Chapter 1

Introduction

This thesis is divided into two sections that focus on different topics: the first part deals with Cenozoic metamorphic core complexes and volcanism in Iran, and the second part is a study of Neoproterozoic strata in the western United States. Despite the obvious differences in geographic locations and time periods, these two projects share common themes in extensional tectonism, volcanism, and sedimentation that are outlined in this introductory chapter.

In the North American Cordillera, the tectonic significance of scattered occurrences of high-grade metamorphic rocks structurally overlain by weakly metamorphosed to unmetamorphosed strata (i.e., "Cordilleran-style metamorphic core complexes") was originally recognized in the 1960s. Early interpretations of these areas tended to link them with Mesozoic contractional structures exposed along the eastern margin of the Great Basin (e.g., Misch, 1960). When K-Ar ages revealed that the footwalls of these core complexes actually cooled in the Tertiary (e.g., Armstrong and Hansen, 1966), it became apparent that their formation was not directly related to the earlier period of shortening and paved the way for our current understanding of large magnitude Tertiary extension in the Basin and Range province.

Within the last few years, similar structures have been recognized in the Iranian segment of the Alpine-Himalayan orogen. Ramezani and Tucker (2003), in a study with implications analogous to those of Armstrong and Hansen (1966), presented high-precision U-Pb data from Proterozoic through Tertiary rocks in eastern Iran. Among other things, their data demonstrated conclusively that mylonitic gneisses near the town of Saghand (Fig. 1), previously considered to be Precambrian based on high metamorphic grade (e.g., Stöcklin, 1968), are, in fact, Eocene. Subsequent field and analytical work (Chapter 2) has revealed that these gneisses form the footwalls of a belt of metamorphic core complexes that are similar in many ways to those found in the southwestern United States. New thermochronology data indicate that these eastern Iranian core complexes were active in the middle Eocene, and reinterpretation of existing geologic maps suggest that they locally accommodated ≥30 km of extension. An additional Eocene core complex has since been documented further west in Iran (Fig. 1, Moritz et al., 2006), and geologic descriptions from an area of recently discovered eclogites in southern Iran (Davoudian et al., 2007) suggest that it may be yet another Eocene core complex. With the recent recognition of these structures, along with evidence of Paleogene brittle normal faulting (Tillman et al., 1981, Guest et al., 2006), it has become reasonably clear that the Eocene epoch was a time of crustal extension in Iran. Extension was accompanied by very large volumes of shallow marine to continental volcanism and sedimentation, as confirmed by new geochronological data (Chapter 3). Primitive basalts erupted during this ~20 My "flare-up" stage have trace element characteristics typical of most continental arcs. In contrast, trace element data from basalts erupted after the flare-up ended, during a much less extensive Oligocene phase of volcanism, suggest that they were generated from an asthenospheric source that was only slightly modified by fluxing from the subducted slab. This set of observations can be explained by a two-stage model for Iranian Tertiary volcanism. In the first stage, previously hydrated lithospheric mantle melted due to pressure release associated with crustal thinning, thus producing large volumes of Eocene volcanic rocks with trace element compositions reflective of their source within the mantle wedge. In the second stage, beginning in the late Eocene or early Oligocene, the supply of previously fluxed lithospheric mantle was exhausted and the dominant source of volcanism became asthenospheric mantle, which continued to upwell in response to extension. It is suggested that slab-rollback was the driving force for extension and may have been preceded by a period of flat-slab subduction which both suppressed volcanism and preconditioned the overriding plate with slab-derived fluids.

