DISCUSSION

Geochronological (Rb-Sr and Sm-Nd) Studies on Intrusive Gabbros and Dolerite Dykes from parts of Northern and Central Indian Cratons: Implications for the Age of Onset of Sedimentation in Bijawar and Chattisgarh Basins and Uranium Mineralisation by U.K. Pandey, D.V.L.N. Sastry, B.K. Pandey, Madhuparna Roy, T.P.S. Rawat, Rajeeva Ranjan and V.K. Shrivastava. Jour. Geol. Soc. India, v.79, 2012, pp.30-40

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In this paper authors have presented valuable Sm-Nd and Rb-Sr isotopic data on mafic intrusives within Paleoproterozoic and Mesoproterozoic sedimentary cover rocks of Northern Indian Bundelkhand craton and Central Indian Bastar craton. The authors have tried to interpret the isotope systematics in order to constrain the age of onset of sedimentation in respective basins, petrogenesis of mafic intrusives and their possible role on uranium mineralization. While the attempt is commendable, the interpretation of these data is rather poor and fraught with some serious differences with the present consensus about geochronological framework of Indian craton in general and Proterozoic sedimentary basins in particular. I outline these as following:

1. The Rb-Sr isochron age of 1967±140 Ma of Dargawan sill of Bijawar basin, Bundelkhand craton is quite different from the data (1789 ± 71 Ma, Rb-Sr age) gathered by Sarkar et al. (1997) on the same formation. This needs some explanation. Geochronology of Bundelkhand massif, which forms basement to the Bijawar sediments, is now firmly established. The oldest TTG gneisses are dated at 3270±3 Ma and the granite plutons that constitute 80% area of the massif (Basu, 1986) are dated to be 2.5 Ga old, with the youngest leucocratic granite component of 2492±10 Ma age (Mondal et al. 2002, zircon $^{207}Pb/^{206}Pb$ ion microprobe data). After stabilisation (~2.5 Ga) of the massif, a series of minor intrusions followed, most spectacular among those are NE-SW trending quartz reefs and NW-SE trending mafic dyke swarms and all these intrusions forms basement to the Proterozoic sedimentary covers and do not intrude into them (Basu, 1986). Recent geochronology of the youngest NW-SE trending mafic dyke swarms suggest two phases of intrusion at 2150 Ma and 2000 Ma (Rao et al. 2005, $^{40}Ar/^{39}Ar$ data). Most recent high precision U-Pb data collected on zircon/baddeleyite define a precise U-Pb concordia age of 1979 ± 8 Ma for the NW–SE trending dykes (Pradhan et al. 2012). Therefore, all the three Proterozoic basins, viz. Bijawar basin, Sonrai basin and Gwalior basin that are developed at the peripheries of the massif must be younger than 1979 Ma and hence c.1967 Ma age of Dargawan sill that itself intrude basal Moli sub-group of Bijawar Group is untenable. The joint regression of all ten data points of the present work and Sarkar et al. (1997) corresponds to the age of 1825±160 Ma ($^{87}Sr/^{86}Sr_i$=0.7057±0.0010, MSWD = 3.1) and robust regression (Ludwig, 2003) of the same data points yield 1793 +160/-90 Ma age with initial $^{87}Sr/^{86}Sr$ of 0.7060±0.0010. Therefore, the age of 1789±71 Ma by Sarkar et al. (1997) seems to be more appropriate in terms of both precision and geological significance, since it agrees with the 1791±200 Ma Rb-Sr age of Gwalior intrusive (Crawford and Compston, 1969), Rb-Sr age of Kurrat volcanics (1691±180 Ma, Pandey et al. 1995), 1914±120 Ma - 1866±250 Ma Pb-Pb age for Gwalior Group carbonates and BIF respectively (Absar et al. 2009, 2010) and 1854±7 Ma age (U-Pb zircon age, Deb et al. 2002) of Hindoli tuff horizon.

