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Strontium isotopic constraints for the origin of barite mineralization of Tons Valley, Lesser Himalaya

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Veins, pockets and lenticles of barite are found to be associated with Neo-Proterozoic Nagthat Formation in Tons Valley. The relation of barite mineralization with the siliciclastic host rocks and its depositional characters favour a stratabound syngenetic origin for barite. However, late event of remobilization partly obliterates the primary features. The strontium isotope ratios of barite are presented here and the data have been used to understand the source and origin of barite. The obtained $^{87}Sr/^{86}Sr$ ratios range from 0.720448 ± 0.000034 to 0.728637 ± 0.000039; these values rule out the possibility of involvement of mantle/magmatic source in the deposition of the Lesser Himalayan barite. Isotopic data reveal that strontium in barite is derived from the crustal source rocks and the local process like recrystallization has influenced this barite mineralization.

AS the isotopic composition of strontium has been changing during the evolutionary processes of the earth, a variation in isotopic initial ratios of strontium is evident in the rocks and minerals of different origins and ages. It is low (0.7000 to 0.7040) in mantle-derived rocks and generally above 0.7100 in the continental crust[1]. Isotopic initial ratios of strontium $^{87}Sr/^{86}Sr$ of the source rocks are also found preserved in various minerals of sedimentary origin. It is well understood that the strontium isotope geochemistry of barite provides an insight to the source and the origin of this mineral[2–8]. Here, we present the estimated strontium isotope ratios of Tons Valley barite and comment on the source of this Lesser Himalayan barite. This information may also be helpful in commenting upon the source and origin of other barite occurrences in Lesser Himalaya, because a regional correlation exists in the Lesser Himalayan barites in terms of their association with the shallow marine Proterozoic siliciclastics, as well as with the calcareous host rocks[9].

Barite occurs about 65 km in the western fringes of Dehra Dun in Tons Valley (Figure 1), wherein it is found on both the sides of the river, i.e. in the Sirmur district and the Dehra Dun district. The stringers, veins, pockets, beds and lenticles of barite occur in siliciclastic host rocks offering workable deposits. Adjacent to the Tons River, a barite mine is present in the Kumla–Andhra area of Sirmur district. The extension of this mineralization is exposed in the adjacent area of Dehra Dun district. Significant barite mineralization is also found in other localities of Sirmur district, e.g. Kanti, Tatyana and Batewari areas[9]. Petrographic studies of barite and the geochemical data of host rocks are indicative of barite deposition in passive continental margin setting. They also signify that the barite was stratabound, which later on remobilized[10]. Fluid-inclusion studies carried out earlier on barite mineralization suggest that barite deposition occurred in an aqueous solution with salinity of < 14 wt per cent NaCl equiv. at a temperature of < 200°C. Involvement of meteoric water during barite deposition is also apparent from fluid data[11]. Absence of any large-scale Pb–Zn–fluorite mineralization in association with barite may rule out possibility of its hydrothermal origin. However, in the Tethys zone of Garhwal and Kumaun Himalaya, polymetallic sulphides are found with barite near Barmatiya, Milam and near Lesser Yangti[12,13]. Hydrothermal origin of barite from Tethys zone is evident from detailed field, petrographic and geochemical studies[13].

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The barite under study is confined to the terminal Proterozoic Nagthat Formation, which is an uppermost unit of the Jaunsar Group and an integral part of the Krol Belt Succession[14,15]. Host Nagthat Formation overlies phyllites, shales and sandstone of the Chandpur Formation and is succeeded by glacio-marine rocks of Blaini Formation (Table 1). Nagthat Formation comprises shallow marine, shore face deposits characterized by the presence of purple, fawn, white-to-grey-coloured siliciclastics and argillites[16]. Thick veins and lenticles of barite are sandwiched between ferruginous, purplish and greyish quartzite. Recent geochemical studies suggest that the source material of the Nagthat siliciclastics was supplied by the granite/granitic gneiss[17]. These evidences coupled with the palaeo-current direction have been interpreted to suggest that the source of host Nagthat siliciclastic rocks might be the southernly situated Banded Gneissic Complex (BGC) of Aravali–Bundelkhand craton[17].