In eastern California, metamorphic core complexes are found along both margins of Death Valley. In the Panamint Range (west side of Death Valley) and Funeral Mountains (east side), Miocene detachment faults separate underlying Proterozoic high-grade rocks from overlying Proterozoic through Tertiary low-grade to unmetamorphosed strata (Fig. 1, e.g., Hodges et al., 1990, Wright and Troxel, 1993). Late Proterozoic sedimentary rocks in these areas were deposited within the western Laurentian continental margin during the break-up of the supercontinent Rodinia (e.g., Hoffman, 1991) and the subsequent development of a passive-margin. These rocks comprise one of the world’s most complete records of the geochemical and geobiological events that occurred during the Ediacaran Period, i.e., the time from cap carbonate deposition following the Marinoan “Snowball Earth” glaciation until the Precambrian-Cambrian boundary, roughly 635 to 542 Ma. Most modern studies of Ediacaran strata from the Death Valley region (e.g., Corsetti and Kaufman, 2003) have focused on platformal facies to the southeast of Death

Valley, where it has subsequently been shown that much of the rock record is missing along disconformities (Petterson et al., 2007). Chapter 4 is focused on assembling a more complete Death Valley stratigraphic and isotopic record of the Johnnie Fm. and Stirling Quartzite from basinal facies exposed in the Panamint Range and Funeral Mountains. Isotopic data from these two formations in eastern California, as well as equivalent strata in Oman, Australia, and China, constitute evidence for the final oxygenation of the oceans during the Late Proterozoic (e.g., Fike et al., 2006).

These Death Valley strata are part of a westward-thickening package of Proterozoic rift-related sedimentary and volcanic rocks that extends from Mexico to Canada (Fig. 2, Stewart, 1972). A very generalized stratigraphy of these deposits consists of two parts: a lower section of Cryogenian (850-635 Ma) mafic volcanics, glacial diamictites, and shallow marine sedimentary rocks, and an upper section of Ediacaran to Cambrian sediments (e.g., Stewart, 1972). Most studies of these rocks have concluded that rifting of Laurentia occurred during deposition of the lower part, and post-rift subsidence is represented by the upper part (e.g., Stewart, 1972, Prave, 1999). In northern Utah, a spatially-restricted Proterozoic basalt flow is situated at a stratigraphic level above glacigenic sediments and below rocks containing Cambrian trace fossils. Previous correlations of the northern Utah section with better characterized strata in the Death Valley area have been tenuous at best (e.g., Corsetti et al., 2007). In Chapter 5, pre-existing C isotope data are used to show that eruption of the northern Utah basalt postdated deposition of the Marinoan cap carbonate sequence and is therefore within the upper part of the generalized Laurentian rift-to-drift stratigraphy. New trace element data from the basalt share similarities with older Laurentian rift-related basalts (Harper and Link, 1986) and with Tertiary basalts in Iran that accompanied extension (Fig. 3, Chapter 3). These observations suggest that in at least one place, rifting of Laurentia seems to have continued later than estimated by most geological studies and is more consistent with the long-standing findings of tectonic subsidence models (e.g., Bond et al. 1985).

Both parts of this thesis therefore deal with large-magnitude extension and volcanic and sedimentary rocks deposited in rifts. An interesting outcome of the Iran project is the similarity in Cenozoic tectonic histories of Iran and the western U.S. Both regions were affected by Tertiary extension and volcanic flare-ups, and Iran may have experienced a Cretaceous period of flat-slab subduction analogous to the Laramide orogeny. Pre-extensional arc magmatism was more extensive in the western U.S., while syn-extensional volcanism was greater in Iran. This inverse relationship may be fundamentally related to convergence rate (which was 2 to 3 times greater in the North American Cordillera than in Iran) which at least partially controls the extent of mantle melting prior to the additional influence of decompression accompanying extension.

REFERENCES

Armstrong, R.L., and Hansen, E., 1966, Cordilleran infrastructure in the eastern Great Basin: American Journal of Science, v. 264, p. 112-127.

Bond, G.C., Christie-Blick, N., Kominz, M.A., and Devlin, W.J., 1985, An early Cambrian rift to post-rift transition in the Cordillera of western North America: Nature, v. 315, p. 742-746.

Corsetti, F.A., and Kaufman, A.J., 2003, Stratigraphic investigations of carbon isotope anomalies and Neoproterozoic ice ages in Death Valley, California: Geological Society of America Bulletin, v. 115, p. 916-932.

