Structural Geology and Stability Issue of the Giral Lignite Mine, Rajasthan, India

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Abstract This field study is focused on normal faults and tension cracks of the Giral lignite mine, Barmer basin Rajasthan (India). Besides normal faults, lignite cleat and bedding data have been collected. Cleats and beddings are perpendicular to each other and filled with salt at the northern portion of the mine. Two normal faults are first time documented in the Giral mine, those can be related to initiation of strike-slip movement between India and Madagascar and main Barmer rifting. F1 fault group has trend NE–SW and F2 trend in approximately E–W. Due to the persence of these faults, northern slope of the mine shows slope failure. This slope failure can be seen on the plan view in the form of multiple stages of tension cracks. Fractured block on the slope show horizontal and vertical rotation towards N112° with 10–30° inclination. To find out the detail solution of the mine slope failure, more detail study is required.

Keywords Giral mine · Lignite · Fault · Barmer basin · Tension cracks

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1 Introduction

Lignite deposits in India occur mainly in the Tertiary sediments of the peninsular shield. These deposits are situated in Tamil Nadu, Puducherry, Kerala, Gujarat, Rajasthan and Jammu and Kashmir.

The Giral lignite mine is situated ~43 km away towards which direction to be stated from the Barmer city (Barmer district, western Rajasthan, India) (Fig. 1). It is an open cast mine and started operational since 1994. Besides Giral mine, there

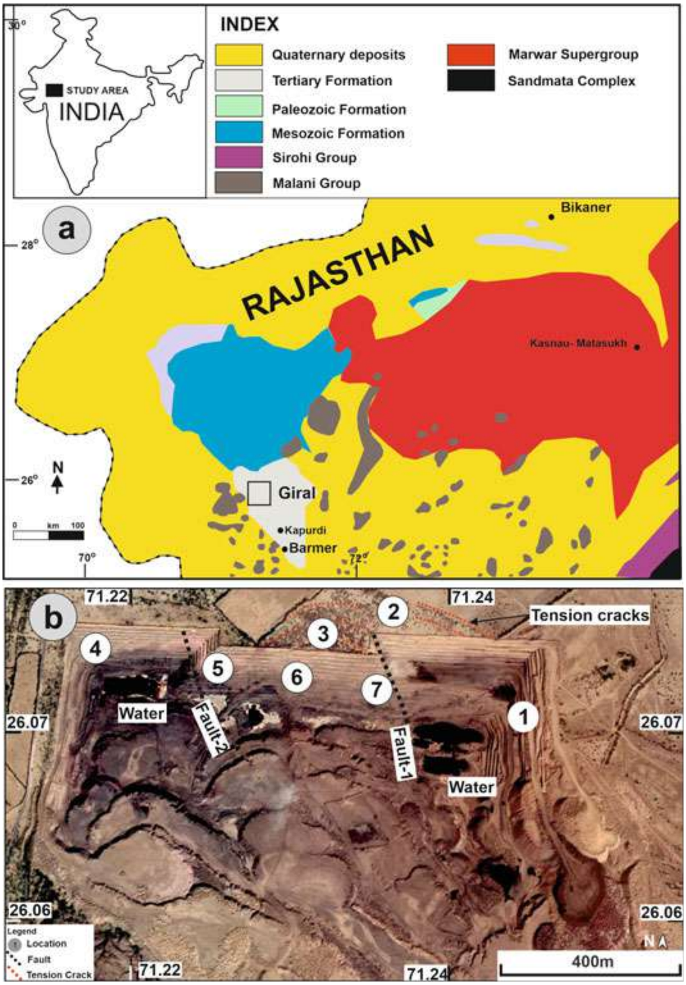

Fig. 1 Maps of the area; **a** Location and geological map of the area (after Roy & Jakhar, 2002); **b** Google Earth image showing locations of data collection sites and faults in the Giral lignite mine, Barmer (Rajasthan)

are other lignite mines too in Rajasthan- Matasukh and Kasnau (Nagaur), Sonari (Barmer) etc. Open cast mines are more cost-effective than the underground mines. The life of opencast mines depend on the steepness and stability of the slope.

