Vesuvianite–wollastonite–grossular-bearing calc-silicate rock near Tatapani, Surguja district, Chhattisgarh

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This paper reports the occurrence of vesuvianite + wollastonite + grossular + diopside + microcline + quartz assemblage in an enclave of calc-silicate rocks occurring within quartzofeldspathic gneiss near Tatapani in the western part of Chhotanagpur Gneissic Complex. The enclave contains phlogopite-absent and phlogopite-bearing calc-silicate rocks, the latter being much more abundant than the former. The above assemblage occurs in the phlogopite-absent rock. Phlogopite-bearing rock contains the assemblage phlogopite + salite + microcline + plagioclase + quartz. A strong schistosity is developed in both the calc-silicate rocks and the minerals are syntectonic with the major foliation-forming event in the area. The vesuvianite-bearing assemblage is formed by amphibolite facies regional metamorphism of a calcareous protolith at pressure < 4 kbar and X_{CO_2} (fluid) < 0.15.

1. Introduction

Vesuvianite (idocrase) is a major or accessory silicate mineral found in skarns, rodingites, altered syenites and hydrothermal veins (Galuskin *et al* 2003 and references therein). To date, it has only rarely been reported within regional metamorphic rocks (Bogoch *et al* 1997). Experimental and theoretical phase-equilibrium studies of vesuvianite suggest that it is stable over a wide range of pressures (P) and temperatures (T). In this study, I report an unusual calc-silicate enclave containing the assemblage vesuvianite + wollastonite + grossular + diopside + microcline + quartz occurring within quartzofeldspathic gneiss in the western part of Chhotanagpur Gneissic Complex (CGC) (figure 1).

2. Geological setting

The CGC is a Proterozoic crustal block of quartzofeldspathic gneiss with enclaves and belts of supracrustal rocks, which mainly include pelites and psammites with minor calcareous metasediments (Mazumdar 1988; Ghose 1992). The supracrustal enclaves vary in size from small patches to bands of several hundred metres length. Large supracrustal belts occurring in the western and central parts of the CGC show varying grades of metamorphism from greenschist to amphibolite facies with local attainment of granulite facies conditions (Ghose 1992).

An E–W trending enclave of calc-silicate rocks which is ∼25 m wide and ∼150 m long occurs about 5 km south of Tatapani in the Surguja district of Chhattisgarh (figure 1). It is located across Ambikapur–Ramanujganj district road, near the 88 km stone from Ambikapur. The enclave occurs within biotite quartzofeldspathic gneiss, and is intruded by a pegmatite body in the north. The calc-silicate rocks are fine-grained and show millimetre to centimetre-scale felsic and mafic layers (figure 2a). Felsic layers are white in colour, whereas mafic layers range from green, brown to grey colour depending on the modal abundance of different mafic minerals. Layers rich in diopside are green coloured and those rich in garnet are brown

Keywords. Vesuvianite; wollastonite; grossular; diopside; calc-silicate rock.

