Field Observations of Dykes and Geometry of Igneous Enclaves in Ladakh Batholith Granitoids Around Taru, Leh, Ladakh, North India

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Abstract The Ladakh Batholith is part of Andean-type Trans-Himalaya (Gangdese) plutonic belt that extends for 2500 km from Afghanistan in the west to east of Lhasa in Tibet. Dykes of varied composition e.g. doleritic, andesitic, basaltic andesite with 24–54 Ma age intrude Ladakh batholith along the southern margin at a number of places like Taru, Umla, Saboo, Thikse, Hemis-Shangpuchan etc. Ladakh batholith is also intruded by pegmatitic and aplite veins throughout its length and breadth. In the present work, dykes intruding Ladakh batholith at Taru village of Leh district of the Union Territory Ladakh have been studied to understand their mineralogical characteristics and stress regimes. The studied dykes are post-plutonic and extend from a few metres to several metres along with 1–3 m width. Nine dykes exist within ~5 km^2 area around Taru. Mostly these are composed of plagioclase, pyroxenes, hornblende, k-feldspars, quartz and biotite. The phenocrysts have sizes between 1 to 10 mm. The studied dykes around Taru village have dominant NE-SW trend. Rose diagram of joints of the studied dykes shows that NE is the dominant trend of joints followed by NW, SW and SE as the other trends. The dominant strikes of the studied dykes and those of the joints is NE-SW. Igneous enclaves occur at places as grey to blackish blobs in the Ladakh granitoids around the study area. These enclaves are mafic, felsic and hybrid, fine to medium grained, melanocratic to mesocratic, without or with phenocrysts and vary in size significantly. The enclaves have varied shapes like schlieren, spindle, star, batman, tear drop, elongated, fish etc. The presences of these igneous enclaves indicate that the mingling process of mafic

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and felsic composition magmas had occurred within these granitic plutons present around Taru village.

Keyword Ladakh batholith · Dykes · Igneous enclaves

1 Introduction

The Himalayan Mountain range is formed due to subduction of Tethys Ocean and subsequent collision between the Indian and the Eurasian tectonic plates (Aitchison et al., 2009; Mukherjee et al., 2013, 2015). Trans-Himalaya is situated north of the main Himalayan belt. The Ladakh batholith (LB) is part of the Trans-Himalaya. LB is made up of multiple calc-alkaline magmatic bodies, extends NW to SE for ~600 km with 30–50 km width. LB is delimited by two suture zones- the Shyok and the Indus Suture zones at north and south, respectively (Fig. 1). The rock types of LB are norites, gabbros, granodiorites, diorites and leco-granite (Honegger et al., 1982). Biotite-bearing granites and granodiorites are the chief rock types. Crystallization ages of few granitoids of LB are 102-60 Ma (Honegger et al., 1982). LB is intruded by dykes at several places in west of Leh, such as around Phyang, Taru, Umla, Tunglung, Likir, Yangthang and Hemis-Shugpachan, and also east of Leh (e.g. Nyoam) (Ahmad et al., 1998). These dykes are 54–24 Ma old (Ravikant & Guha, 2002; Hari et al. 2015). LB also encloses igneous enclaves of varied shapes (rounded, elongated, lenticular etc.). The study of dykes is important for understanding the geodynamic processes of the area, in addition to their significant role for scrutinizing the geochemical evolution of mantle (Mir et al., 2010; Tarney, 1992). The host rock type of all studied dykes is Ladakh granitoids. The present work focuses on mineralogy, structural data of joints of dykes and geometry of igneous enclaves, which are present in the LB around the Taru village (Fig. 2). The location of studied dykes is shown in Google Earth map (Fig. 3) and geographical coordinates of each studied dyke is given in Table 1. The studied area is near the Leh-Srinagar highway. Structural data (including dip and trend) of joints within dykes were recorded in the field with the help of Brunton Compass and is given in Table 2. Data were plotted stereographically using the STEREONET software, version 9.96 of 2017. Field observations like colour, nature and contact relationship of igneous enclaves with host rock and geometry of these enclaves were documented. Dykes have been taken as reliable deformation indicators to decipher tectonics (e.g. Babar et al., 2017; Misra & Mukherjee, 2017).

