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10 th Annual Symposium on Caribbean Geology

Feb 20- 24, 1991

Department of Geology R.U.M.

Mayagüez, Puerto Rico

Tectonics and Mineral Deposits of the Caribbean

FIELD GUIDE

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Field trips
10 th Annual Symposium on Caribbean Geology

Department of Geology
University of Puerto Rico
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INTRODUCTION

In 1982 the Department of Geology decided to organize its first symposium on Caribbean geology. The department consisted in that time of only four faculty and we thought it would be a good idea to expose our students and ourselves to new and different ideas as presented by experts in various fields in geology. The dean of the Faculty of Arts and Sciences was willing to provide us with funds to invite first two and later more guest speakers. Around these guests we organized our symposia, which included conferences, field trips, and a lot of informal contact between faculty, guests, and students. In addition we found that the symposia began to attract other geologist and after a few years the symposia grew into well-attended annual meetings, and this year it will be the tenth consecutive time we are able to welcome visitors from off-and-on island to our "Annual Symposium on Caribbean Geology".

This year the purpose of the field trips is to illustrate mineral deposits present in an island-arc and give some sense of the geologic setting of these deposits. The field guide has evolved over the years and represents the work of most of the faculty.

Geology of Puerto Rico

Puerto Rico is the eastern-most island of the Greater Antilles and is a translational island-arc terrane with a geologic record of 140 million years.The island lies within the seismically active Caribbean-North American Plate boundary zone. The relative motion between the two plates is on the order of 2 cm per year and is mainly taken up by strongly oblique underthrusting and left-lateral faulting in the Puerto Rico trench (figure 1). A well defined southward dipping Benioff zone occurs under the eastern half of the island, but is missing under the west side (McCann and Sykes, 1984; Sykes and others, 1982; Schell and Tarr, 1978). Some plate motion and underthrusting also occurs south of Puerto Rico in the Muertos Trough (figure 1).

Puerto Rico and the Virgin Islands appear to be a separate tectonic block within the plate boundary zone. Puerto Rico is separated from Hispaniola on the west by a zone of active extension, which runs from the Mona canyon through the southwestern quarter of the island. On land extensional faulting has produced the distinctive ridge and valley topography and generally low elevations of southwestern Puerto Rico. Eastern Puerto Rico and the northern Virgin Islands are separated from St. Croix and the Lesser Antilles by another active zone of extension which formed the Whiting Basin (south of Puerto Rico, the Virgin Islands basin, and the Anegada Passage (figure 1).

Puerto Rico consists of volcanic, volcaniclastic, and sedimentary rocks of Late Jurassic to Early Tertiary age, which were intruded by felsic plutonic rocks during the Late Cretaceous and Early Tertiary, and are overlain by slightly tilted Oligocene and younger sedimentary rocks and sediments (figure 2) (Briggs and Akers, 1965).

Island-wide lithostratigraphic correlation within the basement rocks is difficult because individual units appear to have limited original lateral extent and the rocks have been subsequently strongly deformed and faulted. To overcome these correlation problems earlier workers divided the island into structural blocks (Cox and Briggs, 1973) or subprovinces (Barabas, 1977). Here the island is divided into three igneous provinces, the southwestern igneous province (SIP), the central igneous province (CIP), and the northeastern igneous province (NIP) based on differences in stratigraphy, lithology, petrology and geochemistry (figure 2).

Each igneous province contains a number of volcano-stratigraphic associations, that are defined as packets of volcanic and interstratified sedimentary rocks, where the age of the association is defined based on fossils in the sedimentary rocks. The boundaries of the volcano-stratigraphic association may be disconformities or unconformities (Schellekens, 1991).

Igneous Provinces

The Bermeja Complex, the oldest rocks of SIP, consists of serpentinite containing rafts of chert and metabasalt. The metabasalts can be subdivided into two groups: gneissic and massive amphibolites of possible ocean floor heritage, and low grade metavolcanic rocks and dikes of probable island-arc origin (Schellekens and others, 1990). Post-Bermeja Complex rocks include volcanic, volcaniclastic, and calcareous rocks, locally intruded by small intrusions of Late Cretaceous to Eocene age. The Eocene rocks, which outcrop in a zone extending from the northwest coast to the southcentral part of the island (figure 1) constitute the youngest rocks of the SIP and form the boundary with the CIP. Volcano-stratigraphic associations in the SIP are Late Jurassic to Early Cretaceous, Albian or older, Santonian?-Campanian, Maastrichtian, and Eocene. The Maastrichtian association is the least well constrained in time, and may overlap with the older and younger associations.

Structurally the S.I.P. is characterized by NW-trending regional folds which are tighter than the folds in the other two provinces (Mattson, 1974; Mattson and Schwartz, 1971). The Late Cretaceous rocks form packets of folded units between the linear serpentinite bodies of the Bermeja Complex (Mattson, 1960, 1974; Volckmann, 1984 abcd). East-west trending faults and ridges occur at the western end of the province, whereas northwest trending faults and ridges occur at the eastern end. The "Eocene Belt" of Late

Cretaceous to Eocene volcanic and sedimentary rocks are cut by numerous NW trending left-lateral strike-slip faults (Krushensky, 1978). The Late Cretaceous and Early Tertiary rocks are folded about shallow NW-SE axes and show evidence of gravity gliding (Mattson and Glover, 1973) and thrust faulting.

The CIP is characterized by extensive exposures of Late Cretaceous plutonic rocks, that have intruded a sequence of Cretaceous rocks (Briggs and Akers, 1965; Cox and others, 1977). In the CIP three volcano-stratigraphic associations have been recognized: Albian and older, Albian to Santonian, and Campanian to Maastrichtian.

The oldest formations ("pre-Robles" of Briggs and Gelabert, 1962) consist predominantly of volcanic flows and breccias, volcaniclastic sedimentary rocks and minor limestones. Overlying the pre-Robles formations are a series of interfingering volcanic flow rocks, volcaniclastic rocks and minor limestones of Albian to probably Santonian age (Robles-Río Orocovis sequence) (Briggs,1971).

The Robles - Río Orocovis sequence is in turn overlain by a volcano-stratigraphic association of approximately Santonian to Maastrichtian age, which includes both marine and subaerial deposited formations. Briggs (1971) noted that the rocks of this association have a lower metamorphic grade (zeolite) than the older Robles - Río Orocovis sequence (greenschist). Structurally the CIP is characterized by large wavelength folds and fault blocks bounded by north, west, and northwest trending faults (Mattson, 1974).

The NIP contains a sequence of stratified volcanic and sedimentary rocks which range in age from Early Cretaceous to Early Tertiary. This sequence was intruded by a number of small plutons in the Late Cretaceous and Eocene (Cox and others, 1977). The NIP is distinguished from the other provinces by the occurrence of a swarm of mostly EW-striking diabase dikes of Early Tertiary age (eg. Seiders, 1971). The province is traversed by numerous NW trending faults.

The volcanic rocks of NIP have been divided into four volcano-stratigraphic associations: Albian and older, Albian to Cenomanian, Cenomanian to Campanian, and Maastrichtian to Eocene (Briggs, 1973, M'Gonigle, 1978, 1979). The oldest association consists predominantly of basic to felsic flow rocks with associated volcaniclastic sedimentary rocks and is found in the southern part of the province (M'Gonigle, 1978, 1979). Albian to Cenomanian flows, in contrast, crop out in the north suggesting that volcanic activity shifted northward. These older rocks are unconformably overlain by rocks ranging in age from Cenomanian to Campanian. The final association includes volcaniclastic rocks and limestones, associated with minor flow rocks of Maastrichtian to Eocene age which disconformably overlies the older rocks.

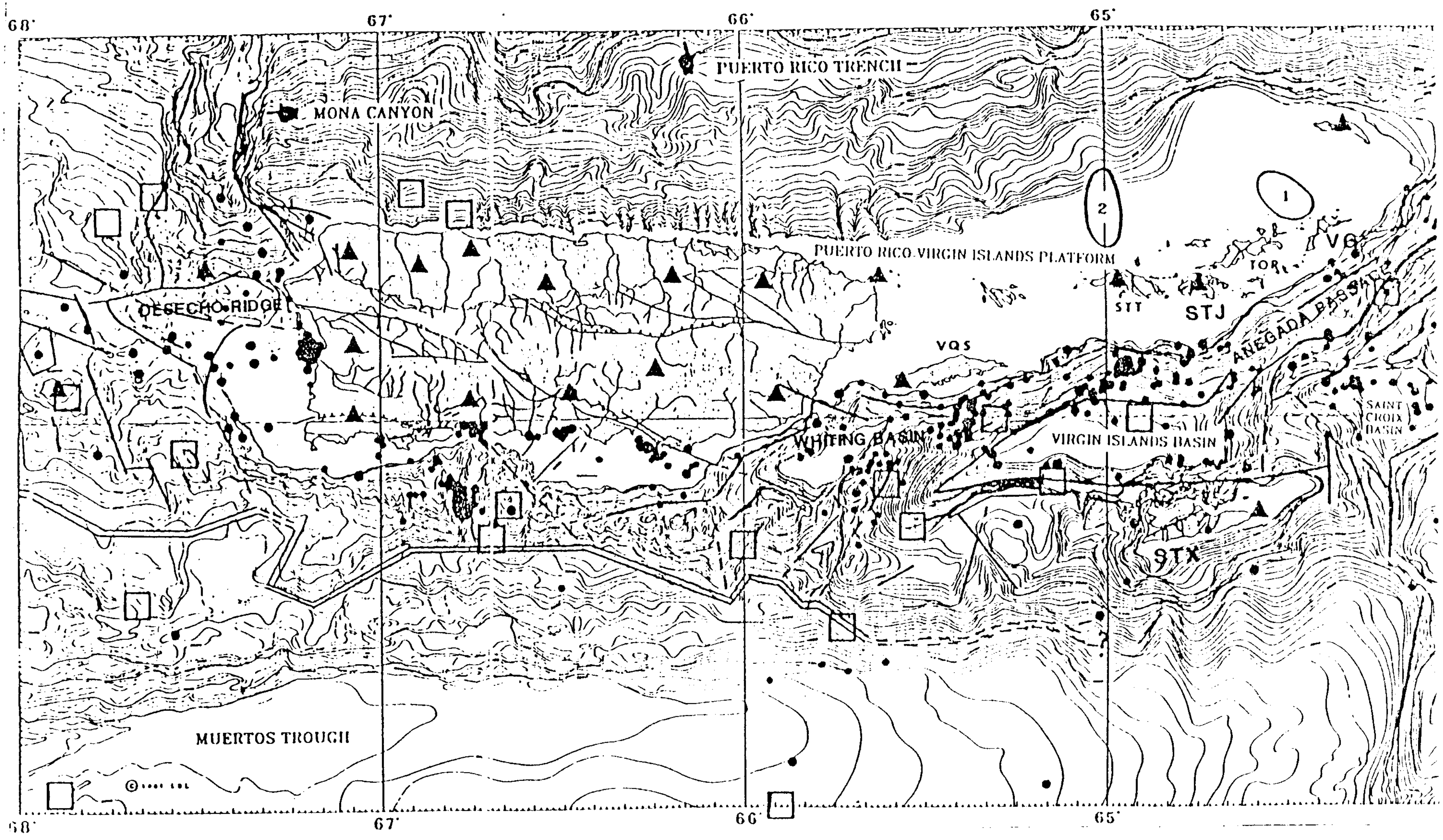


Figure 1: Location Map of Puerto Rico and the Virgin Islands.
STX = St. Croix, STT = St. Thomas, STJ = St. John, TOR = Tortola,
VG = Virgin Gorda. Locations of microseismic stations (triangles) and of offshore microearthquakes (circles) and faults (solid lines) are also shown.

