



Field evidences as a tool to determine space – time relationships of intrusive rocks of Chhota Udaipur Alkaline-Carbonatite Sub- Province, Lower Narmada Valley, Deccan Large Igneous Province, India

Sanjeevani Jawadand

Department of Geology, RTM Nagpur University, Nagpur (MH), India.

Abstract

The Chhota Udaipur Alkaline-Carbonatite Subprovince (CUACS) lies in the lower extents of the E-W trending Narmada rift valley, stretching an area of about 1,200 km². The CUACS has strong imprint on the structures which are the artifact of major Narmada lineament (rift valley). Based on the observable field relationships and their interpretations viz., physical characteristics, principle of inclusions and the principle of cross-cutting, the relative ages of intrusive igneous rocks present in the CUACS were established. The map pattern suggests that the dykes trending at an angle with one another would cross each other and such intrusive relationship. One set of faults runs parallel to the Narmada, while the other runs perpendicular; these faults are contemporaneous and have oblique cross-cutting at 120°. However, apart from two locations, the direct field evidence of temporal hierarchy between intrusive could not be established. The dykes trending in EW and NW-SE directions are of, by and large, similar compositions, those trending ENE-WSW direction are of mostly calcareo-siliceous dykes. It is, therefore, possible that there may be some time gap between two events. Based on the surface evidences, it is possible to affirm that the calcareosiliceous dykes are younger than the lamprophyre, microbasalt, carbonatite and alkaline rocks occurring in the area.

Keywords: Chhota Udaipur Alkaline-Carbonatite Sub-Province, dykes, field evidences

1. Introduction

The Deccan Large Igneous Province (DLIP) in India is of global interest as one of the largest continental flood basalt provinces on Earth with the horizontal stack of ~1.5km thick tholeiitic basalt flows spreading over half a million km². It is crisscrossed by a number of dykes and related intrusive in three well-known swarms and the Narmada- Tapi swarm is the most illustrious amongst them. The study area i.e. Chhota Udaipur Alkaline-carbonatite Sub-province (CUACS), Gujarat which is a part of the Deccan Large Igneous Province represents a spectacular manifestation of mantle melting processes in terms of associated dykes, sills, plugs and veins marking the intrusive phases. Based on the observable field relationships and their interpretations viz., physical characteristics, principle of inclusions and the principle of cross-cutting, the relative ages of intrusive igneous rocks present in the Chhota Udaipur alkaline-carbonatite sub-province were established. Several extensive dykes have been distinguished in different sectors of Chhota Udaipur sub-province. The plugs and dykes of alkaline rocks i.e., nephelinite and phonolite, occur surrounding the ring dyke of Amba Dongar. The trachytic and doleritic dykes are found intruding lower Bagh sediments as well as upper Deccan Trap basalts. Phenai Mata igneous complex is variously intruded by dykes of dolerite, basalt, microgranite lamprophyre and breccia dykes (Sukheswala and Sethna, 1964; 1969; 1973; Sukheswala

et al., 1971; Durgadmath, 1984; Gwalani et al, 1993, 1995; Kumar, 1996). The cross-cutting relationships of dykes observed in the field indicated several dyke swarms of different ages in the area. The dominant dyke trend is NW-SE or almost N-S direction, although some trend ENE-WSW and E-W trends (Misra et al. 2014; Misra 2015; Randive et al. 2005; Randive 2005; Randive et al., 2011). Furthermore, the earlier field structural studies of Misra and Mukherjee (2016) revealed differences in the structural deformation of different age groups of basaltic dykes in the sub-province. An older 65.5 Ma group of dykes (Group I) are faulted/sheared and lacking in a uniform trend. Younger 65–63 Ma groups II and III dykes are syn- to post-deformation intrusions and intrude into the faults/shears.

The assembly of igneous intrusions occurs through the amalgamation of numerous pulses of magma. Multiple intrusions of basaltic and doleritic dykes have been reported from the Ambadongar complex. Igneous inclusions (e.g., xenoliths) incorporated in the matrix are older than the rock that contains them. Several mafic xenoliths varying in size, shape and composition were recorded from the lamprophyre dykes in the area.

