Hydrogeological characteristics of Deccan trap formations of India

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Abstract The Deccan traps occupy an area of about 500 000 km^2 in central parts of India. They are of late Cretaceous to early Eocene in age. The thickness of traps is about 2000 m in the western part of India while towards east the thickness is only 50 to 10 m. The average annual rainfall in the area varies from 400 cm in the west to about 30 cm in the central parts of Deccan trap country. The Deccan trap consist of as many as 32 lava flow units. The main aquifer horizons are in vesicular, fractured and weathered basalts. The inter-trap formations also form aquifer horizons at places. In recent years, extensive groundwater development has been made by putting large number of dug wells dug-cum-bore and borewells. The transmissivity T, is found to vary from 1 $m^2 day^{-1}$ to about 500 $m^2 day^{-1}$. Specific capacity and specific capacity index values are useful in determining productivity of different flow units. Well yield depends mainly on the intensity of fracturing rather the age of the basalts.

INTRODUCTION

The Deccan traps occupy an area of about 500 000 km^2 in central, western and southern part of India. Deccan traps form flat topped ridges which are due to the presence of more resistant basaltic flow units forming a series of step-like terraces.

The isohyets in the western portion are parallel to the western coast (Ghats). The rainfall decreases from west towards central Maharashtra. In the western districts of Maharashtra, the average annual rainfall is about 400 cm. The rain shadow area having lowest rainfall (70 cm) is about 150 to 200 km east of Bombay.

GEOLOGY

The traps have been divided into three groups — Upper, Middle and Lower. The Lower traps are about 150 m thick. They occupy the eastern areas. The Middle traps which are about 1200 m thick occur in central India while Upper traps are of about 450 m thickness in the western part of the area. Therefore, the older flows are towards east while the younger flows are in the west. The maximum thickness of the traps is near Bombay coast where it is estimated to be about 2000 m. The thickness is less towards east where it is not more than 150 m.

The Deccan traps consist of a number of flows separated from each other at some places by inter-trap ash beds and ancient buried soils (red bole). The individual flows vary in thickness from less than 1 m to 35 m, the average thickness of the individual flow unit is 15 m. The individual flows have a greater areal extent. Some of the flows have been traced for distances more than 100 km. The flows are generally horizontal to subhorizontal.

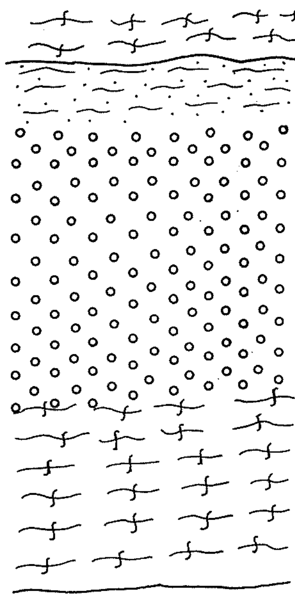

Fig. 1 Schematic vertical section across a flow unit in Deccan traps.

The predominant rock type is basalt which is usually of tholeiitic composition although rocks with alkaline affinities have been reported from the western areas. At places the flows are traversed by a system of dykes which are also significant from the point of view of groundwater occurrence.

The basalt forming the various flows varies in colour from dark grey to purple and pink. Some of the flow units are massive which are fractured to varying extent. Both sheet joints and vertical joints are seen. At places the rocks show vesicular character which are generally filled with secondary minerals like zeolites, carbonate minerals and secondary silica i.e. agate etc. giving rise to amygdaloidal character. Pipe amygdales are also observed. The lower part of a flow unit is usually of massive character which passes upwards into a vesicular or amygdaloidal (zeolitic) horizon. Vesicles and amygdales increase towards the top of a flow unit which in turn merges into a red bole, at some places. The red bole is overlain by the massive horizon of the next younger flow unit (Fig. 1).

The red bole which generally occurs in the upper part of pink zeolitic basalt varies in thickness from few cm. to about 1 m. At places it also occurs as stringers or veins within basalt. The origin of red bole is controversial. In all probability, it is a product of atmospheric weathering representing the ancient soil profile which was later buried under the next younger flow. This might have also caused the baking of the underlying soil to some extent due to which typical columnar jointing is developed in red bole in some sections. Hydrothermal alterations might have also been responsible to a limited extent for the formation of red bole. As the permeability of red bole is poor, it usually forms confining layers. At places where it has joints, it forms moderate to good aquifers.