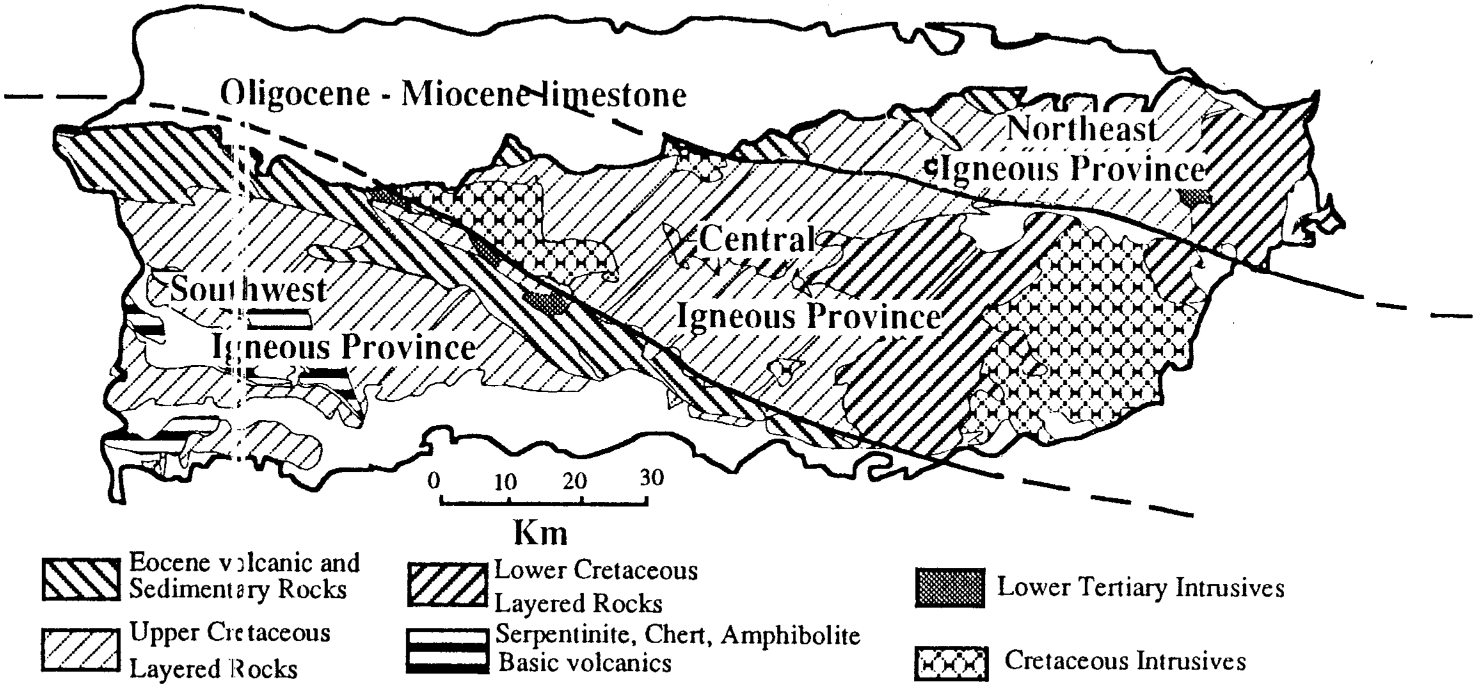


Fig. 2. Simplified geologic map of Puerto Rico.

Thursday February 21, 1991

<u>Porphyry Copper Deposits & Magnetite Skarn Deposit</u>

Geology

The Late Cretaceous to Lower Tertiary volcanogenic rocks that occur south of the Late Cretaceous Utuado Batholith, are intruded by Lower Tertiary plutons, some of which may be mineralized (figure 3) (Cox, 1972; Cox and others, 1973, 1975; Barabas, 1977). About 25 km north of Ponce (figure 4) the Cala Abajo and Piedra Hueca ore bodies and the Sapo Alegre prospect occur within 0.5 km of each other along the Río Viví (figure 5). The three mineralized quartz diorite porphyry stocks have, despite their close spatial association, considerably different characteristics. The Piedra Hueca porphyry is oval shaped (450 x 250 m) and strongly silicified. It contains chalcopyrite, pyrite, magnetite, K-feldspar, hydrothermal biotite, chlorite and leonhardite. The deposit is only weakly fractured and leaching and secondary enrichment are negligible (Bradley, 1971). The Cala Abajo deposit is tubular-shaped (1,200 x 200 m), highly fractured and cut by a major fault. The intrusion has been recrystallized, albitized, sericitized, chloritized and pyritized. Magnetite is abundant. K-feldspar is absent. Hydrothermal biotite is also absent and was probably completely converted to chlorite . The deposit is intensely leached, with supergene argillization and secondary chalcocite deposition (Bradley, 1971). The Sapo Alegre prospect is an elongate (500 x 100 m) porphyry copper-molybdenite occurrence. The quartz diorite porphyry is hydrothermally altered and contains pyrite, chalcopyrite, and molybdenite. Hydrothermal alteration includes: Kaoline-pyrite, quartz-sericite-pyrite, sericite-albite-chlorite, and biotite-chlorite (figure 6). Biotite-chlorite alteration coincides closely with the copper and molybdenite rich zone near the contact (Cox and others, 1975).

History of the porphyry copper deposits

Kennecott Copper Corporation recognized the possibility of porphyry copper mineralization in Puerto Rico in 1956. After a reconnaissance under direction of George Ordoñez an exploration concession was obtained in west - central Puerto Rico in 1958. Surface mapping and stream-sediment geochemistry was carried out under direction of Johan Brinck and drilling was started in July 1959. The first deposit drilled was Laundry Creek, followed later by the deposits at Copper Creek, Helecho, and Tanamá. By 1965, 155 holes were drilled with a total length of 44,000 m (Cox, 1985). Reserves are estimated at about 139 million tons @ 0.64 % copper (Lutjen, 1971).

The Río Viví mineralized area was discovered by W.R. Bergey in 1957, when he was looking for the source of copper and molybdenum anomalies in the stream sediments of the Río Viví (Bergey, 1966). He discovered mineralized porphyry in the walls of the canyon of this river (figures 5 and 6). In 1960 the Ponce Mining Company, a subsidiary of the American Metal Climax Inc. acquired the concession and carried out a geochemical soil survey. This resulted in a drilling program. This exploration program showed that this deposit (Sapo Alegre) was not economic (Cox and others, 1975). The nearby

Piedra Hueca deposit and the northwestern part of the Cala Abajo deposit were drilled early in the exploration program, but the supergene-enriched zone of Cala Abajo was not penetrated until 1964 when, based on petrologic identification and geologic mapping, it was decided to drill also the Cala Abajo deposit (R.A.Bradley pers. comm., 1972 in Learned and Boissen, 1973) . The Piedra Hueca and Cala Abajo deposits have now been extensively drilled and contain together about 104 million tons @ 0.82 % Cu (Lutjen, 1971).

In 1965 Kennecott Copper Corp. and American Metal Climax Corp. (Amex) through their subsidiaries Cobre Caribe S.A. and Ponce Mining Co., Inc. applied without success for a mining lease (Lutjen, 1971).

Skarn Deposits in Puerto Rico

Two subclasses of skarn deposits (Einaudi and others, 1981) are present in Puerto Rico. The most abundant are the iron skarns, these occur in the contact aureole surrounding the San Lorenzo Batholith (Broedel, 1961; M'Gonigle, 1979, Cox and Briggs, 1973) and in two locations north of the town of Ponce (Krushensky and Monroe, 1975). Two of the magnetite deposits north of the San Lorenzo Batholith (Keystone Iron Mine, Island Queen Mine) were mined in the early 1950' s (Knoerr, 1952). The second subclass present is the Cu(-Au) skarn, of which only one deposit is known on the island, La Mina, south of the Río Blanco stock in the El Yunque quadrangle (Seiders, 1971) (figure 7).

Magnetite skarn of Barrio Tibes, north of Ponce

Eocene hornblende-augite diorite and quartz diorite intruded and contact-metamorphosed the interbedded Lago Garzas and Yauco Formation (Maastrichtian and Campanian?) north of Ponce (figure 8). The rocks were hornfelsed into light-greenish or brownish-gray, fine to coarse crystalline marble and bright green pelitic or arenaceous calc-silicate hornfels. West of the intrusion the rock is a coarse- to fine-crystalline marble with abundant diopsidic augite, to the north occur irregular masses of hydrogrossularite-grossularite and vesuvianite and sparse pods of massive coarse crystalline magnetite with subordinate epidote and quartz (Krushensky and Monroe, 1978).

In 1923 an attempt was made to mine the magnetite that cropped out in the area along the Río Portugues. Several tunnels and pits were made, but he project was quickly abandoned. In the late 1930's the area was further explored, but the deposit appeared not to be economical (P.R. Bur. Mines, 1941)

Itinerary (figure 4)

Departure from the Department of Geology, R.U.M. From Mayagüez south on route 2 , towards Ponce. Between km 160 -176 the highway follows along the edge of the Guanajibo serpentinite. Most of the outcrops along the road are conglomerates mapped as part of the Yauco Formation (Curet, 1984). Serpentinite crops out along the road near San German. Limestone bluffs on the ridge to the south are composed of Cotui Limestone (Campanian - Maastrichtian).

At km 183.1 the road crosses the Río Guanajibo. Serpentinite crops out in a quarry along the river.

Between km 183.5 and 185.3 we pass through a fault zone containing Late Cretaceous to early Tertiary volcanics, volcaniclastics and limestones.

Between km 183.5 and 195, route 2 follows along the north edge of the Lajas Valley. South of the fault zone, early Tertiary marine sediments of the Jicara Formation crop out in the valley. A melange of limestones and volcaniclastic rocks are exposed in borrow cuts on the north side of the highway. The prominent ridges to the south are composed of Late Cretaceous limestone (Parguera Limestone). Ridges straight ahead to the east are composed of the Oligocene Juana Diaz Formation. Juana Diaz conglomerates crop out on both sides of the highway between the Guanica and Yauco exits (km 193-198).

On the left hand side of the road at the ~~Guanica~~ Guanilla exit, in roadcuts of route 132 and route 2, we can see a Middle Oligocene reef. The outcrop exposes the last of four cycles of reef development in the Oligocene. The section starts with fore-reef Lepidocyclina coquinite and shows a shallowing cycle of substrate stabilization and reef development . To the east the reef rocks grade into, and are unconformably overlain by island slope deposits of late Oligocene and Miocene age. Oligocene slope deposits are dominantly clay-rich and the Miocene deposits are marly. The Ponce Limestone (Middle Miocene - Pliocene) unconformably overlies the slope and reef rocks (Frost and others, 1982).

At km 217 (Peñon de Ponce) the Upper Miocene Ponce Limestone is exposed. The section is composed of four units. Unit 1 is composed of large coral heads in a muddy fossiliferous matrix; Unit 2 is composed of columnar and finger coral accumulations of a single species of Porites; Unit 3 is a laminated mud layer which is burrowed but lacks macrofossils; Unit 4 is like unit 1 but lacks coral heads. A large foraminifera Miosorites is present throughout this unit. The four units represent changes in the environment of deposition.

In Ponce turn left ~~at "Chicken and Pizza Pala~~ce" on route 2 ramal, and left again in Route 585 pass behind the stadium towards route 10. Follow route 10 north towards Adjuntas. At the outskirts of Ponce we pass the Ponce Cement factory and quarries. Cement is produced from the Middle Tertiary limestones. Route 10 climbs the south side of the Cordillera Central and winds through outcrops of Late Cretaceous volcanic and volcaniclastic rocks and limestones of the Yauco and Lago Garzas Formations,that are intruded by Eocene dacites and diorites (Krushensky and Monroe, 1978). After about 26 km we turn right (east) on route 143 (Ruta Panoramica). Immediately we cross the Cerrillos Fault into rocks of Early Tertiary age (Mattson, 1968a).

Continue east on route 143 for about 7 km, until route 140. Turn left, (north) towards Jayuya. After about 2 km turn left on route 605. This road follows the Río Viví. We pass the Hacienda El Progreso at the left hand side of the road. About 1 km past Hacienda La Esperanza is a white chapel on the right side of the road opposite an outcrop of the Sapo Alegre copper-molybdenum porphyry prospect.

At 605 km 8.1

Stop 1: Sapo Alegre Porphyry Copper Molybdenum prospect.

The Sapo Alegre deposit is well exposed in the bed of the Río Viví. The river runs here through a canyon and is not easy to visit (figure 6). Fortunately the deposit is also partly exposed in a roadcut. ~~Hydrothermally altered porphyry can be seen cut by partly oxidized pyrite veins~~.

to km 9.5

Return on route 605 south for about 1 km. Here an unsurfaced road leads to a pass between the two hills. A foot path starting near a house under construction leads through a coffee and orange plantation to the Piedra Hueca deposit.

Stop 2: Piedra Hueca Porphyry Copper deposit:

In the side of the path outcrops of hydrothermally altered porphyry with malachite occur. Return to unsurfaced road.

Continue on unsurfaced road until a fence is reached at the left side. Follow jeep trail until fork in road, continue on foot.

Stop 3: Cala Abajo Porphyry Copper deposit:

Here occurs the extremely altered top of the Cala Abajo deposit.

Return to route 605, continue this road southward. Follow route 605 and route 140 south. Turn right (west) on route 143, follow the road for about 2 km, turn left (south) on route 503. This road follows the Río Portugues.

Stop 4: Tibes magnetite skarn deposit.

In Barrio Tibes route 503 between km-markers 9.6 and 9.4. The road crosses a magnetite skarn. Excellent outcrop can be found in the river bed. White marble with irregular magnetite concentrations. Veins with quartz and epidote. Euhedral pyrite. A dike cutting the marble shows contact skarns where apparently garnet formed at the contact between the two incompatible rock types.

Continue on route 503 through Ponce to route 2. Route 2 leads west back to Mayagüez.

