CHAPTER IX A SELF-CONSISTENT MODEL FOR SAGAR AND DHANUKA FLOWS

Any self-consistent model for Sagar flows should be able to account for the physical, chemical and distributional characters of the basalts and the absence of dykes in the area. The principal features of the Sagar flows are accounted for individually.

1. The Deccan Traps of Sagar are in the form of simple flows with large areal extent, and are characterised by the absence of dykes:

The lava which gave rise to Sagar flows must have been of low viscosity and high fluidity. It must have got extruded at a fast rate (say, \(x 1000 \text{ m}^3/\text{sec.}\)) through fissures, as there are no dykes at all in the proximity which could have served as feeders (the nearest dyke to Sagar is 120 kms. away and from the north-eastern corner of the Deccan province as a whole, there is no dyke nearer than 300 kms).

West (1959) pointed out that no dykes are to be found over about two-thirds of the Deccan Trap outcrop. Flows could be traced continually for tens of kilometres in the Sagar area. The lava "must have been extremely fluid more like a thin oil than viscous magma" (West, 1959). That lava floods could travel considerable distances is indicated by the fact that a thick lava flow could be traced
continuously for about 200 kms. in the case of Columbia River basalts (Waters, 1955). Possibly, the fissures followed the "grain" of the Archaean basement and the orientation of the Narmada-Son lineament (M.W.?). The aero-magnetic surveys at two heights across the Deccan Traps that are being undertaken by the National Geophysical Research Institute, Hyderabad, may be able to delineate the geometry and frequency of the fissures in the eastern part of the Deccan Traps.

That fissure eruption may not be the principal mode of extrusion in the case of the Deccan Traps in Western India is indicated by the identification of central type volcanicity and transitional alkali basalts in several localities in Western Maharashtra (Agashe and Gupta, 1971).

Walker (1971) has explained the relationship between simple and compound lava flows in terms of the rate of extrusion and the viscosity of the lava (Fig. 42). When the rate of extrusion is high (e.g. Laki lava, Iceland, with extrusion at the rate of 5000 m³/sec.; Thorarinsson, 1967 & 1968), the flows tend to be simple. When the rate of extrusion is low (e.g. Etna, with extrusion at 1 m³/sec.; Walker, 1967), the flows tend to be compound.
Postulated relationship between simple and compound lava flows as dependent on the rate of extrusion (R) and the viscosity of the lava (\eta, poises). Appropriate values for $R_1$ and $R_2$ might be $10^{-1}$ and $10^4$ m$^3$/sec respectively.
According to Stoke's law, the velocity \( B \) of a particle of radius \( r \) moving under unit force in a medium of viscosity \( \eta \) is given by

\[
B = \frac{1}{6\pi\eta r}
\]

The low indicates that the velocity of lava flood and hence the ultimate areal extent of a flow will be high for lavas of low viscosity.

The high fluidity of the lava has been attributed to various causes, such as superheating at the time of extrusion, due to pressure release on eclogite shell (Fermor, 1938), presence of high percentage of iron oxides and especially of ferrous iron (Washington, 1922) and exothermic reactions (West, 1959). The thinness of the indurated contact (15 cms.) with the Vindhyan sandstone-quartzite at the base of the flows in bore-hole 1 indicates that though the lava was hot, it was highly fluid and the duration of the contact was short as the flow might have moved off quickly.

2. The Sagar flows have K-Ar ages ranging from 50 m.y. to 42 m.y.

As the samples dated are fresh (under the microscope) core material, there is a strong possibility that the K-Ar
ages are true ages. Except in the case of flows 8 and 9, the K-Ar ages are concordant with stratigraphic sequence.

The K-Ar ages are consistent with palaeomagnetic time-scale also. Verma and Mital (1972) showed that the palaeo-latitudes of Mount Girnar and Jabalpur were 41° N and 43° N respectively, Verma and Mital (1974) found that India drifted through 19° through the period between the Rajmahal Traps (100-105 m.y.) and Girnar (64 m.y.). Projecting this rate of movement (5.2 cm./yr.), it could be shown that the Deccan Traps of Jabalpur are about 15 m.y. younger than those of Girnar, i.e. about 50 m.y. old. This is an elegant, independent evidence in favour of the younger age of the Deccan Traps in its north-east part.

The following time scale of events is consistent with the seafloor spreading chronology of Le Pichon and Heirtzscher (1968).

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, Australia and Antarctica on the S.E. side of the ridge. This coincides with the extrusion of Rajmahal flows (McDougall and
McElhinny, 1970) and the earliest Deccan Trap flows in Dhanduka bore-hole sequence (present work).

3. 65-60 m.y. B.P.: The first major episode of Deccan Trap activity (McElhinny, 1968; Wellman and McElhinny, 1970; present work in respect of the upper flows in the Dhanduka bore-hole sequence; Agarwal and Rama, 1973).