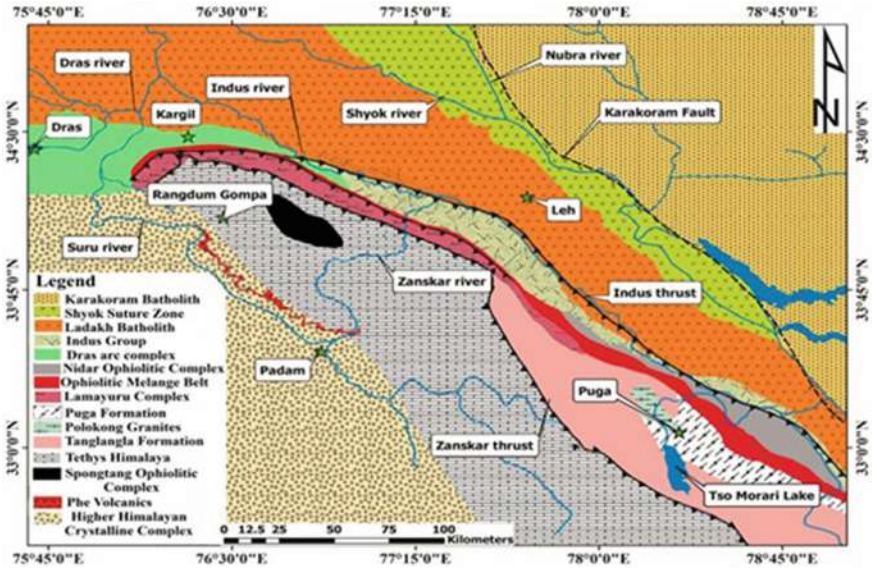

Fig. 1 Simplified geological map of the northern Ladakh–Zanskar Himalaya (after Maheo et al., 2004)

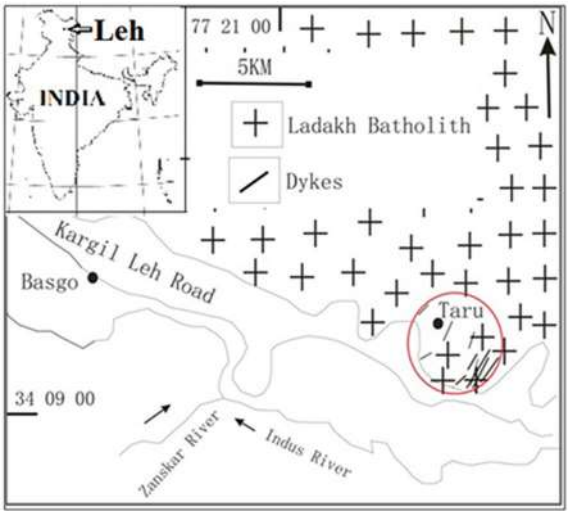

Fig. 2 Geological map around Taru village (after, Heri et al., 2015), showing study area in red circle

Fig. 3 Google earth map showing location of studied dykes near Taru village, Leh, Ladakh

Table 1 Geographical coordinates of studied dykes around Taru village, Leh, Ladakh

S. no.	Dyke number	Latitudes	Longitudes
01	Dyke-1	34°11′ 23″N	77°24′ 09″E
02	Dyke-2	34°10′ 49″N	77°25′ 43″E
03	Dyke-3	34°11′ 59″N	77°25′ 60″E
04	Dyke-4	34°10′ 25″N	77° 25′ 55″E
05	Dyke-5	34°10′ 33″N	77°26′ 14″E
06	Dyke-6	34°10′ 0.5″N	77° 26′ 55″E
07	Dyke-7	34° 10′ 45″N	77° 26′ 08″E
08	Dyke-8	34°10′ 19″N	77°26′ 51″E
09	Dyke-9	34°10′ 42″N	77°26′ 51″E

2 Field Characteristics of Dykes

Dyke 1

It is situated ~1 km away from the Leh campus, University of Ladakh near the Gurdawara Pathar Sahib. Here, post-plutonic dyke exists adjacent to ~10 m wide syn-plutonic dyke (Fig. 4). The host rock of both these dykes is the Ladakh Granite. The strike of post-plutonic dyke is N50°W. Dip amount and dip direction of this dyke are 45° and N40ºE, respectively. Three sets of joints are observed in post-plutonic dyke. These are oblique, cross and longitudinal joints. The cross joint also cuts through the host rock. Spheroidal weathering pattern is noticed in parts of this dyke (Fig. 5).

