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Granitoids[1] around the Malanjkhand copper deposit: Types and age relationship

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Abstract. On the basis of field relations, petrography and chemistry, three types of granitoids are recognized at Malanjkhand in and around the copper deposit over an area of about 200 km^2. These are (i) a fine grained 'leucogranite' of restricted occurrence in the surrounding area (Gr-I); (ii) coarse-grained, grey in most parts, gneissose granitoid of regional extension (Gr-II); and (iii) the pink-feldspar bearing massive type hosting the mineralization with occasional representatives in the surrounding country (Gr-III). Gr-I comes out as a distinct entity on the basis of cross-cutting relation and mineralogical and chemical composition, the Rb-Sr whole rock isochron also giving a younger age than the other two groups irrespective of the regression model used. Gr-II comes out as the oldest unit but its age relationship with Gr-III cannot be established unequivocally. An uncorrelated error regression model establishes the age relationship as Gr-I < Gr-III < Gr-II, whereas a two-error regression model establishes temporal closeness between Gr-II and III.

Keywords. Malanjkhand; copper deposit; granitoids; geochronology; isochrons; initial ratio; temporal relation.

1. Introduction

Temporal relationship of granitoids and associated base-metal deposits is crucial for answering several queries on the genesis of such deposits. The age relationship among different discrete phases, wherever identifiable, is also necessary for unraveling the records of crustal evolution in the area. Determining the age of granitoids at Malanjkhand in particular, is warranted in order to record the latest granitic activity in the area, keeping in mind the fact that, many workers (Tripathy 1974; Sikka 1989) have described the deposit as a 'porphyry-type' which is typically restricted to younger (late and post-Mesozoic) granitic activity in well-defined tectonomagmatic settings. The granitoids around the Malanjkhand copper deposit have so far received least attention of previous workers. Based on the Rb-Sr analysis of four whole-rock samples of granite gneiss, Ghosh *et al* (1986) reported an age of 2362 ± 58 Ma and considered these granitoids to be synkinematic with the Amgaon Orogeny. No attempt was however made to group the different types of granitoids on petrochemical and geochronological basis. The present communication aims at refining the work in terms

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[1] The term 'granitoids' is being used broadly to include rocks ranging in composition from alkali-granite to tonalite.

of age relationship among different recognizable groups of granitoids with adequate support to the grouping on the basis of petrography and chemical features.

2. Geological setting

An area of roughly 200 km^2 around the Malanjkhand copper deposit, Balaghat district, MP (21°55′ to 22°05′N and 80°40′ to 80°55′E) was taken up for petrogenetic study

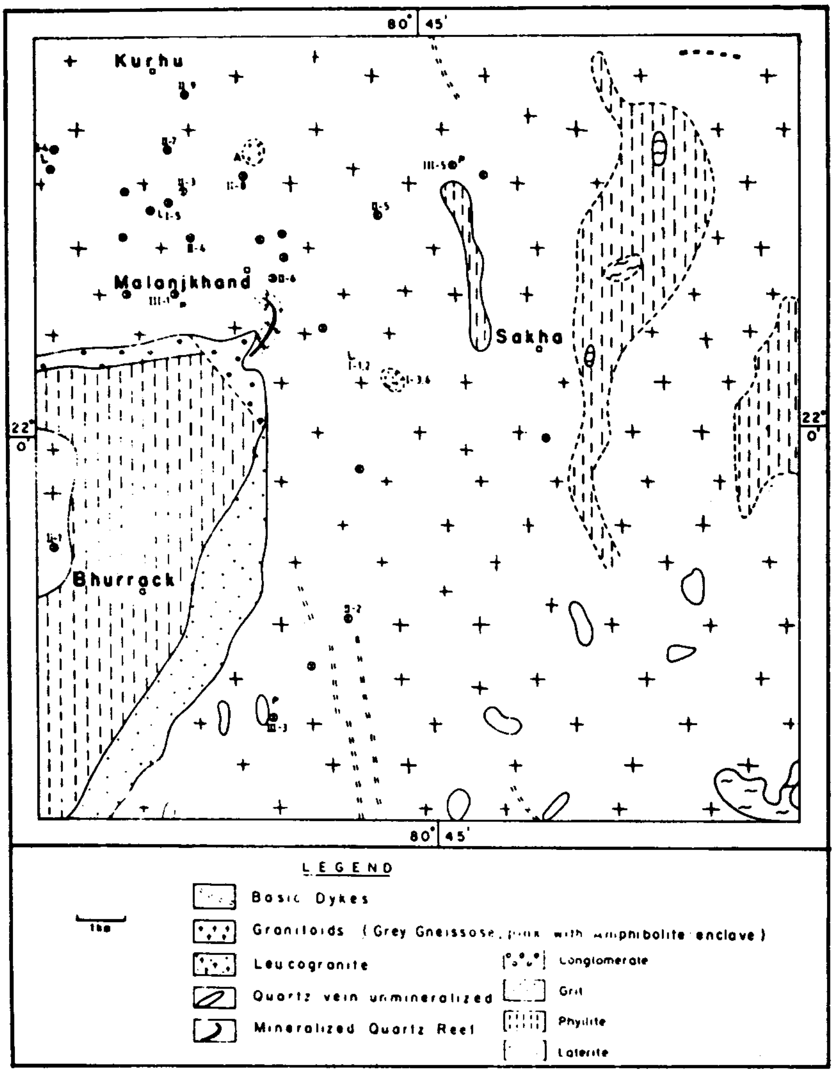

Figure 1. Geological map of the area showing the sample locations (numbers correspond to those samples analyzed for Rb-Sr radio-isotope) (encircled 'X'). 'P' near the exposure locations indicate occurrence of 'pink-granitoid' in the surrounding region. 'A' – for occurrence of amphibolite enclave and 'L' – for Leucogranite occurrence other than that defined in the legend. (The base map with the Chilpi outliers is from the Malanjkhand Copper Project, HCL).

