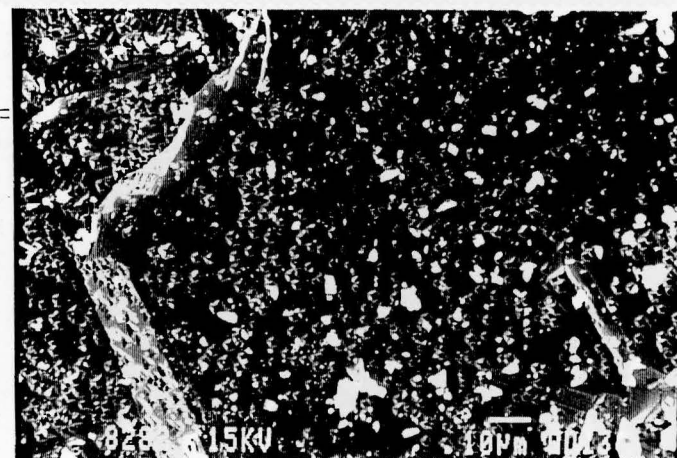
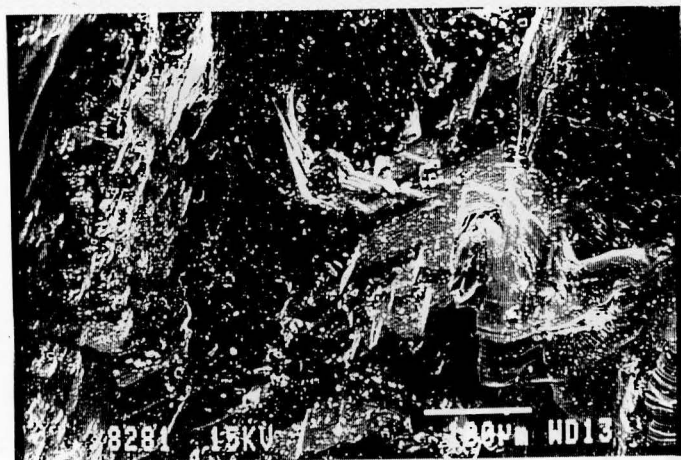


Fig.III.38:- SEM photomicrographs of pyrite grain from the Twangiza deposit.
(Mag: x 200, x 750, x 4000, x 4000).

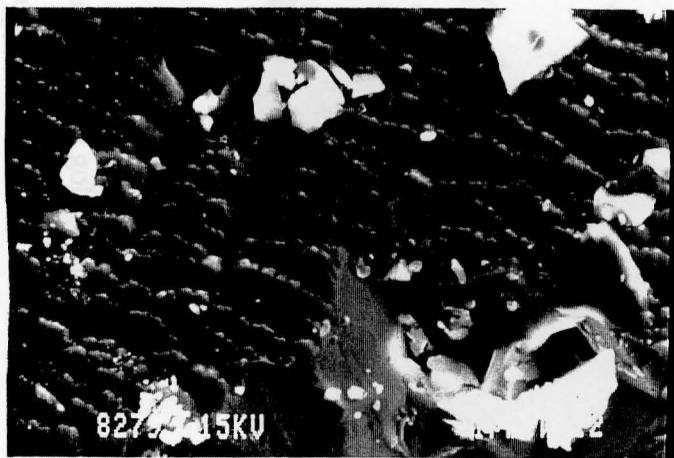
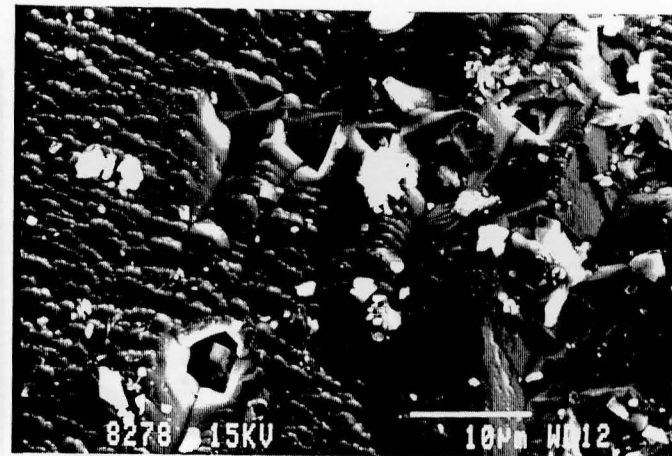
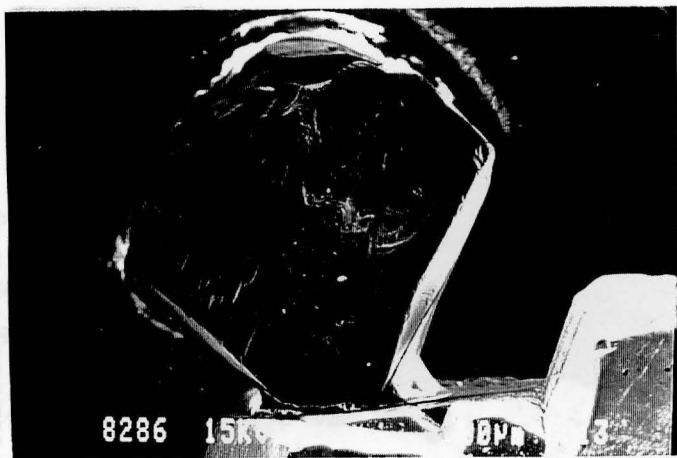


Fig.III.39:- - SEM photomicrographs of pyrite grain
from the Twangiza deposit.
(Mag: x40, x200, x750).

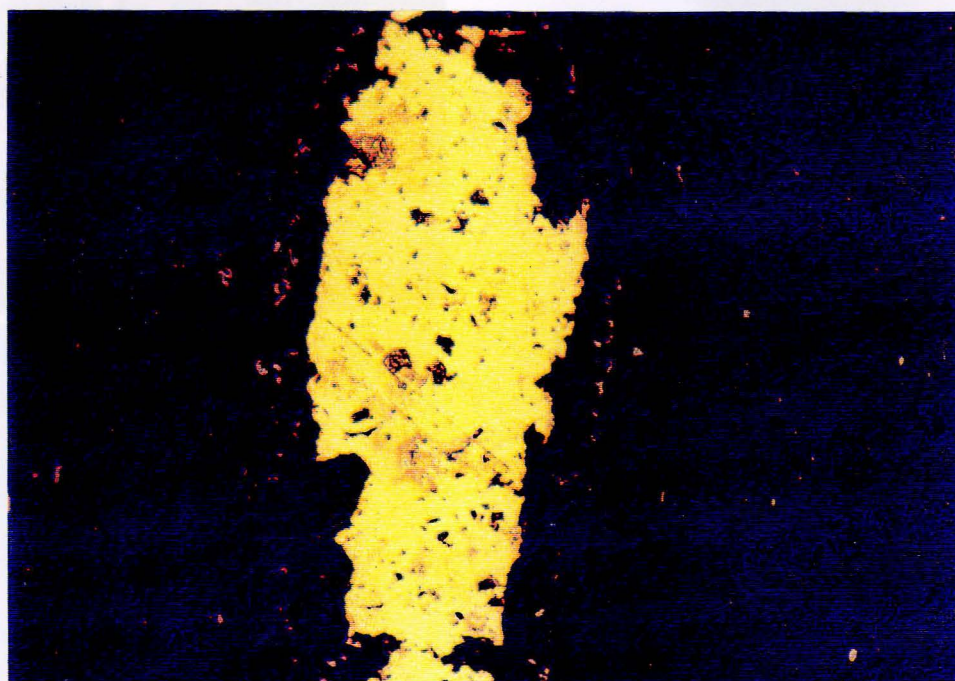
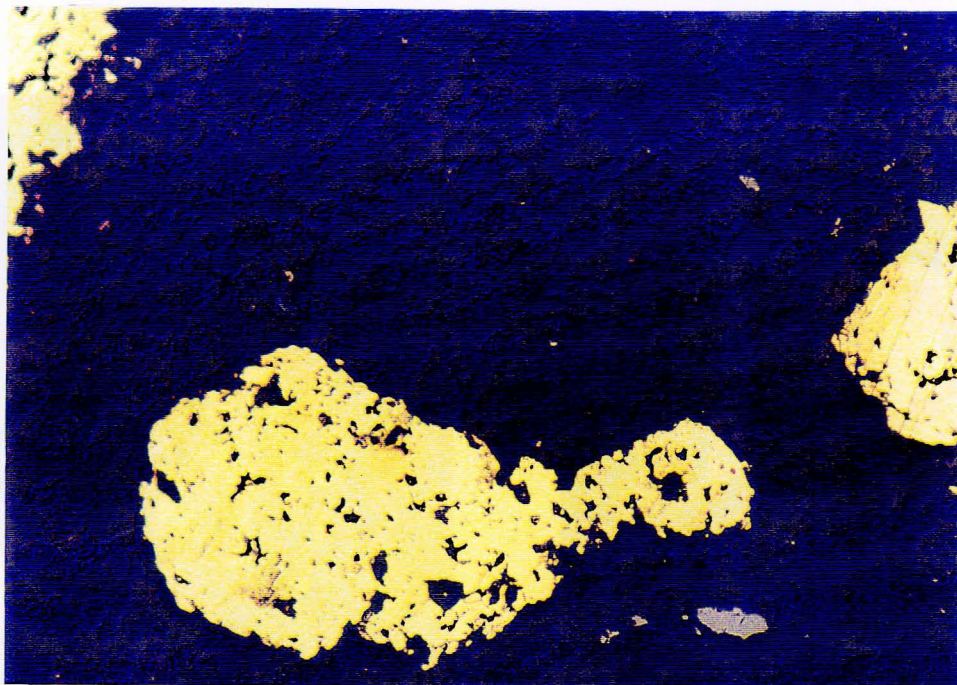


Fig.III.40:- Photomicrograph of arsenopyrite and gold grains from the Twangiza gold deposit.

Fig.III.41: - Hand specimens of native gold from Twangiza gold deposit.



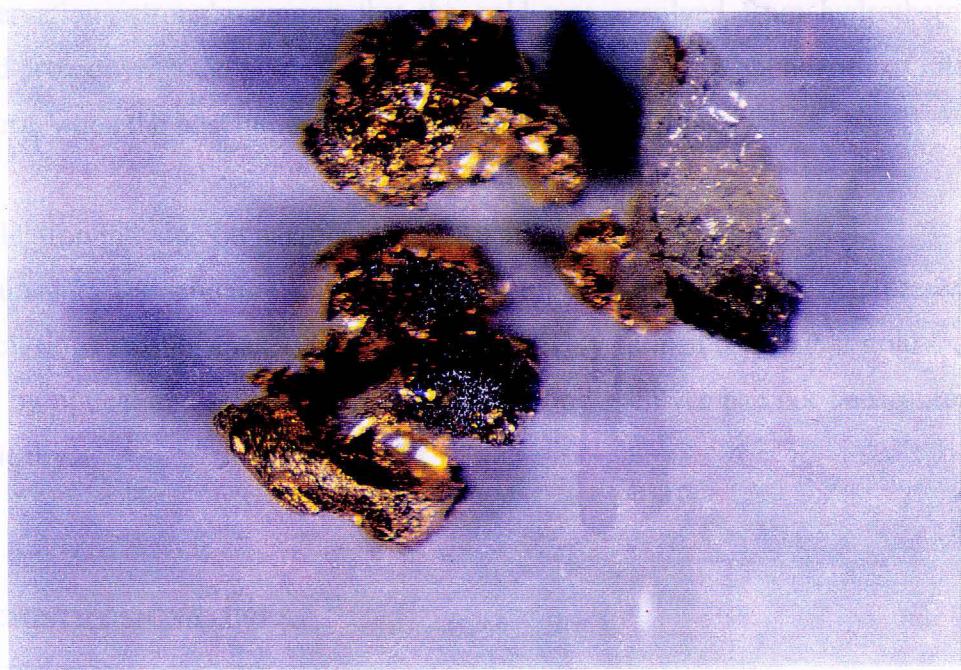
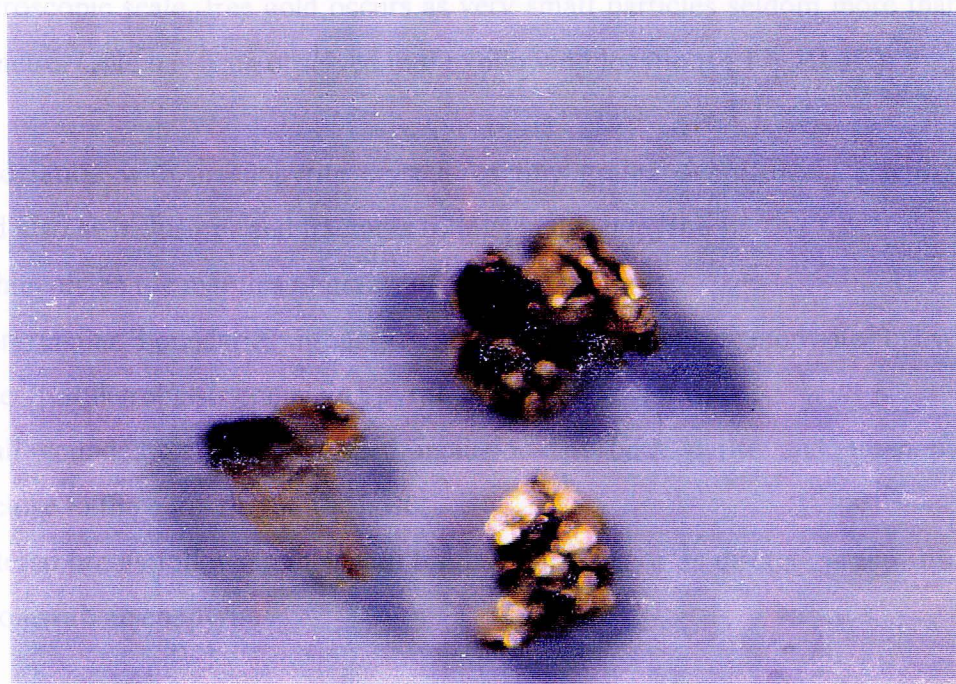


Fig.III.42:- - Nuggets of gold from Twangiza gold deposit.

On the microscopic scale, free gold occurs as very small particles seldom more than 0.5 mm in diameter. Gold has been observed in the following locations (Fig.III.43):

- 1.- in association with arsenopyrite crystals as tiny grains overgrowing arsenopyrite crystals and also as inclusions and fractures fillings in arsenopyrite ;
- 2.- as attachments on the margins of grains of arsenopyrite ;
- 3.- at intergranular boundaries in aggregates of pyrite and arsenopyrite or within arsenopyrite porphyroblasts containing pyrite inclusions;
- 4.- as small rounded or spindle-shaped inclusions in both pyrite and arsenopyrite, especially close to the outer rim of the host ;
- 5.- as scattered grains following inclusion trains in sulfides or as discrete grains, usually in association with arsenopyrite .

These observations strongly suggest that the gold was exsolved from hydrothermally precipitated arsenopyrite and pyrite, especially close to, or at, grain boundaries or internal microfracture, when the host mineral tried to rid itself of impurities.

Scanning electron microprobe micrographs of Au are seen in Fig.III.44.

Gold contained in the structure of the common sulphide minerals and that present as discrete inclusions smaller than 1000 Å are collectively termed " invisible gold " , not detectable by optical and scanning electron microscopy . Silver has not been observed macroscopically.

12.5.3.- CHEMISTRY SIGNATURES.

Chemistry signatures of gold, pyrite and arsenopyrite have been investigated. 10 single crystal samples and 6 polished thin sections from QV₁ and QV₂ and associated wall-rock alteration zones have been selected and analysed for all elements by Ion microprobe.

Quantitative ion microanalyses results of pyrite, arsenopyrite and gold are presented respectively in Table III.2, Table III.3, and Table III.4.

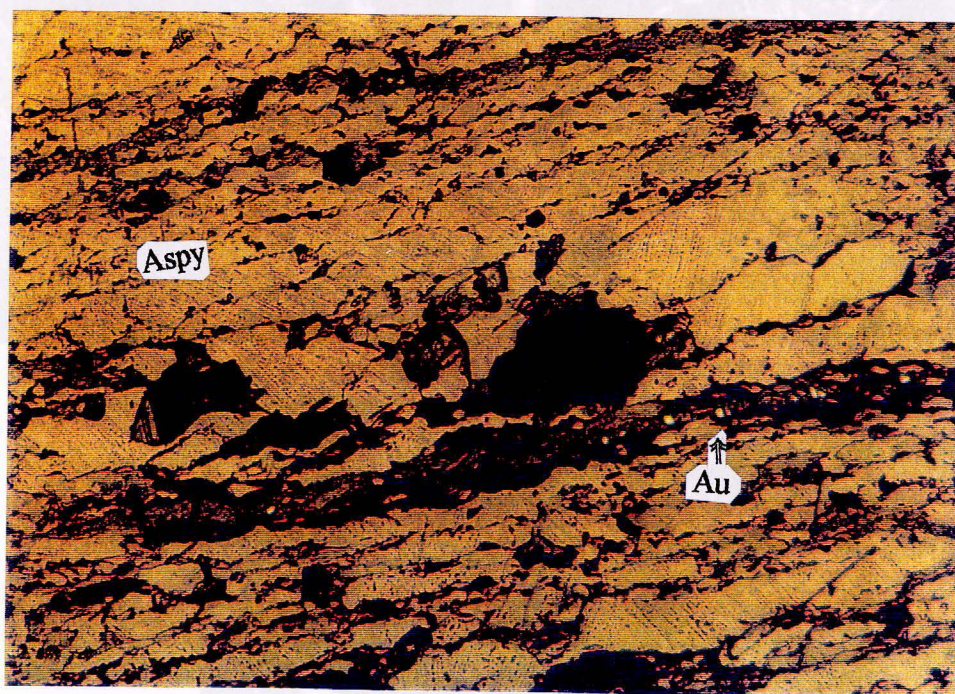
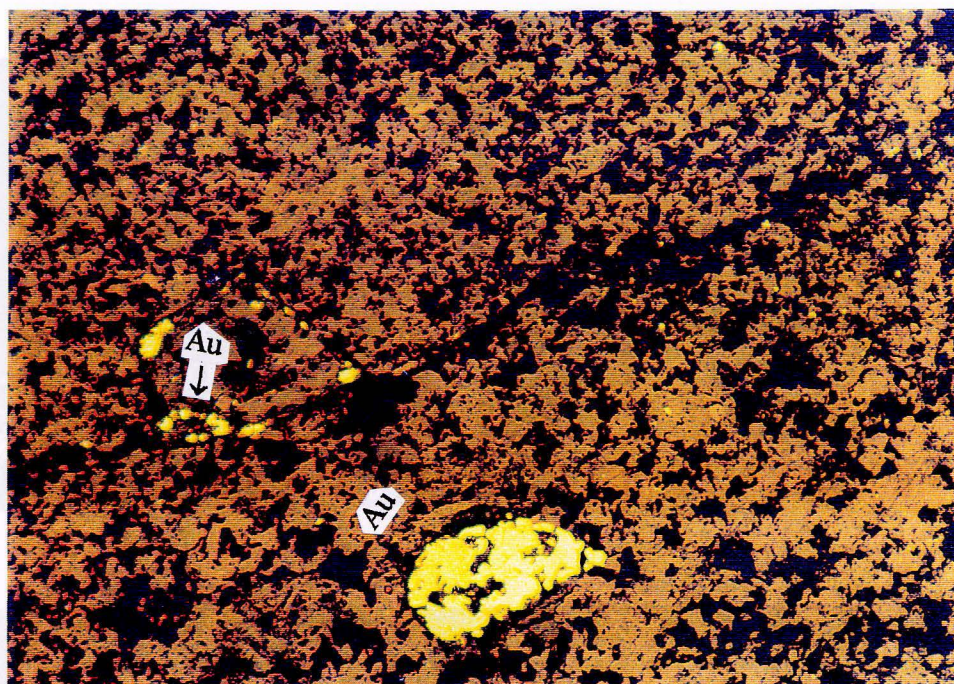


Fig.III.43:- - Photomicrograph of gold grains.

Fig.III.44:- - SEM of native gold from the Twangaza gold deposit

(Mag. x 10, x 200, x 750, x 4000, x 9000)

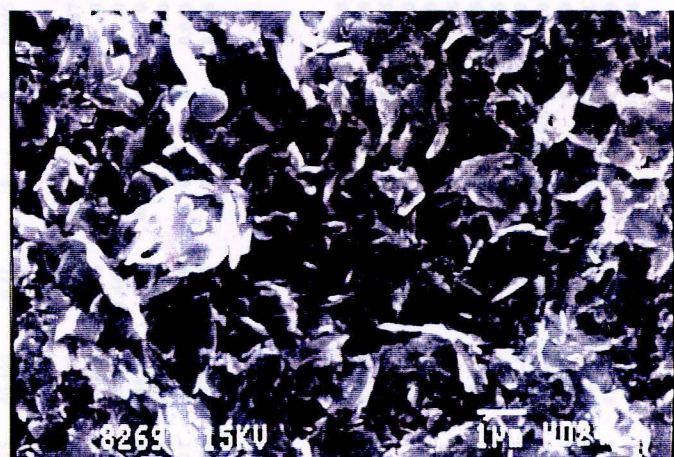
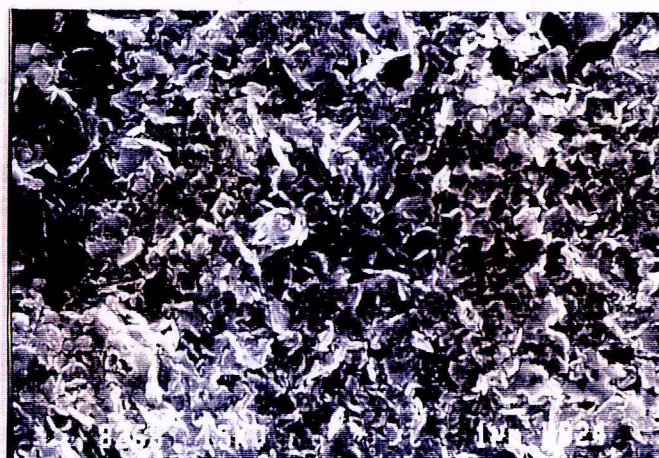
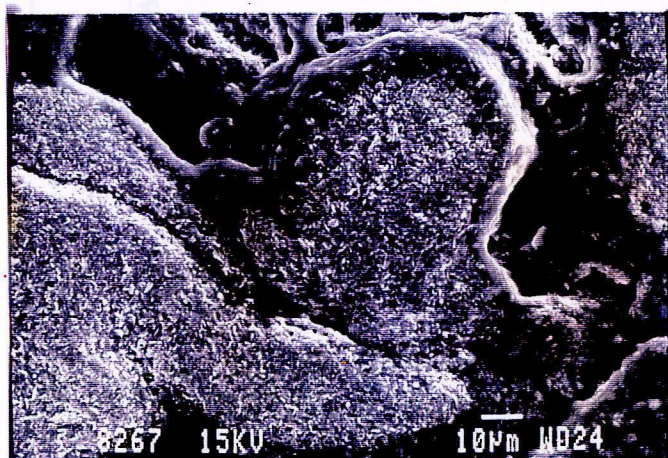
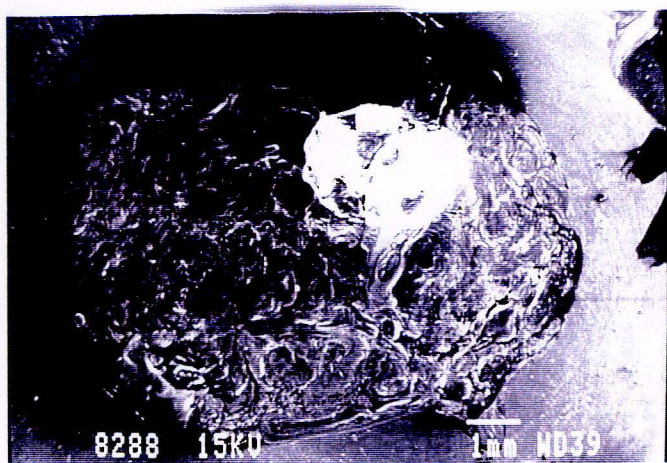


Fig. III.44:- - SEM of native gold from the Twangiza gold deposit.

(Mag: x 10, x 200, x 750, x 4000, x 9000).

TABLE III.2 :- QUANTITATIVE ION - MICROANALYSES OF PYRITE

Sample	SKA	FeKA	AsLA	AgLA	AuLA	HgLA	CdLA	PdLA	CuKA	TOT	As	FeKA/SKA	d34S	d13C	d18O
KW 420	50.042	46.35	0.741	0.057	0	0	0.058	0.056	0.004	97.308	74.1	0.93			
KW 430	53.009	46.493	0.113	0.047	0.074	0	0.075	0	0.036	99.847	11.3	0.88	2.69		
KW 430-1	47.316	48.203	0.391	0	0.374	0	0	0	0	96.285	39.1	1.02			
KW 430-2	43.948	47.745	1.865	0.038	0.382	0	0.18	0	0.072	94.23	186.5	1.09			
KW 430B													2.62		
KW 430C													2.7		
KW 444	52.597	45.754	0.19	0	0.044	0.15	0.106	1.164	0.013	100.019	19	0.87	2.68		
KW 444B													2.7		
KW 448	52.375	46.464	0.41	0	0	0.045	0.005	1.097	0.011	100.407	41	0.89	3.26	-3.71	18.46
KW 448B													3.34		
KW 448c													3.3		
KW 617-A	46.613	48.292	2.036	0.039	0	0.087	0.06	0	0.011	97.138	203.6	1.04	3.11		
KW 617-C	46.567	48.076	1.606	0.053	0	0	0	0.03	0.04	96.371	160.6	1.03	3.1		
KW 617-E	47.048	48.024	1.445	0	0	0	0.069	0	0.017	96.603	144.5	1.02			
KW 617-F	46.532	48.07	1.645	0.053	0.036	0	0	0.074	0.005	96.416	164.5	1.03			
KW 617-G	46.258	47.783	1.278	0	0	0	0.06	0.045	0.051	95.476	127.8	1.03			
KW 617-H	47.421	48.321	0.469	0	0	0.033	0.086	0.003	0.015	96.348	46.9	1.02			
KW 617-I	46.133	47.703	0.855	0	0.538	0.195	0	0	0.04	95.463	85.5	1.03			
KW 618B													2.9	-9.03	13.07
KW 618E1													2.93	-9.85	14.2
KW 618E1b													2.9		
KW 620A													3.37		
KW 620Ab													1.03		
KW 621-A	46.166	45.544	0.298	0	0.027	0	0.139	0.015	0	92.188	29.8	0.99	2.8		
KW 621-B	46.73	47.561	2.214	0.06	0.091	0	0	0	0.008	96.663	221.4	1.02	2.8		
KW 621-C	45.754	45.6	3.508	0	0.145	0.216	0	0.027	0.073	95.323	350.8	1			
KW 621-D	46.385	47.149	2.362	0	0	0	0	0	0.064	95.961	236.2	1.02			
KW 621-E	47.489	47.98	0.522	0	0.648	0	0.009	0	0	96.648	52.2	1.01			
KW 621-F	47.069	48.212	0.709	0	0.173	0.336	121	0	0	96.621	70.9	1.02			
KW 621-G	46.988	48.165	0.402	0	0.11	0.25	0	0.63	0	95.977	40.2	1.03			
KW 621-H	47.226	48.64	0.611	0	0	0.586	0	0	0	97.063	61.1	1.03			
KW 621-I	41.434	46.9	0.28	0	0.265	0	0	0.02	0	88.899	28	1.13			
KW 621-J	47.74	48.727	0.19	0.08	0.064	0	0.104	0	0	96.905	19	1.02			
KW 621-K	47.364	49.238	0.159	0.033	0	0	0	0	0	96.794	15.9	1.04			
KW 621-L	51.103	46.293	1.929	0	0.02	0.101	0.042	0.538	0	100.026	192.9	0.91			
KW 621-M	50.823	47.172	0.17	0	0.072	0.019	0	0.516	0	98.772	17	0.93			
KW 621-N	51.442	46.594	0.216	0	0.004	0.04	0	0.074	0.001	98.371	21.6	0.91			
KW 622A															
KW 622Ab													8.05		
KW 622Ac													8.48		
KW 617-1	40.224	40.093	1.647	0	0	0.162	0.32	0.089	0.049	82.584			8.3		
KW 617-3	40.894	42.713	2.266	0.065	0	0	0	0	0	85.939					
KW 617-4	46.774	45.488	1.356	0.08	0.046	0.13	0.061	0	0	94.035					
Meso/pyrite			3.6	6.3	97			2.1	190		360				

TABLE. III.3 :- QUANTITATIVE ION - MICROANALYSES OF ARSENOPYRITE.

Sample	SKA	FeKA	AsLA	AgLA	AuLA	HgLA	CdLA	PdLA	CuKA	TOTAL
KW 617- AB	-	-	-	-	-	-	-	-	-	-
KW 617-10	19.471	33.957	45.806	0	0.534	0.01	0	0.019	0.047	99.843
KW 617-2	19.949	33.806	45.599	0.092	0	0	0.104	0.157	0	99.706
KW 617-5	22.265	36.778	46.557	0.011	0	0	0	0.075	0.033	105.719
KW 617-6	19.906	34.412	46.02	-	-	-	-	-	-	100.337
KW 617-7	20.391	34.728	47.194	-	-	-	-	-	-	102.313
KW 617-8	21.528	38.037	47.527	0.128	0	0	0.008	0.205	0.013	107.447
KW 617-9	19.476	34.117	45.787	0.079	0.076	0	0	0	0	99.535
KW 617-A	-	-	-	-	-	-	-	-	-	-

Sample	Sat	Feat	Asat	As/S	Au/Ag	Au/S
KW 617- AB	33.18	33.217	33.402	-	-	-
KW 617-1	35.15	33.33	31.453	0.04	0	0
KW 617-10	33.538	33.282	33.18	2.35	0	0.03
KW 617-2	33.692	32.939	33.368	2.29	0	0
KW 617-3	33.738	34.219	31.873	0.06	0	0
KW 617-4	63.558	35.56	0.789	0.03	0.58	0
KW 617-5	61.585	36.925	1.461	2.09	0	0
KW 617-6	33.827	32.907	33.089	2.31	-	-
KW 617-7	-	-	-	2.31	-	-
KW 617-8	62.74	35.898	1.099	2.21	0	0
KW 617-9	33.18	33.217	33.402	2.35	0.96	0
KW 617-A	33.184	33.37	33.385	-	-	-

TABLE. III.4 : - QUANTITATIVE ION - MICROANALYSES FOR GOLD.

Sample	SKA	FeKA	PdLA	CuKA	AsLA	AgLA	AuLA	HgLA	CdLA	TOTAL
KW 800-Tw1	0.022	0.001	0	0.069	0.045	0.52	81.241	0	0.133	81.562
KW 800-Tw2	0.147	0.047	0.109	0.048	0.075	0.218	91.044	0	0.173	91.862
KW 800-Tw3	0.132	0.04	0.442	0.049	0.02	0.103	60.424	0	0	61.211
KW 800-Tw4	0.134	0.01	0	0.028	0.044	0.4	70.86	0	0	71.116
KW 800-Tw5	0.045	0.11	0	0.051	0.3	0.556	83.698	0	0	84.391
KW 800-Tw6	0.086	0	0.142	0.032	0.06	0.509	85.764	0	0.11	86.703
KW 800-Tw7	0.032	0	0	0.005	0.074	0.43	100.85	0	0	101.391
KW 800-Tw8	0.015	0.011	0	0.006	0.075	0.35	90.851	0	0.012	91.318

Sample	Fineness	Au/Ag	Au/S	Au/Fe
KW 800-Tw1	993.64	156.23	3692.77	81241
KW 800-Tw2	997.61	417.63	619.35	1937.11
KW 800-Tw3	998.3	586.64	457.76	1510.6
KW 800-Tw4	994.39	177.15	528.81	7086
KW 800-Tw5	993.4	150.54	1859.96	760.89
KW 800-Tw6	994.1	168.5	997.26	0
KW 800-Tw7	995.75	234.53	3151.56	0
KW 800-Tw8	996.16	259.57	6056.73	8259.18

III.5.5.3.1.- PYRITE.

Ion microanalyses reveal two distinct populations of pyrite: a " normal " pyrite containing less than 2.00 ppm As , and an arsenian variety with As contents ranging from 2.00 ppm to 4.00 ppm.

Table III.2 shows the quantitative ion-microanalyses of pyrite from Twangiza deposit.

Histograms respectively of As, S, and Fe contents of pyrite show bimodal distribution of As, S, and Fe between normal pyrite and arsenian pyrite. (Fig.III.45; Fig.III.46). Ternary diagram (S - Fe - As*100) of pyrite show also two pyrites types. (Fig. III.47). On the other hand, pyrite in the late-stage quartz/sulphide veins was significantly enriched in arsenic.

Scatter diagrams for S, Fe, As, Ag , Hg, and Cd with Au are shown in Fig. III.48, in gold grains and correlation of Cu, Hg, and Pd versus Au in pyrite are seen in Fig.III.49.

There is a positive correlation between the concentrations of Au and Fe, As, Hg, Cu and negative correlation with S and Ag (Fig. III.48 ; Fig. III.49).

To examine the concentration and covariation of a suite of elements, Twangiza pyrite (sample KW 617C) has been compared to standard mesothermal pyrite (Ho et al., 1991), (normalizing values for standard mesothermal pyrite : Au = 97, Ag = 6.3; As = 3.6; Pd = 2.1; Cu = 190). Twangiza pyrite shows a strong depletion in As, Au, Pd, and Cu elements (Fig.III.51). These data are also illustrated by spider plots for elements of the ore suite (Fig.III.52).

To provide information of the sources of sulfur, selenium, and by inference, gold in the ore fluids, the S/Se ratios in hypogene pyrites from the QV₂ and QV₃ veins were investigated.

Studies by Huston et al., (1995, 1997) have shown consistently that pyrites formed in sedimentary environments have S/Se ratios > 1000,000 , whereas pyrites of magmatic hydrothermal origin (ie., porphyry copper deposits) have S/Se ratios < 20,000 .

AuLA

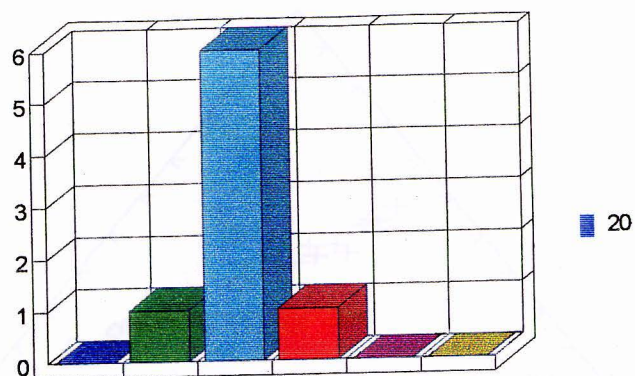
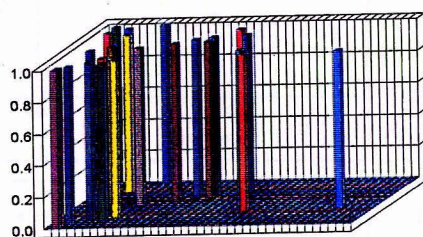
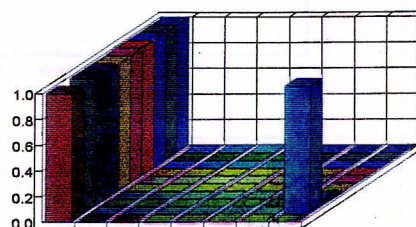


Fig.III.45 : - Histograms of Au contents of pyrite and arsenical pyrite .

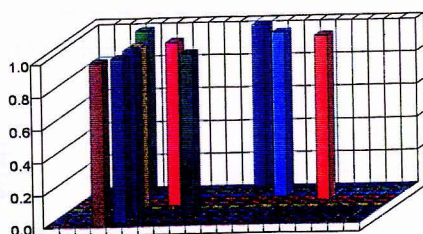
AsLA



AsLA



FeKA



SKA

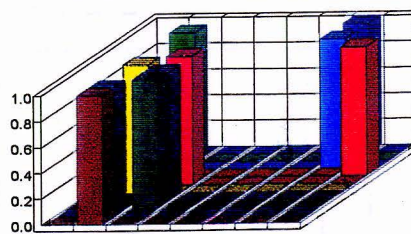


Fig.III.46:- Histograms of respectively As, S, and Fe contents of pyrite and arsenical pyrite.

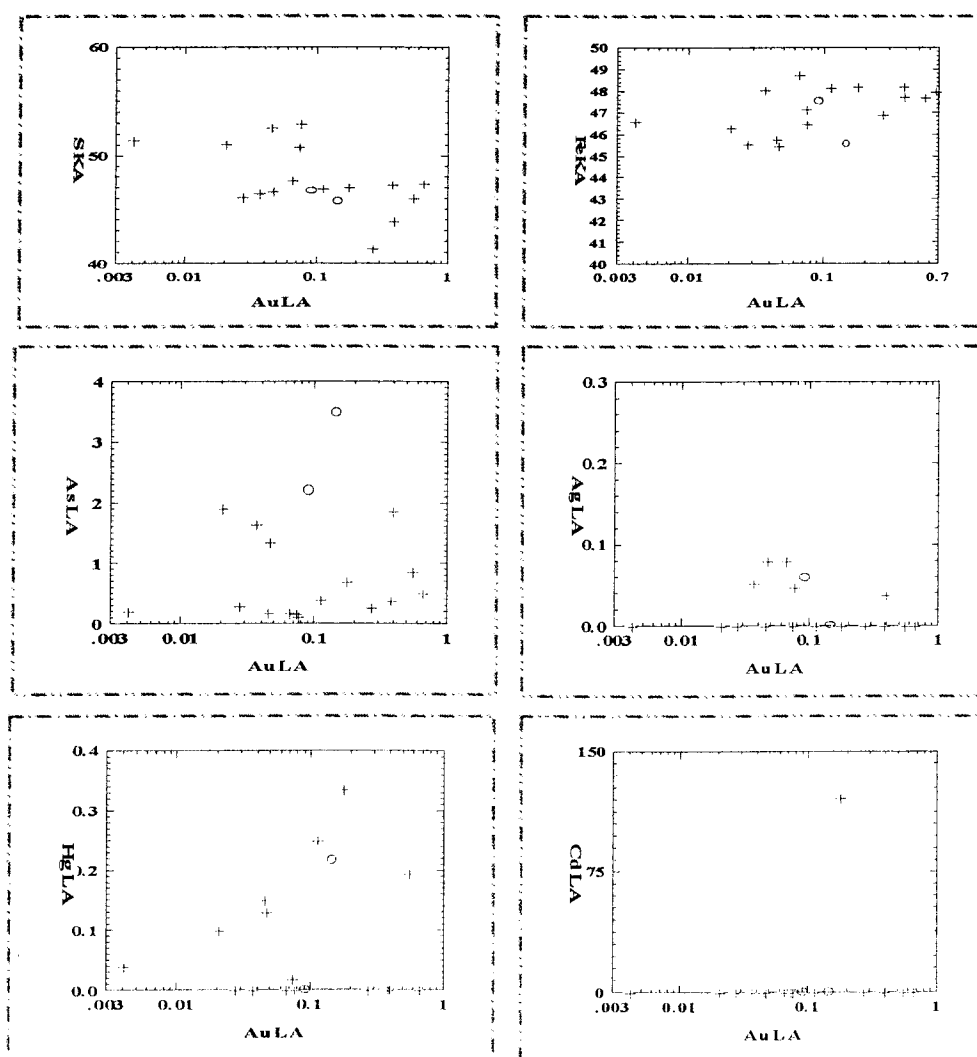
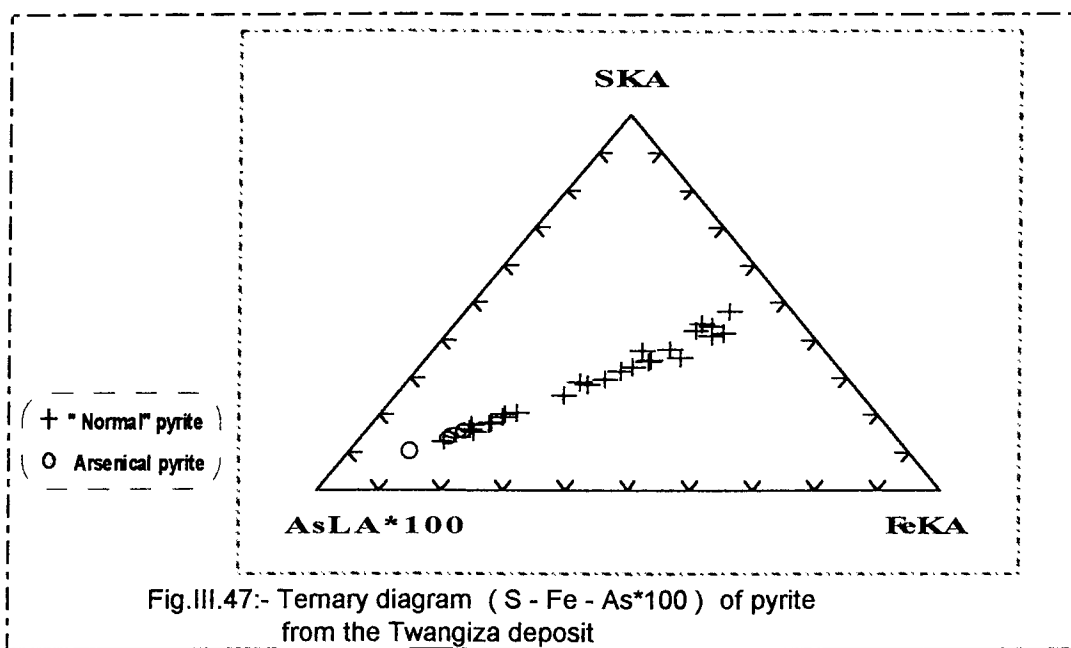


Fig.III.48:- Scatter diagrams of S, As, Ag, Fe, Hg, and Cd with Au in gold grains.

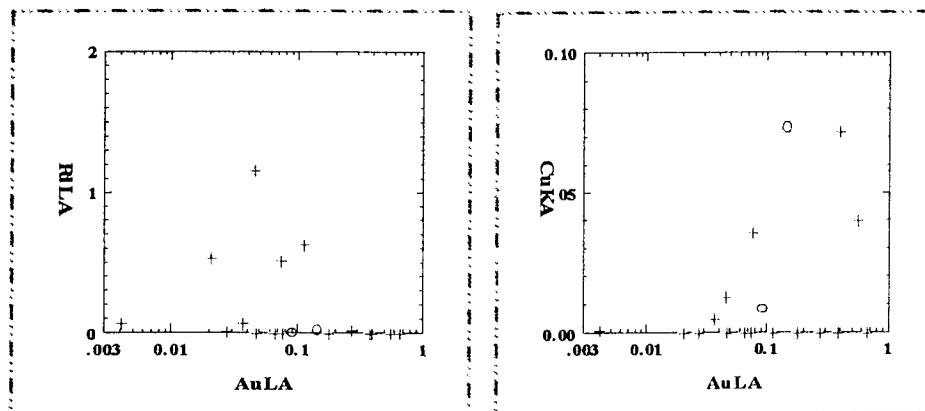


Fig.III.49:- Correlations of Pd and Cu versus Au in pyrite. (+ "Normal" pyrite, o Arsenical pyrite)

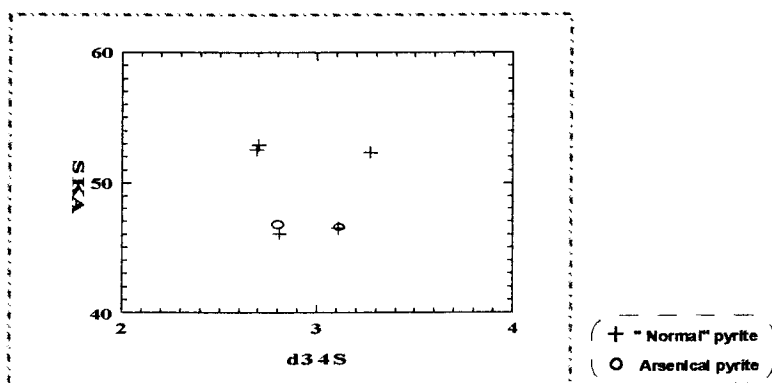


Fig.III.50:- Binary plot of d34S versus S for Twangiza pyrite.

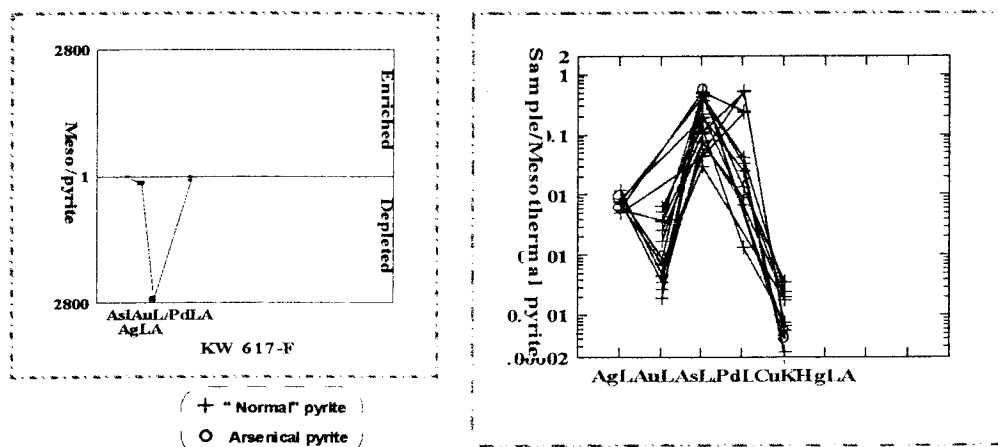


Fig.III.51:- Enrichment / depletion diagram of the Twangiza pyrite compared to standard mesothermal pyrite of Ho et al., (1991).

Fig.III.52:- Spider plots for elements of ore suite of the Twangiza deposit compared to standard mesothermal pyrite of Ho et al., (1991).

The concentration of selenium was determined in Twangiza pyrites using Ion microprobe. The detection limit for selenium was 0.5 ppm. The selenium concentrations in pyrites from both veins QV₃ and saddle reefs QV₂ of mineralization, are consistently very below detection limit (0.5 ppm), yielding minimum S/Se ratios < 20,000 .

Thus the very low S/Se ratios of Twangiza pyrites support the interpretation, that the sulfur and selenium in the various sulphide generations is mostly of magmatic origin, since S/Se ratios are consistently below 20,000

This conclusion is in agreement with the results from sulfur isotope studies, that the ore fluids are of magmatic origin.

12.5.3.2.-ARSENOPYRITE.

Arsenopyrite is a complex mineral species because of its considerable non stoichiometry , the ratio As : S ranging from 1.22 to 0.82 (Kostov 1981). The similar size of the As and Au atoms explains the relative ease of incorporation of Au into arsenopyrite relative to pyrite.

This hypothesis is largely based on comparisons of radii of covalently bonded As and Au . The covalent radius of Au in aurostibite AuSb₂ is 1.40 Å (Marin et al., 1986) and that of As in FeAsS is 1.39 Å

" Invisible gold " appears to be preferentially concentrated in arsenopyrite, which is the main sulfide mineral incorporating gold into its structure, related to its crystal chemistry.

Table III.3 shows the quantitative ion-microanalyses of arsenopyrite from Twangiza deposit.

Plot of As content against concentration of " invisible gold " in arsenopyrite from the Twangiza deposit, indicating the correlation between gold and arsenic in each case is shown in Fig.III.53. (The plot of Au versus S, Fe, Ag, Hg, Cd, Pd, and Cu in arsenopyrite) .

In the ores that contain arsenopyrite, there is not a strong positive correlation between the concentrations of Au and As in arsenopyrite. However, more additional data are needed to picture the tendency.

Fig.III.53:- Scatter diagrams of S, Fe, Ag, Hg, Cd, and Pd with Au in arsenopyrite.

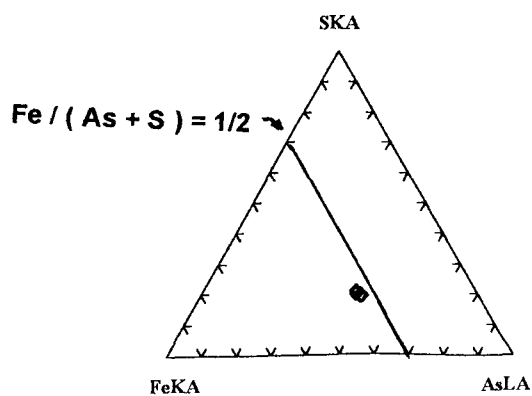
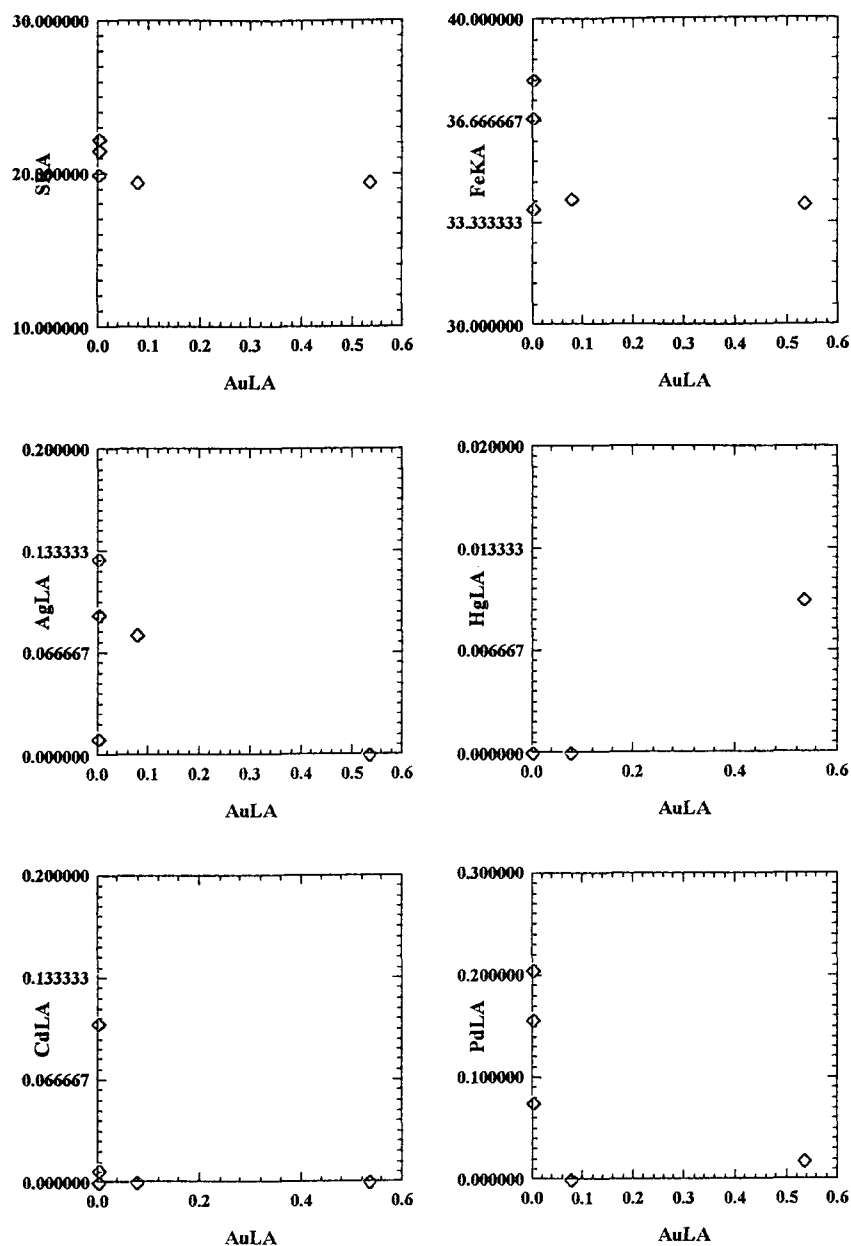


Fig.III.54:- Arsenopyrite compositions in atomic % in ternary system Fe - As - S

Arsenopyrite compositions in (atomic%) have been plotted in ternary system Fe-S-As. (Fig.III.54). All the data lie close to the line representing the stoichiometric composition $[\text{Fe} / (\text{As} + \text{S}) = 1/2]$ and plot in one field.

12.5.3.3.- GOLD.

The same grains used for SEM were also analysed for ion microprobe. A total of 5 grains of gold were analysed for all elements. The size of gold grains varied between 125 μm and 170 μm . The result of micronalysis of gold from Twangiza deposit is depicted in Table III.4.

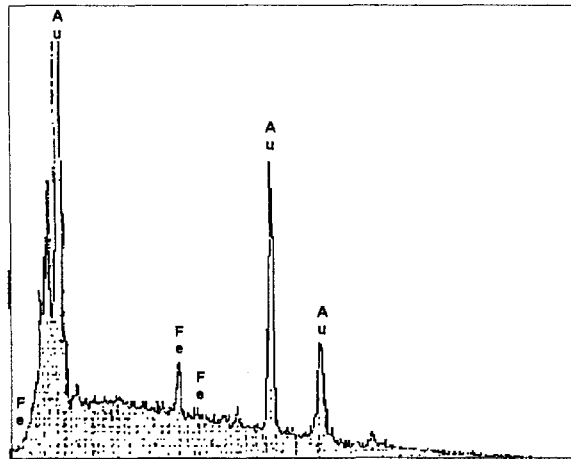
The spectra of SEM of individual gold grains are shown in Fig.III.55, and exhibit minor metallic components. Base metal and total sulphide abundances are low, Au/Ag ratios are high, and Au/S ratios are also high. The low Au/As is characteristic for this deposit.

Scatter plots of Au are shown in Fig.III.56. These data indicate not considerable variation in the Au content from grain to grain.

The frequency diagram of gold grains (Fig. III.57) shows that grains with Au contents of 0 to 2 ppm prevail in these samples. Fig.III.58 shows respectively the histograms of Au, As, S, Fe, Pd, Ag and Cu in gold grain from the Twangiza deposit. Gold fineness, $[1000 \cdot \text{Au} / (\text{Au} + \text{Ag})]$ for the Twangiza ores range from 991.95 to 998.30 and the ratio of Au/Ag varies from 123.17 to 586.64. (Table.III.5); (Fig.III.59).

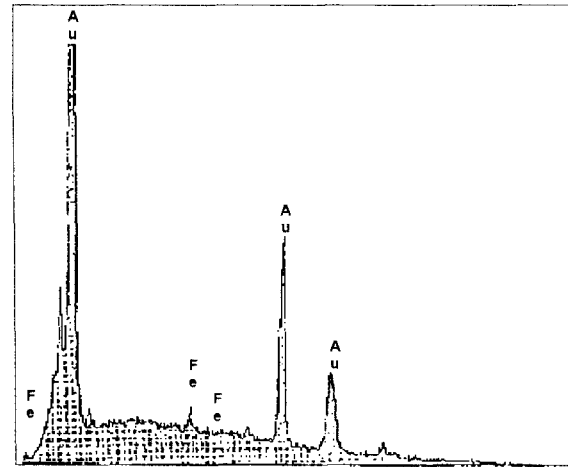
These gold values are obtained on a limited number of analyses and the picture could slightly change as additional information is obtained. However, these values are in accordance with those recorded for slate belt by Morrison et al., (1991) .

X - RAY : 0 - 20 KeV
 Live : 100 S Preset : 100 S Remaining : 0 S
 Real : 139 S 28 % Dead.



< .2 10.580 KeV
 FS = 2K Ch 539 = 137 cts
 MEM1 : KW GOLD 800

X - RAY : 0 - 20 KeV
 Live : 100 S Preset : 100 S Remaining : 0 S
 Real : 127 S 21 % Dead.



< .2 10.400 KeV
 FS = 2K Ch 530 = 97 cts
 MEM1 : KW 800 GOLD

Fig.III.55:- The Spectra of individual gold grains.

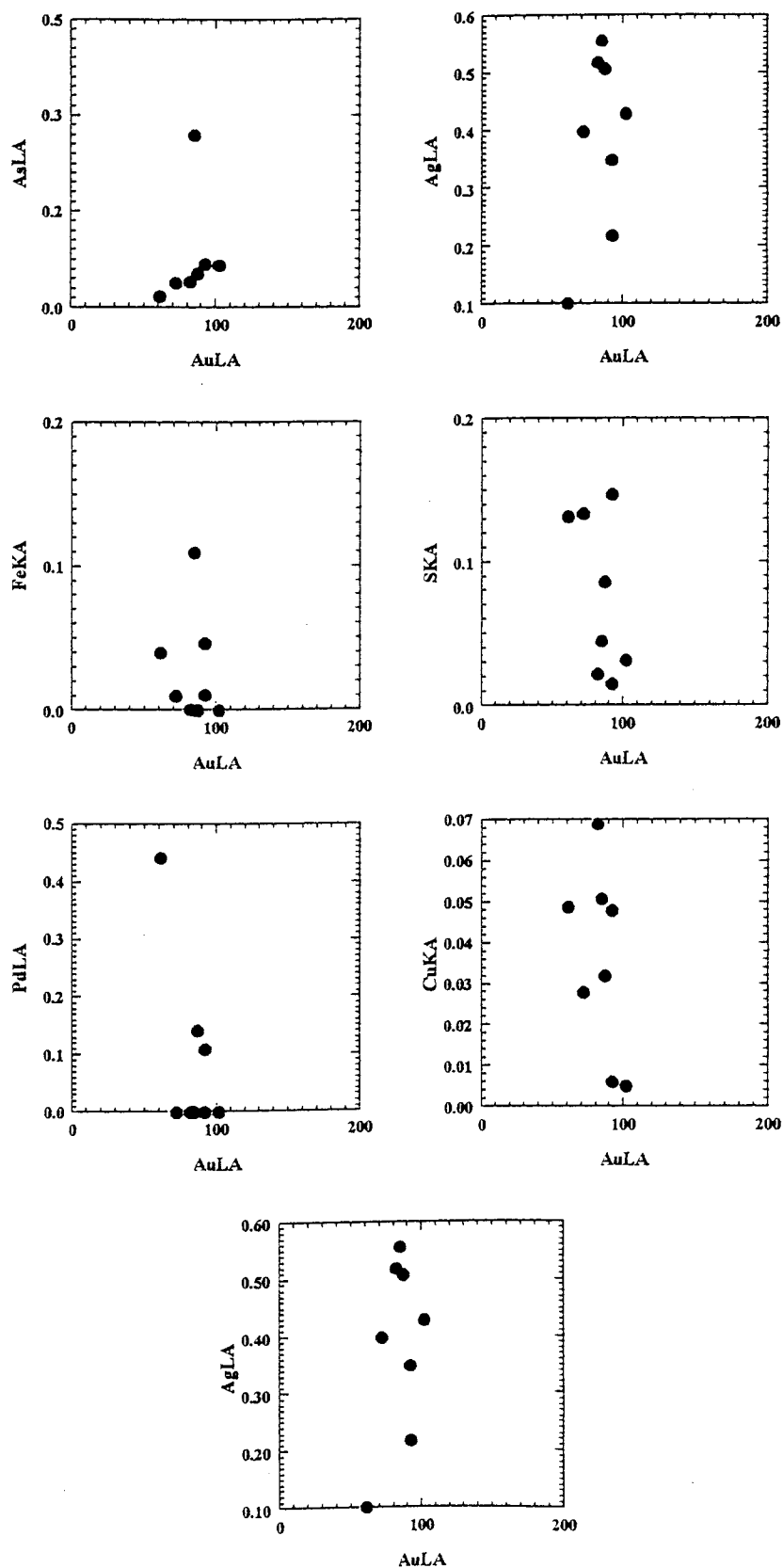


Fig.III.56:- Correlation diagrams of Au versus As, Ag, Fe, S, Pd, Cu, and Cd .

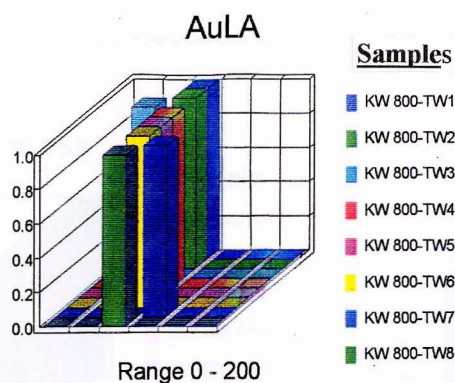


Fig.III.57:- Frequency diagrams of gold grains for the Twangiza deposit .

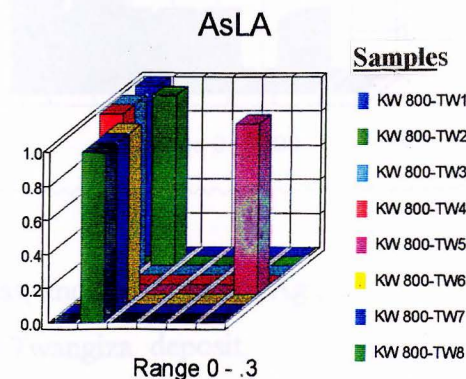
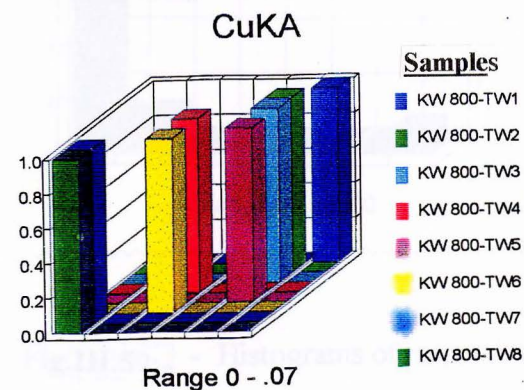
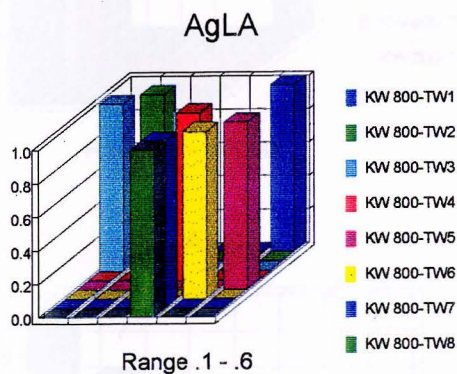
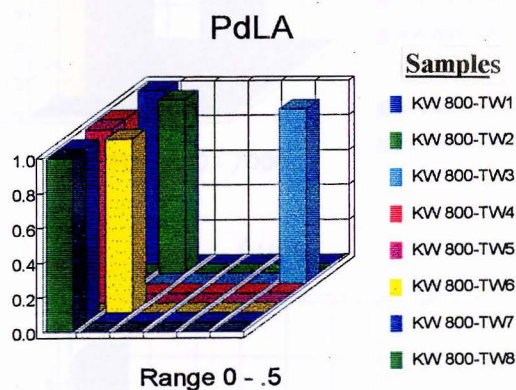
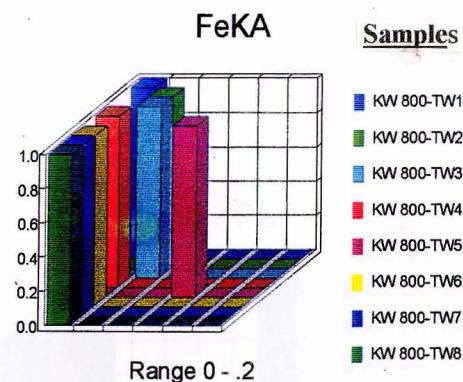
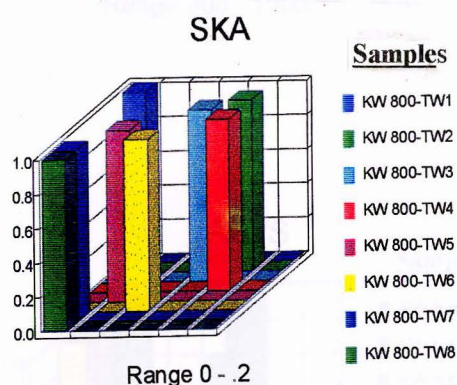


Fig.III.58:- - Histograms of respectively
Au, Fe, As, S , Ag,Cu, Pd,
in gold from the Twangiza deposit.

