# JADEITE-BEARING METAGRAYWACKES IN CALIFORNIA

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### Abstract

At several localities in California jadeite-bearing rocks have developed from the metamorphism of Franciscan graywackes. In the field the jadeite-bearing rocks are almost indistinguishable from somewhat sheared graywackes. Preservation of clastic structures and relict minerals in the jadeite-bearing rocks suggests metamorphism at low temperature. The presence of glaucophane and lawsonite in the jadeite-bearing rocks shows that these minerals are stable in the same environment that favors crystallization of jadeite.

The jadeite-bearing rocks occur in areas regionally occupied by unmetamorphosed rocks, so that metamorphic conditions must have been subject to marked fluctuations within short distances. As in many of the associated glaucophane schists, albite is typically absent in the rocks containing quartz and jadeite. It is concluded that jadeite is a product of the reaction: albite = jadeite + quartz.

Pressure, locally augmented by deformation, is a possible factor in their formation, while the composition of the original graywacke may also play a part. It is most likely that rocks of this nature may occur in other parts of California but have hitherto escaped notice because of their resemblance to unmetamorphosed graywacke.

## Introduction

Occurrences of jadeite in California have previously been confined to small exposures in the form of lenses in serpentinite (Yoder and Chesterman, 1951); masses or veins in loose boulders of uncertain relationships (Wolfe, 1955); and as a constituent of certain rare varieties of glaucophane schist. Associated with the glaucophane schists are eclogites, the pyroxene of which is diopside-jadeite, not approaching the composition of pure jadeite (Switzer, 1945).

Recent mapping and mineralogical studies in various parts of California by the writer have revealed the presence of jadeite in metamorphosed sandstones or graywackes of the Franciscan formation. Rocks of this type were first discovered by Maddock (1955) in the Mt. Hamilton Range, Stanislaws County, and independently by the present writer at numerous other localities in California. Throughout this paper such rocks will be termed "quartz-jadeite rock" or "metagraywacke."

## Field Relationships

*Eastern El Cerrito, Berkeley Hills:* In this area quartz-jadeite rocks with some cherts form a prominent ridge lying a few hundred yards to the west of the Hayward fault and associated serpentinite and glaucophane schist. They are terminated to the north by a mass of felsite, but relationships to the south are obscure. The locality is the same as that indicated by Brothers (1954, pp. 615, 619) for his specimens numbered 19 and 22.

*North of Valley Ford, Sonoma County:* The locality is on the north side of a small creek, immediately to the west of the point where it is crossed by a small farm road, 2½ miles north 17° east of Valley Ford. The farm road is accessible from the main highway from Valley Ford to Freestone. Outcrops of quartz-jadeite rock trend E.–W. with almost vertical foliation, and are in fault contact with a large area of unaltered Franciscan to the west. Lenses of unaltered Franciscan graywacke and tuffaceous material also occur within the quartz-jadeite rocks. There are no exposures of serpentinite at this locality.

*Angel Island:* On the shore mid-way between Point Ione and a mass of "fourchite," steeply dipping Franciscan graywackes are locally jadeitized (Ransome, 1894, p. 154). Specimens of "altered sandstone" collected by Ransome from Angel Island, at present in the collection of the Department of Geology, University of California, Berkeley, are jadeite-bearing. The jadeite in these was mistaken for zoisite.

*Panoche Valley, San Benito County:* The locality lies on the west side of Panoche Valley, opposite the "Glaucophane Ridge." The precise area is defined by the map references; T14S, R10E, 32, 33; Panoche Valley Quadrangle. Tightly folded beds of jadeite-bearing metagraywacke, glaucophane schist and interfolded sills or phacolithic bodies of antigoritized and actinolitized serpentinite, plunge steeply to the northwest. Here it is evident that the metamorphism giving rise to the metagraywackes and associated glaucophane schists post-dates the intrusion of the ultrabasic rocks.