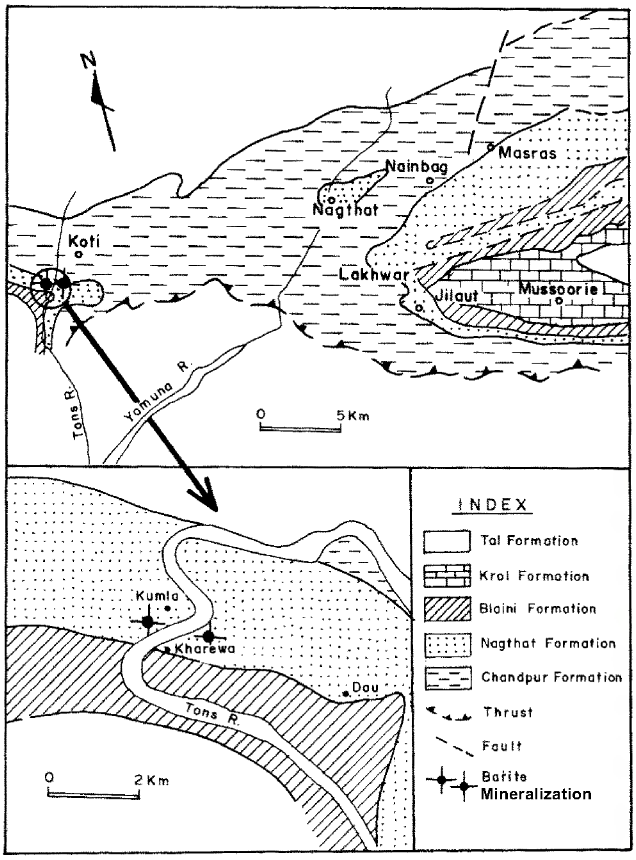

Figure 1. Geological map of part of the Tons Valley showing barite mineralization (after Valdiya[15]).

Veins of barite (Figure 2) are distributed along the joints; fine veins are also found along the random fractures. Barite varies from massive, coarse crystalline to fine crystalline, wherein barite grains are euhedral to subhedral in shape. Coarse grains represent primary deposition and are generally surrounded by the recrystallized barite matrix. Features like annealing texture with triple point junction, sutured and wavy grain margins observed in barite represent the recrystallization effects. Original coarse grains of barite underwent post-depositional strain effects and deformation banding. The associated coarse-

Figure 2. Field photograph of barite veins in Tons Valley.

Table 1. Generalized geological succession of Lesser Himalayan sedimentary formations

Age	Formation	Lithology
Lr Cambrian	Tal Formation	Carbonaceous shale, greywacke, quartzite, talc, phosphorite-bearing chert, calcareous sandstone, limestone, shale
Vendian	Krol Formation	Dolomite, calc-argilite, lenses of gypsum, spherulitic conglomerate
	Infrakrol Formation	Siltstone, shale, greywacke, thin quartzite
Riphean	Blaini Formation	Boulder bed, slate, conglomerate, grey-siltstone, argillite, minor quartzite
	Nagthat Formation	Quartz arenite, subordinate slate and shale
	Chandpur Formation	Grey-green-maroon phyllite, slate and shale
	Mandhali Formation	Phyllites, slates, interbedded limestorne
------------------- Unconformity -------------------		
Middle Proterozoic	Shali–Largi–Deoban zone of Pithoragarh	

grained quartz also shows deformational lamellae. Uncommonly, matrix of the clay minerals is also noticed. The field and textural evidences indicate that the primary deposition of barite occurred along with the host rocks and later it was recrystallized[9,10].