Corsetti, F.A., Link, P.K., and Lorentz, N.J., 2007, $\delta^{13}C$ chemostratigraphy of the Neoproterozoic succession near Pocatello, Idaho, U.S.A.: implications for glacial chronology and regional correlations: SEPM Special Publication No. 86, p. 193-205.

Davoudian, A.R., Genser, J., Dachs, E., and Shabanian, N., 2007, Petrology of eclogites from north of Shahrekord, Sanandaj-Sirjan zone, Iran: Mineralogy and Petrology, doi: 10.1007/s00710-007-0204-6.

Fike, D.A., Grotzinger, J.P., Pratt, L.M., and Summons, R.E., 2006, Oxidation of the Ediacaran ocean: Nature, v. 444, p. 744-747.

Guest, B., Axen, G.J., Lam, P.S., and Hassanzadeh, J., 2006a, Late Cenozoic shortening in the west-central Alborz Mountains, northern Iran, by combined conjugate strike-slip and thin-skinned deformation: Geosphere, v. 2, p. 35-52.

Harper, G.D., and Link, P.K., 1986, Geochemistry of Upper Proterozoic rift-related volcanics, northern Utah and southeastern Idaho: Geology, v. 14, p. 864-867.

Hodges, K.V., McKenna, L.W., and Harding, M.B., 1990, Structural unroofing of the central Panamint Mountains, Death Valley region, southeastern California, *in* Wernicke, B.P., ed., Basin and Range extensional tectonics near the latitude of Las Vegas, Nevada: Geological Society of America Memoir 176, Boulder, p. 377-390.

Hoffman, P.F., 1991, Did the breakout of Laurentia turn Gondwanaland inside-out?: Science, v. 252, p. 1409-1412.

Misch, P., 1960, Regional structural reconnaissance in central-northeast Nevada and some adjacent areas: observations and interpretations: Intermountain Association of Petroleum Geologists Guidebook for 11th Annual Field Conference, p. 17-42.

Moritz, R., Ghazban, F., and Singer, B.S., 2006, Eocene gold ore formation at Muteh, Sanandaj-Sirjan tectonic zone, western Iran: a result of late-stage extension and exhumation of metamorphic basement rocks within the Zagros orogen: Economic Geology, v. 101, p. 1497-1524.

Petterson, R., Prave, A., Wernicke, B., and Fallick, A.E., 2007, New stratigraphic and isotopic constraints on the Cryogenian-Ediacaran strata of Death Valley region, Geological Society of America Abstracts with Programs, v. 39, no. 6, p. 222.

Prave, A.R., 1999, Two diamictites, two cap carbonates, two $\delta^{13}C$ excursions, two rifts: the Neoproterozoic Kingston Peak Formation, Death Valley, California: Geology, v. 27, p. 339-342.

Ramezani, J., and Tucker, R.D., 2003, The Saghand region, central Iran: U-Pb geochronology, petrogenesis and implications for Gondwana tectonics: American Journal of Science, v. 303, p. 622-665.

Stewart, J.H., 1972, Initial deposits in the Cordilleran geosyncline: evidence of a late Precambrian (<850 m.y.) continental separation: Geological Society of America Bulletin, v. 83, p. 1345-1360.

Stöcklin, J., 1968, Structural history and tectonics of Iran: a review: American Association of Petroleum Geologists Bulletin, v. 52, p. 1229-1258.

Sun, S.S., and McDonough, W.F., 1989, Chemical and isotopic systematics of oceanic basalts; implications for mantle composition and processes, *in* Saunders, A.D., and Norry, M.J., eds., Magmatism in the oceanic basins: Geological Society of London Spec. Pub. 42, p. 313-345.

Tillman, J.E., Poosti, A., Rossello, S., and Eckert, A., 1981, Structural evolution of Sanandaj-Sirjan ranges near Esfahan, Iran: American Association of Petroleum Geologists Bulletin, v. 65, p. 674-687.

Wright, L.A., and Troxel, B.W., 1993, Geologic map of the central and northern Funeral Mountains and adjacent areas, Death Valley region, southern California: U.S. Geological Survey Miscellaneous Investigations Series Map I-2305, scale 1:48,000, 1 sheet.

