

Low-temperature recrystallization of Franciscan greywackes from Pacheco Pass, California

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ABSTRACT. Low-temperature metamorphism of the Franciscan complex at Pacheco Pass occurs at P - T conditions near the so-called jadeite isograd. Along Highway 152 in the Diablo Range, from west to east, four distinct prograde metamorphic zones are defined: (I) albite-quartz zone, (II) albite-rich, albite-quartz-clinopyroxene assemblage, (III) clinopyroxene-rich, albite-quartz-clinopyroxene assemblage, and (IV) clinopyroxene zone. Metamorphic pyroxenes are restricted to zones II, III, and IV in metagreywackes, but metabasites contain augite-rich pyroxenes even in zone I. With increasing grade, the compositions of pyroxene in metagreywackes change in X_{Jd} from nearly 100 in zone II to about 60 in zone III. The diopside component has little effect on the X_{Jd} of pyroxene. The apparent change of X_{Jd} reflects differences in pressure and temperature rather than in bulk rock composition. In metagreywackes, at the onset of zone II, albite breaks down to form Jd_{100} according to the reaction $\text{Ab} = \text{Jd} + \text{Qz}$. With increasing grade, this reaction leads to less jadeitic pyroxene. From zones II to III, a continuous reaction is delineated: $\text{Qz} + 2 \text{ pyroxenes } (\text{Jd}_{80}\text{Ac}_{15}\text{Aug}_5) = \text{pyroxene } (\text{Jd}_{60}\text{Ac}_{30}\text{Aug}_{10}) + \text{Ab}$.

The metamorphic temperatures are estimated to be about 170°C in zones I and II, and about 230°C in zones II and III. The temperature variation recorded in a single rock is probably less than 30°C. The pressure estimate depends on the choice of experimental data for the jadeite-albite-quartz curve; it ranges from 4.5 to 8 kbar. A gently folded thermal structure of the Cretaceous subduction zone metamorphism is postulated for this area.

KEYWORDS: metamorphism, greywackes, Franciscan complex, Pacheco Pass, California.

THE late Jurassic to Cretaceous Central Belt of the Franciscan subduction complex in the California Coast Ranges consists largely of moderately well-bedded turbidite units and blocks of cherts, green-

stone, serpentinite, and blueschist enveloped in a highly sheared argillaceous matrix. The turbidite units are composed mainly of greywacke and microgreywacke with minor intercalated black shale and, less commonly, chert. All of the Franciscan lithologic units in the Diablo Range have been feebly to thoroughly metamorphosed under high P - T conditions. Some units of the Franciscan Complex preserve a moderately well-bedded sequence (Blake and Jones, 1974; Ernst, 1965) while others are chaotic mélanges (Hsu, 1968). The type locality of the coherent Franciscan turbidites is the Pacheco Pass area (fig. 1), where the jadeite isograd has been delineated by McKee (1962a), Ernst (1965), and Ernst *et al.* (1970). However, the sporadic occurrence of albite in jadeite-bearing metagreywackes has long been controversial; the question is whether or not albite is in equilibrium with jadeite and quartz (Kerrick and Cotton, 1971). The purpose of this paper is to elucidate the clinopyroxene sliding equilibria on the jadeite isograd in the Pacheco Pass area. The approach starts from the assumption of equilibrium within the area of one thin section; then the domain equilibrium is discussed after extensive analysis of jadeitic pyroxenes.

Petrology of metabasites, thermal structure of metamorphism, and the tectonic significance of these factors were also investigated; they will be discussed elsewhere. In this paper, the primary focus is on the textural and mineralogical evolution of Franciscan turbidites during progressive subduction zone metamorphism.

Geologic setting. Pacheco Pass is located about 130 km southeast of San Francisco in the central Diablo Range (fig. 1). The geology of the Diablo Range has been extensively investigated (for review, see Page, 1981). The central core of the Diablo

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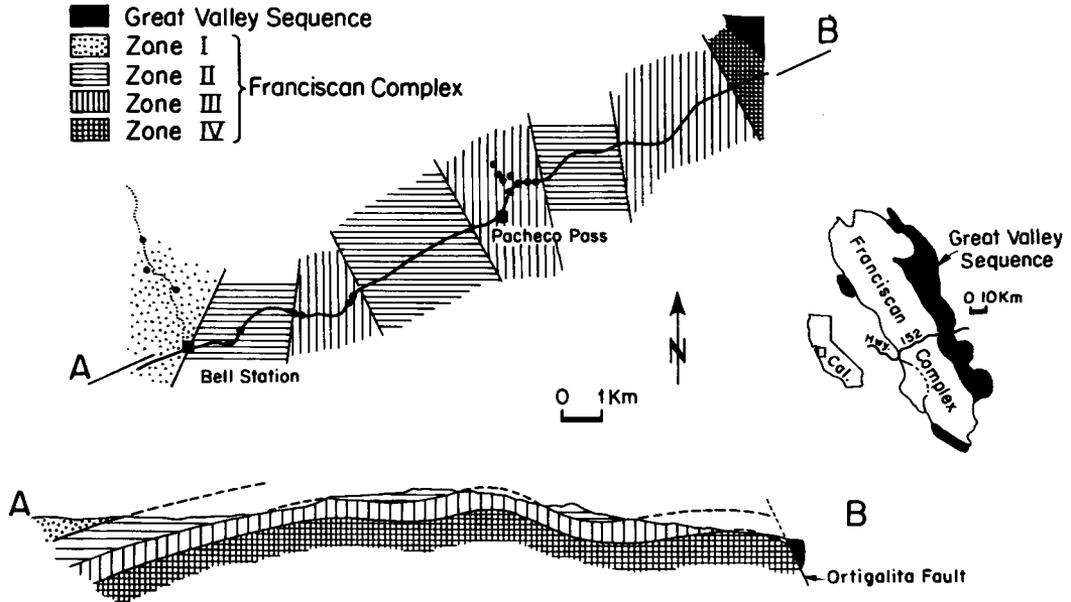


FIG. 1. Location of the Pacheco Pass area along Highway 152 in the Diablo Range, and regional distributions of four metamorphic zones. Small black circles are localities where aragonite was positively identified. Thermal structure deduced from the present study is shown in cross-section A-B to explain the disposition of these four metamorphic zones.

