

**PETROGRAPHY AND GEOCHEMISTRY OF
AEGIRINE –ARFVEDSONITE BEARING GRANITE
GNEISS FROM DIMRA PAHAR, HAZARIBAGH
DISTRICT, JHARKHAND, EASTERN INDIA:
IMPLICATION FOR PETROGENETIC EVOLUTION**

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ABSTRACT

This paper reports for the first time occurrence of an alkali granite gneiss from Dimra Pahar, Hazaribagh district, Jharkhand. Alkali granite gneisses containing arfvedsonite and aegirine occur as a E-W trending elongate pluton (max^m length = 4.25 km and max^m width = 1.25 km) within biotite granite gneiss of Chhotanagpur Gneissic Complex. This alkaline pluton, lying on western extension of North Puruliya Shear Zone, has suffered shearing. The chemistry is highly alkaline and Ca-depleted. The dominant mineral phases are quartz, potash feldspar, arfvedsonite and aegirine. The chemical data of both the minerals and whole rock of alkaline granite gneisses are reported. The mineral assemblages and whole rock chemistry suggests A- type nature of the alkaline granite gneisses and zircon saturation temperature correspond to 1071°C to 801°C. . The petrographic study and mineral chemistry suggest that the alkaline pluton was subjected to amphibolite facies metamorphism followed by shearing. The parent magma of the granite gneisses was emplaced along the North Puruliya Shear Zone in a within-plate, rift- setting.

Keywords: *Alkaline Granite Gneiss, Arfvedsonite-Aegirine, North Puruliya Shear Zone, Amphibolite Facies*

I. INTRODUCTION

North Puruliya Shear Zone (NPSZ) of Puruliya district, West Bengal hosts variety of pralkaline and alkaline igneous rocks. A marked and distinct lineament in LANDSAT map coincides with the shear zone. The NPSZ has been established to an extent over a distance of around 80 Km from Raghunathpur in east (and possibly further east) through Panrkiidih, Nowahata, Jhalda of Puruliya district to Pehando Pahar of the Jharkhand state in the west. The NPSZ shows evidence of polyphase tectonic and granitic activities along the multifarious mineralization (apatite, magnetite, barite, beryl, allanite and bastnaesite) ([1];[2]). Occurrences of deformed

porphyritic granite gneisses, aegirine-riebeckite granite gneiss, alkali-feldspar-salite granite/syenite, nepheline syenite and other associated rocks (apatite-magnetite rock, minor carbonatite and pegmatite) have been reported from this shear zone ([3]).

The objective of this paper is to report new occurrence of an alkali granite gneiss from Dimra Pahar, about 3 Km west of Pehando Pahar lying on the same strike line, Hazaribagh district, Jharkhand and suggest the magmato- metamorphic evolution of this peralkaline granite gneiss on the basis of field occurrence, petrography and geochemistry.

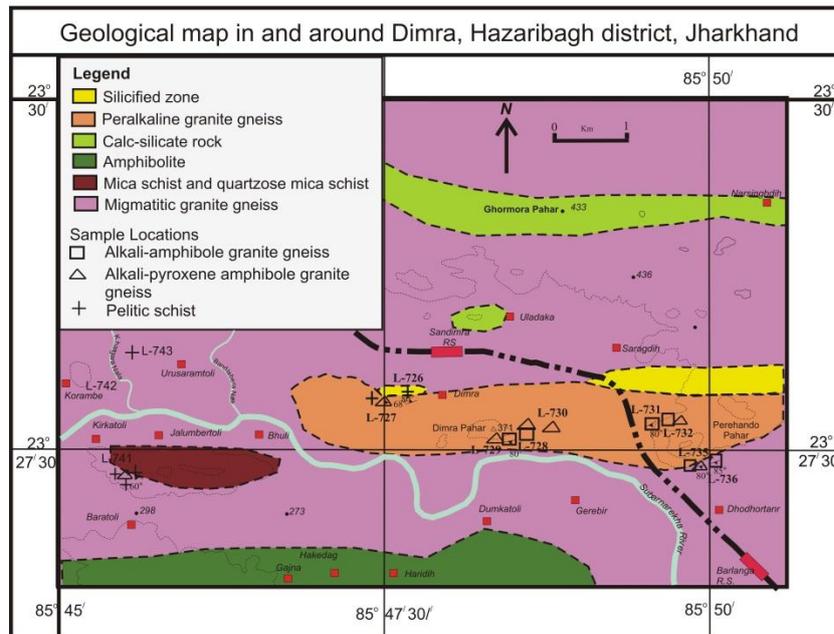


Fig 1 Geological map of the area around Dimra, Hazaribagh district, Jharkhand

II. GEOLOGICAL SET-UP

The major parts of Chhotanagpur Granite Gneiss Complex (CGGC) occurring in South Bihar and northern part of Jharkhand, is a vast gneissic terrain exposing complex assemblages of diversified rocks which witnessed several periods of magmatism, tectonism, sedimentation, metamorphism, partial melting and mineralisation that altered the pre-existing volcanic, plutonic and sedimentary rocks to a gneiss-granulite-granite association. The CGGC comprises extensive felsic gneisses and migmatites, enclaves of pelitic and mafic granulites, mica schist, metamorphosed dolomite and later intrusive represented by meta-gabbro, metadolerite, amphibolite, metamorphosed ultramafic rocks, anorthosite, granite, granodiorite, syenite, nepheline syenite, lamproite, pegmatite, alkaline lamprophyre, aplite etc. ([4]; [5]; [6]; [7]; [8];[9];[10]).

Ghose (1983) [11] classified the rock groups of CGC into three distinct lithostratigraphic units, viz; (a) crystalline basement (older granite gneiss) (b) older metasediments(pelitic, calcareous, psammitic metasediments) (c) late intrusives .They considered that these units are products of two major orogenic phases, namely the Chhotanagpur orogeny (1.6-1.5 Ga) and Satpura Orogeny (0.90-0.85Ga). Two tectonothermal events characterised by profuse granite magmatism occurred at $\sim 1600 \pm 50$ Ma and other more dominant, at 900-1000 Ma.

