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Major and Minor Elements and their Relationship to Gold Mineralization, Beaconsfield Mine, Tasmania, Australia

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Abstract

Major and minor elements in bulk rocks are due to occurrence of mostly quartz, ankerite, illite and minor pyrite. Silicification forms megaquartz by dissolution and replacement of carbonates. Illite is unaffected during ankerite formation. Gold mineralization is unrelated to quartz, illite and pyrite contents. Gold mineralization is related to ankerite formation because gold content increases with increasing ankerite values.

Gold mineralization occurred in a reducing burial environment. Fe in solution was high due to alteration of ultramafics and leaching of clay minerals during silicification. During silicification fluids were acidic and as these solutions progressively dissolved and replaced carbonate, the alkalinity of fluids increased and formed ankerite. In alkaline conditions, gold precipitated along with ankerite.

Keywords: *Elemental Composition, Gold Mineralization, Tasmania, Australia*

1. Introduction

Major and minor elements in bulk rocks are valuable to understand the geochemical signatures of major minerals and mineral forming fluids. The relation between major and minor elements to Au is important to study the formation of minerals during gold mineralization. Understanding fluid composition during Au mineralization is critical in evaluating geological conditions required for Au mineralization.

2. Regional Geology

Beaconsfield gold mine is located in northern Tasmania, and geologically occurs within the Beconsfield Block which consists of rocks ranging from Cambrian to Tertiary in age (Fig.1). To the west the Beaconsfield Block is bounded by the Badger Head Block and the River Tamar provides the eastern boundary (Elliott *et al.*, 1993; Fig.1).

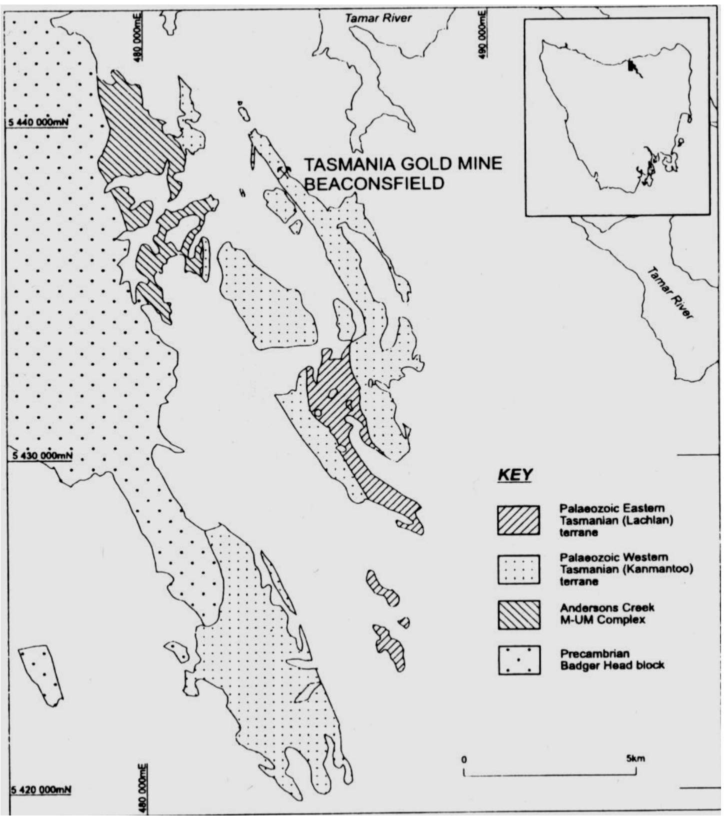


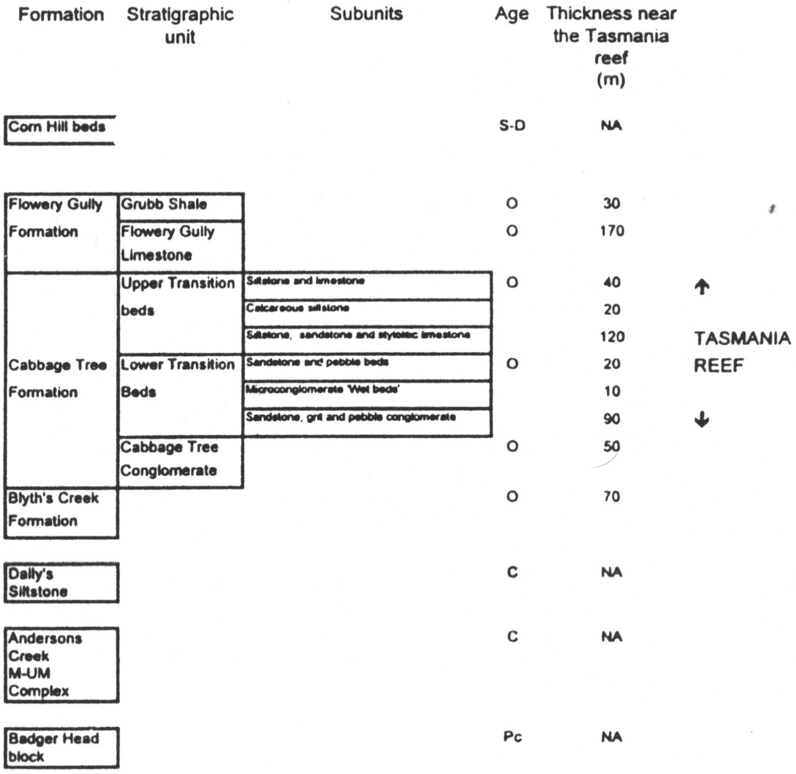
Figure 1 - Regional geological map of the Beaconsfield gold mine (after Hills, 1998).

Gold mineralization occurs within the Tasmania Reef. The Tasmania Reef itself is a steeply dipping fault-hosted quartz-ankerite (carbonate) which cross-cuts local stratigraphy (Hills, 1988). The Tasmania Reef is a fissure reef, with an overall length of about 395m and width of about 2cm to 8m, averaging 2.5m (McClenagham, 1994; Russell, 1995).