2. Geology of the study area

The Chhota Udaipur Alkaline-Carbonatite Subprovince (CUACS), a notable geotectonic structure in western India, lies in the lower extents of the E-W trending Narmada rift valley, stretching about 1,200 km² (Fig. 1) (Gwalani et al., 1993; Randive et al., 2005; Chalapathi Rao et al., 2012). The study area i.e. CUP comprises a variety of mafic, sub-alkaline, alkaline and carbonatite intrusive rocks. This area has been divided by Gwalani et al. (1993) into five sectors on the basis of their spatial association: 1) Amba Dongar, 2) Siriwasan-Dugdha, 3) Panwad-Kawant, 4) Phenai Mata, and 5) Bakhatgarh-Phulmal; five temporally associated suites: 1) the tholeiitic Deccan Trap lavas, 2) a layered tholeiitic gabbro-anorthosite-granophyre intrusive complex at Phenai Mata, 3) the main alkaline intrusive suite comprised of alkaline rocks and carbonatites, 4) a trachytic suite of dykes and plugs, and 5) a late basic-ultrabasic suite of dykes and plugs of basalt, picrite and dolerite; and three genetically linked series: 1) alkaline, 2) tholeiitic (sub-alkaline), and 3) transitional.

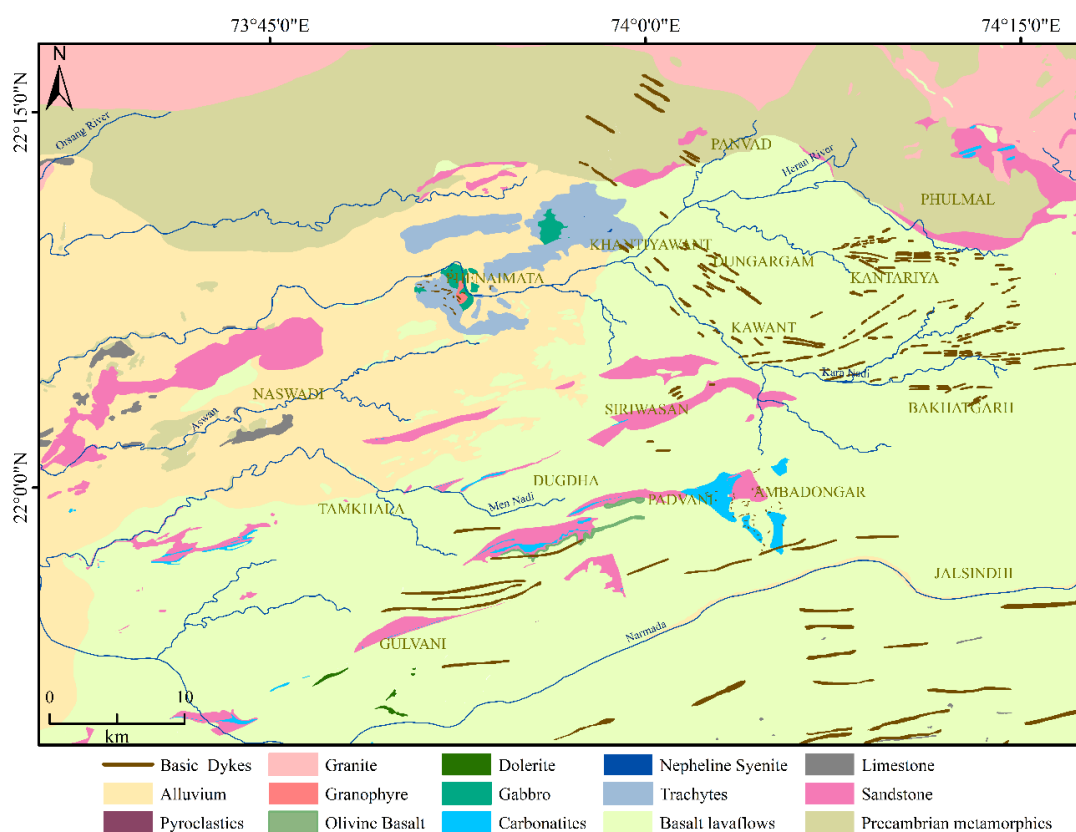


Fig. 1 Geological map of study area

3. *Map and Map patterns*

The available geological map of the entire Chhota Udaipur alkaline-carbonatite sub-province (CUACS) is given by Gwalani et al. (1993), which is mapped between 1963-1986 by Sukeshwala, Udas, Sethna, Awasia, Master Viladkar, Bourges, Akhilesh-Narayan, Mahambre and Gwalani. This compilation is the only compilation available of the Chhota Udaipur intrusive complex. However, there have been several new additions in the recently published maps of different parts of the province. Nevertheless, the hierarchy of intrusives with a sense of space-time relationships is given only by Gwalani et al. (1993).

