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PETROLOGY OF HIGH-GRADE METAPELITIC XENOLITHS IN AN OLIGOCENE RHYODACITE PLUG—PRECAMBRIAN CRUST BENEATH THE SOUTHERN GUERRERO TERRANE, MEXICO?

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INTRODUCTION

The Guerrero terrane in southern Mexico (Figure 1) is considered a major tectonostratigraphic accretion to the Mesozoic continental crust of Mexico, and essentially lacking an old continental basement (Campa and Coney, 1993; Centeno-García *et al.*, 1993). One of the main reasons for this hypothesis is the virtual absence of outcrops of high-grade metamorphic rocks in the terrane such as those profusely found in the adjacent Mixteco and Zapoteco terranes of Paleozoic and Precambrian ages, respectively. Nevertheless, some geological data (Elías-Herrera and Sánchez-Zavala, 1990) indicate the possible presence of evolved crustal rocks beneath parts of the volcanic-sedimentary units that make up most of the southern Guerrero terrane. Moreover, in contrast to the region of northern Mexico, Cenozoic volcanic rocks in southern Mexico are of calc-alkaline character and apparently do not contain xenoliths from the lower crust and upper mantle. This paper constitutes the first formal report on the presence in these volcanic rocks of high-grade, mid-crustal metamorphic xenoliths whose compositions and micro-structures strongly suggest the existence of pre-Mesozoic, probably Precambrian, crust beneath the Guerrero terrane of southern Mexico. The possible occurrence of continental crust of that age beneath lithotectonic suites, currently considered as Mesozoic oceanic additions to the continent, is germane to a better understanding of the paleogeographic and tectonic evolution of this part of the American Cordillera.

In this paper, two fresh high-grade xenoliths collected in the northern border of the La Goleta volcanic field of the Tejupilco region (Figure 1) from an Oligocene rhyodacitic plug are reported. Both consist of strongly foliated gneiss of mainly pelitic composition; their metamorphic P-T conditions are semiquantitatively determined, and their tectonic implications discussed.

GEOLOGICAL SETTING

The southern Guerrero terrane in the Tejupilco region (Figure 1) consists of two tectonically juxtaposed, Mesozoic, arc-related sequences, being the lower the Tejupilco metamorphic suite and the upper the Amatepec-Palmar Chico group.

The Tejupilco metamorphic suite is a metavolcanic-sedimentary sequence intensely deformed and with greenschist facies metamorphism affecting more than 2,000 m of structural thickness (Elías-Herrera *et al.*, in press). It mostly consists of black phyllite, pelitic sericite schist, greenschist (with a protolith of mainly andesitic and dacitic lahars), rhyolitic metatuff, and metagranite. The suite, previously described as pre-Upper Jurassic basement Taxco Schist and Taxco Viejo Greenstone, with inferred late Paleozoic and Late Triassic-Early Jurassic ages respectively (de Cserna and Fries, 1981; de Cserna, 1982), is currently interpreted as an Upper Jurassic-Lower Cretaceous or Lower Cretaceous island-arc constructed on oceanic lithosphere (Tardy *et al.*, 1992; 1994; Lapierre *et al.*, 1992; Talavera-Mendoza *et al.*, 1995). However, according to stratigraphic and structural data, isotopic ages (Elías-Herrera *et al.*, in press), and geochemical data (Elías-Herrera, unpublished data), the suite represents the lowermost structural levels of the southern Guerrero terrane, and it is considered as an evolved volcanic arc of Late Triassic-lower Middle Jurassic age developed on continental crust. This interpretation is strongly supported by the high-grade pelitic xenoliths examined here.

The Amatepec-Palmar Chico group is composed of silty and argillaceous limestone, sandstone, calcareous argillite, Albian-Cenomanian tuffaceous and radiolarian-siliceous sediments (Dávila-Alcocer and Guerrero-Suástegui, 1990), black slate, Albian-Cenomanian basaltic-andesite pillow lava and hyaloclastite (Elías-Herrera *et al.*, in press), and Albian mafic-ultramafic cumulates, small tectonic wedges of serpentinized peridotite, and numerous diabase to microgabbro dikes genetically related to the pillow lavas (Delgado-Argote *et al.*, 1992; Ortiz-Hernández *et al.*, 1991). The group, which has an estimated structural thickness of more than 2,500 m, is mildly to moderately deformed and shows a non-penetrative prehnite-pumpellyite facies metamorphism. Although the Amatepec-Palmar Chico group could be interpreted as an Albian-Cenomanian primitive oceanic island arc-back arc basin system (*e.g.*, Talavera-Mendoza *et al.*, 1993), its age range, lateral and vertical extension, paleogeographic setting, and relationship with the Tejupilco metamorphic suite remain undetermined.