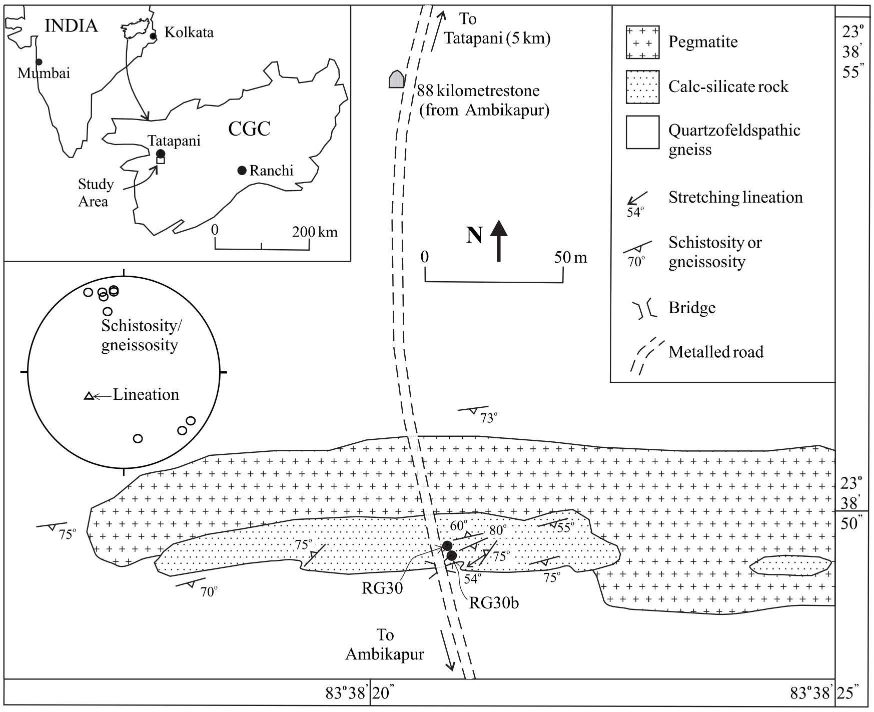

Figure 1. Generalised geologic map of the study area (Toposheet no. 64N/10). Equal area projection shows poles of foliation (open circle) and lineation (open triangle). Inset shows outline of Chhotanagpur Gneissic Complex (CGC) in India after Mazumdar (1988), and enlarged CGC with location of study area.

coloured. Honey-brown coloured equant grains of garnet of up to 3 mm size can be seen on a fresh surface. White acicular grains of wollastonite of up to 3 mm length are distinct in some layers.

A strong secondary foliation (S_1) is observed in the calc-silicate enclave (schistosity) and the country gneiss (gneissosity). Small scale open to tight folds defined by S_1 are locally seen in calc-silicate rocks. Small kinks can even be seen in hand specimens (figure 2a). An equal area plot of S_1 from both calc-silicate rocks and country gneiss shows that the dominant strike is ENE–WSW with steep northerly and southerly dips (figure 1). The pegmatite body is devoid of any foliation.

3. Mineralogy and microtexture

Mineralogically, the calc-silicate rocks are classified into phlogopite-absent and phlogopite-bearing varieties. Phlogopite-absent rock contains the assemblage vesuvianite + wollastonite + grossular + diopside + microcline + quartz (sample RG30). The assemblage in phlogopite-bearing rock is phlogopite + salite + microcline + plagioclase + quartz with sphene as a common accessory (sample RG30b). Calcite is not found in any of the samples. Phlogopite-absent rock occurs locally as minor patches within phlogopite-bearing rock. The protolith of the phlogopite-bearing rock must have been highly rich in pelitic clay. The assemblage in the phlogopite-absent rock requires bulk composition much richer in silica compared to calcium.

In RG30 diopside and grossular are the dominant mafic minerals which commonly occur as tiny grains (< 0.5 mm size) (figure 2b). Diopside varies from being equant to slightly elongated in shape. Individual layers in RG30 are rich in grossular + diopside, grossular + quartz, microcline or wollastonite. The diverse mineralogy of different layers reflects original compositional layering in the sedimentary protolith. Vesuvianite occurs sporadically as euhedral (six-sided) (figure 2b) to subhedral (figure 2c) grains of up to 1.5 mm size. It is pleochroic in shades of pale yellow, and shows first order greyish white interference colour and uniaxial negative interference figure. Inclusions of quartz and diopside are common in vesuvianite. Diopside is weakly pleochroic in shades of green. In RG30b phlogopite + microcline-rich layers alternate with layers rich in microcline + salite or quartz + salite. Microcline in both RG30 and RG30b is perthitic in nature with typical cross-hatched twinning. Plagioclase occurs rarely in microcline-rich layers in RG30 but is relatively more common in such layers in RG30b.

Boundaries among feldspar grains in calc-silicate rocks are straight to slightly curved (equilibrium boundaries; Spray 1969), and 120° triple junctions are common. Quartz shows irregular grain

