

# **ISOTOPIC AND ELEMENTAL STUDIES OF GONDWANA CARBONATES AND THEIR IMPLICATIONS**

**A Thesis submitted to**

**DEVI AHILAYA VISHWA VIDHYALAYA  
INDORE**

**For**

**THE DEGREE OF  
DOCTOR OF PHILOSOPHY IN  
PHYSICS**

**By**

**PROSENJIT GHOSH**

*Dedicated  
To  
My beloved parents*

## CERTIFICATE

I hereby declare that the work presented in this thesis is original and has not formed the basis for the award of any degree or diploma by any university or Institution.

*Prosenjit Ghosh*  
**Author**

(PROSENJIT GHOSH)

*S.K. Bhattacharya*

**Thesis Supervisor**

(Prof. S.K.Bhattacharya.)

## *Acknowledgement*

I am indebted to Prof. S.K. Bhattacharya, my cherished guru, for his guidance and encouragement provided throughout the investigation and during the preparation of this thesis. Many of the ideas incorporated in this thesis originated from him. I also express my deep sense of gratitude to him for teaching me the art of stable isotope mass spectrometry. I am beholden to many people, whose inspiration, advice and precious time have helped me considerably in the creation of this thesis. Mr. R.A. Jani and Dr. R. Ramesh of Stable isotope Laboratory, PRL provided me all essential facilities and encouragement for the analyses of samples. I am grateful to Prof. Krishnaswami, Prof. K. Gopalan, Prof. J.N. Goswami, Dr. R. Ramesh Dr. M.M. Sarin, Prof. B.L.K. Somayajulu, Prof. N. Bhandari and Dr. G. Srinivasan for valuable discussions during group seminars and annual review. Dr. A.M. Dayal, Dr. J.R. Trivedi and Dr. M.M. Sarin helped me enormously for analytical works. Many thanks are due to them. REE and Trace elemental analyses of the samples presented in the thesis, would have been impossible without the help of Prof. Ebihara of Tokyo metropolitan University. I am thankful to Prof. Ebihara and Dr. Anindya Sarkar for timely analyzing the samples and sending me the results.

This study would have been impossible without the generous supply of samples and guidance during field work from Prof. Amitava Chakrabarti of IIT Kharagpur. I gratefully acknowledge his help and cooperation during various stages of this work. His continuous support and suggestion helped me improving the quality of this work. My thanks are due to Dr. Partha Sarathi Ghosh of ISI Calcutta for his help in field work and providing me some of the precious samples used during investigation.

I had a pleasure of working with many members of Earth Science group, PRL. Dr. P.N. Sukhla, Dr. Kanchan Pandey, Dr. Supriya Chakrabarti, Mr. Navin Juyal, Mr. J.T. Padia, Mr. Deshpande, Mr. Ravi Bhushan, Dr. Ashish Sarkar, Dr. Sunil Singh, Dr. J.S. Ray, Mr. M. Yadava, Mr. D.K. Rao, Dr. D. Yadav, Mr. Kaushik Dutta, Mr. Rajesh Agnihotri, Mr. Subrata Chakrabarty, Mr. A.D. Sukhla, and Mr. Tarun Dalai. My special thanks are due to Dr. J.S. Ray for quickly analyzing a few thin section samples using CL facility at Ottawa University. I am thankful to Prof. K. Gopalan and Dr. A.M. Dayal of N.G.R.I. for their help in analysing large number of samples for Sr isotopes. Dr. Sudipta Sarkar of GSI, Gandhinagar helped me in clay extraction work and taught me the technique. Dr. Simon Prosser of former Europa helped me in Inter-laboratory calibration exercise by analysing a few Z-Cararra and MMB laboratory standards in GE020-20 mass spectrometer at Utah University, USA.

I wish to extend special thanks to Dr. Supriya Chakrabarti and R. Ramesh for reading the manuscript and for their valuable suggestion and criticisms towards the improvement of manuscript.

I learnt many aspects of electronics and software usage from Mr. V.G. Shah, Mr. Pandian, Mr. Pranav, and Mr. Rahul Sharma. I am extremely thankful to all these people, who had the patience to make me understand the subject. I have always enjoyed the favour of Mr. Kurup and Mr. Sivasankaran, for various glass blowing job. I have learnt from them the initial art of glass blowing. I am extremely thankful to both of them for support and encouragement. I am thankful to Mr. J.P. Bhavsar and Mr. N.B. Vaghela for help and assistance.

