CHAPTER IV

SUMMARY AND CONCLUSIONS

The primary aim of this thesis is to assess the utility of corals from the northern Indian Ocean coasts as a source of high resolution records of climatologic and oceanographic parameters of this region. Towards this, detailed measurements of stable oxygen and carbon isotopes and radiocarbon and preliminary studies of Cd were made in the annual bands of corals collected from the Lakshadweep islands and the Gulf of Kutch. In addition, oxygen and carbon isotope studies on two tracks in a coral from the Stanley Reef, Australia were also done to assess the intraband isotopic variability and its effect on the retrieval of climatic information from the isotopic records, and also for identifying the factors controlling the density band formation. A brief summary of the work and the conclusions arising from it are given below.

The corals studied are from three locations (i) the Lakshadweep islands (10°N, 73°E) (ii) the Gulf of Kutch (22.6°N, 70°E) and (iii) the Stanley Reef (19°15'S, 148°07'E). Of these the Lakshadweep islands and the Gulf of Kutch though are in the Arabian Sea, they are influenced by different climatic regimes. The SST variations in the Lakshadweep are upwelling dominated whereas in the Gulf of Kutch it is controlled mainly by summer heating and winter cooling.

P. compressa is the most abundant coral species in the Lakshadweep region. It secretes bands which are clearly discernible in an X-ray picture. These bands are about 15-20 mm thick and are deposited yearly as evidenced from oxygen isotopic studies.

The $\delta^{18}O$ of corals from this location shows a seasonal fluctuation of about 0.8‰ corresponding to a 3-4 °C change in SST. This is consistent with the seasonal SST change in this region resulting from the monsoonal upwelling. The absolute values of $\delta^{18}O$ and its seasonal amplitude in samples of the same species collected from different locations of Kavaratti lagoon of the Lakshadweep Archipelago are quite similar. This consistent behaviour and spatial coherency in the oxygen isotope systematics indicate that it is a reliable SST indicator for this region. The absolute values of $\delta^{18}O$ of this species of coral, however was found to be depleted by ~5‰ compared to that expected for equilibrium $CaCO_3$ precipitation. By comparing the $\delta^{18}O$ of *P. compressa* with the $\delta^{18}O$ in time contemporaneous samples of a giant clam (*Tridacna maximus*), which is known to precipitate $CaCO_3$ in equilibrium, we have quantitatively determined the "disequilibrium offset" in this coral. Using the "disequilibrium offset" we have established a $\delta^{18}O$-SST relation for *Porites* corals from this region. This relation can provide SST with a precision better than about ±1.4 °C.

Comparison of the coral derived SST for the last 17 years with the available instrumental data shows a reasonable agreement between these two sets of data (±1°C on an average). This result suggests that the coral $\delta^{18}O$ can be used to derive the actual SST of the ambient water. More precise determination of SST is possible if data on temporal variations of the oxygen isotopic composition of water for this region is available.

The carbon isotopic composition of the Lakshadweep coral seems to be controlled by endosymbiotic photosynthesis coupled with growth rate dependent fractionation. The $\delta^{13}C$ shows a seasonal cyclicity of about 1‰. The $\delta^{13}C$ seasonality appears to be controlled indirectly by monsoon activity. During the monsoon season cloud cover increases, strong wind enhances the ocean currents and sediment suspension. These factors reduce the light level in the water causing reduction in zooxanthellar photosynthesis and hence $\delta^{13}C$ in coral. The reduced $\delta^{13}C$ is associated with high density band, as during monsoon reduction in photosynthesis reduces the coral growth resulting in high density band formation.

The absolute values of $\delta^{13}C$ among samples collected from locations which are within ±60km shows significant variability, though all of these exhibit seasonal cyclicity of ~1‰ with a dip in the monsoon season. Thus $\delta^{13}C$ does not show spatially consistent behaviour among samples from nearby locations. This is unlike $\delta^{18}O$ which shows spatial coherency. However the seasonal cyclicity of both $\delta^{18}O$ and $\delta^{13}C$ appear to be monsoon related. Therefore studies on the temporal changes in the seasonal cyclicities of $\delta^{18}O$ and $\delta^{13}C$ would be helpful in monitoring changes in monsoon intensity and upwelling, once quantified.

