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GLAUCOPHANE SCHIST IN THE ANDES AT JAMBALÓ, COLOMBIA

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Abstract

Glaucophane schist at Jambaló (2°46.9′N; 76°19.6′W) in the Colombian Andes includes the assemblages albite–quartz–paragonite–glaucophane–garnet–chlorite–calcite and quartz–albite–paragonite–muscovite–glaucophane–epidote–chlorite. Metamorphism of the glaucophane schist at Jambaló is interpreted to have taken place at 350–400°C, under P_{total} = 5-7 kbar, with a mixed-volatile fluid phase ($P_f \simeq P_{total}$) of locally variable H_2O/CO_2 ratios. This interpretation is based on phase petrology supported by microprobe analyses and a comparison with analogous schists in the lowest-grade part of the epidote zone from the Ouégoa district, New Caledonia. High-pressure rocks at Jambaló constitute a new occurrence on the discontinuous circum-Pacific belt. They may have an origin similar to that proposed for eclogite and associated rocks, also of Early Cretaceous age, 800 km away in southwestern Ecuador. If so, it would suggest that (1) a major period of subduction terminated abruptly in Early Cretaceous time; (2) other outcrops of high-pressure rocks may be expected in a belt just east of the Romeral fault; and (3) the Romeral fault was the active boundary between the continental South American plate and an oceanic plate to the northwest, at least during the beginning of the Cretaceous Period.

Keywords: blueschist, glaucophane, Andes, Colombia.

Sommaire

Les schistes à glaucophane de Jambaló, dans les Andes colombiennes (2°46.9′N, 76°19.6′0) contiennent les assemblages albite–quartz–paragonite–glaucophane–grenat–chlorite–calcite et quartz–albite–paragonite–muscovite–glaucophane–epidote–chlorite. A la lumière des relations entre les phases, des données analytiques (microsonde) et d'une comparaison avec des schistes analogues dans la portion la plus faiblement métamorphosée de la zone à épidote du district Ouégoa (Nouvelle-Calédonie), le métamorphisme des schistes à glaucophane de Jambaló impliquerait les conditions suivantes: T entre 350 et 400°C, P_{totale} entre 5 et 7 kbar avec présence d'une phase fluide mixte ($P_{fluide} \simeq P_{totale}$) de rapport H_2O/CO_2 variable localement. Ces roches de haute pression constituent une nouvelle occurrence dans la ceinture discontinue circumpacifique. Leur origine pourrait être analogue à celle des éclogites et des roches associées, datant aussi du Crétacé inférieur, situées à 800 km de distance dans le Sud-Ouest de l'Equateur. Dans ce cas, cette ceinture indiquerait une importante période de subduction s'est terminée soudainement au Crétacé inférieur. D'autres affleurements de telles roches constitueraient alors une ceinture immédiatement à l'est de la faille Romeral. Cette faille aurait formé la frontière active entre la plaque continentale Sud-Américaine et une plaque océanique vers le Nord-Ouest, du moins au début du Crétacé.

(Traduit par la Rédaction)

Mots-clés: schistes bleus, glaucophane, Andes, Colombie.

Introduction

Metamorphic rocks of high-pressure baric type, including glaucophane schist, have been mapped by Colombian geologists near the town of Jambaló (2°46.9′N, 76°19.6′W) in the Andean Central Cordillera (Orrego *et al.* 1980a). In the present report the phase petrology of the glaucophane schist at Jambaló is described briefly, and comment is made on the regional significance of the occurrence.

Regional Setting

The bulk of the Andean Central Cordillera of Colombia is underlain by diverse low-pressure metamorphic rocks of Paleozoic age, cut by granitic plutons chiefly of Mesozoic age (INGEOMINAS 1976). Continental volcanic deposits of Tertiary and Quaternary age blanket parts of the Cordillera in the south. A major inactive transform fault system, called the Romeral fault, follows the Central Cordillera near its western base throughout Colombia.

