Geochemical characteristics of gold related Ben Giang-Que Son granitoids in the southern part of Truong Son Fold Belt of Vietnam

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***Abstract**: Granitoids of the Ben Giang – Que Son complex are exposed in the southwestern part of the Truong Son mountain range in Vietnam. Tectonically, the range consists of Truong Son Fold Belt and Kontum Massif. This magmatic complex is composed of mafic to felsic intrusions with petrographical composition ranging from gabbro to biotite-hornblende-bearing granite and granosyenite. The main rock-forming minerals are: Plagioclase, quartz, K-feldspar, hornblende and biotite. The granitoids associated with gold mineralization are recognized in Dak Blo commune, Dak Glei district, Kontum province. They underwent K-feldspar alteration; following is sericitisation, which partially overprint the earlier alkali alteration. These granitoid rocks have a relatively low and wide range of SiO_2 contents (50 to 70 wt%), low TiO_2 (<1.0 wt%), but high total alkaline content (6.9-9.6 wt%) with most K_2O/Na_2O ratios>1.0. They are calc-alkaline, metaluminous to weakly peraluminous, and show characteristics of I-type granites. Generally, the granitoids are enriched in large ion lithophile elements, and depleted in high field strength elements when compared to primitive mantle values. Rocks associated with gold mineralization are mainly biotite-bearing granites, which are beresitized. Two main styles of gold mineralization are recognized: (1) quartz-vein hosted, this style occur mainly in felsic granitoids and gold concentrated within the veins together with sulphides; and (2) disseminated, gold occurs as free native metal with sulphides, hematite in the alteration zone of beresitized granites. The ore-forming fluids have relative high salinity (13-24 wt% NaCl equiv.) and low temperature (150–250°C).*

1. Introduction

The study region is located in the south-western Truong Son Mountain Range (TSMR) and borders to Laos and Cambodia in the West. Tectonically, The TSMR consists of Truong Son Fold Belt and Kon Tum Massif, of which the Kontum Massif is considered as the Precambrian core of the Indochina Block (Hutchison, 1989). This region mainly consisted of high grade metamorphic rocks of greenschist and amphibolite-facies and magmatic rocks of the Paleozoic to Mesozoic ages. The granitoids associated with gold mineralization are recognized in Dak Glei district, Kontum province (Chi et al, 1998; Kiem et al, 2006). They are attributed to the Ben Giang-Que Son complex, which is composed of mafic to felsic intrusions (e.g, Bao et al, 2000). Previous studies of the Ben Giang-Que Son complex concentrated on intrusions in the south-eastern part of the range, whereas little attention has been paid to the western part due to the complicated topography and dense forest (Chi et al, 1998). In this study, we focus on petro-geochemistry of Ben Giang-Que Son granitoids as well as characteristics of altered granites, and their relationship to gold mineralization is also discussed based on chemical composition of fluid inclusions, hydrothermal process and tectonic regime.

2. Geological background

The study region is made up of Precambrian basement rocks, Paleozoic to Early Mesozoic igneous and rhyolite rocks (Figure 1). The Precambrian basement rocks mainly include greenschist, granulite and amphibolite facies of the Kham Duc, Kannak and Ngoc Linh complexes, respectively (Tran and Vu, 2011; Nakano et al, 2013). The Sr-Nd isotope composition of the basement rocks were stied by Lan et al (2003). Magmatic activities occurred during Paleozoic and the Early Mesozoic through the TSMR can be roughly divided into three stages: Ordovician–Silurian (480 – 420 Ma) (Thuy et al, 2017), Late Carboniferous-Early Permian (300-250 Ma), Late Permian to Triassic (250-200 Ma). Ben Giang-Que Son granitoids were emplaced at age of ca. 290-250 Ma (Sang, 2011) and have petrographical composition ranging from gabbro through diorite, granodiorite to biotite-hornblende-bearing granite and granosyenite. The rocks underwent K-feldspar alteration as indicated by presence of myrmekite; following is sericitisation, which partially overprint the earlier potassium alteration. The main rock-forming minerals are plagioclase, hornblende, biotite and less K-feldspar for mafic rocks; plagioclase, quartz, K-feldspar, hornblende and biotite for intermediate rocks; and feldspar, quartz, biotite and less hornblende for acid rocks. Granites related to gold mineralization in the study area found in Dak Blo commune, Dak Glei District. These rocks underwent intensively hydrothermal alteration forming beresitic rocks containing gold and sulphides.

