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Geological Structures near Purna River in Jalna District in the Vicinity of Lonar Crater, Maharashtra

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Abstract
The studies on geological structures along the Purna river in Jalna district is carried out with reference to field characters, extent and occurrence of the dykes, volcanic breccias, vesicular cylinders, pipe amygdales, and columnar jointing found in the Deccan basaltic formations. Geologically, the entire study area belongs to the Deccan Basaltic Province (DBP) and comprising of the Compact/massive (aa type) and vesicular-amygdaloidal (pahoehoe type) of basalt flows. During the field work four flows of basalt are observed along the Purna river. Total numbers of 17 dykes have been identified, having the vertical, horizontal and inclined outcrop. The top surface of the pahoehoe type of flow is chilled showing the formation of ropy lava structure, while the bottom of the flow is indicated by the presence of pipe vesicular-amygdaloidal structure. Bending of the pahoehoe flows, occurrence of vesicular cylinder, volcanic breccias and columnar jointing structure are also taken into consideration in the present study.
***(Key words:** Geological structures, Deccan basalts, Dykes, Purna river, Lonar Lake)*

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I. INTRODUCTION

The end of the Mesozoic era was manifested by the outburst of huge lava flows which spread over vast areas of western, central, and southern India. These lava flows are erupted through long but narrow cracks or fissure on the earth's crust, from a large magma chamber and known fissure eruptions. Because of step-like or terrace like appearance of their outcrop the flows of basalt are called as traps (Krishnan 1982). The Deccan basalt province is spread over an area of 500,000 sq. km., which consist dominantly of tholeitic basalt with alkaline and picritic basalt. The entire thickness of Deccan basalt flows is 3.4 km (Mahoney et al. 2000), containing 3 subgroups and 12 formation of which the basalt of Ambenali formation are largely exposed on the southern part of the Deccan province (Mitchell and Widdowson 1991).

Deccan flood basalt was erupted at the Cretaceous-Tertiary boundary (65 Ma) in the Indian Peninsular shield. Dykes, sills and plugs in the flood basalt province form an important component of the magmatic plumbing system. Dykes in Deccan Volcanic Province are reported from ‘Nandurbar-Dhule’, ‘Betul-Jabalpur’, ‘Saurashtra’, ‘Western Ghats’ and ‘Pachmari’ etc. Lot of study has been carried out on ‘Intrusions (*mostly Dykes*) in Deccan Trap’ by earlier researchers. Crookshank (1936) has discussed the age and age relationships among Deccan dykes, sills and lava flows, disposed on the northern slopes of the Satpura Mountain. Sen and Cohen (1994) have studied the mean 40Ar/39Ar ages (65.8±0.3 Ma) for Chakhla-Delakhari sill. They observed that these ages lie within the age range of 63.6 - 67.6 Ma. Shrivastava et al. (2008) have studied one of the most extensive Deccan basalt intrusive that attains its maximum thickness in the area referred to Chakhla-Delakhari Intrusive Complex (CDIC), this intrusive complex covers a large part of the Eastern Deccan Volcanic Province (EDVP) (Kaplay et al. 2017). For EDVP, Mahoney (1988) hypothesized an independent fissure system. Mishra (2008) studied the geological setting of dyke swarms exposed in the Deccan volcanic province (DVP) and enumerated the relationship between extensional tectonics, decompression melting, effusion of lava flows and the emplacement of dyke swarms. The thickness of the dykes within the same intrusion domain may vary for example the Narmada-Tapti dykes are thicker in the western part, whereas, these dykes are thinner in the eastern part of the DVP. The ENE-WSW trending dyke swarms (*Narmada-Tapi dykes*) are older and formed in a single forceful injection, confined only within the lower flow along Narmada valley. The dykes and dyke swarms are also related to tensional events. Lot of study has been carried on this aspect also. Karkare and Srivastava (1990) discussed that the dyke swarms represent tensional events preceding the main eruption of basaltic rocks, and related to the alkaline provinces of Deccan, are either linear or radial. Babar et al. (2017) elucidated that the dykes at Aurangabad (Maharashtra) show primary deformation structures, viz. offset, feeder dykes and deformed vesicles, as well as secondary ones. The offset of the dyke along the vicinity of the stratigraphic joint is the major one. This offset possibly developed due to stress barriers related to abrupt variations in rheological properties between porphyritic basalt and amygdaloidal basalt.