The high-pressure metamorphic rocks at Jambaló lie between the Romeral fault to the northwest and basement gneisses and schists of the Central Cordillera to the southeast (Fig. 1). The rocks at Jambaló have been divided into three units: (1) Jambaló Glaucophane Schist, (2) La Mina Greenschist and (3) San Antonio Amphibolite (Orrego *et al.* 1980a). Although the Jambaló Glaucophane Schist belongs to a blueschist facies, there is no evidence that the two other units belong to or ever were part of

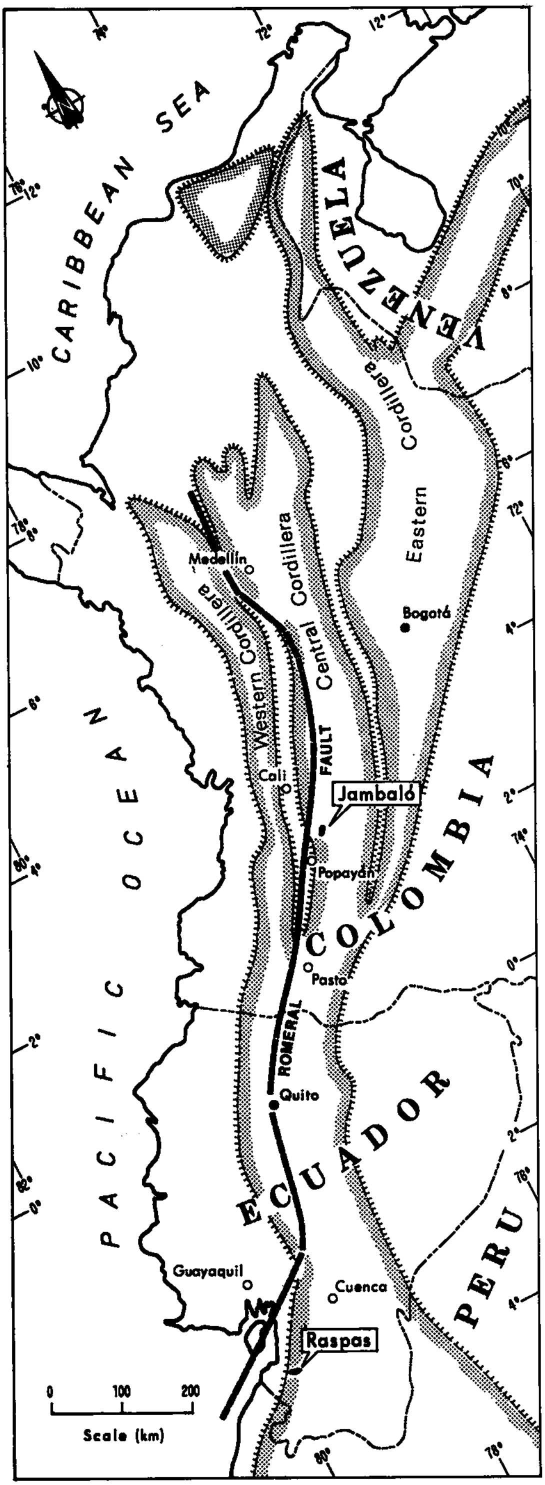

FIG. 1. High-pressure metamorphic rocks at Jambaló, Colombia, and the Raspas Formation, Ecuador.

a high-pressure facies series. Indeed, each of the three units constitutes a discrete block, isolated from the other units and from country rocks by faults that are in part filled by sheared serpentinite. Neither structural nor mineralogical evidence (Orrego *et al.* 1980a) supports a genetic link between the Jambaló Glaucophane Schist and the La Mina or San Antonio units.

JAMBALÓ GLAUCOPHANE SCHIST

The block of Jambaló Glaucophane Schist is elongated north-northeast, parallel with the regional Andean tectonic trend. The long axis of the block is at least 25 km, the transverse axis 7 km. The northern contact is incompletely mapped. Foliation in the schist dips uniformly to the west (Orrego *et al.* 1980a). A single whole-rock K–Ar determination has given an Early Cretaceous age of 125 ± 15 *Ma* (Orrego *et al.* 1980b). Three small stocks of andesite porphyry of Tertiary age cut the body in the south.

