Modern Approaches in Solid Earth Sciences

Volume 20

Background and motivation

Earth Sciences are going through an interesting phase as the traditional disciplinary boundaries are collapsing. Disciplines or sub-disciplines that have been traditionally separated in the past have started interacting more closely, and some new fields have emerged at their interfaces. Disciplinary boundaries between geology, geophysics and geochemistry have become more transparent during the last ten years. Geodesy has developed close interactions with geophysics and geology (tectonics). Specialized research fields, which have been important in development of fundamental expertise, are being interfaced in solving common problems.

In Earth Sciences the term System Earth and, correspondingly, Earth System Science have become overall common denominators. Of this full System Earth, Solid Earth Sciences – predominantly addressing the Inner Earth - constitute a major component, whereas others focus on the Oceans, the Atmosphere, and their interaction. This integrated nature in Solid Earth Sciences can be recognized clearly in the field of Geodynamics. The broad research field of Geodynamics builds on contributions from a wide variety of Earth Science disciplines, encompassing geophysics, geology, geochemistry, and geodesy. Continuing theoretical and numerical advances in seismological methods, new developments in computational science, inverse modelling, and space geodetic methods directed to solid Earth problems, new analytical and experimental methods in geochemistry, geology and materials science have contributed to the investigation of challenging problems in geodynamics. Among these problems are the high-resolution 3D structure and composition of the Earth's interior, the thermal evolution of the Earth on a planetary scale, mantle convection, deformation and dynamics of the lithosphere (including orogeny and basin formation), and landscape evolution through tectonic and surface processes. A characteristic aspect of geodynamic processes is the wide range of spatial and temporal scales involved. An integrated approach to the investigation of geodynamic problems is required to link these scales by incorporating their interactions. Scope and aims of the new series.

The book series "Modern Approaches in Solid Earth Sciences" provides an integrated publication outlet for innovative and interdisciplinary approaches to problems and processes in Solid Earth Sciences, including Geodynamics.

It acknowledges the fact that traditionally separate disciplines or sub-disciplines have started interacting more closely, and some new fields have emerged at their interfaces. Disciplinary boundaries between geology, geophysics and geochemistry have become more transparent during the last ten years. Geodesy has developed close interactions with geophysics and geology (tectonics). Specialized research fields (seismic tomography, double difference techniques etc), which have been important in development of fundamental expertise, are being interfaced in solving common problems.

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Ashoka G. Dessai

The Lithosphere Beneath the Indian Shield

A Geodynamic Perspective

Springer

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To
Arpita, Anushka, and Aniket

Foreword

Cratons are the foundations of our continents, and thus of human life; their highly depleted and buoyant Archaean roots, up to 350 km deep, are difficult to destroy and have provided a 'life raft' for the continental crust. However, tectonic and magmatic processes can modify the cratonic roots, thinning them and increasing their density over time, and ultimately affecting their long-term stability. These processes have attracted the attention of many petrologists over the past few decades, and the ongoing integration of petrology/geochemistry with geophysics and numerical geodynamic modelling is producing many answers and raising just as many new questions.

Peninsular India—the Indian shield—has proven to be an excellent natural laboratory for such studies. Like many shields, it is composed of several (6 or 7, depending on who is counting) smaller cratons, each with its unique crustal history and an equally unique subcontinental lithospheric mantle (SCLM). Data on mantle xenoliths are available from many of these units and several time slices, establishing a basic petrological framework, and the country has an abundance of geophysical data to which petrological interpretations can be applied. The Indian shield is notable among the cratons of the world because today there is little evidence of a thick lithospheric root beneath most of the shield although geophysical interpretations remain contradictory in some areas. India is of course geodynamically interesting because of its rapid trek from the southern hemisphere to its present location: ca 6000 km northwards drift after its separation from Gondwana (120–130 Ma) to collision with Eurasia at ca. 40 Ma, accelerating over the last 20 m.y., while collecting the Kohistan Arc and over-running the Reunion plume and other hotspots along the way. Could it move like this because it had lost some of its cratonic roots before drifting even started, or were they modified along the way?

In this book, Professor Ashoka G. Dessai has summarised a lifetime of research on the lithosphere of the Indian shield and demonstrates the value of an integrated approach, which commonly is not incorporated in individual (especially older) studies. The main chapters outline the geological and tectonic history of the shield, the distribution and nature of the available xenolith suites, and the geophysical

studies, with a strong emphasis on seismic and geothermal data and their interpretation. These aspects are drawn together in the longest chapter 'Integration of Insights', which culminates in an overview of the evolutionary differences among the individual cratons of the shield. Prof. Dessai's own words nicely sum up the essential scientific methodology underlying the book: '. . . an integration of detailed petrological-geochemical-geophysical data inputs can provide a better and deeper insight into the processes during the Archaean and their subsequent modification over time'.