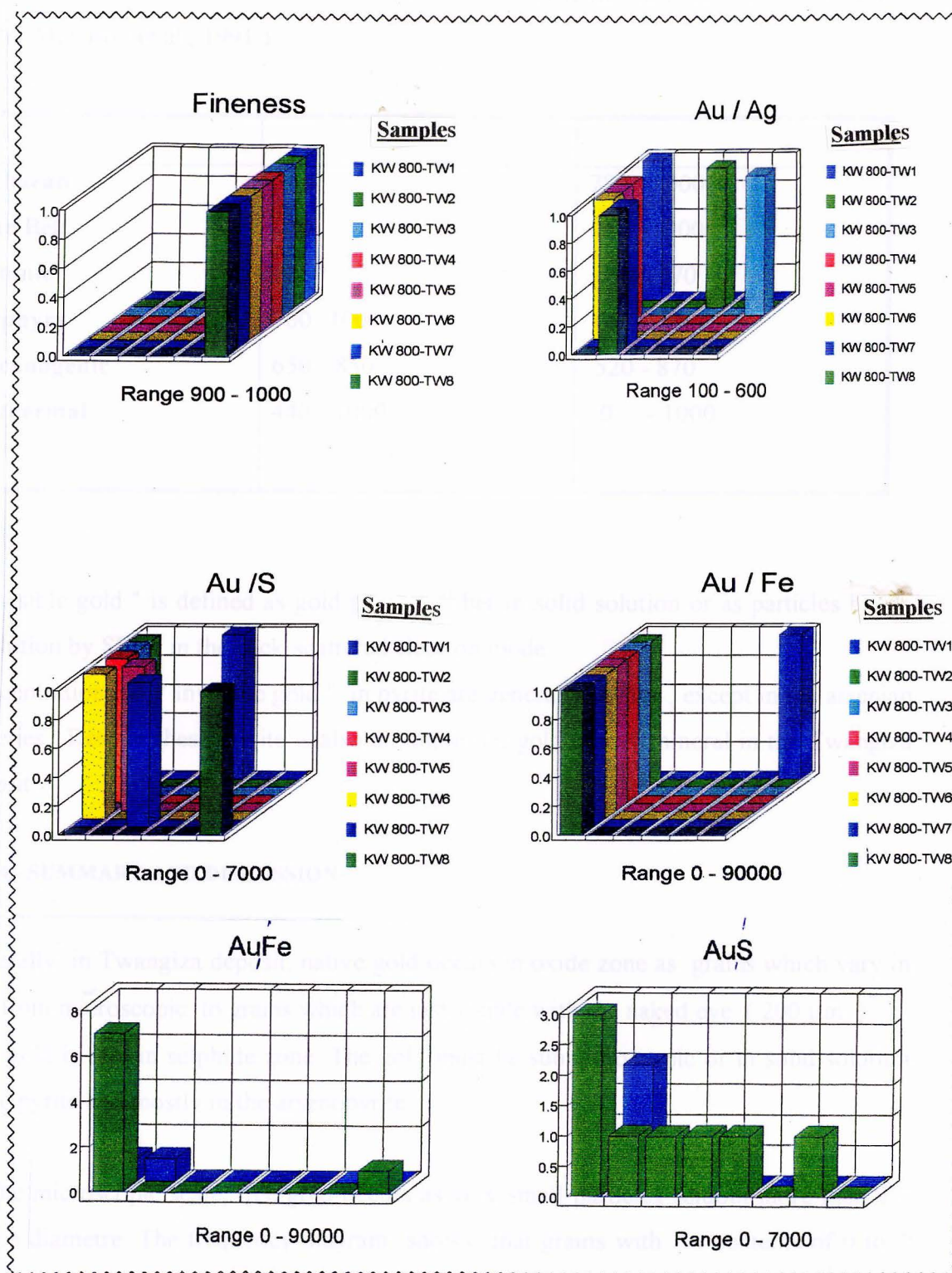


Fig.III.59:- - Histograms of respectively fineness, and the ratios Au/Ag , Au/Fe, and Au/S in gold from the Twangiza deposit.

Table III.5: Average fineness values for gold from different depositional environments (after Morrison et al., 1991).

Archaean	940	780 - 1000
Slate Belt	920	800 -1000
Plutonic	825	650 - 970
Porphyry	700 -1000	650 - 1000
Volcanogenic	650 - 850	520 - 870
Epithermal	440 - 1000	0 - 1000

" Invisible gold " is defined as gold present either in solid solution or as particles below resolution by SEM in the back-scattered electron mode.

Concentrations of " invisible gold " in pyrite are generally minor , except in the arsenian varieties. Despite these, pyrite is also an important gold-carrier mineral in the Twangiza deposit.

12.5.4.- SUMMARY AND DISCUSSION.

Generally, in Twangiza deposit, native gold occurs in oxide zone as grains which vary in size from microscopic to grains which are just visible with the naked eye (200 μm).

Free gold is rare in sulphide zone. The gold must be submicroscopic or in solid solution in the pyrite and mostly in the arsenopyrite.

On the microscopic scale, free gold occurs as very small particles seldom more than 0.5 mm in diameter. The frequency diagram shows that grains with Au contents of 0 to 2 ppm prevail in these samples. Gold fineness, $[1000 \cdot \text{Au}/(\text{Au} + \text{Ag})]$ for the Twangiza ores range from 991.95 to 998.30 and the ratio of Au/Ag varies from 123.17 to 586.64 .

The dominant form of pyrite is the modified , striated cubes, commonly with octahedral and pyritohedral modifications and/or striations. Ion microanalyses, revealed that the Twangiza ore contain two distinct populations of pyrite : a " normal " pyrite containing less than 2.00 ppm As, and an arsenian variety with As contents ranging from 2.00 ppm to 4.00 ppm.

On the other hand, pyrite in the late-stage quartz/sulphide veins was significantly enriched in arsenic . These two types of pyrite, distinguished from one another by textural criteria, and mineral chemistry indicate multiphase ore genesis, inhomogeneous metamorphism, or both.

In both pyrites, there is a positive correlation between the concentrations of Au versus Fe, As , Hg, Cu, and negative correlation with S and Ag .

The results of this study indicate that arsenopyrite is a good and common host for " invisible gold " , but that pyrite is also a very good gold-carrier. Boyle (1979) suggested that Au substitutes for As in arsenopyrite. However, the positive correlation between Au versus As and negative correlation between Au versus S, suggest that sulfur could have been replaced by Au than As.

In the ores that contain arsenopyrite, there is not a strong positive correlation between the concentrations of Au and As in arsenopyrite .

Compared to standard mesothermal pyrite of Ho et al.,(1991), Twangiza pyrite shows a strong depletion in As, Ag, Pd, and Cu trace elements .

The very low S / Se ratios of Twangiza pyrites support the interpretation, that the sulfur, selenium and thus gold in the various sulphide generations is mostly of magmatic origin since S / Se ratios are consistently very below 20,000 .

This conclusion is in agreement with the results from sulfur isotope studies, that the ore fluids are of magmatic hydrothermal origin.

Arsenopyrite and gold paragenetic relationship strongly suggest that the gold was exsolved from hydrothermally precipitated arsenopyrite and pyrite.

Apart from As and S, the formation of arsenopyrite and pyrite in the altered wall rocks depends on availability of Fe which, likewise can be derived from the ore fluids or the host rock.

Fe was probably derived largely from the host rock as the analyses indicate that little Fe was added or subtracted from the wall rocks. (See the following chapter of chemical mass transfer for detail). Fe may have been released during muscovite-carbonate alteration of chlorite or detrital Fe oxides.

However due to widespread occurrence of pyrite and arsenopyrite in the host rock lithology, most pyrite porphyroblasts in metasedimentary rocks (black shale, arkosic sandstone) may be considered to represent recrystallised iron sulphide originally present in the rock. Both hydrothermally introduced and extensively varying amounts of synsedimentary pyrite commonly recrystallised after cleavage development and vein introduction, and it is therefore difficult to establish the extent of a hydrothermal pyrite halo with accuracy.

12.6.- CHEMICAL MASS TRANSFER AND THE PATH OF METASOMATIC REACTIONS.

12.6.1.- INTRODUCTION.

Estimates of mass transfer in fluid -rock interaction require assumptions on either element immobility or volume change. Al, Ti, Zr, Y and Nb are commonly assumed to be immobile elements in hydrothermal alteration associated with ore deposit.

In the studied deposit, there is abundant evidence of alteration zoning and element mobility on a hand -specimen scale, as well as in surface outcrop.

Two procedures were used to decipher the process of fluid-rock interaction and to monitor mass transfer: Maclean & Kranidiotis (1987) method based on element immobility and Mountain & Williams-Jones (1995) method based on alteration zones

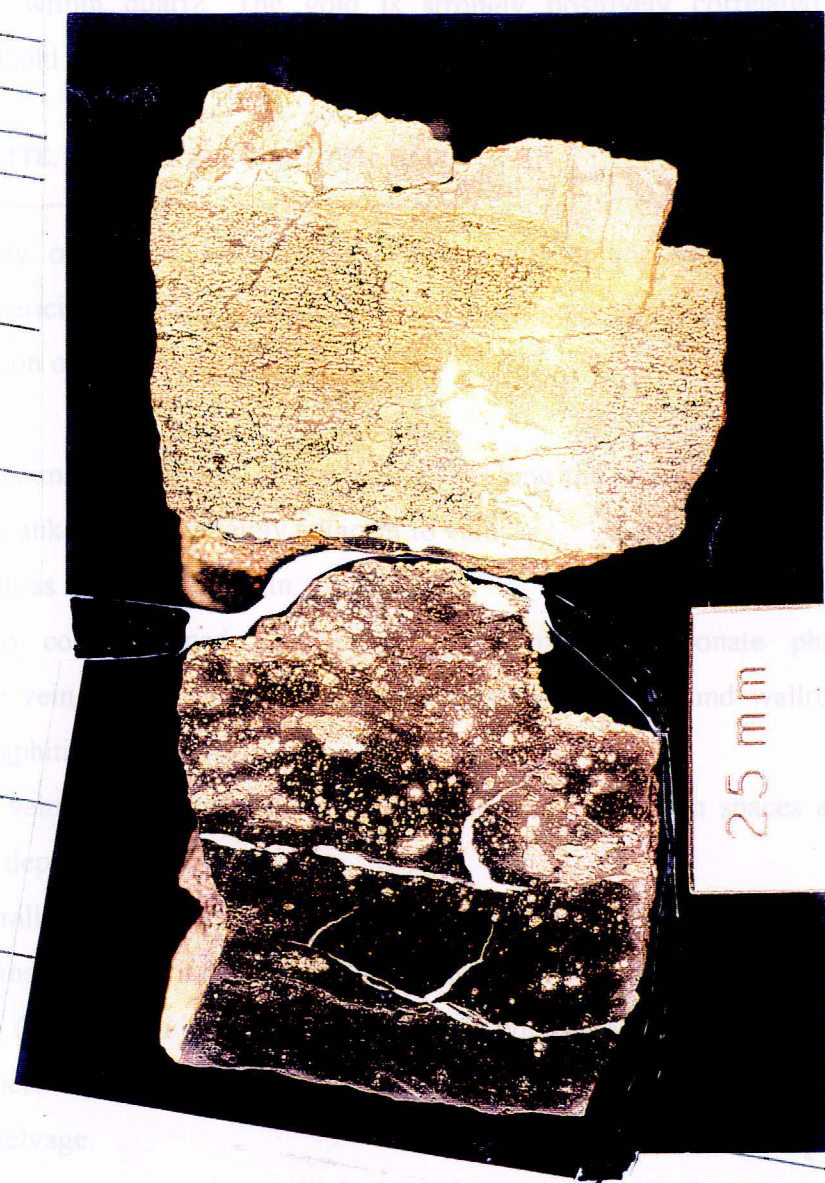
12.6.2.- DESCRIPTION OF VEINS MINERALOGY AND PARAGENESIS FOR SELECTED SAMPLES : KW 617 (B1-B2-B3) AND KW 618E3.

12.6.2.1.- QV2 IN BLACK SHALE. SAMPLE KW 617 (B1-B2-B3). (Fig. IIL60).

Multi-stage tension vein with three " ribbon " of vein minerals. The mineralogical composition vary from one ribbon to the other :

- The early central zone of ribbons occupied chiefly by abundant mass colloform of arsenopyrite, grey-blackish, hard, heavy, with crosscutting veinlets of pyrite. Pyrite occurs also as dissemination. (KW 617B1).
- The outer zone along the vein -wall rock interfaces, blackish, consisting predominantly of multiple laminae of sulphides (pyrite) and carbonaceous matter, separated by millimetre -thick slivers of black shale wall-rock. Fissures filled with carbonate mineral (ferroan dolomite) crosscut the thick sliver. (KW 617B2).
- Along wall rock-vein filling contact, massive and abundant euhedral pyrites cubes occur mostly in the interstice and as dissemination. Hydroxides of iron are present as coatings on the rock and a crosscutting network of spider veinle (KW 617B3).

KW 617B1
 KW 617B2
 KW 617B3
 KW 448A
 KW 448A2
 KW 448C
 KW 448C2
 KW 622A
 KW 152



25 mm

Fig.III.60:- Polished slab of QV₂ multi -stage tension vein with three" ribbons"
 of vein minerals and associated altered black shale wall -rock .
 (alteration zonation along black shale host rock).

Gold occurs as inclusions or as fracture fillings in sulphides, as coatings on grain surfaces or as isolated grains within quartz. The gold is strongly positively correlated to arsenopyrite content. Gold occurs in concentrations up to 100ppm .

12.6.2.2.- QV1 IN ALBITITE. SAMPLE KW 618E3. (Fig.III.61).

It is composed mainly of quartz, ankerite, and albite with minor calcite, pyrite, arsenopyrite, chlorite, sericite and trace of gold. The vein mineralogy appears to be partly related to the composition of the albitite host.

- Albite is more abundant, and occurs discontinuously along the veins margins or is intergrown with ankerite immediately adjacent to vein.
- Quartz is present as fracture fillings in albite.
- Fine-grained to coarse-grained ankerite is the dominant carbonate phase throughout the vein growth and commonly occur as selvage around wallrock segments of graphitic black shale.
- The texture of vein suggest that ankerite and albite grew into open spaces and that quartz was deposited later.
- Sulphides generally make up less than 15 % of the vein volume. The dominant phases, pyrite and arsenopyrite, occur as extremely coarse-grained disseminated porphyroblasts (up to 2cm) throughout the veins, but can also form clusters, aggregates or nets. Pyrite and/or arsenopyrite is preferably concentrated in the ankerite-albite selvage.
- Pyrrhotite grains occurs mainly as inclusion phases being at least partially replaced, where free grains are relatively rare.
- Coarse aggregates of magnesite occur as replacement phase.
- Dolomitic carbonate appears to be the last carbonate to be deposited.
- Fine-grained sericite occurs along the vein wallrock-vein contacts.
- Fluoroapatite and Rutile occur sporadically.

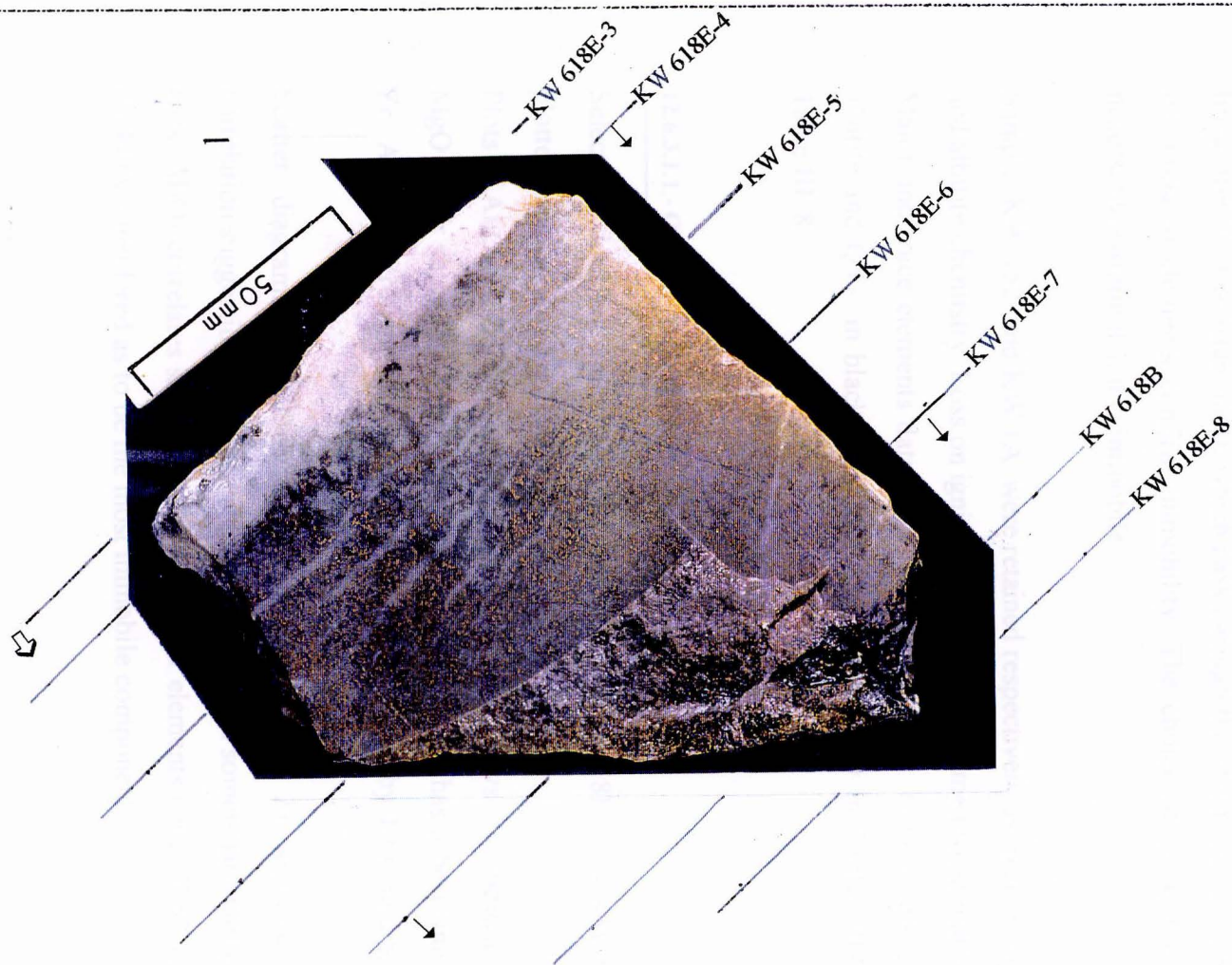


Fig.III.61:- - Polished slab of QV₁ vein and associated altered albitite wall -rock.
(alteration halo along albitite host rock).

12.6.3.- MINERAL AND ALTERATION GEOCHEMISTRY.

12.6.3.1.- MACLEAN AND KRANIDIOTIS METHOD.

Maclean and Kranidiotis (1987) proposed that binary plots of immobile elements should yield linear arrays, with high correlation coefficients, that pass through both bulk composition and origin.

Following this method a diagram of Zr versus selected elements was constructed in order to compare their behavior during alteration and confirm their immobility. Only linear trends at constant ratio, which pass through the origin and are displayed by a group of unrelated elements confirm immobility. The choice of Zr as the abscissa does not necessarily assume that it is immobile.

Sample KW 152 and KW 1A were retained respectively as fresh samples of black shale and albitite chemistry. Loss on ignition (L.O.I) is assumed to be mainly water.

Major and trace elements data from alteration haloes respectively of QV_1 & QV_2 in albitite and QV_2 in black shale are listed respectively in Table .III.6, Table .III.7 and Table.III. 8.

12.6.3.1.1.- QV_1 IN ALBITITE.

Selected oxides and trace elements samples (KW 618E-1 $\rightarrow$ KW 620A) have been plotted against Zr (Fig.III.62).

Plots of Al_2O_3 vs. Zr, SiO_2 vs. Zr, TiO_2 vs. Zr and Nb vs. Zr show a simple correlation. MgO vs. Zr show that MgO decreases throughout and has a best linear correlation with Zr. Al_2O_3 vs.Zr being the most immobile pair followed by TiO_2 , and SiO_2 .

Scatter diagrams of Fe_2O_3 vs.Zr, La vs. Zr and Y vs. Zr show no simple systematic correlation suggesting that these elements have been somewhat mobile in altered albitite rock. Al_2O_3 correlates slightly better with other elements (Fig.III.63) than does Zr , and could be considered as to be the most immobile component.

TABLE III.6 - MAJOR AND TRACE ELEMENTS FROM ALTERATION HALOES OF QV2 VEIN IN THE BLACK SHALE.

Sample	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	F	LOI	Total	Cr ₂ O ₃	FeOT	FeO	Fe ₂ O ₃ T	V ₂ O ₅	NiO	CuO	ZnO	SO ₃
KW 152	82.78	0.9	20.92	8.31	0.01	1.13	0.08	0.45	4.83	0.23	-	-	97.71	0.01	42.07	36.3	46.84	-	0.02	0.04	0.01	0.03
KW 448A	56.02	1.17	20.13	4.74	0.02	0.88	0.04	7.77	1.99	0.08	-	8.38	98.95	-	31.8	27.28	35.03	-	-	-	-	-
KW 448A2	53.19	1.24	18.83	3.39	0	1.83	0.14	3.7	2.54	0.12	0.08	-	86.32	0.02	22.6	19.5	25.05	0.02	0.01	0.01	0	1.83
KW 448C	85.11	0.83	12.98	8.55	0.01	0.34	0.03	8.83	0.21	0.05	-	4.85	100.78	-	43.87	37.88	48.41	-	-	-	-	-
KW 448C2	83.18	0.75	11.58	5.89	0.01	0.88	0.13	4.2	0.29	0.14	0.07	-	88.55	0.01	37.93	32.73	42.05	0	0.01	0.01	0	1.61
KW 617B1	3.18	0	0	28.25	0.01	28.83	0.02	0.78	0.05	0.28	0.5	-	68.22	0	175	151.02	184.03	-	-	-	-	-
KW 617B2	40.74	0.86	11.58	18.75	0	1.12	0.08	4.46	0.22	0.22	-	-	93.51	0.01	125	107.87	138.59	-	-	-	-	-
KW 617B3	50.59	0.85	14.81	7.93	0.01	1.8	0.81	4.15	0.18	0.59	-	-	93.51	0.01	52.87	45.02	58.81	0.01	0.01	0.01	0	1.8

Sample	Ba	Rb	Sr	Y	Zr	Nb	Th	Pb	Ga	Zn	Cu	Ni	V	Cr	Ta	Co	Li	U	W	Sn	Mo	Au
KW 152	1073	188	23	23	222	18	23	3	-	71	174	79	171	108	8	19	-	-	5	-	7	-
KW 448A	238	92	14	37	235	22	-	-	-	-	-	10	257	118	-	18	-	-	-	-	3	0.35
KW 448A2	-	-	-	38	252	24	29	4	-	23	-	0	278	173	-	7	-	4	-	-	4	0.15
KW 448C	28	25	14	25	213	19	-	-	-	-	21	26	108	88	-	19	-	12	-	-	4	0.2
KW 448C2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KW 617B1	21	32	49	30	39	-	315	64	-	96	99	293	7	14	43	38	-	29	357	-	-	10.3
KW 617B2	30	17	13	27	204	19	77	26	-	22	-	118	109	177	14	56	-	22	48	-	7	1.35
KW 617B3	-	12	13	23	171	12	28	10	-	26	-	43	341	418	0	26	-	17	55	-	5	0.85

Sample	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	d348	Te	Se	Bi	Sb	Ag	As
KW 152	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	12
KW 448A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4038
KW 448A2	35	87	8	32	4	1	4	-	2	-	1	-	2	-	-	-	-	-	-	-	-
KW 448C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1302
KW 448C2	18	36	4	13	3	1	2	-	2	-	1	-	2	-	-	-	-	-	-	-	-
KW 617B1	58.8	117	8.9	29.8	8	1.4	8.7	1.2	7.9	1.6	4.6	0.6	3.7	-	3.11	-	745	1303	-	0.3	4834
KW 617B2	284.4	568	52	182.9	35.9	12.3	24.8	2.3	8.2	0.9	2.4	0.3	2.4	-	-	4	14	52	-	0.1	4431
KW 617B3	78.9	172	15.6	57.6	11.7	3.9	10.4	1.3	5.3	0.8	2	0.3	1.8	-	-	-	5	3	-	-	4418

TABLE. III. 7 : - MAJOR AND TRACE ELEMENTS FROM ALTERATION HALOES OF QV1 VEIN IN ALBITITE ROCK.

Sample	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	F	LOI	Total	FeOT	FeO	Fe ₂ O ₃ T	Cr ₂ O ₃
KW 1A	45	1.35	13.48	12.41	0.13	7.8	11.61	2.3	0.07	0.46	0.07	-	94.83	82.73	71.39	91.72	0.03
KW 618B	41.53	1.88	13.61	12.4	0.11	6.97	7.8	3.26	0.29	0.32	0.07	-	88.28	82.67	71.34	91.66	-
KW 618E-3	20.65	0.2	3.83	23.93	0	11.82	0.13	2.99	0.11	0.04	0	-	78.11	159.53	137.67	176.88	0.01
KW 618E-4	43.22	1.52	14.04	3.99	0.13	5.13	8.9	4.72	2.22	0.3	-	14.96	99.14	26.6	22.95	29.49	-
KW 618E-5	41.37	1.75	13.44	3.64	0.15	6.05	10.58	5.46	1.39	0.24	-	16.3	100.39	24.27	20.94	26.9	-
KW 618E-6	42.77	1.85	14.53	3.47	0.14	5.31	9.29	5.62	2.05	0.24	-	14.74	100.01	23.13	19.95	25.63	-
KW 618E-7	42.31	2.06	15.49	7.06	0.17	6.24	6.98	5.27	1.51	0.67	-	11.66	99.4	47.07	40.61	52.18	-
KW 620A	46.57	2.5	17.29	15.66	0.09	6.79	2.36	4.02	0.07	0.32	-	3.22	98.88	104.4	90.09	115.75	-

Sample	NiO	CuO	ZnO	Nb ₂ O ₅	Ba	Rb	Sr	Y	Zr	Nb	Th	Pb	Zn	Cu	Ni	V
KW 1A	-	-	-	-	68	7	335	24	122	42	1	5	61	67	175	238
KW 618B	-	-	-	-	59	15	67	16	107	29	8	1	27	-	76	256
KW 618E-3	0.03	0.03	0	6.52	-	22.51	27.25	38.34	104.37	-	159.91	46.27	85.94	-	176.35	54.4
KW 618E-4	-	-	-	-	158	72	55	24	171	30	-	-	-	-	37	360
KW 618E-5	-	-	-	-	119	45	59	20	135	29	-	-	-	-	16	269
KW 618E-6	-	-	-	-	165	58	62	22	163	33	-	-	-	-	17	-
KW 618E-7	-	-	-	-	150	45	72	24	171	34	1	-	-	-	50	282
KW 620A	-	-	-	-	47	22	79	27	159	33	1	2	12	12	62	335

Sample	Bi	Sb	La	Ce	Pr	Nd	Sm	Eu	Gd	Dy	Ho	Er	Yb	Lu	As	Sn
KW 1A	-	-	52	69	6	21	5	2	4	3	1	2	1	-	8	-
KW 618B	-	-	10	18	3	11	2	1	2	1	-	-	-	-	13	-
KW 618E-3	517.64	-	-	-	-	-	-	-	-	-	-	-	-	-	20109	-
KW 618E-4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	80	13
KW 618E-5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	28	-
KW 618E-6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	34	-
KW 618E-7	-	-	10	18	3	11	2	1	2	1	-	-	-	-	28	-
KW 620A	-	-	12	26	3	12	2	1	3	1	-	-	-	-	106	-

Sample	Mo	W	Au	Cr	Ta	Co	U	Sr ⁸⁷ /Sr ⁸⁶	87Rb/86Sr	143Nd/144Nd	147Sm/144Nd	d34S	d13C	d18O _{pd}	d18O _{smow}
KW 1A	0	-	0.05	396	4	42	12	-	-	-	-	-	-	-	-
KW 618B	-	-	-	162	-	31	1	-	-	-	-	-	-	-	-
KW 618E-3	0.22	98.64	-	64.3	-	47.6	27.32	-	-	-	-	-	-	-	-
KW 618E-4	4	21	0.05	69	-	54	21	-	-	-	-	-	-	-	-
KW 618E-5	4	-	0.05	59	-	34	16	-	-	-	-	-	-	-	-
KW 618E-6	3	24	0.05	-	-	29	20	-	-	-	-	-	-	-	-
KW 618E-7	4	-	-	26	-	37	19	0.734298	3.347	0.51259	0.14852	2.89	-9.03	-16.78	13.07
KW 620A	4	-	0.35	118	-	37	16	-	-	-	-	3.37	-	-	-

TABLE. III.8 :- MAJOR AND TRACE ELEMENTS FROM ALTERATION
HALOES OF QV2 VEIN IN WEATHERED ALBITITE ROCK.

TWANGIZA GOLD DEPOSIT

Major oxides

Sample	KW 87A1	KW 87A2	KW 87B2
SiO2 (wt%)	37.26	46.44	42.45
TiO2	0.85	1.49	1.74
Al2O3	29.11	34.52	33.25
Cr2O3	0.01	0.02 *	
Fe2O3	25.58	8.98	5.39
MnO	0.02	0.01 *	
MgO	1.23	0.04	0.42
CaO	0.05	0.04 *	
Na2O	0.35	0.3 *	
K2O	0.33	0.51	0.59
P2O5	0.15	0.08	0.1
V2O5	0.01	0.01	
NiO	0.02	0.01	
CuO	0.01	0.01	
ZnO	• •		
SO3	0.02	0.02	
F	•		
LOI	• •		
Total	95.06	93.31	

Trace Elements.

Sample	KW 87A1	KW 87A2
V (ppm)	161	163
Cr	163	183
Co	36	16
Ni	114	33
Cu	•	•
Zn	30	29
As	9982	2348
Se	6	•
Rb	18	23
Sr	14	12
Y	33	46
Zr	232	404
Nb	18	31
Mo	4	5
Sn		
Sb		
Te		
Ba	83	83
Ta		
W		8
Pb		
Bi	6	
Th	8	11
U	3	
Ag		
Au	0.35	0.4

Rare Earth Elements.

	KW 87A1	KW 87A2
La	33.2	43.9
Ce	82	110
Pr	8.2	10.6
Nd	31.9	40.6
Sm	7	8.5
Eu	1.8	2
Gd	7.5	7.3
Tb	1.1	1
Dy	6.6	5.6
Ho	1.3	1.1
Er	3.7	2.9
Tm	0.5	0.4
Yb	3.4	2.8
Lu	•	•
Th	•	•
U	•	•

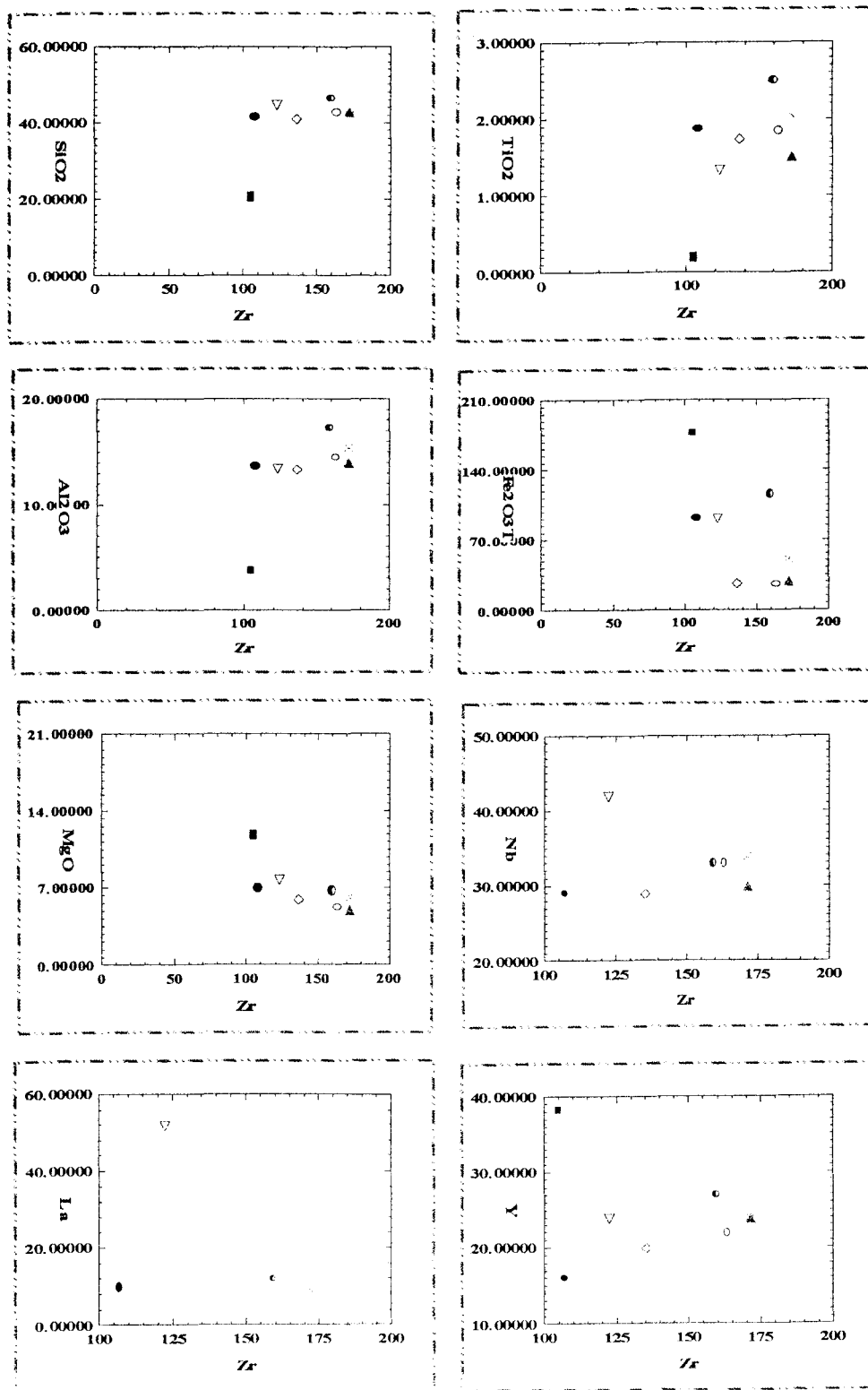
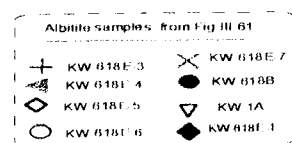


Fig.III.62:- Scatter diagrams of Zr versus SiO₂, TiO₂, Al₂O₃, Fe₂O₃, MgO, La, Nb, Y of QV1 in albitite.



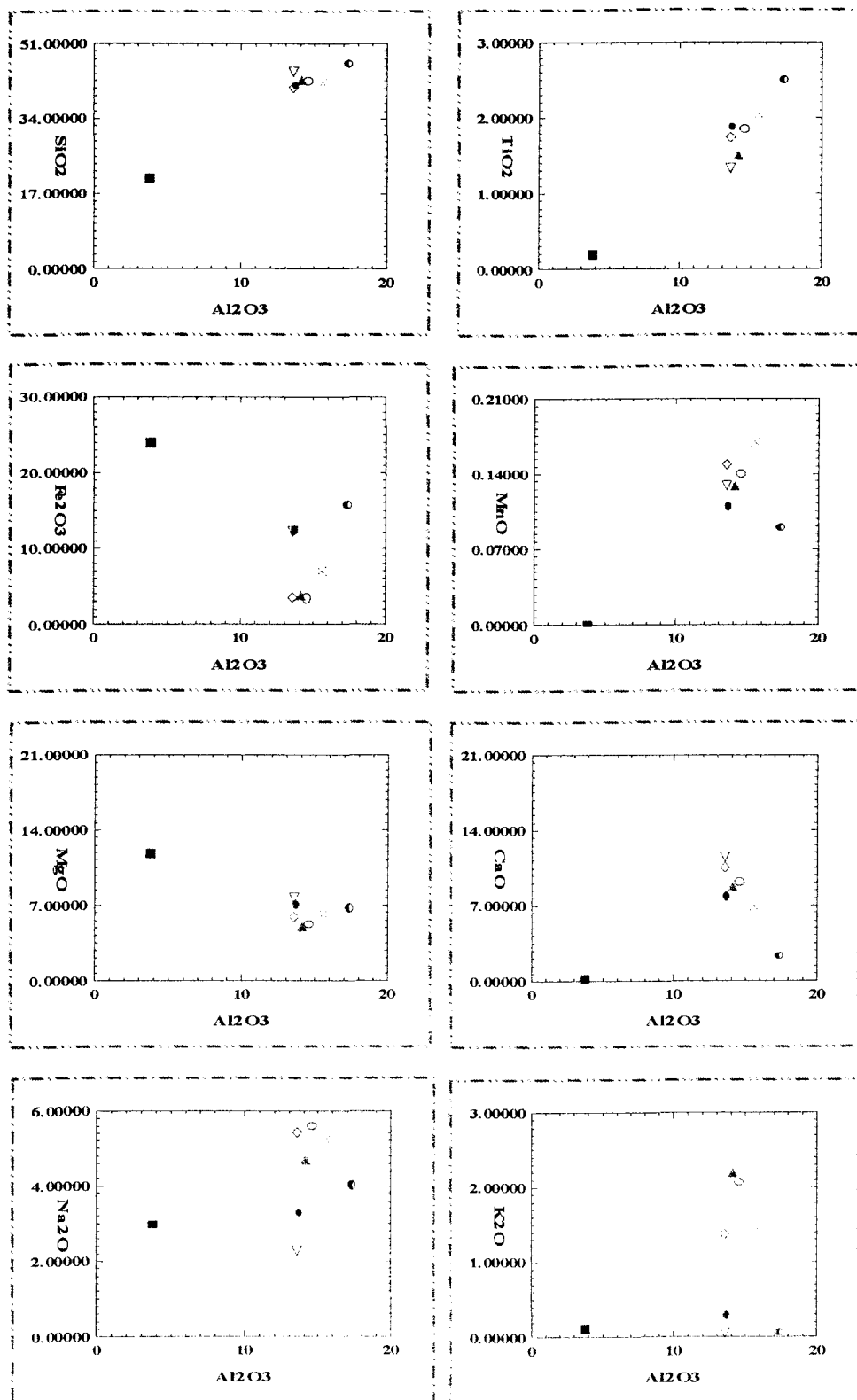
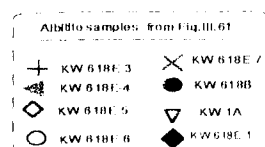


Fig.III.63:- Correlation diagrams of Al_2O_3 versus SiO_2 , TiO_2 , Fe_2O_3T , MgO , MnO , Na_2O , CaO , K_2O



Plot of LOI vs. $\text{Na}_2\text{O}+\text{CaO}$ show a strong correlation from unaltered primary albitite rock (KW 620A) to most altered one (KW 618E1). (Fig.III.64). The Na_2O and CaO are gained at a very early stage of alteration. Subsequent increases in loss on ignition could be to the replacement of quartz by chlorite. Plots of SiO_2 vs $\text{K}_2\text{O}/\text{Al}_2\text{O}_3$ and Al_2O_3 vs $\text{Fe}_2\text{O}_3/\text{Al}_2\text{O}_3$ show an inverse correlation (Fig.III.65).

The REE patterns from the unaltered primary albitite sample (KW 1A), compared to the altered and/or mineralized samples were not similar (Fig.III.66). These samples are enriched in LREE with positive europium. REE abundance appear to have been largely inherited from protoliths of the altered rocks. Mobility and fractionation of REE during alteration is suggested.

Hence, Al_2O_3 was very immobile followed by Zr. TiO_2 , SiO_2 , Nb have been very slightly mobile. La, Fe_2O_3 , Y, show a complex changes of both addition and subtraction.

12.6.3.1.2.- QV₂ IN BLACK SHALE.

Trends of SiO_2 - Zr, TiO_2 - Zr, and Al_2O_3 - Zr for the samples close to the vein QV₂, show slightly, the required characteristics of immobile elements pairs. On the other hand, Nb - Zr, La - Zr, Y - Zr, MgO - Zr, Fe_2O_3 - Zr don't display immobile behavior (Fig.III.67).

Al_2O_3 versus selected elements, (Fig.III.68) show positive correlation with SiO_2 , TiO_2 and negative with Fe_2O_3 . Against MgO, CaO, and Na_2O , Al_2O_3 doesn't correlate.

REE from the unaltered rock (KW 152) and from each alteration assemblage have been collected and analysed. The REE patterns from the unaltered rock were similar, with a slight enrichment in LREE, a relatively steep pattern for M-HREE and a negative europium anomaly. (Fig.III.69).

REE values were normalised respectively against primitive chondrite material, post-Archean sediments, shale composite NA and plotted in Fig. III.69, 70 & 71.

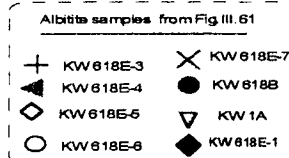
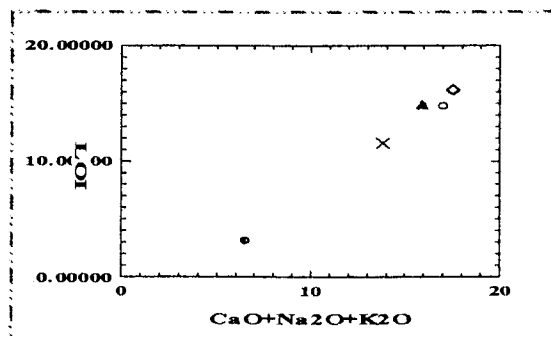


Fig.III.64:- Binary plot of LOI versus (CaO + Na₂O + K₂O) of albite samples.

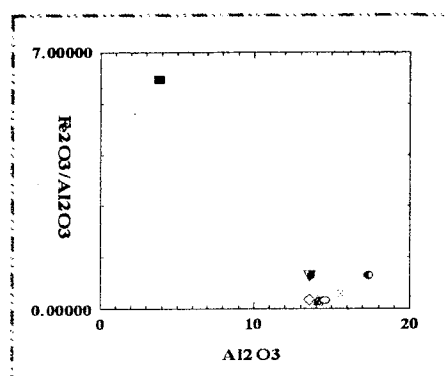
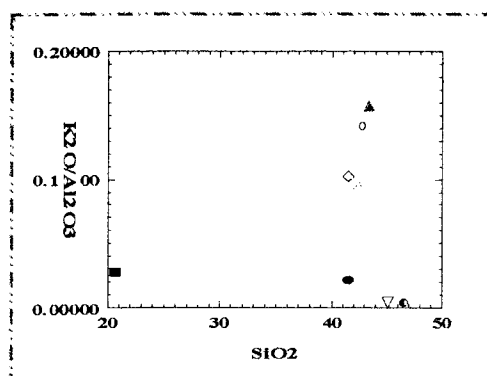


Fig.III.65:- Binary plots of SiO₂ versus K₂O/Al₂O₃ and Al₂O₃ versus Fe₂O₃/Al₂O₃

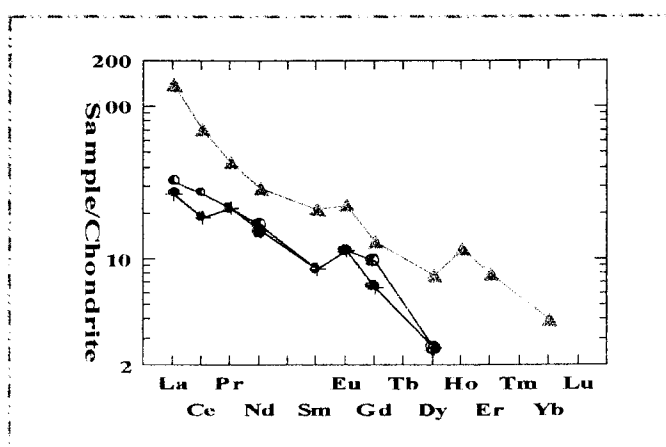
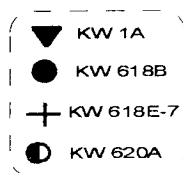
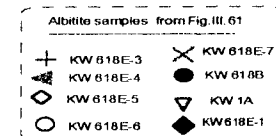
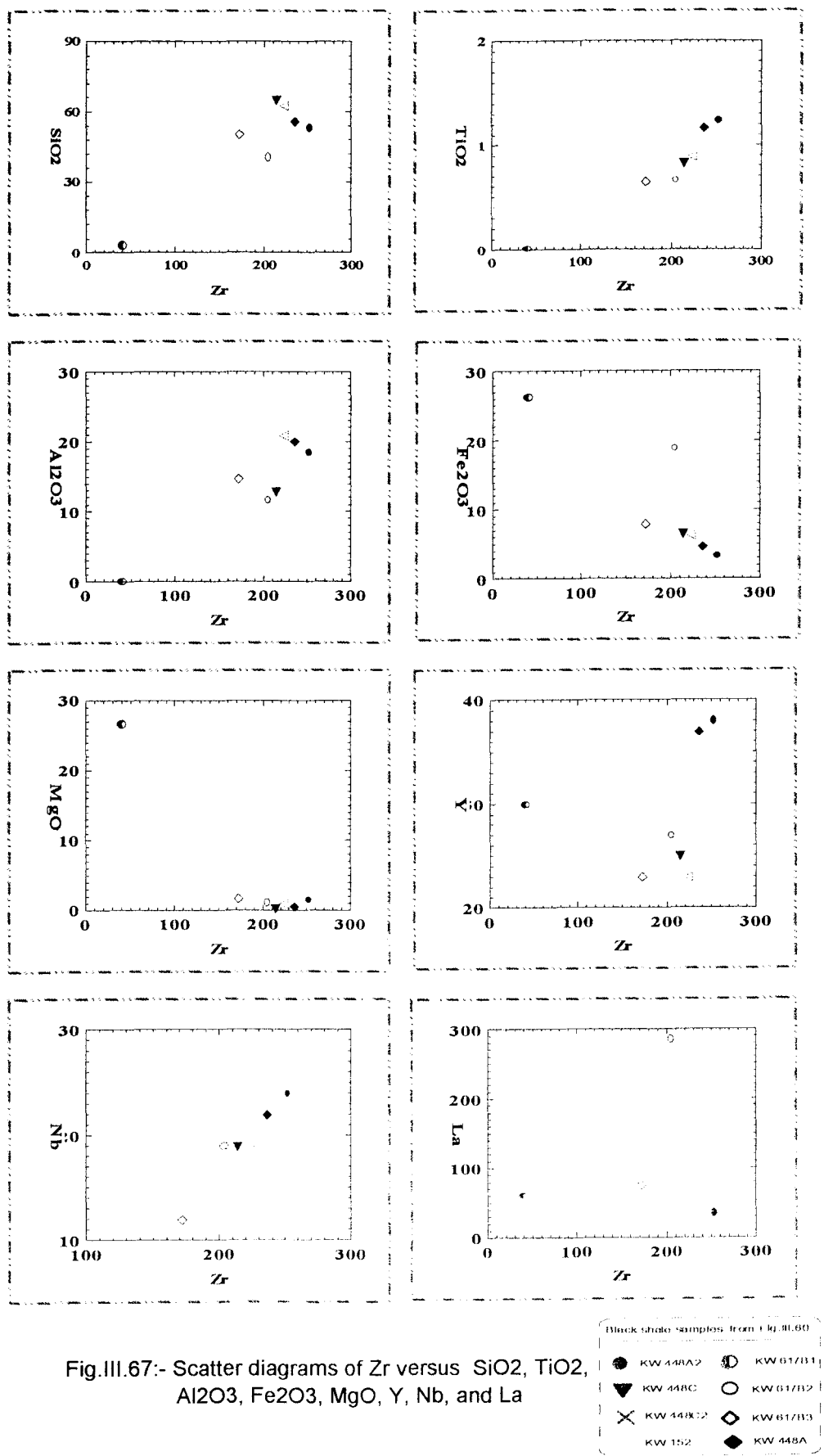


Fig.III.66:- REE patterns from the fresh albite sample (KW 1A) compared to the most altered and / or mineralized samples (KW 618, KW 618E-7, and KW 620A).



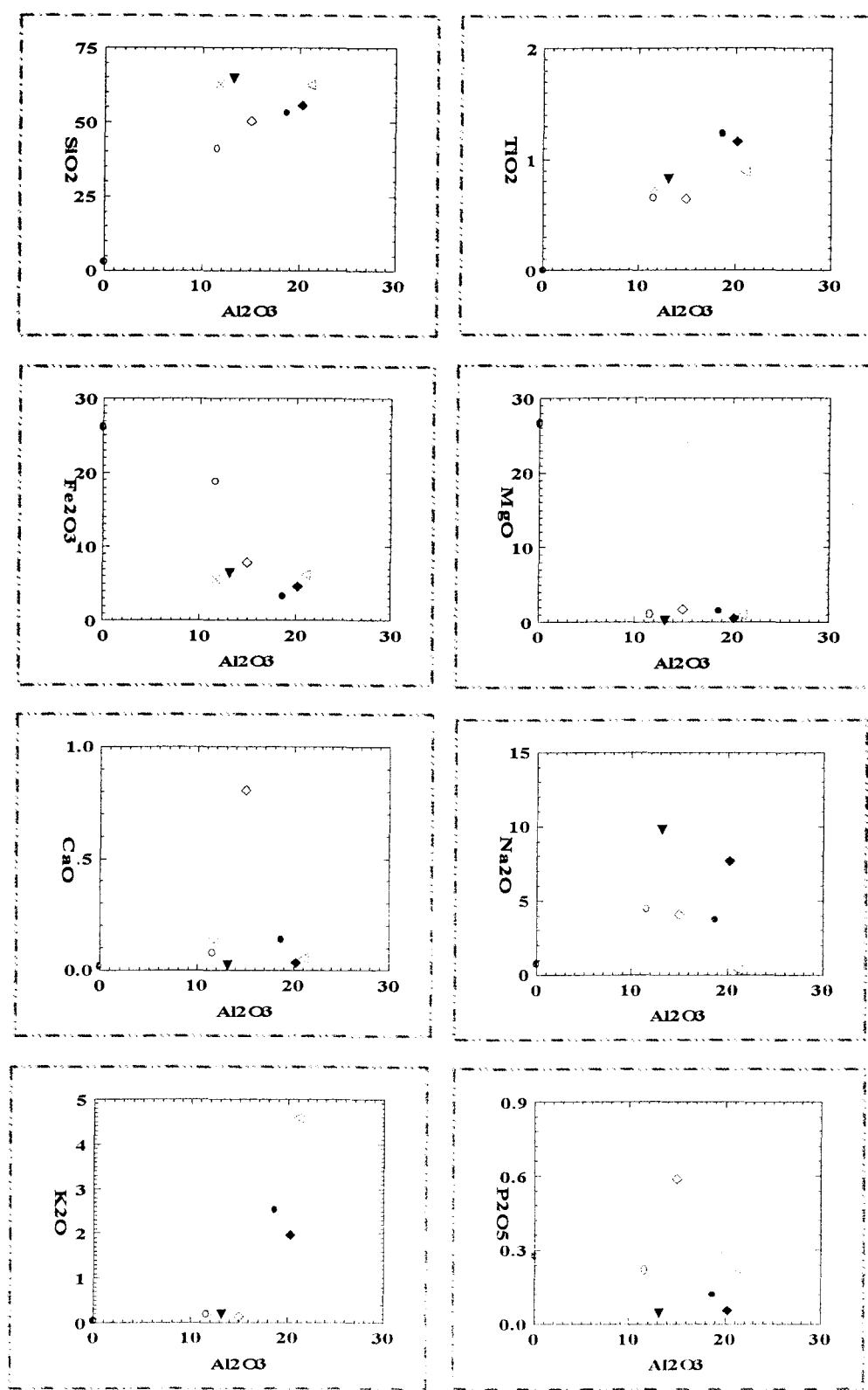


Fig.III.68:- Correlation diagrams of Al_2O_3 versus SiO_2 , TiO_2 , Fe_2O_3 , MgO , CaO , Na_2O , K_2O , P_2O_5

Black shale samples from Fig. III.60

- KW 448A2 ○ KW 617B1
- ▼ KW 448C ○ KW 617B2
- × KW 448C2 ◇ KW 617B3
- KW 152 ◆ KW 448A

Fig.III.69 :- REE patterns from the less altered black shale sample (KW 448C2) compared to the most altered and mineralized samples (KW 448A2, KW 617 B3, KW 617B2).

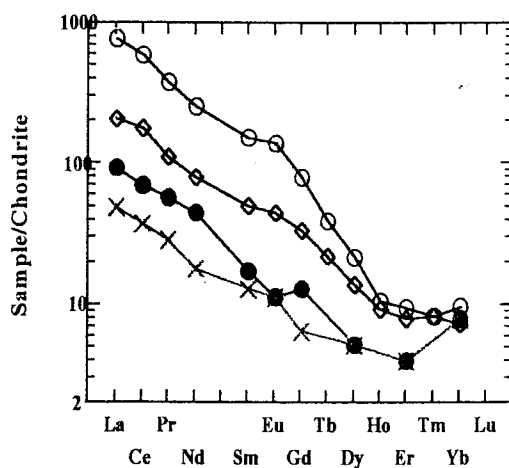
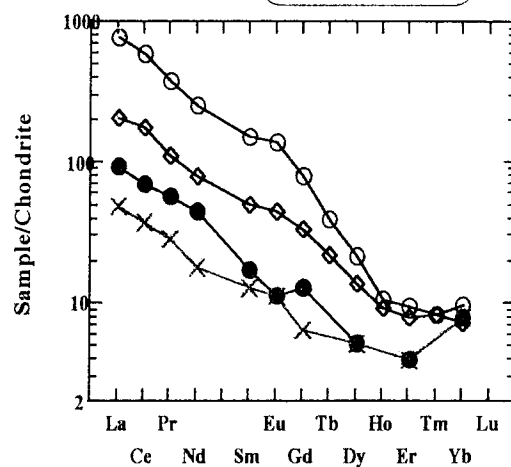
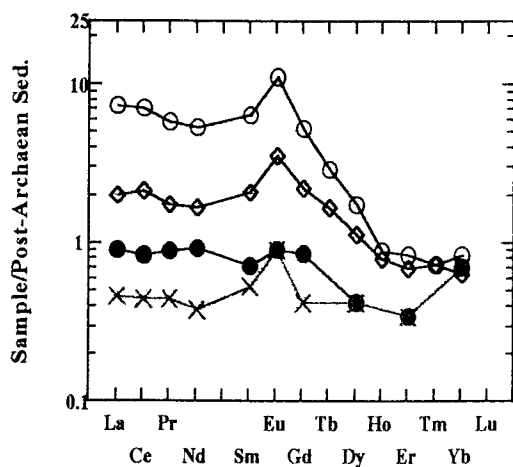


Fig.III.70 :- Chondrite normalized REE patterns for selected black shale samples associated with vein-type (QV2) sulphide mineralization.

Black shale samples from Fig.III.60

- KW 617B2
- KW 448A2
- ◇ KW 617B3
- × KW 448 C2

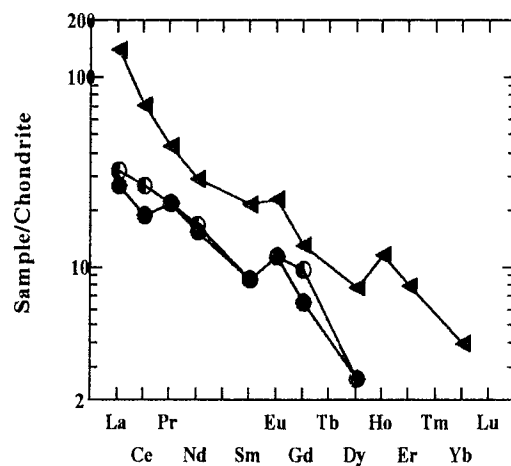


Fig.III.71 :- Chondrite normalized REE patterns for selected altered albitite samples associated with vein - type (QV1) mineralization.

Albitite samples from Fig.III.61

- ◄ KW 1A
- KW 618B
- ◐ KW 620A
- + KW 618E-7

According to Bierlein (1995); REE distributions in metasediments associated with sulphide mineralization reflect both physico-chemical characteristics of the ore-bearing fluids and rocks compositions. Interpretations are by no means straightforward, since the relative mobility of REE in hydrothermal systems is influenced by a number of important factors such as fluid-rock interactions, physico-chemical properties of the fluid and changes in temperatures and pressure (Bau, 1991, Lottermoser, 1992).

Positive Eu anomalies are generally attributed to hydrothermal precipitates reflecting derivation from hot, reducing fluids (Taylor and McLennan, 1985). Therefore, positive Eu anomalies found in metasediments associated with sulphide mineralisation from the Twangiza deposit suggest deposition under relatively hot and reducing condition (Sverjensky; 1984).

Comparison between most altered albitite (KW 618E-4, close to QV₃ vein) and black shale (KW 448A, close to QV₂ vein) samples from the Twangiza deposit, and those similar unaltered samples not associated with mineralization. (KW 1A and KW 152 respectively), has been undertaken in order to establish the anomalous in composition at least in major and trace constituents (Fig.III.72 and Fig.III.73).

In the first case, altered albitite rock, the sample is most enriched in Na₂O, As, Rb, Ba, U and depleted in Fe₂O₃, Cr, Ni, Sr. In the second case; altered black shale, the sample is enriched in Na₂O, As and depleted in P₂O₅.

These differences are interpreted as due to the fact that, samples close to veins have been largely hydrothermally altered.

When plotted on a ternary diagram of Al₂O₃ - (CaO+Na₂O +K₂O) - (FeO+MgO), (Nesbitt and Young; 1989 and Bierlein, 1995) hydrothermally altered black shale, and albitite samples from Twangiza deposit, plot outside the field of unaltered siliciclastic protoliths and define a trend characteristic of Mg-metasomatism.

The effect of Mg metasomatism on this black shale and albitite is evident in a shift towards the Fe₂O₃+MgO apex in Fig. III.74. Hydrothermal fluids combined with dilution by quartz and sulphides probably account for the relative depletion in HFSE and higher U/Th ratios in these samples.(Fig. III.75).

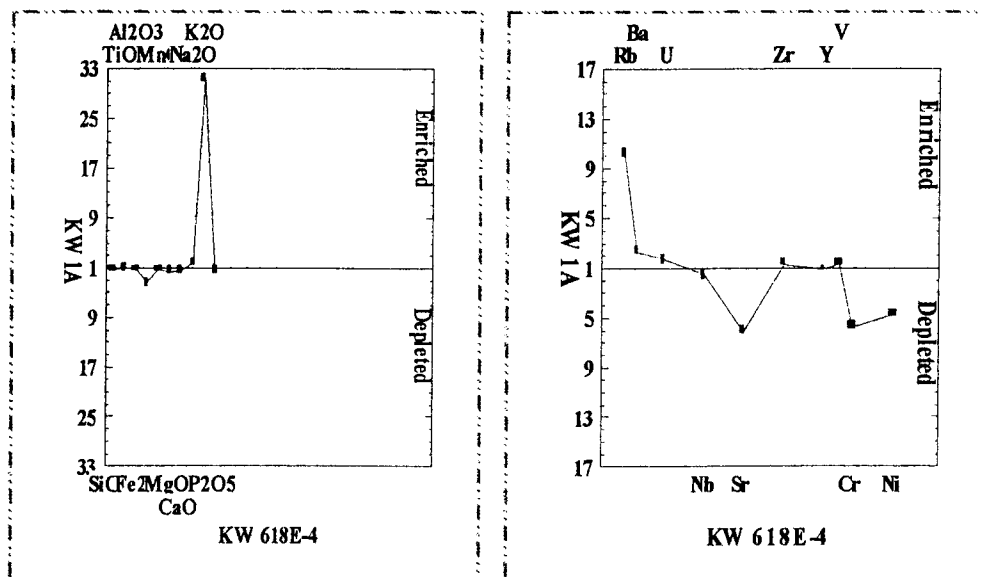


Fig.III.72:- comparison of major and trace elements between most altered albite sample (KW 618E-4) , close to a QV1 vein, and a similar unaltered sample (KW 1A) not associated with mineralization.

