Among multilateral research output, R&D institutions from nearly 40 countries collaborated in clusters of sizes varying from 3 to 72 institutions per paper. The clusters formed by 41 to 72 institutions accounted for 50% papers, and those formed by 3 to 10 institutions accounted for 30% papers.

Even as both India and Russia are potentially and scientifically strong for making bigger contributions, their cooperation at the bilateral level in terms of quantity and quality publications is still weak. Institutional participation is also low, as it remained confined to two institutions per paper only. Physics and earth and space sciences were the preferred areas for collaborative research at the bilateral level. Within physics, 93% output pertained to papers in nuclear and particle physics, general physics, and applied physics. This may be attributed to the strong interest India and Russia share in defence, space, aeronautics and nuclear research for which physics provides the base. In terms of impact, the earth and space sciences and chemistry have shown better performance and received above the average impact of all disciplines. These two disciplines occupied 1st and 2nd rank under bilateral research compared to their 4th and 5th rank under multilateral research. It suggests that the impact of bilateral co-authored papers in these two disciplines was good and comparable to international standards. The low output from bilateral research might have been due to the applied nature of joint research, which sometimes leads to outputs such as technology development, normally not documented for public consumption.

The collaborative research at multilateral level involving participation of India, Russia and other countries has been relatively better in terms of impact compared to bilateral research. The study shows that participation by as many as 40 countries of the world along with India and Russia in collaborated research could be instrumental in influencing high-impact research output. In multilateral papers, India and Russia were apparently secondary players. The key players were USA, Italy and Germany. They were the first authors in about 70% of co-authored multilateral papers. India and Russia were first authors in just about 14% co-authored papers. The impact of multilateral papers was quite high. About 74% of multilateral papers had an impact factor higher than the average value of all multilateral papers. The top two major disciplines under multilateral research were clinical medicine and physics.

In order to make collaboration between India and Russia more effective, there is a need to understand the shortcomings in the mechanism of participatory research by Indian institutions. This mechanism needs to be modified in the light of the changing priorities of the two countries in S&T. For promoting collaborative research, both Russian and Indian institutions may offer more fellowships, travel grants, etc. to researchers. There is also a need to extend the scope of cooperation to frontier areas of S&T, particularly to those areas where Russia has a strong base.

The findings reported in this study could be of interest to managers in various scientific agencies in planning future collaborations with Russia and nearer home, with other neighbouring countries.

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# Rb–Sr isotopic studies of Puga gneiss and Polokongka La granite from Tso-Morari region of Ladakh, J&K, India

The Rb–Sr dating using thermal ionization mass spectrometer coupled with isotope dilution technique is widely used in the studies of granite rocks to understand their petrogenesis and emplacement ages. This technique has been used to carry out Rb–Sr dating of Puga gneiss from Kiagar La and granites from Polokongka La of the Tso-Morari Crystallines in Ladakh Himalaya, J&K.

The NW-SE trending Tso-Morari crystallines lie between Indus Suture Zone to the north and Tethyan Himalaya to the south (Figure 1). The Puga Formation of the Tso-Morari crystallines comprises quartzo-feldspathic gneisses (Puga gneiss), schistose bands, and lenticular bodies of garnet amphibolites and eclogitic rocks. Also, undeformed granite is exposed at several places within this gneissic complex. One such body is observed at Polokongka La forming main outcrop, while several other undeformed granite bodies of variable size have been encountered at various places in the higher regions of Tso-Morari gneisses (cf. Girard and Bussy[1]). For many decades, the Puga gneiss was considered to host the medium-to-coarse-grained undeformed Polokongka La granite[2–6]. However, Girard and Bussy[1], based on U–Pb dating of zircons, suggested that the Polokongka La granite and the Tso-Morari gneiss (Puga gneiss) from Gyambarma Sumdo have identical ages of 479 ± 2 Ma. They observed identical zircon morphology which shows growth zoning, inherited cores, trace elemental concentrations, and inclusions within the zircons from both these rock types. From their studies they suggested that the Polokongka La granite, classically interpreted as a younger intrusive into Tso-Morari gneiss, in fact represents the undeformed facies of the Puga gneiss.

Taking into consideration the significant new finding of Girard and Bussy[1], we have used a different isotopic systematics, the Rb–Sr dating technique on the samples collected from different localities within the widespread Tso-Morari crystallines (Figure 1). Here we (i) study the genetic relation between Puga gneiss from Kiagar La and granites from Polokongka La, and (ii) give the detailed procedure that is followed at the geochronological laboratories of Wadia Institute of Himalayan Geology, Dehradun, on the recently installed VG-354 thermal ionization mass spectrometer. However, the tectonic implication of these granite bodies along with other granite bodies of Ladakh is currently being investigated (Islam *et al.*, in preparation).