I appreciate the help and encouragement provided by Prof. Amitabha Chakrabarti, Prof. Pradip Bose, Prof. V. Rajamani, Prof. K. Balakrishnan, Prof. D.M. Banerjee, Prof. S. Kumar, Prof. S.K. Tandon, Dr. Shishuti Ray and Dr. Parthasarathi Ghosh for petrographical studies. Discussion with Prof. S. Kumar and Prof. Pradip Bose were helpful in explaining some of the experimental observations.



*I am thankful to Council of Scientific and Industrial Research (CSIR), PRL and Committee for International conference on Geochronology and Cosmochronology (ICOG) for providing me travel assistance and opportunity for participation in ICOG-9, Beijing, 1998.*

*The help and cooperation extended by the authorities: PRL's Academic committee, Administration and Workshop, and Devi Ahilaya Vishwavidyalaya, Indore in particular Prof. K.P. Maheshwari is gratefully acknowledged. I applaud the help provided by PRL Library members. I am thankful to Mrs. Panna Thakkar, Mrs. Rohini Patil, Mrs. Nisitha, Mr. Kewar and Mrs. Giya for support and timely help.*

*The Inspiration and cheers given by my friends and admirer of my elegant stories, Dr. Ramachandran, Dr. Tarun Pant, Dr. Prashant Rawat, Dr. Siva Kumaran, Dr. Debasish Banerjee, Dr. Debabrata Banerjee were of tremendous value during the course of this work. Biannual field session and PRL sports clubs and members kept my health in good condition through continuous involvements in various sports and tournaments.*

*Special thanks are due to Mr. Dholakia and Mr. P.S. Shah of computer section for assistance. I am really appreciating the enormous support provided by all colleague and fellow mates during concluding stage of the thesis. I express special gratitude to Mr. Anirban Das, Mr. Subrata Chakrabarty Mr. Supriya Chakrabarty, Mr. Koushik Dutta, Mr. A.D. Sukhla, Miss Debjani, Miss Leena, Miss Basu and Miss Kaur.*

# Abstract

## Section-A

Ubiquitous presence of carbonate nodules in glaciogene sediments of various Permo-Carboniferous basins in peninsular India offers promise for delineating the climate and environment of deposition at that time. Isotopic composition of carbon and oxygen have been determined in carbonate nodules collected from the basal formation (Talchir) of three Gondwana basins of East-Central India along with a few samples from contemporaneous Dwyka tillite of South Africa. Petrographic, cathodoluminescence and sedimentary evidences suggest that many of these nodules contain primary carbonate precipitates and therefore their geochemical signatures can be used for palaeoclimatic inference. The mean  $\delta^{18}\text{O}$ ,  $\delta^{13}\text{C}$  and  $^{87}\text{Sr}/^{86}\text{Sr}$  values of the calcites in the nodules are 10.8 ‰ w.r.t. SMOW, -9.7 ‰ w.r.t. PDB and 0.730 respectively suggesting a freshwater environment (probably lacustrine) for formation of these concretions. The mean oxygen isotopic composition of meteoric water at that time (Early Permian) and location (70 °S palaeolatitude) estimated from  $\delta^{18}\text{O}$  of calcite is -22.5 ‰ and is close to the expected isotopic composition of precipitation (-21.0‰) at this latitude. This similarity suggests that (i) assignment of palaeolatitude of this location is reasonably correct and (ii) the global hydrological cycle in Early Permian was operating in a similar way as that of today. There is a slight depletion in value, which can be interpreted either in terms of an amount effect due to enhanced rainfall or an altitude effect if the precipitation occurred at high altitude as expected for development of the Talchir glacier. Nodules are analyzed for Sr isotopic composition and results indicate that samples from Damodar valley region (with Sr ratio ~0.730), received water draining from adjoining granitic terrain of Chotanagpur region as suggested by isotopic ratio of 0.730 for its most weatherable component i.e. plagioclase mineral. Similarly, nodules from Mahanadi valley have  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio of 0.720 similar to the ratio observed in mafic granulite of eastern ghat suggesting this region to be water source for Talchir basin in Mahanadi valley. This inference is supported by REE pattern and trace element concentration of carbonate phase of bulk nodule samples.