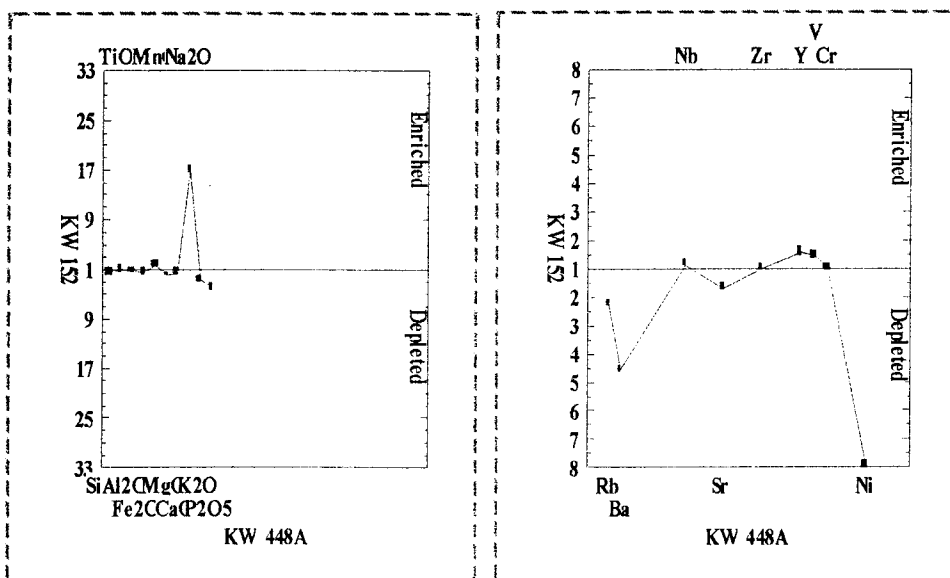
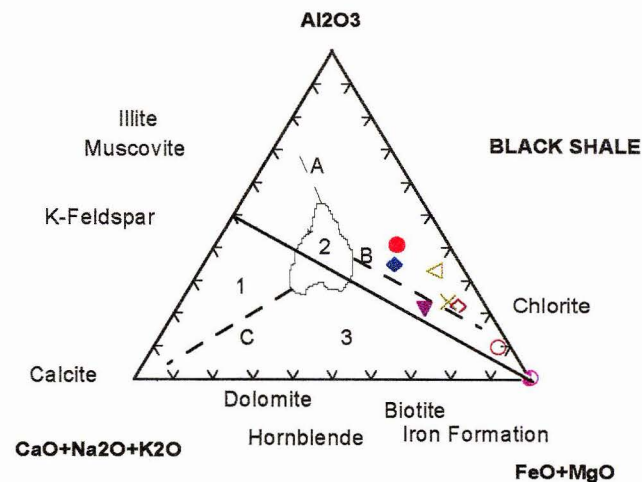
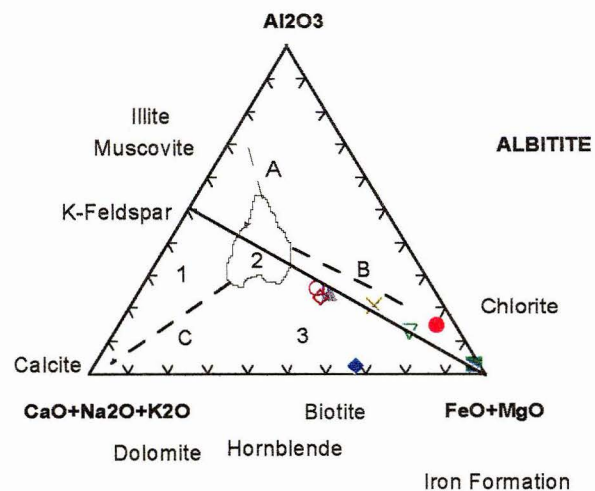
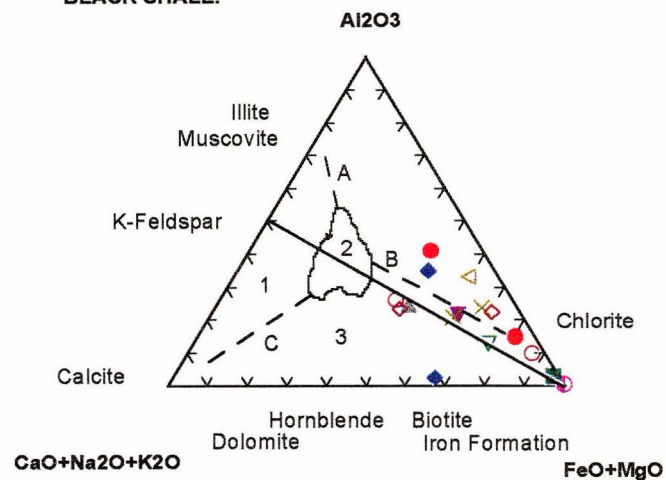


Fig.III.73:- Comparison of major and trace elements between most altered black shale sample (KW 448) , close to a QV2 vein, and a similar unaltered sample (KW 152) not associated with mineralization.



ALBITITE & BLACK SHALE.



Black shale samples from Fig.III.60

- KW 617B1
- KW 617B2
- ◇ KW 617B3
- ◇ KW 448A
- KW 448A2
- ▽ KW 448C
- × KW 448C2
- ◇ KW 152

Albitite samples from Fig.III.61

- +
- △ KW 618E-4
- ◇ KW 618E-5
- KW 618E-6
- × KW 618E-7
- KW 618B
- ▽ KW 1A
- ◇ KW 618E-1

Arrows A indicates metasomatic transformation into muscovite with fluids characterised by high K^+ / H^+ ratios ; trends moves away from the $CaO + Na_2O + K_2O$ apex due to relative depletion in CaO and Na_2O with subsequent K_2O and Al_2O_3 enrichment.

Arrow B indicates metasomatic transformation into chlorite with fluids characterised by high Mg^{2+} / H^{2+} ratios.

A — — — — —> K - Metasomatism
 B — — — — —> Mg - Metasomatism
 C — — — — —> Carbonatisation or calcite-rich Protoliths.

1 : - Granitic , 2 : - Siliclastic Protoliths , 3 :- Basaltic igneous rocks.

Fig.III.74:- Ternary diagram of molecular Al_2O_3 - $(CaO+Na_2O+K_2O)$ - $(FeO+MgO)$ showing compositional variations and metasomatism in the analysed hydrothermally altered samples. [A: Black shale , B: Albitite, and C: Black shale + Albitite]. After Nesbitt and Young (1989), Camire et al., 1993 and Bierlein (1998).

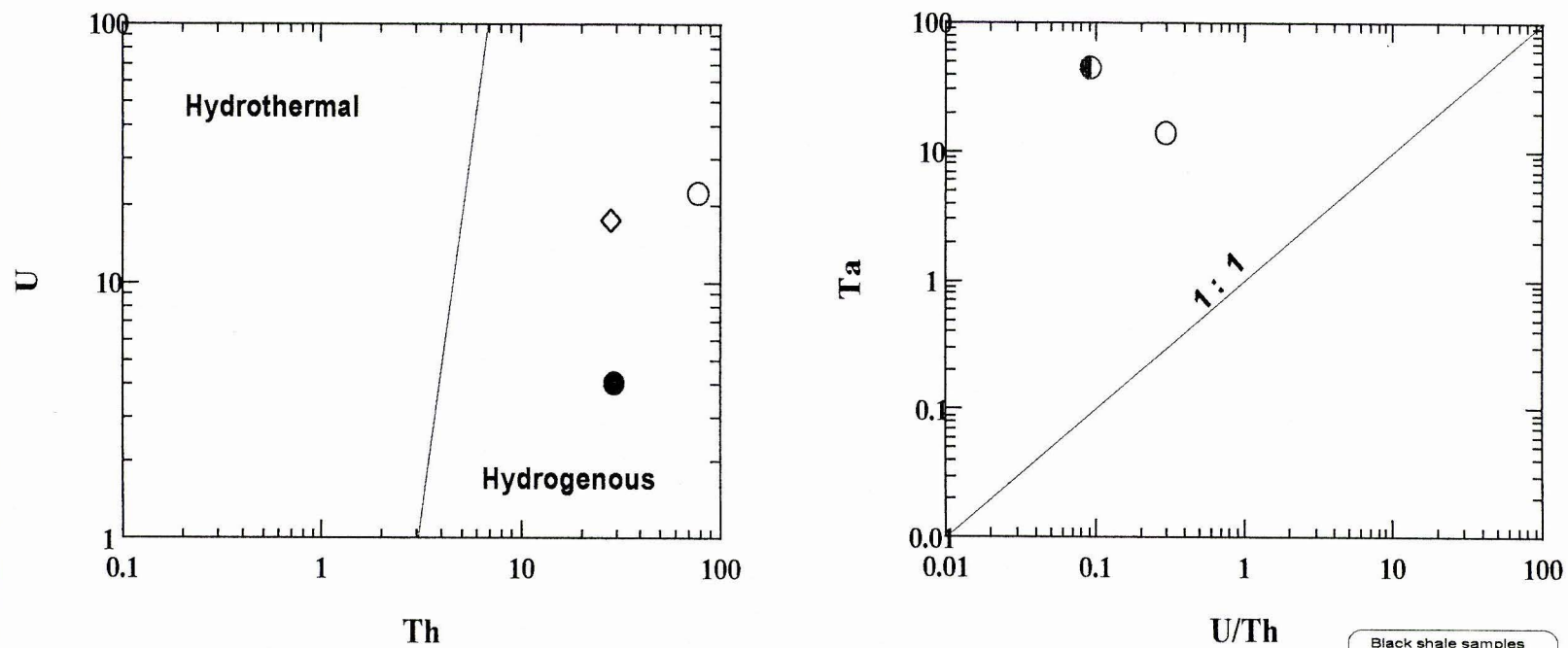


Fig.III.75:- Trace element plots for the Kadubu black shale metasediments associated with the vein - type QV2 sulphide mineralization.

- Black shale samples from Fig.III.60
- KW 617B1
 - KW 617B2
 - ◇ KW 617B3
 - ◆ KW 448A
 - KW 448A2
 - ▼ KW 448C
 - × KW 448C2
 - KW 152

Epigenetic veinlets of chlorite and sericite are present in albitite samples, which suggests subordinate hydrothermal alteration with subsequent K and Mg metasomatism.

12.6.3.2.- MOUNTAIN AND WILLIAN-JONE'S METHOD.

Following the method of Mountain and Willian-Jones, (1995); alteration zones have been used to decipher the process of fluid – rock interaction .

One –dimensional flow-line model has been developed and applied to interpret the chemical change resulting from rock alteration due to advection of hydrothermal fluid.

Two samples (Fig.III.60 & Fig.III.61) from two different type veins (QV₂ : KW 617, KW 448, KW 622 , KW 512 and QV₁ : KW 618E) with its associated alterations ,were used to generate detailed mineralogical and geochemical profiles .

These samples are considered to be representative of alteration zonation along respectively albitite and black shale host rocks, and there was no overprinting of alteration from another vein.

A third sample (KW 87A) from a weathered profile of QV₂ in albitite rock (Fig.III.73) has been also investigated for element mobility which took place in the vein and in albitite wall-rock during weathering after hydrothermal activity.

The alteration halo on one side of the vein was cut into small samples , parallel to the vein in order to make an accurate determination of the changes in major elements and minor element abundances that occurred during hydrothermal alteration and weathering

Petrographic studies of these samples was supported by XRD analysis of each of them.

Thus after, these samples were analysed for major and trace elements. (Table.III.6, Table.III.7, and Table.III.8).

To show the mass changes in spatial context ;selected major and trace elements changes were plotted versus distance, respectively for the three different type veins and associated alteration haloes. Sr, K, Rb, Ba and Nb, Ce, P, Zr, Ti, Y are considered respectively as mobile and immobile elements.

12.6.3.2.1.-QV₂ IN BLACK SHALE (Fig.III.76 , Fig.III.77). Table. III.6.

In accordance with the geochemical profile, five main zones have been defined (arsenopyrite zone, pyrite zone, sulphide plus carbonate zone, carbonate zone and fresh rock).

In the Fig.III.76 and Fig.III.77, the Rb, Nb and Al₂O₃ elements are the ones which exhibit the most systematic variation with distance. Little change can be observed in most of the trace and major elements (Fig.III.76; Fig.III.77). Fig.III.78 shows the variation of As and Au relative to distance from the QV₂ vein.

Fig.III.79 and Fig.III.80 show the variation of Ni, V, Cr, and Co within 150mm into black shale host rock.

12.6.3.2.2.- QV₁ IN ALBITITE (Fig.III.81, 82, 83).Table.III.7.

Three zones have been defined . For samples (KW 618E-4 and KW 618E-5) in *the zone 1* (Albite- pyrite-arsenopyrite-dolomite-quartz zone), and samples (KW 618E-6 and KW 618E-7) in *the zone 2* (Albite- pyrite- dolomite- magnesite-zone) there was relatively little change in most of the major elements.

Na₂O, TiO₂, and Al₂O₃ show small positive departures probably reflecting a slight increase in albite and ankerite content without significant change in quartz content.

Fe₂O₃ show a negative departure from the vein to the host rock but after, very little change occur. (Fig.III.81 and Fig.III.82).

Among the trace elements, Y and Zr show a negative departures from the zero mass change line in sample KW 618E-4; while Sr, and La show little changes. Fig. III.83 shows the variation of As along the profile.

Thus samples KW618E4 to KW 618E-7, appear to be, more or less, isochemically altered and are representative of the most altered albitite rock.

The zone 3 (Clinocllore-albite -magnesite –muscovite zone) with samples KW 618B and KW 620A , exhibits loses of Na₂O, K₂O, Rb, Sr, Zr, Y and gains in MgO, CaO, Fe₂O₃ . TiO₂ and P₂O₅ show very little change and can be considered to have been relatively immobile.

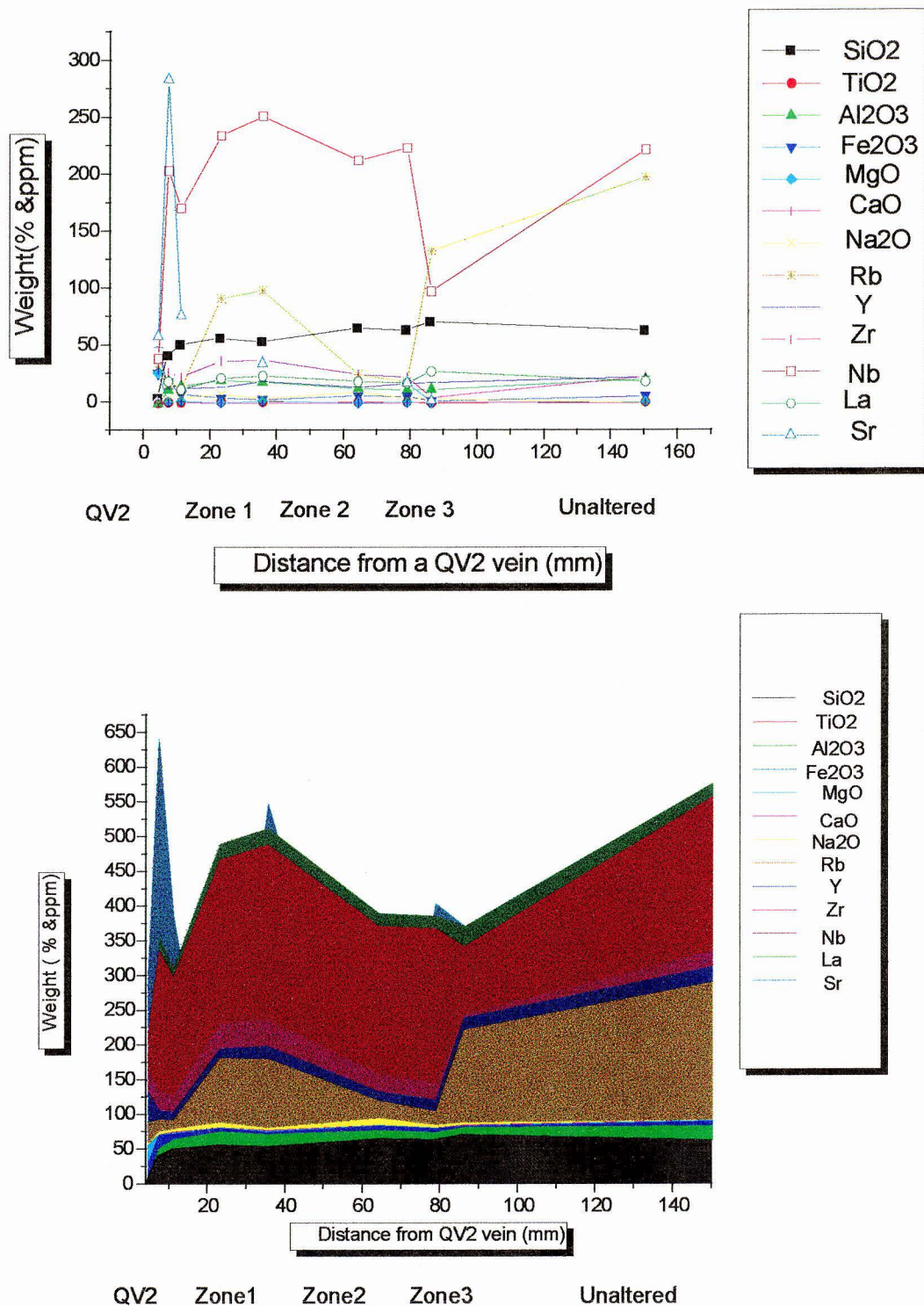


Fig.III.76:- Element distribution in black shale from Twangiza deposit showing significant variation within 150mm from a QV2 vein.

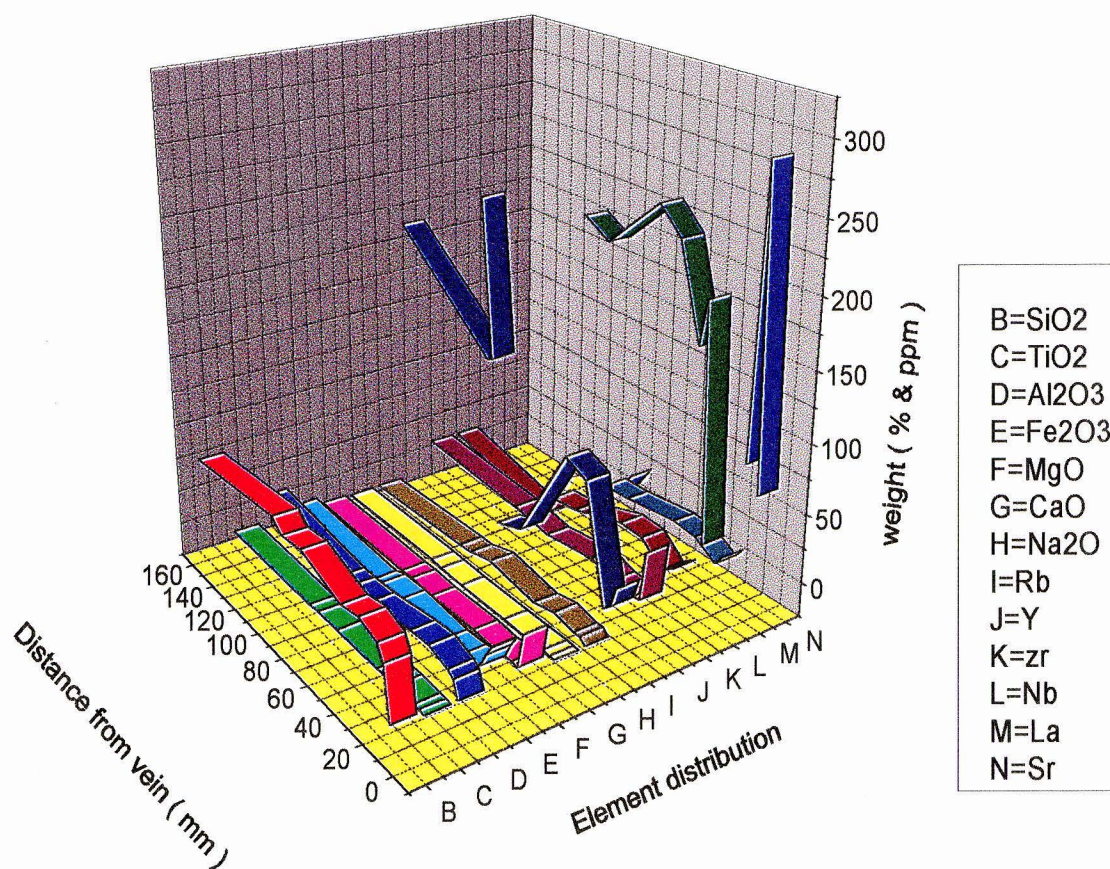


Fig.III.77:- 3D portrayal of elemental distribution in black shale from the Twangiza deposit, plotted against increasing distance from QV2 vein.

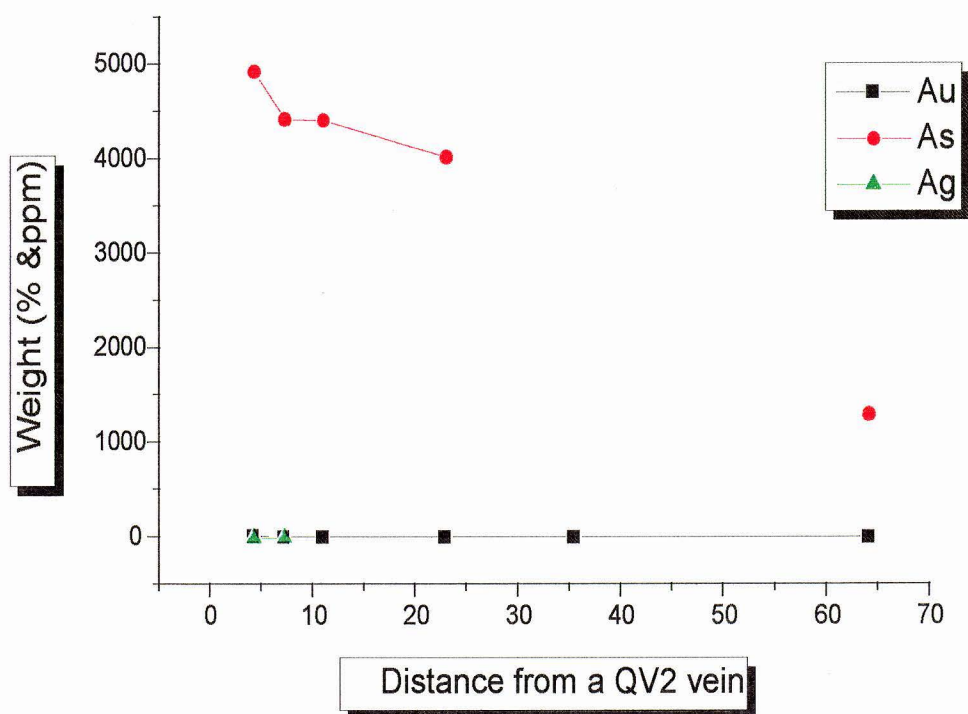


Fig.III.78:- Variation of As, and Au relative to distance from a QV2 vein.

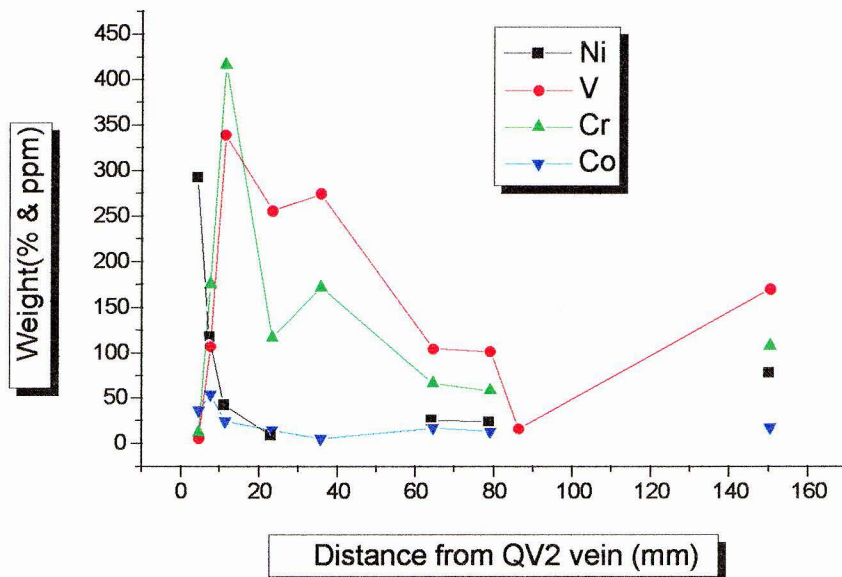


Fig.III.79:- Ni, V, Cr, and Co variation within 150mm of a QV2 vein into black shale host rock.

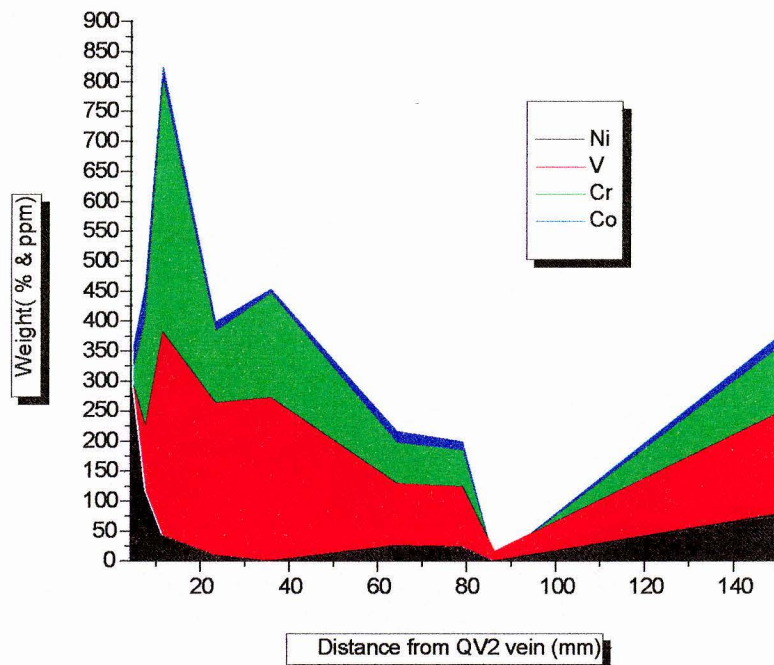


Fig.III.80:- Elemental distribution of Ni, V, Cr and Co in black shale from the Twangiza deposit, plotted against increasing distance from QV2 vein.

Fig.III.81:- Mass change profiles for selected major element oxides and trace elements , plotted against increasing distance from a QV1 vein , across the albitite alteration haloe.

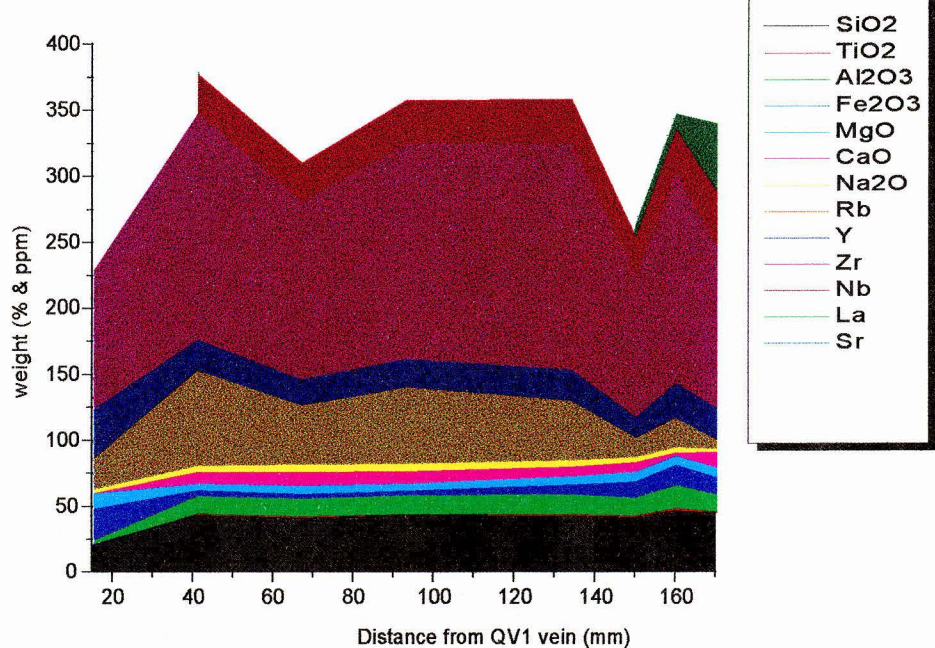
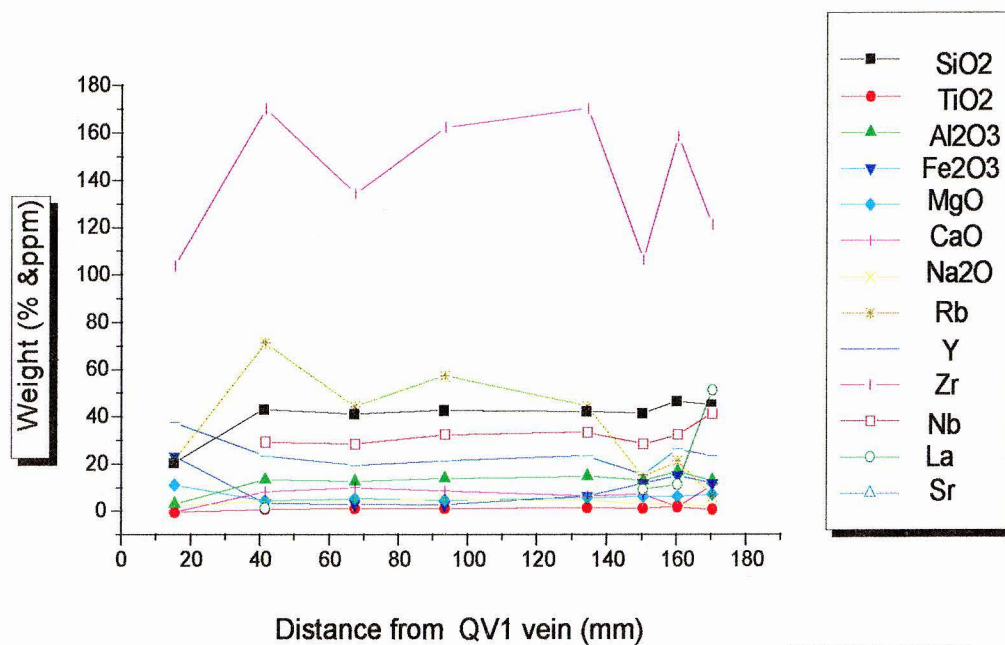


Fig.III.82:- Mass change profiles for selected major element oxides and trace elements plotted against increasing distance from a QV1 vein , across the albitite alteration haloe.

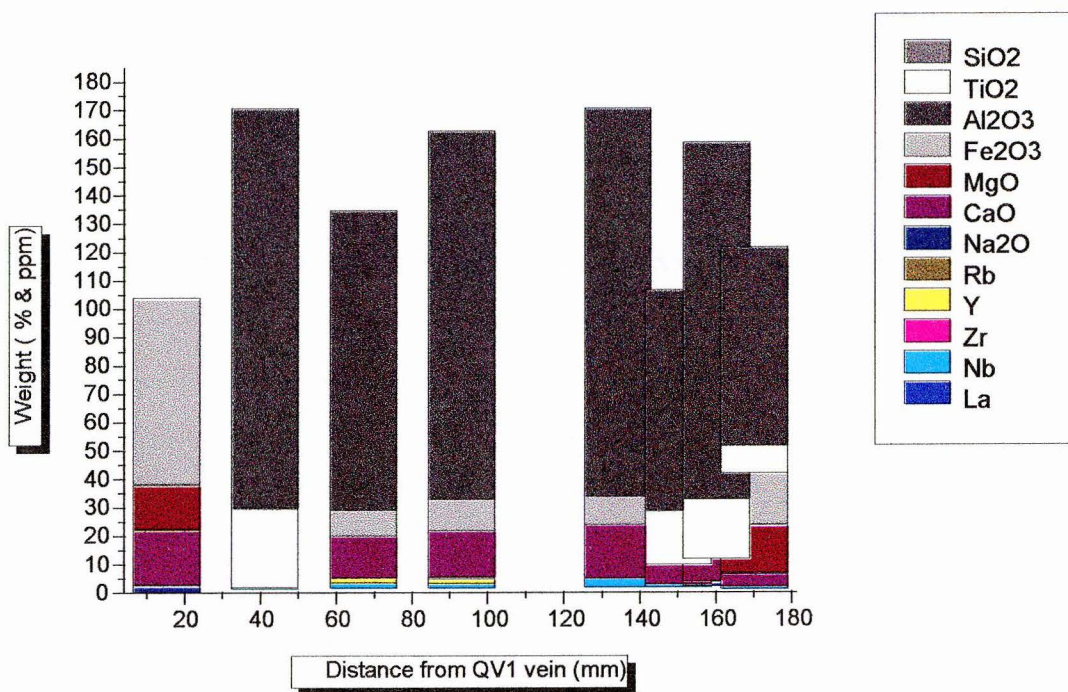


Fig.III.82:-Flotting column portrayal of mass change profiles for selected major element oxides and trace elements, plotted against increasing distance from a QV1 vein, across the albitite alteration haloe.

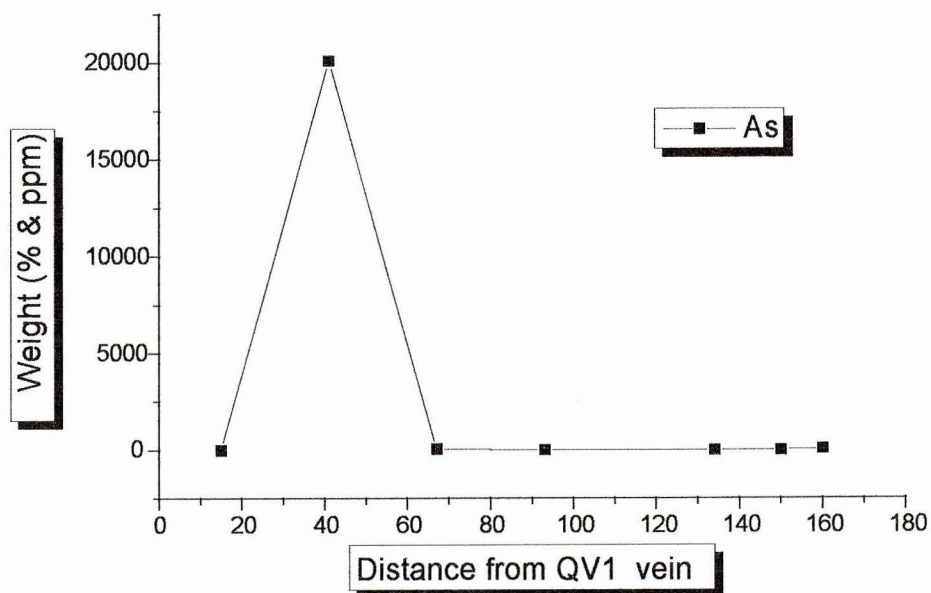


Fig.III.83:- Variation of As along a profile within an albitite haloe.

This zone is characterized by a gradual drop in carbonate (ferroan dolomite) content ; increase in quartz, albite and apparition of ferroan clinocllore, ferroan magnesite and muscovite.

QV₁ mineralogy : pyrite, arsenopyrite , calcian albite, quartz, muscovite, chlorapatite.

12.6.3.2.3.-QV₂ – IN WEATHERED ALBITITE (Fig.III.84, 85, 86, 87) ; Table.III.8.

These samples have been subdivided into two zones : rutile- kaolinite-muscovite zone (KW 87A-2) and kaolinite- goethite- quartz zone. (KW 87B). The first zone located immediately adjacent to the vein is characterized by depletion in TiO₂, K₂O, P₂O₅ and enrichment in SiO₂, Al₂O₃, Fe₂O₃ (Fig.III.85).

This slight loss of Ti (curiously) is reflected by the coarse rutile grains in visible alteration close to the QV₂, vein (Fig III.84).

Vein mineralogy (KW 87A-1) : kaolinite, goethite, muscovite, quartz, hematite.

Mineralogy of weathered albitite rock : kaolinite, muscovite, quartz, goethite, rutile and albite.

Fig.III.86 & 87 show the mass change profile for selected major elements oxides and traces elements with increasing distance from the QV₂ vein, across the weathered halo of altered albitite.

12.6.4.- SUMMARY AND DISCUSSIONS.

Rocks which experienced significant alteration by hydrothermal fluids display variable trends of REE mobility. Positive anomalies in any of the hydrothermally altered samples, combined with other geochemical constraints, suggest that sulphides were precipitated probably from hot fluids of variable redox states.

The variations of major elements observed correlate with the mineralogical variation .

The geochemical data indicate that most elements were mobile during hydrothermal alteration.

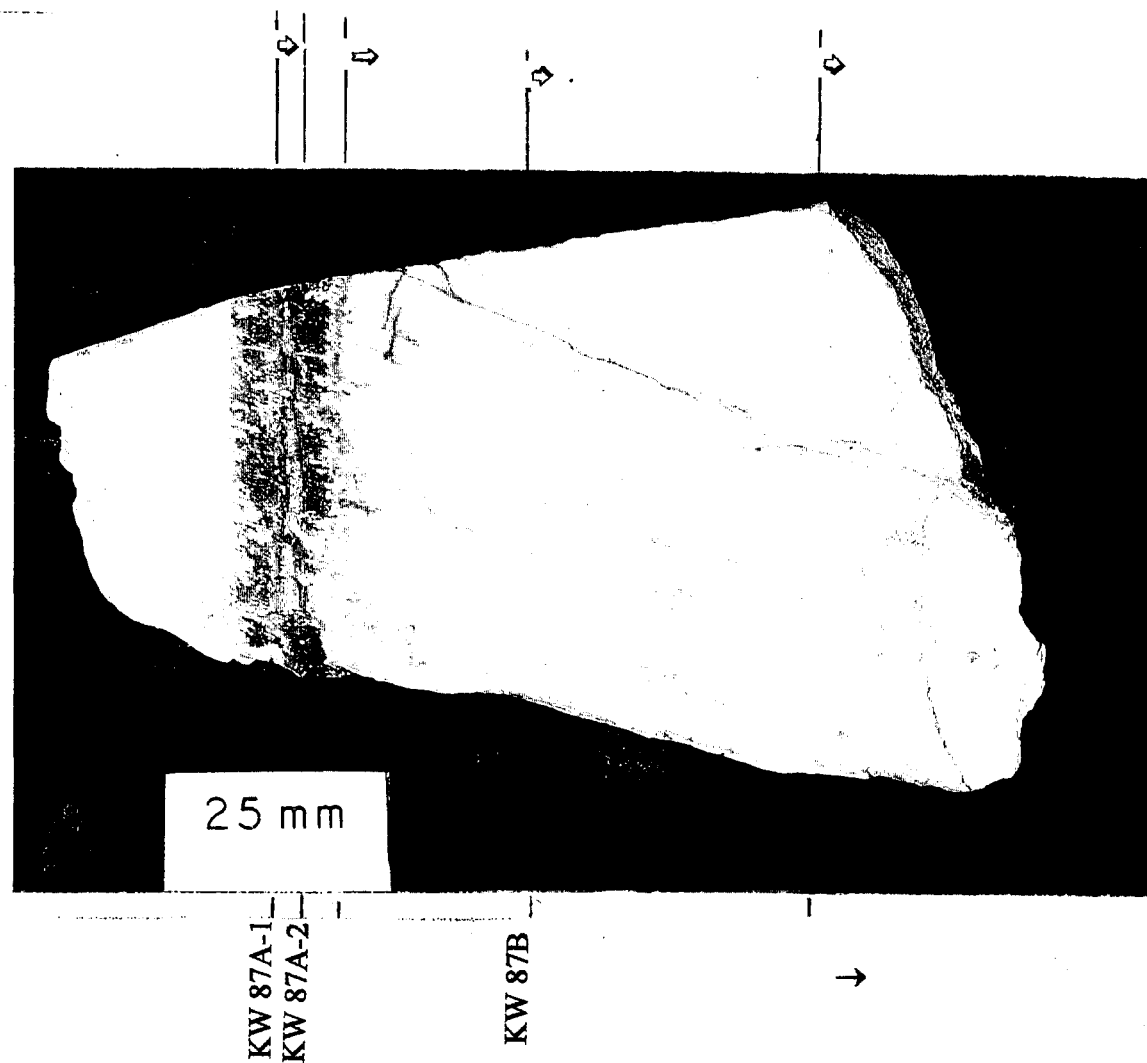


Fig. III.84. Hand specimen of alteration material adjoining a weathered QV_2 vein associated with albitite host rock. Twangiza gold deposit.

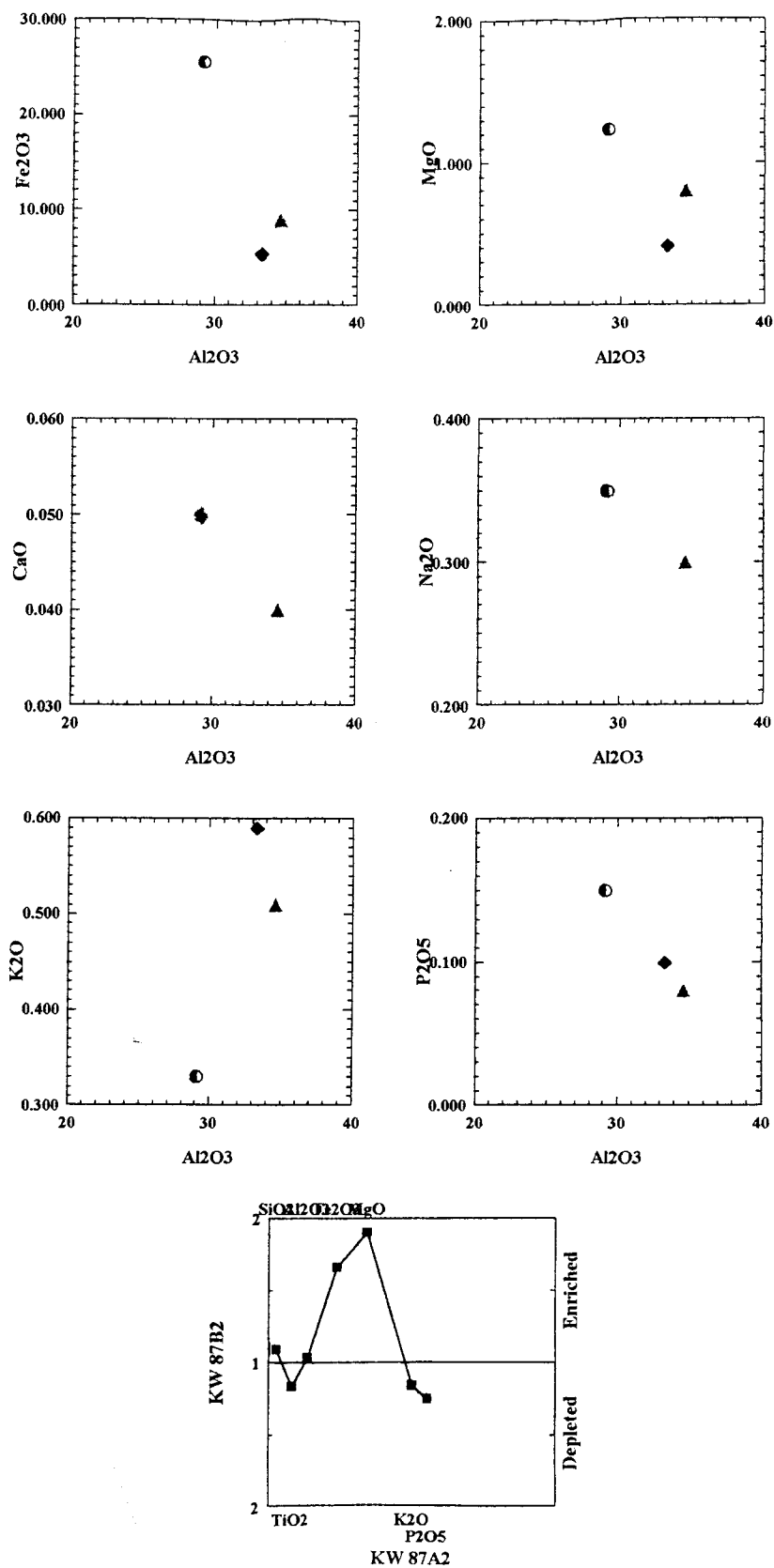


Fig.III.85:- Some geochemical characteristic of the weathered albitite, and enrichment / depletion diagram between the first and second zones of weathered albitite host rock.

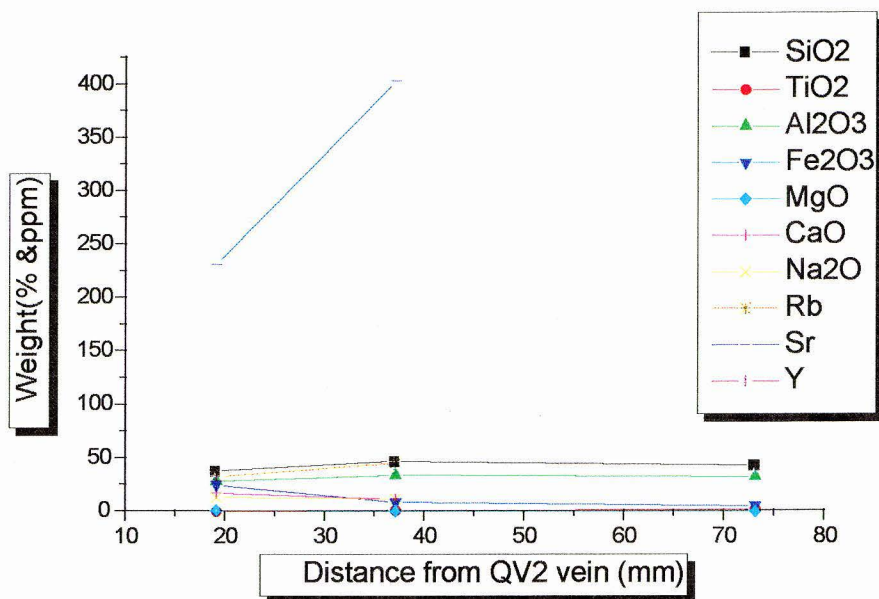


Fig.III.86:- Elemental distribution in weathered albitite from the Twangiza deposit , plotted against increasing distance from a QV2 vein.

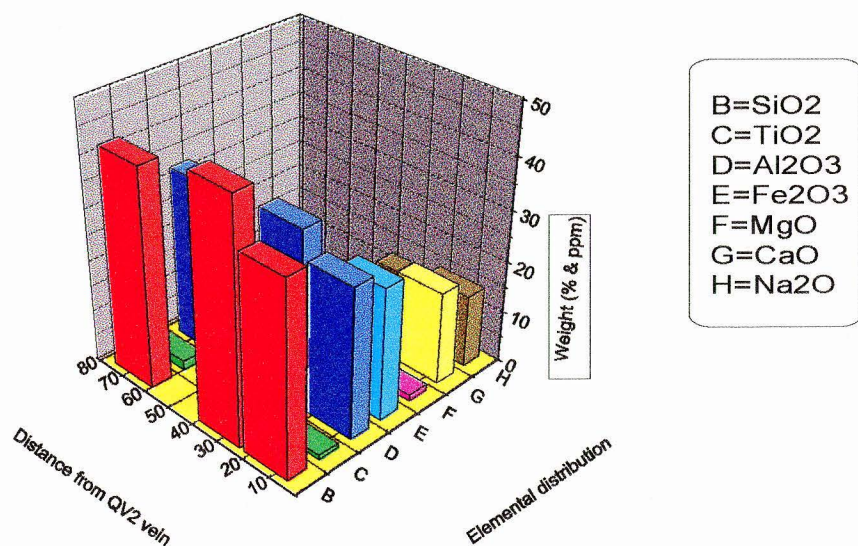


Fig.III.87:- 3D portrayal elemental distribution in weathered albitite from the Twangiza deposit, plotted against increasing distance from a QV2 vein.

Deposits are enriched in rare elements (As, Sb, Te, Bi, B), lithophile elements (LILE: Ba, Li, K, Rb, Cs, TL), volatiles (H_2O , CO_2 , H_2S) and precious elements (Au, Ag). Element such as Fe, Mg, Ca, Si, and Na may be added or depleted. Cu, Zn and Pb are generally low in the wall rocks as well as the veins.

High-field-strength elements (HFSE: Th, Nb, Ta, Zr, Ti, Y, P, Al, Ga), rare earth elements (La through Lu), and compatible trace elements like V, Cr, Sc, and Ni, have been more or less sensitive to alteration.

As, Au, CO_2 , S, Cr, V, Ni, K, Al, and Rb increased in the altered rocks while Si, Na, Mg, Sr and, to lesser extent, Y, generally decreased. The increase of V, Ni, and Cr in the wall rocks may relate to a source of the ore fluids enriched in these components.

It is suggested that these components may be derived from a granitic pluton at depth.

In the case of the Twangiza deposit, where graphite is present in the wall rocks, the question as to whether the CO_2 was locally generated or introduced from a distant reservoir does not bear critically on wall-rock alteration in that the f_{O_2} of the incoming fluid controls the proportion of CO_2 in the fluid in contact with graphite.

The interaction of the ore fluids with graphite-bearing black-shale would also be a likely precipitation mechanism for Au by decreasing the oxygen fugacity.

The addition of CO_2 , together with H_2O and to a lesser extent K_2O resulted in carbonatization and hydroxyl mineral alteration, such as sericitization.

The presence of sericite in the vein assemblage (rather than kaolinite or K-feldspar) indicates that the vein-forming fluids had a near neutral to slightly acidic pH. (between 4 and 5).

Hydrothermal alteration assemblages surrounding veins in fracture systems or fault/shear zones reflect open-system metasomatic interaction of fluids with adjacent wallrocks.

12.7.- $^{40}\text{Ar}/^{39}\text{Ar}$, Rb-Sr AND Sm - Nd AGES CONSTRAINTS ON THE TIMING OF GOLD MINERALIZATION.

12.7.1.- INTRODUCTION.

$^{40}\text{Ar}/^{39}\text{Ar}$ dating study of hydrothermal muscovite has been undertaken to investigate the time of mineralization at the Twangiza gold deposit. The sampled hydrothermal muscovite grains are associated with stage II gold mineralization.

Isotopic dating of minerals which form during hydrothermal mineralization is an important tool for studying the genesis of hydrothermal mineral deposits. Particularly in regions, such as the Kadubu area, where ambient temperatures during mineralization were below the temperature for argon diffusion in muscovite ($350 \pm 50^\circ \text{C}$; McDougall and Harrison, 1988), hydrothermal muscovite could cool to below its closure temperature immediately after cessation of hydrothermal activity.

Comparison of the $^{40}\text{Ar}/^{39}\text{Ar}$ hydrothermal muscovite age data with timing constraints on albitite intrusion, (Rb - Sr age), regional metamorphism ($^{40}\text{Ar}/^{39}\text{Ar}$ age), and emplacement of Kasika granite ($^{40}\text{Ar}/^{39}\text{Ar}$ and Rb-Sr ages) in the Kadubu area, allow evaluation of hypotheses for the formation of the Twangiza gold deposit.

The sample preparation and analytical techniques are described in appendix .

12.7.2.- DESCRIPTION OF THE SAMPLES .

Six muscovite grains from sample KW 622A, an albitised black shale, were analysed individually. Rim and core analyses were carried out on all six muscovite grains. The muscovite grains were very small and, consequently, only one or two analytical steps could be obtained per grain.

The sample was taken from a pervasively hydrothermally altered and bleached haloe close to the contact with auriferous sulphide veins (saddle reef). The sample contains arsenopyrite and pyrite, the most definitive indication of an association with gold mineralization.

Hydrothermally altered and mineralized sample KW 622A. (Fig. III.88), is a very fine grained carbonaceous sediment which has been patchily albitised. The fabric of matrix, including streaks of carbon, continues through the albitised areas. Aligned flakes of muscovite, up to 200 μm long, occur throughout the groundmass. Minor amounts of epidote, pyrite and quartz are associated with the secondary feldspar.

The composition and texture of the sample KW 622A is as follow ; (Estimation abundances are in vol%):

- *.- Albite : 55 (I) very fine material as irregular to rhomboid, elongate bodies, 0,5 to 2,8mm across , aligned within the fabric of the matrix.
(II) very fine matrix constituent.
- *.- Quartz :13 Fine , granular material narrowly rimming albitised areas and dispersed throughout matrix.
- *.- Epidote : <1 Fine alteration product of feldspar ;
- *.- Pyrite : < 1 Irregular shaped bodies 0,03 to 0,25mm across , in central zones of albitised areas.
- *.- Carbon (graphite) : 25 Cryptocrystalline matrix material;
- *.- Sericite :5 Aligned flakes , up to 0,2mm long , in matrix .
- *.- Rutile : < 1 Very small grains throughout matrix.

12.7.3.- RESULTS.

$^{40}\text{Ar}/^{39}\text{Ar}$ age spectra ,derived from resistance furnace step-heating, for hydrothermal muscovite samples are graphically depicted in Fig. III.89 and the argon release data are given in Table III.9

Apparent ages determined from the muscovite grains range from $274 \pm 7 \text{ Ma}$ to $588 \pm 9 \text{ Ma}$. These apparent ages can be bracketed in terms of $274 \pm 7 \text{ Ma}$ - $491 \pm 15 \text{ Ma}$ and $522 \pm 7 \text{ Ma}$ - $635 \pm 24 \text{ Ma}$ age grouping .Excluding anomalous results , a mean age of $522 \pm 15 \text{ Ma}$ has been calculated for the muscovite grains.

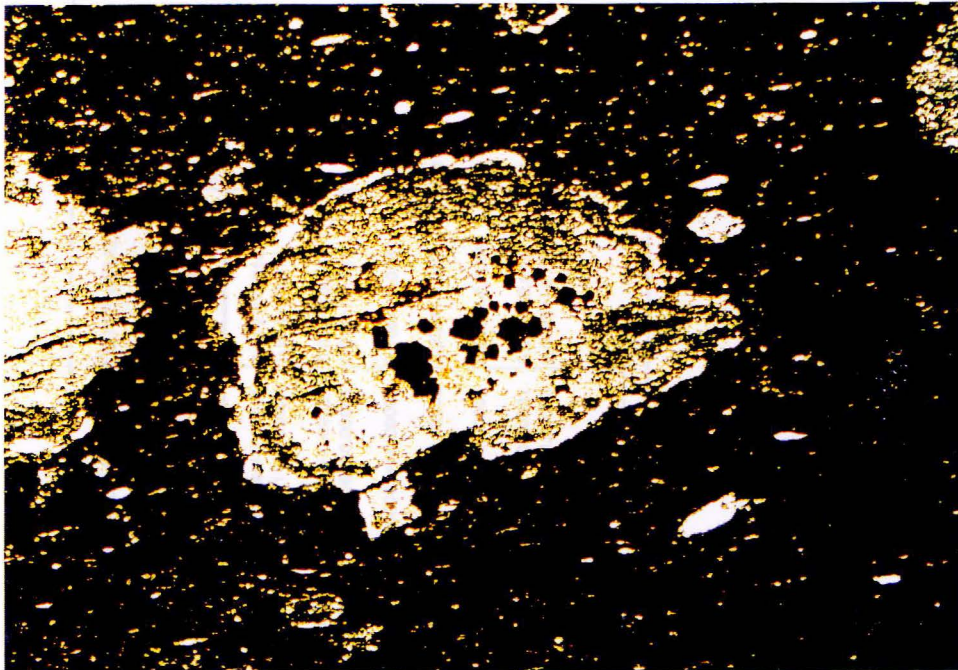


Fig.III.88:- Photomicrograph of hydrothermally altered and mineralized black shale. Showing aligned flakes of albites, muscovites and minor amounts of quartz, epidote, pyrite, within a sericite- carbonaceous matrix.

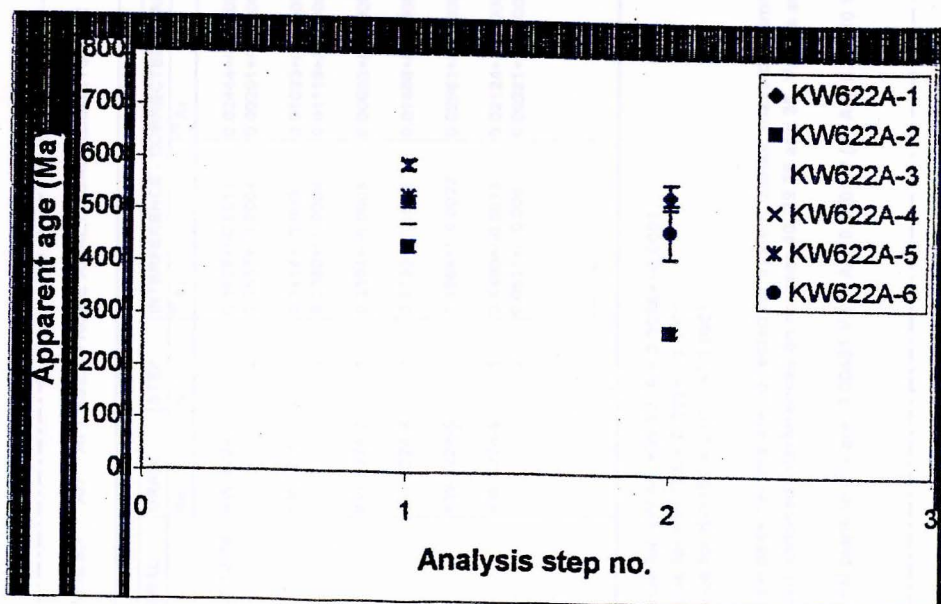


Fig.III.89:- $^{40}\text{Ar}/^{39}\text{Ar}$ age spectra derived from resistance furnace step-heating for hydrothermal muscovite samples.

Table.III.9;- $^{40}\text{Ar}/^{39}\text{Ar}$ LASER PROBE ANALYTICAL RESULTS FOR MUSCOVITE GRAINS FROM HYDROTHERMALLY ALTERED AND MINERALIZED BLACK SHALE.

MINERAL	GRAIN	STEP	INTERFERENCE - CORRECTED PEAK HEIGHTS					$^{37}\text{Ar}_{\text{ca}}/^{36}\text{Ar}_{\text{Ark}}$	ATMOS	AGE (Ma)
			^{40}Ar	^{39}Ar	^{38}Ar	^{37}Ar	^{36}Ar			
MUSCOVITE	KW 622A-1	1	0.9628+/-0.0011	0.02444+/-0.00027	0.00021+/-0.00004	0.0003+/-0.0003	0.00004+/-0.00001	0.012+/-0.010	1.28	521+/-7
		2	0.0837+/-0.0004	0.00201+/-0.00007	0.00001+/-0.00001	0.0001+/-0.0003	0.00001+/-0.00001	0.014+/-0.014	3.41	535+/-24
	KW622A-2	1	0.3414+/-0.0004	0.01033+/-0.00006	0.00016+/-0.00004	0.0008+/-0.0003	0.00006+/-0.00002	0.070+/-0.024	5	431+/-11
		2	0.2360+/-0.0004	0.01119+/-0.00004	0.00006+/-0.00001	0.0024+/-0.0002	0.00006+/-0.00001	0.212+/-0.031	9	274+/-7
	KW 622A-3	1	0.2394+/-0.0005	0.00603+/-0.00003	0.00023+/-0.00006	0.0006+/-0.0003	0.00007+/-0.00002	0.106+/-0.043	8.23	491+/-15
	KW 622A-4	1	0.6733+/-0.0013	0.01488+/-0.00003	0.00001+/-0.00001	0.0005+/-0.0003	0.00002+/-0.00002	0.035+/-0.012	0.81	508+/-9
	KW 622A-5	1	1.1966+/-0.0023	0.02961+/-0.00005	0.00003+/-0.00008	0.0009+/-0.0003	0.00008+/-0.00002	0.030+/-0.0009	1.8	529+/-7
	KW 622A-6	1	0.8480+/-0.0013	0.02124+/-0.00002	0.00018+/-0.00006	0.0004+/-0.0003	0.00007+/-0.00001	0.018+/-0.013	2.5	522+/-7
		2	0.0911+/-0.005	0.00231+/-0.00006	0.00004+/-0.00001	0.0002+/-0.0002	0.00004+/-0.00003	0.0807+/-0.06	12.04	468+/-52

J-Value for KW 44, KW 622A = 0.0086+/-0.0001

J-Value for KW 705 = 0.009+/-0.0001

J-Value for KW152 = 0.0087+/-0.0001

Isotope peak heights are corrected for system blanks, mass discrimination, radioactive decay of ^{37}Ar and ^{39}Ar , and reactor induced interferences on masses 40, 39, 38 and 36. Values are recorded as volts (V).

Typical blank levels are: 0.00461 V (^{40}Ar), 0.0001 V (^{39}Ar), 0.00010 V (^{38}Ar), 0.00346 V (^{37}Ar), 0.00030 V (^{36}Ar)

The $^{40}\text{Ar}/^{39}\text{Ar}$ age of **$575 \pm 83 \text{ Ma}$** for metamorphic muscovite grain from sample KW 152 ; a carbonaceous sericite-quartz schist ; provides a minimum estimate for the timing of D_2 - M_2 , main regional compression and greenschist metamorphism .

For this study, a feldspar grain from sample KW 618 Felds of Twangiza albitite was analysed for Sm- Nd and Rb - Sr isotopes. It yielded a Rb - Sr and Sm - Nd isochron age of **$1078 \pm 27 \text{ Ma}$** with an initial ϵ_{Nd} of 0.512590 ± 23 (MSWD = 0.00) and an initial $^{87}\text{Sr} / ^{86}\text{Sr}$ ratio of 0.734298 ± 11 (MSWD= 0.00). This age is not in agreement with the field evidence and indicates a very old emplacement age of this albitite (Kibaran age) compared to the age of the host metasediments (**$575 \pm 83 \text{ Ma}$** , Pan African age). Field evidence suggest a synkinematic emplacement and cooling of this albitite relative to the D_2 event and thus, this age is interpreted as an evidence that this albitite derived from a Kibaran granite.

At regional scale, in the Western branch of the East African Rift system, there is growing recognition of small Neoproterozoic alkaline complexes containing both Si-oversaturated and Si-undersaturated rocks (+ Carbonatite) at this time (Pan African event). It is suggested that the Twangiza albitite could have been emplaced in the same time by the same tectono-thermal events.

Three muscovite and three feldspar grains from sample KW 44 (Kasika leucogranite), were analysed individually by the $^{40}\text{Ar}/^{39}\text{Ar}$ age method.

Excluding anomalous results, a mean age of **$436 \pm 8 \text{ Ma}$** and **$528 \pm 3 \text{ Ma}$** are calculated respectively for feldspar grains and muscovite grains.