To verify the veracity of the 1967±140 Ma Rb-Sr regression line, I plot 1/Sr and $^{87}Sr/^{86}Sr$ data in figure 1a which show strong positive correlation (r=0.95) for four samples, except sample no GC3246. It is imperative to note that the sample GC3246 is drawn from quite a large distance (Fig.1 of Pandey et al. 2012) with respect to other samples and do not affect the slope of best fit line, since regression of other four data points correspond to the age of 1976± 140 Ma with initial $^{87}Sr/^{86}Sr$ ratio of 0.70442±0.00089 and MSWD of 1.5. Therefore, the data clearly suggest a mixing between two end members with (i) high radiogenic $^{87}Sr/^{86}Sr$ ratio, low Sr concentration and (ii) low radiogenic $^{87}Sr/^{86}Sr$ ratio and high Sr concentration. Therefore 1967±140 Ma Rb-Sr regression line of Pandey et al. (2012) have no age significance and rather define a mixing line. The $^{87}Sr/^{86}Sr$ vs. $^{143}Nd/^{144}Nd$ diagram (Fig.6) of Pandey et al. (2012) also suggests such a possibility.

2.. The Chhattisgarh Supergroup, Proterozoic epicratonic succession in Bastar craton, comprises ~2300 m thick succession of mixed siliciclastic–carbonate strata that unconformably overlie granitic/gneissic basement of Bastar craton and is classified into three Groups, viz. Singhora Group, Chandarpur Group and Raipur Group (Das et al. 1992). EPMA based chemical U–Th–Pb dating of monazites from stratified tuffaceous unit (Khariar tuff) from Singhora Group suggest 1455 Ma age (Das et al. 2009), whereas, more precise U-Pb SHRIMP data of zircons establish a 1405±9 Ma age for Singhora tuffs (Bickford et al. 2011). Earlier, Patranabis-Deb et al. (2007) reported 1000 Ma age for Sukhda tuff horizon for Upper Raipur Group. These reports suggests 1405±9 Ma depositional age of Singhora Group and firmly establish a Mesoproterozoic time frame (1405±9 Ma to 990±23 Ma) for the Chattishgarh sedimentation. Therefore the Rb-Sr regression line of 1641±120 Ma by Pandey et al. (2012) for Damdama dolerite dyke that intrude Chandarpur Group seems to be far too old to have any geochronological significance. Additionally, the regression line is statistically poorly defined with extremely low MSWD value of 0.004 and suggest over estimation of analytical errors. A cross plot between 1/Sr and $^{87}Sr/^{86}Sr$ data (Fig.1b) show strong negative correlation (r=0.96), which indeed suggest mixing between two end members with possible involvement of either ‘intercalated carbonate-shale sedimentary rock’ or lower crust as one of the end member is having both high $^{87}Sr/^{86}Sr$ ratios as well as high Sr concentration. Therefore, the 1641±120 Ma regression line seems to represent rather a mixing line and do not have any age significance. Therefore, the authors claim in conclusions (point 3) that “Total time of sedimentation in Chattishgarh Supergroup may be 1.9 to 1 Ga” is flawed. Recently, similar NW-SE trending diabasic intrusive within Singhora Group has yielded an emplacement age of 1421±23 Ma (Das et al. 2011).

3. The interpretation of 1223±140 Ma Sm-Nd regression line of mineral separates of Damdama dyke sample as age of hydrothermal alteration is quite surprising. The authors do not give any credible explanation why they consider Rb-Sr system remain closed during hydrothermal alteration while Sm-Nd system behaved as open system. This is quite contrary to the fact that in hydrothermal fluids and low temperatures fluids, Rb and Sr are many fold mobile than LREEs. Moreover, internal mineral Sm-Nd isochron are more likely to retain magmatic crystallization signatures. The present Sm-Nd age 1223±140 Ma agree more or less (within their error limits) with the age given by Das et al. (2011) on samples of similar geological setting, therefore this age seems to be more close to crystallization age and their interpretation as reset of Sm-Nd isotope system during hydrothermal alteration and uranium mineralisation is quite far fetched.