The geological map of Gwalani et al. (op. cit.) indicates following geological units (Fig.1):

- 1) The Precambrian Metamorphics which includes quartzite and quartz-mica schist, granitic gneisses and granites, belonging to Aravalli Supergroup.
- 2) The Cretaceous sandstones and limestones belonging to infratrappean Bagh sediments.
- 3) The basaltic lavaflores of the Deccan trap magmatic episodes. These lavaflores have been punctuated by presence of intertrappean green bole and red bole beds; sometimes ash beds are also present.
- 4) Gwalani et al. (1993), then indicates presence of trachytic intrusives over the Deccan lavaflores.
- 5) The intrusive rocks of the Ambadongar Phenai mata and surrounding areas have been broadly divided into three categories; namely, carbonatite-alkali complex, phenai mata tholeiitic complex and the dykes of picritic basalt, alkaline, basic and carbonatite.
- 6) The intrusives under the group carbonatite-alkali complex includes tinguaitite, nephelinite, phonolitic nephelinite, carbonatite breccia, carbonatites and also calcareosiliceous rocks.
- 7) Younger to this, a group of rocks is mentioned under the Phenai mata tholeiitic complex. It includes anorthosite, layered gabbro, gabbro, granulitic dolerite, hornblende dolerite, basalt, epidiorite, pulaskite and granophyre.
- 8) The youngest of all the units is considered to be the dykes of various composition including the picritic basalts and carbonatites.

The mapping pattern of the rocks mentioned above allows spatial distribution of these rocks into five sectors as mentioned by Gwalani et al. (1993). However, there are only few, if any, tell-tale evidences of the cross-cutting of these dykes or presence of xenoliths of one into other. As intrusion volume increases, the evidence of the magma pulses constituting each body becomes increasingly obscure (Horsman et al., 2005). Numerous processes may obfuscate evidence of pulses, and these processes are generally more potent at deeper crustal depths. Therefore, the absence of direct evidences does not always indicate the absence of pulsed assembly.