FIGURE CAPTIONS

Figure 1. Simplified tectonic maps of some Cordilleran-style metamorphic core complexes in eastern California and Iran, shown at the same scale. See Chapters 2 and 4 for references.

Figure 2. Shaded relief map showing locations of the Panamint Range (Chapter 4) and Huntsville, UT (Chapter 5) and thickness (in feet) of late Proterozoic to Cambrian strata in the western US (after Stewart, 1972). Blue arrow points to estimated original position of the Huntsville area prior to eastward transport in the hanging wall of the Willard thrust (Stewart, 1972).

Figure 3. Primitive mantle normalized trace element diagram. Note similarities between the Proterozoic Browns Hole basalt in Utah and a typical Oligocene basalt from Iran, both of which are believed to be rift-related. In contrast, Eocene basalts from Iran have trace element characteristics much more typical of volcanic arcs, for example the depletion of Nb. Primitive mantle composition from Sun and McDonough (1989).

Figure 1

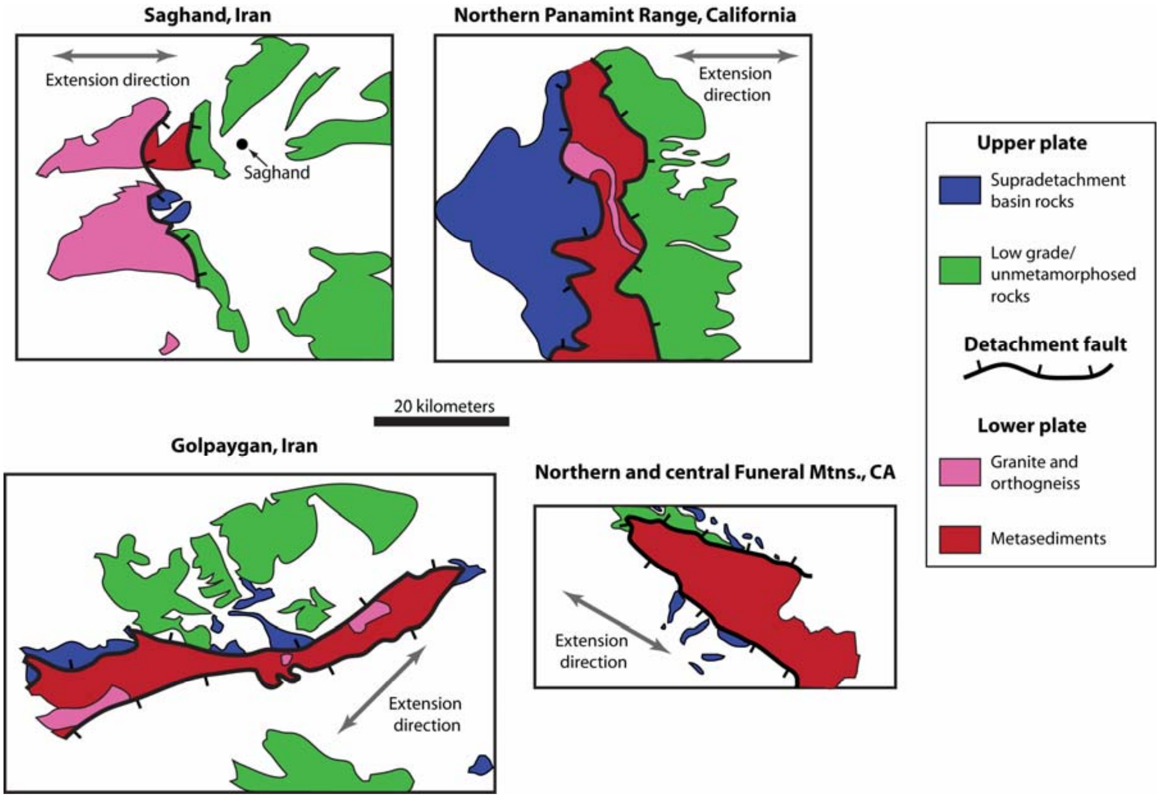

Saghand, Iran
Extension direction
Saghand
Northern Panamint Range, California
Extension direction
Upper plate
Supradetachment basin rocks
Low grade/ unmetamorphosed rocks
Detachment fault
Lower plate
Granite and orthogneiss
Metasediments
20 kilometers
Golpaygan, Iran
Extension direction
Northern and central Funeral Mtns., CA
Extension direction

