THE UNIVERSITY OF SYDNEY

Regional plate tectonic reconstructions of the Indian Ocean

Thesis

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DECLARATION

I declare that this thesis contains less than 100,000 words and contains no work that has been submitted for a higher degree at any other university or institution.

No animal or ethical approvals were applicable to this study. The use of any published written material or data has been duly acknowledged.

Ana Gibbons

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ACRONYMS

BNS (Bangong-Nujiang suture, Tibet)

BK (Batavia Knoll, West Australian margin)

CHRISP (Christmas Island Seamount Province research cruise in 2008)

CRFZ (Cape Range Fracture Zone, West Australian margin)

CNS (Cretaceous Normal Superchron)

COB (Continent-ocean boundary)

MBT (Main Boundary Thrust)

WZFZ (Wallaby-Zenith Fracture Zone, West Australian margin)

YTS (Yarlung-Tsangpo suture, Tibet)

GDK (Gulden Draak Knoll, West Australian margin)

TABLE OF CONTENTS

LIST OF FIGURES

Chapter 1

Chapter 2

LIST OF TABLES

TECTONIC MODEL

To view the model, download GPlates reconstruction visualisation software from:

http://www.gplates.org/

Files and instructions for viewing the model can be downloaded from:

ftp.earthbyte.org/papers/Gibbons_etal_Indian_Ocean/

INTRODUCTION

Plate tectonics and Gondwana

Plate tectonics describes the motion of the earth's surface, a fragmented carapace composed of several 'plates', which meet along three types of boundaries: convergent, divergent and strike slip. Tectonic plates can contain both continental and oceanic crust. Several plates can make up a transitional plate, such as the Capricorn plate, encompassing over 1,000,000 km^2 of oceanic crust between Australia and India. Over time, the plates reorganise into larger or smaller plates by rifting apart or combining with other plates. New oceanic plates are created more frequently to 'fill-the-gap', and they grow or shrink so that the earth's surface is continually covered as it evolves. Seafloor spreading forms the divergent boundaries of the Earth. One of the best-known divergent plate boundaries is the Mid-Atlantic ridge, currently dividing North and South America from Africa and Europe. This marine mountain range spans ~14,000 km from the Arctic to beyond the southern tip of Africa and South America. New seafloor emerges along its spreading axis, which pushes the American and African plates apart at a full rate of ~2.5 cm/yr, enlarging the Atlantic Ocean. The rate of plate motions vary from less than 2.5 cm/yr, such as at the Arctic ridge, to over 15 cm/yr, such as at the East Pacific Rise, west of Chile.

The motion of the plates is necessitated by the convection and escape of heat from the mantle, which underlies the earth's crust. The heat escapes through ruptures in the earth's surface mainly along mid-oceanic ridges, which force the plates to move apart and form new seafloor. This motion causes collision at the opposing plate edges, and strike-slip along the plate edges leading up to them. If two continents collide, they form plateaus and mountain ranges, where the continental crust can thicken to ~75 km, such as beneath the Tibetan Plateau. When oceanic and continental crust collides, it forms a subduction zone where the denser oceanic crust slips beneath the continental edge. This process eventually thickens the continental margin and recycles the oceanic crust. When continental crust becomes excessively thickened it becomes heated and the breakup process can commence again with rifting. Several supercontinents have formed and dispersed over time this way.

Gondwana, the southern portion of the supercontinent Pangaea, began to break up when East Gondwana rifted from Africa in the Mid Jurassic. East Gondwana was comprised of India, Australia, the Seychelles, Madagascar, Sri Lanka, and Antarctica. Continental slivers repeatedly rifted off Gondwana's northern margin, migrated northwards and collided with the Eurasian margin. Each migration created and destroyed a Tethys Ocean, finally forming the NeoTethys and Indian Oceans in the Late Jurassic and Early Cretaceous, respectively, as Argoland and then Greater India migrated north. What we see of the eastern Indian Ocean today is only the portion not yet subducted beneath Southeast Asia (roughly a quarter was destroyed along the Sunda-Java subduction trench). A very minor portion of the older NeoTethys Ocean is found off northwest Australia.

