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DETRITAL GLAUCOPHANE SCHIST PEBBLES FROM FRANCISCAN METACONGLOMERATES OF THE NORTHEAST DIABLO RANGE, CALIFORNIA

DIANE E. MOORE* and J. G. LIOU

Department of Geology, Stanford University, Stanford, California 94305

ABSTRACT. Petrology and mineral chemistry of the pebbles and matrix of many Franciscan metaconglomerates from the Diablo Range were investigated. The consistent mineral assemblages among pebbles, matrix, and nearby graywackes indicate postdepositional blueschist facies metamorphism of the conglomerates. However, five glaucophane schist clasts from metaconglomerates of the northeastern Diablo Range are texturally and mineralogically different from the other pebbles and may represent detritus from an older blueschist terrane, based on the following evidence: (1) the detrital blueschist clasts are coarse-grained schists with no traces of pre-metamorphic textures, whereas the other sodic amphibole-bearing pebbles in the same metaconglomerates preserve both relict igneous textures and minerals; (2) distinct foliation in the detrital blueschist clasts lies at an angle to the modest fabric in the matrix and is not related to deformation of the metaconglomerates; (3) the presence of garnet and rutile, the occurrence of glaucophane rather than crossite, and element distribution between glaucophane and phengite suggest that the detrital blueschist pebbles may have recrystallized at higher pressures and temperatures than did the metaconglomerates; and (4) some glaucophane crystals in the detrital blueschist pebbles have been partly altered to crossite along fractures and at the clast boundaries during blueschist facies metamorphism of the conglomerates. The detrital glaucophane schist pebbles in the metaconglomerates may have been derived from the same source as Franciscan blueschists occurring as tectonic blocks.

INTRODUCTION

Conglomerate bodies containing pebbles of various lithologies in a graywacke matrix are widely distributed throughout the Franciscan Complex of California (Taliaferro, 1943; Bailey, Irwin, and Jones, 1964), and study of the pebbles and cobbles in the conglomerates is significant in ascertaining the sources of Franciscan detritus. Of particular interest are clasts that contain blueschist facies mineral assemblages. Prior to the recognition of widespread blueschist facies metamorphism of Franciscan sedimentary rocks, all such pebbles were considered to be blueschist detritus (Maddock, ms; Soliman, ms; Bailey, Irwin, and Jones, 1964). In recent years, however, the pervasive subduction zone metamorphism of Franciscan sedimentary rocks has been documented, and the areal distribution of critical metamorphic minerals has been mapped (Bloxam, 1956, 1960; McKee, 1962; Coleman and Lee, 1962, 1963; Coleman, 1965; and Ernst, 1965, 1971a,b). In the light of such discoveries, a few workers have critically investigated previously reported occurrences of detrital glaucophane schists in Franciscan metaconglomerates to determine whether the blueschist facies minerals in the pebbles formed before or after deposition.

In Upper Cretaceous Franciscan metaconglomerates from the Salinian Block, Cowan and Page (1975) found large blueschist pebbles that have been more highly metamorphosed than the surrounding matrix

*Present address: U.S. Geological Survey, 345 Middlefield Road, Menlo Park, California 94025

and that show no evidence of the growth of blueschist facies minerals across pebble boundaries. They concluded that such pebbles represent blueschist detritus recycled from an older Franciscan metamorphic terrane. In coastal belt Franciscan rocks north of San Francisco, O'Day and Kramer (1972) found conglomerates containing pebbles of blueschist, greenstone, chert, ultramafic rock, graywacke, and shale, which may also be recycled Franciscan detritus. In contrast, other investigations of the older and more highly metamorphosed conglomerates of the Diablo Range did not yield any evidence of blueschist detritus (Fyfe and Zardini, 1967; Platt, Liou, and Page, 1976); rather, the metamorphism of the pebbles is consistent with one episode of blueschist facies metamorphism subsequent to deposition of the conglomerates.

As part of a detailed study of several Franciscan metaconglomerates from the northern and central Diablo Range (Moore, ms), an attempt was made to identify blueschist detritus. Two conglomerate bodies from the northeastern Diablo Range contain glaucophane schist pebbles that are texturally and mineralogically different from the other sodic amphibole-bearing pebbles and that are considered to be second-cycle glaucophane schists. The purpose of this paper is to describe the detrital glaucophane schists and to present the evidence indicating polymetamorphism. The evidence for and against sources in the Sierra Nevada and Klamath Mountains and in the Franciscan itself are discussed.

