CHAPTER X

SUMMARY AND CONCLUSIONS.

In contrast to the Deccan Traps in parts of Western India, the flows around Sagar tend to be simple flows with large areal extent and low potassium content, and devoid of dykes. The objective of the present study is to generate a self-consistent model to account for the physical and chemical characteristics and distribution of Sagar flows, by delineating (i) the time and mode of their emplacement, (ii) the nature and chemistry of the parent magma, (iii) the environment of extrusion, etc. Basalts from some localities in Western India (15 samples), and the Karroo basalts of Lesotho, South Africa (6 samples) have also been studied to effect comparison with Sagar basalts.

In pursuance of the above objective, the author mapped an area of 250 km² around Sagar on a scale of 1:63,360, collected 150 samples and studied their petrography. Twelve flows and several impersistent intertrappean beds could be delineated in the area on the basis of morphology. At the request of Prof. W.D. West, the Geological Survey of India kindly drilled three bore-holes piercing all the flows overlying the Vindhyan and the Lametas. The author logged the cores which had an aggregate thickness of 190 metres, and identified ten
flows (composed of fine-grained tholeiitic basalts) and two inter-trappian beds (mostly limestones and cherts). Fifty thin sections have been made use of to study the petrography of the rocks and the optical characters of individual minerals. Modal analysis of the samples could not be attempted because of the fine-grained nature of the basalts. Fossil palms have been collected from the inter-trappian bed and one of them has been identified as Palmoxylon of Tertiary age (courtesy of the British Museum). Three samples covering the bottom, middle and top part of each flow, have been taken up for detailed study.

The principal thrust of the present study is in the area of geochemistry (including isotopic geochemistry which led to K-Ar age dating). The quantum of experimental work accomplished by the author while at Leeds, England, during 1974-76, could be adjudged from the following summary statement:

(i) 13 major element oxides in 60 samples by wet chemical methods and X-ray fluorescence spectroscopy (XRF).

(ii) 19 trace elements (Be, Ba, Cr, Co, Cu, Ga, La, Mo, Nb, Ni, Pb, Sn, Rb, Sr, V, Y, Yb, Zn & Zr) in 60 samples by XRF and emission spectroscopy.

(iii) Ten Rare Earth Elements (Ce, Nd, Eu, Gd, Tb, Tm, Yb and Lu by neutron activation and La, Sm
by XRF) in 21 samples of Dhanduka flows (Since REE data are available only for Dhanduka but not yet for Sagar, the REE data in respect of Dhanduka have been published separately - vide paper in the pouch, under publication in "Lithos").

(iv) Determination of Rb and Sr contents and the measurement of the isotopic composition of Sr, in 18 samples.

(v) Determination of K (flame-photometrically) and radiogenic argon - 40 (by mass-spectrometric isotope dilution), and computation of age, for 13 samples (6 samples from Sagar, 2 samples from Dhanduka, one sample each from Koyna, Dohad, Pavagadh, Pachmarhi and Saurashtra).

On the basis of the discontinuity in the chemical characters which coincides with the presence of intertrappean bed, the flow sequence in Sagar could be divided into two cycles with distinctive features, as indicated below:

<table>
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<tr>
<th>Flow 9 (54.1 m.y.)</th>
<th>Generally characterised by low $^{87}\text{Sr}/^{86}\text{Sr}$ ratio</th>
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<tr>
<td>(10.37 mts.)</td>
<td>(0.7045 to 0.7057); $\text{SiO}_2$</td>
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<tr>
<td>Cycle II</td>
<td>(24 mts.) and $\text{K}_2\text{O}$, and trace elements</td>
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Flow 6 (41.7 m.y.)
(17 mts.)
Flow X (12 mts.)

Ba, Rb, Pb, Nb, Cu, Zr & Zn increase, and CaO and MgO and trace elements Ni, Cr decrease, from flow X to 9, indicating magmatic differentiation (?).

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Inter-trappean bed (2)

Sample Z/20 in the flow has the lowest $^{87}\text{Sr}/^{86}\text{Sr}$ (0.7039), $\text{SiO}_2$ (43.1%), and $\text{K}_2\text{O}$ (0.23%), and is hence the most "primitive" (i.e. least evolved) among the Sagar flows.

