Abstract

Mechanisms of melt migration in geodynamic processes: theoretical and experimental modelling

Dip Ghosh (Index No. 178/15/Geol. Sc./24)

Department of Geological Sciences, Jadavpur University, Kolkata, India

Rocks undergo partial melting in a wide range of geological conditions, such as ultra-high temperature metamorphism of crustal rocks, lithospheric subduction, adiabatic decompression of upwelling mantle beneath mid-oceanic ridges, and at the thermal boundary layer above core-mantle boundary (CMB). The partially molten materials generally ascend to Earth's surface under action of the buoyancy forces that act upon them due to their density difference with the ambience. Understanding the driving mechanisms of melt migration phenomena is one of the key challenges in solid earth geophysics, especially to address a number of questions: how do melts create their pathways, what control them to constitute a specific network of the pathways, and how does a melt network eventually produce melt pools? The present thesis primarily aims to study some of these phenomena through laboratory experiments and theoretical modelling.

Buoyancy driven melt transport phenomena play a critical role in dictating a range of geodynamic processes, such as arc volcanism in subduction zones. It is still enigmatic why volcanic spots in many arcs are spatially scattered, whereas some of them form well-defined trench-parallel linear chains. This present thesis investigates the mode of partial-melt transport under natural buoyancy, taking into account the effects of slab dip and the thickness of partially-molten layers, produced by dehydration melting in the mantle wedge above the slab. It is demonstrated from scaled laboratory experiments that Rayleigh-Taylor (RT) instability in the melt-rich layers controls the upwelling dynamics of the melt-bearing materials in the form of regular waves, ultimately to produce a set of plumes, often described as *cold plumes*. The experiments show a transition in the mode of RT instabilities (global to localized) at a critical slab dip, resulting in a change in spatially distributed plumes down the slab to focused plume activities at the up-dip region of the slab. The experimental findings are supported by real scale computational fluid dynamics (CFD) simulations. The thesis develops a theory within a framework of lubrication approximation to study the two competing processes: RT instability and slab-parallel advection in the melt-rich layer atop the subducting slab. The theoretical treatment invokes convective and absolute instabilities to determine the criticality of local versus global instability, which, in turn decides the locations of volcanoes on the surface. The 2D theoretical analysis is extended to 3D to obtain a complete picture of the instabilities at the interface, treating the 3D structures as a product of the interference between two waves trending along and across the slab strike. The thesis also presents both linear and non-linear theories for RT instabilities to predict the three-dimensional interfacial geometry as a function of the inclination angle of the slab dip. Finally, the experimental and theoretical findings are used to explain varying volcano

distributions observed in natural subduction zones, such as the presently active Mexican subduction system and the Java-Sumatra subduction system and the ancient subduction zones, e.g., the Andean subduction system. This study suggests that the time-dependent variation in subduction can be one of the factors to determine the evolution of contrasting volcano distribution patterns in different subduction zones or within the same subduction zones in their geological history.

Another direction of this thesis deals with the mechanism of melt migration through the mushy zone in mid oceanic ridges (MOR). The melts produced at divergent plate boundaries via adiabatic melting begin to ascend under buoyancy forces under critical dynamic states and eventually focus into the spreading center. Despite a significant advance in the MOR studies in recent time, the exact mechanics of melt migration and their accretion into the overlying lithosphere has remained a lively topic of research in geodynamics. The present study uses laboratory experiments to show the relative importance of the following competing dynamics: gravitational instability versus interfacial instability in deciding the modes of melt pathways in the porous system of mushy zones. The experimental results find the density contrast, viscosity ratio and the surface tension of the solid-melt system as the guiding factors. Increasing density contrast facilitates the pathways dominated by gravitational instability, whereas low density contrast and high surface tension favour the melt migration by interfacial instabilities.

The final part of this thesis is dedicated to explore the origin of the Deccan volcanism in a periodic fashion, established from geophysical and geochemical studies. The geodynamics of such pulsating volcanism is not yet understood. With the help of CFD simulations the present work provides a new geodynamic model to show the ascent dynamics of thermochemical plumes beneath the Deccan province during 70 to 60 Ma. The model suggests that plumes can ascend either in a continuous process to form a single large head or in a pulsating manner to produce multiple plume heads with a particular time gap between each pulse, depending upon a specific set of physical conditions. The model results are correlated with appropriate initial and boundary conditions prevailed in Deccan during 70-60 Ma to estimate the periodicity of pulsating plume formation, leading to a sequence of eruption events at a time interval of 0.4-0.7 Ma.

Sadhana M. Chatterjee 27/07/2022 | Nibir Mandal 27/07/2022 | Dip Ghosh 28/07/2022

(Signature of Supervisor & date with official seal) | **(Signature of Supervisor & date with official seal)** | **(Signature of Candidate)**

Dr. Sadhana M Chatterjee
Associate Professor
Department of Geological Sciences
Jadavpur University
Kolkata-700 032

NIBIR MANDAL
Professor
Dept. of Geological Sciences
Jadavpur University
Kolkata - 700 032