## Section-B

Satpura basin of Central India contains four well-developed soil horizons belonging to Permian (Motur Formation), Triassic (Denwa Formation), Jurassic (Bagra Formation) and Cretaceous (Lameta Formation) periods. These soils contain pedogenic carbonates in the form of rhizocretion and nodules. The oxygen isotopic composition of these carbonates is used for inferring the soil temperature during those periods. The carbon isotopic compositions of the soil carbonate and coexisting soil organic matter are used to infer the  $\delta^{13}\text{C}$  of atmospheric  $\text{CO}_2$  and its concentration using the model developed by Cerling. It is seen that the atmospheric  $\text{CO}_2$  level increased by a factor of 8 from Permian to Jurassic and declined again during Cretaceous. The nature of the change agrees with the result of the  $\text{CO}_2$  evolution model of Berner (GEOCARB II) but the magnitude of the  $\text{CO}_2$  increase in Middle Jurassic and Late Cretaceous was higher than the predicted value. The rapid increase in  $\text{CO}_2$  concentration is consistent with the observed increase in the maturity of the soil profiles along the stratigraphic column. Degassing of Earth's interior due to rapid break-up of the Gondwana landmass during Triassic and Jurassic period could have caused the rapid  $\text{CO}_2$  evolution.

# Contents

List of figures and Tables	i
<b>Chapter 1 Introduction</b>	
Introduction	1
Purpose of this study	13
The outline of the thesis	14
<b>Chapter 2 Materials &amp; Experimental Techniques</b>	16
2.1 Geology and Stratigraphy of Gondwana basins	16
2.1.1 Damodar valley basin	19
2.1.2 Mahanadi valley basin	26
2.1.3 Godavari valley basin	28
2.1.4 Development of concretions in siltstone bed and their classification	30
2.1.5 South African nodules	32
2.1.6 Satpura valley basin	33
2.2 Experimental Techniques	44
<b>Chapter 3 Results and Discussion</b>	62
Section-A (nodular carbonates from Talchir)	
3A.1 Morphology of nodules	62
3A.2 Petrography	65
3A.3 Cathodoluminescence	65
3A.4 Clays in nodules	67
3A.5 Mn, Fe, and Sr concentration in carbonates as diagenetic indicator	68
3A.6 Stable isotopic study	73
3A.6.1 Oxygen isotopes	76
3A.6.2 Carbon isotopes in the nodular carbonates	81
3A.6.3 Presence of Organic matter in the nodules	82
3A.6.4. Environment during Talchir sedimentation: monsoonal implications	83
3A.6.5 Stable isotopic variation within a nodule	84
3A.6.6 Enigmatic objects in the basal Gondwana of Eastern India	88
3A.6.6a Stable Isotopes	90
3A.6.6b Carbon and Nitrogen in the suspected algae	91
3A.7 Provenance of Talchir Basin sediments	92
3A.7.1 Rare Earth Elements	92
3A.7.2 Trace elements	95
3A.7.3 Strontium isotopic composition	101
3A.7.4 Sr isotopic composition of Mahanadi river water and Talchir carbonates	104
Section-B (Palaeosol studies from Satpura basin)	106
3B.1 Results and discussion	106
3B.2 Preservation of Geochemical signature	109
3B.3 Estimation of atmospheric pCO <sub>2</sub>	110
3B.4 The pCO <sub>2</sub> determination	119
3B.5 Berner's model of pCO <sub>2</sub> and the observed values	121
3B.8 Atmospheric CO <sub>2</sub> and Soil Maturity	123
<b>Chapter 4 Summary and Conclusion</b>	125
4.1 Environment of Talchir sedimentation	125
4.2 Provenance information	126
Enigmatic objects, in Gondwana sediments:	
fresh water Stromatolites	127
4.4 Suggested future work	128
<b>References</b>	131

## List of figures in Chapter 1

Figure 1.1: Schematic representation of Pangean continental configuration during Permo-Carboniferous period

Figure 1.2: Global map showing mean annual precipitation over Pangea. Note high precipitation (6mm/day) in coastal region and widespread aridity in the continental interior (Kutzbach and Gallimore, 1989).

Figure 1.3: Global record from late Precambrian to Cretaceous. Note presence of glaciers on all the southern continents during Permo-Carboniferous indicating a global scale glacier era (Price, 1999).