bearing on the events of crustal evolution in the area and genetic links of the granitoids with the mineralization. The area is a part of the north-central region of the Indian shield. The Dongargarh granite (2466 ± 22 Ma, Sarkar *et al* 1990) lies 150 km to the south, the Sausar and Sakoli metamorphic belts to the SW and SSW respectively and the Chhatisgarh sediments (youngest Precambrian unit in the region) lie to the SE of the area (figure 1 of Ghosh *et al* 1986). The area is likely to have been affected by the Amgaon orogeny (2400 Ma) and subsequent orogenic cycles but the *unmetamorphosed* and *undeformed* Chilpi outliers (Sausar equivalents) in the area (figure 1) indicate that the area does not register any effect of the latest orogenic cycles (Sausar and Sakoli – 850 to 950 Ma). The area is extensively soil-covered resulting in an overall scarcity of exposures of the lithounits other than those of the quartz-bodies (lenses) and the Chilpi outliers. Small exposures of granitoids with rare amphibolite enclaves and basic dykes are exposed at the localities shown in figure 1. Mineralization is confined mainly within an arcuate quartz reef (figure 1) occupying a deep seated fracture zone within a pink-granitoid body where unmineralized late aplite dykes also occur. Basic dykes constitute the youngest pre-Chilpi rock type in the area.

3. Granitoid types

The area is a vast granitic country with scattered scanty exposures (figure 1). The majority of exposures surrounding the mineralized zone are composed of granitoids which are grey, coarse-grained with variable degrees of gneissosity and sometimes with conspicuous quartz bands. This type contains amphibolite enclaves. The proportion of felsic/mafic minerals is more or less uniform. The granitoids of the mineralized zone are comparable to their barren counterparts elsewhere in grain-size, color index, mineralogy and presence of amphibolite enclaves; but their pink color (presence of pink K-feldspar) and complete lack of gneissosity are very characteristic and justify a separate grouping. This variety also occurs in the region surrounding the Malanjkhand copper deposit in isolated exposures. Occurrence of this variety at about 7 to 8 km south of the mineralized zone has been noted. A third variety of granitoid distinctly finer (relative to the other two) massive and leucocratic, has been encountered in the area. This has not been reported by earlier workers (Tripathy 1974; Nath *et al* 1973; Narang *et al* 1974). Exposures of this group in one or two quarries ESE of the mineralized area were studied. Its occurrence as distinct bands amongst the grey granitoid country has also been found. But they are not mappable in the scale of the map given in figure 1. Based on the field features, a subdivision of the granitoids of the area is made and results of routine investigation are described under three groups: Gr-I the Leucogranite (the term is being freely used in a descriptive sense, refer Schalteggar 1990); Gr-II – the grey gneissose granitoids and Gr-III – the pink-feldspar bearing granitoids. As shown later, this three fold grouping is further strengthened by textural, mineralogical and chemical signatures of each type.

3.1 *Comparative features*

The salient petrographic and chemical features are collated in table 1. Total absence of hornblende and sphene, negligible biotite and zircon and fine-grained massive nature are considered characteristic features distinguishing the Gr-I from the other

Table 1. Comparative mineralogical and chemical features of the three groups of granitoids.

Parameters/Characters	Gr-I	Gr-II	Gr-III
A. Field relations	As bands and pockets with sharp contact	Extensive in regional scale, mostly gneissose	Occurs in the mineralized zone; rarely elsewhere within Gr-II; cut by aplite.
		Contains amphibolite enclave and cut by basic dykes.	
B. Petrography			
i) Color, grain-size texture	Leucocratic, grey, medium grained, hypidiomorphic	Mesocratic, grey, coarse-grained, gneissose	Mesocratic, pink, coarse-grained, massive.
ii) Major minerals	Qtz, Plag, K-feld; Plag. zoned	Qtz, Plag, K-feld, Hbl, Bt; Plag. unzoned.	
iii) Accessories	Rare Ap., zircon	Abundant Ap. and zircon as inclusions in major phases.	
iv) Nature of biotite	Rare isolated flakes, brown	Primary sphene in greater proportion deformed, sometimes with prefered orientation, brown	Rare primary sphene large flakes, deformed, dominantly green.
v) Nature of Hbl.	Absent	Coarse with different stages of breakdown.	
vi) Deformation	Virtually undeformed	Conspicuously deformed, Boehem-lamellae in Qtz, bent twin lamellae in Plag., kinked biotite, fractured apatite and sphene.	
vii) Special textural feature		Presence of both deformed and undeformed Qtz in the interstices	Transverse and radial fractures in K-feld with Qtz + Chl + Ep as infilling.
C. Nature of alteration			
i) Overall degree	Moderate	Extensive without any zonality	
ii) Nature of Plag. alteration	Dominantly sericitic alteration of Plag. with core more altered than rim	Extensively saussuritized	Saussuritized, sometimes epidotized.
iii) Nature of Hbl alteration		Breakdown to Ep. + brown Bt + Chl + Sph; often pure chloritic	Breakdown to Ep. + green Bt + Chl + Sph.

