# Granitic Rocks Underlying Deccan Trap Along the Margin of East Dharwar Craton, Mutnyal (Maharashtra)—Bhaisa (Telangana), India—General Description and Deformation

**R. D. Kaplay, Md. Babar, Soumyajit Mukherjee, Deepak Wable, and Kunal Pisal**

**Abstract** The contact between the Eastern Dharwar Craton with the Deccan trap, in the vertical section, is less studied structurally. A field study at the margin of the Deccan trap with East Dharwar Craton displays strong deformations in the Dharwar Craton just underneath the Deccan trap. We report small faults, folds, boudins and shear zones within veins in the Dharwar Craton. These are the first physical evidence of faults and other structures in granites below the cover of Deccan trap. The zone along the contact of Dharwar granite with Deccan trap, stretching NE-SW for ~60 km, is designated as the 'East Dharwar Margin Deformation Zone' (EDMDZ). No deformations are observed in the Deccan trap overlying the Dharwar Craton. Dominant reverse fault tectonics along the contact of South East Deccan Volcanic Province with East Dharwar Craton is revealed. NW verging reverse faults are observed in the underlying basement granites. This suggests that the maximum horizontal compression direction in the study area trends NW–SE.

## 1 Introduction

The Eastern Dharwar Craton (EDC) covering parts of the states Andhra Pradesh and Karnataka (India) mainly consists of reactivated young granitoid and belongs to the unclassified Peninsular Gneissic Complex (PGC). This perhaps marks the last phase of the evolution of Dharwar Craton (review in Ramakrishna and Vaidyanadhan 2008).

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The northern extension of PGC is reported in part of the Nanded district, Maharashtra, and is referred to as EDC. These granitoids are also called the 'Nanded Granitoids' (NG) (Banerjee et al. 1993; Wesanekar and Patil 2000; Banerjee 2007). The study area lies SE of Nanded and is just at the contact between the South East Deccan Volcanic Province (SEDVP) and the EDC (Fig. 1).

The region is a stretch of ~60 km from L1 (Mutnyal: Nanded district, Maharashtra) to L4 (Bhaisa: Nirmal district, Telangana). This segment is predominantly represented by thin basalt cover, which is underlain by pink and grey coarse-grained/porphyritic granite.

Granites at L4 also show patches and enclaves of mafic rocks (Banerjee et al. 2012). In some parts of the study area, Upper Cretaceous 'infratrappean' limestones expose in between granitoid and overlying Deccan trap basalt (Banerjee et al. 2012). Granitic rocks here belong to Palaeoproterozoic age as the oldest rock unit. These granitic rocks are intruded by quartzo-feldspathic/quartz veins or basic Palaeoproterozoic to Mesoproterozoic intrusions. The overlying Deccan trap belongs to Upper Cretaceous to Lower Palaeogene in age (Banerjee et al. 2012).

The Nanded city lies ~58 km NW of the study area and documents Deccan trap tectonics (Kaplay et al 2013). The Kaddam region, ~68 km NE of the study area, has NW trending tectonic element in the form of Kaddam fault/lineament with strike-slip tectonics (Sangode et al. 2013).

Regional litho-structural studies carried out by Banerjee et al (2008) show several N, NNE, NE, NW, and E trending lineaments in the granitoid and basalts. They interpret these lineaments as faults/fractures/shear zones. Frequently minor faults/fractures, shear zones, and minor folds close to the contact between the South East Deccan Volcanic Province (SEDVP) and the EDC exist (Banerjee et al. 2012). The focus of their study (Banerjee et al 2008, 2012) was geochemistry and petrogenesis of granitoid, and structural details were missing. The present study first reports reverse faults, grabens, normal faults, strike-slip faults, boudins, etc. in the granitic rocks of the EDC underlying the SEDVP. Detail fieldwork in the areas with intrusions such as quartzo-feldspathic/pegmatite/quartz/epidote veins and other basic enclaves are targeted as these features act as distinct markers for deformation. In all, nine sites from L1-L4 are studied in detail.

## 2 Field Characters of Deccan Trap-Granitic Contact

The Deccan trap in the entire study area is 1.36 m (at L4) to 7.03 m thick (at L2) (Table 1).

L1 (Mutnyal): the contact between the Deccan and the Dharwar shows red boles (tachylitic basalt) in contact with granite. This layer is overlain by green tachylitic basalt, which is followed by the top layer of compact aa-type basalt flow (Fig. 2). The compact basalt is weathered spheroidally. This layer of compact basalt is covered by thin black cotton soil, the product of weathering of basalt. Elsewhere at L1, the red bole shows characteristic pinching and at other places red and green tachylitic

