CHAPTER 6

SUMMARY AND CONCLUSION

A glimpse of the literature would reveal that very meagre work has been carried out on the petrochemical aspects of Rajahmundry basalts. Though this area has attracted many workers because of its palaeontological potential, it is otherwise important as these volcanic eruptions are manifestation of the dynamic processes through which the Indian sub-continent has passed.

The present work has been taken up to investigate petrochemical and genetic aspects of these isolated outliers of the basaltic rocks which are considered coeval to the Deccan flood basalts. Though the RJ basalts are coeval to the main Deccan basalts, the former are essentially associated with Godavari graben. In other words they are integral part of the lithostratigraphic succession of Godavari graben. The present work has been summarised as follows.

The basaltic traps along with Inter-trappean and Infra-trappeans are exposed on both the banks of the river Godavari as it cuts through the rocks. The Inter-trappeans are exposed in Kateru and Pangidi areas of the East and West Godavari Districts respectively, while the Infra-trappeans are recorded in the West Godavari District only. Structurally, the area is undisturbed and the Infra-trappean beds dip with a low angle of 0 to 10 degrees. The Infra-trappeans and Inter-trappeans consist of
sandstones and limestones respectively and are fossiliferous in nature. The macro, and micro-fossil studies suggest that these beds were deposited under shallow marine to esturine conditions and are of the Paleocene age.

The upper and lower flows are 25 m and 3 m thick respectively. The lower trap is in unconformable relationship with Infra-trappeans and at places it is rests directly on the formations further lower in the succession.

The simple, blocky flow characteristics without any pyroclastic material indicate that they are not central eruptions but are fissure type. The presence of faults inferred from satellite imagery passing through the area probably suggest the closeness of the site of eruption.

The optical studies carried out on large number of samples are in close confirmity with the microprobe data carried out on representative samples. The presence of the two (Ca and Fe rich) pyroxenes, plagioclase and iron oxides with subordinate amount of interstitial altered glass and conspicuous absence of olivine both as mineral and normative phase is an important feature indicating the evolved character of the RJY basalts.

The relatively less common glomeroporphyritic texture, especially in the lower flow, indicate the presence of intra-telluric crystals of pyroxene and plagioclase in the melt. Complex physico-chemical conditions such as fluctuations of $P_{H2O}$ and temperature, are inferred from the zoned crystals of plagioclase. The textural relationship of opaque minerals and presence of skeletal iron oxide indicate their late stage origin. The various textural patterns seen such as ophitic, sub-ophitic, intergranular, interstitial and occasional flow textures indicate varying cooling conditions of the basaltic flows. The ophitic to sub-ophitic
texture reflects the near simultaneous crystallization of the mineral phases. The groundmass of Ca-poor pyroxenes in the interstices between the microphenocrysts reveal the rapid cooling conditions after eruption.

The geothermometric estimations (see chapter-5, Table-5.2) suggest progressive decrease of temperatures resulting in the appearance of augite (1259°C), pigeonite (1246°C), and plagioclase (1169°C). The textural patterns observed are also in confirmation with the geo-thermometric estimations. Also, it has been inferred that though the lower and upper flows have similar temperatures of crystallisation of minerals, the upper flow shows slightly higher degrees of crystallisation. The plagioclase temperatures estimated from the Glazner's (1984) method shows that temperature of crystallisation increases with the increasing An % and are consistent with the basaltic trends.

The vesicle filling minerals such as silica, zeolites and altered glasses (palagonites and chlorophaeites) indicate influence of the low temperature deuteric alteration. At places, the palagonitisation of clinopyroxene has also been observed in these rocks. Geochemically, the effect of alteration i.e. mostly weathering and post consolidation leaching on various elements has been investigated and the results indicate that SiO2, MgO, FeO(t), Al2O3, TiO2, Na2O, Ni, Cr, Zn and Y values show reasonable confidence while, K2O, Rb, Sr, Ba and CaO values show some alteration effects. The selective enrichment of Yb in RJY basalts is attributed to break down of clinopyroxene. However, the observed negative anomalies of Ce were attributed to seawater-rock interaction caused by marine transgressions post dating the eruption of the flows.
The major and trace element variations within the flow (vertically and horizontally) shows monotonous trends without much differentiation. The studies show that the upper and lower flows show similar mineralogical and chemical features. The study of REE of these basalts indicate that they are enriched particularly in LREE. All the samples of RJY basalts (both lower and upper flows) show similar enrichment of REE but only differ slightly in their absolute enrichment. Especially, the lower flow shows higher REE contents.