Dasgupta and Mukherjee (2017) compiled the stratigraphy of the Barmer basin in their repository file. Puniya et al. (2022) summarized the geology and tectonics of Barmer basin. Besides, the geomorphological information about the Barmer (and the Jaisalmer) basin can be found at Biswas et al. (2022a, 2022b). Kar et al. (2022) presented the organic geochemical studies from a lignite mine in Barmer. The key information relevan to this artilce is as follows. The Barmer Basin is situated at the western part of Rajasthan, India, most of the part of this region is covered by the Thar Desert (Sisodia & Singh, 2000) (Fig. 1). The age of the rocks in Barmer basin ranges from Upper Proterozoic to Quaternary. Malani Igneous Suite (MIS) constitutes the base of the Barmer Basin, MIS overlain by Birmania Formation (Hughes et al., 2015; Sharma, 2007). The age of Randha and Birmania Fm is not clear. It is assumed to be of Paleozoic age (Hughes et al., 2015). Lower Jurassic Lathi Formation is exposed in the northern most portion of the Barmer basin and it overlains the Birmania Formation. Lower Jurassic Lathi Formation is exposed in the northern portion of the Barmer basin and is separated by the Fathegarh Fault from Fathegarh Formation of Maastrichtian to Early Paleocene age (Compton, 2009). Fathegarh Formation overlain by Dharvi Dungar Formation (Compton, 2009; Dolson et al., 2015; Kumar et al., 2020). Giral lignite mine and also the Sonari mine belong to the Dharvi Dungar Formation (Kumar et al., 2020). Lignite alternating with clay occurs in Giral. Singh et al. (2016) have done petrological studies of Grail mine and state that lignite of Grail mine composed of huminite group macerals, mainly telohuminite and detrohuminite, however liptinite and inertinite group macerals occur in subordinate amounts. Rajak et al. (2018) done the geochemical analysis of the Grail mine lignite and conclude that elements like Cu, Cd, Co, Ni, Zn, Pb, Na, and K occur in high concentration, while Mg and Ca have their concentrations lower than World Clarke average.

The stability of the opencast mine slopes depend on the the slope angle, rock type, joints orientations, faults, shear zones, groundwater, precipitation, earthquake and excavation method (Kumar et al., 2017; Tang et al., 2015; Xue et al., 2018). The failure of mine slope adversely affect the mining operation, and can lead to losses of human lives and degradation of agriculture land/environment.

2 Field Findings and Discussions

The Giral mine is destabilized locally by two normal faults those trend NW–SE (F-1 and F-2) and can be observed at the northern portion of the mine (Figs. 1b and 2). These faults have same trend as rift fracture in the Barmer Basin (Dasgupta and Mukherjee, 2017). These faults are new report in this study. In this mine alternate layers of lignite and shale are observed (Fig. 3b).Bedding of the lignite and shale dips

Fig. 2 Expression of fault on north face of the Giral lignite mine trending NE-SW. S. Mukherjee (170 cm) as marker

25° towards N107° direction. Cleats are near-perpendicular to the bedding planes and dipping towards N335° with dip amount 80° (Fig. 3a, a′). Few N035° trending sub-vertical joints almost orthogonal to the cleat sharply terminate against the shale bands (Fig. 3c).

As observed in a sub-vertical section inside the mine, F-1 and F-2 form a graben structure in the mine area (Fig. 4). F-1 dips64° towards N195°, and F-2 dips 58° towards N350° (Fig. 4).

The mine has been excavated ~120 m deep from the initial ground level. So the stability of the bench and berms are highly controlled by the sets of normal faults in the mine area. Parallel sets of normal faults (parallel to F1 dip direction ranges N160–195°) intersect the beds of lignite and shale at location-6 (Fig. 5). Total 14 such normal fault planes are observed within 1–2 m long outcrop at the berm and they dip 31–47° towards N160–172° (Fig. 5a′). Lignite deposit in this area shows ductile deformation before the brittle deformation in the form of normal faults. This ductile deformation is preserved in the form of asymmetric folding and later superposed by brittle deformation (Fig. 5a, a′).Asymmetric folds show top-to-N011° (NE) shear and terminate against the normal fault with N191° dip direction at location-7 (Fig. 6). Secondary mineralization of salt along the brittle planes is common in the northern portion of the mine (Fig. 5 and 6).