Beaconsfield gold mine occurs within the Lower to Middle Paleozoic sequence of the Beaconsfield Block (Elliott et al., 1993). In the Beaconsfield area, the Badger Head Block (Precambrian) is overlain by the fault-bounded Andersons Creek Mafic-Ultramafic Complex (Berry and Crawford, 1988) and Dally's marine siltstone of Cambrian age (Hills, 1998; Fig. 2). The Cambrian Sequence is followed unconformably by the Ordovician marine tidal flat sequences, consisting of Blyth's Creek Formation, Cabbage Tree Formation and Flowery Gully Formation (Fig. 2). The Ordovician Cabbage Tree Formation, consisting of Lower and Upper Transition Beds host Tasmania Reef. The term "Transition Beds" was coined by the early miners to describe the gradational sequence from conglomerate (the Cabbage Tree Conglomerate) to limestone (Flowery Gully Limestone) hosting the Tasmania Reef. The Lower Transition Beds, which is divided into three units with a true thickness of 120m, is predominantly a sandstone although conglomeratic facies persist (Wet Beds member) to varying degrees throughout. The Upper Transition Beds is also divided into three units with a total thickness of 180m. A shallow marine depositional environment is indicated by a variety of clastic and limey facies and the presence of shallow marine fossils. The lower member of the Upper Transition Beds, with a true thickness of around 120m, is siltstone, sandstone and stylolitic limestone member (Fig. 2). This unit is overlain by about 20m thick fine-grained calcareous siltstone member. The top of the Upper Transition Beds is defined by the siltstone and limestone unit, with a total thickness of 40m (Fig. 2). The sequence then grades conformably to the Grubb Shale (Hills, 1998). At Flowery Gully, 8km South of Beaconsfield, the Late Silurian or Devonian Corn Hill Beds (Hills, 1982, Fig. 2) overlie and is imbricated within thrust slices of the Ordovician succession.

Four structural events are recorded within the Ordovician rocks (Hills, 1998). The Ordovician rocks and the underlying Cambrian sediments and ultramafics were emplaced by west directed thrusting against the Badger Head Block. The lode-style mineralization coincided with a second phase of compressional deformation related to the Devonian Tabberabberan Orogeny (Russell, 1995; Hills, 1998). It has been suggested that a series of gently west-dipping thrust wedges have controlled the gold mineralization in the area (Keele *et al.*, 1994).

There is in excess of 1 million ounces of gold within the quartz-carbonate Tasmanian Reef (Hills, 1998). The Tasmania Reef at Beaconsfield is one of the most important gold mines in Tasmania. Ankerite forms later than calcite and dolomite as ankerite occurs in veins, fillings in breccia and pods in the Ordovician sequences. Hence, the ankerite formed during the Devonian Orogenic period in a burial environment (Russell, 1995; Hills, 1998).



Formation	Stratigraphic unit	Subunits	Age	Thickness near the Tasmania reef (m)	
Corn Hill beds			S-D	NA	
Flowery Gully Formation	Grubb Shale		O	30	
	Flowery Gully Limestone		O	170	
Cabbage Tree Formation	Upper Transition beds	Siltstone and limestone	O	40	↑
		Calcareous siltstone		20	
		Siltstone, sandstone and stylolitic limestone		120	TASMANIA
	Lower Transition Beds	Sandstone and pebble beds	O	20	REEF
		Microconglomerate 'Wet beds'		10	
		Sandstone, grit and pebble conglomerate		90	↓
	Cabbage Tree Conglomerate		O	50	
Blyth's Creek Formation			O	70	
Daily's Siltstone			C	NA	
Andersons Creek M-UM Complex			C	NA	
Badger Head block			Pc	NA	

Figure 2 - Local stratigraphic succession (Lower to Middle Palaeozoic) in the Beaconsfield area (after Hills, 1998).

3. Analytical methods

Twenty five bulk samples from three different drill holes (B23, B27 and C2) were powdered by a vibrating ring mill with a tungsten carbide head. The powders were used in the preparation of fusion discs, which were analysed for SiO_2, Al_2O_3, CaO, MgO, K_2O, Fe_2O_3, MnO, total S and P_2O_5 by Phillips PW 1480 automated X-ray fluorescence spectrometer, at the School of Earth Sciences, University of Tasmania, Australia. The level of precision in analysis was ± 0.12 for SiO_2; ± 0.004 for CaO and P_2O_5; ±0.02 for Al_2O_3 and Na_2O; ± 0.01 for Fe_2O_3 and K_2O and ± 0.005 for MgO. Tasman Granite (TASGRAN, 1and 2) standards were used to monitor the precision. The data were analysed for correlation and factor analysis using the Statview programme.

4. Mineralogy

In Beaconsfield gold mine, carbonate minerals such as magnesian ankerite and calcian dolomites, along with illite and silicate minerals such as megaquartz are the most important minerals. Ankerite is the major carbonate mineral in the sample studied and is formed from dissolution of precursor limestone and dolomite during silicification in alkaline conditions. Megaquartz which is the major silicate mineral in most samples was formed by leaching of clay minerals and dissolution of carbonates.

5. Data structure

Major elements (Fig. 3) are SiO_2 (46% to 97%; mean 80.7%), Al_2O_3 (0.5% to 13.7%; mean 4.1%), CaO (0.1 to 15%; mean 3.5%) and MgO (0.2% to 8%; mean 1.6%) due to occurrence of quartz, clay and carbonate minerals in most bulk rocks. The distribution of Al_2O_3 (0.5 to 13.7%; mean 4.1%), K_2O (0.2% to 4.6%; mean 1.4%) and Na_2O (0.03% to 2.73%; mean 0.5%) indicate that clay minerals mostly contain Al_2O_3, K_2O and minor Na_2O (Fig. 4). The concentrations of Fe_2O_3 (0.5% to 6.7%; mean 2.8%) are much higher than those of MnO (0.01% to 0.3%; mean 0.09%), total S (0.01% to 0.46%; mean 0.1%) and P_2O_5 (0.01% to 0.12%; mean 0.06%; Fig. 5) because these elements are not interdependent and pyrite is minor. As explained later, Fe_2O_3 concentration are mostly in carbonate (ankerite).

