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REPUBLIC OF ECUADOR
Ministry of Industries and Commerce
NATIONAL GEOLOGICAL AND MINING SERVICE

UNITED NATIONS DEVELOPMENT PROGRAMME

SURVEY OF METALLIC AND NON - METALLIC
MINERALS

TECHNICAL REPORT
No. 1
COAL INVESTIGATIONS
(Operation No. 1, Cuenca - Biblián
and Loja)

FINAL TECHNICAL REPORT
PREPARED FOR THE GOVERNMENT OF ECUADOR
BY THE UNITED NATIONS ACTING AS PARTICIPATING AND EXECUTING
AGENCY FOR THE UNITED NATIONS DEVELOPMENT PROGRAMME

REPUBLIC OF ECUADOR

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National Geological and Mining Service

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Final Technical Report prepared for the Government of Ecuador by the
United Nations acting as Participating and Executing Agency for the
United Nations Development Programme

Quito.

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OPERATION No.1

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1. INTRODUCTION - OBJECTIVE

The Government of Ecuador requested the United Nations Development Programme for technical assistance to help in the search for mineral deposits over six operation areas, or zones, which were decreed Government Reserves. The so formed Survey of Metallic and Non-Metallic Minerals (otherwise known as the Mineral Project) has been performed by the United Nations in their capacity as designated Executing Agency. The Plan of Operations was signed on 24 December 1964 and work was continued until 30 June 1969.

Of the six operation areas, two zones were designated in the Plan of Operations for the assessment of coal deposits. This aspect of the Mineral Project's activities was denominated Operation No. 1. One of the areas, No. 1-a, is located in the Azuay Province covering an area of 2,610 sq. km., in which the city of Cuenca, and towns of Azogues and Biblián are located. The other area, No. 1-b, lies in the Loja Province and has an area of 1,125 sq. kms including the city of Loja and the town of Malacatus.

This Technical Report No. 1 issued as Annex No. 1 to the Interim Final Summary Report deals both with the geological investigations and assessment of coal deposits in the Operation Area No. 1. Work described in this report was initiated in May 1965 and terminated in March 1968.

2. CONCLUSIONS AND RECOMMENDATIONS

1. Under the terms of reference of the Plan of Operations, an assessment was made of the coal (lignite) deposits in the Cañar-Azuay Basin of the Cuenca area, and the Loja and Malacatus Basins in the south of the country. Because of its greater economic significance principal work was concentrated in the Cuenca area; Cuenca being both nearer to the principal industrial cities of Quito and Guayaquil, and itself a developing centre of minor industry. One of the objects of the investigation was to see if possibilities existed for the installation of a thermo-electric plant in the Cuenca area fueled by coal. Government's plan was to include this in a high voltage loop from Quito-Cuenca-Guayaquil and back to Quito. The purpose was to cover daily peak loads and to take on load when water was low for maximum generation of hydroelectric power during the dry periods of the year.

2. Considered a very important part of these investigations has been the geological mapping of the Cañar-Azuay intra-montane sedimentary basin. For the first time the full stratigraphical correlation of this area has been attempted. Apart from bringing to light other important aspects, mapping has shown that the geological column is thicker and older than previously described and contributed substantially to the geological knowledge of Ecuador.

3. The most important conclusions to be drawn from these studies are:

A. The coal seams where potentially mineable, i.e. near surface, especially in the Cañar-Azuay Basin, have extremely high-angled and variable dips, are constantly affected by faulting, vary in width and lens out so rapidly, that mining costs would be excessive. The technical difficulties of drilling the steeply dipping coal-seams are paramount under the geological conditions prevailing, and even if this were possible, the irregularity of the seams would prevent accurate tonnage calculations. Such calculations would only be possible during actual development work.

B. Geological mapping has shown with some certainty that coal underlies approximately 200 sq km of sediments in the less structurally disturbed western half of the Cañar-Azuay Basin. However, two deep drillholes, 325 m and 366 m respectively, which were sited at most advantageous points in this area, proved by non-intersection, that this coal is too deep to be mined.

C. The accessible steeply dipping coal in the eastern half of the basin had been previously referred to as lignite. Further analyses done show that although a great deal of lignite is present, calorific values indicate that much of it, also in the Loja and Malacatus areas, should be classified as Sub-Bituminous C coal, one grade above lignite. Even so the low calorific value and objectionable amounts of sulphur (1% to 18%) and ash (6% to 60%) make the coal unsuitable for most uses except power generation.

D. One mine, San Luis near Biblián, which was in operation during the time of the Project's field activities was producing approximately 30 tons/day before excessive costs forced closure. Statistics available for the latter part of 1966 show that the production cost per ton was S/ 480 or US\$ 21.⁰⁰ at present exchange rates. High costs were mainly due to the technical difficulties previously mentioned.

To be competitive with oil at the present maximum price of S/ 53 per barrel on the coast, coal would have to be mined and delivered for approximately S/ 140 per ton. On last known mining costs this would result in an economic disadvantage for the same heat value compared with oil of at least S/ 340 per ton of coal used. With projected hydroelectric plants near to Cuenca and recent discoveries of good quality petroleum reserves in northeastern Ecuador it is considered extremely doubtful that coal mining costs could ever be reduced to make this fuel competitive as a power source.

E. Geological mapping has permitted correlation of hydrocarbon showings and seeps, with bituminous sediments of Upper Cretaceous age which underlie the Cañar-Azuay Basin. There are many points in common between this area and the Napo Putumayo region of northeastern Ecuador.

Distillation may have been effected by post-Cretaceous intrusions. Only very detailed structural mapping will indicate whether there is a possibility of locating small areas of trapped gas or petroleum.

F. The stratigraphy has been described in sufficient detail to permit regional correlation.

As a result of the foregoing conclusions it is recommended that:

A. Because of both poor quality and unfavorable structural conditions, the coal contained within the sedimentary basins of Cuenca and Loja-Malacatus, should be no further considered as a potential source of power if it has to be exploited by conventional mining methods.

B. For future electricity needs, development plans should be based on hydro or fuel-oil generation particularly now that petroleum discoveries have been made within the country which should soon reach the production stage.

C. Should for unforeseeable reasons there be needed additional power sources to those soon to become available, then further necessary expensive studies could be effected over the Cañar-Azuay Basin with two objectives in mind.

i) The possibility of underground gasification of the coal to provide 'synthesis gas' as a raw material for petro-chemical industries. Although this subject is not further elaborated in this report, the idea was developed during investigations when it was realized that the coal could not be mined economically by conventional methods. Techniques for this process have been investigated in various areas around the world. A comprehensive annotated bibliography of the results of gasification experiments has been published by the United States Bureau of Mines, Capp and Lowe (5). Some points in favour for this as yet little developed process, can be found in the Cañar-Azuay region; the high percentage of volatiles in the coals; during underground burning the steep dip of the seams would improve the required draft, and the intense fracturing of the zone would tend to aid combustion.

ii) The development of the suggestion that there could be small gas or petroleum traps in the Cañar-Azuay area as indicated by hydrocarbon seeps.

3. GEOGRAPHY

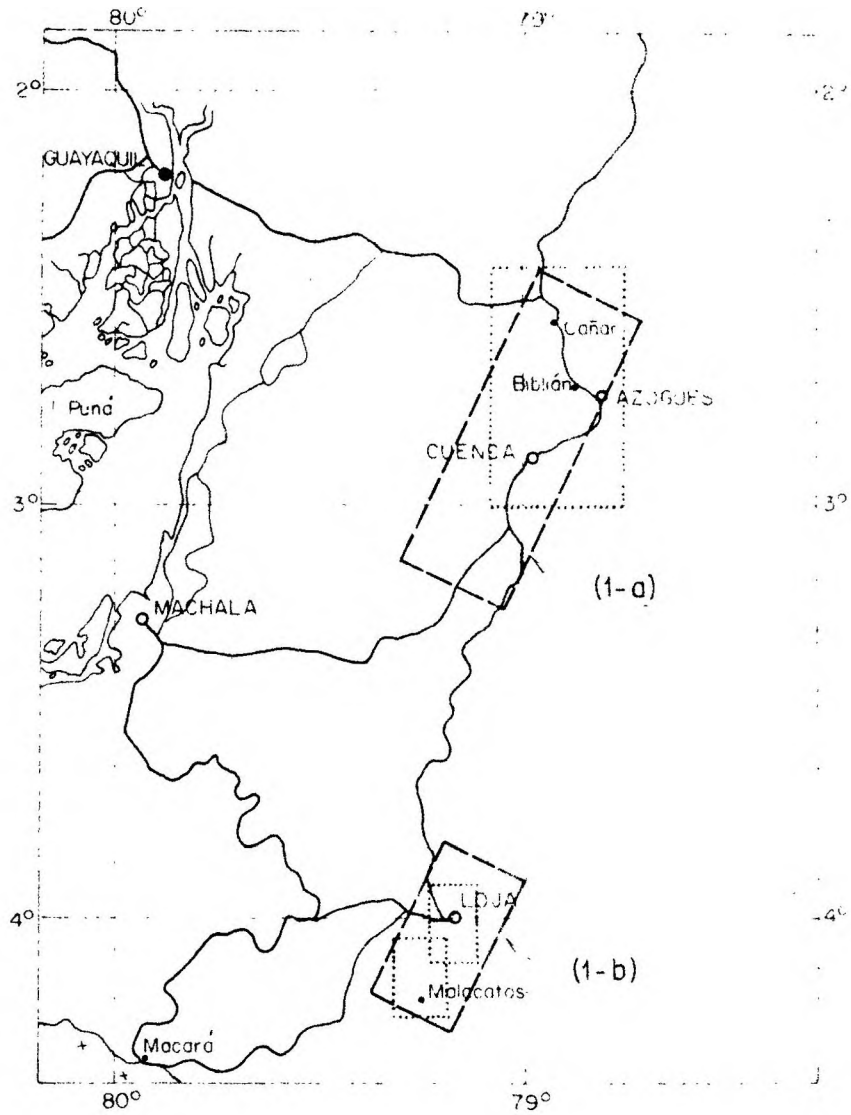
3.1 Location

The largest town in southern Ecuador, Cuenca, with about 90,000 inhabitants, is situated near the centre of the Cañar-Azuay basin, at Latitude 2°52'S, Longitude 72°57'W (see map N° 1). Several airlines provide services from Guayaquil and Quito six days a week. The government railroad (120 cm gauge) runs from Cuenca to Guayaquil (220 km) with connections near Chunchi for Quito (473 km). The Pan American highway, parts of which are paved, links Quito with Cuenca and continues southward through Loja to Peru. Two airlines fly six days a week from Guayaquil to La Toma, 50 minutes by car west of Loja (4°0'S, 79°12'W). Malacatus (4°15'S, 79°15'W) is 34 km by road south of Loja. Accessibility within the basins is good. The Cañar-Azuay region has over a thousand kilometres of all-weather roads, many of which are maintained by village cooperatives. Almost any point within the basins can be reached in less than an hour's drive and a short walk. Moving heavy equipment, however, can be difficult.

3.2 Climate

Altitude is considered the primary control of climate in the region. The lower reaches of the rivers draining the basins, as at Santa Isabel (1598m) and La Toma (1238m), are warm and semi-arid, with average annual temperatures between 18°C and 25°C. The basins proper, where most of the population is concentrated, range in elevation from 2000 to 3000 m, have average annual temperatures around 14° or 15°C, and rainfall of about 1000 mm. The surrounding mountains, with elevations not quite reaching the snow-line, (4500 m) have cold, damp weather and are uninhabited. Climate also appears to be influenced by degree of exposure to the prevalent easterly winds. Valleys orientated toward the Amazon Basin (Río Paute from Cuenca, Río Zamora from Loja) seem to be more humid than those leading westward (Río Cañar, Río Jubones, Río Catamayo). This may be an indirect influence of the Humboldt Current. The months from December to May are considered to give more rain, but the weather would be more meaningfully divided into periods of weeks rather than months. The daily range of temperatures is greater than the annual. Cuenca meteorological station (2562 m), shows an average daily maximum of about 20°C, and a minimum of about 8°C, or a daily range of roughly 12°C. The difference in maximum between the warmest and coldest months is only about 2°C. This is true of the other stations in the region, regardless of altitude and is, of course, an effect of the equinoctial latitude.

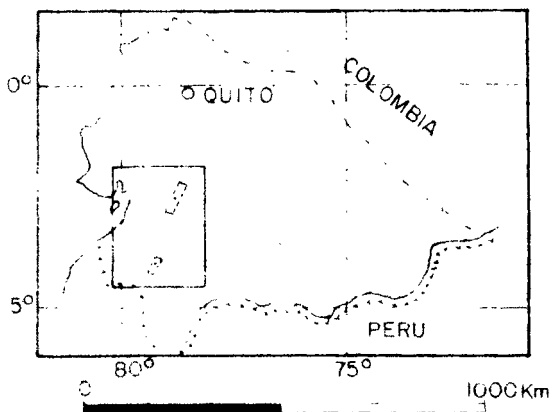
Vegetation is sparse, even in the rainy areas, except for lush belts along some of the river flats, Centuries of over-grazing have eliminated the indigenous trees everywhere except in the most inaccessible corners, where a few groves of valuable



Limit of operation area



Limit of area mapped on 1:50,000 scale



SURVEY OF METALLIC AND NON-METALLIC MINERALS
 Servicio Nacional de Geología y Minería
 United Nations - Development Programme

ECUADOR
 OPERATION Nº 1
 CUENCA - BIBLIAN (1-a), LOJA (1-b)
 LOCATION MAP



MAP Nº 1

hardwoods remain. The capulí (Prunus), and tocte (Juglans), have been semi-cultivated for their fruit, which bear a close resemblance to the "wild cherry" and "black walnut" of more temperate climates. Many other fruit trees, timber and ornamental plants have been imported among which Eucalyptus predominates.

3.3 Physiography

The Andes of Ecuador are divided by geographers into the Cordillera Occidental and Cordillera Oriental (the Cordillera Real of Columbia). They are relatively narrow, (100 to 150 km) compared with the rest of the chain, but contain many of the highest volcanoes in the world. Significantly, all the snow-capped peaks (+4500 m) are in the northern half of the country, where Quaternary vulcanism has been intense. None of the peaks south of Cañar exceeds 4200 m. This separation probably has a structural control, as do many of the nodes that link the two ranges at intervals. Travelling the Pan American highway the length of the Tertiary basins in southern Ecuador, one crosses the continental divide four times within 250 km. The Cañar river flows into the Pacific, the Paute river into the Atlantic, the Jubones to the Pacific, the Zamora to the Atlantic, and the Catamayo to the Pacific.

The contrast in gradient between segments of the streams flowing parallel to the ranges, within the basins, and those cutting eastward or westward across the strike is, in many cases, extreme. The Cañar and Paute have deeply incised canyons in their lower parts, and may be controlled by a single major fault zone. The divide between the flat headwaters of the Paute, (Río Tarqui) and the steep Río Jubones has had strategic significance. Tupac Yupanqui used the route to capture Tumipampa (Cuenca) in the 15th Century, but other invaders from the south, in the 19th Century, were met on the divide itself, and decimated.

Pleistocene and Pliocene drainage in the Cañar-Azuay basin can be traced to some extent by the distribution of the fluviatile sediments. The Turi and Santa Rosa formations, along the foot of the Cordillera Occidental, have linear facies of boulder conglomerates probably representing the main river beds of the ancient equivalents of the Río Tarqui and upper Río Azogues. A closer control is seen in the distributions of the Quaternary Llacao volcanics: the old valleys were filled with resistant pyroclastics which remained as ridge cappings when the streams shifted laterally, as explained below.

Differential erosion has etched out parallel ridges where dips are steep, (for example, in the Mangán Formation of the Delog valley) but the general drainage pattern of the basins is dendritic. Rock weathering has been intense, and unaltered Tertiary sediments are scarce.

4. PREVIOUS PERTINENT REPORTS

Among others, a number of reports dealing with different aspects of this Operation exist and are briefly mentioned: In 1952 E. Bennett (3) for the U.N. Technical Assistance Programme carried out an investigation of the exploitability of the Biblián coal and reached the following conclusions:

- 1) The Biblián coal can be used nearly in all industries; however, it cannot be used as domestic fuel due to its high sulphur content.
- 2) The overall reserves in the Biblián field amount to some 1.6 million tons.

