

I. CENOZOIC GEOLOGY OF IRAN: AN INTEGRATED STUDY OF
EXTENSIONAL TECTONICS AND RELATED VOLCANISM

II. EDIACARAN STRATIGRAPHY OF THE NORTH AMERICAN
CORDILLERA: NEW OBSERVATIONS FROM EASTERN CALIFORNIA AND
NORTHERN UTAH

Thesis by
Charles Verdel

In Partial Fulfillment of the Requirements

For the Degree of
Doctor of Philosophy

California Institute of Technology

Pasadena, California

2009

(Defended August 27, 2008)

© 2009

Charles Verdel

All Rights Reserved

ACKNOWLEDGEMENTS

Because of difficulties that arose in obtaining Iranian visas, my graduate student career has been spent working on a number of projects that are only loosely related. Although not the original plan, in the end I think I have become a better geologist for being exposed to a wide variety of topics. I would like to thank Brian Wernicke for his assistance in formulating the two major projects that comprise this thesis, and for the helpful discussions that we have had over the last six years. None of our work in Iran would have been possible without the efforts of Jamshid Hassanzadeh, and I would like to thank him for all of his contributions to the first half of this thesis. Discussions with Bernard Guest, Jahandar Ramezani, and Jean-Philippe Avouac on the subject of Iranian tectonics have been invaluable. John Eiler allowed me to measure O isotopes in his lab during my first year at Caltech, and ever since then he has been the source of useful (and entertaining) advice. Joe Kirschvink and Ken Farley graciously provided access to their labs. Lindsey Hedges invested a great deal of her time to help me obtain results from the He lab. Ryan Petterson's input was instrumental to the work I did in the Panamint Range, and he has always been a great person to go into the field with. I have benefited greatly from discussions about Neoproterozoic stratigraphy with Ryan, David Fike and John Grotzinger. Finally, I would like to thank my parents for their never-ending support.

ABSTRACT

I.

The late Oligocene to Miocene collision of Arabia and Eurasia was preceded by ~175 My of subduction of Neotethyan oceanic crust. Associated magmatic activity includes late Triassic(?) to Jurassic plutons in the Sanandaj-Sirjan zone of southern Iran, limited Cretaceous magmatism in the Alborz Mountains of northern Iran, and widespread Eocene volcanism across central Iran. Metamorphic core complexes of Eocene age have recently been recognized in widely separated parts of Iran, suggesting that Tertiary volcanism was related to extension. Geochemical data indicate that Eocene volcanism was typical of continental arcs and was followed by less voluminous Oligocene basaltic volcanism of the type often associated with back-arc basins. This set of observations suggests that mid-Mesozoic plutons in southern Iran are the remnants of an original volcanic arc that was only weakly developed because of slow subduction rate. Magmatic activity largely ceased in southern and central Iran during the Cretaceous and shifted to the north, suggesting a period of flat slab subduction. Subsequent slab-rollback during the Eocene extended the overriding plate, forming metamorphic core complexes and inducing pressure-release melting of partially hydrated lithospheric mantle and upwelling of asthenosphere.

II.

The Ediacaran Period spans from the base of cap carbonates overlying glacial deposits of the Marinoan “Snowball Earth” event to the Precambrian-Cambrian boundary, ~635 to 542 Ma. Sediments deposited during the rifting of southwest Laurentia, which are now

exposed in a relatively narrow belt in the western US, are one of the best records on earth of the geological, geochemical, and geobiological events that occurred during this period. Evidence for one of the most significant of these, the final oxygenation of the oceans, is found within the upper Johnnie Formation in the southern Great Basin. C isotope data from thick, basinal facies of the Johnnie Fm. in the Panamint Range provide a more complete record of ocean chemistry associated with this event than previously determined from thinner, platformal facies. Strata in northern Utah of roughly the same age include a rift-related basalt, providing some of the youngest geologic evidence for the rifting of western Laurentia.