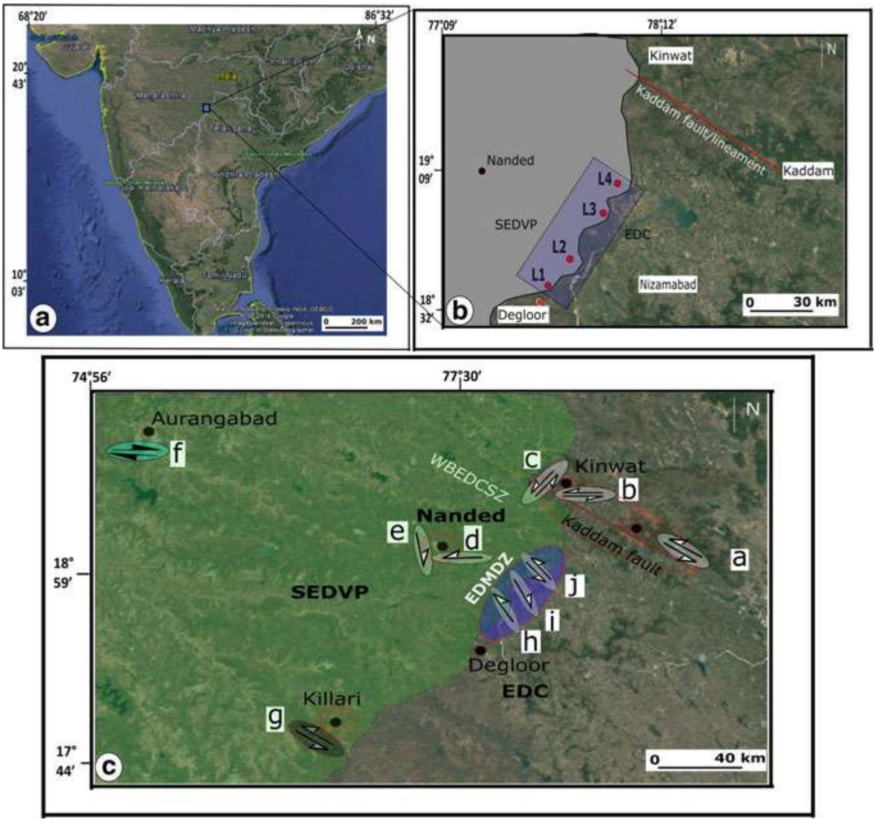


**Fig. 1** **a** Location map. Study area marked by red rectangle. **b** Magnified view of the study area. L1 (Mutnyal), L2 (Biloli), L3 (Dharmabad) and L4 (Bhaisa) are the four sites studied near Nanded. Gray area: South East Deccan Volcanic Province (SEDVP), unshaded area: East Dharwar Craton (EDC). Red bordered transparent black ellipse: approximate extent of East Dharwar Margin Deformation Zone (EDMDZ). Red solid line: Kaddam fault/lineament. Black lined white ellipse(s) with arrows indicate maximum compressive stress direction ($\sigma_1$) of reverse fault tectonics deduced from this study. Half white-headed arrows: NE-SW compression resulting from the strike-slip faults. **c** Summary of our recent geoscientific work ('b', 'c', 'd', 'e' and 'f') and other related work ('a' and 'g') in and around Nanded. 'a': NW–SE strike-slip faults near Kaddam (Sangode et al. 2012), 'b': ~E trending strike-slip faults in granites near Kinwat (Kaplay et al. 2017b, 2019), 'c': NE trending Strike-slip faults (in granites) NW of Kinwat (RD Kaplay's work), 'd': W verging thrusts in Deccan trap in intracratonic microseismically active Nanded city (Kaplay et al 2013), 'e': steeply dipping normal faults in Deccan trap in Nanded (Kaplay et al. 2017a, b), 'f': offset of dykes in Deccan trap presumably caused by local stress in Aurangabad city (Babar et al. 2017) and 'g': a 'slow-deforming non-rifted zone (intracratonic seismicity) (Rajendran et al. 1986). 'SEDVP'—South East Deccan Volcanic Province. 'EDC'—East Dharwar Craton. 'WBEDCSZ'—West Boundary East Dharwar Craton Strike-slip Zone', marked by red ellipse, is reported by Kaplay et al. (2017a, b). White half arrows: deformation style of the faults. Black half arrow: offset direction of dyke in Aurangabad. Blue filled red bordered ellipse: present study area (at the contact of SEDVP and EDC) and is designated as 'EDMDZ'—East Dharwar Margin Deformation Zone'. 'h': NW–SE reverse faults and 'i': mormal faults and 'j': NW trending strike-slip faults. Red dash circles indicate seismicity/microseismicity

**Table 1** Field character of contact of Deccan trap-granite

| S. No. | Locations | Sites | Type of Basalt | Thickness (m) | Total thickness (m) | Structures | Contact |
|---|---|---|---|---|---|---|---|
| 1 | L1 | S1 (Mutnyal) | Weathered compact basalt | 0.97 | 05.23 | | Sharp |
| | | | Red tachylitic basalt | 1.46 | | | Gradational |
| | | | Green tachylitic basalt | 02.8 | | | |
| | | S2 (Minki) | Weathered compact basalt | 01.06 | 01.64 | | Sharp |
| | | | Weathered green amygdaloidal basalt | 00.58 | | | |
| 2 | L2 | S1 (Pokharni) | Weathered compact basalt | 06.09 | 06.69 | | |
| | | | Amygdaloidal basalt | 00.60 | | | |
| | | S2 (Biloli) | Weathered compact basalt | 02.43 | 03.22 | Vertical joints in basalt and spheroidal weathering | Sharp |
| | | | Weathered greenish amygdaloidal basalt | 00.79 | | | Gradational |

(continued)

**Table 1** (continued)

| S. No. | Locations | Sites | Type of Basalt | Thickness (m) | Total thickness (m) | Structures | Contact |
|---|---|---|---|---|---|---|---|
| 3 | L3 | S1 (Pimpalgaon) | Soil | – | – | – | – |
| | | S2 (Mudhol) | Weathered compact basalt | 01.24 | 1.60 | | Sharp |
| | | | Red bole | 00.36 | | | |
| 4 | L4 | S1 (Degam) | Soil | – | – | – | – |
| | | S2 (Bhainsa) | Weathered basalt | 0.73 | 01.36 | | |
| | | | Red bole | 0.24 | | | |
| | | | Greenish tachylitic | 0.39 | | | |
| | | S3 (Bhainsa) | Weathered compact basalt | 03.96 | 04.26 | Weathered columnar joints, Quartz vein in basalt and speroidal weathering | Sharp |
| | | | Red bole | 00.30 | | Pinching | |

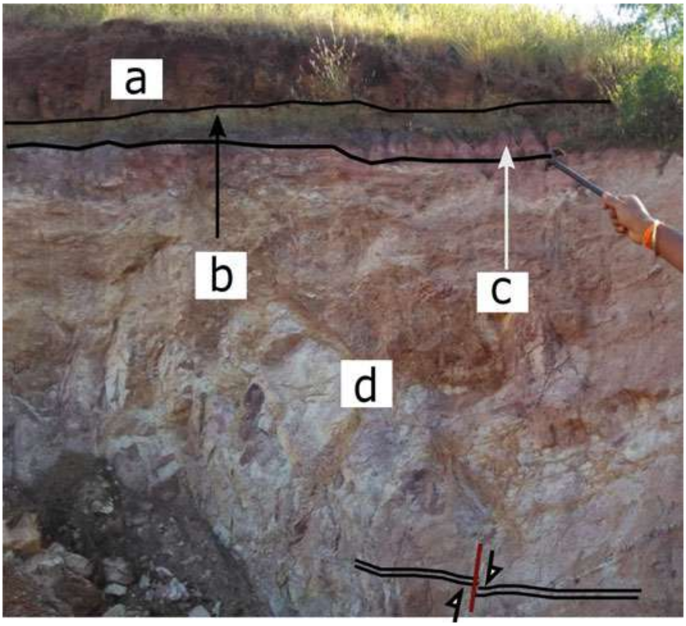


**Fig. 2** Contact between the Deccan trap and the EDC (vertical section). 'a': Compact Basalt, 'b': green tachylitic basalt, 'c': red tachylitic basalt and 'd': granite. Faulting, at the bottom of the photograph, is observed in granites (Loc: L1, 18° 40′ N, 77° 38′ E)

basalt is absent. The granite in these sections is directly overlain by compact basalt and black cotton soil.

L2 (Biloli district, Nanded): Unlike other sections, the contact between the basalt and the underlying granite does not show red and green tachylitic basalts. The Deccan trap here is 3.22–7.3 m thick. Here the compact basalt, as in Muynyal, is weathered spheroidally and jointed vertically.

L4 (Bhaisa Nirmal District, Telangana): Granite expose at the surface while at other places of road cutting on Biloli to Mirzapur road, beautiful basalt-granite single contact expose. Granites here, on Biloli-Mirzapur road section, are overlain by pinched red tachylitic basalt (Fig. 3), which is overlain by green tachylitic basalt with top compact basalt layer. The compact basalt is weathered spheroidally, and the vertical columnar joints in basalt are intruded by thin quartz- and zeolitic veins. Basalt is 1.36–4.26 m thick. The topmost layer of basalt is the compact type. The Deccan trap here is 1.60 m thick.

At places flowing basalt followed the topography of granite. At specific spots, basalt entered the crevices of underlying granite (Fig. 4).

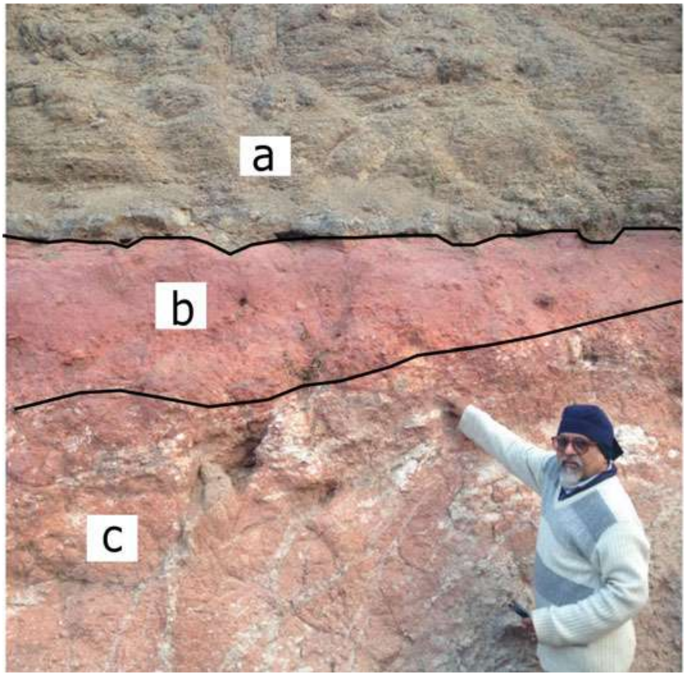


**Fig. 3** Basalt-granite contact at L4. ‘a’: basalt, ‘b’: pinching red tachylitic basalt, ‘c’: granite with profuse intrusions of pegmatites. (Loc: L4, 19° 07′ N, 77° 57′ E)