Table 2 Structural data of joints of dykes intruding Ladakh Batholith around Taru, Leh, Ladakh

Parameters	Strike (in degrees)	Dip amount (in degrees)	Dip direction (in degrees)
Dyke 1, Taru, West of Taru Campus, UoL, Near Gurduwara			
Dyke 1	310 (N50ºW)	45	40 (N40ºE)
Oblique joint-1	275 (N85ºW)	80	05 (N5ºE)
Oblique joint-2	220 (S40ºW)	75	130 (S50ºW)
Oblique joint-3	55 (N55ºE)	58	145 (S35ºE)
Cross joint-1	240 (S60ºW)	45	330 (N30ºW)
Cross joint-2	N55ºE	50	325 (N35ºE)
Cross joint-3	N45ºE	76	135 (S45ºE)
Longitudinal joint-1	340 (N20ºW)	70	70 (N70ºE)
Longitudinal joint-2	115 (S65ºE)	71	205 (S25ºW)
Dyke 2, Taru, East of Taru Campus, UoL			
Dyke 2	24 (N24ºE)	90	Vertical
Oblique joint-1	95 (S85ºE)	71	5 (N5ºE)
Oblique joint-2	95 (S85ºE)	84	Vertical
Pegmatite vein	315 (N45ºW)	60	45 (N45ºE)
Dyke 3, Taru, East of Taru Campus, UoL			
Dyke 3	75 (N75ºE)	80	165 (S15ºE)
Oblique joint	70 (N70ºE)	60	340 (N20ºW)
Cross joint	15 (N15ºE)	30	105 (S75ºE)
Longitudinal joint	80 (N80ºE)	60	170 (S10ºE)
Dyke 4, Taru, East of Taru Campus, UoL			
Dyke 4	75 (N75ºE)	80	165 (S15ºE)
Oblique joint	10 (N10ºE)	45	100 (S80ºE)
Cross joint-1	130 (S50ºE)	50	40 (N40ºE)
Cross joint-2	340 (N20ºW)	80	250 (S70ºW)
Dyke 5, Taru, East of Taru Campus, UoL			
Dyke 5	80 (N80ºE)	90	Vertical
Oblique joint	50 (N50ºE)	60	140 (S40ºE)
Cross joint	330 (N30ºW)	85	60 (N60ºE)
Dyke 6, Taru, East of Taru Campus, UoL			
Dyke 6	75 (N75ºE)	75	165 (S15ºE)
Oblique joint	105 (S75ºE)	45	195 (S15ºW)
Cross joint-1	130 (S50ºE)	50	40 (N40ºE)
Cross joint-2	190 (S10ºW)	55	100 (S80ºE)
Longitudinal joint	290 (N70ºW)	54	200 (S20ºW)
Dyke 7, Taru, East of Taru Campus, UoL			
Dyke 7	85 (N85ºE)	90	Vertical

(continued)

Table 2 (continued)