TABLE OF CONTENTS

Acknowledgements.....	iii
Abstract.....	iv
Table of Contents.....	vi
List of Figures and Tables.....	ix
Chapter 1: Introduction.....	I-1
PART I: CENOZOIC GEOLOGY OF IRAN: AN INTEGRATED STUDY OF EXTENSIONAL TECTONICS AND RELATED VOLCANISM	
Chapter 2: Geology and thermochronology of Tertiary Cordilleran-style metamorphic core complexes in the Saghand region of central Iran.....	II-1
Abstract.....	II-1
Introduction.....	II-3
Tectonic setting.....	II-4
Geology of the Saghand region.....	II-6
Stratified rocks.....	II-7
Crystalline rocks.....	II-8
Structural and stratigraphic observations of the Neybaz-Chatak detachment system.....	II-10
Neybaz-Chatak detachment fault and hanging-wall splays.....	II-10
Mylonites.....	II-12
Supradetachment and postextensional basinal deposits and structures..	II-13
Geochronology and thermochronology.....	II-15
U-Pb geochronology.....	II-15
⁴⁰ Ar/ ³⁹ Ar geochronology.....	II-16
(U-Th)/He thermochronology.....	II-17
Western domain.....	II-18
Eastern domain.....	II-19
Discussion and conclusions.....	II-20
Timing of extension.....	II-22
Kinematics of extension.....	II-23
Cretaceous and Miocene (U-Th)/He cooling ages.....	II-26
Regional significance.....	II-28
Acknowledgements.....	II-29
References.....	II-30
Chapter 3: Geochronology and geochemistry of Iranian Paleogene volcanism: an extensional arc flare-up.....	III-1
Abstract.....	III-1
Introduction.....	III-2
Regional geology.....	III-5
Arc stratigraphy.....	III-7
Geochronology.....	III-9
Urumieh-Dokhtar U-Pb and ⁴⁰ Ar/ ³⁹ Ar geochronology.....	III-9

Karaj Formation U-Pb geochronology.....	III-10
Additional U-Pb and $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology and a composite stratigraphic section.....	III-10
Geochemistry.....	III-13
Previous work.....	III-13
Major and trace element data.....	III-14
Iranian shoshonites.....	III-21
Discussion.....	III-25
Mechanism for the Iranian Tertiary flare-up.....	III-26
Changes in subduction rate.....	III-27
Changes in subduction angle.....	III-28
Slab melting.....	III-29
Rifting/back-arc basin development.....	III-30
Conceptual model for the Eocene magmatic flare-up.....	III-31
Conclusions.....	III-37
References.....	III-37

PART II: EDIACARAN STRATIGRAPHY OF THE NORTH AMERICAN CORDILLERA: NEW OBSERVATIONS FROM EASTERN CALIFORNIA AND NORTHERN UTAH

Chapter 4: Litho- and chemostratigraphy of the Johnnie Formation and Stirling

Quartzite, Panamint Range and Funeral Mountains, eastern California: implications for the Death Valley record of Ediacaran ocean chemistry..	IV-1
Abstract.....	IV-1
Introduction.....	IV-2
Stratigraphic and tectonic setting.....	IV-3
Stratigraphy of the Johnnie Formation and Stirling Quartzite.....	IV-5
Background.....	IV-5
Lithostratigraphy and C isotope data from the Panamint Range.....	IV-9
Johnson Canyon.....	IV-10
South Fork of Hanaupah Canyon.....	IV-12
North Fork of Hanaupah Canyon.....	IV-13
Wildrose Peak area.....	IV-15
Trail Canyon.....	IV-17
Lithostratigraphy and C isotope data from the Funeral Mountains.....	IV-22
Discussion and conclusions.....	IV-24
Correlations within the Panamint Range.....	IV-24
Record of the Shuram anomaly in the Death Valley region.....	IV-27
Comparison with the Wonoka Formation, South Australia.....	IV-29
References.....	IV-31

Chapter 5: Geochemistry of the Ediacaran Browns Hole basalt, Utah: implications

for the timing of western Laurentian rifting.....	V-1
Abstract.....	V-1
Introduction.....	V-1

Northern Utah Neoproterozoic-Cambrian stratigraphy.....	V-3
Analytical data.....	V-5
Trace element data, Browns Hole basalt.....	V-5
Geochronology.....	V-7
Paleomagnetic data.....	V-8
Discussion.....	V-10
Correlations with Death Valley.....	V-10
Conclusions.....	V-13
References.....	V-14

FIGURES AND TABLES

CHAPTER 1:

Figure captions.....	I-10
Fig. 1 Tectonic maps of Cordilleran-style metamorphic core complexes in eastern California and Iran.....	I-11
Fig. 2 Shaded relief map of part of the Great Basin.....	I-12
Fig. 3 Primitive mantle normalized trace element diagram.....	I-13

CHAPTER 2:

Fig. 1 Geologic map of Iran.....	II-51
Fig. 2 Geologic map of the Saghand area.....	II-52
Fig. 3 Geologic map of Khoushoumi Mountain.....	II-53
Fig. 4 High-resolution satellite images of the Saghand area.....	II-54
Fig. 5 Field photographs of extensional features.....	II-55
Fig. 6 Fault- and shear zone-related rocks	II-57
Fig. 7 Mylonitic foliation and lineation orientations	II-58
Fig. 8 U-Pb concordia plot.....	II-59
Fig. 9 $^{40}\text{Ar}/^{39}\text{Ar}$ inverse isochron diagrams.....	II-60
Fig. 10 Thermochronologic data from the eastern domain.....	II-61
Fig. 11 Summary of superposition relationships for the Khoushoumi Mtn. area.....	II-63
Fig. 12 Map of metamorphic core complexes along the Alpine-Himalaya orogen... ..	II-64