TABLE 1. MODES OF TWO GLAUCOPHANE SCHISTS FROM JAMBALÓ, COLOMBIA

Sample	J-1	J-2
Quartz, Albite	15.7 (1)	35.5 (2)
Paragonite	16.8	18.0
Muscovite	0.0	6.0 (3)
Chlorite	5.0	5.7
Glaucophane	43.3	28.2
Garnet	1.0	0.0
Epidote	0.0	2.1
Sphene	6.7	2.9
Apatite	0.2	0.3
Calcite	10.8	0.0
Pyrite	0.4	1.3
TOTAL	99.9	100.0
Points (4)	1635	1539
Density (5)	2.97	2.92

Notes: 1) Albite > quartz; 2) quartz > albite; 3) paragonite /muscovite ratio estimated by relative intensities of basal reflections measured on a diffractogram of a mica concentrate; 4) spaced on a 0.6 x 0.6 mm grid; 5) $gm \cdot cm^{-3}$.

The glaucophane schist is a thoroughly recrystallized, fine- to medium-grained, grey to blue-grey rock. Dark slender prisms of glaucophane, commonly less than 5 mm long, are, in places, oriented and impart a strong lineation to the schist. Nowhere have vestiges of premetamorphic textures been preserved. In some samples, metamorphic segregation has imparted a pronounced lamination of felsic *versus* glaucophane-rich layers.

Two samples of glaucophane schist were selected for detailed study (Table 1). Specimen J–1 is a fine grained, dark blue-grey schist with the mineral assemblage glaucophane–paragonite–albite–quartz–calcite–chlorite–garnet. Specimen J–2 is a fine- to medium-grained, laminated and lineated schist with the mineral assemblage glaucophane–paragonite–quartz–albite–muscovite–chlorite–epidote. Accessory sphene, apatite and pyrite are common to both samples. All phases are in mutual contact and have smooth boundaries. These observations, coupled with the nearly equigranular texture of the rocks, indicate that mineralogical equilibrium was attained during metamorphism, at least on the scale of a thin section.

TABLE 2. ELECTRON-MICROPROBE ANALYSES OF GLAUCOPHANES FROM SCHIST AT JAMBALÓ, COLOMBIA

	J-1 (core)		J-1 (rim)		J-2 (core)		J-2 (rim)	
SiO_2	55.94		55.88		55.45		56.56	
TiO_2	0.08		0.03		0.10		0.00	
Al_2O_3	10.07		11.90		9.45		10.56	
FeO*	17.88		15.35		16.71		14.04	
MnO	0.25		0.19		0.19		0.15	
MgO	6.88		6.83		8.54		8.85	
CaO	0.78		0.38		0.70		0.24	
Na_2O	7.05		7.48		7.37		7.45	
K_2O	0.01		0.01		0.04		0.02	
TOTAL	98.94		98.05		98.55		97.87	
Number of ions on the basis of 23 (O):								
Si	7.90	8.00	7.85	8.00	7.85	8.00	7.92	8.00
Al^{iv}	0.10		0.15		0.15		0.08	
Al^{vi}	1.58	5.00	1.82	5.00	1.42	5.00	1.66	5.00
Ti	0.01		0.00		0.01		0.00	
Mg	1.45		1.43		1.80		1.85	
Fe^{2+}	1.96		1.75		1.77		1.49	
Fe^{2+}	0.15	2.00	0.06	2.00	0.21	2.00	0.16	2.00
Mn	0.03		0.02		0.02		0.02	
Ca	0.12		0.06		0.11		0.04	
Na	1.70		1.86		1.66		1.78	
Na	0.23	0.23	0.18	0.18	0.36	0.36	0.24	0.24
K	0.00		0.00		0.00		0.00	

* Total iron as FeO.

Quartz and albite

Both minerals occur as clear, nonstrained, polygonal anhedra. Albite ($An_{1.0}$ to $An_{1.3}$ determined by microprobe analysis) is mostly untwinned.

White mica

Paragonite (d_{006} 3.216 Å, K_2O 0.70%) is the only mica present in J–1. In J–2, paragonite (d_{006} 3.210 Å, K_2O 0.35%) coexists with phengitic muscovite (d_{006} 3.325 Å). The two micas occur in subhedral, slightly bent flakes that are optically indistinguishable from one another.

Glaucophane

Strongly pleochroic (X very pale yellow, Y medium lavender, Z medium blue; $X < Y = Z$) sodic amphibole, chiefly present in subhedral to euhedral prisms, is the most prominent mineral. The amphibole is glaucophane (Table 2), because charge-balance calculations indicate a low content of ferric iron; the relatively high Al^{vi} content in each formula unit suggests $Fe^{3+}/(Fe^{3+} + Al^{vi})$ ratios below those found in crossite. Correspondingly, $Mg/(Mg + Fe^*)$ ratios are artificially low, because all iron was calculated as Fe^{2+}. The glaucophanes are zoned, with rims consistently characterized by enrichment in Al_2O_3 and higher $Mg/(Mg + Fe^*)$ ratios relative to cores. This zoning is visible optically because of the relatively stronger absorption of amphibole cores. The cores of glaucophane in J–1 may be ferroglaucophane (Table 2).

