IRS-1A AND LANDSAT DATA IN MAPPING DECCAN TRAP FLOWS AROUND PUNE, INDIA : IMPLICATIONS ON HYDROGEOLOGICAL MODELLING

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ABSTRACT

Hardcopy multispectral data from IRS-1A and LANDSAT were used in conjunction with aerial photographs and field verification for mapping the Deccan Trap basaltic lava flows in the region around Pune. This region, a part of the Deccan Trap Volcanic Terrain of Western India, is perpetually drought-prone and the groundwater from the basaltic aquifers is the prime source of water during summer.

The IRS-1A and LANDSAT data not only allow the extrapolation of individual basaltic flows across tens of kilometres, but also brings out their irregular geometry. The amygdaloidal and compact nature of the bedrock can be interpreted from the FCCs. The extension of regional fracture zones can be traced as lineaments. These and other related factors have a direct influence on the groundwater potential of the basalts.

It is therefore concluded that the IRS-1A and LANDSAT multispectral data are extremely useful tools for rapid extrapolations and efficient targetting of groundwater resources in the Deccan Trap basaltic terrain around Pune.

KEY WORDS : Multispectral data; Deccan Trap basaltic flows; Mapping; Groundwater exploration and modelling.

INTRODUCTION

The major asset of remote sensing, namely its, capability of rapid and accurate areal coverage, becomes crucial during the groundwater exploration in water-scarce regions. Unfortunately its populist publicity has raised expectations of this tool far beyond its real capability, often ending up in criticism that it fails to satisfy these (hyperinflated) expectations. The experience of groundwater exploration in the Deccan Trap basaltic terrain of Western India could be cited as a typical example of this problem.

Several strategies such as "soil moisture estimation using MSS data", "lineament intersection loci contouring" and so on were proposed for exploring groundwater in this pile of basaltic flows. Not that any of these strategies were complete failures, rather they did succeed in their test sites. However, their extrapolations to adjoining sectors often proved disastrous. The failure lay, not with the remotely sensed data, but with its handling without appreciating the vagaries of the Deccan Trap basaltic aquifer systems and without making due allowances for the complexities of these basaltic flows themselves. An appropriate understanding of such factors would allow a more efficient use of the remotely sensed data in exploration of the groundwater resource.

DECCAN TRAPS OF WESTERN INDIA

The Deccan Trap Volcanic Province of Western India (Fig. 1) occupies more than 500,000 sq.km. in a tropical - subtropical region. This stack of subhorizontal basaltic flows with an estimated thickness of over 1500 m, which erupted around 65 $\pm$ 10 million years ago, has been classified on the basis of chemical composition and petrological variations, into 12 Formations (Subbarao, 1988). The constituent flows, primarily of basalts, with thicknesses varying from less than a metre to almost 100 m individually, are presumed to have a flat, tabular geometry and have been traced to extend across long distances (Mitchell and Cox, 1988). In the field, they are classified into "simple flows and compound flows" or as "compact basalts and amygdaloidal/vesicular basalts" or as the analogs of the Hawaiian "aa-type and pahoehoe-type flows". These field classifications are besides the petrological and chemical classifications of the Deccan Trap flows.

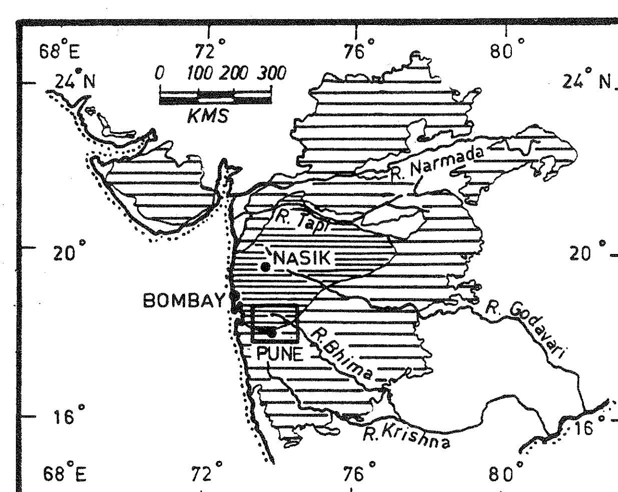


FIG.1 : The Deccan Trap volcanic province of western India. The close spaced shading is the sector of dominant compound flows, while simple flows dominate in the wide spaced shaded region (after Deshmukh, 1988). The three major zones of known post-Trappean structural disturbances, characterised by proliferation of fracture zones and dykes are the ENE-WSW trending Narmada Son Structure (along the Narmada river valley), the NW-SE Kurduwadi Lineament (along which the Bhima river valley is aligned) and the roughly N-S trending Konkan Coastal Belt (along the western edge of this province). [adapted from Kale,et al.,1992]. The rectangle marks the study area.