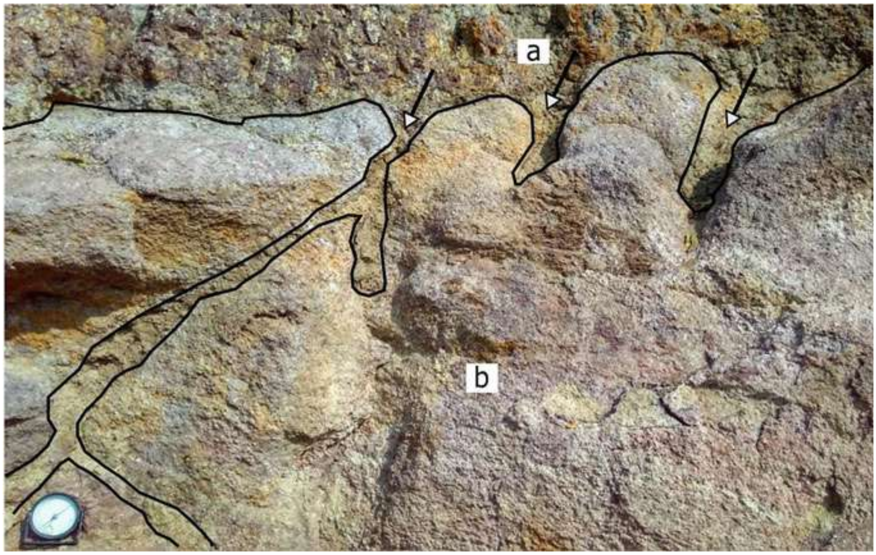


**Fig. 4** Contact between basalt and granite, exposed in a vertical section, where basalt (**a**) has followed the undulating topography of granite (**b**) at L2 (Pokharni, 18° 45′ N, 77° 41′ E)

# 3 Structures

## 3.1 *Intrusives (Dykes/Veins/Sills)*

At Mutnyal, 0.2–1 m thick 12 vertical veins are found at one spot. The veins are vertical to gently/moderately dipping (30° due to W). Some of the veins show offshoots (Fig. 5a). A few places, the veins dip steeply (Fig. 5b). Pegmatite veins show several offshoots (Fig. 5c). Further, each branch of offshoot folded intricately. At L4, the pegmatite vein continues as a thick but a bit irregular sill (Fig. 5d).

Total of 62 intrusions are observed in the study area. Most (88%) of the intrusions are pegmatites. The rest are veins of quarto-feldspathic minerals, pure quartz, and epidote. The intrusions constitute a swarm. At L3, a basic intrusion is observed. The basic intrusion here also shows the intrusion of thin veins of younger granitic rock with similar features as that of the host rock (Fig. 6).

At L3, we observed a rare case of the intersection of three veins in nearly in the same region (Fig. 7). It shows a cross-cut relation among the three veins. Vein ‘a’ is the oldest, which is cut by veins ‘b’, and ‘c’ is the youngest.

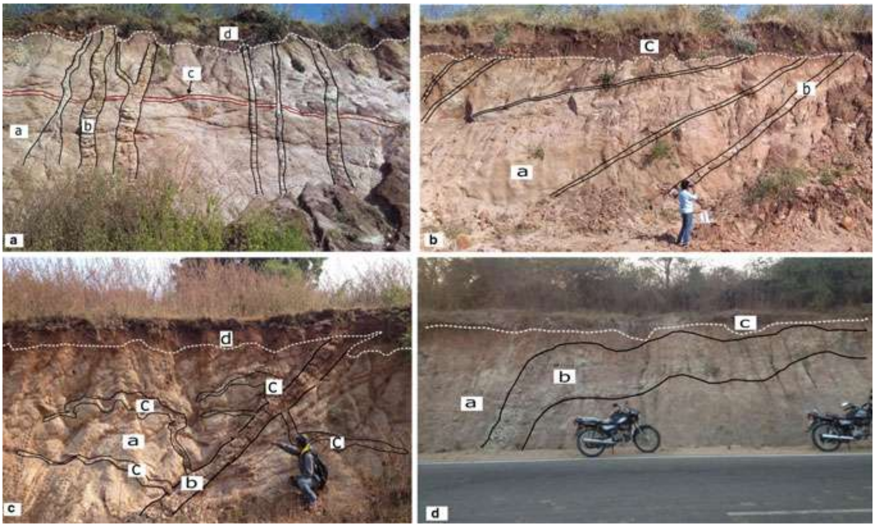


**Fig. 5** **a** Vertical pegmatite vein swarm at L1 (18° 40′ 49″ N, 77° 38′ 17″ E). The third pegmatite vein from left shows offshoot. ‘a’: granite (E Dharwar Craton), ‘b’: Pegmatite veins, ‘c’: Sill, ‘d’: Basalt boulders and black cotton soil (Deccan trap). **b** Inclined pegmatite vein swarm at L1 (18°40′46″N, 77°38′17″E). ‘a’: granite (E Dharwar Craton), ‘b’: pegmatite veins, ‘c’: basalt boulders and black cotton soil (Deccan trap), **c** inclined pegmatite vein with intricately folded offshoots on both sides. Loc: L1 18° 40′ 34″ N, 77° 38′ 21″ E. ‘a’: granite, ‘b’: pegmatite vein, ‘c’: intricately folded offshoots, ‘d’: black cotton soil. **d** Granite (a) shows intrusion of dyke (b), which look like a sill just underneath the basaltic cover (c). All snaps are of vertical exposures

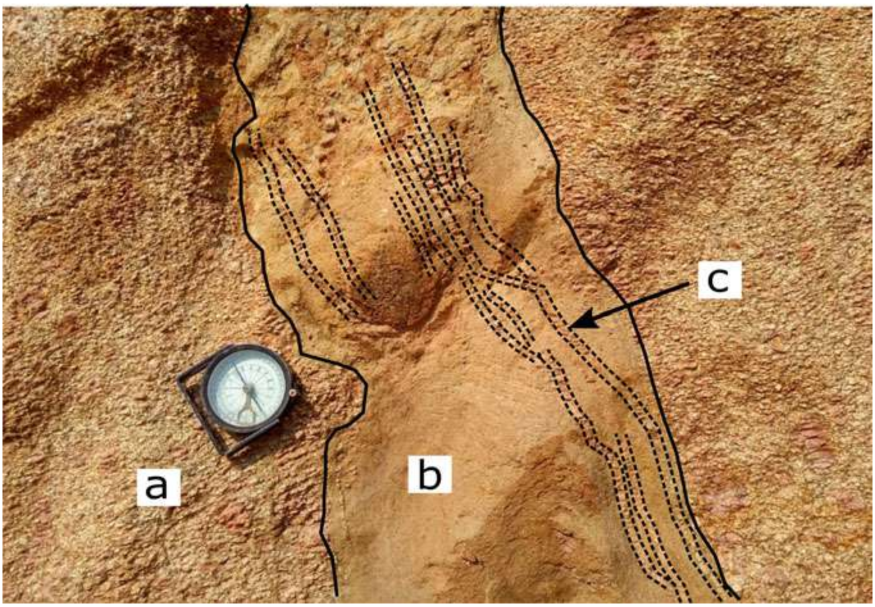


**Fig. 6** Basic intrusion show intrusion of thin veins of host granitic rock. 'a': granite host rock, 'b': basic intrusion, and 'c': intrusion of granite in basic rock (sub-vertical exposure at L2; 18°48′ 24″ N, 77° 46′ 04″ E)