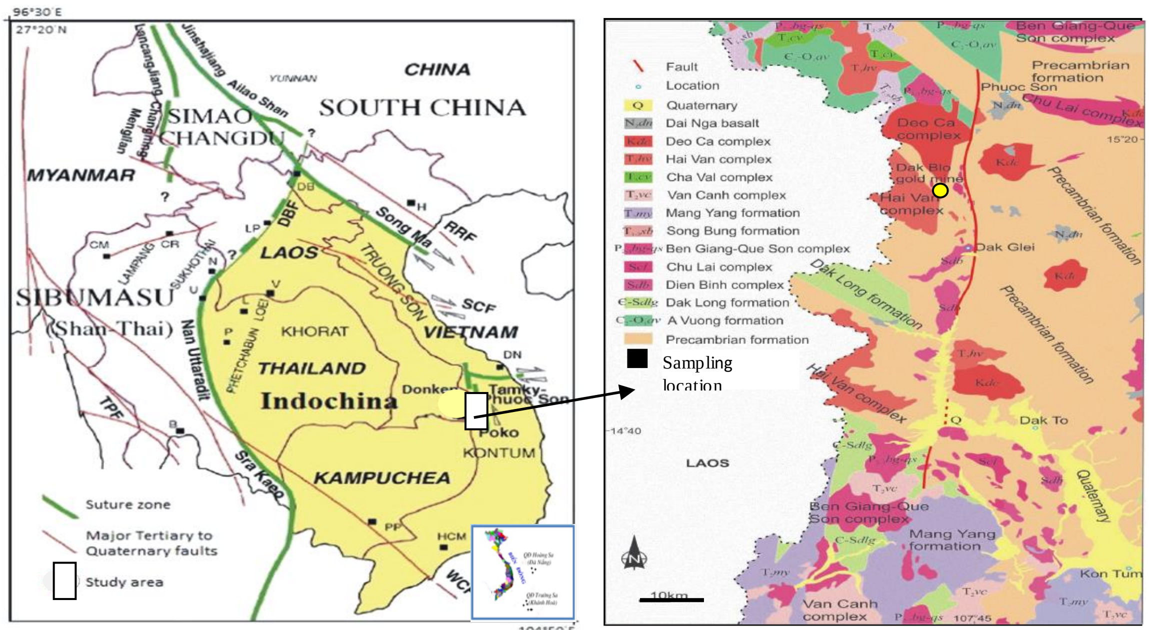

Figure 1. *a) tectonic framework of South China and Indochina Blocks; b) Simplified geological scheme of the study area showing distribution of granitoids and the basement rocks (modified from Kiem at al, 2006).*

3. Analytical method

Rock samples were partially cut for thin section preparation, the rest was used for major and trace element analysis. Thin and polished sections were prepared and analyzed at Vietnam Institute of Geosciences and Mineral Resources.

For major and trace element analyses, the rock samples were crushed and then powdered to a grain size of <0.074 mm. These powdered samples were dried at 120°C overnight before weighing. Chemical composition of the samples was performed using X-ray fluorescence (XRF) spectrometry at the Institute of Geology and Geophysics, Chinese Academy of Sciences. Total iron concentration is expressed as Fe_2O_3. The analytical uncertainty is generally from 0.5 to 2.1% for the major elements and less than 10% for trace elements depending on their concentration in the rocks.