The coral (*F. speciosa*) from the Gulf of Kutch is characterized by lower growth rate

(~ 4mm/yr) compared to the Lakshadweep corals. The oxygen isotopic composition of this coral shows an average seasonal cyclicity of ~ 0.3‰, much less than the expected value (1.1‰) for a 6°C change in SST and ~ 0.3‰ change in oxygen isotopic composition of water between summer and winter. A major contributor to this damping in the seasonal $\delta^{18}O$ amplitude seems to be the artifact of sampling corals having a slow growth rate. Sampling of corals having a growth rate of ~ 4mm/yr can yield only 2-4 months resolution which is insufficient to retrieve the full seasonal amplitude. Model simulation on the effect of sampling interval and sample thickness on the retrieval of seasonal amplitude suggests that for corals having growth rate of ~ 4mm/yr and sampled similar to the GKh coral, the seasonal amplitude could be damped by as much as ~ 50% because of sampling.

The $\delta^{18}O$ time variations of the GKh coral show a higher order cyclicity (~ 7 yrs) a result not observed in the Lakshadweep corals. This long term change in $\delta^{18}O$ shows a negative correlation with interannual rainfall variability. This can be explained in terms of SST-rainfall relationship. Since $\delta^{18}O$ of coral decreases with increase in SST which also enhances the evaporation rate and hence precipitation, coral $\delta^{18}O$ shows a negative correlation with rainfall.

The $\delta^{13}C$ of the GKh coral also shows a seasonal cyclicity ~ 1‰, and appears to be controlled by endosymbiotic photosynthesis. The absolute $\delta^{13}C$ values of GKh coral is significantly higher (~ 0.6-1.7 ‰) compared to the LDP corals. This could be because of several factors, species dependent fractionation, higher $\delta^{13}C$ of ambient water resulting from enhanced rate of biological productivity and slower growth rate of the GKh coral. The coastal regions of the northern Arabian Sea has a higher productivity which can enrich the ΣCO_2 of water (in $\delta^{13}C$) and hence the coralline $\delta^{13}C$. Another reason for the $\delta^{13}C$ enrichment in the GKh coral is its slower growth rate. Slower growth rate leads to isotopic values which are closer to equilibrium precipitation, hence the GKh coral shows higher values of both the $\delta^{13}C$ and $\delta^{18}O$ compared to the LDP corals.

Density and stable isotopic analyses were carried out in a coral *P. lutea* from the Stanley Reef, Australia in order to assess the intraband isotopic variability and their effect on the retrieval of climatic information from the isotopic records. Two tracks, one close to the central growth axis (~10°) and another ~ 20° off the growth axis were analyzed. The $\delta^{18}O$ shows inverse relation with SST and rainfall variability of the surrounding region. The carbon isotopic variation is related to insolation. This study reveals that the $\delta^{18}O$-density correlation shows a progressive regression off the central growth axis. The lack of significant correlation between $\delta^{18}O$ and density in either track suggests that the density band variations are not controlled by the SST variations.

Radiocarbon analyses were made in the annual bands of the GKh coral and in the rings of a teak tree collected from Thane (19°14'N, 73°24'E) near Bombay. These measurements were made to obtain the rates of air-sea exchange of CO_2 and the advective mixing of water in this region. The $\Delta^{14}C$ peak value of the Thane tree in the year 1964 is ~ 630 ‰, significantly lower than that of the atmospheric $\Delta^{14}C$ of the northern hemisphere (~ 1000 ‰). The radiocarbon time series of the GKh coral was modelled considering the supply of $^{12}CO_2$ and $^{14}CO_2$ to the gulf (GKh) through air-sea exchange and advective water transport from the Arabian Sea. Reasonable fit for the GKh coral data was obtained with air-sea exchange rate of 11-12 mol m^{-2} yr^{-1}, upwelling velocity ~10 m yr^{-1} (in the Arabian Sea) and advective velocity of 28 m yr^{-1} between Arabian Sea and the Gulf of Kutch. The model results also suggest that it is not possible to reproduce the radiocarbon time series in the GKh coral without considering the advective supply of carbon and radiocarbon to the gulf from the Arabian Sea. Further the model also predicts that with the typical CO_2 exchange rate of 8-25 mol m^{-2} yr^{-1} the $\Delta^{14}C$ in corals would be much higher than commonly observed if dilution by advective supply is not considered. The deduced velocity (~ 28 m/yr) of the advective transport of water between the gulf and the Arabian Sea is much lower than the surface current velocity in this region, but can be understood in terms of fluxes of carbon and radiocarbon to the gulf to match the observed coral $\Delta^{14}C$ time series.