iv) Nature of Bt alteration	Chloritic	Chloritic with release of Sph	Chloritic with release of Sph, occasional presence of fluorite.
v) Nature and extent of microclinzation	Moderate, K-feld as discrete, interstitial grain often replacing Plag	Moderate, K-feld. always replaces alt. Plag, non-perthitic	Extensive with inclusion of alt. • Plag, non-perthitic.
vi) Nature of ferro-magnesian clot	Absent	Abundant with brown Bt + Chl	Abundant with green Bt + Chl, frequently associated with opaque.
D. Chemical Features			
a) Al_2O_3, TiO_2, CaO, MgO, Sr	Gr-I <	Gr-II >	Gr-III
b) Na_2O, K_2O and Rb	Gr-I >	Gr-II <	Gr-III
c) average Cr	31·15 ppm	81·33 ppm	87 ppm
d) average P_2O_5	0·05 wt%	0·199 wt%	0·176 wt%
e) ASI (av.)	1·044	1·042	1·123
f) Zr (av) in ppm	102·65	139·29	130·99
g) Ce_N/Yb_N	11·016	16·12	16·3
E. Rb-Sr systematics and age			
i) Age in Ma	2106 ± 102 *(2199 ± 178)	2467 ± 38 (2405 ± 63)	2243 ± 217 (2425 ± 321)
ii) Initial ratio	0·7098 ± ·0011 *(·7075 ± ·0047)	0·7014 ± ·00122 (·7021 ± ·0005)	0·70488 ± ·003 (0·7035 ± ·0021)

*Values in brackets are those obtained by calculation on correlated error basis.

Abbreviations: Plag – plagioclase; Bt – biotite; K-feld – potash feldspar;
Hbl – hornblende; Qtz – quartz; Sph – sphene; Ap – apatite;
Chl – chlorite; Ep – epidote.

two groups. Chemically also Gr-I comes out as a distinct entity by virtue of its highest average SiO_2, K_2O and Na_2O (wt%) contents. The P_2O_5(wt%) and Cr contents are remarkably low and the Zr content is lower than in the granitoids of Gr-II and III. The P_2O_5 wt% of Gr-I is much below the value of about 0·12 wt%, which is the experimentally determined solubility of P_2O_5 (Watson and Capobianco 1981) in a granitic liquid corresponding to the observed SiO_2 content in Gr-I. This indicates a difference in source between Gr-I and Gr-II and III granitoids. As seen from table 1, Gr-II and III are similar in their mineralogy and bulk chemistry and therefore may be genetically related. The discrimination is mainly spatial; also, Gr-III is characterized by pink K-feldspar and green biotite/chlorite (as against ubiquitous brown biotite/chlorite in Gr-II). The brown to green color transition of biotite has been ascribed by Hine *et al* (1978) to decreasing $Al/(K + Na + Ca/2)$ value whereas Ague and Brimhall (1988) hold the Ti content as the cause for the brown color. Considering the facts that close ASI (Aluminum Saturation Index) values are observed in both the groups and sphene occurs as an alteration product of biotite in both, the difference in color of biotite/chlorite could be due to other factors. The greater extent of alteration and the nonuniform distribution of alteration products (mainly K-feldspar) in Gr-III is envisaged as due to the greater extent of fluid interaction therein, this being the site of mineralization. As summarized in table 1, these granitoids, especially Gr-II and III, display various types of alteration features such as breakdown of hornblende (to clots of biotite + epidote + chlorite and also simple chloritization), chloritization of biotite and saussuritization of plagioclase. Replacement of these pre-existing alteration assemblages, especially saussuritized plagioclase, by fresh microcline – feeble in Gr-II and pronounced in Gr-III – and replacement of all the pre-existing altered phases by quartz megacrysts, containing residual iso-oriented inclusions, strongly indicate that microclinization and silicification followed the alteration of the ferromagnesians and plagioclase. This is explainable as a close-system redistribution – early alterations being simple hydrolysis reactions with accompanying enrichment of the fluid with respect to K_2O and silica, which are later precipitated at lower temperature (Giggenbach 1984). Low temperature range ($\sim$ 100 to 225°C) of homogenization of primary inclusions in quartz in the granitoids (Panigrahi 1992) favors the contention of such a close system redistribution, more than a 'metasomatic' addition of species like K_2O and SiO_2. Hence, following the discussion on the chemistry of these granitoids is worthwhile.

Figure 2 does not help in making a sharp chemical discrimination of Gr-I except restricting it to the 'granite proper' field (GR) (figure 2a, after Barker and Arth 1976). In figure 2b, c, and d a more or less similar 'calc-alkaline' trend is observed for all the groups (with greater scatter in Gr-III – shifting of points to Or/K corner) indicating a similar line of evolution of these granitoids. Figure 3 is the Harker's variation diagram where all the groups are plotted together. Gr-I occupies extreme positions wherever a usual covariation is observed e.g. SiO_2 -vs- CaO(-ve), MgO(-ve) Fe^{Tot}(-ve) thus giving the impression of Gr-I being the extreme fraction in the crystallization sequence. Gr-II and III are inseparable on such plots but together follow the trend (with greater scatter in Gr-III) further suggesting their cogenetic (coeval ?) nature. Use of parameters suggested by Hine *et al* (1978) for I- and S-type discrimination (figure 3 – SiO_2-vs-Na_2O and figure 4d K_2O-vs-Na_2O) does not serve the purpose. Besides, petrography does not reveal the presence of fragment of any protolith. Moreover, the mineralogy as such, does not give first hand information on the