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Inter-trappean bed (1)

Flow 4 (29 mts.)
Flow 3 (8 mts.)

Generally characterised by higher $^{87}\text{Sr}/^{86}\text{Sr}$ ratios (0.7052 to 0.7084) and negative correlation between the $\text{Sr}$ isotopic ratio and $\text{K}_2\text{O}$ and $\text{SiO}_2$ contents. The $\text{SiO}_2$ and $\text{K}_2\text{O}$ contents and trace
Flow 2 (50 m.y.) elements Rb and Ba decrease, from flow 1 to 4, indicating crystallisation from a magma that suffered crustal contamination (?)..

Though cycles I and II have contrasting trends, the internal geochemical variation within each cycle is smooth. Hence an attempt is made to calculate the average composition of the magma reservoirs in respect of cycles I and II, on the basis of the weighted averages (weighted by the thickness in metres of the flow concerned) of various elements.

Geochemical data (particularly SiO₂, K₂O and Rb contents) are indicative of a close resemblance between Sagar flows and abyssal tholeiites. The patent magma for Sagar flows may have been of low-K tholeiite composition, possibly derived by an almost total melting of upper mantle (hornblende-eclogite?).

The REE data on Dhandhuka flows are consistent with the models of West (1958) and Krishnamurthy (1974) involving a picritic parent magma derived from the partial melting of an upper mantle of garnet peridotite composition. The absence of Eu anomaly, however, suggests that plagioclase was not a major residual phase in the mantle and that the
removal of plagioclase by low pressure crystallisation was not a significant factor in producing the observed chemical variation in the Dhandhuka bore-hole suite.

The K-Ar ages in respect of flows 1 to 6 accord well with stratigraphic sequence of the flows. The ages of the flows 9 and 8 are aberrant in that they are in conflict with stratigraphy. Such erratic ages may arise from factors such as:

(i) The nature of distribution of potassium in the lattices of the minerals composing the basalt and their susceptibility to loss or gain of K,

(ii) Entrapment of excess argon at the time of crystallisation of the rock,

(iii) Loss of argon due to weathering.

That there is an younger episode of volcanism 50-45 m.y. B.P. in the N.E. part of the Deccan Traps is evident from the concordance between the K-Ar ages of Sagar flows and those of Chindwara and Amarkantak Traps (about 47 m.y.; Agrawal and Rama, 1976) and from palaeomagnetic evidence (Verma and Mital, 1972, 1974) which would lead to an age of about 50 m.y. to Jabalpur flows. This conclusion is in consonance with the view of West (1967) that "the earliest eruptions may have started in the west and spread gradually to the east ...".
and brings into question the traditional view (Chose, 1976) that the Deccan Traps in the eastern part constitute the lower and hence older flows.

The new geochemical and age data obtained by the author in respect of Sagar and Dhanduka flows when examined in the light of the published information, permit the delineation in the Deccan Traps, of geochemical sub-provinces with distinctive characters (Table 10.1).

**Table - 10.1**

<table>
<thead>
<tr>
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<th>Older flows</th>
<th>Younger flows</th>
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<td>65-60 m.y. B.P.</td>
<td>50-45 m.y. B.P.</td>
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<tr>
<td>1. Spatial distribution.</td>
<td>A large part of the Deccan Traps, particularly that of Western India.</td>
<td>N.E. part of the Deccan Traps (Sagar, Amarkantak Plateau etc.); probably upper flows in the peripheral parts of Deccan Traps, such as Tandur, Koyna.</td>
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<td>2. Mode of eruption.</td>
<td>Related to the initiation and spreading of the Carlsberg Ridge; Central type of volcanic activity in some parts.</td>
<td>Fissure eruptions; No evidences of Central type of volcanic activity.</td>
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<tr>
<td>3. Nature of flows.</td>
<td>Compound flows common; low rate of extrusion, possibly of the order of 1 m³/sec on the analogy of the compound lavas of Etna (Walker, 1967). Magma of high viscosity (x 10⁵ poises?). Presence of rhyolites in a few cases.</td>
<td>Compound flows absent; simple flows with considerable lateral extent (of the order of tens of kms.) common; Magma of low viscosity; High rate of extrusion; possibly of the order of 5000 m³/sec on the analogy of the simple flows of Iceland (Thorarinsson, 1967, 1968). Magma of low viscosity (x 10⁹ poises?). No rhyolites present.</td>
</tr>
</tbody>
</table>
4. Environment. Presence of alkali basalts and carbonatites. High heat flows; volcanic activity controlled by Narmada-Son lineament, the deep faults flanking the Cambay Basin and the L-shaped rift in Maharashtra; Dyke swarms common in some areas. No alkali basalts and carbonatites; Heat flow data not available; Dykes absent or rare.