4. *Linear fractures/ Structures*

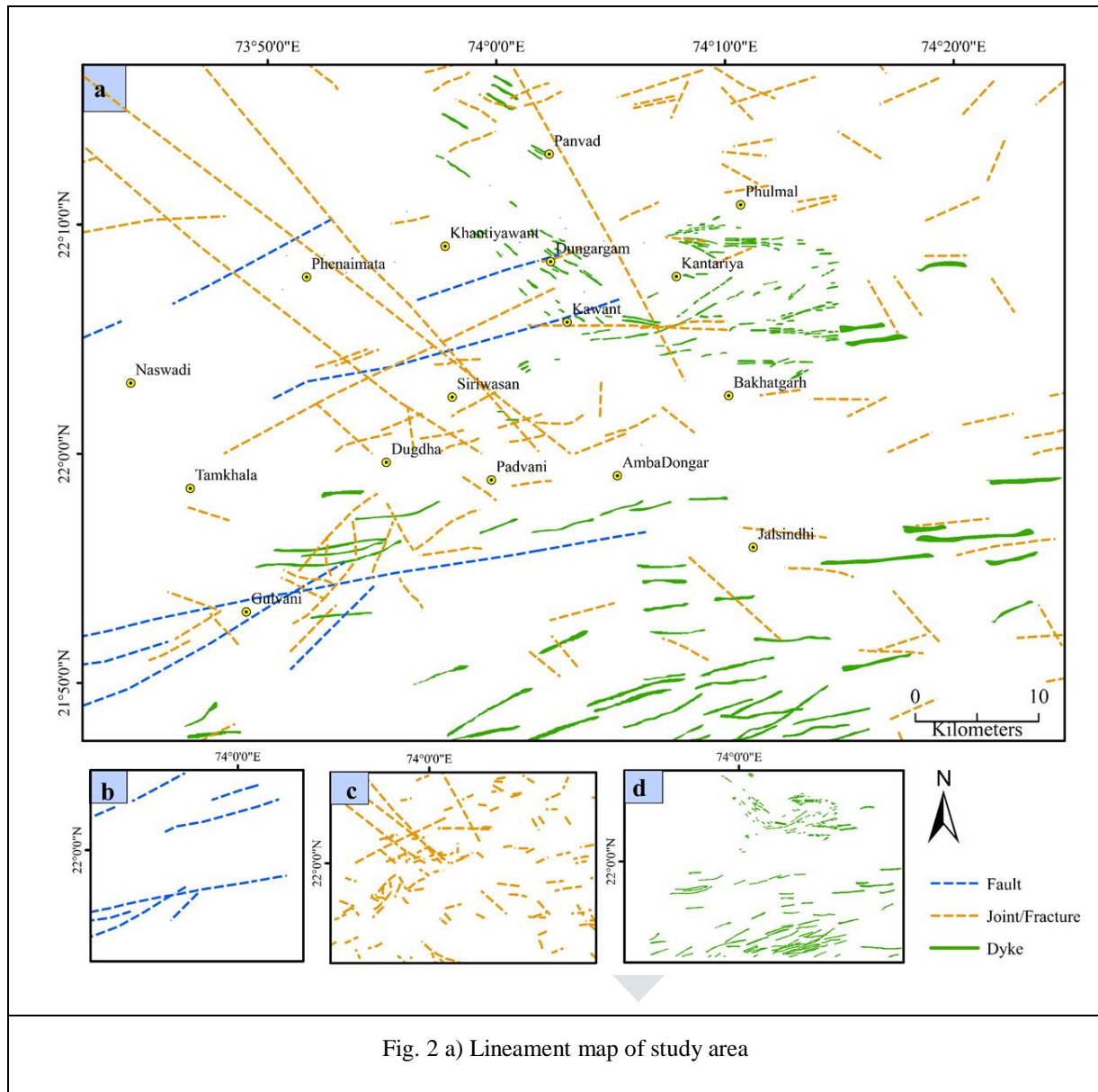
Linear structures such as fractures, joints, faults being collectively referred to as lineaments. In the following discussion, are divided into two categories on the basis of their relative displacement, namely faults (with displacement) and joints and fractures (without displacement).

a. *Faults:*

The CUACS has strong imprint on the structures which are the artifact of major Narmada lineament (rift valley). Sukeshwala and coworkers have reported series of step-faults which are formed consequent to Narmada rifting (parallel) and off-setting (perpendicular) to the E-W trending structural grain of Narmada lineament zone. In the study area, two distinguishing trends are seen; the NNE-SSW and ENE-WSW trending faults which show oblique cross-cutting at 120° (Fig. 2 a and b). It is clear that one set is parallel to Narmada and another set is perpendicular. It is clear that both sets of faults are contemporaneous. The dykes are exploited both the fault planes and therefore, although they appear to show cross-cutting relationship, they are unlikely to be of different ages.

b. Joints and Fractures:

These are at least three sets of joints/fractures namely, i) E-W trending ii) NW-SE trending and iii) ENE-WSW trending. Apart from these trends, sometimes branching of the lineaments is commonly observed giving a feeling of more sets of joints and fractures. They apparently show cross-cutting relationship on the map pattern (Fig.2 a and c). However, in the field, it is very arduous to see any such direct cross-cutting between different dykes. The dykes trending in EW and NW-SE directions are of, by and large, similar compositions, those trending ENE-WSW direction are of mostly calcareo-siliceous dykes. It is, therefore, possible that there may be some time gap between two events.



c. Dykes:

There are plethora of dykes present in CUACS. They vary in composition and trends in which they occur. However, their direct cross-cutting relation could not be seen. Their map pattern is suggestive of their possible cross-cutting (Fig. 2 a and d) but in the field, their direct contacts are missing. Similarly, lamprophyres, microbasalts, alkaline and carbonatite rocks occur along NW–SE trends. These dykes abut against the ENE-WSW trending, mostly calcareosiliceous, dykes. There is another trend for basic and lamprophyre dykes near Kanthari, Biswani, Undri and towards Bakhatgarh. These dykes' trend in E-W direction and mostly parallel to one another. In field, dykes occurring in either of the above discussed trends do not show tell-tale evidences such as chilled contacts, truncation of one against another, dislocation, enduring-fritting-burning effect etc.