The aim of the present study is to carry out the detailed field studies with reference to dykes, volcanic breccias, vesicular cylinders, pipe amygdales, columnar jointing, etc. different types of structures occurring in the Deccan Traps. The study area includes the areas along the Purna river at Garteki, Jambhrun and Incha villages in Jalna district (Fig. 1).

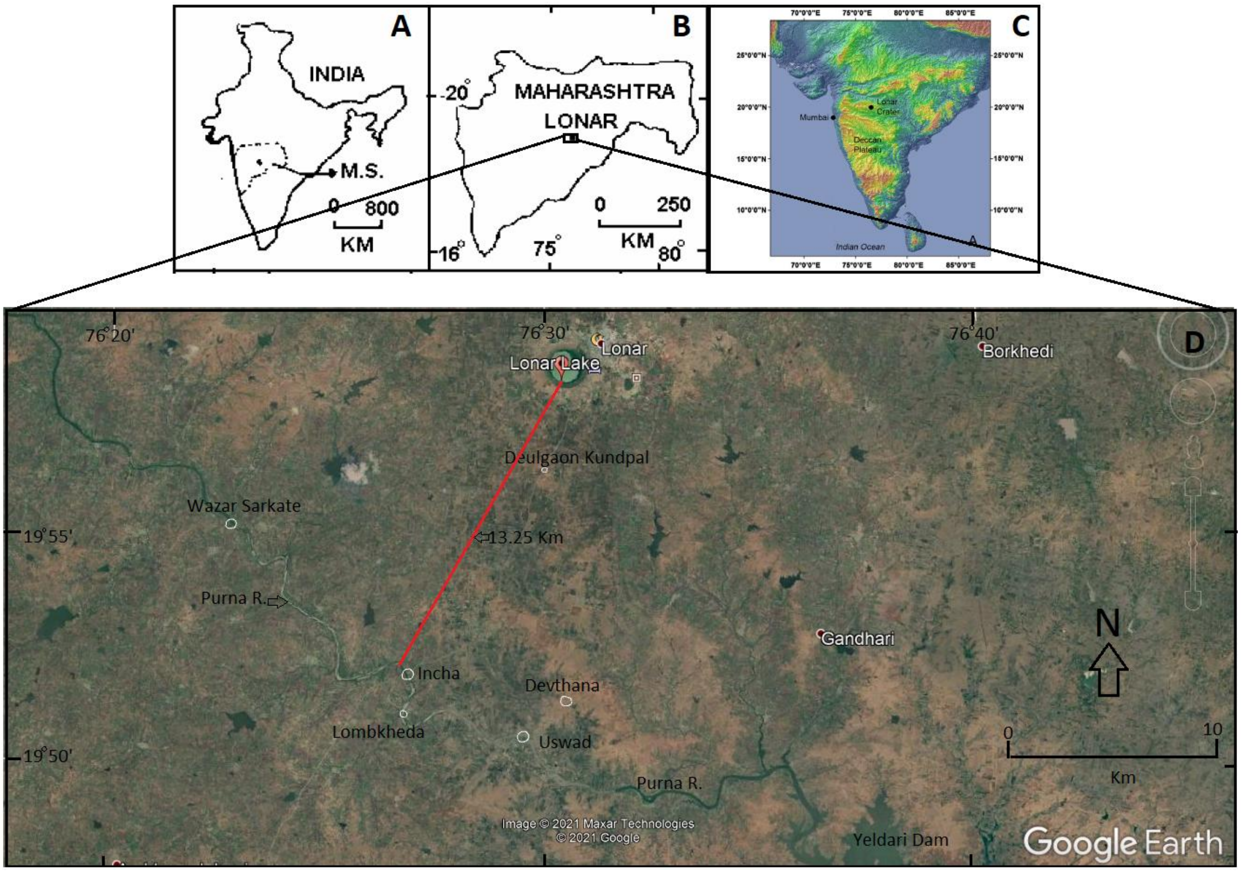

Fig. 1. A) Location in India B) In Maharashtra C) Location of Lonar in background topographic produced from the SRTM DEM data by Komatsu et al. (2014) and D) Google earth image of the Study area.