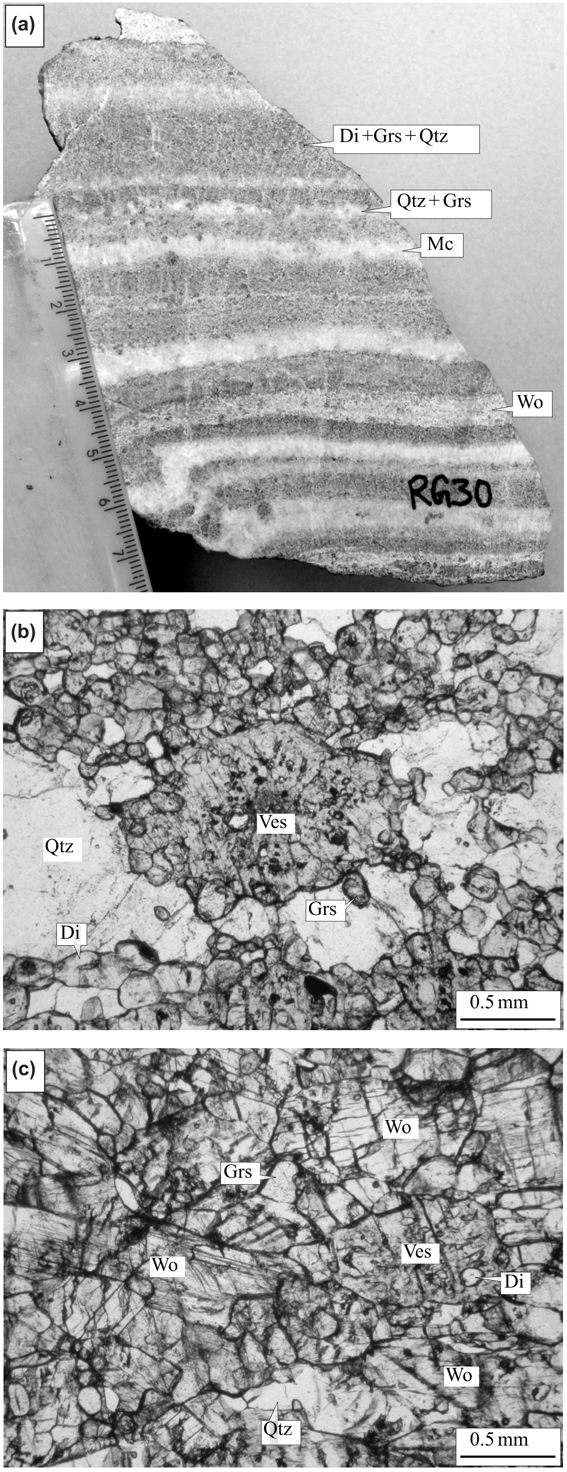

Figure 2. **(a)** Polished hand specimen photograph of sample RG30 showing felsic and mafic layering. Grossular grains of up to 3 mm diameter appear as grey spots. Note the kink in the lower left. Small divisions in the scale are millimetres. See table 1 for mineral abbreviations. **(b)** Photomicrograph showing euhedral, six-sided grain of vesuvianite with inclusions of diopside and quartz. Upper and lower mafic layers comprise aggregates of diopside and grossular. Long axes of elongated grains of diopside in the lower left and of vesuvianite is oriented E–W (plane polarised light; sample RG30). **(c)** Photomicrograph showing prismatic wollastonite and subhedral vesuvianite aligned in an E–W direction (plane polarised light; sample RG30).

boundary, wavy extinction and deformation bands. Schistosity is defined mainly by preferred orientation of elongated quartz, wollastonite prisms and phlogopite flakes. Although most diopside grains are equant in shape, some are elongated and aligned along schistosity (figure 2b). Figure 2(c) shows schistosity defined by preferred orientation of wollastonite prisms. The long axis of vesuvianite in figures 2(b) and 2(c) is also parallel to the schistosity. These microtextural features show that the peak metamorphism in calc-silicate rocks was syntectonic with the major foliation-forming event in the area.

4. Mineral chemistry

Electron microprobe analysis was carried out using the JEOL-JXA-8600M Superprobe at the University of Roorkee with an accelerating voltage of 15 kV, specimen current of 20 nA, and beam diameter of 3 μm. Both minerals and synthetic phases were used as standards. Analytical uncertainties on major element determinations are up to 2 wt%. Representative analyses of minerals are given in table 1.

Vesuvianite has a low total of oxides which indicates the presence of a significant amount of fluid in its crystal structure. The optic sign of vesuvianite is a reflection of the presence or absence of boron. Boron-bearing vesuvianite is optically positive, whereas boron-free vesuvianite is optically negative (Groat *et al* 1992). The negative optic sign of the studied vesuvianite indicates that it is boron-free. The fluid in the vesuvianite is likely to be mainly H_2O with some fluorine (e.g., Groat *et al* 1992). Vesuvianite composition was calculated on the basis of 50 cations assuming all Fe as ferric. No appreciable difference is found between the core and rim compositions of vesuvianite. The MgO content is $\sim$2 wt% and the Fe content expressed as Fe_2O_3 is $\sim$3.5 wt%. In comparison to an average of the twenty-four compositions of vesuvianite in Deer *et al* (1982) and the twenty compositions in Groat *et al* (1992), the studied vesuvianite is slightly enriched in its Ti content (2.2 wt% TiO_2) and depleted in Mg and Ca, although it falls within the ranges of those reported therein. The vesuvianite of Ahmed-Said and Leake (1996) is not much different, containing little more Al.