Samples for the strontium isotope geochemistry were selected from (i) Kumla–Andhra mine, in Sirmur district and (ii) veins of barite present to the east of this mine, along the Tons River in Uttaranchal (Figure 2). Samples selected from Kumla mine were from level 600 mrl. Herein, barite is hosted by greyish quartzite. Four snow-white fresh samples without any contamination and alteration were selected and the purity of barite was checked under the binocular microscope. Samples for strontium isotope systematics were analysed on Finganam-Mat 252 mass spectrometer at the Isotope Geology Laboratory of Geological Survey, Prague (Czech Republic). Barite does not have affinity for rubidium and the Rb/Sr ratios of barite are extremely low[18,19]. Therefore, for all practical purposes Sr isotopic values measured in barite may be considered as the initial values and the $^{87}Sr/^{86}Sr$ as the initial ratios. Strontium isotope ratios of four samples from Tons Valley are given in Table 2 and the data are graphically presented in Figure 3. These $^{87}Sr/^{86}Sr$ ratios vary from 0.720448 ± 0.000034 to 0.728637 ± 0.000039. One sample with high percentage of recrystallized grains of barite shows higher strontium isotope initial ratio. The elevated values obtained here can be discussed considering (i) the strontium isotope ratios in various processes of barite formation and (ii) the host-rock deposition.

The $^{87}Sr/^{86}Sr$ initial ratios help to distinguish the origin of barite; Figure 3 shows the distribution of their ratios in barite of various origins. Data of Tons Valley barite under study are also plotted. $^{87}Sr/^{86}Sr$ values generally about 0.707 to 0.709 are indicative of the barite deposited from Karst-type formation process. This is evident from the $^{87}Sr/^{86}Sr$ values of Karst-type barite deposits of Sardinia (0.70947 ± 0.00001) and Calbria (0.70703 to 0.70710) in Italy[3,4]. Stratiform marine barite deposits show $^{87}Sr/^{86}Sr$ ratios slightly below these values. However, in hydrothermal barite deposits these ratios are higher, about 0.71. In the Sierra Del Guadarrama, Spain, $^{87}Sr/^{86}Sr$ ratios varying between 0.715567 and 0.717164 have been used to suggest hydrothermal origin of barite[20]. Strontium isotope ratios of about 0.720 and above are considered to be due to material derived from the crustal source. Anomalous high $^{87}Sr/^{86}Sr$ ratios (0.7234 ± 0.0003) are estimated in the Aravalli barite deposit, which suggest a highly radiogenic crustal source of the Aravalli barite[6]. In addition to the various processes of barite formation, we can also assess the possibility of contribution of strontium from sea water. In the present case this may be considered for the deposition of host shallow marine Neo-Proterozoic Nagthat siliciclastics. Isotopic ratios $^{87}Sr/^{86}Sr$ of sea water during late Proterozoic are estimated to vary from 0.707 to 0.709 (ref. 21). These values may be little enhanced locally because of leaching of radiogenic strontium from feldspathic rocks. However, with such sea water it is difficult to reach the elevated values recorded for Tons Valley barite.

High strontium isotope ratios in Tons Valley barite may be explained as follows: (i) the strontium was derived entirely from crustal rocks of sialic origin which supplied high radiogenic strontium isotope, and (ii) these are the result of a modification of the earlier lower values of strontium isotope ratios by mixing/contamination from high radiogenic ^{87}Sr-bearing source. In any case, these elevated values of $^{87}Sr/^{86}Sr$ ratios are strong evidence of derivation of the element from crustal material having high radiogenic strontium. In the deposition of barite under study, the involvement of strontium from any mantle/magmatic material cannot be invoked. We can explore the possibility that high radiogenic strontium in Tons Valley barite was derived along with the grains of host rocks from the crustal source. For this purpose several evidences should be investigated, including the relation of barite with the host rocks, source of host rocks, and strontium isotope probabilities of the source area. The mode of barite occurrence in lenticular and vein forms,

Table 2. Strontium isotope ratios of Tons Valley barite

Locality	Sample	$^{87}Sr/^{86}Sr$	1 δ
Kumla mine	HS 1	0.726613	± 0.000058
Kumla mine	HS 2	0.728637	± 0.000039
Kumla mine	HS 3	0.720448	± 0.000034
Tons River (Dehra Dun)	HS 4	0.720705	± 0.000039