The same granite sample KW44 was also analysed by Rb-Sr and Sm-Nd dating method (apatite and mica model ages) , and yielded an age of **$703 \pm 13 \text{ Ma}$** ; mica model age , with an initial ratio of 0.8828 ± 1 , ϵ_{Nd} of 2542.624 ± 1.562 and an Rb- Sr with an initial $^{87}\text{Sr} / ^{86}\text{Sr} = 18.2770 \pm 26$ (MSWD = 0.000). This $^{87}\text{Sr} / ^{86}\text{Sr}$ ratio is very high .

It is suggested that ^{87}Sr evolved since Kibaran , moving into other hosts. This granite is very evolved. Resetting has resulted at $\sim 700\text{Ma}$ (metamorphosed ?) and during the Pan African , Neoproterozoic events ($\sim 500\text{Ma}$).

The Rb-Sr system is known to be highly susceptible to resetting by hydrothermal, diagenetic and metamorphic processes, whereas the susceptibility of the Sm-Nd system has been subject to debate.

Sr and Rb have " moved ... " by the hydrothermal process/fluids. Several factors may have influenced the Sr and Rb compositions :

- Transport away from the rock by fluid. Even fractionating isotopically if preference exist for specific minerals ;
- Introduction of Sr and Rb with different isotopic composition by the fluid from other rocks. Rb and Sr can be fractionated isotopically relative to the total source by this process;
- Rearrangement of Sr and Rb between the minerals internal in the rock.

12.7.4.- RELATIVE TIMING OF GOLD MINERALIZATION.

The $^{40}\text{Ar}/^{39}\text{Ar}$ data, Rb-Sr and Sm -Nd data provide constraints on the temporal relationships of the deformation, the porphyry albitite system and the gold deposit.

The relative timing of geological events within the Twangiza deposit indicates two main phases of gold mineralization : one producing the saddle reef-style and occupying the flanks of the Twangiza anticlinal structure; the other producing quartz veining, brecciation and dissemination and occupying mostly the axial zone of the Twangiza anticlinal structure.

Phase 1 ; saddle reefs: gold mineralization postdated the peak of regional metamorphism and deformations (D_1 & D_2). This phase produced and correspond to stage I & II gold mineralizations .

Phase 2 ; fault reefs : gold mineralization postdated the peak of regional metamorphism , albitite intrusion , D_2 deformation and was synchronous with dextral strike-slip faulting . This phase produced and correspond to Stage III gold mineralization.

Assuming that albitite intrusion occurred broadly synchronously throughout the field and synkinematically emplaced this age of **$575 \pm 83 \text{ Ma}$** , provide an estimate of the timing of porphyry albitite emplacement, which is related to a Kibaran (**$1078 \pm 27 \text{ Ma}$**) granite at depth.

If it is assumed that $^{40}\text{Ar}/^{39}\text{Ar}$ age of hydrothermal muscovite (**$522 \pm 15 \text{ Ma}$**) from Twangiza deposit represent the timing of gold mineralization in this deposit, then mineralization postdated peak regional metamorphism, deformation and porphyry albitite intrusion in the Twangiza region by at least **$53 \pm 68 \text{ Ma}$** .

The available field evidences suggest that the $^{40}\text{Ar}/^{39}\text{Ar}$ ages of hydrothermal muscovites (**$522 \pm 15 \text{ Ma}$**) from Twangiza deposit do provide a good estimate of timing of saddle reef-type of gold mineralization.

Evidence for this includes the following :

1.- To some extent, the intense folding postdates the mineralization, or at least was synchronous, since sulphide veins were deformed and remobilised during folding. However the preferred concentration of gold-bearing sulphide lodes along the fold limbs, rather than in the lower strain fold hinge give an idea of the role played by parasitic folds and flexural slip during folding. The positions of bedding parallel veins have been used to relate bedding slip increments to the overall development of chevron folds (Ghosh, 1968, Tanner ,1989).

However a detailed study of the microstructures in these bedding parallel veins is needed in order to sustain the role of fluid pressure fluctuations and to constrain the model of its origin.

2.- The mineralization postdates albitite intrusions. Albitite is cut and offset by lode structures and by faults which control the distribution of gold mineralization.

3.- Albitite is also hydrothermally altered by vein fluid -rock interaction process .

4.-Some parts of the albitite have S-C fabrics indicating dextral strike -slip and these grade into mylonitic fabrics in the Twangiza and Kekombe faults.

This fact indicates that foliation development on the albitite pluton was related to fault movement on the Twangiza and Kekombe faults. Pluton emplacement was probably associated with Twangiza fault. The foliation is locally parallel to igneous layering (and schlieren ?) suggesting that magmatic activity continued locally during and after foliation development.

In view of the above considerations, the $^{40}\text{Ar}/^{39}\text{Ar}$ ages of hydrothermal muscovites from Twangiza deposit are interpreted to represent the time of mineralization. The six ages measured have a combined weighted mean of 522 ± 15 Ma and this is considered to be the time of formation of saddle reefs -style gold mineralization in the Twangiza deposit. This age is in agreement with field and petrographic relationships that also constrain vein formation to syn-or postintrusion of albitite and also postdate peak regional metamorphism.

12.7.5.- SUMMARY AND DISCUSSIONS.

$^{40}\text{Ar}/^{39}\text{Ar}$ analyses were performed to assess the timing of gold mineralization relative to deformations and igneous activity .

Interpretation of hydrothermal muscovite $^{40}\text{Ar}/^{39}\text{Ar}$ ages from the Twangiza deposit requires care. Since six grain samples cannot be considered truly representative of such a huge mineral deposit as the Twangiza deposit. Moreover, the overall time span of mineralization activity that encompassed the two phases must be dated.

The evidence of faulting and hydrothermal activity subsequent to formation of the Twangiza deposit suggest that ages from Twangiza hydrothermal muscovite sample be considered only as a minimum estimates of the timing of gold mineralization, due to the possibility of argon loss during this postmineralization activity.

Thus, further work is required to substantiate the findings presented here.

However, despite this, the available evidence suggest that the $^{40}\text{Ar}/^{39}\text{Ar}$ ages (mean : $522 \pm 15\text{Ma}$) of hydrothermal muscovites from Twangiza deposit do provide a good estimate of timing of saddle reefs gold mineralization.

Two separate phases of mineralization are indicated, the earlier localized within classic saddle reef structures and containing the highest Au, and a later in fault reefs, synchronous with dextral strike-slip faulting; cross-cutting stage of mineralization associated with ground preparation and kinematic emplacement of albitite rock and related to hydrothermal fluids migrating out of the Twangiza fault feeder zone. The first phase produced and correspond to stages I & II gold mineralization, while this late phase correspond to Stage III gold mineralization.

Stuwe et al., (1993), suggested that there is no conflict between the observation that the emplacement of many gold deposits occurred demonstrably after peak metamorphism of their host rocks and the interpretation that metamorphic fluids are responsible for the mineralization.

However, for us, it is suggested that small volumes of fluids derived from devolatilization reactions during regional metamorphism of metaturbidite sequence or emplacement of spatially related porphyry albitite intrusion, but surface fluids (meteoric water) seeping down are one of the major volume of fluids involved in these processes. Literature reports existence of surface fluids (meteoric water) at depths of 12 - 18 km, and probably they occurs even deeper.

The relationship between this albitite intrusion, magmatism and gold mineralization in Twangiza region is not yet sufficiently documented to allow direct links to be made. This relationship will be examined afterwards in the light of fluid inclusions, stable and radiogenic isotopes studies.

However, the question related to the longevity of igneous-related hydrothermal systems in continental environment would be considered hereafter.

Marsh and McWilliams, 1997, pointed out that rather than being driven by the heat of a large, deep batholith for some million years required to cool such a large pluton, hydrothermal activity in several large systems tends to be driven by smaller, shorter lived, shallowly emplaced intrusions.

Other studies (Phillip, G.N., 1986) have shown that a closer relationship exists between small porphyry stocks, high-temperature hydrothermal alteration and mineralization, than between large batholithic masses and such alteration. Little relation exists between the large Kasika granite batholiths and hydrothermal alteration, whereas small albitite porphyry stocks are loci for gold mineralization in the Twangiza region.

Ambrus, 1977 and Fourier, 1991 stressed that one reason that small, shallowly emplaced intrusions might play a greater role than large, deep batholiths in driving hydrothermal activity is the rheological state of the rocks surrounding the intrusion. It is probable that fractures in a hot carapace surrounding the magma body have been annealed by plastic deformation, preventing significant convective hydrothermal flow.

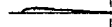
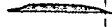
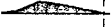
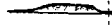
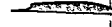
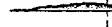
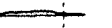
Only where shallow intrusions are emplaced into cooler, brittle rocks would fractures be expected to stay open long enough to sustain convective flow.

It seems that in the Twangiza region, small intrusive albitite porphyry, crescent shaped with about 200m x 50m, were perfectly suited for driving ore-forming hydrothermal system. Based on field relations, textural and geochemical evidences and geochronological informations, we, therefore argue that the albitite intrusion pre-dates emplacement of saddle reefs and fault reefs by at least 53 Ma.

The interpretation of the combined results from studies of mineral paragenesis, geologic relationships, and geochronology ($^{40}\text{Ar}/^{39}\text{Ar}$, Rb-Sr and Sm-Nd) can be synthesized to provide a coherent composite of the relationships between the different tectonothermal events (deformation, metamorphism, magmatism and mineralization) within the Kadubu area.

Table.III.10 shows the schematic sketch illustrating the nomenclature and timing relationships of deformation, metamorphism, magmatism and mineralization in the Kadubu area. R : stand for resetting.

These relationships are summarized in the following Table III.10.

Orogenic belts	Kibaran Orogeny		Pan African Orogeny					Rifting event	
AGES & EVENTS	1078 ±27 Ma	703 ± 13 Ma	575 ± 83 Ma	533 ± 7 Ma	529 ±5 Ma	522 ±15 Ma	436±8 Ma	65Ma	to present day
Regional Metamorphisms		M ₁	M ₂ 			M ₃ 			
Deformations (D ₁ , D ₂ & D ₃)		D ₁ 	D ₂ 			D ₃ 		R...	
Kasika granite Intrusion					R...		R...		
Albitite Intrusion.									
Hydrothermal Alteration								R...	
Mineralizations (Phase1,2 & 3)			Au 	Tin 		Au 		R...	

12.8.- FLUID INCLUSIONS .

12.8.1.- INTRODUCTION .

The comprehensive theoretical background to fluid inclusion studies is largely provided by Roedder, 1977, 1984a, 1984b ; Collins , 1979 ; Shepherd, 1981 ; Crawford, 1992 and the practical aspects by Crawford, 1981 ; Shepherd et al., 1985 .

Fluid inclusions are microsamples of fluid trapped as imperfections within crystals during or subsequent to mineral formation. Fluid inclusions in quartz veins have been studied in order to gain further understanding of the physical and chemical conditions and the mineralizing fluid evolution for the formation of the Twangiza gold deposit.

Microthermometric measurements were used to provide information on temperature, pressure, salinity, density and quantitative compositions of fluids associated with gold mineralization. This dataset of fluid inclusions was used to discuss the source of the fluids.

Doubly polished thin sections, approximately 200 - 300 μm thick, were prepared from more than 10 quartz vein samples for a preliminary petrographic study, of which 5 samples containing representative populations of inclusions were finally selected for detailed fluid inclusion studies (Fig.III.90). The possibility of post-entrapment modification has been considered and eliminated.

12.8.2.- PETROGRAPHY.

Fluid inclusions were studied in hydrothermal quartz occurring in matrix of vuggy silica QV₁ vein and in advanced argillic alteration (Fig.III.90). Quartz is euhedral to granoblastic with grains showing variable degrees of undulose extinction (Fig.III.91). It is characterized by abundant and relatively large fluid inclusions (up to 45 μm). The inclusions are classified according to their microthermometric characteristics and phase proportions observed at room temperature. (Fig.III.92, Fig.III.93) .

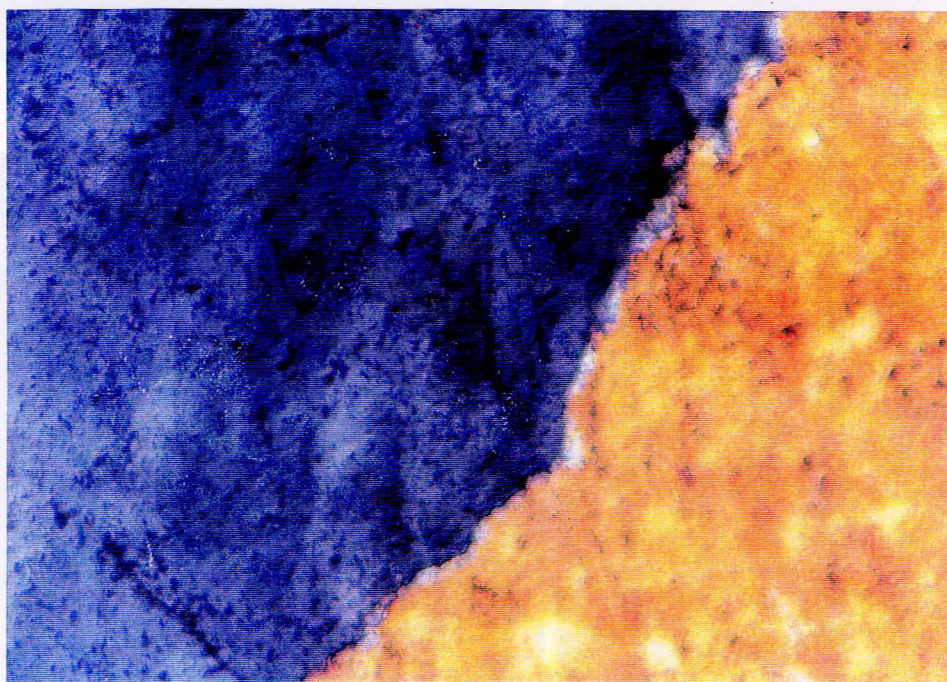


Fig.III.90:- Handspecimen of quartz-vein (QV₁) with sulphide mineralization used for fluid inclusion studies.

Fig.III.91:- - Photomicrograph of quartz-vein (QV₁) with sulphide mineralization used for fluid inclusion studies.

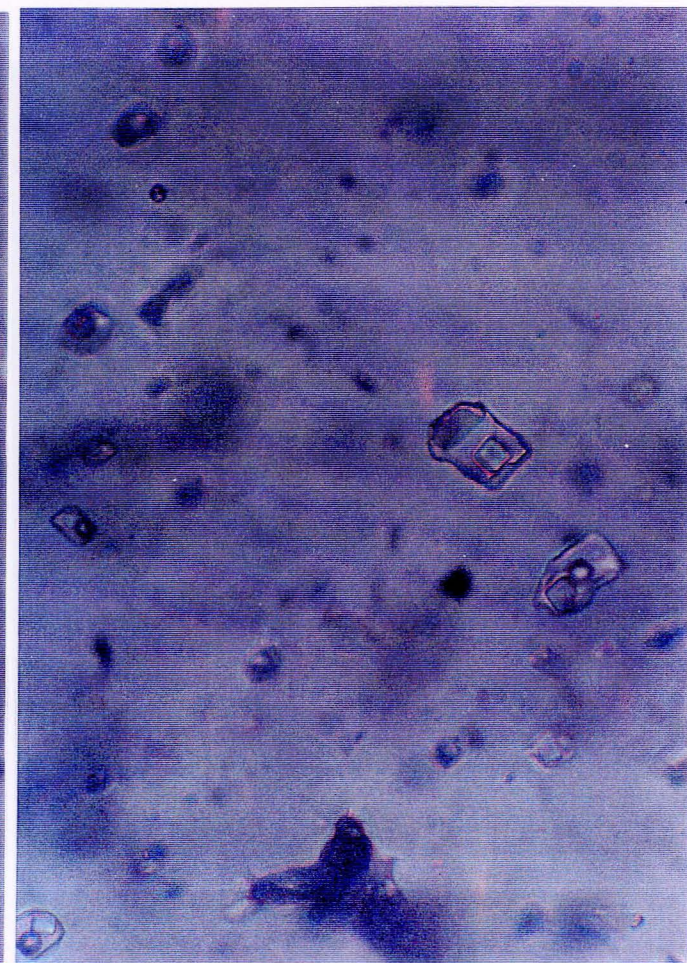
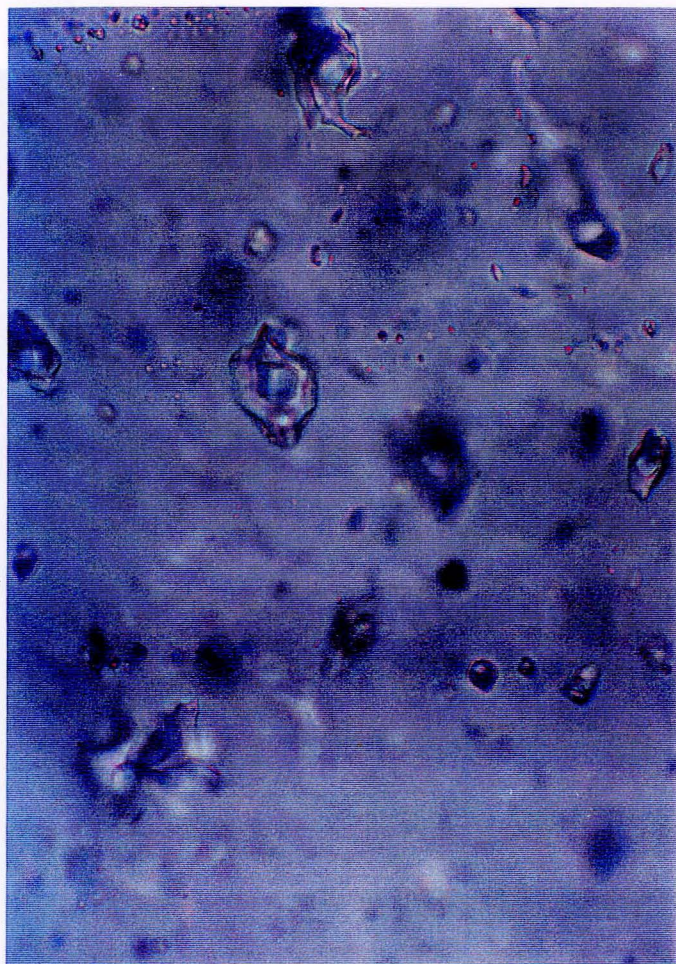
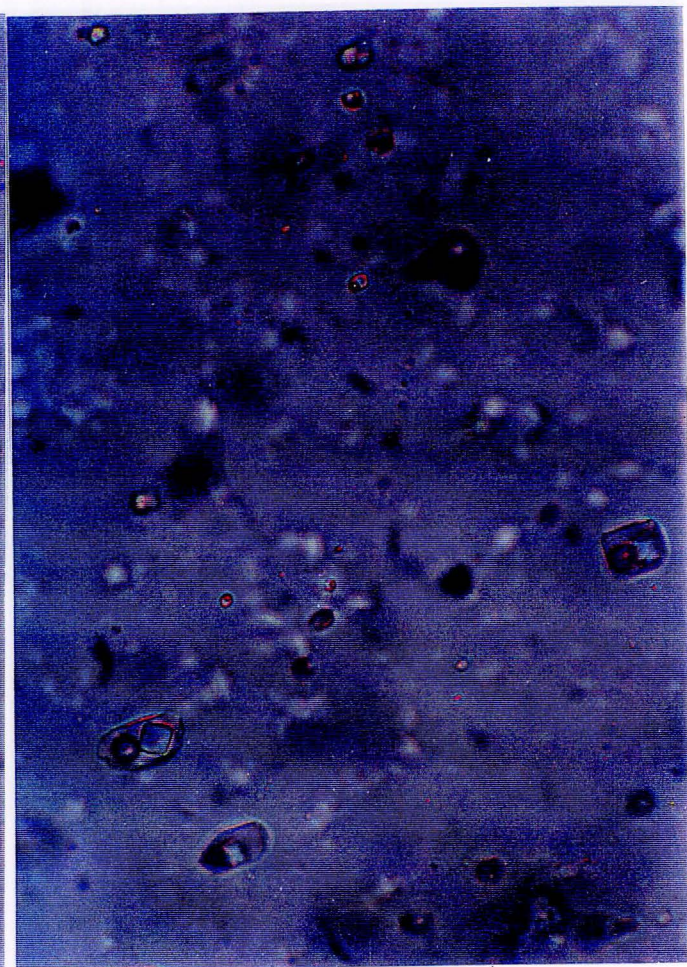
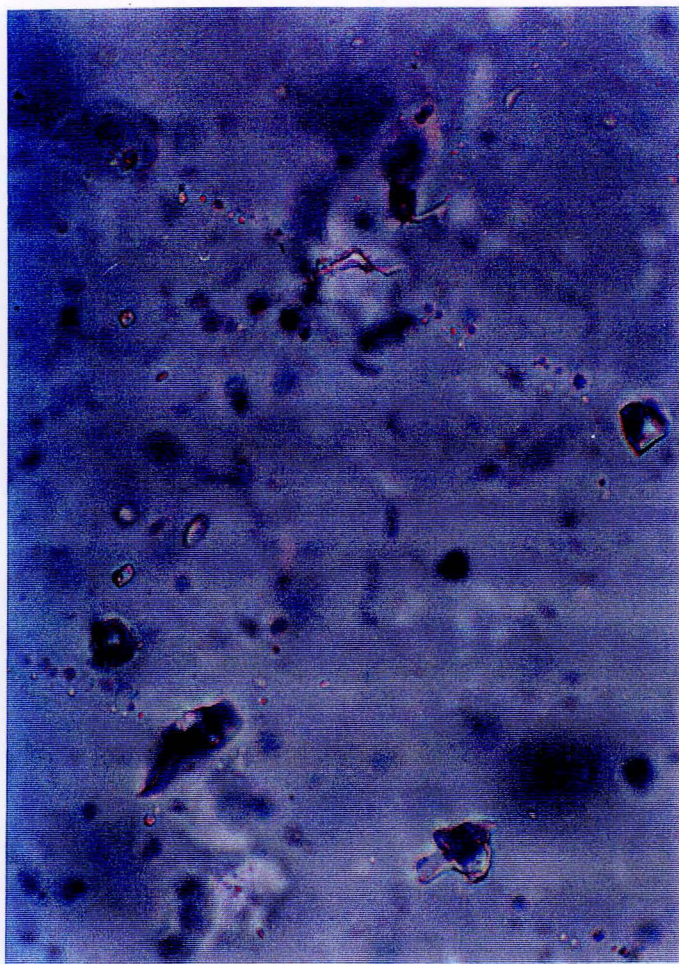
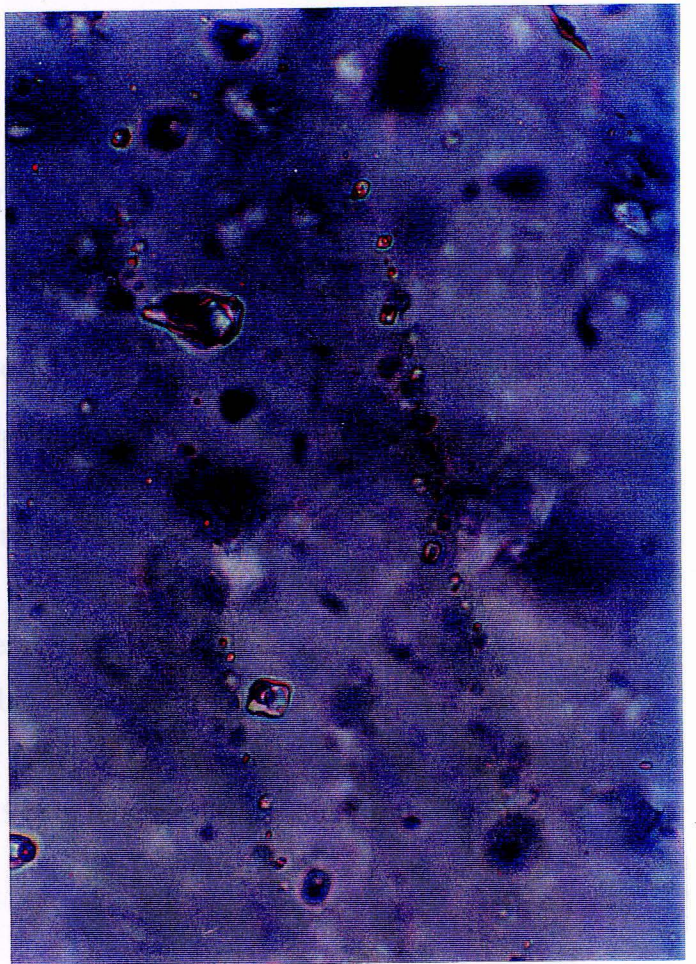
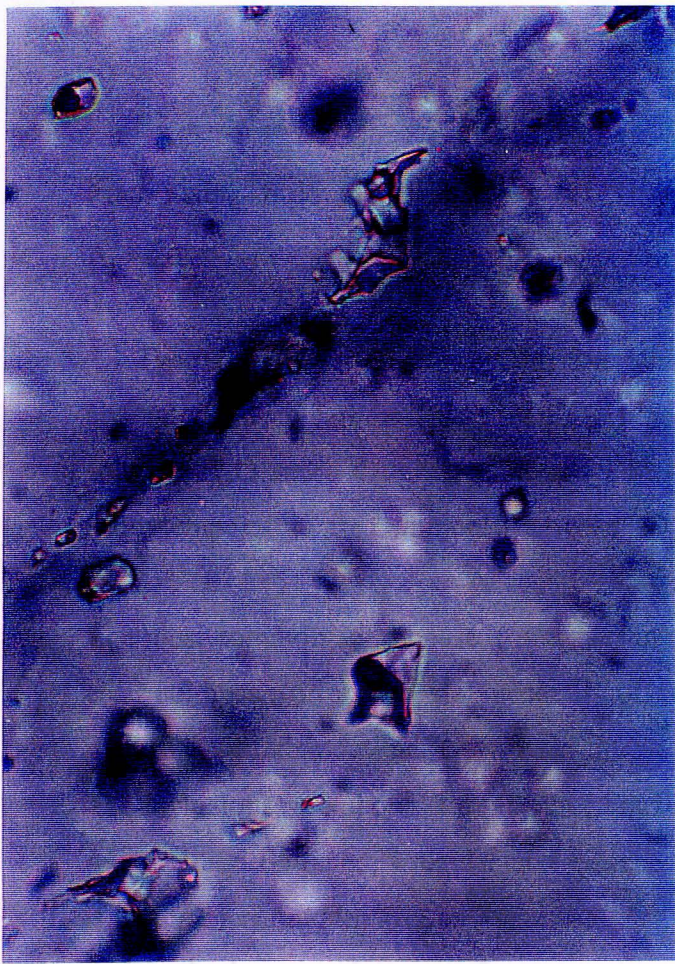


Fig.III.92:- - Optical photomicrographs of selected fluid inclusion types in a quartz sulphide vein from the Twangiza deposit taken in transmitted light.



Although the growth zone of quartz was not observed in the samples studied, fluid inclusions that occur in intergranular quartz are referred to Primary with respect to grain boundary. They are termed Primary (P). (Roedder, 1984)

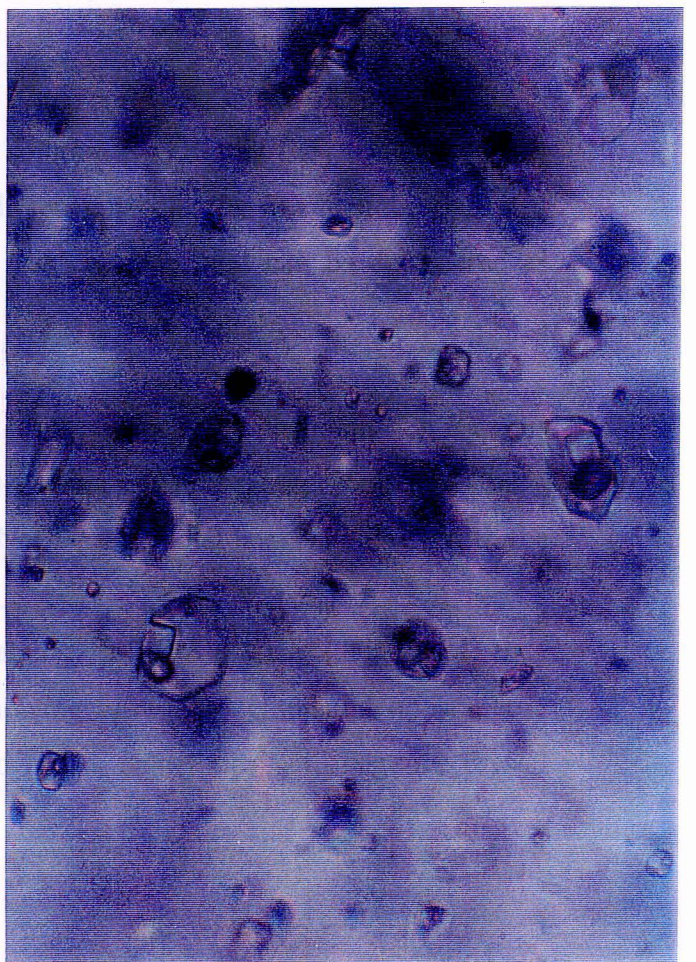
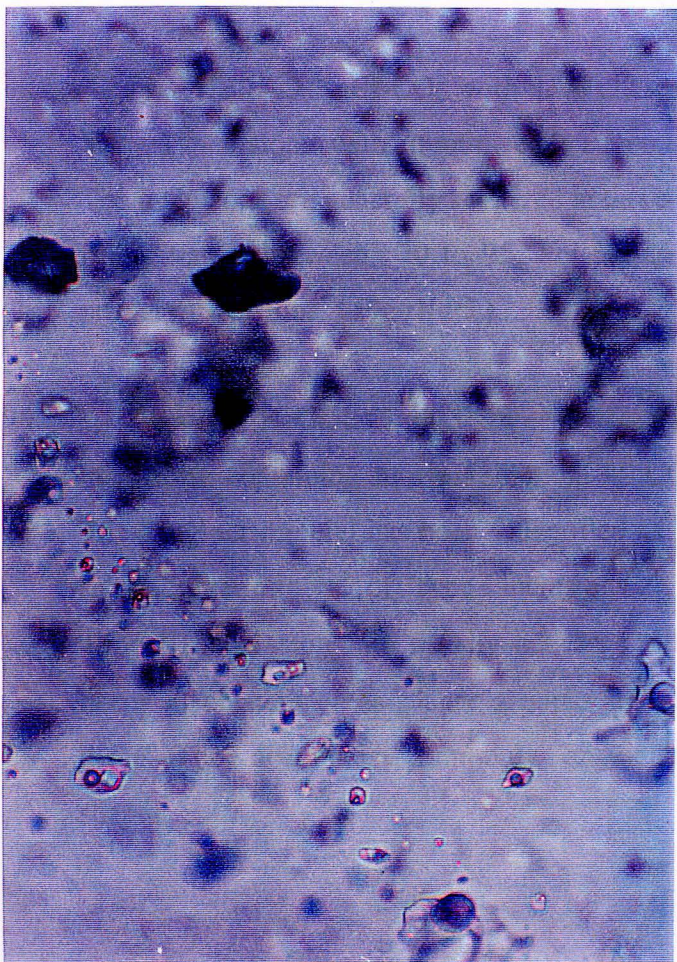


Fig.III.93: - Optical photomicrographs of selected fluid inclusion types in a quartz sulphide vein from the Twangiza deposit taken in transmitted light.

Four main fluid inclusion types (I, II, III, & IV) (Fig.III.92, Fig.III.93) were recognized :

*.- **Type I** : $\text{H}_2\text{O}-\text{NaCl}-\text{CO}_2$ - DM, four phase (L, V_{CO_2} , L_{CO_2} , DM) inclusions are characterized by carbonic phases (CO_2 liquid, +/- CO_2 vapor), an immiscible aqueous solution H_2O and a daughter mineral (DM = salt). The CO_2 volume ratios estimated at room temperature are commonly between 50 and 70 %.

The most common solid phase, (daughter mineral =DM), identified as NaCl, (salt) is a clear colorless isotropic crystal, generally of cubic shape, but occasionally with a round or imperfect squarish outline.

The inclusions are about 5 to 45 μm (Fig.III.94) in length with various forms (slightly rounded and flattened, irregular and flattened, spheroidal or oblate shape) and occur in isolation or in random groups.

Although the growth zone of quartz was not observed in the samples studied, fluid inclusions that occur in intergranular quartz are referred to Primary with respect to grain boundary. They are termed Primary (P), (Roedder, 1984) .

*.- **Type II** : $\text{H}_2\text{O}-\text{NaCl}-\text{CO}_2$, with three phases (L, V_{CO_2} , L_{CO_2}) or two phases (L, V_{CO_2}), inclusions with an immiscible aqueous solution H_2O , liquid CO_2 and CO_2 vapour. The inclusions are generally scattered in three-dimensional clusters in which the degree of filling varies between 70 to 95 vol %, are less common, and can be considered as primary inclusions. (Fig.III.95).

*.- **Type III** : $\text{H}_2\text{O}-\text{NaCl}$ - DM ; three phases (L, V, S) inclusions with liquid-rich aqueous inclusions, containing aqueous solution, +/- CO_2 vapour and one daughter mineral (salt). The daughter mineral has been identified as NaCl (salt) and bear similarity with the salt daughter mineral of Type I inclusions.

Type III inclusions are usually not large, attaining 5-7 μm in size, (Fig.III.94) they occur in clusters or as planar groups, and showing irregular, elongated or isometric forms. They are almost commonly angular to round, sometimes with negative crystal shapes.

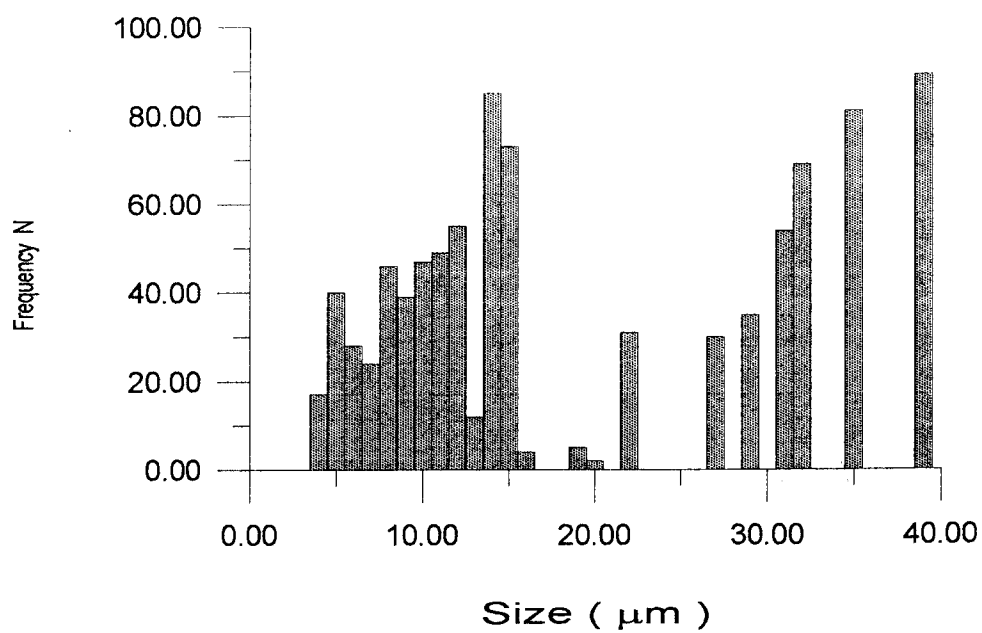


Fig.III.94:- Size of fluid inclusions (Type I, II, III & IV).

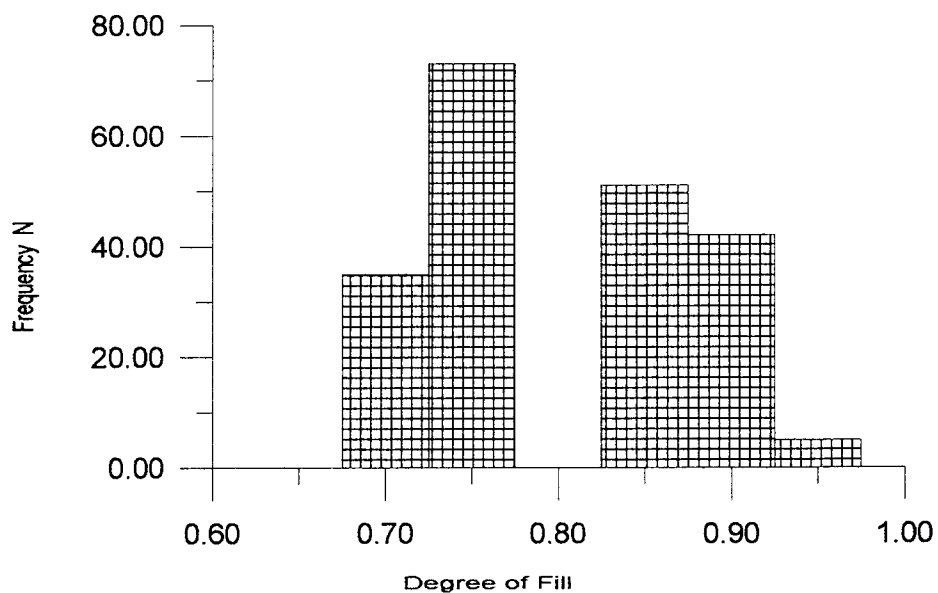


Fig.III.95:- Degree of fill of fluid inclusions (Type I, II, III, & IV).

*.- **Type IV** : $\text{H}_2\text{O}-\text{NaCl}$; two phase (L,V) inclusions with liquid-rich aqueous inclusions, containing aqueous solution and $\pm \text{CO}_2$ vapour. The clusters of $\text{H}_2\text{O} - \text{NaCl}$ inclusions show variable degrees of filling probably, indicative of reworking of $\text{H}_2\text{O} - \text{NaCl}$ inclusion by plastic deformation.

In addition to above fluid inclusion types, vapor-rich and/or liquid-rich inclusions were also observed in all the studied samples, and containing one phase at room temperature (respectively vapor /or liquid). (Fig.III.92 ,Fig.III.93).

Some inclusions show evidence of necking -down, occur along healed fractures. These later inclusions may sometimes be characterized by an elongated trail and very irregular, angular shape. They occur in clusters or as planar groups outlining healed fractures crosscutting grain boundaries.

It was not possible to relate these flat and often irregular fluid inclusions to the crystallographic growth zone of quartz. Hence, they are termed Secondary (S). (Roedder, 1984).

Postentrapment (e.g., necking down) and /or heterogeneous trapping phenomena can explain the presence of these one phase vapor/liquid-rich inclusions. (Bodnar, 1985). Heterogeneous trapping and postentrapment phenomena (necking down) are common features in fluid inclusions from epithermal systems (Bodnar et al., 1985). Therefore, we do not report these data.

The cross-cutting relationship of the Type I and Type IV inclusions was observed (Fig.III.92, Fig.III.93). Both types are also observed in secondary inclusions. The close association of the two types is also significant .

12.8.3.- MICROTHERMOMETRY.

In an attempt to avoid collection of erroneous data, we studied fluid inclusions trails , groups and clusters where all inclusions showed similar liquid to vapor ratios.

The inclusions studied have not necked down into two or more inclusions since their original formation and do represent the original condition.

Heating runs, and freezing data of fluid inclusions and statistical evaluation of these data are summarized in Table III.11.

12.8.3.1.- Type I & II : H₂O-NaCl-CO₂ -DM and H₂O-NaCl-CO₂

This type of fluid inclusions are very common . The degree of fill of this inclusion type were found to be between 0.70 and 0.95 (Fig.III.95).

A limited range of melting temperatures of CO₂ (-56.1 °C to -61.7 °C) were measured, (Fig.III.96). Melting of Ice and final freezing temperatures of the aqueous parts of these inclusions are respectively found to be between -33.8 to -10.9 °C and -13.9 to - 0.1 °C. (Fig.III.97 and Fig.III.98).

During freezing, the absence of clathrate has been observed and could indicates that the inclusions contain less than 4 wt% CO₂ (Hedenquist and Henley, 1985a).

Melting temperatures of salt range from 318.7 to 367.2 °C indicating total fluid salinity ranging from 39.5 to 45.2 wt% eq.NaCl. (Fig.III.99).

According to Davis et al., (1990), observed first melting temperatures in the H₂O- NaCl and H₂O-NaCl-KCl systems may be up to 15 °C, below their respective equilibrium eutectic temperatures (-21.2 and -22.9 °C)

During homogenization , the heating rate in the temperature range of daughter mineral dissolution was about 2-3 °C /min. The dissolution of daughter minerals was reproducible with +/-5 confidence in verification measurement. The re-precipitation of halite daughter minerals was usually observed after their homogenization.

On heating, halite dissolved before the homogenisation of the fluid phase.

Homogenization temperatures of the CO₂ phase range from 19.8°C to 31.8°C to the gaseous phase. (Fig.III.100).

Fig.III.101 shows the frequency distribution of homogenization temperatures total measured in Type I and Type II inclusions. These temperatures range from 182.7 to > 475 °C .

The vapor phase of Type I and Type II inclusions homogenized at a lower temperature than the dissolution temperature of the solid phase in most runs.

TABLE.III.11 :- MICROTHERMOMETRIC DATA FOR MEASURED FLUID INCLUSIONS IN THE TWANGIZA GOLD DEPOSIT.

SAMPLE No	SHAPE	SIZE	PHASE	TYPE	FILL	TmCO2	ThCO2	V _L C	Ice/Te	TfmIce	TmNaCL	Th	V _L	SALINITY
1		22	LV	III	0.9			V	-12.1	-13.9	254.2	280.1	V	
2	--	20	LV	III	0.8	--	--	V	-14.7	-4.5	255	280.3	V	--
3	--	19	LV	III	0.9	--	--	V	-15.8	-3.7	262.4	290.2	V	--
4	--	16	LV	III	0.9	--	--	V	-15.2	-3.1	270.1	300.2	V	--
5	--	19	LV	IV	0.95	--	--	V	-16.5	-3.3	223.2	221.7	V	--
7	--	27	LV	IV	0.8	--	--	V	-15.9	-3.3	224.7	224.9	V	--
8	--	12	LV	IV	0.8	--	--	V	-22.8	-3.4	225.6	227.6	V	--
9	--	8	LV	IV	0.9	--	--	V	-21.9	-4.5	227.1	230.4	--	--
10	0	10	LVS	II	0.9	--	--	V	-33.8	-8.7	--	293.6	V	11.1
11	--	6	LVS	I	0.9	--	30.1	V	-17.9	-13.9	--	279.6	V	6.3
12	--	13	LVS	I	0.8	--	20.2	V	-18.9	-4.5	--	294.5	V	7.17
15	--	5	LVS	I	0.9	-56.9	21.5	V	-15.8	-3.7	--	294	V	6.01
17	--	4	LVS	I	0.9	--	20.2	V	-15.2	-3.1	--	299.6	V	5.4
19	--	5	LVS	I	0.95	--	20	V	-16.5	-3.3	--	32	V	5.41
24	--	7	LVS	I	0.8	--	30.2	V	-15.9	-3.3	--	328.4	V	5.42
25	--	9	LV	II	0.8	--	--	V	-22.8	-3.4	--	>475	--	5.56
28	--	6	LVS	I	0.9	--	21.4	V	-21.9	-4.5	--	>475	--	7.17
30	--	27	LVS	I	0.9	--	21.3	V	-33.8	-8.7	--	358.8	V	12.51
31	0	22	LVS	I	0.8	-56.7	21.6	V	-17.9	-7.8	--	354.7	V	11.46
32	--	32	LVS	II	0.95	-56.9	21.9	V	-18.9	-3.4	320.6	354.2	V	40.28
35	--	29	LVS	II	0.7	-58.4	21.4	V	-20.7	-3.1	319.9	354.5	V	39.7
37	--	32	LVS	I	0.75	-56.9	19.9	V	-17.9	-3	318.9	375.2	V	39.5
39	C	9	LVS	I	0.85	-56.2	19.8	V	-17.1	-2.9	318.7	373.9	V	39.5
40	C	5	LVS	I	0.95	-57.2	20.5	V	-10.9	-2.8	327.8	375.2	V	40.4
42	B	11	LVS	I	0.9	-56.1	20.9	V	-21.3	-3.1	333.1	383.2	V	40.87
46	0	8	LV	I	0.9	--	--	V	-20.7	-3.2	339.9	376.5	V	41.49
47	0	10	LVS	I	0.85	-57.2	31.8	V	-24.1	-3.4	354.9	382.2	L	42.89
49	C	11	LV	II	0.9	--	--	V	-20.9	-0.1	360.1	>475	--	43.4
51	C	12	LVS	I	0.85	-57.4	30.2	V	-13.2	-0.7	367.2	386.1	--	45.2
54	0	31	LVS	I	0.95	-56.5	30.1	V	-20.7	-3.3	--	280.1	--	--
55	C	12	LVS	I	0.8	-61.7	22.5	V	-27.6	-1	--	268.9	--	--
69	--	32	LV	II	0.95	--	--	--	-26.2	-4.1	--	219.7	--	--
73	--	15	LV	II	0.75	--	--	--	-19.9	-6.1	--	202.5	--	--
81	--	35	LS	II	0.8	--	--	--	-18.5	-6.7	--	178.9	--	--
85	--	14	LV	II	0.85	--	--	--	--	--	--	182.7	--	--
89	--	39	LV	II	0.9	--	--	--	--	--	--	194.8	--	--

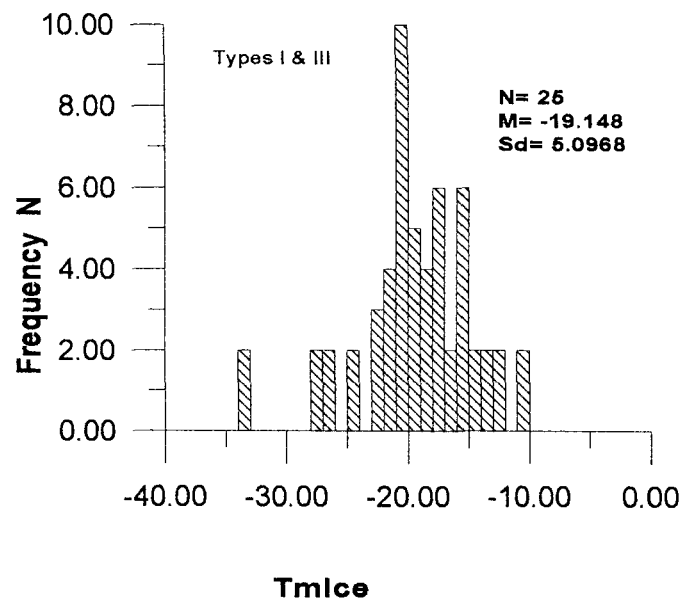
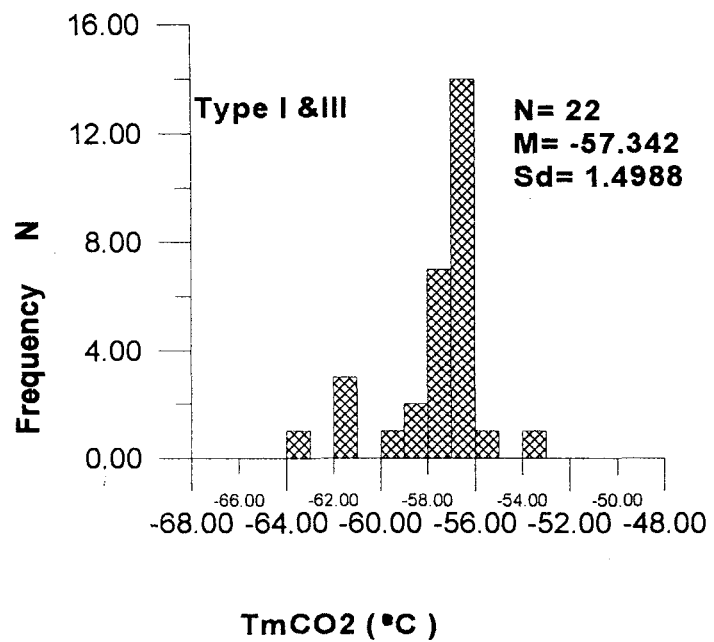


Fig.III.96:- Frequency histogram of melting of CO_2 ,from microthermometric data.

Type I : H_2O -NaCL- CO_2 - DM and Type II : H_2O - NaCL - CO_2 .

Fig.III.97:- Frequency histogram of melting of Ice, from microthermometric data.

(Type I, & II, and Type III & IV).

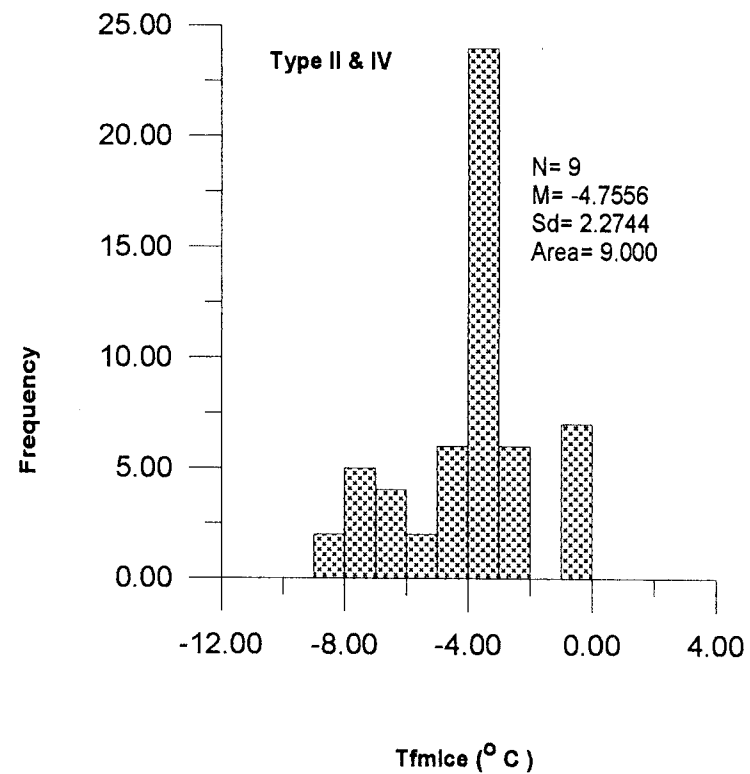
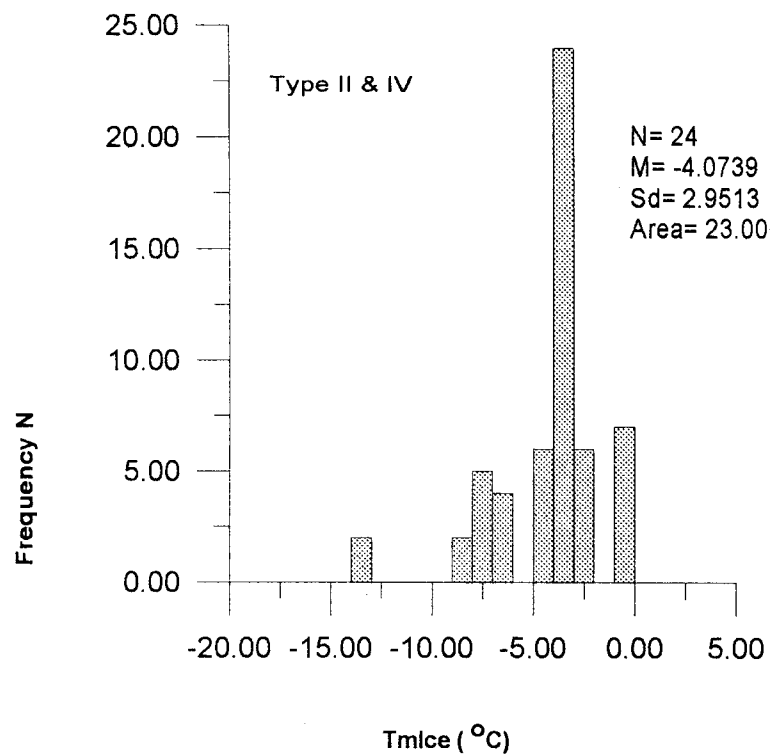


Fig.III.98:- Frequency histogram of melting of Ice, from microthermometric data.
(Type II and type IV).

Fig.III.99:- Frequency histogram of final melting of Ice, from microthermometric data.
(Type II and Type IV).

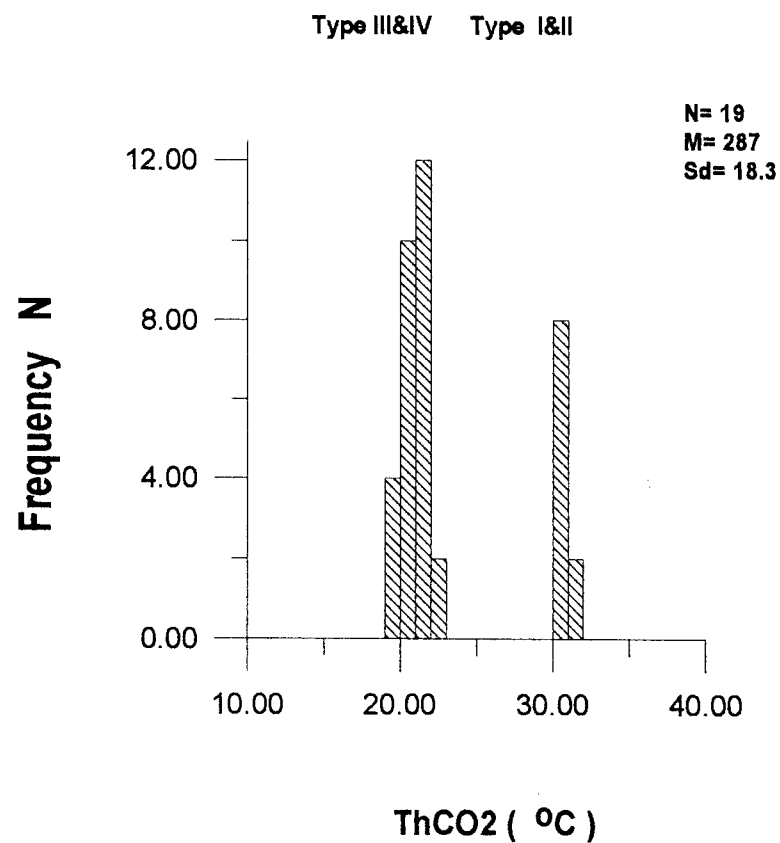
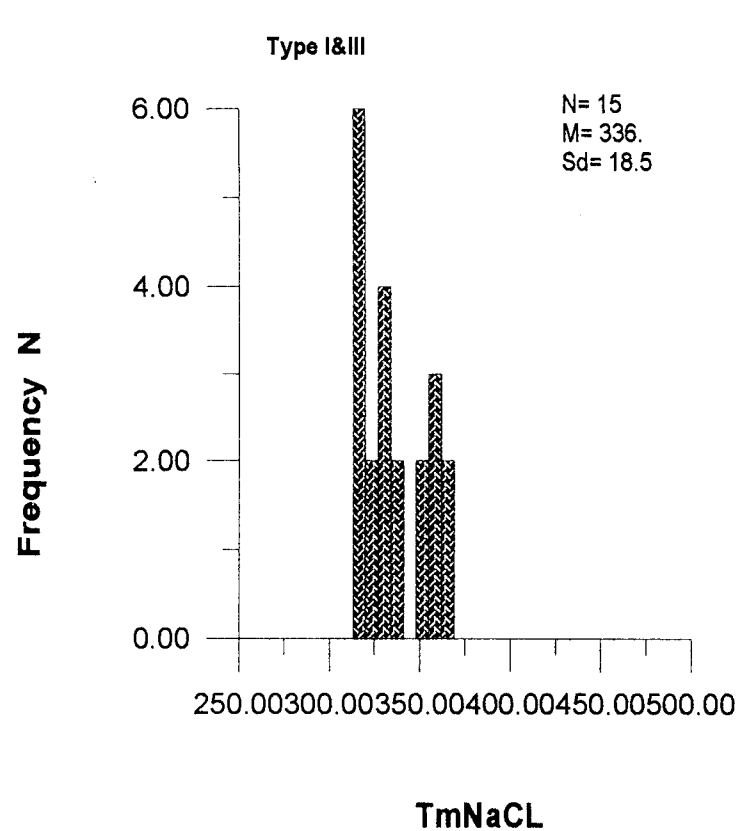


Fig.III.100:- Frequency histogram of melting of salt ,from microthermometric data.
(Type I :- H₂O - NaCL - CO₂ - DM and Type III: H₂O - NaCL - DM)

Fig.III.101:- Frequency histogram of temperature of homogenization of CO₂ , from
microthermometric data (Type I and Type II).

Fig.III.102 shows the optical photograph and SEM photomicrographs of quartz vein (QV1) -hosted decrepitated fluid inclusions. The inclusion decrepitates were produced by heating a doubly polished thin section sufficient to induce inclusion decrepitation. Most inclusions decrepitated above 300°C. Comparatively to homogenization temperatures of inclusions, an overheating of more than 100°C was required for decrepitation.

The decrepitates have a variety of morphologies when viewed using SEM but can best be described as miniature volcanoes or mounds, ranging from 1 to 15 μm in diameter. (Fig.III.102). It is assumed that volatile components, (H_2O and CO_2) were lost to the atmosphere and volcano-shaped salt precipitates (decrepitates) were deposited when the fluids were released upon decrepitation.

12.8.3.2.- Type III & IV : H_2O -NaCl - DM and H_2O -NaCl .

Melting temperature of ice and salt hydrate ($T_{\text{m-ice}}$) range from -22°C to -3.1°C (Fig.III.97) and temperature of final melting ice values are between - 0.1 °C to -7.5 °C (Fig. III.98). The last solid phase upon " heating - cooling " inclusions is ice, not clathrate. Total homogenization temperatures into the vapor phase are between 278 °C and > 475 °C . (Fig. III.103).

The total homogenization of the relatively large fluid inclusions (Type III) was not achieved in many runs due to leaking or decrepitation after homogenization of the vapor phase. Decrepitation phenomena before reaching T_{h} were found to occur frequently in type III inclusions.

Some inclusions have halite dissolving above the total homogenization temperature ($T_{\text{h}} < T_{\text{mNaCl}}$) and total fluid salinity ranges from 5.4 to 12.51 wt% eq.NaCl (Fig. III.104). Then it may imply that the trapped fluids have underwent some processes of compositional variations after entrapment.

For the majority of the pseudosecondary/primary inclusions ,eutectic temperatures were measured between -27.6 to -33.8 °C.

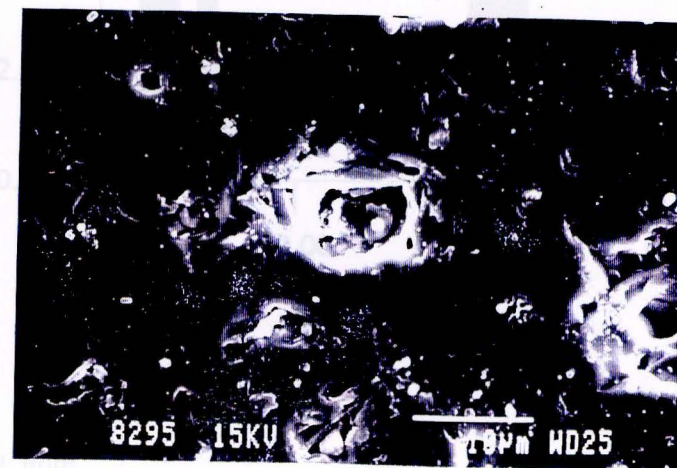
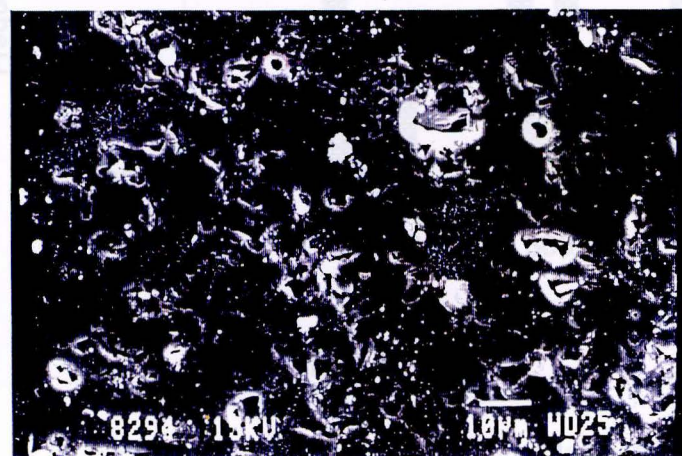
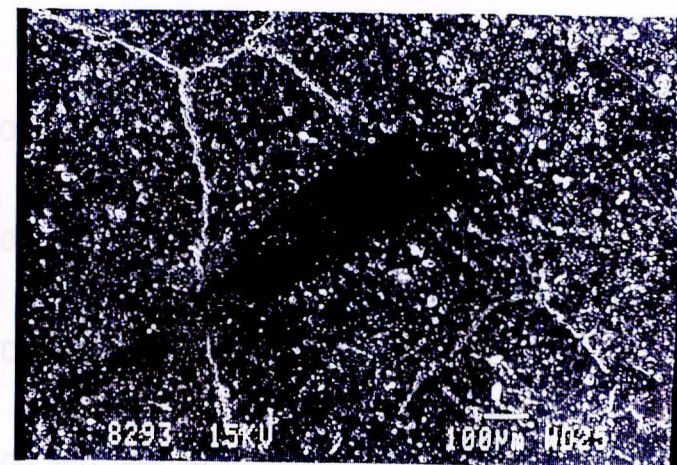
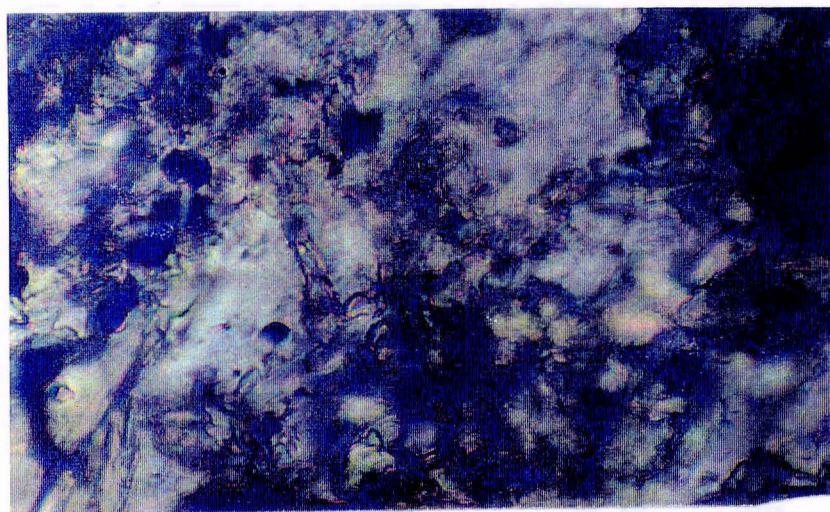


Fig.III.102:- - Optical photomicrograph and SEM photomicrographs of quartz vein (QV₁) - hosted decrepitates fluid inclusions .(Mag. x 85, x 950, x 2300). SEM of fluid inclusion-derived decrepitates salts. Note the spatters spewn out during decrepitation and the different central craters where the volatiles presumably escaped.

