# FORUM

# Comment and Reply on "Geochemical evidence for the tectonic setting of the Coast Range ophiolite: A composite island arc–oceanic crust terrane in western California"

## COMMENT

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We wish to clarify some apparent misunderstandings in Shervais and Kimbrough's (1985) article reporting on a reconnaissance study of the chemistry of the Coast Range ophiolite of California (CRO) and to correct and add to some of Shervais and Kimbrough's citations. We have studied other ophiolitic rocks in the Coast Ranges that may be part of, or related to, the CRO, and one of us (Phipps) has concluded, like Shervais and Kimbrough, that the CRO is very diverse (MacPherson, 1977, 1981, 1983; Phipps et al., 1979; Phipps, 1982, 1984a, 1984b[1]).

Our comments concern (1) the development of present ideas about Snow Mountain, its similarities to and differences from the CRO and the reasons for identifying it as an accreted seamount; (2) the naming and correlation of the Snow Mountain Complex; (3) the reasons for the assignment of the Snow Mountain Complex to the Franciscan Complex; and (4) the possible relationships and distinctions among the CRO, the Franciscan, and the Great Valley sequence (GVS).

Bailey and Blake (1974) were the first to recognize that the CRO is a very diverse unit. Although they identified the titaniferous volcanic rocks at Snow Mountain and west of Stonyford with the CRO, rather than with the Franciscan (as we now believe to be correct), their point was correct even if misguided, and should be cited. The data presented in Hopson et al. (1981) also indicates that the CRO is highly variable from one locality to another (Phipps, 1984a, 1984b).

Bailey and Blake (1974) were also the first to point out that the whole-rock chemistry of the volcanic rocks in the Snow Mountain *area* resembles that of oceanic island basalts. However, their samples were all taken from the Stonyford volcanics, a small body of volcanic rocks in the valley of Stony Creek, west of Stonyford but east of Snow Mountain (Fig. 1) (Blake, 1985, personal commun.). These rocks are physically separated from the larger masses of volcanic rocks on Snow Mountain and St. Johns Mountain (Fig. 1). MacPherson (1977, 1981, 1983) conducted detailed field, petrologic, and mineral-chemical studies on Snow Mountain and St. Johns Mountain, and concluded that these rocks indeed represent an on-land seamount that has been incorporated into the Franciscan Complex. MacPherson (1983) included several field observations critical to this conclusion. However, his identification of Snow Mountain as a seamount does not rest primarily on field evidence, as might be inferred from Shervais and Kimbrough's citation, but on 37 whole-rock chemical analyses and on about 300 clinopyroxene analyses. Snow Mountain basalts are uniformly titanium-rich, contain titaniferous clinopyroxene, and are associated with alkalic differentiates—characteristics common to many mid-ocean islands (MacPherson, 1981; representative data published in MacPherson, 1983, Tables 1 and 2). We are puzzled that Shervais and Kimbrough did not refer to this data.

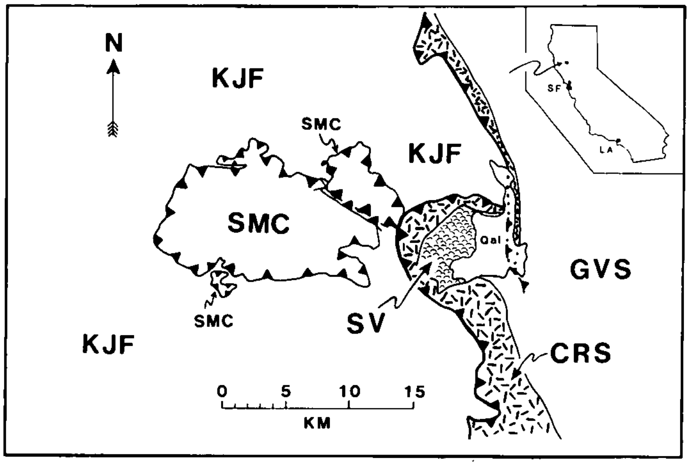


**Figure 1. Geologic sketch map of Snow Mountain area. KJF = Franciscan Complex; SMC = Snow Mountain Complex; SV = Stonyford Volcanics; Qal = Quaternary alluvium; CRS = serpentinite of Coast Range ophiolite; GVS = Great Valley Sequence. Largest mass of SMC is Snow Mountain massif; smaller mass to northeast is St. Johns Mountain; smallest mass, immediately to south of Snow Mountain, is Potato Hill. Town of Stonyford lies within Qal valley. From Jennings and Strand (1960) and MacPherson (1983).**