The Mesozoic arc-related rocks are unconformably overlain by continental clastic rocks of the Paleogene Balsas Formation, Oligocene ignimbrites, and Neogene-Quaternary volcanic and volcaniclastic rocks. The La Goleta volcanic field, as part of the Oligocene ignimbrite cover (Figure 1),

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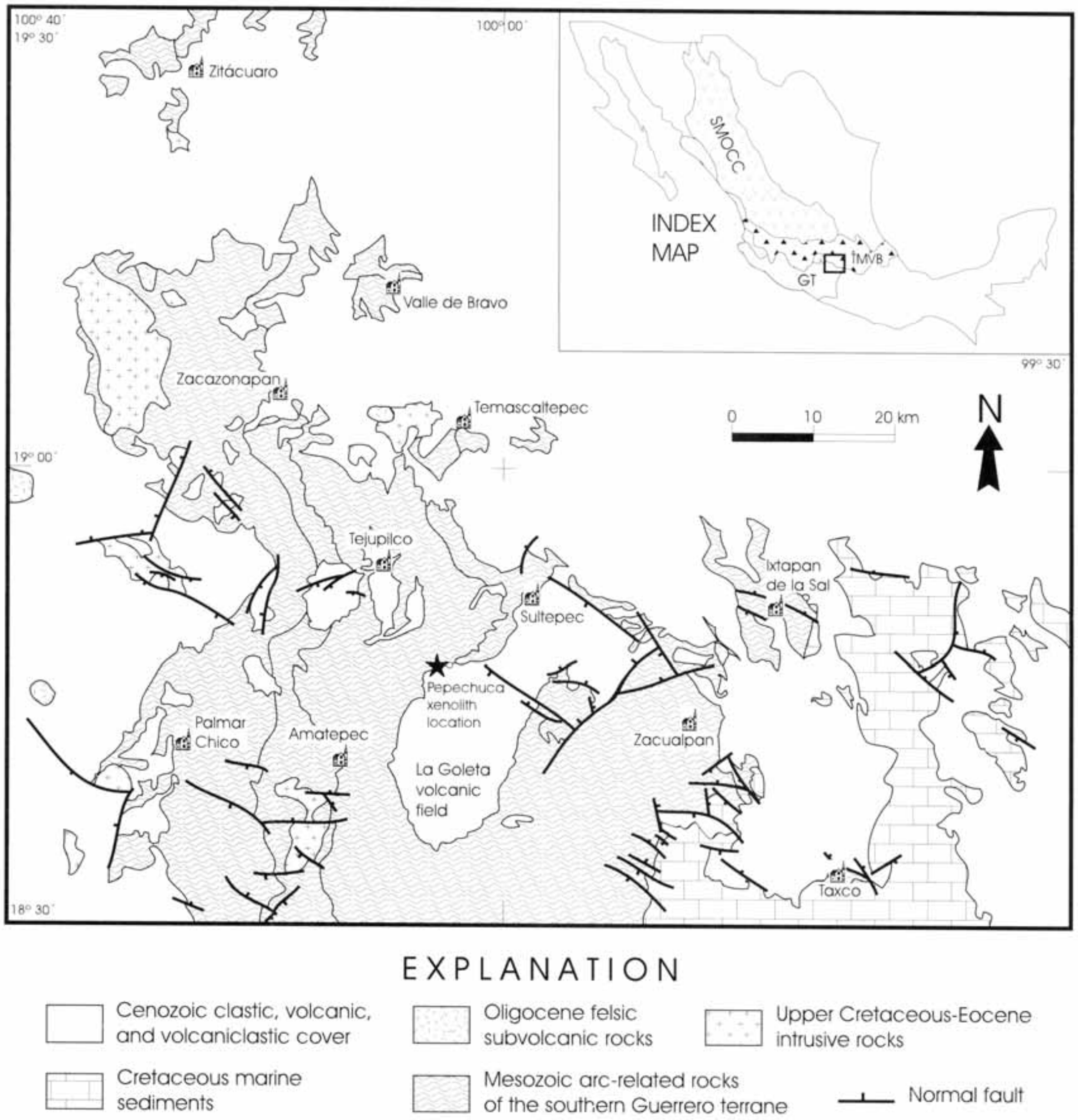

Figure 1. Simplified geologic map of the Tejupilco region (modified from de Cserna and Fries, 1981; de Cserna, 1982) showing the Pepechuca xenolith location within the southern Guerrero terrane. In the index map the Guerrero terrane (Campa and Coney, 1983) and volcanic rocks of the Sierra Madre Occidental (SMOCC) and Transmexican Volcanic Belt (TMVB) are shown. Contacts inside the Mesozoic arc-related rocks unit correspond to subunits not discussed in this paper.