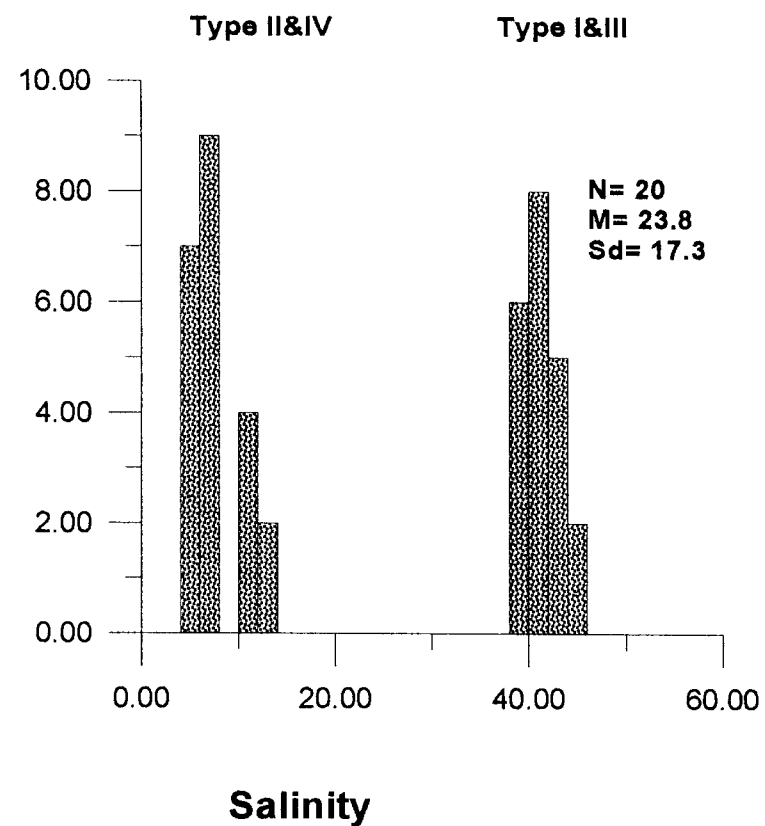
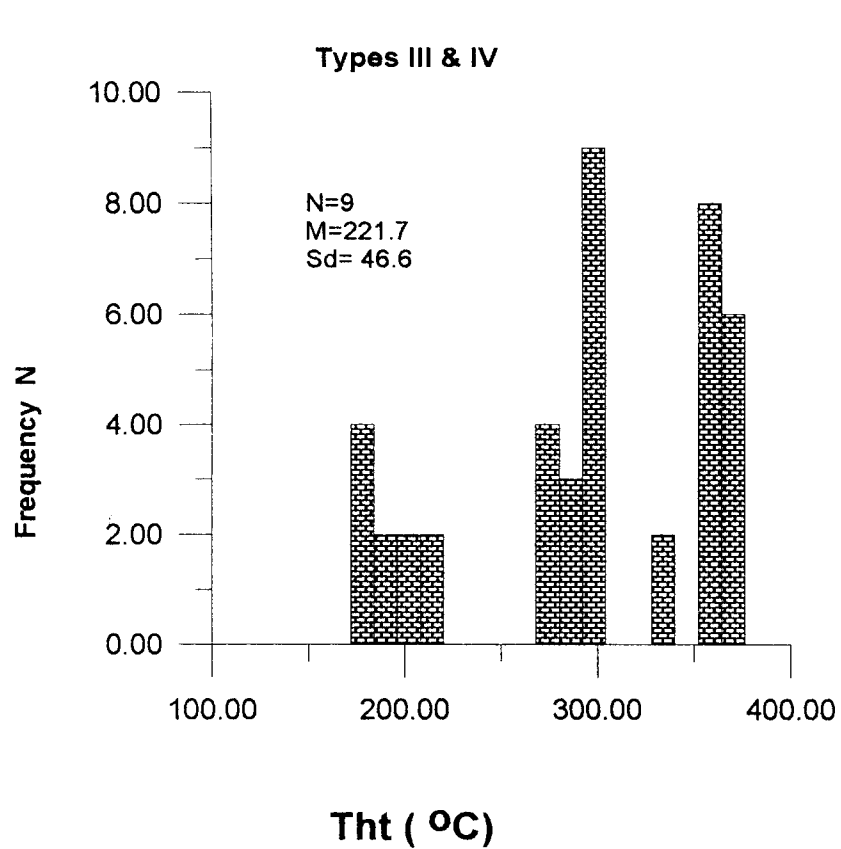


Fig.III.103:- Frequency histogram of temperature of homogenization total, from microthermometric data (Type III : H₂O - NaCL - DM and Type IV: H₂O - NaCL)

Fig.III.104:- Frequency histogram of salinity from microthermometric data. (Type I, Type II, Type III, Type IV).

12.8.3.3.- SALINITY.

Salinity calculations from the melting temperature of halite in the system $\text{H}_2\text{O}-\text{NaCl}$ by the equation of Sterner et al., (1988) give a salinity range of 39.5 to 45.2 wt% NaCl equivalent . (Table III.11; Fig.III.104). Type I & III.

Salinity corresponding to measured freezing point depression range from 5.4 to 12.51 wt% NaCl equivalent.(Bodnar , 1993). (Table III.14 ; Fig.III.104). Type II & IV.

The diagrams of respectively $T_h(t)$ versus $T_m\text{NaCl}$ (Fig. III.105) and T_h ($^{\circ}\text{C}$) versus Salinity (Fig. III.106) show a positive correlation, and thus it is likely to represent internal evolution of fluids from high salinity to low salinity. The apparent gap in salinities (Fig. III.106) may be partly due to the limited data and partly due to metastability of halite in solutions which are only just saturated (Alderton and Rankin, 1983).

These double positive correlations could be due to the separation of solid daughter products from a salt-saturated brine as it cooled , and /or mixing of saline brine with less saline , under saturated fluids .

The relationship between homogenization temperatures and salinities (Fig. III.106) suggests also a paleohydrologic model that involves overall a tendency of dilution of high-temperature , high -saline fluids (~ 40 wt% NaCl equiv.) by low-temperature, low - saline fluids. (~ 20 wt% NaCl equiv.).

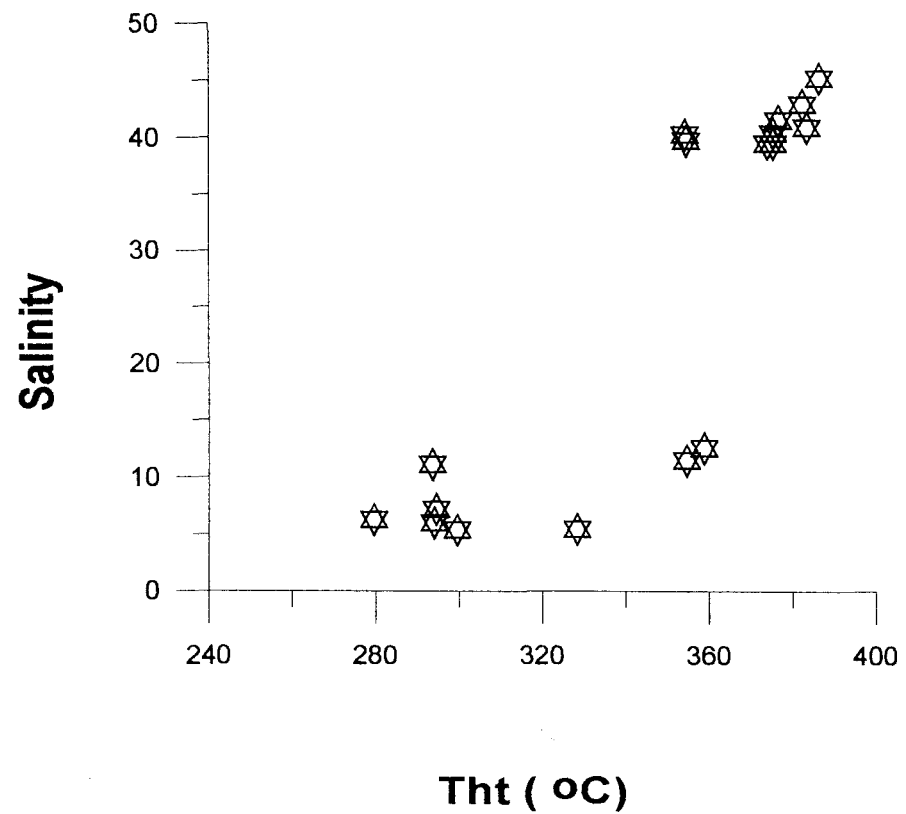
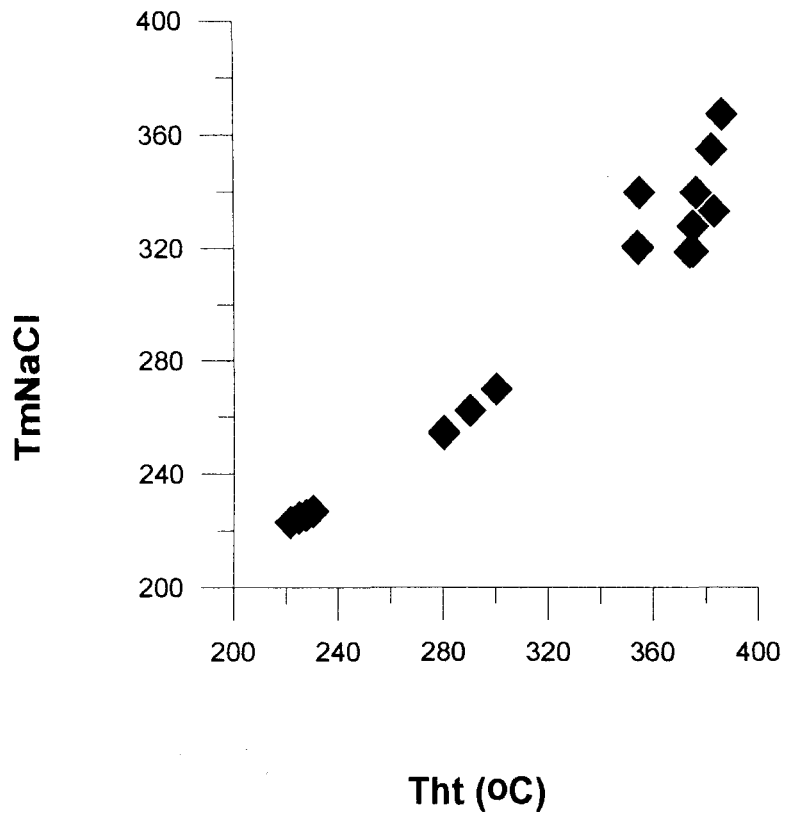


Fig.III.105:- Binary plot of temperature of homogenization and temperature of melting of NaCl.

Fig.III.106:- Relationship between homogenization temperature and salinities.

Homogenization temperatures versus salinity diagram for fluid inclusion in quartz - sulphide vein from the Twangiza gold deposit.

The synthesis of microthermometric fluid inclusions data is given in the following Table III.12.

Sample	TYPE:I&II: H ₂ O-NaCl-CO ₂ -(DM).	TYPE:III &IV: H ₂ O-NaCl-(DM).
	Type I  Type II.  10μm	Type III  Type IV 
QVI; crack-seal quartz vein.	Abundance: 75% Fill : 0.70 to 0.95 TmCO₂ : -56.1 to -61.7 °C Th CO₂ : 19.8 to 31.8 - - TmNaCl : 318.7 to 367.2 °C Tht (v) : 375.2 to 386.1 °C Salinity: 12.51 to 45.2 wt %NaCl equiv.	Abundance: 25% Fill : 0.75 to 0.95 - - TmIce : -18.4 to -26.2 °C TfmIce : -.0.1 to -7.5 °C TmNaCl : 279.6 to > 475 °C Tht (v) : 279.6 to 386.1 °C Salinity: 5.56 to 11.1 wt%NaCl Equiv.

TmCO₂ : melting temperature of the carbonic phase;
ThCO₂ (L or V) : homogenization temperature of the carbonic phase to the liquid (L) or to the vapor (V) phase.
TmIce : melting temperature of the ice or of salt hydrate;
TmNaCl : melting temperature of the salt mineral;
Tht (L or V) : homogenization temperature to the (L or V) phase
NaCl : salt mineral; DM.

12.8.4.- RAMAN SPECTROSCOPY.

Laser Raman analysis utilises the effect of molecular vibrations on the wavelength of light (The Raman effect, Raman and Krishnan, 1928) to provide semi-quantitative compositional data. The technique as applied to fluid inclusions is discussed by Dhamelincourt et al.,(1979) ; Dubessy et al., (1989). Raman analysis is non-destructive, and can be used on inclusions for which microthermometric data are known .

The technique is limited to species containing molecular bonds, such as the gases CO_2 , CH_4 , N_2 , and molecular ions such as SO_4^{2-} and CO_3^{2-} . Single ions solution (e.g. Na^+ , Ca^{2+} , Cl^-) cannot be detected. The results of laser Raman Spectroscopy are only semi-quantitative: the relative molecular proportions of gases can be determined, but their absolute concentrations can not.

The composition of the volatile phases in fluid inclusions is very important in understanding the physical and chemical nature of the ore-forming fluids (Dubessy et al., 1989).

Laser Raman spectroscopy was used in this study to scan for gaseous compositions (H_2S , CO , CO_2 , CH_4 , SO_2 , H_2 , NH_3 , N_2 , and C_2H_6) of selected inclusions in different quartz samples .

Analysis of the gaseous phase was performed on the same 39 inclusions measured by microthermometry. No quantitative analysis was attempted. Only qualitative analysis was made for inclusions gases .

The obtained spectra are shown in (Fig.III.107, Fig.III.108), and contain the peaks indicative of CO_2 .

The Raman spectrum of CO_2 usually contains 4 peaks: the Fermi resonance diad with the ν_1 peak at $\sim 1285 \text{ cm}^{-1}$ and the $2\nu_2$ peak at $\sim 1388 \text{ cm}^{-1}$, and the two " hot bands" on the outsides of the Fermi diad at respectively $\sim 1265 \text{ cm}^{-1}$ and $\sim 1410 \text{ cm}^{-1}$.

Many inclusions produce an additional peak on the inside shoulder of the $2\nu_2$ peak at $\sim 1370 \text{ cm}^{-1}$. This peak is due to the $2\nu_2$ vibration of $^{13}\text{CO}_2$. It is generally of quite low intensity, and common irregularities in the shoulder of the much larger $2\nu_2$ peak of $^{13}\text{CO}_2$ impede its quantification. (Burke, E.A.J., 1989).

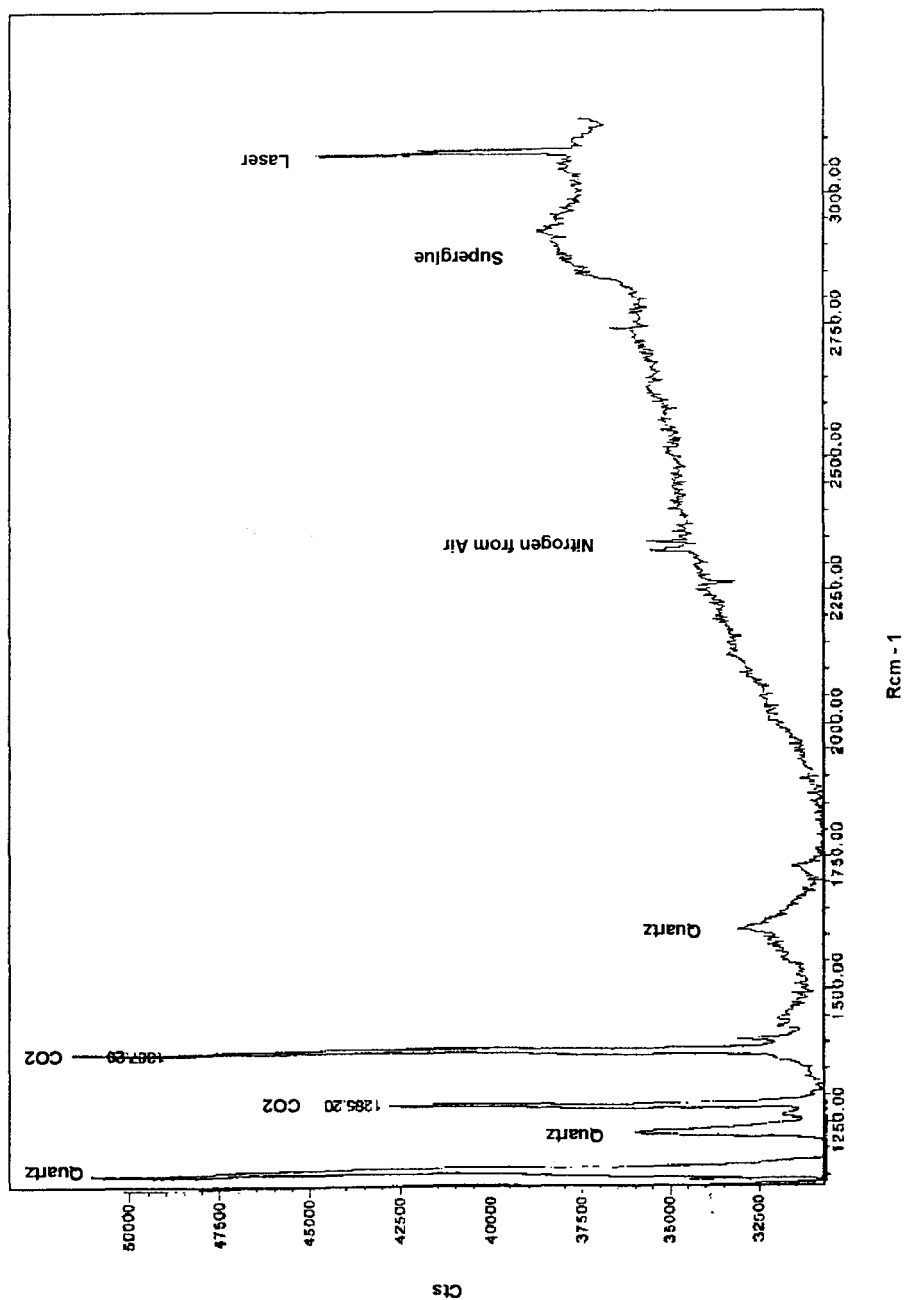
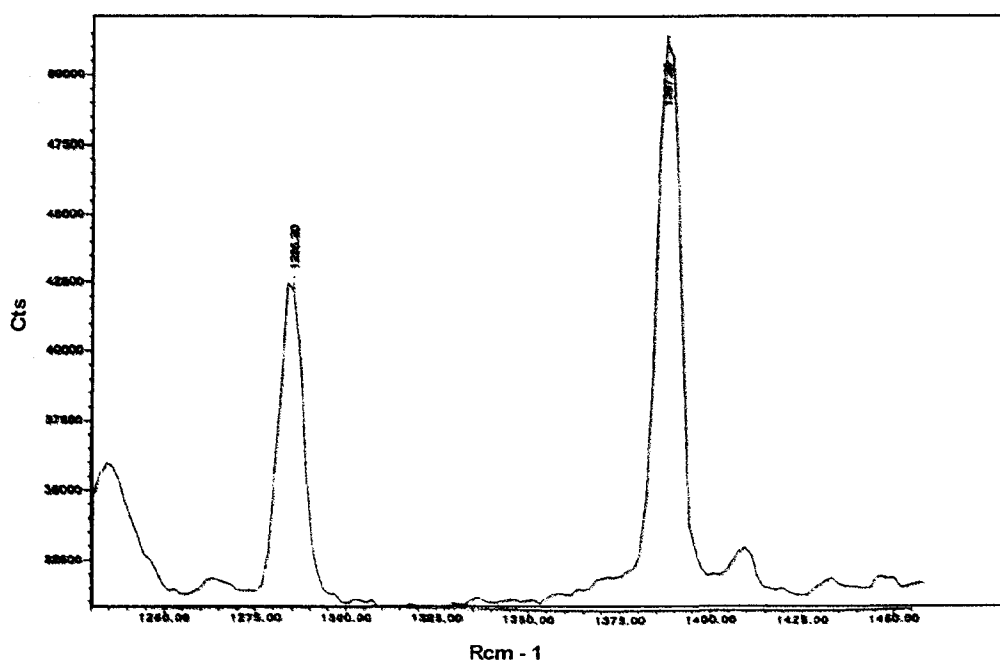
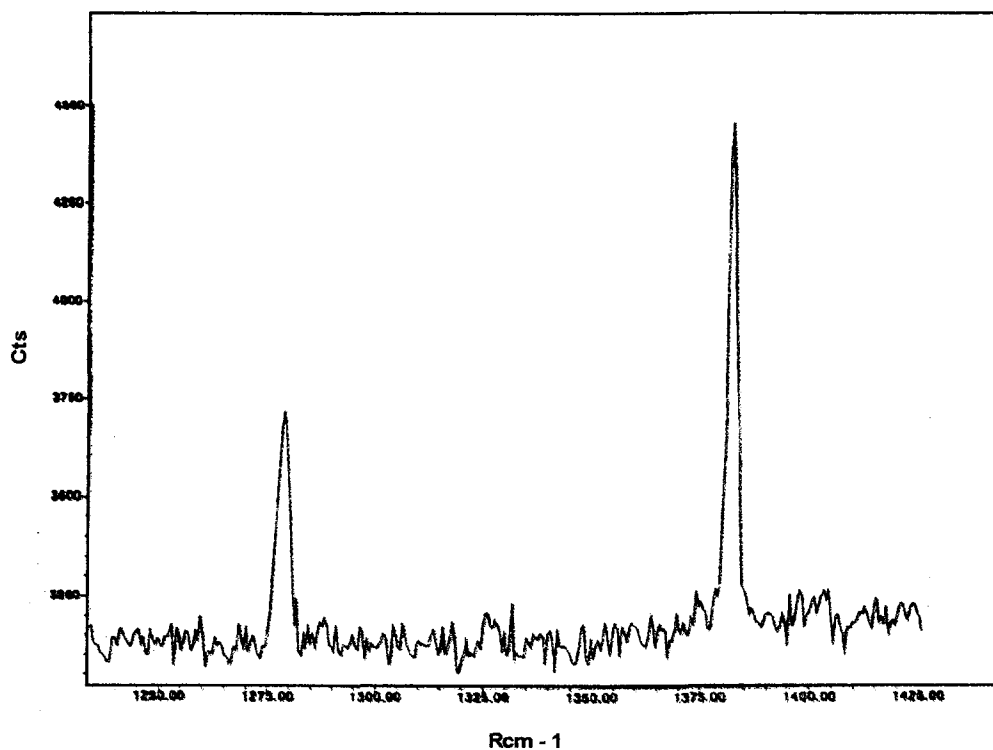


Fig.III. 107:- The Raman Spectrum of quartz and CO2 from fluid inclusions from quartz vein (QV1).

Fig.III.108:- The Raman Spectrum of quartz and CO₂ from fluid inclusions from quartz vein (QV1) (continued).



Figs.III.107 and Figs.III.108 show that the Raman spectrum of CO₂ consists of two peaks, referred to as the Fermi diad, with a higher intensity peak ($2\nu_2$) at 1387.20 and a lower-intensity one (ν_1) at 1285.20

Small peaks located at the sides of the main peaks are hot bands, which represent interaction frequencies ($\nu_1 + \nu_1$) and ($\nu_1 + 3\nu_2$) due to the thermal energy of the molecules (Howard-Lock and Stoicheff, 1971).

The relatively high intensity of the CO₂ bands at 1387.20 and 1285.20 cm suggests that the CO₂ content is very far from detection limits of 0.1 mole%.

The results of the Raman analyses show a good correlation with the microthermometric measurements.

12.8.5.- DISCUSSIONS.

12.8.5.1- TRAPPING P-T CONDITIONS FOR MINERALIZATION.

In order to estimate the true temperature of mineralization from homogenization temperatures of fluid inclusions, the pressure of the trapped fluids must be known.

The array of data presented above for homogenization temperatures of fluid inclusions allows for various estimates of pressure regime during the mineralization of the Twangiza deposit.

However, the fact that there is no evidence for boiling or fluid immiscibility from fluid inclusion petrography and microthermometric data, the homogenization temperatures of fluid inclusions represent a minimum estimate of trapping temperature of fluid inclusions for ore formation (e.g., Roedder, 1984).

Determination of pressure of entrapment is more difficult than temperature. Fluid inclusion pressure estimates represent fluid pressure prevailing in the fissure at the time of entrapment.

Pressure estimates are obtained from type I & II inclusions and determined from placement of fluid inclusion data on the $\text{H}_2\text{O}-\text{CO}_2-\text{NaCl}$ solvus (Takenouchi and Kennedy, 1964; Roedder and Bodnar, 1980; Craw., 1988) and are plotted versus temperature.

The pressure estimate is in the range of 200 bars to 600 bars. The most notable feature of the data is the wide range of pressures and temperatures of entrapment of the fluids. In spite of the uncertainties in the method, the different clusters of inclusions are distinctly different .

To estimate depth of vein formation, it is necessary to know whether this fluid pressure was due to hydrostatic or lithostatic load. Fluid trapped in rock below the brittle-ductile transition is unlikely to be directly connected to the surface, and lithostatic pressure prevail (Roedder, 1984).

At shallower levels, QV₂, QV₃ and QV₄ veins were probably formed by hydrofracturing and fluids within them were therefore also assumed to be subject to lithostatic pressure.

Using these assumptions, the pressure-temperature profile for Twangiza vein system is a lithostatic profile.

The maximum homogenization temperature recorded for Type II fluid inclusions is about 387 °C. Assuming an $\text{H}_2\text{O}-\text{NaCl}$ system for fluid inclusions, the pressure of at least (210) bars is necessary to prevent boiling at 387 °C and ~ 30wt% NaCl equiv. (Knight and Bodnar, 1989). This corresponds to minimum mineralization depths of about 1 and 3 km under lithostatic and hydrostatic pressure regimes, respectively.

Considering the shallow level of emplacement and the fact that epithermal systems are mostly characterized by hydrostatic pressure, the pressure correction should be minimal, and the Th of type I and type III inclusions are probably close to actual trapping temperatures and it is assumed that the veins formed between about 1km and 5km depth, although most veins formed in the shallower portion of this range.

The available barometric estimates during the full period of mineralization indicate a pressure regime that fluctuated between 200 and 600 bars.

Inasmuch as the depth of cover could hardly have changed significantly during the mineralization sequence, it appears that the pressures during most of mineralization event may have fluctuated between hydrostatic and lithostatic .

12.8.5.2.-SALINITY- Th RELATIONSHIP.

At least, four major types of fluids, two with moderate salinity and two with high salinity, deposited the quartz vein and that at least one of the high salinity type was accompanied by vapor.

The high salinity fluid, which is the most common type in most of the specimens, contains 30 to 40 wt% NaCl equivalent and was apparently saturated with NaCl below 300°C . Obvious secondary inclusions contain the same two types of fluids but tend to fill at lower temperature .

Examination of Fig.III.109, could suggest that fluids with two general ranges of salinity are present : one fluid with salinity of 30 to > 40% NaCl equivalent , and another with 10 to 20% NaCl equivalent. Only a few inclusions fall outside these ranges of salinity, and a complete gap exists between 20 and 30% NaCl equivalent.

The lack of moderate salinities may be attributed to a small data set from fluids inclusions measurements.

However, this gap can be explained by the limited number of data and the existence of a single continuum of fluids ranging from 10 to > 40 wt % NaCl equivalent is not excluded. ➡

This diagram shows that the wide gap of salinity, estimated from fluid inclusions types, is likely to result from one trapped fluid with high trapping temperature and high salinity in a closed fluid evolution system through time.

High trapping temperatures and high salinities suggest a magmatic origin for the hydrothermal fluids.

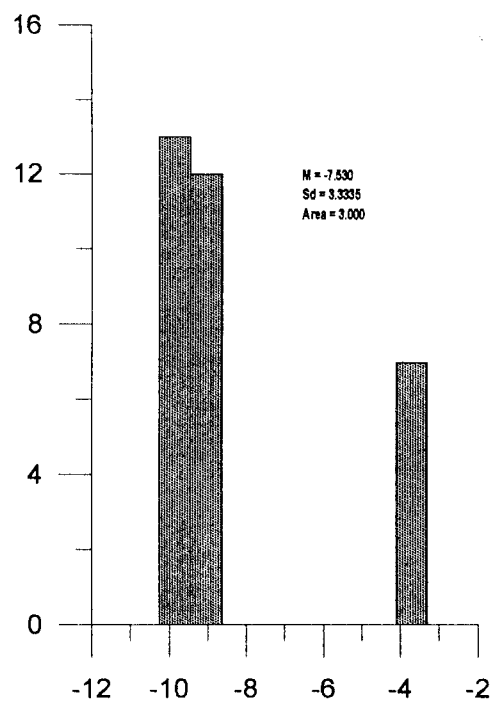


Fig.III.109- Histogram of carbonate isotope data (PDB) on carbonate from Twangiza deposit.

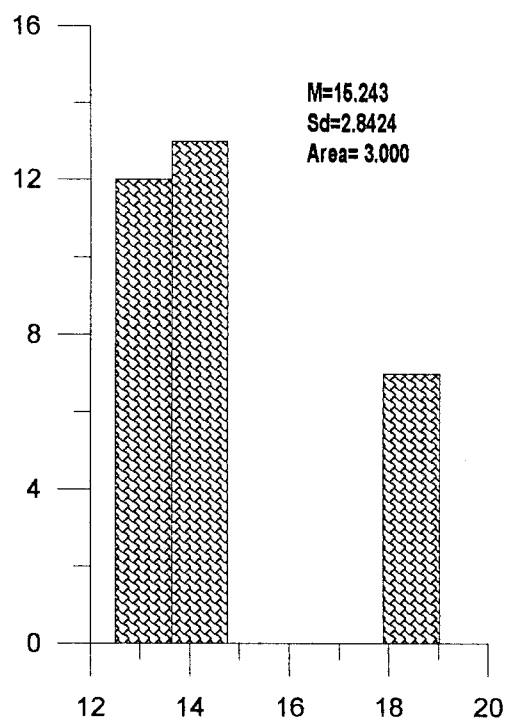


Fig.III.110:- Histogram of oxygen isotope data (SMOW) on carbonate from Twangiza deposit.

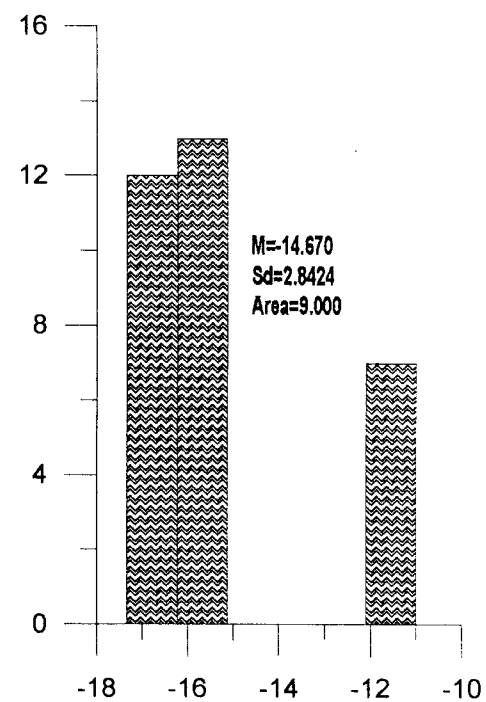


Fig.III.111:-Histogram of oxygen isotope data (PDB) on carbonate from Twangiza deposit.

12.8.5.3.- FLUID COMPOSITION AND ORIGIN.

Possible origins of the more saline fluid are :

- by exsolution from underlying magmas,
- by boiling of less saline fluids, or,
- by high-temperature solution of evaporites in a meteoric water.

An evaporite origin seems unlikely at Twangiza because of lack of evaporites in the stratigraphic section of the region, but the other two alternatives appear possible.

The derivation of high salinity fluids from magma has been discussed by Henley and McNabb, 1978. Using the system H_2O -NaCl , Henley and McNabb suggest that the high salinity brine and vapor-rich inclusions are readily explainable by derivation from any underlying magma.

An origin by boiling of a low salinity liquid is also possible but requires supplying a large amount of heat to the water. (Ahmad and Rose, 1980).

All three of the above mechanisms involve a very close relation of the high salinity fluid to magma, either as a source of the fluid itself or as a nearby source of heat or high temperature vapor.

An origin directly from the magma seems most reasonable, in view of the isotopic evidence for magmatic fluids.

The close association of moderate and high salinity inclusions can be explained by alternation of lithostatic and hydrostatic pressure conditions, controlled by episodic release of magmatic fluid, followed by fracturing to the surface, then choking of the veins by silica deposition.

The great variability of temperature and salinity of these inclusions seems to allow fluids in some to be meteoric or a mixture of meteoric and magmatic fluid.

The high salinity fluids (type I & III) probably were formed as a condensate from a supercritical fluid emitted by an underlying magma and following a P-T path that intersected the two phase field for the fluid, under conditions approaching hydrostatic pressure. (Ahmad and Rose , 1980).

The lower to moderate salinity fluids (type II & IV) can be explained as a similar supercritical fluid that remained near lithostatic pressure and followed a P-T path that did not intersect the two -phase field. Mixing with high salinity fluid and meteoric water may explain some occurrences of the lower salinity fluid .

Fluctuation between hydrostatic and lithostatic conditions caused by recurrent episodes of emission of fluid from magma, fracturing to the surface, and finally choking of the fractures by quartz deposition can explain the intimate association of the two types of fluids, the large range in pressure, and the range in temperature.

The hypothesis of magmatic derivation under alternating hydrostatic and lithostatic conditions seems to explain the gross features of the data most simply, but obvious much more detail remains to be worked out.

12.8.5.4.- FLUID EVOLUTION AND ORE FORMATION.

The H₂O-NaCl-CO₂ fluids responsible for mineralization were external to the volumes of rocks encompassing the QV₁ vein deposits and were not pore fluids within, and adjacent to, mineralized faults.

The available data for H₂O-NaCl-CO₂ system show that the solubility of CO₂ in aqueous saline liquid or solubility of saline liquid in CO₂ is very restricted even at relatively high temperature as salinity increases in this pressure range (Bowers and Helgeson, 1983). The circulation of highly saline hot fluids was probably driven by intrusive activity of the Twangiza albitite. The origin of CO₂ may be related to both underlying granitic magma and graphitic vein wall.

The interaction of hot, saline fluids with primary magmatic ore could cause the mobilization of base and precious metals with subsequent deposition as sulphides in veins.

Through the *fault valve model* (Sibson et al., 1988; Cox et al., 1991; Boullier and Robert, 1992), cyclic vein development has been previously correlated with the earthquake cycle.

According to Robert et al., 1995, during the " seismic rupture stage " , an important consequence of rupture is the breaching of the pressure seal and the consequent drop in Pf (near lithostatic Pressure). One of the consequence of the drop in Pf, is the interpreted unmixing of a parent H₂O-NaCl-CO₂ fluid into immiscible H₂O- rich and CO₂-rich fluids, which may be physically separated into different sites and microcracks within the veins due to their different wetting properties. (Watson and Brennan, 1987).

During the "immediate postrupture stage " , the postrupture drop in Pf, as well as the postrupture renewed ascent of deeper fluids along the (now) permeable fault, will likely promote precipitation of quartz and similarly, any fluid unmixing related to Pf drop will promote precipitation of carbonate within fault veins.

The rate of fault sealing will depend largely on the volume of external fluid infiltrating the permeable fault after rupture, precipitating quartz and carbonate due to changing P-T conditions.

12.8.5.5.- COMPARISON WITH THE PORPHYRY SYSTEM.

The microthermometric characteristics and daughter phases of type I & II inclusions are similar to those found in many porphyry system (Roedder, 1984).

Recent research has also shown that high-salinity inclusions occur in a number of high-sulfidation deposits, such as in the Nansatsu district, Japan (Hedenquist et al., 1994), Rodalquilar, Spain (Arribas et al., 1995) and Furtei, Italy (Ruggieri et al., 1997).

These inclusions in high-sulfidation deposits may represent fluids of magmatic origin or the result of the mixing of magmatic and meteoric fluids (Arribas et al., 1995).

High-temperature, liquid-rich high-salinity (Type I) inclusions coexisting with high-temperature, vapor-rich, low-to moderate-salinity inclusions (Type III) in the same sample KW 98A-3 , signify that these fluids may be the result of the boiling of a high - temperature liquid, or they may reflect immiscible vapor and hypersaline liquid derived from emplaced magma (Hedenquist and Lowenstern, 1994).

12.8.6.- SUMMARY AND DISCUSSION.

A fluid inclusion study was undertaken on quartz samples from QV1 vein of Twangiza deposit. Raman microprobe analysis was used to characterize the gaseous phase of the ore-forming fluids. No component other than CO₂ could be detected.

Four main fluid inclusion types (I : H₂O-NaCl-CO₂ -DM ; II : H₂O-NaCl-CO₂ ; III : H₂O-NaCl-DM & IV: H₂O-NaCl) were recognized according to their microthermometric characteristics and phase proportions observed at room temperature. The close association of moderate and high salinity inclusions can be explained by alternation of lithostatic and hydrostatic pressure conditions, controlled by episodic release of magmatic fluid, followed by fracturing to the surface, then choking of the veins by silica deposition.

The great variability of temperature and salinity of these inclusions seems to allow fluids in some to be meteoric or a mixture of meteoric and magmatic fluid. The positive correlation between salinity and Th (°C) could be due to: the separation of solid daughter products from a salt-saturated brine as it cooled, and /or mixing of saline brine with less saline, under saturated fluids. The apparent gap in salinities may be partly due to the limited data and partly due to metastability of halite in solutions which are only just saturated .

The circulation of highly saline hot fluids was probably driven by intrusive activity of the Twangiza albitite and Kasika granite. The origin of CO₂ may be related to both underlying granitic magma and graphitic vein wall.

The interaction of hot, saline fluids with primary magmatic ore could cause the mobilization of base and precious metals with subsequent deposition as sulphides in veins.

These fluid inclusion data presented above indicate significant fluctuations in fluid pressure during vein development between hydrostatic and lithostatic.

The available barometric estimates during the full period of mineralization indicate a pressure regime that fluctuated between 200 and 600 bars.

It is assumed that the thermobarometric evolution occurred in two stages:

*.- Fluid inclusion from the $\text{H}_2\text{O}-\text{NaCl}-\text{CO}_2$ system correspond to a drop of pressure and an opening in a lithostatic regime and accompanied early As, As ore deposition .

*.- Fluid inclusions from the $\text{H}_2\text{O}-\text{NaCl}$ system correspond to a drop in temperature and an opening in a hydrostatic regime. It is associated with late Au, As, Sb Ore deposition.

12.9.- STABLE ISOTOPE SYSTEMATICS.

12.9.1.- INTRODUCTION.

Studies of stable isotopes have shown their usefulness in elucidating the origin and history of hydrothermal fluids and their constituents.

In order to identify and constraint the source (s) of gold and associated base-metals and to understand the geological process responsible of the gold mineralization ,in Twangiza deposit, sulphide (pyrite) and carbonate (Fe-dolomite and calcite) from QV₂ (bedding -parallel sulphide vein) and QV₃ (quartz -carbonate vein) veins and host rocks adjacent to these veins, have been analyzed for stable isotopes .

Emphasis here was placed on the stable isotope systematic of saddle reef / quartz - sulphide vein hydrothermal pyrites and carbonates because of the abundance of these minerals at Twangiza deposit and their potential for providing critical information about the conditions of their formation. (Rye et al., 1992).

12.9.2.- ANALYTICAL RESULTS.

Results of bulk analyses of pyrites and carbonates are summarized in Table III.13. All the samples come from the main auriferous vein systems (QV₁ and QV₂) and Hydrothermal alteration zones adjacent to veins. Vein materials have been sampled and herein is reported the isotopic (S, C, O) geochemistry of vein minerals (pyrites & carbonates).

Table.III. 13:- Isotopic Data for selected veins and wall-rock from Twangiza gold deposit.

Sample No	Habit unit	$\delta^{34}\text{S}$ (‰)					$\delta^{18}\text{O}$ (‰)		$\delta^{13}\text{C}$ (‰)
		pyrite					carbonate		carbonate
		Weight sample (mg)	Weight Cu_2O (mg)	P_{co_2}	P_{so_2}	$\delta^{34}\text{S}$ PDB	SMOW	PDB	PDB
KW 430	QV ₁ vein	7.98	212.1	2.6	>100	2.71 2.64			
KW 444	Albitite	6.54	200.7	3.32	>100	2.70 2.72			
KW 448	Black shale	7.03	155.4	3.41	>100	3.28 3.36 3.32	+18.46	-11.55	-3.71
KW 617	QV ₂ vein	8.41	207.2	3.29	>100	3.13 3.12			
KW 618B	QV ₃ vein						+13.07	-16.78	-9.03
KW618E1	QV ₃ vein	6.57	200.6	4.5	>100	2.95 2.92	+14.20	-15.68	-9.85
KW 620A	Albitite	2.61	110.3	2.29	31.06	3.39 1.05			
KW621A2	QV ₃ vein	9.42	200.1	4	>100	2.80 2.82			
KW 622A	Black shale	7.1	201.7	3.28	>100	8.07 8.50 8.32			

*.-132 samples representative of QV₁ and QV₂ veins were selected. From these, optically pure grains of sulphides of about 3mm were hand-picked under a binocular microscope (BPI laboratory, Wits University).

*.-3 samples of carbonates (Ferroan dolomite, dolomite and calcite), free of sulphides, were performed. XRD work confirmed the nature of these different carbonates types in the deposit. Combined carbon and oxygen isotopes on carbonate minerals were done at Schonland Research Center by Prof. B. Verhagen.

The ratios $^{13}\text{C}/^{12}\text{C}$ was measured on CO₂ derived by oxidation of organic carbon (carbonate).

*.-21 sulphur isotope analyses were performed (20 pyrites and 1 arsenopyrite), which represent the first two of three stages of sulphide - bearing mineralization.

A total of 21 $\delta^{34}\text{S}$ (‰), measurements were made of which 7 are measured in duplicate.

Sulphur isotopes were done at the stable isotope laboratory of EGRU, geology department, Wits by Dr P. de Groot and measured at the Council for Geoscience on a Finigan Mat 250 mass spectrometer by W. Jordan and J Bester.

Method used is combustion with Cu₂O at 1000 °C under vacuum after Kusahabe and Robinson (1968). Sulphur isotope values are given in per mil (‰) against the V-CAT standard IAEA -SI defined at - 0.3 ‰.

Precision of the measured values is better than ± 0.1 ‰

12.9.3.- COMBINED OXYGEN AND CARBON ISOTOPES ON CARBONATES.

Carbonate occurs as laminae (< 1-2 cm) within bedding -parallel sulphide vein QV₂, as clots or infilling vugs coexisting with euhedral quartz in QV₁.

Ferroan dolomite is the predominant variety of carbonate mineral , but calcite, magnesite or dolomite are sporadically abundant. Fe-dolomites are interpreted as hydrothermal minerals formed later and at deep levels.

Carbon and oxygen isotope data are presented in Table III.13. There is a spread in $\delta^{13}\text{C}$ values from -3.71 to - 9.85 per mil for all the data. (Fig. III.109).

The most ^{13}C enriched value is represented by sample KW 448 B, wall rock of QV₂ vein. Collectively, there is a spread in $\delta^{18}\text{O}$ -values from +13.07 to +18.46 per mil (SMOW), (Fig. III.110) and from - 11.55 to - 15.68 ‰ (PDB), (Fig. III.111). For individual samples, the variation of $\delta^{13}\text{C}$ is positively correlated with $\delta^{18}\text{O}$ (Fig. III.111).

Plotted in the diagram of compilation of oxygen and carbon isotope values of carbonates and for carbon isotopic values of carbon - containing phases from different settings (Kerrich, 1987). (Fig.III.112), the Twangiza carbonates plots in the field of carbonate reservoir of gold occurrence.

For comparison , the Twangiza carbonates, have been also plotted in the diagram of $\delta^{13}\text{C}$ (PDB) values versus $\delta^{18}\text{O}$ -values (SMOW) for gold-associated carbonates in Abitibi belt lode gold deposits (Kerrich, 1987). (Fig.III.113).

12.9.3.1.- ORIGIN OF THE CARBON.

The $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ carbonate database is too limited to draw any definitive conclusions regarding the source(s) of carbon in ore fluids. However these preliminary data can be interpreted in the light of the following considerations :

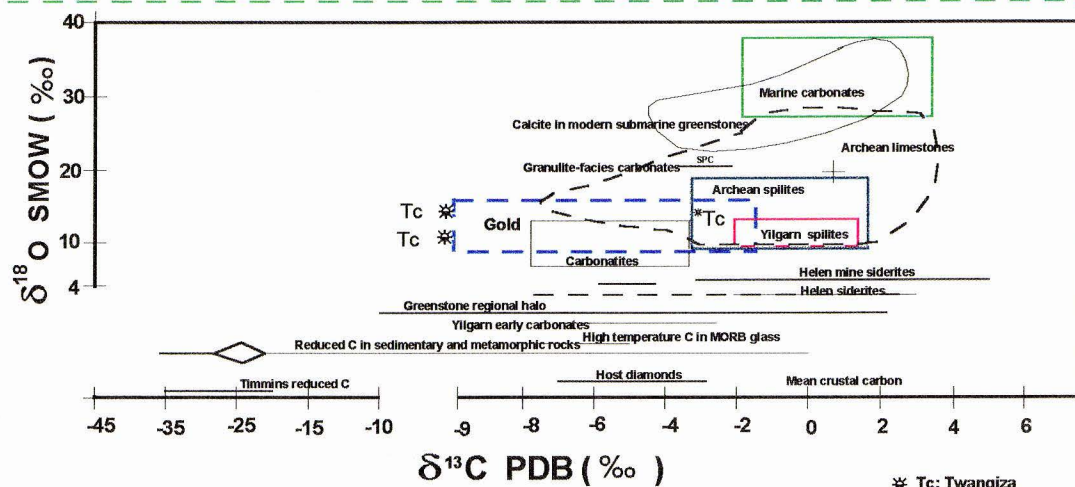


Fig.III.112:- The oxygen and carbon isotope compositions of vein calcite and ferron dolomites from gold ore at Twangiza plotted in the compilation of oxygen and carbon isotope values diagram of carbonates and for carbon isotopic values of carbon-containing phases from different settings (Kerrick, 1987).

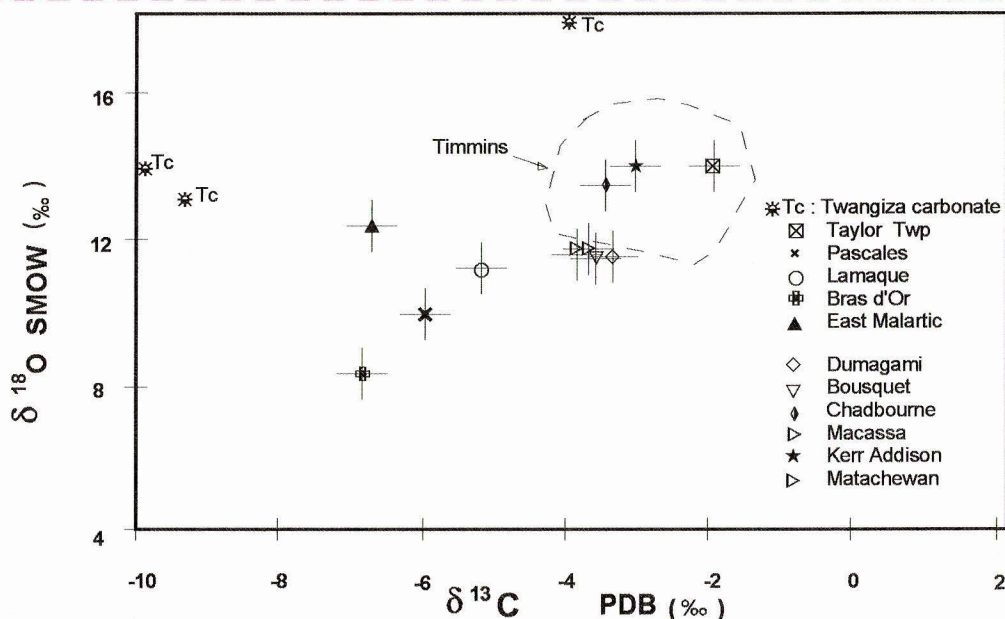


Fig.III.113:- The oxygen and carbon isotope compositions of vein calcite and ferron dolomites from gold ore at Twangiza compared to mean values for the $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ of Fe dolomites associated with gold deposits of the Abitibi greenstone belt. (after Kerrich, 1986)

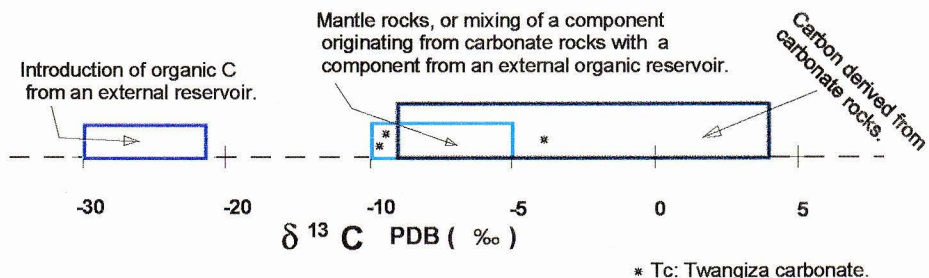


Fig.III.114:- $\delta^{13}\text{C}$ data points indicated relative to ranges of values given by Ohmoto, (1986), for carbon derived from external reservoir, mantle or carbonate source.

*.- Metamorphic fluids may have carbon isotope compositions anywhere in the interval of - 46 to + 4 ‰ (Kerrich , 1987).

*.- $\delta^{13}\text{C}$ values of $- 7 \pm 2$ ‰ are difficult to interpret with regard to the carbon source , precisely because magmatic , and metamorphic rocks are all characterized by average $\delta^{13}\text{C}$ values in the range of $(- 5 \pm 2$ ‰) close to these values; (Ohmoto and Rye, 1979); $\delta^{13}\text{C}$ values of of metasomatic fluids in the crust tends generally towards this $(- 5 \pm 2$ ‰) value, which is the value of carbonatite also.

*.-The $\delta^{13}\text{C}$ values from calcite veins associated with porphyry deposits are also generally consistent with a magmatic origin. Magmatic CO_2 typically has $\delta^{13}\text{C} \sim -5$ ‰ (Buick, 1998)

*.- $\delta^{13}\text{C}$ values of hydrothermal Fe-dolomites may shift by ± 3 per mil where fluids encounter graphite-bearing rocks (Fyon et al., 1984a)

*.- $\delta^{13}\text{C}$ values of -10 to -8 ‰ have been interpreted as reflecting a contribution of ^{13}C - depleted carbon of biogenic origin in source regions to the Golden deposit (Kerrich et al., 1987)

*.- Most metamorphic waters have δD between 0 and -70 ‰ and $\delta^{18}\text{O}$ between + 3 and + 20 ‰ , and that of primary magmatic waters have compositions in range of $\delta\text{D} = - 40$ to - 80 and $\delta^{18}\text{O} \sim + 5.5$ to + 9.5 ‰ (Sheppard , 1986).

*.- The $\delta^{18}\text{O}$ values (13.07 to 18.46 ‰) is estimated at $\sim 15 \pm 3$ per mil, (for 350 - 400 °C), typical for mesothermal veins throughout the geologic record and of varied setting, and is equivocal in terms of either a metamorphic or magmatic source.

It is clear that any source of carbon can not be resolved with certainty ; even the most depleted values measured ($\delta^{13}\text{C}$ circa $\sim - 10$ per mil) could arise either from oxidation of depleted carbon, or its assimilation into magma. (Kerrich , 1987).

Thus, It is suggested that, hydrothermal carbonate forming will be more likely to incorporate light carbon derived from the oxidation or hydrolysis of ^{13}C -depleted carbonaceous matter.

12.9.3.2.- SOURCE OF ORE-FORMING FLUIDS.

The $\delta^{13}\text{C}$ value of hydrothermal carbonates is a function of several variables, including T , f_{O_2} and pH during mineral precipitation and the $\delta^{13}\text{C}_{\Sigma\text{c}}$ of the fluid (Ohmoto and Rye, 1979 ; Ohmoto , 1986).

It is assumed that the $\delta^{13}\text{C}_{\Sigma\text{c}}$ of the fluid approximates the measured $\delta^{13}\text{C}$ values of Fe-dolomite and dolomite.

$\delta^{13}\text{C}$ values of hydrothermal carbonates from Twangiza have a range from - 3.71 to - 9.85 per mil, which presumably reflects corresponding uniformity in the $\delta^{13}\text{C}$ value of the fluid, and suggest a corresponding values of $\delta^{13}\text{C}_{\Sigma\text{c}}$ for ore forming fluids.

The $\delta^{13}\text{C}$ values of hydrothermal carbonates from Twangiza (Fig.III.114) fall in the fields respectively of mantle derived fluids and carbonate derived fluids defined by Ohmoto (1986).

An outstanding feature of hydrothermal alteration in the Twangiza deposit is the enrichment in carbonates (dolomite, ankerite, calcite, magnesite), indicating infiltration of CO_2 - bearing fluids.

There is a consensus that reactions between CO_2 and Ca -, Fe - and Mg - bearing silicates in the wall rocks are implicated in formation of the carbonate minerals. Solution of Ca, Mg (and some Fe), indigenous to peripheral alteration regions, combining with CO_2 from the mineralising reservoir, appears to be the process for forming the abundant ferri-dolomite gangue ; with wall rocks donating the bivalent metal cations, and hydrothermal fluids the CO_2 (Kerrich and Fyfe, 1981).

The presence of graphite in black shale wall-rocks imposes important constraints on the composition of the infiltrating fluid. In a hydrothermal system where large amounts of externally generated fluid encounter graphite - bearing rocks, the proportion of the various gas species depends on the f_{O_2} of the incoming fluid. If the oxidation state of such a fluid is high, the reaction $\text{C} + \text{O}_2 = \text{CO}_2$ dominates and the fluid becomes CO_2 - rich, independent of CO_2 content prior to interaction with graphite. More reduced fluids may contain CH_4 . (Eugster and Skippen, 1967).

In the C - O - H system, CO is negligible at temperature below 600 °C and the fluid can be considered as a mixture of H₂O, CO₂ and CH₄ (Ohmoto and Kerrick, 1977).

In the case of the Twangiza deposit , where graphite is present in the wall rocks ,the most likely source for isotopically light C is reduced organic matter in the form of graphite (Ohmoto and Rye, 1979), then oxidation and /or hydrolysis could have generated the oxidized carbonic species within the ore-forming fluid.

Possible other sources of the carbon; dominantly as CO₂ , in the fluids include calcite and dolomite. CO₂ could have also generated through thermal decomposition of organic matter and /or graphite in black shale. A third and more likely possible mechanism is Rayleigh distillation.

Therefore, we surmise that the carbon in the ore-forming fluids was a mixture organic (graphitic) carbon and recycled carbonate material from deeper parts of the crust (magmatic carbon and /or mantle carbon).

The importance of meteoric water in the mineralizing system has not be assessed. The δD values of the local meteoric water at the time of mineralization is not known and the hydrogen isotope study has not been undertaken.

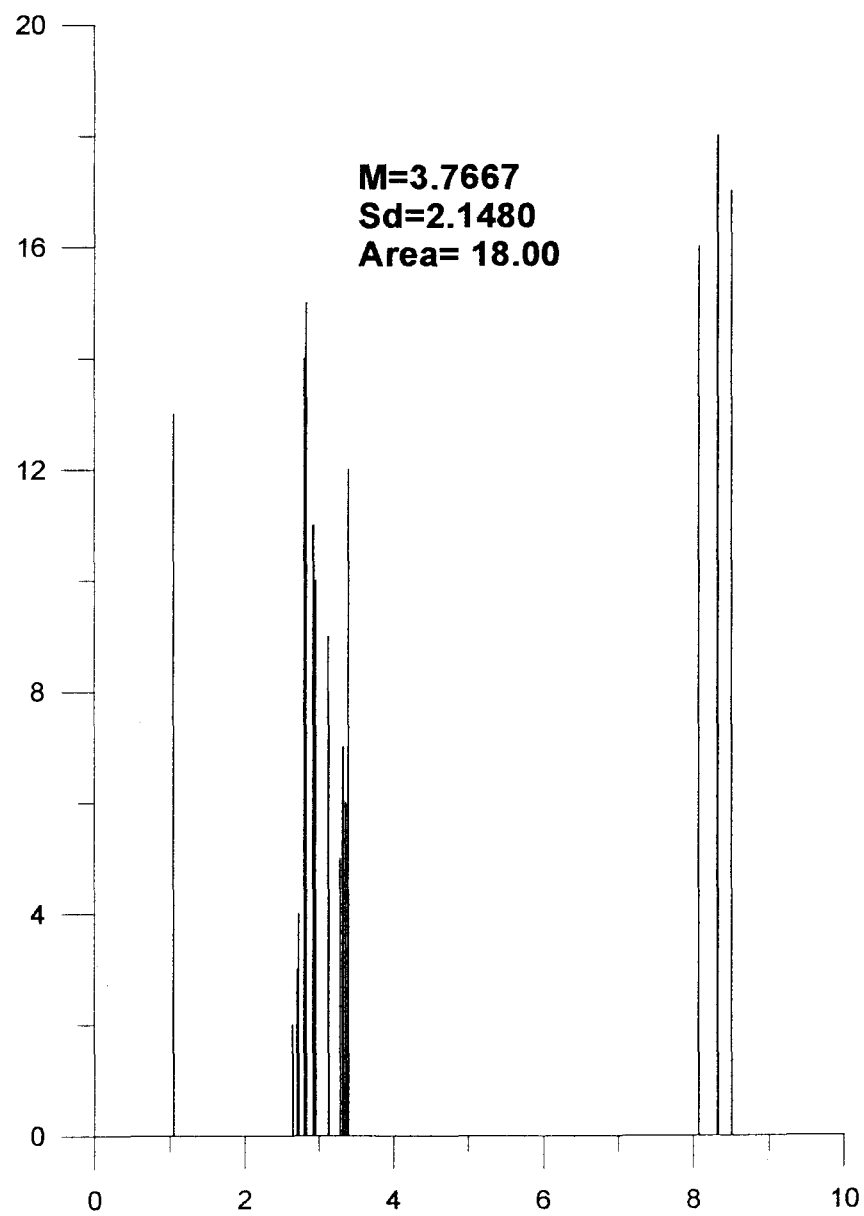
12.9.4.- SULPHUR ISOTOPES.

Results of sulfur isotope on saddle reef (QV₂) and quartz-carbonate vein (QV₃) pyrites are summarized in Table III.13, and graphically presented in Fig.III.115.

The data indicate a range in $\delta^{34}S$ values from 1.03 to 8.48 ‰ , isotopically moderately heavy. However the majority (95%) of data are defined by the narrower range of 2.62 to 3.37 with a marked concentration at 2.68 ‰ and an average of 3.62 per mil; both with respect to mode of occurrence (i.e., saddle reef versus fault reef) and stratigraphic position within the deposit.

The values for individual mineral phases could reflect the polyphase metallogenic history of the Twangiza gold deposit, consisting of three successive phases (stages) with tectonic breaks between them.

**Fig.III.115:- Histogram of sulphur isotope data (PDB)
from pyrite of the Twangiza deposit.**



12.9.4.1.- ORIGIN OF THE SULPHUR .

Sulphur isotope compositions of hydrothermal S-bearing minerals are controlled by the total sulphur isotope composition of the fluids and by the temperature, Eh and pH at the site of mineralization (Rye and Ohmoto, 1974; Ohmoto and Rye; 1979 ; Ohmoto, 1986). The first parameter can be regarded as a characteristic of the source, whereas the latter three relate to the environment of deposition (Kerrich , 1987).

The main results of the sulfur isotope data are as follow :

*.-The restricted range of measured $\delta^{34}\text{S}$ values for sulfides (pyrites) from the deposit at 2.62 to 3.37 ‰ (except for four values 1.03 ,8.05, 8.3 and 8.48 ‰ out of 21) indicates that any fluctuation in the physico -chemical conditions attending vein formation were either negligible or transient (Ohmoto and Rye , 1979).

The values of 8.0 to 8.5 ‰ may be explained by the following mechanisms: organic bacteriologic influence , weathering, importation of oxidized sulfur from the surface, eg., with meteoric water .

*.- Dissolving of sulphur from the diagenetic pyrites of the host rocks is not consistent with the moderately heavy isotopic signature of pyrite and arsenopyrite of the Twangiza gold deposit. Isotopically heavy $\delta^{34}\text{S}$ value (mode around 16 per mil) could be expected from a diagenetic pyrite (Longstaffe, 1987).

Thus the possibility that sulphide material was derived by dissolving of pre-existing sulphides extracted from surrounding rocks is unlikely.

*.- The data indicate that the following processes and variables exerted little apparent control in terms of modifying substantially the $\delta^{34}\text{S}$ signature of sulphide phases :

- Overprinting deformation which may have resulted in the growth of idioblastic pyrite;
- Wall-rock metasedimentary rocks which are the host for sulphide-bearing samples.

*.-Collectively, these isotopic data indicate that a common source of sulphur existed throughout all stages of sulfide growth or, conversely , that sulfide of similar isotopic composition was dissolved by a mobilizing fluid.

This can result in preserving the original $\delta^{34}\text{S}$ signature if the solution chemistry is appropriate (e.g., low f_{O_2} environment) and no fractionation occurs during subsequent sulphide precipitation (Ohmoto and Rye , 1979).

12.9.4.2.-ORIGIN OF THE ORE-FORMING FLUIDS.