Nevertheless, at some places such as near Dhorat and Kanthari, the calcareosiliceous dyke appears to cut across 2PB dyke (Fig.3) Similarly, near Dungaragam, a lamprophyre dyke appears to cut across gabbro (Fig.4). Based on these evidences, it is possible to affirm that the calcareosiliceous dykes are younger than the lamprophyre, picobasalt, carbonatite and alkaline rocks occurring in the area.

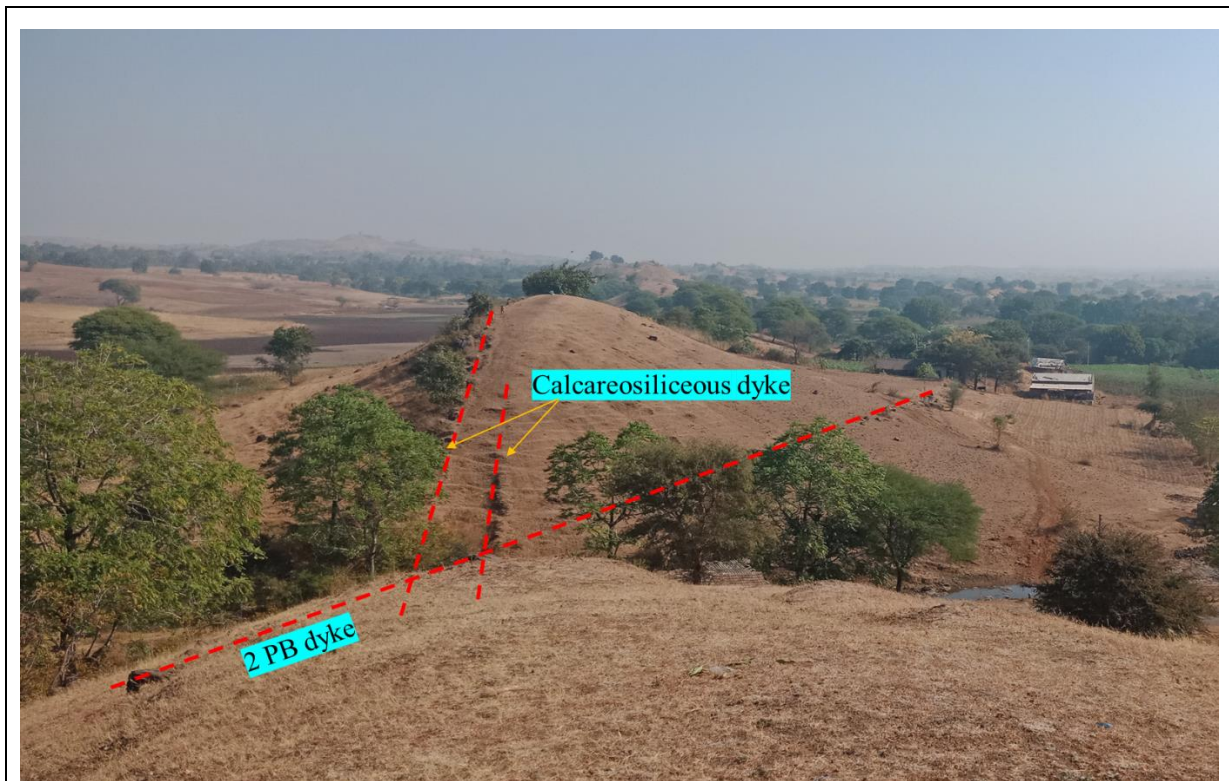


Fig. 3 Showing possible cross-cutting between calcareosiliceous and 2 PB dyke near Dhorat village



Fig. 4 Showing intrusion of lamprophyre dyke in gabbroic rock

d. Relation between faults, joints/fractures and dyke emplacement:

The CUACS area being in close proximity of the Narmada river and one of the major centres of dyke emplacement, is the centre of major tectonic activities. The Narmada river being a rift valley represents a wagon having series of step-faults contemporaneous to the major Narmada fault. The step-faults indicate presence of two types of faults, E-W trending extensional faults and another set of off-setting fault which is roughly perpendicular to this direction. However, the cropping-out of a ring dyke at Ambadongar and other intrusive centres such as Phenai mata, Dungargam, Rajawant, Biswani, etc. has also significant effect on formation of joints and fractures in the area.