Garnet

Subhedral to euhedral small porphyroblasts of almandine garnet, averaging 0.75 mm in diameter, constitute 1% of sample J–1. The porphyroblasts are uniformly speckled with inclusions (chiefly quartz, glaucophane, calcite and sphene) that in places define planes that lie at low angles to the foliation of the schist. The foliation is not deflected by the porphyroblasts. Relative to the cores, the rims of the garnets are strongly enriched in almandine, weakly enriched in pyrope and depleted in spessartine (Table 3). The zoning follows the general pattern observed by Dudley (1969) in garnets of glaucophane schists from a variety of localities. The rims of the Jambaló garnets contain about twice as much spessartine as those reported by Dudley, a feature that probably reflects a difference in the bulk composition of the schist from Jambaló.

TABLE 3. ELECTRON-MICROPROBE ANALYSES OF A GARNET FROM GLAUCOPHANE SCHIST AT JAMBALÓ, COLOMBIA

	J-1 (core)		J-1 (rim)	
SiO_2	36.97		36.33	
Al_2O_3	20.71		20.96	
FeO*	17.03		22.73	
MnO	14.81		9.09	
MgO	0.46		0.63	
CaO	8.94		9.18	
TOTAL	98.92		98.92	
Number of ions on the basis of 12 (O):				
Si	3.01	3.01	2.96	3.00
Al^{iv}	0.00		0.04	
Al^{vi}	1.99	2.00	1.98	2.00
Fe^{3+}	0.01		0.02	
Fe^{2+}	1.14	3.00	1.53	3.04
Mn	1.02		0.63	
Mg	0.06		0.08	
Ca	0.78		0.80	
alm	38.0		50.3	
spess	34.0		20.7	
pyr	2.0		2.6	
gross	25.7		25.7	
and	0.3		0.7	

* Total iron as FeO; Fe^{3+}/Fe^{2+} chosen to satisfy stoichiometry, with two trivalent ions in sixfold coordination per formula unit.

Epidote

Subhedral, strongly birefringent, colorless to faintly chartreuse prisms of epidote, commonly about 0.1 mm in length, constitute 2.1% of sample J–2. The epidote is poor in iron. A partial microprobe analysis gave Fe*/(Fe* + Al) = 0.18.

Chlorite

The chlorite is pale and pleochroic (straw yellow to light grey-green), and forms robust flakes in both samples J–1 and J–2. However, the other optical properties are dissimilar. Chlorite that coexists with garnet in J–1 is length-slow, shows no birefringence, and has a deep blue anomalous interference color. Chlorite in garnet-free J–2 is length-fast and has a golden yellow interference color, with $2V\gamma \simeq 0°$. Chlorite in J–1 is considerably more iron-rich [Mg/(Mg + Fe*) = 0.47] than that in J–2 [Mg/(Mg + Fe*) = 0.59]. This difference reflects the dissimilar bulk composition of the two rocks.

Glaucophane Schists at Jambaló and in the Ouégoa District, New Caledonia

The Jambaló Glaucophane Schist is strikingly similar to glaucophane schist from the Ouégoa district of New Caledonia (Black 1977). This offers a useful comparison, because the phase petrology and isotope geochemistry of the unusual rocks from the Ouégoa district have been described in great detail (Black 1973a, b, 1974, 1975).

Mineral assemblages of the Jambaló Glaucophane Schist are duplicated in metasedimentary rocks from the lower epidote zone at Ouégoa (Black 1977, Fig. 2). Also, like the rocks at Ouégoa, samples from Jambaló lack the critical minerals lawsonite, spessartine, jadeite, hornblende, actinolite, aragonite and rutile.