The most likely source (s) of sulfur (and ore-forming fluids) can be argued in the light of the following considerations:

- *.- The relatively small range : +1 to + 3.4 ‰ and values close to zero are pointing to a magmatic source of sulfur.
- *.- The consistency of $\delta^{34}\text{S}$ value suggest a constant $\delta^{34}\text{S}_{\text{fluid}}$ and the absence of significant changes in $\text{H}_2\text{S}/\text{SO}_4$ during the evolution of the hydrothermal system.
- *.- The observed isotopic unhomogeneity likely implies isotopic no equilibrium conditions at the scale of gold vein . The equilibrium fractionation factors for pyrite - H_2S (Ohmoto and Rye, 1979) are -1 per mil at (340°C) , the temperature determined by fluid inclusions in associated quartz. The equilibrium isotope fractionation factors for arsenopyrite - H_2S is assumed to be similar (Layne et al., 1991).
- *.- Linkage of isotopic results with fluid inclusions study and mineralogical composition , geothermal chemistry , indicate that sulphur in the fluids was predominantly H_2S .
- *.- The narrow range (+1 to + 3.4 ‰) of sulfur isotope ratios in all the sulphides, combined with the lack of sulfates, suggest the combined effects of high $\text{H}_2\text{S}/\text{SO}_4^{+2}$ ratios and low $\delta^{34}\text{S}_\Sigma - \delta^{34}\text{S}_{\text{H}_2\text{S}}$ values in ore fluids, and thus suggests that the estimated $\delta^{34}\text{S}_{\text{H}_2\text{S}}$ values could have been equal to the $\delta^{34}\text{S}_\Sigma$ values.
- *.- The relatively tight clustering of $\delta^{34}\text{S}$ values in the interval of +1 to + 3.4 per mil can be interpreted to indicate that the fluid redox state was below the $\text{SO}_2/\text{H}_2\text{O}$ boundary, and that the sulphur source was isotopically uniform. Sulphur of this composition could be derived either directly from magmas, or indirectly by dissolution and/or desulphidation of primary magmatic sulphide minerals (Kerrich , 1987).
- *.- The average of 3.64 per mil of $\delta^{34}\text{S}$ values obtained is within the 0 +/- 5 per mil range normally assigned to magmatic sulfur values (Ohmoto, 1986).

12.9.5.- SUMMARY AND DISCUSSION.

Isotopic analyses of veins pyrites and carbonates from QV₁ and QV₂ constrain the characteristics of the ore-forming source fluid and the source rocks.

Based on this study, the Hydrothermal fluids which generated the vein minerals examined, namely QV₁ and QV₂, are considered to have originated from a magmatic source.

The isotopic data collectively indicate that the vein fluids were external with respect to the Tsibangu formation.

On the basis of carbon isotope data and geological considerations, it is argued that the hydrothermal CO₂ in the ore-forming fluids is derived from a mixture of organic (graphitic) carbon and recycled carbonate material from deeper parts of the crust (magmatic carbon and mantle carbon).

In the light of these considerations, the relatively tight clustering of $\delta^{34}\text{S}$ values of Au-related sulphides and the results of paragenetic studies can be interpreted to indicate that the hydrothermal fluids of stage I, II, III and IV were dominated by H₂S.

There is an uniform $\delta^{34}\text{S}$ composition of sulphide (2.62 - 8.48 per mil). This consistency reflects a similar reservoir for the sulfur and constant chemistry for the ore fluid which was reduced and contained H₂S as the dominant sulphide species.

In the H₂S predominant field (low f_{O_2} , and low pH region), sulphide minerals precipitating from solutions would exhibit $\delta^{34}\text{S}$ values similar to the $\delta^{34}\text{S}_{\Sigma}$ (value, then in the stages I and II, $\delta^{34}\text{S}$ of pyrite will be 1 per mil enriched relative to the total sulphur isotope composition of the fluid, which would have between 3.62 and 9.48 per mil).

Most mesothermal gold deposits have also H₂S as the dominant sulphur species (Ayora et al., 1992). The fluids responsible for vein formation ultimately originated at deep crustal levels (3 -12 km), (a magmatic source) but that interaction with wall rocks during fluid ascent variably modified slightly primary isotope signatures.

12.10.- GENETIC MODEL FOR THE TWANGIZA GOLD DEPOSIT.

Those parameters and relevant data that constrain genetic models are discussed in the following sections .

12.10.1.- REVIEW OF RELEVANT RESEARCH AND THEORIES ON A GENETIC MODEL FOR GOLD MINERALIZATION .

In the last decade, the upsurge in gold exploration and mining, has led to a better documentation, understanding and interpretation of gold deposits, (Precambrian gold deposits, epithermal gold deposits in volcanic terrains, intrusion -related gold deposits, Carlin-type gold deposits, auriferous hydrothermal precipitated gold on the modern sea floor, and alluvial including paleoplacer gold deposits).

There is a satisfying degree of agreement and a growing convergence of genetic concepts towards models that emphasize structural control of fluid infiltration and Au deposition (e.g. Viljoen et al., 1970; Seward,G., 1979; 1984; Ho,S.E and Groves,D.I; 1988; Foster,R.P., 1991).

There is however a great disagreement, if not controversy concerning the source of ore fluid as well as its composition. This controversy pertains essentially to the chemical and isotopic composition of the fluid, its source rock and timing of mineralization.

Some authors (Kerrich,R., 1983; Groves,D.I. and Phillips,G.N., 1987 ; Colvine et al., 1988 ; Groves et al., 1988); emphasize “ the derivation of gold from large masses of rock through fluid-rock reactions in the deep crust ”.

Others (Viljoen et al., 1970 ; Etheridge et al., 1983; 1984 ; Keays,R.R., 1984 ; Perring et al., 1987); stress “ the importance of relatively restricted petrogenetic groups of rocks termed source rocks that concentrate gold above the norm” (Foster,R.P., 1991).

Two very distinct Precambrian metallogenic periods, each with a large number of major economic gold deposits, have been well defined :

The Archæan era (particularly the great deposit in greenstone belts { ca 2.7Ga} and the vast Witwatersrand paleoplacer) and the Phanerozoic period (Mesozoic to the present). (Woodall, 1988; Keays et al., 1988).

Concerning the source of ore fluid , the following possibilities exist :

- *.- Metamorphic fluid (Binns et al., 1976; Kerrich, R and Fryer,B.J., 1981; Boulter et al., 1987; ; Groves et al., 1988b) ;
- *.- Mantle degassing fluid (Gold,T and Soter,S.,1981; Perring et al., 1987) ;
- *.- Magmatic fluid with two potential sources : namely, the external batholithic granitoids and internal granitoids, porphyry and lamprophyre intrusions (Anhaeusser.C.R., 1976; Hattori,K and Cameron,E.M. 1976; Hallberg,J.A 1985, 1988; Burrows et al ., 1986; Bettenay,L.F., 1988; Grove et al., 1988; Perring et al., 1988; Robb.L.J and Meyer, F.M. 1995 ; Robb.L.J et al., 1997) ;
- *.- Meteoric fluid (Nesbitt et al., 1986, 1987) ;
- *.- Connate fluid (Burnham.C.W,1967; Archibald et al.,1981; Golding.S.D and Wilson.A.F., 1982; Smith et al., 1984; Skwarnecki.M.S., 1987).

A Genetic model for mesothermal gold deposits includes :

- *.- Magmatic model : derivation of ore from magmatic source with a close age-relation between late tectonic granites and the ores ; (Sandiford and Keays, 1986 ; Sketcheley et al., 1986 ; Sang and Ho, 1987 , Spooner, E.T.C. 1991)
 - *.- Metamorphic model : derivation from metamorphic processes and metamorphic fluids (Groves and Zentilli, 1982; Kontack and Smith, 1988) ;
 - *.- Meteoric water model : deep convection of meteoric water in the brittle continental crust as the principal process in ore formation (Nesbitt et al., 1986 ; Shelton et al., 1988).
- The two last principal genetic models (metamorphic and meteoric) are similar in many respects, such as the importance of regional structure and the chemistry of the ore deposits , and differ in the source and migration paths of the fluids (Foster, R.P , 1991).

The possibility that a comprehensive genetic explanation may involve multiple processes, may be envisaged. Some deposits could be formed from different fluid sources and a combined model ; (example: magmatic-metamorphic fluid), have been reviewed (Rock et al., 1987; Rock and Groves., 1988a, 1988b; Hutchinson.R.W.,1987; 1993).

The major components of gold mineralizing ore fluid are: Au, S, CO₂ + K (and associated base-metals) and these can come from different sources, in particular magmatic from the upper or lower crust (Phillips., 1986; Phillips et al., 1987; Rock et al., 1987) .

The mechanism of gold sourcing , transport , and deposition are extremely complex and have been reviewed by various workers (e.g. Seward, 1973, 1991 ; Hayashi and Ohmoto, 1991) .

12.10.2.- NATURE AND CONDITIONS OF ORE-BEARING FLUIDS.

The nature of the ore fluids has been deduced from fluid inclusion studies of quartz veins interpreted to be synchronous with , or slightly post- dating , the main stage of gold mineralization. The fluids were $\text{H}_2\text{O}-\text{NaCl} \pm \text{DM}$ and $\text{H}_2\text{O}-\text{NaCl}-\text{CO}_2 \pm \text{DM}$. They were of high salinity (5.56 - 45.2 wt % NaCl equivalent), inferred moderate density ($\sim 0.9 \text{ g/cm}^3$) , near-neutral pH (albite and muscovite are stable) and reducing. Minimum gold depositional conditions were 280°C to $> 450^\circ\text{C}$ and 0.5 - 4.5 kb . No methane has been detected. Although significant methane in fluids could have interacted with carbonaceous metasedimentary rocks.

Minimum gold deposition conditions were 178.9°C to $> 475^\circ\text{C}$ as determined from homogenization temperatures of fluid inclusions and 0.5 to 4.5 kb on the basis of phase separation of $\text{H}_2\text{O}-\text{NaCl}-\text{CO}_2$ fluid inclusions. The lack of sulfates in the Twangiza deposit indicates a relatively reduced state of ore fluids.

The overall uniformity of values of the ore-forming fluid within the Twangiza deposit, signifies very large and uniform fluid and rock source volumes , and approximately isothermal conditions of alteration and mineralization .

12.10.3.- GOLD TRANSPORT AND PRECIPITATION.

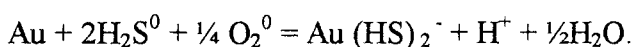
Gold is transported as a thiosulphide complex $[\text{Au} (\text{HS})_2^-]$, under greenschist and subgreenschist facies conditions. Gold-chloride complexes are probably insignificant contributors to gold solubility at temperatures less than 400°C but may be important at higher temperatures (Mikucki and Grooves, 1990 ; Romberg, 1990).

In the Twangiza deposit, the very low gold / base metal ratios of the deposit reflect the relatively restricted potential for chloride complexing of the base metals in the normally

high salinity. In the near neutral solutions, gold occurs probably largely as the bisulphide complex. The fluid may also destabilize As-bearing complexes and precipitate arsenopyrite, as pointed out by Wall (1987), and precipitation of sulphides may also lower the stability of the gold thiocomplex. At this stage pyrrhotite could be deposited and then replaced by pyrite .

The nature of the ore fluid, the ore-element association, very low gold / base -metal ratios, and commonly intimate association of gold with Fe- sulphides all suggest gold transport as reduced sulphur complexes (Philips and Groves , 1983), and exclude significant Au transport as chloride complexes (Henley, 1973).

Gold solubility could probably have been controlled by reactions such as :



Under certain ore-fluid conditions, temperature and pressure may also influence gold solubility (Seward, 1973), but temperature gradients are unlikely to provide a major depositional mechanism.

Under the reducing conditions of gold deposition, precipitation will be favoured by either a decrease in ore-fluid pH , a decrease in the total reduced sulphur content of the fluid, or fluid reduction.

In order to form an economic orebody, it is necessary to induce a change in the fluid chemistry that will efficiently remove gold from solution by destabilizing gold complexes.

Gold deposition is primarily related to these changes in fluid chemistry : fluid-mixing, fluid / wall -rock interaction, and phase separation into CO₂ - rich and H₂O - rich fluids :

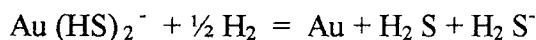
1*.- Fluid /wall-rock reactions could have resulted in changes in $f\text{O}_2$ and pH , causing gold precipitation. With high Fe/(Fe + Mg) ratios; (1 - 2.78), in the black shale and albitite host rocks, sulphidation reactions destabilized gold reduced sulphur complexes causing gold precipitation . The locally variable gold grades typically found in veins could be explained by the fluid / wall- rock reactions.

However, most gold precipitation occurred in veins rather than in wall rocks, indicating that fluid / wall-rock interactions were not particularly important.

2*.-Fluid - mixing seems a more unlikely process in the Twangiza deposit taking into consideration the nature and conditions of ore-bearing fluids present.

3*.- Phase separation will generally result in increased pH and fO_2 and decreased sulphur species in the remaining aqueous phase. This results from the partitioning of acid volatile species (for example, H_2S , CO_2 , SO_2) into the co-existing vapour phase and the tendency for preferential removal of the reduced vapour species (CH_4 , H_2S) with respect to their more oxidized counterparts (CO_2 , SO_2 , H_2O). (Solomon and Groves, 1994).

Based on available data from the Twangiza deposit, it is suggested that modification of fluid chemistry has been achieved by transient pressure fluctuations inducing phase immiscibility in the fluid , which lead to the reduction of the fluid and lowering ΣS in the fluid . This process can lead to gold precipitation through reactions such as :



Fluid pressure cycling leading to sudden pressure drops during quartz vein formation and hence phase immiscibility provides a gold depositional mechanism, controlled by processes operating strictly within the fluid, that can explain orebodies where gold is sited dominantly within veins (Sibson et al., 1988 ; Wilkinson and Johnston, 1996).

Crack -seal veins (QV_3) requires a protracted history of pressure fluctuation from $< P_1$ to $>> P_1 + T$, the fault acting as a valve with respect to fluid flow (Sibson et al. 1988, Cox et al. 1991b). Mineralization appears to have taken place during the main late stages of deformation and occurred at, or above the brittle-ductile transition . Brittle - ductile transition deformation occurs characteristically at depths of 10-15km, perhaps greater in some cases (Sibson. 1990) .

Gold is sited in sulphide lattice structures and as inclusions in sulphides, and hence appears paragenetically late as native metal or introduced and deposited coevally with hydrothermal alteration and quartz vein emplacement. Gold is associated with primary vein-forming minerals .

12.10.4.- FLUID FOCUSING.

Most ore shoots lie in classic saddle reef and fault reefs and associated spur veins on anticlinal flanks, the hinge zones being low grade.

The intensity of quartz/sulphide veining and mineralization indicates that there has been a strong focusing of fluid flow in vertical or steeply dipping zones of considerable strike (> 5 km), width (> 250 m) and down-dip extent. The ore fluids were mostly focused into anticlinal flanks and the vein systems have great vertical depth (> 1 km).

The large-scale folded geometry of interbedded low permeability units (arkosic sandstones) and higher permeability units (black shale) has presumably served to guide progressive upward migration of fluids along high permeability beds and bedding-concordant fault zones, towards anticlinal flanks zones.

The Twangiza high angle reverse fault zone is considered to represent the main feeder zone along which hydrothermal fluids moved upward towards the upper metaturbidite sequence.

The Twangiza and Kekombe fault zones are inferred to form a linked fault system imbricating from gently dipping major faults or a detachment zone at deeper crustal levels. The source region is likely to be to the east and at deeper crustal levels.

Deformation within the mineralized zones does not appear to be much more severe than in the region generally, suggesting that fluid focusing was controlled by deeper structures. The spatial localization of gold and tin deposits within the Kadubu area (N-S trending belts, and faults) supports a conclusion that the location of goldfields and the pattern of fluid migration between source regions and goldfields was probably controlled by the large-scale crustal fault architecture which developed during regional deformation and low grade metamorphism.

12.10.5.- SOURCE (S) OF FLUID (S) AND ORE METAL COMPONENTS.

The potential source reservoirs within the immediate environment of the deposit area include the Tsibangu group metasedimentary rocks and the Twangiza albitite pluton.

The consensus for metatubidite- hosted mesothermal gold deposits is that the fluids originated at depth due to devolatilization reactions and were released during subsequent orogenic activity, perhaps in a manner similar to the fault-valve model discussed by Sibson et al., (1988) and Kontak and Kerrich., (1995).

Possible source reservoirs involved in a collisional and/or transpressive geodynamic regime include: metamorphic fluids from dehydration of subcreted oceanic lithosphere and magmatic fluids from trondhjenites generated by melting at the base of subcreted lithosphere (Cuaig and Kerrich. , 1998).

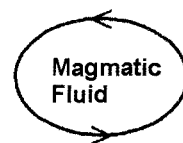
The results of Sulphur, Oxygen, and Carbon isotope studies and fluid inclusion studies provide a basis for constraining potential source reservoirs for vein-forming fluids and ore components.

The fluid inclusions and isotopic data collectively indicate that the vein fluids and associated ore -metal components were external with respect to the immediate environment of the Twangiza deposit : the Tsibangu Formation within the Itombwe synclinorium. The reduced nature of the metatubidites is considered to have been more important as a chemical trap for exotic, Au-bearing fluids.

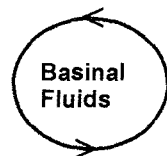
The hypothesis, which involves magmatic and shallow-level, near -surface fluids , could be advanced for the origin of the ore- fluids in the Twangiza gold deposit. A magmatic derivation under alternating hydrostatic and lithostatic conditions seems to explain the gross features of the data. (Fig.III.116). A magmatic source is consistent with $\delta^{34}\text{S}$ data for the Twangiza deposit, which collectively, span a range of 2.62 to 3.37 ‰ (n= 21) with a mean of 3.615 ‰ and two extreme values ; at 1.03 ‰ from albitite wall rock and 8.48 ‰ from black shale wall rock. There is a uniform $\delta^{34}\text{S}$ composition of sulphide (2.62 - 8.48 per mil). This consistency reflects a similar reservoir for the sulfur and constant chemistry for the ore fluid which was reduced and contained H_2S as the dominant sulphide species.

FLUID RESERVOIRS.

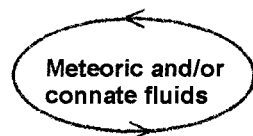
Collisional and transpressive geodynamic regime (accreted terrane).



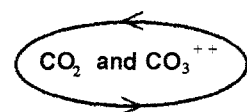
: Primary fluids : magmatic fluids enriched in S, Au, Ag, W, Nb,Ta, Sn, As, Cr, Ni, V, Rb, CO₂



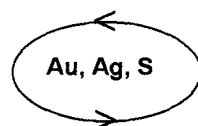
: Formation waters tectonically expelled from cover thrust units, advect along detachment fault; (mixing with hydrothermal fluids related to (pre)-rifting event ?).



: Meteoric and/or connate fluids from the surface and from the Kadubu metasediments.



: Reaction of primary ore fluids with the black shale producing , CO₂, and CO₃⁺⁺



: Minor convecting formational and contact metamorphic fluids.

KMA Walemba, 2000

Fig.III.116 :- Schematic diagram of fluid reservoirs of the Twangiza gold deposit.

The $\delta^{18}\text{O}$ signature for fluids (+ 13.07 to + 18.46 ‰ , with a mean of + 15.243 ‰) is consistent with both magmatic and metamorphic origin.

The $\delta^{13}\text{C}$ data (-5 +/- 2 ‰) are compatible with a magmatic origin for the CO_2 (Colvine et al., 1984; Burrows et al., 1986), whereas others have suggested metamorphic dissolution of mantle-derived carbonation zones along regional and /or transcraton shear zones that also host the gold mineralization (Groves et al., 1988a,b).

Some degree of mixing of graphitic carbon with marine carbon could effectively lead to the negative $\delta^{13}\text{C}$ values (~ -7 per mil) of ore fluids. Therefore, on the basis of carbon isotope data and geological considerations, it is argued that the hydrothermal CO_2 in the ore-forming fluids is derived from a mixture of organic (graphitic) carbon and recycled carbonate material from deeper parts of the crust (magmatic carbon and mantle carbon).

The importance of meteoric water in the mineralizing system has not been assessed. The δD values of the local meteoric water at the time of mineralization is not known and a hydrogen isotope study has not been undertaken. However, the great variability of temperature and salinity of these inclusions seems to allow some fluids to be meteoric or a mixture of meteoric and magmatic fluid.

Fluid inclusion data suggests that the high salinity brine and vapor-rich inclusions are readily explainable by derivation from any underlying magma. This high salinity fluid from the Twangiza deposit indicates a magmatic source. However, the presence of albitite felsic plutons in and /near the Twangiza deposit suggest that the nature of the fluids deserves further investigation. It is crucial to establish whether a real spatial relationship between porphyritic albitite intrusion and gold mineralization exists in the Twangiza area, or whether it is a function of selective exposure.

The development of Albite-rich rocks (albitite) is usually associated with " rare element " mineralization (Nb, Ta, Sn, W, Li, Be). Na- enrichment is often accompanied by concentrations of Fe, U, Th, Zr, Nb, Sn , Zn, and HREE. (Kinnaird et al., 1985 ; Pirajno, 1992).

The significance of porphyritic albitite intrusions to ore genesis, and their apparent influence on the economic status and ore mineralogy, is assessed in the light of this model.

In the previous chapter, the importance of structure in both focussing fluid flow and providing sites suited to gold mineralization has been stressed. Structure can effect a spatial coincidence in at least two ways and it seems that both have acted in the Twangiza deposit :

1*- Magma and ore fluids may exploit the same conduits in their ascent from deeper crustal levels, resulting in albitite intrusion and gold mineralization occupying the same structures ;

2*- Rheological contrasts between the predominantly albitite intrusion and surrounding less competent country-rock can result in the intrusion acting as a structurally favourable site for gold deposition. Thus, the spatial association between albitite intrusion and gold mineralization reflects the paramount importance of structure in the localization of gold mineralization.

The presence of the Kashwa sheeted tin deposit with tourmalinization of country rocks suggest the presence of a greisen system.

Greisen systems result from complex , and as yet not completely understood, late to post magmatic metasomatic processes that affect and take place within a nearly consolidated granitic body and the adjacent country rocks .

They are normally associated with Sn, W, Mo, Be, Bi, Li and F mineralization. The highly evolved granitic melts that promote the development of greisenisation phenomena and associated mineralization are strongly enriched in volatile components, Cl, B, F , and metallic elements , such as Sn, W, Mo, Bi, U, Be.

Thus the presence of albitite intrusions and greisen systems in the Kabubu area suggests the existence of a granitic rock at depth. Spatial and temporal distribution of gold deposits in the Kadubu area suggest a metamorphic core complex/detachment fault model to explain the source for the mineralization.

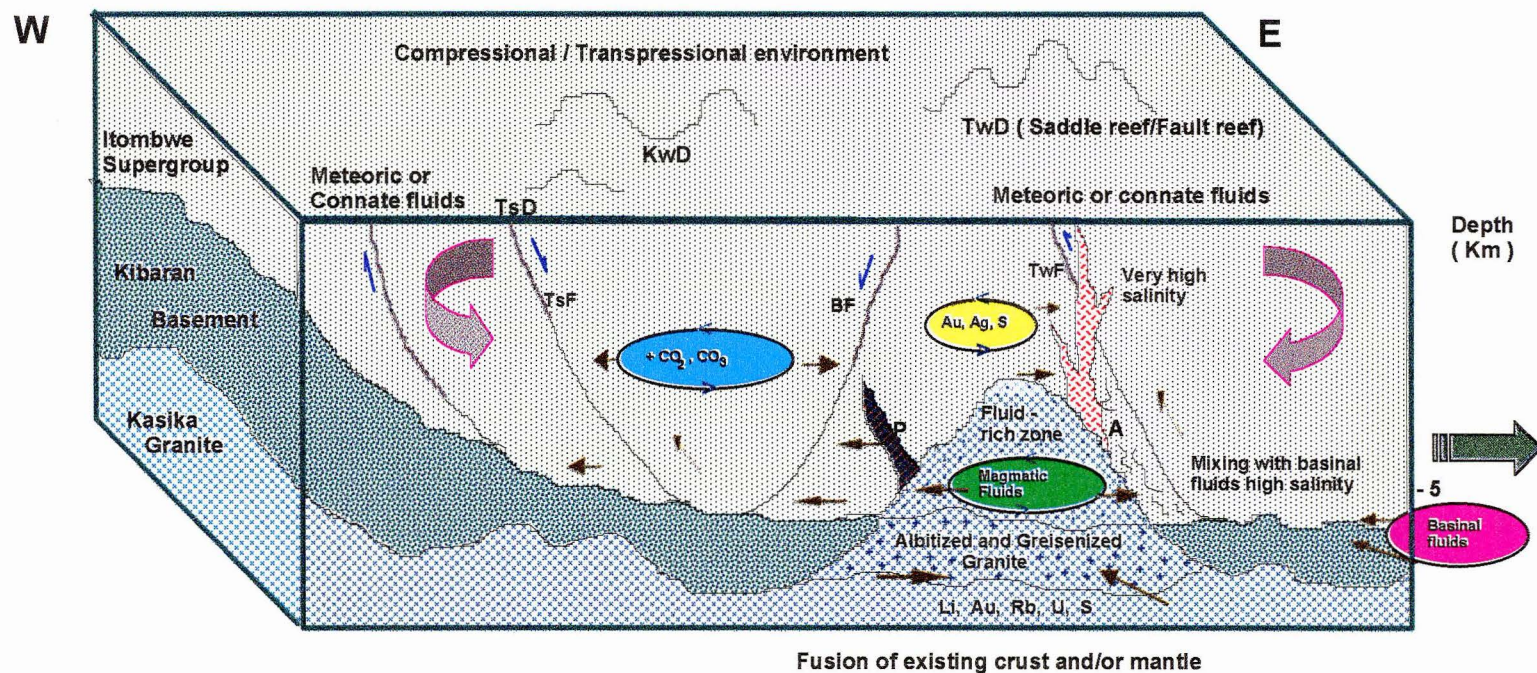
In this model, intense hydrothermal circulation, silification, brecciation and even magmatism (granitization & albitization), are features often seen on permeable detachment zones, with mineralization occurring along cover/basement contacts as well as along relatively high-angled reverse, and/or listric faults.

High-angled, listric (such as the Tshondo fault) or reverse (such as the Twangiza fault) emanating from the detachment fault sole, may have channeled mineralized fluids to higher levels. Fig.III.116 shows the possible fluid reservoirs for Twangiza gold deposit.

12.10.6.- GENETIC MODEL.

The following sequence of events is envisaged as having given rise to the Twangiza gold deposit (Fig.III.117) :

- 1*.- Metamorphism of the Itombwe synclinorium and associated E-W shortening compressive events. This was followed by subvertical extension associated with subhorizontal shortening due to folding and cleavage formation as part of the overall plane strain .
Continued compression produced reverse faulting at acute angles to the maximum principal stress plane, particularly near the apices of the anticlinal axis.(e.g. the Twangiza high-angle reverse fault).
- 2*.- Intrusion of a granitic stock from which several apophyses of albitite rock penetrated syntectonically to shallow depths, and up to the surface. Crystallisation of these plugs produced limited amounts of magmatic water which fractured and mineralized the country rocks locally.
- 3*.- Regional structures played the role of localizing igneous activity (Twangiza albitite and Kasika granite) that supplied the energy to drive the hydrothermal system as well as the stress required for mechanical ground preparation.
- 4*.- Circumstances that developed and contributed to the sudden discharge of a large volume of hydrothermal fluid from (an overpressured ?) reservoir at depth.



➔ Fluid flow (fluid pathway / fracture).

— Strike slip fault.

TwD : Twangiza gold deposit.

TsD : Tshondo gold deposit.

KwD : Kashwa tin deposit.

➔ Extension direction.

TwF : Twangiza fault.

TsF : Tshondo fault.

BF : Bugoyi fault.

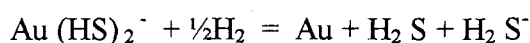
A : Albitite.

P : Pegmatite.

Fig.III.117: Schematic diagram of genetic model for Twangiza gold deposit showing movement of degassing magmatic hydrothermal fluids, mixing with basinal fluids, partial meteoric and/ or connate fluids, minor convecting formational and contact metamorphic fluids in brittle deformation regime within a collisional and transpressive geodynamic regime. Not to scale.

5*.- The ore fluids responsible for gold mineralization were magmatically derived from the spatially associated Kasika peraluminous leucogranite.

The fluids were largely of a composition $\text{H}_2\text{O}-\text{NaCl}-\text{CO}_2 \pm (\text{DM})$ and $\text{H}_2\text{O}-\text{NaCl} \pm (\text{DM})$. Low, moderate and high salinities (5.56 - 45.2 wt % NaCl equivalent) were typical together with inferred moderate density (0.9 g/cm³) and near-neutral pH and normally reducing. The modification of fluid chemistry was achieved by transient-pressure fluctuations inducing phase immiscibility in the fluid , which lead to the reduction of the fluid and lowering ΣS in the fluid. This process lead to gold precipitation through reactions such as



6*.- Gold deposition probably developed in the temperature range 280 °C to >450 °C at pressures of 0.2 - 4.5 kb , which are considered to be the minimum pressure temperature conditions for gold deposition. This corresponds to minimum a mineralization depth of about 1 to 3 km under lithostatic and hydrostatic pressure regimes, respectively.

7*.- Upward focussing of magmatic waters and some additional meteoric waters near the Twangiza region was controlled by pre-existing fractures. Magma and ore fluids exploited the same conduits in their ascent from deeper crustal levels. These fluids caused extensive phyllic and argillic alteration .

8*.- The ore fluids were mostly focused into anticlinal flanks with the Twangiza high-angle reverse fault representing the channelway along which hydrothermal fluids moved upward towards the upper metaturbidite sequence and playing a role as fluid-pressure - activated valves.

12.10.7.- SUMMARY.

This model derives the gold and the fluid- mobilizing heat from the spatially associated Kasika granite which is assumed to lie at a shallow depth below the deposit. As stated above, there is a clear association between intrusive rocks and gold deposits.

The auriferous veins are emplaced into more brittle, competent units such as meta-arkose and greywackes, and in more ductile units such as black shale.

Generally, in the Twangiza deposit, native gold occurs in the zone of oxidation as grains which vary in size from microscopic to grains which are just visible to the naked eye (200 μm). Free gold is rare in the sulphide zone.

On the microscopic scale, free gold in the pyrite and mostly in the arsenopyrite occurs as very small particles seldom more than 0.5 mm in diameter.

The frequency diagram shows that grains of Au prevail in samples with Au contents of 0 to 2 ppm .

Gold fineness, $[1000 \cdot \text{Au} / (\text{Au} + \text{Ag})]$ for the Twangiza ores range from 991.95 to 998.30 and the ratio of Au/Ag varies from 123.17 to 586.64

The results of this study indicate that arsenopyrite is a good host for " invisible gold " , but that pyrite is also a very good gold-carrier. The dominant form of pyrite is the modified, striated cube, commonly with octahedral and pyritohedral modifications and/or striations.

Ion microanalyses, revealed that the Twangiza ore contains two distinct populations of pyrite : a " normal " pyrite containing less than 0.5 ppm As, and an arsenian variety with As contents ranging from 1 to 4 ppm. On the other hand, pyrite in the late-stage quartz/sulphide veins was significantly enriched in arsenic .

These two types of pyrite, distinguished from one another by textural criteria, and mineral chemistry indicate multiphase ore genesis, inhomogeneous metamorphism, or both. In both pyrites, there is a positive correlation between the concentrations of Au versus Fe, As, Ag, Cu and negative correlation with S and Pd .

In the ores that contain arsenopyrite, there is not a strong positive correlation between the concentrations of Au and As in arsenopyrite

Compared to mesothermal pyrite, and to pyrite of the Witwatersrand gold deposits, the Twangiza pyrite shows a strong depletion in As, Ag, Pd, and Cu trace elements .

Arsenopyrite and gold paragenetic relations strongly suggest that the gold was exsolved from hydrothermally precipitated arsenopyrite and pyrite, especially close to, or at, grain boundaries or internal microfracture, when the host mineral tried to rid itself of impurities.

The magmatic model for the origin of the Neoproterozoic Twangiza Au - quartz/sulphide vein ore systems suggests that Au was derived by partition between silicate (+/- sulphide) melts of certain compositions and H₂O-NaCl-CO₂ +/- (DM) and H₂O-NaCl +/- (DM) magmatic fluids, transported in solution which underwent fluid mixing with meteoric /connate fluids before deposition.

In the Twangiza deposit, there is significant geological and geochemical evidence for magmatic Au derivation ; among them:

- Spatial and structural geological relationships: D₂ structure, high -angle reverse fault and albitite association.
- Relative and absolute timing relationships: Clear cross-cutting evidence between albitite and QV₂ main stage Au -quartz/sulphide vein mineralization, ⁴⁰Ar/³⁹Ar ages and Rb/Sr age constraints.
- Geochemical evidence : radiogenic (Rb/Sr, Sm/Nd) and stable isotopes ($\delta^{18}\text{O}$, $\delta^{13}\text{C}$ and $\delta^{34}\text{S}$ values).
- Fluid inclusion geochemistry : Very high salinity H₂O-NaCl-CO₂ +/- (DM) and H₂O-NaCl +/- (DM) fluids.

CHAPTER 13. THE TSHONDO GOLD DEPOSIT.

13.1.- INTRODUCTION.

The Tshondo gold deposit, located in Tshondo locality, is one of two significant gold deposits in the Kadubu area. The deposit is located ~9 Km east of the Twangiza deposit at latitude $2^{\circ} 52'S$ and, longitude $28^{\circ} 40' E$. (Fig.II.7; Fig.III.118), and lies in a NNW - trending zone of the Tsibangu formation, bounded by the N-S trending Tshondo fault zone to the west. The deposit tends to be restricted to the roll-over anticline deformation, in particular to well developed planar antithetic faults, westernmost of the Bugoyi syncline in the Tshondo locality. The regional orientation of the main foliation, S_2 , is steeply dipping to the southwest.

The deposit has not been yet explored and/or mined. Only artisanal working is under way. (Fig.III.119).

13.2.- GOLD MINERALIZATION.

13.2.1.- STYLE OF MINERALIZATION .

Gold mineralization is directly related to Quartz/sulphide veining and intimately associated with pyrite and arsenopyrite. Pyrite and arsenopyrite are widespread, and occur particularly at contacts with black shale host rocks, but are not visible in the wall-rock.

Supergene mineralizations are characterized by limonite, kaolinite, jarosite. These minerals were observed in quartz vein surface samples.

Hence, the vein mineralogy associated with precious metals is characterized by variable clays minerals in oxidised zone.

In the primary zone, gold is present in sulphide vein as the native metal with less than $5\mu m$ in diameter and rich shoot occurs locally.



Fig.III.118:- - The Tshondo gold deposit , looking south. Tshondo locality.



Fig.III.119:- - Artisanal workings, Tshondo gold deposit.

The veins are dominantly quartz, but also contain sulphides (pyrite and arsenopyrite), with minor ankerite, and local albite, white mica. Quartz shows a variety of forms ranging from very fine - grained massive quartz to vuggy and euhedral quartz crystals.

Three sets of veins have been recognized (Fig.III.120) :

1*- *Bedding-concordant quartz veins* (TV_1): subvertical bedding -concordant quartz veins (TV_1) , with moderate variation in thickness and a length to width ratio > 10 . They follow bedding contacts and postdate the Bugoyi syncline. This type of vein is not associated with gold mineralization. (Fig. III. 120)

2*- *Bedding-concordant quartz /sulphide veins* (TV_2): occurring as thick (10- 50 cm) veins that lie on bedding with gold-rich flat. Gold mineralization is genetically linked with their formation. Bands of sheared-wall rock inclusions parallel to the vein walls give locally their laminated like textures. These veins can be followed for up to 200m length. (Fig. III. 120) .

3*- *Bedding - discordant* (TV_3): subvertical quartz vein; coarsely crystalline, continuous, straight , massive recrystallised. Length $> 50m$, width $< 25cm$.

They contains sub-economic amount of gold, are oblique to bedding, and strike consistently north- northwest or northeast, highlighting their late formation. They show mutual cross-cutting relationships with TV_1 and TV_2 .(Fig. III.120) .

13.2.2.- STYLE OF HYDROTHERMAL ALTERATION.

The host to gold mineralization is the black shale, strongly foliated. Hydrothermal alteration is strongly developed near the veins and decreases outward. The proximal alteration surrounding the veins is characterized by pervasive silicification. Silicified zone are , in turn ,enveloped by an argillic zone. Within this envelope, the original rock texture has been strongly destroyed. Propylitic alteration is exposed in the outer zone. (Fig.III.120).

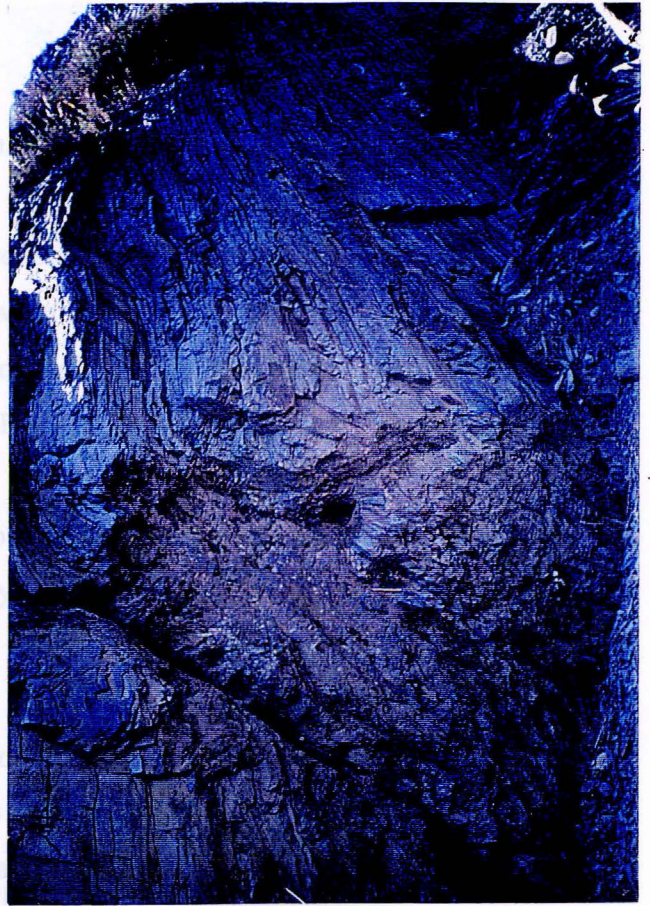


Fig.III.120:- Quartz and sulphide veining , Tshondo gold deposit.

13.2.3.- ORE MINERALOGY AND GEOCHEMISTRY.

The geochemistry results of quartz /sulphide vein (TV₂) and associated wall rocks are depicted in Table.III.14 and Table.III.15.

A total of 5 grains of gold were analysed simultaneously by SEM and by ion microprobe for all elements . The size of gold grains varied between 125 µm and 170 µm .

The photomicrographs of native gold and their spectra of SEM of individual gold grains are respectively shown in Fig.III.121, Fig.III.122, Fig.III.123 and Fig.III.124. The result of micronalysis are depicted in Table III.16.

Fig.III.125 and 126 show the frequency diagrams of respectively Au, S, As, Fe and Pd, Ag, Cu, Cd . Scatter plot of Au versus respectively As, Ag, S, Fe, Pd, Cu and Cd with the regression line are show in Fig.III.127.

Gold fineness ,[$1000 \cdot \text{Au} / (\text{Au} + \text{Ag})$] for the Tshondo ores range from 991.95 to 998.30 and the ratio of Au/Ag varies from 123.17 to 586.64 (Table.III.15).

Mesothermal Au-Ag deposits are further characterized by Au/Ag averaging 5. Au/Ag ratios are high , (123.17 to 259.57) ; and Au/S ratios are also very high. (895.32 to 6056.73). (Fig.III.128). Base metal and total sulphide abundances are low, the silver content of the gold vein is low (0.350 to 0.756) .

The very high Au/ As ratio is characteristic. Arsenic content of gold ranges from 0.016 to 0.077 ppm and the concentration of other metals is not significant.

13.3.- OXYGEN ISOTOPE.

In the present investigation, the isotopic data obtained , combined with the data from Twangiza gold deposit , are used to infer potential source reservoirs for the vein forming fluids .

13.3.1.- SAMPLE PREPARATION.

A total of 3 samples from Tshondo quartz veins were collected. All samples were fresh, and visible sulphides were extracted from the quartz vein samples before grinding to a powder of particle size less than 45µm in diameter.

TABLE.III.14 :- CHEMICAL COMPOSITION OF QUARTZ /SULPHIDE VEIN (TV2)
FROM THE TSHONDO GOLD DEPOSIT.

	KW 202	KW 205A	KW 206	KW 210	KW 213	KW 218	KW2 205	KW2 206
SiO ₂	89.82	92.81	74.87	58.75	67.9	72.43	93.86	68.19
TiO ₂	0.51	0.17	0.58	0.89	0.98	1.01	0.07	0.66
Al ₂ O ₃	6.04	0.7	8.95	17.84	16.09	12.12	2.35	13.28
Cr ₂ O ₃	*	*	*	*	*	*	0	0.01
Fe ₂ O ₃	0.98	4.38	10.11	8.2	6.6	1.41	3.68	11.68
MnO	0.02	0.01	0.04	0.14	0.03	0.03	0.01	0.04
MgO	0.01	0	0.15	0.29	0.3	1.71	0.31	0.72
CaO	0	0	0	0.17	0	0	0.05	0.05
Na ₂ O	0.09	0	0.11	9.31	0.14	0.03	0.43	0.43
K ₂ O	1.76	0.17	1.75	0.03	3.1	3.2	0.31	2.99
P ₂ O ₅	0.03	0.04	0.08	0.15	0.1	0.08	0.4	0.26
V ₂ O ₅	*	*	*	*	*	*	0	0
NiO	*	*	*	*	*	*	0.01	0.01
CuO	*	*	*	*	*	*	0.01	0.01
ZnO	*	*	*	*	*	*	0	0
SO ₃	*	*	*	*	*	*	0.04	0.04
F	*	*	*	*	*	*	0.07	0.07
Loi	1.52	1.25	4.23	5.2	5.66	9.02	*	*
Total	100.79	99.55	100.89	100.98	100.91	101.05	101.6	98.44

Trace Elements.

	KW 202	KW 205A	KW 206	KW 210	KW 213	KW 218	KW2 205	KW2 206
V (ppm)	52	< 15	81	255	136	797	30	94
Cr	44	20	76	108	101	130	12	75
Co	11	6	7	111	10	10	< 5	8
Ni	< 9	< 9	< 9	52	15	< 9	12	10
Cu	< 2	8	7	11	11	< 2	3	14
Zn	< 9	11	18	11	14	12	30	39
As	35	24	271	547	202	< 24	7	372
Se	*	*	*	*	*	*	1	3
Rb	91	21	98	11	172	96	18	122
Sr	11	< 6	9	23	19	19	7	13
Y	7	< 3	16	21	21	53	< 4	13
Zr	137	23	174	207	297	224	< 27	185
Nb	11	6	14	21	23	17	< 1	12
Mo	< 2	4	< 2	3	< 2	< 2	0	2
Sn	< 12	< 12	< 12	< 12	< 12	< 12	< 10	< 6
Sb	*	*	*	*	*	*	< 24	< 18
Te	*	*	*	*	*	*	< 36	3
Ba	470	67	616	231	817	4055	86	< 38
Ta	< 19	< 19	< 19	< 19	< 19	< 19	5	9
W	15	< 15	< 15	35	< 15	< 15	< 4	4
Pb	*	*	*	*	*	*	< 2	0
Bi	*	*	*	*	*	*	1	2
Th	*	*	*	*	*	*	< 7	16
U	10	10	17	18			< 8	< 11
Ag	< 0.10	< 0.10	1	< 0.10	< 0.10	0.15	< 0.1	1
Au	0.05	0.05	69.1	0.05	1.4	24.2	< 0.05	69.1

Rare Earth Elements. (REE)

	KW2 205	KW2 206
La	3	18
Ce	5	45
Pr	1	4
Nd	2	18
Sm	< 1	5
Eu	< 1	1
Gd	< 1	3
Te	< 1	< 1
Dy	< 1	4
Ho	< 1	1
Er	< 1	2
Tm	< 1	< 1
Yb	< 1	3
Lu	< 1	< 1
Th	< 7	16
U	1	4

TABLE. III.15 :- CHEMICAL COMPOSITION OF WALL-ROCK ASSOCIATED
WITH QUARTZ/SULPHIDE VEIN (TV2) FROM TSHONDO GOLG DEPOSIT.

	KW 203	KW 203A	KW 204	KW 205B	KW 207
SiO ₂ (wt%)	58.83	49.68	79.89	52.58	61.72
TiO ₂	1.2	2	0.79	0.86	1.03
Al ₂ O ₃	23.88	31.59	8.8	18.85	19.96
Cr ₂ O ₃	0.01	*	*	*	*
Fe ₂ O ₃	1.92	1.92	5.59	13.91	5.45
MnO	0.01	0.03	0.05	0.03	0.01
MgO	1.05	0.86	0.04	0.57	0.51
CaO	0.06	0	0	0	0
Na ₂ O	0.55	0.39	0.05	0.13	0.21
K ₂ O	7.08	8.66	1.14	4.33	4.26
P ₂ O ₅	0.2	0.01	0.09	0.16	0.06
V ₂ O ₅	0	*	*	*	*
NiO	0.01	*	*	*	*
CuO	0.01	*	*	*	*
ZnO	0	*	*	*	*
SO ₃	0.03	*	*	*	*
F	0.05	*	*	*	*
LOI	*	5.7	4.08	8.07	6.95
Total	94.89	100.86	100.52	99.51	100.18

Trace Elements.

	KW 203	KW 203A	KW 204	KW 205B	KW 207
V (ppm)	145	226	62	166	154
Cr	118	211	48	148	142
Co	5	8	7	< 9	7
Ni	2	11	9	22	< 9
Cu	< 12	11	10	82	< 2
Zn	29	< 9	< 9	14	< 9
As	36	62	37	41	129
Se	0	*	*	*	*
Rb	284	412	67	224	222
Sr	23	31	13	16	13
Y	3	18	14	19	27
Zr	415	600	284	194	245
Nb	25	35	18	19	19
Mo	7	< 2	< 2	< 2	< 2
Sn	12	20	< 12	< 12	< 12
Sb	< 11	*	*	*	*
Te	< 4	*	*	*	*
Tb	*	*	*	*	*
Ba	1409	2025	371	1043	974
Ta	5	< 19	< 19	< 19	< 19
W	6	< 15	< 15	< 15	< 15
Pb	1	*	*	*	*
Bi	< 6	*	*	*	*
Th	9	*	*	*	*
U	17	11	12	18	15
Ag					
Au					

Rare Earth Elements.

	KW 203	KW 203A
La	16	22
Ce	16	22
Pr	1	2
Nd	3	6
Sm	1	2
Eu	1	1
Gd	1	1
Tb	< 1	< 1
Dy	1	1
Ho	< 1	< 1
Er	1	1
Tm	< 1	< 1
Yb	2	2
Lu	< 1	< 1
Th	*	*
U	2	3

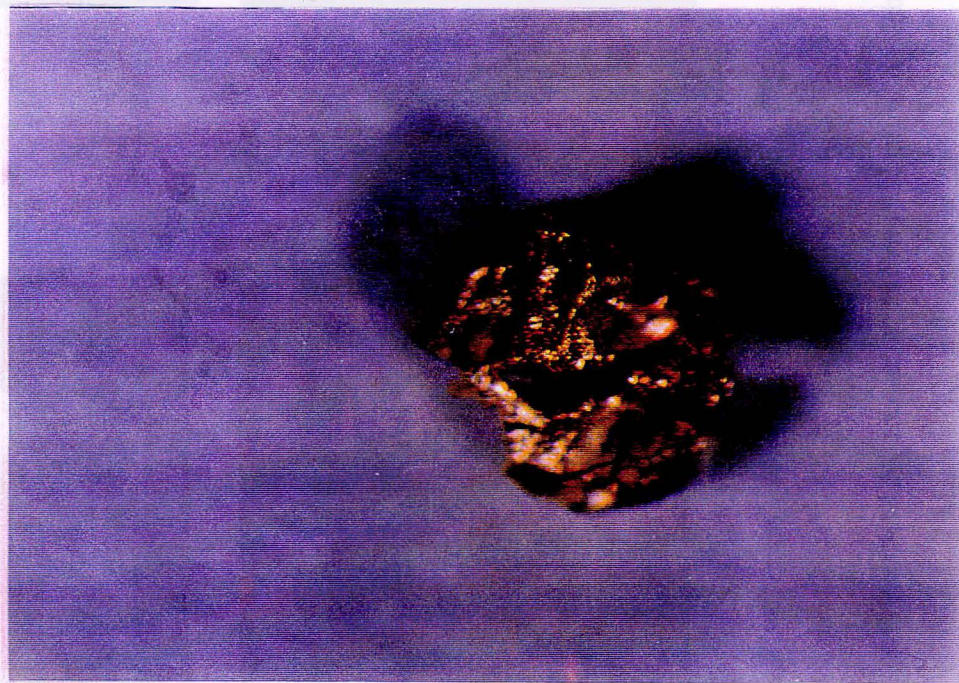


Fig.III.121:- Photomicrograph of native and nugget gold. Tshondo gold deposit.

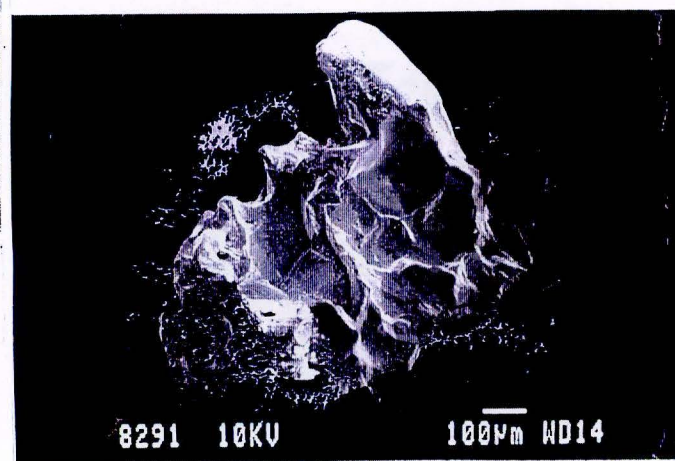
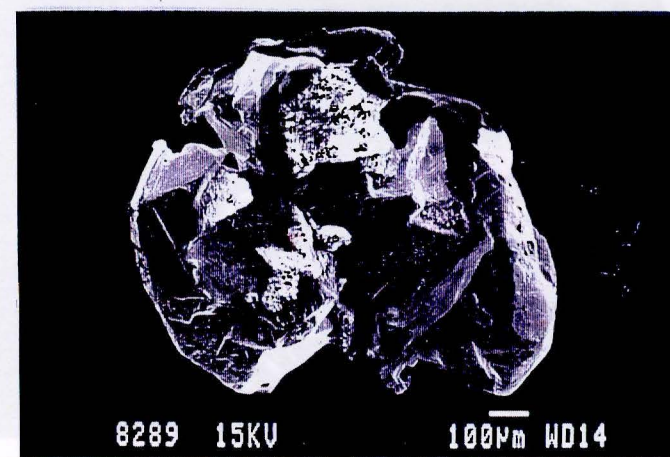
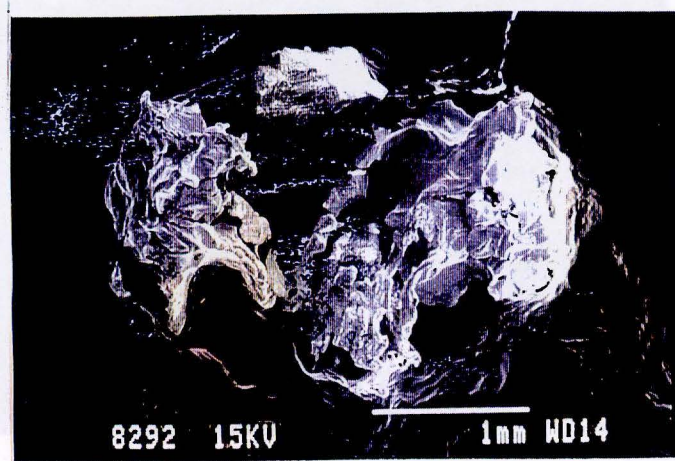
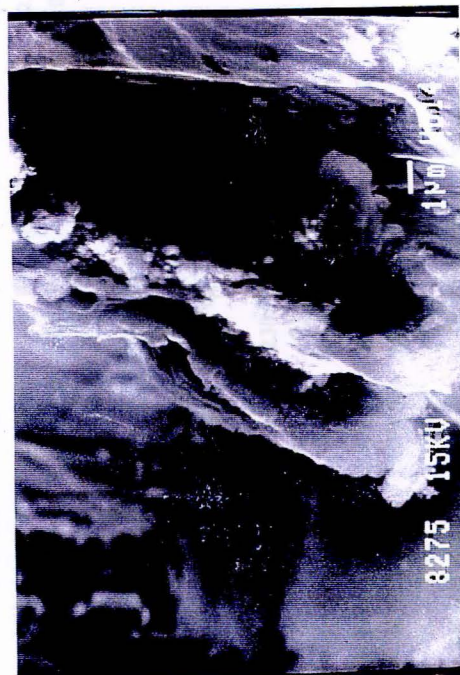


Fig.III.122:- - SEM images of native gold from the Tshondo deposit.
(Mag. x 30, x 75, x 85, x 200).



1 Fig. III.123:-- SEM images of native gold from the Tshondo deposit.
(Mag. x 750, x 4000, x 6000 , x 9000).

TABLE. III.16 :- QUANTITATIVE ION-MICROANALYSES OF GOLD FROM TSHONDO GOLD DEPOSIT.

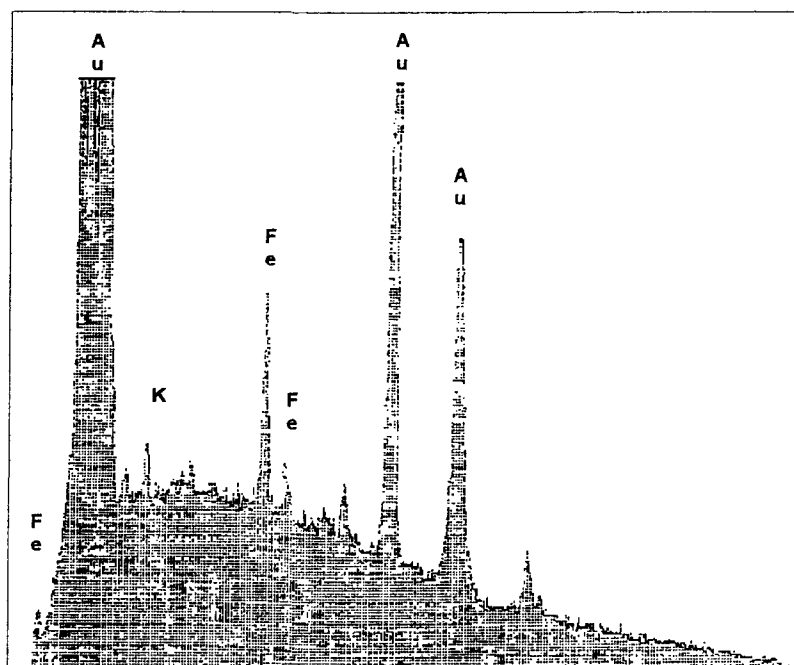
Sample	SKA	FeKA	PdLA	CuKA	AsLA	AgLA	AuLA	HgLA	CdLA	TOTAL
KW 206-Ts1	0.084	0.005	0	0.018	0.077	0.395	91.171	0	0	91.751
KW 206-Ts2	0.104	0.01	0	0.054	0.016	0.756	93.113	0	0.046	94.099
KW 206-Ts3	0.045	0.011	0	0.051	0.03	0.556	83.698	0	0	84.391
KW 206-Ts4	0.084	0.005	0	0.018	0.077	0.654	91.171	0	0	91.751
KW 206-Ts5	0.104	0.01	0	0.054	0.016	0.756	93.113	0	0.046	94.099
KW 206-Ts6	0.086	0	0.142	0.032	0.06	0.509	85.764	0	0.11	86.703
KW 206-Ts7	0.015	0.011	0	0.006	0.075	0.35	90.851	0	0.012	91.318

Sample	Fineness	Au/Ag	Au/S	Au/Fe
KW 206-Ts1	995.69	230.81	1085.37	18234.2
KW 206-Ts2	991.95	123.17	895.32	9311.3
KW 206-Ts3	993.4	150.54	1859.96	7608.91
KW 206-Ts4	992.88	139.41	1085.37	18234.2
KW 206-Ts5	991.95	123.17	895.32	9311.3
KW 206-Ts6	994.1	168.5	997.26	0
KW 206-Ts7	996.16	259.57	6056.73	8259.18

X - RAY: - 0 - 20 KeV

Live : 100 S Preset : 100 S Remaining : 0 S

Real : 176 S 43% Dead.



< .2

10.400 KeV

FS = 2K

Ch 530 = 351

cts

MEM1 : KW 206AU1

Fig.III.124:- The Spectra of individual gold grains.
Tshondo gold deposit.

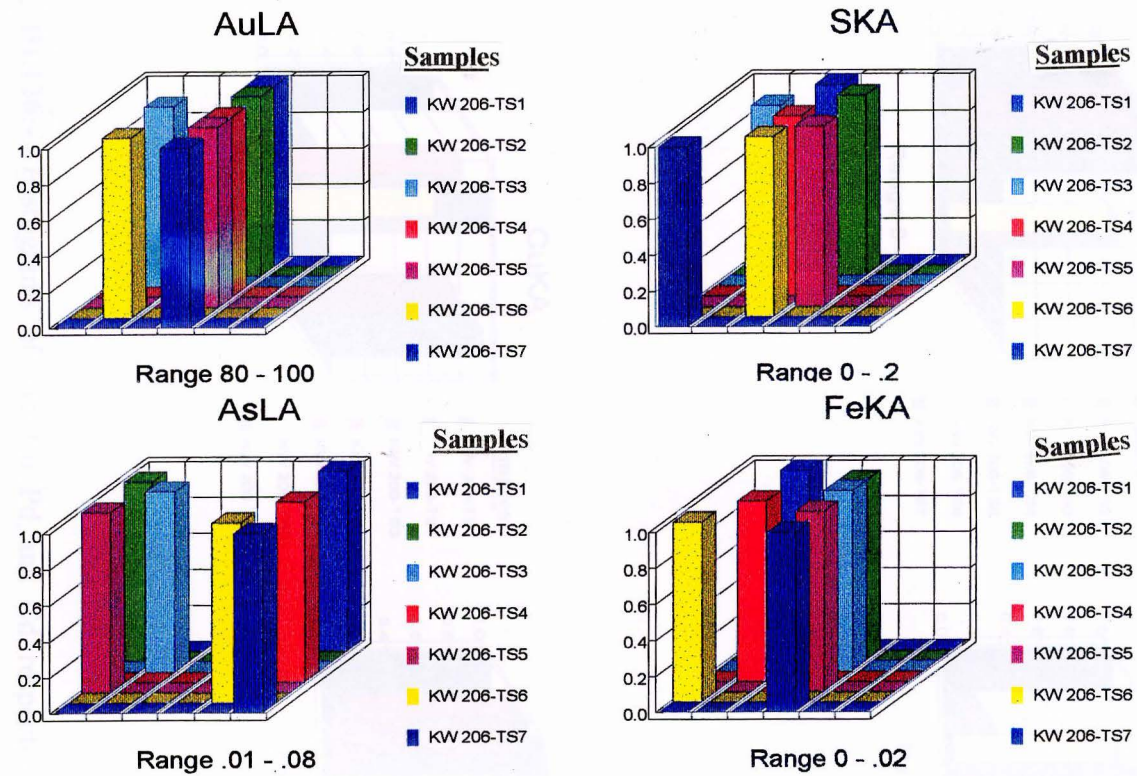


Fig.III.125:- Histograms of Au, Fe, As, and S respectively from the Tshondo deposit.

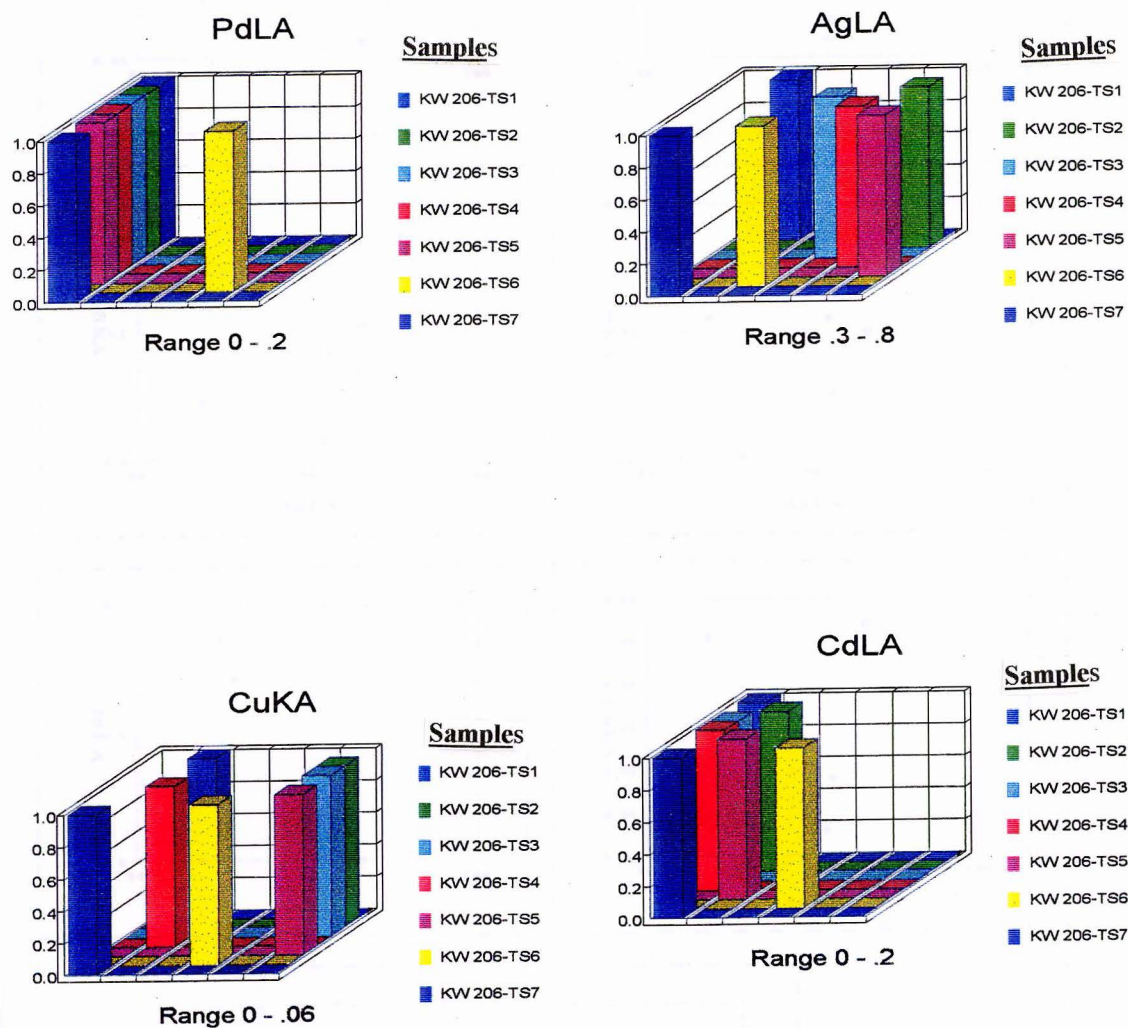


Fig.III.126:- - Histograms of Ag, Cu, Pd, and Cd respectively from theTshondo deposit.