4. As per the authors (p.38), occurrence of uranium mineralization (brannerite) are mostly associated with older mafic dykes and they do not cut into the sediment cover. If this is the fact, then the link between the uranium mineralization and emplacement of other mafic dyke sets that are the subject matter of present study is rather imaginary.

5. Sample locations are incorrectly plotted in Fig.1 with sample GC3247- GC3248 missing. In Fig.2 either longitude-latitude or a full inset map of Chattishgarh basin is required for the readers to understand the locations of the study area, also there is error in scale bar.

U.K. Pandey, D.V.L.N., Sastry, B.K. Pandey, Madhuparna Roy, T.P.S. Rawat, Rajeeva Ranjan and **V.K. Shrivastava**, Atomic Minerals Directorate for Exploration and Research. Email: upkishore@rediffmail.com reply:

We thank Dr. Nurul Absar for taking interest in our work. We are highly pleased with his valuable observations and comments. It is a matter of great satisfaction for us as he has commented that our isotopic data (Rb-Sr and Sm-Nd), presented in this paper, are not only valuable but the whole attempt as a commendable effort. In this paper we have published our results without bias which comprise of geochronological studies mainly Rb-Sr and Sm-Nd on mafic rocks from two important basins i.e. Bijawar (Dargawan gabbro) and Chhattisgarh basin (Damdama dolerite) *vis a vis* their indirect impact if any on uranium mineralization. But as he has pointed out that the interpretation of the data is rather poor and fraught with some serious differences with the present consensus with respect to the geochronological frame work of Indian craton in general and Proterozoic sedimentary basins in particular, we would like to explain in the following point wise reply.

1. We agree with the facts given in the comments with respect to the work of Basu (1986), Mondal et al. (2002) and Rao et al. (2005) and all these works are referred in our paper. We have also got similar age for Bundelkhand granite and andesites as well as for their protolith (Pandey et al. 2011). As far as age published by Sarkar et al. (1997) is concerned neither isotopic data nor details of petrographic studies on his samples are available with us. Hence, we cannot comment on this age. But we respect his work and have referred it in our paper. Secondly if our dates are slightly older does not mean that our data is erroneous. Here we would like to clear that our differing age, with that of Sarkar et al. (1997), indicates unbias reporting. We would like to bring here the very fact that most of the Purana basins opined