As an integral part of the Project's work, the United Nations Special Fund in 1966 contracted the consulting firm Pierce Management Corporation, Scranton, Pennsylvania, U.S.A., to investigate the exploration methods and economics of the Biblián Coal field. Their principal results of that study are:

- 1) There is a potential market for standby power and the present nearby cement plant to justify a mine with a daily capacity of 700 tons.
- 2) The estimated mining costs per ton of such a mine plus delivery to a nearby power plant will be approximately S/ 130-151 equalling US\$ 6.50-7.55. These costs include interests and depreciation on S/ 3E, 500,000 or approximately US\$ 2,000,000, the estimated capital costs of the mine.
- 3) To be competitive with the heat value costs of Bunker C oil delivered at Manta, the mining costs per ton would have to be S/ 104-140 equalling US\$ 5.20 to 7.00, depending on petroleum source and procurement methods.
- 4) The economic disadvantage of generating power at Cuenca-Biblián with lignite as against generating power at Manta with imported oil will be S/ 26 or US\$ 1.30 per ton of coal used.
- 5) The whole situation would be altered if new petroleum discoveries were made in Ecuador. +

+ Very promising petroleum discoveries have since been made during 1967-1969 by Texaco-Gulf in the northern part of the "Oriente" just south of the Colombian border.

In 1965 the counterpart organization, Servicio Nacional de Geología y Minería, contracted the service of Société Anonyme de Prospection Aeroportée (SAPA) to carry out airborne magnetometer survey over the southern part of the country, including the area of Operation N° 1.

5. GEOLOGY

5.1 Stratigraphy of the Cañar-Azuay Basin

A. Introduction

For a complete study of the possible coal potential of the most important sedimentary basin, that of Cañar-Azuay, it was important that an attempt was made at sorting out the confusion surrounding the stratigraphical interpretation of this area.

For the first time important stratigraphical horizons and breaks have been recognized, and correlations made of the rapid facies changes that are found across the basin from the peripheral area of overlap to the central area of greater deposition. Important differences between the western and eastern halves of the basin are described and discussed. The effect of the three major Andean orogenies (Laramide, Pyrenian and Cascadian) on deposition are recognized, and correlation is made with other areas in northwestern South America.

Although new fossil localities were found during the work which aided correlation and mapping, it is emphasized that all following descriptions are based more on lithological differences than on strict paleontological control. It is certain that when more detailed fossil recognition is forthcoming that changes will be made to the stratigraphical sequence here presented. For the time-being, however, this work can be regarded as an important step towards the geological evaluation of the Cañar-Azuay sedimentary basin, and has allowed a more exact positioning of the coal horizons.

B. Background Information

The earliest mention of the sediments of the Cañar-Azuay Basin was by von Humboldt during his visit in 1803, (11). Additional observations were recorded by Wolf near the end of the century (27). The first attempts at mapping and stratigraphic subdivision date from oil company exploration in the thirties, of which publications by Sheppard (21) and Liddle and Palmer (12) are available to the field worker. These investigations were handicapped by lack of base maps and air photos. The lithologic similarity of the sediments and paucity of reference horizons led to much confusion. Erazo (6) tried to sort out the nomenclature, but the names used by the earlier authors just do not match: his own observations have proved correct in many cases. The stratigraphic column set up early in the present project retained some of the old names, but the corresponding rock units were mapped so accurately that there is now no doubt what is meant. Later, the stratigraphy on the eastern and western edges of the basin was refined, and an attempt was made to correlate the stratigraphy of the Cañar-Azuay Basin with other sedimentary belts of the country.

Mapping of the Cañar-Azuay Basin was done by the Project on 1:50:000 scale (Map N° 2). The area of investigation is underlain by rocks ranging in age from Palaeozoic (?) to Holocene (?) as shown in Table I.

TABLE I
Stratigraphical Column
Cañar-Azuay Basin

<u>AGE</u>	<u>FORMATION</u>	<u>LITHOLOGY</u>	<u>FOSSILS</u>
Quaternary - Recent	Irquis Piedmont debris	Piedmont debris	
Quaternary	Llacao Volcanics	Agglomerates, valley fill.	
Quaternary	Tumipampa Boulder Gravels	Boulder gravels.	
Quaternary	Tarqui Volcanics	Agglomerates, ignimbrites.	Wood (charcoal)
Quaternary	Turi Formation	Conglomerates, siltstone, tuff.	Wood
	<u>Ayancay Group</u>		
Plio-Pleistocene	Santa Rosa Formation	Red clay with conglomerates, channel fill, piedmont wedge.	
Miocene (?)	Mangán Formation	Shale, coal, bentonite, sandstone, conglomerate and clay.	Pelecypods, vertebrate remains, plants.
Miocene (?)	Cushumaute Formation	Siltstone, shale.	Gastropods.
	<u>Azogues Group</u>		
Oligocene (?)	Guapán Formation	Black shale, bentonite.	Plants.
Uppermost Eocene to Oligocene	Azogues Formation	Massive tuffaceous sand- stone, minor siltstone.	<u>Nucula</u> .
Upper Eocene	Loyola Formation	Conglomerates and sand- stones, black shales with leaves.	<u>Hemisinus</u> and <u>Turritella</u> .
Maestrichtian to Lower Eocene	Biblián Formation	Red ferruginous clay, lenses of conglomerate, minor sandstone.	
Upper Cretaceous	San Marcos Formation	Black argillite and limestone, lydite, minor pyroclastics, andesitic sills.	Unidentified pelecypods and gastropods. <u>Inoceramus</u> .
Upper Jurassic to Mid-Cretaceous	Piñon Volcanics	Pyroclastics, chert andesitic sills and flows.	
Palaeozoic	Paute Series	Metamorphic schists, shales, quartzites.	

5.11 Paute Series

As defined by Olsson (16), the Paute Series embraces a metamorphic complex consisting of sandstones and schists without any fossils, and probably Palaeozoic in age. Its type locality is south of San Cristobal in the valley of the Paute River forming the eastern border of the sedimentary basin (see Map N° 2).

South of Gualaceo and southwest of Paute phyllites are predominant, and limestones are slightly recrystallized and drawn out into elongated lenses. Black colouration is persistent, and this together with the general lithology could indicate a relationship to the San Marcos Formation not far to the west. In the Gualaceo and Paute areas, however, red and variegated tinted shales and phyllites are quite common.

High in the Cordillera Oriental on the road to Gualaquiza, predominant rocks are graphite schists with lenticular zones of very fine quartzite. These may be a more highly metamorphosed equivalent of the Paute Series or, on the other hand, correlated with Palaeozoic rocks exposed in the Cordillera Real of Colombia. More difficult still to place are the greenstones just north of Gualaceo, and 1 km E of Taday. These highly altered schists and quartzites are composed of chlorite, feldspar, quartz, calcite, and epidote. They probably include meta-volcanics as well as meta-sediments. Their relation to the Paute rocks is unknown.

5.12 Piñon Volcanics (Upper Jurassic to Mid-Cretaceous)

The geologic maps of Ecuador by Wolf (27) and Sauer (19) show a thick (+1000 m) section of volcanics along the entire front of the Cordillera Occidental. These rocks are interlayered with upper Cretaceous sediments at the top, but their bottom limit is undefined and may extend down into the Jurassic, as in Peru. These Piñon Volcanics dip under the Tertiary sediments on the west side of the Cañar-Azuay basin, and are probably overlain, deeper in the basin, by the San Marcos Formation as well.

The rocks along the piedmont are mostly pyroclastics whereas those farther into the hills contain more lavas. Andesite forms massive homogenous sheets several tens of metres thick in the canyon of the Río Matadero west of Cuenca: some of the porphyritic units are very probably intrusives. A belt of red, slightly quartzose tuff with a pronounced fabric, possibly an ignimbrite, can be traced along the piedmont. Outcrops were noted at Checa, Chiquintad, Sayausid, and Yanuncay. White tuff, black chert, red jasper, and other minor but distinctive rock types in the same area are also found as pebbles in the upper part of the Tertiary sequence. Hydrothermal alteration is intense along the belt of travertine deposits, but not so pervasive as in the younger volcanics.

5.13 San Marcos Formation

This Formation is of Upper Cretaceous age and consists of a sequence of marine sediments which can be followed for several tens of kilometres.

The predominant rock type is black argillite, which grades imperceptibly into black shales. The weathered rock is dark brown, commonly with stains of limonite, manganese-oxide, and, in moist, protected cavities, powdered ferrous sulphate. Where covered by thick, acidic, humus of the highlands, the weathered portion is bleached white. The black colour is seen, in thin section, to be due to finely disseminated organic matter, and probably also to sub-microscopic iron-sulphide. Visible pyrite is abundant. Carbonate is a common constituent, and gradation can be found between calcareous argillite and massive limestones. In the Tabacay area, the limestone occurs as balls 5 to 10 cm in diameter. In the section between Azogues and San Marcos, it forms beds up to 15 m thick, with partings of shale. Elsewhere, as at Quebrada Umbe near San Miguel, Quebrada Quinoa near Santa Ana, and Quebrada Guavahuaico on the road to Jadan, it is found as lenses 10 to 30 cm thick enclosed within shale. This limestone is also black and very fine-grained. Under the microscope it is seen to consist of brown carbonate, speckled with opaque organic matter and traces of silt. A rock specimen from Quebrada Guavahuaico shows lacerated micro-fossils in thin section. Black chert (lydite, or "touchstone") in beds less than a metre thick was found east of Hacienda Josefina (Tahual canyon) and in Quebrada Umbe. This rock is very fine-grained, has a velvety lustre, is dense, tough, and when broken exhibits a sub-conchoidal fracture. Thin sections show a felt of silica with streaks of black, opaque organic matter and rare specks of sericite and carbonate. Sandstone was found only at a few places, in beds less than 50 cm thick. It is dark, fine-grained, slightly laminated, and composed of quartz, sericite, and small chips of shale. A bed of such material along the road about 500 m south of Tabacay power station contains unidentified gastropods.

Fossils found within the argillite are more diagnostic and were determined to be of the species Inoceramus from the Upper Cretaceous (Santonian or Coniacian). Apart from the one shown in Photo I, another cast was found on the road to San Marcos (Luis Cordero) near the first stream-crossing east of Azogues.

Cast of pelecypods and other remains were found in outcrops 300 m west and 1 km S of Cumbe. Unspecified fossils have been reported from the series by Erazo (6).



Photograph I: Inoceramus cast in San Marcos shale, San Cristóbal Road
2 Kms. E of Descanso bridge.

Fotografía I: Molde de Inoceramus en lutita de San Marcos, camino a
San Cristóbal, 2 Km al este del puente del Descanso.

It should be pointed out that the rocks of the San Marcos Formation along the edge of the basin, where the fossils have been found, are slightly metamorphosed. They are more highly indurated and less heavily weathered, than the Tertiary sediments, but would not be called metamorphic rocks except by this comparison. The limestones, for example, are very fine-grained, i.e. microcrystalline, and the shales show only local suggestions of secondary cleavage.

The relationship of the fossiliferous San Marcos Formation with the Tertiary sediments, can now be established. From Josefina, in Tahuall Canyon, south to the vicinity of Cumbe, the Cretaceous rocks are overlain by the Biblián Formation. The ferruginous conglomerates just below Jadan village contain pebbles of black slate, black chert, and milky vein quartz. Similar clastics on the road 1 km east of Santa Ana overlie the black shales conformably, and cross lamination shows they are not overturned. The change in lithology from bituminous marine sediments to ferruginous clay and conglomerate of probable continental origin, however, indicates a significant orogenic break. The fact that the andesite sills, numerous in the San Marcos Formation, do not penetrate the Tertiary sequence supports this interpretation. The large composite sill at the entrance to Tahuall canyon is overlain, in the first tributary east of El Descanso, by the Loyola Formation, which has a basal conglomerate containing angular fragments of weathered andesite. The Biblián Formation has apparently been removed. At several places, e.g. in the Río Tabacay, on the road west of Cerro Abuga, in the cliffs immediately east of Azogues; in the stream-cuts just north of San Miguel; in Quebrada Guavahaico on the road to Jadan; etc., the San Marcos series is overlain by the Azogues Formation with pronounced discordance. At the last-named locality, for example, the San Marcos rocks strike 150° and dip 70° SW; the younger beds strike 50° and dip 15° NW. Both the Biblián and Loyola Formations, therefore, have been overlapped along the edge of the basin. The significance of these unconformities is discussed in the regional correlation.

5.14 Biblián Formation (Maestrichtian to Lower Eocene?).

The name Biblián Formation was applied by the Project to the oldest Tertiary sediments of the basin exposed in the core of an anticline at the town of Biblián. The term had been used previously by Humbolt and Sauer (11, 19) for the fossiliferous rocks along the railroad bridge between Biblián and Azogues which are really the basal part of the Loyola Formation, because elsewhere they rest on the San Marcos Formation.

Aside from the scattered remnants near Santa Ana, the other principal occurrence of the Formation is in the core of the anticline that extends from Biblián southward past Cojitambo and Nulty to El Valle, east of Cuenca. The base is not exposed except possibly in the water gap between Biblián and Azogues where the Formation lies adjacent to a volcanic complex of uncertain age. Since younger sediments lie directly on San Marcos rocks at several places just to the east, the thickness probably averages only a few hundred metres.

The Biblián is composed of variable proportions of clay and coarse clastics. The clay is purplish red, variegated with streaks of green. A chip sample from Jadan analyzed 20.9% Fe_2O_3 . The coarse clastics are light grey, or less commonly, brown. They are in the size range between coarse sand and pebble conglomerate. The rounded fragments are mostly devitrified tuff, with black chert, shale, and vein quartz in the lower units. At Biblián the coarse clastics are lenses, up to 5 m thick and 20 m long, enclosed in clay, and probably represent channel fillings. In the area around Quingeo, north of Cumbe, the coarse clastics form thicker and more extensive beds.

As noted previously, the Biblián Formation probably rests disconformably on the San Marcos. No fossils have been found, but for reasons given in the regional correlation, the age is probably somewhere between the uppermost Cretaceous and Lower Eocene.

Azogues Group

5.15 Loyola Formation (Upper Eocene)

Flanking the Biblián Formation, on both limbs of the central anticline, lies the Loyola Formation, named from the town also called Chuquipata, roughly midway between Azogues and Descanso. This unit has been traced almost continuously, as far south as Chilcapampa, near Cuenca, where it passes beneath Quaternary volcanics, and as far north as Biblián, where it is occluded by faulting.

A basal conglomerate, up to 40 m thick, has been found at several localities along the eastern limb of the Guapán syncline. In the first stream east of Descanso it rests directly on a late Cretaceous intrusive, and is composed of angular fragments of weathered andesite. In exposures 1 km east of the Río Azogues water gap, the conglomerate overlies a remnant of the Biblián Formation, but consists mainly of boulders of tuff, quartzite and quartz. At the San José railroad bridge, 1 km farther east, the basal unit, in contact with the Biblián Formation, has alternating beds of pebble conglomerate, sandstone, siltstone, and clay. These radical facies changes probably reflect proximity to the edge of the basin of deposition, as does the apparent lack of the conglomerate on the western limb of the anticline.

The upper two-thirds of the Loyola Formation, roughly 250 m thick, consists almost entirely of shale (Photo II). This material is very heavily weathered, coated with yellow limonite, and veined with selenite. At Chuquipata, El Valle, and Paccha, the residual soil is mined and screened for the gypsum content (15). The unaltered rock seems to be a black, pyritic, finely laminated, very fissile shale. Limestone lenses, up to 2 m long and 50 cm thick, are enclosed in the shale at several places along the road between Azogues and Biblián. Megascopically this rock is dark grey or black, very fine-grained, and dense; microscopically it is seen to consist of carbonate with tiny nests of chalcedony.



Photograph II: Anticline in Loyola Shale, San José railway bridge between Azogues and Biblián.