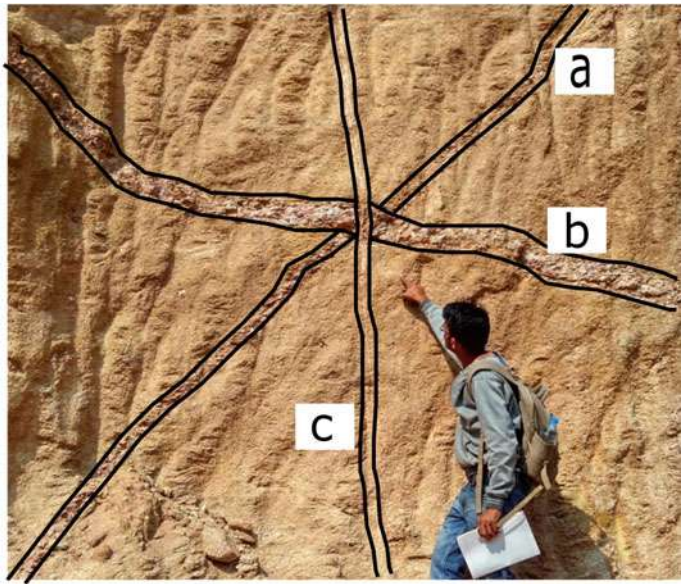


**Fig. 7** Intersection of three veins. Vertical exposure at L2: 18° 48′ 27″ N, 77° 46′ 02″ E

## 3.2 Deformation of EDC Underneath the Deccan Trap

### 3.2.1 Faults

In Fig. 8a, 'A' ~3 cm thick sill at L1 is reverse faulted at two places. It shows minute drag along the fault. At F1 the vein shows the same sense of drag, while at F2 the drag is seen only at one side of the cross-cutting element. Therefore as per Fig. 19 of Mukherjee (2014a, b), it is a 'b.1.1' kind of flanking structure. At F3, the steeply dipping vein slips along a gently dipping reverse fault (Fig. 8a).

In Fig. 8b, a sill is both normal- (F4) and reverse faulted (F5). At F4, the sense of drag across the cross-cutting element is the same (case b.1.2.2 of Fig. 19 in Mukherjee 2014a, b) while at F5, there is no drag (case b.2 of Fig. 19 in Mukherjee 2014a, b). An inclined (50° due ~ S) pegmatite vein is faulted at two places (Fig. 8c). Both F6 and F7 are normal faults (Fig. 8c). One of the faulted blocks of F6 is reverse dragged (Mukherjee and Koyi 2009). In Fig. 8d pegmatite vein has cut through a sill (a). It

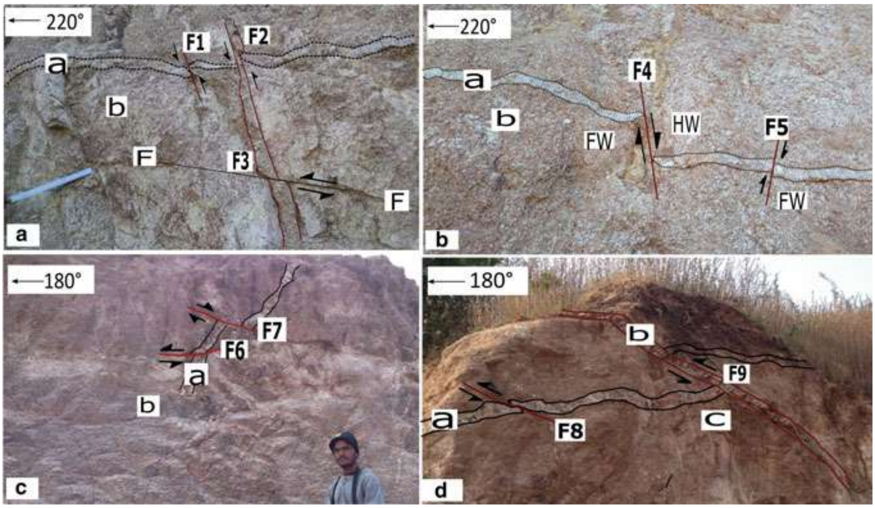


**Fig. 8** **a** Thin sill (a) in host granite (b) shows step-type of reverse fault at F1 and F2 (Loc: L1; 18° 40′ 53″ N, 77° 38′ 26″ E). F1 slips 2.5 cm with 72° dip; while at F2 the slip is 3 cm with 75° dipping fault plane. Both these faults dip towards N30° W. At F3 an inclined vein slips to 2 cm, at very low angle (10°) towards N65° W across the fault (F-F). **b** A sill (a) in host granite (b) shows faulting at F4 (normal fault dipping 83° towards N35° E), 18 cm slip. F5 (reverse fault with fault plane dipping 80° towards N70°W, 2 cm slip. Loc: L1; 18°40′55″N, 77°38′28″E. HW: hanging wall, FW: footwall. **c** Pegmatite vein (a) in host granite (b), shows normal faulting at F6 and F7 (Loc: L2; 18° 46′ 40″ N, 77°42′40″E). At F6 the fault plane dips 10° towards N85° E, while at F7 the fault plane dips 20° towards N85° W. **(D)** Folded sill (a), in host granitic rock (c), shows reverse fault at F8. Loc: L1; 18° 40′ 54″ N, 77° 38′ 29″ E. The fault plane dips 25° towards N70° W. Inclined pegmatite vein (b) displace sill (a) at F9. It is a reverse fault that dips 35° towards NW. All snaps are of vertical exposures

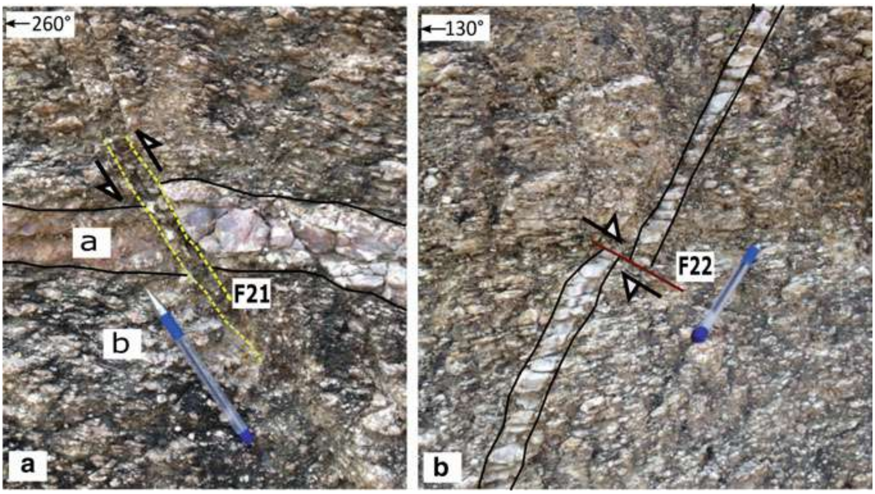


**Fig. 9** **a** Pegmatite vein (a) in host granitic rock (b) shows reverse fault. The fault plane dips 60° towards N17°E with 2.5 cm slip. Vertical exposure. **b** A normal faulted quartzo-feldspathic vein with 3.5 cm slip. The fault plane dips 30° towards N20°W. Vertical exposure at L3; 18° 58′ 27″ N, 77° 54′ 45″ E

is a reverse fault. The sill also shows a minor drag related to the fault plane F8. In Fig. 8d, a folded sill (a) is cut by a dipping pegmatite vein (b).