4. Analytical results and discussions

Petrography and mineralogy

The Ben Giang-Que Son complex exhibits a wide range of petrographic composition: from mafic through intermediate to acid rocks, of which intermediate rocks are dominant. Mafic rocks consist of gabbro and gabrodiorite, they are fine to medium grained and exhibit anhedral granular texture. Intermediate rocks are medium grained hornblende-biotite diorite, quartz diorite and granodiorite, while acid rocks are medium to coarse grained biotite-bearing granite with scare hornblende having sub-euhedral texture. The main rock-forming minerals of the complex are plagioclase, hornblende, biotite, quartz and K-feldspar, but amount of these minerals widely varies depending on petrographic composition of rocks. Accessory minerals are common apatite, zircon and titanite. The Ben Giang-Que Son granitoids experienced a significantly hydrothermal alteration: The early alteration stage is alkalization process as indicated by presence of myrmekite and distorted and fresh K-feldspar (microcline) crystals in the rocks; the following is berezitization, which related to gold mineralization. The granitoids are intensively altered to form berezitic rocks are recognized in the Dak Blo gold mine. The main mineral assemblage of these berezitic rocks are sericite (up to 60%) and quartz.

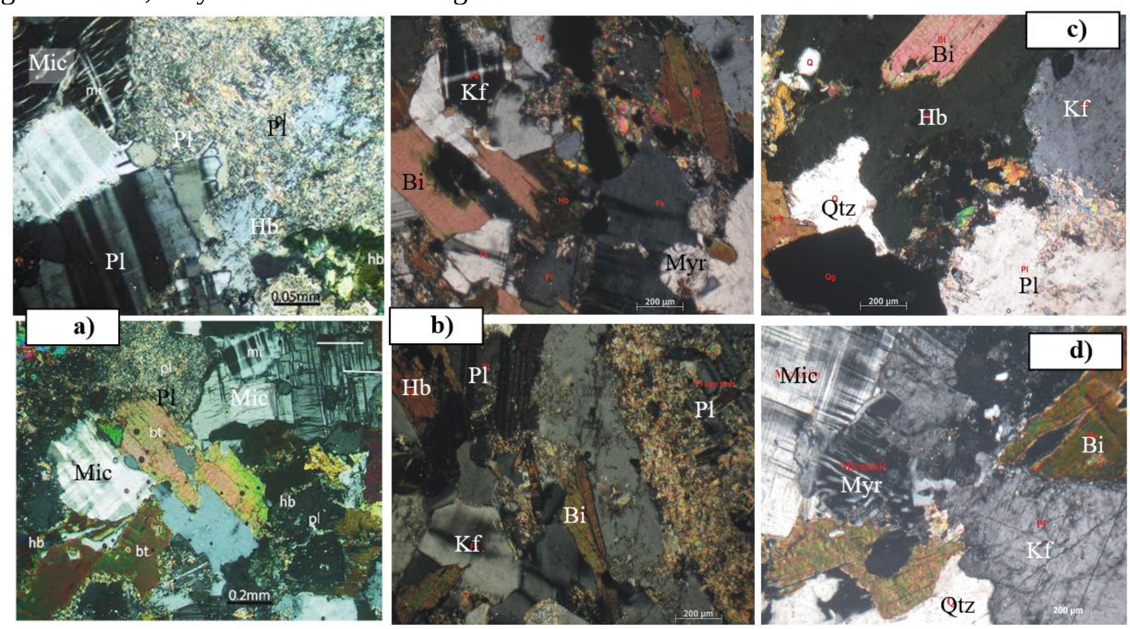

Photo 1. *Thin section photomicrographs of gabbro (a); diorite (b), granodiorite (c), and coarse grained granite (d) from the Ben Giang-Que Son complex. Abbreviation: Bi=Biotite, Hbl=Hornblende, Kf=K-feldspar, Mic=Microcline, Myr=Myrmekite, Pl=Plagioclase, Qtz=quartz under crossed polarizers.*