Clinopyroxene in RG30 is diopside with X_{Mg} (= Mg/Fe + Mg) of 0.87, whereas that in RG30b is salite with X_{Mg} of 0.75. Plagioclases in RG30 and RG30b are oligoclase and labradorite in composition respectively. Phlogopite in RG30b has X_{Mg} of 0.82. Titanium, which is accommodated in vesuvianite in RG30, forms sphene in RG30b where vesuvianite is absent.

Table 1. *Electron probe microanalyses of minerals (dash = not analysed; blank = below detection limit).*

	RG30							RG30b			
	Ves										
	Core	Rim	Grs	Di	Wo	Pl	Mc	Sal	Phl	Pl	Mc
SiO_2	35.50	35.61	38.93	55.03	51.51	59.39	65.66	54.73	39.17	53.79	65.97
TiO_2	2.26	2.15	–			–	–		0.68	–	–
Al_2O_3	14.89	15.14	19.45	0.22		25.61	18.12	0.44	16.69	29.37	18.06
$Fe_2O_3^*$	3.53	3.77	3.77	–	–			–	–		
FeO	–	–	–	4.29	0.13	–	–	7.97	7.74	–	–
MnO	0.11	0.11	0.56	0.48	0.25	–	–	0.36	0.07	–	–
MgO	1.98	2.05	0.07	16.05	0.07	–	–	13.76	20.04	–	–
CaO	35.56	35.19	36.11	25.57	47.88	7.89	0.02	24.45	0.03	12.14	
Na_2O			–		0.12	7.68	0.52			4.67	1.35
K_2O			–			0.09	16.11		10.15	0.09	15.48
Total	93.83	94.02	98.89	101.64	99.96	100.66	100.43	101.71	94.57	100.06	100.86
Oxygen	ψ	ψ	12	6	6	8	8	6	22	8	8
Si	18.011	18.028	2.999	1.992	1.996	2.639	3.016	2.003	5.677	2.430	3.015
Ti	0.862	0.819	–			–	–		0.074	–	–
Al	8.904	9.034	1.766	0.009		1.341	0.981	0.019	2.851	1.564	0.973
Fe^{3+}	1.348	1.436	0.219	–	–			–	–		
Fe^{2+}	–	–	–	0.130	0.004	–	–	0.244	0.938	–	–
Mn	0.047	0.047	0.037	0.015	0.008	–	–	0.011	0.009	–	–
Mg	1.498	1.547	0.008	0.866	0.004	–	–	0.751	4.330	–	–
Ca	19.330	19.089	2.981	0.992	1.988	0.376	0.001	0.959	0.005	0.588	
Na			–		0.009	0.662	0.046			0.409	0.120
K			–			0.005	0.944		1.877	0.005	0.902
Total	50.000	50.000	8.010	4.004	4.009	5.023	4.988	3.987	15.761	4.996	5.010
X_{Mg}	–	–	–	0.87	–	–	–	0.75	0.82	–	–
X_{An}	–	–	–	–	–	0.360	–	–	–	0.587	–
X_{And}	–	–	0.109	–	–	–	–	–	–	–	–
X_{Gr}	–	–	0.877	–	–	–	–	–	–	–	–
X_{Py}	–	–	0.003	–	–	–	–	–	–	–	–
X_{Sps}	–	–	0.012	–	–	–	–	–	–	–	–

Abbreviations: Di: diospide; Grs: grossular; Mc: microcline; Pl: plagioclase; Phl: phlogopite; Qtz: quartz; Sal: salite (clinopyroxene); Ves: vesuvianite; Wo: wollastonite.

*Total iron as Fe_2O_3 in vesuvianite and garnet.

$^\psi$Normalised to 50 cations.

$X_{Mg} = Mg/(Mg + Fe)$; $X_{An} = Ca/(Ca + Na + K)$.

5. Discussion

Phase relations in sample RG30 are shown in a projection from diopside and fluid onto the plane SiO_2-CaO-Al_2O_3 with correction for albite component in plagioclase (figure 3). The projection shows crossing of vesuvianite + quartz and wollastonite + grossular tie-lines which most probably resulted from unequal Fe–Mg partitioning between grossular and vesuvianite. Determination of ferrous/ferric ratio in the minerals is required to verify this conclusion.