Fotografía II: Anticlinal dentro de las lutitas de la Formación Loyola, puente del ferrocarril San José entre Azogues y Biblián.

Fossil leaves were found in the shale at Chuchingcay, along the road about 1 km north from the railroad bridge between Azogues and Biblián. The rocks at the north end of the bridge, representing the coarser clastics at the base of the Formation, contain fossils described by Sheppard (21) Liddle and Palmer (12) and Marshall and Bowles (13). They include the gastropods Hemisinus (Sheppardiconcha) biblianus and Potamolithides biblianus, as well as the pelecypods Ecuadorea bibliana, Diplodon Liddlei, and others. Nearly all are new species, and, since they are fresh water types, very difficult to date.

Fossils found near the south end of the bridge have been identified by the College de France, Mendon, as Turritella aff. chira Olseon, said to occur in brackish water deposits of Colombia and north western Peru in the Upper Eocene. This dating agrees well with that worked out by tectonic analysis discussed later in the regional correlation (5C).

5.16 Azogues Formation (Uppermost Eocene to Oligocene)

The term Azogues sandstones was used by Wolf (27) to indicate all the sediments of the Cañar-Azuay basin, but was restricted by later workers to parts of the section. In the mapping done by the Project the Azogues Formation designates a unit of massive sandstone, with minor siltstone, clay, and shale, overlying the Loyola Formation. On the east side of the basin it overlaps the Loyola and Biblián at many places and lies directly on the San Marcos Formation. In this zone it forms the most resistant rib of the east limb of the Guapán syncline, and can be followed continuously from Guapán southward, under the town of Azogues, past Charasol to Descanso, where it crosses the River Tomebamba, thence past Faccha to the vicinity of El Valle, where it disappears under the Quaternary volcanics. In the west limb of the syncline, the Azogues forms a conspicuous hogback between the towns of Guapán and Loyola, whence it crosses the Azogues river, and, lacking a cover of younger sediments, constitutes the whole keel of the fold. On the west limb of the main anticline the Formation is missing north of Cojitambo, and poorly exposed to the south, except along the Río Tomebamba where it forms steep cliffs on both banks.

The Azogues Formation consists largely of coarse-grained, massive sandstone, slightly tuffaceous, with rock fragments being almost as abundant as quartz. The colour, as seen on weathered surface, is nearly always brown, but the rock is probably grey or dark green where fresh. The sandstone beds are thick, with faint bedding and very rare cross-lamination. Clay, siltstone, and shale, in beds less than a metre thick, are more common in the uppermost and lowermost parts. The contacts with the Loyola and Guapán Formations are probably gradational or interfingering.

Pelecypods found near the base of the Formation 500 m north of San Miguel were identified by the College de France as Nucula cf. andersoni Clarke 1946. Erazo claims to have found a fragment of an echinoderm near the same locality (?).

5.17 Guapán Formation (Oligocene ?)

The centre of the syncline of the Azogues area, between Guapán and Chuquipata, is occupied by a unit of shale somewhat more than a hundred metres thick. The only other occurrence of this Guapán Formation is in the hills near Cojitambo (on the east side of the anticline) where it is much thinner. To the south it lenses out entirely. It was confused, in early reports, with the Loyola Formation, specimens of shale from the two units being indistinguishable.

The typical rock is a finely-laminated, fissile, heavily weathered paper-shale. Argillite, clay, and siltstone are also present. No limestone was seen. Fresh rock is rare: most of the surface material is bleached and coated with yellow limonite. The original sediment was probably a bentonitic mud, rich in organic matter and very fine pyrite. Beds of bentonite up to 10 m thick have been studied by the Project around Charasol (24). This material is composed almost entirely of montmorillonite. (Tests run by the American Colloid Co., show it would make an excellent foundry clay.) The associated shales here and at Guapán contain abundant, well-preserved leaves and seed pods. At least a dozen genera of tropical plants are represented. Specimens collected have been sent to Europe for identification. The boundary with the underlying Azogues Formation was not studied in detail, but appears to be a zone of interlayered sandstone, siltstone and shale. The upper boundary shows a slightly angular unconformity.

Ayancay Group (Coal-bearing)

The western part of the basin is occupied by younger sediments which are almost entirely lacking in the eastern half. The early investigators, with the exception of Erazo, did not realize this and made no provision for these sediments in their geologic columns. On the accompanying maps (Maps N° 2,3) an attempt has been made to subdivide the rocks which lie, with slightly angular unconformity, over the Guapán Formation. The Ayancay Group divided into Cushumaute, Mangán, and Santa Rosa Formation (from the oldest to the youngest) is made up entirely of clastics and includes the known coal seams of the basin. It is not possible to measure a complete section of the Group, because of faulting and lack of marker horizons. Facies changes are pronounced, and it is doubtful whether the subdivisions can be recognized at the extremes of the basin. They were made, however, because of the needs of local exploration. For reasons given below, these rocks are considered to be of Miocene age.

5.18 Cushumaute Formation.

The unit from the unconformity at the base of the Ayancay Group up to the lowest coal seam consists of siltstone, shale, and fine-grained sandstone, interbedded in layers generally less than a meter thick (Photo III). Siltstone, a compact, grey rock with polygonal cracks, is especially characteristic of the Formation. Some of the thicker beds, (or rather assemblages of beds in the order of 10 m thick) show cross-bedding when viewed from a distance. The



Photograph III: Siltstone and shale of the Cushumaute Formation, type section, San Nicolás road.

Fotografía III: Arena fina y lutita de la Formación Cushumaute, sección típica, camino a San Nicolás.

shales and clays are mostly light colored, similar to those of the Guapán Formation. A selvedge of coal a few centimetres thick is exposed on the road to Ayancay. A bed, 30 cm thick, composed of small gastropods in a silty matrix, was found by the Project on the road to San Nicolas, in the type section. The formation extends from Cojitambo, where it is thought to be faulted out, southward as far as Turi, where it passes beneath the Quaternary volcanics. The average thickness is estimated at 400 m.

5.19 Mangán Formation

The Mangán Formation is composed mainly of fine green or red coloured clastics, variegated clay, and lenses of siltstone or fine-grained sandstone. This Formation contains the principal coal horizons of the basin: The Washington coal seams at the base and the higher Cañari seam. Shale is found in close association with the Washington coal seams at the base, but not above this horizon. The younger strata are more predominantly of clay. Bentonite, in beds up to 15 m thick, was noted at several places west of Curiquingue, and immediately adjacent to a coal seam, at the San Nicolas mine. It has physical and chemical properties similar to that in the Guapán Formation at Charasol.

Fossils were found in black shale immediately overlying one of the Washington coal seams, in an old adit at Cochahuaico, about 5 km NW of Biblián. Pelecypods (clams) are especially abundant, but not sufficiently well preserved to be identified. Crocodile teeth and other vertebrate remains have been reported from the coal. Plants are also abundant at many places in shales of the same stratigraphic zone. They include various grasses and delicate, compound tree leaves in an excellent state of preservation. Some of the coal-seams also contain recognizable plant remains, but mostly stems, branches and other wood debris. Isolated fragments of drift-wood, completely carbonized, are found all through the upper part of the Formation, but these are the only fossils that occur above the Washington zone. Significantly, the upper limit of fauna coincides with that of the shale.

The coal measures are best developed in the central sector of the basin, and thin noticeably toward north and south. The Washington zone does not reach Río Sidcay, and the Cañari seam there is contaminated with clastics. Neither is well developed north of Nazón. An isolated outcrop of coal near Chiquintad, at the foot of the Cordillera Occidental, shows that the Formation was once more extensive westward, but there is no clear evidence that it was deposited in the eastern half of the basin.

A conspicuous, persistent bed of hard white rock, about 2 m thick occurs about 20 to 30 m below the Cañari seam, and being relatively resistant to erosion, can be followed almost continuously from the Cañar divide to the Río Sidcay. The rock is dense, hard, white, and breaks into small rectangular blocks. Specimens analyzed by Wolf (27) turned out to be nearly pure silica, but in most of the



Photograph IV: Upper Mangán Formation, cross-bedded sandstone and conglomerates, Río Sidcay.

Fotografía IV: Mantos cruzados de areniscas y conglomerados. Formación superior Mangán, Río Sidcay.

material, phenocrysts of feldspar and flakes of biotite can be discerned. Another layer of similar material, much less extensive, was noted an unknown distance above the Cañari seam in Río Sidcay. The latter rock has a clastic structure and may be an especially well-indurated, siliceous tuff. Whether sills or pyroclastics, they can serve as excellent marker horizons. Dark green tuffs were seen in the San Luis mine, and are probably common, but not easily recognized because of heavy weathering.

The upper fourth of the Mangán Formation has abundant lenses of coarse sandstone, (Photo IV). In a few places (Río Sidcay) the contact with the overlying Santa Rosa Formation can be distinguished by a change in colour of the associated clay, otherwise a separation is difficult, even though there may be a disconformity.

5.110 Santa Rosa Formation (Plio-Pleistocene ?)

The western border of the basin between Cañar and Cuenca has a wedge of piedmont clastics up to several hundred metres thick described here as the Santa Rosa Formation. One of the best sections is at Santa Rosa, about 20 km north of Cuenca, where the Formation consists of red clay with lenses of coarse grey sand several metres thick and several tens of metres long. The lenses commonly have flat tops and convex bottoms, and are probably channel fillings on mud flats. Two X-ray analyses of clay from Río Sidcay and Quebrada Miraflores, near Cuenca, show mostly quartz and montmorillonite; minor kaolinite and plagioclase; with traces of limonite and illite. This differs from the clays of the lower Mangán and Guapán Formations, which are nearly pure montmorillonite. The facies in the Burgay area, in the headwaters of the Río Azogues, differs by having an abundance of boulder gravels, presumably representing old river deposits. The facies east of Cuenca contains more sandstone and less clay, resembling the upper part of the Mangán Formation. Both units are composed of debris from the Cretaceous crystalline rocks of the Cordillera Occidental, plus altered volcanic ash, and are distinguishable only where the Santa Rosa has its characteristic red clay with sandstone lenses. The Formation thins radically eastward, and has not been found beyond the Turi Fault. It lies directly on the Cretaceous (San Marcos) rocks at some places along the edge of the basin, having overlapped the Mangán Formation. The Santa Rosa Formation is overlain disconformably by the Turi Formation, which covers it completely, southward from Cuenca. Presumably the sediments along the foot of the Cordillera at Giron and Santa Isabel are the equivalent of the Santa Rosa Formation. They consist mainly of sandstone and red, gypsiferous clay. The limit of the Formation at the north end of the basin was not determined. It extends at least as far as the Cañar divide.

5.111 Turi Formation (Quaternary ?)

The youngest of the sedimentary deposits of the basin, except for superficial piedmont debris and volcanics, is the Turi Formation, named by Erazo (6) from a well-exposed section at the

village of that name a few kilometres south of Cuenca. The same unit was traced, in the present work, as far south as Giron, and as far north as the Cañar divide. It is not known to occur east of the Turi Fault except for a possible remnant between El Valle and Río Maluay. The Formation is about 200 m thick, and nearly continuous from the type section southward, but remains only as patches, less than 100 m thick, to the north. The basal, cliff-forming portion, 40 to 50 m thick, is in every case conglomeratic, but shows abrupt changes in fragment size along strike. From Turi southward, boulder gravel predominates; northward to Nazón, pebble conglomerate, thereafter, the lowermost unit is a massive siltstone or sandstone with sparse, angular rock fragments. The boulders in the exposures from Turi southward, in the Tarqui Valley, are inbricated at an angle that indicates a source in that direction. The cross-bedding tends to confirm this, but shows more variation. The linear distribution of this facies may therefore be due to fluvial deposition in an ancient stream system flowing northward, along the foot of the Cordillera Occidental, much as the Tarqui does today. The other facies change coincides with the upper reaches of the Azogues drainage.

Most of the rock fragments in the coarse clastics are a distinctive porphyry, with phenocrysts of hornblende and feldspar in a white or grey aphanitic matrix. Pebbles of this type can be seen in the Ayancay and Azogues Formations, but only in traces, whereas they are so abundant in the Turi as to be characteristic. They are rather similar to the intrusive rock that forms Cojitambo peak. Pebbles of this rock type are relatively rare in the facies north of Nazón, where the basal conglomerate contains mostly angular fragments of greenstone and pyroclastics. The upper part of the Formation has much more volcanic debris, including layers of fine-grained, white, quartzose tuff. Siltstone, also light in colour, is common. Silicified and carbonized tree trunks have been found at many places.

The Turi Formation overlies the Santa Rosa Formation, east of the village of this name, with a sharp contact which is concordant but may be a disconformity. It is in turn overlain, in some places, by both the Tarqui and Llacao Volcanics.

5.112 Tarqui Volcanics (Quaternary ?)

The thick cover of young unconsolidated volcanic debris that blankets northern Ecuador is missing in the south, but much of the region has a cover, equally thick, of slightly older volcanics. They cap the ranges east of the basin, and the divide between Tarqui and Giron, and are described here as the Tarqui Volcanics.

Their original lithology has been obscured by pervasive alteration, which is partly hydrothermal, but also due to the intense weathering on the highlands. At Tinajillas, (41 km south of Cuenca), Shiña Abuga, (7 km northeast of Azogues) and elsewhere, the alteration has gone far enough to produce kaolin of commercial interest. (24).

It is thought that the rocks were, for the most part, pyroclastics, but may have included some flows and fluviatile sediments. The rocks exposed between Tinajillas and Río León, on the road to Loja, show many features typical of ignimbrites: rhyolitic composition, stretched fragments of pumice and other eruptive rocks, columnar jointing, etc. The section here is several hundred metres thick.

The Tarqui Volcanics, for the most part horizontal, overlie the Turi Formation concordantly, and the older Formation discordantly, e.g. in Río Rircay, southeast of Giron, they rest on Santa Rosa Formation equivalent (?), which dips moderately north-westward; in the area between Turi and El Valle they overlie folded Lower Tertiary Formations; and on the road south of Sigsig they sit directly on schists. Where the latter road crosses the Cordillera Oriental, on the way to Gualaquiza, the volcanics contain branches and logs completely converted to charcoal; otherwise, fossils are lacking.

After the principal compilation of this report in March 1968 a carbon (C^{14}) dating was made on a sample of this charcoal and gave the following results:

<u>Sample N°</u>	<u>Location</u>	<u>- C^{14}</u>	<u>Age in Years</u>	<u>B.C.</u>
			<u>B.P.</u>	<u>Date</u>
J.139	44 kms. S of Gualaceo on road to Gualaquiza (approx. 78°49'W:3°11'S).	955±6	24,900±1,200	22,950

NOTE: Analysis by Westwood Labs., New Jersey, U.S.A. (Isotopes, Inc.)
B.P. = before present, B.C. = before Christ.

Assuming that both dating and correlation of the host andesites of this "fossil-wood" specimen with the Tarqui Volcanics are correct, then stratigraphic sequences from Turi upwards are relatively recent and a great deal younger than previously supposed.

5.113 Tumipampa Boulder Gravels (Quaternary)

The longer streams flowing eastward from the Cordillera Occidental have U-shaped valleys and cirque lakes, showing that they were glaciated in the Pleistocene. The boulder gravels thus produced have accumulated in terraces, up to 30 m thick, in the Machangara, Matadero, Yanuncay, and Tarqui rivers, which unite near Cuenca to form the Río Tomebamba. The streams in the eastern edge of the basin (Río Azogues, Río Jadan), also have gravel banks, but not nearly as thick and broad. The Río Machangara, above Ochoa León, shows three terrace levels, the highest being 50 m above present stream level. The terraces on which Cuenca stands have a capping of silt, clay, volcanic ash, and "diatomite" was examined at the foot of Cerro San Pablo, 5 km north of San Agustín, or 15 km north of the road to Santa Isabel. Such deposits are said to be

common in the Pleistocene. According to Sauer (19) the boulder gravels of the upper Río Jubones below Giron are moraines, which means that Pleistocene glaciers extended down to elevations of 1750 m, now in the sub-tropical zone.

5.114 Llacao Volcanics (Quaternary).

Within the Cañar-Azuay Basin there are deposits of volcanic material, locally thick, that form a higher and younger sequence within the Quaternary pile of which the Tarqui Volcanics are a more basal member.