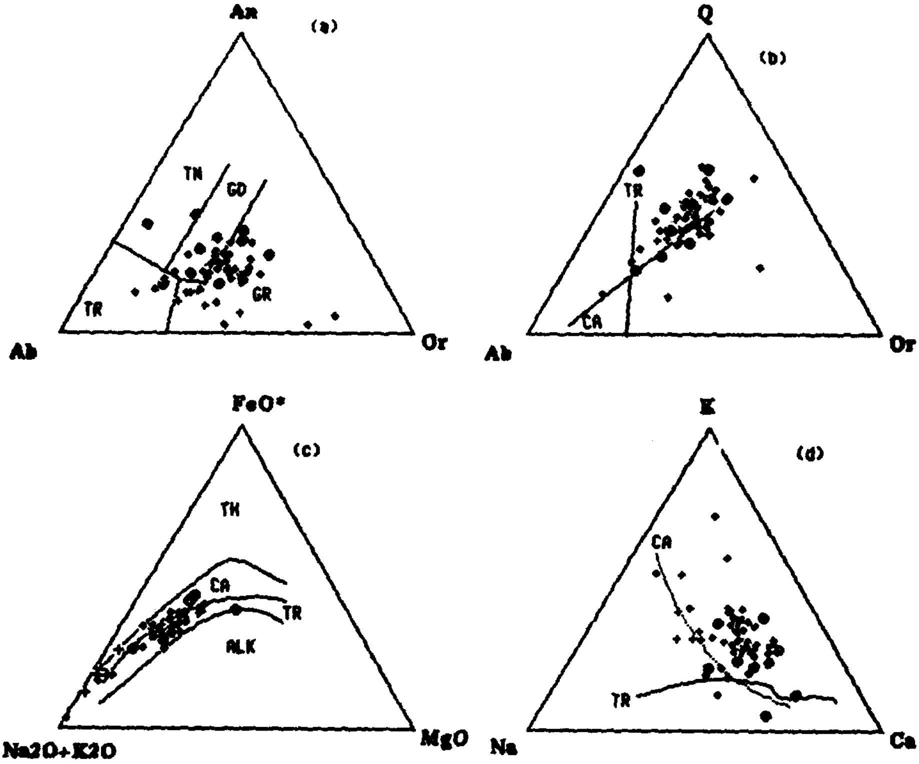

Figure 2. Triangular normative and chemical plots of the three groups of granitoids. The field and trends are as defined by Barker and Arth (1976). Symbols: '+' for Gr-I, '⊕' for Gr-II and '◆' for Gr-III. The symbols are followed in figures 3 and 4. Numbers of samples analyzed for major elements are: Gr-I – 6, Gr-II – 14 and Gr-III – 42.

prevalent f_{O_2} (oxygen fugacity) of crystallization; thus, ruling out direct/indirect discrimination of these granitoids to I-/S-types. However, the parameters suggested by Ague and Brimhall (1988) are found to be useful in the present context. Even though we do not intend to stick to their nomenclature [I-WC (weakly contaminated), I-MC (moderately contaminated), I-SC (strongly contaminated) and I-SCR (strongly contaminated and reduced)], the parameters help in further distinguishing Gr-I, which mostly occupies the I-SC field in the ASI-vs-SiO$_2$, FM index-vs-SiO$_2$ and Mn index--vs-SiO$_2$[†] (figure 4a, b and c) plots. No regular spatial variation of the different groups has been observed at Malanjkhand – unlike the situation obtained in the Peninsular Range Batholith (PRB) (Ague and Brimhall 1988) for which the terms have been coined. Also, there is no signature of a magmatic arc regime at Malanjkhand. Still, the involvement of a more acidic upper crustal material in the origin of the leucogranite (GR-I) is indicated from such plots. This is corroborated by the total absence of amphibole (refer I-SC type of PRB) and other chemical features pointed out earlier. The Gr-II and III being dominantly granodioritic to tonalitic (see figure 2a) roughly occupy the I-WC field (not shown in the figure).

[†] *FM index* and *Mn index* are being used for the ordinates of figure 4 b and c for convenience here, not used by Ague and Brimhall (1988).