FRANCISCAN METACONGLOMERATES

The conglomerates containing blueschist detritus are shown in figure 1. Both conglomerate bodies occur in mélange terranes; the con-

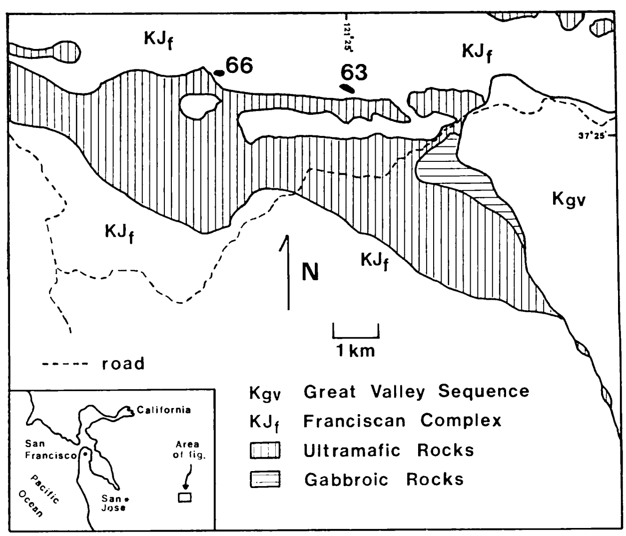


Fig. 1. Locality map of Franciscan metaconglomerates from the Diablo Range that contain blueschist detritus (geology after Maddock, ms).

glomerate at locality 66 is a tectonic block approx 8 m in diameter, and locality 63 is a 1 m-thick pebbly lens in a graywacke block. Pebbles of sedimentary and igneous origin predominate in the two conglomerates. Sedimentary pebbles include quartz-rich sandstone and quartzite, graywacke, gray and black chert, siltstone, and shale. Most of the igneous pebbles are andesite, basaltic andesite, or basalt (Moore and Liou, 1977); several are porphyritic and some are amygdaloidal. Few felsic volcanic or plutonic rocks occur. A few small, irregularly shaped clasts consisting of Mg-rich chlorite may be altered serpentinite. Most of the pebbles show one episode of blueschist facies metamorphism, and the mineral assemblages of the pebbles and conglomerate matrix are consistent. In addition, metamorphic minerals overgrow pebble boundaries and extend into the surrounding matrix, indicating post-depositional crystallization. The degree of metamorphism of the two conglomerates and of associated metasediments is similar; characteristics of that metamorphism are described briefly below, to form a basis on which to compare the detrital blueschists.

All feldspars in both pebbles and matrix have been albitized. Jadeitic pyroxene occurs sporadically as sprays of thin, wispy crystals in the albite, but no albite crystal is totally replaced by jadeite. Albite commonly occurs with lawsonite or pumpellyite as a replacement of calcic plagioclase. Lawsonite also occurs in shale clasts and is intergrown with phengite in the conglomerate matrix. Pumpellyite is also commonly associated with chlorite in volcanic detritus and with phyllosilicates in the conglomerate matrix. Very fine-grained, brownish sphene is characteristically found with chlorite. Aragonite is the stable polymorph of calcium carbonate in the metaconglomerates.

Sodic amphiboles are characteristically deep blue in color and have 3 principal modes of occurrence in the metaconglomerates; (1) non-oriented, blade-like crystals approx 0.1 mm long predominate in the groundmass of some volcanic pebbles; (2) fringes of sodic amphibole occur at the edges of relict hornblende crystals in the igneous pebbles, and bands of sodic amphibole occur along fractures within the hornblendes; (3) wisps of sodic amphibole up to 0.3 mm long extend from patches of chloritic phyllosilicate into albite. Sodic amphiboles in different occurrences (table 1) contain considerable amounts of Fe and less Al than pure glaucophane. The compositions are plotted in figure 2, with iron apportioned to di- and trivalent states such that the 2 octahedral sites are filled as completely as possible. For all such estimates, Si closely approaches the ideal value of 8 cations per formula unit, and the sum of all cations lies between 14.9 and 15.1. As shown in figure 2, the sodic amphiboles are either crossite or ferroglaucophane near crossite in composition.

Despite metamorphic recrystallization, most pebbles retain their original sedimentary or igneous textures. Some relict textures are illustrated in plate 1. The groundmass of a mafic volcanic pebble, shown in plate 1-A, contains chlorite + albite + sphene + pumpellyite.

TABLE 1

Chemical analyses of sodic amphiboles from pebbles and matrix of Franciscan conglomerates of the northeast Diablo Range, Calif.

	1	2	3	4	5	6	7
SiO_2	54.90	55.77	56.29	55.73	54.83	55.03	56.04
TiO_2	0.48	0.11	0.38	0.17	0.31	0.49	0.12
Al_2O_3	8.91	7.54	8.99	9.21	7.00	7.06	7.18
FeO^*	18.50	18.05	18.52	18.45	22.23	21.40	20.70
MgO	6.14	6.30	5.66	5.12	5.37	5.79	5.04
CaO	0.53	0.55	0.35	0.64	0.49	0.71	0.54
Na_2O	6.18	7.12	7.30	7.38	6.64	6.45	7.26
K_2O	0.12	0.11	0.07	0.09	0.09	0.15	0.10
Anhydrous Total	95.76	95.55	97.55	96.79	96.96	97.08	96.97
	Atomic Proportions O = 23						
Si	7.93	8.05	7.99	7.98	7.93	7.92	8.06
Al^{IV}	0.07	...	0.01	0.02	0.07	0.08	...
Al^{VI}	1.44	1.28	1.50	1.53	1.12	1.12	1.22
Ti	0.05	0.01	0.04	0.02	0.03	0.05	0.01
Fe^{3+**}	0.50	0.63	0.44	0.40	0.83	0.82	0.69
Fe^{2+**}	1.73	1.55	1.76	1.85	1.85	1.76	1.82
Mg	1.32	1.35	1.20	1.09	1.16	1.24	1.08
Ca	0.08	0.08	0.05	0.10	0.08	0.11	0.08
Na	1.73	1.99	2.01	2.05	1.86	1.80	2.03
K	0.02	0.02	0.01	0.02	0.02	0.03	0.02