On the basis of low Mg numbers, Ni and Cr contents of the RJY basalts, it has been inferred that they are not primary melt. The present compositions presumably represent the products of magmatic evolution during its upword movement from the source, i.e. a larger degrees of partial melting at the source region and extensive differentiation-fractionation probably in the sub-crustal magmatic chambers. It is inferred from the LREE enrichment patterns that garnet is the principle residual phase in the source region for the parental rocks of RJY basalts. The estimated partial melting ranges from 30±5% indicate higher degrees of melting. The studies suggest extensive fractional crystallization of gabbroic material in the evolution of the RJY basalts similar to Deccan basalts. However, the RJY tholeiitic basalts with its characteristic iron enrichment suggest evolved character than the Deccan basalts. Fractionation of both olivine and pyroxene phases is suggested from the major and trace element patterns. The other geochemical features such as increasing Al2O3 percent and buffering of Sr values with increasing fractional crystallization suggest the plagioclase fractionation. Though, Sr is considered to be partly affected by secondary mobilization, its strong negative anamoly in the spidergram
would reflect the plagioclase (gabbro) fractionation.

The incompatible trace elements enrichment in these basalts is may be due to single or combination of processes - fractionation of olivine, clinopyroxene and or due to partial melting of metasomatically enriched source region. The preliminary studies indicate that in the evolution of these basalts crustal component has no major role to play. However, the crustal contamination can't be ruled out completely.

The flow characteristics as well as the geochemical characters indicate their continental condition of eruption. But oceanic character has also been suggested by some variation diagrams. Accordingly they are grouped as basalts belonging to ambiguous tectonic setting erupted at the interface of continent and oceanic environments. Thus RJY basalts have been described as basalts belonging to initial rift tectonic setting (Chatti and Sharma, 1990).

From the above geochemical and petrogenetic studies together with the limited earlier data, a synthesis of the tectono-magmatic processes of eruption of these RJY basalts has been attempted.

Except for the minor aberrant rock types within the flood basalt provinces all over the world, there are overwhelming evidences that majority of the basalts are tholeiitic and have erupted within a short span of geological time. In RJY region, the Inter-trappean sedimentary beds between lava flows are thin and show characteristically faster depositional features (Bhalla, 1966). The similarity of mineralogical and chemical features of the upper and lower flows suggest periodic tapping of the same magmatic chamber after a shorter gap of time. These features substantiate the idea of shorter span of magmatic event in RJY region.
Regarding their origin, two alternatives seem possible. One in which a more primitive parental magma than the RJY basalts (c. 5-8% MgO range) of picritic composition as a result of partial melting of a Fe-rich pyrolite or garnet peridotite differentiates into basalts through fractionation of olivine and clinopyroxene or both. The amount of fractionation needed to produce basalts depends upon the MgO contents of the initial picritic liquid. The higher the MgO contents, the larger are the amounts of olivine required to be removed. Approximately, 8-15% olivine loss is sufficient to produce normal basalts (c. 5-8% MgO range) from picritic compositions with 10-15% of MgO. On the other hand, high degree or total melting of an appropriate source rock such as eclogite or amphibolite can also produce basaltic liquid in the range of 5-8% MgO. Since large amounts of liquids are produced, rapid flooding or eruption is possible (Cox, 1980). The only objection to such a scheme being the availability of high degree of heat for total melting. But then, flood basalt provinces are an enigma when one considers the enormous volume of hot liquids (1100°C), made available for eruption in relatively shorter span of time. Pressure relief, as a consequence of tensional forces developed during the foundering of the Gondwanaland might have induced or assisted in large scale melting either total or at high degrees.

Considering the above evidences a tectono-magmatic model proposed by Cox (1980) would explain better the RJY volcanics also. According to him - the uprising magma from mantle that equilibrate in crustal magmatic chambers in the form of sills before they eventually erupt. The high density of picritic magma (which is supposed to be parental to RJY basalts) inhibits its movement and eruption. The sill form has an advantage because it is capable of accommodating large amounts of material without posing a
space problem. Another advantage is that it provides an ideal environment for the fractionation of large volumes of magma within comparatively restricted pressure range.

Comparatively, one would find broad similarities of mineralogical and chemical features for the time equivalent RJY basalts and Deccan basalts.

A distinct feature of RJY and Deccan tholeiitic basalts when compared to average continental tholeiites is that the former are significantly enriched in FeO(t) and TiO2. The higher content of these elements of Deccan basalts suggest higher degree of fractionation prior to extrusion. It is interesting to note that the RJY basalts and the basalts drilled from NE Indian ocean show general enrichment of iron compared to Deccan basalts from northern regions. This aspect needs special attention to study as it may indicate a general enrichment of iron in this part of the mantle or progression of Indian plate over hot spot and the subsequent enrichment of iron in the later melts.

There is a fair amount of gradation between the alkali and tholeiitic basalts for the Deccan province as a whole although samples from individual areas have discrete groupings or show transitional features. RJY basalts show monotonous nature and does not show any such transition as seen in the Deccan basalts.

The common tholeiites of the Deccan traps are genetically related to primary magmas with 9 to10% MgO, which are generated in a heterogenous but dominantly Indian ocean MORB type presumably at mantle depths of 35 to 45 km. Approximately $1.2 \times 10^6$ km$^3$ volume of primary magma has been generated in the upper mantle of this region out of which a large fraction of the magma crystallized as gabbros and troctolites over a wide range of
depths in crustal magma chambers (Sen, 1988).