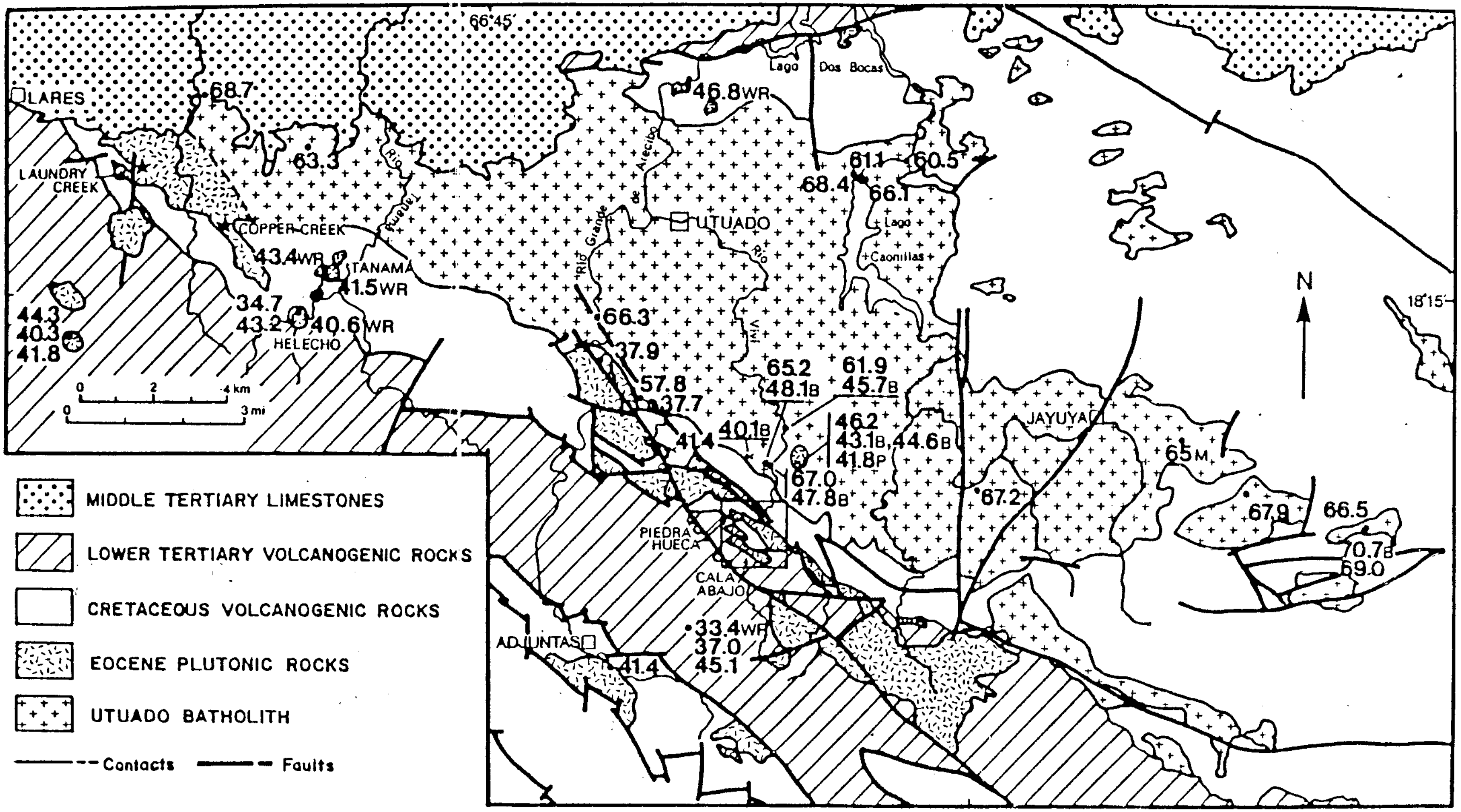


Fig. 3. Simplified geologic map of the Utuado batholith region showing locations of copper deposits and prospects and locations and ages of dated samples (Barabas, 1982, Cox and others, 1977, Mattson, 1968b). All determinations on hornblende except those on biotite (B), plagioclase (P), and whole rock (WR). Box is outline of map in figure 5. (Barabas, 1982)

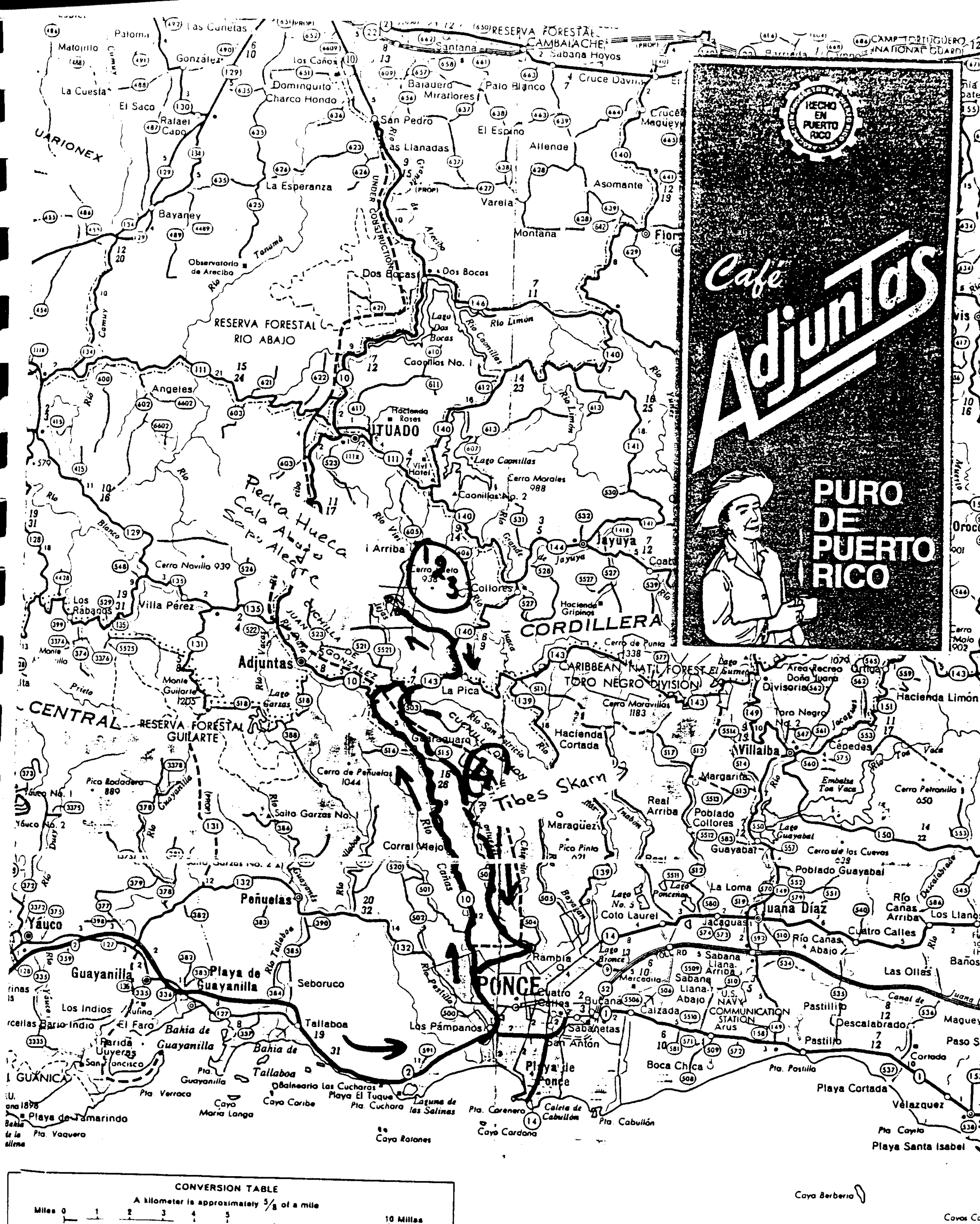


Fig.4. Road map with itinerary and locations of porphyry copper deposits and magnetite skarn.

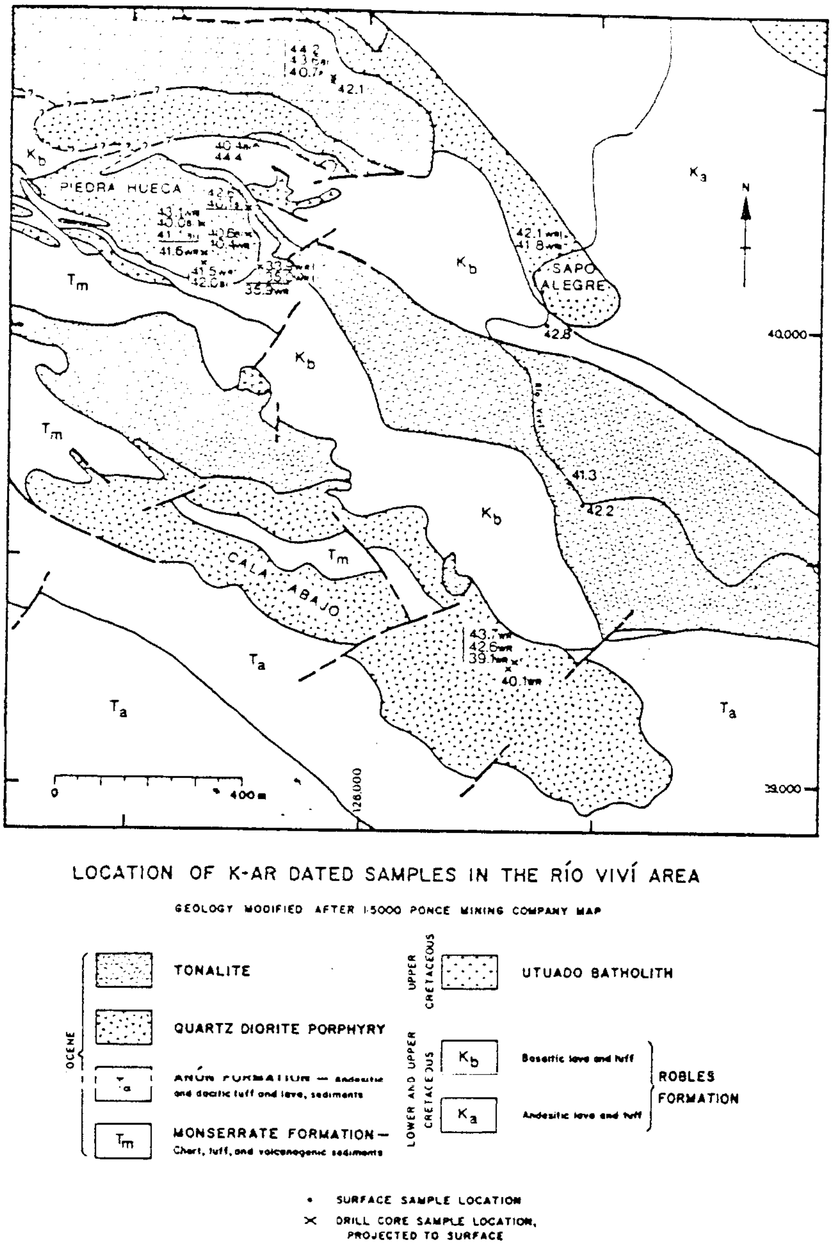


Fig.5 Geologic map of the Río Viví mineralized area, showing locations of the Sapo Alegre,Piedra Hueca, and Calo Abajo deposits, and ages of the intrusives (Barabas, 1982).