*Total Fe as FeO

**Fe^{3+}/Fe^{2+} ratios estimated from microprobe data

Column

1. 64-4; sodic amphibole replacing hornblende in plutonic pebble.
2. 65-4a; blue amphibole fringes around aggregate of hornblende crystals in volcanic pebble.
3. 65-8; blue amphibole fringe on hornblende phenocryst in volcanic pebble.
4. 65-15; sodic amphibole fringes on hornblende crystals in porphyritic volcanic pebble.
5. 63-1a; sodic amphibole partially replacing hornblende clast in graywacke matrix.
6. 63-1b; sodic amphibole associated with quartz clast in graywacke matrix.
7. 66-6c; sodic amphibole in quartz-feldspar pebble.

Plagioclase phenocrysts in that pebble are replaced by albite with included crystals of pumpellyite. Hornblende phenocrysts in a second volcanic pebble (pl. 1-B) have been partly replaced and fringed by crossite.

DETRITAL GLAUCOPHANE SCHIST PEBBLES

In contrast to the other clasts, 5 well-rounded pebbles from 2 of the metaconglomerates display textural and compositional evidence that they were glaucophane schists at the time of deposition, and that they have been subjected to a second, lower grade of blueschist facies metamorphism as pebbles in the conglomerates. One pebble is from locality 63, and the other 4 pebbles are from locality 66.

Petrography.—The single pebble from locality 63 (#63-1, pl. 2-A) is a coarse-grained, well foliated schist consisting of pale blue sodic amphibole and white mica, some crystals of which are 4 mm long. The pale coloring of the sodic amphibole contrasts with the deep blue of amphiboles that formed after the conglomerate as a whole was metamorphosed. The schistosity of the pebbles is considerably more pronounced than, and at an angle to, the mild foliation developed in the surrounding metagraywacke matrix. The only other mineral in this pebble is sphene, occurring as clear, idioblastic crystals in bands parallel to the foliation. Its habit contrasts to the brownish, fine-grained sphene in other pebbles. No traces of premetamorphic texture remain in the pebble, and none of the sodic amphiboles crosses the pebble boundary. These features, together with the difference in grain size and foliation, suggest that the blueschist minerals in this pebble did not crystallize during the metamorphism of the conglomerates.

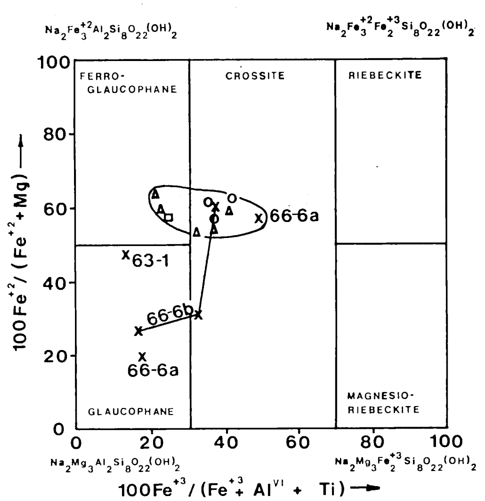
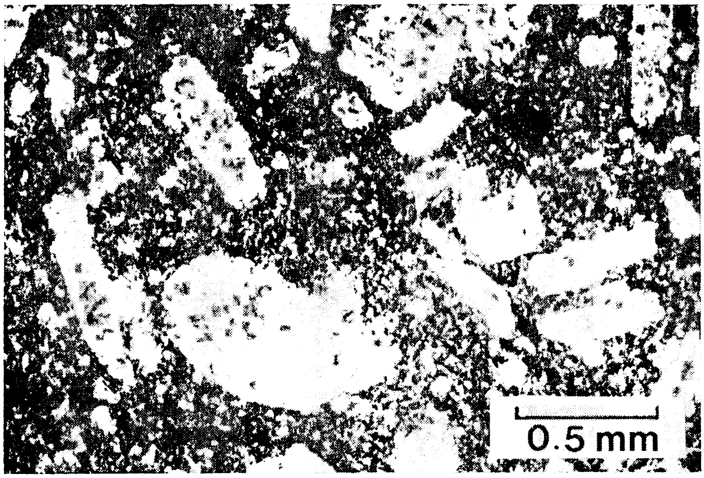
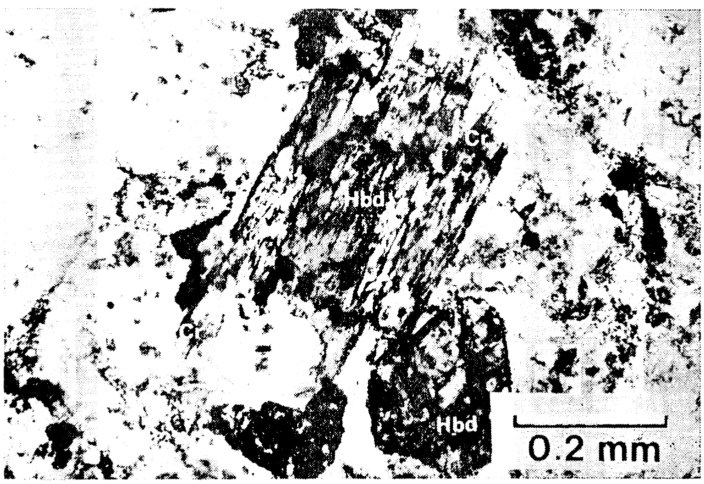


Fig. 2. Compositions of sodic amphiboles from the pebbles and matrix of metaconglomerates of the northeast Diablo Range.