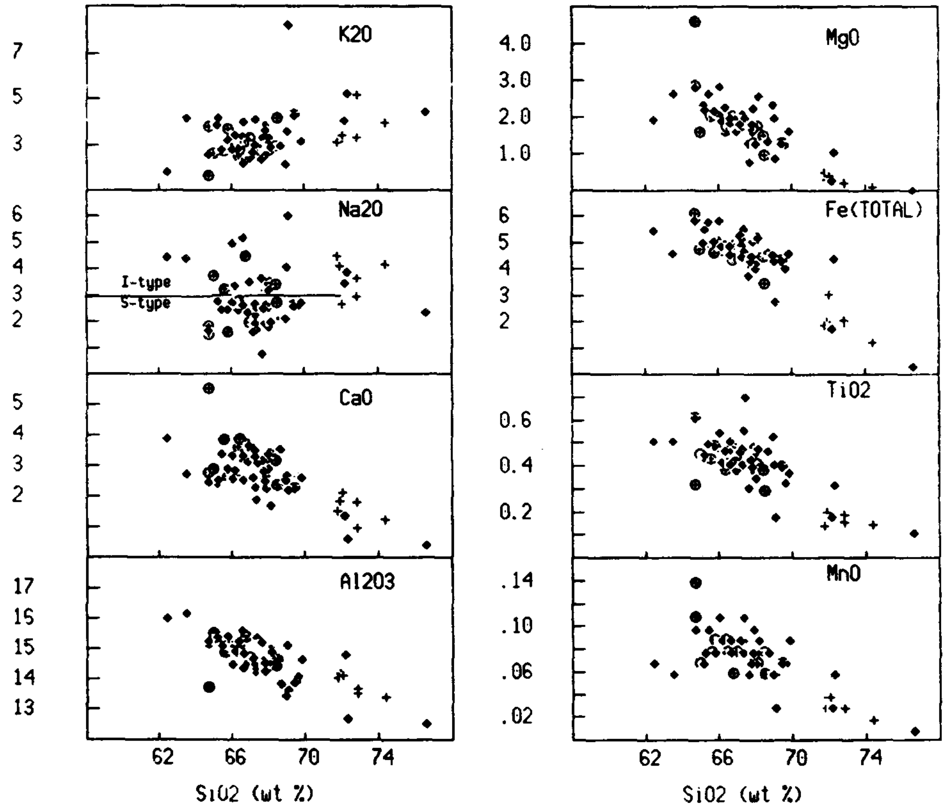

Figure 3. Variation diagrams for all the groups of granitoids together. The I and S type boundary is as shown by Ague and Brimhall (1988).

4. Rb-Sr Isotopic systematics

Gr-I and II are fairly homogeneous and do not present any sampling problem. Larger samples were taken from Gr-III to minimize the inhomogeneity. Representative powdered fractions were used for isotopic analyses, the choice of samples being guided by the range (maximum) in Rb/Sr values. Rb-Sr analytical procedures are as given in Subba Rao *et al* (1989). The precision in the measurement of the Rb/Sr ratio is better than ± 1% and that for $^{87}Sr/^{86}Sr$ is given as 2σ of the mean of each measurement. Mean of several analyses of SRM-987 Sr standard is 0·71028 ± 5.

Table 2 summarizes the results of analyses and the calculated parameters for the three groups. The Sr-isotope evolution diagram of the three groups of granitoids are presented in figure 5a, b and c. Gr-I and II are represented by a fairly colinear array of points giving 6 and 8 point isochrons respectively. Considerable scatter is observed in the case of Gr-III. The results of statistical treatment of data are also given in the table. It can be seen that the errors in $X(^{87}Rb/^{86}Sr)$ and $Y(^{87}Sr/^{86}Sr)$ are rather poorly correlated and in all cases the value of Y is less than unity. Brooks *et al* (1972) prefer an uncorrelated error treatment of data in such a situation to the 'two-error' treatment of York (1969). The two error regression

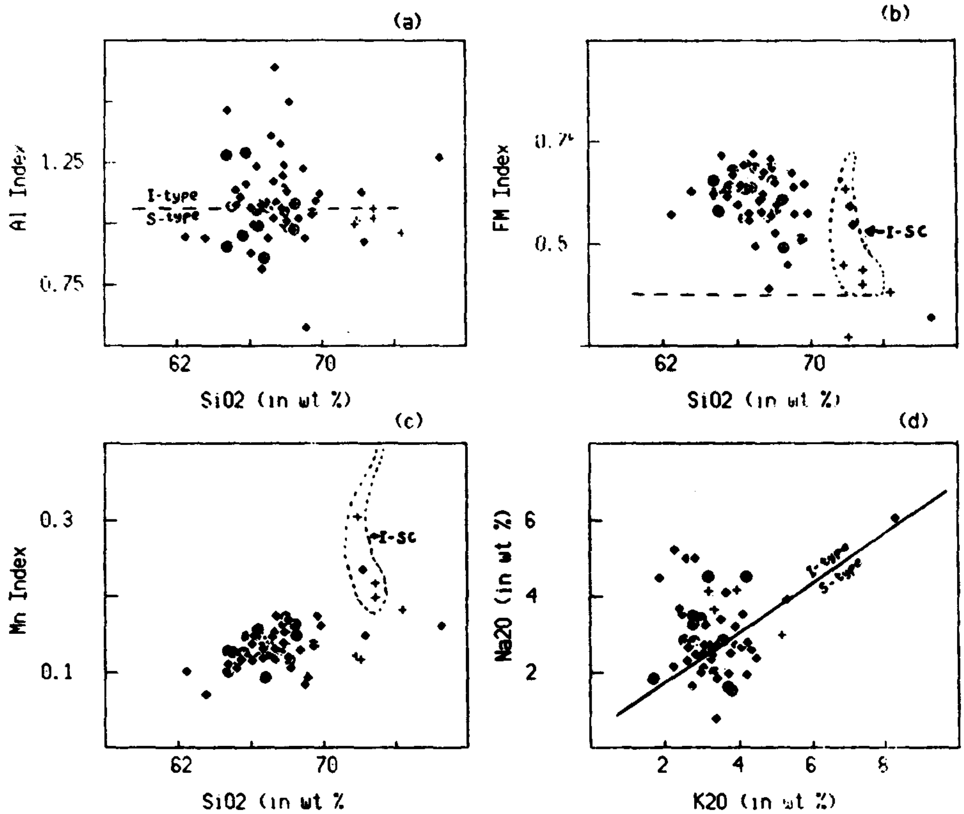

Figure 4. (a) ASI-vs-SiO_2, (b) FM index $(MgO/(MgO + FeO))$-vs-SiO_2, (c) Mn index $[MnO/(MnO + TiO_2 + FeO + MgO)]$-vs-$SiO_2$ plots (Ague and Brimhall 1988) and (d) Na_2O-vs-K_2O plot (after Hine *et al* 1978) for all the groups of granitoids.

