Structural Characterization of the Point Delgada Tectonostratigraphic Terrane, Northern California

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The Point Delgada tectonostratigraphic terrane (PDT) is a small subterrane located the southwestern part of the King Rangewith in the Franciscan Complex of coastal northern California. Geologically, the PDT is bordered to the east by the King Peak subterrane, also part of the King Range terrane, and to the west by the submerged Vizcaino block which is believed to be a remnant of the Cascadia subduction trench. The subterrane displays structural features that indicate Cretaceous-middle Miocene (K-Ar- of a basalt 16.5 +- 0.5my) bedrock of the exotic terrane was amalgamated during the early-mid Tertiary in a dominantly tectonic melange with minor olistostromal processes. Rocks of this subterrane consist of sand to clay sized material derived from turbidity currents on the continental slope of North America and oceanic crust consisting of chert, lime mud, limestone, pillow lavas, sheeted sills and isolated dikes derived from subduction off-scrape of a volcanic edifice. X-Ray fluorescence (XRF) analysis of the immobile elements Nb, Ti, V, Y, and Zr in 10 hydrothermally altered and pumpellyite facies metamorphosed whole rock samples from the PDT suggests that the obducted volcanic edifice may have been a back-arc spreading center.

The internal structure of rocks exposed on uplifted marine terraces on Point Delgada is characterized by an anticline(s) which is segmented by northwest trending melanges (shear zones), reverse, and strike-slip faults. The core of this anticline consists of rocks from the volcanic edifice which have been exposed by erosion in the middle of the subterrane. The structurally and stratigraphically higher terrestrially-derived turbiditic layers are exposed on either side of this northwest trending structure. This anticline is tilted towards the contientent in the northern 1.5 km, exhibiting an isoclinal structure. Because this structure in some cases exhibits limbs of the fold which both dip towards the northeast at 3-12°, it suggests tilting of the entire structure of the subterrane towards the continent. Bedding of Cretaceous rocks has been overturned from an original subhorizontal position on the trench slope and is oriented subparallel to the continent striking at N20-50°W and dipping at 69-88°, primarily to the NE.

The folded structure of Point Delgada has been segmented by early northeast and northwest trending faults of possible conjugate nature. These faults are likely fault splays related to obduction of the terrane in the accretionary wedge. They offset a set of northeast trending hydrothermal sulfide veins. These veins dated by K-Ar of adularia at 13.8 +- 0.5 my have been interpreted to be a product of high heat flow related to the passing of the Mendocino triple junction through the King Range terrane which at present is located 50 km north of Point Delgada. Finally, these veins and all structure is cross-cut by right-lateral strike-slip faults exhibiting an orientation of N2-23°W/72-90° NE-SW, similar to that of a mapped trace of the San Andreas Fault located 0.5-1.0 km to the east.

INTRODUCTION

The King Range of the Franciscan Coastal Ranges of California is located 250 miles north of San Francisco Bay. The two subterranes which comprise this post-middle Miocene accreted, partially exotic, melange terrane (McLaughlin, et al., 1982) are the King Peak Subterrane and the Point Delgada Subterrane. The much larger King Peak Subterrane lies juxtaposed aganist the Point Delgada terrane along a broad subvertical shear zone striking N2°W. As a result of paleotemperature dating through the K-Ar fission track method of apatite crystals (Dumitru, 1991) and vitrinite reflectance (Laughland, 1991), this fault is believed to have experienced vertical displacement resulting in two to five km of uplift of the KPT since the middle Miocene. However, dating of adularia in hydrothermal veins (McLaughlin, et al., 1985) which cross-cut the supposed terrane boundary (Blake, et al., 1985) shows that the two terranes have been amalgamated since 13.8 +-0.4mya. Thus, any vertical movement along this north-south trending shear zone must have occurred over a wide span of several hundred meters, not a single discrete fault. The PDT was not uplifted as large a degree as the KPT as a result of triple junction tectonics.

While this fault has recently seen right-lateral strike-slip motion, the magnitude of such displacements are significantly less than any vertical movements. Displacements have been interpreted (McLaughlin, et al., 1982) to be the result of space constraints related to the Mendocino triple junction at the northern termination of the San

Andreas fault. As a result of early subduction related obduction of the King Peak subterrane and vertical movements associated with space constraints and high heat flow related to the northward passage of the Mendocino triple junction, the King Range has a maximum elevation of over 1000 meters while the maximum elevation of the PDT is just over 20 meters above sea level on uplifted wave-cut marine and fluvial terraces (figure 1).