PLATE 1



A. Sample 65-13, porphyritic mafic volcanic pebble; albite + pumpellyite after calcic plagioclase retain phenocryst outlines.



B. Sample 65-8, relict igneous hornblendes fringed by blue amphiboles in plutonic pebble.

The three small pebbles from locality 66 are very similar to each other both texturally and compositionally, and they may all be fragments of the same rock body. Therefore, they are considered together as 66-6a. The pebbles are nonfoliated and consist of equigranular, nearly colorless sodic amphiboles approx 0.1 mm in length, small idioblasts of clear sphene, and a few scattered crystals of white mica. As with 63-1, no traces of premetamorphic textures or minerals are present in the pebbles. Along fractures through the pebbles and at the pebble boundaries, the pale-blue sodic amphiboles have been partly converted to a medium-blue crossitic amphibole (pl. 2-B) similar to those that crystallized during the metamorphism of the conglomerates. Some of the crossite rims extend across the pebble boundaries into adjacent matrix and have clearly formed after deposition of the pebbles in the conglomerates.

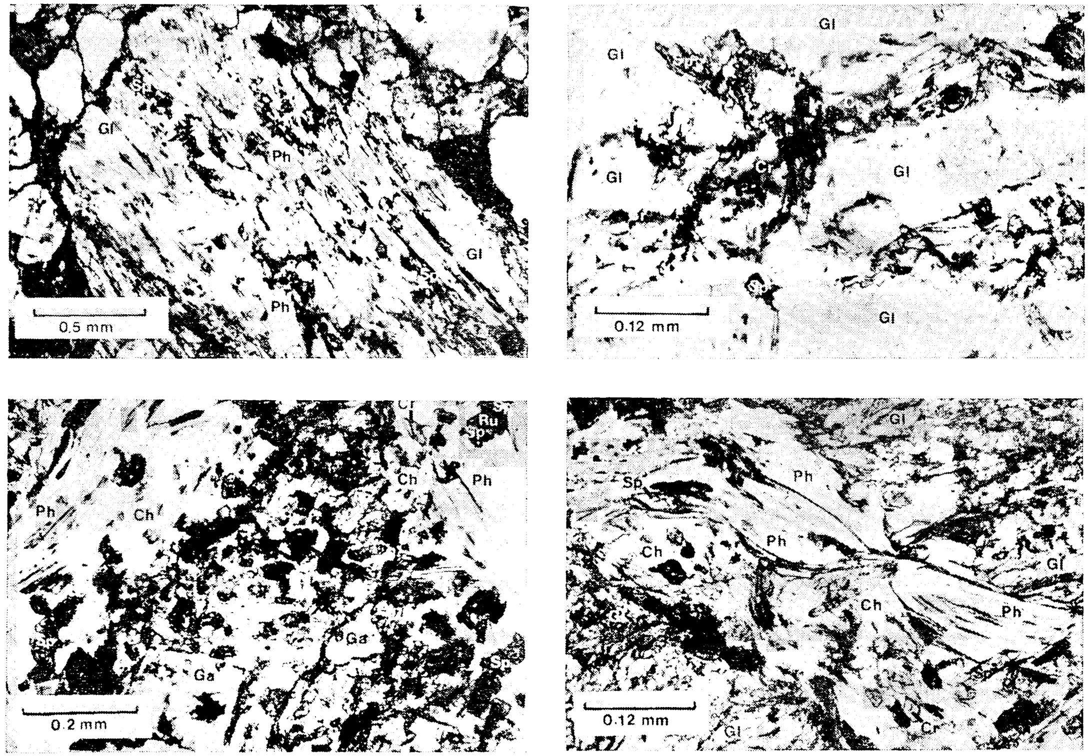
Textural relationships in the large pebble from locality 66 (#66-6b) suggest that the clast has undergone 3 periods of blueschist facies metamorphism. The initial mineral assemblage consists of sodic amphibole + white mica + garnet + rutile. Crystals 0.1 to 0.3mm in length of white mica and pale-blue sodic amphibole, along with irregular bands of fine-grained, yellow-brown rutile, define a moderate foliation in the pebble. The foliation of the pebble bears no relationship to that of the conglomerate matrix. The garnets occur as colorless idioblasts, up to 1 mm in diameter, that are scattered throughout the pebble. Neither garnet nor rutile occurs elsewhere in the metaconglomerates, and in the Franciscan as a whole, rutile is restricted to high-grade tectonic blocks (Coleman and Lee, 1963). Therefore, pebble 66-6b may have formed at a higher grade of blueschist facies metamorphism than that of the conglomerates.