III. PREVIOUS WORK

Several studies have been made so far on the petrology and geochemistry of alkaline gneisses of NPSZ. Das and Bhattacharyya (2007)[12] have reported occurrence of aegirine-riebeckite granite-gneiss from Pehando Pahar (Lat. 23°27'30"N, Long. 85°50' E) and salite-granitoids from Panrkidih (Lat. 23°25'N, Long. 85°50' E). Goswami and Bhattacharyya (2008)[13] studied the metamorphism of miaskitic nepheline syenite from Kankarkiari and Kusumda lying on the eastern extremity of NPSZ. Bhowmik et al. (1990) studied the geochemistry and mineralogy of Kankarkiari and Kusumda occurrences.

Very brief petrographic description of aegirine-arfvedsonite bearing syenite has been given by Verma and Barla (Progress Report, Geol. Surv. India, 1994-1995) from south of Dimra without giving any details of geochemistry and mineral chemistry.

IV. FIELD OCCURRENCE

The peralkaline granite gneiss body is composed dominantly of biotite granite gneiss with subordinate patches of arfvedsonite-aegirine granite gneiss. This composite granite gneiss occurs as an E-W elongate lensoid body (max =4.25Km and max width =1.25Km) with in the migmatitic granite gneiss country (Fig.1). Along the northern boundary of the peralkaline granite gneiss body with the migmatitic granite gneiss country rock there is a discontinuous E-W belt of silicified zone. The peralkaline granite gneiss body, generally with steeply dipping NE-SW strike encloses enclaves of mica schist and quartz mica schist in the western and central part. Apart from the metapelitic schists such as almandine-muscovite-biotite schist the other metamorphites include amphibolite and calc-silicate rock. The general trend of strips of metasedimentaries is nearly E-W.

V. PETROGRAPHY

The rock body under study is a light coloured, medium-grained strongly gneissic. The gneissosity is clearly defined by extremely thin layers of ferromagnesian minerals alternating with thicker bands of patchy quartzo-feldspathic minerals. It can be noted that the elongation of both quartzo-feldspathic and ferromagnesian minerals is strongly oriented along the trend of gneissosity and foliation (Fig.3).

The primary minerals present are quartz, K-feldspar (microcline), sodic amphibole, and aegirine. The accessory minerals are zircon, plagioclase, sphene, ilmenite, and allanite. Alteration minerals include sericite, chlorite and hydrous iron oxides such as limonite. There are no primary micas.

Quartz grains exhibit a slightly ellipsoidal or lenticular shape with the elongation parallel to the direction of gneissosity and shearing. Undulose extinction is common, and subgrain development has been observed in the mylonitic slides. Average size of grain is around ~0.05 mm.

Abundant fluid inclusions following paths along grain boundaries (and sometimes through grains where there may have once been boundaries) and cracks are seen best in slide L736D. This observation is consistent with the suggestion that these quartz grains crystallized from a late, volatile-saturated magma. The feldspar is almost exclusively K-feldspar (fresh microcline), although several plagioclase grains have been identified slide (731A). Tartan-twinning, sericitization, and perfect cleavage are the commonly present distinguishing features of K-feldspar. Grain sizes range from ~0.1-2.0mm. Feldspar grains are generally coarser than their quartz. It may

contain inclusions of aegirine and alkali-amphibole. Very few feldspar grains appear to be significantly altered. EPMA studies have shown a consistent chemical composition of (Or₉₄ to Or₉₇) of potash feldspar grains (Table 1).

The amphiboles are dark blue to opaque, exhibiting blue-green and blue to blue-black pleochroism, which is characteristic of both arfvedsonite and riebeckite. However, grains have also been found exhibiting distinctly arfvedsonitic characteristics (anomalous extinction), but they are less common than grains exhibiting normal extinction. Grain size (long diameter) ranges from ~0.05-1.5mm. The grains are typically prismatic and occasionally occur as thin laths. Amphibole rarely occurs as medium-sized, elongate bluish inclusions within green aegirine.

The sodic amphibole grains are essentially arfvedsonite. The existence of sodic amphibole as a single phase has been supported by EPMA studies, which show a consistent chemical composition among grains (Table 1).

Green pleochroic grains of aegirine are present in very few slides, and when present, are always less abundant than alkali-amphiboles in unaltered slides. These occur as sub-idiomorphic to xenoblastic, elongate, generally prismatic, and occasionally tabular grains. They are typically oriented parallel to the gneissic trend. It commonly occurs associated with arfvedsonite in unaltered slides. Aegirine occurs as poorly formed, cracked and altered grains typically concentrated in gneissic banding. Grain sizes range from ~0.05-2.0 mm. Chemical compositions of aegirine are given in Table 1.

Aegirine has been observed altering to brown iron oxides (Slide 731). Some of these altered grains are weakly pleochroic to nonpleochroic. The colour of heavily altered grains is generally paler than less altered grains. This is likely to be the result of leaching of Na and/or Fe³⁺ from aegirine.

The accessory minerals present in these slides, as already mentioned, are (in order of abundance): zircon, sphene, ilmenite, plagioclase, and allanite. Sodic amphiboles at high temperatures are known to accommodate elevated levels of Zr which may have been expelled below a certain temperature threshold. The expelled Zr would then form zircon.

Sphene occurs as medium-sized, equant, subidiomorphic, squarish grain within quartzo-feldspathic aggregates and occasionally at the margin of quartzo-feldspathic and ferromagnesian minerals. The presence of sphene again points to an incomplete Ca fractionation. Zircon occurs as inclusion in quartz or feldspar and also at the contact between them as small elongate pyramidal ends. The presence of ilmenite has been confirmed through EPMA studies. Metamic allanite is present with radial fine opaque filled fibrous cracks.

