Chapter 5
Summary and Conclusion

5.1 Summary of Analytical Methods

I summarise the analytical methods developed for this research work, in terms of chemistry and mass spectrometry. A chemical separation protocol was developed using α – HIBA chemistry to obtain a pure Nd fraction from rock matrices. Using this protocol, I was able to attain a successful separation of Nd from Ce, where Ce was removed to the background level. This ensured no isobaric interference in the measurement of $^{142}Nd/^{144}Nd$ by TIMS. The effects of data acquisition and data reduction methods on the accuracy of ^{142}Nd results were studied in detail. In particular, the effect of the number of sequences employed in a multi-dynamic data acquisition scheme on the accuracy of results was investigated in light of higher average fractionation rates. No such effect was observed. However, we observed that the accuracy of $^{142}Nd/^{144}Nd$ data heavily depended on the method of mass fractionation correction used. The power-normalised exponential law was found to be the most appropriate method for the mass fractionation correction for data acquired by TIMS. The homogeneity of terrestrial $^{142}Nd/^{144}Nd$ is crucial for inter-comparison of $\mu^{142}Nd$ data which uses ratio measured in terrestrial standards. To validate this point we analysed two commonly used terrestrial standards; Ames Nd and JNdi-1, for their ^{142}Nd isotopic compositions. To our surprise, a 6 ppm difference in their ^{142}Nd isotopic compositions was observed, which is significant in context of the magnitude of the anomalies reported and therefore, is important for the inferences on the early silicate Earth differentiation since this can lead to appearance or disappearance of the anomalies in the μ notation. We observed this effect in our data for the 1.48 Ga alkaline igneous rocks of Khariar. Our study finds that JNdi-1 is a homogeneous standard and we strongly encourage use of JNdi-1 as terrestrial reference. We also provide a cross-calibration for the $^{142}Nd/^{144}Nd$ of JNdi-1 and Ames Nd: $(^{142}Nd/^{144}Nd)_{JNdi\text{-}1} = 0.809695\times(^{142}Nd/^{144}Nd)_{Ames\ Nd} + 0.2172901$. Using this relationship we obtained a value of 1.1418302 for JNdi-1 corresponding to our long term average of 1.1418375 for Ames Nd. This value was used for the calculation of $\mu^{142}Nd$ for various rocks analysed in the present study.

5.2 Summary of ^{142}Nd Isotope Composition of the Analysed Rocks

Using the analytical protocols and measuring techniques developed by us, I carefully analysed and reduced the data obtained for different magmatic rocks of India. The analyses of Archean rocks from Singhbhum (3.45 Ga) and Aravalli (3.3 Ga) Cratons reveal that the granitoids from Aravalli Craton do not possess any signature of early silicate Earth differentiation, whereas the TTGs from Singhbhum appears to carry a positive μ^{142}Nd anomaly with respect to JNdi-1 standard. This hints at involvement of the EDR in generation of the Singhbhum TTGs, which in turn suggests that positive ^{142}Nd anomalies persisted for at least 350 million years beyond the formation of the TTGs of Greenland. Analyses of SCLM derived alkaline silicate rocks, kimberlites and carbonatites of varying ages (1.5 Ga to 65 Ma) from various parts of India did not yield any anomalous ^{142}Nd isotopic composition.

5.3 Important Findings

The major findings of my thesis work are the following:

1. The number of sequences used to acquire data during multi-dynamic mode of data acquisition in Nd isotopic analysis by TIMS has no effect on the average (and relative) fractionation rate and hence, does not affect the accuracy of the data acquired.
2. The accuracy of the Nd isotopic data depends on the method of mass fractionation correction used. For data acquired using multi-dynamic mode, a power-normalised exponential law is the most appropriate method for fractionation correction.
3. A comparative study of the two commonly used Nd standards, Ames Nd (used for routine measurements in our laboratory) and JNdi-1, was done and we find that ^{142}Nd/^{144}Nd isotopic composition of JNdi-1 is lower by 6ppm (in μ^{142}Nd notation) with respect to that of Ames Nd.
4. We obtained a cross-calibration relation: $(^{142}Nd/^{144}Nd)_{JNdi-1} = 0.809695\times(^{142}Nd/^{144}Nd)_{Ames\ Nd} + 0.2172901$ ($R^2 = 0.89$), for inter-comparison of ^{142}Nd/^{144}Nd data with respect to JNdi-1 and Ames Nd.
5. The value of μ^{142}Nd varies with the choice of the terrestrial standard used for calculation of μ. This has important implications for the discovery of anomalous compositions.
6. Alkaline rocks from Khariar show no resolvable anomaly in μ^{142}Nd notation, with respect to Ames Nd. However, the values obtained were nominally negative. These negative values became zero (in μ^{142}Nd notation) when normalised with respect to JNdi-1.
7. A combined effect of the choice of fractionation correction method and of the terrestrial standard used for normalization, led to the two contradicting results from the same sample aliquots of Khariar alkaline rocks, as were reported by Upadhyay et al. (2009) and Roth et al. (2014).

8. The 3.45 Ga Archean rocks of India (TTGs from Singhbhum Craton) hint at preservation of EDR signature in their mantle source. This suggests preservation of the positive anomalies for at least 350 million years beyond the formation of TTGs of Greenland.
9. The alkaline rocks and carbonatites derived from SCLM do not carry and/or preserve the early silicate Earth differentiation signatures beyond 1.5 Ga in the Indian mantle domains.

5.4 Concluding Remarks

In conclusion, I would like to stress on the importance of understanding the role of analytical methods in the possible generation of the analytical artefacts in the measurements of ^{142}Nd for study of early silicate Earth differentiation. A significant dependency is observed between the method of fractionation correction employed for data reduction and accuracy of the results obtained. However, the mode of data acquisition is found to of have little effect on the accuracy of the final results. In addition, the difference in the ^{142}Nd/^{144}Nd isotopic compositions of the two most commonly used terrestrial standards - Ames Nd and JNdi-1, may lead to appearance or disappearance of anomalous μ^{142}Nd, depending upon the choice of standard used for calculation of μ. It is therefore, strongly recommended for the future studies to use a homogenous standard like JNdi-1 for easy comparison and reproduction of ^{142}Nd results. Non-convecting mantle domains may not be the sites for preservation of the signatures of the EER. The oldest Archean craton of India may have preserved evidence of the EDR.

5.5 Future Studies

^{146}Sm-^{142}Nd is the best known tracer to understand the early silicate earth differentiation. Since analytical methods and choice of terrestrial (lab/international) standard have profound effect on the accuracy of measurements and calculation of μ^{142}Nd, I would like to propose the following investigations to make the methodology robust and free of errors.

1) Cross-calibration of the various commonly used Nd terrestrial standards, in particular La Jolla, JNdi-1 and Ames Nd. This will facilitate comparison of data from different labs.
2) International campaign to provide an accurate and precise ^{142}Nd/^{144}Nd ratio for the highly homogeneous standard JNdi-1.
3) Further studies on Archean rocks, in particular TTGs, from different Indian cratons in my continued effort in search of the illusive EER.