Range antiform is formed by the late-Mesozoic Franciscan Complex flanked to the east and west by Cretaceous Great Valley sediments. The contacts between the two series are high-angle faults along which serpentinites and the Coast Range ophiolite occur locally. The Franciscan Complex consists of both coherent well-bedded sandstone units as sheet-like slabs, and mélangé units, in which the greywacke-shale matrix encloses abundant tectonic blocks. In general, many of the structural units dip gently to moderately and the bedding orientation of coherent units is discordant with respect to adjacent mélanges.

In the Pacheco Pass area, the Franciscan Complex west of the summit of the pass is mainly mélangé consisting of highly sheared argillaceous matrix and blocks of metagreywacke, basaltic greenstone, pelagic chert and minor metaconglomerate, serpentinite, and high-grade blueschist. East of the summit of the pass, the Franciscan contains 95% metagreywackes, 4% metabasites, 1% metachert and trace metaconglomerates and serpentinites. The metagreywackes here are coherent and well-bedded, and some contain chert beds that are continuous for hundreds of metres.

In spite of extensive investigations, progressive metamorphism of coherent Franciscan greywackes

in terms of the clinopyroxene sliding equilibria has not been described. In the present study, closely spaced metagreywackes along Highway 152 and in a small valley north of the Pacheco Pass were sampled and their mineralogical zones and compositions of clinopyroxenes were determined.

Metamorphic zones. Metamorphic carbonates occur in the matrix and the veins of the metagreywackes; both aragonite and calcite were identified. Aragonite is difficult to distinguish from calcite by microscopic observation, and the carbonates are usually present in amounts too small to be separated for XRD identification. In the present study, both Friedman's stain method (1959) and XRD were used. Stained aragonite turns black, but stained calcite remains transparent. In carbonate veins, the earlier coarse-grained aragonites are rimmed by fine-grained calcite along crystal margins or along irregular cracks. Several isolated grains of aragonite form islands enveloped by calcite and have the same optical orientation; this feature suggests that they once formed a large aragonite grain. Carbonate crystals less than 100 μm in greywacke matrix are calcite and are interpreted to have formerly been aragonite. Aragonite is apparently stable throughout the entire area (fig. 1). This conclusion differs from that of McKee (1962b) and Ernst

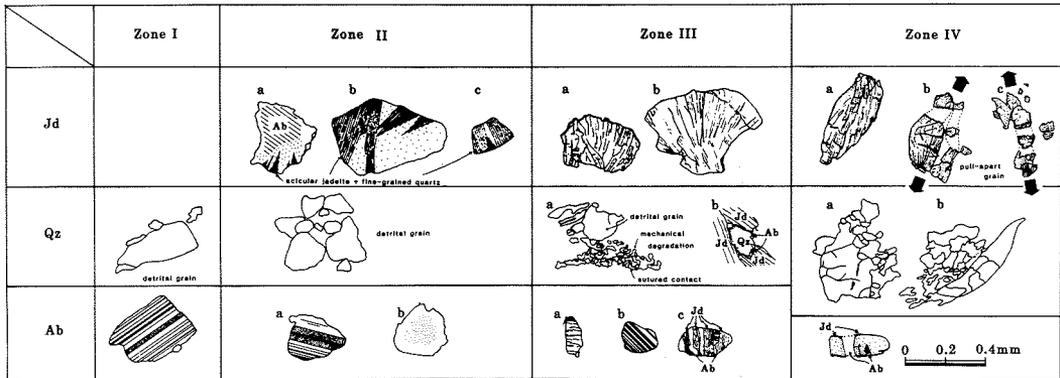


FIG. 3. Textural evolution of jadeitic pyroxene, quartz and albite with increasing grade in the four zoned metagreywackes.

outline of detrital albite. Microprobe analyses of acicular jadeite prisms show excess SiO_2 , suggesting that the jadeite crystal sheaves are composed of jadeitic pyroxene and fine-grained quartz aggregates after albite. With increasing grade, individual acicular crystals become coarser and have higher relief.

In zone II metagreywackes, 57% of the jadeite-bearing rocks have acicular jadeite and 43% contain larger jadeite crystals. In zone III, most metagreywackes (98%) have coarse-grained jadeite. Some jadeites appear as coarse prisms and others as radially disposed blocky crystals, some of which exceed 0.5 mm in width, but most of which are about 0.2 mm or less. The size of the pyroxene crystals seems to depend on the grain size of the replaced detrital albite. In the uppermost parts of zones III and IV, all jadeitic pyroxenes are fragmented and are pulled apart or stretched by ductile deformation. Several isolated grains preserve the same crystallographic and optical orientation. The outlines of such crystal aggregates are subrounded and rimmed by minute albite grains, which also are present along irregular cracks.