Thus the present studies reveal that geochemically and geochronologically the RJY basalts are comparable to the Deccan basalts. However, a question remains to be answered, i.e. whether the RJY (East coast) basalts and Deccan basalts came from a single source or not? Before finding answer to such a question it would be relevant either to relate or to unrelate the RJY volcanism with Deccan basalts proper. The fact that these RJY basalts are intrinsically associated with litho-stratigraphic sequence of the Gondwana basin lends support to deassociate it from main Deccan basalts proper, which are presumably erupted due to Reunion hot spot activity. Moreover, the wide gap (spatial) between these two basaltic bodies raise doubt regarding the single source concept. The recent DSS profile studies reveal (V.K. Kaila, Personal discussion, 1988) a separate source for the RJY basalts. A mega sill underneath the RJY region has been suggested with the help of geophysical studies, carried out by ONGC during its exploratory work on On-Shore and Off-Shore of Godavari basin (Biswas, Personal discussion, 1988). It suggests altogether an independent magmatic activity coeval to Deccan volcanism.

TECTONICS

The relation between the type of volcanism and tectonic movements give a positive proof of the fact that the volcanic activity in the Rajahmundry area was invariably manifested under tensile stress conditions. Compressive folds are singularly absent in this region (Kumar, 1982). It is interesting to note in this context that not a single region where volcanic activity was associated with firmly established compressive structures at
this Mesozoic-Tertiary boundary is known in the Peninsular India.

In the speculative schematic evolution of the Gondwanic belts of India and Southwest Australia (Katz, 1976), four episodes are postulated—leaving the first and second Precambrian episodes, the third episode of Phanerozoic activity along transforms of Mid Indian Ridge which include the formation of the Gondwana rift, i.e. the Godavari graben. It is important to note that the Godavari graben has been extended further eastward into the Bay of Bengal and joined with the negative lineament (see Chapter-2) inferred from the Satellite altimetry data map of Gahagen et al. (1988). Moreover, the other faults and lineaments recognised in the south India can be shown to be the continental extension of major contemporary transforms of the Indian Ridge (Katz, 1989). The fourth and latest episode was an intense reactivation during the early Cretaceous that led to the break up and fragmentation of Gondwanaland. Strong dextral transform movements lead to the development of the new dormant 90 E ridge, which played a major role in the evolution of the Indian ocean.

The eruption of RJY basalts during the Paleocene, may be due to the reactivation of the failed rift, where tensional forces might have stretched the graben basement and the eventual drop of lithospheric pressure must have lead to melting of mantle and generation of melts. The other remote possibility where the contemporary 90° E hot spot plume suppling molten material to the Godavari rift tensional zones can’t be ruled out.

The outpouring of lavas must have taken place during Paleocene and possibly could have formed barriers from the sea, simultaneously developing a coastal lagoon in which the Inter-trappean beds were deposited. The complete absence of terrigenous material in the Inter-trappean sediments
indicate that there was no inland drainage from the land areas and the lagoon might have been connected to the ocean only and the sedimentation of Inter-trappeans beds could have been under calm and quite conditions with varying salinity.

Marine transgressions are evident from the fauna of Inter-trappean and Infra-trappeans marine sedimentary beds associated with the basaltic flows in this region. The effect of sea water interaction with basaltic rocks during these marine transgression(s) was reflected in the mobility of some elements as discussed earlier.

FUTURE STUDIES

The limited extent of the RJY basalts erupted at the continent-ocean interface, perhaps only indicate the tip of an iceberg, i.e. the major portion of the melt generated due to the dynamic processes must have consolidated underneath the continent as well as in the oceanic region adjacent to it. Thus it is quite essential to consider samples from the drill data in order to develop any comprehensive model of this area in particular and Godavari graben in general. The ongoing exploration of oil and gas by ONGC (Oil and Natural Gas Commission) in the Godavari basin has yielded a wealth of drill data which can possibly widen the scope of such studies related to volcanism and associated marine sedimentation. The available published information by ONGC indicate that RJY basalts do extend into the Bay of Bengal continuing under the coastal Godavari Deltaic sediments. Perhaps, these traps may show transition as oceanic crust into Bay of Bengal? The possible role of these basaltic rocks as "oil and gas traps" adds to the significance of such studies. It is important to study in detail regarding the extent, timing and processes of these volcanics
which have documented a record of the extensive drift of the Indian plate.

The following studies can be taken up if the new drill data is made available:

Detailed studies to establish the actual thickness of the trap rocks throughout the subsurface; Studies of the basalts sampled from successive flows in the sub-surface would enable to develop better petrogenetic models; Geochronological studies to constrain the possible limits on the age of the volcanic rocks; Better comparision of these volcanics with the time equivalent Deccan basalts to develop tectono-magmatic models in order to understand and to relate them it with the global tectonics processes.