earlier as of Neo to Mesoproterozoic age are now considered as minimum 500 Ma older based on new geochronological data (Patranabis-Deb et al. 2007; Basu et al. 2008). This has been proved true in case of Gwalior basin (Absar et al. 2009, 2010) as well as Cuddapah basin (Bhaskar Rao et al.1995; Zakariah et al. 1999) which are now c. 2000 Ma old and we are very much sure that Bijawar and Chhattisgarh basins are not different. Patranabis-Deb et al. (2007) suggested a 500 Ma revision to the age of the Chhattisgarh basin on the basis of dating of rhyolitic tuffs at the top of that basin (c. 1000 Ma), and favour a similar downward revision for other Purana basins as they are considered to have similar origin and age. Hence, our present age results are in stratigraphic coherence and may be treated with respect to the changing age concepts not the older views. We agree here that our age of Dargawan gabbro has higher error i.e. 1976±140 and further age data with less error on these rocks may more precisely constrain the age of Bijawar sedimentation. However, this age indicates that in Bijawar also, like Cuddapah and Gwalior basins, sedimentation started before 1967 Ma and age of onset of sedimentation may be c. 2000 Ma. Since the basement dykes to the Bijawar basin as well to the Cuddapah basin have similar ages i.e. 2150 Ma (Rao et al. 2005) and 2173 Ma (Pandey et al. 1997) respectively. The 1967 Ma age of Dargawan gabbro is close to earlier reported ages of carbonates and BIF from Gwalior Group as 1914±120 Ma and 1866±250 Ma respectively (Absar et al. 2009, 2010) and 1885 Ma age of Pulivendla sill from Cuddapah basin (French et al. 2008). All these ages are older than Sarkar's age of 1789 Ma. The younger 1500 to 1700 Ma ages are considered as the age of later magmatic and metamorphic events in all most all the mobile belts and cratonic areas of India. As for as the age of Dargawan gabbro reported by us as 1976±140 Ma is concerned, we do not agree with Dr.Absar, that it is a mixing line. Brooks et al. (1976) have observed that even though 1/Sr vs $^{87}Sr/^{86}Sr$ have positive correlation the age can be treated as the age of rocks from the mantle as such correlation may result from disequilibrium melting or mixing of heterogeneous mantle. Therefore above positive correlation can not be considered diagnostic. Positive correlation between 1/Sr vs $^{87}Sr/^{86}Sr$ also shows that neither Sr concentration nor $^{87}Sr/^{86}Sr^{87}$ ratio were modified after emplacement of gabbroic magma in the present paper. Further if any later contamination takes place then oxygen isotope study is needed to establish that. The andesitic and granitic rocks from Bundelkhand and present Dargawan gabbro invariably gave Sm-Nd $_{TDM}$ model ages as 2.8 to 3.1 Ga for their protolith and agree with the ages obtained by others. Hence it does not show any mixing as for as Dargawan gabrro is concerned but indicate a homogeneous source. If it is considered mixing then all the whole rocks ages intruding the crust have to be considered as mixing line which is certainly not the case. The two examples from Cuddapah basin will clarify this. The whole rock dating of Pulivendla sill by Rb-Sr gave c. 1817 Ma age (Bhaskar Rao et al. 1995), whereas, beddeleyite from same sill gave U-Pb age as 1885 Ma and both the ages match within error limits. Similar is the case with Vinukonda granite intruding in to the Cumbum Formation of Upper Cuddaph Supergroup in which whole rock Rb-Sr age of c.1615 Ma (Gupta et al. 1984) matches well with the U-Pb zircon age of 1589 Ma (Dobmeier et al. 2006). Both the Pulivendla sill and Vinukonda granites whole rock samples were analysed at Hyderabad by NGRI and AMD respectively. Further this indicates that whole rock ages are as reliable as mineral ages and do not indicate mixing line in most of the cases. Further Dargawan gabbro shows negative e_{Nd} value and according to DePaolo (1981), any basic intrusive in older crust, as is the case of the present study of Dargawan gabbro intruding Lower Bijawar, may have negative e_{Nd} and enriched initial $^{87}Sr/^{86}Sr$ and therefore its age does not indicate a mixing line. $^{143}Nd/^{144}Nd$ initial vs $^{87}Sr/^{86}Sr$ initial diagram, Fig.6, in our paper corroborates the above observation.

2. It is very surprising that Dr. Absar has suggested time frame as Mesoproterozoic i.e. c.1400 to 990 Ma, for the Chhattishgarh Supergroup. c.1400-1500 Ma ages are from basic and felsic intrusives (Das et al. 2009; Bickfoerd et al. 2011) into the Saraipalli Formation of Singhora basin. This indicates that sedimentation in the Saraipalli and further older Rehatikhol Formations of the Singhora basin must have taken place before c.1500 Ma. Hence c.1400 to 990 Ma age frame for Chhattisgarh Supergroup does not support the age data and also does not fit with well established age ranges for similar Proterozoic basins of India like Gwalior, Bijawar and Cuddapah (age of on set of sedimentation c. 2000Ma). The youngest basement rocks of the Chhattisgarh basin in Bastar craton have ages ranging from 1900 to 2100 Ma e.g. youngest basement dykes of Chhattisgarh basin are 1900 Ma old (French et al. 2008) and volcanics of basement Sonakhan Group are 2100 Ma old (Ghosh et al. 1995) which are similar to the basement ages in other Proterozoic basins as mentioned above. Earlier Das et al. (2001) has also summarized all the isolated and detailed studies done by various workers on various disciplines and suggested 1800-1600 Ma age for the Singhora Group. Babu and Singh (2011) also suggested Palaeoproterozoic age for the Singhora Group based on faunal evidences. Hence our age for intrusive Damdama dolerite, c.1600 Ma, stands more acceptable and