The Llacao Volcanics, named from a village about 10 km northeast of Cuenca, caps many of the higher hills between Ricaurte and Cañar, and attains, in places, a thickness of 200 m. It is known to overly all the formations previously described, (including the Tumipampa Boulder Gravels, which represent one or more stages of the Pleistocene glaciation), and is one of the youngest bedrock formations exposed.

The pattern of distribution and the relationship with the gravel terraces reveal a former drainage system. The resistant volcanics now cap hills, but in several natural cross-sections it is clear that they once filled valleys: a typical example of volcanic inversion of topography. For example, in the cuts east of Nulty, and along the Pan-American highway just south of Descanso, the upper surface of the formation is flat, while the bottom surface is convex, in contact with the boulder gravels, which, in turn, rest on the Azogues Formation. As the volcanics filled the channels, the streams were diverted to softer ground. The remnants of the formation are linear strips, parallel to the present drainage system, but offset to the west and south. The old network unites at the entrance to Tahuall canyon, showing that the upper Paute drainage system of the earlier Pleistocene was very similar to that of the present.

The source and mode of deposition of the Llacao Volcanics are unknown. The predominant lithology is agglomerate, composed of angular to rounded rock fragments up to 1 m edge to edge, in a matrix of white, devitrified glass. Fragments of hornblende porphyry, similar to that found in the Turi Formation, are especially abundant. Well-bedded white tuff can be seen in the road cuts north of Llacao. A minor rock type of possible economic use was brought to notice at Quebrada Dique, about 1 km east of Solano. It contains 69% SiO₂, 9% H₂O, and has an apparent density of only 0.4. The bed, exposed at the top of the south bank of the stream cut, is about 5 m thick, with layers 50-100 cm thick, of slightly different composition. The material is neither diatomite nor pumice, but is probably a lacustrine deposit within the Llacao Volcanics.

Another occurrence of volcanics, not mapped, is found in patches of a few hectares in area over the Azogues and Guapán Formations south of Charasol.

5.115 Irquis Piedmont Debris (Quaternary - Recent)

Piedmont debris up to ten metres thick, are found all along the foot of the Cordillera Occidental, and reach as far east as Cuenca. Although strictly a superficial deposit, it has been shown on the map because, 1) it obscures large areas of bedrock and possibly some major faults; 2) it contains most of the brick clay of the Cuenca district.

The typical material consists of rounded boulders in a fine volcanic debris and clay. It is not clear whether the soil used for bricks has originated from weathering in place, or has been sorted out by rain wash into shallow depressions.

The age of the deposits is indicated by their advanced state of dissection, and by the fact that they are overlain by thick crusts of travertine.

5.116 Travertine (Quaternary: Pleistocene to Present)

The travertine deposits of the region have been described in detail in a separate report (24), because they are mined for cement, lime, fertilizer, and ornamental stone. Four types can be distinguished: 1) terraces or crusts up to 20 m thick and many hectares broad (e.g. Baños, Guapán, Patamarca, Cachipampa, Tabacay, etc.); 2) veins, up to ten metres thick and 150 m long (Checa, San Vicente, Baños) 3) eluvial blocks, enclosed in residual clay (Milagros, Rocar, Verdillo, etc.) 4) alluvial blocks, up to 10 m edge to edge, scattered along river banks. Deposition from hot springs is still taking place in the terraces, but has ceased in the other three types, where erosion has laid bare the veins representing the conduits through which the terraces were supplied, and, in the older deposits, has loosened and dispersed the vein material. Fossils (calcified human bones and snail shells) have been found only in the CREA quarry at Guapán, which is a contemporary terrace. The age of the eroded deposits is unknown. The so-called "marble" of the region is banded travertine.

Map N° 2 shows that all the travertine deposits of the Cañar-Azuay basin, (and the single example of Tenería, in the Loja basin) are situated around the edges of the sedimentary basins; none are found in the central portions. Fault-control is obvious, and it is assumed that the hot springs, ascending along such fractures, reached the surface only where the cover was shallow. Travertine deposits occur at many other places northward along the Cordillera Occidental (San Juan de Riobamba, Pujilí, Saquisilí, Nieblí, etc.), associated, as pointed out by Sauer, with the belt of upper Cretaceous sediments. Apparently carbonate has been leached from the underlying Cretaceous limestones and deposited at the surface as travertine. In the case of the Cañar-Azuay basin, the source may, therefore, be the San Marcos Formation.

5.117 Intrusives.

Two groups of intrusives can be recognized: 1) those in the Piñon Volcanics and San Marcos Formation, 2) those in the Tertiary sediments. The oldest set cuts late Cretaceous rocks, but not the Biblián Formation (Maestrichtian to Lower Eocene ?) and therefore can be dated rather accurately. The second group appears to intrude the Biblián and Loyola Formations (unless the contacts are faults) and can only be considered post-Eocene.

The first group comprises numerous sills, sheets and laccoliths in the San Marcos rocks along the east edge of the basin, and in the Piñon series of the Cordillera Occidental. These bodies, tabular and concordant with the enclosing rock, may in some cases be lava flows, but most have a crystalline texture coarser than that of extrusives. The majority of the sills in the San Marcos Formation are 5 to 10 m in thickness; the intrusives in the canyons of Río Matadero and Río Paute have outcrop belts several hundred metres broad; the one at the entrance to Tahuai canyon is probably a composite sheet, with the individual layers indicated by columnar jointing.

The rock in the smaller intrusives is dark green, almost aphanitic, brittle with blocky jointing. Some, as at Quebrada Umbe, show a slight degree of chloritization. A thin section of the aphanitic rock from the head of Tahuai canyon shows fine, euhedral, zoned crystals of plagioclase in a very fine matrix of feldspar, quartz, and shredded mafics. The rock at Hacienda Josefina, used in large quantities for road ballast, has phenocrysts of hornblende up to 1 cm long, in an aphanitic matrix of plagioclase, (much altered to chlorite and sericite) plus epidote, chlorite, and less than 5% quartz. All degrees of alteration of this rock type, with pyrite, epidote, chlorite, and calcite, can be seen in the canyon. Leached, kaolinized portions may represent acidic hydrothermal alteration, or may be faulted inclusions of the overlying Pliocene volcanics.

It should be noted that Wolf (27) and Sauer (19) who have studied the Mesozoic rocks at many other places, often refer to these altered andesites as "diabase" or "porphyrite".

The other group of intrusives are concentrated in the northeast corner of the basin between Ingapirca and Azogues. The most obvious member is the peak called Cojitambo, a conspicuous, landmark. This igneous mass is about 1600 m long, 100 to 500 m wide, and stands perhaps 200 m above the surrounding sediments. It has been emplaced along the contact between the Loyola and Biblián Formations, whether by intrusion or faulting is not clear. The rather homogeneous rock is a light grey, massive, and isotropic. It is composed of stubby phenocrysts of andesine, and needle shaped crystals of hornblende in an aphanitic matrix. Very similar rock can be seen in the quarries at Shalal, about 2 km northeast of

Biblián, but the size of the intrusive here is not known. The material from the quarries on the south tip of Cerro Abuga 3 km north of Azogues is too highly altered to be identified, but some investigators have suggested it is related to the Cojitambo intrusive. (21).

Another doubtful case is the igneous complex exposed in the water gap between Biblián and Azogues. Here crystalline intrusives are mixed with several types of pyroclastics. Whether this is a "breccia pipe" or a fault block of Cretaceous volcanics, has yet to be determined. A line traced northward from this point bounds the present basin as far as Río Cañar. A line southward passes just to the east of Cojitambo and more or less coincides with the main anticlinal axis of the basin. A string of magnetic anomalies suggests that the intrusives extend farther south but do not reach surface.

Fragments of rock similar in lithology to the Cojitambo andesite porphyry are very abundant in the Turi and Llacao Formations, which suggests that the intrusives of this second group may have been emplaced in the late Miocene epoch and unroofed in the Pliocene and Pleistocene.

C. Regional Correlation

Although some new macro-fossil localities were found, which are listed in Table II, diagnostic fossils are still very scarce. An attempt, however, is made to correlate the rock units observed in the Cañar-Azuay-Basin with those of other regions.

TABLE II

New Fossil Localities

<u>Unit</u>	<u>Location</u>	<u>Fossil Type</u>
1) San Marcos	San Cristobal rd, 2km. NE El Descanso	<u>Inoceramus</u>
2) San Marcos	San Marcos rd, 1km. E Azogues	<u>Inoceramus</u>
3) San Marcos	Jadan rd, Quebrada Guavahuaico	<u>Foraminifera</u>
4) San Marcos	Tabacay rd, 4km. N. Azogues	Gastropoda
5) San Marcos	Cumbe 300m. W, & 1km. S of town	Pelecypoda
6) Loyola	Railroad bridge, 2.5km. NW Azogues	<u>Turitella</u>
7) Loyola	Chuchingay, 4km. NW Azogues	Leaves
8) Azogues	San Miguel rd, 1km. N town	<u>Nucula</u>
9) Guapán	Type section, E of cement works	Leaves
10) Guapán	Charasol, 500m. SE of guard post	Leaves
11) Cushumaute	Type section, San Nicolas road	Gastropoda
12) Mangán	Cochahuaico, 1.5km. W Biblián	Pelecypoda
13) Mangán	Cushumaute, 1.5km. N San Nicolas	Leaves
14) Mangán	Curiquingue, 2.5km. W Cojitambo	Leaves
15) Travertine	Guapán, CREA quarry	Human bones

Palaeozoic rocks have been identified in the Sierra Amotape in northern Peru, the Cordillera Real in Colombia, and the Sierra de Macuma in eastern Ecuador, but no fossils have been found in any of the metamorphics commonly mapped as Palaeozoic in the Cordillera Oriental. It is not known, therefore, whether the schists and gneisses near Loja, and the greenstones along the Gualaceo River are definitely Palaeozoic. (9).

The massive andesites and other crystalline volcanics which form a large part of the Cordillera Occidental are also lacking in fossils, but from their structural position are believed to correspond to the Piñon Volcanics of the coast. The well-bedded pyroclastics along the base of the range, between Chiquintad and Baños, may represent a younger level, possibly equivalent in part to the Callo series, i.e. Cenomanian to Senonian.

The rocks designated as the San Marcos Formation have now been shown to be Upper Cretaceous, by the discovery of two forms of Inoceramus, but the exact age remains to be determined. The black argillites, black limestones, and lydites, all rich in organic matter and fine-grained pyrite, must have been deposited in a marine environment, under reducing conditions. A suite of similar rocks was studied by geologists of the Institut Français du Pétrole at Nono, in the Cordillera Occidental northwest of Quito. Thalmann (25) designated it the Yungilla series, dated Maestrichtian, which would correspond to the age of the Guayaquil chert, but the French geologists believe that part of the section, at least, is Palaeocene. The Napo Formation, in the Ecuadorian section of the Amazon Basin (Oriente) also has black shale and bituminous limestone, and has been dated Cenomanian to Coniacian. A major break, recorded in the Oriente, the coast, the southern Colombian basins, and elsewhere in northwestern South America followed the deposition of these sediments near the end of the Cretaceous period.

The Biblián Formation rests unconformably on the San Marcos Formation, but its lithology, (red ferruginous clay with lenses of sandstone) indicates a pronounced change of environment from marine to continental. It resembles the Tena Formation, which, in the outcrops the author examined, near the type section, consists of red, silty clay, with minor facies of sandstone. The Tena Formation overlies the Napo Formation disconformably and is dated Uppermost Cretaceous to Lower Eocene. A similar relationship can be seen in the Nono-Nanegal and the Río Saloya sections west of Quito, where beds of red shale, conglomerate, and agglomerate rest unconformably on Cretaceous sediments, volcanics, and intrusives near the foot of the Cordillera Occidental. It is suggested, therefore, that the red beds in these areas are the products of an orogeny in the interval between the latest Cretaceous and early Eocene, corresponding roughly to the Laramide. Lacking fossils, the Biblián is assigned to the same interval.

Both the Loyola and Azogues Formations rest, along the eastern edge of the present basin, directly on the San Marcos Formation with sharp angular unconformity, although they show a conformable

succession basinward. Patches of the Biblián Formation must have been removed before deposition of the younger Formations. Making a comparison with the Oriente, we see that the Tena Formation is said to be overlain unconformably by coarse continental clastics of the Tiyuyacu Formation, dated Upper Eocene to Oligocene. As emphasized by Olsson (16) an unconformity at the base of the Upper Eocene is widespread in northwestern South America. From these considerations, the unconformity at the base of the Loyola marked by 30 to 40 m of coarse clastics, would correspond to this regional break. The Loyola is overlapped by the Azogues, but this may be regarded as a minor effect at the edge of the basin, because the contact is conformable, and even interfingered in the basin. The close similarity between the black pyritic shales of the Upper Loyola and those of the Guapán Formation indicates that conditions of deposition remained the same during that interval of time. On the basis of tectonics, therefore, the Loyola may be regarded as Upper Eocene, with the Azogues and Guapán Formations extending up through the Oligocene. This agrees well with the palaeontological dating cited above.

The disconformity at the top of the Guapán Formation does not indicate any radical change in environment. The overlying Cushumaute and Mangán Formations are also composed of fine-grained clastics, with bentonite and black pyritic shale. Leaves of tropical plants, crocodile teeth, and other vertebrate remains suggest that the coal was deposited under paludal or estuarine conditions not much different from those of the Guapán. The coal in the Malacatus, Loja, Cañar-Azuay, and Pichincha basins seems to be limited to the central sectors, which were probably deeper. Cross-faults may have controlled basin depth. The linearity of the Cenozoic basins, concordant with major rivers of the present drainage cycle, suggests that they may originally have been long estuaries, similar to those represented by the Cauca and Magdalena basins of Colombia, but were broken up in the Mio-Pliocene orogeny.

A much more significant change can be detected toward the top of the Mangán Formation, where small lenses of coarse, cross-bedded sandstone and conglomerate gradually become abundant, and in the overlying Santa Rosa Formation, in which the red beds and boulder conglomerates indicate a transition to a continental environment. No sharp contact can be designated, but the effects can be ascribed to the important orogeny of folding and faulting that has been dated, elsewhere in the northern Andes, as Mio-Pliocene.

The Turi Formation, also a fluvial deposit, marks a period of intense vulcanism that, according to the one C^{14} dating obtained (p.22) was still active until late Quaternary times. The abundance of carbonized or silicified tree trunks and the presence of ignimbrites in the Tarqui Volcanics indicates that the region remained dry land after the Mio-Pliocene orogeny.

The slight shifts in drainage discussed in the section on the Llacao Volcanics suggest that diastrophism during later Quaternary times was limited to adjustment along faults attendant upon a general elevation.

Summarizing, the three main changes in lithology in the Cañar-Azuay section (between the San Marcos and Biblián, the Biblián and Loyola, the Mangán and Santa Rosa Formations) correspond in three major orogenies known in other parts of the Andes, namely: the Laramide at the close of the Cretaceous, the Pyrenian, between Middle and Upper Eocene, and the Cascadian, at Mio-Pliocene. Such fossils as now available support this correlation.