The initial mineral assemblage of 66-6b has been modified extensively during retrograde blueschist facies metamorphism. One retrograde assemblage may have formed prior to incorporation of the pebble in the conglomerates, whereas a second assemblage is probably post-depositional in origin. The first retrograde assemblage consists of chlorite + sphene + white mica + lawsonite + medium blue sodic amphibole + quartz + pyrite. Rutile has been partly replaced by fine-grained sphene aggregates. Garnets are partly recrystallized to chlorite + white mica + lawsonite + sphene + sodic amphibole (pl. 2-C). Coarse-grained, pale-green chlorite is concentrated in the center of the altered crystals. Small crystals of sphene and sodic amphibole are commonly associated with this chlorite; the sodic amphiboles in this occurrence are somewhat deeper blue in color than those forming the bulk of the pebble. Interleaved white mica and lawsonite crystals wrap around the chlorite-rich core. Averaging 0.8 mm in length, these white micas are coarser-grained than those associated with the pale-blue amphiboles in the pebble. Coarse-grained chlorite, white mica, and lawsonite together with sphene, quartz, and pyrite also occur in veins (pl. 2-D) which terminate abruptly at the pebble boundary and may have formed prior to deposition of the pebble in the conglomerates. The similarities between the alteration minerals in the veins and those replacing garnet and rutile suggest that both groups of minerals crystallized at the same time.

A second episode of retrograde metamorphism, developed after deposition of the conglomerates, is characterized by the crystallization of deep-blue sodic amphibole fringes on the pale-blue amphiboles at the pebble boundary or along fractures through the pebble. As observed in 66-6a, a few dark-blue amphiboles extend across the pebble boundary into adjacent graywacke matrix. The deep blue color of the fringes is

PLATE 2

A. B. C. D.



A. Sample 63-1, coarse-grained glaucophane–sphene–phengite pebble. The schistosity of this pebble is more marked than the feebly deformed graywacke matrix of the conglomerate. Bands of sphene in the pebble are paralled to the foliation direction.

B. Sample 66-6a, one of three small glaucophane–phengite–sphene pebbles from locality 66, showing partial alteration of pale blue glaucophane to darker blue crossite along fractures through the pebble.

C. 66-6b, relict garnet surrounded by chlorite and white mica in large detrital blueschist pebble.

D. 66-6b, bands of coarse-grained white mica and chlorite.

somewhat darker than that of the small amphiboles associated with chlorite.

The complete absence of albite and the occurrence of chlorite only as a retrograde mineral in the 5 detrital blueschist pebbles is in marked contrast to many of the other pebbles, in which albite and chlorite coexist stably or have but partly reacted to form sodic amphibole. Reactions producing glaucophane from albite and Fe–Mg minerals such as chlorite are favored by increasing pressures of metamorphism (Ernst, 1963). Therefore, the absence of albite + chlorite in the detrital blueschist pebbles suggests that they were used up during higher pressures of metamorphism than those prevailing during the metamorphism of the conglomerates.

Mineral composition.—Compositions of minerals from the detrital glaucophane schist pebbles are listed in table 2. White micas are all phengites of varying compositions. Those from 63-1 have the lowest SiO_2 and highest Al_2O_3 contents (table 2, #1), and their Na_2O and TiO_2 contents are also relatively high. White micas in 66-6b show 2 distinct compositions (table 2, #3 and 4): the fine-grained white micas associated with the pale-blue amphiboles are slightly lower in SiO_2 and Fe_2O_3 and higher in Al_2O_3 than the coarse-grained white micas associated with chlorite and lawsonite. The composition of white mica has been correlated with the grade of metamorphism; white micas crystallized at higher grades of metamorphism more closely approach muscovite compositions than those crystallized at lower metamorphic grades (Ernst, 1972). Therefore, the compositional differences observed between the texturally distinct white micas in 66-6b are consistent with crystallization of the fine-grained white micas at a slightly higher grade of metamorphism than the coarser-grained crystals. The garnets from 66-6b, with composition 62.6 percent almandine, 24.3 percent grossularite, 8.4 percent pyrope, and 4.7 percent spessartine (table 2, #5), are nearly identical to garnets from high-grade tectonic blocks in the Franciscan (Coleman and Lee, 1963; Lee, Coleman, and Erd, 1963).

Sodic amphibole compositions are listed in table 2 and compared with other analyzed crossites in figure 2. The pale-blue amphiboles from each of the detrital blueschist pebbles are glaucophanes enriched in Al_2O_3 compared with the crossites characteristic of the metaconglomerates. The medium-blue fringed sodic amphiboles in 66-6a are crossites similar in composition to sodic amphiboles in the other pebbles and the matrix. In pebble 66-6b, the medium-blue sodic amphiboles associated with chloritic alteration of garnet are crossites with high Mg-contents. The late-formed dark-blue amphibole fringes are also crossites; however, they have slightly lower Al_2O_3 and considerably lower MgO contents than those associated with chlorite in the pebble.