The compositions of minerals are similar. Jambaló paragonite has a potassium content (0.70% K_2O) and a d_{006} value (3.210–3.216 Å) comparable to that of analyzed paragonite from Ouégoa (1.5% K_2O, d_{006} 3.209 Å; Black 1975, Table 1). The d_{006} value (3.325 Å) of phengitic muscovite from Jambaló is slightly greater than the limit of d_{006} (3.302–3.323 Å) of phengites from the Ouégoa schist (Black 1975). Glaucophane rims from Jambaló are comparable to sodic amphiboles from metasedimentary rocks in the epidote (rather than the lawsonite) zone at Ouégoa in terms of a plot of Na/(Na + Ca) *versus* Mg/(Mg + Fe*) (Black 1973b, Fig. 1). Garnet from schist at Jambaló shares the composition and pattern of zoning of metasedimentary garnets in the epidote and lawsonite–epidote transitional metamorphic zones of the Ouégoa district (Black 1973a, Fig. 3). Epidote from Jambaló with Fe*/(Fe* + Al) = 0.18 is similar to Ouégoa metasedimentary epidotes, which have (Fe* + Mn + Mg)/(Fe* + Mn +Mg + Al) ratios that cluster around 0.16 (Black 1977, Fig. 5).

Conditions of Metamorphism

The presence of glaucophane in the schist at Jambaló points to metamorphism at relatively high pressure, as part of a high-P, low-T facies series. As the samples from Jambaló are taken from outcrops in the western side of the unit, the conditions of metamorphism here adduced apply only to that portion of the glaucophane schist. The possibility of a change in metamorphic conditions eastward (across strike and structurally downward) remains unstudied.

In J–1, a metamorphic temperature of 350–400°C is given by the partitioning of Mg/(Mg + Fe + Mn) between rims of coexisting garnet and glaucophane, using the Perchuk diagram reproduced in Dóbretsov *et al.* (1975, Fig. 23). This corresponds well with an estimate of 385°C obtained from Fe–Mg partitioning between rims of the same two minerals, using the experimental–empirical geothermometer of Church (1978). In close agreement with these temperatures, the distribution of oxygen isotopes between phases in metasedimentary rocks led Black (1974) to conclude that the metamorphic temperature of the lowest-grade part of the lawsonite-free epidote zone in the Ouégoa district was 400°C.

A knowledge of the temperature of metamorphism allows limits to be placed on the pressure that prevailed. The absence of lawsonite shows that metamorphism took place at a lower pressure [$P_{total} = P(H_2O)$] than that of the stability field of lawsonite, which at 400°C is about 6.5 kbar (Nitsch 1972, Fig. 5). At the same temperature, the minimum pressures at which aragonite and jadeite are stable are 9 and 12 kbar, respectively (Johannes & Puhan 1971, Fig. 5; Newton & Smith 1967, Fig. 6), which accounts for the absence of these minerals at Jambaló. The minimum pressure possible during metamorphism would be the maximum pressure of the greenschist facies, in which case glaucophane would have been replaced by the assemblage chlorite + albite ± actinolite. This is a divariant reaction that has not been determined experimentally. The minimum pressure for the stability of natural, Fe-poor glaucophane, however, has been studied in the laboratory by Maresch (1977). His curve passes through the points 4 kbar and 350°C, 6 kbar and 400°C, 8 kbar and 450°C.

Metamorphism took place in the presence of a fluid phase probably composed nearly exclusively of H_2O and CO_2, with $P_{total} \simeq P_f$. The composition of the fluid phase, buffered by local parageneses, must have varied from place to place. For example, chemographic analyses using Schreinemakers bundles led Black (1977) to conclude that at Ouégoa, the assemblage glaucophane + paragonite (without epidote) was favored by $P(H_2O) < P_{total}$, whereas the assemblage glaucophane + epidote was favored by $P(H_2O) \simeq P_{total}$. This conclusion is borne out qualitatively by the rocks at Jambaló. Sample J–1, which is epidote-free, contains glaucophane + paragonite + quartz + calcite. The assemblage paragonite–quartz–calcite is stable only under relatively high $P(CO)_2$ in a mixed-volatile fluid phase composed of $H_2O + CO_2$ (Chatterjee 1972). If P_f was broadly uniform from place to place during metamorphism, $P(H_2O)$ must have been lower in sample J–1 than in J–2, which bears no petrographic evidence of appreciable CO_2 having been present in the fluid phase. Of the two samples, J–2, with the assemblage glaucophane + epidote, was the "wetter" rock.