For mafic rocks, plagioclase occupies about 55-67 vol%, hornblende 10-20, biotite 10-14% with minor amount of K-feldspar 2-8%, and secondary minerals (7-9). Sericitised plagioclase is often seen in these rocks. K-feldspar is microcline with grid-twinning, which is also alteration product of plagioclase (Photo 1a). Intermediate rocks comprise plagioclase (40-55%), quartz (1-20%), hornblende (9-18%), K-feldspar (8-15%), biotite (8-12%), and hydrothermal minerals including epidote, calcite and chlorite (6-9%). The rocks experienced an early alkalization process as indicated by presence of myrmekite and distorted and fresh K-feldspar. This secondary K-feldspar formed by K-metasomatism of primary plagioclase (Photo 1b). Acid rocks contain more abundant plagioclase (33-50%) than K-feldspar (10-28%), quartz (27-30%), biotite and hornblende are mafic minerals occupying about 9-12% (Photo 1c). Myrmekite and cataclastic fragments of remnant K-feldspar are along the border between the microcline and the K-feldspar (Photo 1d).

Beresitized granite

Most granites of the Ben Giang - Que Son complex are strongly beresitized to form beresitic rocks, which contain gold. The main mineral assemblage of beresitic rocks includes: Quartz (40-50 vol%), sericite (35-50 vol%), remnant K-feldspar (5–7 vol%), together with sulphide and gold (Photo 2a-c).

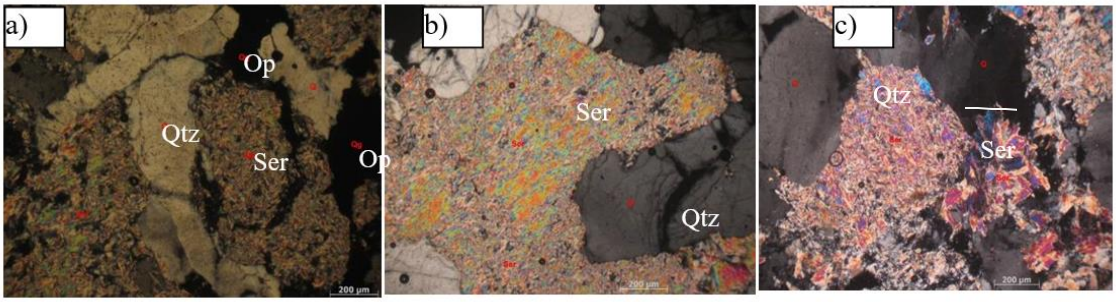

Photo 2.a-c. Thin section photomicrographs of berezitized granites in Dak Blo gold mine. Abbreviation: Ser=sericite, Qtz= quartz, Op=opaque mineral under crossed polarizers.

Major and trace element geochemistry

Analytical data for major and trace elements of representative samples are given in Table ***1***. The bulk-rock concentrations of the Ben Giang-Que Son granitoid rocks are characterized by a wide range in SiO_2 (49-70 wt.%) and MgO (0.8-6.5 wt.%) contents, low TiO_2 (<1.0 wt.%), high K_2O+Na_2O (6.5-9.6 wt.%) with most K_2O/Na_2O ratios >1, high Al_2O_3 (up to 19 wt.%) in the intermediate rocks. Most analytical samples are of sub-alkaline affinity and belong to the medium to high K, calc-alkaline series (Figure 2a).

Table 1. Major (wt%) and trace element (ppm) concentration and analytical results of fluid inclusions of representative samples from the Ben Giang-Que Son complex.