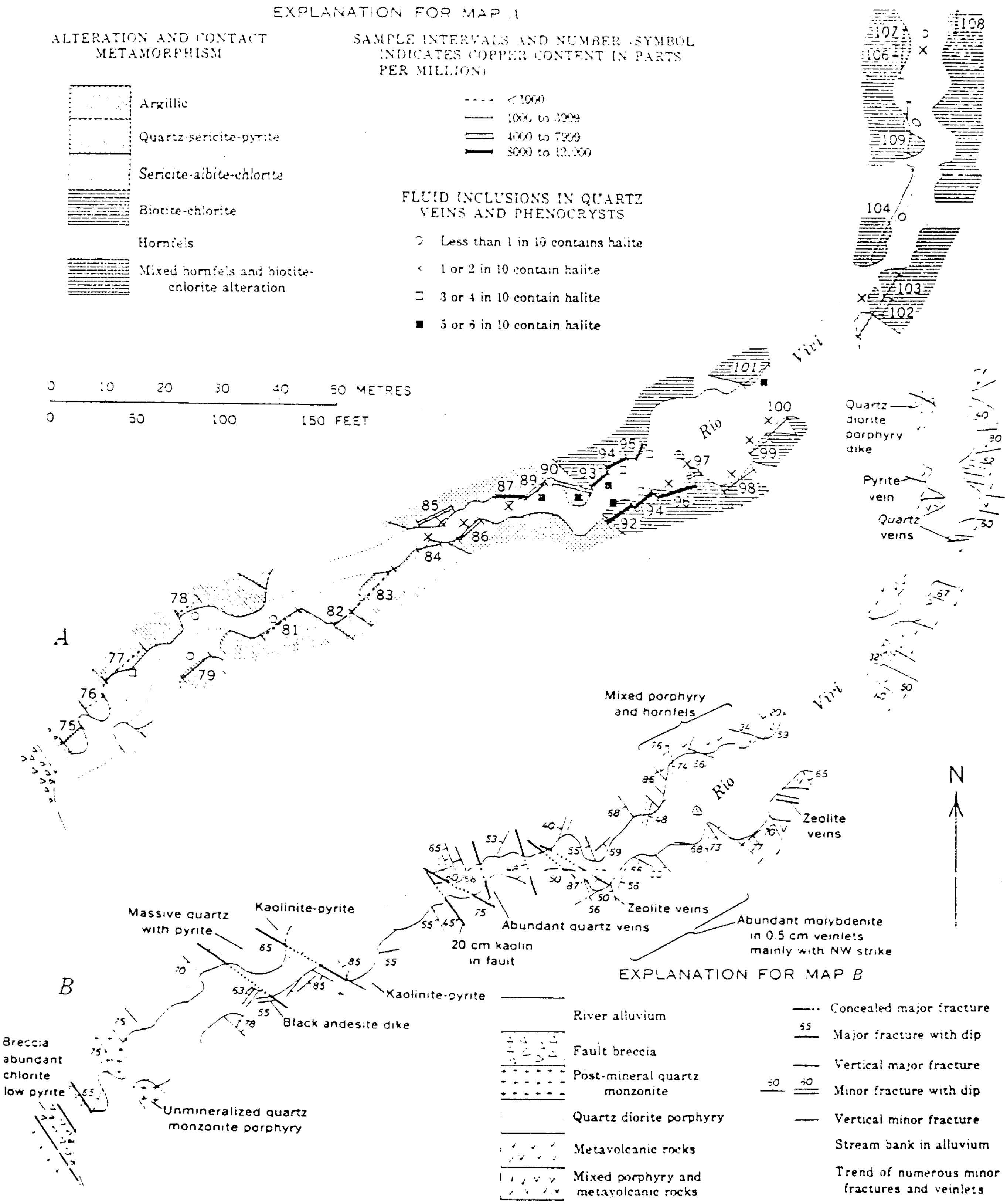


Fig.6 Maps of Sapo Alegre prospect showing geology, hydrothermal alteration, fluid-inclusion petrography, sample intervals, and copper content Cox and others, 1975).

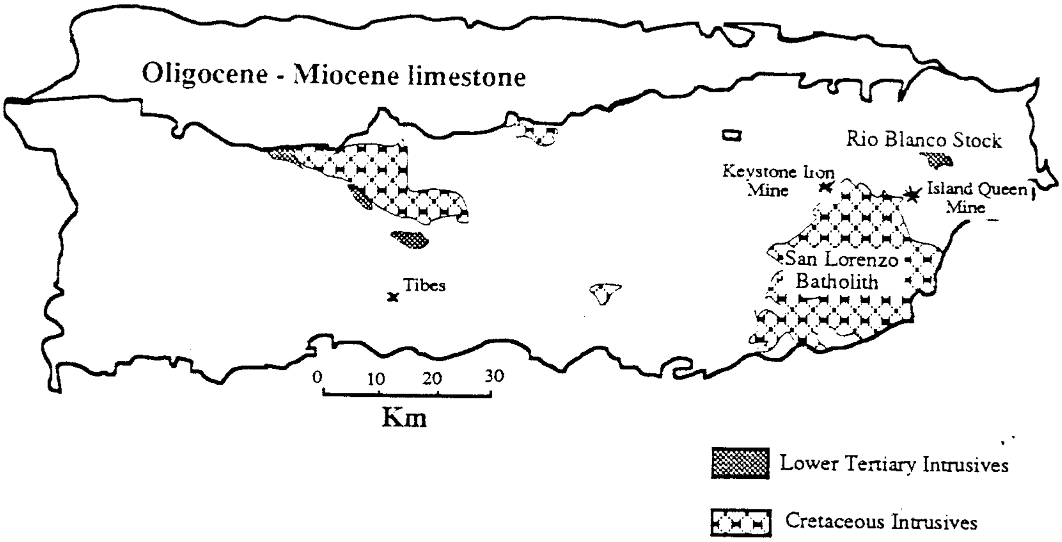
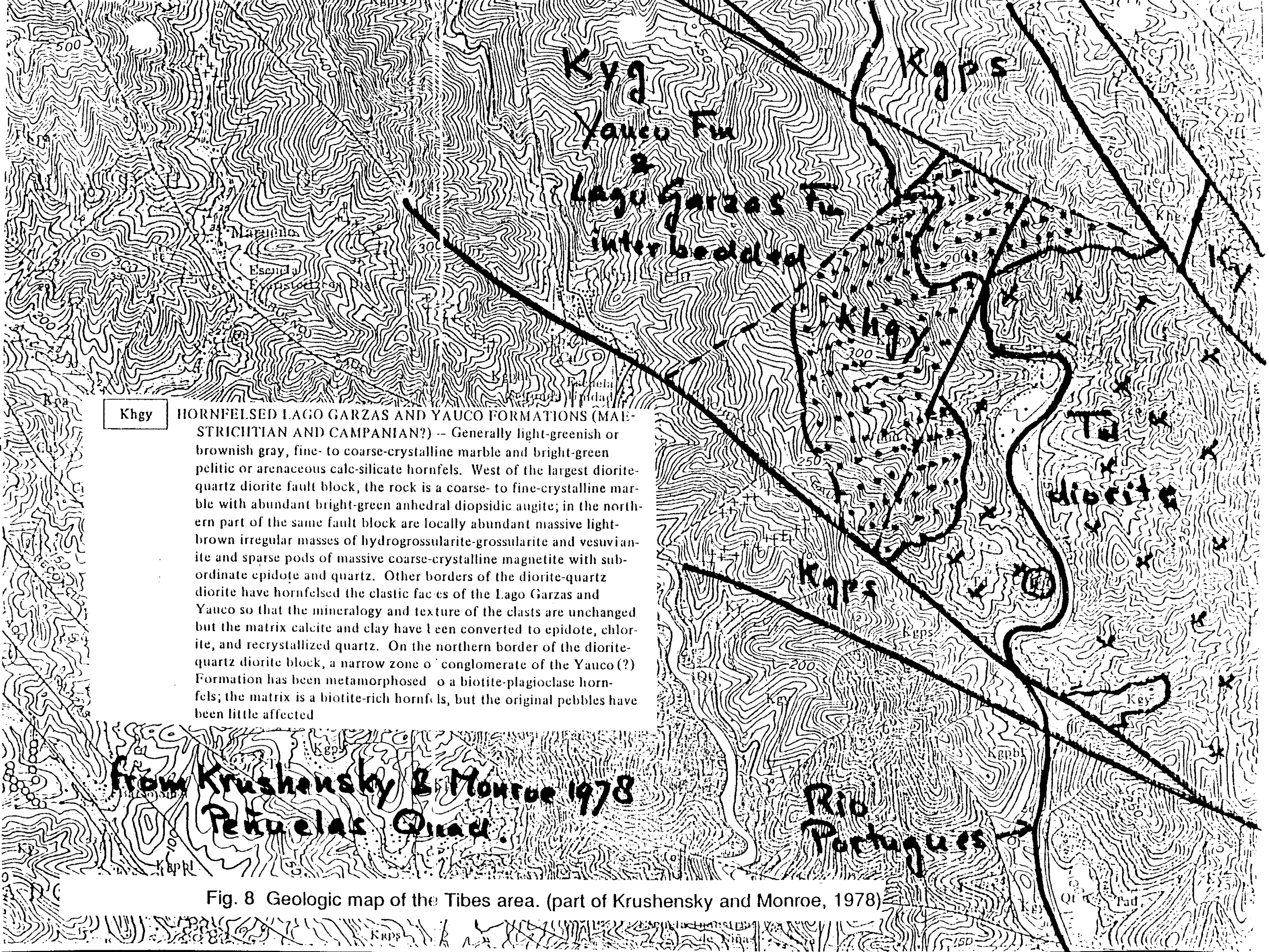


Fig. 7 Location map of the Late Cretaceous and Eocene plutonic rocks and the location of the Tibes skarn deposit, and the Keystone Iron and Island Queen Mines.



Khgy HORNFELSED LAGO GARZAS AND YAUCO FORMATIONS (MAESTRICHTIAN AND CAMPANIAN?) -- Generally light-greenish or brownish gray, fine- to coarse-crystalline marble and bright-green pelitic or arenaceous calc-silicate hornfels. West of the largest diorite-quartz diorite fault block, the rock is a coarse- to fine-crystalline marble with abundant bright-green anhedral diopsidic augite; in the northern part of the same fault block are locally abundant massive light-brown irregular masses of hydrogrossularite-grossularite and vesuvianite and sparse pods of massive coarse-crystalline magnetite with subordinate epidote and quartz. Other borders of the diorite-quartz diorite have hornfelsed the clastic fac es of the Lago Garzas and Yauco so that the mineralogy and texture of the clasts are unchanged but the matrix calcite and clay have l een converted to epidote, chlorite, and recrystallized quartz. On the northern border of the diorite-quartz diorite block, a narrow zone o ' conglomerate of the Yauco (?) Formation has been metamorphosed o a biotite-plagioclase hornfels; the matrix is a biotite-rich hornf ls, but the original pebbles have been little affected

Fig. 8 Geologic map of the Tibes area. (part of Krushensky and Monroe, 1978)

Saturday February 23, 1991

<u>Cerro Avispa & Autopista de las Americas</u>

Introduction

The purpose of this field trip is to show the Cerro Avispa deposit and the to give an impression of some of the Early and Late Cretaceous volcanic rocks of the Central Igneous Province.

Geology

The Central Igneous Province is here defined as those rocks that occur east of the Eocene Belt and south of the San Francisco - Cerro Mula Fault. This province is characterized by stratified rocks ranging in age from Early Cretaceous to Eocene, and flow rocks of Early Cretaceous to Maastrichtian, which were intruded by a number of felsic plutons in the Late Cretaceous, such as the San Lorenzo Batholith , and the Utuado, Ciales, and Morovis Plutons (M'Gonigle, 1978, 1979; Rogers, 1977; Rogers and others, 1979; Broedel, 1961; Cox and others, 1977) (figure 2).

Early Cretaceous rocks occur adjacent to the San Lorenzo Batholith, and in the Barranquitas and Orocovis quadrangles. The formations west of the San Lorenzo Batholith were differentiated by letters, A, B, C, etc. by the initial workers in order to assign better type sections establish better correlations as mapping progressed (Berryhill and Glover, 1960, Pease and Briggs, 1961). Formations of this age are generally called the "pre-Robles" formation, because they were deposited before the well-defined Robles Formation (Berryhill and Glover, 1960; Briggs and Gelabert, 1962).

Overlying the pre-Robles formations is the Robles-Río Orocovis sequence (Briggs,1971). These rocks form a volcano-stratigraphic association (Schellekens, 1991) that ranges in age from Early Cretaceous (Albian) to Late Cretaceous (probably Santonian) (Briggs, 1967, p.A23; 1969).The metamorphic grade of this sequence is generally in the greenschist facies (Briggs, 1971).

The Robles - Río Orocovis sequence is overlain by a number of formations of Santonian to Maastrichtian age, ranging from submarine to subaerial, that interfinger and grade into each other laterally and vertically. These formations are named the Cariblanco - Pozas volcano-stratigraphic association for the two most important formations. Briggs (1971) noted that the rocks of this sequence have a lower metamorphic grade (zeolite) than the older Robles - Río Orocovis sequence.

Cerro Avispa Gold-Silver-Copper Prospect

Geology

The Cerro Avispa deposit occurs at the northwestern end of a large area of hydrothermal alteration about 8 km. long and 0.5 to 2 km. wide running WNW - ESE, southeast of the town of Cayey. The alteration is superimposed on a sequence of WNW dipping volcanic flows and flow breccia ranging in composition from basaltic andesite to andesite. To the NE and the SW the flows are interstratified with volcanic siltstones and sandstones (Berryhill and Glover, 1960). These lithologies suggest an association of proximal volcanic rocks flanked by more distal volcaniclastic rocks (figure 9). The volcanics often contain abundant pyrite. Along a NW striking deformation zone the pyrite has broken down, bleaching the rocks and leaving pyrite casts and Fe-hyroxides on fracture planes (Schellekens, 1987). Mineralization occurs at the top of this pile of volcanic rocks at the northwestern end of the hydrothermal altered zone, in intensely altered volcanic breccia.