Parameters	Strike (in degrees)	Dip amount (in degrees)	Dip direction (in degrees)
Cross joint	190 (S15ºE)	80	280 (N80ºW)
Longitudinal joint-1	85 (N85ºE)	80	175 (S5ºE)
Longitudinal joint-2	90 E	45	360 N
Oblique joint-1	315 (N45ºW)	65	225 (S 45ºW)
Oblique joint-2	305 (N55ºW	70	35 (N35ºE)
Dyke 8, Phyang (NW of Phyang Petrol pump)			
Dyke 8	55 (N55ºE)	90	Vertical
Oblique joint-1	10 (N10 ºE)	40	100 (S80ºE)
Oblique joint-2	295 (N65ºW)	20	25 (N25ºE)
Oblique joint-3	45 (N45ºE)	25	145 (S35ºE)
Cross joint-1	135 (S45ºE)	80	225 (S45ºW)
Cross joint-2	160 (S20ºE)	65	70 (N70ºE)
Dyke 9, Phyang (NW of Phyang Petrol pump)			
Dyke 9	70 (S70ºE)	80	340 (N20ºW)
Cross-1	20 (N20ºE)	55	110 (S70ºE)
Cross-2	20 (N20ºE)	65	290 (N70ºW)
Cross-3	140 (S40ºE)	85	230 (S50ºW)
Longitudinal joint-1	235 (S55ºW)	65	145 (S35ºE)
Longitudinal joint-2	70 (N70ºE)	80	160 (S20ºE)
Oblique joint-1	210 (S30ºW)	65	300 (N60ºW)
Oblique joint-2	295 (N65ºW)	82	25 (N25ºE)
Oblique joint-3	120 (S60ºE)	60	210 (S30ºW)

Dyke 2

This dyke is situated ~1 km from the University of Ladakh Leh Campus towards Phyang village along NE (Fig. 6). The strike of this dyke is N24ºE and dips vertically. Extension of this dyke is ~150 m. Aplite vein also intrudes in Ladakh granitoids in the vicinity of this dyke (Fig. 7). Attitude data of joint sets as documented in field (Fig. 8) is given in Table 1.

Dyke 3

This dyke is situated in Taru village and ~1.5 km away from the University of Ladakh, Leh Campus towards north. The strike of this dyke is N75ºE with dip amount of 80º and dip direction of S15ºE. The dyke is oblique-slip faulted at two places (Fig. 9). The dyke is also cut by pegmatite vein. Three sets of joints- oblique, cross and longitudinal are documented at this dyke.

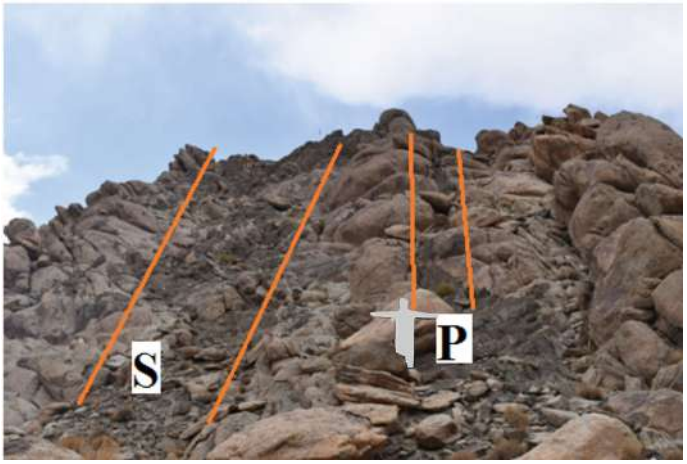

Fig. 4 Syn (S) and post-plutonic (P) dykes intruded in the Ladakh granitoids near Gurduwara Pathar Sahib, ~1 km from the Leh campus, UoL. Marker: Akhtar R. Mir (5.6 feet height)

Fig. 5 Spheroidal weathering on dyke 1. Marker: Geological hammer (1.9 feet length)

Dyke 4

This dyke is situated at a distance of nearly 1 km from UoL, Leh Campus in South-east direction towards Phyang village (Fig. 10). The orientation of dyke is N 75° E. It dips 80º and towards S15°E. The dyke contained 3 sets of joints they are oblique joint, cross joint-1, and cross joint-2.

Dyke 5

This dyke is situated towards east of dyke 4. The dip of this dyke is vertical having N80ºE strike. This is a fine-grained dyke (Fig. 11). Width of this dyke is ~3 m and is ~300 m long. The dyke contains two sets of joint (Fig. 12).