II. METHODOLOGY

Deccan volcanism, representing a tremendous outburst of volcanic activity, marks an important episode in Indian Geological History. The Deccan Trap lava pile is thickest in the western part of the province reaching an exposed thickness of 1.7 km in parts of Western Ghats. During the detailed field studies, we encountered the small scale dykes, flows marked with volcanic breccias, vesicular cylinders, pipe amygdales, columnar jointing in massive basalt, etc. structures occurred in Deccan basalt formations. The dykes are small and varying in thickness and length. The maximum length of the dykes is 498 cm and minimum length is 120 cm.

During the field study the dykes are found at Garteki, Jambhrun and Incha in Jalna district along the Purna river. Identification of rock type of the dyke, trend, thickness of the dyke and the detailed field characters of the individual dykes have been marked during the fieldwork itself. The most characteristic feature of the dyke is the development of definite horizontal pattern of jointing in them.

The dykes in the study area show a perfect horizontal set of jointing pattern. Due to this feature, dykes can be readily recognized in the field from the enclosing jointed basalts.

During the field study, other features are also seen, like the quartz veins, columnar joints and potholes in river bed. The columnar joints are pentagonal to hexagonal in outline. At Wazar Sarkate, Uswad, Devthana, beautiful small potholes are observed. The depth of the potholes varies from 0.76 m to 2.46 m.

GEOLOGY OF THE AREA

The entire study area in Jalna dist. Maharashtra is covered by the Deccan trap formation comprising nearly horizontal lava flows. The flows have been considered to be a result of lava eruption during late

Cretaceous to early Eocene period. The types of basalt occurring in the area are compact basalt, vesicular basalt and amygdaloidal basalt. As the basalt are formed by cooling and solidification of the lava, they contain gas cavities and also joints which are the contrasting cracks developed during cooling of the lavas. But all the basalt flows do not contain gas cavities and joints and therefore on the basis of presence or absence of gas cavities, study area is part of Deccan Volcanic Province which generally shows pipe amygdales flows shows irregular vesicles, columnar jointing patterns (Kale and Kulkarni 1992).

Field Characters of Basalt Along Purna River :

The study along Purna river bed at Limbkheda village is carried out from the point of view of the exposure of basalt flows. Geologically, the study area belongs to Deccan Basalt flows. The types of basalt flows occurring in the area are compact basalt 'aa' type massive basalt and vesicular-amygdaloidal basalt 'pahoehoe' type compound basalt flow as observed in the vertical valley section of Purna river. The Deccan Basalt in this area is equivalent of the Ajanta formations, which are stratigraphic comparable with the Upper Ratangad formations of Western Maharashtra comprising compound flows (Godbole et al, 1996).

The Deccan Trap flows are generally horizontal in attitude, these lava flows are believed to have erupted subaerially through fissures in the earth crust. Majority of the Deccan Trap flows are basaltic (specific gravity, 2.65) with chemical composition of essential minerals present in the Deccan Traps basalt such as labradorite feldspar, augite, iron oxide and may or may not be the presence of olivine. The secondary minerals like calcite, quartz, zeolites, glauconite, etc. which generally fill the cavities and veins in original rock also occur in the area. The traps are essentially a basic rock of basaltic composition and dark coloured or melanocratic.

As cooling and solidification of the lava form the basalts, they contain gas cavities and also joints, which are the contraction cracks developed during cooling of the lava. But all the basalt flows do not contain gas cavities and joints and therefore on the basis of presence or absence of gas cavities, basalt flows are grouped into two categories:

i) Massive/compact basalt (aa type).

ii) Vesicular amygdaloidal basalt (Pahoehoe type).

These two types of basalt flows have distinct field characters, which are described below:

i) Field characters of compact basalt (aa) flow:

Compact basalt flows are thick and extensive having tabular form (Fig. 2). In compact basalt flows there is variation in the field characters from its top to bottom.