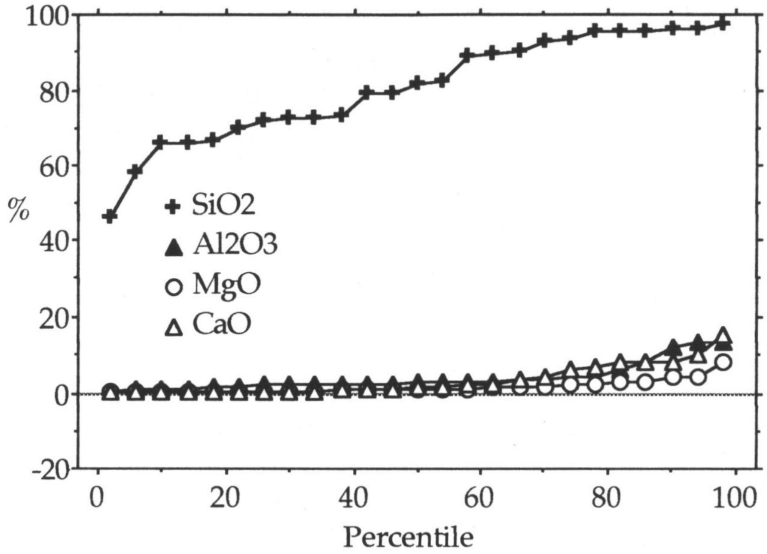


Figure 3 - Percentile distribution (number of samples converted to range from 1 to 100) of SiO_2, Al_2O_3, MgO and CaO.

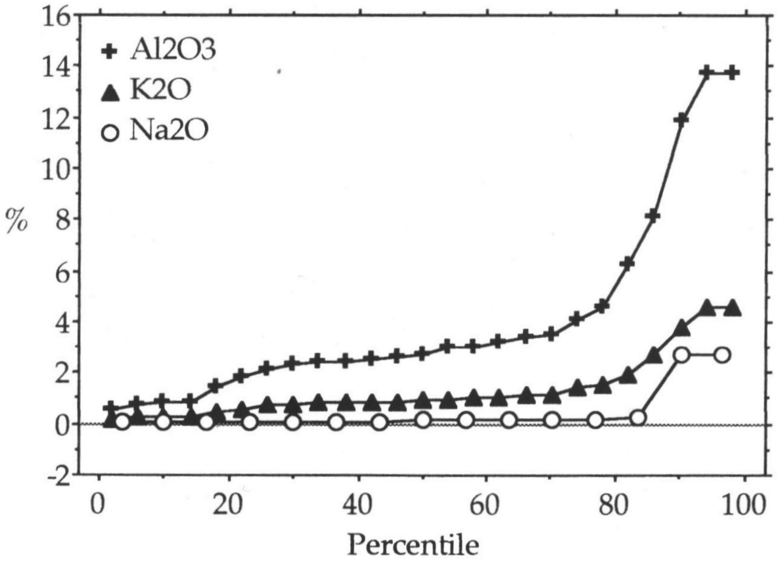


Figure 4 - Percentile distribution of Al_2O_3, K_2O and Na_2O.

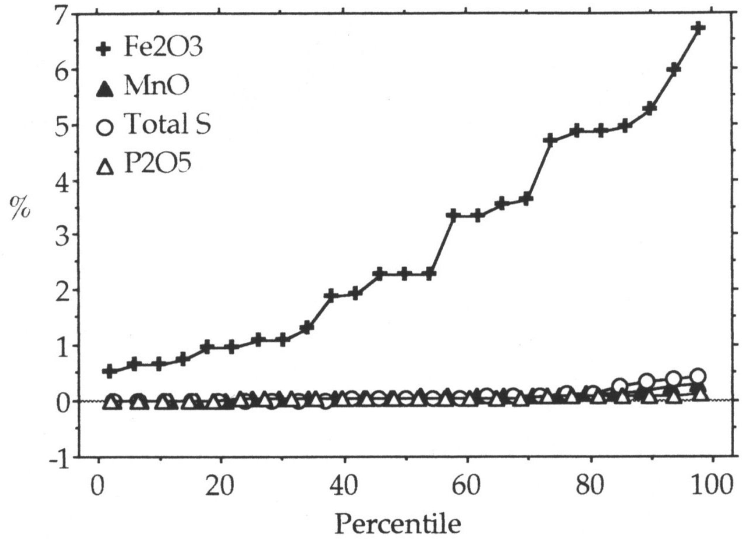


Figure 5. Percentile distribution of Fe_2O_3, MnO, total S and P_2O_5.

6. Correlation

Correlation matrix of chemical variables (Table 1) shows that SiO_2 values are negatively correlated with all elements except for Na_2O. Since silicification is widespread in the samples studied, SiO_2 values represent mostly silica precipitation rather than detrital quartz and document that silicification replaces both carbonate and clay minerals in appreciable amounts. The positive relationship between SiO_2 and Na_2O may be due to high salinity of fluids during silicification. The Al_2O_3 values show very strong positive correlation with K_2O (1), TiO_2 (0.91) and Fe_2O_3 (0.7) due to occurrence of these elements in clay minerals.