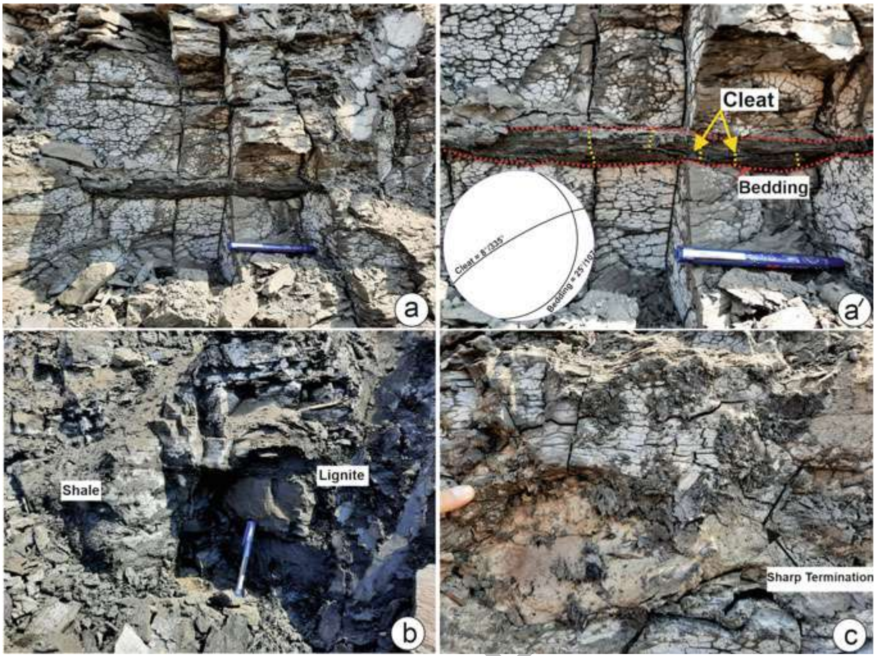

Fig. 3 Field photographs of Giral mine at location-1; **a** cleat and bedding structures structure original **a**′ and with interpretation, bedding planes are well observed dipping towards N107° and inclined at an angle 25°; cleats are near-perpendicular to the bedding. Cleats strike N075° and dip towards N335°; **b** alternate bands of shale and lignite, pen (12 cm) as scale; **c** sharp termination of vertical joint in lignite against the shale with trend N035°, part of finger (2 cm) as scale

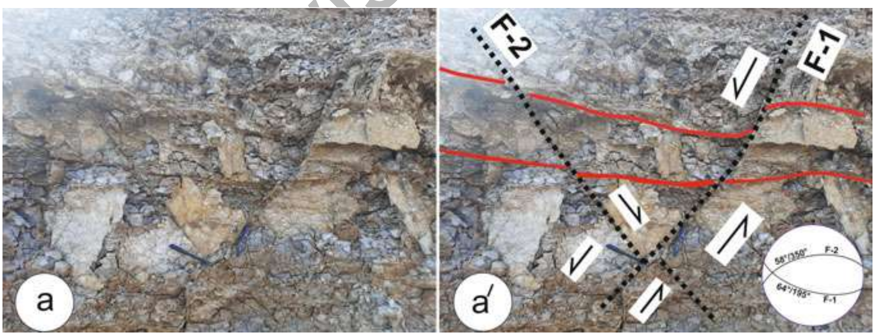

Fig. 4 Field photographs of Giral lignite mine show graben structure on a vertical plane, at location-5. **a** uninterpreted, and **a**′ interpreted image., Fault-1 dips 58° towards N350°. Fault-2 dips 64° towards S015°. Brittle planes filled up by secondarily precipitated salt in the eastern portion of the mine at location-1. Pen (12 cm) as scale