consists of at least 200 km^3 of pyroclastic rhyolitic and rhyodacitic flow deposits. These pyroclastic rocks are genetically related to felsic subvolcanic bodies such as the El Picacho de Pepechuca, which contains xenoliths. The El Picacho de Pepechuca is a rhyodacitic volcanic plug in the northern border of the La Goleta volcanic field, which is located 15 km SE from Tejupilco (Figure 1), and has an intrusive contact with phyllite and sericite schist of the upper part of the Tejupilco metamorphic suite. Virtually no contact metamorphic aureole (thin centimetric baked zone in some places) was developed in the country rock due to rapid ascent and fast cooling of the rhyodacitic magma, as indicated by the textural relationships of the shallow intrusive body. The El Picacho de Pepechuca rhyodacite is characterized by porphyritic texture with abundant cryptocrystalline to devitrified glassy matrix surrounding phenocrysts of quartz, sanidine, and sodic plagioclase.

PETROLOGY

The high-grade metapelitic xenoliths in the El Picacho de Pepechuca occur together with other types of xenoliths such as deformed and undeformed granitic rocks, slate, phyllite, quartzite, marl, epidote marble, and metavolcanic fragments. Although the population of xenoliths is diverse, mafic granulitic or ultramafic xenoliths have not been observed. The low-grade (chlorite zone) phyllite and sericitic schist of the Tejupilco metamorphic suite nearby the rhyodacitic plug, and the absence of a contact aureole, indicate that many of the xenoliths were incorporated at the upper levels of the intrusion, and most of them correspond to the local exposed arc-related sequence. The high-grade xenoliths were scavenged from deeper levels of the crust.

The high-grade pelitic xenoliths have mostly irregular shapes and range from 1 to 10 cm in their largest dimension. For the purposes of this paper, only two fresh samples of the largest sized xenoliths were collected (samples Pep-2 and Pep-3). They have a well-developed gneissic structure with alternating felsic layers (2–10 mm thick) separated by biotite-rich discontinuous partings (1–3 mm thick). Sample Pep-3 is characterized by an áugen gneiss-like structure with porphyroblasts of feldspar (Figure 2, *A*). Their contacts with the rhyodacitic host are sharp suggesting no interaction between the felsic magma and the xenoliths.

The mineralogy of the xenoliths consists, in decreasing abundance order, of quartz, K-feldspar (orthoclase, perthite in some megacrystals), plagioclase (antiperthitic in megacrystals), biotite, sillimanite, cordierite, opaque minerals, apatite, spinel, zircon, corundum, rutile, and topaz (Table 1). These minerals are arranged in complex granoblastic and grano-lepidoblastic or nematoblastic textures. Quartzo-feldspathic lenticular bands with granoblastic polygonal texture (triple junctions with dihedral angles of about 120°) are complexly interlayered with heterogranular quartzo-feldspathic bands. In the granoblastic polygonal aggregates, spherical inclusions of quartz, apatite and biotite are common. Biotite also occurs among polygonal grains of quartz. Other types of inclusions such as acicular rutile, opaque mineral trails in parallel array perpendicular to gneissic foliation (remnants of sedimentary structure?, previous metamorphic event?), and unidentified rare inclusions are abundant in the polygonal quartz.

In the heterogranular quartzo-feldspathic bands, a complex fine-grained assemblage of K-feldspar, plagioclase and quartz occurs. Granophyric and myrmekitic textures, and grain boundary migration recrystallization are common. Some grains of plagioclase are gently curved. The assemblage biotite + sillimanite + cordierite + spinel + corundum is present within the heterogranular quartzo-feldspathic layers. Biotite is titaniferous with abundance of exsolved Fe-Ti oxides; it forms lepidoblastic domains that define the gneissic foliation. Several crystals of biotite are folded or curved into folia, some of them with a mica fish shape indicating microscopic ductile shear zone. Fine-grained biotite clearly defines a tectonic foliation in several portions within the xenoliths. Some ribbons of quartz and/or K-feldspar are also observed. Sillimanite (fibrolite) is present in fibrous form, parallel to radiating aggregates with minor prismatic crystals in lenticular and discontinuous nematoblastic domains closely related to (replacing?) cordierite (Figure 2, *B*), K-feldspar and plagioclase. Prismatic sillimanite in association with plagioclase, cordierite, spinel, and corundum are also present in discontinuous layers parallel to the gneissic foliation (Figure 2, *C*). Sillimanite, like biotite, is slightly folded or curved into folia in some fibrolitic aggregates. Cordierite, together with K-feldspar, conforms complex xenoblastic aggregates. Cordierite invariably shows typical pinitic alteration (Figure 2, *B*). Spinel is dark green (probably hercynitic) and the individual euhedral crystals (5–70 μm) are mostly enclosed within cordierite. Spinel also occurs as rims around opaque grains (probably magnetite). Corundum, in small amounts of hypidiomorphic grains (10–150 μm) (Figure 2, *C* and *D*), is another important paragenetic mineral; it is associated with fine-grained plagioclase, cordierite, prismatic sillimanite and spinel in discontinuous and thin layers within heterogeneous quartzo-feldspathic sectors. Sporadic grains of topaz also occur. This mineralogy clearly implies that bulk and individual layers of the xenoliths are peraluminous.