There is a great deal of diversity in composition of the dykes. Although, these dykes occur along three structural trends discussed earlier, there is no guarantee that a particular trend is followed by a dyke of a particular composition. Following observations are pertinent to be mentioned here:

- 1) The lamprophyres and picrobasalts occur along NW-SE as well as E-W trends.
- 2) The dolerites, 2PB, 3PB and GPB dykes occur mostly along E-W and ENE-WSW trends.
- 3) The calcareosiliceous dykes mostly occur along ENE-WSW trend; however, several smaller calcareosiliceous dykes, calcite, quartz veins occur randomly oriented.

The planes of weaknesses formed in the region are, in all probability related to major Narmada rifting event and it is only logical to believe that the emplacement of dykes is related, by and large, to that one major episode of rifting. The reason for occurrence of dykes of similar composition along different structural grains is because of the same reason. Having said that, it is also important to note that the Narmada rift zone, which is part of the Son-Narmada-Tapti (SONATA) rift zone, has been continuously active since the Mesoproterozoic time (Jain et al., 1995). Moreover, the Narmada graben-Satpura horst is continuously active since Cretaceous, and even today the Neotectonic activities are known to occur in this region. Therefore, activation and reactivation of faults and emplacement of younger magmas along such reactivated faults is an obvious possibility. The field criteria may not provide clear-cut evidences, but indicates a possibility of episodic magmatism in the region.

5. Xenoliths

The occurrence of xenoliths is relatively uncommon in the Chhota Udaipur rock. However, there are exceptions such as the calcareo-siliceous dykes which are studded with xenoliths. The xenoliths are mostly of older Precambrian metamorphic rocks, Bagh sediments and Deccan trap basaltic lava flows (Fig. 5). The xenoliths are various intrusive phases such as carbonatites, alkaline rocks, lamprophyres etc. Moreover, it greatly constraint establishing the space-time relationship of calcareo-siliceous rocks with other intrusive.

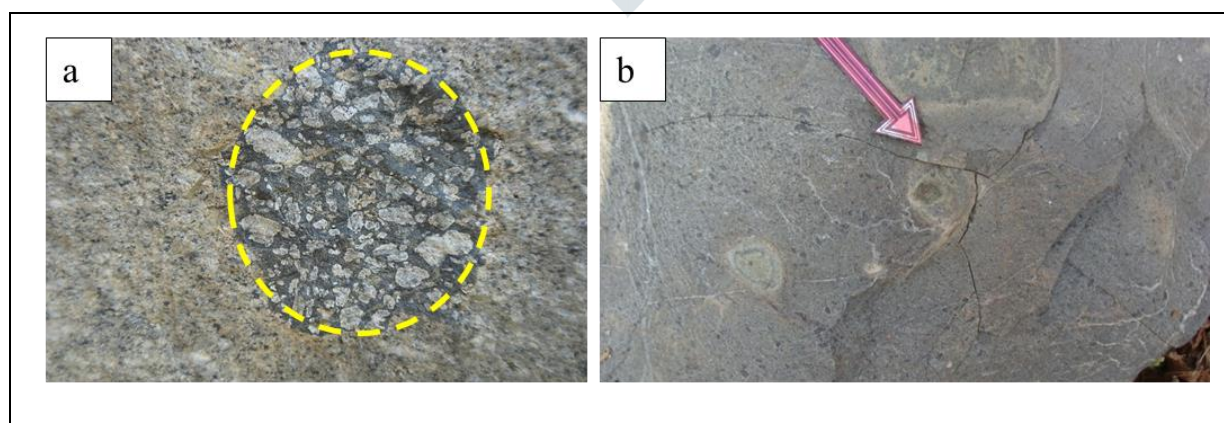


Fig. 5 Field photographs showing (a) basaltic xenolith engulfed calcic plagioclase within it in the parent rock granite, (b) smaller sub-rounded xenoliths with irregular veins.