Occurrence of pegmatite adjacent to the calc-silicate enclave raises the question that the unusual calc-silicate mineralogy might have developed due to contact metamorphism and metasomatism by pegmatite-derived fluid. However, the metamorphism of calc-silicate rocks was syntectonic with the major foliation-forming event in the area. On the other hand, the intrusion of pegmatite was post-tectonic because no foliation is developed in it. Thus, a contact metamorphic origin for the calc-silicate assemblages is ruled out.

Regional metamorphism in the Tatapani area took place at $P < 4$ kbar because reactions in a pelitic sequence 15 km north of Tatapani occurred below the aluminosilicate triple point and prograded from the stability field of andalusite to the sillimanite field (Sundararaman 2004). Plagioclase occurs in RG30, but is confined to microcline-rich layers, and is not found in direct contact with wollastonite. Grossular stably coexists with quartz, and therefore peak metamorphic temperature must have been below the reaction:

Grossular + quartz = anorthite + wollastonite.

The equilibrium temperatures for this reaction are 590 and 680°C at pressures of 2 and 4 kbar respectively, and the fluid composition for the stability of the assemblage grossular + quartz is

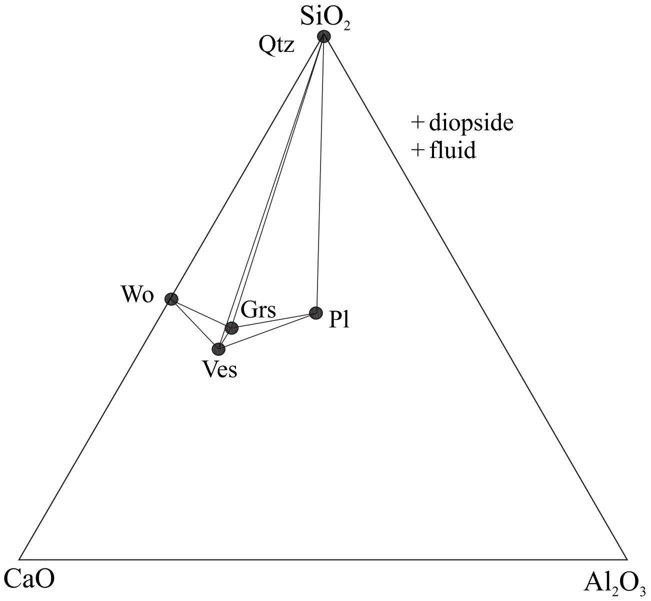

Figure 3. Chemographic projection from diopside and fluid onto the plane SiO_2-CaO-Al_2O_3 in the system SiO_2-CaO-Al_2O_3-MgO-H_2O-CO_2.

$X_{CO_2} (= H_2O/CO_2 + H_2O) < 0.15$ (Newton 1966; Gordon and Greenwood 1971). From these restrictions the metamorphism of Tatapani calc-silicate rocks is interpreted to be in the amphibolite facies at $P < 4\,\text{kbar}, T < 700°\text{C}$ and X_{CO_2} (fluid) < 0.15.

Contact metamorphic vesuvianite–wollastonite–grossular–calcite skarns have been in the Dalradian rocks by Ahmed-Said and Leake (1996) in Connemara, Ireland, and Johnson *et al* (2000) in Fraserburgh, Scotland. Ahmed-Said and Leake (1996) calculated $T = 620$ to $660°\text{C}$ and X_{CO_2} (fluid) $= 0.10$ to 0.20 at pressure of $3.3 \pm 0.3\,\text{kbar}$ for the Connemara scarn. Johnson *et al* (2000) deduced X_{CO_2} (fluid) < 0.20 in the Fraserburgh skarn at peak *P–T* conditions of 2.5 kbar and 600°C obtained from associated metapelites. The original bulk compositions of the Connemara and Fraserburgh skarns were poor in silica because they contain calcite and wollastonite. On the other hand, the Tatapani calc-silicate rocks are rich in quartz. The P–T–X_{CO_2} conditions of the Tatapani area and the above skarns are broadly similar even though the metamorphism in Tatapani is regional in nature. H_2O-rich composition of the ambient metamorphic fluid in the vesuvianite–wollastonite–grossular-bearing rock of Tatapani can be explained by the fact that the rock occurs in minor amount within phlogopite-bearing rock, which was originally rich in pelitic clay with abundant H_2O.

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