In zones I and II metagreywackes, detrital quartz grains are abundant and retain their original clastic anhedral shapes; they have dusty inclusions and do not show undulose extinction at metamorphic grades below higher zone II. From the onset of zone III, recrystallization proceeds with fragmentation and degradation. A range of degradation from large detrital grains with some irregular cracks to completely brecciated and elongated quartz is observed (fig. 3). The mosaic quartz grains are characterized in higher grade metagreywackes where they occur near or are enclosed by jadeite and do not have cracks and inclusions within individual crystals. In zone IV metagreywackes, detrital quartz is rare,

and recrystallized quartz shows overgrowth and degradation and is coarser-grained. Some large detrital quartz grains may persist as cores surrounded by elongated smaller grains forming an augen texture.

Albite with distinct twinning also retains clastic grain boundaries in zones I and II metagreywackes (fig. 3), but albite grains from some zone II samples show dusty cores and clear overgrowth rims; the dusty material is too fine-grained to be identified. In twinned albite, such dusty material is distributed along twin planes. If such fine-grained material is a precursor for jadeitic pyroxene, then jadeite may have been nucleated at the centre of some albites. The modal abundance of albite decreases abruptly in zone III metagreywackes, but some aggregates of tiny albite grains occur at the expense of twinned albite. Some of the albite grains are sandwiched by jadeitic pyroxene and may preserve partially twinned lamellae.

Phengitic mica and lawsonite are ubiquitous, although lawsonite is absent in some zone I samples. In zones I and II, fine-grained mica randomly occurs in the matrix of greywacke, but at higher grades, it becomes coarser and fibrous in habit, whilst in zone IV, white mica is arranged parallel to the elongated pull-apart jadeite grains to define a schistosity. Lawsonite randomly grew in lower grade rocks but is oriented roughly parallel to the schistosity of the zone IV metagreywackes.

Chlorite and glaucophane contrast markedly in modal abundance. In zones I and II rocks, both detrital and authigenic chlorites are common. As the metamorphic grade increases, chlorite becomes less abundant and it finally disappears in zone III rocks. A few glaucophane grains appear as fibrous needles of zone II and sodic amphiboles are ubiquitous in zone IV rocks. Such an inverse

relationship suggests that a reaction of chlorite + albite to form glaucophane controls the presence of chlorite in the metagreywackes.

Compositional variation of jadeitic pyroxenes. Chemical analysis of minerals was done using a JEOL Superprobe (tabulated data are available from the senior author). Formulae of pyroxenes and the ferric and ferrous iron content were calculated after the method of Brown and Ghent (1983). To evaluate the compositional variation of Ca-Na pyroxene coexisting with albite and quartz in one thin section and to exemplify the details of our pyroxene study, sample no. 187 from zone III was used. In this section, seventeen pyroxene grains ranging from about 100 to 500 μm in size were sketched and eight to sixteen spot analyses for each grain were performed (fig. 4).

As shown in fig. 4, most of the jadeite crystals display highly complex zoning patterns and no systematic compositional variation from the core to rim was shown. The analysed pyroxenes in metagreywackes range from 64 to 76 mole % jadeite

and lie along a straight line between the jadeite apex and a point with an augite/acmite ratio of 1/3 in the ternary system jadeite-augite-acmite. The compositional difference in each grain varies from 8 to 19 mole % jadeite. Such large differences and complex zoning patterns suggest that these pyroxene crystals have undergone a complex history of crystallization and recrystallization.

Fig. 5 displays the compositional range in terms of the jadeite end-member among seventeen grains in sample no. 187. The highest X_{Jd} value for each grain ranges from 89 to 72 whereas the lowest X_{Jd} value is less variable, ranging from 70 to 64. Such a difference may be attributed to the kinetic control for nucleation of new pyroxene crystals. At higher temperatures, the nucleation rate and the size of the equilibrium domain is increased. The decrease in X_{Jd} values with increasing temperature at a given pressure has been suggested by Essene and Fyfe (1967).

Figs. 4 and 5 suggest that the representative compositions of jadeitic pyroxenes in a single