The top surface of compact basalt flow is rather undulating. Top of the flow up to some thickness is hydrothermally altered, purple or greenish coloured and vesicular-amygdaloidal. The middle and lower portions of compact basalt flows are free from vesicles and amygdules and they occur in true senses as compact basalt. Joints, which are contraction cracks developed during cooling and solidification of the lava, always occur in middle and lower portions of the flow. There is variation in the pattern of jointing and joint spacing. In the present study area two flows of compact basalt are exposed (Fig. 2).

ii) Field characters of vesicular amygdaloidal basalt (compound Pahoehoe) flows:

These flows are formed by the outpouring of comparatively viscous lava in small quantities through a large number of outlets (Babar 2005 and Kulkarni et al, 1980). Therefore, amygdaloidal basalt flows have small sizes having irregular forms and limited lateral extent (Fig. 2). The vesicles are filled with secondary minerals like zeolites, calcite, silica, chlorophaeite etc. The veins and cavities of quarts occurring as geodes are also found in the area. There are two basalt flows of vesicular-amygdaloidal in the area along Purna river (Fig. 2). The flows vary in average thickness about 3-4 m. The top surface of this lava flow is marked with the ropy lava structure (Fig. 3A) and the bottom is indicated by the presence of pipe-amygdules (Fig. 3B).

Fig. 2. Four Basalt flows exposed along the left bank of the Purna river

GEOLOGICAL STRUCTURES

Geological structures in the present study include the ropy lava structures, pipe amygdales, vesicular cylinders, dykes, volcanic breccias, columnar jointing as found in the Deccan Traps. These structures are explained below:

i) Ropy Lava Structures

'Pahoehoe Lava' is one of the most abundant lava flows in DVP. The characteristic feature of such lava flows is that, it is very smooth or it shows 'ropy surface' on the top surface after cooling of the lava flows. These lava flows are very thin and their thickness varies from few inches to few feet (Kaplay et al. 2017). Ropy lava is marked with wrinkles which look like rope. The flowing lava twists like the making of a rope. This structure is well exposed in the Incha village along Purna river (Fig. 3A)

ii) Pipe vesicle-Amygdaloidal Structure

Pipe vesicles are formed at the base of the basaltic flow. These are the places in the outpoured lava flows through which the gases from the lower part of the flow might have tried to escape out and formed the cylindrical pipes sometimes appeared as inverted Y shape. A flow near Vishnupuri Dam shows such pipe-vesicles at the base of the basaltic flow (Kaplay et al 2017). A very thin 'Red Tachylitic basalt' flow is exposed just underneath this pipe-vesicle flow. In the study area along the Purna river also the bottom of the Pahoehoe flow is indicated by the presence of pipe vesicle-amygdules (Fig. 3B).

Fig. 3 (A)Exposure of ropy lava structure indicating the top of lava flow (B) Pipe vesicles and amygdales indication of base of lava flow

iii) Bending of the pahoehoe flows

The Amygdaloidal basalt flow observed at left bank of the Purna rive (15 km south of Lonar lake) shows the bending of the vesicular amygdaloidal basalt like a fold (Fig. 4A). This may be due to the fact that the pahoehoe flows are outpoured as thin irregular flows and deposited over the earlier elevated part of flow.

iv) Vesicular Cylinder

The vesicle cylinders are vertical pipes filled with bubbles and residual melt (Fraser, 1996). Basaltic lava produces a variety of tubes, vein-lets, and pods that evolve in-situ from the parent magma by fractional crystallisation (Bowen 1928; Anderson and Gottfried 1971; Anderson, et al. 1984; Hon, et al. 1994). At first the description of vesicle cylinders in the Warner Basalt of north-eastern California was carried out by Kuno (1965). The vesicle cylinders are also found in the Precambrian Keweenawan plateau basalts of Michigan and the Coumbia River Basalt of Washington (Cornwell, 1951). They are found in alkali and tholeiitic basalts of Miocene to Quaternary age in Arizona and New Mexico (Hiza, 1988). The vesicle cylinders are also reported from Chile (Renaud Merle, et al. 2005). The vesicle cylinders and sheets are reported for the first time from Nanded (Ratneswari Hill) (Kaplay et al. 2017) which is covered by South East Deccan Volcanic Province.