It is concluded that jadeite-bearing rocks of this type occur widely in California, their close resemblance to unaltered sedimentary rocks resulting in their passing unnoticed for so long.

## Texture and Mineralogy of the Quartz-Jadeite Rocks

The textural and mineralogical characters of the quartz-jadeite rocks collected from widely separated localities are extremely constant. In the field they are almost indistinguishable from unaltered Franciscan sandstones and graywackes, except that they nearly always appear somewhat sheared. The average density of the jadeite-bearing rocks is higher however, being 2.82; while that of the graywacke is 2.67 (average of 6 determinations each). When fresh they are gray in color, becoming buff-colored in weathered outcrops. Most have a rather crude shear-foliation parallel to the bedding, but occasionally they are unfoliated (302/144).* Their clastic granular texture is always obvious and original bedding clearly visible. Flakey carbonaceous material, characteristic of many unaltered Franciscan graywackes, can be seen on bedding surfaces (cf. Taliaferro, 1943, p. 132). Similarity in texture to unaltered graywacke is

* Numbers refer to specimens in the Department of Geology, University of California, Berkeley.

also evident in thin sections (Plates 1 and 2). Relict detrital fragments of basic rock, chert and angular quartz grains that have escaped recrystallization are common (302/*EC*3), while the crude foliation, like the bedding in the graywackes, is defined by streaks of sericite, chlorite and opaque carbonaecous material.

Jadeite occurs as evenly distributed crystals or clusters with rounded or sub-radiate form; colorless in thin sections but frequently very turbid in appearance owing to minute inclusions of material too fine in grain for optical determination, but by *x*-ray study found to be quartz. In some cases the jadeite is present as closely sutured aggregates of small, variously orientated granules, producing a characteristic appearance

TABLE 1

| | 1 | 2 | 3 |
|---|---|---|---|
| X=Y=Z | Colorless | Colorless | Colorless |
| $\alpha$ | 1.659 } ±0.003 | 1.654 | 1.640 } ±0.003 |
| $\beta$ | 1.663 | 1.657 | 1.645 |
| $\gamma$ | 1.670 | 1.666 | 1.652 |
| $\gamma-\alpha$ | 0.012 | 0.012 | 0.012 |
| 2V*z* | 86°± | 70°± | 67° |
| Z:*c* | 53°±(Y=*b*) | 34° | 40°(Y=*b*) |
| Disp. | Very strong | — | None |
| S.G. | 3.27(±0.03) | 3.43(±0.01) | 3.245 |

1. Jadeite from metagraywacke, Valley Ford, California.
2. Jadeite, Clear Creek, California (Coleman, 1954, p. 1241).
3. Jadeite, Cloverdale, California (Wolfe, 1955, p. 258).

under crossed nicols. Occasionally albite occurs with the jadeite and is in the process of replacement by the latter. The optical properties of the jadeite are rather variable, and because of very strong dispersion, are difficult to determine. Values of 2V*z* and Z:*c* in Table 1; 1 are averages of determinations made on a universal stage in sodium light. Optical data previously recorded for jadeite from Clear Creek and Cloverdale are included in Table 1; 2 and 3.

In addition to clastic fragments and angular individuals, quartz occurs as a fine-grained recrystallized mosaic, frequently forming bands parallel to the foliation. Glaucophane is not uncommon in the rocks, although occasionally it is absent or insignificant (302/138*b*, 302/30). The mineral occurs as small prisms or in sub-radiating acicular sheaves, generally confined to the darker (chloritic) parts of the rock. In a few cases it forms intergrowths (replacements?) with jadeite. Glaucophane is particularly abundant in one rock with a marked blue color and better developed foliation (302/33). Probably this rock was more argillaceous