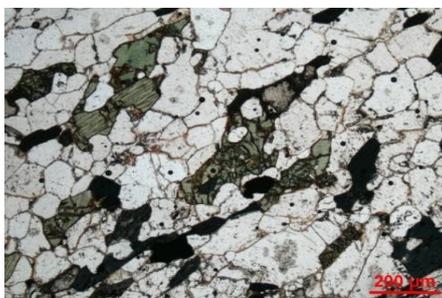


Fig.3 Gneissic texture in arfvedonite- aegirine (dark colour and green coloured) granite gneiss

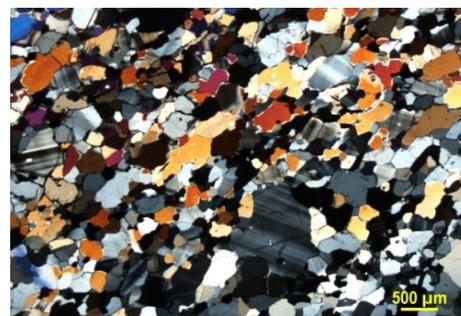


Fig.4 Lenticular quartz oriented along the gneissic trend in alkaline granite gneiss. Note shadowy extinction of coarser microcline

VI. MINERAL CHEMISTRY

6.1. Aegirine

The aegirine analyzed is represented by essentially pure end-member aegirine, with only minor (<1.6%) Ca (Fig.3A and Fig 3B). The average Na₂O content is 12.61%. Although this is a higher sodium content than in arfvedsonite, arfvedsonite is hypothesized to be the more favorable sodium sink due to its superior modal volume. This may have resulted from metamorphic recrystallization, when aegirine was breaking down in favor of forming arfvedsonite.

The aegirine was chemically similar to that from Quincy, Massachusetts ([15]) where it occurs with riebeckite in microperthitic granites at Quincy. At Quincy, the rock is more silica rich, which is also seen in the present area. This could indicate similar magmatic evolutionary paths ([16])

6.2 Arfvedsonite

The plots in Ca + IV Al vs. Na+K+Si diagram ([17]) that amphiboles are represented by essentially pure end members arfvedsonite (Fig.4). The chemical composition of each grain is highly consistent, with the highest disparity in concentrations seen in FeO_t (0.81% difference). The crystallization of arfvedsonite over riebeckite may indicate higher K saturation. Arfvedsonite and aegirine are the only two minerals with any appreciable Ca concentration. The concentration of Ca in the arfvedsonite grains varies from 0.27-0.53%, while the concentration of Ca in aegirine varies from 0.98-1.6%.

It is possible that Ca entered into arfvedsonite after aegirine destabilized, which may have provided the ingredients to crystallize more arfvedsonite. The chemistry of this arfvedsonite was similar to arfvedsonite from an arfvedsonite-aegirine syenite from Kap Boswell, Greenland ([15]).

Arfvedsonites generally crystallize at the late-stage magmatic stage ([17]). However, Pla Cid et al. (2001) ([18]) have shown that magmatic Riebeckite / arfvedsonite / winchite grains can be discriminated from metamorphic grains with their higher Ca-contents at a constant (Na + K) concentrations. Arfvedsonites of the present study plot between the areas of magmatic and metamorphic amphibole signifying partial recrystallization of the Dimra Pahar amphiboles.

Giret et al. (1980) shown that in rocks whose agpaitic index ($A.I. = \frac{Na_2O + K_2O}{Al_2O_3}$) is less than 0.9, the Ca + Al^{iv} content of amphiboles is more than 2.5, whereas it is less than 2.5 in agpaitic rocks with A.I.> 0.9. Ca+Al^{iv} of arfvedsonite of present ranges between 0.239 and 0.353 per formula unit (Table1) which clearly states that the granitoids of present study are agpaitic in nature.compared to the normal granites.

6.3 Feldspar

EPMA results for the alkali feldspar grains were very surprising in that the chemistry was both consistent and represents essentially a purely potassic end-member (Fig.5D). This together with the absence of detectable Ca stand as evidence against the presence of the microperthitic feldspar. It is theorized that a metamorphic recrystallization event occurred which allowed the grains to purge themselves of impurities.

Fe was detected in an appreciable concentration (0.36%), which, this is likely due to micro-inclusions of opaque oxide.

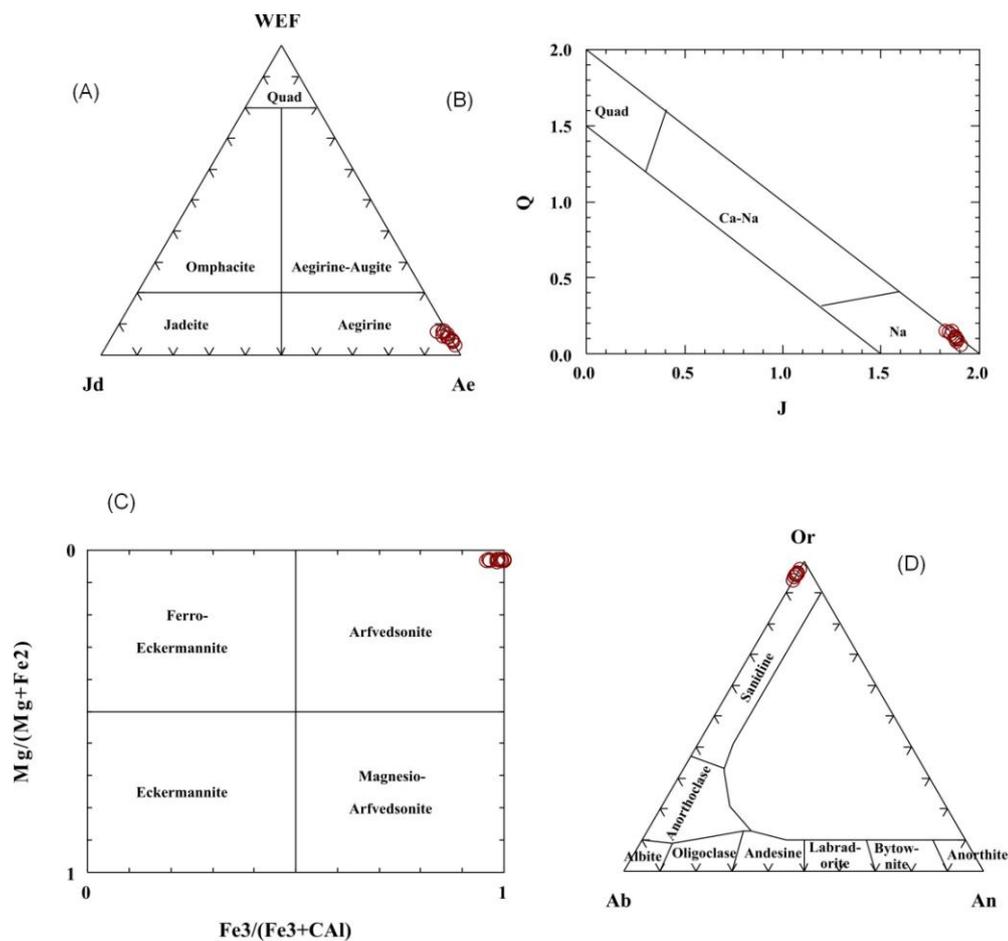


Fig 5 (A) and (B) Plots of alkali pyroxenes in the classification diagrams of pyroxenes proposed by Morimoto (1980)(41). $Q = Ca + Mg + Fe_{2+}$ and $J = 2Na$. (C) Plots of alkali amphiboles of Dimra Pahar granitoids in the classification diagram of Leake et al. (1997) (42). (D) Compositional plots of K- feldspar.