RESULTS AND DISCUSSION

Structural synthesis of features in the rocks of the PDT (figure 2) including bedding, folding, veining, and faulting in the northern 4 kilometers of PDT bedrock exposures on Point Delgada has discovered several structural trends which served to characterize the terrane in terms of its stratigraphic and tectonic evolution. First of all, bedding within the terrane strikes northwest parallel with the continent and always dips at steep angles in either direction. Facing directions for pillow basalts, Bouma sequences, and layered sandy conglomerates show that the structure of the terrane consists of an exposed anticline with a hinge line that is oriented N35°W/10°NW. The structure is also tilted in some exposures so that the axial plane dips 80-85° to the northeast to form an isocline. Small order slump folds within Bouma sequences mirror this anticlinal to isoclinal structure.

Fold structure is cross-cut and segmented by northwest trending melanges (shear zones) and two sets of presumably obduction related faults. These melanges include vertically pulled apart phacoids and boudins of arkosic greywacke or volcanogenic material which show that movement in these shear zones was vertical in sense. In addition, slickensides on adjacent rocks show that the movement was reverse in sense. Thus, these melanges likely represented either broad scale reverse faults or diapiric tectonic squeezing within the melange (Cloos, 1985). These melanges and shear zones appear to have formed at relatively the same time from evidence of cross-cutting relationships. These two sets of cross-cutting faults include a set of dominantly steeply dipping, northwest trending reverse faults and a set of steeply dipping northeast trending normal faults. Both sets of faults exhibit relatively vertical original slickenlines which have been overprinted by younger slickenlines which plunge more horizontally. Most of these faults exhibit components of vertical horizontal movement in that their slickenlines typically plunge between 30-60° to the southeast. There are however a few examples of thrust faults which exhibit dip-slip motion that also cross-cut folding. These thrusts are usually very pronounced in outcrop and may be master faults for the steeper dipping reverse faults which may represent splays. The normal faults are commonly veined with sulfides or calcite. These faults exhibit left-lateral slickenlines while the northwest trending reverse faults have right-lateral slickenlines.

A younger structural trend is a set of hydrothermal sulfide veins dated at around 14 mysbp which strike to the northeast along the same trend as the early normal faults and dip subvertically in both directions. These veins cross-cut all features including folds, bedding, melanges, and the two sets of "early" faults, that appear to be "melange' in nature or related to obduction in the accretionary wedge.

The youngest structure in the melange are north-northwest trending right-lateral, strike-slip faults which dip, in most cases 75-85°SW, with a few dipping NE. This generation of faults offsets all other structural features of the PDT including hydrothermal veins and overlying horizontally bedded Quaternary fluvial terraces (Merritts, et al., 1989) in some outcrops. These faults become more organized in orientation, becoming all southwest dipping and very similar in strike (N3-21°w) as they get closer to mapped trace of the San Andreas fault on Point Delgada at the northeasternmost outcrops (Brown, 1995). This feature is located 0.5 km east of the northern outcrop of the Point Delgada Subterrane on the south bank of Telegraph Creek. The San Andreas fault at the latitude of the PDT has a orientation of N15°W/79°NW.

CONCLUSIONS

Based on the stratigraphy of the subterrane, it appears that ocean crust from a back-arc spreading center approached the subduction trench during the late Cretaceous to early Tertiary. These rocks included ultramafics (located at depth and off-shore (McLaughlin, et al., 1982)), sheeted sills, dikes, and layered pillow lavas of bimodal chemistry which are presently exposed on outcrop along the coast of Pt. Delgada. The pillow lavas are interlayered by pelagic lime mud, crystalline limestone, and were covered over by fining-upward turbidites including Bouma sequences of varying thicknesses, massive greywacke, and massive argillite either prior to or sometime during obduction. These late Cretaceous rocks (McLaughlin, et al., 1982) and sediments which presently make-up the rocks of the PDT were off-scraped by the North American Plate in the Subduction trench.

During offscrape and resultant obduction of these rocks and sediments, the terrane was tilted into the continent, folded, and finally thrust faulted upward in the accretionary wedge. At the time of obduction, normal faults also developed along zones of weakness because of flexural expansion in the rocks. After obduction, subduction was cut off at the latitude of the accretionary wedge as the Mendocino triple junction migrated northward. The northward passage of the MTJ created high heat flow and hydrothermal circulation as a result of ridge-trench interaction or asthenospheric upwelling (Merritts, et al., 1989). Once the MTJ migrated north of the PDT, the San Andreas transform or the proto San Andreas fault cut through the terrane. It is believed (McLaughlin, et al., 1982) that the PDT was accreted at approximately the latitude of Monterey Bay and migrated north on the western margin of the SAF approximately 700km to a present latitude in northern California.