Our second comment concerns the naming and local correlation of the volcanic rocks at and near Snow Mountain. In particular, we suggest that the term "Snow Mountain volcanic complex" is preferred, because it has formal precedence and because other terms may cause confusion about the correlation of the rocks. We are especially concerned that the term "Stonyford seamount," used by Shervais and Kimbrough (1985) and Hopson et al. (1981), is genetic in nature, incorrect in geography, and may imply a miscorrelation.

Brown (1964) referred to the rocks around Snow Mountain as the "St. John Mountain—Snow Mountain klippe;" Bailey and Blake (1974) referred to them informally as the "Stonyford volcanics." MacPherson (1977) was the first to propose a formal stratigraphic name for the rocks, and termed them the "Snow Mountain Complex."

Beyond the question of precedence, the name Snow Mountain Complex is most appropriate for several geologic reasons. The term "complex" is both descriptive and formally correct, because the volcanic

[1]Because of delays in production, Phipps (1984b) was not publicly available until mid-1985, and we recognize that Shervais and Kimbrough would have had no reason to be aware of it.

pile includes interbedded sedimentary rocks. Bailey and Blake's term "Stonyford volcanics" is not appropriate for the rocks on Snow Mountain and St. Johns Mountain because the affinities of the volcanic rocks in the Stonyford outlier (Fig. 1)—the only rocks that Bailey and Blake analyzed—are not clear. Although these rocks are titanium-rich, they are separated from the rocks on Snow Mountain, and because no one has reported high-pressure metamorphic phases from them, it is not clear (although we think it likely) that they are Franciscan. Finally, even if the Stonyford volcanics *are* Franciscan, we prefer the geographic modifier "Snow Mountain" because the largest mass of the rocks, the most complete section, and the best and most critical exposures are on Snow Mountain.

Our third comment concerns the metamorphism of the rocks on Snow Mountain, the reasons for assigning them to the Franciscan, and the general question of the correlation of ophiolitic rocks in the Coast Ranges. We believe that textural or mineralogic evidence of high-pressure metamorphism is the *only* unequivocal criterion for assigning a rock unit to the Franciscan. As Shervais and Kimbrough stated at one point (1985, p. 37), MacPherson (1977, 1981, 1983) assigned the rocks of the Snow Mountain Complex to the Franciscan on the basis of their blueschist-facies metamorphic overprint. However, Shervais and Kimbrough state: "The compositional similarity of the Stonyford and Paskenta spilites to Franciscan volcanic rocks suggests that these rocks may be part of the Franciscan Complex and not true CRO." The implication is that "Franciscan" mafic rocks and those of the CRO are *by definition* distinct *compositionally*. This is not the case; thus assignments based on composition alone are at best premature.