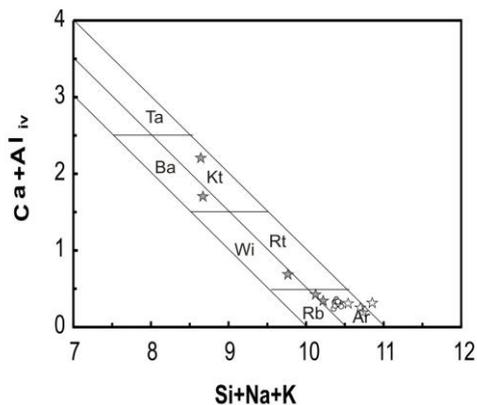


Fig 6. Composition of amphiboles of Dimra Pahar plotted on the Aliv+Ca vs. Si+Na+K classification diagram of Giret et al (1980).

VII. WHOLE ROCK CHEMISTRY

Major element data of six samples (Table 2) indicate that the granite gneiss are high in silica (88.39-73.64%) and alkali content, Na₂O (4.52-1.08%) and K₂O (5.07-2.04%). Al₂O₃ varies from 12.03%-0.25%. The rocks are characterized by total iron content as Fe₂O₃(t) from 4.85 to 0.74%, low content of MgO (0.86-0.04), CaO (0.32-0.02), TiO₂ (.43-0.13%) and MnO (0.06-0.01%). In general the granites are enriched in Zr(111-2011ppm).

Table 1. Compositions of sodic-pyroxene, sodic amphibole and feldspars from Dimra Pahar peralkaline pluton

Minerals	Pyroxene		Amphibole					K-Feldspar					Na-Feldspar		
	Sample No.	727	730A	735	735 C	727A	730	735	735	735C	735A	727	730	735C	735
No of points	n=6	n=12	n=5	n=8	n=5	n=6	n=4	n=3	n=3	n=10	n=4	n=10	n=2	n=2	n=1
SiO ₂	52.27	51.54	49.06	48.59	43.71	48.76	48.96	64.61	64.04	64.42	64.87	63.72	68.5	68.65	69
TiO ₂	0.24	0.48	0.41	0.62	0.58	0.71	0.62	0	0	0.02	0.01	0.01	0	0.01	0
Al ₂ O ₃	0.56	0.72	1.19	1.07	1.3	1.38	1.14	18.21	17.95	17.94	18.04	17.9	19.19	19.05	19.09
FeO(t)	30.93	30.78	35.02	33.7	35.28	35.42	34.44	0.34	0.5	0.27	0.38	0.4	0.65	0.51	0.42
MnO	0.1	0.1	0.56	0.52	0.53	0.59	0.52	0	0.02	0.01	0.01	0.02	0.02	0.05	0
MgO	0.05	0.05	0.11	0.79	0.5	0.46	0.71	0.01	0	0.01	0.02	0.01	0	0	0
CaO	1.09	1.32	0.13	0.33	0.39	0.43	0.37	0	0	0	0	0	0	0.01	0.01
Na ₂ O	12.4	12.6	7.42	7.25	7.22	7.45	7.39	0.31	0.42	0.49	0.56	0.49	11.12	11.485	11.38
K ₂ O	0	0.01	1.96	1.63	1.65	1.85	1.75	17.4	16.94	16.99	16.5	16.78	0.13	0.18	0.14
Cr ₂ O ₃	0	0	0.03	0.41	0.05	0.01	0.06	0.02	0.01	0.01	0	0.02	0.04	0.06	0.07
Total	97.64	97.60	95.90	94.92	91.18	97.06	95.91	100.90	99.88	100.16	100.39	99.35	99.65	100.01	100.11

Table 2. Major and trace element composition of Dimra Pahar peralkaline granites.

Sl No	1	2	3	4	5	6	7	8	9
Sample	727A	736 D	730A	732C	735C	728F	AD225b	AD271a	AD259a
SiO ₂	74.21	73.76	74.05	74.54	73.64	88.39	78.7	74.67	75.09
Al ₂ O ₃	11.53	11.31	12.03	11.11	11.77	6.14	10.08	12.36	11.5
TiO ₂	0.24	0.25	0.24	0.24	0.28	0.03	0.25	0.28	0.43
Fe ₂ O ₃	3.84	4.85	3.66	4.84	3.64	0.74	1.77	0.45	0.32
FeO	nd	nd	nd	nd	nd	nd	0	2.01	1.5
MnO	0.05	0.05	0.04	0.02	0.04	0.01	0.02	0.03	0.06
MgO	0.54	0.53	0.52	0.53	0.57	0.86	0.25	0.04	0.09
CaO	0.32	0.04	0.08	0.04	0.08	0.07	0.02	0.16	0.17
Na ₂ O	4.21	4.06	4.13	3.32	4.52	1.08	2.77	3.82	3.9
K ₂ O	4.73	4.64	4.83	4.68	4.73	2.04	4.48	5.07	4.73
P ₂ O ₅	0.01	0.03	0.03	0.02	0.01	0.02	0.04	0.02	0.02
LOI							1.09	0.03	0.03
Total	99.68	99.52	99.61	99.34	99.28	99.38	99.47	98.94	97.84
Ba	<15	<15	<15	14	<15	18			
Rb	246	227	272	279	232	101			
Sr	17	11	13	15	12	13			
Ni	<5	<5	<5	<5	<5	<5			
Cr	<5	<5	<5	<5	<5	<5			
Cu	<5	<5	<5	<5	<5	8			
Pb	10	14	12	6	17	6			
Nb	109	108	142	192	123	8			
Zr	543	623	773	2011	741	111			
Y	51	65	45	55	66	30			
T Zr	889	911	938	1071	924	801			
A.I.	1.04	1.03	1	0.95	1.07	0.65	0.93	0.95	1

