STRUCTURAL GEOLOGY OF THE JOSEPHINE PERIDOTITE, NORTHERN CALIFORNIA: IMPLICATIONS FOR STRUCTURAL PROCESSES AT SLOW SPREADING CENTERS

by

Gregory Thomas Norrell

A Dissertation

Submitted to the State University of New York at Albany

in Partial Fulfillment of

the Requirements for the Degree of

Doctor of Philosophy

College of Science and Mathematics

Department of Geological Sciences

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ABSTRACT

The Josephine Peridotite is a large ultramafic complex exposed in northern California and southern Oregon and represents the mantle portion of the Late Jurassic Josephine ophiolite. This unit has been subjected to deformation over a broad range of physical conditions. Deformation at temperatures below ~550°C invariably appears to have been accompanied by serpentinization. At relatively low temperatures, the dominant mode of deformation apparently was cataclasis. The products of such deformation are referred to as incohesive serpentinites, since the primary cohesion was greatly reduced during the extensive fracturing associated with cataclasis. Despite abundant indications of cataclasis, these rocks typically have planar anisotropies, and occasionally composite planar fabrics.

Deformation and concomitant serpentinization near the upper limit of antigorite stability (based on oxygen isotope data and microstructural observations) resulted in the formation of serpentinite mylonites which are strongly foliatied, typically lineated mylonitic rocks with microstructures very similar to those commonly found in quartzofeldspathic mylonites. Of particular interest are the shear band foliations and porphyroclast systems observed in these rocks.

Several deformation styles have been inferred to have resulted from deformation above ~550°C. These include: (a) distributed flow - which probably occurred at asthenospheric conditions, (b) localized olivine plasticity within shear zones with extensive recovery - which is interpreted to have occurred at high temperature lithospheric conditions, (c) localized olivine plasticity associated with some cataclasis producing strongly foliated peridotite mylonites - which is interpreted to have occurred near the lower limits of olivine plasticity, (d) and

extensive cataclasis of peridotite which is interpreted to have occurred below the lower limits of olivine plasticity, but above the upper limit of antigorite stability.

Serpentinite mylonites and subordinate peridotite mylonites occur within an extensive, originally subhorizontal shear zone which occurs approximately one kilometer beneath the base of the crustal sequence. This structure is interpreted to represent an extensional detachment shear zone which formed from amagmatic lithospheric extension during periods of low magma supply, and is considered to have accommodated the previously determined rotations of the overlying crustal sequence.

ACKNOWLEDGEMENTS

Since this dissertation is partly a combination of papers published during my graduate work at SUNY-Albany, I acknowledge the contributions of my coauthors (discussed below) on those papers, Gregory D. Harper and Antonio Teixell. I am also grateful to the formal and informal reviewers of these manuscripts, which include A. Nicolas, C. Simpson, A. Snoke, H.G. Ave Lallemant, J.M. Casas, W.D. Means, S.E. Delong, G. Draper, R. Speed, F. Heck, and E.T. Wallin. I appreciate the financial support provided by Harper through the past three years. I express additional thanks for financial support to attend meetings provided both from Harper, and also from the State University of New York at Albany. I also gratefully acknowledge the assistance in the field provided by Antonio Teixell during my first field season. Without his help during the first field season, this project might not have been completed.

I acknowledge the valuable comments made along the way by all members of the Department of Geological Sciences at SUNYA, including my graduate committee of Greg Harper, Bill Kidd, and W. Means, and by my fellow graduate students, including Terry Spell, Rob Alexander, Dave Foster, and Pete Copeland. A discussion with Pete Copeland after a department seminar is responsible for the origin of the term "amagmatic" extension, which has since been popularized. I gratefully thank John Delano for his personal support and encouragement during my graduate studies and especially during the final five months. Assistance with some figures was provided by Matthias Ohr. Thanks also is extended to Brian Smith for providing stable isotope data.

Special thanks is given to my family, support group, and fan club, Karen and Catherine Norrell. Without their support, this work would never have been contemplated, much less accomplished. I am especially thankful for their diligent, steadfast support during the difficult period when this dissertation was completed. I thank them most for occasionally allowing me to be something besides a geologist. Their assistance during the second field season is also acknowledged. I also thank my parents and brothers for encouragement along the way.

Contributions From Coauthors:

All map data pertaining to the crustal sequence in this dissertation are from Greg Harper. The maps of the ophiolite were prepared mostly by Harper, with minor modifications as more data became available.

Some material from Chapter III was discussed by Norrell et al. (1989), and Antonio Teixell (second author) and Greg Harper (third author) are thanked for their comments regarding that section on *Incohesive Serpentinites*. Discusions concerning these rocks with Rob Alexander and Greg Harper have been instrumental in the development of some of the ideas presented. Harper has especially emphasized the importance of diffusive mass transfer processes in these rocks.

Most of Chapter IV was published by Norrell et al. (1989). Greg Harper found the first exposure of a serpentinite mylonite shear zone which inspired this work. Antonio Teixell and I jointly made the microstructural observations presented in that paper. Teixell focused primarily on the porphyroclast systems. He suggested the terminology "neocrystallization tails", and prepared the original draft of the *Porphyroclast Systems* system, which I revised. Harper provided the original draft on *Geologic Setting* for that paper. Both coauthors made many comments, at various stages of manuscript preparation, which were incorporated in the final version. Isotope data in Chapter IV was provided by Brian Smith.

Chapter VI includes material published in Norrell and Harper (1988) and Norrell and Harper (1989). The general geologic map in Figure 6.1 (from Norrell and Harper,

1989) was compiled primarily by Harper (Toll Road and Red Mountain shear zones, and identification of the Felsic Porphyry are from my data). The map data on the crustal sequence in Figure 6.2 (from Norrell and Harper, 1989) was collected by Harper. Figure 6.3 (from Norrell and Harper, 1989) is mostly based on Harper's data (ultramafic shear zone data from me), and the figure was originally sketched by Harper, and drafted by Matthias Ohr. Many of the interpretations in this chapter were reached jointly after many discussions between Harper and myself, including the hypothesis that the ultramafic shear zone represents an extensional detachment shear zone. Harper originally pointed out the possible effects of rotational faulting on the magnetic stripes on the seafloor (schematically illustrated in Figure 6.11). Matt Heizler helped in the acquistion of argon data in this chapter.

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Well I'm sitting down by the highway,
Down by that highway side.
Everybody's going somewhere,
Riding just as fast as they can ride.
I guess they've got a lot to do
Before they can rest assured
Their lives are justified.
Pray to God for me, babe,
He can let me slide.

Well I've been up and down this highway,
Far as my eyes can see.
No matter how fast I run,
I can never seem to get away from me.
No matter where I am,
I can't help thinking I'm just a day away
From where I want to be.
Well I'm running home now,
Like a river to the sea.

Jackson Browne