Table 1 – Correlation matrix of elements

	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	Total S
SiO_2	1									
TiO_2	-0.8	1								
Al_2O_3	-0.58	0.91	1							
Fe_2O_3	-0.97	0.89	0.7	1						
MnO	-0.53	0.01	-0.22	0.39	1					
MgO	-0.93	0.56	0.26	0.84	0.66	1				
CaO	-0.75	0.22	-0.11	0.6	0.82	0.93	1			
Na_2O	0.34	-0.11	0.13	-0.32	-0.58	-0.4	-0.49	1		
K_2O	-0.62	0.93	1	0.74	-0.18	0.31	-0.05	0.11	1	
Total S	-0.38	0.18	0.3	0.32	0.62	0.36	0.4	-0.15	0.05	1

Dissolution or leaching of clay minerals releases large Fe concentrations in solution. The values of MgO show strong positive correlation with CaO (0.9), Fe_2O_3 (0.8). MnO (0.7) and TiO_2 (0.6) and negatively to SiO_2 values (-0.9) due to occurrence of ankerite that forms from dissolution of precursor carbonate and clay minerals during silicification. The CaO values reveal positive correlation with MgO (0.9), MnO (0.8) and Fe_2O_3 (0.6) and negative relationship with SiO_2 values (-0.75) due to occurrence of ankerite that forms from dissolution of precursor limestone and dolomite during silicification.

7. Minerals

Major minerals were calculated from elemental composition. This quantitative mineralogical data can then be used to assess interrelationships between minerals to understand geological processes operating in the area. From interrelationship between minerals and Au concentrations, gold mineralization can be deduced.

Carbonate minerals

Variation of CaO and MgO values (Fig. 6) shows that ideal dolomites are rare and most carbonates are calcian dolomites. The calcian dolomites dominate because of low MgO values in the samples due to replacement of Mg by Fe and Mn in carbonate. Variation between CaO and total concentrations of MgO, Fe_2O_3 and MnO shows very strong correlations with a ratio of 1:1 (Fig. 7). Therefore, the major carbonate mineral in the samples studied is ankerite rich in Mg, which is a magnesian ankerite. Calcite is minor.

Clay minerals

Positive unit correlation (1) (Table 1) between K_2O and Al_2O_3 values with a ratio of 1:3 documents that the only clay mineral is illite (Fig. 8), which is the only clay mineral observed to occur in Ordovician carbonates (Rao, 1989). This is probably due to either occurrence of only illite in Ordovician sedimentary rocks or diagenetic alteration of various clay minerals to illite, which is a common feature in ancient sedimentary rocks worldwide.

Quartz

Quartz content is calculated by subtracting SiO_2 value required for illite, which is thrice the value of Al_2O_3 in the sample. This quartz is mainly a megaquartz that forms by silicification and not a clastic grain. The megaquartz is the major mineral in most samples and ranges from about 40% to 95% (Fig. 9) with moderate amount of ankerite (5% to 95%) and minor illite (0% to 28%).

Pyrite

The total sulphur content represents minor pyrite in the samples (Fig. 10). Since total sulphur values do not increase with Fe_2O_3 values, the pyrite content is low and that Fe_2O_3 concentrations are mainly in ankerite (Fig. 11).

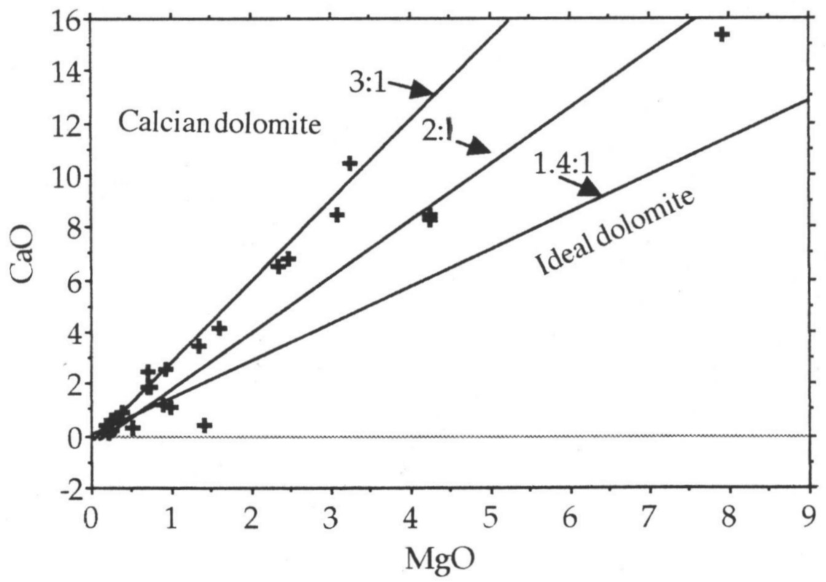


Figure 6 - Variation of CaO and MgO. Note that most carbonates are calcian dolomite and that calcite is absent.

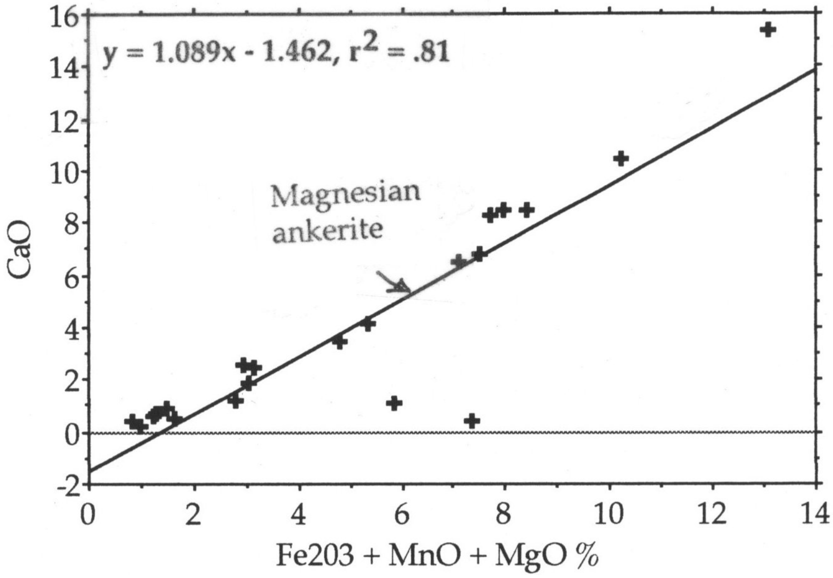


Figure 7- Variation of CaO and total Fe_2O_3 + MnO + MgO %. Note occurrence of abundant magnesian ankerite.

