ABSTRACT

The Chhotanagpur Granite Gneissic Complex (CGGC) covering an area of about 80,000 sq. km. represents the northern part of the eastern Indian craton bordered in the south by the Singhbhum mobile belt and the Singhbhum Orissa Iron Ore Craton (SOIOC) in succession. Studies on the geochemistry of the felsic and mafic (meta-) igneous rocks in this vast terrain have so far been sporadic and often unsystematic. As a consequence, understanding of the crustal evolution of this part of the craton has remained till date rather controversial. To make a probe into this aspect, we have chosen a small area in the Lohardaga district of Jharkhand (formerly Bihar) around Lohardaga (23°16'N:84°41'E) for detailed geochemical (major and trace element) studies of the granite gneisses, massive granites and amphibolites with a view to integrating the results to decipher the comprehensive plan of development of the crustal ensemble in this part of CGGC. For this purpose 35 samples of granite gneisses, 22 samples of massive granites and 24 amphibolites from the area under investigations have been analysed for major and a number of trace elements. In addition, new geochemical data on 13 samples of Bonai metavolcanics, 14 samples of Dhanjori and 15 samples of Jagannathpur basaltic lava are used for this study.

Medium to coarse grained, pre- to syn- tectonic, grey gneisses with general foliation/ gneissosity trending E-W and dipping around 50° towards north occur as small hillocks around Koel river. The essential minerals in the gneisses include plagioclase feldspar, alkali feldspar and quartz; biotite, hornblende, epidote, zoisite, sphene, zircon, apatite, allanite, ilmenite, Ti-magnetite occur as minor and accessory minerals. Plagioclase (oligoclase-andesine) feldspar is bimodal in grain size with large grains/ porphyroclasts showing extensive marginal granulation and elongation parallel to gneissosity (pre- to syn-tectonic). Some plagioclase grains, partly altered and with complex twins, also occur as inclusions in fresh plagioclases. Biotite, more commonly parallel to gneissosity also describes at places a second orientation at a low angle to the principal fabric. The mafic minerals ilmenite/ Ti-magnetite or sphene, biotite, hornblende at places form clusters in which sphene often mantles the opaque grains and indicate reaction.

Certain conspicuous chemical features of these gneisses are highly felsic character, sporadic unusual titanium and parallel iron enrichment, high rubidium and zirconium; and rather low strontium. Petrography and various plots involving chemical compositions, modes and norms indicate that the Koel gneisses dominantly represent a highly felsic, peraluminous tonalite-granodiorite-trondhjemite (TTG) [low-alumina type] series. Major and trace element variation diagrams of the Harker type, against Thornton and Tuttle differentiation Index (D.I.) and even with respect to Rb/Sr ratio, which is also considered to be an index of differentiation, indicate that there has been considerable fractional crystallization and/or restite separation in the melt during its evolution.

Petrographic observations and chemical data compared with experimental observations (Conrad et al., 1988) together suggest that the Koel gneisses have variable proportions of restites or cognate inclusions (not xenoliths or chance inclusions) of high Ti-Fe (ilmenite-magnetite) and high Ca (plagioclase) minerals which have been progressively eliminated from the melt during its emplacement. The relatively high LREE concentration and a large $(Ce/Yb)_N$ ratio in the Koel gneisses indicate a source enriched in LREE, unlike a MORB like mantle derived basaltic/amphibolitic precursor; morover, HREE around chondrite X 10 indicate absence of garnet in the residual source material. A negative Eu anomaly in the REE distribution confirms plagioclase as a restite- a possibility also suggested from the low Sr content in these rocks. Strong evidence of fractionation and restite separation of the Koel TTGs indicate that the initial melt must have been enriched in volatiles in order to have a low viscosity to allow these mechanisms to operate.

Enrichment of the more incompatible elements like Rb, Zr, Pb and LREE in the Koel TTGs, multielement diagrams, and the LREE/HREE ratio indicate that these rocks are recycled crustal material. A comparison of the chemical and mineralogical criteria for the S-type granites clearly reveal that for Koel TTGs the source can not be either a pelitic or greywacke type of rock of sedimentary parentage.