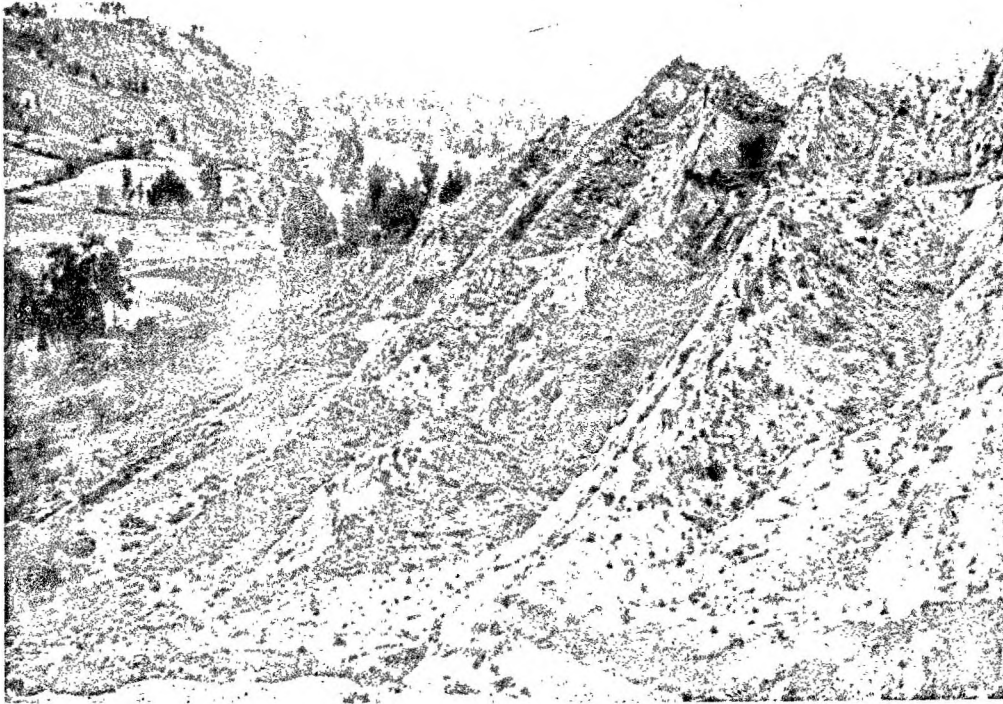
D. Structure

The Andes in Southern Ecuador trend slightly east of north. The main folds and faults also have this direction, but there are important cross structures, many of which coincide with nodes in the ranges, or with deeply incised canyons. The most fundamental division, at the north end of the Cañar-Azuay Basin, where the Río Cañar cuts a gorge westward, separates the North of Ecuador, with its high snow-capped volcanoes and thick cover of unconsolidated volcanic ash, from the South, where this cover is lacking, and older rocks, including a thick section of Tertiary sediments and volcanics, has been preserved. This cross structure, apparently a zone of faulting, is aligned with EW trending Sierra de Colonche, on the coast, and the canyon of the Río Paute as it descends to the Amazon Basin.

In the Cañar-Azuay area, the volcanics of the Cordillera Occidental trend northeasterly and dip moderately to the southeast. The rocks of the Cordillera Oriental also trend northerly, but show complex faulting. The basin itself has two main structural divisions, trending NE to NNE. The eastern half is moderately folded, with a zone of thrust faulting; the western half is only slightly folded, dips of 5° to 15° being typical. The older rocks are exposed in the eastern half, the younger in the western.

Cross structures have been mapped at many places, but since they are, for the most part, older than the northerly trends, their total effect is not always apparent. A fault, trending E-W passes through Santa Rosa, offsetting the Santa Rosa and Turi Formations. Another passing through Sidcay, raising Cretaceous volcanics to a level with the Santa Rosa Formation, may coincide with a line of anomalies indicated by the results of the airborne magnetic survey (22). Numerous minor cross faults, some of them apparently tear faults at the ends of thrusts, have been mapped in the eastern half of the basin. A cross fold, with dips of 10° to 20° can be seen from vantage points along the upper course of the Río Azogues, westward from Nazón.

The main anticline on the eastern half of the basin can be followed from Biblián southward past Cojitambo to the vicinity of Descanso, (where the strike of the axis changes from northerly to northeasterly) then as far as Chilicapampa, near Cuenca. The Biblián Formation occupies the central zone, (Map N°4). It is flanked by the Azogues Group to the east, and by this group plus the Ayancay to the west. The corresponding syncline has the Guapán Formation in its central area around Azogues: south of Chuquipata, where the Guapán is missing, it has only the Azogues.



Photograph V: Turi fault - steeply inclined Mangán Formation (foreground) and flat-lying Turi Formation (background).

Fotografía V: Falla de Turi - Formación Mangán con fuerte pendiente (primer plano) y Formación Turi horizontal (segundo plano).

The dips on the limbs of these two complementary folds range from 25° to 55°. A set of minor anticlines and synclines, in the order of 100 to 200 m broad, can be seen along the road from Azogues to Biblián (Photo II).

The flexures in the western half of the basin are much broader (1 to 5 km in wavelength), with flat dips. They are not persistent in length, and since they involve only the younger formations, where markers are lacking, just the well established examples are shown on the maps. The Burgay anticline, which was drilled to a depth of 325 m, is about 5 km broad, with a smaller, well-defined syncline to the east. The Sidcay anticline has a breadth of about a kilometre, with moderately steep limbs. Both these folds border the main fault which divides the basin in two.

The Turi fault, like most of the others in the district is nowhere exposed to view, but it can be mapped accurately at a 1:50,000 scale, from its effects on basin sediments. Near Turi it is marked by a zone 100 m wide of vertical and overturned beds. The Ayancay and older Formations on the east side of the zone are moderately folded; the Turi Formation on the west side dips 10° southward. Near the bridge at the north end of Cuenca airport, the Ayancay beds east of the fault dip 75° NW; those on the west dip 25° SW. On the Río Sidcay, north of Ricaurte, the beds on the east side dip 30° NW; those on the west side are folded into an open syncline. For the length of the Río Deleg the fault zone is poorly exposed, but separates steep or overturned beds on one hand, and flat (5°-10°) beds on the other (Photo V). At Turupamba and also at Nazon, the less deformed beds are folded into an open syncline. The Turi fault has been traced by a strong lineament, with lakes, as far north as El Tambo, and as far south as the vicinity of Tarqui; beyond this its effects are undetermined.

Another fault, possibly of the same set, extends north-eastward from the Ricaurte road across the Río Sidcay. Within the fault zone, about 150 m wide, the strata are steep or vertical, but to either side they are nearly flat. The contact between the Turi and Santa Rosa Formations has been raised about 200 m on the east side. The effect is that of a reverse or steep thrust fault. The vertical strata are presumed to be isoclinally folded. A similar relationship is seen in the Llacao Volcanics near the type section. Although dips in this young series are generally less than 10°, the EW trending zone in the canyon north of the village has dips as steep as 80°.

Faulting is also indicated by the alignment of travertine deposits, especially those along the base of the Cordillera Occidental. The main belt N20-30°E, has been traced more than 70 km from Baños to El Tambo. Deposits within the belt are localized by EW faults.

The ages of the faults in the Cañar-Azuay area are difficult to determine. Most of the E-W set are probably older, but movement along some of them may have been repeated.

The thrust faults mapped in the Cojitambo area are probably related to the folding in the main Andean Mio-Pliocene orogeny. Many of the strike faults in the same sector may have a strike-slip component, in keeping with similar faults elsewhere along the Pacific coast of the Americas.

5.2 Loja Basin

This basin is a part of Operation N° 1-b located south of the Cañar-Azuay Basin described above.

During the Project an area of some 200 km² were mapped with the use of aerial photographs on a scale of approximately 1:50,000 (Map N°5).

The present form of the basin is elliptical and measures some 20 by 10 km elongated in a N-S direction. The area is drained by the Río Zamora and its tributaries, which flow northward through the centre of the basin, and turns then eastward and descends into the Amazon system.

The Loja Basin is made up by rocks ranging in age from probably Palaeozoic to Quaternary. The stratigraphical units are not as finely defined as in the Cañar-Azuay Basin, but it appears that the divisions used (1) meet their purposes. Table III gives the stratigraphical column as elaborated by Alvarado (1) and used in the attached map of that area (Map N°5).

The surroundings and the basement of that basin are formed by metamorphics of probable Palaeozoic age. This series consists of schists, quartzite and gneiss and appears to be unconformably overlain by the Lower Tertiary Trigal, (argillites, pelites) which outcrop along the northwestern side of the basin. There the Trigal appears to form the western limit of some NE trending folds. Their core is underlain by the Middle Tertiary Belen consisting of conglomerates and limestones. The central zone along the eastern side of the Zamora River consists of easterly dipping Upper Tertiary sediments, mostly siliceous shales, limestones and marl, and intercalated coal seams. These siliceous shales, bleached white, form conspicuous outcrops in a belt of several kilometres wide. Some beds, up to 5 m thick, are composed of a very fissile laminated rock, containing an average 84% silica, with a density of less than 0.7. Samples collected and analysed by the Project have the results presented on Table IV.

TABLE III
Stratigraphical Column

<u>Loja Basin</u>		
FORMATION	LITHOLOGY	OBSERVATIONS
Loja	terraces, valley fill	
Quillollaco Quaternary	conglomerates	
San Cayetano Upper Tertiary	conglomerates shales	intercalated coal seams
Belen Middle Tertiary	conglomerates limestones	
Trigal Lower Tertiary	argillites, pelites	
? Palaeozoic	metamorphics: schists, quartzite, phyllites	

TABLE IV
Siliceous Shales (Sinterite or Diatomite)

Sample N°	SiO ₂	Fe ₂ O ₃ & Al ₂ O ₃	<u>Loja Basin</u>		MgO	Apparent Density (60 mesh)
			CaO	MgO		
J-142A	81.2	2.5	0.05	0.11	0.7	
J-142D	86.3	3.2	0.06	0.07	0.7	
J-142E	84.7	2.2	0.18	0.08	n.d.	
J-144	84.9	2.5	0.09	tr	0.6	

n.d. = not determined

Locations.

- J-142A: 300 m SE Loja stadium: channel sample 3 m across.
 J-142D: road E of Loja waterworks: zone 3 m across.
 J-142E: Zamora road, first sharp bend: channel sample 4 m across.
 J-144: San Cayetano, along road: channel sample, zone 5 m across.

Intercalated with these siliceous shales are several layers of dense, white, siliceous dolomitic marl, which is quarried for lime. This marl was also sampled and analysed giving the following results:

TABLE V

Dolomitic Marl

Chiguilanchi Area, Loja

Sample N°	CaO	MgO	SiO ₂	Fe ₂ O ₃ & Al ₂ O ₃	CO ₂	P ₂ O ₅
S-1601	26.6	14.4	14.0	6.8	37.5	tr
S-1602	15.5	6.6	43.1	12.9	21.6	tr
S-1603	24.8	11.6	24.8	5.9	32.4	tr
S-1604	14.5	4.9	49.1	13.6	17.7	tr

Locations

S-1601 : Pitas, Q. Cajas.

S-1602 : Chinguilanchi quarry.

S-1603 : Bolonia, 'Q. Cajas.

S-1604 : Río Japiro.

This sedimentary series carries an abundance of tropical plant leaves, fresh water fishes (Carrionellus) and gastropods (Pyrgula), that suggest a lacustrine environment.

The belt of Upper Tertiary San Cayetano is surrounded by Quaternary conglomerates, which apparently show slight depositional dips.

5.3 Malacatus Basin

This sedimentary basin lies south of Loja and is named after the township Malacatus located in the southern part of the basin. It extends for some 40 km north-northwest from the Yangana village to Catamayo. An area of some 280 km² has been mapped by the Project (Map N° 6).

This area of investigation is underlain by similar stratigraphic and lithological units as the Loja Basin. The rocks range in age from probably Palaeozoic to Quaternary and comprise metamorphics, clastic sediments and volcanics as shown in the following Table VI.

TABLE VI
Stratigraphical Column
Malacatus Basin

FORMATION	LITHOLOGY	OBSERVATIONS
Quaternary	volcanics; boulder gravel	
Upper Tertiary	siltstone, shale, clay, sandstone	intercalated coal seams
Lower Tertiary	conglomerate, shale clay	
Mesozoic	volcanics	
Palaeozoic (?)	metamorphics: schists, quartzite	

The metamorphic series of probable Palaeozoic age forms the eastern boundary of the Tertiary sedimentary basin, while it is limited to the west by Mesozoic volcanics. From the Loja Basin it is separated by several kilometres of graphitic schists. The Tertiary sediments are found in two roughly N-S aligned belts, that appear to be separated by NW striking faults, now covered by younger gravel. Both belts show a N-NW strike and a 30-50° easterly dip. This Tertiary sequence consists of a lower part, made up by clastics, conglomerates, shales, clay, etc., and a higher section, where coal seams are intercalated with shale, clay and siltstone and overlain by beds rich in gypsum and sandstones impregnated with hydrocarbons. A great part of the central area is covered by Quaternary conglomerates, while in the NW part some volcanics of the same age occur.

6. GEOPHYSICS

An airborne magnetometer survey of the southern Ecuadorian Andes was made in 1964-65 by S.A.P.A. (22) under sub-contract by the Projects' counterpart organization, the Servicio Nacional de Geología y Minería. Scintillometer readings were taken simultaneously over parts of the region, but difficult flying conditions prevented a complete report.

The contractor's interpretation, on 1:250,000, agrees well with the Project's geological mapping. The present limits of the Cañar-Azuay basin are clearly outlined because of the strong contrast

between the sediments and volcanics. In the area west of Cuenca, along the Río Matadero, however, the contact is obscured, possibly by piedmont debris. The distinction between ? Cretaceous and younger volcanics is also accurate for the most part.

The most conspicuous single anomaly is that of Cojitambo, an isolated peak of andesite porphyry surrounded by sediments. Lesser anomalies to the north coincide with similar intrusives in the volcanics, and others, in line southward, suggest that the belt is unexposed in that direction. Cerro Abuga on the east edge of the basin north of Azogues, is not discernible, probably because much of the rock is highly altered.

A line of magnetic lows, trending westward through the basin from the end of Tahuall canyon, was interpreted by the contractor as a major fault. Although precise correlation is not possible, faults with this trend have been mapped in the area, and probably also control the drainage and emplacement of intrusives in the canyon. Westward along the same line, in the Molleturo area of the Cordillera Occidental, the scintillometer detected a reasonable anomaly, which was one of several similar anomalies checked on the ground with negative results by the International Atomic Energy Authority (4).

7. COAL

7.1 Introduction

Except for small lignite occurrences reported from Miocene sediments in the Amazon basin and from the San Mateo Formation of the Pacific coast, the known deposits of coal and lignite in Ecuador are in the high Andean Basins situated between the Cordillera Occidental and the Cordillera Oriental. The setting is geologically similar to that of the Cauca valley of southern Colombia where coal is being mined on a relatively large scale (2).

Peat or lignite, mixed with silt, occurs at San Antonio de Pichincha, 32 km by road north of Quito. The seam, 2 to 4 m thick, is exposed in the Río Monjas at the municipal swimming pool, and on the west bank about 1800 m to the south. The topographic expression on the Quinche 1:50,000 sheet suggests an early Pleistocene lake, 2 km x 10 km, filled with plant debris, and covered by 15 to 20 m of pumice and cangagua (loess). An attempt in the late 1940's to mine the mineral for use in the nearby lime kilns was given up for unknown reasons.

Lenticular seams of lignite, interbedded with sandstone and shale, have been reported from Nabon, on the upper reaches of Río León, roughly half-way between Cuenca and Loja. They are considered too small to exploit, (2C). The question of continuity of the coal measures between the Cañar-Azuay, Loja and Malacatus basins is thus raised. So much of the region is covered by thick Pliocene volcanics, however, that chances of finding concealed deposits are negligible. For this reason, the project concentrated on the main basins.



Photograph VI: Cañari coal seam, Ayancay, note numerous partings of clay and shale.

Fotografía VI: Veta de carbón de Cañari, Ayancay, se puede observar las numerosas láminas de arcilla y lutita.

7.2 Cañar-Azuay Basin, Cuenca

The Cañar-Azuay coalfield has been investigated by numerous engineers and geologists over the last 15 years.

As already mentioned earlier the coal-seams in the Cañar-Azuay Basin occur within the Miocene(?) Mangán Formation over a N-S extension of some 25 km. Although the Formation extends much further in both directions, apparently only the central deeper part of the basin was favorable to coal deposition. This is indicated by the higher ash content of the coal at both ends of the 25 km belt.

Detailed mapping at 1:10.000 (Map N°s 3 and 4) was therefore limited to the sector between Burgay and Ayancay, a distance of about 15 km.