is within the stratigraphic framework. Another important point is the field relation which can supersede any geochronological data. The Damdama dolerite has been seen by the field geologists who are co-authors in this paper and it not only intrudes the basement but also the sediments of Chandrapur Group hence the age of Damdama dolerite is more valuable and of significance in establishing the age range of Chhattisgarh Supergroup. As for as Damdama dolerite is concerned 1/Sr vs $^{87}Sr/^{86}Sr$ have negative correlation, hence, as per Dr. Absar it should not be a mixing line. We again repeat here that 1/Sr vs $^{87}Sr/^{86}Sr$ is not a conclusive tool for such an interpretation (Brooks et al. 1976).

3. We have never said that Rb-Sr systematics in Damdama dolerite has not got mobilized during hydrothermal activity. We agree that most of these rocks were also effected by later activity and got altered that is why these samples could not define whole rock Rb-Sr isochron age and show large scatter. This was the reason why we have selected one whole rock sample which was least altered petrographically and separated mineral fractions from this rock as mentioned in the paper to have internal isochron. This is the common methodology generally followed mostly in case of basic rocks which are more akin to weathering and alteration (Pandey et al. 1997). We also agree with Dr. Absar that REE's are least mobile among all the elements as a convention but in recent literature mobility of REE has been observed even in hydrothermal stage. We should not consider immobility of REE as rigid formula but each geological system or event has to be dealt case by case. As for as mobility of REE is concerned we have mentioned this in our paper. Mobility of REE has been observed during the Variscan uranium mineralization, Czech Republic, due to low temperature hydrothermal basinal fluids (Milos Rene**,** 2008). Similarly mobility of REE has been explained without much effecting major oxides, in the sheeted dyke complex, from Costa Rica Rift zone (Wolfgang Bach and Wolfgang Irber, 1998). Apart from this the mobility of rare earths has been observed in the granitic system by the later hydrothermal fluids on mineral scale (Pandey et al. 1998). In the present Damdama dolerite case hydrothermal activity has mobilized the REE as REE's are associated with uranium mineralization in such hydrothermal activity and may be because of this later infiltration of REE's reseting of the Sm-Nd systematics took place on mineral scale in Damdama dolerite without effecting much the Rb-Sr on mineral scale similar to the observation of Wolfgang Bach and Wolfgang Irber, 1998, on sheeted dyke complex, from Costa Rica Rift zone. To support our Sm-Nd age on Damdama dolerite and its correlation with uranium mineralization in Chhattisgarh we would like to bring the fact that the c.1200-1300 Ma age of uranium mineralisation has been reported not only in Indian Proterozoic basins (Pandey et al. 2009) e.g. in Cuddappah basin (Lambapur uranium mineralization, c.1327 Ma by Sm-Nd method, hosted by basement granite and Gandi uranium mineralisation c. 1336 Ma by U-Pb method, fracture control) and in Bhima basin (Gogi uranium mineralisation c.1247 Ma by U-Pb method) but also in the worlds richest uranium deposit i.e. Cigar lake, Canada (age of the major uranium mineralising episode is 1300 Ma). We expect similar age of uranium mineralization in Chhattisgarh basin which has similar geological set as that of Cuddapah and Bhima basins.

4. Similar to the Cuddapph basin in which same uranium mineralization episode affected both the basement granites/basic dykes as well as overlying sediments, we expect in Chhattisgarh basin also same thing might have happened. In the present paper we have reported evidence of minerlised basic dyke intruding basement. The Damdama dolerite also show radioactivity wherever it is fractured, altered and feruginised. The difference is that Damdama dolerite is feebly mineralised in comparison to that of the older basement dykes not cutting the sediments. But we feel that same hydrothermal and uranium mineralization event have affected dolerites of both the basement and within the basin also, similar to that of Cuddapah basin, for which evidences are there as mentioned above and in the paper.

5. We accept that there is error in numbering of sample in location map of sample GC3247 to GC3248 in Fig.1 and scale bar in Fig.2 for which we extremely regret to the readers for the inconvenience.

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