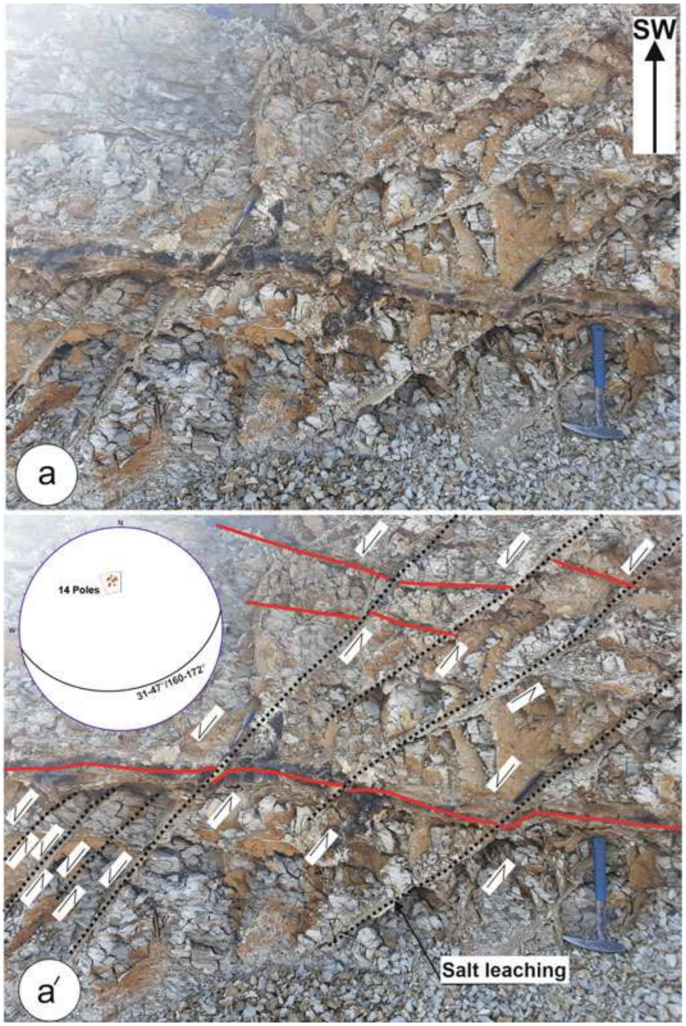

Fig. 5 Field photographs of Giral lignite mine area shows a vertical section with parallel normal faults at location-6; (**a**) and with interpretation (**a′**), the 6–9 cm thick lignite seam faulted by parallel normal faults dip 31–47° towards N160–170° at the eastern portion of the mine at location-2. Hammer (30 cm) as scale