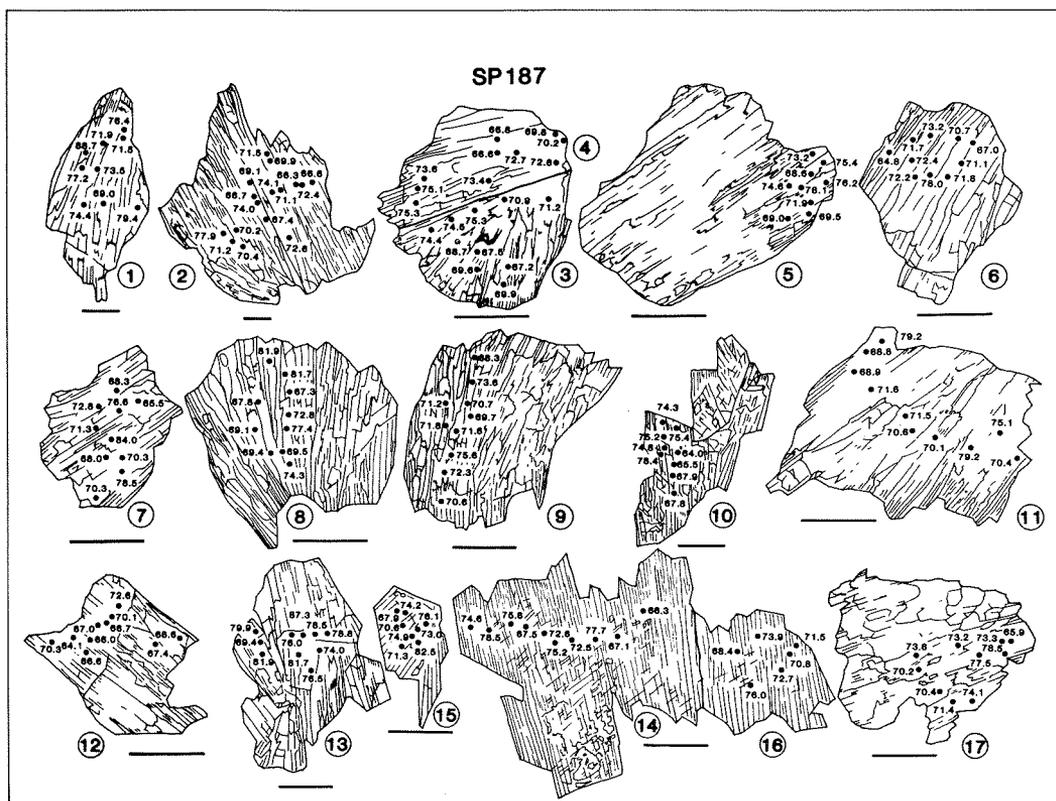


Fig. 4. Size, shape, and compositional variations of seventeen pyroxene crystals in a single section of a zone III metagreywacke no. 187. Pyroxene compositions are shown as jadeite mol %. Scale bar = 100 μm .

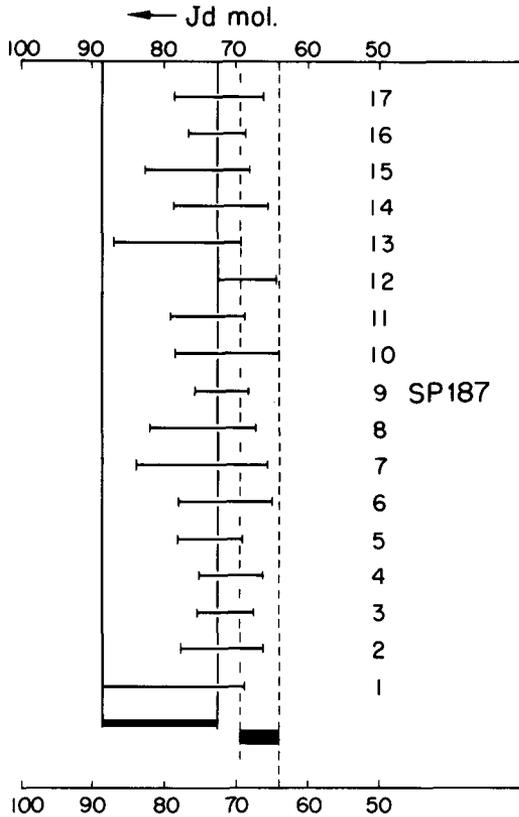


FIG. 5. Compositional ranges of the seventeen pyroxene crystals shown in fig. 4. Both maximum and minimum X_{Jd} values are indicated for each sample. The ranges for maximum and minimum X_{Jd} values for the seventeen samples are respectively shown as thin and thick bars at the bottom.

section can be determined using five grains with three spot analyses for each grain. Using this procedure, we have analysed pyroxenes coexisting with albite and quartz from thirty-two metagreywackes and fourteen metabasites; the results are plotted in terms of jadeite, acmite, and augite components in figs. 6 and 7. All pyroxenes from zone I are from metabasites, whereas those from zones II and III are from metagreywackes. Zone I pyroxenes in metabasites are characterized by low jadeitic and acmitic components. Pyroxenes in the lowest grade (no. 284) range in composition from 5 to 18 X_{Jd} , and those in higher zone I metabasites range from 39 to 42 X_{Jd} . The absence of such pyroxenes in zone I metagreywackes is due to the low basaltic component in the sediments.

At the onset of zone II, acicular jadeites with 70–90 X_{Jd} begin to occur in metagreywackes. The

most jadeite-rich pyroxene was found in the middle of zone II (no. 244) and has a nearly pure jadeite composition of $X_{Jd} = 94$ –99. The pyroxenes from the uppermost part of zone II and zone III metagreywackes are less jadeitic. The overall ranges for pyroxenes of zones II and III are $X_{Jd} = 100$ –70 and $X_{Jd} = 89$ –58 respectively. Furthermore, the most abundant pyroxene composition also shifts towards less jadeitic component with increasing metamorphic grade.

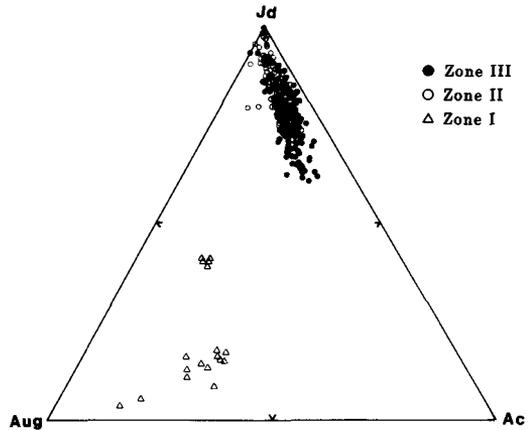


FIG. 6. Compositional plots of analysed pyroxenes in the buffered assemblage $Px + Ab + Qz$ from zones II, III, and IV metagreywackes and zone I metabasites in terms of mol % of augite, jadeite, and acmite components.