T Zr :Zircon saturation temperatures, in degree Celsius

A.I.: Apatitic Index

Data source of Sl 7, 8, 9: Das and Bhattacharyya (2007)

7.1 Granite Classification in A-I-S-M Types

High $\text{Na}_2\text{O}+\text{K}_2\text{O}$, Fe/Mg, Zr, Y, Nb and REE (except Eu), Rb/Sr>1, and low abundances of CaO and MgO, Al_2O_3 , Ba, Sr are characteristics of A-type granite ([19];[20]). One or more of such ferromagnesian minerals as ferromagnetite, alkali amphibole, and sodic pyroxene ([19];[20];[21]) are typical of A-type granite.

7.2. Temperature of Crystallization of Alkali Granite Magma

The zircon concentration of DimraPahar pluton has wide range (2011-111ppm). The estimated Zr saturation temperatures ($T_{\text{Zr}}^{\circ}\text{C}$) were calculated for pluton. The Dimra Pahar granites gave the range of estimated temperatures between 1071°C and 801°C. The temperature estimates for Dimra Pahar pluton are within the expected temperature range of some A- type granitic rocks (870-950°C) ([22], [23],[24],[25]). The high temperature estimates would suggest that the magmas were dry. Considering the basaltic origin of the peralkaline granitoids and experimental studies, magmatic temperature estimates are not unreasonable ([26];[27]).

In Dimra Pahar granites, the upper stability limit for F-free arfvedsonite is nearly 700°C ([28]). F is expected to increase the thermal stability of arfvedsonite significantly because experimental data for richterite composition ([29]) show a difference in the F and OH stabilities of 300°C in low-pressure range. Thus, the crystallization of the magmatic assemblage of granite occur at temperatures >750° C.

7.3 Magma Oxidation State

The presence of titanite (sphene), quartz and ilmenite in DimraPahar Granites indicates $f\text{O}_2$ condition at or above the FMQ buffer ([29];[30];[31];[32]). Applying the equilibrium equation of Wones (1989), estimated Log $f\text{O}_2$ values for the DimraPahar fall along the TMQ-HDIL curve. The calculated values ($\log f\text{O}_2 = -11$ bar at around 850°C) are assumed to be maximum. The low-Mg amphibole in the DimraPahar granitoid is consistent with experimentally derived amphiboles from reducing ($f\text{O}_2 = \text{FMQ}-1$) conditions (Fig 7) ([33];[34]).

7.4 Pressure of Crystallization of magma

Presence of aegirine and sphene in some of the samples of Dimra Pahar suggest $f\text{O}_2$ was higher than the NNO buffer. However, absence of biotite in Dimra samples suggests that the magma was not saturated with water. This in turn suggests that the crystallization of arfvedsonite from the magma took place 670°C. But absence of fluorite strongly suggests that the magma was not absolutely dry and water could act to stabilize the arfvedsonite. It would be not unjust to take arfvedsonite crystallization temperature at around 700°C at $\text{H}_2\text{O}=4\%$ and pressure 1.5 kbar ([35]).

7.5 Magmatic history of DimraPahar Granites

The presence of arfvedsonite clearly indicates that the parental magma of this granite was agapatic. The studied A-type granites are highly siliceous, have extremely high Rb/Sr ratios, and display distinct Sr, Ba and Eu depletions. These features clearly indicate that they were highly evolved, and thus, large amounts of fractional

crystallisation are necessary to account for both major- and trace-element compositions. The mineralogical and chemical compositions of Dimra Pahar granites are homogeneous, indicative of near-solidus crystallisation ([36]). This also characterises high degrees of fractional crystallisation, and consequently, the A-type Dimra Pahar granitic magma can be considered as residual liquids originated by crystallization of mafic parental magma.

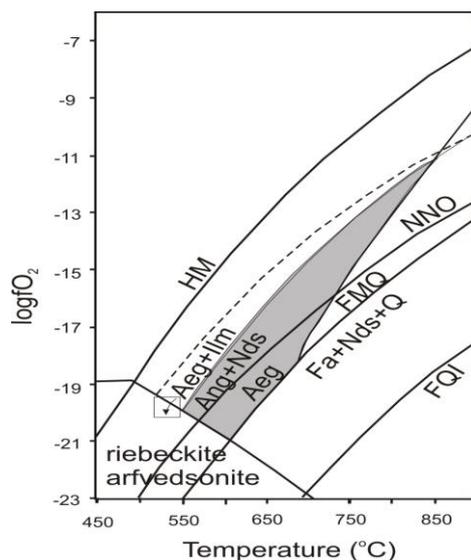


Fig. 7. Log fO_2 -Temperature diagram showing magmatic and metamorphic evolution of an alkaline granite gneiss, Note the temperature and O_2 fugacity (box with arrow) of subsolidus assemblage of aegirine + ilmenite + arfvedsonite. The system evolved between Ni-NiO (NNO) and ilmenite- sphene buffer from more than 1000 to around 500° C.

7.5. Tectonic Setting of Emplacement

The study granites plot in the field of within plate granites in the Rb vs. Nb + Y tectonic discrimination diagram after Pearce et al. (1984) (Fig.8A). In the Y vs. Nb tectonic discrimination diagram (Pearce op. cit), most of the samples plot in the field of within plate granite (Fig. 8B). In the Maniar and Piccoli (1989) plot, the granites of the study area fall in the field of rift related granites (Fig. 8C). In the Y/Nb vs. Rb/Nb diagram the Dimra samples plot in the A1-type granitoid field signifying that the magma generated from a OIB-type basaltic magma in a within-plate setting (Fig. 8D).