This map shows two parallel coal zones, 500 to 700 m apart called the Washington and Cañari. The older Washington has, on average, three or four seams, and numerous thin layers within a zone of argillite and clay about 50 m thick. All the seams are lenticular, and vary radically in thickness. At the San Nicolas (Cushumaute) mine, for example, the seam in the western adit is 6 m thick at the entry, but less than a metre thick at the top of the hill. The Cañari zone has one main seam with a few associated selvedges. It ranges in thickness from 2 to 5 m and is both more nearly continuous and more extensive than the other zone. This coal zone forms the eastern limb of a number of N-S striking folds, and its dip varies from 30° - 70° W to 30° - 70° E (overturned).

The seams are composed of coal and lignite, in variable proportions, with partings of clay and shale, (Photo VI). The thicker beds have a higher proportion of coal (vitrain, with minor fusain), but all have layers of lignite.

A typical cross-section mapped (18) at the Quebrada Cochahuaico is given below:

Strike 175° - 200°, dip 50 - 75° W.

TABLE VII

Hanging wall:	argillaceous shales	
	"Cañar seam" consisting of:	
	pure coal	0.25 m
	brown shales	0.20 m
	pure coal with pyrite	0.55 m
	argillaceous shales with coal layers	0.30 m
Hanging wall:	shales and sandstones	300-400 m
	"Washington 3" seam	0.90 m
	whitish shales	4.00 m
	brown sandstone	1.80 m
	sandy shales and argillites	20.00 m
Hanging wall:	"Washington 2" seam	1.20 m
	brown sandy shales	0.20 m
	coal shales	0.90 m
	argillites	15.00 m
Foot wall:	"Washington 1" seam	0.45 m
	coal with gypsum	
	sandstones	

7.3 Loja and Malacatus Basins

The coal belts of Loja and Malacatus were already described before this Project (18) and mapped in detail (23).

In the Loja Basin, the coal beds occur in the Upper Tertiary San Cayetano Formation. This has a northerly strike and a dip between 20 and 85° E. A total of five seams between 0.65 and 1.20 m wide intercalated in clastic sediments such as argillites, shales and argillaceous sandstones are described (18).

A similar geological setting is mapped in the Malacatus Basin, where 8 coal seams occur with an average 40° strike and 30° dip to the south. The Upper Tertiary sediments consist of conglomerates, sandstones, clays, and argillites intercalated with gypsum layers. The following profile is mapped and described by the German Geological Mission (18):



Photograph VII: Coal seam, Malacatus.

Fotografía VII: Veta de Carbón, Malacatus.

TABLE VIII

Hanging wall:	clays with gypsum layers in ratio 3:1	+100 m thickness
	Seam 8, pure brilliant coal	2.00 m
	light grey + grey argillaceous sandstones	36.00 m
	conglomeratic sandstone	2.00 m
	grey argillaceous sandstone	10.00 m
	carbonaceous shales	0.50 m
	brown shales with carbonaceous matter	3.20 m
	Seam 7 coal	0.20 m
	brown shales and argillaceous sandstones	1.70 m
	Seam 6 coal with bands of brilliant coal and appreciable quantities of pyrite	1.30 m
	shale	0.15 m
	argillaceous sandstones	1.80 m
	Seam 5 brilliant coal with 0.10 m intercalated clay	0.30 m
	argillaceous sandstones	1.20 m
	clay and argillaceous sandstone with gypsum	1.90 m
	Seam 4	0.10 m
	grey-brown clay	1.70 m
	Seam 3 brilliant coal with pyrite	0.10 m
	clays of different colour	8.40 m

TABLE VIII (cont'd)

Seam 2 coal	0.25 m
carbonaceous shales	1.20 m
Seam 1 total	3.50 m
upper part: pure coal	0.15 m
shale	0.45 m
brilliant coal	0.45 m
grey shale	0.10 m
coal	0.12 m
shale	0.20 m
central part: brilliant	
coal with high pyrite	1.00 m
lower part: shales	0.45 m
brilliant coal	0.70 m
grey-brown shales	4.00 m
Foot wall:	
conglomerates	+2.50 m

7.4 Evaluation

7.4.1 Introduction

Operation 1 was orientated towards the assessment of the coal basins of Cuenca-Biblián and Loja (including Malacatus). As mapping progressed the enormity of this task, considering funds and time allocated, became more and more apparent. After brief preliminary work in the latter part of 1965 and early 1966 it could be clearly seen that, due to the quality of the coal and its structural configuration, that large scale mechanized mining to produce coal for thermo-electric power was hardly economically feasible. Over the 25 km strike of the coal-bearing section of the Mangán Formation coal seams are lenticular, sheared, faulted and otherwise unpredictably discontinuous. Dips of the coal seams are always near-vertical and both foot and hanging walls are generally composed of brittle fissile shales, bentonitic clays and irregular blocky sandstones. It was known that the one mine in production, San Luis near Biblián, which was supplying coal to the nearby Guapán cement factory could barely keep their costs below \$1,000 (US\$ 50.00) per usable ton of recovered coal before its closure in 1967. This extreme cost was due mainly to the aforementioned conditions (i.e. timbering costs due to extremely weak wall rocks, near-vertical position of the seams, and the poor quality coal, or lignite, excessively intercalated with, and therefore diluted by, barren shale seams).

The excessive costs of retreat longwall mining methods due to the numerous coal gangways that would have to be developed over the long narrow zone, plus the expensive backfilling required, would not be in keeping with the poor quality product. The only other feasible mining method for the area, that of sub-level caving, would be too prone to fire developments (19).

Even taking into account the above situation a preliminary drilling programme was drawn up. This was aimed at: 1) an investigation of the steeply dipping seams at some depth away from the existing mining works, and; 2) testing the possibility that the same coal seams exist at mineable depths in the less structurally disturbed western half of the basin. The first objective was attempted by the drilling of 269 m (880 ft) in the Ayancay area. Because of the steeply dipping seams the three holes attempted had to be well inclined. This necessary situation and the fact that wall rocks consisted of hard tuffaceous sandstone interbedded with soft bentonic clay caused grave and costly technical difficulties. Coal seams were not intersected and it was decided to abandon this phase of the drilling programme. The second objective was carried out under sub-contract by Anglo Ecuadorian Oilfields Ltd. using a Failing rotary oil-well type rig. A total of 841 m (2760 ft) were drilled, but even the deepest well (366 m) failed to intersect coal at one of the most advantageous points in the western part of the basin. Even if intersection had been made, mining could not be effected at this depth.

At about this time (1967) good petroleum discoveries were made in the north of the Ecuadorian "Oriente" region. This changed the whole economic significance of the Operation, for with the possibility that Ecuador is to become a net exporter of petroleum this power source must obviously be preferred (19). Unless some extreme crisis develops whereby other fuel supplies, including the countries' own oil reserves, are cut off, it is recommended that no further industrial development is carried out on the coal-seams as now known and herein described.

7.42 Drilling

The geological mapping of the Project was followed by some test drilling, done by both Project personnel using a Winkie GW 10, Longyear 34, and Longyear 32, and under sub-contract with a Failing 2500.

The holes A1W, A2OW and A1OC drilled by Project personnel are located west of Ayancay (see Maps N^os 2 and 3) and were aimed at intersections of the Cañari and/or Washington seams. Due to technical difficulties all holes were abandoned: 159 feet (A1W), 370' (A2OW) and 359' (A1OC) without having reached their targets.

A total of three holes were drilled, under sub-contract, the two deepest being used to test the continuation of the coal seams at depth in the western part of the Basin.

Hole N° 1 was drilled some 600 m west-northwest of the Deleg village and was sited to check the presence of the coal seams underneath the Santa Rosa Formation. This site was specially selected as being located on an anticlinal structure, where the Carboniferous Mangán Formation probably approached near surface thereby reducing the drilling distance required for intersection. After about 10 m of soil and recent stream deposits, the hole entered bedrock consisting of sandstones composed mainly of fragments of volcanic rock with minor quartz, as well as of siltstone and clays. At 110 m green and grey bentonitic clays were encountered, which passed over at 204 m into siltstone and silty clay. At 302 m bentonitic and carbonaceous clays were encountered which indicated fair proximity to the coal measures (Appendix N° 1.) The hole was stopped at 366 m without intersection; virtually the limit of the machine at this altitude (2,300 m).

At San Nicolas, some 16 km west of Azogues hole N° 2 was drilled (Appendix N° 2) where two principal coal seams of the Washington group had been exposed previously by shallow depth mining. These coal beds enclosed in bentonitic clay with small lenses of siltstone strike about 20° and dip 35° - 60° NE (overturned). The hole intersected the structurally higher northeastern seam, (stratigraphically the oldest) at the predicted depth of 12 m. One metre of coal was recovered by coring over 18 m, and later only chips from two lenses at 64 and 67 m depth were indicated. The next seam was not intersected before the hole was stopped at 150 m. This fact indicates an abrupt steepening of the dip of the coal seam to more than 70°, and confirms geological observations over the whole coal basin that structures are extremely fickle.

The last hole, N° 3, was drilled at Burgay, in the northwestern part of the area (Appendix N° 3), located on the roof of a shallow anticlinal structure and was aimed at testing the depth of the coal horizons in the less structurally disturbed western part of the basin. The hole was started in piedmont debris (0 - 12 m), underlain by 6 m of agglomerate (Llacao Volcanics), to a depth of 18 m. Boulder conglomerates of the Santa Rosa Formation were intersected up to 52 m, and these in turn were followed by alternating beds of coarse and fine clastics, composed of fragments of volcanic rocks in red and grey clay to 207 m. From this depth until bottom at 325 m, bentonitic clays, sandstone, carbonaceous and pyritiferous clay as well as siltstone were encountered.

The conclusions to be drawn from these drilling results are, that the coal-bearing Mangán Formation may be present in the western part of the basin but is too deep to be mined. That coal seams lense out and were not intersected at these depths because of their absence is improbable because the white marker horizon just below the Cañari seam (p. 18) was not intersected in either hole N° 1 or N° 3.

7.43 Quality and Reserves

7.431 Cañar-Azuay

The chemical composition of numerous coal samples taken at the Cañar-Azuay Basin were published prior to this work (3). These were generally confirmed by the analytical results of samples collected by the Project. The obtained humidity percentages vary from 0.3 to 16%, the ash content from 6.5 to 60%, while the sulphur content ranges from 1 to nearly 18%, with an average around 5%. The calorific value varies according to the different ash contents from 1.000 Cal/kg. up to 6.500 Cal/kg, with an average of some 4.000 Cal/kg. A coal with this calorific value is to be classified as sub-bituminous C-coal according to ASTM standards. (3) This is one grade above lignite.

The following table presents the more detailed results of the chemical analyses of coal samples from the Cañar-Azuay Basin.

TABLE IX

COAL ANALYSES

CAÑAR - AZUAY BASIN

Sample N°	Humidity%	Ash%	Sulphur%	Cal/kg.	Location
S 1055	0.3	18.2	3.2	6523	Chiquintad Washington Seam
S 1045	0.1	19.6	11.0	6598	" "
S 1056	2.0	25.9	17.3	4489	Cochahuaico "
S 1052	3.4	27.2	17.6	4276	" "
S 1000	3.0 (air)	17.2	6.2	4410	" "
S 1001	3.6 "	24.1	5.0	3970	" "
S 1002	2.3 "	34.0	5.7	3410	" "
S 1003	3.2 "	11.2	5.2	5315	" "
S 1005	3.5 "	11.6	6.2	4400	" "
S 1007	2.7 "	48.1	5.7	2500	San Luis "
S 1008	1.3 "	29.1	6.8	3781	" "
S 1009	2.6 "	24.8	3.1	4094	" "
S 1026	6.2	37.5	4.1	3241	Biblián "
S 1030	11.7	7.2	1.1	5358	S.C. "
S 1031	12.1	7.2	1.0	5393	" "
S 1032	12.6	6.4	1.0	5539	" "
S 1033	13.0	7.6	6.7	5788	" "
S 1015	15.3	45.4	4.9	2634	Corasapel "
S 1016	10.5	45.1	2.1	2354	" "
S 1017	6.6	41.2	11.1	2368	" "
S 1018	9.6	46.4	7.9	2113	" "
S 1019	9.0	35.7	8.9	2511	" "
S 1020	16.5	50.8	7.3	1201	" "
S 1021	7.9	60.2	4.0	1021	Jatun Loma "

TABLE IX (cont'd)

Sample N°	Humidity%	Ash%	Sulphur%	Cal/kg.	Location
S 1022	13.6	36.1	4.4	2931	Matun Loma Washington Seam
S 1023	11.9	53.1	4.9	1736	"
S 1024	13.3	44.4	3.8	2141	"
S 1025	12.7	41.9	3.5	2432	"
S 1010	11.6	42.3	5.8	2444	Rochan Cañari Seam
S 1011	16.1	42.3	4.0	2309	" "
S 1012	12.3	42.9	4.1	2055	Caldera "
S 1013	7.0	24.3	6.3	3226	Capa Rosa "
S 1014	8.3	42.3	5.9	1989	" "

Within this area the calculation of coal reserves in advance of mining is very difficult, if not impossible, due to the numerous irregularities in the thickness of the seams that have rather the form of lenses than that of a continuous coal measure. There are, however, some recent appraisals of this coal belt, which show probable reserves between 15 and 25 million tons (14, 18, 28). The factors used as a basis for these are shown in Table X.

TABLE X

Source Reference	Seam	Strike (m)	Depth (m)	average width (m)	Sp. grav.	Reserves
(28)	total zone	10,000	500	3	1.4	21,000,000
(14)	total zone	7,500	500	3	1.4	15,750,000
(18)	Cañari	14,000	500	0.95	1.4	9,300,000
	Wash. 4	2,000	250	0.65	1.4	450,000
	Wash. 3	10,000	400	1.10	1.4	6,200,000
	Wash. 2	8,000	400	1.10	1.4	4,900,000
	Wash. 1	5,000	400	0.60	1.4	1,700,000
						22,550,000 metric tons

7.432 Loja

The chemical properties of the Loja coal are similar to those described above, with humidity between 3 and 12%, ash between 8 and 48% and sulphur varying from 2 to 11%. The calorific values average 4000 Cal/kg. The following table lists analyses of samples collected by the Project.

TABLE XI

<u>Sample N°</u>	<u>Humidity %</u>	<u>Ash %</u>	<u>Sulphur %</u>	<u>Cal/kg.</u>
B 1	12.1 (at 20°)	9.0	8.7	5360
B 2	12.0 "	9.3	6.5	5525
B 3	5.4 "	7.9	8.1	4732
S 1034	10.4 (free)	21.2	1.9	4592
S 1036	11.0 "	28.4	2.9	3661
S 1037	9.7 "	32.6	2.5	3364
S 1038	5.8 "	48.4	9.7	5878
S 1039	4.3 "	12.3	7.5	2652
S 1040	6.4 "	13.1	8.4	5792
S 1041	7.4 "	29.5	2.9	3968
S 1042	7.3 "	36.1	2.7	3439
S 1043	4.2 "	39.8	7.9	3301
S 1044	4.7 "	37.3	3.8	2728
S 1054	3.2 "	40.9	11.1	2972

Analyses by Laboratories of the National Geological and Mining Service, Quito.

The lower calorific power of these samples indicates that according to the ASTM classification the Loja coal is between sub-bituminous C coal and lignite.

An appraisal of the coal potential of this district shows the same uncertainties as previously described in relation to the Cañar-Azuay Basin. The Loja area, being somewhat remote from the centres of industrial development within the country, makes coal exploitation from here even less attractive than from the Cañar-Azuay area. An attempt, however, was made to evaluate the probable reserves (18, 23) which amount to between 1 and 3 million tons. Table XII summarizes the basis for these calculations:

TABLE XII

Source Reference	Seam	Strike (m)	Depth (m)	Average		Reserves (+)
				Width (m)	Speç Weight	
(18)	Seam 1	2,000	300	1.00	1.4	840,000
	Seam 2	2,000	300	1.00	1.4	840,000
	Seam 4	2,000	300	1.10	1.4	924,000
	Seam 5	2,000	300	0.80	1.4	672,000
	Seam 6	2,000	300	0.60	1.4	504,000
						metric tons
(23)	Seam 1					310,000
	2					155,000
	4					58,000
	5					70,000
						metric tons

7.433 Malacatus The composition of Malacatus coal was determined for 8 samples, and the results are listed in the following table:

TABLE XIII

<u>Sample N°</u>	<u>Humidity %</u>	<u>Sulphur %</u>	<u>Ash %</u>	<u>Cal/kg.</u>
S 1047	2.8 (free)	9.4	17.1	3852
S 1048	1.3 "	9.9	12.7	4822
S 1049	1.2 "	8.9	15.6	4429
S 1050	2.4 "	8.8	16.9	4319
S 1051	2.4 "	9.4	15.1	4284
S 1052	0.6 "	9.1	11.5	5033
S 1053	3.8 "	3.6	16.2	4954
S 1035	7.5 "	2.9	48.3	2342

The calorific value is similar to the average of the Loja coal and is thus classified as a sub-bituminous C-coal.

