INTEGRATED AND COMPARATIVE GEOPHYSICAL STUDIES OF CRUSTAL STRUCTURE OF PULL-APART BASINS: THE SALTON TROUGH AND DEATH VALLEY, CALIFORNIA REGIONS

MUSA JAD HUSSEIN

Department of Geological Sciences

APPROVED

Diane Doser Ph.D. Co-Chair

Laura Serpa, Ph.D. Co-chair

Aaron Velasco, Ph.D.

William Cornell, Ph.D.

Terry Pavlis, Ph.D.

Vladik Kreinovich, Ph.D.

Pablo Arenaz, Ph.D.
Dean of Graduate School

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by

MUSA JAD HUSSEIN, B.S., M.S.

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ABSTRACT

I have constructed new crustal scale models of two pull apart basins, the Salton Trough of southwestern California, which is inferred to be an incipient ocean basin and Death Valley to the east of the Salton Trough, which is a highly extended continental basin. For this work I have used receiver functions, controlled source seismic, gravity and magnetic data to constrain crustal structure. Analysis of gravity data shows that the anomalies in the Salton Trough are deeper than anomalies of Death Valley. My modeling suggests the Moho is 21 km deep south of the Salton Sea and deepens to 33 km in the region west of the Salton Trough, while in Death Valley the Moho is 26 km deep in the central part of the basin and deepens to 32 km on either side. Another significant difference between the two basins is the density of the lower crust, which is 2950 kg/m^3 for the Salton Trough and 2750 kg/m^3 for Death Valley. Density of the upper crust varies from 2750 kg/m^3 to 2450 kg/m^3 in the Salton Trough and from 2650 kg/m^3 to 2450 kg/m^3 in Death Valley. Sedimentary rocks and meta-sedimentary rocks in Death Valley are thick and reach a depth of 15 km, while in the Salton Trough the depth of sedimentary rocks and meta-sedimentary rocks is 8-9 km. The Salton Trough is formed from magmatism in the lower crust and sedimentation in the upper crust. Rising of upper mantle material causes uplifting, thinning, and crustal extension (rifting) in the central part of the Salton Trough south of the Salton Sea, and in the southern part of Death Valley. Magnetic anomalies are shallow in both regions. The anomalies in Death Valley show higher relief (~ 420 nT, compared to 250 nT) than in Salton Trough. Salton Trough magnetic anomalies are almost flat with some exceptions in the marginal areas. Curie point depth (CPD) in the Salton Trough ranges from 14-22 km, which is consistent with other geothermal studies and measurements, while measurements for Death Valley CPD range from 12-35 Km.

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Chapter 1

INTRODUCTION

This is an integrated geophysical study of two unique pull apart basins, the Salton Trough and Death Valley. Receiver functions, gravity, magnetic and seismic refraction/reflection models were used to construct crustal scale models to determine the regional and deep structures of the two areas. Gravity data was modeled to determine the density variations of subsurface rocks. Modeling is a powerful tool to map in detail the anatomy of plate boundaries, especially when combined with analysis of seismic and well data. Integration of gravity models with previous seismic studies (e.g. Parsons and McCarthy, 1996; Parsons et al. 2001; Fuis et al. 1984) provided additional constraints on the composition and structure of the crust and upper mantle.

The Salton Trough is a modern example of the evolution from content to oceanic crust or rifting within a transtensional regime. The Trough is characterized by high heat flow, young volcanism and the presence of several pull part basins.

The Death Valley region represents one of the premier sites where strike-slip deformation is occurring contemporaneously with crustal extension. Death Valley is a deep topographic feature that extends for about 200 km in a generally north-northwest direction.

Continental rifts represent the fundamental tectonic process by which continents are fragmented. Rifts have developed in continents since plate tectonic was established early in Earth's history (Adams, 1995). Active rifting is characterized by regional uplift of the crust and local development of normal faults and basins with graben and horst structure (Wessel, 1986).

Continental rifts are economically important at all stages of development. High heat flow makes active rifts a significant source of geothermal energy. Igneous rocks associated with rifts are sources of mineral deposits including platinum group elements and diamonds. The

sedimentary rocks associated with rift basins and associated with regional subsidence related basins are sources of evaporates minerals and petroleum resources (Wessel, 1986).

This dissertation is concerned with integrated and comparative geophysical studies of the Salton Trough and Death Valley. The dissertation is organized as a series of four independent papers. Chapter two, the first paper, is entitled “Integrated geophysical study of pull apart basin, the Salton Trough California Region”. Chapter three, the second paper, is entitled “Integrated geophysical study of pull apart basin Death Valley, California Region”. Chapter four is comparison between the Curie point depth for the Salton Trough and Death Valley. This paper is entitled as “Curie point depth for Salton Trough and Death Valley, California Regions”.

All the results and models from the first three papers will be summarized in one paper entitled “Integrated and comparative geophysical study of pull apart basins the Salton Trough and Death Valley, California Regions”. All papers will eventually be submitted to professional journals.

Chapter 2

INTEGRATED GEOPHYSICAL STUDY OF CRUSTAL STRUCTURE OF THE SALTON TROUGH, CALIFORNIA REGION.

2.1 Introduction

The Salton Trough lies in the transition zone between the East Pacific Rise (divergent plate boundary) and the right-lateral San Andreas Fault (transform boundary). It is a modern example of the evolution from continent to ocean or rifting within a transtensional regime. The Salton Trough is characterized by young volcanism and the presence of several pull-apart basins both north and south of the U.S–Mexico border in which heat flow is higher than in other areas of the Salton Trough (Larsen and Reilinger, 1991). Thus, it has been inferred to be in the early stage of evolution from continental to oceanic crust (Fig. 2.1).