The mineralization consists of sulfide-bearing quartz veins in an area of general silicification and pyritization. Reconnaissance sampling by Bergey (1960) gave contents ranging from 1 to 17 oz/ton Au and 0.1 to 14 oz/ton Ag. The highest gold and silver values were apparently found in samples with visible chalcopyrite and sphalerite (Bergey, 1960). Chip samples of quartz veins with abundant sulfides yielded 2.1% Cu, 1.2% Zn, and 15.1% Pb (Ludden, 1961a). Ludden (1961a) reports that the NW striking alteration zone showed Cu contents of 80-420 ppm, but no Au and Ag.

History

In 1956 a mineral exploration program was initiated by A.D. Fraser from Kingston, Jamaica (Ludden, 1961a; Bergey, 1963). In 1957 Mr. Fraser was granted a number of Exclusive Prospecting Permits by the Mining Commission of the Commonwealth of Puerto Rico, one of these permit areas was the Cayey permit area of about 206 sq. miles In June 1960 quartz veins were discovered with Au, Ag, and Cu values in the Cerro Avispa Area, southeast of Cayey in the Cayey permit area.

Prospecting and sampling of the prospect area indicated a large number of mineralized veins in an area of about 2 x 1 miles. About one mile to the west of the first discovery numerous excavations were noted, including an open cut of more than 30 m. (200 feet) long and at least 3 m. (10 feet) deep. According to the local farmers, this mining activity was carried out around 1860 by the Spaniards. Based on this first reconnaissance, a map delineating areas of interest was produced in which the gold contents were displayed. Gold contents ranged from 434 to 3 ppm, silver values from 527 to 31 ppm.

In August 1960, R.W. Ludden carried out a preliminary investigation and based on his recommendation, Phelps Dodge acquired an option on the Fraser prospects, and in November 1960 started a program of geologic reconnaissance and geochemical sampling (Ludden, 1961a). The study of the Cerro Avispa gold-silver-copper vein prospect by this company revealed a fairly large area of narrow, wide-spread steeply dipping quartz veins varying in strike from N-S to NW-SE. In the quartz veins and the adjacent country rock varying amounts of pyrite, chalcopyrite, sphalerite, and supergene chalcocite were reported (Ludden, 1961a).

Following the initial exploration a detailed proposal for intensive exploration was submitted. Within the prospect, four vein systems with high grade Au-Ag quartz veins, sometimes with Cu, located in the central and eastern part of the Cerro Avispa area were selected. The company proposed to undertake 1800 ft. of drilling; drive an exploratory adit of 1250 ft., and carry out 40 days of trenching. As far as is known, these exploration activities were never carried out.

Probably in 1983, COMINCO initiated a new exploration program in Puerto Rico. One of the prospects of interest to this company was the Cerro Avispa deposit. They carried out an initial geological and geochemical investigation and applied for an exploration permit.

Origin of the deposits

Pease (1976) suggested that the sulfide deposits at Cerro Avispa may have formed from hydrothermal fluids carried along NW-SE faults zones from late magmatic differentiates of the San Lorenzo Batholith at Punta Tuna near Puerto Maunabo. Schellekens (1987) proposed that the sulfide deposits were the result of emanations near a volcanic center on top of the Early Cretaceous volcanic pile composed of formations A to C. The subaerial environment for the volcanics as suggested by Berryhill and Glover (1960) combined with precious metal bearing quartz vein-system seems to point to an epithermal vein deposit.

Itinerary (figure10)

From Mayagüez south on route 2 towards Ponce. For a description of the geology along the road to Ponce see the itinerary of field trip on Day 1(February 21, 1991). In Ponce turn right at route 1 towards autopista and San Juan. Take exit right to route 52 direction San Juan. Continue on the Autopista (route 52) towards San Juan.

To the left we pass limestones of the Oligocene Juana Diaz Formation, to the right we can see the rum distillery of Don Q.

The geology of this part of the autopista is more extensively described in the itinerary of the way back this afternoon.

At Km 97.1 on the left hand side of road, occurs a large slide block(?) in the Juana Diaz Formation.

At km 95, if one looks towards the left a large landslide is visible. A block of Cuevas Limestone slid into a limestone quarry near the town of Juana Diaz.

Through toll station

From km 88.7 to 86.5, on both sides of the road, occur outcrops of the conglomerate facies of the Oligocene Juana Diaz Formation.

From km 87.3 to 86.5 we pass vertical beds of turbidites of the Eocene Raspaldo Formation.

At km 68.5 melange of limestone and volcanic rocks.

Exit at "Salida 67" towards Salinas. Cross route 1 to route 180, towards Guayama. After about 2 km this road intersects route 3. Turn left on route 3 towards Guayama. This road parallels the south coast in the rain shadow of the Cordillara Central. Continue on route 3 into Guayama. Turn right at "no entry" sign. This street connects with route 3 direction San Juan and Cayey. Turn left on route 3, follow the directions to route 15 towards Cayey.

Continue on route 15. Outside Guayama and just after we have crossed the bridge over the Río Guamaní the road cuts through the plutonic rocks of the San Lorenzo Batholith. Continuing on route 15 the road passes through volcanic and volcaniclastic outcrops of the pre-Robles sequence from formation A through C (Berryhill and Glover, 1960). The road also at time intersects the WNW trending hydrothermally altered zone.

Stop 1 : Route 15, km 7.4

Short stop to look at the volcanics of the Early Cretaceous formation A, the oldest of the pre-Robles sequence. Feldspar-phyric andesite flows.

Stop 2: Route 15, km 11.0 - 11.1 Opposite abandoned old school building.

Hydrothermally altered volcanics. Volcanic rocks are altered to white clay with iron oxides.

At km 16.8 the road intersects hydrothermally altered volcanic rocks. At km 17.1, to the left of the road is the summer residence of the governor.

At km 19.8 turn left on route 7737. From km 0.6 the road passes through outcrops with hydrothermally altered volcanics on the flanks of Monte El Gato. The rock was probably a feldspar-phyric flow rock, now the feldspars are altered to white clay occurring in a red clay groundmass. The rocks are cut by many small veinlets and a few larger veins.

From km 2.9 to 3.1 the hydrothermal alteration appears to be more intense. The groundmass now consists of bleached white clay and veins with white clay cut the rock. Abundant iron oxide casts are present.

At km 3.4 turn left on route 715 to the Cerro Avispa deposits.

Rt 715 Km 2.8. Block of silicified rocks from higher up the slope.

Stop 3: ~~Quartz-veins with~~ clay alteration and pyrite.

Rt 715 Km 5.

Stop 4: Hydrothermally altered volcanic rocks with mineralized quartz veins (old Spanish mine?)

Return on route 715, cross under the auto pista, to route 1. Turn right on route 1 north, towards Cayey. In Cayey take autopista, towards Ponce (south).

At Km 44.2 the autopista intersects the hydrothermal alteration zone related to the Cerro Avispa deposit.

Jibaro Monument: (Route 52, Km 49.7)
The surrounding rocks are Early Cretaceous volcaniclastic rocks. The Las Tetas Lava Member of the Robles Formation (Albian to Santonian) crop out to the northwest, in a conspicuous pair of bald knobs bearing the same name.

Between Km 54.4 and 59 we see volcanic and volcaniclastic rocks mapped as the Early Cretaceous "pre-Robles formations" (formation C) (Berryhill and Glover, 1960). The low ridges in the valley below are the eastern extension of the Eocene Belt.

Stop 5: Route 52, Km 59.8 - 60.9 : Lapa Lava Member of the Robles Formation (Albian - Santonian).
The outcrop exposes spectacular pillows and other submarine lava flow features. The basaltic rocks are pyroxene- and feldspar-phyric with the often characteristic cruciform texture of the feldspars (Jolly, 1971). These calc-alkaline lavas with high K_2O contents are more or less contemporaneous with the tholeiitic low K_2O Las Tetas lavas.

At Km 68.3 we see an outcrop consisting of folded limestone in the northeast and a melange of limestone and purple volcaniclastic blocks in a bedded sandy matrix in the southern part. The section is mapped as Cuevas Limestone (Eocene) and Coamo Formation (late Cretaceous). The section is part of the Eocene Belt and the Great Southern Puerto Rico Fault zone (Glover, 1971; Glover and Mattson, 1973).

At Km 82.9 the highway intersects outcrops of the almost vertical beds of interbedded sandstones and mudstones containing sedimentary structures of typical turbidite deposits. The rocks probably belong to the Eocene Raspaldo Formation.

At Km 87.3-86.8 outcrops occur on both of the highway of coarse conglomerate interlayered with red colored finer-grained sediments. Bottom contacts of the conglomerates are scoured and often show reverse grading. The unit is mapped as part of the lower clastic member of the Oligocene Juana Diaz Formation (Krushensky and Monroe, 1975).

Route 52, Km. 97.3 Juana Diaz Formation

A limestone mass of about 115 m wide and 15 m thick occurs within the pelagic claystones of the Juana Diaz Formation. The limestone is made up entirely of biogenic material, predominantly that calcareous tests and skeletal fragments of shallow-water organisms. The limestone mass was interpreted as a dislodged block of an algal bank that had slid into a deep-water environment (Moussa, 1977).

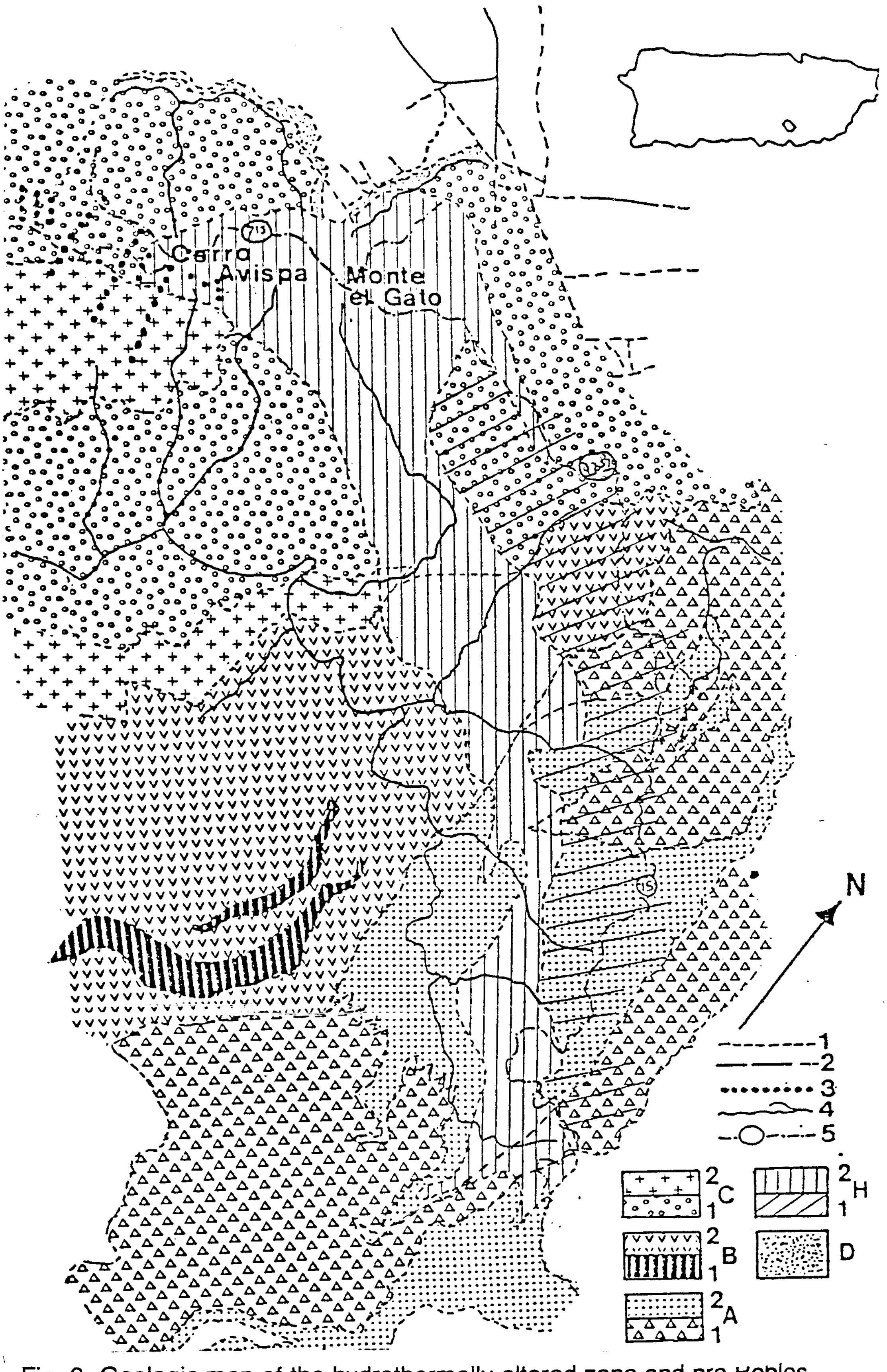


Fig. 9 Geologic map of the hydrothermally altered zone and pre Robles formations along rt 15 from Guayama to Cayey with location of Cerro Avispa deposit. Geology after Berryhill and Glover (1960) (Schellekens, 1987). Legend: 1: boundary; 2:fault; 3:veins; 4: river; 5: road; H:hydrothermal alteration; A, B, C, and D: formations A, B, C, and D, with 1: flows, 2: volcaniclastics.