treatment of York suffers from some flaws as recently pointed out by Vistelius and Faas (1991). According to them, the 'weights' (inverse of variance) that York's model give to X and Y do not guarantee consistency of the slope and intercept. Besides, further uncertainties in calculation of slope would arise from the use of r_i (correlation of X and Y errors) which, in order to be dependable, should be calculated from a large number of replicate analyses. However, the ages obtained by both two-error regression and uncorrelated error regression methods are given in the table along with the results obtained by using the program of Vistelius and Faas (1991). Gr-I and II give very clearcut ages: Gr-I – 2199 ± 178 Ma, Gr-II – 2405 ± 63 Ma by two-error regression and Gr-I – 2106 ± 124 and Gr-II – 2467 ± 38 Ma by uncorrelated regression method. The MSWD values for the uncorrelated error method was calculated by the equation of Wendt and Carl (1991) [$MSWD = f^{-1}\Sigma(\Delta Y_i/\sigma_i^2)$ where $Y = Y_i - aX_i - b$ and $\sigma_i = a^2\sigma_{X_i}^2 + \sigma_{Y_i}^2$] and was found to be always less than one. Higher values of the Mean Square of Weighted Deviates (MSWD)–14 in case of Gr-III was observed from treatment with York's model (or as high as 56 by Williamson's (1968) method). Considering the small number of samples, the MSWD values in this case are still less than the theoretical expectation (Brooks *et al* 1972) and hence it can be assumed that the data points define isochrons in all the three groups. In Gr-III inclusion of

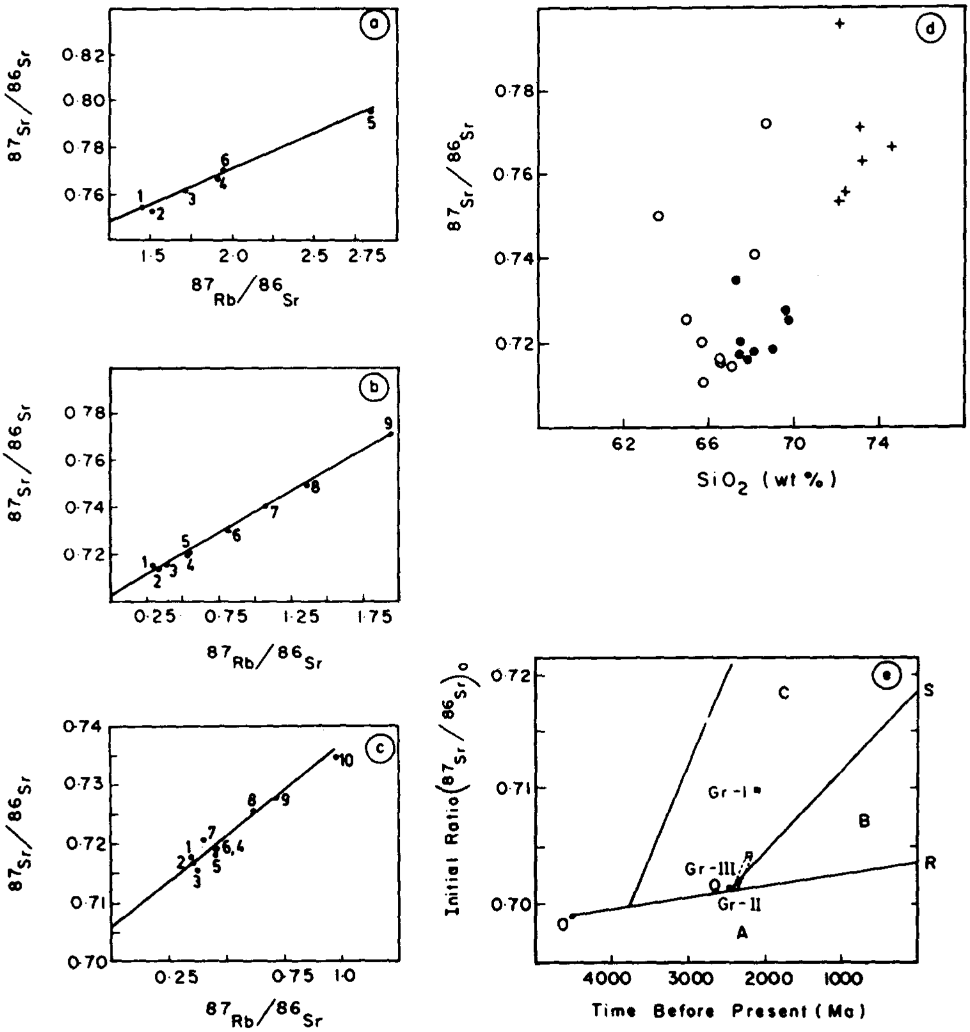

Figure 5(a–e). Isochron diagram of the three groups of granitoids (a – Gr-I, b – Gr-II and c – Gr-III). d – $^{87}Sr/^{86}Sr$ -vs- SiO_2 plot for the three groups of granitoids. Symbols: '+' – Gr-I, '○' – Gr-II and '●' – Gr-III. e – Plots of the three groups of granitoids on 'Initial Ratio'-vs-time diagram (after Faure and Powell 1972). 'B' – Basalt Field. QS – Continental Evolution line. 'O' – primordial and 'R' – present-day $^{87}Sr/^{86}Sr$ value of the mantle. Fields 'A' and 'C' are for granitoids of direct mantle derivation and of exclusively upper-crustal derivation respectively.