4. 50-45 m.y. B.P.: Second major episode, particularly manifest in the N.E. part of Deccan Traps (Sagar, Jabalpur, Amarkantak plateau etc.) (present work; Agarwal and Rama, 1976).

While the present work is indicative of the presence of (at least) two geochemical sub-provinces, the temporal relationship between the two is exactly the reverse of what has been proposed by Ghose (1976), i.e. his "Lower Traps" are actually younger and his "Upper Traps" are actually older, in terms of K-Ar and palaeomagnetic time-scales.

3. The Sagar flows are composed of olivine-free quartz-tholeiites

(i) Nature of magma:

The well documented and much quoted model of West (1953) for the petrogenesis of basalts, involves a
tholeiitic parent magma (more basic than normal tholeiite),
formation of cumulates of ferro-magnesian materials in the
magma reservoir, their later remelting and extrusion to
give rise to picritic and alkali-olivine basalts.
Krishnamurthy (1974) on the basis of his work on Dhanduka
flows extended the model to show that the parent magma was
generated by the partial melting of a garnet-peridotite
Upper Mantle at about 25-30 Kb. with the production 20% 
primary picritic liquids. The model of Krishnamurthy (1974)
is not applicable to Sagar flows which do not have picrites
or alkali-olivine basalts. The parental magma of Sagar
flows may have been of low-K tholeiites composition, similar
to abyssal tholeiites on the ocean floor. It might have
been derived from the "pyrolite" of Green and Ringwood
(1969) by a small degree of partial melting. According to
Green and Ringwood (1969), quartz tholeiites might not
have been derived by direct melting and magma segregation
from parental pyrolite at very shallow depths.

(ii) Nature of mantle source :

The composition of a magma is controlled by two
parameters: (i) composition of the solid undergoing
melting or reaction with the liquid and (ii) pressure-
temperature conditions (i.e. depth) of melting and of
solid-liquid equilibration (Harris, 1972). Middlemost
(1975) has given the possible chemical composition of
the Upper Mantle (Table 9(ii), which could be considered
as the parent source of the Deccan Trap magma. Experimental work (Kushiro et al., 1963; Green and Ringwood, 1967; O'Hara, 1968) indicates that at different depths and pressures, the liquid composition will be equivalent to the following rock types:

<table>
<thead>
<tr>
<th>Pressures (Kbs.)</th>
<th>Depth (Kms.)</th>
<th>Rock Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>Silica-saturated tholeiites</td>
</tr>
<tr>
<td>5 - 10</td>
<td>15 - 30</td>
<td>Olivine tholeiites</td>
</tr>
<tr>
<td>15 - 20</td>
<td>45 - 60</td>
<td>Alkali basalts</td>
</tr>
<tr>
<td>20 - 30</td>
<td>60 - 90</td>
<td>Nephelinite</td>
</tr>
<tr>
<td>30 - 40</td>
<td>90 - 120</td>
<td>Picrite</td>
</tr>
<tr>
<td>7 - 40</td>
<td>7 - 120</td>
<td>Increasingly ultramafic.</td>
</tr>
</tbody>
</table>

Though the details cited above may not be universally acceptable, a generalised statement could be made to the effect that a magma tends to be less alkaline when formed at low pressures and higher degrees of partial melting.

Models of basalt genesis in respect of Sagar flows would have to consider variables such as (i) nature of the upper mantle (garnet-peridotite/hornblende-eclogite) and (ii) degree of partial melting. A garnet-peridotite
upper mantle when melted partially, would tend to give rise to olivine tholeiites. Since olivine is absent among the tholeiites of Sagar, this model is not acceptable. A hornblende, eclogite upper mantle when melted almost totally could give rise to the olivine-free tholeiites of Sagar. On the basis of the trace element geochemistry of the possible mantle-derived rocks in the Archaean of South India, Gangharam and Aswathanarayana (1971) suggested that "the Upper Mantle could conceivably correspond to eclogites characterised by the amphibolite-ultramafic rock association (within the meaning of Sorensen, 1967)". As far back as 1938, Fennor suggested that reduction of load pressure on the eclogite shell could give rise to copious, superheated basalt melts. The experimental work of Yoder and Tilley (1962) is indicative of eclogite as the source of basalts.

4. The Dhanduka lavas and the lower cycle of Sagar flows show effects of crustal contamination

The magnitude of the initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of a basalt is a sensitive indicator of its petrogenesis and may be the end result of the operation of the following processes, individually or in combination:

(i) **Inhomogeneity in the upper mantle**:

Ringwood (1966) recognised the following variants of pyrolite assemblages; Ampholite (olivine + amphibole),
plagioclase-pyrolite (olivine + Al-poor pyroxene + plagioclase), pyroxene-pyrolite (olivine + Al-poor pyroxene + spinel) and garnet pyrolite (olivine + Al-poor pyroxene + pyrope-rich garnet). Hornblende seems to be the key mineral in the upper mantle whose abundance has significant control on the trace element geochemistry of the basalt derived from the upper mantle (Griffin and Rama Murthy, 1969).