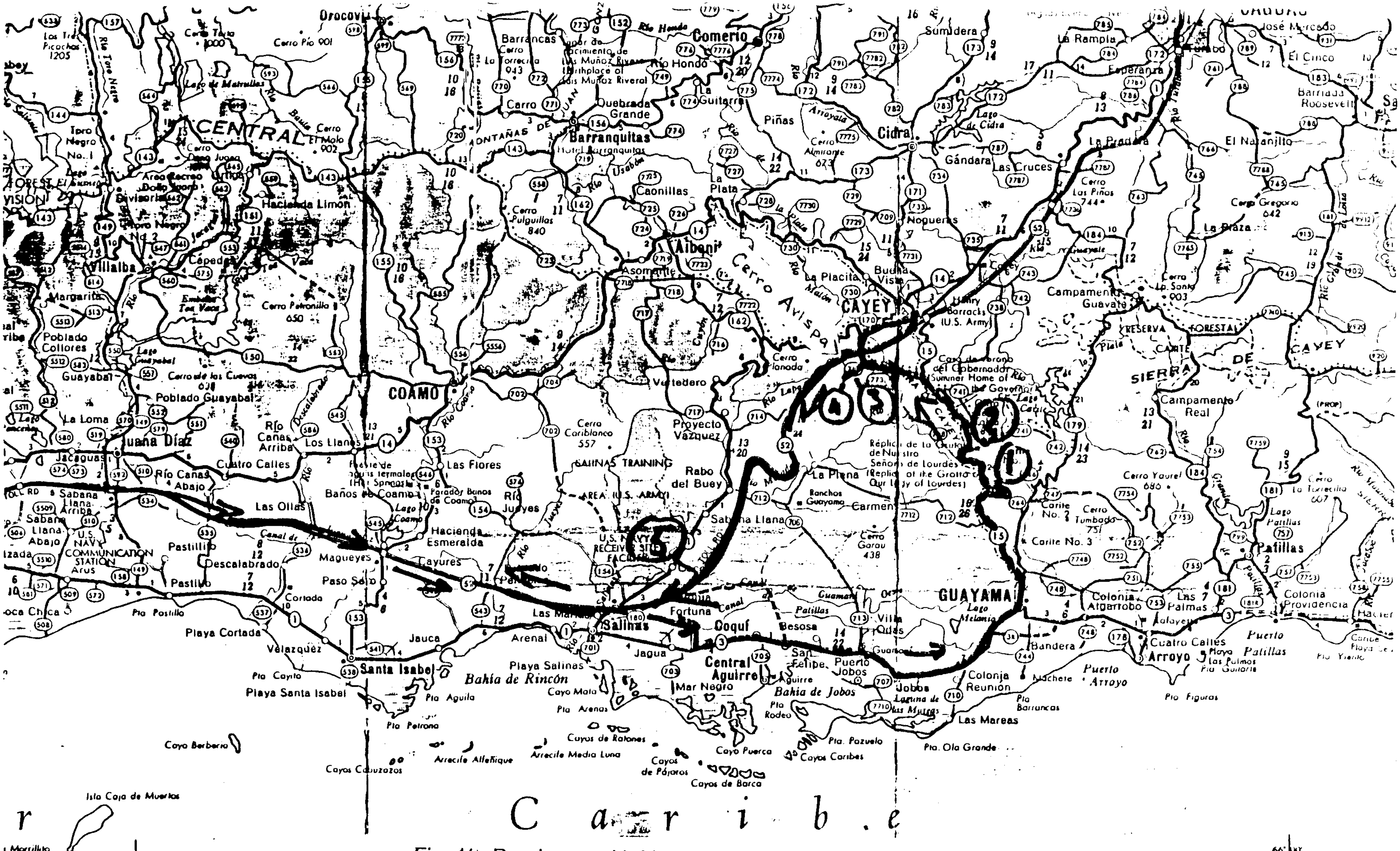


Fig. 10 Road map with itinerary and location of Cerro Avispa

Sunday February 24, 1991

Amphibolites, Nickel laterites, Hydrothermal Alteration, and Gold-Quartz Veins

Introduction

This field trip will take a look at an area that is of interest both geologically and for mineral exploration. Gold was washed by the Spaniards in the Guanajibo river (Garcia, undated), gold and copper were mined in the beginning of this century (P.R. Bur. Mines, 1941), nickel laterites were studied as a source for nickel and cobalt (Heidenreich and Reynolds, 1959), and the hydrothermal alteration zones were a focus for exploration in the last decades (eg. Ludden, 1961b). The oldest dated rocks of Puerto Rico: cherts of Kimmeridgian age (Montgomery, 1990) and amphibolites of 126 Ma (Cox and others, 1977) are also exposed in the area.

Geology of the area.

The Southwest Igneous Province of Puerto Rico is distinct from the rest of Puerto Rico in the occurrence of outcrops of three serpentinite belts. These serpentinites contain rafts of metavolcanic rocks and cherts that are dated as being the oldest rocks of Puerto Rico and were mapped as the Bermeja Complex (Mattson, 1960). Cherts as old as Kimmeridgian (Montgomery, 1990; Schellekens and others, 1990) and amphibolites dated at 126 Ma (Cox and others, 1977) occur in the Sierra Bermeja. These rocks are overlain by Cenomanian to Eocene, basic to intermediate volcanic and volcaniclastic rocks, and limestones which are intruded by small, probably shallow, plutonic rocks (figure 2).

Bermeja Complex

The Bermeja Complex (Fig. 1a) was first described by Mattson (1960), who distinguished four rock types: serpentinized peridotite (Mattson, 1960, 1964), spilite (later named the Las Mesas Greenstone; Schellekens and others, 1990), amphibolite (later named the Las Palmas Hornblende Schist and Amphibolite; Mattson, 1973), and silicified volcanic rock and/or chert (later named the Mariquita Chert by Mattson, 1973).

The serpentinite of the southernmost belt contain amphibolite blocks some of which are on the order of tens of meters in diameter (Mattson, 1960, Renz and Verspyck, 1962, Tobisch, 1968). In the largest amphibolite raft, near Barrio Las Palmas, foliated amphibolites are cut by meta-basaltic dikes, which cross-cut the foliation, and they themselves may be off-set along small faults. The serpentinite of this southern belt is intruded by Late Cretaceous intrusions, the most prominent of which is the diorite stock of the Maguayo Porphyry.

Maguayo Volcanic Center

In the southwest of Puerto Rico, overlying and flanking the serpentinites of the Bermeja Complex, occurs a sequence of basic to intermediate volcanic and volcaniclastic rocks, mapped as the Boqueron basalt, Lajas Formation, and Basaltic-andesite. Based on the spatial, age, and geochemical relationships, these volcanics and the Maguayo Porphyry are considered to be one volcanic center, the Maguayo Volcanic Center (Schellekens and others, 1990) (figure 12 and 13). These volcanic rocks are overlain by the Campanian to Maastrichtian Cotui Limestone in the north and the Santonian to Maastrichtian Parguera Limestone in the south (Volckmann, 1984a). Locally the Cotui Limestone starts with a transgressive beach deposit (Santos and Kauffman, 1989) indicating that at least at the onset of the Cotui Limestone time (Campanian) the lavas were exposed. Extensive zones of hydrothermal alteration occur in the intermediate volcanic rocks west of the town of Lajas (Lajas Formation). Because the overlying limestones were not affected, it is assumed that the alteration was the result of late volcanic hot-spring activity before deposition of the limestones.

Nickel Laterites

Of the three serpentinite belts that crop out in southwest Puerto Rico (Mattson, 1960) the two northern belts are locally capped by laterite deposits (figure 11) These have been studied in the past to assess their potential as a source for nickel, cobalt, iron, and chromium. The two largest deposits Las Mesas and the Guanajibo-Punta Guanajibo, were extensively drilled, the other small deposits were tested with only a few holes at readily accessible sites. A total of 10,856.5 feet in 279 holes was drilled. Based on a cutoff of 0.6 % Ni the reserves were inferred to be 90.5 million short tons with an average nickel content of 0.88 %. The enriched zones averaged in thickness from 10.5 to 51 feet, with a mean of about 19.5 ft. (Heidenreich and Reynolds, 1959). A later recalculation almost doubled the reserves (Kingston and others,1972). A restudy of the Guanajibo deposit by the "Comisión de Minería" of Puerto Rico, that put in 12 drill holes, with a total length of 545.1 feet, came up with even better figures (Cram, 1972).

Hydrothermally altered zones in southwest Puerto Rico

Several hydrothermally altered zones are mapped in southwest Puerto Rico (Slodowski, 1956; Mattson, 1960; Volckmann, 1984 bcd; figure 14). These hydrothermally altered zones have been targets for exploration in the 1950's. In 1956 and 1958 two permit areas, San Germán-Sabana Grande and Cabo Rojo (total area 125 sq.miles), were granted to A.D.Fraser of Kingston, Jamaica. In 1960 Phelps Dodge took an option on these permit areas and carried out geological reconnaissance and geochemical prospecting. The study concluded, that except for the Minillas and Lajas Arriba prospects and the laterites, no economic mineralization was present (Ludden, 1961b).

The most extensive zones of hydrothermal alteration occur in the Lajas Formation (intermediate volcanic and volcaniclastic rocks of the Maguayo Volcanic Center, north of the Lajas Valley). Extensive zones occur where the volcanic rocks have been completely altered to white, purple, or light brown clay minerals. The rocks are often fractured with iron hydroxide on the fracture planes and contains casts and goethite pseudomorphs after pyrite, and occasional quartz veins. Locally thick beds of chert, with vugs lined with quartz crystals, replace and overlie the hydrothermally altered purple volcanics.

Minillas Prospect

The Minillas Prospect is located in the municipality of San Germán, east of route 118, north of route 117, and southwest of route 329 (figure 15). Gold copper bearing quartz veins occur at the contact between serpentinite and altered andesitic? volcanic and volcaniclastic rocks. The area falls in the Sabana Grande quadrangle for which no recent geological map is available, but the rock types can be correlated with those of the San Germán quadrangle (Volckmann, 1984c). The area is underlain by volcanic sandstones that can be correlated to rocks of the Late Cretaceous Yauco Formation, and basaltic volcanic and volcaniclastic rocks with limestones possibly belonging to the Maastrichtian El Rayo Formation. Serpentinitized peridotite was emplaced along faults. The rocks are intruded by porphyritic diorites, that have produced contact aureoles in the serpentinite and stratified rocks (figure 16).

The mineralization occurs in quartz veins near the contacts of the serpentinite and the volcanics. At the west side of the deposit the veins are almost completely removed by the mining operation. The veins apparently were continuous for several tens of meters, with some oblique cross cutting veins. At the east side deformed pieces of veins occur suspended in the serpentinite. Some of these pockets of mineralization were also mined as suggested by shallow pits in the hill side with gossanous mineralization remnants.

The gold-copper bearing quartz veins in the Barrio Minillas (San Germán) were first worked from 1918 to 1921 by the La Plata Mining Company, that shipped a total of 180 ton of ore with 2.4 % Cu, 1.07 oz/ton Ag, and 0.892 oz/ton Au. The mine contains four tunnels lying over one another (total length 700 ft) The top three tunnels can be reached by an inclined shaft with a length of 65 ft. In 1935 new claims were taken up by the Industria Minera Puertorriqueña and new development was carried out (P.R.B.M., 1941)

Itinerary (figure 16).

South from Mayaguëz on route 2, just past the Mayagüez Mall turn right on route 100, towards Cabo Rojo.

On both sides of the road hydrothermally altered volcaniclastics mapped as Yauco Formation are exposed.

Stop 1: Route 100, km 3.0 Nickel laterite of the Guanajibo Deposit

Serpentinites, weathered serpentinite, and laterite. The contact between serpentinite and laterite is extremely irregular, however the zone of iron-oxide nodules in the laterite more or less parallels the surface. The serpentinite is cut by another weathered rock type, but there is no obvious change in the overlying laterite.

Continue along route 100. After the intersection with route 308 the road intersects a succession of rocks from younger to older.

The first outcrops consists of volcaniclastic rocks of the Sabana Grande Formation, that overly a limestone, that was mapped as Cotui (Campanian - Lower Maastrichtian) (Volckmann, 1984d), but was later determined to be a younger Maastrichtian limestone (Sohl, pers.comm.).