Figure 1.4: Suggested marine transgression in peninsular India during Permian period based on marine fossils found in Mahendragarh, Daltonganj and Umaria shown in the map. A probable trans-Indian seaway is shown by hatched zone (Ghosh, 1954). The Latitude\_longitude mark denotes 8 degree interval.

Figure 1.5: Present day variation in oxygen isotopic composition of rainfall at various latitudes given by range of colours corresponding to various  $\delta^{18}\text{O}$  values (IAEA data compiled by Rozanski, 1989).

Figure 1.6: Atmospheric  $\text{CO}_2$  versus time for Phanerozoic (past 550 million year). The parameter  $\text{RCO}_2$  is defined as the ratio of concentration of  $\text{CO}_2$  in the atmosphere at some time in the past to that at present (i.e. a preindustrial value of 280 ppmV). The heavier black line represents the best estimate from GEOCARBII model. The shaded area denotes the approximate range of uncertainty of the model based on sensitivity analysis. Vertical bars represent estimates of  $\text{CO}_2$  levels based on study of palaeosols (Mora et al., 1996; Sinha and Scott, 1994; Andrew et al., 1995; Ghosh et al., 1995; Yapp and Poth, 1993; Cerling, 1991)

## List of figures in Chapter 2

Figure 2.1: Gondwana basins of Peninsular India.

Figure 2.2: Geological map showing lithological units of the West Bokaro sub-basin, Damodar valley.

Figure 2.3: Bluish grey siltstone containing nodules.

Figure 2.4: Climbing ripple lamination showing oppositely oriented direction of climb.

Figure 2.5: Hummocky cross stratification in bluish grey siltstone bed.

Figure 2.6: Interference ripples in the upper sandy part of the varve like siltstone facies.

Figure 2.7: Suspected trails marking of gastropod preserved in the fine grained silty sediments of rhythmite facies.

Figure 2.8: Schematic diagram showing lateral transition of sedimentary units in Talchir formation around Dudhi Nala area.

Figure 2.9: Geological map showing Talchir sequence, Dhenkanal district, Orissa.

Figure 2.10: Suspected stromatolite with concentric growth laminations, resembling cabbage in structure.

Figure 2.11: Striated Vindhyan pavement at Irai, Godavari basin.

Figure 2.12: Thin section photograph showing calcareous fine grained core of a nodule.

Figure 2.13: Picture showing continuation of lamination from host to interior of nodule.

Figure 2.14: Draping of laminations over and around the nodules.

Figure 2.15: Occurrence of nodules as isolated bodies.

Figure 2.16: Compact cementation of nodule at the core, showing presence of growth ring.

Figure 2.17: Succession of sedimentary rocks of different formations in Satpura basin.

Figure 2.18: The lithological units in Satpura valley, Gondwana basin.

Figure 2.19: Schematic representation showing the morphological pattern of calcrete development in motur formation. A field photograph of palaeosol as inset.

Figure 2.20: Denwa formation with internally cross stratified sediments hosting the soil carbonates. (b) Thin section showing development of glaebules and radial fractures. (c) microphotograph of a glaebule.

Figure 2.21: Large cylindrical rhizocretions in the palaeosol profile of Bagra formation, Anjan Nala.

Figure 2.22: Histogram showing the distribution of  $\delta$ -values (carbon and oxygen), in Z-Carrara laboratory standard measured against working gas. Measurements were made in VG602 updated to 903, conversion to VPDB reference done through working gas calibration (based on Table 2.5).

Figure 2.23: Histogram showing the distribution of  $\delta$ -values (carbon and oxygen), in MMB laboratory standard measured against working gas. Measurements were made in VG602 updated to 903, conversion to VPDB reference done through working gas calibration.

Figure 2.24: Histogram showing the distribution of  $\delta$ -values for Z-Carrara standard w.r.t VPDB.

Measurements were made w.r.t. working gas CD-197 in order to check the long term reproducibility of laboratory standard (based on data shown in Table 2.7).

Figure 2.25: Results of analysis of  $\delta^{13}\text{C}$  of  $\text{CO}_2$  obtained by combusting the UCLA glucose (laboratory standard) measured w.r.t. working gas during 197-99 work. Conversion to VPDB reference done through working gas calibration.

### List of Tables in Chapter 2

Table 2.1 : Stratigraphic correlation of sediments occurring in four Gondwana basins of peninsular India and their equivalent in South Africa, Antarctica and South America.