SCOPE FOR FURTHER WORK

The work presented in this thesis represents the first detailed study of stable isotopic and radiocarbon systematics in corals from the Indian coasts. The study was conducted to explore the utility of these corals as a source of climatic and oceanographic recorders for this region. The results, as summarized in the earlier pages are very encouraging and attest to the use of corals as high resolution records of "ocean climate".

The reconstruction of the historical SST data using the coralline $\delta^{18}O$ in both spatial and temporal domain would be important for climate models aimed at establishing relation between the SST and monsoon and eventually predicting monsoon rainfall. Such models would naturally require high precision historical data, which at present are difficult to retrieve from coral studies. Availability of data of the temporal variability of $\delta^{18}O$ of ambient water, and more precise estimate of the disequilibrium offset should help retrieve the historical SST with better precision. An independent approach would be to use the Sr/Ca thermometry in coral.

One of the important climate systems in the tropics is monsoon. To understand the monsoon dynamics, its characteristic behaviour in seasonal and interannual time scale, it is essential to have a detailed knowledge of its past variability. Analysis of longer cores of corals from the Lakshadweep region will be extremely helpful in this aspect. The present work has revealed that the $\delta^{18}O$ of coral faithfully records the seasonal sea surface cooling induced by monsoon upwelling. Our results show that the enhancement of the $\delta^{18}O$ and the depletion in the $\delta^{13}C$ of coral take place during the monsoon period. Detailed investigation in this direction is necessary to quantify the $\delta^{18}O$-$\delta^{13}C$ relationship. These characteristics can be used as indices to quantify the changes in monsoon intensity. This can be further augmented by the combined analyses of stable isotope and cadmium data, since cadmium concentration is a measure of upwelling.

The interpretation of carbon isotopic records, as already mentioned has been difficult since the factors contributing to its fractionation are not well understood. We have shown that in the Lakshadweep region the seasonal cyclicity in the $\delta^{13}C$ of coral is controlled by zooxanthellar photosynthesis modulated by monsoon activities. However the causes for difference in the $\delta^{13}C$ absolute values among samples collected from nearby locations and its long term trends need to be better understood. It is essential to know more about the causative mechanisms of the spatial and temporal (decadal timescale) trend in $\delta^{13}C$ which would help in developing better models for the oceanic uptake of fossil fuel CO_2. To gain a better knowledge on the controlling factors of the coralline $\delta^{13}C$, better data on seasonal variability of water column productivity and $\delta^{13}C$ of ΣCO_2 of water are needed.

The *Favia* coral from the Gulf of Kutch is characterized by lower growth rate, which limits its utility for retrieving climatic information on seasonal time scale. However the analysis of oxygen isotopes seems to be promising in retrieving qualitative information of rainfall variability and the carbon isotope would be useful to estimate the past productivity. Combined analyses of time contemporaneous samples of the coralline $\delta^{13}C$ and sea surface productivity is warranted to quantify the $\delta^{13}C$-productivity relation. Analysis of other coral species having higher growth rate like *Porites* from this region will be useful to understand the monsoon related phenomena in finer resolution.

The extension of the radiocarbon analysis in coral bands dated back to 30's or 40's will provide the pre-bomb surface sea $\Delta^{14}C$. Since many of the oceanic models deal with steady state conditions, an accurate determination of the steady state difference in atmosphere and oceanic $\Delta^{14}C$ would be essential to constrain these models. A longer time series of coral bands back in time would provide information of "Suess effect" in the Arabian Sea vis-a-vis in other oceanic regions. High resolution measurements of oceanic and atmospheric $\Delta^{14}C$ may give valuable information about the seasonal dependence of the CO_2 exchange rate, and also the role of the Arabian Sea in the overall air-sea exchange and carbon budget. Extension of the modelling work on $\Delta^{14}C$ from steady state to transient case, incorporating the temporal change in atmospheric CO_2 concentration would provide better constraints on the CO_2 air-sea exchange and ocean water mixing rates.