TEXTURAL INTERPRETATION

Textural contrasts, and the relationship between granoblastic polygonal quartzo-feldspathic lenticular bands and heterogranular quartzo-feldspathic layers suggest a complex tectonothermal history for the xenoliths. The granoblastic polygonal aggregates could correspond to annealing recrystallization under high-grade metamorphic conditions, in which a high degree of crystalline stability was attained. The heterogranular quartzo-feldspathic layers, characterized by a complex fine-grained assemblage of K-feldspar, plagioclase and quartz, with granophyric and myrmekitic textures and grain boundary migration recrystallization, are apparently post-granoblastic polygonal assemblages. The heterogranular quartzo-feldspathic layers with anastomosing and irregular bands, seem to be a leucosome formed by late partial melting. Prismatic sillimanite, spinel, corundum, and minor cordierite, which are only observed in irregular bands parallel to the foliation within heterogranular quartzo-feldspathic layers, could be restite components of anatexis. However,

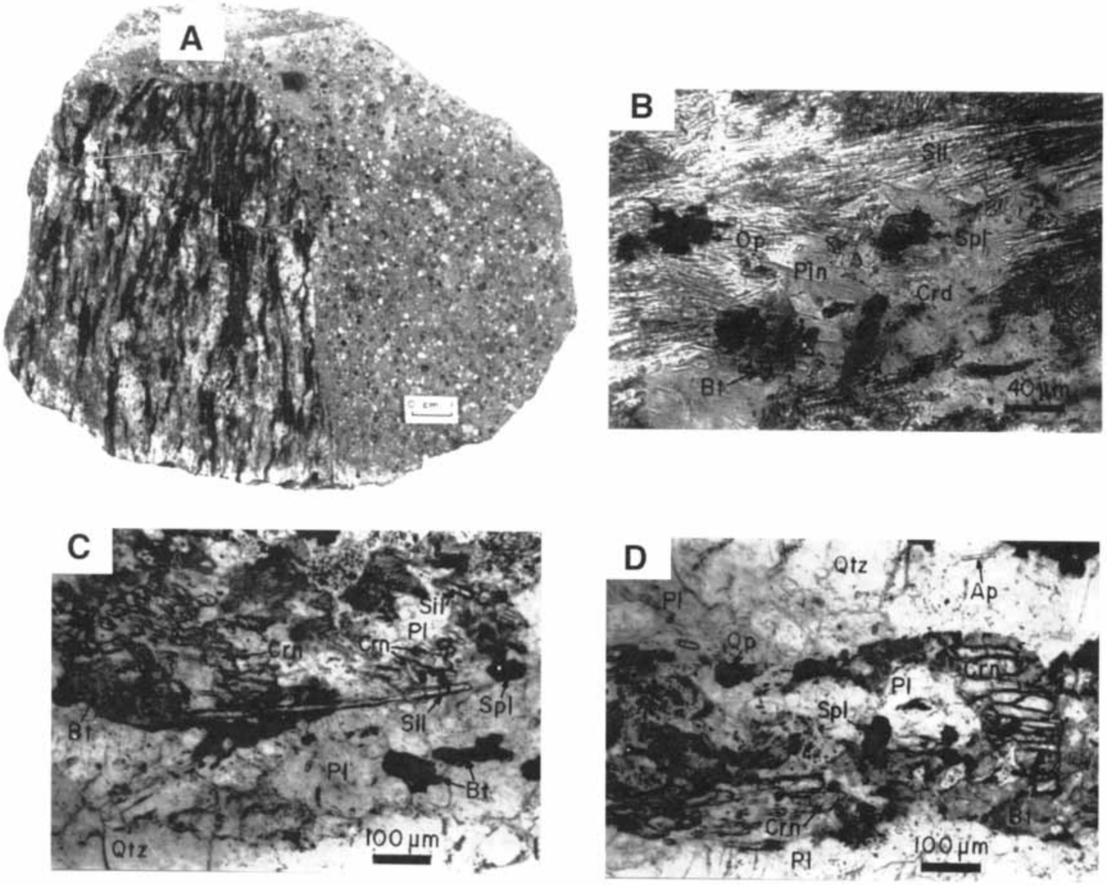

Figure 2. (*A*) High-grade metapelitic xenoliths in hand sample (sample Pep-3) showing well-developed augen-gneiss structure in sharp contact with the enclosing rhyodacitic rock. (*B*) Photomicrograph (sample Pep-2) depicting fibrous sillimanite (Sil) closely related to cordierite (Crd) with its classical pinitic alteration (Pin), with enclosed small grains of spinel (Spl), opaque minerals (Op) and biotite (Bt). (*C*) Photomicrograph (sample Pep-3) showing the association of prismatic sillimanite (Sil) + corundum (Crn) + spinel (Spl) + plagioclase (Pl) + subhedral grains of biotite (Bt) with exsolved Fe-Ti oxides. (*D*) Another detailed view (sample Pep-3) of the occurrence of corundum (Crn) in a sector rich in plagioclase (Pl) with grains of spinel (Spl), opaque minerals (Op) and some prismatic crystal of apatite (Ap). In the last two cases, the irregular dark-gray patches (Bt), which are of a rare vitreous-like material, may represent incongruent melting of the biotite. It is important to remark that quartz (Qtz), which is abundant in the xenoliths, is not in contact with spinel or corundum as depicted in (*C*) and (*D*).

diagnostic textural relationships indicating extensive crystallization of a melt, such as xenomorphic or oikocrystic quartz containing idiomorphic or hypidiomorphic K-feldspar, plagioclase (with idiomorphic zoning), cordierite, and sillimanite (McLellan, 1983; Ashworth and McLellan, 1985; Pattison and Harte, 1988; Vernon and Collins, 1988; Grant and Frost, 1990; Vernon *et al.*, 1990), do not occur in the heterogranular quartzo-feldspathic layers. Therefore, though these layers may be interpreted as leucosome they formed essentially in a solid-state. Nonetheless, granophyric and myrmekitic inter-

Table 1. Mineralogy of the high-grade metapelitic xenoliths.