Sample	TS015	TS017	TS020	Sample	TS015	TS017	TS020
SiO_2	54.30	66.83	53.32	Rb	57.19	114.9	87.66
TiO_2	0.79	0.35	0.96	Sr	646.1	414.9	592.2
Al_2O_3	18.37	15.86	16.75	Y	44.03	23.96	34.81
Fe_2O_3	7.24	3.70	7.32	Zr	337.3	298.1	178.1
MnO	0.15	0.06	0.18	Nb	25.82	22.55	30.48
MgO	2.88	1.01	4.66	Cs	1.85	1.73	1.45
CaO	5.49	2.69	7.80	Ba	1551	1094	878.5
Na_2O	3.88	3.18	3.83	La	149.8	83.53	143.6
K_2O	4.67	4.53	2.99	Ce	285.6	148.9	269.9
P_2O_5	0.81	0.23	0.48	Pr	29.84	16.45	30.23
LOI	0.98	1.76	1.19	Nd	100.1	53.60	105.0
TOL	99.54	100.20	99.58	Sm	15.53	7.98	15.33
Na_2O+K_2O	8.55	7.71	6.74	Eu	2.88	1.45	3.76

Sample	TS015	TS017	TS020	Sample	TS015	TS017	TS020
K_2O/Na_2O	1.20	1.42	0.77	Gd	14.98	7.64	13.36
Fe_2O_3/FeO	0.78	0.77	0.64	Tb	1.96	1.01	1.70
ASI	0.86	1.05	0.71	Dy	9.84	4.95	7.65
$(Hf/Sm)_{PM}$	0.78	1.70	0.61	Ho	1.77	0.91	1.43
$(Ta/La)_{PM}$	0.16	0.44	0.27	Er	5.25	2.76	4.17
$(La/Yb)_N$	24.99	25.17	25.37	Tm	0.69	0.38	0.71
				Yb	4.30	2.38	4.06
Sample	**TS015**	**TS017**	**TS020**	Lu	0.64	0.37	0.71
				Hf	8.41	9.45	6.87
Homogeneous T	176	201	240	Ta	0.91	2.17	2.34
Salinity %(Nacl)	12	23	18	Th	46.13	62.80	44.35
Inclusion system	H_2O-NaCl	H_2O-NaCl	H_2O-NaCl	U	3.19	9.62	8.21

Some samples have higher contents of K_2O as usual due to early alkalinization of the rocks, therefore falling in shoshonite field. The A/CNK vs. A/NK diagram (Maniar and Piccoli, 1989) defines the rocks as metaluminous, and of I-type character (Figure 2c). This character is also supported by high Fe_2O_3/FeO ratios >0.64-0.78 (Table 1).

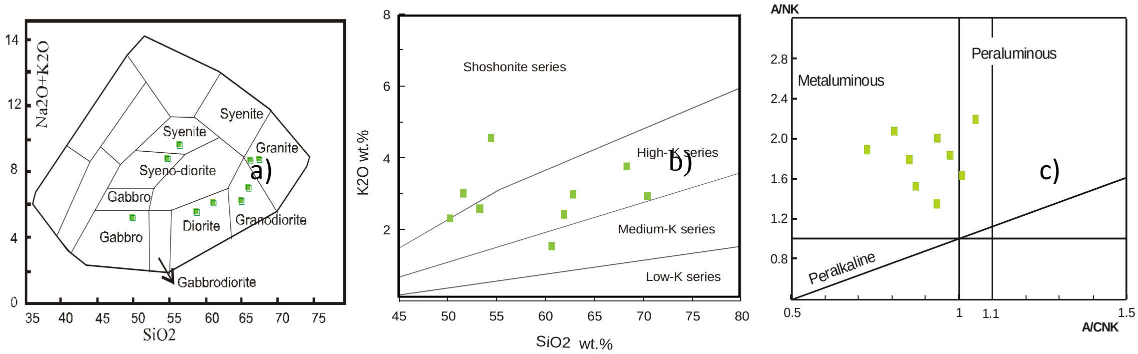

Figure 2. a. *Chemical composition of granitoids plotted in the TAS classification diagram Cox et al. (1979). b. SiO2 – K2O diagram of magma series division according to Peccerillo and Taylor (1976). C. The A/CNK vs. A/NK diagram (Maniar and Piccoli, 1989)*