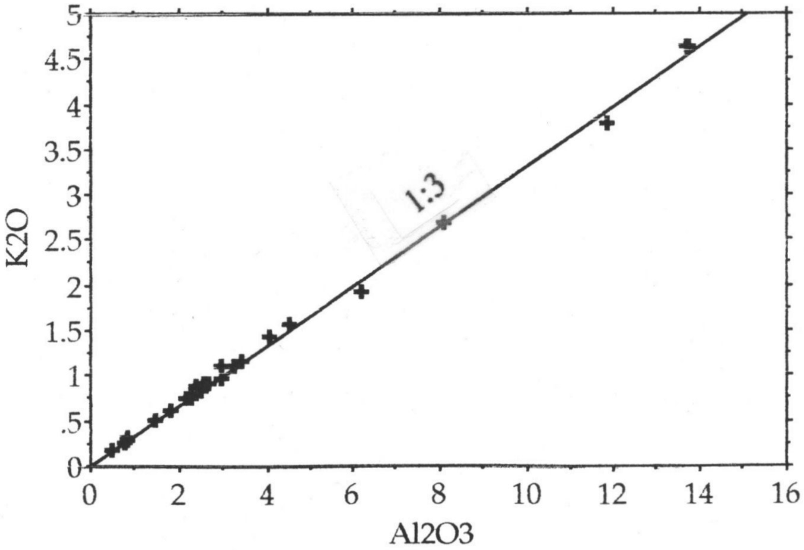


Figure 8 - Variation of K_2O and Al_2O_3 indicates the occurrence of clay mineral illite.

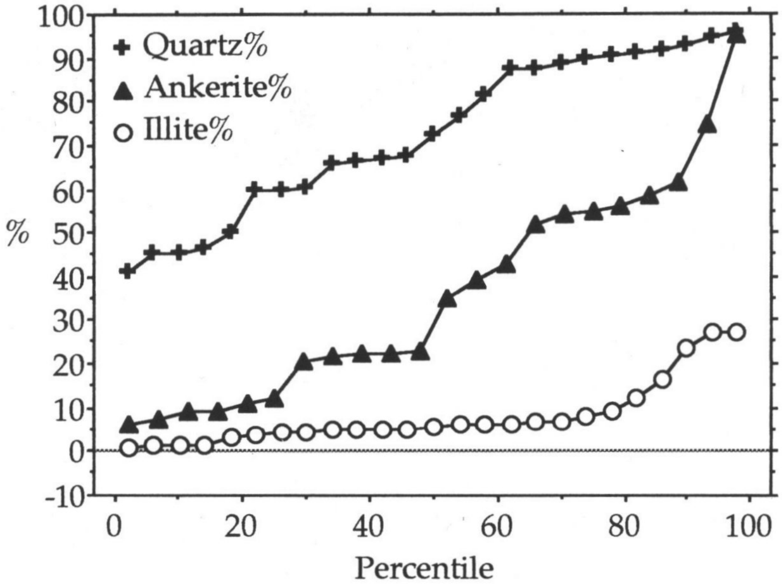


Figure 9 - Percentile distribution of quartz%, ankerite% and illite%.

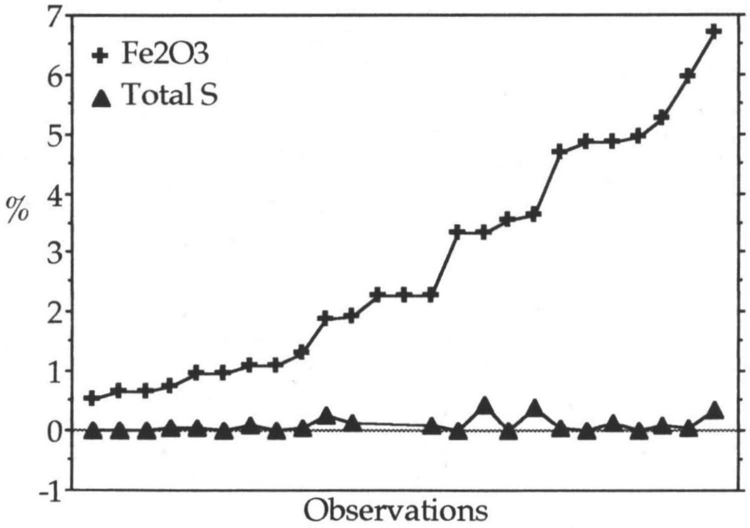


Figure 10 - Variation of total S% relative to sorted values of Fe_2O_3%.

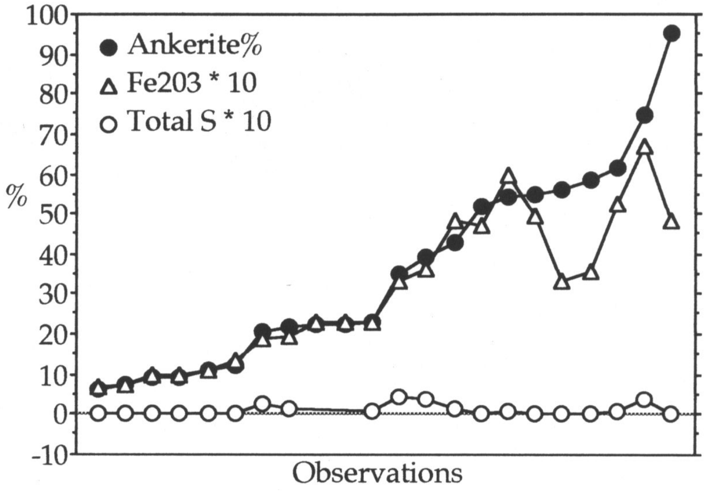


Figure 11 - Variation of Fe_2O_3 and total S% relative to sorted values of ankerite%.