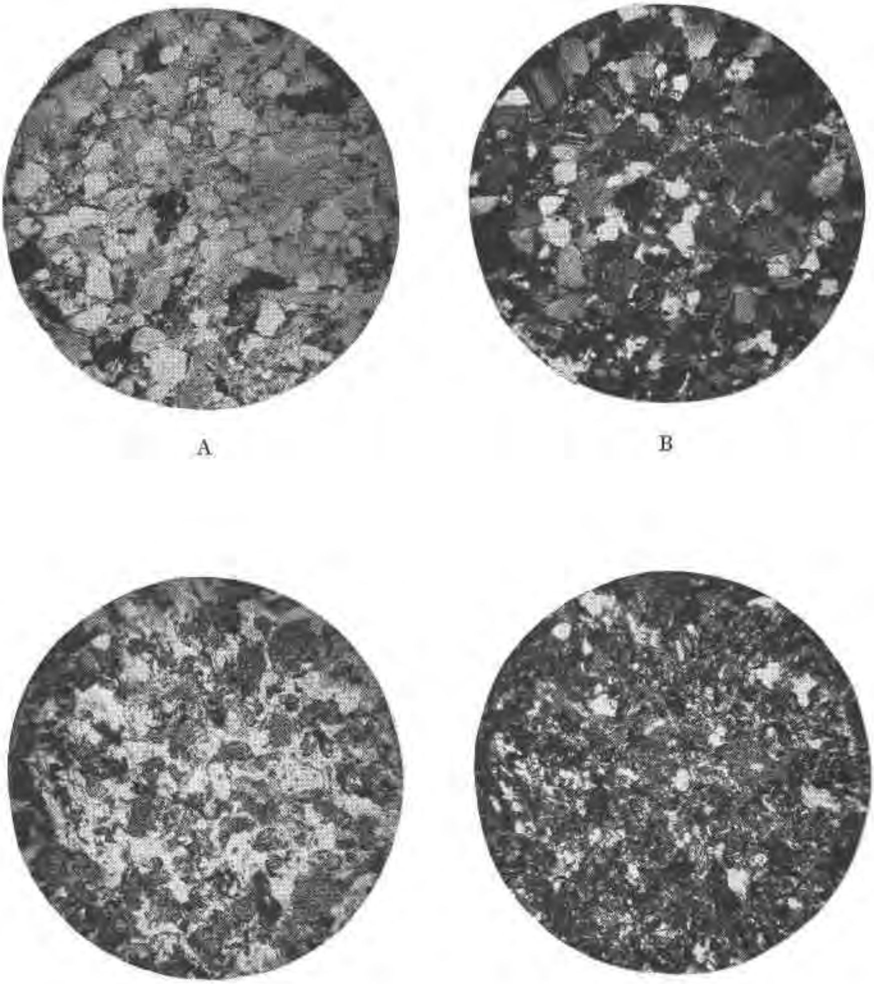


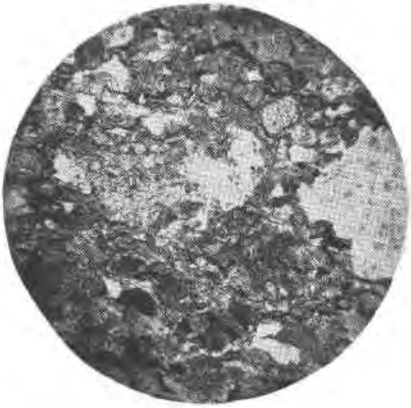

PLATE 1

A. Graywacke, Valley Ford. The lighter-colored constituents are angular grains of clastic quartz, plagioclase (albite/oligoclase) and finely crystalline chert fragments, together with sericite. Darker minerals are mainly chlorite, ilmenite/leucoxene and shaley or carbonaceous material. Ordinary light ×7.5.

B. As *A*, nicols crossed.

C. Quartz-jadeite rock, Valley Ford. Sub-rounded crystals of jadeite with strong cleavage and fractures are associated with quartz. Glaucophane, lawsonite, sericite and chlorite also occur, but are not readily distinguished at this magnification. Ordinary light ×7.5.