A DECCAN TRAP FLOW

In any independent flow of the Deccan Trap Volcanic Province, normally three subunits can be discerned (Fig. 2), namely :

a) Pipe amygdaloidal base : Characterised by tubular amygdales with irregular vesicles, often glassy in composition, and transected by weak, subhorizontal sheet joints at times. The tubular amygdales often coalesce giving an 'inverted-Y' geometry.

b) Compact middle part : generally free of vesicles, amygdales and sheetjoints. If present, columnar subvertical joints or fracture zones cut across this sector.

c) Sheetjointed, amygdaloidal top : Characterised by spheroidal amygdales and unfilled vesicles, upward enrichment in pyroclastic material and a network of subhorizontal sheetjoints; and capped by either a scoriaceous / pyroclastic layer or by ropy, chilled surfaces.

The boundaries between these three sectors of a flow are always gradational. Their relative thicknesses vary from flow to flow. Some flows are devoid of the hard compact middle sector, so that the pipe amygdaloidal base appears to grade upward directly into the spheroid amygdale bearing, sheetjointed top. Such flows are recognised as (purely) amygdaloidal flows. In others, the amygdale/vesicle-bearing base and top may be insignificantly small (or even almost absent) in comparison to the compact sector, leading to their recognition as compact or massive flows. All variations between these two extremes exist in the Deccan Volcanic Province.

Successive flows may rest directly upon one another. Some are separated by fine grained, tuffaceous or scoriaceous or pyroclastic material having reddish or greenish brown colour. Such interflow horizons (previously termed loosely as red boles and green boles, depending upon their colour) are normally traversed by close spaced sheetjoints, making them very friable.

WEATHERING AND EROSION OF DECCAN TRAPS

The hot subtropical climate with seasonal rains has accentuated the chemical degradation of these basalts yielding lateritic and black-cotton soil profiles, within the framework of the subhorizontal disposition of the flows and the joint-fracture systems transecting them. In this terrain which was tectonically uplifted (Radhakrishna, 1991), swift and deep erosion along the jointed segments of the flows (with a network of subhorizontal sheetjoints and subvertical fracture zones) and along the dykes, alternates with the more resistant blocks of compact basalts. This has yielded a typical step-like topographic profile ("trappa"-ean [Swedish]) in the Deccan plateau (Fig. 3) flanked on the west by the Western Ghats Escarpment and further westward, by the Konkan Coastal Plains (Subramanyan, 1981; Kale and Rajguru, 1988). On a smaller scale, spheroidal weathering is common.