6. Chilled margins

The time delay between pulses allows preservation of internal ‘chilled margins’ and the development of near-rigid surfaces at their contacts, increasing the alignment and clustering of crystals during magma replenishment (Lino and Vlach, 2021). At the south bank of Kara river, the epidote dyke clearly cut the exposure of lava flow (pyroclastic material) which alongside shows the chilling effect (Fig. 6).

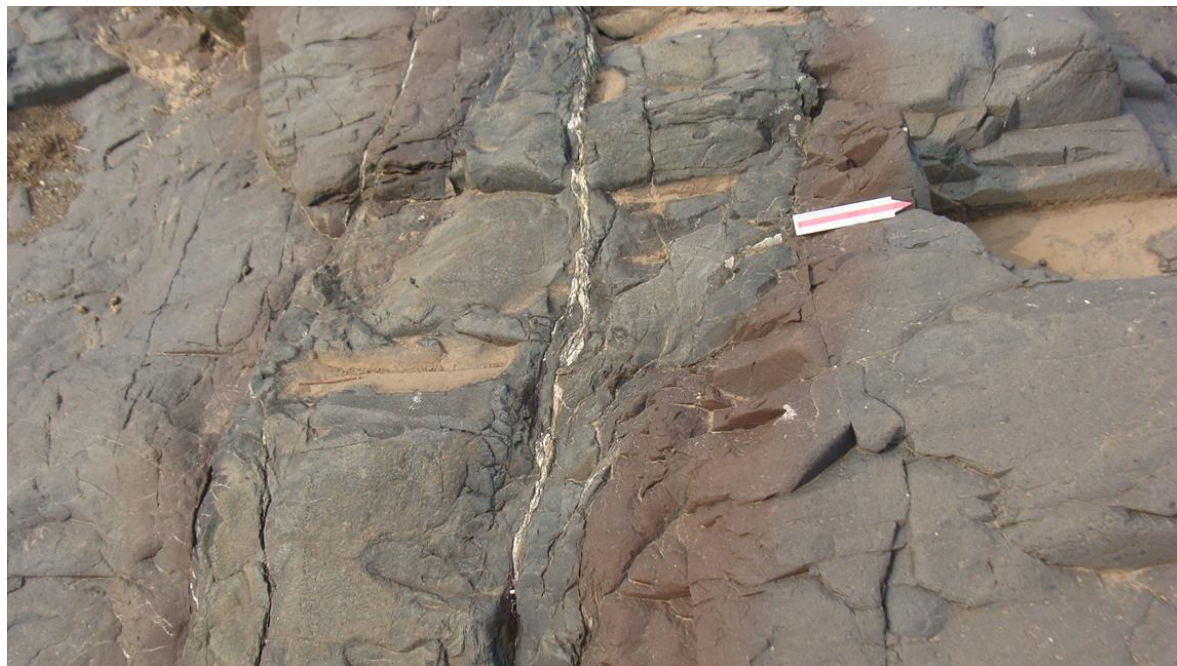


Fig. 6 Field photographs showing chilling effect where the epidote dyke cuts the exposure of lava flow near Kara river

Concluding remark

Although the field criteria may not give conclusive evidences, they do suggest that there may be periodic magmatism in the area. It suggests that the emplacement of CUACS took place over a considerable time span indicating the contemporaneous existence of primitive and more evolved mafic magmas.

Acknowledgment

I am very thankful to Prof. K. R. Randive for his valuable guidance and support.

References:

- [1] Chalapathi Rao, N.V., Dharma Rao, C.V., Das, S. 2012. Petrogenesis of lamprophyres from Chhota Udaipur area, Narmada rift zone, and its relation to Deccan magmatism. *Journal of Asian Earth Sciences*, 12: 24–39.
- [2] Durgadmath, M.B. 1984. Lamprophyre dykes from Phenai Mata area, Baroda district. *Spec. Publ. Geol. Surv. India*, 12: 3-7.
- [3] Gwalani, L.G., Fernandez, S., Karanth, R, V., Demeny, A., Chang, W-J and Avasia, R. K. 1995. Alkaline and tholeiitic dyke swarm associated with AmbaDongar and Phenai Mata complexes, Chhota Udaipur alkaline sub-province, western India. *Mem. Geol. Soc. India*, 33: 391-423.
- [4] Gwalani, L.G., Rock, N.M.S., Chang, W.J., Fernandez, S., Allegre, C.J. and Prinzhofer, A. 1993. Alkaline rocks and carbonatites of AmbaDongar and adjacent areas, Deccan Igneous Province, Gujarat, India. 1. *Geology, petrography and petrochemistry. Mineral Petrol.*, 47:219 – 253.