Since no new data was obtained for a reserve calculation the results are listed of previous investigations (18,23) which calculated the potential as between 0.8 and 3 million tons, as shown in the following table:

TABLE XIV

Source Reference	Seam	Strike (m)	Depth (m)	Average Width (m)	Spec Weight	Reserves (+)
(18)	Seam 3	1,000	500	2.00	1.4	1,400,000
	Seam 1	1,000	500	2.70	1.4	1,390,000
						3,290,000 metric tons
(23)	Seam A	---	---	---		
	Seam B	---	---	---		712,500
	Seam C	---	---	---		metric tons

7.5 Economic Considerations

As part of the United Nations work regarding the assessment of the lignite-coal deposits of Southern Ecuador, an exploitability analysis was carried out under sub-contract by Pierce Management Corporation, Engineers and Mine Managers, Scranton, Pennsylvania, U.S.A. (17). The referenced report so produced is in some sense regarded as complimentary to this Technical Report N° 1.

As mentioned previously, a decisive factor on the economic feasibility of mining the poor quality coal for electric power has been the recent discovery of petroleum reserves within Ecuador.

7.51 Markets

As shown above the coals of the three sedimentary basins studied are only of low quality due to their high ash and sulphur contents. This makes the coal unsuitable for domestic fuel, especially since tests made by the US Bureau of Mines at Denver, Colorado, in April 1952 failed to reduce the sulphur content to a point where it would be acceptable for this purpose.

Even its use for cement manufacture is, according to USA standards, not feasible, since a maximum sulphur content of 1.2% in the fuel is required to avoid difficulties in the process and deleterious effects on the product.

The coal/lignite is suitable for power generation, if the costs of coal versus oil are competitive. A high voltage loop is planned from Quito to Cuenca and Guayaquil and back to Quito, and is to serve as a base of power for the entire country. Electricity is planned to be generated by existing and projected hydroelectric plants and only one thermal generating plant of some 60 megawatt was considered for two reasons: to supply power for the daily peak load and to generate power when water is low during dry seasons. Based on calculations effected by Pierce Management (17) a yearly supply of some 150,000 tons of coal would be needed, which, calculated on a 250 working day year indicates a daily mine production of 600 tons. With feasibility studies well advanced on a new projected hydroelectric station on the Cola de San Pablo (Río Paute) approximately 45 kms to the NE of Cuenca, and with considerably increased petroleum production well in sight, it is strongly recommended that no further development work be considered for the coal areas.

7.52 Mining costs

Mining costs at the San Luis Mine operated for the Guapán cement factory near Biblián are reported for a four month period (July-October 1966). During this time the daily production amounted to some 30 tons, mostly from development work, and the number of workers reached 120. The costs broken down into the most important items are reported as follows:

Labour	231.60	Sucres/t +
Material	92.03	"
Miscellaneous	9.92	"
Amortization and Depletion	146.85	"
TOTAL	480.40	Sucres/t

+ At the time of publication S/ 23 = US\$ 1.00

These high costs which are known to have increased considerably after this period reflect the technical difficulties encountered at San Luis Mine:

- 1) Unfavourable roof and floor conditions of the fine clastic sedimentary shaly host rock, which requires heavy timbering of all rock tunnels, coal gangways and raises on metre centres or less.
- 2) lenticular seam structures, and limited thickness.
- 3) moderate to steep dip of the coal seams, and
- 4) faulting which results in the unminability of some 25% of the possible mining area.

All of these factors led finally to the point where the San Luis Mine had to cease operations.

The theoretical mining cost as estimated by the consultant (17) ranges from 350 sucres (480 sucres actual cost minus a reduced amortization and depletion, which seems to be exaggerated) to 150 sucres/ton.

7.53 Oil versus Coal for Electric Power

If the planned peak-load generation plant should use oil as fuel it would probably be located on the coast at the projected Ecuadorian pipeline terminal, or, as at present, tanker docking facilities. At the time of writing oil is reported to be available on the coast at S/ 58 per barrel, this being somewhat higher than the world price: probably S/ 40 to S/ 46 per barrel for Bunker C oil in tanker lots, and even cheaper when the Ecuadorian "Oriente" fields become productive (?1970-71). Based on the heat value of 1.5 million Cal/kg. per barrel the cost for that value will be S/ 56, S/ 40 to S/ 46 or even cheaper depending on final oil-procurement.

The heat value of one ton of Cuenca coal approximates 3.8 million Cal/kg. and as such in heat value, 2.5 barrels of oil would be equivalent to one metric ton of Cuenca coal.

Based on these calculations Cuenca coal, to be even competitive with the presently highest quoted price of available oil (S/ 56) would have to be delivered to the plant at S/ 140 per ton. As can be seen from these quoted costs this represents an economic disadvantage of using coal against oil for the same heat value of at least S/ 340 per ton of coal used based on last available coal-mining costs (p. 50). It is the Project's opinion that mining costs of Cuenca coal considering quality of its seams and geological conditions, could never be reduced to a competitive level.

8. HYDROCARBONS

Asphalt seeps - Several oil companies investigated the Cañar-Azuay Basin in the 1930's and found asphalt seeps at numerous localities, but lacking base maps, they could not correlate them with the stratigraphy and structure. In this brief section an attempt is made to place the seeps in their geological setting and to explain their origin. Reference is made to Map N° 2 where the occurrences are plotted.

Starting from the south to north, the first asphalt occurrence in the basin is near Chilcapampa, 5 km east of Cuenca on the road to El Valle, on top of the hill 1 km east of town, and 100 m south of the road junction. Excavation for a house, in 1966, brought to light a vein of asphalt about 50 cm thick, and further examination revealed discontinuous masses for another 600 m northward. The material is dark brown to black, hard, massive, with a vitreous luster and conchoidal fracture. It burns with a hot, yellow flame, and distinct intumescence, and appears to resemble gilsonite found in the petroleum regions of the Oriente. Trenching indicates that the deposit is very irregular and not of sufficient size to be mined for asphalt as such.

Its location, however, near the crest of the main anticline of the basin, is significant.

Other occurrences of asphalt, coating fractures in sandstone, were noted by Wolf (27, p.249) and Liddle (12, p.384) along Quebrada Paccha. These were not examined, but thin films of waxy bitumen coating fractures were found in the sandstone at the entry to Quebrada Malpaso.

The oil seep that Liddle describes from La Union, on the Río Ayancay, is apparently just off the west flank of the main anticline, between the Biblián and Loyola Formations.

Asphalt has been reported from the south slopes of Cerro Cojitambo by Wolf (27, p.249) and by contemporary inhabitants.

The exact location and setting of the asphalt on Quebrada Pichumazu, west of Biblián, cannot be determined from Liddle's description, but is apparently upstream of the coal deposits, possibly along the Turi fault.

Numerous showings of asphalt were observed in the area of Nazón and Burgay. Most are veinlets, a few centimetres thick, are along minor shear zones. The material is flexible, stretching like chewing gum, black, and burns with a smoky flame. A vein, 30 cm thick, of massive asphalt, similar to that from Chilcapampa, was uncovered at Patacorral ford. Asphalt, or a similar hydrocarbon, lines the cavities around cobbles in weathered conglomerate in a belt 2 km long northward from Nazón. These occurrences centre around the Burgay anticline: drillhole N° 3, 325 m deep, drilled by the Project on the axial plane (p.44) disclosed chips of asphalt in nearly every sample below 170 m, and, according to the villagers, oily artesian water began to pour out of the hole a few weeks after it was plugged.

To recapitulate: the asphalt of Chilcapampa, Río Paccha, La Union, and Cojitambo are along the western side of the core of the main anticline; the Pichumazu occurrence is apparently in the Mangán Formation, near the Turi fault; and the numerous Burgay showings appear to be related to the Burgay anticline, also in the upper part of the section. Since the rocks exposed in the core of the main anticline belong to the Biblián Formation, the oldest Tertiary unit in the area, the source rocks must be still older, i.e. in the San Marcos Formation. As shown previously, the black shales, black limestones, and lydites of this series contain considerable opaque organic material, either carbonaceous or bituminous. Weathered argillites of this series south of Quingeo have coatings of grey organic matter on joints. It seems very likely, therefore, that the asphalt in the Tertiary sediments has migrated upward from older Cretaceous strata. Distillation may have been effected in some cases by intrusives. The line of magnetic anomalies extending southward from Cojitambo (22) also coincides with the belt of asphalt seeps.

Although the Cretaceous series is exposed only along the east side of the basin, the extensive travertine deposits along the western side suggest that it also underlies the basin, inasmuch as the carbonate in these deposits was probably derived, by the leaching action of ascending hot water, from the San Marcos limestones or their equivalents.

Gas - No gas seeps have been found, but it has been suggested that methane may have been driven off the coal, over a long period of time, to accumulate under impermeable beds in anticlines, as in the Groningen field of the Netherlands. The thick clay beds of the Santa Rosa Formation may provide the requisite barrier, but whether there was originally a thickness of overlying sediments sufficient to provide adequate pressure is not known. A gas specialist, examining the area for the Institut Français du Pétrole is said to have considered conditions favourable. (Personal communication)

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DRILL LOG

AREA / ZONE - DELEG-20 Km W of Azogues

HOLE N° 1

START - 22/8/67 STOP - 4/9/67

AZIMUTH - 0 ANGLE - 90°

MACHINE - Failing 2500 DRILLER - Anglo Ecuadorian Oilfields

TOTAL DEPTH 366 m.

METERS	LOG	GEOLOGICAL DESCRIPTION	OBSERVATIONS
0-20		0-10 m - soil, stream gravel grey plastic clay	artesian water at 20 m.
20-40			
40-60		10-110 m - tuffaceous sandstone, siltstone and clays	carbonized driftwood at 25 m.
60-80			
80-100			
100-120			
120-140			
140-160			
160-180		110-204 m - bentonitic clay (green and grey)	
180-200			carbonized driftwood at 175 m.
200-220			
220-240			
240-260			
260-280			
280-300			
300-320		204-302 m - siltstone and silty clay	
320-340			
340-360			
360-366		302-366 - clay (dark green, bentonitic) and clay (brown carbonaceous).	
366		hole stopped at 366 m.	

DRILL LOG

AREA / ZONE CUSHUMAUTE MINE, near San Nicolás

HOLE N° 2

START 7/9/67 STOP 8/9/67

AZIMUTH 0 ANGLE 90°

COMPANY Falling 2500 DRILLER Anglo
Ecuadorian Oilfields

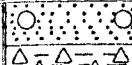
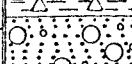
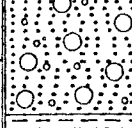



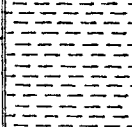
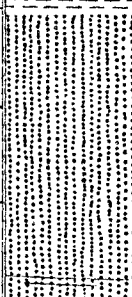
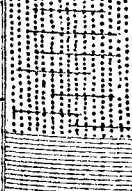
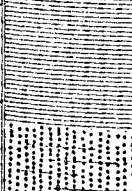
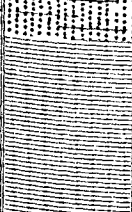
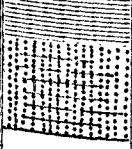
TOTAL DEPTH 150 m.

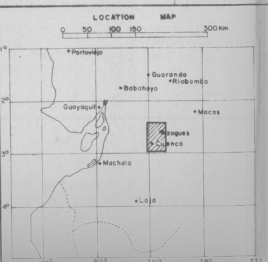
METERS	LOG	GEOLOGICAL DESCRIPTION	OBSERVATIONS
0		0-12 m: clay and silty clay.	
0		12-18 m: coal (one metre of coal recovered by coring probably comes from 17 to 18 m; plus 0.2 m of footwall).	
0		18-20 m: clay (green), bentonite.	hole inclined 0.3° at 38m.
0		20-150 m: clay (green), silty, bentonitic, with siltstone lenses 0.5 to 1.0 m thick.	
0		coal seams 0.5 m thick at 64 m and 67 m.	
0		clay, black, with coal fragments at 70 m.	
0			
0			
0		clay, carbonaceous, with coal fragments at 113 m.	
0			
0			
0		hole stopped at 150 m.	
0			
0		Note: stratigraphic sequence overturned.	

DRILL LOG

EA / ZONE BURGAY, 10 Km WNW of Azogues
 ART 12/9/67 STOP 20/9/67
 CHINE Falling 2500 DRILLER Anglo
 Ecuadorian Oilfields

HOLE N° 3
 AZIMUTH 0 ANGLE 90°
 TOTAL DEPTH 325 m.

TRES	LOG	GEOLOGICAL DESCRIPTION	OBSERVATIONS
		0-12 m: soil and piedmont boulder clay	
20		12-18.2 m: Llacao volc: hornblende-porphyr fragments in grey clay matrix.	
40		18.2-52 m: boulder conglomerate: volcanic fragments in red clay.	
60		52-67 m: siltstone, red clay, and fine-grained sandstone.	
80		67-78 m: conglomerate, volcanic pebbles in clay matrix.	
100		78-125 m: siltstone and red clay.	
120		125-177 m: sandstone; hard fine-grained, tuffaceous	Carbonized driftwood at 155 m. 169 m. 256 m.
140		177-207.5 m: argillaceous sandstone and clay.	asphalt fragments at 171, 174, 177, 201, 210, 225, 235, 241, 274, 253, 255, etc.
160		207.5-244 m: bentonitic clay; dark green, with silt.	coal chips at 296 m. 305 m. 317 m.
180		244-264 m: sandstone; dark grey, argillaceous, pyritiferous	oily asphalt at 320 m.
200		264-303 m: clay (dark brown); carbonaceous, bentonitic, pyritiferous.	
220		303-325 m: siltstone and dark silty clay.	
240		hole stopped at 325 m.	