The relationships between composition, rock chemistry, and conditions of crystallization of sodic amphiboles are incompletely understood. However, some evidence suggests that, for a given assemblage, the crystallization of Al-rich sodic amphibole takes place at higher pressures

TABLE 2

Chemical analyses of minerals in detrital glaucophane schist pebbles from Franciscan conglomerates of the northeast Diablo Range, California.

	White Mica				Garnet	Chlorite	Sodic Amphibole					
	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	48.60	51.05	50.32	50.73	38.26	27.64	56.34	57.11	57.46	55.01	56.83	55.10
TiO_2	0.43	0.36	0.29	0.20	0.14	0.06	0.03	---	0.03	---	0.05	0.20
Al_2O_3	31.22	25.34	26.80	25.61	22.46	19.10	11.01	10.68	10.99	6.00	8.85	7.85
Fe_2O_3*	3.36	3.27	3.05	3.54								
FeO**					28.68	20.85	14.39	8.44	9.92	22.26	13.43	21.10
MnO					2.14	0.53						
MgO	2.75	3.59	3.50	3.65	2.19	18.81	7.51	10.61	10.82	5.80	10.02	5.62
CaO	0.01	0.07	0.08	0.07	8.62	0.30	0.78	1.77	1.68	0.31	1.68	0.31
Na_2O	0.74	0.26	0.39	0.24	0.03	0.02	7.11	6.35	6.69	6.88	6.67	6.65
K_2O	9.90	10.47	10.24	10.51	0.04	0.05	0.07	0.05	0.07	0.06	0.08	0.08
Anhydrous Total	97.23	94.41	94.69	94.55	102.56	87.36	97.24	95.01	97.66	96.32	97.61	96.83
Atomic Proportions												
	O = 22				O=12	O=28	O = 23					
Si	6.36	6.87	6.74	6.82	2.97	5.72	7.89	7.87	7.85	7.99	7.86	7.93
Al^{IV}	1.64	1.13	1.26	1.18	0.03	2.28	0.11	0.13	0.15	0.01	0.14	0.07
Al^{VI}	3.18	2.89	2.97	2.88	2.02	2.37	1.71	1.61	1.62	1.02	1.31	1.26
Ti	0.04	0.04	0.03	0.03	0.01	0.01	0.03	---	0.01	...	0.01	0.02
Fe^{3+}	0.33	0.33	0.31	0.36			0.26#	0.36#	0.34#	0.99#	0.65#	0.74#
Fe^{2+}					1.86	3.60	1.42#	0.62#	0.79#	1.72#	0.91#	1.79#
Mn					0.14	0.09						
Mg	0.54	0.72	0.70	0.74	0.25	5.80	1.57	2.39	2.20	1.26	2.07	1.20
Ca	---	0.01	0.01	0.01	0.72	0.06	0.12	0.26	0.25	0.05	0.25	0.05
Na	0.19	0.07	0.10	0.06	---	0.01	1.93	1.70	1.77	1.94	1.79	1.85
K	1.65	1.80	1.76	1.81	---	0.02	0.01	0.01	0.02	0.01	0.02	0.02

(higher P/T ratios) than required for the crystallization of crossite (Miyashiro and Banno, 1958; Brown, 1974, fig. 11; de Roever, Beunk, and Kieft, 1976). If so, then the crystallization of glaucophane in the detrital blueschist pebbles must have occurred at relatively higher pressure conditions than the crystallization of crossite during subsequent metamorphism of the Franciscan conglomerates.

Element distribution.—Element partitioning for blue amphibole–phengite pairs from detrital glaucophane schist pebbles and from some igneous pebbles were examined and compared. The type of distribution coefficient used by Kretz (1959, 1961), Mueller (1960), and Saxena (1966, 1968), in which a single independent chemical parameter is used, was adopted in the present study because of the uncertainty regarding Fe^{2+}/Fe^{3+} ratios. Values of the distribution coefficients for Mg, Fe^{tot}, and Al^{VI} between sodic amphibole and phengite are plotted in figure 3. There is a wide scatter of data in each diagram. K_D^{Mg} ranges from 3.0 to 6.1, $K_D^{Fe^{tot}}$ from 2.7 to 13.8, and $K_D^{Al^{VI}}$ from 5.5 to 20.1. The disparity of the distribution coefficients indicates a lack of chemical equilibrium for metamorphism of the conglomerates. Values of the distribution coefficient for glaucophane and phengite in the detrital blueschist pebbles may reflect the original conditions of metamorphism of the pebbles. As seen in figure 3, all the distribution coefficients for the detrital glaucophane schists are significantly closer to unit values than are those of the igneous pebbles. Such relationships are consistent with crystallization of white mica and glaucophane in the blueschist pebbles at higher temperatures than attained during the metamorphism of the igneous pebbles.

Summary.—The lower K_D values for element partitioning of coexisting phengites and sodic amphiboles, the occurrence of the garnet + rutile-bearing assemblage, and the coarse-grained, well-foliated nature all indicate that the mineral assemblages of the detrital glaucophane

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Footnote to table 2

* Total Fe as Fe_2O_3. ** Total Fe as FeO. ♯ Fe^{3+}/Fe^{2+} estimated from microprobe data.