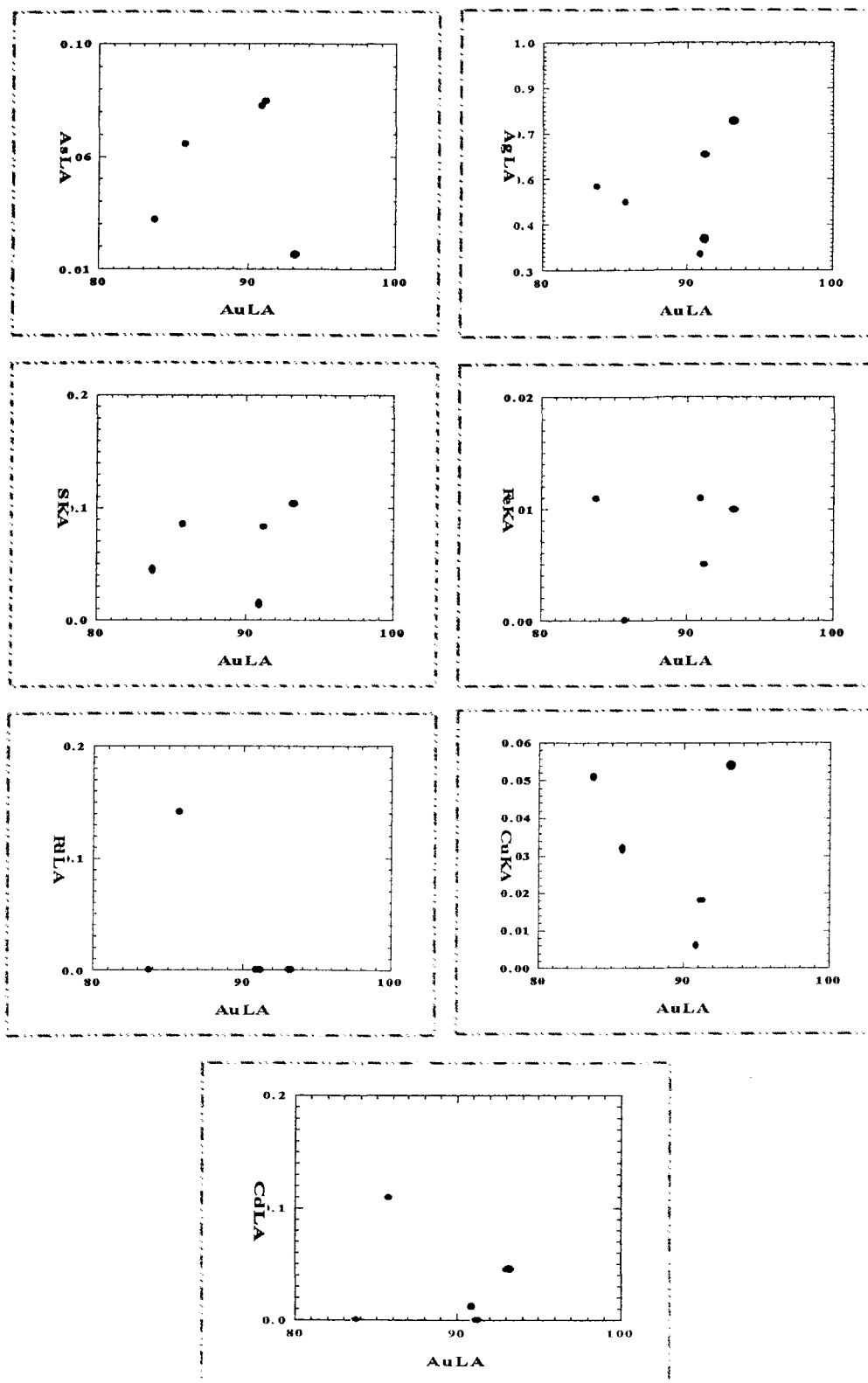


Fig.III.127:- Correlataion diagrams of Au , versus As, S, Ag, Fe, Pd, Cu and Cd from a TV2 vein of the Tshondo gold deposit. Ion microprobe results.

Fig.III.128:- Histograms of the fineness and of the ratios Au/Ag, Au/Fe and Au/S respectively from the Tshondo deposit.

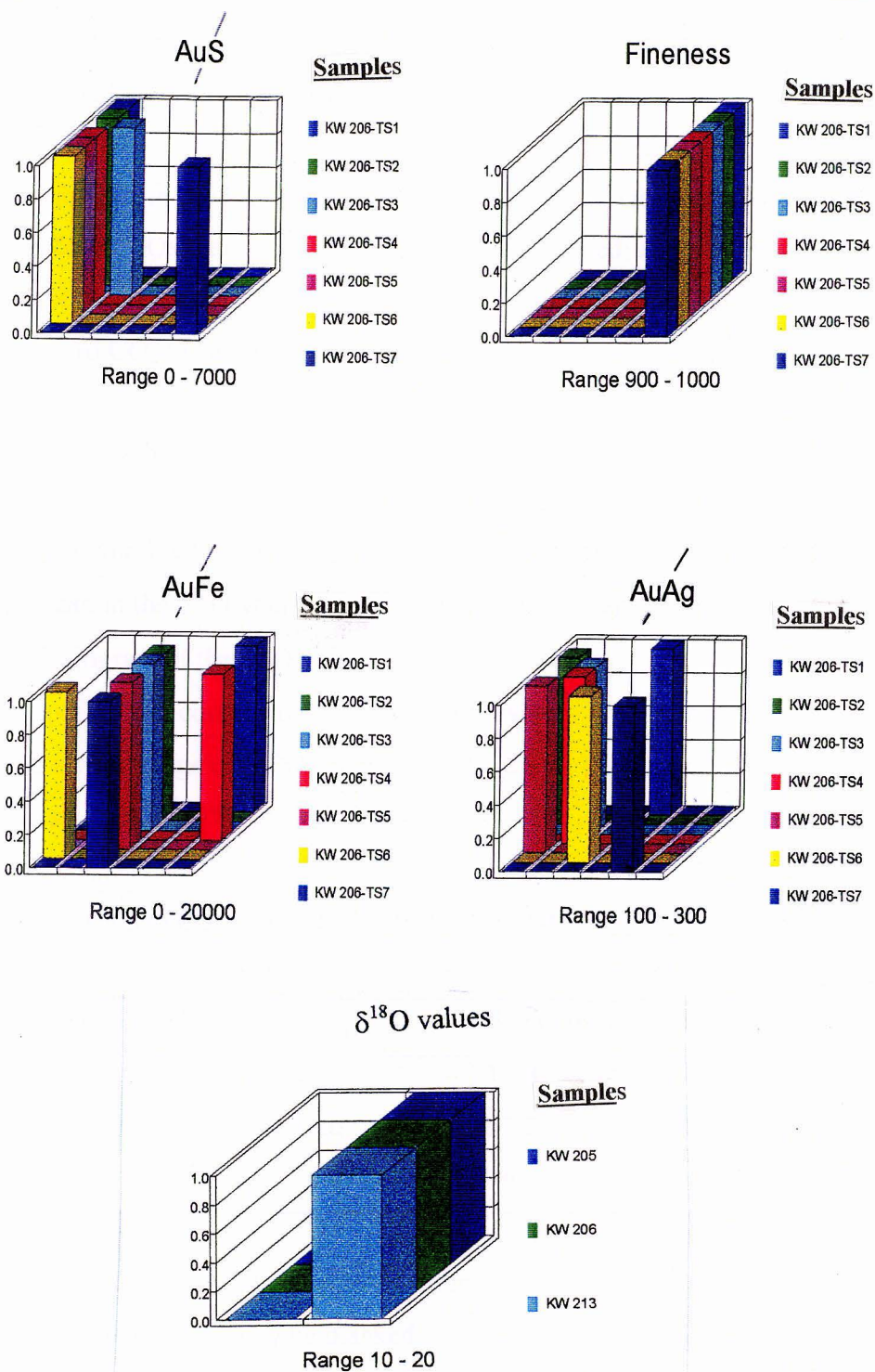


Fig.III.129:- Histogram of $\delta^{18}\text{O}$ values, Tshondo gold deposit.

High-quality mineral separates used in the study were prepared using conventional techniques. Quartz collected from monomineralic clots, was hand picked from comminuted and sieved (-35 to +60 mesh) .Material estimates of purity were based on visual inspection and XRD analyses. All samples were thoroughly washed in acetone and deionized water, dried and stored in plastic vials prior to analyses.

All analyses were performed in the laboratory of the Department of Geological sciences, University of Cape Town. Oxygen isotope ratios were determined using conventional procedures. Silicate separates, were reacted with bromine pentafluoride , followed by quantitative conversion to CO₂ (Clayton and Mayeda , 1963).

13.3.2.-RESULTS OF ANALYSES.

Quartz is the only phase analysed . The $\delta^{18}\text{O}$ values for vein quartz are shown in Table III.17 . There is a spread in the $\delta^{18}\text{O}$ values from 16.3 to 19.2 (average 17.73 per mil). Fig.III.129 show the histogram of the $\delta^{18}\text{O}$ values.

The calculated range of isotopic composition for magmatic waters is commonly 6- 10 ‰ for $\delta^{18}\text{O}$ - values and a wide range of $\delta^{18}\text{O}$ - values (5 to 25 ‰) is generally attributed to metamorphic waters (Taylor, 1979).

Table III .17:- RESULTS OF OXYGEN ISOTOPE OF HYDROTHERMAL QUARTZ.

SAMPLE No	HABIT UNIT	$\delta^{18}\text{O}$ values (SMOW)
KW 205	Hydrothermal Quartz vein	19.8
KW 206	Hydrothermal Quartz vein	17.2
KW 213	Hydrothermal Quartz vein	16.2

At first point of view, these values can be attributed to metamorphic fluid. However, the isotopic signatures of magmatic fluid may be masked or erased during later events such as the influx of meteoric waters (Rye, 1993).

An extensive interaction with rocks along fluid pathways that the original isotopic signature of the fluid has been destroyed.

Based on hydrogen and oxygen data alone, it is not possible to discriminate between fluids of magmatic or metamorphic origin as the prime hydrothermal reservoir involved in the mesothermal deposits. Some formation brines, and geothermal systems, with a significant component of meteoric water, may undergo extensive oxygen and limited hydrothermal isotope exchange with sedimentary rocks, thereby evolving into the magmatic and metamorphic fields. (Kerrich and Watson, 1984).

Compared to the $\delta^{18}\text{O}$ values of hydrothermal quartz from mesothermal deposits in the Abitibi subprovince, (total range 12.5 to 15.0 per mil), (Kerrich, 1987), the $\delta^{18}\text{O}$ values of hydrothermal quartz from Tshondo deposit show an enrichment of $\pm 4\%$. Variations in the $\delta^{18}\text{O}$ values of hydrothermally precipitated quartz may occur in response to a number of independent parameters. Quantitatively the most important of these are the $\delta^{18}\text{O}$ values of the fluid and ambient temperature of mineralization.

In source regions, the $\delta^{18}\text{O}_{\text{H}_2\text{O}}$ is governed by the original isotopic composition of the fluid reservoir, the $\delta^{18}\text{O}$ values of the rock reservoir at source, the water/rock ratio, and exchange temperature.

At the site of mineralization the $\delta^{18}\text{O}$ of hydrothermal fluid may be modified by ;

- 1.- exchange reactions with wall rocks;
- 2.- precipitation or solution of an oxygen bearing phase either depleted or enriched in $\delta^{18}\text{O}$ with respect to the fluid, and in a closed system;
- 3.- immiscible separation of CO_2 , or ;
- 4.- mixing with an isotopically distinct fluid reservoir. (Kerrich, 1987).

At present, the various alternative can not be resolved.

13.4.- SUMMARY AND DISCUSSIONS.

Tshondo gold deposit lies in a NNW-trending zone of the Tsibangu formation, bounded by the N-S trending Tshondo fault zone to the west .

The deposit tends to be restricted to the roll-over anticline deformation, in particular to well developed planar antithetic faults, westernmost of the Bugoyi syncline and the regional orientation of the main foliation, S_2 , is steeply dipping to the SW.

The host to gold mineralization is the black shale, strongly foliated. Hydrothermal alteration is strongly developed near the veins and decreases outward.

The veins are dominantly quartz, but also contain sulphides (pyrite and arsenopyrite), with minor ankerite, and local albite, white mica. Quartz shows a variety of forms ranging from very fine-grained massive quartz to vuggy and euhedral quartz crystals.

Three sets of veins have been recognized : Bedding-concordant quartz veins (TV_1), Bedding-concordant quartz /sulphide veins (TV_2), and Bedding - discordant veins (TV_3). Gold fineness, $[1000 \cdot Au/(Au+Ag)]$ for the Tshondo ores range from 991.95 to 998.30 and the ratio of Au/Ag varies from 123.17 to 586.64. Au/Ag ratios are high, and Au/S ratios are also very high. Base metal and total sulphide abundances are low, the silver content of the gold vein is low. The very high Au/As ratio is characteristic. Arsenic content of gold ranges from 0.016 to 0.077 ppm and the concentration of other metals is not significant.

The measured $\delta^{18}O$ values of hydrothermal quartz veins are in the restricted interval between 16.1 and 19.8 per mil and are relatively $\delta^{18}O$ enriched quartz veins. This uniformity in $\delta^{18}O$ values of quartz in vein deposit, implies a corresponding homogeneity to both the $\delta^{18}O$ values of hydrothermal fluids, as well as the ambient temperature of mineralization .

These oxygen isotopic signatures are interpreted as of magmatic fluid masked or erased during later events such as the influx of meteoric waters and/or exchange reactions with black shale wall rocks.

CHAPTER 14.-THE KASHWA TIN DEPOSIT.

14.1.- INTRODUCTION.

The Tin province of Kivu region is part of a continuous, orogenic, tin-rich belt of Central Africa that extends from north Katanga province to the Kivu province in eastern DR Congo (Fig.I.1 ; Fig.II.7) .

The Kashwa tin deposit is located approximately 2.5 km northeast of Kakwende locality, at latitude $2^{\circ} 49'S$ and longitude $28^{\circ} 39' E$. The deposit is located in the steep sided valley of Kashwa stream , a tributary of the Kadubu river. (Fig, III.130) .

The tin bearing veins have been emplaced within the western limb of the Bugoyi syncline and all the veins have NNW-SSE strike-trends. The choice of opening direction was probably facilitated by the NW-SE directed horizontal stress generated by the collision event of Porada (1979, 1989), Sacchi (1984), Cahen et al., (1984), Daly (1986, 1988) , Key et al., 1989 and Meert et al., (1995) .

The deposit has been worked by opencast method in a small way, but it is of interesting economic importance (Fig.III.131). Some of veins have been mined over a vertical depth of about 10m (Fig.III.132 ; Fig.III.133) .

No previous surveys have been undertaken and the data for this study were derived from the author's own observations.

Recent useful reviews of the geology and origin of tin deposits in orogenic belts and their associated granites include those by Taylor,R.G (1979), McCathy,T.S (1989) and Lehmann (1990) .

14.2.- THE HYDROTHERMAL TIN -BEARING VEINS AND STRUCTURE.

In the Kashwa deposit , sheeted vein systems occur in metasedimentary rocks of the Tsibangu formation. Tin mineralization occurs as multiple simple-vein system.

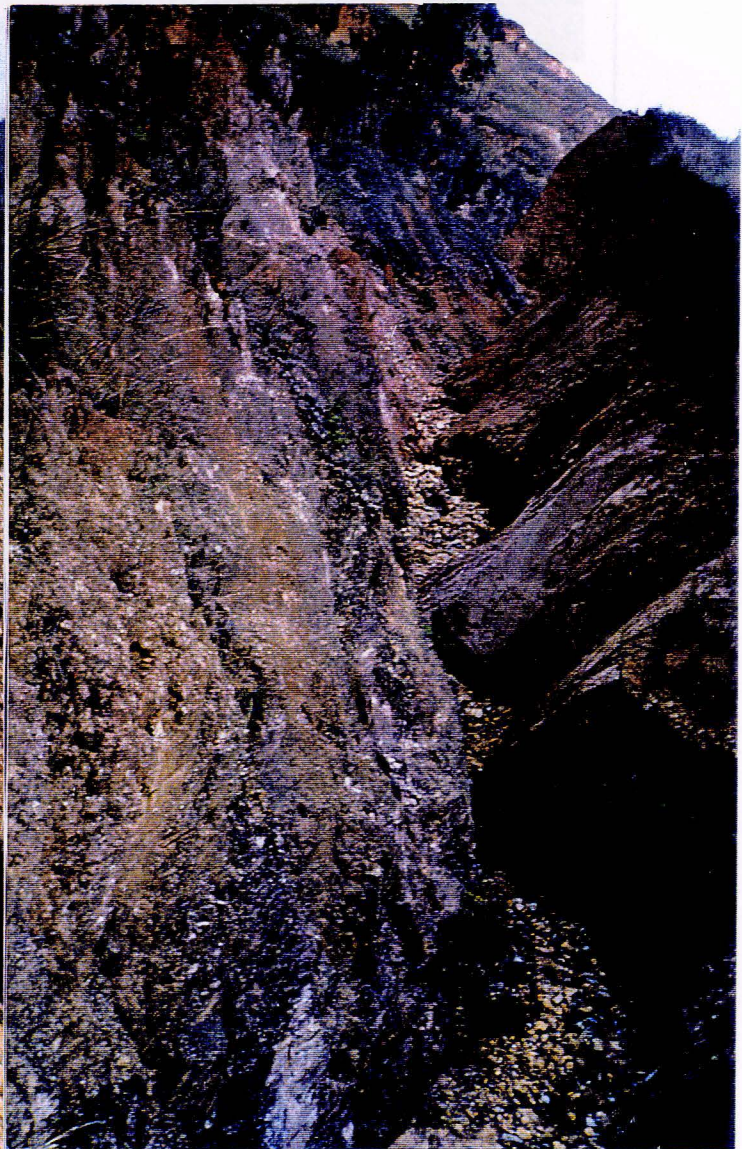


Fig. III.130: - View of Kashwa tin deposit looking northeast and showing trenches.

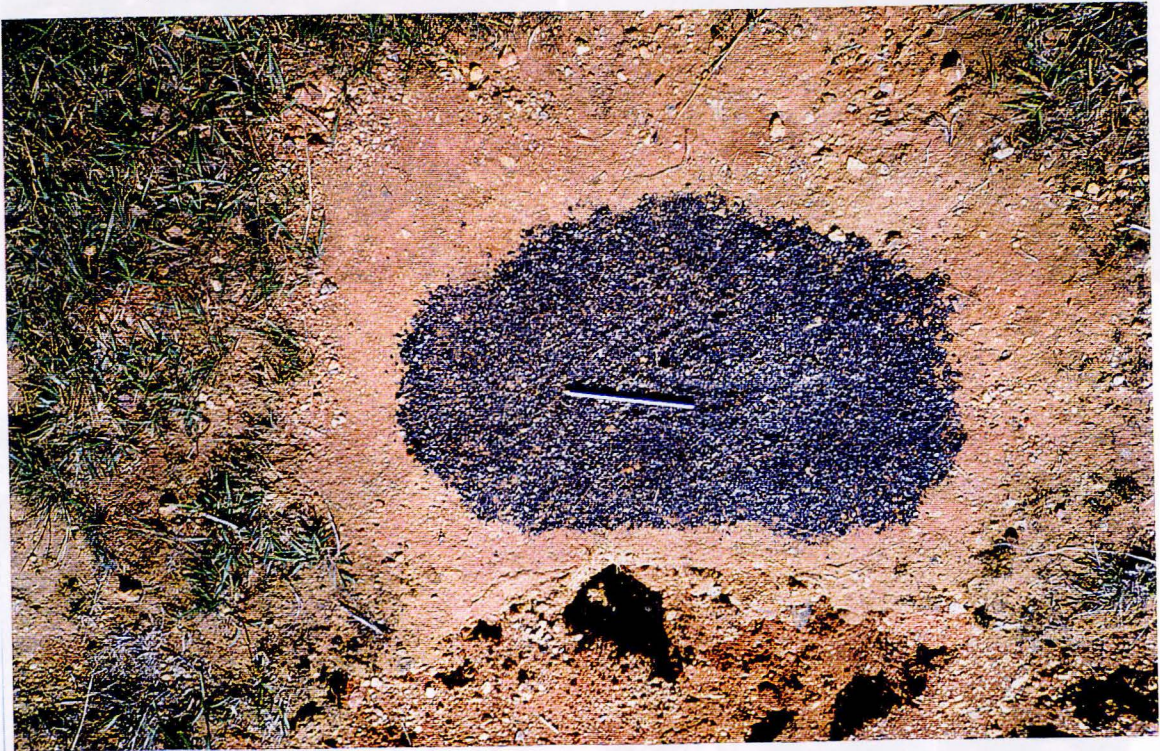


Fig.III.131:- - Artisanal working within the Kashwa river, with tin output.



Fig.III.132:- Sheeted tin veins, Kashwa tin deposit.



Fig.III.133:- Vein type system, Kashwa tin deposit.

There are five main veins, and many subsidiary veins which dip southeasterly at 65 -90 °C in the upper level. The veins vary in size from small stringers a few centimetres in width and up to hundreds of metres in length.

The veins extend along strike for about 500m, are up to 2m thick, commonly with north-northwest trend (N10 ° - 20° W), subparallel to the foliation of the interbedded black shale and greywacke.

The veins occur as lenticular or irregular bodies, being parallel to the country rock schistosity and/or bedding. Some of the veins may branch or send off irregular off-shoots which strike and dip differently from the main part.

Vein systems dip steeply, and in the larger vein, there is not evidence of repeated opening. The veins comprise largely quartz with tourmaline. The tin ore is defined by quartz -tourmaline-cassiterite-assemblage (Fig.III.134). No paragenetic sequence has been established.

Fig.III.135 shows sample KW 705. This sample represents a quartz-tourmaline-cassiterite vein which contains approximately 1 % sericite peripherally developed around some of the finer grained tourmaline. A dravite, ferrian tourmaline .

Wall rock alteration is detectable as much as 50m from the vein. Quartz and tourmaline are the typical minerals of the altered wall rock bordering the veins. Sericite and scheelite are also present. In the vicinity of the veins, disseminations of cassiterite are found. The quartz forms a coarse band along the vein walls. The wall rocks is ornamented by vein systems. (Tourmalinized phyllites). (Fig. III.136 and Fig. III.137).

The margins of the veins are commonly characterized by shearing or slickensiding ,with alignment of muscovites (sericite) parallel to the contacts, probably resulting from movement during injection.

Bedding and schistosity have controlled the location of the veins and these late were injected concordantly to the country rock structures. The restricted structural control by bedding planes and schistosity indicates that others structures provided minimum resistance to the injection.

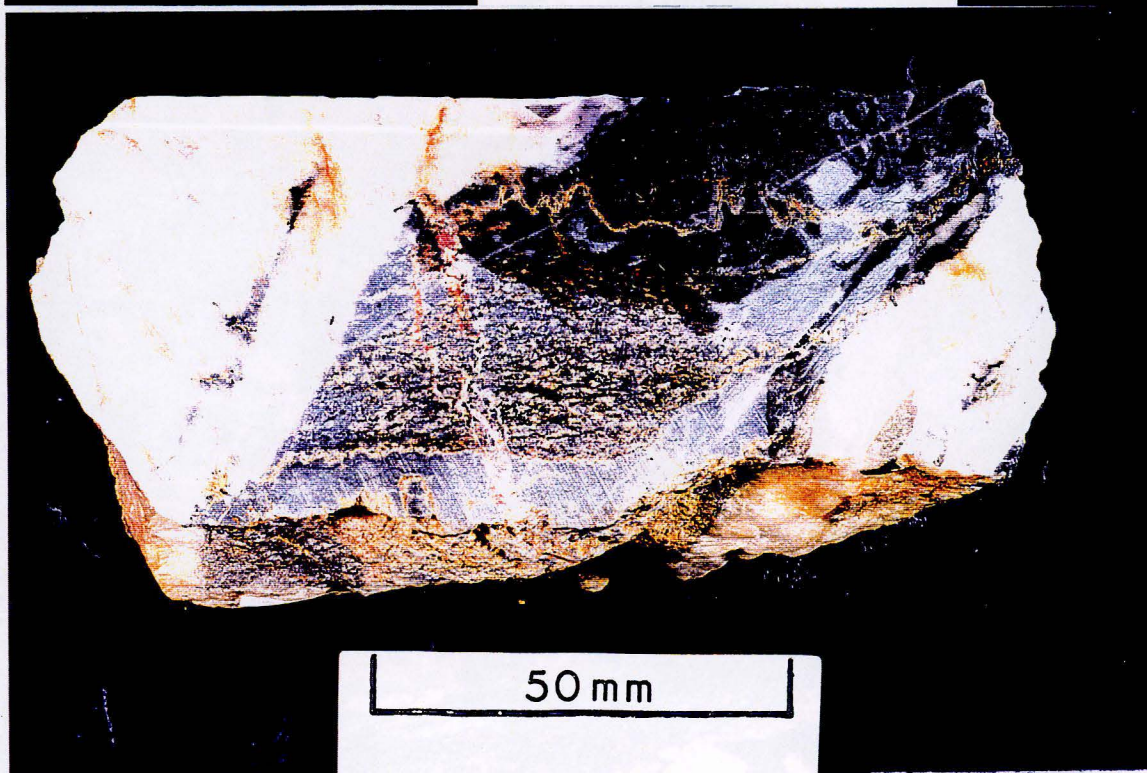


Fig. III.134:- - Hand specimen, tin vein ore, Kashwa tin deposit.

Fig. III.135:- - Hand specimen of tin vein ore, Kashwa tin deposit.

Showing quartz, tourmaline with minor amounts of cassiterite, sericite and goethite.

Fig.III.136:-- Wall-rock alteration in the form of silicification and tourmalinization of black shale unit within the Kashwa tin deposit.

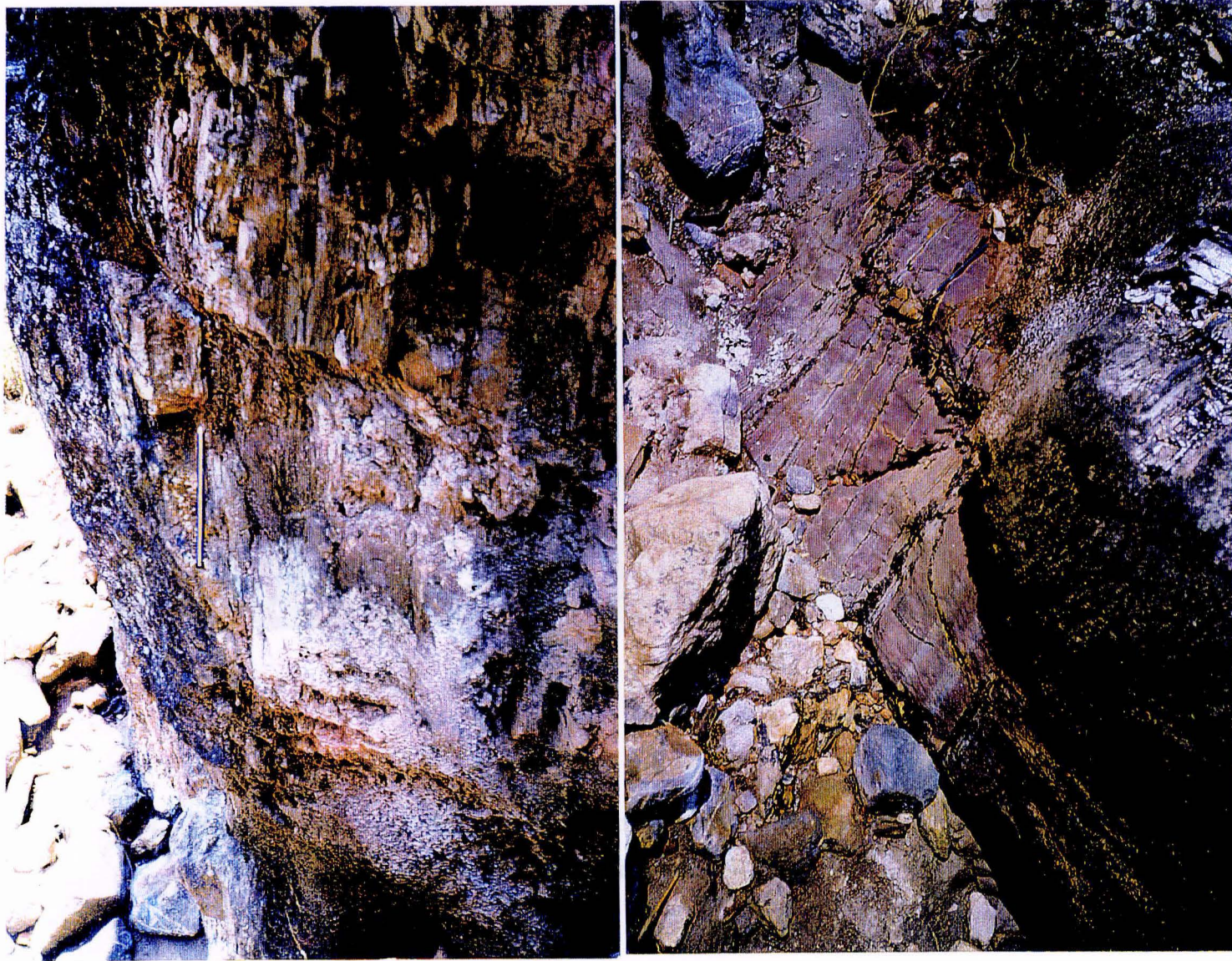




Fig.III.137:- - Wall-rock alteration in the form of silicification and tourmalinization of black shale unit within the Kashwa tin deposit.

It is also suggested that the veins could have been emplaced along structures that were axially planar to the folds namely the fractures and cleavages which had orientations parallel to the plane of minimum resistance. The preference of the fractures and cleavages to bedding planes and schistosity as the intrusive sites for a principal stress axis parallel to these structures would also normally be expected to explain the location of this deposit.

The predominantly NNW-SSE trend of the veins suggests that the older Kibaran structures with this orientation presented the least resistance to the injected fluids because they were oriented parallel, or nearly so, to the principal stress axis.

14.3.- GEOCHEMISTRY.

The results of XRD and XRF analyses of the veins and wall rock from Kashwa tin deposit are listed in Table III.18 : Geochemistry data of Tin vein from Kashwa deposit. Fig.III.138 shown the different histograms of the ratios of Sn/W, Sn/Mg and Sn/F .

14.4.- OXYGEN ISOTOPE.

14.4.1.- SAMPLE PREPARATION.

A total of 2 samples, KW 705 and KW171 from respectively two quartz veins were selected and analysed for oxygen isotope. The quartz samples were essentially 99%.

14.4.2.- RESULTS OF $\delta^{18}\text{O}$ ANALYSES.

Quartz veins possess $\delta^{18}\text{O}$ values ranging from 16.1 to 18.8 per mil (average 17.45 per mil); relative to SMOW .

This quartz $\delta^{18}\text{O}$ values are restricted to a narrow range, reflecting the uniformity of the quartz vein forming fluid, and giving a range of equilibrium water compositions from (> 8) to (> 10) per mil (for 3 samples) typical of magmatic values elsewhere. (Taylor.H.P, 1979).

TABLE.III.18 :- CHEMICAL COMPOSITION OF THE HYDROTHERMAL TIN-BEARING VEIN FROM KASHWA SHEETED TIN DEPOSIT.

Sample	KW 171	KW 175	KW 176	KW 705	KW2 705	KW 707A	KW 708	KW3 705
SiO2 (wt%)	53.1	53.29	59.25	82.86	88.01	83.66	91.25	85.77
TiO2	0.36	1.13	0.92	0.38	0.19	0.39	0.36	0.4
Al2O3	4.87	19.95	11.87	7.79	3.25	8.29	4.25	6.09
Cr2O3	*	*	*	*	0	*	*	*
Fe2O3	11.79	10.44	15.13	6.33	3.21	5.63	0.69	5.66
MnO	19.08	3.87	3.43	0.03	0.01	0.08	0.01	0.02
MgO	0.37	0.55	0.93	0.14	0.52	0.08	0	0.49
CaO	0	0	0.04	0.03	0.15	0.02	0	0.16
Na2O	0	0	0.01	0.37	0.46	0.27	0	0.54
K2O	2.27	1.73	0.08	0	0	0	1.28	0.14
P2O5	0.21	0.06	0.11	0.93	0.26	0.01	0.01	0.22
V2O5	*	*	*	*	0	*	*	0
NiO	*	*	*	*	0	*	*	0
CuO	*	*	*	*	0.01	*	*	0.01
ZnO	*	*	*	*	0	*	*	0
SO3	*	*	*	*	0.04	*	*	0.04
F	*	*	*	*	0.06	*	*	0.5
Loi	4.85	7.7	6.95	0.93 *		0.23	0.86 *	
Total	96.93	98.74	98.71	98.89	96.16	98.66	98.73	99.66

Trace Elements.

Sample	KW 705	KW2 705	KW3 705
V (ppm)	42	30	53
Cr	39	15	48
Co	< 9	5	8
Ni	< 9	4	1
Cu	< 2	< 21	< 15
Zn	15	34	40
As	623	115	75
Se	*	0	0
Rb	18	15	30
Sr	20	11	16
Y	3	2	< 2
Zr	134	147	135
Nb	15	2	5
Mo	6	3	1
Sn	1041	1350	1990
Sb	*	8	21
Te	*	< 26	< 8
Ba	12	39	38
Ta	< 19	3	5
W	73	40	16
Pb	*	5	7
Bi	*	< 1	25
Th	3	3	16

Rare Earth Elements.

Sample	KW 705	KW2 705
La	4	4
Ce	6	6
Pr	< 1	< 1
Nd	< 1	< 1
Sm	< 1	< 1
Eu	< 1	< 1
Gd	< 1	< 1
Tb	< 1	< 1
Dy	< 1	< 1
Ho	< 1	< 1
Er	< 1	< 1
Tm	< 1	< 1
Yb	< 1	< 1
Lu	< 1	< 1
Th	1	1
U		

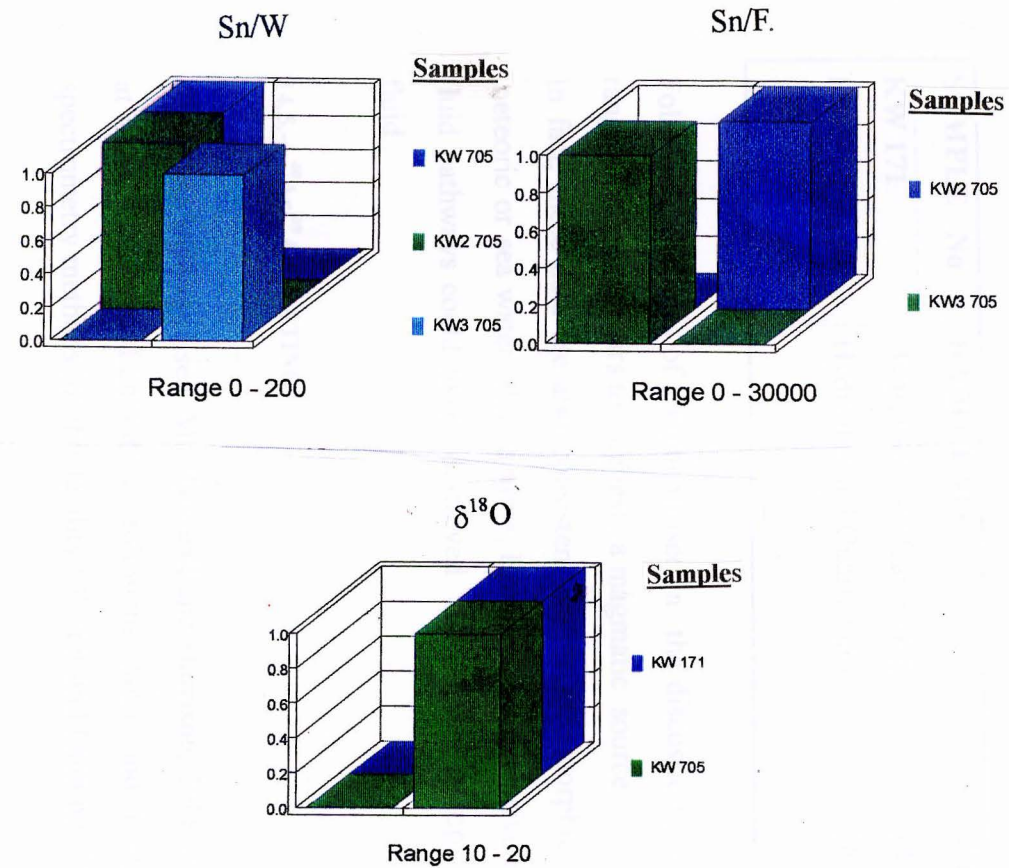


Fig.III.138:- Histograms of the ratios of Sn/W and Sn/F from a tin vein, Kashwa tin deposit.

Fig.III.139:- Histogram of $\delta^{18}\text{O}$ values of the Kashwa sheeted tin deposit.

These quartz $\delta^{18}\text{O}$ values are interpreted as of magmatic origin, mixing with an isotopically distinct fluid reservoir. (Kerrich , 1987). Fig.III.139 shows the histogram of $\delta^{18}\text{O}$ values.

Table III.19 : RESULTS OF OXYGEN ISOTOPE DETERMINATION OF HYDROTHERMAL QUARTZ - TOURMALINE VEIN . KASHWA TIN DEPOSIT.

SAMPLE No	HABIT UNIT	$\delta^{18}\text{O}$ values (SMOW)
KW 171	Hydrothermal Quartz vein	18.8
KW 705	Hydrothermal Quartz vein	16.1

Following the lines of argument used in the discussion on Tshondo gold deposit, this range of values appears to suggest a magmatic source.

In fact, these data are also consistent with a metamorphic fluid source, but exclude a meteoric or sea water fluid source. However, an extensive interaction with rocks along fluid pathways could have destroyed the original isotopic magmatic signature of the fluid .

14.5.- $^{40}\text{Ar}/^{39}\text{Ar}$ DATING.

$^{40}\text{Ar}/^{39}\text{Ar}$ analyses (see Mc Dougall and Harrison, 1988, for review) were undertaken at AAC Research Laboratory, following laser and furnace extraction and mass spectrometry methods for this facility (Foster and Fanning, 1997).

In the following section, we present $^{40}\text{Ar}/^{39}\text{Ar}$ data from the Kashwa tin deposit obtained from sericite in a quartz -tourmaline vein.

14.5.1.- SAMPLE DESCRIPTION.

Sample KW 705 was obtained from a quartz -tourmaline vein containing tin from the Kashwa deposit. The specimen shows a quartz, tourmaline and cassiterite. (Fig.III.135)

Microscopically, the sample consists essentially of milky white, partially recrystallised, vein quartz intergrown with fine-grained tourmaline. Minor amounts of sericite are peripherally developed around the tourmaline. Later, coarse grained veins of both quartz and tourmaline traverse the rock. (Fig.III.135).

The composition (estimation are in volume %) and texture of the sample are as follow (Fig. III.140) :

*.- Quartz : 58 % (I) Recrystallised, polygonal grains, averaging 0.1mm across, enclosing orientated, elongated, strained quartz clasts up to 1mm in length .
(II) coarse-grained vein material traversing recrystallised material.

*.- Tourmaline : 30 % (I) Fine-grained, irregularly -shaped, often poikilitic aggregates, < 0.5 mm in length, throughout masses of recrystallised quartz.

(II) Coarse -grained crystals, up to 3mm in length, associated with late quartz - veining.

*.- Sericite : 1 % ; Ragged shreds, up to 0.2 mm but usually < 0.1mm long, peripherally developed around tourmaline.

*.- Goethite : < 1 % ; Secondary iron oxide staining some of the tourmaline.

*.- Sheelite : < 1 % ; Irregular bodies , up to 0.3 mm across, intergrown with tourmaline.

*.- Cassiterite : Trace ; Rare occurrences in quartz veining.

14.5.2.- RESULTS.

Step-heating analyses were undertaken on three muscovite grains from sample KW 705, quartz-tourmaline veining (Fig.III.140). The grains were very small and only single analysis steps could be undertaken. The $^{40}\text{Ar}/^{39}\text{Ar}$ step heating and total results for the muscovites samples are given in Table III.20. Two of the grains produced ages of $559 \pm 10 \text{ Ma}$ and $533 \pm 7 \text{ Ma}$, respectively, while the remaining grain released insignificant amounts of argon and no age calculations could be made.

The two apparent age components in these two samples probably reflect the different closure ages of these two micas.

The age-date obtained from this sericite may reflect either that of vein formation or a later alteration event.

We interpret the mean age of $546 \pm 8 \text{ Ma}$, as the relative timing of Tin mineralization in the Kashwa tin deposit.

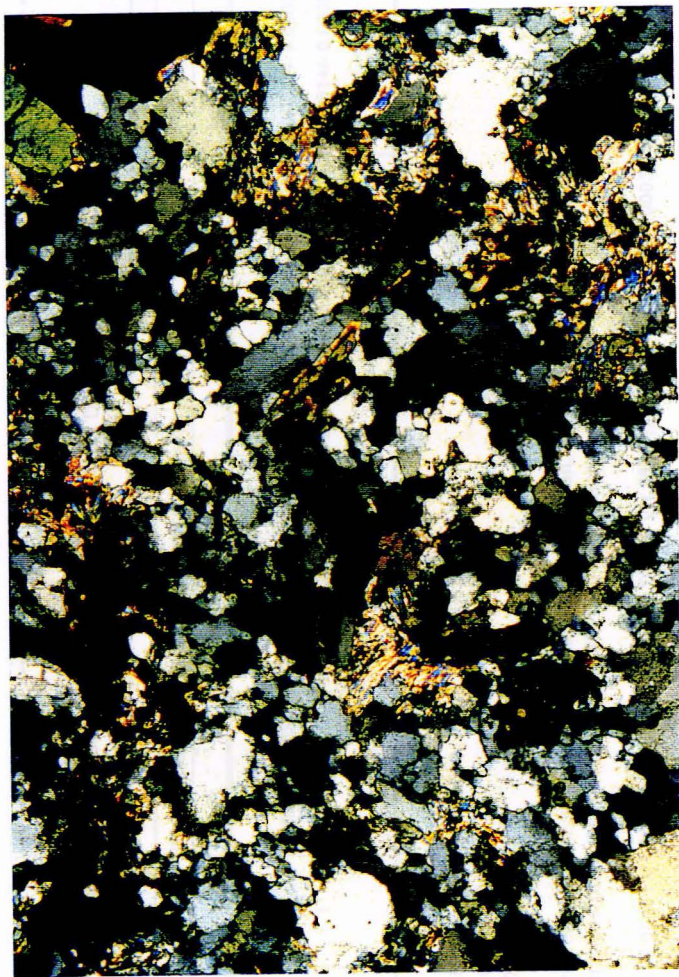


Fig. III.140: - Photomicrograph of a quartz-tourmaline vein containing tin from the Kashwa tin deposit.

Table.III.20:- $^{40}\text{Ar}/^{39}\text{Ar}$ LASER PROBE ANALYTICAL RESULTS FOR SERICITE MINERAL
OF QUARTZ-TOURMALINE VEIN FROM KASHWA TIN DEPOSIT.

MINERAL	GRAIN No.	STEP No.	INTERFERENCE - CORRECTED PEAK HEIGHTS					$^{37}\text{Ar}_{\text{ca}}/^{36}\text{Ar}_{\text{k}}$	ATMOS	AGE (Ma)
			^{40}Ar	^{39}Ar	^{38}Ar	^{37}Ar	^{36}Ar		%	
MUSCOVITE	KW 705-1	1	0.3084+/- 0.0002	0.00763+/- 0.00005	0.00001+/- 0.00003	0.00002+/- 0.0001	0.00002+/- 0.0002	0.120+/- 0.010	1.62	559 +/- 10
	KW 705-3	1	1.1110+/- 0.001	0.0290+/- 0.00032	0.00232+/- 0.00003	0.0001+/- 0.0001	0.00001+/- 0.00001	0.001+/- 0.001	0.25	533 +/- 7

J-Value for KW 44, KW 622A = 0.0086+/-0.0001

J-Value for KW 705 = 0.009+/- 0.0001

J-Value for KW152 = 0.0087+/-0.0001

Isotope peak heights are corrected for system blanks, mass discrimination, radioactive decay of ^{37}Ar and ^{39}Ar , and reactor induced interferences on masses 40, 39, 38 and 36. Values are recorded as volts (V).

Typical blank levels are: 0.00461 V (^{40}Ar), 0.0001 V (^{39}Ar), 0.00010 V (^{38}Ar), 0.00346 V (^{37}Ar), 0.00030 V (^{36}Ar)

14.6.- STRESS FIELDS AND EMPLACEMENT OF THE HYDROTHERMAL TIN - BEARING VEINS.

The attempt to interpret the conditions under which the hydrothermal veins were formed is based on the principle that magmatic fluids such as those from which these mineralizations were formed, intrude their host rocks mostly under their own fluid pressures (Brisbin., 1986., McCarthy., 1989).

Examination of the mineralized bodies discussed herein shows that most them were intruded along pre-existing planes of weaknesses. These included bedding planes, schistosity , axial plane cleavages and fault zones. The NW- SE regional geometries of the folds has determined the attitudes of the first four structures.

The choice of particular planes of weaknesses as sites for the intrusion of these melts depended on the orientation of these structures with respect to the ambient minimum normal stress. The hydrothermal tin-bearing veins are post-tectonic with respect to the D₂ discussed earlier.

Bedding plane and schistosity appear to have been the most favourably oriented structures with respect to the prevailing stress field at the time of intrusion of the hydrothermal veins. According to the proposed stress field situation, the direction of minimum resistance was NW-SE.

The collision event of Porada (1979, 1989), Sacchi (1984), Cahen et al., 1984, Daly (1986, 1988) , Key et al., 1989 , which took place during mid Kibaran to Pan African (1000 - 530 Ma) and that of Meert et al., (1995) (Kuunga orogen : 550 Ma) is believed to have generated the compressive stress in the NW-SE direction which facilitated opening preferentially in these directions.

Characteristics of veins suggest formation at depth where the vertical normal stress is greater than or nearly equal to the directed horizontal stress. This is the depth zone between the transition zone and the critical depth ca. 3-10km.

At the critical depth which corresponds to a depth of approximately 3km, the vertical normal stress + vertical tensile stress = horizontal normal stress + horizontal tensile stress. The critical depth is characterized by no preferred orientation. (Brisbin , 1986).

14.7.- GENETIC LINK BETWEEN GOLD AND TIN MINERALIZATIONS.

Primary tin mineralization is commonly associated with peraluminous leucocratic granites which represent late phases of late-orogenic to anorogenic granite complexes.

These " Tin " granites ", show petrographic and geochemical characteristics (e.g, the occurrence of topaz, Li - Fe mica and albite ; high F, Li, Rb, Ga, Sn, and Nb ; low Mg, Ti, Zr, Ba, Sr, and Eu) which can be used to distinguish, them from barren granites. (Tischendorf, 1977).

Na- metasomatism is associated with most H, (-K) metasomatism - producing systems (muscovitisation and greisen) elsewhere (Shcherba, 1970 ; Pollard et al., 1988).

Experimental data suggest a possible magmatic trend toward albite enrichment for some F-rich granitic suites associated with Sn- W mineralization (Manning, 1981, Pollard, 1983).

Fractional crystallization of F-rich melts yields unusual, quartz-poor, albite rich rocks, referred to as apiogranites and albitites (Beus and Zalashkov 1964; Stemprok and Slecak, 1969 ; Beus, 1982) .

Field and geochemical evidence would indicate that albitite porphyritic intrusion spatially related to gold mineralization in the Twangiza deposit may be genetically related to Kashwa sheeted tin vein and both to the Kasika granitoid batholith inferred in depth.

Geochemical studies suggest that the greisen and albitite were formed by alteration of the Kasika leucogranite. Greisenization produced an enrichment in SiO₂, Sn , W, As, Cr , Zr, as well as a depletion of TiO₂, Na₂O, K₂O, and V.

Albitization which is also present, is characterized by an enrichment in Na₂O, CaO, Al₂O₃, as well as V,Cr, Ni, Sr, Y, Nb, Ta, U and a depletion of K₂O, MgO, SiO₂, as well as Rb and Pb. Albitite is characterized by low concentrations of Sn and W .

On the basis of high resolution $^{40}\text{Ar}/^{39}\text{Ar}$ analyses, a genetic link between gold mineralization and tin mineralization can be also claimed.

A mean age of $522 \pm 15 \text{ Ma}$ has been calculated from the hydrothermal muscovite grains of Twangiza deposit and has been considered to provide a good estimate of timing of saddle reefs -type gold mineralization. Two bracket grouping ages have been identified for Twangiza gold deposit : $274\text{--}491 \text{ Ma}$ and $522\text{--}635 \text{ Ma}$. The mean age of $546 \pm 8 \text{ Ma}$, is interpreted as the relative timing of Tin mineralization in the Kashwa tin deposit.

Kashwa tin deposit is located 8.5 km northwest from Twangiza deposit. This close association in time and space support the general concept of a genetic link between these two types of deposits. The contrasting sites of emplacement of the hydrothermal tin-bearing veins in relation to that of the gold deposits are reflections of the differences in the intrusion level and its control.

The hydrothermal tin-bearing veins were formed at shallower depths in more brittle environments while the gold deposits were intruded in deeper and less brittle environment.

The NW-SE trend of the veins is consistent with the proposed stress field.

14.8.- SUMMARY AND DISCUSSIONS.

Sheeted vein systems occur in metasedimentary rocks of the Tsibangu formation in the Kashwa tin deposit . There are five main veins, and many subsidiary veins which dip southeasterly at 60-80 °C in the upper parts of the deposit.

Tin mineralization occurs as multiple simple-vein system which dip steeply. The veins occur as lenticular or irregular bodies, parallel to the country rock schistosity and/or bedding with no evidence of repeated opening. Some of the veins may branch or have irregular off-shoots which strike and dip differently from the main part.

The veins are comprised largely of quartz with tourmaline and the tin ore is defined by cassiterite- tourmaline-quartz assemblage. The presence of scheelite in wall rock alteration suggest that this deposit contain a late stage precipitates from solutions and scheelite could have been replaced wolframite. The quartz forms a coarse band along the vein walls. The margins of the veins are commonly characterized by shearing or slickensiding.

The tin bearing veins have been emplaced within the western limb of the Bugoyi syncline and all the veins have a NNW-SSE orientation. The choice of opening direction was probably facilitated by the NW-SE directed horizontal stress generated by the continent-continent collision event between the Congo craton and the Tanzania craton during the *Kuunga orogen* of Meert et al ., (1995).

Bedding and schistosity have controlled the location of the veins and these late were injected concordantly into country rock structures. The restricted structural control by bedding planes and schistosity indicates that others structures provided minimum resistance to the injection and dominated vein control. The predominantly NNW-SSE trend of the veins suggests that the older Kibaran structures with this orientation presented the least resistance to the injected fluids because they were oriented parallel, or nearly so, to the principal stress axis.

Characteristics of veins suggest formation at depth conditions where the vertical normal stress is greater than or nearly equal to the directed horizontal stress. This is the depth zone between the transition zone and the critical depth ca. 3-10km.

The $\delta^{18}\text{O}$ values of quartz vein range from 16.1 to 18.8 per mil have been interpreted also as of magmatic signature. An extensive interaction with rocks along fluid pathways could have been destroyed the original isotopic magmatic signature of the fluid .

This $^{40}\text{Ar}/^{39}\text{Ar}$ age of 533 - 559 Ma (mean age of $546 \pm 8\text{Ma}$) for quartz - tourmaline veining broadly agree with the geological and structural observations that deformation and veining were initiated during a Pan African event (*Kuunga orogen*), at which time bedding planes would have been the major anisotropy available for fluid migration.

The main stage of Sn-W mineralization involved magmatic fluids ; and the high salinity fluids found in quartz-tourmaline vein were most likely derived from immiscibility in magmatic systems. Petrographic study of fluid inclusions (not reported here) has revealed that the Kashwa ore fluids types are similar to those of the Twangiza gold mineralizing fluids. Gold and tin mineralization form one continuous ore spectrum. The mineralization is considered to have originated in the underlying granitic bodies (Kasika granite) and migrated into the metasedimentary sequence along the Bugoyi fault zone .

A close association in time (respectively $522 \pm 15\text{Ma}$ for gold and $533 - 559\text{Ma}$ for tin) and space (8.5 km apart) support also the general concept of a genetic link between gold and tin deposits. Geochemical studies suggest that the greisen and albitite were formed by alteration of Kasika leucogranite. Greisenization produced an enrichment in SiO_2 , Sn , W, As, Cr , Zr, as well as a depletion of TiO_2 , Na_2O , K_2O , and V.

Albitization which is also present, is characterized by an enrichment in Na_2O , CaO , Al_2O_3 , ..as well as V, Cr, Ni, Sr, Y, Nb, Ta, U and a depletion of K_2O , MgO , SiO_2 , as well as Rb and Pb. Albitite is characterized by low concentrations of Sn and W .

PART. IV .- SUMMARY AND CONCLUSION.

The Kadubu area constitutes the type area of the Itombwe synclinorium supergroup and is located approximately between 28°33' - 28°50' longitude east and 2°45' - 2°57' latitude south, covering about 750 s.q.km, (30 km x 25 km).

The aims of this study are to construct the first geological and structural map of the Kadubu area and to elucidate the genesis and evolution of the gold and base- metal mineralizations and their geological setting. The present study area which forms a part of the Itombwe synclinorium, represents the first area to be investigated in detailed using modern techniques, from systematic geological mapping through structural, tectonic, petrographic, geochronological and geochemical analysis to ore genesis .

The Kadubu area is made up of a metaturbidite sequence exhibiting characteristic Bouma cycles in the western branch of the East african Rift system, with two structural zones bordered by major thrust-faults. These bounding faults and major internal, normal shear-faults, strike-slip faults and high-angle reverse faults are interpreted to have a listric geometry and to flatten at depth. They are inferred to pass into major mid-crustal detachment faults forming a west-vergent thrust system. The inferred detachment - faulting is at the interface of the Itombwe supergroup and the Kibaran basement. High -angle reverse faults, chevron folds and spaced cleavage characterize crustal shortening above subsurface detachment in the metaturbidite succession of the Itombwe synclinorium.

This sequence has been folded into upright,north to northwest -trending, tight to isoclinal folds which were intruded by late to post-orogenic, alkaline, metaluminous albitites. Three multiphase deformations [D_1 , D_2 (compressions) & D_3 (extension)], have been metamorphosed to lower-middle greenschist facies. The metamorphic grade increases slowly towards the west with the lower tectonostratigraphic level, across the upper Kadubu group, ranging from subgreenschist to greenschist facies.

The Kadubu metamorphic complex consists of two geochemically and structurally distinct groups: The lower Kadubu group and the upper Kadubu group separated by the Tshondo fault/ shear zone which is a clear tectonic, metamorphic and geochemical discontinuity within the Kadubu area.

The Kadubu metaturbidite sequence has been intruded by a late to post-orogenic , alkaline, metaluminous albitite rock. Kasika granite is also intruded into the Kibaran metasediments in the southwesternmost corner of the study area. This granite is leucocratic, peraluminous, subalkaline, syn-to post collisional, and fits the criteria for being S-type granite.

$^{39}\text{Ar} / ^{40}\text{Ar}$, Rb/Sr and Sm/Nd constrain the history of deformation, metamorphism, magmatism and mineralization. Both field evidence and radiogenic ages indicate a series of Neoproterozoic events. The Kasika granite yielded mean ages of $529 \pm 5 \text{ Ma}$ and $436 \pm 8 \text{ Ma}$ ($^{39}\text{Ar} / ^{40}\text{Ar}$) and $703 \pm 14 \text{ Ma}$ (Rb/ Sr). The Albitite rock yielded an age of $1078 \pm 27 \text{ Ma}$ implying that this albitite is related to a Kibaran granite ($1400 -900 \text{ Ma}$). The initial Sr isotope ratios ($^{87}\text{Sr} / ^{86}\text{Sr}$) for feldspar (albitite) and apatite & mica (granite) have a mean of 0.734298 ± 0.0001 and $(0.885419 \text{ \& } 18.277000)$ respectively.

Sm/ Nd isotope ratios for feldspar (albitite) and apatite (granite) are respectively 0.14852 and 0.36422 . Sr and Nd isotopic ratios indicate a common crustal source and suggest a genetic relationship between the albitite and granite.

$^{39}\text{Ar} / ^{40}\text{Ar}$ dating of metamorphic muscovite in phyllite gives an age of $575 \pm 83 \text{ Ma}$. The muscovite comes from within the D₂ - NNW- directed tight to isoclinal folded and dominated structural domain with the interpreted age coinciding with F₂ folding. The structure of the Kadubu area is essentially a “detachment (nappe) – thrust “ stack that has resulted from compressional thrust tectonics that was later transformed into strike-slip dominated tectonics. The structure and age ($530- 540 \text{ Ma}$) of the complex accords with a Pan african collisional history. It is assumed that the orogeny [continent – continent collision.] resulted from a collision between the Congo and the Tanzania plates during the *Kuunga orogen* .

In formulating the models of geodynamic evolution of the Itombwe basin, and taking into account the different geodynamic models of the Kibaran basement, the Itombwe basin is considered to have evolved in a strike-slip setting within a pull-apart structure showing a transition from compressional (transpression) to extensional (transtension) regimes.

The geochemistry of the clastic metasediments suggest a tectonic model for the Kadubu area (Itombwe synclinorium), as an intracontinental extensional rift receiving clastic detritus from the adjacent uplifted Kibaran basement. The development of the Itombwe basin, and subsequent Kadubu area is related to its location at divergent plate boundaries (Congo and Tanzania cratons), and /or active margin (Western branch of the East African Rift system).

Mineralization within the Kadubu area is represented by two important gold deposits (Twangiza and Tshondo) and one tin deposit (the Kashwa sheeted tin deposit). Small occurrences of gold (Kakere, Mufwa and Mwanza), travertine deposits, thermal hot springs and alluvial terraces are also recognised in the study area.

*.-Two active thermal hot spring sites (the Luidja and Bugoyi hot-springs) form the geothermal field recognized in the study area and testify to the existence, today, of a heat source at depth and of an active geothermal system with high heat flow forming large-scale convection patterns.

*.- The Bugoyi hot-spring travertine deposit occurring in the Tiruembwe river, consists of soft highly porous aragonite associated with minor calcite and various accessory minerals.

*.- In the Nambo stone line river terrace, gold occurs disseminated in the package, but tends to be concentrated along the stone line horizon close to the base of the gravels.

*.-The Twangiza gold deposit is exposed by erosion on a steep slope and a zone of gold mineralization follows the NNW-SSE ($\sim 10^\circ$ W) trending Twangiza anticlinal axis, with steep dips ($\sim 80^\circ$) to the east and pitch to the south. The location of this deposit is typically controlled by the intersection of two regional lineament structures (NNW-SSE and E-W), with flexures in shear-fault zones, and the interplay of the geometry and rheology of the enclosed albitite and black shale lithologies controlling gold mineralization.

The host to gold mineralization is a black shale unit (up to 1000m thick) with interbedded siltstone (up to 60cm thick) and arkosic sandstone grading to greywacke (up to 1m thick beds) in which albitite lenses are emplaced. From bottom to top, the detailed lithostratigraphy within the deposit is as follows: Black shale, siltstone, and greywacke : These units belong to the metaturbidite sequence of the Tsibangu Formation which has been metamorphosed to greenschist facies

The Twangiza deposit exhibits three clear structural controls of gold mineralization:

- *- Tight folding: mineralization occurs as classic concordant saddle reefs at the interface between competent arenites and albitites, and less competent black shales, on the flanks of the Twangiza anticline near the Twangiza high-angle reverse fault, along a strike length of 5kms.
- *- Faulting: the size and geometry of the orebody is controlled by the N- S striking Twangiza high-angle reverse fault, which is interpreted as the main fluid pathway for the mineralizing solutions.
- *- Lithology and geochemistry: mineralization is strongly controlled by structure and geochemistry of the host rock black shale unit and albitite at different scales.

The shape and geometry of the ore shoots for the Twangiza deposit is reasonably well constrained. Preliminary data indicate that gold in the Twangiza deposit takes two forms. Classic saddle reefs with high grade material and fault reefs with associated spur veins. The general geometry of the ore shoot comprises a feeder zone controlled by the Twangiza high-angle reverse fault, and an upper stratiform black shale zone, acting as a reactive lithology.

The high Au-grades (> 10gm/tonne) tend to be localized, either in the proximity of the interface between albitite and black shale where they are closely associated with fault-breccia zones (fault reef system); or on the flanks of anticlinal zones and closely associated with sulphide veins (saddle reefs system). Beyond this domain, the grade falls progressively.

Four distinct vein-types are present in the Twangiza deposit: Vein set QV₁, (irregular crack- seal quartz veins); QV₂, (folded bedding-parallel veins); QV₃, (vuggy fault-breccia) and QV₄, (stockwork veining, brecciation, and/or dissemination).

Paragenetic relationships indicate that gold is associated with three mineralogically distinct assemblages that are thought to represent distinct episodes of mineralization termed stage I (quartz $\pm$ sulphide $\pm$ gold stage); stage II (sulphide - gold stage); and stage III (postore carbonate - quartz $\pm$ sulphide $\pm$ gold stage), and separated by major fracturing and brecciation events.