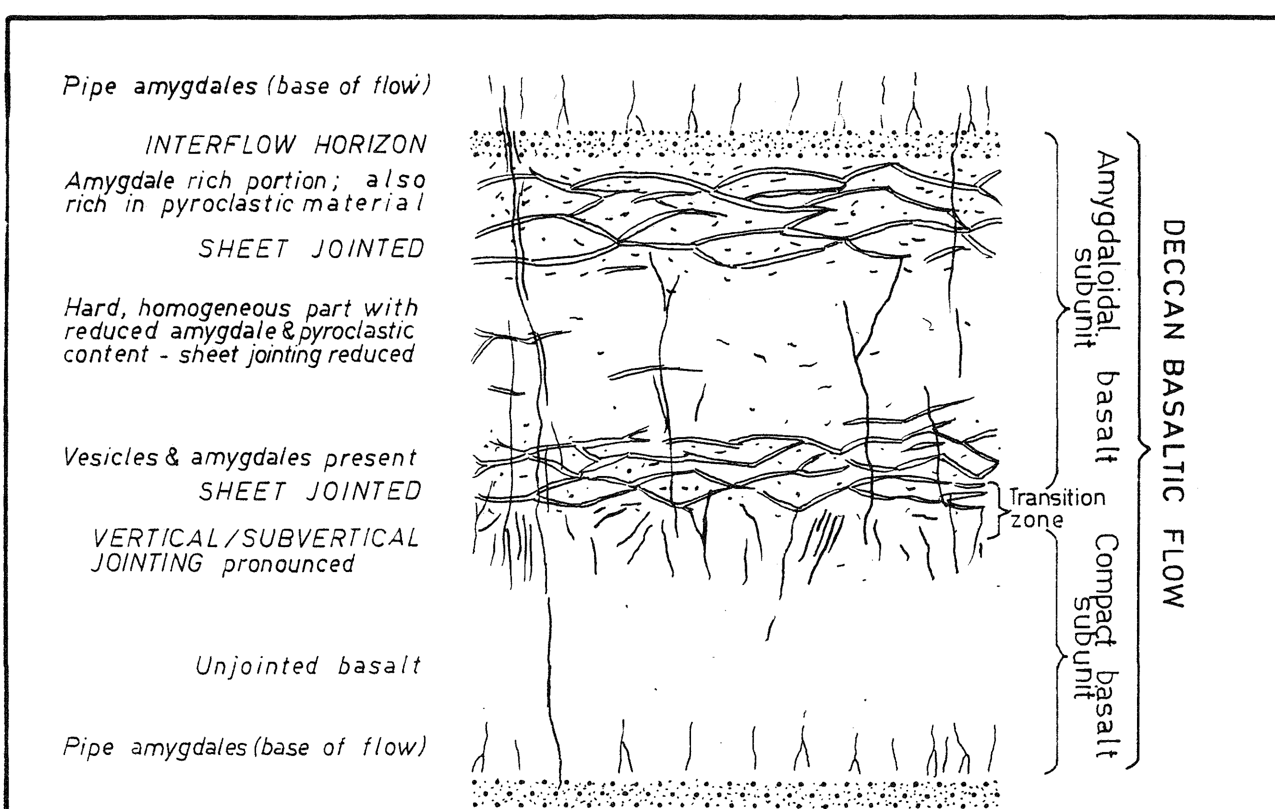


FIG. 2 : Schematic vertical section of a typical Deccan Trap basalt flow. The interflow horizons (wherever present) separate successive flows. The subdivisions of the flow described on the left of this sketch are based on petrological considerations. The subunits on the right are based on the hydrogeological characters (modified after Kulkarni, 1987; Kulkarni and Deolankar, 1990). The relative thicknesses of any of the subdivisions vary significantly from flow to flow.

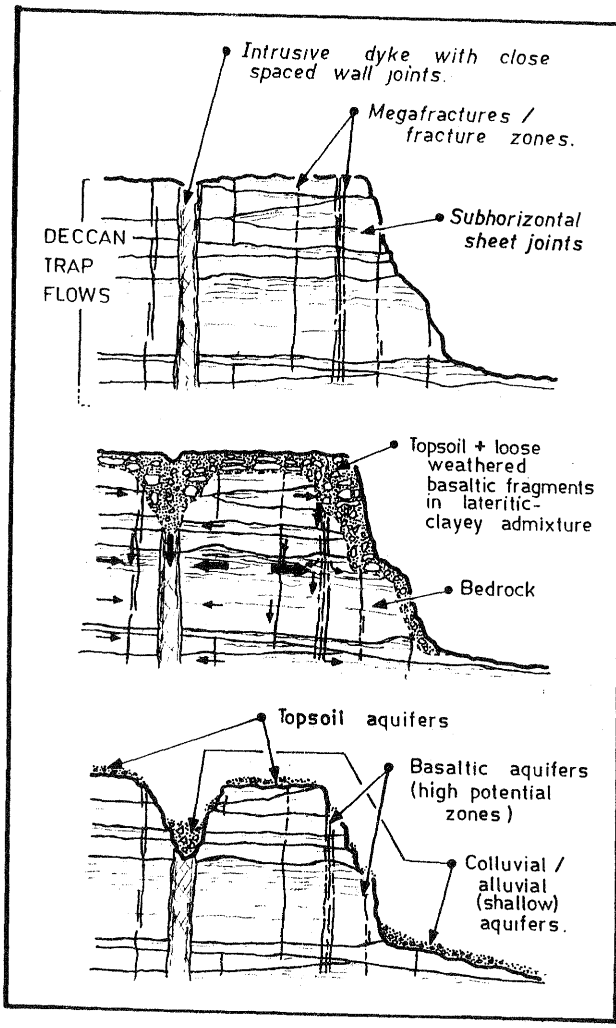


FIG.3 : Schematic sequence of the geomorphic evolution of a Deccan Trap flow pile (modified after Peshwa and Kale, 1988). Note the uneven and irregular nature of individual flows. Arrows in the middle profile represent the movement of water through these flows, and are depicted proportional to the transmissivity of the basaltic rock in the relevant direction.