The Lonar lake inside the crater also show the typical vesicular cylinder structure occurring in the basalt block (Fig. 4B) used for the construction of the temple in the Lonar lake bed (found as fallen ruined block).

Fig. 4 A) Amygdaloidal basalt flow showing the bending like fold at left bank of Purna river, B) the vesicular cylinder occurring in the basalt block used for the construction of the temple in the Lonar lake bed.

v) Volcanic Breccia

Approximately 4 km south of Lonar lake at Deulgaon Kundpal village there is a exposure of Volcanic breccias showing the red tachylitic basalt flow mixed with the fragments of vecicula-amygdaloidal basalt (Fig. 5A) volcanic breccia with fragments of amygdaloidal basalt. In Fig. 5B there is occurrence of volcanic breccia with fragments of compact basalt. The bigger boulders of angular to elongated fragments of compact/massive basalt are clearly visible (Fig. 5B). Similar types of basalts have been also found in the Lonar crater (Maloof et al. 2010). The volcanic breccias are the xenolith fragments caught up in some lava such as fragments of basalt in red or green tachylitic basalt matrix, vesicular basalt fragments in massive basalt, and massive basalt fragments in vesicular basalt flows A xenolith is a Greek word, which means 'foreign rock'. It is a rock fragment which is enveloped in a larger rock during the latter's development and hardening. The term *xenolith* is used to describe inclusions in igneous rock during magma emplacement and eruption. Xenoliths may be engulfed along the margins of a magma chamber, torn loose from the walls of an erupting lava conduit. A xenocryst is an individual foreign crystal included within an igneous body. There are many examples of xenolith. Xenoliths provide valuable information about the interior of the earth which is not accessible.

Fig. 5. Exposure of Volcanic breccias near Lonar lake (A) volcanic breccia with fragments of amygdaloidal basalt embedded in red bole (tachylitic) lava matrix (B) volcanic breccia with fragments of compact basalt embedded in red bole (tachylitic) matrix.

vi) Dykes

The discordant igneous intrusion cutting across the country rock, which is a wall like intrusion is known as a dyke. In the area near Lonar lake along the Purna river in Jalna district there are total 17 dykes visible shown in Fig. 6 and location details are represented in Table 1.

Table 1. Details of location and trend of the dykes found along the Purna river near Lonar lake.

Dyke No.	Dyke View	Location	Dyke Trend	Length (m)	Varying Thickness (cm)
1.	Horizontal	Lat. - 19°54'9" Long. - 76°29'3"	NW 286°	5	3.5-61.5
2.	Horizontal	Lat. - 19°54'9" Long. - 76°29'3"	NW 345°	3	33-59
3.	Horizontal	Lat. - 19°54'9" Long. - 76°29'3"	NW 290°	4.2	32-86
4.	Horizontal	Lat. - 19°54'9" Long. - 76°29'3"	NW 329°	1.2	7.2-23
5.	Horizontal	Lat. - 19°54'9" Long. - 76°29'3"	NW 31°	2.5	25-49

6.	Horizontal	Lat. - 19°54'9" Long. - 76°29'3"	N 8°	2.8	16-75
7.	Horizontal	Lat. - 19°54'9" Long. - 76°29'3"	NE 69°	3	30-63
8.	Horizontal	Lat. - 19°54'9" Long. - 76°29'3"	E 83°	2.5	32-57
9.	Horizontal	Lat. - 19°54'9" Long. - 76°29'3"	S 196°	2	10-69
10.	Horizontal	Lat. - 19°54'9" Long. - 76°29'3"	N 9°	1.7	13-82
11.	Horizontal	Lat. - 19°54'1" Long. - 76°27'9"	NE 62°	3	7-27
12.	Inclined	Lat. - 19°54'1" Long. - 76°27'9"	NE 53°	1.3	14-19
13.	Horizontal	Lat. - 19°54'1" Long. - 76°27'9"	NE 24°	1.5	18-27
14.	Horizontal	Lat. - 19°54'1" Long. - 76°27'9"	E 107°	3	14-18
15.	Horizontal	Lat. - 19°54'1" Long. - 76°27'9"	NE 75°	3.3	9-34
16.	Vertical	Lat. - 19°54'1" Long. - 76°27'9"	E 82°	4	7-20
17.	Vertical	Lat. - 19°54'1" Long. - 76°27'9"	NE 37°	2	28-33