The pegmatite vein, at L2, is faulted in a reverse manner along with ~2 cm thick fault core (Fig. 9a). In Fig. 9b, a quartzo-feldspathic vein, with antithetic shear within the vein, is normal faulted at L2.

At L2, four faults are observed: F36-39. Here the central block relatively moved down. These are conjugate faults forming central grabens (Fig. 10a). Along the fault plane, an epidote vein intrudes (Fig. 10b, magnified view of F37 in Fig. 10a). The magnified view of F38 and F39 are Fig. 10c, d.

At Pimpalgaon in Dharmabad taluka (L3), thin pegmatite sill (A), in host granitic rock (B), is multi-faulted at five places (Fig. 11a). It shows conjugate faults. F16 and F18 are curviplanar fault planes. The same vein, towards its right side, shows two more faults with graben (F19 and F20 in Fig. 11b).

A thin inclined pegmatite vein at L2 shows a steep normal fault dipping N50°W and dip 75° (Fig. 12a). While at L4 of the folded pegmatite veins, one of them is faulted (Fig. 12b). Its magnified view is Fig. 12c shows two faults: one normal and another reverse. The epidote vein on horizontal exposure at L3 is a sinistral strike-slip faulted (Fig. 12d).

A folded sill at L1 is faulted along a wavy horizontal plane (Fig. 13a). In Fig. 13b, a pegmatite vein is a chevron and gentle folded. Its limb on right side is reverse faulted (F27). The pegmatite vein, at L1 is locally ductile sheared with the shear plane along the vein itself (where half arrows are placed: F12 in Fig. 13c), while one more pegmatite vein at L1 to is ductile sheared (F10 in Fig. 13d). Together with its sharp dragging pattern, the vein overall resembles a fold.

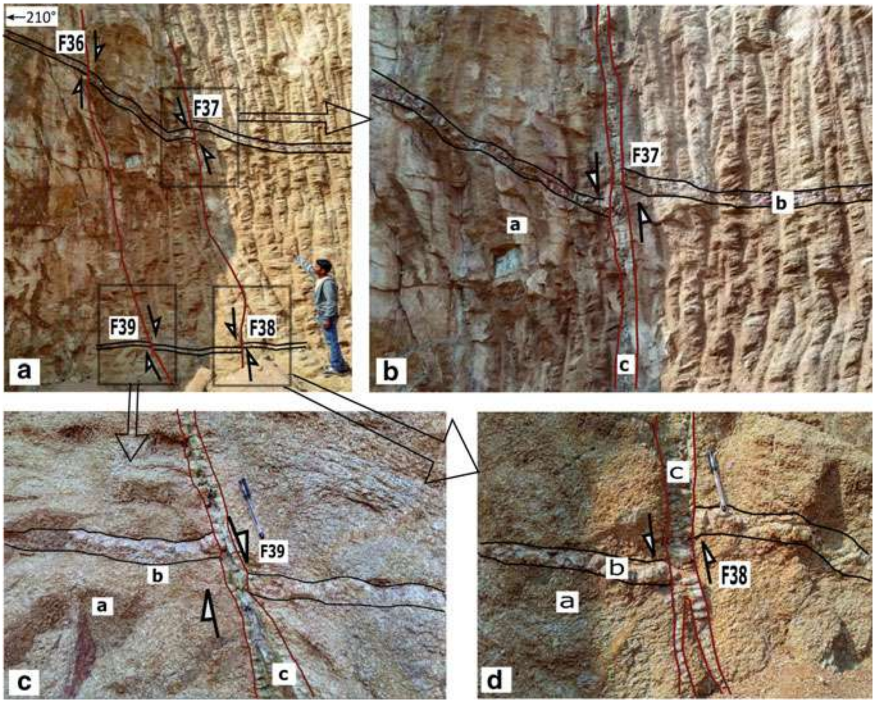


**Fig. 10** A Graben structure exposed on vertical section (Loc: L2; 18° 48′ 23″ N, 77° 45′ 54″ E). At F36 and F39 the fault plane is dipping towards N75° E at an angle of 80° and 65° respectively, while at F37 and F38 the fault plane is vertical. The displacement at F38 and F39 is 9 cm, the displacements at F36 and F37 could not be measured due to steepness of the exposure. **b** Magnified view of F37. 'a': host granitic rock, 'b': pegmatite vein and 'c': epidote vein. **c** Magnified view of F38. 'a': host granitic rock, 'b': pegmatite vein and 'c': epidote and quartz vein. **d** Magnified view of F39. 'a': host granitic rock, 'b': pegmatite vein and 'c': epidote vein

We report total of 39 faults in the study area: 17 normal- and 17 reverse-, two vertical- and three strike-slip faults (Table 2). Out of the eight reverse faults at L1, seven dip NW, while only a single SE. The maximum stress axis trends NW. At L2, a single reverse fault dips NE, and the other two dip SW. The maximum stress axis trends NE. At L3, two reverse faults dip NW, one towards SE and two NE. The maximum stress axes trend both NW and NE. At L4, the reverse fault dips towards SE indicating that the maximum stress direction is NW.

Note the $\sigma_1$ direction for strike-slip faults is ~N–S/NE–SW, which does not match with the known faults reported from the coastal region or the western part of Deccan trap around Mumbai (Misra and Mukherjee 2015, 2017; Misra et al. 2014, 2015; Mukherjee et al. 2017)