Below the limestones are volcanic and volcaniclastic rocks of the Lajas Formation. The andesite flows overlie volcaniclastic rocks that consist of subrounded fragments (up to 50 cm) of andesite in a matrix of feldspar and mafic crystals (block and ash flows?). The Lajas Formation conformably overlies the Boqueron Basalt, the top of which consists of thin bedded (10 cm) graded volcaniclastic sandstones and siltstones overlying basaltic volcaniclastic rocks composed of subrounded fragments of fine feldspar-phyric basalt in a matrix of feldspar and mafic crystals.

Straight ahead we can see Boqueron Bay with the hills of Sierra Bermeja in the distance. The top of Sierra Bermeja (Vermillion Range) is made up of reddish chert, that gave the sierra its name. The range consists of serpentinite with rafts of amphibolite, capped by late Jurassic to Early Cretaceous chert. A quarry in the north side of the range exposes cherts and the probably Early Cretaceous Cajul Basalts.

At the end of route 100 turn left (east) on route 101. Follow route 101 to the turn off to Combate. Turn right (south) on route 301. Follow route 301 south to route 303, turn left towards Las Palmas. Follow route 303 until the colmado just before the bridge over the Arroyo Cajul.

Stop 2: Gneissic amphibolites, Bermeja Complex: Arroyo Cajul

The gneissic amphibolites of the Bermeja Complex are well exposed in the intermittent stream valley of Arroyo Cajul near Barrio Las Palmas. Tobisch (1968) interprets the following sequence of events in the amphibolites:

1. amphibolite facies regional metamorphism with formation of some hornblende lineation.
2. increase in intensity of metamorphism producing quartz-feldspathic segregations.
3. decrease in metamorphic intensity and tectonism as evidenced by mafic dikes, that are metamorphosed but not foliated.
4. development of late-stage kink bands at high angles to earlier small scale folding.

5. "intrusion" of serpentinite causing overprinting of incipient contact metamorphism and Ca-metasomatism in the northern end of the amphibolite block.

The composition of the metamorphic rocks is basaltic and could represent metamorphosed equivalents of oceanic crust or rocks belonging to the initial stages of an island arc (Schellekens and others, 1990).

Continue on route 303 east . The road becomes an unsurfaced jeep trail. To the north are outcrops of Mariquita Chert "overlying" serpentinite. A hydrothermally altered zone parallels the road just to the north. Hydrothermal alteration consists of silicification with abundant iron oxides, often with well developed slicken-sides. (If time permits a short stop at route 303, km 8.1 can be made to look at these rocks).

Follow route 303 north to route 101. Follow route 101 north past Barrio Palmarejo, turn left on route 316. Follow route 316 until end, continue on route 312 until end. The road stops in a strongly hydrothermally altered zone.

Stop 3: Hydrothermally altered volcanic rocks of the Lajas Formation

Here the volcanic rocks of the Lajas Formation are completely argillitized with only sparse quartz veins.

Return on route 312 and route 316 to route 101. Turn left towards Lajas. Go through the town of Lajas and turn right on route 116 south. Follow route 116 for about 2 km and turn left on route 117. Continue on route 117 to Lajas Arriba. Turn left (north) on route 118 (Tea Road). After about 2 km turn right on road to sector Piñalejo. Continue on this narrow road, until the old mine entrance at the right hand side of the road.

Stop 4: Old Mines of Minillas.

One of entrances to the old mine is easy to reach. Feldspar-phyric andesite occurs around the entrance. The gold-copper bearing quartz veins at the contact of the andesite with the serpentinite are completely mined out. Some malachite and azurite can be found on the hill. Samples collected near the entrance of gossanous veins in the andesites contained some pyrite remnants and visible gold.

Continue on this road until route 329. Turn left on route 329. Continue route 329 to 102. Turn left on route 102 towards San German. In San German turn right on route 22. Continue route 22 until T-junction with route 2. Turn left towards Mayagüez.

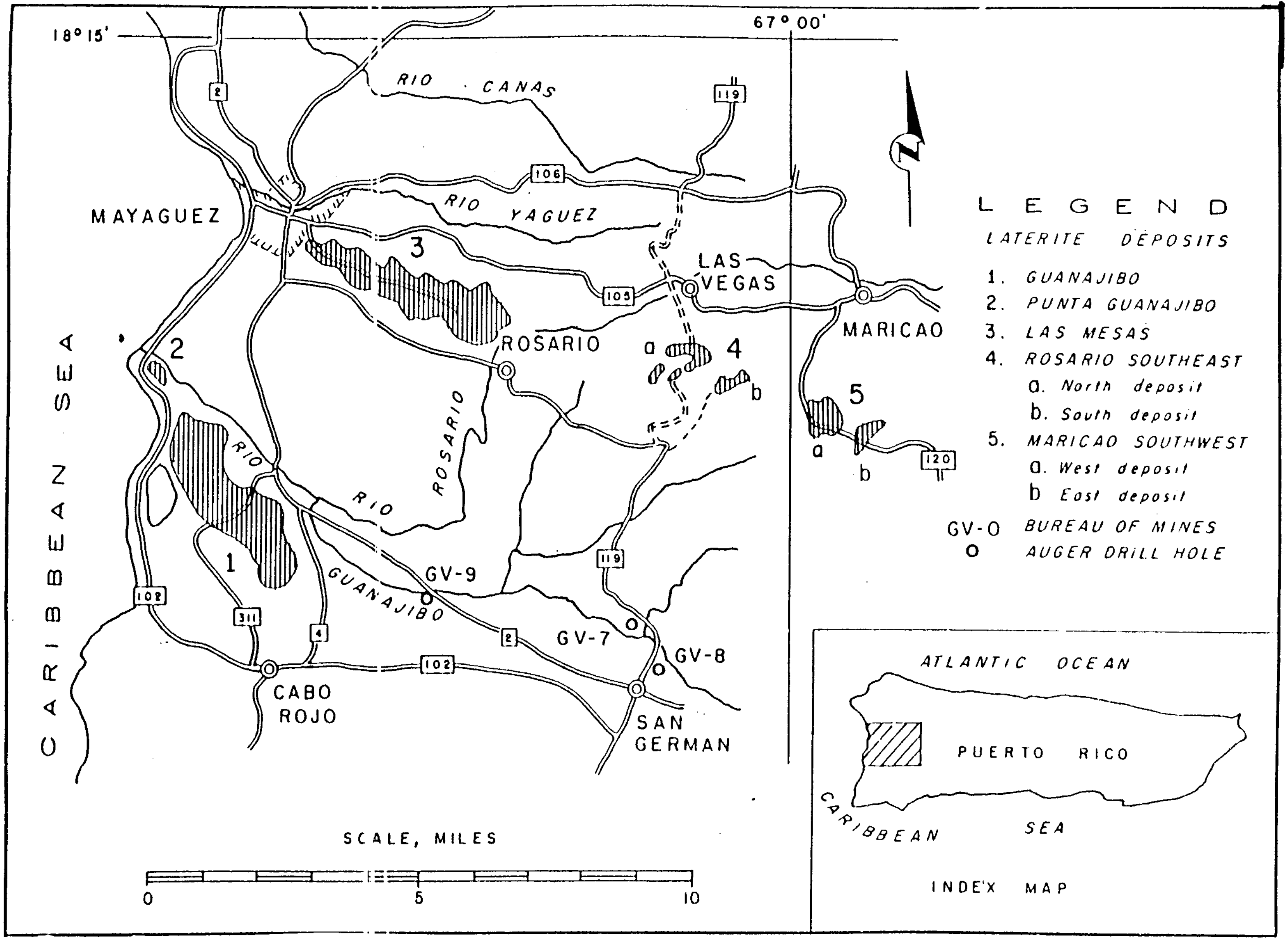


Fig. 11 Laterite deposits in western Puerto Rico (Heidenreich and Reynolds, 1959)

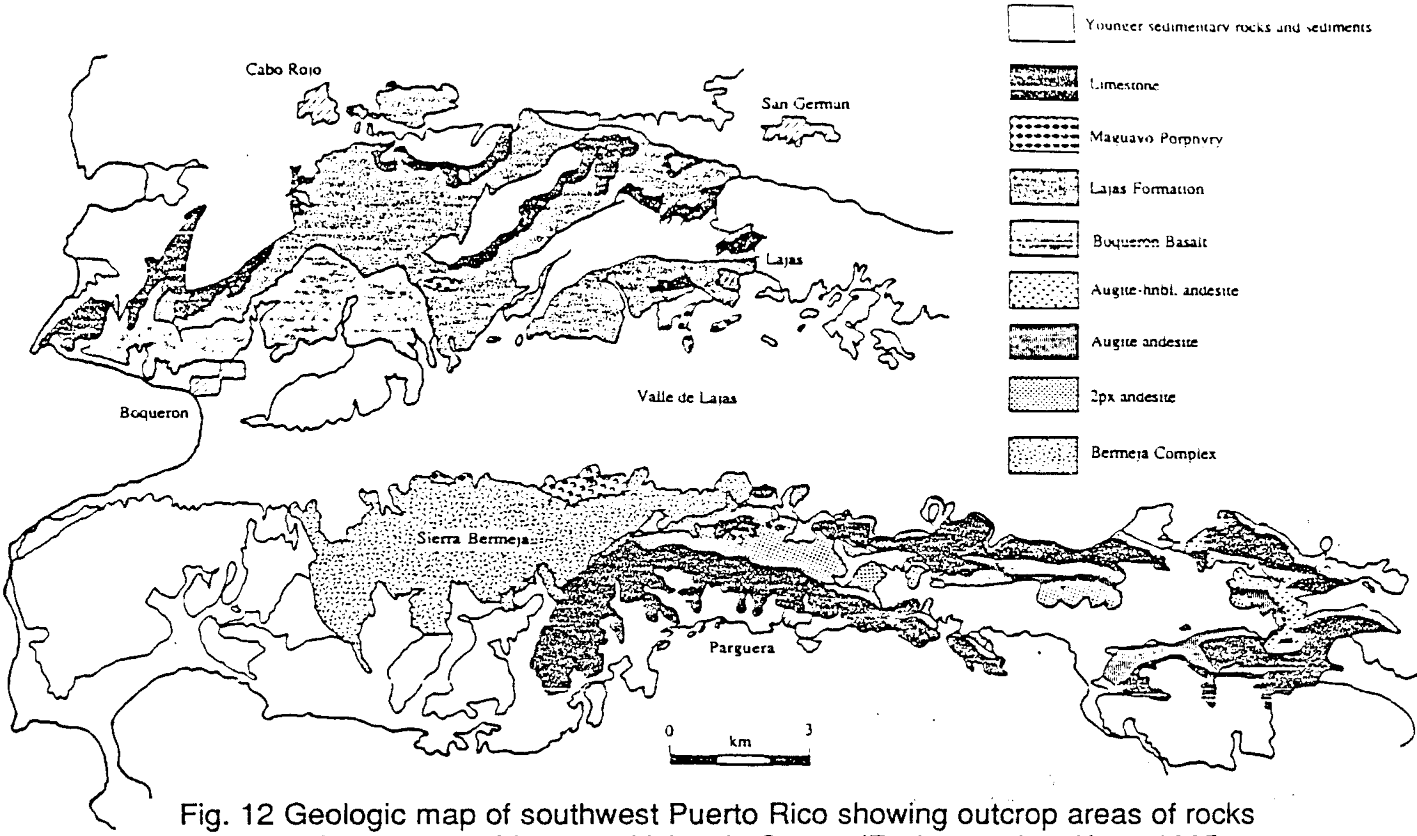


Fig. 12 Geologic map of southwest Puerto Rico showing outcrop areas of rocks assigned to the Maguayo Volcanic Center (Redrawn after Almy, 1965 and Volckmann, 1984 abc) (Schellekens and others, 1990).

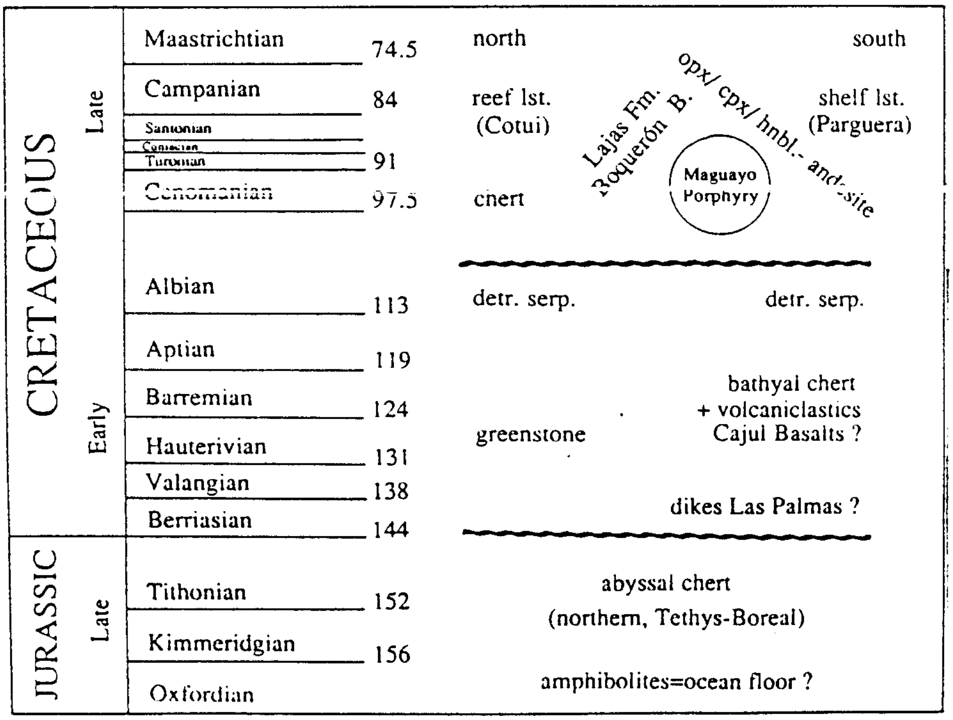


Fig. 13 Summary of the stratigraphy of southwest Puerto Rico (Schellekens and others, 1990).