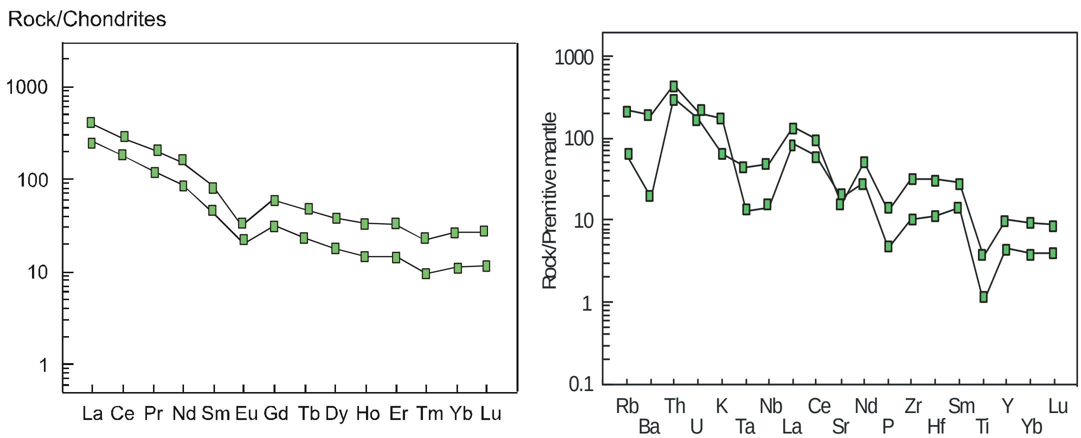

Figure 3. a) Chondrite - normalized rare earth element concentrations for the Ben Giang - Que Son granitoids (normalizing values from Sun, 1982); b) Primitive mantle - normalized trace element concentrations for the Ben Giang-Que Son granitoids. The normalizing values are from Taylor and Mclennan (1985).

The chondrite-normalized REE patterns of all analyzed samples are characterized by moderate fractionation between the light and heavy REEs ([La/Yb]n=14–30) and slightly negative Eu-anomalies (Eu/Eu* =0.5-0.8) (

Figure 3. a) Chondrite - normalized rare earth element concentrations for the Ben Giang - Que Son granitoids (normalizing values from Sun, 1982); b) Primitive mantle - normalized trace element concentrations for the Ben Giang-Que Son granitoids. The normalizing values are from Taylor and Mclennan (1985).

Figure 3a). The primitive mantle-normalized spidergrams show enrichment in large ion lithophile (LIL) elements (e.g. Rb and K) and exhibit distinct negative anomalies for high field strength (HFS) elements (Nb, Ta and Ti) indicating subduction related magma (

Figure 3b).

The Ben Giang-Que Son granitoids are enriched in Sr-Nd isotope with initial $^{87}Sr/^{86}Sr$ >0.71 and negative εNd (up to -7.5), low SiO_2 content and have relative high Mg number of 35-38, 40-48 and 50-56 for granite, granodiorite and gabbrodiorite, respectively. All these characteristics of the granitoids suggest a derivation from enriched mantle source region. The low values of $(Hf/Sm)_{PM}$=0.61÷1.70 and $(Ta/La)_{PM}$=0.16÷0.44 of the granitoids indicated that the mantle source has been enriched by fluids released from the subducted plate in the past (Fleche et al, 1998).

Style of Gold mineralization

From field observation and analytical results of the polished sections collected from the Dak Blo gold mine showing that gold mineralization occurred in two styles: (1) a quartz-vein mineralization style, in which gold is found within quartz veins, principally associated with pyrite (Figure 4a). The quartz veins are hosted in Bi-Hbl granite and Bi-bearing granite, which are intensively altered; and (2) a disseminated mineralization style, where gold occurs as disseminated particles dominantly associated with sulphides (Figure 4b) within the alteration zone of beresitized granites. The sulphide minerals are pyrite, less chalcopyrite, galenite-spharelite and bismuth-bearing minerals. The second mineral is limonite and goethite, which replace pyrite (Figure 4b).