Table 2.2: Description of samples collected from Talchir formation of peninsular India.

Table 2.3 : Palaeosol samples from Satpura basins and their descriptions.

Table 2.4:  $\delta^{18}\text{O}$ ,  $\delta^{13}\text{C}$  values of carbonate check standard MAKMARB (MMB)\* (prepared from Makrana Marble, Rajasthan, India) analysed in VG-903 mass spectrometer (1995-98) (50°C online extraction procedure).

Table 2.5:  $\delta^{18}\text{O}$ ,  $\delta^{13}\text{C}$  values of carbonate standard new Z-Carrara\* (provided by N.J. Shackleton) analysed in VG-903 mass spectrometer (1995-98) (50°C online extraction procedure).

Table 2.6: Typical examples of  $\delta$ -Values of standard Z-Carrara carbonate run on single day.

Table 2.7:  $\delta^{18}\text{O}$ ,  $\delta^{13}\text{C}$  values of carbonate standard new Z-Carrara\* (provided by N.J. Shackleton) analysed in GEO20-20 mass spectrometer (80°C online extraction procedure, CAPS).

Table 2.8: Comparison of carbonate standard used during experiment measured at PRL (with VG903 and GEO20-20 mass spectrometer) and two other laboratories (Cambridge Univ., U.K. and Cornell University, New York).

Table 2.9:  $\delta^{13}\text{C}$  value of UCLA glucose measured along with samples of  $\text{CO}_2$  obtained from decomposition of organic matter.

Table 2.10: Observed concentration of Fe, Sr, Mn of Laboratory standard NOVA and MAG-1 compared with expected values.

Table 2.11: Comparison of observed concentration of Fe, Sr, Mn with expected concentration in three laboratory check standards (prepared gravimetrically).

### List of figures in Chapter 3

Figure 3.1a: Microphotograph of DN/N7 nodule, comprising angular grains of Quartz (Q) and felspar (F) with calcite occurring in pore spaces.

Figure 3.1b: Microphotograph of DN/N1 nodule, indicating presence of micritic carbonates around detrital quartz and felspar grain denoting percolation of saturated carbonate solution in between detritals.

Figure 3.1c: Microphotograph of nodule showing poikilotopic cements replacing pore spaces.

Figure 3.1d: Microphotograph showing presence of biotite, amphibole, plagioclase and felspar within the nodule sample DN/N/2/95

Figure 3.1e: microphotograph of nodule from Bhunipara locality showing Fe rich smectite clay skin and presence of organic matter in isolated patches.

Figure 3.2: (a) Image of sample DN-7 in plane polarised light.

Figure 3.2: (b) CL image of the same section; blue colour are quartz and darker patches denotes clay and felspars. Bright red CL represents carbonates with high Mn/Fe whereas the dull red represents low Mn/Fe.

Figure 3.3: Histogram showing frequency distribution of Mn/Fe ratio in carbonate phase of Talchir nodules. Large number of samples have low Mn/Fe ratio indicating alteration subsequent to their formation. NL denotes zone of non luminescent calcite in CL. An average value of Mn/Fe in modern day lake carbonate is shown by arrow.

Figure 3.4a: Frequency distribution of  $\delta^{18}\text{O}$  values in the unaltered nodule with gaussian fit to the data. The mean value is 11.0‰

Figure 3.4b: Frequency distribution of  $\delta^{13}\text{C}$  values in the unaltered nodules with gaussian fit to the data. The mean value is -11‰

Figure 3.5: Proposed schematic picture of glaciofluvial and glaciolacustrine environment leading to Talchir sedimentation and subsequent nodule formation.

Figure 3.6: Covariation plot of oxygen and carbon isotopic ratios in the micritic calcite from nodules and associated matrix.

Figure 3.7a : Variation of oxygen isotope ratio within nodules collected from West Bokaro basin and Ramgarh basin. Note depleted core and enriched rim in most of the nodules.

Figure 3.7b : Correlation of carbon and oxygen isotope ratios in samples from nodule sections. Green triangle represents Damodar valley nodules whereas red circles denote data for one nodule from Ramgarh basin, which has anomalously low  $\delta^{18}\text{O}$  at the center.

Figure 3.8a : Growth of calcite lamination parallel to the bedding surface resembling growth and deposition of algal bodies (bar represents 1 cm).