D. As *C*, nicols crossed. Quartz occurs as relict detrital fragments and as a fine-grained recrystallized mosaic. A fragment of chert lies to the right of the center of the field. The similarity in texture to the graywacke (*A* and *B*) is evident.



E

F

G

H

PLATE 2

E. Foliated quartz-jadeite rock, Valley Ford. An angular fragment of chert is prominent at the right-hand margin of the field. Ordinary light ×7.5.

F. As *E*, nicols crossed.

G. Quartz-jadeite rock, El Cerrito. Jadeite in subradiate clusters, elongate prisms of lawsonite, and quartz mosaic. Ordinary light approx. ×40.

H. As *G*, nicols crossed.

since the glaucophane is developed quite independently of the jadeite.

Lawsonite is a constant associate in the form of cross-fractured elongate prisms scattered throughout the rock and as inclusions in some of the jadeite crystals. Sericite and chlorite form discontinuous aggregates and bands, together with streaks of spongy opaque material which appears to be carbonaceous matter, although some may be ore (ilmenite/leucoxene).

## Associated Graywackes

The Franciscan sandstones have a texture and mineralogy typical of graywacke; fresh grains of quartz, feldspar, chert and basic rock fragments making up the bulk of the rock (Taliaferro, 1943, pp. 134–135). The feldspar is chiefly a sodic plagioclase (albite/oligoclase) and generally constitutes 30% or more of the rock. The matrix is composed of a colorless mica or clay, chlorite, carbonaceous material and ilmenite/leucoxene.

Chemical analyses show that the Franciscan sandstones contain

Table 2

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| $SiO_2$ | 70.61 | 69.14 | 71.18 | 71.72 | 68.84 |
| $TiO_2$ | 0.53 | 0.37 | 0.44 | 0.35 | 0.25 |
| $Al_2O_3$ | 11.99 | 15.08 | 13.14 | 13.23 | 14.54 |
| $Fe_2O_3$ | 1.59 | 1.51 | 1.05 | 0.30 | 0.62 |
| FeO | 2.22 | 0.84 | 2.37 | 3.58 | 2.47 |
| MnO | 0.05 | 0.03 | 0.06 | nil | nil |
| MgO | 2.82 | 1.08 | 2.25 | 1.81 | 1.94 |
| CaO | 2.41 | 2.79 | 1.48 | 1.80 | 2.23 |
| BaO | — | — | — | — | 0.04 |
| $Na_2O$ | 2.86 | 5.31 | 4.31 | 2.72 | 3.83 |
| $K_2O$ | 1.64 | 1.28 | 1.11 | 1.29 | 2.68 |
| $ZrO_2$ | — | — | — | 0.04 | 0.05 |
| $H_2O^+$ | 2.81 | 1.96 | 1.91 | 2.53 | 1.60 |
| $H_2O^-$ | 0.20 | 0.08 | 0.32 | 0.15 | 0.35 |
| $CO_2$ | 0.03 | 0.00 | 0.15 | 0.32 | 0.14 |
| $P_2O_5$ | 0.07 | 0.12 | 0.08 | 0.09 | 0.15 |
| $SO_3$ | — | — | — | — | 0.15 |
| | 99.83 | 99.59 | 99.85 | 99.93 | 99.88 |
| S.G. | 2.86 | 2.91 | 2.70 | — | 2.72 |

1. Quartz-jadeite rock (302/*EC*2), Berkeley Hills. Anal. E. H. Oslund, Minnesota.
2. Quartz-jadeite rock (302/138*e*), Valley Ford. Anal. E. H. Oslund, Minnesota.
3. Graywacke (302/74), Valley Ford. Anal. E. H. Oslund, Minnesota.
4. Graywacke, Buckeye Gulch (Taliaferro, 1943, p. 136).
5. Graywacke, Piedmont (David, 1918, p. 22).

rather less total $Fe_2O_3$, FeO and MgO than many rocks classed as graywacke (Table 2; 3, 4 and 5). Nevertheless their textural and mineralogical characters are those of graywacke (Pettijohn, 1948, pp. 250–251).