The universal presence of accessory pyrite in the schist at Jambaló shows that $f(O_2)/f(S_2)$ was relatively low during metamorphism. This is in keeping with the observation that ferroglaucophane rather than crossite constitutes the cores of sodic amphibole in J–1 (Black 1977).

In summary, the conditions of metamorphism of the Jambaló Glaucophane Schist are assumed to have been: T between 350 and 400°C and P_{total} in the range 5–7 kbar. A mixed-volatile fluid phase with locally variable H_2O/CO_2 ratios probably approximated P_{total}. Low $f(O_2)/f(S_2)$ prevailed.

Regional Significance of the Jambaló Glaucophane Schist

Until recently, the discontinuous belt of circum-Pacific high-pressure metamorphic rocks had not been recognized on the west coast of South America north of latitude 41° S (Dóbretsov *et al.* 1975, Fig. 26). This situation changed with the discovery of the glaucophane schist at Jambaló (Orrego *et al.* 1980a, this paper) and eclogite and associated high-pressure metamorphic rocks from the Raspas Formation of southwestern Ecuador (Feininger 1980). The two occurrences, although 800 km apart, are sufficiently similar to warrant speculation about a common origin.

The Jambaló Glaucophane Schist and the Raspas Formation are both located on the ancient, continental South American plate, within 50 km of its edge at the Romeral fault. Rocks northwest of the Romeral fault lie on relatively younger oceanic lithosphere, which may have been added by accretion and a seaward jump of the continental-border subduction zone during Cretaceous and Paleogene time (Feininger & Bristow 1980). The Colombian and Ecuadorian high-pressure rocks occur in fault-bounded bodies (the Raspas Formation is partly encased in serpentinized harzburgite) that were emplaced tectonically. Finally, rocks from the two widely separated localities both have Earliest Cretaceous K–Ar uplift ages: 125 ± 15 *Ma* at Jambaló (Orrego *et al.* 1980b) and 132 ± 5 *Ma* for the Raspas (Feininger 1980).

In my report on the Ecuadorian high-pressure rocks, I suggested that the Raspas Formation was metamorphosed in a subduction zone beneath the South American continental border; the formation was emplaced diapirically in rocks of relatively high density, buoyed upward by serpentinized harzburgite, beginning when subduction ceased. A synchronous radiometric date on the youngest lava of the coeval volcanic arc in eastern Ecuador was cited in support of this proposed mechanism. A similar history could apply to the Jambaló Glaucophane Schist, as most of the required elements are present. The schist occurs in a fault-bounded block, in part emplaced against dense metabasites. Serpentinite, although not occurring in large masses, is found as sheared bodies along the fault between the glaucophane schist and the San Antonio Amphibolite. Roots of a possibly coeval arc constitute immense granitic batholiths of Jurassic and Triassic age, between 70 and 140 km southeast of Jambaló (INGEOMINAS 1976).

If the Jambaló Glaucophane Schist and the Raspas Formation share an analogous and synchronous origin, as I suggest they may, one can draw three conclusions with important regional significance: (1) A major episode of subduction in northwestern South America terminated abruptly in Early Cretaceous time. (2) Outcrops of high-pressure metamorphic rocks of Early Cretaceous age may occur elsewhere just east of the Romeral fault in a 50-km-wide belt on the geologically complex northwestern corner of the South American continent. These rocks may extend from the Raspas Formation in the south to a point 170 km north of Medellín (and 550 km north of Jambaló), where the crystalline Central Cordillera plunges beneath Tertiary and Quaternary sedimentary rocks in northern Colombia (Fig. 1). (3) The Romeral fault marked the active boundary between the northwestern corner of the continental South American plate and an oceanic plate to the northwest, at least during the beginning of the Cretaceous Period.

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Photomicrographs of glaucophane schists from Jambaló. Plane light, field of view, 1.1 × 0.75 mm. A. Sample J-1. Euhedral garnet (left), calcite (right), glaucophane (grey with dark cores), albite and quartz (colorless), chlorite (boot-shaped grain, centre), paragonite (clear flakes), sphene (very dark), and pyrite (lower right corner). B. Sample J-2. Subhedral prismatic glaucophane, quartz and albite (colorless), paragonite and muscovite (bottom), chlorite (centre), epidote (small grains with high relief), sphene (wedge-shape grains with very high relief), and pyrite (upper left).