Sample	Qtz	Kfs	Pl	Bt	Sil	Crd	Op	Ap	Spl	Zrn	Crn	Rt	Toz
Pep-2	xxxx	xxxx	xxx	xxx	xxx	xxx	xx	x	xx	x	x	x	x
Pep-3	xxxx	xxxx	xxx	xxx	xx	x	xx	xx	x	x	x	x	

Qtz: quartz; Kfs: K- feldspar; Pl: plagioclase; Bt: biotite; Sil: sillimanite; Crd: cordierite, Op: opaque minerals; Ap: apatite; Spl: spinel; Zrn: zircon; Rt: rutile; Crn: corundum; Toz: topaz. Approximate modal contents: xxxx ≥ 20%, xxx = 20 – 5%, xx = 5 – 1%, x ≤ 1%.

growths (Ashworth and McLellan, 1985), grain boundary migration recrystallization with localized interstitial quartz and K-feldspar, oscillatory zoning in some grains of plagioclase, acicular apatite, and myriad dactilar fluid inclusions suggest the presence of some melt. In a few bands, biotite associated with sillimanite, spinel, corundum and opaque minerals, could also indicate incongruent melting of the mica (Figure 2, *C* and *D*).

Because the xenoliths contain aluminous metamorphic minerals such as sillimanite, cordierite, spinel, and corundum in K-feldspar-plagioclase-biotite assemblages, and these mineralogical associations occur not only in low-pressure granulitic terranes (Bucher and Frey, 1994; Miyashiro, 1994), but also in metapelites with high-temperature contact metamorphism in aureoles (Tyler and Ashworth, 1983; Pattison, 1989; Pattison and Harte, 1988; Grant and Frost, 1990), and in xenoliths (Vielzeuf, 1983; Evans and Speer, 1984; Grapes, 1986), the genetic interpretation of the metamorphism in the present case is ambiguous. The textural relationships, however, are a key factor for distinguishing between contact and regional metamorphism (*e.g.*, Dickerson and Holdaway, 1989; Pattison and Tracy, 1991). The grano-lepidoblastic or nematoblastic textures with parallel arrangement of biotite and some of sillimanite, both defining tectonic foliation, suggest that the mineral assemblages of the Pepechuca xenoliths essentially correspond to high-grade regional and not to contact metamorphism.

Although the thermal effect of the enclosing rhyodacitic magma on the xenoliths is difficult to evaluate, it is probable that it did not substantially modified their original mineralogical and textural features. In argillaceous xenoliths with intense local thermal metamorphism (sanidinite facies; Turner, 1981), high-temperature or refractory minerals such as sillimanite and/or mullite, cordierite, spinel, corundum, Fe-Ti oxides and tridymite are enclosed by glassy (or buchitic) material (*e.g.*, Pederson, 1978, 1979; Grapes, 1986; Vielzeuf, 1983). Neither glassy material nor granofels textures, that might suggest ultra- or moderate thermal metamorphism related to the enclosing rhyodacite, were observed in the xenoliths. It is, therefore, concluded that the metamorphism of the xenoliths is of regional type and developed under tectonically differential stresses prior to the transportation of the xenoliths to near surface carried out by the rhyodacitic intrusion.