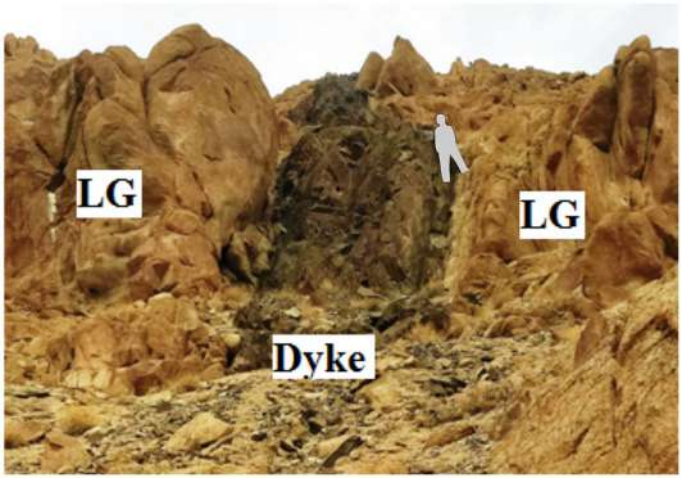

Fig. 6 Dyke 2 having strike NE-SW and having almost vertical dip intruding in Ladakh granitoids (LG). Marker: Nazir A. (5.2 feet height)

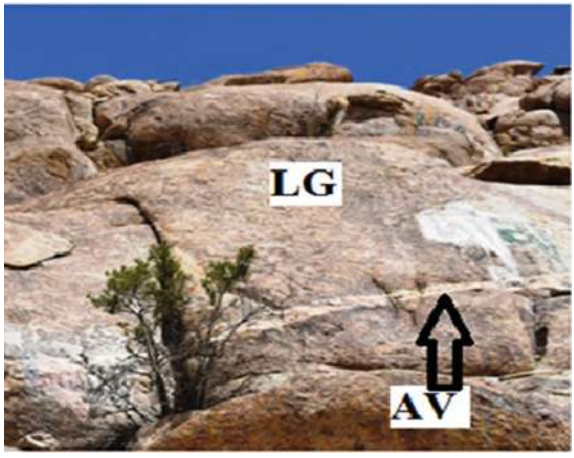

Fig. 7 Aplite vein (AV) intruding in the Ladakh granitoids (LG) in the vicinity of dyke-2

Dyke 6

This dyke is east of dyke 5 towards Phyang village. It is andesitic in nature and shows porphyritic texture (Fig. 13). The width of this dyke is ~5 m and extends for more than 100 m. The strike of the dyke is 75^0, the dip amount is 75 and the dip direction is S15 ºE. The dyke contains four sets of joints (oblique, cross and longitudinal joints). This dyke shows zoned phenocrysts of k-feldspars embedded in fine groundmass (Fig. 14).

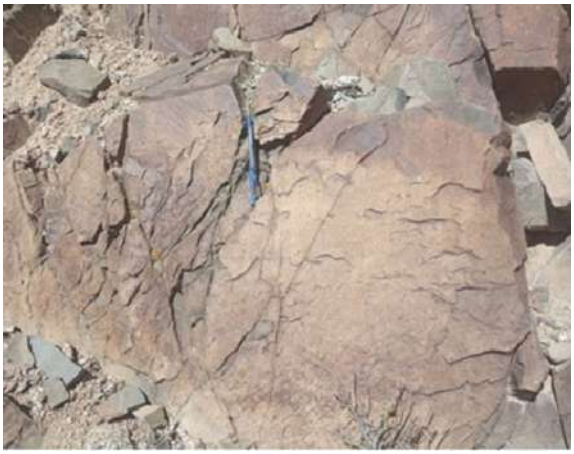

Fig. 8 Joints within dyke 2. Marker: Ball pen (5.5 inches long)

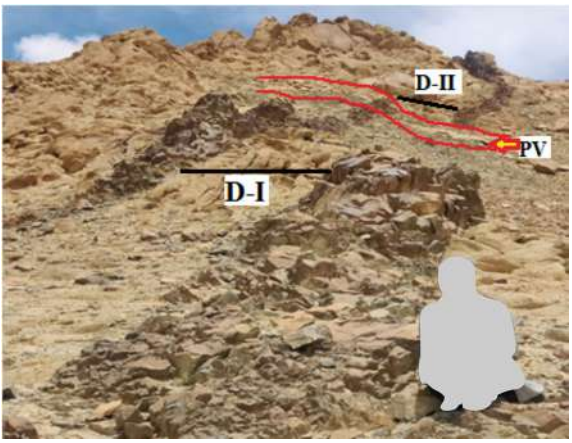

Fig. 9 Displacement of dyke-3 at two places marked as D-I and D-II. Pegmatite vein (PV) also cuts through this dyke. Marker: Shaida (3 feet- waist to head height)