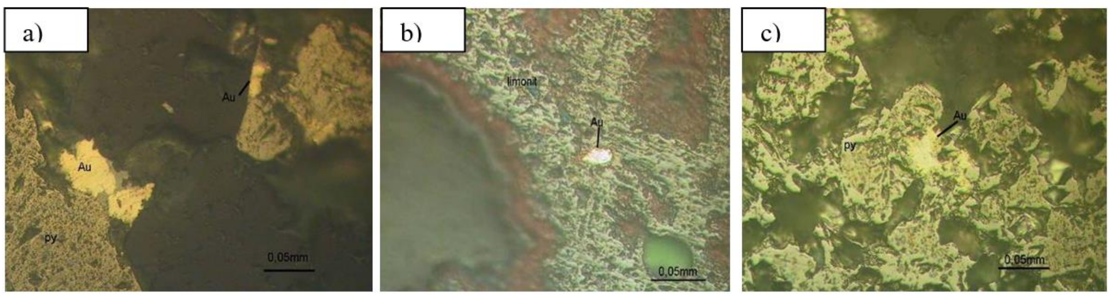

Figure 4.a-c: Ore mineral of the gold Dak Blo gold mine in polished section under reflected light. (a) native gold and pyrite in quartz vein; (b, c) native gold (Au) in pyrite (Py) in beresitized granite. Pyrite is partly altered to form limonite (b).

Pyrite is the most abundant and the important gold-bearing mineral, about 85% of gold is associated with pyrite and 15% associated with quartz. Most pyrite grains are idiomorphic but sub-idiomorphic. Along the fracture and around the margin of pyrites replacement identifies by limonite (Figure 4b). Brecciation that occurred in some pyrites can be as result of dynamic or fluids pressure.

Fluid inclusions

Inclusions trap in quartz from Ben Giang-Que Son granites and quartz veins collected from the Dak Blo gold mine were studied for their homogenization temperature and composition. Primary fluid inclusions were analysed. Fluid inclusion chemistry can be described by the systems H_2O-NaCl, also H_2O-NaCl-$CaCl_2$ and H_2O-CO_2. Fluid inclusions have moderate to high salinity (10-24 wt% NaCl equiv) and low homogenization temperature (150-250℃) indicating a relationship with magmatism. The gold content in the fresh diorite and granodiorite reaches 100-200 ppb, 25-50 times higher than the Clark values. In the beresitized granites, the gold content increased dramatically (900-30000 ppb), 220-7700 times higher than the Clark value. All these features indicate the high potential of gold mineralization for the Ben Giang-Que Son complex.

Conclusion

The Ben Giang-Que Son complex has a wide range in petrographic composition: from gabbro, gabbrodiorit through granitoid to granite. The main rock-forming minerals are plagioclase, hornblende, biotite, K-feldspar and quartz, the amount of mineral in the rocks depends on their petrographic composition. The rocks underwent an early alkalinisation process as indicated by the presence of myrmekite and replacement of plagioclase by K-feldspar (microcline), following is sericitisation, which partially overprint the earlier alkali alteration.

Geochemically, the Ben Giang-Que Son granitoids exhibit I-type granite and are of sub-alkaline affinity, and belong to medium to high K–calc alkaline series. The rocks have high $^{87}Sr/^{86}Sr$ ratios (>0.71), significantly negative εNd and high Mg# suggest a derivation from enriched mantle source region.

Rocks associated with gold mineralization are mainly biotite-bearing granites, which are beresitized. Gold mineralization occurred in two styles: (1) a quartz-vein mineralization style, in which gold is found within quartz veins, principally associated with pyrite; and (2) a disseminated mineralization style, where gold occurs as disseminated particles with sulphides within the alteration zone of beresitized granites. The ore-forming fluids have relative high salinity (13-24 wt% NaCl equiv.) and low temperature (150–250℃).

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