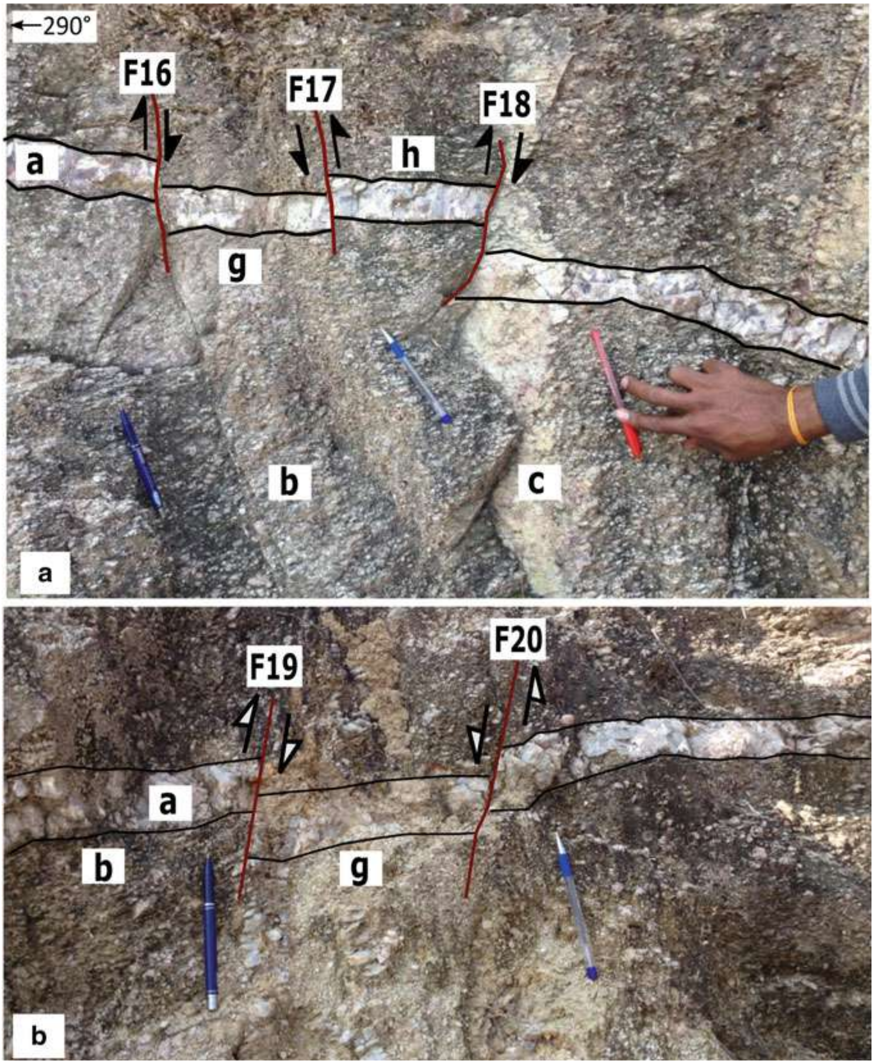


**Fig. 11** A Horst and graben structure exposed on vertical section at L3 (18° 55′ 13″ N, 77° 51′ 46″ E). A pegmatite vein (a) is faulted at F16, F17, F18, F19 and F20. The displacement at F16, F17 and F18 is 3.5 cm, 1.5 cm and 10 cm respectively. At F16 and F17 the fault planes are dipping towards N20° E direction at an angle of 81° and 85° respectively. At F18 the fault plane dips towards N8° W at 56°. 'a': pegmatite vein, 'b': horst granite rock and 'c': curtain of epidote & quartz vein. 'g': graben and 'h': horst. **(B)** The vein shows 'graben' structure. Slip on F19 and F20 are 3.0 and 2.5 cm, respectively. F19 and F20 dip towards S35° E at 78° and 70°, respectively

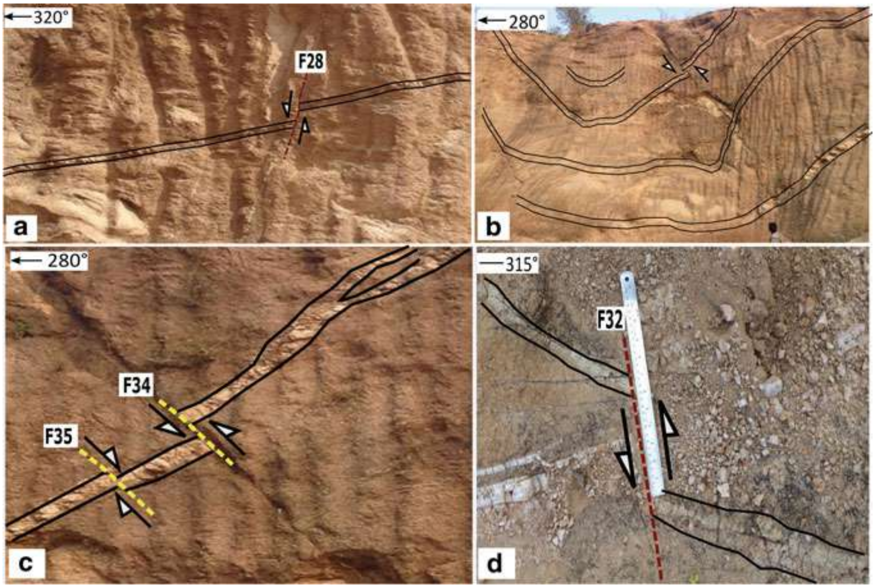


**Fig. 12** **a** A thin gently dipping pegmatite vein is normal faulted (vertical section at L2; 18° 40′ 38″ N, 77° 42′ 44″ E). **b** One of the folded pegmatite veins is reverse faulted (vertical section at L4; 10° 07′ 16″ N, 77° 57′ 55″ E). **c** Magnified view of F34 in vertical section. The vein shows normal- and reverse faulting, the fault planes are dipping towards S30° E at an angle of 48°. **d** Direction of strike-slip fault is N45°W with 15 cm slip (horizontal exposure at L3; 19° 01′ 53″ N, 77° 56′ 07″ E)

### 3.2.2 Folding

Folds are observed in individual pegmatite sill and veins. At Mutnyal (L1), a pegmatite sill is a cuspate syncline (Fig. 14a). At L2, two pegmatite veins show chevron folding (Figs. 14b, c). The folds show sharp hinges with near-vertical axial surfaces. At L1, the westward dipping pegmatite vein becomes horizontal as observed at three places (Fig. 14d). A similar type of folding of pegmatite vein is observed at L2. In Figs. 15a–c, the axial plane strikes ~N, hence the compression direction is ~E–W.

The maximum stress axis deduced from reverse faults trends NW and NE. This suggests that the compression directions during folding and faulting mismatch. The compression direction switched with time from E–W to NW and NE.

### 3.2.3 Shear Along Veins

Shear sense within quartz, pegmatite and epidote veins developed at L-2 and L3 (Fig. 15a, b). Brittle P-planes develop exclusively within the veins. This is comparable to P-planes restricted within dykes are reported by Misra and Mukherjee (2017) from

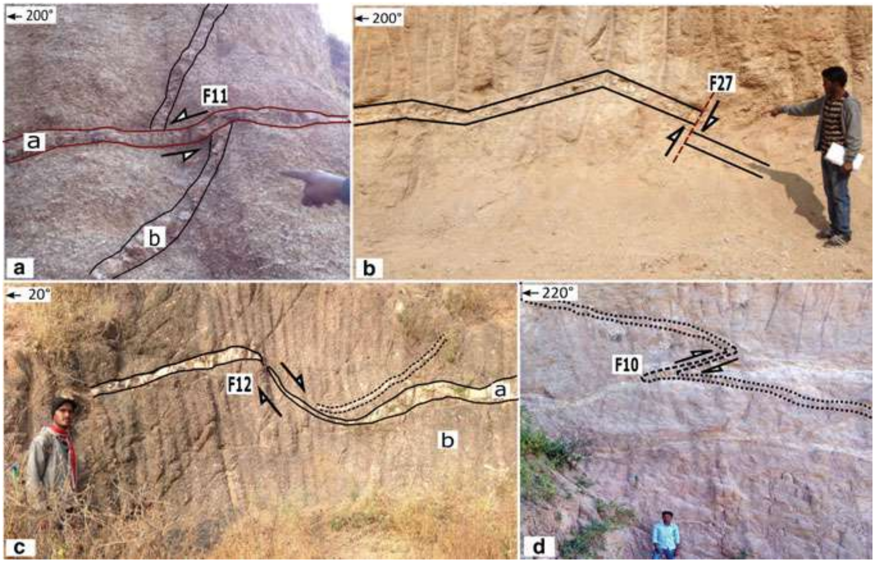


**Fig. 13** **a** A pegmatite vein ('b') displaced along/by a sill ('a') by 19.6 cm (Loc: L1; 18° 40′ 50″ N, 77° 38′ 22″ E). The fault plane dips gently (16°) towards S20°W. **b** Chevron folded pegmatite vein (Loc: L2; 18° 46′ 39″ N, 77° 42′ 35″ E). One of its limbs slips 20 cm, the fault plane dips 68° towards S20° W (F27: reverse fault). **c** A pegmatite vein (a) in granitic rock (b) at L1 shows ductile–brittle deformation (Loc: L1; 18° 40′ 12″ N, 77° 37′ 22″ E). **d** Ductile deformed pegmatite vein. F10 dips towards SE (Loc: L1; 18° 40′ 49″ N, 77° 38′ 21″ E).. All snaps are of vertical exposures

**Table 2** Location wise different types of the faults

| Locations | Total No. of faults | Normal faults | Vertical faults | Reverse faults | Strike-slip faults |
|---|---|---|---|---|---|
| L1 | 15 | 07 | – | 08 | – |
| L2 | 09 | 04 | 02 | 03 | – |
| L3 | 11 | 03 | – | 05 | 03 |
| L4 | 04 | 03 | – | 01 | – |
| Total | 39 | 17 | 02 | 17 | 03 |

coastal region of Deccan trap. In all the cases the shear within the vein is left lateral (Mukherjee 2013, 2014a, b, 2015).