Both superficial meteoric alteration and hydrothermal alteration are present. Deeply weathered alteration has affected the distribution and abundance of iron oxides/sulphides, carbonate minerals, clay minerals, carbonaceous matter and their permeability and porosity. Limonitization is the most intense surficial meteoric alteration.

Hydrothermal alteration in auriferous quartz /sulphide veins is characterized by a diffuse albitization, sericitisation, chloritization, sulphidation, carbonatisation, and (de-) silicification. Aside from the sulphides, the main alteration phases are dolomite, magnesite, ankerite, chlorite, sericite, quartz and albite. Pyrite and arsenopyrite are the dominant sulphide phases.

Alteration of host-rock is minor, of limited extent (4-5cm wide) and intensity and restricted mainly to narrow zones surround and/or adjacent to major quartz/sulphide vein systems and fault-breccia veins, and in which the host-rocks are discoloured and softened. Chemical data indicate that SiO₂, Al₂O₃, FeO, MgO, CaO, K₂O, and Na₂O moved relative to each other during wall-rock alteration. High (FeO+MgO), low CaO and Na₂O, and very low K₂O are the characteristic chemical features of both profiles.

Metal associations comprise Au, Ag, As, Bi, Se and low concentrations of Zn, Cu, Ni, V, Nb, Pb, Cr, Co, Ta, W, Mo. In the Twangiza deposit, native gold occurs in the oxide zone as grains which vary in size from microscopic to grains which are just visible to the naked eye (200 μ m). Free gold is rare in the sulphide zone. On the microscopic scale, free gold in the pyrite and mostly in the arsenopyrite occurs as very small particles seldom more than 0.5 mm in diameter. The frequency diagram shows that grains with Au contents of 0 to 2 ppm prevail in these samples.

Gold fineness, $[1000 \cdot \text{Au}/(\text{Au} + \text{Ag})]$ for the Twangiza ores range from 991.95 to 998.30 and the ratio of Au/Ag varies from 123.17 to 586.64. The results of this study indicate that arsenopyrite is a good host for "invisible gold", but that pyrite is also a very good gold-carrier. The dominant form of pyrite is the modified, striated cubes, commonly with octahedral and pyritohedral modifications and/or striations.

Ion microanalyses, revealed that the Twangiza ore contains two distinct populations of pyrite: a "normal" pyrite containing less than 0.5 ppm As, and an arsenical variety with As contents ranging from 1 to 4 ppm. On the other hand, pyrite in the late-stage quartz/sulphide veins is significantly enriched in arsenic.

These two types of pyrite, distinguished from one another by textural criteria and mineral chemistry, indicate multiphase ore genesis, inhomogeneous metamorphism, or both. In both pyrites, there is a positive correlation between the concentrations of Au versus Fe, As, Ag, Cu and negative correlation with S and Pd. In the ores that contain arsenopyrite, there is not a strong positive correlation between the concentrations of Au and As in arsenopyrite. Compared to mesothermal pyrite, and to pyrite of the Witwatersrand gold deposits, the Twangiza pyrite shows a strong depletion in As, Ag, Pd, and Cu trace elements. The very low S/S_e ratios of Twangiza pyrites supports the interpretation that the sulfur, selenium and thus gold in the various sulphide generations is mostly of magmatic hydrothermal origin.

The Twangiza deposit is enriched in rare elements (As, Se, Sb, Te, Bi, B), lithophile elements (LILE: Ba, Li, K, Rb, Cs, TL), volatiles (H_2O , CO_2 , CH_4 , H_2S) and precious elements (Au, Ag). Elements such as Fe, Mg, Ca, Si, and Na may be added or depleted. Cu, Zn and Pb are generally low in the wall rocks as well as the veins.

High-field-strength elements (HFSE: Th, Nb, Ta, Zr, Ti, Y, P, Al, Ga), rare earth elements (La through Lu), and compatible trace elements like V, Cr, Sc, and Ni, generally are insensitive to alteration. As, Au, CO_2 , S, Cr, V, Ni, K, Al, and Rb increase in the altered rocks while Si, Na, Mg, Sr and, to lesser extent, Y, generally decrease. The increase of V, Ni, and Cr in the wall rocks may relate to a source of the ore fluids enriched in these components. It is suggested that these components may be derived from a granitic pluton at depth.

The specific loci of gold-bearing shear zones is along, or adjacent to, lithological contacts where there is a marked competency contrast between rock types. Proximity to albitite intrusions significantly influences the spatial distribution of gold mineralization. The Twangiza albitite rock, related to the Kasika granite at depth, has played an active role by acting passively as rigid (competent) blocks within the slate belt or they have also played an active role during their forceful intrusion, and by generating structures during their cooling and contraction after emplacement.

Based on field relations, textural and geochemical evidences as well as geochronological information, it is argued that the albitite intrusions pre-date emplacement of saddle reefs and fault reefs by at least *53 Ma*.

The interpretation of the combined results from studies of mineral paragenesis, geologic relationships, and geochronology ($^{40}\text{Ar}/^{39}\text{Ar}$, Rb-Sr and Sm-Nd) have been synthesized to provide a coherent composite of the relationships between the different tectonothermal events (deformation, metamorphism, magmatism and mineralization) within the Kadubu area.

$^{40}\text{Ar}/^{39}\text{Ar}$ analyses were performed to assess the timing of gold mineralization relative to deformations and igneous activity. It is concluded that the $^{40}\text{Ar}/^{39}\text{Ar}$ ages (mean: $522 \pm 15\text{Ma}$) of hydrothermal muscovites from the Twangiza deposit do provide a good estimate of timing of saddle reef gold mineralization. Two separate phases of mineralization are indicated, the earlier localized within classic saddle reef structures and containing the highest Au, and a later, fault controlled reef, synchronous with dextral strike-slip faulting. The cross-cutting stage of mineralization is associated with ground preparation and kinematic emplacement of albitite rock and is related to hydrothermal fluids migrating out of the Twangiza fault feeder zone. The first of mineralization produced and correspond to stages I & II gold mineralization, while the late phase correspond to Stage III gold mineralization.

A fluid inclusion study was undertaken on quartz samples from QV₁ veins, of the Twangiza deposit. Non-destructive microthermometry and Raman microprobe analysis were used to characterize the ore-forming fluids.

Four types of fluids have been recognized: $\text{H}_2\text{O}-\text{NaCl}-\text{CO}_2$ +/- DM and $\text{H}_2\text{O}-\text{NaCl}$ +/- DM. Thermobarometric evolution occurred in two stages:

*.- Fluid inclusions from the $\text{H}_2\text{O}-\text{NaCl}-\text{CO}_2$ +/- DM systems correspond to a drop of pressure and an opening in a lithostatic regime and accompanied early Au, As ore deposition.

*.- Fluid inclusions from the $\text{H}_2\text{O}-\text{NaCl}$ +/- DM system correspond to a drop in temperature and an opening in a hydrostatic regime and is associated with late Au, As, Sb ..., ore deposition. It is concluded that at least two major types of fluids were deposited; a high salinity fluid and a moderate and low salinity fluid.

The high salinity fluid, which is the most common type in most specimens, contains 30 to 60 wt% NaCl equivalent and was apparently saturated with NaCl below 300°C. It was accompanied by vapor phase. Obvious secondary inclusions contain the same two types of fluids but tended to fill at lower temperatures.

The close association of moderate and high salinity inclusions can be explained by alternation of lithostatic and hydrostatic pressure conditions, controlled by episodic release of magmatic fluid, followed by fracturing to the surface, then choking of the veins by silica deposition. The great variability of temperature and salinity of these inclusions seems to allow fluids in some to be meteoric or a mixture of meteoric and magmatic fluid. The hypothesis of magmatic derivation under alternating hydrostatic and lithostatic conditions seems to explain the gross features of the data most simply, although more detail remains to be worked out.

Isotopic analyses of vein pyrite and carbonate from QV₁ and QV₂ constrain the characteristics of the ore-forming source fluid and the source rocks. The isotopic data collectively indicate that the vein fluids were exotic with respect to the Tsibangu formation.

The Carbon isotope signature (- 3.71 to -9.85 per mil) of the fluids best reflects an igneous source as derivation of the carbonic species.

There is a uniform $\delta^{34}\text{S}$ composition of sulphide (2.62 - 8.48 per mil) and this consistency reflects a similar reservoir for the sulfur and constant chemistry for the ore fluid which was reduced and contained H_2S as the dominant sulphide species

It is concluded that the fluids responsible for vein formation ultimately originated at deep crustal levels but that interaction with wall rocks during fluid ascent variably modified primary isotope signatures to a minor degree. Based on this study, the hydrothermal fluids which generated the vein minerals examined, are considered to have originated from a magmatic source. This model derives the gold and the fluid mobilizing heat from the associated Kasika leucogranite.

Spatial and temporal distribution of gold deposits in the Kadubu area suggest a metamorphic core complex/detachment fault model to explain the source for the mineralization. In this model, intense hydrothermal circulation, silicification, brecciation and even magmatism (granitization & albitization), are features seen on permeable detachment zones, with mineralization occurring along cover/basement contacts as well as along relatively high-angled reverse, and/or listric faults. High-angled, listric (such as the Tshondo) or reverse (such as the Twangiza) faults emanating from the detachment fault sole, have channeled mineralized fluids to higher levels.

The Tshondo gold deposit lies in a NNW-trending zone of the Tsibangu formation, bounded by the N-S trending Tshondo fault zone to the west. The deposit tends to be restricted to the roll-over anticline deformation, in particular to well developed planar antithetic faults, westernmost of the Bugoyi syncline. The regional orientation of the main foliation, S_2 , is steeply dipping to the SW.

The host to gold mineralization is a strongly foliated black shale. Hydrothermal alteration is strongly developed near the veins and decreases outward. Three sets of veins have been recognized: Bedding-concordant quartz veins (TV_1), Bedding-concordant quartz/sulphide veins (TV_2) and Bedding - discordant (TV_3) quartz veins.

Gold fineness, $[1000 \cdot Au/(Au+Ag)]$ for the Tshondo ores range from 991.95 to 998.30 and the ratio of Au/Ag varies from 123.17 to 586.64. Au/Ag ratios are high, and Au/S ratios are also very high.

Base metal and total sulphide abundances are low. The very high Au/As ratio is characteristic. Arsenic content of gold ranges from 0.016 to 0.077 ppm and the concentration of other metals is not significant.

The measured $\delta^{18}\text{O}$ values of hydrothermal quartz veins are in the restricted interval between 16.1 and 19.8 per mil and are therefore relatively $\delta^{18}\text{O}$ enriched. These oxygen isotopic signatures are interpreted as of magmatic fluid type masked or erased during later events such as the influx of meteoric waters and/or exchange reactions with black shale wall rocks.

Sheeted vein systems occur in metasedimentary rocks of the Tsibangu formation in the Kashwa tin deposit. There are five main veins, and many subsidiary veins which dip southeasterly at $60\text{--}80^\circ$ in the upper parts of the deposit. The veins are comprised largely of quartz with tourmaline and the tin ore is defined by a cassiterite-tourmaline-quartz assemblage. The tin bearing veins have been emplaced within the western limb of the Bugoyi syncline and all the veins have a NNW-SSE orientation

The $\delta^{18}\text{O}$ values of quartz vein range from 16.1 to 18.8 per mil and have also been interpreted as being of a magmatic signature. An extensive interaction with rocks along fluid pathways could have destroyed the original isotopic magmatic signature of the fluid.

This $^{40}\text{Ar}/^{39}\text{Ar}$ age of $533 - 559 \text{ Ma}$ (mean age of $546 \pm 8 \text{ Ma}$) for quartz - tourmaline veining broadly agrees with the geological and structural observations that deformation and veining were initiated during a Pan African event, at which time bedding planes would have been the major anisotropy available for fluid migration.

The main stage of Sn-W mineralization involved magmatic fluids; and the high salinity fluids found in quartz-tourmaline vein were most likely derived from immiscibility in magmatic systems.

The mineralization is considered to have originated in the underlying granitic bodies (Kasika granite) and migrated into the metasedimentary sequence along the Bugoyi fault zone.

A close association in time (respectively $522 \pm 15 \text{ Ma}$ for gold and $533 - 559 \text{ Ma}$ for tin) and space (8.5 km apart) support also the general concept of a genetic link between gold and tin deposits.

Geochemical studies suggest that the greisen and albitite were formed by alteration of the Kasika leucogranite. Greisenization produced an enrichment in SiO_2 , Sn, W, As, Cr, Zr, as well as a depletion of TiO_2 , Na_2O , K_2O , and V. Albitization which is also present, is characterized by an enrichment in Na_2O , CaO, Al_2O_3 , ..as well as V, Cr, Ni, Sr, Y, Nb, Ta, U, and a depletion of K_2O , MgO, SiO_2 as well as Rb and Pb. Albitite is characterized by low concentrations of Sn and W.

The following sequence of events giving rise to the Twangiza and Tshondo gold deposits and Kashwa tin deposit have been envisaged :

1*.- Metamorphism of the Itombwe synclinorium and associated E-W shortening compressive events;

2*.- Intrusion of a granitic stock from which several apophyses of albitite rock and pegmatite penetrated syntectonically to shallow depths, and up to the surface. The spatial association between albitite intrusion and gold mineralization reflects the paramount importance of structure in the localization of gold mineralization;

3*.- Regional structures have played the role of localizing igneous activity (Twangiza albitite and Kasika granite) that supplied the energy to drive the hydrothermal system as well as the stress required for mechanical ground preparation;

4*.- Circumstances that developed and contributed to the sudden discharge of a large volume of hydrothermal fluid from (an overpressured ?) reservoir at depth;

5*.-The ore fluids responsible for gold mineralization were magmatically derived from the spatially associated Kasika peraluminous leucogranite. The fluids were largely of a composition of H_2O -NaCl +/- DM, (lower to moderate salinity) and H_2O -NaCl- CO_2 +/- DM(high salinity : 5.56 - 45.2 wt % NaCl equivalent);

6*.- Gold deposition probably developed in the temperature range of 280°C to $>450^\circ\text{C}$ at pressures of 0.5 - 4.5 kb which are considered to be the minimum conditions for gold deposition. This corresponds to a minimum mineralization depth of about 1 to 3 km under lithostatic and hydrostatic pressure regimes, respectively;

7*.- Upward focussing of magmatic waters and some additional meteoric waters near the Twangiza region was controlled by pre-existing fractures. Magma and ore fluids exploited the same conduits in their ascent from deeper crustal levels resulting in albitite intrusion and gold mineralization occupying the same structures. These fluids caused extensive phyllic and argillic alteration ;

8*.- The ore fluids were mostly focused into anticlinal flanks with the Twangiza high-angle reverse fault representing the chanelway along which hydrothermal fluids moved upward towards the upper metaturbidite sequence and playing a role as fluid- pressure - activated valves;

9*.- Migration of the gold mineralized fluids along the detachment fault towards the fault breakaway and deposition of gold within the Tshondo roll-over anticline deformation and associated planar antithetic faults. Depositions also of the small occurrences of golds : Kakere, Bugoyi , etc.....

10*.- Injection and deposition of the tin mineralized fluids concordantly into country rock structures;

11*.- The resulting mineralizing style is a turbidite-hosted mesothermal (orogenic) type gold deposit.

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APPENDIX .

LABORATORY INVESTIGATIONS INCLUDED :

1*.- 275 *thin and polished sections*, approximately, were studied with the goal of to identify the mineralogical composition and microstructure of the metasediments.

2*.- In order to determine the *chemistry* of these metasediments , analyses of 501 samples, giving rise to up 12.091 elements ,were carried out by *XRF* (309 samples), *XRD* (44 samples), *REE* (41 samples), and *Fire ICPI*, gold & silver (107 samples) respectively at Anglo - American Research Laboratory (AARL) and at Wits, Geology Department.

Major elements were determined using the fusion techniques of Norrish and Hutton (1969). Trace element concentrations were determined on whole-rock powder pellets. The total iron concentration is expressed as the ferric ion. Loss on ignition (L.O.I.) includes the H₂O and CO₂ content of the rocks. Analyses are not normalized on a water free basis.

3*.- 7 samples were analysed at the HAL (BPI) ; Wits, for *Radiogenic isotopes* (3 for *Rb/Sr*, and 4 for *Sm/Nd*) in order to identify geological processes and sources ,and to determine the age of the regional Kasika tin granite and Twangiza albitite.

4*.- 5 samples were submitted and analysed at AARL for *⁴⁰Ar / ³⁹Ar dating* in order to constraint the timing of the tectono-thermal , magmatism and mineralization events.

5*.- 17 samples from 3 alteration halos , considered to be representatives, were used to generate *detailed mineralogical and geochemical profiles* in order to decipher the process of *fluid - rock interaction*.

6*.- A study of *fluid inclusion* has been conducted on 5 double polished sections from gold quartz/sulphide -veins and tin quartz -veins in order to understand the entire fluid history and the genetic link between gold and tin ore-vein fluids.

The *microthermometric* study of fluid inclusions was carried out by use of a Leitz microscope equipped with a Linkham TH 600 heating-cooling stage. The measured chips were from 5 doubly-polished sections of about 300 μm thick.

Standard procedures for microthermometry were adapted from Diamond (1990) and New and Grundmann (1990). The stage was calibrated with the melting-points of solid standards at $T > 450^\circ\text{C}$ and natural and synthetic inclusions at $< 0^\circ\text{C}$.

The rate of heating was monitored in order to get an accuracy of ± 0.2 during freezing, and ± 1 when heating over the 25 to 450°C range.

The data are reproducible to $\pm 1^\circ\text{C}$ for heating runs and $\pm 0.2^\circ\text{C}$ for freezing runs.

Salinity, expressed as wt%NaCl equivalent, and fluid density of volatile-free fluid inclusions in quartz, were determined by microthermometry (Bodnar, 1993).

7 *.- *Raman spectroscopy* study was undertaken for the identification of gases and analysis of the volatile phase of individual inclusions.

The *Raman microprobe* used for the (qualitative) analysis of CO_2 , CH_4 , and N_2 in the gaseous parts of the fluid inclusions consists of a Jobin-Yvon triple monochromator T64000 equipped with a CCD multichannel detection unit and an olympus microscope (BH2-UMA). The measurements were performed with the 514.5nm radiation emitted from an Ar^+ laser. The laser beam was focused to about 2 μm by means of a 50x objective lens with working distance of 8mm. The laser power entering the sample was 27mW.

8 *.- 28 samples were analysed for *Stable isotope* (C,O,S), of which 9 for *sulphur isotope*, 3 for combined *oxygen and carbonate* minerals, 16 for *oxygen isotope*. The aim was to identify and constraint the source(s) of gold deposits, tin deposit and associated base-metals, and to understand the geological process responsible of the gold and tin mineralizations; (ore genesis and crustal growth). They analyses were made respectively at Geology Dept, Wits, (for sulfur isotope), Schonland research Center (for combined carbon and oxygen isotope) and Geology Dept, Cape Town University (for oxygen isotope).

Sulphur isotopes analyses were done at the Isotope Laboratory of the University of Witwatersrand , and at the Council for Geoscience, South Africa.

Some samples have been analysed in duplicate. Overall analytical error is less than $\pm 0.1 \text{ ‰}$.

Sulphur isotope analyses were conducted on pyrite extracted from saddle reef (QV₂) and quartz -carbonate (QV₃), veins using the conventional SO₂ extraction facility and a Finigan Mat 251 & 250 respectively ; gas source mass spectrometers and Elemental Analyser coupled with Isotope Ratio Mass Spectrometry .

The international reference material NBS123 standard was used to calibrate the in-house SO₂ bottle standard. The correction and standard deviation was + 0.02 permil for each analyses.

All the δ^{34} values are reported in per mil relative to Canyon Diablo Troilite (CDT).

The samples selected for isotopic analysis were crushed and the various sulphide types (pyrite and arsenopyrite) were separated by hand-picking. The sulphide aggregates from each sample were then ground into a fine powder using an agate and pestle and prepared for gas extraction line by mixing ± 9 mg of sample material with ± 200 mg of copper-oxide. The samples were then placed into a gas extraction line , evacuated and heated to 1000 °C for 30 minutes to allow for complete degassing of the sample. /

The SO₂ extraction process involved a number of steps :

- 1.- Any H₂O in the gas fraction was trapped using the propanol cooled to - 60 °C by adding liquid nitrogen ;
- 2.- SO₂ and CO₂ were simultaneously froze in using a liquid nitrogen trap;
- 3.- The gases were separated using an ethanol trap, cooled to -113 °C by the addition of liquid nitrogen. At this temperature , CO₂ is liberated and pumped away, while SO₂ remains frozen in
- 4.- SO₂ is transferred to the collection tube using a liquid nitrogen trap where it is sealed by melting of the neck of the tube.

The sulphur ratios of the extracted gases were determined via the mass spectrometer at the Council for Geoscience in Pretoria, South Africa.

Combined carbon and oxygen isotopes on carbonate minerals were done at the Schonland Research Center, Wits University. 1 gram CaCO_3 sample is put in an ampoule followed by 2ml of orthophosphoric acid which is introduced in the side part of the ampoule, and pumped down using high vacuum pump. The ampoule is attached to the vacuum system. The produced CO_2 is introduced to the mass spectrometry for the measurement of $^{13}\text{C}/^{12}\text{C}$.

The ratio $^{13}\text{C}/^{12}\text{C}$ is measured on CO_2 derived by oxidation of organic carbon. Oxidising organic material has been accomplished by passing oxygen gas over a few milligrams of the material held in a quartz tube and heating it from the outside until it ignites. The stream of oxygen is passed through a trap held at the temperature of solid carbon dioxide (-80°C) to trap the water vapour and then through a liquid nitrogen trap to retain the CO_2 . It is then heated to some 1000°C in a furnace and allowed to cool slowly. The tube is attached to a vacuum system and the seal broken. The CO_2 is then trapped in the usual way and transferred to an ampoule.

Oxygen isotope values are reported per mil respectively with respect to Standard Mean Ocean water (SMOW) and Pee Dee Belemnite (PDB). Carbon isotope values being reported per mil relative to PDB.

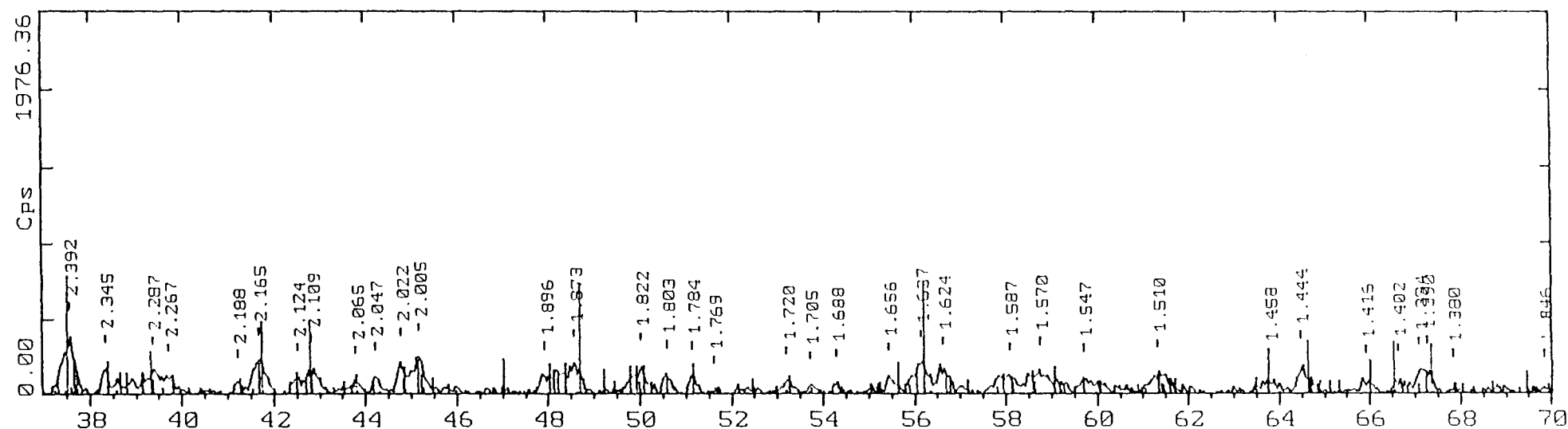
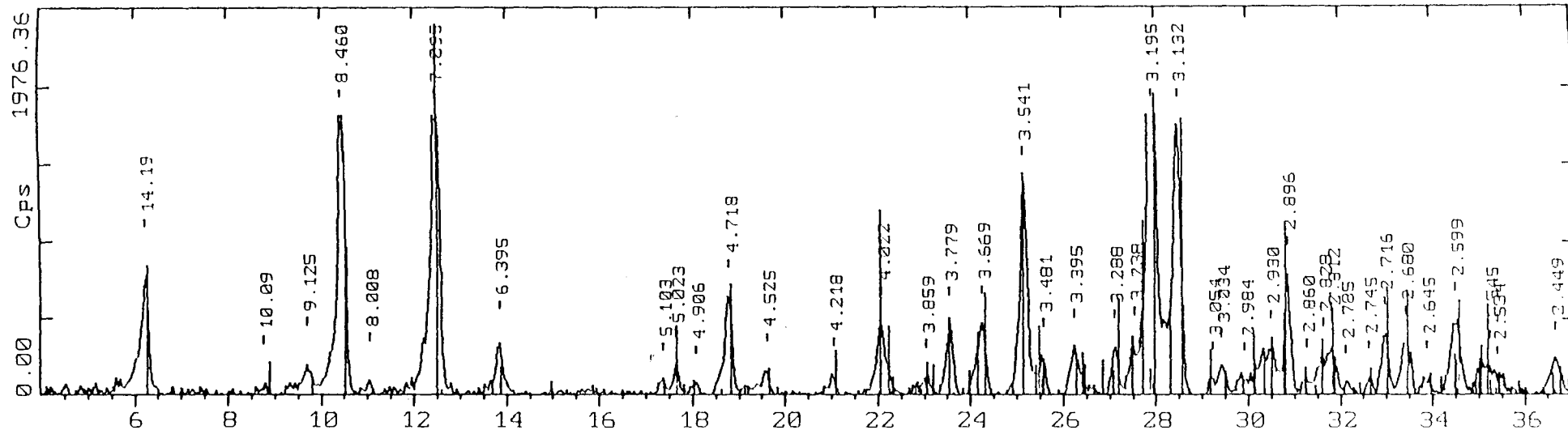
9*.- A *scanning electron microscopy analysis (SEM)* of 9 samples of which 3 native golds, 2 pyrites, 3 arsenopyrites and 1 double polished thin section (fluid inclusion) have been conducted in order to determine ore mineralogy and microcomposition, grain morphology and texture.

10*.- *Ion microprobe analysis* has been performed on native gold, pyrite and arsenopyrite for microcomposition analysis and compositional zoning within single crystals.

9 single crystal samples and 6 polished thin section from quartz-vein and wall-rock alteration zones of gold deposits, have been selected and analysed for all elements.

In total 44 samples have been analysed at the Rand Afrikaans University (RAU), South Africa.

>>>>>>>



C:\DIFFRAC\USERDATA\KW1.RAW KW1 (CT: 0.6s, SS:0.040dg, WL: 1.5406Ao)

29-0701 I (Mg,Fe)6(Si,Al)4O10(OH)8 Clinocllore-1M11b, ferroan (WL: 1.5406Ao)

9-0438 D Ca2(Al,Fe)Al2Si3O12(OH) Epidote (WL: 1.5406Ao)

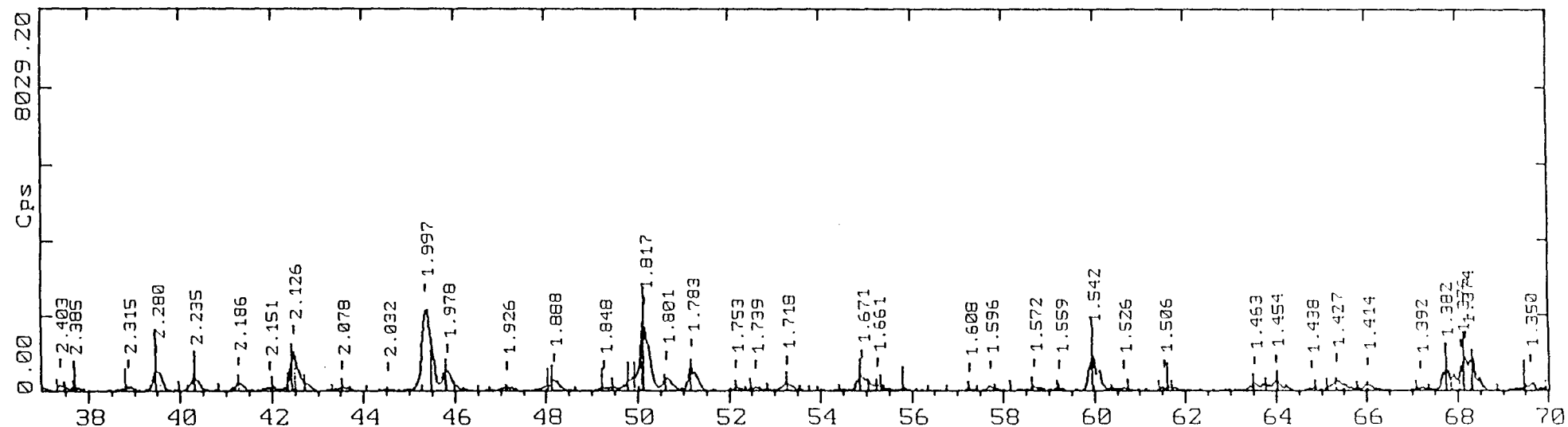
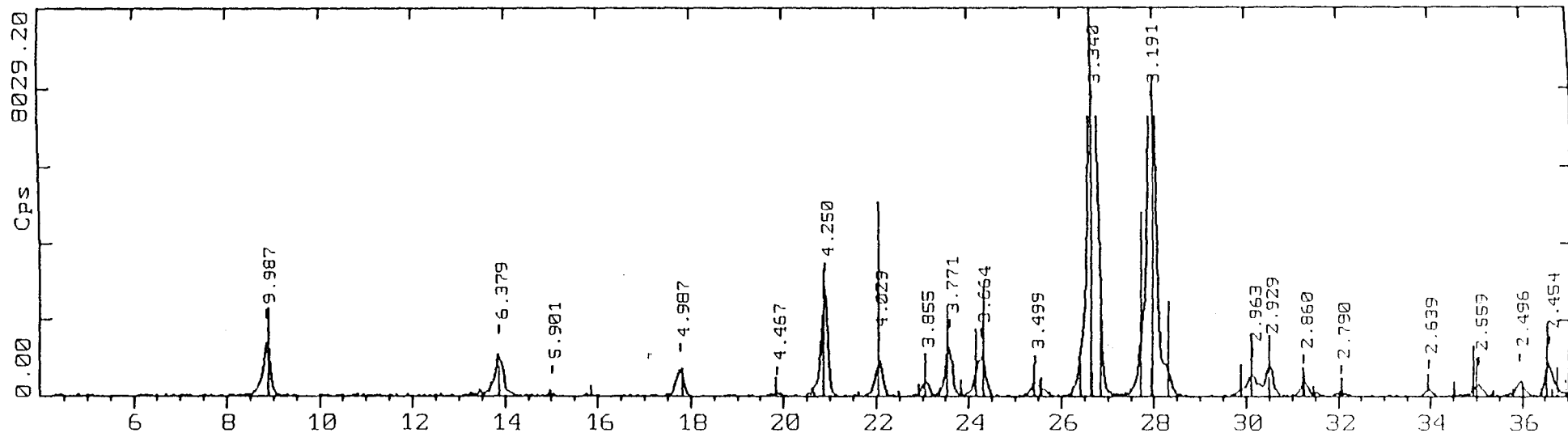
45-1371 I Ca2(Mg,Fe+Z)4Al(Si7Al)O22(OH,F)2 Magnesiohornblende, ferroan (WL: 1.5406Ao)

20-0554 D NaAlSi3O8 Albite, ordered (WL: 1.5406Ao)

6-0263 I KAl2(Si3Al)O10(OH,F)2 Muscovite-2M1 (WL: 1.5406Ao)

10-0479 D KAlSi3O8 Microcline, inter (WL: 1.5406Ao)

2-0604 D (Ca,Mn)CO3 Manganocalcite (WL: 1.5406Ao)

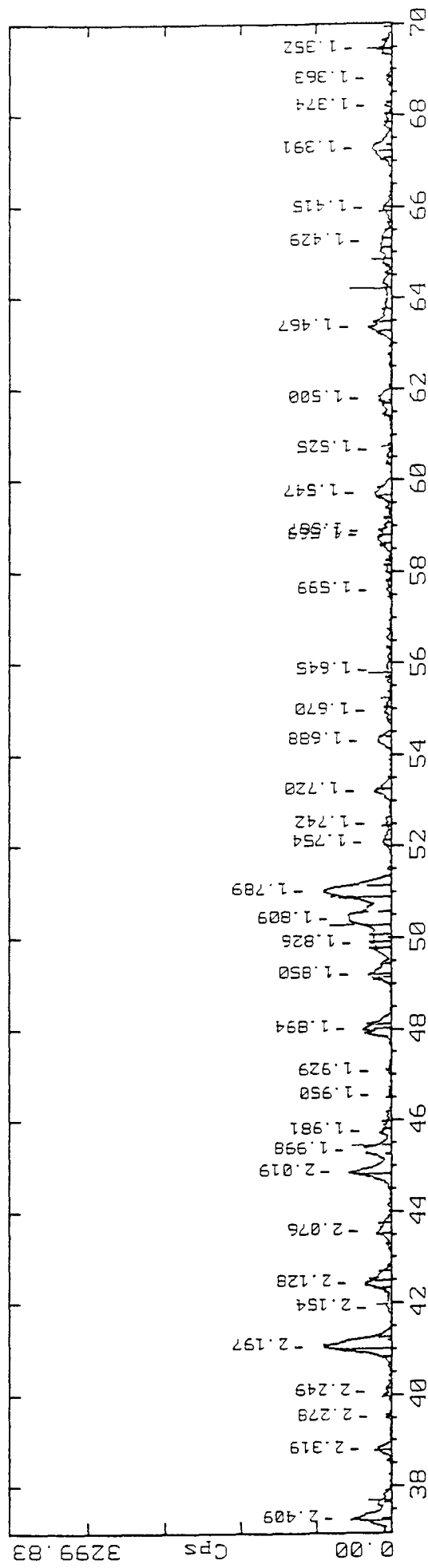
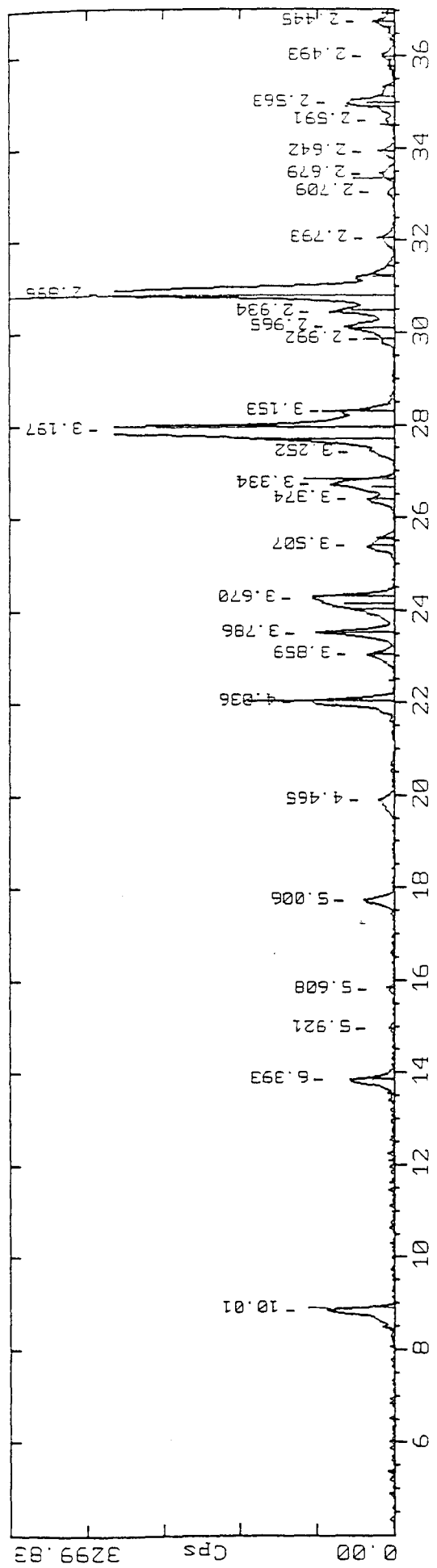


C:\DIFFRAC\USERDATA\RW44.RAW RW44 (CT: 0.6s, SS:0.040dg, WL: 1.5406Ao)

46-1045 * SiO2 Quartz, syn (WL: 1.5406Ao)

20-0554 D NaAlSi3O8 Albite, ordered (WL: 1.5406Ao)

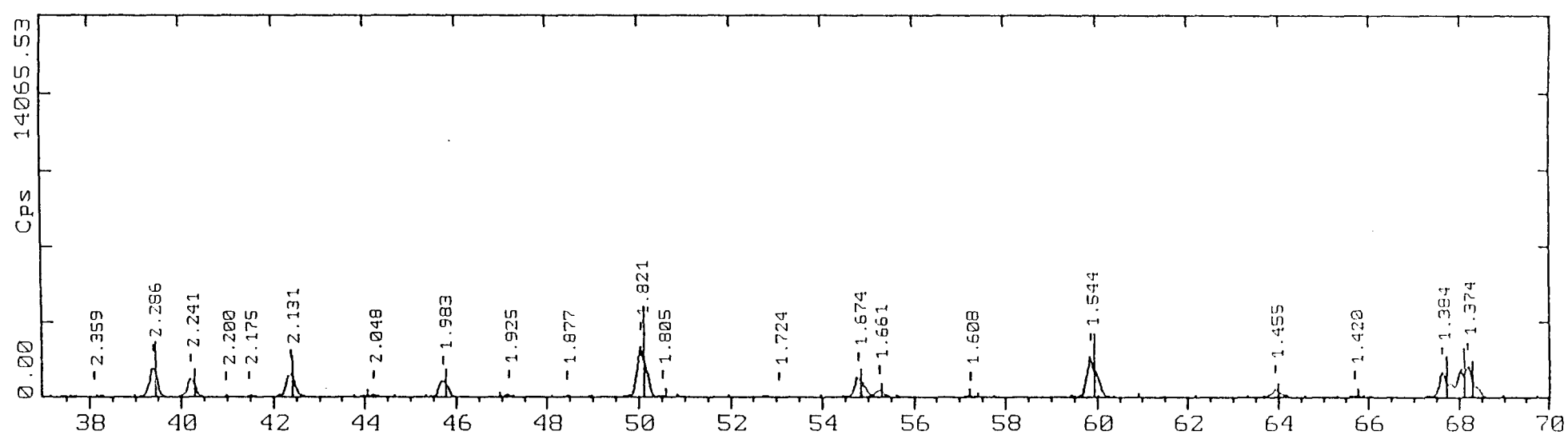
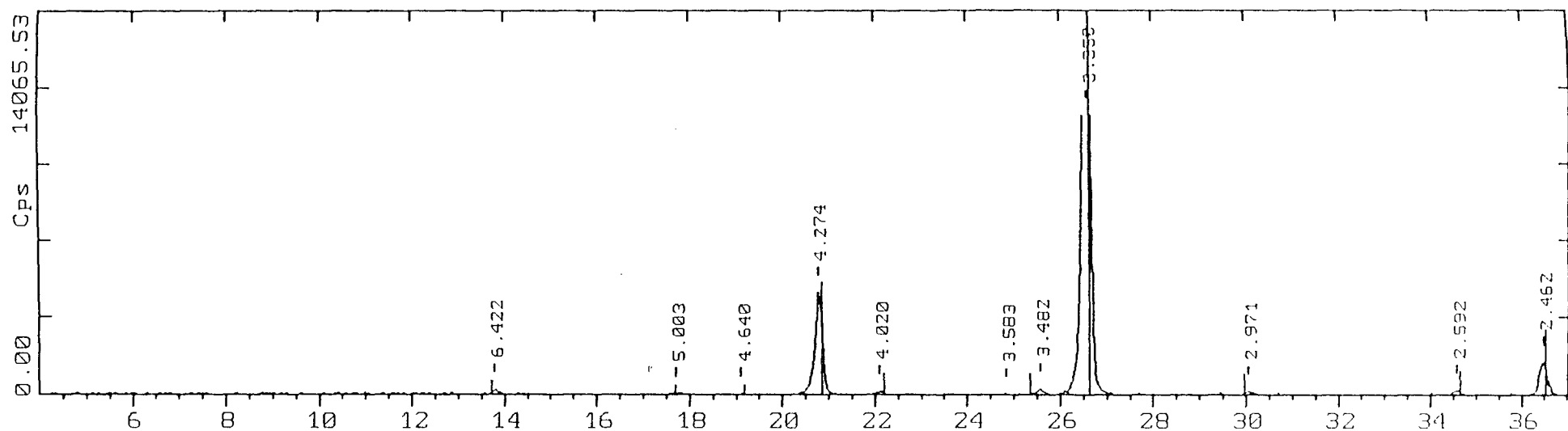
6-0263 I KAl2(Si3Al)O10(OH,F)2 Muscovite-2M1 (WL: 1.5406Ao)



C:\DIFFRAC\USERDATA\KW-617.RAW KW-617 (CT: 0.6s, SS: 0.040dg, WL: 1.5406Ao)
 20-05554 D NaAlSi3O8 Albite, ordered (WL: 1.5406Ao)
 34-0517 D Ca(Al2Fe)(CO3)2 Polymite, ferroan (WL: 1.5406Ao)
 6-02551 (KAl2(Fe13Al)2(OH)F12) Pseudobrookite-2H (WL: 1.5406Ao)

2-Theta - Scale

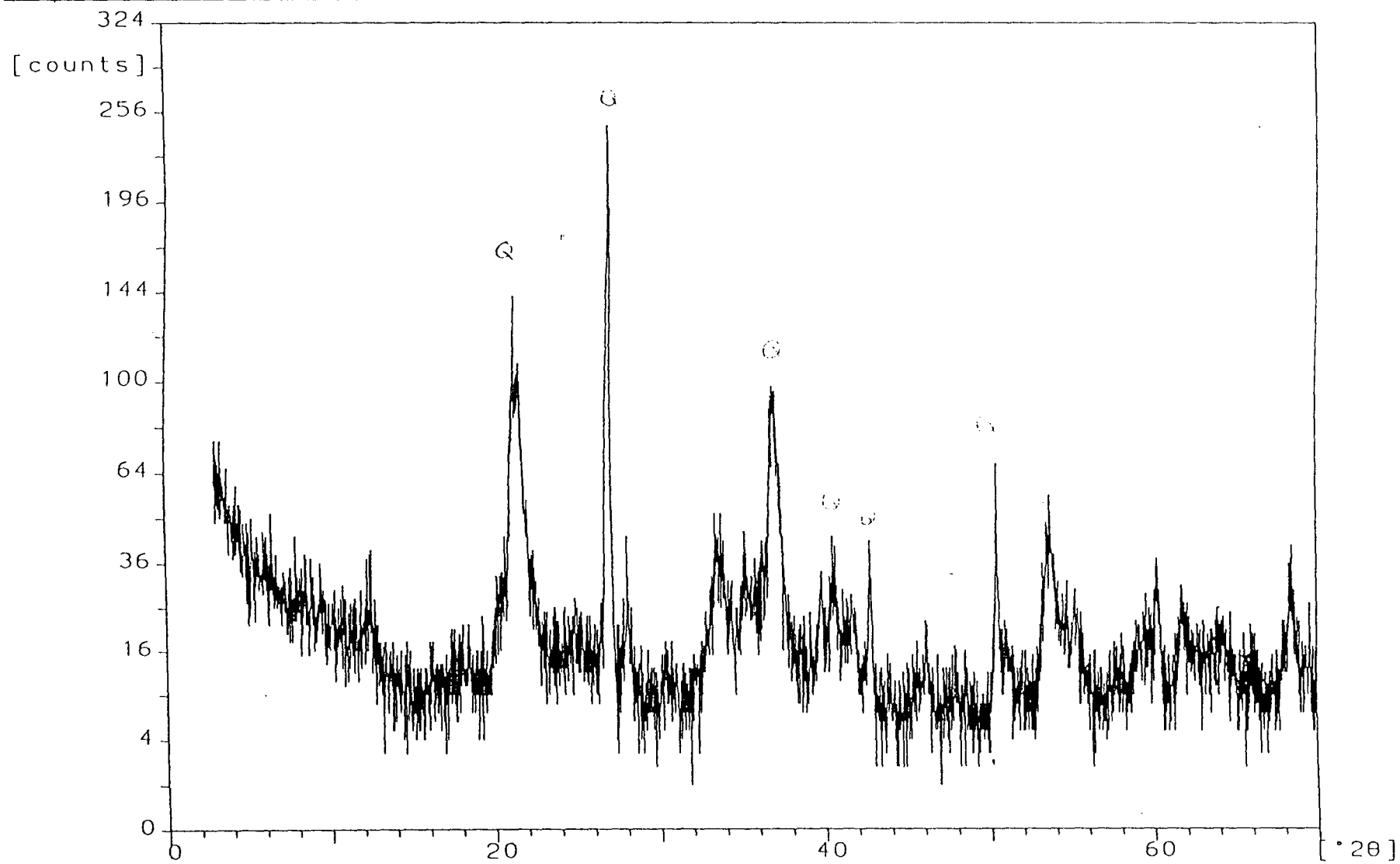
Anglo American Research Laboratories Report 1-10-75



C:\DIFFRAC\USERDATA\KW-705.RAW KW-705 (CT: 0.6s, SS:0.040dg, WL: 1.5406Ao)
 46-1045 * SiO2 Quartz, syn (WL: 1.5406Ao)
 19-1372 D (Na,Ca)2.9(Mg,Fe)2.9(Al,Fe,Ti)6B3Si6O27 Dravite, ferrian (WL: 1.5406Ao)

Sample identification: kw87d

24-Jan-1997 14:49



KW87D_RD

Results file : AMBROSE

Group number : 1

Job label : AMBROSE

System parameters: 30.00 kV TILT= .00 ELEV.= 40.00 AZIM.= .00 COSINE=1.000

Correction procedure: ZAF-4

Element reference file : '30'

Processing option: All elmts analysed

'<' means < .1 sigma

Any result marked with '<' will be excluded from individual totals

but will be included for summary calculations.

Results summarised as: Element atom %

Point	Label	S	K	FeK	AsL	AgL	AuL	HgL	CdL	PdL	CuK	Total
1:	AU	13.0	52.5	13.4	21.1	6.2	<*. * <-6.5 <*. * <- .3 <					100.00
2:	AU	.3	.0	.1	1.2	98.2	-1.1 <- .1 <-1.5 <	.2				100.00
3:	AU/2	.6	.0	.2	.8	98.4	-1.0 <- .1 <-2.8 <	.1				100.00
4:	AU/2ND GRAIN2ND POINT	.7	.0	.0	1.4	97.5	-.9 <- .1 <-2.4 <	.2				100.00
5:	PYRITE	64.9	33.8	1.05	-.01 <	.00	.02	.02	.2	-.01 <		100.00
6:	PYRITE	65.0	34.7	.09	-.02 <	.01	.00	-.00 <	.2	-.01 <		100.00
7:	PYRITE	65.7	34.2	.12	-.04 <	.00 <	.01	-.03 <	.0	.00 <		100.00
8:	AU	.6	-.2 <	.2	1.1	97.5	-.9 <- .2	.3	.1			100.00
9:	AU	.1	.0	.2	.7	98.9	-.9 <- .0	-.6 <	.0			100.00
10:	AU/2ND DISC	.2	.0 <	.1	.1	99.0	-1.1 <- .3	-1.9 <	.3			100.00
11:	AU/2ND DISC	1.0	.2	.2	.4	97.5	-.9 <- .3	.2	.2			100.00
12:	AU/2ND DISC	1.3	.2	.1	.3	96.5	-.8 <- .0 <- 1.3	.2				100.00
13:	AU/2ND DISC	1.1	.0	.2	.1	98.4	-.9 <- .1 <-4.9 <	.1				100.00
14:	AU/2ND DISC	65.0	34.6	.41	.02	-.03 <- .02 <	.02	.0 <	.00			100.00
15:	CIRCLE3	66.4	33.4	.06	.02	.02	-.01 <- .03	-.2 <	.02			100.00
16:	CIRCLE5	65.8	33.5	.22	-.03 <- .02 <	.01	.00 <	.4	.01			100.00

Mean= 25.7 16.1 1.0 1.7 54.7 -1.3 -.4 -6.6 .1

RMSD= 30.9 18.7 3.2 5.0 49.1 2.9 1.6 22.5 .13

Min = .101-.168 .043-.043-.***-.***-.***-.***-.324

Max = 66.4 52.5 13.4 21.1 99.0 .020 .325 1.31 .260

Total of mean concentrations = 91.12

Mean of individual totals = 100.00 +/- .00; Range: 100.00 to 100.00

Directory of DMO

R1.TI 264192 16/10/97 11:38

R1.TIF 264192 16/10/97 10:49

AMEL.CSV 1945 6/ 5/98 11:19

AMAT.CSV 2594 6/ 5/98 11:19

4 File(s) 196608 bytes free

Results file : AMBROSE
Group number : 1
Job label : AMBROSE

System parameters: 30.00 kV TILT= .00 ELEV.= 40.00 AZIM.= .00 COSINE=1.000

Correction procedure: ZAF-4
Element reference file : '30'
Processing option: All elmts analysed

'<' means < .1 sigma
Any result marked with '<' will be excluded from individual totals
but will be included for summary calculations.

Results summarised as: Element weight %

Point	S	K	FeK	AsL	AgL	AuL	HgL	CdL	PdL	CuK	Total
1:	.01	.06	.02	.05	-.03<	-.1<	-.02<	-.2<	-.00<		.14
2:	.05	.01	.03	.6	83.7	-.9<	-.0<	-.7<	.05		84.39
3:	.08	.00	.08	.4	91.2	-.9<	-.0<	-1.4<	.02		91.75
4:	.10	.01	.02	.8	93.1	-.8<	.0	-1.2<	.05		94.10
5:	51.1	46.3	1.93	-.0<	.0	.1	.0	.5	-.02<		100.03
6:	50.8	47.2	.17	-.0<	.1	.0	-.0<	.5	-.02<		98.77
7:	51.4	46.6	.22	-.1<	.0<	.0	-.1<	.1	.00<		98.37
8:	.09	-.04<	.06	.5	85.8	-.8<	.1	.1	.03		86.70
9:	.02	.01	.07	.3	90.9	-.8<	.0	-.3<	.01		91.32
10:	.02	.00<	.04	.1	81.2	-.9<	.1	-.8<	.07		81.56
11:	.15	.05	.08	.2	91.0	-.8<	.2	.1	.05		91.86
12:	.13	.04	.02	.1	60.4	-.5<	-.0<	.4	.05		61.21
13:	.13	.01	.04	.0	70.9	-.7<	-.0<	-1.9<	.03		71.12
14:	50.0	46.3	.74	.1	-.1<	-.1<	.1	.1<	.00		97.25
15:	53.0	46.5	.11	.0	.1	-.1<	.1	-.6<	.04		99.85
16:	52.4	46.5	.41	-.1<	-.1<	.0	.0<	1.1	.01		100.40

Mean= 19.3 17.5 .3 .2 46.8 -.5 .03 -.3 .02
RMSD= 24.9 22.5 .5 .2 42.0-.4 .07 .8 .03
Min = .009-.042 .016-.113-.142-.937-.085-***-.019
Max = 53.0 47.2 1.93 .756 93.1 .101 .173 1.10 .069

Total of mean concentrations = 83.34
Mean of individual totals = 84.30 +/- 24.22; Range: .14 to 100.40

 Initial beam current = 12.38 nA

 Analysis number 1 18/ 3/1998 11:53:45
 Analysis point : ARSENOPYRITE

WD ANALYSIS

	Pk.posn	Peak	Lo.bg	Hi.bg	Pk-Bgnd	Intens. ratio
S	614.386	3002	12.00	-	2990	2.794784
Fe	480.599	2665	12.80	13.20	2652	1.158935
As	376.774	231.9	-	27.40	204.5	.036065
Ag	475.204	6.000	4.600	5.400	.9939	.003423
Au	316.559	21.30	-	28.20	-6.901	-.005798
Hg	307.893	22.30	24.00	-	-1.700	-.001644
Cd	452.555	4.700	-	5.800	-1.100	-.000595
Pd	499.579	3.500	5.400	5.400	-1.900	-.000963
Cu	382.234	16.90	18.20	18.00	-1.209	-.000205

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Apparent concentrations

Elmt	ED/WD	App Conc (%)	Error (wt %)
S :KA	WD	55.029	.319
Fe:KA	WD	39.751	.245
As:LA	WD	1.659	.043
Ag:LA	WD	.068	.072 <2 sigma
Au:LA	WD	-.464	.187 <2 sigma
Hg:LA	WD	-.142	.221 <2 sigma
Cd:LA	WD	-.059	.069 <2 sigma
Pd:LA	WD	-.096	.048 <2 sigma
Cu:KA	WD	-.021	.032 <2 sigma

ZAF Calculations

i 3 iterations

30.00 kV

Spectrum: ARSENOPYRITE WALEMBA

All elmts analysed

ELMT	ZAF	%ELMT	ST.DEV	ATOM.%
S KA 2	1.346	40.894	.237	61.585
FeKA 2	.931	42.713	.263	36.925
AsLA 1	.732	2.266	.059	1.461
AgLA 2	1.050	.065	.069 <1 sd	.029
AuLA 2	.740	.000	.000 <1 sd, below	.0 sigma det. limit (.003 wt%).
HgLA 1	.771	.000	.000 <1 sd, below	.0 sigma det. limit (.003 wt%).
CdLA 1	.629	.000	.000 <1 sd, below	.0 sigma det. limit (.001 wt%).
PdLA 1	.572	.000	.000 <1 sd, below	.0 sigma det. limit (.001 wt%).
CuKA 1	.799	.000	.000 <1 sd, below	.0 sigma det. limit (.000 wt%).
TOTAL		85.939		100

Single point analysis. label : WALEMBA 18/ 3/1998 14:17:20
Element list filename : WDAS

Initial beam current = 12.67 nA

Analysis number 1 18/ 3/1998 14:17:31
Analysis point : PYRITE

WD ANALYSIS

	Pk.posn	Peak	Lo.bg	Hi.bg	Pk-Bgnd	Intens. ratio
S	614.364	3093	12.00	-	3081	1.871316
Fe	480.595	2772	15.20	12.40	2758	.436690
As	376.774	41.50	-	27.40	14.10	.002487
Ag	475.204	3.800	3.600	3.000	.5046	.001738
Au	316.559	23.70	-	25.20	-1.500	-.001260
Hg	307.893	22.90	24.40	-	-1.500	-.001451
Cd	452.555	5.600	-	5.600	.0000	.000000
Pd	499.579	4.300	3.800	5.400	-.3466	-.000176
Cu	382.234	16.30	19.60	17.40	-2.303	-.000391

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Apparent concentrations

Elmt	ED/WD	App Conc (%)	Error (wt %)	
S :KA	WD	61.585	.352	
Fe:KA	WD	43.669	.263	
As:LA	WD	.114	.025	
Ag:LA	WD	.035	.058	<2 sigma
Au:LA	WD	-.101	.133	<2 sigma
Hg:LA	WD	-.125	.223	<2 sigma
Cd:LA	WD	.000	.070	<2 sigma
Pd:LA	WD	-.018	.048	<2 sigma
Cu:KA	WD	-.039	.032	<2 sigma

ZAF Calculations

1 2 iterations:

30.00 kV

Spectrum: PYRITE

WALEMBA

All elmts analysed

ELMT	ZAF	%ELMT	ST.DEV	ATOM.%
S KA 1	1.300	47.364	.270	62.563
FeKA 1	.887	49.238	.297	37.334
AsLA 1	.718	.139	.035	.090
AgLA 2	1.048	.033	.055 <1 sd	.013
AuLA 2	.736	.000	.000 <1 sd, below	.0 sigma det. limit (.002 wt%).
HgLA 1	.767	.000	.000 <1 sd, below	.0 sigma det. limit (.003 wt%).
CdLA 1	.628	.000	.112 <1 sd, below	.0 sigma det. limit (.001 wt%).
PdLA 1	.571	.000	.000 <1 sd, below	.0 sigma det. limit (.001 wt%).
CuKA 1	.794	.000	.000 <1 sd, below	.0 sigma det. limit (.000 wt%).
TOTAL		96.794		100

Initial beam current = 9.64 nA

Analysis number 1 6/ 5/1998 9:49:13
Analysis point : AU

WD ANALYSIS

	Pk.posn	Peak	Lo.bg	Hi.bg	Pk-Bgnd	Intens. ratio
S	614.441	9.500	7.400	-	2.100	.000935
Fe	480.636	48.71	52.21	41.00	1.992	.000114
As	376.795	78.81	-	73.81	5.002	.000183
Ag	475.112	18.80	10.40	7.800	9.703	.004688
Au	316.617	6059	-	185.5	5874	4.157388
Hg	307.853	156.3	212.1	-	-55.85	-.011650
Cd	452.490	13.70	-	14.40	-.7000	-.000229
Pd	499.486	11.50	12.60	12.40	-.9958	-.003397
Cu	382.255	113.5	105.6	96.82	11.91	.000617

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Apparent concentrations

Elmt	ED/WD	App Conc (%)	Error (wt %)
S :KA	WD	.031	.023 <2 sigma
Fe:KA	WD	.011	.018 <2 sigma
As:LA	WD	.018	.017 <2 sigma
Ag:LA	WD	.364	.063
Au:LA	WD	93.250	.400
Hg:LA	WD	-1.004	.137 <2 sigma
Cd:LA	WD	-.023	.067 <2 sigma
Pd:LA	WD	-.340	.329 <2 sigma
Cu:KA	WD	.062	.024

ZAF Calculations

i 2 iterations

30.00 kV

Spectrum: AU

AMEROSE

All elmts analysed

ELMT	ZAF	%ELMT	ST.DEV	ATOM. %
S KA 1	.679	.045	.034 <2 sd	.327
FeKA 1	1.046	.011	.017 <1 sd	.045
AsLA 2	.608	.030	.029 <2 sd	.093
AgLA 1	.654	.556	.096	1.190
AuLA 1	1.114	83.698	.359	98.161
HgLA 1	1.076	.000	.000 <1 sd, below	.0 sigma det. limit (.001 wt%).
CdLA 1	.566	.000	.000 <1 sd, below	.0 sigma det. limit (.001 wt%).
PdLA 1	.491	.000	.000 <1 sd, below	.0 sigma det. limit (.011 wt%).
CuKA 1	1.211	.051	.020 <3 sd	.135
TOTAL		84.391		100

Name	Whose	SampleWt	SpikeWt	type	Method
16:E17:KW618F	FJK	0.210360	0.108580	4	SrSmall

First Frac 88/86 = 8.375000 E

Spike used is Strong 82% 01-Nov-1995

Conc. of 86 = 0.372752

Total Concentration Factor = 10.341400

Collector mass spacings -2 -1 0 1 2 EHT = 7.999430

Peak jumping cycle and extra masses

	83.5	84.0	85.0	86.0	87.0	88.0	82.0	83.0	89.0	90.0
L2	0	1	1	1	1	0	0	0	0	0
L1	0	0	1	1	1	1	0	0	0	0
Ar	0	1	1	1	1	1	1	0	0	0
H1	0	0	1	1	1	1	1	0	0	0
H2	0	0	0	1	1	1	1	0	0	0

Centring done On

Ar Ar H1 Ar Ar L1

Collector gain factors L2,L1,Ar,H1,H2 1.00173 1.00304 1.00000 0.99961 0.99298

SD rejection 2.0

Running Means from Block - 3 to Block - 12 at Centre = 2.637 Side = 0.000 Temperature = 1556

Combined data on 116 of 150 87/ 86

87/ 86 = 0.7342978 Standard Deviation = 0.0001207 Standard Error = 0.0000112 SEZ = 0.00153

Combined data on 113 of 150 84/ 86

84/ 86 = 1.0233278 Standard Deviation = 0.0002852 Standard Error = 0.0000268 SEZ = 0.00262

Combined data on 113 of 150 88/ 86

88/ 86 = 8.2209082 Standard Deviation = 0.0000455 Standard Error = 0.0000043 SEZ = 0.00005

Combined data on 82 of 150 85/ 86

85/ 86 = 0.0000242 Standard Deviation = 0.0000343 Standard Error = 0.0000038 SEZ = 15.65718

Combined data on 114 of 150

Conc. of 86 = 5.0535 Standard Deviation = 0.0016 Standard Error = 0.0001 SEZ = 0.0029

Combined data on 114 of 150

Total Conc. = 52.3946 Standard Deviation = 0.0164 Standard Error = 0.0015 SEZ = 0.0029

Combined data on 114 of 150

Factor Conc. = 52.2692 Standard Deviation = 0.0162 Standard Error = 0.0015 SEZ = 0.0029

Name	Whose	SampleWt	SpikeWt	type	Method
16:E16:KW44M Mica	FJK	0.119010	0.317960	1	RbSmall

Spike used is Rb Standard 15-Oct-1996 Conc. of 87 = 9.703600

Total Concentration Factor = 3.533000

Collector mass spacings -2 -1 0 1 2 EHT = 8.000000

Peak jumping cycle and extra masses

	84.5	85.0	87.0	83.0	84.0	86.0	88.0	89.0
L2	0	0	0	1	0	1	0	0
L1	0	0	0	1	0	1	0	0
Ar	1	1	1	1	0	1	0	0
H1	0	0	0	1	0	1	0	0
H2	0	0	0	1	0	1	0	0

Centring done On

Ar Ar Ar

Collector gain factors L2,L1,Ar,H1,H2 1.00173 1.00304 1.00000 0.99961 0.99298

SD rejection by user on Selected Blocks

1	2	3	4	5	6	7

Combined data on 80 of 120

85/ 87 = 1.730146 SD = 0.249402 2 SE = 0.055768 2 SEZ = 3.22331

Combined data on 120 of 120

87/ 85 = 0.383289 SD = 0.000001 2 SE = 0.000000 2 SEZ = 0.00005

Combined data on 21 of 120

Conc. of 87 = 330.1192 SD = 5.0509 2 SE = 2.2044 2 SEZ = 0.66776

Combined data on 21 of 120

Total Conc. = 1171.6068 SD = 17.9259 2 SE = 7.8235 2 SEZ = 0.66776