SYMBOLS		LEGEND	
	CONTACT		TRAVERTINE, HOLOCENE, 0-15m
	FAULT		ROUS PEDIMENT DEBRIS, QUATERNARY, RECENT, 0-30m
	INFERRED FAULT		LLACAO VOLCANICS, QUATERNARY ASBOLMERATES VALLEY-FILL, PYROCLASTICS, 0-200m
	CONCEALED FAULT		TUMPAHUI SHOULDER GRAVELS, QUATERNARY, 0-30m
	THRUST FAULT		TARAOUI VOLCANICS, QUATERNARY ASBOLMERATES, 0-500m
	DRILL HOLE FOSSILS ASPHALT		TUMPAHUI SHOULDER GRAVELS, QUATERNARY, 0-30m
	LIMIT OF AREA MAPPED IN DETAIL		QUAN Formation, QUATERNARY CONGLONERATE SILTSTONE, 0-1200m
	TRAVERTINE QUARRY		ANDESITE PORPHYRY, LATE-MIOCENE (1)
	ABANDONED COAL MINE		SANTA ROSA FORMATION, PLEISTOCENE RED CLAY WITH CONGLOMERATES, CHANNEL FILL, PEDIMENT WEDGE, 0-300m
	SYNCLINE		MAMBA Formation, MIOCENE (1) SHALE, CALBENTONITE SILTSTONE SANDSTONE, CONGLOMERATE AND CLAY, 800m
	STRIKE AND DIP OF BED		CUSHAMUTE FORMATION, MIOCENE (1) SILTSTONE, SHALE, 400m
	STRIKE AND DIP OF OVER-TURNED BED		QUAN FORMATION, QUATERNARY (1) BLACK SHALES, BENTONITE, 0-100m
	DRILL HOLE FOSSILS ASPHALT		AZOQUES FORMATION, UPPERMOST EOCENE-OLIGOCENE MASSIVE TUFFACEOUS SANDSTONE, MINOR SILTSTONE, 500m
	LIMIT OF AREA MAPPED IN DETAIL		ANDESITE INTRUSIVE, LATE-CRETACEOUS (1)
	TRAVERTINE QUARRY		LIBLIAN FORMATION, MAESTROCHIAN-LOWER EOCENE RED FERRUGINOUS CLAYS, LENSES OF CONGLOMERATES, MINOR SANDSTONE, 0-800m
	ABANDONED COAL MINE		SAN MARCOS FORMATION, UPPER CRETACEOUS BLACK MUDSTONE AND LIMESTONE, MINOR PYROCLASTICS, ANDESITE, SILTS, 400m
	SYNCLINE		MIHUAN VOLCANICS, UPPER JURASSIC TO MIOCENE PYROCLASTICS, CHERT, ANDESITE SILTS AND FLOWS, 1000m
	STRIKE AND DIP OF BED		LAJOLA FORMATION, UPPER EOCENE CONGLOMERATES AND SANDSTONES, BLACK SHALES WITH LEAVES, 0-200m
	STRIKE AND DIP OF OVER-TURNED BED		ANDESITE INTRUSIVE, LATE-CRETACEOUS (1)
	DRILL HOLE FOSSILS ASPHALT		FAULTE SERIES PALAEOZOIC (1) METAMORPHIC SLATES QUARTZITES

SURVEY OF METALLIC AND NON-METALLIC MINERALS
 Servicio Nacional de Geología y Minería
 United Nations Development Programme

ECUADOR
 OPERACION N°1-0

GEOLOGICAL MAP CAÑAR — AZUAY

SCALE 1:50,000
 MAP N° 2



A-A'
B-B' CROSS-SECTIONS, Map No 4
C-C'

LEGEND

	CONTACT		STRIKE AND DIP OF BED		ALLUVIUM		ANDESITE PORPHYRY, LATE MIOCENE (?)		GUAPI FORMATION, OLIгоценE (?) (BLACK SHALE, BENTONITE, 0-100m)
	FAULT		STRIKE AND DIP OF OVERBURDEN		LOCAL VOLCANIC UNIT (TRACHYBASALT, ANDALUSITE, VALLEY-FILL, PLEISTOCENE 0-1000m)		SANTA ROSA FORMATION, PLEISTOCENE (RED CLAY WITH CONGLOMERATES, CHANNEL FILL, PRESENT WEDGE 0-500m)		AGDESUÉS FORMATION, UPPER MIOCENE-OLIGOCENE (MASSIVE TUFFACEOUS SANDSTONE, MINOR SILTSTONE 100m)
	THRUST FAULT		ANTICLINE		TANGUA VOLCANIC (QUATERNARY ANDALUSITE, SANDSTONES, 50m)		MANGAR FORMATION, MIOCENE (?) (SHALE, COAL, BENTONITE, SILTSTONE, SANDSTONE, CONGLOMERATE AND CLAY, 50m)		LOJA FORMATION, UPPER EOCENE CONGLOMERATES AND SANDSTONES, BLACK SHALES WITH LEAST 10-100m
	STRIKE-SLIP FAULT		EMBAYMENT		TOTA FORMATION, SLATY SHALES, (SAND, METAL, SILTSTONE, CLAY, 100m)		BIBLIAN FORMATION, MIOCENE-OLIGOCENE (RED CLAY, BENTONITE, SANDSTONE, CONGLOMERATE AND CLAY, 50m)		BIBLIAN FORMATION, WESTERN MIOCENE-OLIGOCENE (RED CLAY, BENTONITE, SANDSTONE, CONGLOMERATE AND CLAY, 50m)

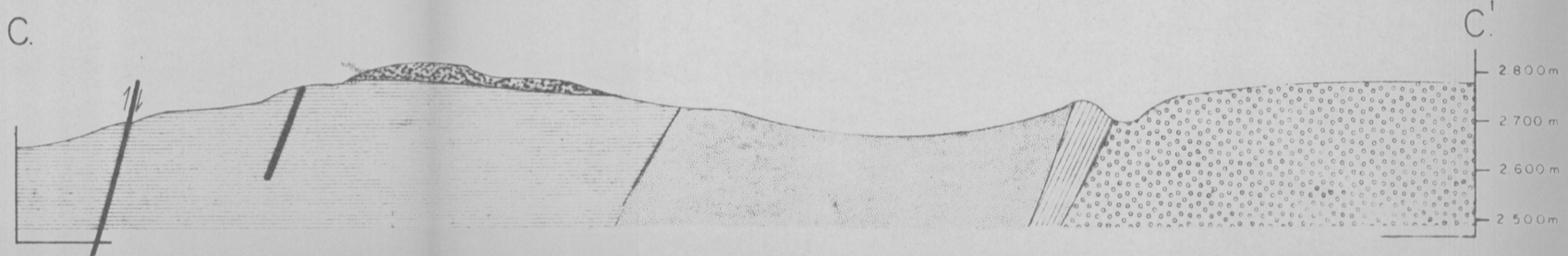
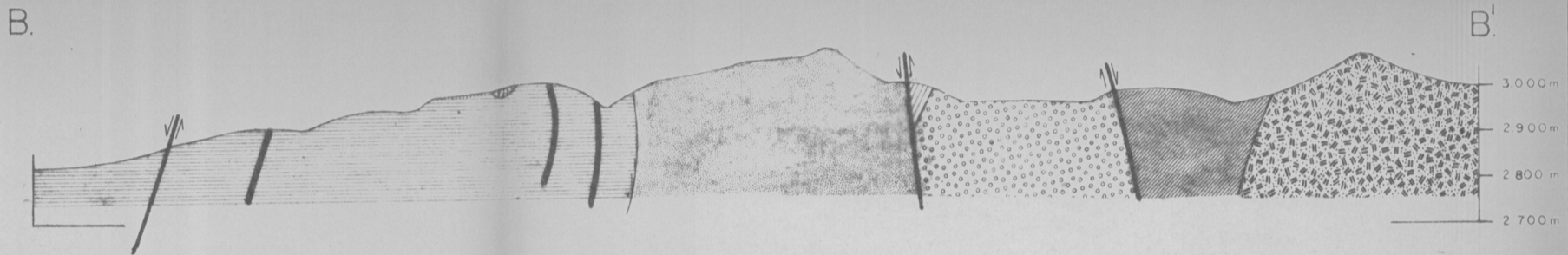
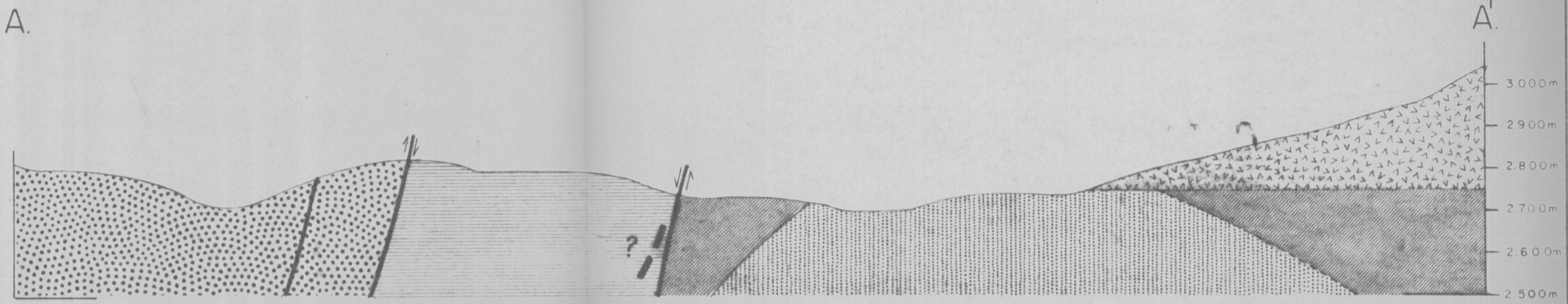
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 Servicio Nacional de Geología y Minería
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ECUADOR
 OPERACION N°11-Q

GEOLOGICAL MAP, BIBLIAN COALFIELD

MAP No 3

Scale: 1:100,000



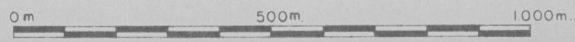
LEGEND

- | | | | |
|--|---|--|--|
| | LLacoo volcanics, Quaternary, agglomerates, valley-fill, pyroclastics. | | Guapan Formation, Oligocene (?): black shale, bentonite. |
| | Tarqui volcanics, Quaternary, agglomerates, ignimbrites. | | Azogues Formation, uppermost Eocene - Oligocene: massive tuffaceous sandstone, minor siltstone. |
| | Andesite porphyry, Late Miocene (?). | | Loyola Formation, upper Eocene: conglomerates and sandstones, black shales with leaves. |
| | Santa Rosa Formation, Plio-Pleistocene: red clay with conglomerates, channel fill, piedmont wedge | | Biblian Formation, Maestrichtian-lower Eocene, red ferruginous clay, lenses of conglomerate, minor sandstone |
| | Mangan Formation, Miocene (?): shale, coal, bentonite, siltstone, sandstone, conglomerate and clay. | | Contact |
| | Cushumate Formation, Miocene (?): siltstone, shale. | | Fault |
| | | | Coal seams |

SURVEY OF METALLIC AND NON METALLIC MINERALS

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ECUADOR
OPERATION N° 1-a
CUENCA — BIBLIAN
GEOLOGICAL CROSS - SECTIONS



Scale 1:10,000

June 1969












MAP N° 4



LOCATION MAP
OPERATION 1b



LEGEND

- | | | | |
|--|--|---|-----------------------------------|
|  | Loja Formation, Holocene, valley fill, terraces. |  | Strike and dip, bedding 50 |
|  | Quilloto Formation, Quaternary, conglomerates. |  | a) synclinal, b) anticlinal axis. |
|  | San Cayetano Formation, upper Tertiary, shale, conglomerate, coal. |  | Geological contact |
|  | Belen Formation, middle Tertiary, conglomerate, limestone. |  | Fault, a) observed, b) concealed |
|  | Injal Formation, lower Tertiary, pelites, argillites. |  | coal seam. |
|  | Metamorphics, Palaeozoic, phillites schists. | | |

SURVEY OF METALLIC AND NON-METALLIC MINERALS

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ECUADOR
OPERATION AREA N° 1-b

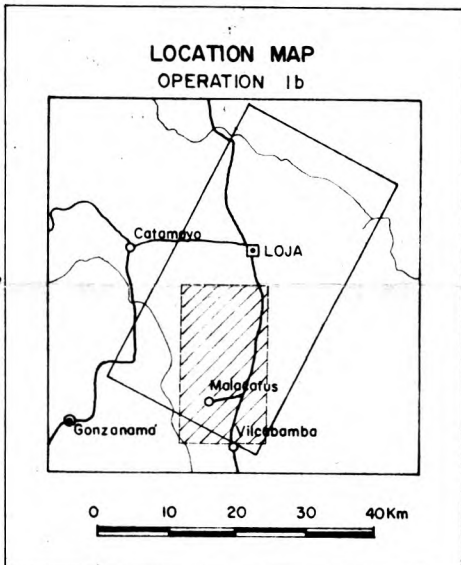
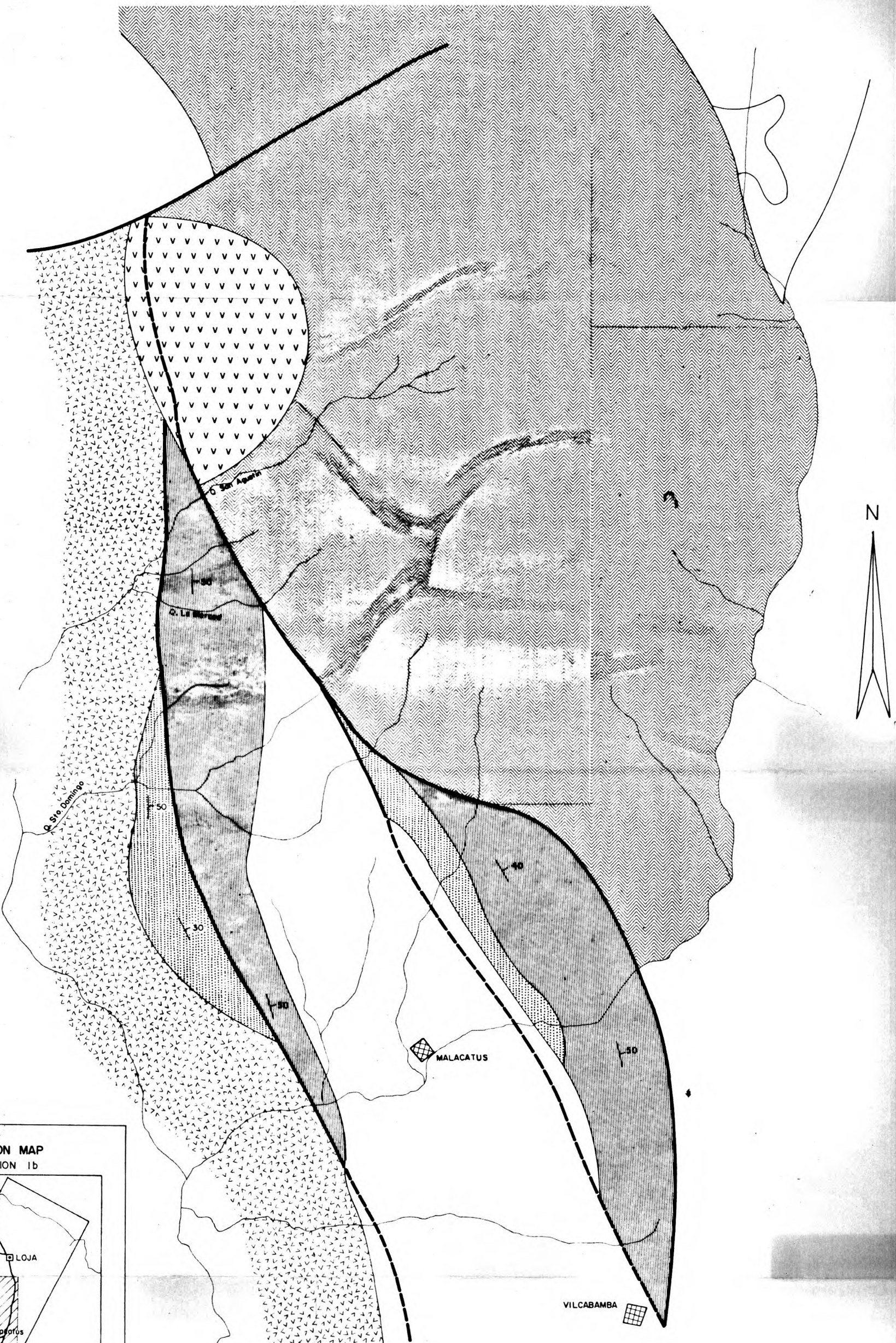
LOJA BASIN
GEOLOGICAL MAP



Scale
1:50,000

JUNE 1969

MAP N° 5

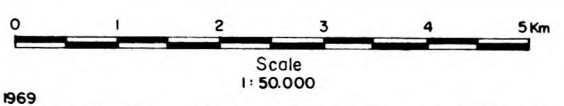


LEGEND

- | | | | |
|--|---|--|--------------------------------|
| | Quaternary; volcanics | | Paleozoic; metamorphics |
| | Quaternary; alluvial cover | | Geological contact |
| | Upper Tertiary; shale, siltstone, coal | | Fault; a) mapped; b) concealed |
| | Lower Tertiary; sandstone, conglomerate | | Strike and dip, bedding |
| | Mesozoic; volcanics | | Drainage |

SURVEY OF METALLIC AND NON-METALLIC MINERALS
 Servicio Nacional de Geología y Minería
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ECUADOR
 OPERATION AREA N° 1-b
 MALACATUS BASIN
 GEOLOGICAL MAP



JUNE 1969

MAP N° 6