The Puga gneiss from Kiagar La and granites from Polokongka La, Ladakh, were collected within a small area of less than one square kilometre. Samples of about 50–100 mg were weighed into clean Savillex© 15 ml PTFE vials, moistened with MQ and treated with distilled HF + $HNO_3$ mixture. They were kept overnight to ensure complete dissolution, and then digested on a Teflon-coated hot plate at ~ 90°C. This was followed by treatment with distilled HCl, and evaporation to dryness was repeated twice. The digested samples were spiked with pure $^{87}$Rb tracer of 5.053E-6 g/g concentration and with more than 99% pure $^{84}$Sr tracer of 6.646E-7 g/g concentration. The spiked sample solutions were first homogenized on the hot plate and then centrifuged for cation separation using Bio Rad AG 50W X8 resin of 200–400 mesh, with 2 N HCl as eluant. After chemical separation, ~ 1 μl of Rb and Sr elements (in fluoride and nitride forms respectively) was loaded onto a single Ta filament along with 1 : 1 0.5 M $H_3PO_4$ using Teflon micro-tips.

The isotopic analyses were carried out using GPJ program on a single axial collector of VG-354 TIMS, on-line with a DOS compatible computer for data acquisition and evaluation. The $^{87}Sr/^{86}Sr$ ratio was normalized to $^{86}Sr/^{88}Sr$ value of 0.1194. All final errors in this paper are given at 2σ, the decay constant following Steiger and Jager[7], i.e. ($^{87}$Rb) = 1.42 × $10^{-11}$ yr$^{-1}$, and sample regression is done using Provost's[8] program. The reproducibility of the $^{87}Sr/^{86}Sr$ ratio measurement was tested by repetitive analyses of the NBS SRM-987 Sr standard. The measured value and total variability carried out on 50 odd analyses during the last one year was found to be 0.71022 ± 6. These values are within errors of the results of 0.71014 ± 20 given by NBS[9]. In order to keep the contamination levels at a minimum, sample processing is also carried out in wooden cubicles fitted with HEPA filters for clean air (Class 100). Also, ultra-pure milli-pore water (MQ) having conductivity < 0.1 μs/cm is used at various stages of cleaning and processing the samples, and for making reagents. The total blank levels observed are Sr < 1 ng and Rb < 1.5 ng.

The results of Rb–Sr dating of the Puga gneiss from Kiagar La gave a well-defined seven-point isochron, age of 499 ± 8 Ma with $Sr_i$ ratio of 0.7276 ± 0.0016; granites from Polokongka La gave a six-point isochron, age of 487 ± 23 Ma with $Sr_i$ ratio of 0.7249 ± 0.0044 (Table 1 and Figure 2). The ages obtained are comparable with U–Pb dates of 479 ± 2 Ma, given by Girard and Bussy[1], for both Polokongka La granite and Puga gneiss, and also with unpublished Rb–Sr age of 487 ± 25 Ma for the Polokongka La granite (Trivedi, J., unpubl. Ph. D thesis), and with 458 ± 14 Ma Rb–Sr age obtained for Polokongka La granite[10].

Mineralogically the Polokongka La granite and Puga gneiss from Kiagar La show wide variation; and have in common quartz, feldspars, muscovite and biotite as common minerals, and apatite, zircon, opaques, secondary chlorite, epidote and sphene as accessory minerals. Garnet, spinel and aluminum silicates have restricted occurrences in these rocks. The field traverse along the hillocks of Kiagar La also showed that at lower levels we find gneissic rocks which pass on gradually into the undeformed granites towards higher levels. The present study includes well-foliated to unfoliated rocks collected from Kiagar La. Geochemically, both these groups of rocks, the Puga gneiss from Kiagar La and granites from Polokongka La, are peraluminous (mol. A/CNK > 1.15), have high $SiO_2$ 70 to 76 wt%, $FeO^T$ in the range of 1.8 to

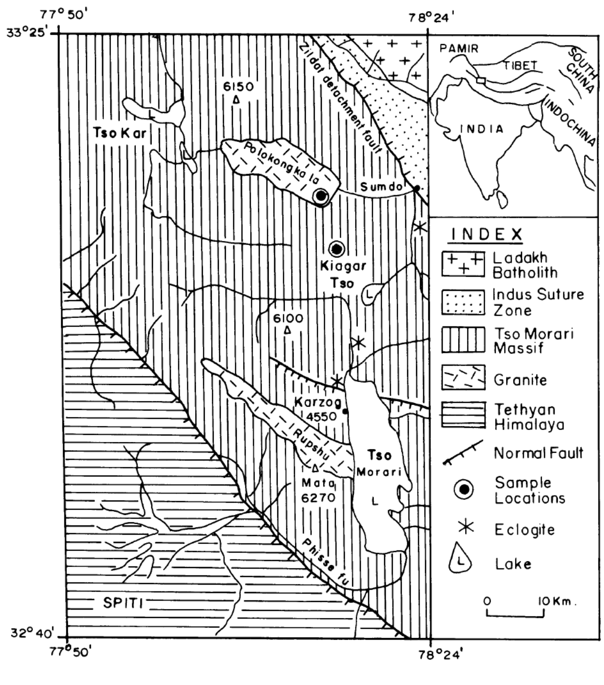


**Figure 1.** Geological map of Tso-Morari, Ladakh, J&K, indicating sample locations of Puga gneiss from Kiagar La and granites from Polokongka La (after Guillot *et al.*[5]).