GEOTHERMOMETRIC CONSTRAINTS

Although microprobe analysis of the mineral assemblages from the xenoliths were not performed, the P-T conditions for their metamorphic assemblages can be approximately estimated from published petrogenetic grids. This preliminary study assumes that the two pelitic xenoliths were sampled from the same crustal level beneath the Tejupilco metamorphic suite by the felsic magma. Because they did not undergo substantial changes during their rise in the crust as indicated by their mineral and textural features, the P-T conditions must essentially correspond to the regional metamorphism that affected an underlying and probably old metamorphic basement.

The absence of kyanite or garnet and the occurrence of cordierite and spinel in the pelitic xenoliths, at first glance, indicate low pressure and high temperature for the metamorphism. The complete absence of muscovite, and the coexistence of sillimanite + K-feldspar ± plagioclase ± biotite (Figure 3; reactions 1 and 2) indicate that the upper temperature limit of muscovite + quartz + plagioclase was exceeded at a pressure enough to stabilize sillimanite, rather than andalusite. This implies minimum metamorphic conditions of about 660° C and 3 kb, or 690° C and 4 kb, according to the andalusite = sillimanite curves of Pattison (1992), or of Richardson and collaborators (1969), respectively (Figure 3). The curve, reported by Pattison (1992), is based on the natural occurrence of sillimanite at or immediately above of the muscovite + quartz = andalusite + K-feldspar isograd, and is partially calibrated with cordierite in natural assemblages in low-pressure contact aureoles (Pattison and Tracy, 1991). This curve could be appropriate for the present case. The curve of Richardson and collaborators (1969), however, the equilibrium of which was based on fibrolitic sillimanite, is probably more relevant taking into account the fibrous nature of most sillimanite in the Pepechuca xenoliths. This later curve has been found more appropriate for metamorphic rocks in low pressure/high temperature terranes (*e.g.*, Vernon, 1982; Vernon *et al.*, 1990).

On the other hand, evidence of partial melting in the xenoliths, in which the melting reaction quartz + K-feldspar + plagioclase + muscovite + water = melt (reaction 4) may be applicable, indicates a minimal temperature of about 650°C and 3.5 kbar. If it is considered that the breakdown of muscovite not only occurred by the reactions: muscovite + plagioclase + quartz = alkali feldspar + sillimanite + biotite + water (reaction 1), and muscovite + quartz = K-feldspar + sillimanite + water (reaction 2), but also by the reaction muscovite = corundum + K-feldspar + water (reaction 3), as indicated by the small amounts of corundum in contact with Na-K feldspar (not with quartz) (Figure 2, *C* and *D*) in some layers of the xenoliths, the intersection of this univariant curve with the minimum melting curve gives a minimum temperature of 675°C and 2 kb (Figure 3). However, as corundum is also associated with prismatic sillimanite, cordierite and spinel, the assemblage implies temperatures greater than 700°C. Since the breakdown of biotite, according to the reaction biotite + plagioclase + sillimanite + quartz = K-feldspar + almanditic garnet ± cordierite (at low pressure) + melt (reaction 5) did not occur, it may define a reliable temperature constraint. Under low pressures (≤ 6 kb) this reaction implies temperatures of about 730 to 760°C within the stability field of sillimanite (Figure 3), and it

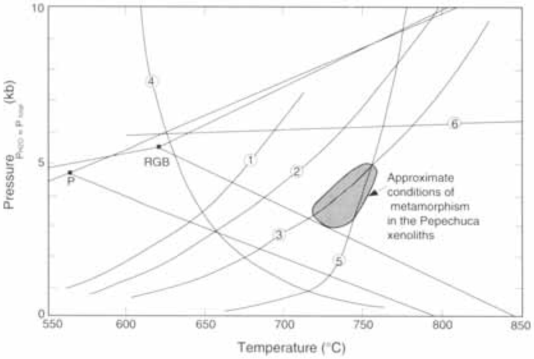

Figure 3. P-T diagram depicting approximate conditions for the metamorphism of the high-grade pelitic xenoliths constrained by a variety of phase equilibria (see text). Al_2SiO_5 polymorph equilibria and triple points are shown as RGB (Richardson *et al.*, 1969), and P (Pattison, 1992). The other univariant curves are: (1) muscovite + albite + quartz = andalusite or sillimanite + alkali feldspar ± biotite + water (Huang and Wyllie, 1974; Thompson and Algor, 1977); (2) muscovite + quartz = K-feldspar + andalusite or sillimanite + water (Huang and Wyllie, 1974; Thompson and Algor, 1977); (3) muscovite = corundum + K-feldspar + water (Huang and Wyllie, 1974; Thompson and Algor, 1977); (4) quartz + K-feldspar + plagioclase + muscovite + water = melt (Huang and Wyllie, 1974; Thompson and Algor, 1977); (5) biotite + plagioclase + sillimanite + quartz = K-feldspar + almandine garnet ± cordierite + melt (Holdaway and Lee, 1977; LeBreton and Thompson, 1988); (6) hydrous Fe-Mg cordierite = Fe-Mg garnet + sillimanite + quartz + water (Newton and Wood, 1979).