The area covered in this study displays this geomorphic setup ideally. Steep, stepped-sided, flat topped hill ranges flank wide, shallow river valleys, with occasional, narrow ridges and valleys which are controlled by fracture zones or dykes (Peshwa and Mulay, 1983; Peshwa and Kale, 1988). The topsoil cover on the planation surfaces, as well as the river alluvium is generally very thin, and is laterally restricted in extent.

JOINTS IN DECCAN TRAPS

Subhorizontal and horizontal sheetjoints are ubiquitous in the Deccan Trap lava flows. They are normally restricted to the amygdaloidal (top and base) sectors of the flow and to the interflow horizons.

Vertical and inclined cooling joints are not prolific in these flows. They are restricted to individual flows only, and generally are unevenly spaced. Polygonal columnar joints are rare, and are observed in exceptional flows (where they have subvertical disposition) and in the intrusive dykes (where they develop perpendicular to the walls).

Regional tectonic fractures and fracture zones cutting across the Deccan Trap flows have discrete distribution in space and orientation and are manifested as closespaced joints, traversing through the flows in the pile. They are normally traceable across several kms, and can be discerned on the aerospace imageries as discrete lineaments (Powar, 1981; Peshwa and Mulay, 1983; Peshwa et al, 1987).

Inherently, the basaltic flows are impervious to water. It is this network of joints and fractures which provides the channels for deep seepage of the water from the surface.

HYDROGEOLOGY OF DECCAN TRAPS

The Konkan Coastal Plains and the region along the crest of the Western Ghats receives heavy monsoon rainfall (around 4000 mm/year) between June and December. The region east of the crest, on the Deccan plateau, falls in the rainshadow zone, and the annual precipitation is only about 500-800 mm/year, restricted to the monsoon season. The rugged topography along the Ghats induces rapid and high runoff and very small infiltration of the rain water. The result is that, the region around Pune suffers acute shortage of water during the dry season, peaking during the hot summer months of April and May, notwithstanding the many small and large artificial reservoirs. The only available water is from the subsurface. Aquifers in the topsoil and the colluvial/alluvial deposits have limited potential and tend to run dry during the summer months. They also have restricted spatial distribution. Consequently the bedrock groundwater system in the basaltic flows remains the only sustained source in this region (Deolankar, 1980).

The inherent igneous nature of the basalts ideally have very limited porespaces and therefore would be expected to have low permeability, transmissivity and storativity. Typical unjointed compact basalts do act as almost perfect aquicludes. However, the presence of vesicles and amygdales, cooling and sheetjoints and the fracture systems transecting these basaltic flows increase the effective porosity; and enhance their potential as aquifers. Table 1 gives the measured transmissivity and permeability of different sectors of a single basaltic flow from the Pabal area (after Kulkarni, 1987), demonstrating the magnitude of these enhancements.

TABLE 1

TRANSMISSIVITY (T) AND PERMEABILITY (k) OF THE CONSTITUENT SEGMENTS OF A BASALT FLOW FROM PABAL

SUBUNIT/SEGMENT TYPE	T m^2/day	k m/day
1) Homogeneous, unjointed compact basalt	6.00	0.04
2) Unjointed amygdaloidal basalt	12.89	0.19
3) Compact basalt along a fracture zone	15.00	1.00
4) Sheetjointed amygdaloidal basalt	79.64	15.17

These are only representative values, which prima facie show that the sheetjointed amygdaloidal basaltic rock would be the choicest candidate as an aquifer, in the Deccan Trap terrain. Its potential would obviously be enhanced, if it were to be cut by a fracture zone. This would suggest a relatively simple picture for the exploration strategy in this terrain. As depicted in Fig. 2, any basaltic flow has an amygdaloidal, sheetjointed top, underlain by the comparatively impervious compact sector. Thus, assuring a tabular, horizontal geometry of these flows would apparently allow easy mapping of the potential zones, by following the topographic contours; as was done by Kulkarni (1987) in Fig. 4. However, in reality, the Deccan Trap basaltic flows have a much more uneven and complex geometry. (See Fig. 3). The flows have uneven thicknesses, undulating tops and bases, and they tend to pinchout or swell laterally (Deshmukh, 1988; Kale et al, 1992). Variations in the joint/fracture patterns are pronounced even across short distances. These characters are the primary features responsible for the hydrogeological heterogeneities in the Deccan Traps, and contribute to the hinderances in the exploration of groundwater in this region.