Dyke 7

This dyke is situated east of Taru towards the Phyang village (Fig. 15). This vertical dyke strikes N85ºE. The dyke contains four sets of joints (oblique joints-1, cross and longitudinal-1, 2) (Fig. 16). Exposed parts of this dyke are more weathered than the other dykes in the surrounding area. A hand specimen sample was collected that shows the contact between dyke and host granite (Fig. 17).

Fig. 10 Dyke-4 intruding in the Ladakh granitoids. Marker: Shaida (5 feet height)

Fig. 11 Dyke-5 intruded in the Ladakh granitoids. Marker: Shaida (5 feet height)

Dyke 8

This dyke is situated north-west of the Phyang petrol pump at ~2 km distance towards Taru village (Fig. 18). The strike of this dyke is N55ºE and dips vertically. This dyke contains oblique, cross, and longitudinal joints.

Dyke 9

This dyke is situated towards north of dyke 8 at a distance of ~150 m (Fig. 19). The strike of this dyke is N70ºE having dip = 80° and dip direction = 340° N. The width

Fig. 12 Close view of joints within dyke 5. Marker: Ball pen (5.5 inch long)

Fig. 13 Dyke 6 intruded in the Ladakh granitoids. Marker: Shaida (5 feet height)

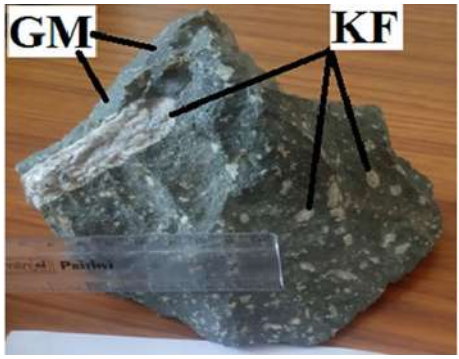

Fig. 14 Handspecimen of andesite dyke 6 showing porphyritic texture wherein phenocrysts of K-feldspars (KF) are embedded in a fine groundmass (GM)

Fig. 15 Dyke 7 intruding in the Ladakh granitoids. Marker: Shaida (5 feet height)

Fig. 16 Joint sets of dyke 7. Marker Ball pen (5 inch long)

Fig. 17 Handspecimen showing contact between dyke 7 (D) and host granite (G)

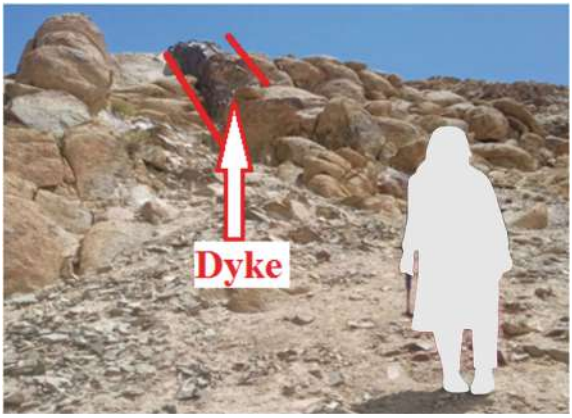

Fig. 18 Dyke 8 intruding in the Ladakh granitoids. Marker: Shaida (5 feet height)

Fig. 19 Dyke 9 intruding in the Ladakh granitoids. Marker: Shaida (5 feet)

and length of this dyke is 2 m and ~500 m respectively. The structural data of joints within this dyke is given in Table 1.

From the attitude data of dykes and joints (within dykes) of study area (Table 1), stereo-projections and rose diagrams have been drawn (Fig. 20). Figure 20a shows that NE is the dominant trend of the dykes within the study area, whereas NW is the second dominant direction. Further, rose diagram of joints (Fig. 20b) inside the dykes shows that NE is the dominant trend followed by NW, SW and SE directions.