### 3.2.4 Boudins

Pegmatite veins at places (L1 and L4) are boudinaged. These boudins are 'drawn boudins'/'tapering boudins' (Goscombe et al. 2004). At L1, the boudins are almost joined with one another (Fig. 16a); while at L4 (Fig. 16b) rather irregular-shaped

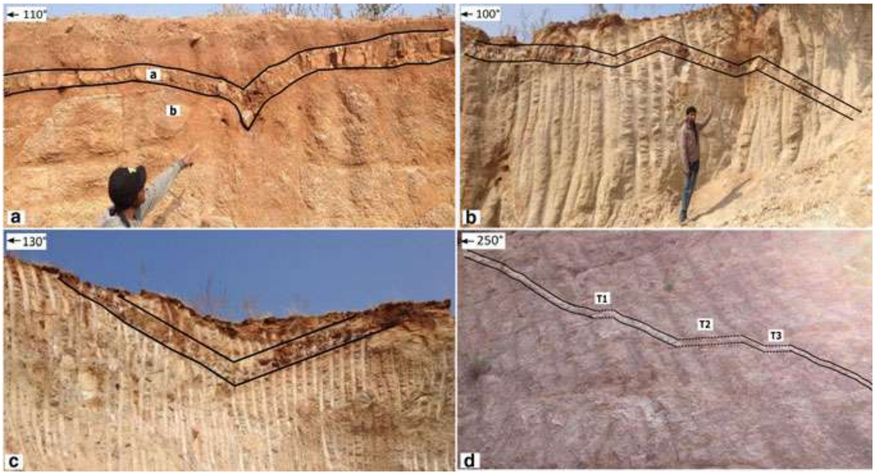


**Fig. 14** **a** Cuspate folded in quartz vein (W-E), axial plane dips 40°due 60° (Loc: L1; 18° 40′ 55″ N, 77° 38′ 22″ E). **b** Chevron folded pegmatite vein (Loc: L2; 18°46′40″N, 77°42′41″E). **c** Chevron fold (Loc: L1; 18° 46′ 41″ N, 77° 42′ 43″ E). **d** Structural terrace at L1; 18° 40′ 50″ N, 77° 38′ 19″ E. All snaps are of vertical exposures

boudins exist indicating possibly extensional strain at L4 to be more than that at L1.

The boudinaged asymmetric clast at right displays a top-to-left (down) shear. This indicates this could be an 'extensional shear boudin' (Ghosh 1993). Boudins indicate NW–SE extension at L1 and L4. All the reported boudins are single-layer boudins, as the boudins developed in a single vein at those locations.

## 4 Discussions

How much thick is the Deccan trap along the SEDVP is not well known. However, Patro and Sarma (2007) reported that the Deccan trap thins towards E. Recent drilling of deeper bore wells (by common people, for drinking purpose in North Nanded) and recovery of chips of granites underneath Deccan trap in Nanded region revealed the thickness of basalt ranges 152–200 m. The thickness of Deccan trap overlying the granites from Dharwar granite ranges from 1.36–7.03 m in the field. The compact basaltic rocks exposed overlying the granites consist mostly of undeformed columnar joints.

The granitoid in the study area are cut profusely by quartzo-feldspathic/pegmatitic veins, quartz reef and mafic enclaves/intrusion, this signifies reactivation and remobilization of granitoid. This feature is also seen in other parts of the EDC (Perraju and Natarajan 1977; Sarvothaman and Leelanandam 1987, 1992; Sarvothaman 1993; Gopal Reddy et al. 1998). The reactivated and remobilized terrain of Eastern Dharwar Craton (EDC) represents northern extensions of the PGC (GSI 1979, 2001). These

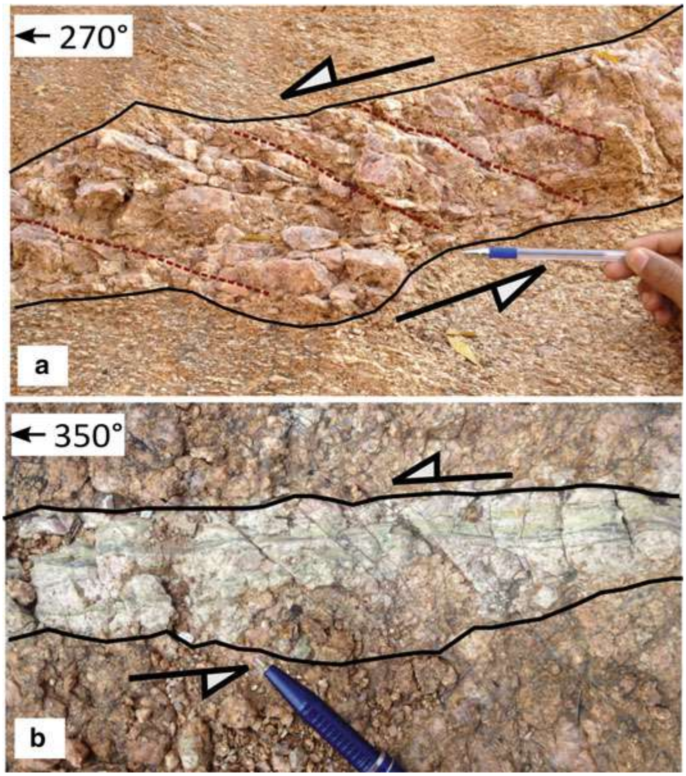


**Fig. 15** **a** Inclined P-planes (N65° W) in pegmatite vein at L2 (sub-horizontal surface) (Loc: L2; 18° 46′ 46″ N, 77° 42′ 50″ E). **b** Inclined P-planes (N35° E) in epidote vein at L3 (horizontal surface) (Loc: L3; 18° 55′13″ N, 77° 51′ 40″ E)

granitic rocks (2385 ± 40 Ma: Banerjee et al. 1993 and 2074 ± 55 Ma: Wesanekar and Patil 2000) have persevered within them and show deformations in the form of small-scale faults, folds, shear within vein and boudins. Such deformations within the Dharwar Craton indicate their antiquity but there is no evidence of their Tertiary reactivation as no comparable deformations are observed in the Deccan trap.

The study area is bound towards NE by Nanded region, where ~W verging thrusts and steeply dipping normal faults are reported from the Deccan trap (Kaplay et al. 2013, 2017a). Reverse- and normal faults are dominant deformations observed in the East Dharwar Craton underlying the relatively thinner Deccan trap as found in the study. The zone is highly deformed. We designate this deformation zone as 'East Dharwar Margin Deformation Zone' (EDMDZ).

SE and NW vergence are observed for the reverse faults in the underlying basement granites suggest NW–SE maximum horizontal compression. This direction mismatch with the E-W horizontal compression direction of the thrusts reported from Deccan trap in Nanded region (Kaplay et al. 2013), which is ~58 km NW of the present study