8. Interrelationship between quartz, ankerite and illite

Quartz values were sorted in increasing order to understand the relationship between quartz, ankerite and illite (Fig. 12). With increasing values of quartz, ankerite and illite contents decrease due to leaching and dissolution of carbonate and clay minerals. This inference is also well supported by petrographic examination that documents extensive replacement of carbonate and clays by silicification (Rao and Adabi, 2000). The dissolution and replacement of carbonate by silica is well supported by chemical data that show increased SiO_2 values with decreasing values of Fe_2O_3, MgO and CaO (Fig. 13). With increasing sorted values of ankerite (Fig. 14), quartz values decrease because of low silicification in pure ankerite samples. The random distribution of illite content with incresing ankerite values is due to illite being unaffected by ankerite formation. With increasing sorted values of illite (Fig.15), quartz content decreases because of decreasing amounts of silicification. The distribution of ankerite with sorted values of illite is random.

9. Gold mineralization

With increasing sorted Au values, quartz content decreases and fluctuates due to Au concentration being unrelated to quartz (megaquartz) content (Fig. 16). Illite content decreases with increasing sorted Au values (Fig. 17) because of illite being unrelated to gold formation. Total S values do not increase with increasing Au concentrations (Fig. 18) because minor amounts of Au occur in pyrite. In contrast to quartz, illite and pyrite contents, ankerite content first decreases and then increases with progressive increase of Au values (Fig. 19) due to the formation of ankerite during gold mineralization. Since large volumes of carbonates dissolve during silicification, acidic fluids become alkaline and precipitate ankerite.

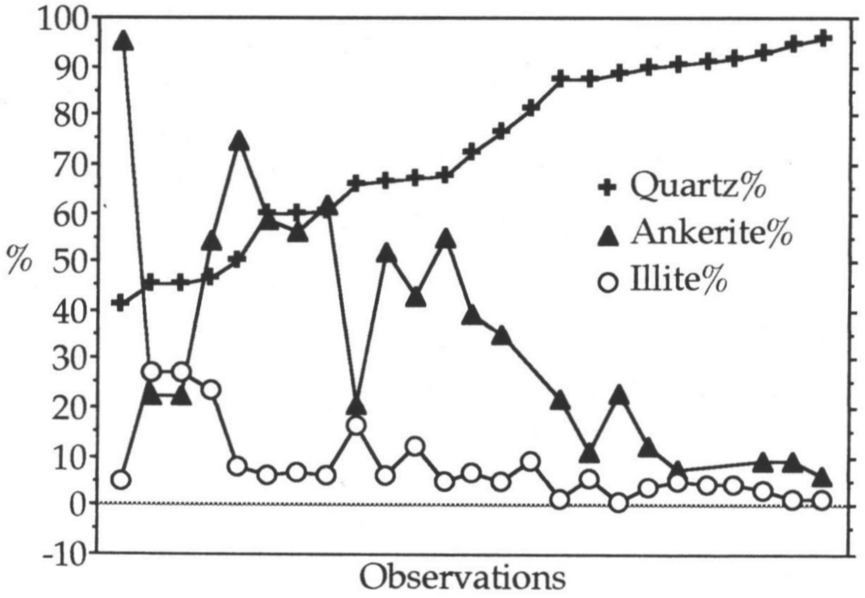


Figure 12 - Variation of ankerite% and illite% relative to sorted values of quartz%.

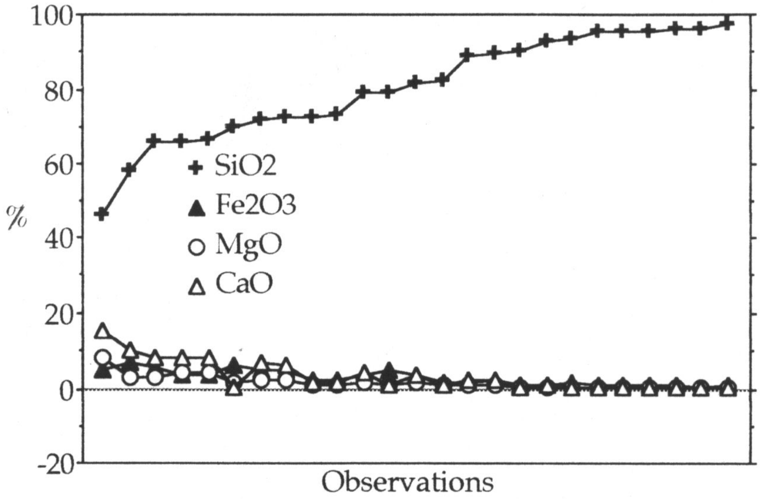


Figure 13 - Variation of Fe_2O_3, MgO and CaO relative to sorted values of SiO_2%.

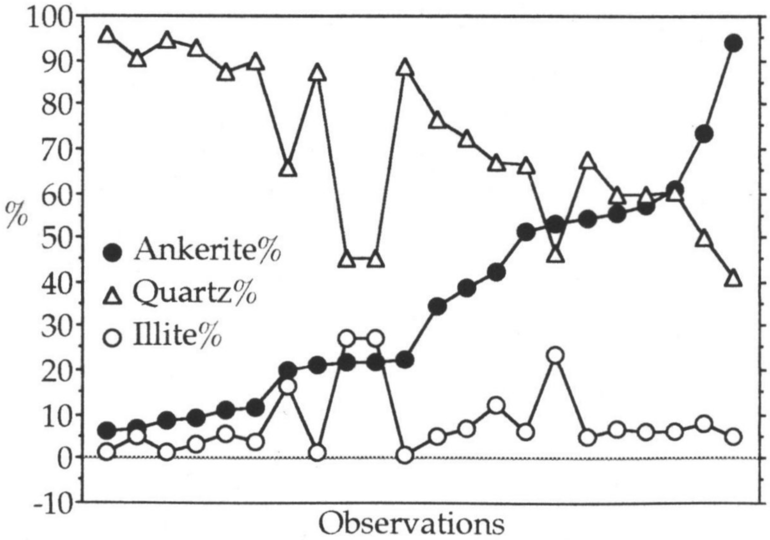


Figure 14 - Variation of quartz% and illite% relative to sorted values of ankerite%.