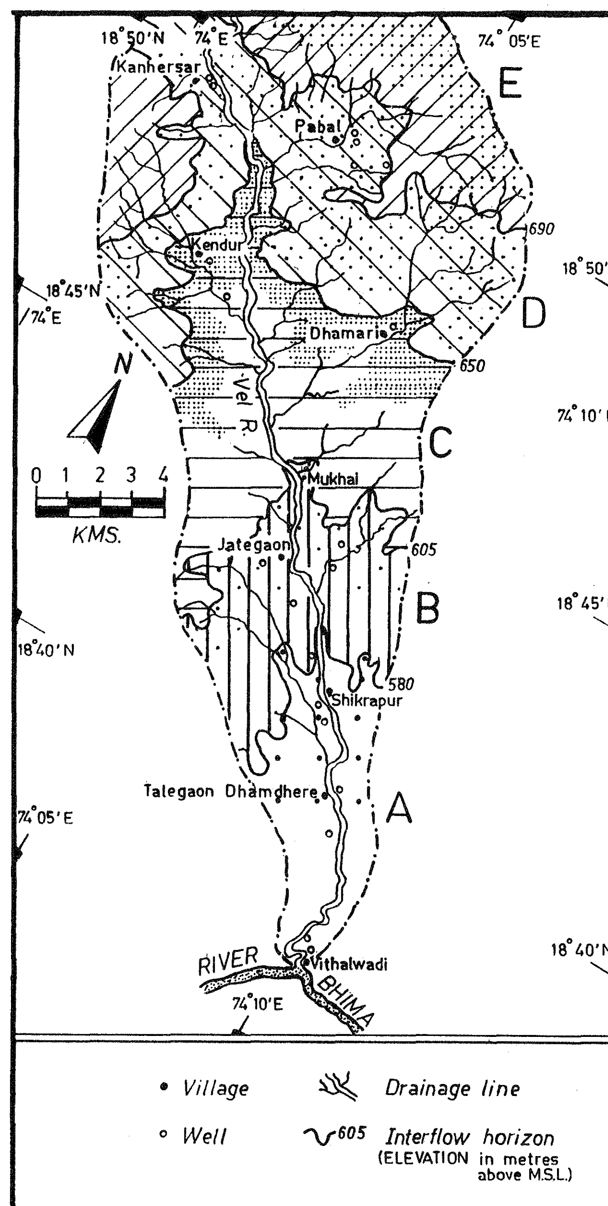
REMOTE SENSING

The Indian Remote Sensing Satellite (IRS-1A) collects data in four spectral bands, with two parallel systems; LISS-1 and LISS-2 having nominal resolutions of 72 m and 36 m respectively. LANDSAT TM data, with an IFOV of 30 m is available in 7 bands, besides the 4 band MSS data having a nominal resolution of 70 m. The aim in this study was to evaluate the efficacy of these data for mapping the Deccan Trap flows in the region around Pune. False colour composites of the TM bands 1 (450-520 nm), 2 (520-600 nm) and 4 (760-900 nm) and the LISS-2 bands 2 (520-590 nm), 3 (620-680 nm) and 4 (770-860 nm) proved to be the most effective in mapping the flows and their regional extrapolations in this study.

Amygdaloidal basalt supports a gentler slope with thicker soil cover than the compact variety, which is largely responsible for the step -like topography of the Deccan Traps. Therefore, the response level from the relatively flatter amygdaloidal sector of the flow yields higher grey level values, particularly in the visible wavelengths. However, these flat sectors support dry grass and shrub type vegetation; in response to the lack of water, which has a greater tendency of downward seepage from the flat surface. On the other hand, inspite of the thinner soil cover and steeper slopes, denser, chlorophyll-rich vegetal cover is supported by the compact sectors of the flow or it displays barren, barerock escarpments. Wherever the green vegetation is supported, the response levels in the near-infrared bands of these compact basalt subunits is higher than that of the amygdaloidal subunits.