could be the maximum temperature range for the metamorphism of the xenoliths. This temperature range is congruent with the coexistence of cordierite and spinel, and with the assemblage sillimanite + cordierite + spinel of natural compositions in spinel-bearing metapelites in low-pressure charnockitic terranes (Harris, 1981). The breakdown of Fe-cordierite into spinel + quartz requires a minimum temperature of about 770° C (Bohlen *et al.*, 1986), which was probably not attained in the studied xenoliths because, although both minerals are present, they are not in mutual contact (Figure 2, *C* and *D*).

GEOBAROMETRIC CONSTRAINTS

The assemblage biotite + sillimanite + plagioclase + quartz, stable in the xenoliths, is probably unstable at pressures below 3 kb (Hoffer, 1978; Wickham, 1987), thus giving an initial minimum-pressure estimate. In similar pelitic gneiss with this assemblage, and from the occasional occurrence of garnet, Wickham (1987) deduced a pressure range of 3–4 kb, or 3–5 kb with high aH$_2$O. At a pressure of about 4 kb anhydrous cordierite + spinel (Vielzeuf, 1983), and K-feldspar + cordierite + silicate liquid, and cordierite + spinel + corundum + silicate liquid (Powers and Bohlen, 1985) coexist. All of these assemblages are in fact present in the studied xenoliths.

The maximum pressure attained can be constrained by the univariant curve cordierite = garnet + sillimanite + quartz ± water (reaction 6, Figure 3) at temperature higher than that of the breakdown of muscovite in the presence of quartz. Although the pressure of this equilibrium reaction varies depending on the contents of H_2O and the Mg/Fe^{2+} ratio in the cordierite (Newton and Wood, 1979). Thus, under $P_{H_2O} = 0$, in the 700–750° C temperature range, the anhydrous Fe- and Mg-endmember cordierites breakdown at about 2.5 kb and 6 kb, respectively; whereas under $P_{H_2O} = P_{total}$, in the same temperature range, the hydrous Fe- and Mg-cordierite end members are unstable at about 3.5 kb and 7 kb, respectively (Newton and Wood, 1979). In the present case, the relative abundance of biotite as hydrous phase (5–20% modal), and the myriads of dactylaroid fluid inclusions found in different minerals, suggest that the cordierite in the xenoliths is hydrous. Also, because the Mg/(Mg + Fe^{2+}) ratio in the cordierite is unknown, a ratio of 0.5 is assumed, which gives equilibrium conditions of about 6 kb in the range of 700–750°C for a hydrous Fe-Mg cordierite (Figure 3). The presence of cordierite and absence of garnet in the studied xenoliths then suggest pressures below 6 kb. This is consistent with the fact that cordierite is usually not stable at pressures greater than 6 kb in most common metapelites (Newton, 1983; Vielzeuf and Holloway, 1988).

In summary, reasonable P-T conditions for the metamorphism of the pelitic xenoliths are P = 3–5 kb and T = 730–760°C, as indicated in Figure 3. This P-T range is common in low-P/high-T type regional metamorphism in granulitic terranes with high geothermal gradients (*e.g.*, Hudson, 1980; Harris, 1981; Wickham, 1987; Vernon *et al.*, 1990), corresponding to the low-pressure granulitic facies (Miyashiro, 1994) at considerable water pressures.

DISCUSSION AND MAIN REGIONAL IMPLICATIONS

Though the granulitic, peraluminous xenoliths from Pepechuca have undoubtedly a crustal origin, their tectonic interpretation without geochronological and isotopic data is poorly constrained. However, the geological relationships and mineralogical textural features of xenoliths described, yield some constraints on which three possible lithotectonic scenarios are now discussed.

1. THE ROOT OF A CENOZOIC VOLCANIC ARC

The xenoliths would be the product of Tertiary migmatization and partial melting of the middle crust due to the thermal input in the core of a continental Oligocene arc. In this scenario, the granitic melt was quickly removed from the site of migmatization carrying part of the remaining solid material as refractory xenoliths to the surface. However, textural evidence as discussed above, suggests: (a) a very limited amount of melt in the xenoliths, and (b) that solid-state processes produced their banded structure.

Furthermore, if the ductile deformation (foliation and banding) observed in the xenoliths was due to tectonothermal processes in the middle crust associated with the subduction that triggered the Oligocene volcanism in the region, such processes would have produced visible deformation also at higher levels in the crust. Evidence of intense tectonic deformation in the Oligocene history of the region has not been reported. This model is rejected because it does not explain the complex ductile deformation of the xenoliths.