Deccan volcanism, representing a tremendous outburst of volcanic activity, marks an important episode in Indian Geological History. The Deccan Trap lava pile is thickest in the western part of the province reaching an exposed thickness of 1.7 km in parts of Western Ghats. During the detailed field studies along Purna river Jalna district, we come across the small scale dykes occurred in Deccan Traps. The field evidences of presence of dykes in study area are reported here (Table 1). These small dykes are varying in thickness. The maximum length of the dyke is 498 cm and minimum length is 120 cm.

During the field study the dykes (Fig. 6 A to F) are observed at Garteki, Jambhrun and Incha villages. Identification of rock type of the dyke, strike direction, thickness and length of the dyke were measured. Most characteristic feature of the dyke is the development of definite horizontal pattern of jointing in them. Due to this features, dykes can be easily recognized in the field from the enclosing host rock basalts. The dykes in Fig. 6 A and B shows the presence of quartz veins in the middle part. The dykes A, C are vertical, B and E are horizontal and D and F are inclined (Fig. 6).

Fig. 6 Exposures of dykes along the Purna river about 15 km due SW of Lonar lake (A) Vertical dyke Incha village (B) Horizontal dyke at Incha (C) Vertical dyke Incha village (D) Inclined dyke trending (Jambhrun) (E) Horizontal dyke at Garteki (F) Inclined dyke trending (Garteki)

vii) Columnar Jointing

Joints are the fractures in rocks, and columnar joints are a specific type of joint pattern. Columnar joints are defined as parallel, prismatic columns in basaltic flows and sometimes other rocks, and this specific pattern is a result of cooling and contraction (Bates et al., 1984). This type of jointing is typical of thick lava flows and shallow dikes and sills (McPhie, et al. 1993). The columns are also found in shallow intrusive or extrusive igneous rock bodies. They are often oriented perpendicular to either the upper surface and base of lava flows and the contact of the tabular igneous bodies with the surrounding rock.

These joints split a rock body into long, prisms or columns. Typically, such columns are hexagonal, although 3-, 4-, and 5- sided columns are relatively common (Fig. 7). The diameter of these prismatic columns ranges from a few centimetres to several metres. The columns with varying sides and size are found in and around Nanded region (Kplay et al. 2017).

During the field study, the columnar joints in basalt in the river bed are visible. The columnar joints are tetragonal, pentagonal to hexagonal in shape (Fig. 7). At Incha, Garteki and Wazar Sarkate villages, these structures are seen (Fig. 7).

Fig.7. Tetragonal, pentagonal and hexagonal sets of columnar joints observed along the Purna river (A) plan view of columnar joints at Incha (B) plan view of columnar joints at Garteki (C) vertical side view of columnar joints at Wazar.

III. CONCLUSION

The rock types found in the area in Jalna district belongs to DBP and consist of nearly horizontal basaltic lava flows. The types of basaltic lava flows occurring in the area are compact basalt ('aa' type), vesicular-amygdaloidal (pahoehoe type) basalt flows. The geological structures identified are dykes, volcanic breccias, vesicular cylinders, pipe amygdales, and columnar jointing. The top of 'pahoehoe type' basalt flow is indicated by the ropy lava structure and bottom is indicated by the presence of pipe-vesicles or pipe amygdules. The bending of the pahoehoe flows, presence of vesicular cylinders and volcanic breccias are also the other structures found in the present area. Total 17 number of small extent dykes are recorded in the present study, out of these 14 dykes are horizontal, 02 dykes are vertical and one dyke is found to be inclined. The columnar jointing besides other regular jointing patterns is found in the locality. Overall, it is a matter of study whether the area is affected due to the Lonar impact crater or not for which detailed Quaternary and neotectonic studies are essential to be carried out.

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