## Analyses

Analyses of quartz-jadeite rock from two localities are given in Table 2; 1 and 2, together with an analysis of graywacke associated with the quartz-jadeite rocks at Valley Ford (3), and two older analyses of graywacke from the Franciscan formation (4 and 5). There is no significant difference in chemical composition between the quartz-jadeite rock and and graywacke. It is also interesting to note the remarkable uniformity in the chemical composition of graywackes from widely separated localities.

In addition to an analysis of jadeite from the metagraywacke (Table 3; 1), two other previously recorded analyses of almost pure jadeite from California are included in Table 3; 2 and 3.

Although the jadeite separated for analyses appeared to be pure under the microscope, an $x$-ray powder photograph revealed strong quartz lines

Table 3

| | 1 | 2 | 3 | 4 | | 5 | | | 6 |
|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 60.64 | 59.38 | 61.66 | 59.44 | Si | .801 | | .831 | 2.000 |
| $TiO_2$ | 1.29 | 0.04 | 0.05 | | Al | .356 | .030 | | |
| $Al_2O_3$ | 18.17 | 25.82 | 21.81 | 25.22 | | | .326 | | |
| $Fe_2O_3$ | 3.68 | 0.45 | 0.32 | | Fe''' | .046 | | | |
| FeO | 0.53 | tr. | 0.24 | | Fe'' | .007 | | .421 | 1.013 |
| MnO | 0.07 | nil. | 0.05 | | Mn | .001 | | | |
| MgO | 1.09 | 0.12 | 0.98 | | Mg | .026 | | | |
| CaO | 2.13 | 0.13 | 1.38 | | Ti | .015 | | | |
| $Na_2O$ | 11.36 | 13.40 | 12.27 | 15.34 | | | | | |
| $K_2O$ | 0.25 | 0.02 | 0.57 | | Ca | .038 | | | |
| $H_2O^+$ | 0.78 | 0.22 | 0.44 | | Na | .367 | | .410 | .987 |
| $H_2O^-$ | 0.11 | 0.16 | 0.10 | | K | .005 | | | |
| $Li_2O$ | 0.005 | — | — | | | | | | |
| $Cr_2O_3$ | — | 0.01 | — | | | | | | |
| | 100.10 | 99.75 | 99.87 | 100.00 | | | | | |

1. Jadeite, Valley Ford. Analysis contains 12.55% quartz. Anal. E. H. Oslund, Minnesota.
2. Jadeite, Clear Creek (Coleman, 1954, p. 1241).
3. Jadeite, Cloverdale. Analysis contains 6% quartz (Switzer and Fahey; Wolfe, 1955, p. 258).
4. Theoretical composition of jadeite ($NaAlSi_2O_6$).
5. Metal atoms in 1. Less 12.55% quartz, $H_2O$ and $Li_2O$.
6. Metal atoms in 1. Less 12.55% quartz, $H_2O$ and $Li_2O$. On the basis of 6 oxygens.

in addition to those of jadeite. It was not possible to determine accurately the amount of quartz contamination since the difference in grain-size between the jadeite and quartz inclusions was considerable. The true value of density of the jadeite will therefore be higher than that given in Table 1 because of the quartz inclusions.

Allocating atomic proportions to the molecules jadeite, acmite, diopside and ($CaTiAl_2O_6$) resulted in an excess of $SiO_2$=12.55% (quartz). The analysis corresponds to jadeite=77.68%, acmite=12.39%, diopside =7.46% and ($CaTiAl_2O_6$)=2.47%. The presence of Ti in the analysis suggests the possibility of rutile or sphene inclusions in the jadeite. However, further investigation revealed neither of these minerals.