Using various chemical thermometers based on experimental studies (Watson and Harrison, 1983; Harrison and Watson, 1984; Montel, 1993; Johannes and Holtz, 1996) and the chemical characters of the Koel gneisses, the temperature of melting of the lower crustal precursor material has been inferred to be in the range of 725-775°C. Evidently, in this low temperature range production of large volumes of felsic magma as in CGGC by partial melting of crustal material would hardly be possible in absence of excess water. Modelling in terms of Rb, Sr and using the average lower/upper crustal compositions and the proportions of fractionating assemblages from the experimental data confirm that the partial melting of a dacitic/granodioritic source rock at high X_{H2O} and relatively low temperatures may indeed give rise to magmas similar in composition to the Koel TTGs with plagioclase and ilmenite as common restites. Using proportions of phenocrysts in natural dacitic lavas, the variations of some trace components in the Koel TTGs have been modelled to test the applicability of the fractional crystallization mechanism to evolve the melt composition. Matching of the modelled trajectory for fractional crystallization with the actual data confirm that fractional crystallization has indeed modified the composition of the Koel TTG melt.

Coarse grained, grey coloured, massive post-tectonic granitic rocks at places with 'fluxion structure' occur around Bhandra (23°22'N:84°47'E) in the form of small isolated bodies forming low mounds or hummocks. Mineralogically Bhandra granitic rocks are similar to the Koel gneisses and comprise plagioclase feldspar, K-feldspar and quartz as the essential minerals, and biotite, hornblende, muscovite, chlorite, epidote, zircon, sphene, apatite and opaque (ilmenite) as accessories. The similarity of the Bhandra granitic rocks with the Koel gneisses is more conspicuous in terms of the major and minor/trace element geochemistry of these rocks. Normative and modal compositions indicate that these rocks are represented by a TTG series (low- alumina type) as in the case of Koel gneisses.

Variation diagrams (Harker type, against D.I. and Rb/Sr ratio) together with textural relations indicate that both restite separation and fractional crystallization have been operative in modifying the compositions of these rocks. In respect of trace elements, Bhandra TTGs are more enriched in Sr and Rb though the ratio Rb/Sr is same relative to Koel TTGs and display positive Eu anomaly in contrast to the Koel TTGs which show negative europium anomaly. These differences can be related to complete melting of plagioclase and K-feldspar, indicating apparently a greater extent of melting of a similar source rock possibly more enriched in Rb and Sr relative to the source for the Koel gneisses. High concentrations of the incompatible elements Rb, Zr, Pb and LREE, together with multielement spidergrams and a consideration of the criteria for S-type granites indicate that the source rock is a typical crustal felsic igneous rock which might be akin to Singhbhum Granite phase III. This is further confirmed by trace element modelling using Rb and Sr. Using chemical thermometers, the temperature of melting of these rocks appears to have been in the range of 725-800°C. On the whole it appears, therefore, that the post-tectonic Bhandra TTGs formed under similar low temperature, high X_{H2O} conditions as in the case of Koel TTGs.

Metabasic rocks are relatively less abundant and occur in the form of a hillock full of huge blocks and rolled boulders made up of jointed and foliated amphibolites in the northeastern part of the area. These metabasics are hypersthene- to minor olivine normative low K-quartz tholeiites which appear to have formed at low pressure (<10Kb) conditions. Chemical data on the amphibolites display coherent and relatively restricted range of variations for both major/trace elements. Variation diagrams involving SiO_2, D.I., MgO and even Zr display more or less regular changes. The rather small range of variations together with mutually coherent and regular patterns of distribution of the major and trace elements suggest that the basaltic melts, precursor to the amphibolites did not undergo any contamination. Tight clustering (strong correlation coefficients) of all data points in Pearce Element Ratio plots indicate unaltered and uncontaminated and comagmatic nature of the (meta)- basic rocks which have been subjected to clinopyroxene, plagioclase and minor olivine fractionation.

Limited data on the distribution of rare earth elements (REE) in these amphibolites displaying HREE ~ chondrite X 10 indicate the absence of garnet as a residual phase in the source and hence support a relatively low pressure regime for their formation. The overall distribution of the REEs in these rocks appear to be intermediate between those of P-type MORB and OIB trends except for a distinct positive Eu anomaly which can be explained in terms of enrichment of Eu and some other incompatible elements in the source rock. A variably enriched depleted mantle plume is considered to be the probable source (from spidergrams) for the low-K tholeiites of the present area. Trace element modelling for a number of compatible-incompatible trace element pairs corroborate 10-15% partial melting of the primitive mantle followed by fractional crystallization of upto 20-30% in the melt as the probable mechanism for the generation of these tholeiites.