Plate tectonic reconstructions are based on deciphering the seafloor spreading record on conjugate segments of oceanic crust. Fracture zones define the direction of plate motion, and can be seen in marine gravity anomalies as linear features running roughly perpendicular to the spreading ridges. The age of the seafloor can most accessibly be identified using magnetic field data, where seafloor-spreading magnetic anomalies signal the magnetic polarity at the time of formation, which was frozen into the iron-rich basalt, forming parallel to the spreading ridge. The age and age progression of seafloor obtained from considering both the magnetic anomalies and fracture zones containing them, defines the growth of the seafloor and thus the plate motions through time. There are several ways to uncover the age and age progression of the seafloor. The cheapest accessible way involves gathering potential field data, such as magnetic and gravity surveys. Though such data are lower resolution than seismic or drill data, they have become more easy and cost effective to obtain (as opposed to drilling basement at 6 km below sea-level).

Magnetic and gravity data can be gathered using magnetometers and gravimeters via air-bourne or ship-bourne surveys, though satellite-derived altimetry can also help reveal the tectonic fabric of the ocean basins via the gravitational pull of sub-crustal structures on the sea surface. Since the oldest potential field surveys date back to the mid-late twentieth century, when navigation was more primitive, these data must be considered in light of this limitation, such as the offsets when plotting the tracks for interpretation. The large time spans involved for magnetic anomaly reversals (roughly 100,000 to 30 million years) and disparities between different timescales, also limit the resolution or accuracy of seafloor age interpretations arising from such work. The pitch and yaw of the research vessel or aircraft gathering the data must also be subject to adequate processing to remove this and other noise, such as diurnal variation in the magnetic field. Once these local effects are removed (usually at the time of data acquisition), a high-pass (300 km) and low pass (10 km) filter can be applied to smooth the magnetic data before visualisation and interpretation. A further problem is that in marginal areas, where the seafloor is oldest or covered by the greatest amount of continental sediments, fracture zones or magnetic anomalies can appear attenuated or non-existent. Here, a regional context applied to plate kinematic software, such as GPlates, allows us to visualise and fine-tune the plate tectonic reconstructions.

Revising Indian Ocean plate reconstructions

Magnetic anomaly interpretations for plate tectonic reconstructions have been underway in parts of the Indian Ocean since the 1970's but are still undertaken today due to the complexity of the problem. Major obstacles to determining early Indian Ocean reconstructions are due to the Sunda-Java subduction zone having destroyed the older oceanic crust northwest of Australia, and the Cretaceous Normal Superchron, when the magnetic polarity reversals did not occur, limiting our ability to determine the age of oceanic crust between 120-83.5 Ma. There is also the vast array of anomalous tectonic features, highlighting the complexity of early growth in these oceans, but these can also add crucial details to a plate kinematic model.

Previous work focussed on subsets or individual abyssal plains, which has resulted in interpretations that imply differential motion within the migrating Greater India plate, yet no evidence of this is visible in the continent today. The reconstruction presented here considers potential field data from all the seafloor off West Australia and East Antarctica, which had not yet been attempted at such a large regional scale.

Objective

This thesis will outline and tackle major outstanding issues of early Indian Ocean tectonic reconstructions using recent advancements in data and technology. Our first chapter is focussed on the original extent of Greater India, using information from the abyssal plains offshore West Australia to incorporate tectonic boundaries that include several major submarine plateaus. In this chapter we also describe the methods employed to construct our plate kinematic models.

Our second chapter investigates the seafloor off East Antarctica, relating it to the conjugate seafloor off East India, where there are several anomalous tectonic features, with disputed origins. This chapter also solves the enigmatic, curved fracture zones located several kilometres off West Australia and East Antarctica, and predicts a diachronous separation between Madagascar and India. The final chapter investigates the implications of the plate reconstruction model further afield, matching the accretions of Greater India, Argoland and various Tethyan oceanic arcs, to the geological evidence in the Eurasia and Southeast Asian margins.