The analyses shown in fig. 6 are expressed in the pseudo-ternary diagram jadeite–acmite–augite, and the Di and Hd components are combined as one single Aug component. Fig. 8 plots the X_{Jd} vs. X_{Di} to evaluate the effect of X_{Di} in the augite component on the Cpx – Ab – Qz sliding equilibria. The zone III pyroxenes appear to have constant X_{Jd} irrespective of their X_{Di} values. However, the zone II pyroxenes tend to increase their X_{Jd} with increasing X_{Di} . In spite of such variation, a systematic difference of X_{Jd} between pyroxenes from zones II and III is apparent when both are compared at a given X_{Di} value. Thus, it is conceivable that the apparent difference of X_{Jd} in fig. 7 is related to the difference in physical conditions.

Metamorphic reactions in metagreywackes from Pacheco Pass. The petrologic system of metagreywacke is discussed in terms of SiO_2 , TiO_2 , Al_2O_3 , Fe_2O_3 , FeO , MgO , CaO , Na_2O , K_2O , H_2O , and CO_2 components. Quartz, sphene, and phengitic mica are ubiquitous and they are treated as excess phases. This, together with the assumption that the

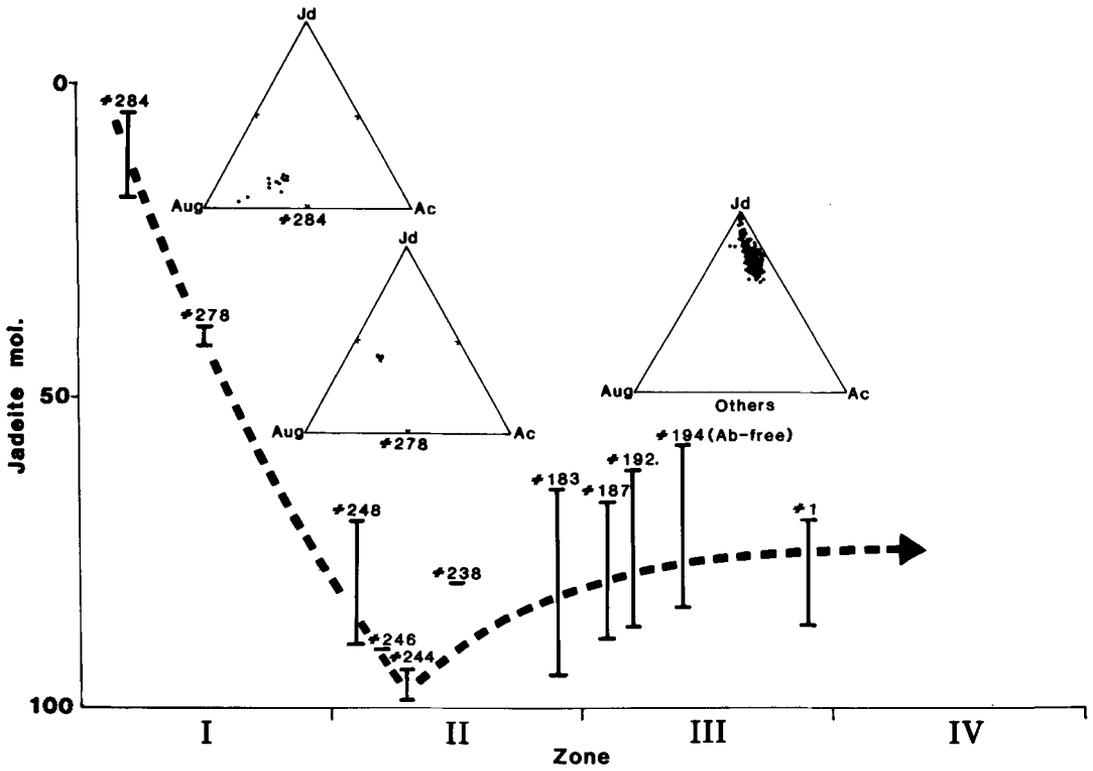


FIG. 7. Variation of X_{Jd} for pyroxenes from zones I to III. Note that all zone I pyroxenes are from metabasites.

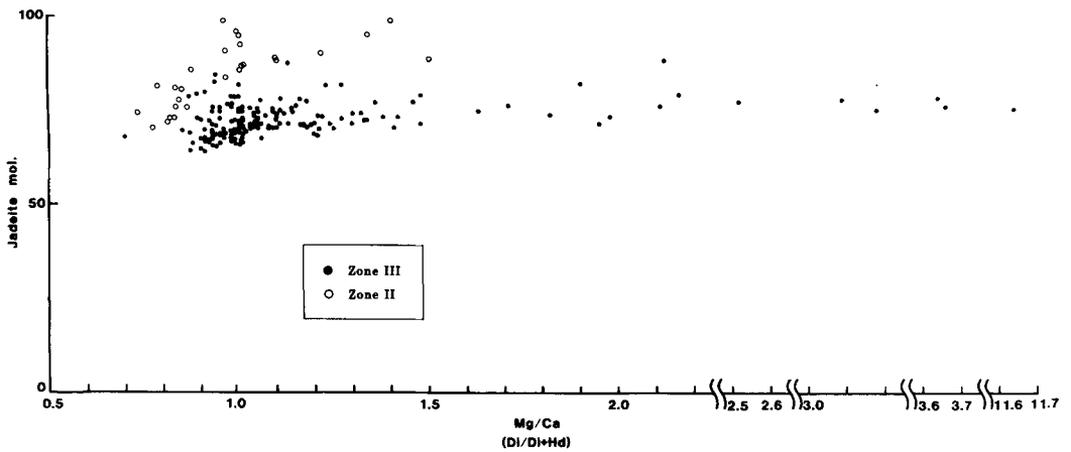


FIG. 8. Plot of X_{Jd} and X_{Di} for analyses of pyroxenes from zones II and III metagreywackes. X_{Di} is defined as Mg/Ca ratio.