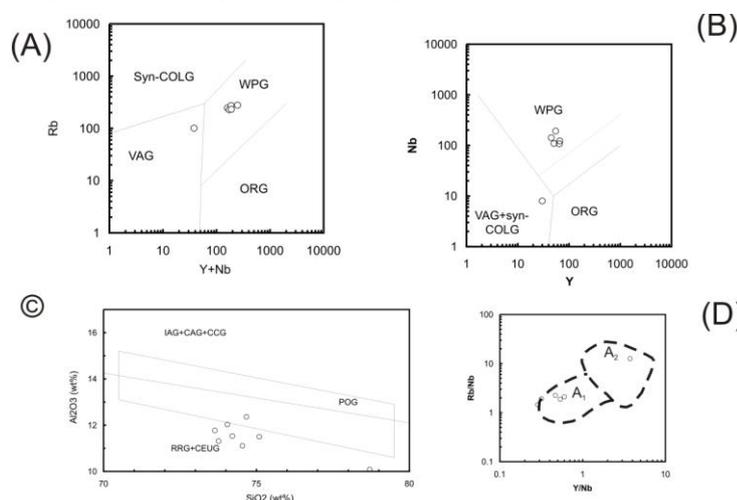


Fig 8. plot of DimraPahar pluton in tectonic discrimination diagrams. (A) Y+Nb vs. Rb, (B) Y vs. Nb, (Pearce et al., 1984) (c) SiO₂ vs. Al₂O₃ (Maniar and Piccoli, 1989) and Y/Nb vs. Rb/Nb (Eby, 1992) diagrams.

VIII. INTRINSIC PARAMETERS OF METAMORPHISM

In the peralkaline granites of Dimra Pahar, all the constituting minerals, such as K-feldspar, aegirine (Fig7), arfvedsonite, ilmenite etc. exhibit nearly pure end-member composition. This character clearly suggests that the rock is likely to be metamorphosed and recrystallized.

The intrinsic parameters for the granite during magmatic cooling are derived from the observation that there is movement out of the aegirine stability field during crystallization (indicated by disseminated and stubby grains). Aegirine utilizes ferric iron in its formula, so it is more stable than sodic amphiboles (which contain both Fe^{2+} and Fe^{3+}) under highly oxidized conditions. The presence of ilmenite suggests that the approximate temperature of aegirine crystallization is $\sim 550^{\circ}C$, with a $\log fO_2$ of -19 to -20 unit, with sodic amphiboles forming when temperatures approached $\sim 500^{\circ}C$ ([15]). "Under oxidation conditions controlled by iron-wüstite and wüstite-magnetite buffers, aegirine ceases to be stable and is replaced by an arfvedsonite-riebeckite solid solution" ([15]). Therefore, a change in oxygen fugacity may have been the catalyst for the assemblage change from sodic pyroxene to sodic amphibole.

The assemblage aegirine + arfvedsonite is stable at high Na_2O activity over a wide range of oxygen fugacities ([37]). However, at high SiO_2 activity, the same assemblage can be stabilized to lower Na_2O activity. At lower fO_2 values, aegirine becomes unstable and arfvedsonite is favored ([37]). The initial fO_2 may have been determined by the magnetite-hematite buffer before the fO_2 in the melt fell to the wüstite-magnetite buffer. The change in fO_2 would cause the assemblage change seen in the samples. It is indeterminate if the change of assemblage from sodic pyroxenes to sodic amphiboles was driven by changes in temperature, oxygen fugacity, or other factors.

After evaluating the molar percent of albite pressure (Kbar) for the mineral assemblage was approximated using the figure given by Deer et al. (1997, Fig. 229 p. 498) ([15]). An approximate feldspar composition of Ab₃ Kf₉₇ was determined using the average ratio of K to Na obtained from EPMA.

The fCO_2 and pH_2O could not be determined. Although a quantitative pH_2O value cannot be calculated, the presence of abundant fluid inclusions in several slides (L735, L736) suggests relatively high water content during the final stages of cooling.

IX. DISCUSSION

9.1 Origin

Peralkaline granitoids are suggested to be formed by differentiation of transitional or alkali basalt magma ([38],[39],[40]) from which early formed minerals like plagioclase etc. removes Ca leaving residual magma to be K-rich (+Na). The peralkaline rocks of present study are almost devoid of plagioclase feldspar and can be formed from the Ca fractionation of basaltic parent magma or very low degree partial melting of mantle rocks ([41]). The Ca fractionation appears to be extensive in rocks of present day.

The overwhelming dominance of K-feldspar over plagioclase feldspar suggest that an extremely Ca-depleted system as indicated by rare presence of the latter and low concentration of Ca in both amphibole and pyroxene. The QAP modal percentages of the alkaline granite gneiss thin sections ranged from Q70 A30P0 to Q88P0, which plot as a quartz-rich granitoid in Streckeisen's (1976) diagram. A high silica content generally indicates highly evolved magma.

The original igneous minerals are postulated to be (in order of abundance): quartz, K-feldspar, arfvedsonite, and aegirine. Accessory minerals are zircon, sphene, plagioclase feldspar and allanite. A shear zone may have facilitated the intrusion of alkaline magma into the country rock and shearing continued after solidification of intruded alkali magma.

The first of the major minerals to crystallize were likely the sodic ferromagnesian minerals: arfvedsonite and aegirine. A low Al, high Fe content may have favored amphiboles and pyroxenes as the dominant mafic phase, leaving Al and K to crystallize K-feldspar instead of muscovite mica. Inclusions of arfvedsonite within aegirine suggest that the former mineral began to crystallize earlier than the latter.

Arfvedsonite grains in these slides are typically euhedral and free from inclusions and alteration. Despite the existence of numerous perfectly euhedral grains, many of the amphibole grain boundaries simultaneously disrupt and are disrupted by quartz and alkali feldspar, with the former being more prevalent. This may mean that arfvedsonite was still crystallizing after other phases began to form. A possible mechanism for fast cooling is conduction with the cooler country rock which may have chilled the magma.

The generally poor development of crystal faces may indicate that aegirine was a late-forming mineral, or that the aegirine grains were being broken down during the formation of gneissic banding by metamorphism and deformation.

As stated previously, aegirine may also break down under IW and WM buffers to form riebeckite-arfvedsonite. Therefore, a change in magmatic f_{O_2} may have caused the destabilization of aegirine, in favor of forming amphiboles. Alternatively, earlier-formed idiomorphic aegirine may have lost some of its subhedral or euhedral crystal outlines due to replacement by Na-amphiboles.