- [5] Horsman, E., Tikoff, B. and Morgan, S. 2005. Emplacement-related fabric and multiple sheets in the Maiden Creek Sill, Henry Mountains, Utah, USA. *Journal of Structural Geology*, 27: 1426–1444.
- [6] Jain, S.C. Nair, K. K. and Yedekar, D. B. 1995. Geology of the Son-Narmada-Tapi lineament zone in Central India. Geoscientific studies of the Son-Narmada-Tapi lineament zone, in Project Crumansonata, Geological Survey of India Special Publication, 10: 1–154.
- [7] Kumar, S. 1996. Chemistry of clinopyroxenes from sub-alkaline and alkaline rocks of Phenai Mata igneous complex, Baroda district, Gujarat, Western India. *Jour. Geol. Soc. India*, 48:547 – 558.
- [8] Lino, Lucas and Vlach, Silvio. 2021. Textural and Geochemical Evidence for Multiple, Sheet-Like Magma Pulses in the Limeira Intrusion - Paraná Magmatic Province, Brazil. *Journal of Petrology*, 62 (3) <https://doi.org/10.1093/petrology/egab011>
- [9] Misra, A.A., Bhattacharya, G., Mukherjee, S. and Bose, N. 2014. Near N–S paleo-extension in the western Deccan region in India: does it link strike-slip tectonics with India–Seychelles rifting? *International Journal of Earth Sciences*, 103: 1645–1680.
- [10] Misra, A.A. 2015. Sheared nature of the Indian western continental margin around Mumbai, India: onshore and offshore geoscientific studies. PhD thesis, Indian Institute of Technology, Bombay.
- [11] Misra, A.A. and Mukherjee, S. 2016. Dyke–brittle shear relationships in the Western Deccan Strike-slip Zone around Mumbai (Maharashtra, India). In: Mukherjee, S., Misra, A.A., Calve's, G. & Nemečok, M. (eds) *Tectonics of the Deccan Large Igneous Province*. Geological Society, London, Special Publications, 445. <https://doi.org/10.1144/SP445.4>
- [12] Randive, K. R. 2005. Intrusive dykes of Chhaktala, Jhabua district, Madhya Pradesh: field relations, petrography and petrochemical characteristics with reference to their PGE concentration. *J. Econ. Geol. Georesour. Manage.*, 2(1–2): 117–137.
- [13] Randive, K. R. 2011. Occurrence of xenoliths in the lamprophyre and picrobasalt dykes of Bakhatgarh–Phulmal area, Jhabua district, Madhya Pradesh, India. In *Dyke Swarms: Keys for Geodynamic Interpretation* (ed. Srivastava, R. K.), Springer-Verlag, Berlin, 301–313.
- [14] Randive, K.R., Prasad, G.J.S., Anil Kumar, A., Rama Rao, R., Bhaskar Rao, Y.J. and Dayal, A.M. 2005. Picrobasalt and lamprophyre dyke swarm of Bakhatgarh– Phulmal area, Chhota Udaipur alkaline complex, Deccan Igneous Province. *Indian J Geochem.* 20: 191-212.
- [15] Sukheswala, R.N. and Sethna, S.F. 1964. Differentiated Gabbro of Deccan Trap age and its associates. *Bull. Geol. Soc. India*, 1(2): 6 – 9.
- [16] Sukheswala, R.N. and Sethna, S.F., 1969. Layered gabbro of the igneous complex of Phenai Mata, Gujarat State. *Jour. Geol. Soc. India*,10:177 – 187
- [17] Sukheswala, R.N. and Sethna, S.F., 1973. Oversaturated and undersaturated differentiates in the tholeiitic igneous complex of Phenai Mata, Baroda district, Gujarat State, India. *Neues.Jahrb. Mineral.Abh.*,118: 159 – 176.
- [18] Sukheswala, R.N., Avasia, R.K. and Master, D.J. 1971. Dyke cluster of Phenaimata region, Chhota Udaipur, Gujarat; In: Murty, TVVGRK (eds.), (West Volume), 608-616.