excess fluid phase consists mainly of H₂O in the carbonate-free assemblages, reduces the number of components to six. If we project the paragenesis from a chlorite of constant composition at a fixed Mg/(Mg + Fe) ratio of 0.45, which is very common for chlorite in high-*P* metamorphic terrains (Banno, 1964; Ernst *et al.*, 1970), the system can be further simplified to four components, CaO–Na₂O–Al₂O₃–Fe₂O₃. The minerals treated here included lawsonite, pumpellyite, albite, epidote, pyroxene, and alkali amphibole. Actinolite is plotted as an infinite point, but if the Al content of chlorite is higher than Al = 2, the actinolite is plotted at a point far from the Na–Al–Fe³⁺ plane (see fig. 9). Riebeckite, augite and Fe³⁺-pumpellyite are plotted outside the tetrahedron. The compositions of Ca–Na pyroxene and amphibole can be expressed on two triangles as shown in fig. 9.

As discussed in the earlier section, the zone I metagreywackes do not contain pyroxene and the jadeitic pyroxenes in zone II rocks have compositions very close to the jadeite end-member. Such relations suggest that the metamorphic reaction for its first appearance may be defined by a simple reaction $Ab = Jd + Qz$. On the other hand, the zone I metabasites contain Ca–Na pyroxene whose composition changes progressively from augite to jadeite through omphacite. Therefore, clinopyroxene with a lower jadeitic component may appear in lower grade metasediments which contain sufficient amounts of basaltic components.

From zones II to III, pyroxenes change their X_{Jd} according to variations in *P–T* conditions. Such changes in assemblage and in pyroxene composition can be explained by the Qz–Ab–Cpx continuous reaction. The metagreywackes in zones II and III contain assemblages of Ab + Cpx + Law + crossite (together with Chl and Qz) which is shown in a tetrahedron of fig. 9A. At a given *P* and *T*, both pyroxene and amphibole compositions are fixed by the four-phase assemblage. The pyroxene shifts its composition toward the point at Ac/Aug = 3/1 with increasing grade (fig. 9C). Thus, a continuous reaction to form the zone III pyroxene $Jd_{60}Ac_{30}Aug_{10}$ from a zone II pyroxene $Jd_{80}Ac_{15}Aug_5$ can be written as $Qz + 2Jd_{80}Ac_{15}Aug_5 = Jd_{60}Ac_{30}Aug_{10} + Ab$. This reaction suggests an increase in modal albite in zones III and IV metagreywackes. Textural features, including the corrosion of some pyroxenes at their rims, the occurrence of stretched pyroxene crystals with minute albite grains, and the presence of crack-filling albites support the above suggestion.

As shown in fig. 9B and C, pyroxenes from albite-free metagreywackes (e.g. $X_{Jd} = 58–83$ in no. 194), or metachert ($X_{Jd} = 21–32$ in no. 60B) are lower in the jadeitic component. Such variations

emphasize the control of bulk rock composition on the pyroxene composition. Only those compositions of pyroxenes from the buffered assemblages Cpx + Ab + Qz + Chl can be used to monitor the physical conditions.

Some constraints on the jadeite–albite–quartz reaction and the fossil subduction-zone geotherm. Previous experiments on the reaction $Jd + Qz = Ab$ are in good agreement with regard to the equilibrium pressure at temperatures of 500–600 °C (Newton and Smith, 1967; Johannes *et al.*, 1971; Hays and Bell, 1973). However, considerable uncertainty remains as to its slope and the *P–T* position at higher temperatures (Birch and LeComte, 1960; Bell and Roseboom, 1969; Boettcher and Wyllie, 1968; Holland, 1983). These uncertainties lead to a large discrepancy for the extrapolated equilibrium pressure at 200–300 °C. For example, if we use Holland's extrapolation curve, jadeite reacts with quartz to form albite at 5.8 kbar at 200 °C, whereas Birch–LeComte's curve requires 8.2 kbar at the same temperature (see fig. 10). Fig. 10 also includes the calibrated isopleths in jadeite mole % for the binary system jadeite–diopside of Holland (1983) and the calcite–aragonite transition of Carlson (1983). The dotted area shows the two immiscibility regions between jadeite and omphacite and between omphacite and diopside. Apparently, aragonite and clinopyroxene of $X_{Jd} = 5$ cannot coexist according to the phase relations shown in fig. 10A. However, the occurrence of augite-rich pyroxene ($X_{Jd} = 5–18$) with albite and quartz was found in some zone I metabasites which are within the stability fields of aragonite and albite. Such field constraints suggest that Holland's calibration curves for the stability of clinopyroxenes may indicate pressures that are too low.

On the basis of compositions of clinopyroxene in the buffered assemblage from zones II, III and IV metagreywackes from the Pacheco Pass area, and the phase relations shown in fig. 10, the *P–T* conditions for their recrystallization were estimated. The results are shown in fig. 10B. Although the *P–T* scales are not given for the diagram, temperature for incipient recrystallization of the zone I metagreywackes is less than 170 °C and the transition from zones II to III may be about 230 °C. As stated above, the pressure estimates are less precise, varying from 4.5 to 8 kbar. Nevertheless, the estimated *P–T* gradient for the defined metamorphic zones is given with respect to the *P–T* position of the clinopyroxene equilibria.