HYDROGEOLOGICAL CHARACTERISTICS

Deccan trap like other basaltic flows, has its distinctive hydrogeological characteristics. Primary porosity is due to the presence of vesicles, flow contacts and lava tubes. Secondary porosity is developed due to jointing and weathering. The various flow units have also been weathered to varying extent giving rise to murum, a lateritic type of soil which represents a potential aquifer horizon tapped by dug wells.

Vesicles in most of the cases are filled with secondary minerals thereby reducing the porosity and permeability. Pink zeolitic basalt is a better aquifer than the grey basalt as the latter is generally of massive character. The pink and purple coloured basalts also show greater intensity of weathering. Flow contacts (interflow spaces) in between two successive flows are often a better source of water supply. Groundwater flow through these intervening spaces represents flow through tortuous conduits.

As mentioned above, the red bole which is usually found on the top of the pink zeolitic basalt, generally serves as a confining layer and the underlying pink zeolitic basalt forms a confined aquifer. It is interesting to note that unlike other hard rocks viz. granites etc., Deccan traps behave as a multiaquifer system, somewhat similar to a sedimentary rock sequence. One can find a potential water bearing horizon (vesicular, amygdaloidal, jointed or weathered basalt), sandwiched between comparatively massive basaltic flows, the former behaves as confined aquifer and the latter as aquifuge or aquitard. As a result of this, it is commonly observed that groundwater in such aquifers is under confined conditions but the piezometric surface is usually below the ground surface.

Unlike the geologically younger basalts of Hawaiian islands and Columbia Snake River area in USA, the Deccan traps of India are comparatively older in age, and less permeable (Table 1). This is due to the fact that the primary porosity in Deccan traps is much less and also because the vesicles are filled with secondary minerals.

Like other hard rock formations the determination of aquifer properties from pumping tests in volcanic rocks is problematical. However, attempts have been made by various workers to determine aquifer properties by using conventional methods of pumping test data analysis.

Walton & Stewart (1961) used the Theis method for determining aquifer parameters from pumping tests in the Snake River basalts of USA. The data curve did not match fully with the Theis type curve on account of the effect of delayed drainage and boundary conditions. T was found in the range 840 to 1080 $m^2 day^{-1}$ and S was computed to be about 0.02. Fernandopulle (1974) and Custodio (1985) have given the results of pumping tests on basaltic aquifers from the Canary Islands, Spain (Table 1). The time–drawdown data indicated effects of well storage and boundary condition of both recharging and discharging type. Leaky aquifer and double-porosity models are also used to estimate aquifer properties (Singhal & Singhal, 1989).

In Deccan traps, the transmissivity is found to vary with wide limits depending on the aquifer type. Deolankar (1981) has concluded that the transmissivity of weathered basalts, vesicular basalts and fractured basalts of the Deccan trap area range from 90 to 200 $m^2 day^{-1}$, 50 to 100 $m^2 day^{-1}$ and 20 to 40 $m^2 day^{-1}$ respectively. The specific capacity of large diameter dug wells (average 5 to 10 m diameter)

Table 1 A comparison of aquifer characteristics of Deccan traps with some other volcanic rocks.

Country	Place/area	Formation	Age	T (m^2 day^{-1})
El Salvador	San Salvador	Lava flows	Pleistocene	1000-15 000 (average 10 000)
		Pyroclastics		100
Nicaragua	Pacific coastal region	Pyroclastics	Quaternary	120-3500 (average 1200)
Afghanistan	Upper Truck Valley	Reworked tuffs		71
	Abe Istaba Nahara basins	Reworked tuffs	Pleistocene	250-1000
Spain	Gran Canaria	Old basalts	Miocene	5-28
		Modern basalts	Post-Miocene	40-200
India	Karnataka	Deccan trap	Early Eocene	10-180
	Andhra Pradesh			1-198
	Maharashtra			0.1 to 500
USA	Snake River	Basalt		1×10^3
				1.8×10^5
				(average 1×10^4)
	Oahu, Hawaii	Tholeiitic	Pliocene	15 000 (in dyke free zone)
		Basalt		1500 in the marginal dyke zone
Mexico		Fissured basalt	Pleistocene to Holocene	605-865

10^{-3} to 3×10^{-3} m^2 s^{-1} and 3×10^{-4} to 1×10^{-3} m^2 s^{-1}.