Column

1. 63-1; coarse-grained white micas in well-foliated glaucophane schist pebble; average of 4 crystals.
2. 66-6a; white mica associated with pale blue amphiboles in small glaucophane–phengite–sphene pebbles.
3. 66-6b; white micas associated with pale blue amphiboles in garnet-bearing blueschist pebble.
4. 66-6b; white micas surrounding chlorites which replace garnets in large detrital blueschist pebble.
5. 66-6b; relict garnet crystal.
6. 66-6b; chlorite replacing garnets; average of 3 crystals.
7. 63-1; four sodic amphiboles.
8. 66-6a; pale blue amphiboles in pebbles grouped as 66-6a; average of 3 crystals.
9. 66-6b; pale blue amphiboles; average of 3 crystals.
10. 66-6a; medium blue amphiboles formed along fractures.
11. 66-6b; small crossite crystals associated with coarse-grained white mica and chlorite replacing a garnet crystal; average of 2 crystals.
12. 66-6b; deep blue crossite fringes to glaucophanes.

schist pebbles crystallized at higher temperatures and pressures than those of the later metamorphism of the conglomerates. The absence of chlorite and albite and the presence of glaucophane rather than crossite in the detrital blueschist pebbles also indicate initially higher pressures of metamorphism for those 5 pebbles compared to the conglomerates as a whole.

SOURCE OF BLUESCHIST DETRITUS

The identification of detrital glaucophane schists in the metaconglomerates of the Diablo Range is significant to pinpointing the sources of Franciscan detritus. Only three blueschist terranes are presently exposed in California: they are Lower Mesozoic blueschist belts in the Sierra Nevada and the Klamath Mountains and metamorphic rocks in the Franciscan itself. Of these, the blueschist facies metamorphic rocks of the Klamath Mountains are Triassic in age (Hotz, Lanphere, and Swanson, 1977) and consist of phyllitic and schistose crossite-bearing metasedimentary rocks and isolated blocks of massive metabasalt. Some blueschists occur as layers in phyllites of the greenschist facies (Hotz, Lanphere, and Swanson, 1977). The metabasalts are fine-grained and massive; they

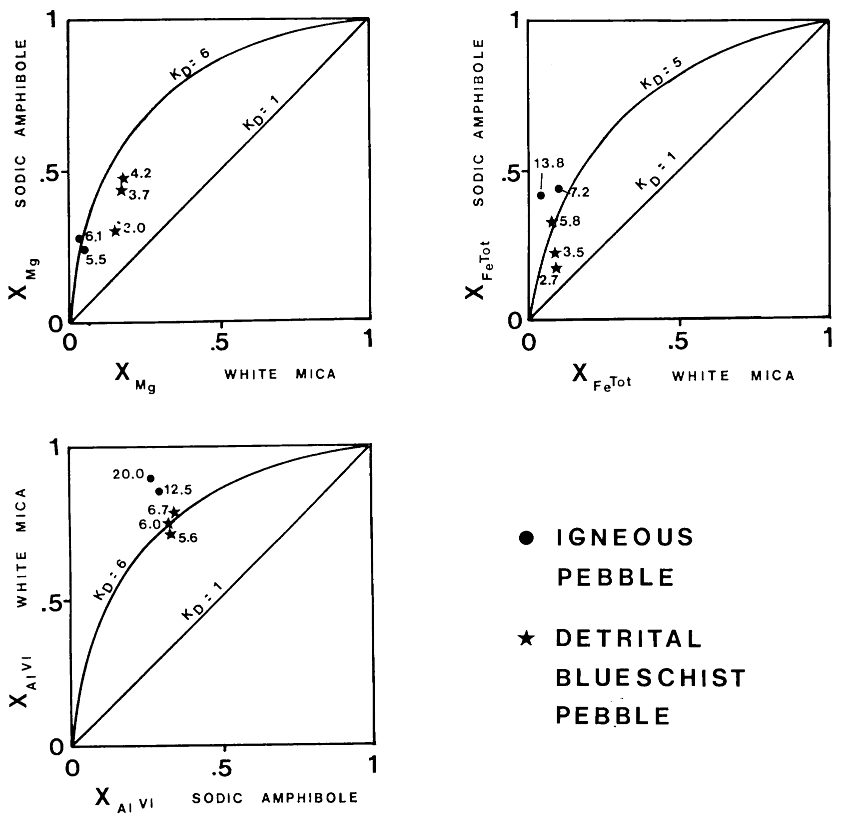

Fig. 3. Partitioning of elements between coexisting sodic amphibole and white mica in igneous pebbles and detrital blueschist pebbles.

contain abundant, finely fibrous sodic amphibole intergrown with stubby prisms of lawsonite (Hotz, 1973). The lower Mesozoic blueschist facies rocks described by Schweickert (1976) in the Sierra Nevada occur as blocks in a tectonic mélange; they consist of schistose metaclastic rocks and thin schistose metatuffs rich in quartz and albite. A basaltic breccia has also been identified in which clasts containing albite + epidote + chlorite + stilpnomelane occur in a matrix recrystallized to glaucophane + quartz + epidote ± riebeckite (Schweickert, 1976). Neither the mineral assemblages nor the textures of the blueschist pebbles closely correspond to the blueschist rocks thus far described from the Sierra Nevada-Klamath terranes. The general absence of albite and epidote and the scarcity of quartz in the detrital glaucophane schist pebbles contrasts with the Sierran blueschists (Schweickert, 1976), and the occurrence of glaucophane rather than crossite in the detrital blueschist pebbles contrasts to metabasalts of the Klamath Mountains.