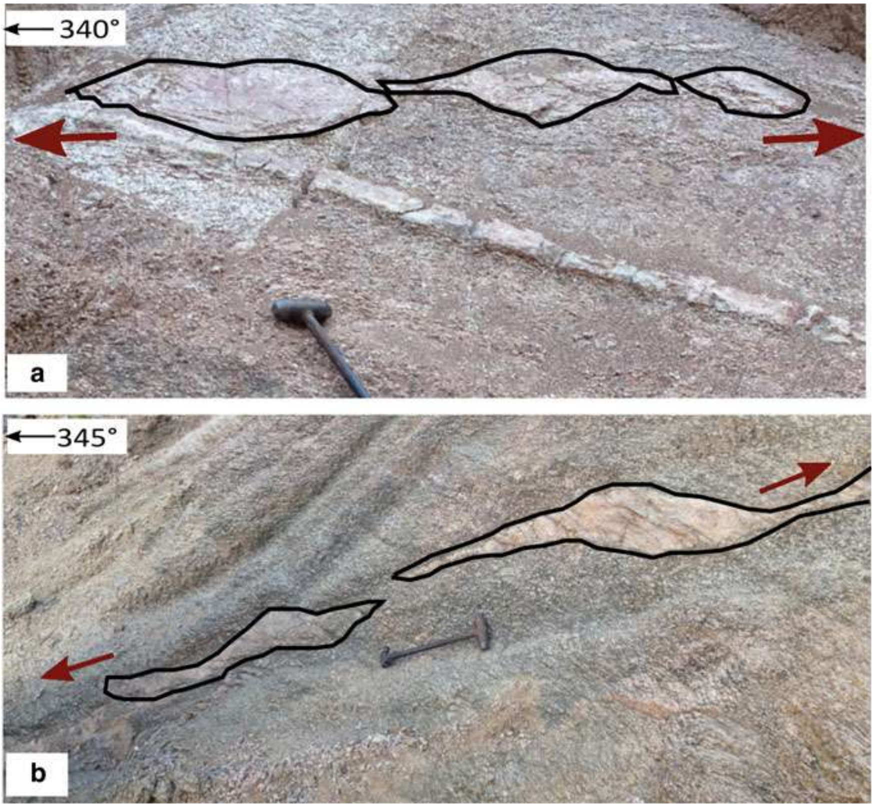


**Fig. 16** **a** Tapering boundins of pegmatite in granitic rocks trends N20° W, at L1 (18° 40′ 50″ N, 77° 38′ 18″ E). **b** Separated boudins (N40° W) at L4 (19° 07′ 15″ N, 77° 57′ 56″ E)

area. Interestingly, the shear direction within the veins from the study area is NW–SE. The extension direction shown by the boudins is also the same. Fold observed at L4 has also experienced horizontal compression in NW–SE direction. This indicates that the study area has dominantly NW–SE stressed. This is significantly different from ~NNE trending brittle shear *Y*-planes as observed by Misra et al. (2014) from the coastal regions of Deccan trap around Mumbai region.

The deformation styles of the NW–SE strike-slip faults from the study area suggest that the region at L3 has experienced NE-SW compression regime from the strike-slip movement. The deformation style from the study area corroborates with that of the strike-slip faults reported from Kaddam region by Sangode et al. (2013), which is ~125 NE from the study area. This indicates that the NW–SE strike-slip faults we observe here could be a manifestation of the far field effect of the NE–SW directed stress resulting from the strike-slip movement along the Kaddam fault.

Apparent higher frequency of minor faults (with no other details of structural features provided by previous authors) in EDC (as surface exposure of granites),

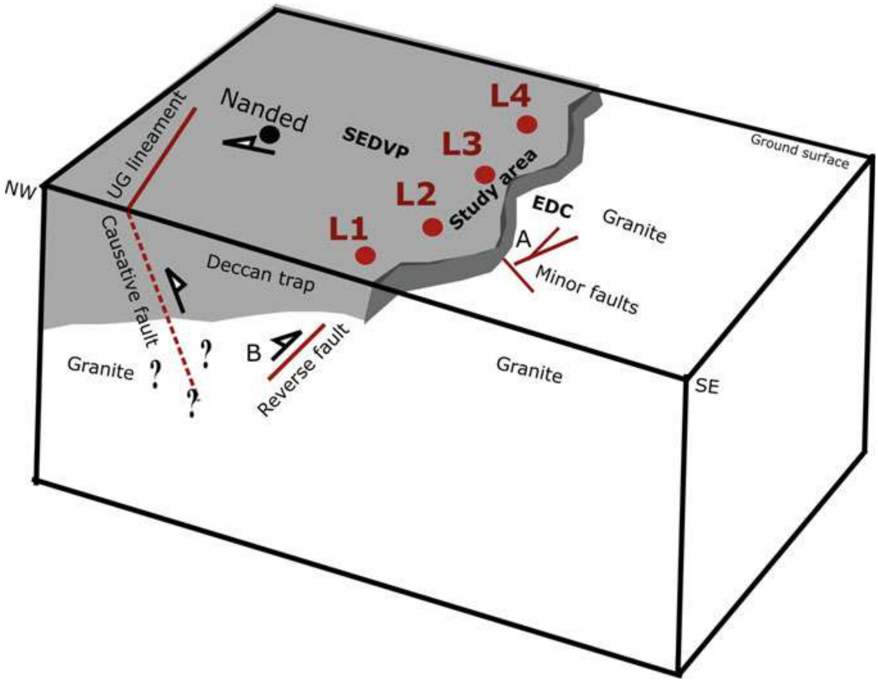


**Fig. 17** Explanatory block diagram (not to the scale) showing minor faults within the EDC, reverse faults in granites under the cover of Deccan trap and blind faults (?) below the Deccan trap in Nanded region. Gray shaded area: SEDVP; white area: EDC. Left lateral sheared vein. The *P*-plane at L1, L2 and L4 trends NW; at L2 it is NE

nearer to the Deccan trap-granite contact ('A' in Fig. 17), is also reported by Bannerjee et al. (2012). This study reports faults from granite, which is present below the Deccan trap ('B' in Fig. 17). This study thus proves that the granites under the cover of Deccan trap hold several crucial structural/tectonic information.

Deformation in the form of reverse faults in Nanded, ~58 km NW of the study area, is reported from weathered amygdaloidal basalts. The compact basalt layer from Nanded region- usually the topmost layer-looks undeformed. Note that in the study area, compact basalt exposed as the topmost layer, which to looks underformed. But leaving aside the reporting of thrusts from Nanded region, no other deformations are reported from nearby Deccan trap including the present study area. Interestingly Kaplay et al. (2017a, b) reported fault-line scarp along the Urvashi Ghat Lineament in the Deccan trap. The epicentre of microseismic events in Nanded region is reported from 4 km depth along this fault-line scarp, which is also a causative fault (Srinagesh et al. 2012). Also, note that Madhnure et al. (manuscript communicated to Environmental Monitoring and Assessment) report that the Deccan trap in Nanded is 150–200 m thick. This suggests that causative fault in Nanded, depth of which is reported as ~4 km by (Srinagesh et al. 2012), is present in basement granite underneath Deccan trap, as beyond 200 m depth granites are encountered in Nanded city. Kaplay et al. (2017a, b) have also reported normal faults from basaltic terrain in Nanded region.

The present study indicates that the reverse faults (Kaplay et al. 2013) and normal faults (Kaplay et al. 2017a) in Deccan trap could be the manifestation of hidden faults in basement granites at ~200 m depth in Nanded region. Likewise, Ernst (2014) referred surface manifestation of structures in other Large Igneous Provinces.

Interestingly, 23 NE and NW trending, lineaments in the form of straight courses of streams are reported N of Godavari River in Nanded (Kaplay et al. 2017b). Are these lineaments including UG Lineament manifestation of some hidden structures (e.g., Bhave et al. 1989)? Detail geophysical research on possible hidden faults below the Deccan trap in and around the study area would be much required.

## 5 Conclusions

The surface exposure of Deccan trap is 0.1–2.55 m thick around the contact between the South East Deccan Volcanic Province and the Dharwar Craton. The granitic rock of Dharwar Craton underwent minor faulting and folding. The deformation zone from L1 to L4 is designated here as the 'East Dharwar Margin Deformation Zone' (EDMDZ). Deformations from granites of Dharwar Craton indicate its possible antiquity, however, reactivation of these faults is not observed in overlying the very thin cover of Deccan trap. Faults, fold, boudins, etc. are reported for the first time from the basement granite (EDC) underlying Deccan trap. Reverse fault and normal fault tectonics are dominant in the region and the compression direction switched with time from E–W to NW and NE.

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