If progressive metamorphic zones of a coherent greywacke unit were formed at nearly the same time along a subduction zone and their subsequent emplacement has not obscured the original zonations, the sequence delineated from the Pacheco

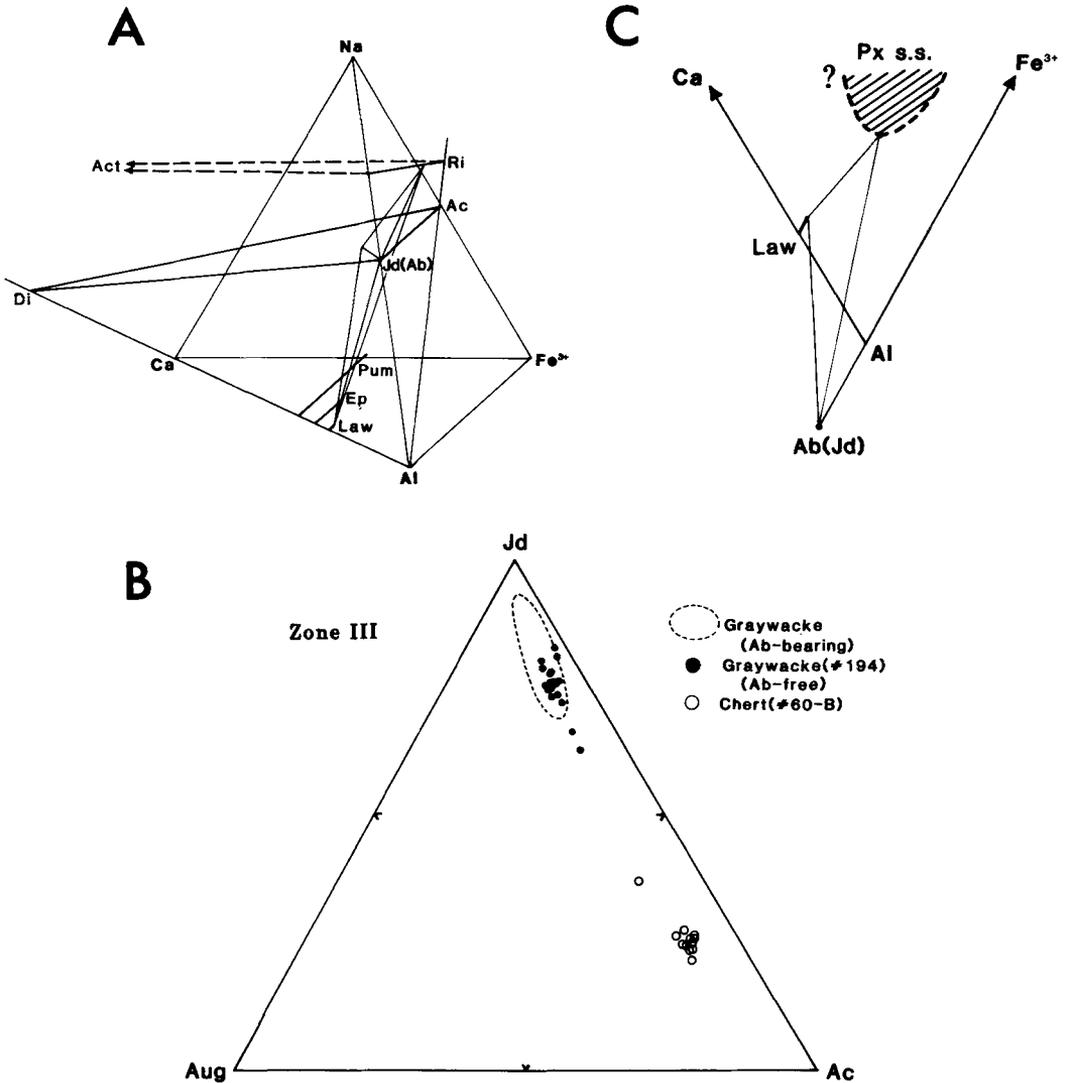


FIG. 9. A. Topologic relations among lawsonite (Law), clinopyroxene, amphibole, albite (Ab), epidote (Ep), and pumpellyite (Pum) in the system Ca-Al-Fe³⁺-Na projected from a chlorite $R_5Al_2Si_3O_{10}(OH)_8$, where R is $Fe^{2+}/(Mg + Fe^{2+}) = 0.45$. All assemblages contain quartz, phengite, sphene, and fluid. Compositional variations of amphibole and pyroxene are respectively defined by two planes and pyroxene composition is fixed for the buffered assemblage Ab + Law + amphibole + pyroxene. B. Jadeite (Jd)-augite (Aug)-acmite (Ac) mole proportions of analysed pyroxenes illustrate the effect of rock composition. In albite-free rocks (e.g. no. 194 metagreywacke and no. 60-B metachert), pyroxenes may be less jadeitic than those from the buffered assemblages. C. A projection from crossite to the basal Ca-Al-Fe³⁺ plane showing a continuous reaction from zone II to III: $Px(I) + Qz = Px(II) + Ab$. The Px(II) is less jadeitic than Px(I) and the stippled area shows composition of pyroxene.

Pass region can be used to define a possible Cretaceous geothermal gradient for Franciscan metamorphism. The results indicate that at relatively shallower depths, the progressive metamorphism took place with increasing P and T with

a very low geothermal gradient. At greater depths the progressive metamorphism evidently took place under a geothermal gradient that was higher than is currently recognized.