In contrast, some rocks within the Franciscan itself closely resemble the detrital blueschist pebbles. The large, rutile + almandine–grossularite garnet-bearing pebble (#66-6b) is identical to certain high-grade blueschists that occur as isolated blocks in disturbed areas such as fault zones and mélanges (Coleman and Lee, 1963; Lee, Coleman, and Erd, 1963; Coleman and Lanphere, 1971). Coleman and Lanphere (1971) have obtained radiometric ages of approx 150 m.y. for several of the blocks. The mineralogy of the other 4 blueschist pebbles is not necessarily restricted to high-grade blocks of the Franciscan. However, rocks with the characteristics of these pebbles *are* commonly observed in the high-grade blueshists, whereas the very coarse grain size and marked foliation of pebble 63-1 and the total lack of observable pre-metamorphic textures are *not* characteristic of the lower grade Franciscan metamorphic rocks. Therefore, these 4 pebbles may also be derived from the same high-grade blueschist terrane that provided blocks and sheets to the Franciscan.

Correlation of these blueschist pebbles with the high-grade schists presently contained within the Franciscan has important implications for Franciscan paleogeography and tectonics. In some manner, high-grade blueschists had to be exposed to erosion in order to provide rounded pebbles to Franciscan conglomerates. Two possible mechanisms exist by which such materials may have been incorporated as detritus in Franciscan conglomerates: first, part of the original metamorphic terrane may have been exposed at the time of deposition of the conglomerates, and second, blocks or fault slivers previously incorporated into the Franciscan may be the source of detritus. Each of these possibilities will be examined in turn.

The correlation of high-grade blueschist blocks in disturbed zones within the Franciscan Complex has led many workers to conclude that all such blocks were tectonically emplaced upward into the Franciscan from some deep-seated source, possibly as a result of the interaction between oceanic and continental plates (Coleman and Lanphere, 1971; Platt, 1975). If such a mechanism is valid, the original high-grade blueschist terrane may never have been subaerially exposed and, itself, could not have provided rounded pebbles to Franciscan conglomerates. However, Crawford (1975) and Raymond (1977) have found high-grade blocks in Franciscan olistostromes of the Diablo Range. In order to account for the introduction of such blocks into the Franciscan by sedimentary processes, Raymond (1977) has proposed that a pre-Franciscan metamorphic sheet, developed at the base of the Great Valley Sequence, subsequently moved upward with respect to the Great Valley such that some parts at least were subaerially exposed. Exposure of such sheets of blueschist-facies rocks could have resulted in detritus being provided to the Franciscan.

Alternatively, high-grade rocks that had previously been emplaced into the Franciscan may have been the sources of detritus. Emplacement may have been accomplished by sedimentary processes as Crawford (1975) and Raymond (1977) suggest or by incorporation along thrusts (Platt, 1975; Suppe and Foland, 1978). Previous studies (O'Day and Kramer, 1972; Cowan and Page, 1975) have shown that old Franciscan metamorphic rocks have contributed detritus to younger Franciscan sediments in the western part of the Coast Ranges. These Franciscan rocks would have been part of an accretionary wedge attached to the continental plate and exposed along an inner trench wall. The inner walls of some trenches are likely sites for sedimentary slumping and sliding (Cowan and Page, 1975). Debris flows that incorporate both Franciscan metamorphic rocks exposed along such sites and detritus supplied from the magmatic arc (Cowan and Page, 1975) may be responsible for the deposition of the conglomerates.

Of the two hypotheses, the first is slightly favored over the second on the basis of the meager evidence available. The Diablo Range contains some of the older metasedimentary terranes of the Franciscan. Insufficient time had probably elapsed to allow for the subduction, metamorphism, and re-ascent of still older metamorphic terranes. In addition, there is a general absence in the conglomerates of other lithologies representative of Franciscan metamorphic terranes. Of the few graywacke pebbles present in these two conglomerates, the sedimentary characteristics of most differ from Franciscan graywacke. The few large, angular graywacke clasts that resemble Franciscan sedimentary rocks show no traces of a previous metamorphism but rather appear to be rip-outs of newly deposited sediments. Nor do any of the other pebbles show traces of previous blueschist facies metamorphism, although, admittedly, a second metamorphism of the same or higher grade than the first would perhaps mask any traces of a previous metamorphism.

CONCLUSION

Based on many lines of evidence, a few glaucophane-bearing pebbles from Franciscan conglomerates of the Diablo Range have been shown to represent high-grade blueschist detritus which was retrograded during metamorphism of the conglomerates. This finding marks the first well documented description of detrital blueschists in highly recrystallized Franciscan rocks. The mineral assemblages and textures of the detrital blueschists are consistent with the high-grade blueschists occurring as tectonic blocks in the Franciscan. The detrital blueschist pebbles in both the conglomerates and the tectonic blocks may have the same ultimate source terrane, part of which must have been exposed to erosion at the time of deposition of the conglomerates.

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