Our final comment concerns the relationships between and the criteria for distinguishing among the Franciscan, the CRO, and the GVS. This distinction is often quite difficult, for several reasons: (1) In many probable Franciscan volcanic blocks, the development of high-pressure phases is weak or nil. (2) As Suppe (1979a, 1979b) and Phipps (1981, 1983, 1984a, 1984b) have demonstrated, multiply imbricate thrust slices of CRO are interleaved with Franciscan and GVS thrust slices throughout the Franciscan-dominated outcrop belt. Some slices of probable CRO are extremely thin, and it may be impossible to assign some thin pods or slices of ophoilitic rock to the Franciscan or to the CRO. (3) It seems clear from the work of many people, including Shervais and Kimbrough, that the mafic parts of each of these three units contain diverse rock types. Finally, Phipps (1982, 1984a, 1984b; Phipps et al., 1979) has shown that the basal GVS regionally contains a 1-km thick unit consisting of ophiolitic blocks—including *low-P*/high-*T* metabasites—in a mudstone and sedimentary serpentinite-flow matrix. Phipps has interpreted this unit as an accumulation of ophiolitic olistostromes and has suggested that the ophiolitic blocks were eroded from the CRO. The olistostromes may have carried serpentinite, basalt, chert, and greenschist and amphibolite facies metabasites completely through the forearc basin and into the trench, where they may have been subducted and overprinted to varying degrees by high $P/T$ Franciscan metamorphism (Phipps, 1984a, 1984b). Our work in progress indicates that the GVS chaotic unit contains basalt blocks with *both* MORB-type *and* highly titaniferous, transitionally alkalic chemistries and mineralogies. Thus, many different types of CRO-derived blocks may have been incorporated into the Franciscan.

In conclusion, we feel that the California Coast Ranges are still so little understood that even studies of a reconnaissance nature are valuable, especially when they present new data, and we laud the efforts of Shervais and Kimbrough and others who attempt broad syntheses. But we also wish to plead that such syntheses use more elements of the available data base. In an area that consists of an accreted complex of subtle and difficult problems, it is important that all interpretations be fully informed by the published literature and, where possible, by direct study of the complicated field relations that characterize the Coast Ranges.

## REPLY

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Shervais and Kimbrough (1985) is a reconnaissance geochemical study of volcanic rocks from ten CRO localities. This work does not represent a broad synthesis of previous results on CRO geology. We presented new data that bear on the original tectonic setting of the CRO—a terrane for which published geochemical data are sparse. These new data were integrated with existing geochemical data and published field relationships to show that most volcanic rocks in the CRO have petrogenetic affinities to volcanic series in island-arc terranes. This is the central conclusion of our study.

Some volcanic rocks in the northern Coast Ranges that have been considered part of the CRO (e.g., the Stonyford and Paskenta volcanics) have stratigraphic, structural, and geochemical characteristics that differ from other CRO localities. Geochemically, these rocks have off-axis seamount or enriched MORB affinities—similar to many volcanic rocks in the Franciscan Complex (e.g., Bailey et al., 1964). We suggest that these rocks may represent either a change of tectonic setting within the CRO or Franciscan terranes that have been juxtaposed tectonically (Shervais and Kimbrough, 1985).

We concur with MacPherson and Phipps that the term "Stonyford seamount" has genetic implications and should be discontinued. The term "Stonyford volcanics," although informal, has been generally accepted and used by geologists working in the Coast Ranges and is preferred. Because the Stonyford volcanics and the Snow Mountain complex are geographically distinct, we believe that both terms should be retained to distinguish between these two areas.

MacPherson and Phipps state that we did not integrate sufficient previous literature into our discussion and conclusions. Most of the examples that MacPherson and Phipps cite are abstracts, unpublished dissertations, or papers that were in press at the time we wrote our paper (e.g., MacPherson, 1977, 1981; Phipps, 1981, 1982, 1983, 1984a, 1984b). Contrary to their assertion, we *did* cite Bailey and Blake (1974) in our discussion of geochemical diversity in the CRO.

Our diagrams include all published analyses of CRO volcanic rocks, with the exception of seven basalt analyses published by MacPherson (1983). This oversight was unintentional; we were aware of these data and their implications. In fact, MacPherson (1983) is cited extensively in our discussion. Addition of these seven analyses to our diagrams does not change our discussion or conclusions in any way.