## Origin of the Quartz-Jadeite Rocks

The fabric and petrographic characters of the quartz-jadeite rocks show that they are derived from the metamorphism of Franciscan graywackes. The preservation of original clastic textures and other features indicate metamorphism at relatively low temperature. Presence of varying amounts of glaucophane and lawsonite suggests that these minerals are stable in the same environment which favors crystallization of jadeite. Absence of feldspar in rocks with abundant jadeite indicates that albite was unstable, its place being taken by jadeite plus quartz, some of the latter appearing as inclusions in the jadeite. However, since the jadeite contains appreciable amounts of diopside and acmite, the relationship is not so simple and involves reaction with Fe, Mg and Ca. It is considered that the diopside represents the anorthite of the original plagioclase, while inclusions of lawsonite in the jadeite may have a similar origin.

The association of quartz-jadeite rock with glaucophane schists, commonly albite-free, is further indication of the instability of albite in the assemblages as a whole. The similarity in chemical composition between associated graywacke and quartz-jadeite rock points to little or no change in bulk composition during metamorphism; the jadeite being derived from clastic albite in the graywacke.

Recently de Roever (1955) has described what appear to be closely similar quartz-jadeite rocks from a glaucophane schist terrane in Celebes. He regards the jadeite " . . . as having been formed at the expense of original albite by a rather extreme local variety of regional metamorphism in the glaucophane-schist facies" (1955, p. 292).

In California the association of quartz-jadeite rocks and various glaucophane and lawsonite-bearing assemblages with indurated but unmetamorphosed graywackes—the regionally prevalent rocks of the Franciscan—rules out the possibility of metamorphism on a regional scale. We must invoke some physical condition subject to marked fluctuation within short distances (Yoder, 1950, p. 325). A possible factor in the formation of the quartz-jadeite rocks may have been pressure, locally augmented by deformation. Taliaferro (1943, p. 186) has concluded that 25,000 feet is not an excessive estimate for the thickness of the Franciscan. At such a depth pressures of the order of 2,000 atmospheres might be expected. In addition, the composition of the original graywacke (low total, Fe, Mg and Ca) is considered to be a factor favoring the formation of jadeite-rock rather than glaucophane and lawsonite-rich assemblages.

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## References

Brothers, N. (1954), Glaucophane schists from the North Berkeley Hills: *Am. Jour. Sci.*, **252,** 614–626.

Coleman, R. G. (1954), Optical and chemical study of jadeite (abstract): *Bull. Geol. Soc. Am.*, **65,** 1241.

Davis, E. F. (1918), The Franciscan sandstone: *Univ. Calif. Pub. Dept. Geol.*, **II,** 1–45.

de Roever, W. P. (1955), Genesis of jadeite by low-grade metamorphism: *Am. Jour. Sci.*, **253,** 283–298.

Maddock, M. (1955), Geology of the Mt. Boardman quadrangle, California: Unpublished Ph.D. thesis, University of California, Berkeley, 106–108.

Pettijohn, F. J. (1948), Sedimentary rocks: Harper.

Ransome, F. L. (1894), Geology of Angel Island: *Univ. Calif. Pub. Dept. Geol.*, **I,** 193–235.

Switzer, G. (1945), Eclogite from the California glaucophane schists: *Am. Jour. Sci.*, **243,** 1–8.

Taliaferro, N. L. (1943), The Franciscan-Knoxville problem: *Am. Assn. Pet. Geol.*, **27,** 109–219.

Wolfe, C. W. (1955), Crystallography of jadeite from California: *Am. Mineral.*, **40,** 248–260.

Yoder, H. S. (1950), Jadeite problem: *Am. Jour. Sci.*, **248,** 225–248; 312–334.

——— and Chesterman, C. W. (1951), Jadeite of San Benito County, California: *Calif. Div. Mines, Special Report* **10-C.**

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