The outstanding questions remain about the Salton Trough: Is the Trough basement oceanic or a mixture of oceanic and crustal material; is the Salton Trough an example of completely new crustal generation (magmatic addition from below, and sedimentary addition from above) as suggested by Fuis et al. (1984)? If so, how does this new crust compare with more typical Phanerozoic crust? Have the crustal spreading centers (southern San Andreas, Sand Hill, Agoldones faults) migrated east to their present configuration and are they less evolved than the currently active centers (Brawley fault zone and Imperial fault zone) as proposed by Parsons et al.(2001)?

To answer these questions, I conducted an integrative geophysical study of this region. Using gravity, magnetic, receiver functions, and seismic data. By utilizing all of this data we can provide unique information about composition variation, underplating, oceanic vs. continental

crust, spreading centers, core complexes, pre-existing fabric, depth to the basement, and depth to the Moho.

2.2 Tectonic settings

Since about 12 Ma, NNW-striking normal faults adjacent to the present Gulf of California have accommodated extension in a broadly ENE direction, perpendicular to the Pacific-North America plate boundary and the present orientation of the Gulf of California (Stock and Hodges, 1989). Opening of the Gulf of California is often attributed to two sequential extensional events: middle to late Miocene "protogulf" extension (Moore and Buffington, 1968; Karig and Jensky, 1972; Moore, 1973), and the Pliocene development of the Pacific-North America plate boundary from about 5.5 Ma to the present (Larson et al. 1968; Curry and Moore, 1984). The 12-6 Ma ENE extension is the earliest episode of Miocene extension recognized immediately adjacent to the Gulf of California. Its relationship to early-mid Miocene "metamorphic core complexes" found in southern Arizona and similar undated structures in NW Sonora is not known (Stock and Hodges, 1989).

The Gulf of California is a modern example of transtension and an ideal place to study the processes related to the interplate transfer of a continental fragment (Axen and Fletcher, 1998). Rifting in the Gulf of California began as a response to major plate-margin reorganization. The western margin of what now is the Baja Peninsula was a subduction boundary prior to 29 Ma, with the Farallon plate descending eastward beneath North America (Stock and Hodges, 1989). The East Pacific Rise, separating the Pacific and Farallon plate, intersected the trench offshore of northern Baja California or southern California at about 28 Ma (Atwater and Stock, 1998). The Pacific-North America plate margin was initiated here as a short, but elongated, transform margin that grew by both triple junction migration and southward ridge

jumps that transferred Farallon plate lithosphere to the Pacific plate. As subduction slowed and then ceased, parts of western North America became coupled to the Pacific plate along the former subduction zone (Stock and Hodges, 1989; Nicholson et al. 1994). Once subduction ceased, extension in the Gulf of California began at 12 Ma, in an east-northeast direction roughly orthogonal to the rift trend (Stock and Hedges, 1989; Axen et al. 2000).

From 12 to 6 Ma relative plate motion near Baja California is thought to have been partitioned between dextral faults of the continental borderland near the trench and roughly margin orthogonal extension in and east of the site of the modern gulf (Stock and Hodges, 1989). Recent reconstructions suggest that significant oblique rifting probably characterized the Gulf since at least 8 Ma, and possibly throughout its history (Axen et al. 2000).

Since 6.5 Ma, most plate margin slip has been concentrated in the gulf, where long dextral transforms link short spreading centers (Lonsdale, 1989). This contrasts with previous commonly held ideas, based mainly on southern California geology, that most plate motion has been in the Gulf since 4-6 Ma, and at present nearly all of the modern Pacific-North America relative plate motion is accommodated within the Gulf and the Salton Trough (Lonsdale, 1989; DeMets, 1995).

Rifting began throughout the Gulf simultaneously, and roughly the same amount of strain has accumulated across the various basins north to south (Axen et al. 2000). In the south the Alarcon Basin, which records only Baja California-North America motion, relative motion appears to have necked and sea floor spreading began at 3.58 Ma. Most of the extensional structures here are presently below sea level, including an apparent failed rift within the segment, and the spreading center is lightly sediment (DeMets, 1995). In the north, extension in the region of the Deflin Basin, for example, has not achieved sea floor spreading (Stock, 2000). Here

most of the deformation is subaerial, including an active low angle detachment fault bounding the extensional province to the west (Axen and Fletcher, 1998).

2.3 Data:

Gravity and aeromagnetic data were downloaded from the web site of the University of Texas at El Paso-Pan American Center of Earth and Environmental Studies-(PACES) http://paces.geo.utep.edu/. The gravity data available at this website are based on U.S. and border region data sets that have been complied from a vast number of sources. Gravity Terrain corrections were calculated by Mike Webring of the U. S. Geological Survey using a digital elevation model and a technique based on the approach of Donald Plouff. Latitude and longitude values are referenced to NAD27 (North American Datum 27; horizontal datum) and elevation values in meter are referenced to NGVD29 (Vertical datum).

A total of 40,784 gravity measurements and 112,436 aeromagnetic measurements were used for this research.

2.3.1 Seismic Data

Results from active and passive seismic surveys provided the critical starting point for constructing geophysical models. We used rock velocities and thicknesses extracted from seismic data (Fuis et al, 1984; Parson and McCarthy, 1996) to distinguish between different types.

2.3.2 Receiver Function

Receiver function produces important information on P-to-S impedance structure and crustal thickness. We used seismic receiver function results to create a contour map of depth to the Moho (Fig. 2.2). Receiver function data was downloaded from Earthscope website http//www.earthscope.org.