sample No. GR26 (with the highest *X* and *Y*; uppermost extreme in the isochron diagram) in the calculation is rather problematic because it drastically reduces the slope; whereas, exclusion of any other datum point does not have any effect. The age obtained for Gr-III by uncorrelated error method is 2243 ± 217 Ma through a 9 point isochron. The value remains the same if the samples from the surrounding region (samples No GR17, GR5, GR6 and GR64) are excluded, whereas, the ages obtained from a 9 point and a 5 point (Gr-IV – 41, 54, 38, 44 and 55) isichron are different (1425 ± 321 Ma and 2280 ± 168 Ma respectively) in the two-error regression model.

A 6 point isochron (mineralized area only including sample No GR26) gives 2126 ± 129 Ma by two-error regression method. This is even younger than Gr-I age obtained by the same method. This age of Gr-III against 2405 ± 63 Ma for Gr-II is not plausible since a temporal and genetic affinity of these two groups is strongly indicated by field relations, comparable mineralogy, overall chemistry and REE fractionation index (Ce_N/Yb_N) (see table 1). Gr-III has undergone a greater degree of alteration during the mineralization resulting in greater extent of inhomogeneity and greater scatter of points about the isochron. A larger number of samples could possibly have given a symmetrical scatter of points near GR26 as is observed in the lower ranges of X and Y. Therefore, the age obtainable with sample number GR26 excluded is preferred. Such *a posteriori* rejection of points has been criticized by Lutz and Srogi (1986) who devised a method of selection of points on 'zero age shift' basis from the absolute Rb and Sr concentration. The method could not be satisfactorily applied to any of the groups in this case. Age shifts estimated by the procedure outlined by them are negligible even in comparison to the errors in regression and hence are ignored.

The ages obtained by using the method outlined by Vistelius and Faas (1991) are 2163·6, 2458·4 and 2194·4 Ma for Gr-I, II and III respectively. The 95% confidence interval obtained are less than the ages calculated from the slope of the isochrons (1719·4 – 1786·9; 2201 – 2242·3 and 1504·8 – 1618·8 Ma for the three groups respectively). Vistelius and Faas (1991) obtained 'left sided' confidence interval for $n = (5, 8$ and $11)$ but believed that "it was too early to conclude anything on the correlation of type of confidence interval and 'n'."

To sum up, the age relationship can be deduced as follows: Gr-I is the youngest representing the latest granitic activity with a gap of about 200 m.y. with respect to Gr-II, the oldest group. Even though Gr-I occupies extreme positions in the variation diagrams (figure 3), this group is unlikely to represent the latest fraction in the crystallization sequence as a melt of crustal source is unlikely to have such a long residence time (Schaltegger 1990). Considering the interval variation of Rb/Sr ratio in Gr-I (0·439 to 0·7616) it is also unlikely to have undergone reequilibration which would otherwise cause an isochron rotation. Gr III comes out to be temporally close or similar to Gr-II (Gr-II – 2405 ± 63; Gr-III – 2425 ± 321 Ma) as a result of two-error regression treatment. This is in accordance with their similarity in overall mineralogy and chemistry. The result obtained by the uncorrelated regression method and the latest regression model (point estimator technique) of Vistelius and Faas (1991), changes the picture a little bit by giving an intermediate age for Gr-III. It can only be suspected that this age is a result of isotope reequilibration and rotation of the isochron as suggested by Schaltegger (1990). If group II and III are the result of the same phase of granitic activity, a narrower spread of 0·13–0·3 in Rb/Sr ratio in Gr-III (as against a spread of 0·12 – 0·58 in Gr-II) might have been due to later reequilibration and this deduced intermediate age is significant. This feature is not observed in the two-error regression treatment.

4.1 *Initial ratio*

The initial ratio obtained for the Gr-II and III are 0·70145 ± ·00123 and 0·70467 ± ·000774 respectively and the difference in the values corresponding to the different regression methods are inconsequential in the sense that a younger age results in a

Table 2. Rb-Sr isotopic data and calculated parameters of the three groups of granitoids.