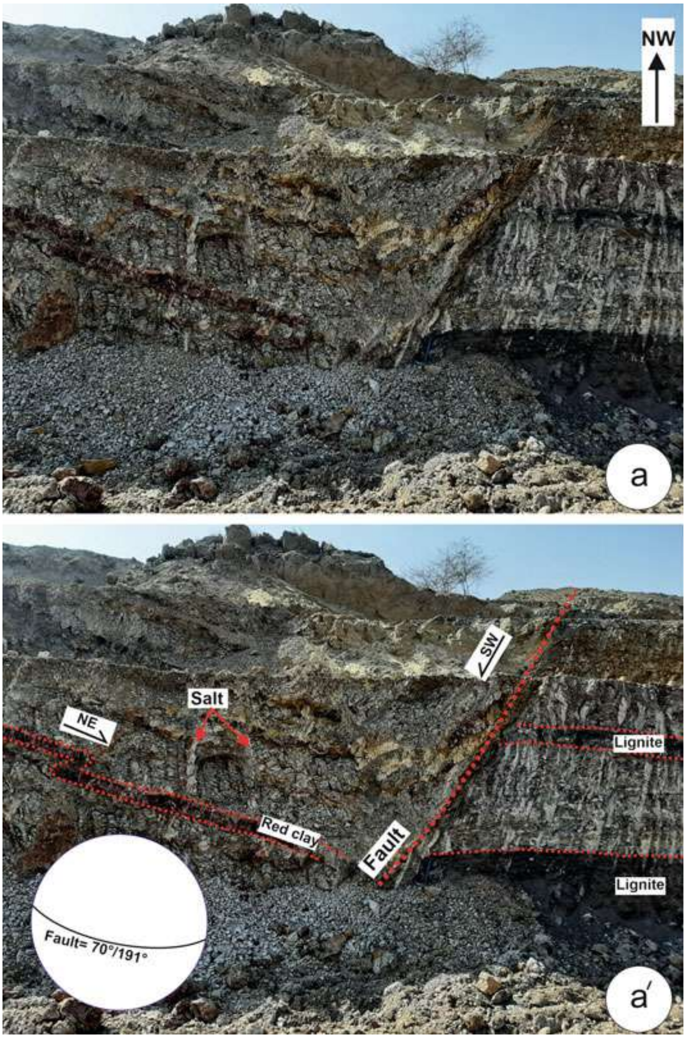

Fig. 6 Field photographs of Giral lignite mine show on a vertical plane parallel normal faulting with ‘z’ shape fold at location-7 (**a**) original and with interpretation (**a′**), a ‘z’ shape fold shows top to N011° shear direction in folded red clay band. A steeply-dipping (70°) normal fault with dip direction N191° cuts the early deformed beds. Secondary precipitation of salt along joints is present. The joints dip 75–80° towards N190°. Geological hammer (30 cm) as scale

At the footwall of the faults (Fault 1) asymmetric boudins show a top-to-South slip (Fig. 7) at location-4. A few “random” normal faults are also observed, dipping 58° towards N085° (Fig. 8).

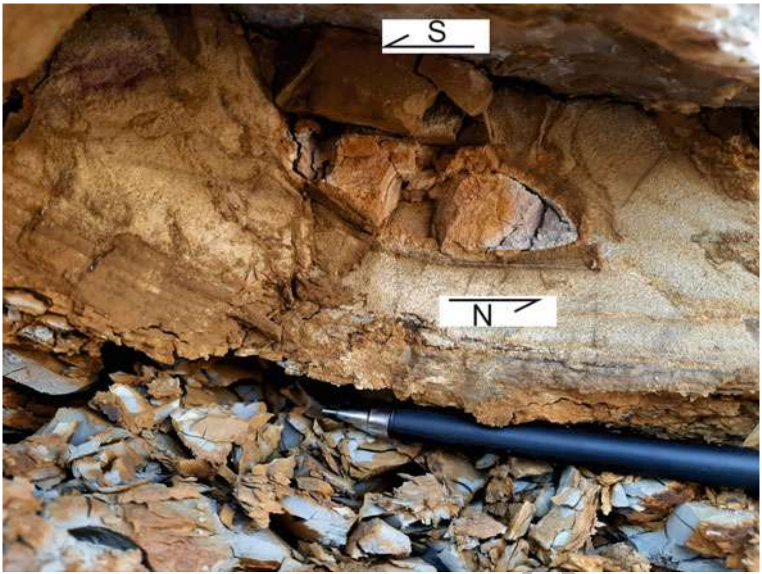

Fig. 7 A rootless clast of a boudin with top-to-S slip, location-4, observed on a vertical exposure. Part of pen (8 cm) as scale

Faulting, lignite mining and leaching of groundwater at the northern portion of mine promote ground failure. The failure is evident in the form of tension cracks at the northern portion of the mine as observed on the ground surface, i.e., on the plan view (Fig. 9). These cracks are sub-circular and show multiple stages of failure.

Fractured blocks show horizontal and vertical movement. Horizontal left-lateral slip along N295 to 308°isdeciphered with the help of curved fractures (Fig. 10a, c). Vertical and rotational movement are preserved. Difference in inclination of the adjacent fractured blocks indicates their rotation (Figs. 10b and 11). The inclination of rotated planes varies from 10 to 30° towards N115° (Fig. 10b). Vertical displacement varies from 10 cm up to 0.7 m at different levels (Fig. 11a, b). From north towards the western crown of the mine, detached block's orientation change from N112 to N210° (Fig. 11). This is due to the change in the direction of slope. Besides structural data, angle of the berm is also responsible for the mine slope stability. In this mine the angle of berm is varies from 78 to 85°. The angle of berm is very steep at northern portion and elevation difference between ground and mine deepest part is > 100 m. The width of bench also varies from place to place. At some places, it is 5 m and at elsewhere 8 m.