Figure 1:- A field photograph of the PDT (foreground) as represented by wave-cut terraces on the coast of the Pacific Ocean on Point Delgada. The King Peak Subterrane is located to the northeast (background).

Figure 2:- Table of the major rock types exposed in the northern four kilometers of the PDT.

Lithology	Rock Type	Description/Stations (see index and/ or geologic maps)	Possible origin in related to the PDT
Volcanoclastic Conglomerate	Volcanisedimentary	Bouldery to sandy conglomerate with clasts of igneous rocks and a matrix consisting of volcanoclastic gwk. Stations 2-11, 30, 35	Debris flow and or turbidity currents from volcanic edifice.
Melange-Sheared Greywacke and shaly turbidites	Tectonosedimentary	Found in shear zones. This unit has been faulted preferentially as a zone of incompetence and high ductility. Found in stations 4, 6-10, 32-45.	Turbidity currents and tectonic melange. May represent early faulting within the melange during assemblage and obduction.
Melange- Sheared pelite and phacoids of sheared volcanoclastic and terrigenous gwk.	Tectonosedimentary/ Metamorphic	Found in zones of early faulting in the melange. Contains dark gray terrestrial sediments and olive colored volcano-genic sediments.Stations 8,10, 12, 31,46, 48	Deep water turbidites assembled in a tectonic melange. Derived from North American and the volcanic edifice.
Volcanoclastic Greywacke	Sedimentary	Bedded and unbedded volcanic sand of an immature texture. Green in color. Stations 8-10, 31-36, 41-42, 48	Turbidity current and gravity flow.
Bouma Sequences	Sedimentary	Bedded and frequently slump folded fining upward sequences of massive arkosic gwk., siltstone, and shale. This arkosic gwk. also exists in large blocks. Stations 35, 40-44, 48.	Turbidity currents that transported sediments off of the continental shelf of North America.
Argillite	Metamorphic	Massive blocks of yellow-green clay-rich rock that has been metamorphosed and altered hydrothermally (veined). Stations 1-2	Clay-rich sediments derived from a continental and or volcanic source. Meta-morphosed by high P and low T in to a massive rock.
Igneous intrusive rocks: Dikes and Sills	Igneous (intrusive)	Intrusions of basalt, diabase, or plagio-granite. Stations 4, 5, 9.	Magma from a oceanic spreading center-likely a back-arc spreading center.
Sheeted Igneous intrusive rocks	Igneous (intrusive)	Bi-tri-modal plutonic rocks (commonly sills) with chilled margins. Complex intrusive sequence. Stations 3, 5.	Generation of ocean crust at a back-arc spreading center.
Volcanic pillow lavas (Basalts or rhyo/dacites)	Igneous (extrusive)	Pillow structures ranging from .25-2m in diameter. Exposed in stations 11-35, 44-48.	Lava which was quenched in a marine setting in a back-arc basin.

References Cited:

Blake, M.C., Jr., Jayko, A, and McLaughlin, R. J., ed., Tectono-stratigrphic terranes of the northern Coast Ranges, California, in Howell, D. G., ed., Tectonostratigraphic terranes of the circum-Pacific region: Circum-Pacific Counsel for Energy and Mineral Resources, Earth Science Series, v. 1, P. 159-171.

Cloos, R. B., and Basu, A.R., 1983, Comparative study of melange and metashales from the Franciscan subduction complex with the basal Great Valley Sequence, California: Journal of Geology, v, 91, p. 291-306.

Laughlin, M. M., 1991, Organic metamorphism and thermal history of selected portions of the Franciscan accretionary prism of coastal California (Ph.D. dissert.): Columbia, University of Missouri, 318 p.

McLaughlin, R. J., Klong, S. A., Poore, R. Z., McDougall, K., Beutner, E. C., 1982, Post-Middle Miocene accretion of Franciscan rocks, northwestern California: Geological Society of American Bulletin, v. 93, p. 595-605.

McLaughlin, R.J., Sorg, D.H., Morton, J. L. Theodore, T. G., Meyer, C. E., Delevaux, M. H., 1985, Paragenesis and tectonic significance of base and precious metal occurrences along the San Andreas fault at Point Delgada, California: Economic Geology, v. 80, p. 344-359.

McLaughin, R.J., Sliter, W. V., Frederiksen, N. O., Harbert, W. P., and McCulloch, D. S., 1994, Plate motions recorded in tectonostratigraphic terranes of the Franciscan Complex and evolution of the Mendocino Triple Junction, northwest California: northwest California: U.S. Geological Survey Bulletin 1997, 60 p.

Merritts, D., and Bull, W. B., 1989, Interpreting Quaternery uplift rates at the Mendocino triple junction, northern California, from uplifted marine terraces: Geology, v. 17, p. 1020, 1024.