We did not imply in our discussion that volcanic rocks from the CRO and the Franciscan Complex are *by definition* compositionally distinct. The definition of the CRO is based on its conformable relationship to the overlying Great Valley Sequence (Bailey et al., 1970; Hopson et al., 1981). However, in the southern Coast Ranges—where structural relationships between the CRO and Franciscan Complex are less complex than the northern Coast Ranges—we observe that unequivocal CRO and Franciscan volcanic rocks are indeed compositionally distinct. Interpretation of these differences in the northern Coast Ranges is complicated by tectonic disruption of ophiolite basement during the Jurassic and by extensive Tertiary thrust and strike-slip faulting (Swe and Dickinson, 1970; McLaughlin, 1981; Hopson et al., 1981; McLaughlin and Ohlin, 1984).

Most ophiolitic rocks in the northern Coast Ranges occur as tectonic inclusions within or adjacent to serpentinite-matrix melange (Hopson et al., 1981). This serpentinite-matrix melange, which forms a belt that extends from Stonyford in the south to Paskenta in the north, has been interpreted as CRO by most recent investigators (e.g., Bailey et al., 1970; Bailey and Blake, 1974; Hopson et al., 1981). We suggest that correlation with the Franciscan complex may be more likely, based on the geochemical similarity between volcanic rocks in the melange and Franciscan volcanic rocks. Furthermore, the serpentinite-matrix melange near Paskenta is in tectonic, not depositional, contact with a polymict breccia that Hopson et al. (1981) interpreted as a submarine talus breccia derived from the CRO. This breccia is overlain depositionally by the Great Valley Sequence (Hopson et al., 1981). Also, the melange contains inclusions of radiolarian chert that are early Tithonian in age (Hopson et al., 1981) and hence younger than the Oxfordian tuffaceous cherts that overlie volcanic rocks of the CRO. These data suggest that the so-called "Coast Range Thrust" (which is a high-angle fault near Paskenta) should be placed to the east of the melange and not to the west, as it is currently.

The submarine talus breccias containing ophiolitic debris, which were deposited on eroded ophiolite basement in the northern Coast Ranges (south fork of Elder Creek), show that this basement was tectonically disrupted shortly after formation (Bailey et al., 1970; Hopson et al., 1981). These talus breccias are distinct from chaotic units described by Phipps (1984b). They contain abundant plutonic as well as volcanic clasts, and the volcanic clasts include keratophyre, suggesting derivation from the arc-like part of the CRO. We have collected a suite of these clasts for chemical analysis to compare to in situ CRO and Franciscan volcanic rocks.

Phipps (1984b) has described chaotic units of ophiolitic debris that underlie the Great Valley Sequence near Lake Berryessa south of Stonyford. MacPherson and Phipps found both MORB-like and high-Ti transitional basalts as clasts within these chaotic units that Phipps (1984b) interpreted as olistostromes derived from the CRO. However, it is unclear whether these olistostromes are derived from the CRO or from the Franciscan Complex. On the basis of their descriptions, the olistostromal units appear to lack arc-derived volcanic rocks, which we suggest are a dominant rock type within the CRO (Shervais and Kimbrough, 1985). The MORB-like and high-Ti basalts reported by MacPherson and Phipps in their Comment are common, however, within the Franciscan Complex (e.g., Bailey et al., 1964; Shervais and Kimbrough, 1986). Further, the upper contact of the chaotic units described by Phipps (1984b) is tectonic and not conformable with the GVS (Phipps, 1984b). The stratigraphic position and provenance of these chaotic units are uncertain.

The geologic development of the Coast Range Ophiolite during the Mesozoic is a complex problem. Detailed field and petrologic studies of specific localities, like those of Page (1972), Hopson and Frano (1977), Evarts (1977), MacPherson (1983), and Phipps (1984b), are crucial to resolving these complexities. Also important are regional studies that consider the development of the CRO and associated rocks as a whole—e.g., Bailey et al. (1970), Bailey and Blake (1974), Hopson et al. (1981), and Shervais and Kimbrough (1985). The purpose of our paper is twofold: (1) to clarify and constrain possible origins of the CRO, and (2) to stimulate further research that will test these working hypotheses. We are currently engaged in more detailed studies of CRO and Franciscan volcanic rocks, and we hope that our paper will encourage others to begin similar studies.

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