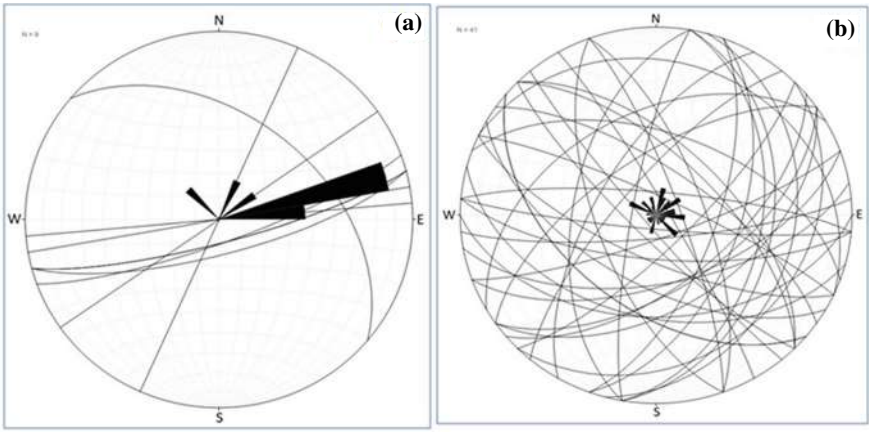

Fig. 20 **a** Showing rose diagram of dykes and **b** rose diagram of joints of dykes around Taru village, Leh, Ladakh

3 Geometry of Igneous Enclaves

Location 1

Near the Taru streamlet, at ~1.5 km from the University campus at Taru towards south-east, mafic schlieren have been noticed within the Ladakh granitoids (Fig. 21). Schlieren are dark, fine-grained, biotite-rich segregations within the host granitoid. They vary in length (several cm to >1 m) and width (<1 cm to 10 cm). Schlieren are most common near the margins of enclave swarms and appear texturally identical to the biotite-rich parts associated with enclaves. Most of these schlieren show diffusive contact with the host granite.

Location 2

Near location 1, a nearly spindle-shaped enclave has been noted. This enclave shows defused contact with the host granitoids (Fig. 22).

Location 3

Felsic enclave including the xenoliths of host granite is seen on the left bank of the Taru streamlet (Fig. 23). This site is ~1.5 km from the Ladakh University Leh campus.

Location 4

Numerous trails of oriented elliptical mafic enclaves showing possibly a magmatic flow structure within the host Ladakh Granite have been documented near the Taru Phyang village boundary at ~2.5 km from the Ladakh University Leh campus towards SE (Fig. 24). Some of these enclaves are tear-drop and deformed star-shaped.

Fig. 21 Schlieren of mafic composition within the Ladakh granitoids

Fig. 22 A spindle-shaped enclave in the Ladakh granitoids

Location 6

Near Taru-Phyang village boundary, elongated mafic enclave has been seen with crenulated contact with host granite. Some K-feldspar crystals of host granite are seen fully and partially enclosed within this enclave as xenocrysts (Fig. 25). From the same location, a mafic enclave quadrilateral is also noted with crenulated contacts (Fig. 26).

Location 7

Two adjacent mafic enclaves were seen in the Ladakh batholith at Taru village (Fig. 27). These enclaves show sharp contact with the host granite.

Fig. 23 Felsic enclave inside the Ladakh granitoids

Fig. 24 Mafic enclave swarm inside the Ladakh granitoids

Location 8

Near Chamba of Ladakh University, Leh Campus (Taru), ~2 feet long fine-grained mafic enclave was noted in the Ladakh granites (Fig. 28).

Fig. 25 Elongated mafic enclave with crenulated contact with the host granite

Fig. 26 A quadrilateral mafic enclave with crenulated contact with the host granite

4 Summary and Conclusion

The dominant strike of the studied dykes is NE followed by subordinate directions of NW and E-W. The dip amount of these dykes varies from 45 to 90°. These dykes extend for ~50–300 m with a width of ~0.5–6 m. In some cases, cross joints inside the dykes extend and cut through the host granite body. Igneous enclaves occur as grey to black blobs throughout the Ladakh batholith granitoids around Taru village. These enclaves are mafic, felsic and hybrid in nature. These enclaves are fine to medium grained, and melan- to mesocratic. While some mafic enclaves have sharp boundaries with the host rock, others have diffuse contacts. Further, these enclaves have different shapes like schlieren, spindle, star, batman, tear drop, elongated, fish etc. The presences of these igneous enclaves indicate that the mingling process of

Fig. 27 Adjacent mafic enclaves in the Ladakh granitoids, near Taru village

Fig. 28 Mafic enclave near the Chamba, University of Ladakh, Leh Campus

mafic and felsic composition magmas had occurred within the granitic plutons near Taru area.

