Geochemical and Isotopic studies of Waters and sediments of Arabian and Andaman Seas

A THESIS

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by

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Under the Supervision of

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D E C L A R A T I O N

I, Mr. **Damodararao Karri**, S/o Mr. Polayya, resident of J-117, PRL residences, Navrangpura, Ahmedabad – 380009, hereby declare that the research work incorporated in the present thesis entitled **"Geochemical and Isotopic studies of Waters and sediments of Arabian and Andaman Seas"** is my own work and is original. This work (in part or in full) has not been submitted to any University for the award of a Degree or a Diploma. I have properly acknowledged the material collected from secondary sources wherever required.

I solely own the responsibility for the originality of the entire content.

Date: (Damodararao Karri)

C E R T I F I C A T E

I feel great pleasure in certifying that the thesis entitled "**Geochemical and Isotopic studies of Waters and sediments of Arabian and Andaman Seas**" embodies a record of the results of investigations carried out by **Damodararao Karri** under my guidance.

He has completed the following requirements as per Ph.D. regulations of the University

(a) Course work as per the university rules

(b) Residential requirements of the university

(c) Presented his work in the departmental committee

(d) Published/accepted minimum of one research paper in a referred research journal.

I am satisfied with the analysis of data, interpretation of results and conclusions drawn.

I recommend the submission of thesis.

Date:

Name and designation of supervisor
Sunil Kumar Singh,
Professor

Countersigned by

Head of the Department

Dedicated

To

My Parents,

Smt. Ramulu & Sri. Polayya

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List of abbreviations and symbols

AABW	: Antarctica bottom waters
AAIW	: Antarctic Intermediate Waters
ACC	: Antarctic Circumpolar Current
AS	: Arabian Sea
ASHSW	: Arabian Sea high saline surface waters
BoB	: Bay of Bengal
BoBSW	: Bay of Bengal surface waters
BRMN	: Brahmani
CCR	: CO_2 consumption rates
CDW	: Circumpolar Deep Water
CER	: Carbonate erosion rate
CGGC	: Chotanagpur Granite Gneiss complex
CV	: Coefficient of Variation
CHUR	: Chondritic Uniform Reservoir
CIA	: Chemical index of alteration
CSI	: Calcite Saturation Index
CTD	: Conductivity-Temperature-Density
DEM	: Digital Elevation Map
DO	: Dissolved Oxygen
EGMB	: Eastern Ghats Mobile Belt
EICC	: East India Coastal Current
EIGB	: East Indian Ghats belt
EJ	: Equatorial Jet
F-AAS	: Flame-Atomic absorption spectroscopy
G-B	: Ganga-Brahmaputra
GDV	: Godavari
GRS	: Godavari River System
HH	: Higher Himalaya
HREEs	: Higher Rare Earth Elements
IBA	: Indo–Burman–Arakan
IC	: Ion chromatography
ICP-AES	: Inductively coupled plasma atomic emission spectroscopy
ID	: Isotope dilution
IIW	: Indonesian Through Flow Intermediate Water
IOG	: Iron Ore group
ITF	: Indonesian Through Flow
IW	: Indonesian Through Flow surface Water
JMC 321	: Neodymium isotope standard solution
JMC 475	: Hafnium isotope standard solution
KR	: Krishna River
L	: Litter

LH : Lower Himalaya
LREEs : Lower Rare Earth Elements
Ma : Million annum
MC-ICP-MS : Multicollector Inductively Coupled Plasma Mass Spectrometer
MND : Mahanadi
MQ : Milli-Q water
MT : Million tons
NADW : North Atlantic deep waters
NASC : North American Shale Composite
NE : North-East
NICB : Normalized inorganic charge balance
NIDW : North Indian Deep Water
NIIW : North Indian Intermediate Water
OMG : Older Metamorphic Group
OMZ : Oxygen minimum zone
ORNL : Oak Ridge National Laboratory
ORV : Ocean Research Vessel
PAAS : Post Archean Australian Shale
PGW : Persian Gulf waters
pp : Poly Propylene
PRL : Physical Research Laboratory
PTFE : Poly tetrafluoroethylene
QD : Quartz distilled
Q-ICM-MS : Quadrupole Inductively Coupled Plasma Mass Spectrometer
REE : Rare Earth Elements
RSD : Relative standard deviation
RSW : Red Sea waters
RTB : Rajahmundry Traps Basin
SER : Silicate erosion rate
SGD : Submarine groundwater discharge
SIS : Stable Introduction System
SK : Sagar Kanya
SLRS-4 : Canadian River water standard
SM : Sagar Manjusha
SPM : Suspended particulate matters
SRM 987 : Strontium Carbonate Isotopic Standard
SS : Sagar Sampada
SW : South-West
TD : Teflon distilled
TDS : Total dissolved solids
TEIs : Trace elements and isotopes
TML : Theoretical mixing line
UC : Upper crust
θ-S-σ_θ : Temperature, salinity and potential density
α : Alpha