Therefore, in the FCCs of LISS (234/BGR) as well as TM (124/BGR), the compact basalt subunits display a distinct reddish hue, overriding the other shades. The steeper slopes also tend to appear darker. Given the alternation of amygdaloidal and compact basalt subunits (of successive flows) in a pile of the Deccan Traps, almost concentric alternations of the reddish compact basalts and the greyish blue-green hue of the amygdaloidal basalts are observed in the FCCs. This allows easy and accurate mapping of the flow

FIG.4 : Basaltic flow map of the lower Vel river basin (modified after Kulkarni, 1987), highlighting the alternation of the amygdaloidal (stippled) and compact basalt subunits of the five flows A - E. This flow map is constructed on the basis of topographic contours, assuming a flat tabular geometry of the individual flows.



units from these FCCs, even by visual interpretation of the hardcopy. For limitations of space, we give here two examples of the flow maps so traced, one of the Lonavala area (around 40 km west of Pune) and the Rajgurunagar - Pabal area (about 30 km north of Pune), as Figs. 5A and 5B respectively. These have been prepared by tracing directly from the FCCs on an approximate scale of 1:100,000.

Most of the fracture zones and dykes appear as lineaments, of which only the most prominent ones are depicted in Fig. 5, to avoid cluttering. It is essential to recognise however that the fracture zones themselves do not yield groundwater, but rather are the subsurface channels, transmitting the infiltrated water to deeper buried flows (see Deolankar et al, 1980).