Discussion. McKee (1962a) first delineated the

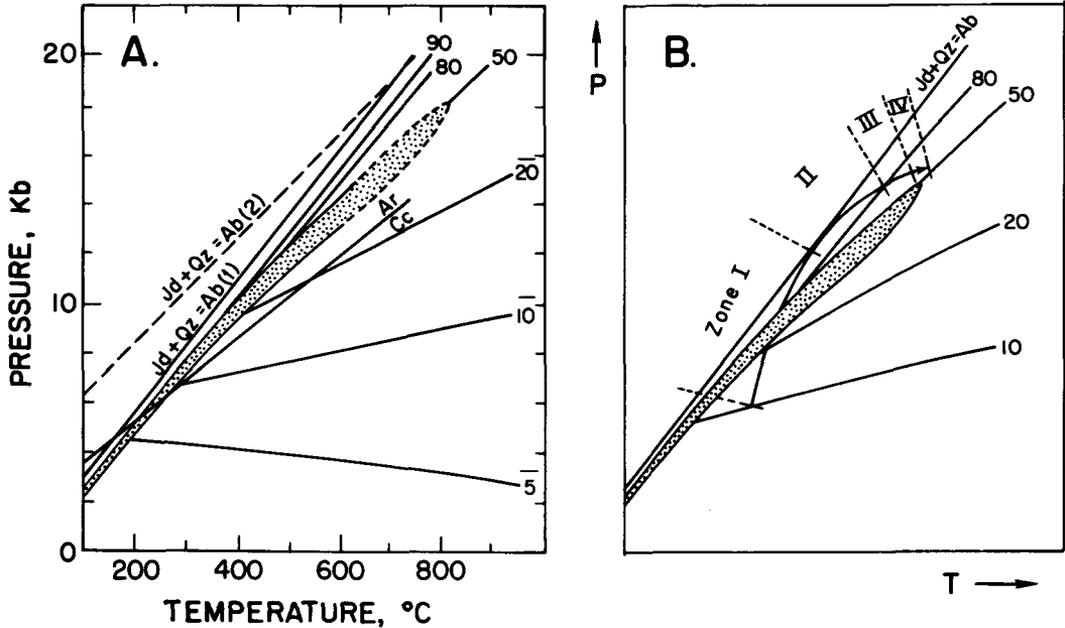


FIG. 10. P - T estimates for the four metamorphic zones in the Pacheco Pass area. A. P - T relations showing stabilities of jadeite + quartz (1) from Holland (1980) and (2) from Birch and LeComte (1960), and aragonite (Carlson, 1983) and isopleths for X_{Jd} of 5, 10, 20, 50, 80, and 90 mol %, calculated by Holland (1983). The stippled area represents immiscible pyroxenes between jadeite (C2/c) and omphacite (P2/n) and between omphacite (P2/n) and augite (C2/c). B. P - T estimates for the four metamorphic zones with respect to the pyroxene equilibria. Geothermal gradient for the progressive metamorphism is qualitatively shown.

jadeite isograd near Bell Station in the Pacheco Pass area. Ernst *et al.* (1970) found albite in McKee's jadeite zone metagreywackes and regarded albite as a metastable phase. However, they discussed the possibility of equilibrium and questioned whether the contact between albite-bearing and jadeite-bearing metagreywackes is a fault or an isograd. Ernst *et al.* (1970) analysed some clinopyroxenes and found that they are not pure jadeite; hence the jadeite isograd is not univariant but a divariant field for stable coexistence of jadeitic pyroxene + albite + quartz. Kerrick and Cotton (1971) interpreted the augite and acmite components in jadeitic pyroxene as a result of the reaction of lawsonite, hematite, chlorite and/or phengitic mica. They regarded the sporadic occurrence of jadeitic pyroxene in the Diablo Range as a result of variations in X_{H_2O}/X_{CO_2} in the fluid phase.

Our detailed compositional and mineralogical studies indicate that systematic and complex variations of pyroxene compositions are controlled by the continuous reaction of clinopyroxene and albite in the presence of quartz. Pyroxenes of less jadeitic composition form at higher grade, and the compositional variation is independent of the local

variation of X_{H_2O}/X_{CO_2} . The apparent absence of jadeitic pyroxene in the eastern part of the Pacheco Pass area is due either to different bulk composition or to the folded thermal structure.

Ernst *et al.* (1970) estimated that the jadeite-bearing metagreywackes in the Pacheco Pass area were recrystallized at temperatures between 200 °C to slightly more than 300 °C and at pressures of about or exceeding 8 kbar. Moore and Liou (1979) proposed the range of metamorphic conditions for the jadeite-bearing metaconglomerates from this area to be about 160 to 250 °C and 6 to 8 kbar. However, the albite breakdown curve of Holland (1980) casts doubt on those pressure estimates. Our recent study on the coherent greenstone block in the Cazadero area, California, delineated three metamorphic zones (Maruyama *et al.*, in prep.) where metamorphic temperatures were independently estimated to be about 170 °C for the lawsonite zone metabasites (Taylor and Coleman, 1968). The mineral assemblages of minor greenstones and their pyroxene compositions in the Pacheco Pass area are comparable with those Cazadero lawsonite-bearing metabasalts. Thus, the temperature for the zone I/II boundary is about 170 °C, and the zone II/III boundary was calculated to be about

60°C higher assuming that the pseudobinary join jadeite-aegirine ($X_{\text{aug}}/X_{\text{ac}} = 3/1$) is comparable with the jadeite-acmite join of Essene and Fyfe (1967). The metamorphic pressure would be about 4.5 kbar at 170°C if we follow Holland's extrapolation curve.

Metamorphic zonations, textural variations among pyroxenes, albite and quartz, and changes in X_{jd} for clinopyroxenes all suggest a gently folded thermal structure for the Cretaceous subduction-zone metamorphism. The tectonic significance of such thermal structures will be described elsewhere.

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