β	: Beta
δ	: Delta
μ	: Micro
ε	: Epsilon
σ	: Sigma
θ	: Theta

ABSTRACT

Distribution of trace elements in the ocean regulates productivity, ecosystem dynamics, carbon cycle and hence the global change. This thesis work attempts to identify and quantify the sources and sinks of selected trace elements by studying them in riverine–estuarine system, in the shelf region and in the open Indian Ocean. Erosion and weathering in the Peninsular Indian Rivers, the Godavari, the Mahanadi and the Brahmani basins seems to be controlled dominantly by lithology and runoff. Annually, they supply 25 MT of total dissolved solids, 150 Mmol of Sr and 12 thousands moles of Nd to their respective estuaries and sequester ~1% of atmospheric CO_2 through silicate weathering, similar to their drainage area proportion. Riverine fluxes get modified significantly in the estuaries before reaching to the open ocean. Release/desorption from the Fe-Mn oxy-hydroxide coating of the continental sediments found to be the potential source of dissolved rare earth elements (REE) and Mn in the East Indian estuaries and supply ~260 Mg of dissolved Nd annually to the Bay of Bengal, quite significant to the missing Nd in its global budget. This study identified submarine groundwater discharge (SGD) as an important source of dissolved Sr to East Indian estuaries. The annual Sr flux through the SGD from East Indian estuaries is 780 Mmol ~3-11% of the global SGD Sr flux and could be very important for the global Sr budget. This study, for the first time, recognized the higher erosion on the western slopes of the granitic ranges of the Southern Myanmar, supplying a significant amount of sediment to the Eastern Andaman Shelf in addition to the Indo-Burman Ranges. Runoff and relief control erosion and weathering in the hinterland of the Irrawaddy, Salween and western Myanmar basins. Further, this study quantified the different water masses present in the Arabian Sea using dissolved ε_{Nd} and ε_{Hf}. Bottom and deep waters of the Arabian Sea are dominated by the Antarctic Bottom Waters (50-85%) and the North Atlantic Deep Waters (25-60%). The Red Sea Waters (25-80%) and the Persian Gulf Waters (5-17%) occupy the intermediate depth. Surface waters of the Arabian Sea are composed of the Arabian Sea High Salinity Waters (40-85%) and the Bay of Bengal (20-50%). Atmospheric dust is found to be an important source of dissolved Nd to the surface waters of the Central Arabian Sea whereas sediments from the Indus Rivers deliver less radiogenic Nd to the Northern Arabian Sea waters.

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LIST OF PUBLICATION

Research publications

1. **K. Damodararao**, Sunil K. Singh, Vinai K. Rai, V. Ramaswamy and P.S. Rao, (2016). Lithology, monsoon and sea-surface current control on provenance, dispersal and deposition of sediments over the Andaman continental shelf, Front. Mar. Sci. 3:118. **doi: 10.3389/fmars.2016.00118**.

Articles (Under Preparation):

1. **K. Damodararao**, Gyana R. Tripathy, Sunil K. Singh and Vinai K. Rai, Chemical weathering in the Mahanadi and Brahmani River basins: Impact on major ions chemistry and radiogenic Sr and their fluxes to the Bay of Bengal.

2. **K. Damodararao** and Sunil K. Singh, Fractionation of rare earth elements and Nd isotope composition during weathering in the Godavari River System.

3. **K. Damodararao**, Sunil K. Singh and Vinai K. Rai, Chemical weathering in the Godavari River system: Impact on carbon cycle and trace elements budgets of the Bay of Bengal.

4. **K. Damodararao**, Sunil K. Singh and Vinai K. Rai, Dissolved Strontium concentration and its isotope composition in the mixing zone of the Eastern India Estuaries: Implications to the submarine groundwater discharge and contribution to the global marine Sr isotope budget.

5. **K. Damodararao**, and Sunil K. Singh, Massive release of trace elements and isotopes in the Ganga (Hooghly) and other East Indian estuaries: Implication to their modern Oceanic budgets.

6. **K. Damodararao**, Sunil K. Singh and Vinai K. Rai, Tracking the erosion pattern in the Godavari River system based on Sr-Nd isotope composition of particulates: Controlling factors and impacts.

7. **K. Damodararao,** Sunil K. Singh, Vineet Goswami and Ravi Bhushan, Dissolved Neodymium and its isotope composition in the Arabian Sea: Water Mass mixing vs. particle – water interaction.

8. **K.Damodararao,** Sunil K. Singh, Vineet Goswami, Ravi Bhushan and R. Rengarajan, The Hafnium concentration and its isotope composition in water columns of the Indian Ocean: Implications to its sources and Water Mass mixing patterns.

Abstracts (Conferences/Symposium):

1. **K. Damodararao** and Sunil K. Singh, Dissolved Sr and its isotopes in estuaries of eastern coast of India: Impact of submarine groundwater discharge. 28^{th} ISMAS symposium cum workshop on mass spectrometry, Parwanoo (India), March 9-13, 2014.

2. **K. Damodararao**, Sunil K. Singh, Ravi Bhushan and Vinai K. Rai. ε_{Nd} in the Arabian Sea: Water Mass mixing vs. particle – water interaction. 25^{th} Goldschmidt conference at Prague, Czech Republic, August 16-21, 2015.

3. **K. Damodararao**, Sunil K. Singh and Vinai K. Rai. Dissolved Sr and $^{87}Sr/^{86}Sr$ in the East Indian Estuaries: Inferences to submarine groundwater discharge. International Symposium on the Indian Ocean at Goa, India, November 30 – December 4, 2015.

4. **K. Damodararao**, Sunil K. Singh and Vinai K. Rai. REEs and ε_{Nd} in the Ganga (Hooghly) and other East Indian Estuaries: Massive desorption of particulate REEs to the Ocean. 26th Goldschmidt conference at Yokohama, Japan, June 26 - July 2, 2016.