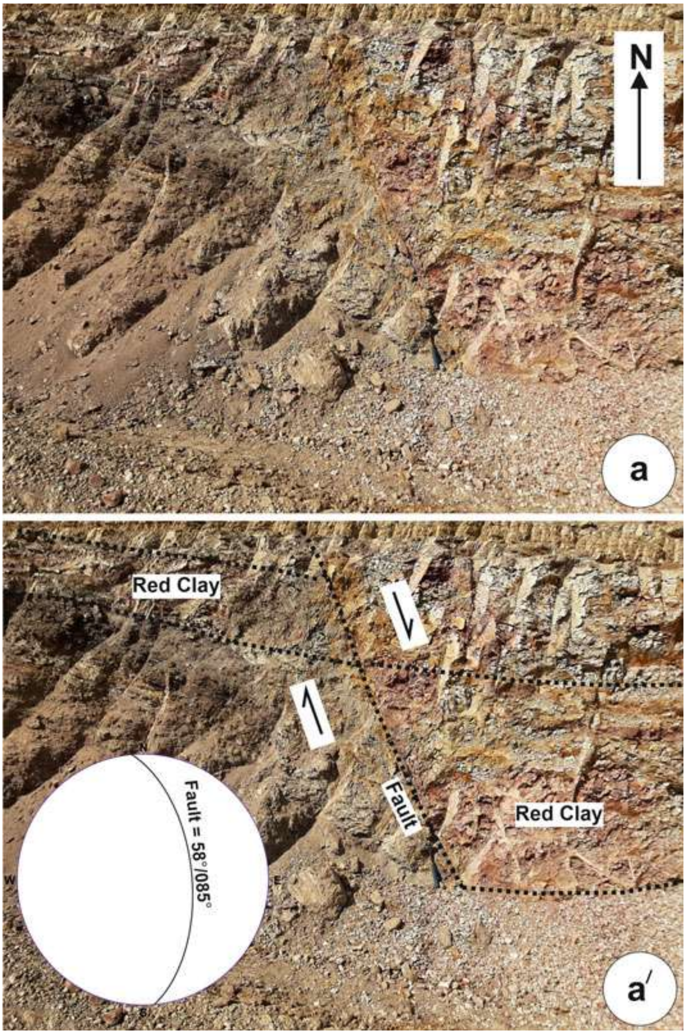

Fig. 8 Field photographs of Giral lignite mine area (**a**—uninterpreted and **a**′—interpreted) shows in a sub-vertical section a normal faulting in red clay bed. The fault dips 58° towards N085° at location-6. Hammer (30 cm) as scale

Fig. 9 Field photographs of Giral lignite mine of Northern slope shows parallel tension cracks of different stages at locations 2 and 3: **a** uninterpreted, and **a**′ interpreted. Tension cracks have developed. Few fractured (cracked) blocks have rotated

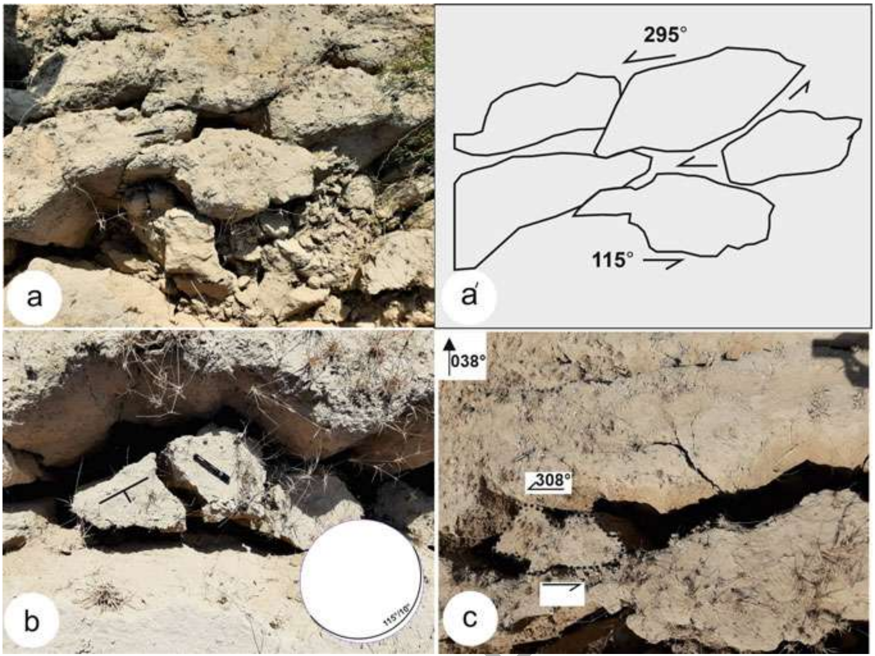

Fig. 10 Field photographs of tension cracks on plan view at location-2. **a** uninterpreted; **a′** interpreted: curved fractures probably show left lateral shear (left hand side N295°); **b** detached irregular block is rotated and dips 10° towards N146°; **c** possibly left laterally sheared curved fractures (left hand side N308); Pen (12 cm) as scale