Table S1 U-Pb data.....	II-65
Table S2 $^{40}\text{Ar}/^{39}\text{Ar}$ data for western domain samples	II-66
Table S3 $^{40}\text{Ar}/^{39}\text{Ar}$ data for eastern domain samples	II-68
Table S4 (U-Th)/He data for western domain samples.....	II-71
Table S5 (U-Th)/He data for eastern domain samples	II-73
Table 1 Alpine-Himalayan metamorphic core complexes	II-76

CHAPTER 3:

Figure captions.....	III-56
Fig. 1 Geologic map of Iran	III-59
Fig. 2 Cretaceous through Miocene stratigraphy in the Tafresh area	III-60
Fig. 3 U-Pb concordia diagrams/Ar spectra.....	III-61
Fig. 4 Cretaceous through Miocene stratigraphy of the Chalus Road area	III-62
Fig. 5 Tertiary stratigraphy of the Alborz Mtns.....	III-63
Fig. 6 Tertiary stratigraphy of the Urumieh-Dokhtar arc	III-64
Fig. 7 Total alkali-silica diagrams.	III-65
Fig. 8 Primitive mantle normalized trace element diagrams.	III-66
Fig. 9 Ti/V vs. Zr/Nb plot for primitive Iranian basalts	III-67
Fig. 10 Generalized Tertiary stratigraphy of Iran	III-68
Fig. 11 Iranian shoshonite.....	III-69
Fig. 12 Diagram summarizing tectonic setting of Iranian Paleogene volcanism.....	III-70
Table 1 U-Pb zircon age data	III-71
Table 2 $^{40}\text{Ar}/^{39}\text{Ar}$ plagioclase age data.....	III-74

CHAPTER 3 (continued):**Table 3** Major and trace element compositions of Iranian Paleogene volcanic rocks.III-76**CHAPTER 4:**

Figure captions.....	IV-40
Fig. 1 Shaded relief map of part of the southern Great Basin	IV-45
Fig. 2 Shaded relief map of the Panamint Range	IV-46
Fig. 3 Proterozoic to earliest Cambrian stratigraphy of the Death Valley region	IV-47
Fig. 4 Photographs from Johnson Canyon and Hanaupah Canyon.....	IV-48
Fig. 5 C isotope data for the upper Johnnie Fm.....	IV-49
Fig. 6 Johnnie Fm. and lower Stirling Quartzite, S. fork of Hanaupah Canyon	IV-50
Fig. 7 Upper Johnnie Fm. dolostone, N. fork of Hanaupah Canyon.....	IV-51
Fig. 8 Photographs of upper Johnnie Fm. carbonates.....	IV-52
Fig. 9 Geologic map of the Johnnie-Stirling contact near Wildrose Peak	IV-53
Fig. 10 Photograph of Trail Canyon.....	IV-54
Fig. 11 Geologic map of the Trail Canyon area.....	IV-55
Fig. 12 Johnnie Fm. breccia bed in Blackwater Wash.	IV-56
Fig. 13 Giant limestone breccia clasts in Trail Canyon	IV-57
Fig. 14 Photographs of the upper Johnnie Fm. in Trail Canyon.....	IV-58
Fig. 15 Trail Canyon C isotope data.....	IV-59
Fig. 16 Photographs of the lower Johnnie Fm. in Trail Canyon.	IV-60
Fig. 17 C isotope data from the Funeral Mtns.	IV-61
Fig. 18 Summary of C isotope data.....	IV-62
Fig. 19 Correlation between Hanaupah Canyon and Trail Canyon.....	IV-63
Fig. 20 Summary of C isotope data from the Wonoka Fm.....	IV-64
Table 1 C and O isotope data tables.....	IV-65

CHAPTER 5:

Figure captions.....	V-22
Fig. 1 Shaded relief map of northern Utah and southern Idaho	V-25
Fig. 2 Late Proterozoic to Cambrian stratigraphy of the Browns Hole Quadrangle...V-26	
Fig. 3 Geologic map of the Browns Hole quadrangle.....	V-27
Fig. 4 Geochemical data from the Browns Hole basalt.....	V-28
Fig. 5 U-Pb concordia diagram for Browns Hole basalt apatites.....	V-29
Fig. 6 Paleomagnetic data from the Browns Hole quadrangle.....	V-30
Fig. 7 Preexisting C isotope data	V-31
Table 1 XRF major and trace element data from the Browns Hole basalt.....	V-32
Table 2 U-Pb geochronology of the Browns Hole basalt.....	V-33