**Table 1.** Rb–Sr isotopic data of Puga gneiss from Kiagar La and granites from Polokongka La, Ladakh, J&K

| Sample no. | $^{87}Rb/^{86}Sr$ | $^{87}Sr/^{86}Sr$ |
|---|---|---|
| Puga Gneiss, Kiagar La | | |
| RH-48 | 14.812 | 0.83402 (± 05) |
| RH-49 | 24.515 | 0.89811 (± 77) |
| RH-51 | 7.156 | 0.77803 (± 24) |
| RH-54 | 17.105 | 0.84608 (± 17) |
| RH-56 | 21.983 | 0.88598 (± 17) |
| RH-76 | 54.331 | 1.11260 (± 34) |
| RH-88 | 14.431 | 0.83290 (± 40) |
| Granites, Polokongka La | | |
| RH-490 | 10.466 | 0.79956 (± 09) |
| RH-495 | 14.698 | 0.82684 (± 05) |
| RH-496 | 12.133 | 0.80630 (± 06) |
| RH-498 | 23.283 | 0.88735 (± 04) |
| RH-500 | 14.144 | 0.82045 (± 12) |
| RH-501 | 14.368 | 0.82457 (± 08) |

Numbers in parentheses refer to 2σ in-run precision, and represent the last two digits of the isotopic ratio.

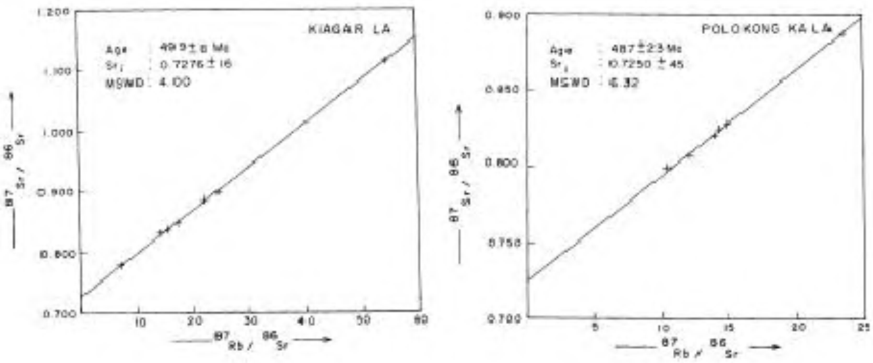


**Figure 2.** Rb–Sr isochrons of Puga gneiss from Kiagar La and granites from Polokongka La, Ladakh, J&K. Regression calculations were performed using an estimated uncertainty of 1% on *X*-axis and 2σ error on *Y*-axis (Table 1).

4 wt%, CaO < 1%, and $K_2O/Na_2O > 1.4$. On the AFM diagram they show a typical calc-alkaline trend. The geochemical coherence of the major oxides and trace elements is evident from the overlapping compositions on the Harker's variation diagram. On this diagram the major oxides like MnO, $FeO^T$, $TiO_2$ and $Al_2O_3$ show negative trend, while CaO, $Na_2O$, $K_2O$ and $P_2O_5$ show uniform distribution. On the other hand, trace elements like Zn, Sr, Ga, Nb and Zr show negative correlation, while other elements like U, Th, Y, Rb, Ba and Ni show much scatter. They also show overlapping REE and multi-elements normalized patterns, with elements like Eu, Ba, Nb, Ti, Sr and Zr showing typical negative anomalies.

The petrochemical similarities along with similar Sr initial ratios of Polokongka La granites and Puga gneiss from Kiagar La as observed earlier, suggest that the rocks have been derived from geochemically and isotopically similar source. Their high $^{87}Sr/^{86}Sr$ initial ratio and peraluminous nature (mol. A/CNK > 1.15) demonstrate that both suites of granites/gneisses were generated by partial melting of a crustal-derived pelitic source. The similar ages obtained for Puga gneiss and Polokongka La granite by Rb–Sr dating (~ 490 Ma) suggest that these rocks are not only derived from similar source, but are also derived from a single source having $^{87}Sr/^{86}Sr$ composition of ~ 0.726.

Summarizing the isotopic and geochemical studies, we conclude that the Puga gneiss from Kiagar La and the granites from the Polokongka La were derived from a single pelitic source, and the Polokongka La granites represent the undeformed segments of Puga gneiss, and that the former is not intrusive into the latter.

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