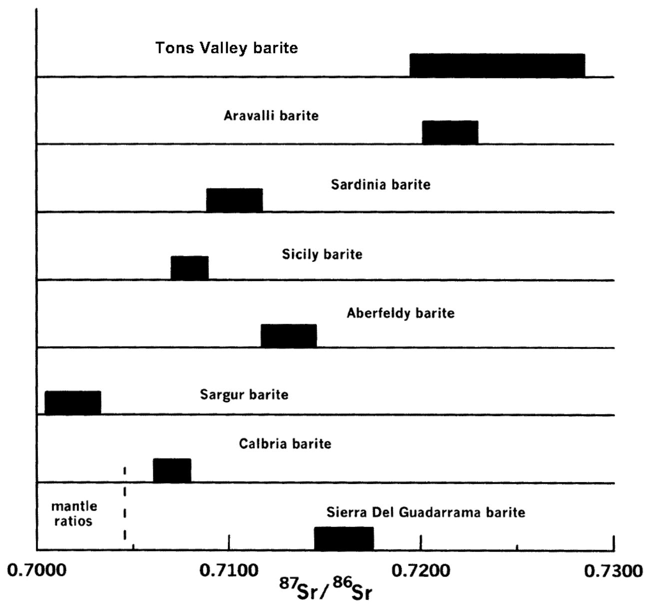

Figure 3. Graphical presentation of strontium isotope data of Tons Valley. $^{87}Sr/^{86}Sr$ ratios in different types of origin of barite are also plotted for comparison.

petrographic features showing presence of two types of grains, viz. original and recrystallized grains, geometry of these grains, and the geochemical data of host quartzite suggest that the primary deposition of barite occurred along with the host rocks, in passive continental margin setting[9,10]. This is unlike barite of Barmatiya–Milam areas in Tethys Himalaya, wherein barite–polymetallic mineralization resulted from hydrothermal solutions migrating through deep conduits[12,13]. The interpretation on barite mineralization of Barmatiya–Milam areas is based on field, petrographic and the geochemical data, including barite affiliation with Cu, Pb, Zn, Sb, As, Ti, Sr and high Ba contents in altered country rocks[12,13].

Further, studies implying the source of host Nagthat siliciclastics demonstrate that the material for their formation was supplied by the BGC. Such conclusion is drawn on the basis of petrographic studies, palaeocurrent direction and the geochemical evidences[16,17]. Material derived from gneissic rocks of BGC is likely to be enriched in radiogenic strontium isotope. This is because weathering products of Precambrian shield areas are rich in radiogenic strontium, with $^{87}Sr/^{86}Sr$ ratios varying from 0.712 to 0.730 (ref. 22). The idea is also strengthened by the strontium isotope geochemistry of the barite mineralization present in quartzites of Aravalli Super Group overlying BGC[6]. Aravalli barite in Jagat area of Rajasthan also shows abnormally high $^{87}Sr/^{86}Sr$ ratios (Figure 2), which match with our data. Thus, evidences supporting barite deposition along with the host Nagthat siliciclastics coupled with source area interpretations for the host rocks favour the idea that the barite was probably derived from the BGC during sedimentation of the host siliciclastics. However, $^{87}Sr/^{86}Sr$ ratios of Tons Valley barite are abnormally high, even higher than Aravalli barite. We suggest that this increase in the ratio of $^{87}Sr/^{86}Sr$ may be a result of barite recrystallization and redistribution in the host Nagthat siliciclastics during Himalayan tectonics. Our interpretation is based on the following: (i) a varied degree of recrystallization is observed in Tons Valley barite (ii) $^{87}Sr/^{86}Sr$ ratios show considerable spread (iii) it is evident that the barite sample with high percentage of recrystallized grains presents a higher strontium isotope initial ratio. During the recrystallization process, an interaction of barite with the basinal fluids may take place. This crustal fluid may enrich the system with the radiogenic strontium, thus raising the $^{87}Sr/^{86}Sr$ ratios. Such increase in strontium isotope ratios with the progressive recrystallization of barite has also been noticed elsewhere[19].

Hence, the initial ratios of strontium isotopes in Tons Valley barite suggest that the strontium is derived from highly radiogenic old crustal source rocks. Influence of magmatic rocks and marine volcanic activity cannot be inferred. An interaction of barite with the crustal fluid present in these Proterozoic host rocks at the time of recrystallization is possible.

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