5. Major elements. Generally somewhat higher $\text{SiO}_2$ (about 48%) and $\text{K}_2\text{O}$ (about 0.60%) contents. Generally low $\text{SiO}_2$ content (about 43%), low $\text{K}_2\text{O}$ content (0.1-0.6%, with an average of 0.23%), indicative of oceanic affinities.

6. Trace elements. Tend to have higher concentration of "compatible" elements like Ba, Rb, Nb, Sr. Tend to have higher concentration of "compatible" elements like Cr, Ni, V & Cu, and low concentrations of Rb (6 ppm), Sr (208 ppm) and Zr (155 ppm).

7. Strontium isotopes. Somewhat higher $^{87}\text{Sr}/^{86}\text{Sr}$ (0.7062-0.7068 for Girnar; 0.7040-0.7060, indicative of oceanic affinities. Dhandhuka). Generally low $^{87}\text{Sr}/^{86}\text{Sr}$, mostly in the range of 0.7062 to 7095 for of oceanic affinities.

The fact that only two contrasting sub-provinces could be delineated on the basis of the present study does not rule out the possibility of there being more than two sub-provinces (say) with a "mix" of the characteristics. When more of such sub-provinces are identified and their spatial and temporal distribution and chemical characters
are worked out, it should be possible to develop models on the history of emplacement of the Deccan Traps.

The following time-scale of events in respect of the spatial and temporal evolution of the Deccan Traps is consistent with the sea-floor spreading chronology (Le Pichon and Heirtzler, 1968), K-Ar ages (McElhinny, 1968; Wellman and McElhinny, 1970; Agrawal and Rama, 1976) and palaeomagnetic time-scale (Verma and Mital, 1972, 1974; Pal & Bhimasankaram, 1971):

1. 140 m.y. B.P. (Upper Jurassic): Separation of India, Australia and Antarctica along the S.W. branch of the Indian Ocean Ridge.

2. 100 m.y. B.P. (Albian): Completion of the opening between Africa on the N.W. side and India and Australia on the S.E. side of the Ridge. Extrusion of Rajmahal Traps (105-100 m.y.) and the earliest Deccan Trap flows in the Dhanduka bore hole sequence (101.7 ± 3.3 m.y.; present work). Significantly, Pascoe (1964) speculated, on the basis of the observations of Fox (1936), that "Further investigations may eventually prove that the Rajmahal Traps represents but the initial phase of Deccan disturbance".

3. 65-60 m.y. B.P. (Palaeocene): Major episode of Deccan Trap activity (related to Carlsberg Ridge), which gave
rise to a major part (say, two-thirds?) of Deccan Traps, particularly of Western India, including the upper flows of Dhanduka (present work).

4. 50-45 m.y. B.P. (Eocene):— Second significant episode of volcanism which gave rise to the Deccan Traps in the N.E. part (Sagar, Jabalpur, Amarkantak, etc.; present work).

5. Continued low intensity volcanism giving rise to some younger flows in the periphery of the Deccan Traps (Koyna? Dohad?) and post-trappean dyke activity right down to Oligocene (about 35 m.y.) (?) (present work).

Further work:

The model given above is based on the premise that a conclusion based on the convergence of multiple lines of evidence is likely to be nearer to the truth (even though individually, a given line of evidence may not be capable of leading to an unequivocal answer). The model can be refined by the following further studies which are in progress:

1. Age dating of the middle flows of the Dhanduka bore hole sequence and the Khandala flows (Verma & Mital, 1972). The model cited above predicts that they should have ages between 100 and 60 m.y.
2. Delineation and drawing the approximate boundaries of, the sub-provinces of the Deccan Traps on the basis of the geological, geochemical (including isotopic) and geophysical studies, with the objective of developing a comprehensive model in respect of the temporal and spatial distribution and chemical characters of the Deccan Traps.