Specific capacity of well has been used widely to estimate the transmissivity of hard rock aquifers (Huntley *et al.*, 1992). Adyalkar & Mani (1972) used specific capacity data to compute transmissivity of Deccan trap aquifers. Computed specific capacity of wells in Deccan trap formations of central India are in the range of 5×10^{-4} to 2×10^{-3} m^2 s^{-1}.

Singhal (1973, 1974) suggested that in large diameter dugwells in basalts and other hard rock formations, the specific capacity values may be divided by the total surface area of the aquifer ($2c\,rh$) tapped by the well where r is the radius of the dug well and h is the saturated thickness of the aquifer tapped by the well. Such a property will give a better idea of the yield characteristics of different rock types in hard rocks as it would take into consideration the variation in well diameter and also its depth.

Davis (1974) showed that well productivity (specific capacity index divided by the saturated thickness of the aquifer) in Deccan traps is much less than that of basalts of the Washington area in the USA (Fig. 2). This is attributed to low permeability of Deccan traps which is of older age as compared with the basalts from the Washington area in the USA.

WELL YIELDS

The common type of wells are dug wells, dug-cum-bore wells and borewells. The dug-cum-bore wells are more successful as they tap the deeper aquifers also and therefore can be a source of assured water supply in drought periods. The yield of

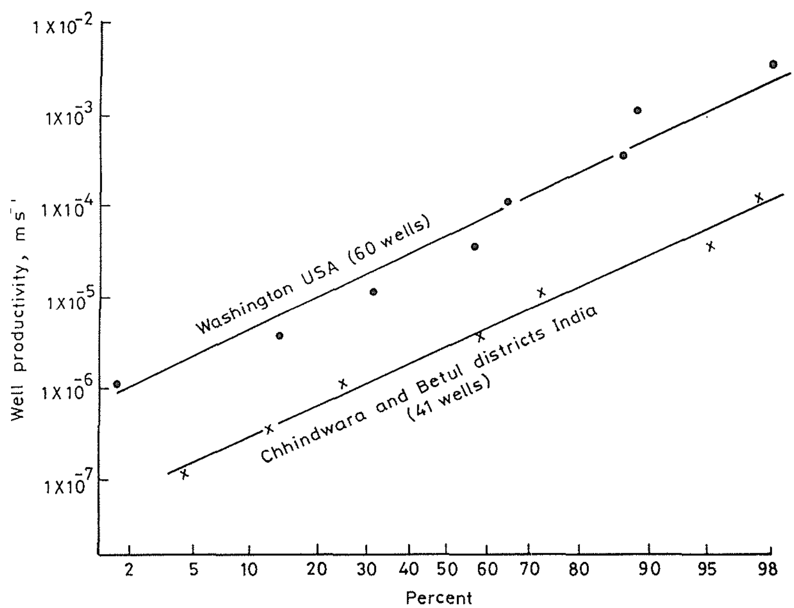

Fig. 2 Log-probability plot of well productivity (specific capacities of well divided by thickness of saturated basalts) penetrated by the wells (after Davis, 1974).

such wells is about 45 $m^3 h^{-1}$ for a drawdown of 3 to 5 m.

Borewells have been constructed in large number in recent years mainly as a source of drinking water supply in rural areas. These are of 10.0 to 15 cm in diameter and 40 to 80 m in depth drilled by down-the-hole hammer rigs. The yield of such wells usually varies from 5 to 10 $m^3 h^{-1}$ but in exceptional cases very high yields have also been reported. Wells drilled on lineaments are reported to have high yield of the order of 0.02 $m^3 s^{-1}$ (Kittu, 1990). Gupta (1991) has also reported a high yielding 45 m deep well having a discharge of 0.02 $m^3 s^{-1}$ from weathered basalt. The well was drilled upto a depth of 45 m, which was fitted with a 10 h.p. submersible pump which is being operated continuously for 24 h.

Geophysical investigation, lithological mapping of different flow units, fracture trace and lineament mapping have helped considerably in the success of water well drilling in Deccan traps.

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