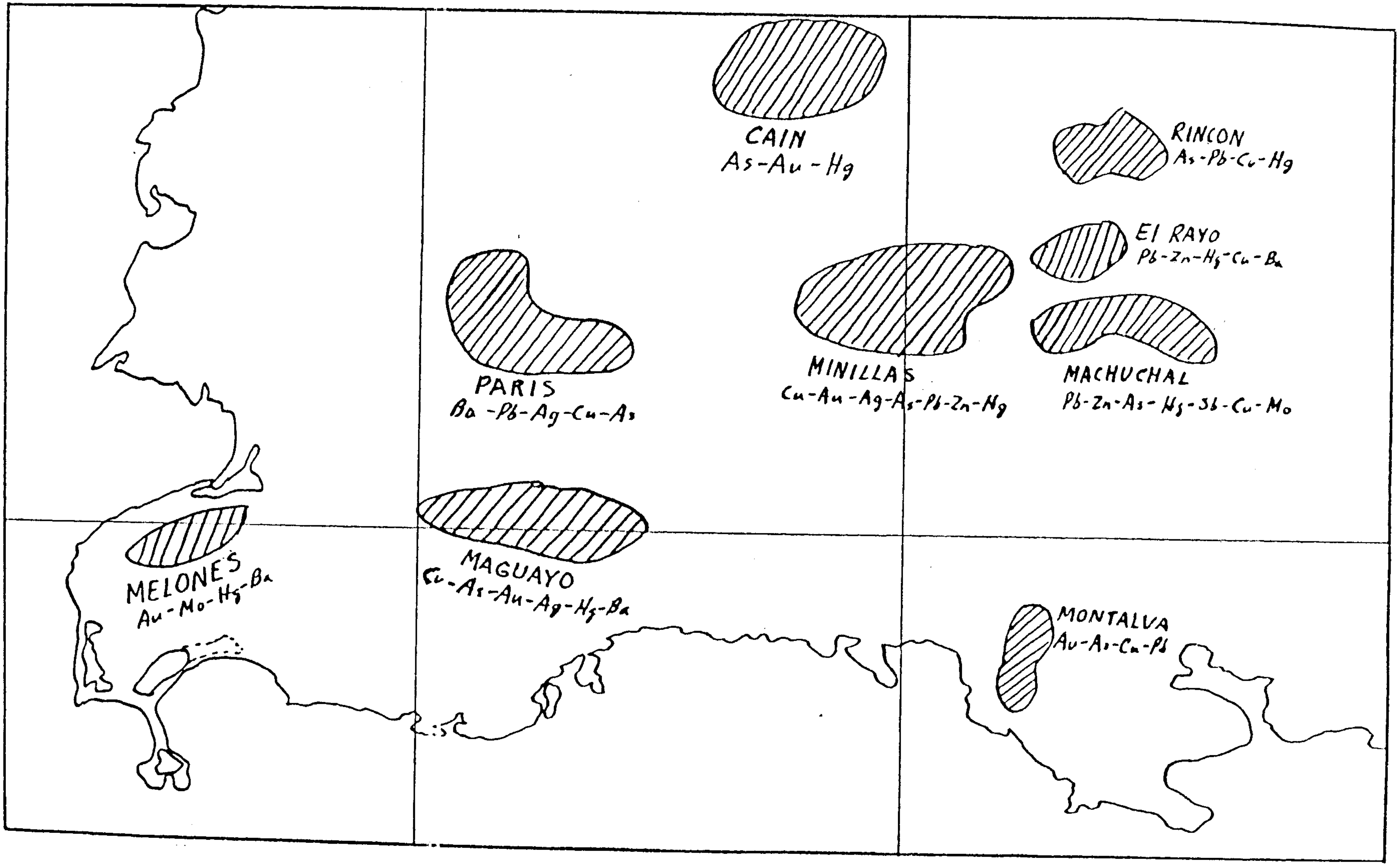


Fig.14 Hydrothermally altered zones of southwest Puerto Rico with elements present in anomalous concentration (García, unpublished).

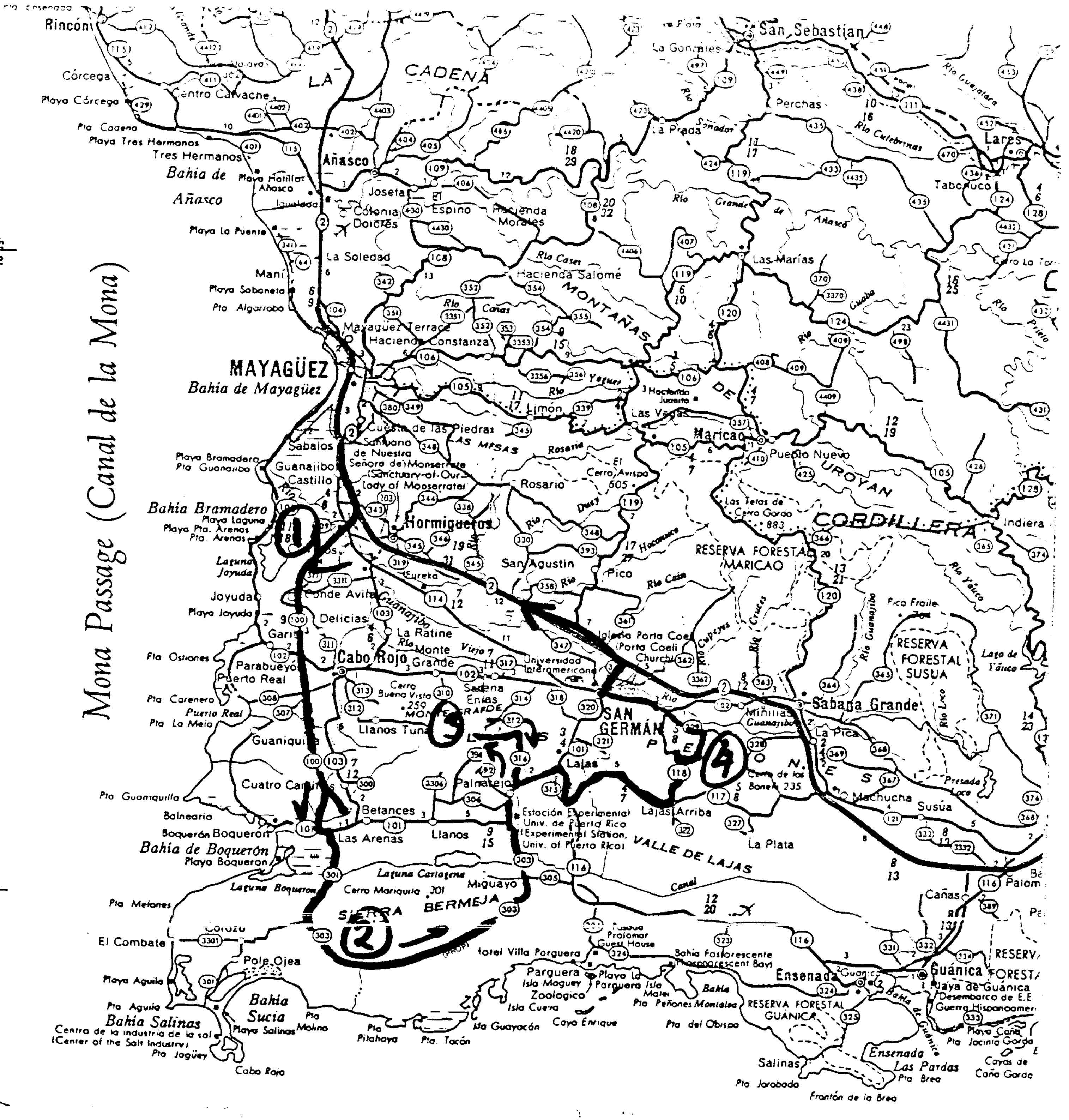


Fig. 15 Road map with itinerary southwest Puerto Rico

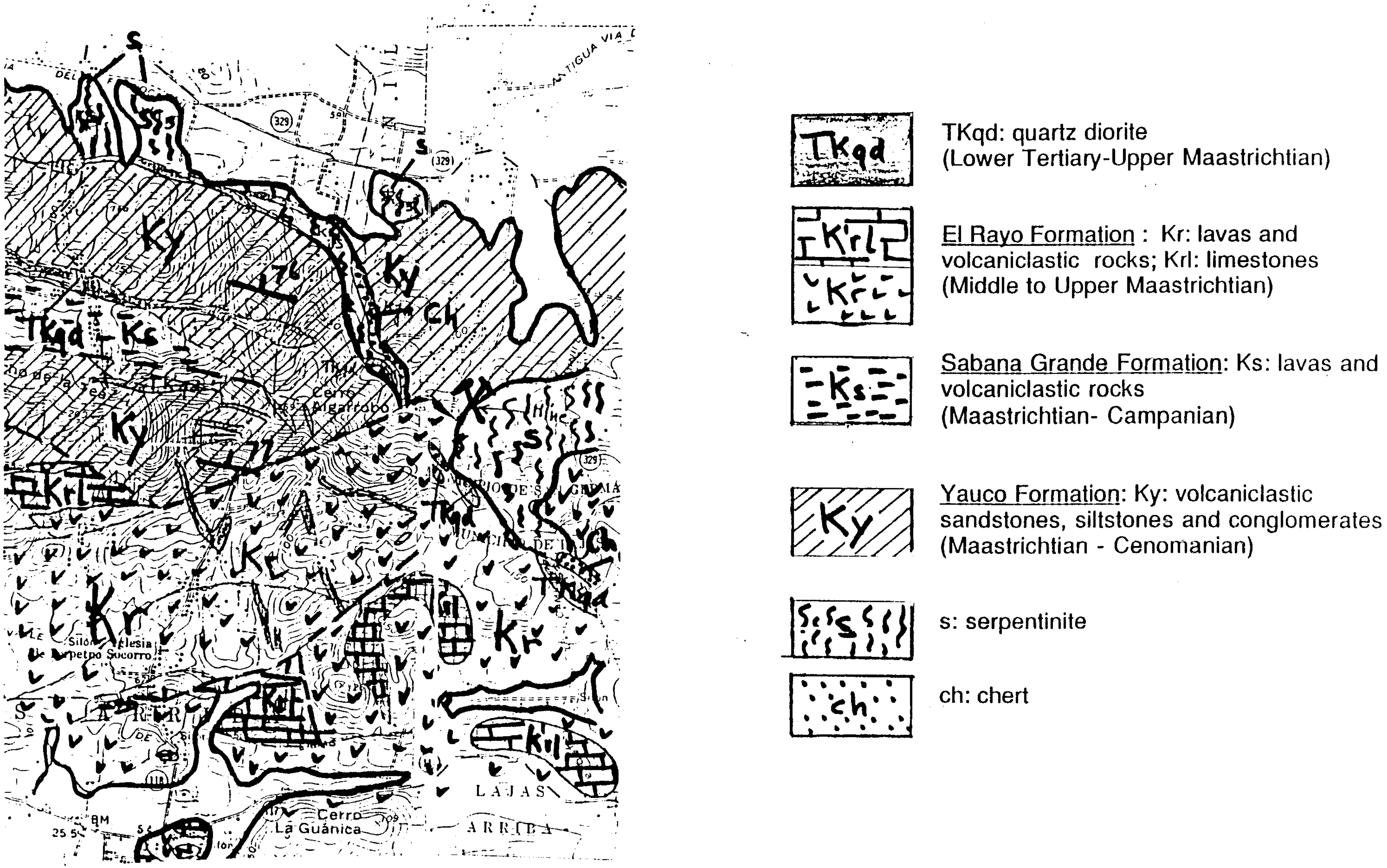


Fig. 16 Geologic map of the Minillas area (adapted from Volckmann, 1984c; Balay, 1990).

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