The application of this methodology to the lithospheric diversity of the Indian shield has produced a book that will become a standard reference on the subject, and hopefully will promote such integrated studies in the continuing investigation of the problems of the shield, and of other cratonic areas worldwide.

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William L. Griffin

Preface

The continental lithosphere preserves a treasure of geological information on the evolution of the planet. Knowledge of its physico-chemical composition, thermal structure, and the mechanism of its evolution are crucial to understanding the processes responsible for the formation of the pristine crust and its subsequent growth by interaction with the mantle plumes and plate tectonics.

Lithosphere studies involve a gamut of disciplines including geology, geochemistry, geophysics among others. Geophysics in particular employs various remotely sensed techniques to generate a multitude of data that are used for imaging the deep lithosphere and understanding its architectural framework. However, an interdisciplinary outlook across sciences is desirable for a comprehensive and inclusive approach to knowledge and its applications between and among disciplines.

This book is a multidisciplinary perspective to comprehend the structure, composition, origin, and evolution of the lithosphere beneath the Indian shield which comprises a collage of cratons formed under varied tectonic environments over the past 3.6 billion years of natural history of the earth. The lithosphere beneath the cratons is supposedly thinner as compared to the cratons globally. Individual cratons reveal independent geotectonic and thermal histories, and this has implications in the formation of the crust and evolution of the lithospheric mantle which are petrologically varied and show considerable spatiotemporal variation in thickness both intracratons and among cratons.

The book addresses in particular the following issues: (a) the petrological and geochemical variation of the deep crust and the extent of its evolution across the cratons of the Indian shield, (b) the nature of the crust-mantle and the lithosphere-asthenosphere boundary in different tectonic domains, (c) evolution of the thermal structure of the lithosphere and its variability in space and time, and (d) integration of the petrological, geophysical, geochemical, and geothermal data inputs towards an improved understanding of the evolutionary processes of the Indian lithosphere in the context of global mantle dynamics and its evolution.

The objective of this book, therefore, is to provide the reader a reference book that utilises the data and results from a combination of disciplines with emphasis on petrochemical studies on crustal and mantle xenoliths towards an updated and improved understanding of the geodynamic evolution of the Indian shield.

Taleigao Plateau, Goa, India Ashoka G. Dessai

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Taleigao Plateau, Goa, India — Ashoka G. Dessai

Contents

Abbreviations

Adr	Andradite
Alm	Almandine
Amp	Amphibole
Apt	Apatite
BXP	Between cross polarisers
CBL	Chemical boundary layer
Cbn	Carbonate
CITZ	Central Indian tectonic zone
CMB	Crust-mantle boundary
Cpx	Clinopyroxene
Cr-spnl	Chrome-spinel
Crt	Chromite
Dun	Dunite
Eclo	Eclogite
EDC	Eastern Dharwar Craton
EGMB	Eastern Ghats Mobile Belt
En	Enstatite
Fo	Forsterite
Fs	Ferrosilite
Gar. Gran	Garnet granulite
Gar. Lher	Garnet lherzolite
Glim	Glimmerite
Gnt	Garnet
Grs	Grossular
Harz	Harzburgite
Ilm	Ilmenite
Kn	Knorringite
LAB	Lithosphere-Asthenosphere boundary
LC	Lower crust

Lher	Lherzolite
LVZ	Low-velocity zone
Mar	MARID (Mica-Amphibole-Rutile-Ilmenite-Diopside)
MBL	Mechanical boundary layer
MC	Middle crust
Ol	Olivine
Opx	Orthopyroxene
PCS	Palghat-Cauvery shear
Phlg	Phlogopite
Plg	Plagioclase
PPL	Plain polarised light
Prp	Pyrope
Pyr	Pyroxenite
RBL	Rheological boundary layer
SCLM	Subcontinental lithospheric mantle
SGT	Southern granulite terrain
Spd	Sulphide
Spnl	Spinel
Sps	Spessartite
TBL	Thermal boundary layer
Ti-mag	Ti-magnetite
Tr	Trace
UC	Upper crust
Uv	Uvarovite
WDC	Western Dharwar Craton
Web	Websterite
Weh	Wehrlite
Wo	Wollastonite