Figure 3.8b : Juxtaposition of separated hemispherical tussocks of different sizes in a thin section of algal carbonate.

Figure 3.8c : Tussocks structure observed in serizian radiolites, Southwest Africa for comparison (scale bar = 100  $\mu\text{m}$ ).

Figure 3.9a : Carbon and oxygen isotope ratio in algal carbonates from Nandirjhor Nala section.

Figure 3.9b : Carbon isotope ratio in the organic matter associated with algal carbonate from Nandirjhor Nala section.

Figure 3.10: Chondrite normalized concentrations of eight rare earth elements in the nodules of West Bokaro region (Damodar valley). Red curve shows the pattern of REE in the nearby Singhbhum granite (south of the basin).

Figure 3.11: Chondrite normalized concentrations of eight rare earth elements in the nodules of Ramgarh region (Damodar valley). Blue curve shows the pattern of REE in the nearby Singhbhum granite (south of the basin).

Figure 3.12: Chondrite normalized concentrations of eight rare earth elements in the nodules of Talchir basin (Mahanadi valley). Red curve shows the pattern of REE in the basic granulite occurring in the southern part of the basin.

Figure 3.13a: Schematic diagram showing palaeocurrent direction based on earlier studies on sedimentary structures and heavy mineral assemblage. Note Damodar valley sediments are derived from Chotanagpur granite and Talchir basin sediments are derived from granulite belt of Eastern Ghat.

Figure 3.13: Cartoon showing concentration of trace elements and Sr isotopic ratios in postulated provinces and sediments in corresponding basins.

Fig 3.14: Frequency distribution showing Sr isotopic ratio in carbonate nodule collected from three Talchir basins of peninsular India.

Fig 3.15:  $\delta^{18}\text{O}$  vs  $\delta^{13}\text{C}$  plot of soil carbonates from Motur, Denwa, Bagra and Lameta formation of Satpura Gondwana basin.

Fig 3.16: The Palaeogeographic reconstruction of Gondwana landmasses indicates that the peninsular region of India was situated at 500° during Permian and at 40° to 30° during Middle Triassic and Middle Jurassic respectively.

Fig 3.17: Plot of  $\text{RCO}_2$  against soil age (in my) where R represent the ratio of concentration of a given age relative to the preindustrial modern value (280 ppmV) compared with Berner's model prediction. The envelope of uncertainty in the model is shown by dashed lines.

Fig 3.18: Change of soil maturity with  $\text{pCO}_2$

### List of Tables in Chapter 3

- Table 3.1 Clay minerals of a few nodules collected from three Talchir basins.
- Table 3.2 Ca, Mg, Fe, Sr and Mn concentrations in carbonate phase<sup>†</sup> of Talchir nodules (% and ppm expressed with respect to bulk).
- Table 3.3 Stable isotopic composition of Talchir nodules along with sample description
- Table 3.3b Calculated excess precipitation required to explain Talchir Oxygen isotope data
- Table 3.4 Stable isotopic composition of Talchir nodules and organic matter present in them along with sample description
- Table 3.5 - Carbon and oxygen isotopic compositions of samples from core to rim of nodules A, B, C, D and BP/N1.
- Table 3.6 Isotopic composition of stromatolitic carbonates and residual organic matter from Nandirjhor nala section, Mahanadi valley basin.
- Table 3.7 REE composition of whole rock samples from three different Talchir basins of Peninsular India (in ppm).
- Table 3.8 Trace composition of whole-rock nodule (in unit of ppm).
- Table 3.9 Ratios used for discriminating the provenance of sediments.

Table 3.10 Strontium isotopic ratios and concentration in the carbonates.

Table 3.11 Isotopic composition of palaeosol carbonates and residual organic matter in the matrix.

Table 3.12. Determination of soil temperature during Motur (260 m.y.), Denwa (240m.y.), Bagra (200m.y.) and Lameta (65m.y.) periods from measured oxygen isotopic composition of soil carbonates and composition of rain water expected during these periods.

Table 3.13 Estimation of concentration of  $\text{CO}_2$  at different times in the past a comparison.

Table 3.14 Estimation of concentration of  $\text{CO}_2$  and its isotopic composition in atmosphere at different times in the past.



For Fulltext Please Contact

To

[pghosh@gps.caltech.edu](mailto:pghosh@gps.caltech.edu)