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References

Ahmad, T., Thakur, V. C., Islam, R., Khanna, P. P., & Mukherjee, P. K. (1998). Geochemistry and geodynamic implications of magmatic rocks from the Trans Himalayan arc. *Geochemical Journal, 32*, 383–404.

Aitchison, J., Jason, R., Chan, A., & Davis, A. (2009). Tectonic implications of felsic tuffs with in the lower Miocene Gangrinboche conglomerates, Southern Tibet. *Journal of Asian Earth Science, 34*, 287–292.

Babar, M., Kaplay, R. D., Mukherjee, S., & Kulkarni, P.S. (2017). Evidences of deformation of dykes from central deccan volcanic province, Aurangabad, Maharashtra, India. In S. Mukherjee, A. A. Misra AA, Calvès G, Nemčok M. (Eds.), *Tectonics of the Deccan Large Igneous Province* (Vol. 445, pp. 337–353). London: Geological Society, Special Publications.

Heri A. R., Arrchison J. C., King, J. A., & Villa, I. M. (2015). Geochronology and isotope geochemistry of Eocene dykes intruded in Ladakh batholith. *Lithos 212–215*,111–121.

Honegger, K., Dietrich, V., Frank, W., Gansser, A., Thoni, M., & Trommsdorf, V. (1982). Magmatic and metamorphism in the Ladakh Himalayas (the Indus-Tsangpo suture zone). *Earth Planetary Science Letters, 60*, 253–292.

Maheo, G., Bertrand, H., Guillot, S., Villa, I. M., Keller, F., & Capiez, P. (2004). The south Ladakh ophiolites (NW Himalaya, India): An intra-oceanic tholeiitic origin with implication for the closure of the Neo-Tethys. *Chemical Geology, 203*, 273–303.

Mir, A. R., Alvi, S. H., & Balaram, V. (2010). Geochemistry of mafic dikes in the Singhbhum Orissa craton: Implications for subduction-related metasomatism of the mantle beneath the eastern Indian craton. *International Geology Review, 52*(1), 79–94.

Misra, A. A., & Mukherjee, S. (2017). Dyke-brittle shear relationships in the Western Deccan Strike Slip Zone around Mumbai (Maharashtra, India). In S. Mukherjee, A. A. Misra, G. Calvès, N. Nemčok (Eds.), *Tectonics of the Deccan Large Igneous Province* (Vol. 445, pp. 269–295). London: Geological Society, Special Publications.

Mukherjee, S. (2026). Introduction to "Structural Geology & Tectonics". In S. Mukherjee (Ed.), *Structural Geology & Tectonics.* Springer. ISBN: 978-981-95-4743-2.

Mukherjee, S., Carosi, R., van der Beek, P. A., Mukherjee, B. K. & Robinson, D. M. (2015). Tectonics of the Himalaya: An introduction. In S. Mukherjee, R. Carosi, P. van der Beek, B. K. Mukherjee & D. Robinson (Eds.), *Geological Society* (Vol. 412, pp. 1–3). London: Special Publications.

Mukherjee, S., Mukherjee, B., & Thiede, R. (2013). Guest Editors. Geosciences of the Himalaya-Karakoram-Tibet Orogen. *International Journal of Earth Sciences 102*, 1757–1758.

Ravikant, V., & Guha, D. (2002). Ultra-potassic post collisional dyke from the Leh batholith, Northwest Himalaya. *Journal of the Geological Society of India, 59*, 473–476.

Tarney, J. (1992). Geochemistry and significance of mafic dyke swarms in the Proterozoic. In K. C. Condie (Ed.), *Proterozoic Crustal Evolution* (pp. 151–179). Elsevier.