9.2 Metamorphic Facies

The presence of Na-amphibole alone in the mineral assemblage of alkali granite gneiss does not necessarily indicate that high pressure metamorphism occurred. The presence of almandine garnet in the surrounding mica schist country rock suggests that the area underwent at least greenschist-amphibolite transition facies metamorphism or lower part of amphibolite facies. Hence it can be inferred that the primary mineral assemblage (quartz-microcline-soda pyroxene-soda amphibole) crystallized from an intrusive magma along the western extension of North Puruliya Shear Zone and was subjected to regional metamorphism under greenschist-amphibolite transitional or lower amphibolite facies metamorphism, giving rise to strong orientation of most minerals parallel to gneissosity.

9.3 Tectonic Settings

Due to the overwhelming evidence in favor of the influence of shear forces on these rocks, and the participation of unstable aegirine in gneissic banding, it is proposed that the magma intruded along a pathway created by a fault. The large L/W ratio of the granite gneiss body implies that this was an intrusion following a pathway rather than a large pluton and hence it is possible that emplacement of magma along narrow channel facilitated development of magmatic foliation. However, forces acting on the magma prior to solidification, resulting in foliation.

It is postulated that later fault activity continued to add shear stress post-crystallization, and may have resulted in the mylonitic texture seen in some slides. High temperature conditions associated with shearing are not favored due to the lack of annealing of mylonitized grain boundaries.

This fault zone corresponds to the western extension (into the adjoining Hazaribagh district of Jharkhand state) of the North Puruliya Shear Zone.

X. CONCLUSION

A rift related fault (North Puruliya Shear Zone) facilitated the intrusion of peralkaline magma into older continental crust suffering amphibolite facies condition. High pressure shearing acting on the solidified rock resulted in metamorphic recrystallization, the destabilization of aegirine, and the creation of mylonite and anisotropic tectonic fabrics in them. The original magma possibly from mantle and plagioclase fractionation is suggested to have produced the granitoid magma.

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REFERENCES

- [1] Das, D.K. "A brief resume of mineral investigation at Puruliya with a proposal." Jour. Mines Metals Fuels, Purulia Seminar, Spl. publication, (1977): 45-49.
- [2] Baidya, Tapan K. "Apatite-magnetite deposit in the chhotanagpur gneissic complex, Panrkidih area, Purulia District, West Bengal." Indian Journal of Geology 64, no. 1 (1992): 88-95.
- [3] Das, A. and Bhattacharyya, C (2007) "Alkaline granitoids from Northern Shear Zone of Puruliya district", J.Geol.Soc. India, 69, 2007, p.1208-1214
- [4] Ghose, N. C. "Geology, tectonics and evolution of the Chhotanagpur granite gneiss complex, Eastern India." Structure and Tectonics of Precambrian Rocks of India, Recent Researches in Geology 10 (1983): 211-247.
- [5] Kent, R. W., M. Storey, A. D. Saunders, N. C. Ghose, P. D. Kempton, Joseph R. Curray, and Tissa Munasinghe. "Comment and Reply on" Origin of the Rajmahal Traps and the 85° E Ridge: Preliminary reconstructions of the trace of the Crozet hotspot"." Geology 20, no. 10 (1992): 957-959.
- [6] Ghose, N. C., and D. Mukherjee. "Chhotanagpur gneissgranulite complex, Eastern India—A kaleidoscope of global events." Geology and Mineral Resources of Bihar and Jharkhand, Platinum Jubilee Commemoration Volume, Indian School of Mines, Dhanbad, Institute of Geoexploration and Environment, Monograph 2 (2000): 33-58.

- [7] Ghosh, Subhasish, A. E. Fallick, D. K. Paul, and P. J. Potts. "Geochemistry and origin of Neoproterozoic granitoids of Meghalaya, Northeast India: Implications for linkage with amalgamation of Gondwana Supercontinent." *Gondwana Research* 8, no. 3 (2005): 421-432.
- [8] Srivastava, Rajesh K., and NV Chalapathi Rao. "Petrology, geochemistry and tectonic significance of Palaeoproterozoic alkaline lamprophyres from the Jungel Valley, Mahakoshal supracrustal belt, Central India." *Mineralogy and Petrology* 89, no. 3-4 (2007): 189-215.
- [9] Mahadevan, T. M. "Precambrian geological and structural features of the Indian Peninsula." *Geological Society of India* 72, no. 1 (2008): 35-55.
- [10] N.C. Ghose, Geology, tectonics and evolution of the Chhotanagpur granite gneiss complex, Eastern India. In *Recent Researches in Geol.*, S. Sinha Roy (ed.), v.10, (1983): 211-247.
- [11] Banerji, A.K. Banerji, A.K., 1991: Presidential address. Geology of the Chhotanagpur region. *Indian Jour. Geol.*, 63(4) (1991): 275-282.
- [12] B.Goswami, and C.Bhattacharyya, (2008): Metamorphism of Nepheline Syenite Gneisses from Chhotanagpur Granite Gneiss Complex, Northeastern Puruliya district, Eastern India, *Jour. Geol. Soc Ind.*, v.71, pp. 209-213.
- [13] T. Bhaumik, , S. Mukherjee, and A.Bose, (1990) Petrology of Nepheline Syenites from Santuri Puruliya District, West Bengal. *Jour. Geol. Soc. Ind.*, v.36, p.589-606.
- [14] B.Goswami, and C.Bhattacharyya, (2014): Petrogenesis of Shoshonitic Raghunathpur porphyritic granitoids, Chhotanagpur Gneissic Complex, Eastern India: Implications for the Late Grenvillian post-collisional magmatism. *Geoscience Frontiers.*, v.5(6) p.821-843.DOI.10.1016/j.gsf.2013.09.003
- [16] Paul C. Lyons, and W. Krueger. Harold. "Petrology, chemistry, and age of the Rattlesnake pluton and implications for other alkalic granite plutons of southern New England." *Geological Society of America Memoirs* 146 (1976): 71-102.
- [17] A. Giret, B. Bonin, J.M. Leger Amphibole compositional trends in oversaturated and undersaturated alkaline plutonic ring-complexes *Can. Mineral.*, 18 (1980), pp. 481–495
- [18] Cid, J. Plá, L. V. S. Nardi, H. Conceicao, and B. Bonin. "Anorogenic alkaline granites from northeastern Brazil: major, trace, and rare earth elements in magmatic and metamorphic biotite and Na-mafic minerals." *Journal of Asian Earth Sciences* 19, no. 3 (2001): 375-397.
- [19] W. J Collins, S. D. Beams, A. J. R. White, & B. W. Chappell 1982. "Nature and origin of A-type granites with particular reference to Southeastern Australia. *Contributions to Mineralogy and Petrology* **80**, 189–200.
- [20] Joseph B. Whalen, Kenneth L. Currie, and Bruce W. Chappell. "A-type granites: geochemical characteristics, discrimination and petrogenesis." *Contributions to mineralogy and petrology* 95, no. 4 (1987): 407-419.
- [21] G. Nelson. Eby, "The A-type granitoids: a review of their occurrence and chemical characteristics and speculations on their petrogenesis." *Lithos* 26, no. 1 (1990): 115-134.
- [22] Stuart F Simmons, Noel C. White, and David A. John. "Geological characteristics of epithermal precious and base metal deposits." *Economic Geology* 100th anniversary volume 29 (2005): 485-522.