Figure 2

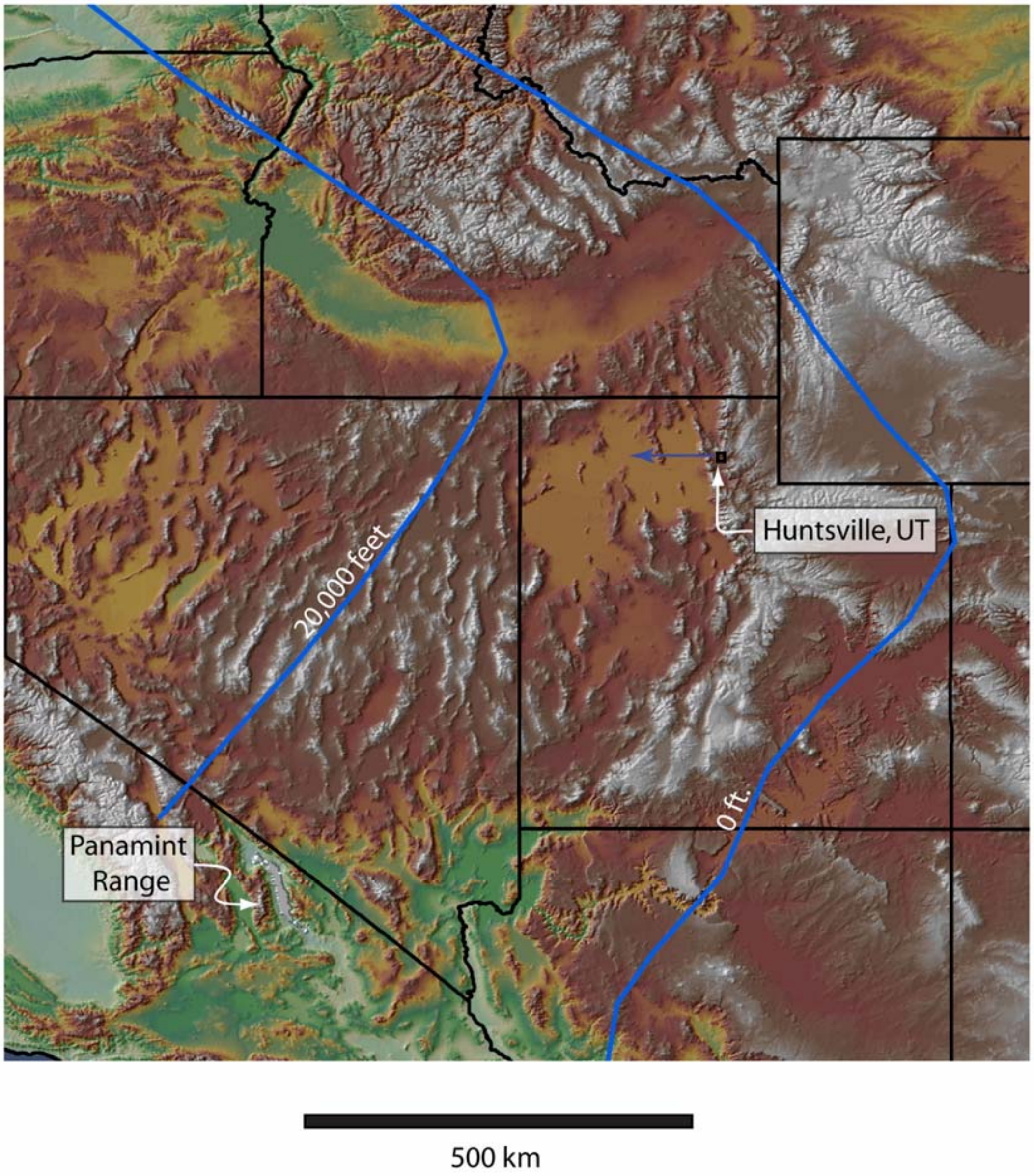
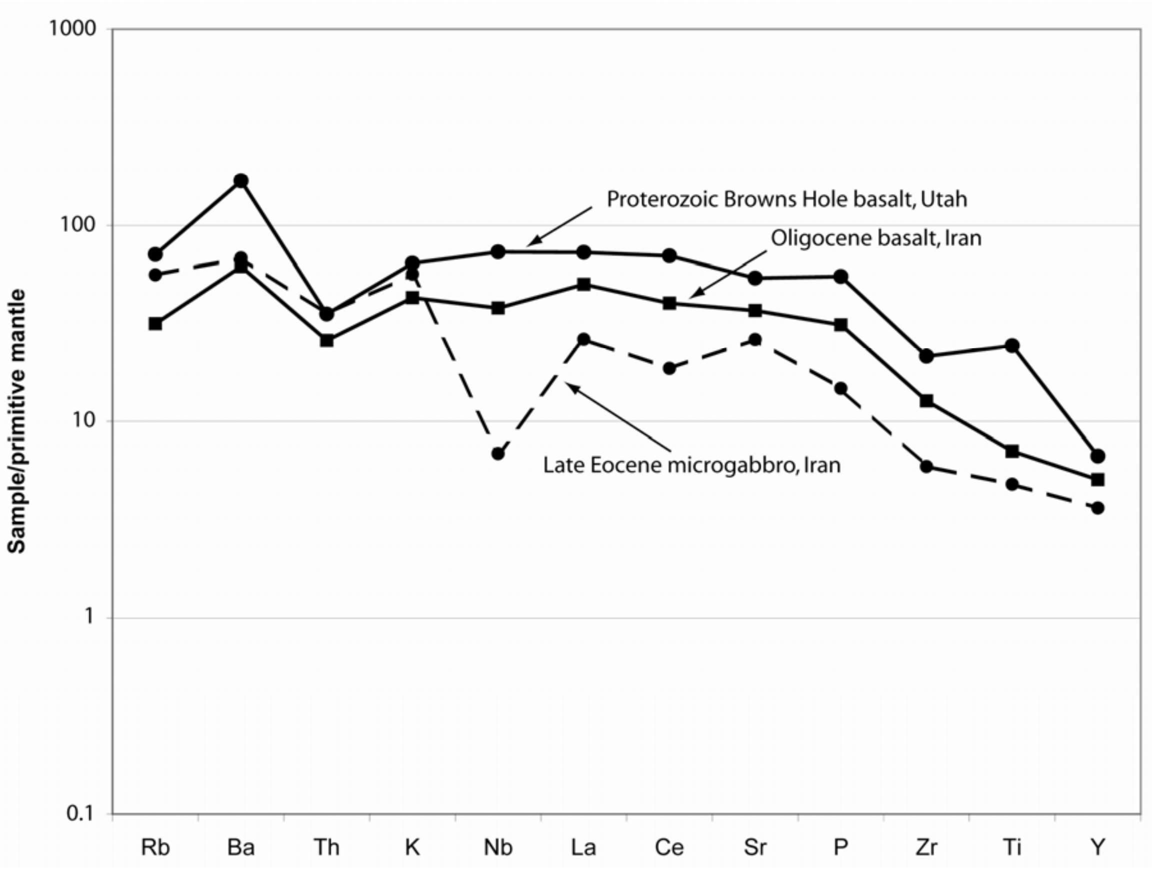


Figure 3


1000
100
10
1
0.1
Sample/primitive mantle
Rb
Ba
Th
K
Nb
La
Ce
Sr
P
Zr
Ti
Y
Proterozoic Browns Hole basalt, Utah
Oligocene basalt, Iran
Late Eocene microgabbro, Iran