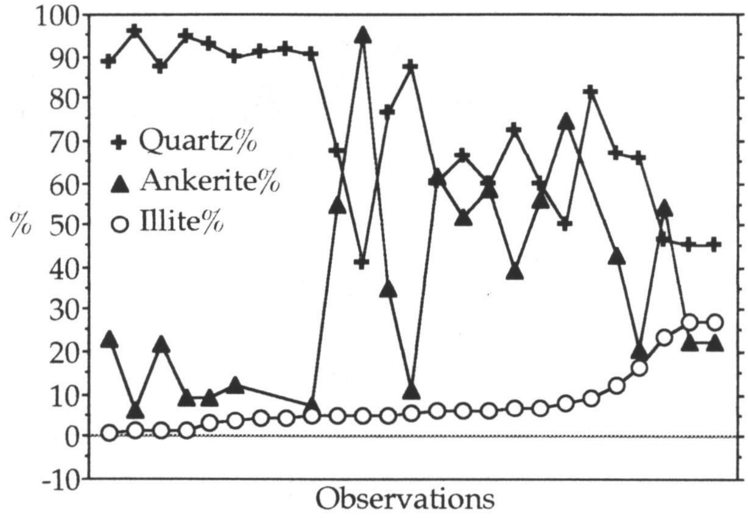


Figure 15 - Variation of quartz% and ankerite% relative to sorted values of illite%.

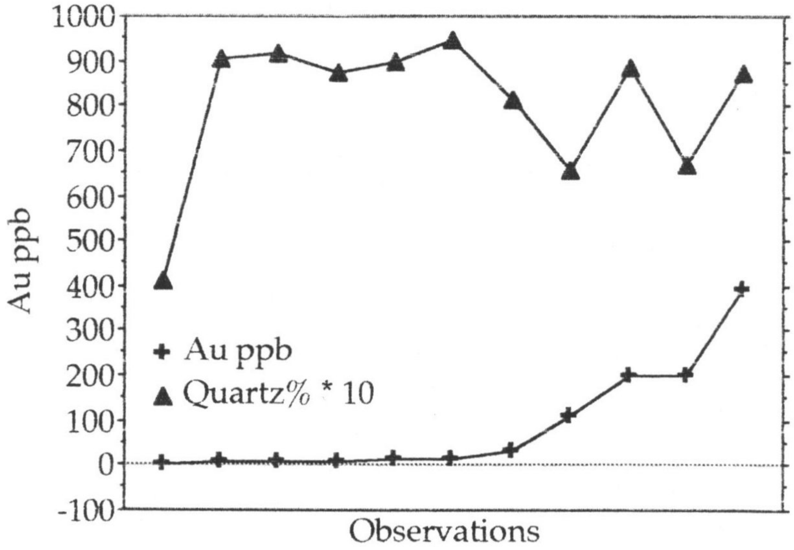


Figure 16 - Variation of quartz% relative to sorted values of Au content.

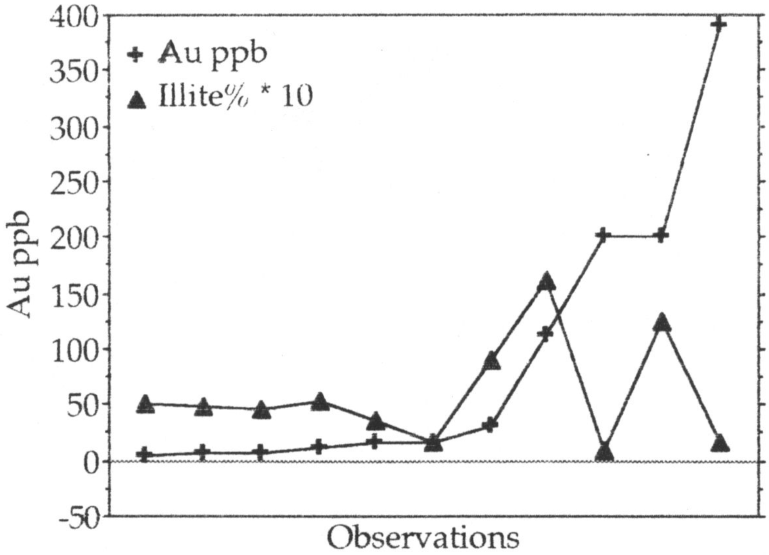


Figure 17 - Variation of illite% relative to sorted values of Au content.