- [23] G. Shellnutt and Y. Iizuka Mineralogy from three peralkaline granitic plutons of the Late Permian Emeishan large igneous province (SW China): evidence for contrasting magmatic conditions of A-type granitoids. *Eur. J. Mineral.* (2011), 23: 45–61
- [24] J. G. Shellnutt, and B-M. Jahn. "Formation of the Late Permian Panzihua plutonic-hypabyssal-volcanic igneous complex: Implications for the genesis of Fe–Ti oxide deposits and A-type granites of SW China." *Earth and Planetary Science Letters* 289, no. 3 (2010): 509-519.
- [24] J. Gregory Shellnutt, , Mei-Fu Zhou, and Georg F. Zellmer. "The role of Fe–Ti oxide crystallization in the formation of A-type granitoids with implications for the Daly gap: an example from the Permian Baima igneous complex, SW China." *Chemical Geology* 259, no. 3 (2009): 204-217.
- [25] White, J.C., Ren, M., Parker, D.F. (2005): "Variation in mineralogy, temperature, and oxygen fugacity in a suite of strongly peralkaline lavas and tuffs, Pantelleria, Italy". *Can Mineral.*, 43, 1331–1347.
- [26] J.D. Clemens, J.D, J.R., Holloway, White, A.J.R. (1986): Origin of an A-type granite: experimental constraints. *Am. Mineral.*, 71, 317–324.
- [27] Jonathan. D. Price, John P. Hogan, M. Charles Gilbert, David London, and George B. Morgan. "Experimental study of titanite-fluorite equilibria in the A-type Mount Scott Granite: Implications for assessing F contents of felsic magma." *Geology* 27, no. 10 (1999): 951-954.
- [28] D. K. Bailey, "The stability of acmite in the presence of H₂O." *Amer. J. Sci.* 267A (1969): 1-16.
- [30] D. R. Wones, "Mafic silicates as indicators of intensive variables in granitic magmas: *Mining Geology*, v. 31." (1981): 191-212.
- [31] Platt, R. Garth, and Alan R. Woolley. "The mafic mineralogy of the peralkaline syenites and granites of the Mulanje complex, Malawi." *Mineralogical Magazine* 50, no. 355 (1986): 85-99.
- [32] D.Xirouchakis., D.H.,Lindsley ,(1998) Equilibria among titanite,hedenbergite, fayalite, quartz, illmenite and magnetite: experiments and internally consistant thermodynamic data for titanite. *Am.Mineral.* 83,712-725
- [33] Wones, D.R. (1989): Significance of the assemblage titanite + magnetite + quartz in granitic rocks. *Am. Mineral.*, 74, 744–749.
- [34] Scaillet, Bruno, and Ray Macdonald. "Experimental and thermodynamic constraints on the sulphur yield of peralkaline and metaluminous silicic flood eruptions." *Journal of Petrology* 47, no. 7 (2006): 1413-1437.
- [35] Scaillet, Bruno, and R. A. Y. Macdonald. "Phase relations of peralkaline silicic magmas and petrogenetic implications." *Journal of Petrology* 42, no. 4 (2001): 825-845.
- [36] Martin, R.F. (2007): Amphiboles in the igneous environment. *Rev. Mineral. Geochem.*, 67, 323–357.
- [37] Marks, Michael AW, Kai Hettmann, Julian Schilling, B. Ronald Frost, and Gregor Markl. "The mineralogical diversity of alkaline igneous rocks: critical factors for the transition from miaskitic to agpaitic phase assemblages." *Journal of Petrology* 52, no. 3 (2011): 439-455.
- [38] B. Bonin (2007) A-type granites and related rocks: evolution of a concept, problems and prospects. *Lithos* 97(1–2):1–29.
- [39] Franco Barberi, and J. Varet. "Recent volcanic units of Afar and their structural significance." In *Afar depression of Ethiopia*, Schweizerbart Stuttgart, vol. 1, 1975, pp. 174-178.

- [40] P.Brotzu, L. Morbidelli, M. Nicoletti, E. M. Piccirillo, and G. Traversa. "Miocene to Quaternary volcanism in eastern Kenya: sequence and geochronology." *Tectonophysics* 101, no. 1 (1984): 75-86.
- [41] C.N. Morimoto, 1988. Nomenclature of pyroxenes. *Mineralogical Magazine* 52, 535-550.
- [42] B.E Leake, A.R.Woolley, C.E.S. Arps, W.D. Birch, E.A.J.Burke, G.FerrarisGrice, J.D., F.C. Hawthorne, H.J.,Kisch, V.G. Krivovichev, J.C. Schumacher, N.C.N.Stephenson, E.J.W.Whittaker, (2004): Nomenclature of amphiboles: additions and revisions to the International Mineralogical Association's amphibole nomenclature. *Eur. J. Mineral.*, 16, 191–196.

Book

- [43] W.A. Deer, R.A. Howie, J. Zussman, (1997a): Rock forming minerals volume 1A: orthosilicates. *Geol. Soc., London*, 919 p —, —, — (1997b): Rock forming minerals. 2B. Double-chain silicates. *Geol. Soc., London*, 764 p.
- [44] Myron G.Best, *Igneous and metamorphic petrology*. John Wiley & Sons, 1982.