According to Faure and Powell (1972), there are three possible ways by which the mantle inhomogeneity may affect the $^{87}$Sr isotopic ratios of the magmas:

(i) The average Rb/Sr ratio of the mantle may decrease with depth. The $^{87}$Sr/$^{86}$Sr ratio of the magma will then depend upon the depth of its origin.

(ii) Individual mineral grains in the mantle may remain isotopically closed for long periods; partial melting of varying proportions of these minerals would then produce melts with different $^{87}$Sr/$^{86}$Sr ratios.

(iii) The Rb/Sr ratio of the mantle may vary laterally, and magmas may come from different sub-crustal sites.
(ii) Rb/Sr ratio of the environment:

Because the mantle has a low Rb/Sr ratio (about 0.03), rocks derived from the mantle tend to have a low initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio (about 0.700 - 0.705). On the other hand, a magma which resided in the crust (Rb/Sr = 0.25) tends to have a higher initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio ($>0.7060$). Thus the final $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of a basalt would depend upon the date of removal of the magma from the upper mantle environment and the duration of the residence of the magma reservoir in the crust.

(iii) Crustal contamination:

Since the crustal Sr is enriched in radiogenic $^{87}\text{Sr}$ (because of the high Rb/Sr ratio of the crust), the incorporation of crustal material by a magma tend to enhance its $^{87}\text{Sr}/^{86}\text{Sr}$ ratio.

Four mechanisms of crustal contamination could be considered: (i) Bulk assimilation (Faure and Hurley, 1963): this would be manifested by marked change in the major element geochemistry of the contaminated magma. This does not seem occur frequently for the simple reason that a differentiating magma may not have enough superheat to assimilate large quantities of crustal material. (ii) Wall-rock reaction (Green and Ringwood, 1967): involving the
transfer from the surrounding rocks to the magma of "incompatible" elements (e.g. K, Rb, Ba, U, Th and Sr) which cannot enter into the lattices of silicates of major elements. (iii) Selective migration (Heier, 1964; Al Rawi and Carmichael, 1967): Since radiogenic strontium in rubidium sites in micas and potash feldspars is more mobile, it may move into an adjacent magma with ease. (iv) Isotope equilibration (Pankhurst, 1969): High \( ^{87}\text{Sr}/^{86}\text{Sr} \) ratios by isotopic exchange or equilibration between a hydrous magma and the country rock.

The major and trace element geochemistry of a basalt and its geological setting could place limits on possible models. Hydrothermal alteration could disturb the Sr and Pb isotopic composition of the rock, but if such alteration took place, it would show up in the \( \delta^{18}O \) value. That \( \delta^{18}O \) value is almost invariant in respect of the various rock types of Gurnar (e.g. gabbro, lamprophyre, diorite and syenite) despite their Sr isotopic ratios varying from 0.7051 to 0.7080, is a clear evidence against hydrothermal alteration in the case of Gurnar, (Paul et. al., in preparation). Though \( \delta^{18}O \) values are not available for Dhanduka and Sagar flows, it is not unreasonable to suggest that these flows also did not undergo hydrothermal alteration. This observation is also consistent with the petrology of these lava flows.
The magnitude of the initial $^{87}\text{Sr}^{86}\text{Sr}$ ratios (about 0.7095) and the existence of positive correlation between these ratios and $\text{SiO}_2$ are strong indicators of crustal contamination in respect of Dhanduka flows. Similarly the magnitude of the initial $^{87}\text{Sr}^{86}\text{Sr}$ ratios (0.7052-0.7084) in the case of the first cycles flows (1-4) of Sagar point to crustal contamination.

Paul et al. (in preparation) analysed one sample of the Precambrian basement granite, which gave a Sr content of 688 ppm. and initial Sr isotopic ratio of 0.7101. Assuming this material to be the source of crustal contamination and assuming that the parent tholeiitic magma of the Deccan Traps has Sr content of about 73 ppm. and initial $^{87}\text{Sr}^{86}\text{Sr}$ ratio of 0.7039, it could be shown that crustal contamination has occurred in the case of Dhanduka and lower cycle Sagar flows.

In the case of the Sagar flows, the fact that sample No.2/20 (flow 5) has a markedly less Sr content (73 ppm) than the flows with comparable Sr isotopic ratio, indicates that radiogenic Sr might have been selectively introduced (by wall-rock alteration mechanism (?) of Green and Ringwood, 1967).

The limitations of this exercise need to be emphasized. Crustal contamination may have been significant in respect of Dhanduka and Sagar (lower cycle) flows,
but the operation of other factors/processes (inhomogeneity in the upper mantle, Rb/Sr ratio of the environment, magmatic differentiation) cannot be ruled out. Similarly the mechanism of wall-rock alteration proposed is just one of the possible mechanisms.