Group/Sample No.	Rb^{87}/Sr^{86}(X)	sX	Sr^{87}/Sr^{86}(Y)	$sY(10^{-5})$	r_{X-Y}	r_{sX-sY}	MSWD[1]	MSWD[2]
Gr-I								
Gr-I - 12(1)	1·467	0·029	0·75568	6				
Gr-I - 13(2)	1·533	0·031	0·75351	2	0·9932	−0·207	3·71	0·073
Gr-I - 37(3)	1·731	0·035	0·76319	3		Age[1] = 2199 ± 178		
Gr-I - 16(4)	1·927	0·039	0·76783	6		Age[2] = 2106 ± 124		
Gr-I - 40(5)	1·956	0·039	0·77144	2		I.R[1] = 0·7075 ± 0·0047		
Gr-I - 61(6)	2·855	0·057	0·79605	3		I.R[2] = 0·7098 ± 0·0011		
Gr-II								
Gr-II - 3(1)	0·317	0·0063	0·71639	3				
Gr-II - 2(2)	0·355	0·0071	0·71495	2				
Gr-II - 1(3)	0·412	0·0082	0·71673	2				
Gr-II - 11(4)	0·416	0·0083	0·71643	2	0·9993	0·0395	3·04	0·054
Gr-II - 10(5)	0·564	0·0113	0·72052	2				
Gr-II - 15(6)	0·842	0·0168	0·73082	3		Age[1] = 2405 ± 63		
Gr-II - 20(7)	1·111	0·0222	0·7414	2		Age[2] = 2467 ± 38		
Gr-II - 62(8)	1·391	0·0278	0·75011	3		I.R[1] = 0·70145 ± 0·00123		
Gr-II - 8(9)	1·966	0·0393	0·77233	2		I.R[2] = 0·70216 ± 0·00052		
Gr-III								
Gr-III - 17(1)	0·368	0·0074	0·71824	2				
Gr-III - 41(2)	0·373	0·0075	0·71712	3				
Gr-III - 5(3)	0·388	0·0078	0·71595	3				
Gr-III - 64(4)	0·466	0·0093	0·7195	2				
Gr-III - 6(5)	0·468	0·0094	0·7185	2	0·969	−0·49	14·41	0·036
Gr-III - 54(6)	0·473	0·0095	0·71944	2		Age[1] = 2425 ± 321		
Gr-III - 38(7)	0·491	0·0098	0·72107	2		Age[2] = 2243 ± 217		
Gr-III - 44(8)	0·632	0·0126	0·72603	2		I.R[1] = 0·70467 ± 0·00073		
Gr-III - 55(9)	0·731	0·0146	0·72817	2		I.R[2] = 0·7035 ± 0·0021		
Gr-III - 26(10)	0·998	0·0200	0·73493	4				

[1] Two error model.

[2] Uncorrelated error model (value of r_{sX-sY} to be seen).

higher initial ratio and vice-versa. But significantly the values are in accordance with those of early-Proterozoic granites (Peterman 1979) and more importantly they fall exactly on the continental evolution line limiting the 'Basalt Field' (Faure and Powell 1972) as is evident from figure 5e, where, the continental evolution line is represented by QS and B is the 'Basalt Field'. Gr-III is represented by a spread taking the uncertainties in the values to consideration. This provides the first hand information about their derivation from lower-crustal basic source of short crustal residence. The 'amphibolite enclaves' could very well represent the residue of such source. The overall mineralogical and chemical signatures obtained from these two groups point towards a basic (amphibolitic) parentage. The initial ratio of Gr-I – 0·709896, falls above the continental evolution line. This is in agreement with its I-SC type character where mixing of more acidic upper-crustal component is involved. Gr-I also occupies extreme positions (highest $^{87}Sr/^{86}Sr$ at highest range of SiO_2) in figure 5d, thus giving support to the involvement of upper-crustal component (Faure and Powell 1972). Gr-II and III show random scatter of points on the diagram indicating 'no control' of SiO_2 on the ratio.

5. Discussion

Study of Rb-Sr isotopic systematics of granitic rocks has been attempted in all types of settings and associations but dependability of isotopic signatures and in turn the age data have hardly been free of ambiguity. Review of published work (Bottino and Fullagar 1968; Naylor *et al* 1970; Roddick and Compston 1977; McCarthy and Cawthorn 1980; Lutz and Srogi 1986; Gerstenberger 1989; Schaltegger 1991) reveals that the scatter of points about the isochrons is, in ultimate analysis, due to sample volume being always less than the volume of reequilibration. Besides, selection of a fresh and larger volume of samples does not ensure good isochrons in terms of MSWD values (Schaltegger 1991). The role of autometasomatism or later fluid activities in isotope reequilibration are also visualized differently: for instance, Schaltegger (1991) proposed 'isochron rotation' in changing the slope as well as intercept whereas Gerstenberger (1989) showed only a lowering of the intercept (initial ratio). These uncertainties notwithstanding, the genetic implications of the deduced ages are as follows. Gr-I is being inferred to represent the youngest phase of granitic activity with considerable involvement of more acidic component than the progenitor of Gr-II. Whether the generation of Gr-I could also be triggered by a later phase of melting of the same source as that of Gr-II remains unresolved. Also, in view of the marked difference in P_2O_5, very low Zr and Cr contents, the possibility of Gr I being entirely a product of restricted melting of (under water saturated conditions in some thermally anomalous zones) of Gr-II cannot also be ruled out. If this had been the case, the isotopic signature, however has remained unaffected in Gr-II. The intermediate age obtained for Gr-III should be tentatively fixed as the age of mineralization. But what remains to be answered in this regard is whether the shift in age due to isotopic reequilibration is directly related to the time of reequilibration or the extent to which the reequilibration has been effective. If the latter is true, the intermediate age of Gr-III may not be the age of mineralization. This particular problem must be addressed to in order to establish the temporal relationship of the granitoids and mineralization or in other words, the complete record of crustal evolution in the area. The fact that the reported age of the Dongargarh Granite (Sarkar *et al* 1990) closely agrees with the deduced age of Gr-II and III granitoids at Malanjkhand raises the interesting possibility of correlation (or coevality) in a much larger regional scale (figure 1 – Ghosh *et al* 1986) than has been visualized.

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