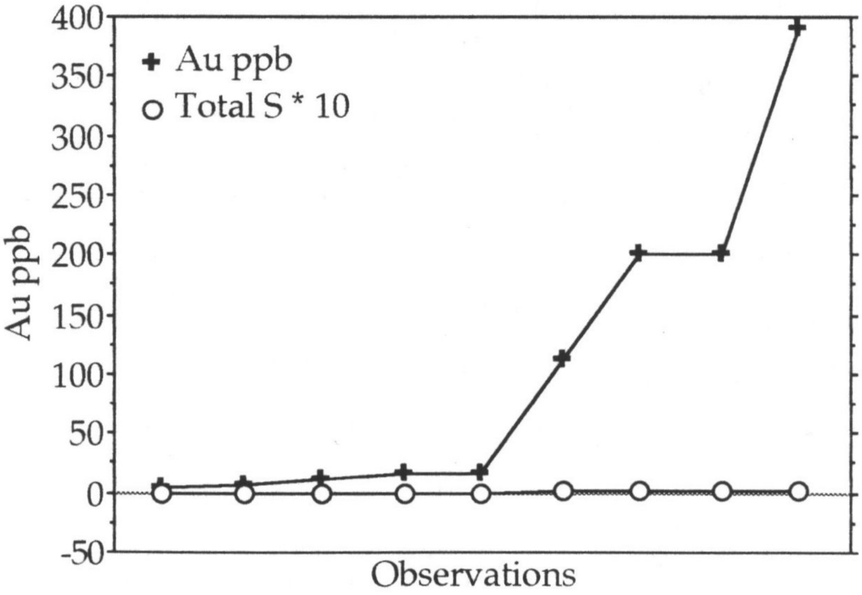


Figure 18 - Variation of total S% relative to sorted values of Au content.

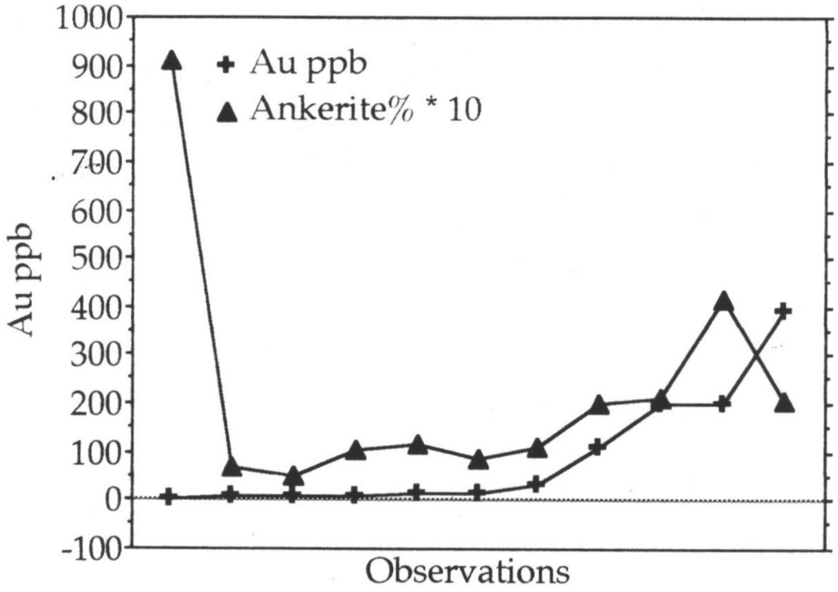


Figure 19 - Variation of ankerite% relative to sorted values of Au content.

10. Composition of fluid

Ca is mainly derived from dissolution of Ordovician limestones that host the gold reef. Since Fe, Mg and Mn concentrations are low in the Tasmanian Ordovician host carbonates (Rao, 1990), these elements are derived from leaching and dissolution of non-carbonate rocks (such as ultramafics) in the area by host meteoric fluids (Adabi, 2000). Ultramafic rocks common in the subsurface sequence in the Beaconsfield area contain large amounts of Mg (MgO mean 34%). Moderate Fe (FeO +Fe_2O_3 mean 6.8%) and low Mn (MnO mean 0.1%, Gee and Legge, 1979). Thus Mg is mainly derived from the leaching of ultramafics, whereas Fe and Mn originated from both ultramafics and alteration of clays during silicification. Extensive silicification is due to acidic fluids that leads dissolution and replacement of carbonate.

Formation of abundant magnesian ankerite is related to the passage of meteoric water through the tectonically affected rocks at Beaconsfield and replacement of Mg by Fe in a reducing burial environment, as higher amounts of Fe enter carbonate lattice in a reducing condition (Rao, 1996).

It has been suggested that gold mineralization coincided with compressional deformation related to the Devonian Tabberabberan Orogeny (Russell, 1995; Hills, 1998). It is postulated by some researchers that the gold bearing fluids were originated either from the leaching of ultramafics (Hills, 1998) or from granitic batholite, east of the Beaconsfield area, along Devonian faults and fractures (Bottrill et al., 1992; Keele et al., 1994). As has been noted ealier, extensive carbonate dissolves during silicification, acid fluids become alkaline and form ankerite. In alkaline conditions, gold precipitates (Foster, 1993; Gray, 1997) along with ankerite. Thus, gold concentrations increase with increasing ankerite content.

Conclusions

1) Distribution of major and minor elements in bulk rocks are related to the presence of quartz, ankerite and illite.

2) Elemental composition of bulk rocks is useful to understand chemical composition of fluids.

3) Variation between CaO and total concentrations of $MgO+Fe_2O_3+MnO$, with correlation ratio of 1:1, indicates that major carbonate minerals in the samples studied are Mg-rich ankerite.

4) Very strong positive correlations between Al_2O_3 and K_2O, TiO_2 and Fe_2O_3 are due to the occurrence of these elements in illite.

5) High Fe and Mg concentrations in solution is due to alteration of ultramafics and leaching of clay minerals during silicification.

6) Formation of magnesian ankerite is related to the passage of meteoric water through the Beaconsfield rocks and replacement of Mg by Fe in a reducing burial environment.

7) Total S values represent minor pyrite in the samples studied.

8) Gold mineralization coincided with the Devonian Tabberabberan Orogeny, and gold-bearing fluids were originated

either from the leaching of ultramafics or from granitic batholites, along major Devonian feeder faults.

9) Silicification occurs by leaching and dissolution of Ordovician limestones and clay minerals.

10) During silicification, acid fluids become alkaline and form ankerite in cavities and along faults and fractures. As gold precipitates in alkaline conditions, gold concentrations increase with increasing ankerite contents.

11) Gold mineralization is not related to quartz, illite and pyrite contents.

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