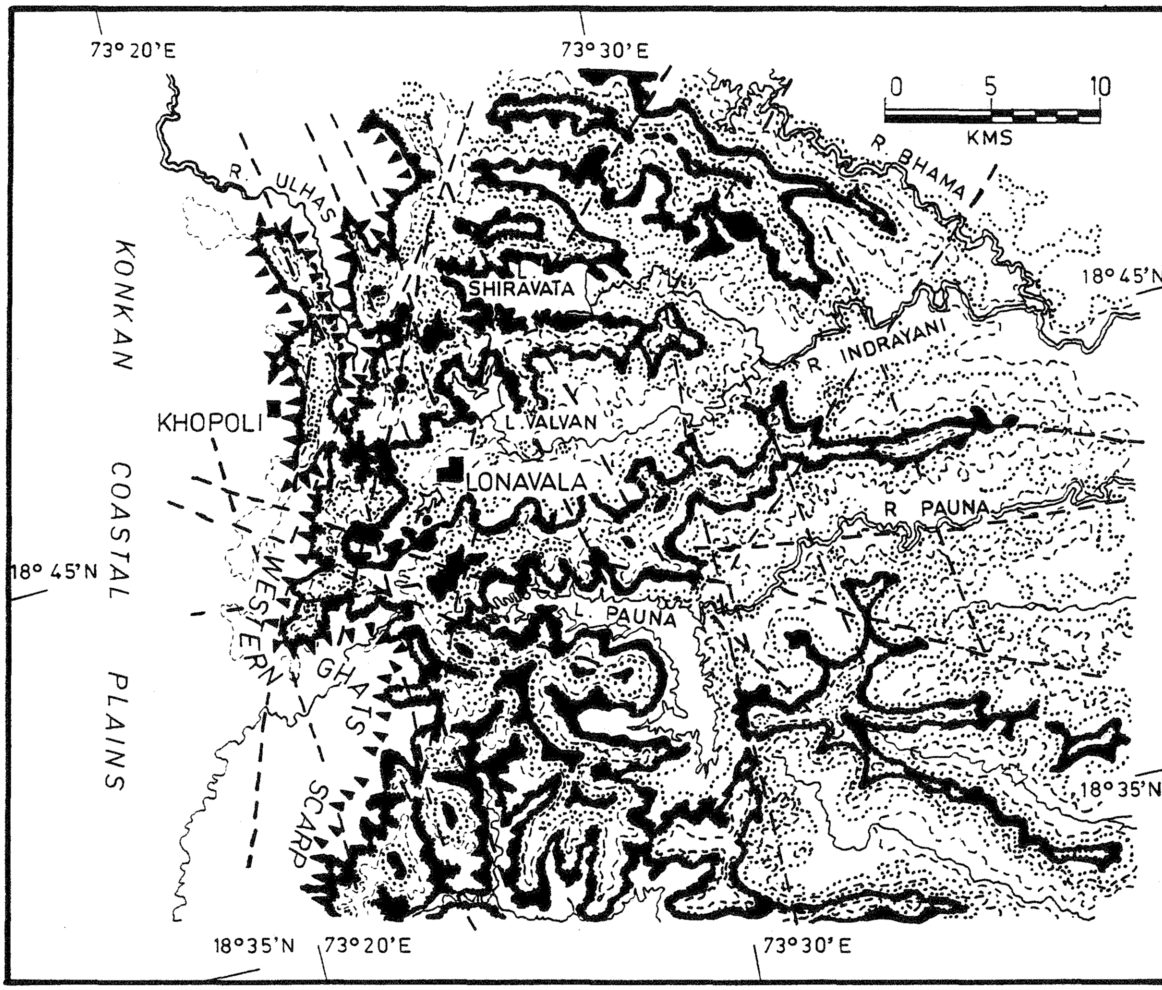


FIG.5(A) : Flow map of the Lonavala area (around 40 km west of Pune), based on visual interpretation of the hard copy False Colour composits of LISS-2 [Bands 2/3/4] and TM [Bands 1/2/4] data.

They are not the loci for groundwater accumulation. This is one of the primary reasons why strategies such as lineament-frequency contouring or lineament-intersection loci contour have failed in the Deccan Traps, for siting groundwater resources. The recognition of dykes and fracture zones from aerial photographs and LANDSAT MSS imageries as lineaments is recorded in numerous studies (eg. Powar, 1981; Peshwa et al, 1987). This is possible due to the fact that both these features display distinct, linear geomorphic expressions (either +ve or -ve reliefs). In the LISS and TM imageries, the same holds true as well, allowing their easy discrimination. However, as in the case of the other data, even in this study, it is realised that, whether a particular lineament in this terrain represents a dyke or a fracture zone cannot be predicted without either some apriori information or field verifications.

Sheetjoints, by themselves cannot be directly recognised from these FCCs. However the sheetjoints in the amygdaloidal basalts tend to be manifested as relatively flat topographic surfaces, either on the top of the hill ranges, or as flat-topped spurs and saddles or in the river-valley sectors. Such surfaces yield a smoother texture and valley distinctive bluish grey hue in the IRS-1A and TM FCCs used. They can therefore be mapped and traced across significant distances, from this data.

Thus, some of the more significant features of the Deccan Trap flows in the region around Pune, which have direct influence on their hydrogeology, are capable of being mapped using the IRS-1A and LANDSAT data. One of the most significant result of this exercise of mapping was that it is possible to demonstrate that the idealised, subhorizontal, flat tabular geometry of the Deccan Trap flows (eg : Cox and Mitchell, 1988; Subbarao, 1988) does not exist in reality at all. Individual flows tend to pinch out or thicken locally as well as laterally. The other aspect which also is obvious through this study is that, the alternation of the amygdaloidal (and generally sheetjointed) and compact basaltic subunits of a flow is primarily responsible for aiding their mappability from the remotely sensed data. It is to be noted that this alternation is to some extent also responsible for groundwater systems in the Deccan Trap basalts in the first place (Kulkarni, 1987).