The chemical and mineralogical characters of Dhanjori (DJ), Jagannathpur (JN) and Bonai (BN) lavas are by and large similar to those of HD/GG area. All these basic volcanic rocks appear to have evolved through small degree of partial melting of slightly enriched depleted mantle source followed by some fractional crystallization. All these lavas are usually considered to be more or less coeval by numerous earlier workers.

The crustal evolution in the CGGC terrain appears to have taken place following the Wilson cycle and has involved rifting of an Archean crust forming a basin with development of mid-ocean volcanic activity and ocean floor basaltic magmatism and sedimentation. Rifting in the eastern Indian craton seem to have taken place along the two arms (E-W and NE-SW) of a trilete fracture system subsequent to which the SBG block gradually moved SSE-ward and progressively opened up the North Singhbhum and the Gangpur basins followed by the Noamundi basin. Movement of the SBG craton towards SSE caused buckling of the eastern and southern fringe of the craton and generated the narrow, peripheral basin where the older Iron Ore Group-I sediments appear to have deposited followed by deposition of Iron Ore Group-II sediments in the NNE-SSW aligned Daiteri-Tomaka basin. The SSE-ward movement of the SBG craton terminated with development of the WNW-ESE trending Sukinda fault in the south. In the final stage of Wilson cycle, the SBG craton began to move northward with continued subduction of the NSMB towards north at low angle. During low angle northward subduction, the depleted mantle wedge beneath the Archean crust was totally displaced and as a result the hydrated oceanic crust came in direct contact with the underside of the CGGC crustal block. Displacement of the depleted mantle wedge due to low angle subduction of oceanic crust prevented development of andesitic melts overlying and adjacent to the subducting slab as in parts of the Andes in South America. Frictional heat dehydrated the subducting oceanic crust yielding volatiles which depressed the melting temperature of the overlying felsic crust that, as a consequence, underwent extensive remelting at low temperature high a_{H2O} condition. Recycling of the lower crustal materials caused subsidence and basin formation at the surface where QPC sediments accumulated. Emplacement of the felsic melt in the pre- to para- tectonic stage and subsequent QPC sedimentation was followed by continued relative movement of the southern SOIOC and northern CGGC crustal blocks. The two crustal blocks approaching each other (2000-1600 Ma ago) deformed the sediments in the mobile belt, on CGGC and the emplaced recycled felsic igneous rocks alike in a dominantly N-S compressive regime. The approximately E-W disposition of the different petro-tectonic zones of CGGC is compatible with this model.

From tectonic point of view, as the Bhandra TTGs are massive, without any development of penetrative structures, they seem to have been emplaced after F_2 and possibly F_3 period. We correlated these two granitic masses with the first and second phase of deformation as outlined by Sarkar (1982). It is postulated that progressive dehydration of the hot, wet oceanic slab, moving north to northeastward with advancing subduction generated the Koel and the Bhandra TTGs in a chronological sequence by recycling of the preexisting Precambrian crust by excess water melting. Some of the extensively recycled granites at different stages could also invade the floor of the mobile belt and thereby impart a continental character to it.

Three distinct phases of tectonic movements and deformations in the crust emplaced basaltic melts into granitic rocks and the overlying sediments in different pulses in the pre-, para- and post-tectonic stages. Differentiation in basaltic magma pools could have yielded anorthosites. Basaltic melts in contact with older CGGC granitoids is likely to have produced anhydrous felsic magma by dehydration melting giving rise to A-type granites due to contact thermal effects. This could provide anorthosite-A type granite association common in Grenville type of orogenic belts and also reported from CGGC terrain and the Eastern Ghats region in India. Differentiated basic magma pools together with the subducted oceanic slab in the region is responsible for the high gravity anomaly characteristic of the CGGC terrain. Recycled granites resulting from partial melting of crustal felsic igneous rocks (and possibly sediments, elsewhere in the craton) effected enrichments in radioactive elements in the crust, producing high heat flow in the terrain.

On the whole, intracratonic rifting and basin formation, low angle subduction, absence of andesite, partial melting of lower crustal rocks in the presence of excess water, basaltic magmatism associated with plume activity from depleted, partly enriched mantle and possible anorthosite-A type granite association and regional metamorphism are the main tectonic activity related crustal evolutionary patterns extending over a period of about a billion years from Mid- to Neo-Proterozoic times in the CGGC terrain.