3 Conclusion

This field work was carried out in Giral lignite mine. During this study following findings are observed;

- Two sets of normal faults are mapped and documented first time in the area. These sets can be divided into two faults group as F1 and F2.
- F1 faults have dips 31–47° and dip direction towards N160 to 172°. F2 faults show NNW (N340–350°) dip direction and dips vary from 50 to 58°. Due to the presence of two sets of normal faults, graben structures are well exposed at the northern portion of the Giral Mine.
- F1 faults generate due to the NE–SW extension. These are probably related to initiation of strike-slip movement between India and Madagascar. F2 probably resulted due to the main Barmer rifting.
- Along these normal faults, secondary precipitation of salt is observed as moderately hard filling.

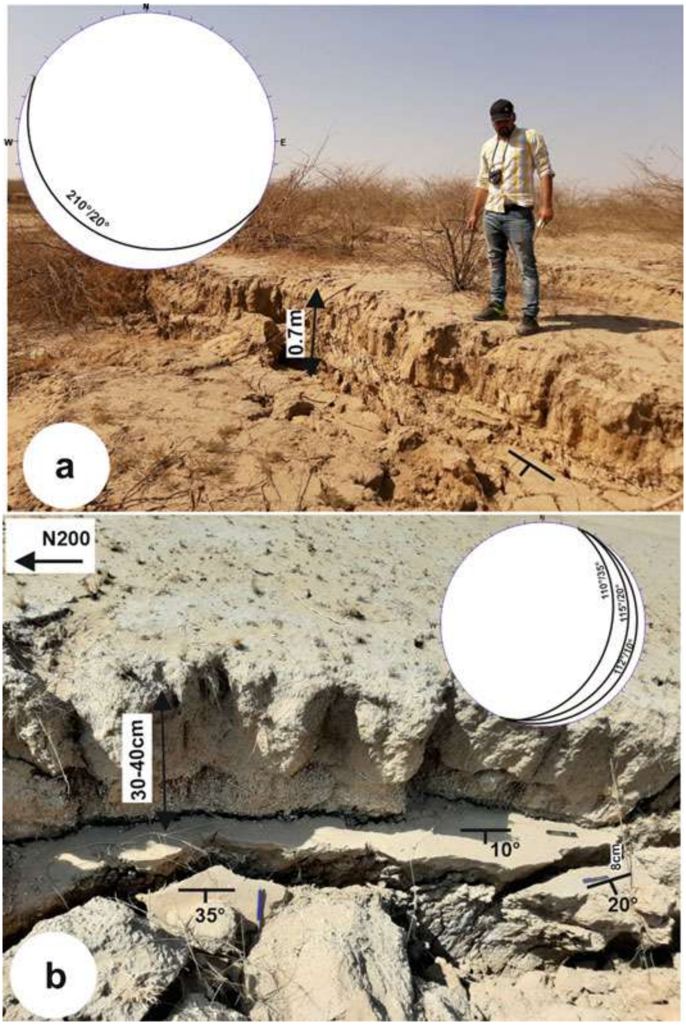

Fig. 11 Field photograph of Giral lignite mine at location-3 shows parallel tension cracks, fractured planes dip at different angles; **a** detached plane shows 0.7 m throw and fractured plane dips 20° towards N210°; **b** 30–40 cm throw observed along the slip plane, this plane dips at 10° towards N112°. Another slip plane shows 8 cm throw and dips 20° towards N115°. The third plane shows a maximum inclination of 35° towards N110°. Pen (12 cm) as scale

- The faulted northern portion creates a slope stability problem in the mine. Tension cracks are the result of the slope failure and can be observed at northern side of the mine.
- Tension cracks are sub-circular and show multiple stages of slope failure. Fractured blocks show horizontal and vertical movement. The inclination of these blocks varies 10–30° with N112° to N210° orientation.

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