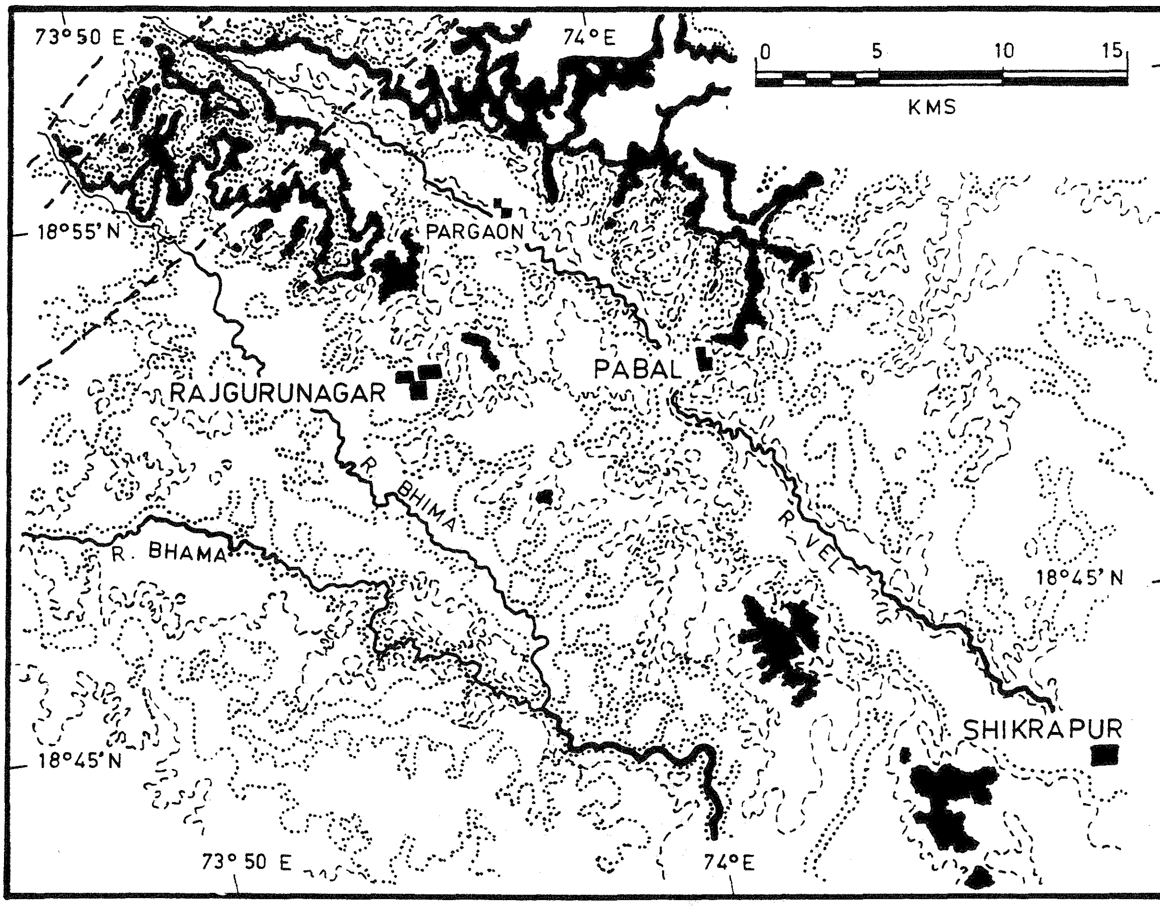


FIG.5(B) : Flow map of the Pabal - Rajgurunagar area (around 30 km north of Pune), based on the visual interpretation of the LISS-2 and TM data as in 5(A).

CONCLUSIONS

In terms of hydrogeological characters, the amygdaloidal basalts are best suited for groundwater accumulation, while the underlying subunit of compact basalts act almost like aquicludes. Reconciling this, within the framework of the petrological subdivisions of a flow, the modified hydrogeological subdivisions of a flow are depicted in Fig. 2. Kulkarni and Deolankar (1990) have shown that the "Transition Zone" between the compact basalt and the overlying amygdaloidal basalt, is in hydraulic continuity with the amygdaloidal subunit. The lower two petrological subdivisions of a flow (compact basalt and basal pipe amygdaloidal subunit) do not contribute to this hydrogeologic system, but rather act as barriers between the aquifers in successive flows, due to the impervious nature of the compact basalts. One of the consequences is that within any flow, horizontal permeability dominates over the vertical permeability, through the subhorizontal sheetjoints. The only conduits, through which significant vertical permeability is effected, are the fracture zones and megafractures which cut across several flows. Therefore the overlying flows in a fractured sequence tend to be drained of water while the accumulation is accentuated in the lower flows.

EXPLORATION GUIDES

From the hydrogeological point of view, in light of this modified version of the model hydrogeological system of the Deccan Trap basaltic flows, it is obvious that :

a) An alternating sequence of the amygdaloidal (higher potential) subunits and the compact (practically impervious) subunits is present in these flows. The amygdaloidal basalt subunits constitute the potential sites for groundwater accumulation and consequent exploitation.

b) Fracture zones and regional joints act as ducts for subsurface infiltration of water. They may not necessarily represent good foci for accumulation of groundwater.

c) The individual flows as well as their subunits display an uneven geometry, which hampers lateral extrapolation of the high potential aquifers.

Each of these features are mappable, using the IRS-1A and LANDSAT data, rapidly and accurately on a regional scale. These data therefore are efficient tools for groundwater exploration in the Deccan Trap basaltic terrain around Pune. This study, which used considerable apriori knowledge and was supplemented by field verifications also demonstrates that the remotely sensed data alone cannot provide the answers or loci for groundwater exploitation. It requires support data as well. It's efficacy lies in the rapid extrapolations over large areas and across long distances..

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