2. THE ROOT OF MESOZOIC OR PALEOZOIC ARC

If deformation and metamorphism of the xenoliths accompanied the evolution of the Mesozoic arc now represented by the lower structural levels of the Tejupilco metamorphic suite, the high geothermal gradient (40–70°C/km), implied from the mineral assemblages of the xenoliths, would require a close distribution of the isotherms across the Mesozoic arc, and consequently the common presence of minerals such as andalusite and biotite in the extensively exposed areas of the Tejupilco sequence. Nonetheless, it is clear that within the over 2,000 m of structural section of the exposed metamorphic complex, andalusite is absent and biotite is extremely rare. Thus, it is concluded that the low-P/high-T metamorphism of the xenoliths is altogether different in nature and age from the metamorphism that affected the Tejupilco metamorphic suite. It should be mentioned at this point that the assemblages cordierite-muscovite-biotite and cordierite-phlogopite-rutile-clinochlore-muscovite formerly reported (Elías-Herrera, 1989) in pelitic schists from the Tejupilco area, are definitely related to the thermal effects of the Eocene Temascaltepec granite (Elías-Herrera *et al.*, in press). Those assemblages are superposed on the chlorite-biotite zone of the Mesozoic regional metamorphism that affected the area. Moreover, rocks with highly pelitic protoliths like that of the studied xenoliths, should be very unusual in the roots of common island arcs, most of which are characterized by primitive amphibolitic, tonalitic, trondhjemitic, and gabbroic rocks (Hamilton, 1988, 1995).

Therefore, it is most difficult to visualize as the source of the xenoliths the deeply eroded roots of a Paleozoic arc beneath the Mesozoic island arc sequences of the southern Guerrero terrane. It is concluded that this second hypothesis is also geologically poorly supported.

3. PRECAMBRIAN BASEMENT

The xenoliths could have been scavenged by Oligocene felsic magma from the walls or roof of a magma chamber developed in Precambrian continental crust underlying Mesozoic rocks. The source of the xenoliths could lie only a few kilometers below the present surface, considering that in some volcanic fields such as the Taupo Volcanic Zone of New Zealand (Stern, 1986), plutonic rocks, crystallized in magma chambers and directly related to the exposed volcanic rocks, have been found at a depth of about 4 km. The apparent absence of mafic or ultramafic xenoliths (lower crust and upper mantle) in the Pepechuca plug, and the maximum pressure conditions estimated for the xenoliths, preclude source depths greater than about 20 km. The Precambrian age of the xenoliths is suggested by: (a) the highly evolved chemical nature of their parent rocks, (b) a complex structural history that includes at least two penetrative phases of deformation, with the earliest one defining a typical granulitic structure and (c) because it is unlikely that highly aluminous rocks could represent the roots of a Phanerozoic island arc. Additional support for the presence of an old crust beneath certain areas of the southern Guerrero terrane is given by regional gravity data suggesting a thick crust beneath most of the Guerrero terrane (Urrutia-Fucugauchi and Molina-Garza, 1992), and by Sm-Nd model ages measured in xenoliths of the Valle de Santiago volcanic field in the neighboring State of Guanajuato (Uribe-Cifuentes and Urrutia-Fucugauchi, 1995). It is clear, however, that a definite answer to the question of the true age of the Pepechuca high-grade crustal xenoliths could come only from the U-Pb dating of its abundant metamorphic zircons.

The tectonic implications associated with the presence of Precambrian crust, either as a stratigraphic basement for this part of the Guerrero terrane, or as part of a continental margin overridden by allochthonous primitive packages of that terrane, are extremely diverse and important. For example, what would be the configuration of this buried inferred sialic terrane?, and what would be their present relationships with the North American craton, or with the recently postulated (Ortega-Gutiérrez *et al.*, 1995) Oaxaquia microcontinent of Grenvillian age? What sort of tectonic history explains the high geothermal gradient responsible for the metamorphism registered in the xenoliths? A stratigraphic relationship between the Guerrero terrane and its possibly underlying continental crust would prompt a reevaluation of the current understanding of the Guerrero terrane as an ocean-floored arc complex. On the other hand, if it is truly of oceanic provenance and then thrust onto continental crust, the Guerrero terrane would need to have traveled tens or hundreds of kilometers over a Precambrian(?) continental margin represented by the xenoliths. Solutions to these questions must await further isotopic and geochronologic studies on the xenoliths discussed here, the search for similar xenolith localities in the whole extension of the Guerrero terrane, and specific geophysical and geochemical surveys designed to reveal more closely the structure and composition of the deep crust beneath the whole extension of the Guerrero terrane.

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