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ANNEX No. 3

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. 3
CLAYS AND TRAVERTINE
(Operation No. 3 - Cuenca)

DECLASSIFIED

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

JUNE 1969

NEW YORK

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REPUBLIC OF ECUADOR

Ministry of Natural Resources and Tourism

General Direction of Geology and Mines

(Department of Geological Investigation)

United Nations
Development Programme

Survey of

Metallic and Non-Metallic Minerals

Technical Report

No. 3

Clays and Travertine
(Operation No. 3 - Cuenca)

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

New York

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OPERATION No. 3

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GENERAL

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, 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. Ecuador's National Service of Geology and Mines was designated as the Cooperating Agency. The Plan of Operations was signed on 24 December 1964 and work was continued until 30 June 1969.

Of the six operation areas, one with an extension of 2.610 km² situated in the south-central part of the Ecuadorian section of the Andes, between the cities of Cuenca and Azogues, was considered by the Government to be a promising area for clay and limestone (travertine) deposits. A small ceramic industry was being developed in Cuenca and a cement plant was operating near Azogues. Details of the materials required for industrial expansion were not known, but it was hoped that clay deposits to provide reserves for bricks, roof tiles and refractory and ceramic industries could be delineated.

Coloured "marble" (travertine) had been mined from the Cuenca area on a cottage-industry scale at least from the Inca period. It was considered that detailed work would ascertain the geological origin of these predominantly eluvial blocks which in turn might lead to mechanisation of the industry and reduce the amount of ornamental stone imports.

The evaluatory work over this area was known as Operation No.3 and is described in this Technical Report No.3 which is issued as Annex No.3 to the Phase I Final Summary Report. Work was initiated in 1965 and was terminated in October 1967 when preliminary technical reports were made available to the Government.

2. THE AREA OF INVESTIGATION

2.1 Location

The operation area is a NE oriented rectangle which covers the intramontane sedimentary basin extending from the SW of Cuenca to the N of Biblián. It is the same area as was investigated by the project under the terms of Operation No.1 in the evaluation of coal deposits and reported on by Technical Report No.1 (7). The area was defined by a Government reserve as follows: from co-ordinate point 02°25'24" S and 78°56'18" W a line of 30 km in direction E 26°30' S (116° 30') and from here a line running in the direction S 26° 30' W (206° 30') for 87 km, these forming the NE and SE sides of a rectangle which is then closed off to the S and W by parallel lines of equal length. (See Map No.1).

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 and longitude 72° 57' W. Several airlines provide daily services from Quito and Guayaquil to Cuenca. The railway (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 well paved, links Quito with Cuenca and continues southward through Loja to Peru. The Cañar-Azuay basin has over 1,000 km of all-weather roads which provide for excellent internal access.

2.2 Physiography

The Andes of Ecuador can be naturally divided into the Cordillera Occidental and the Cordillera Oriental (the Cordillera Real of Colombia). Although relatively narrow, these cordilleras contain many of the highest volcanoes in the world, but most of the snow-capped peaks occur in the north of the country, to the north of the investigated area, where Quaternary volcanism has been more intense. This separation almost certainly has a structural control as do many of the nodes that link the two Andean cordilleras at intervals. The principal and most important of these E-W structural lines which delimits the Cañar-Azuay Basin to the north as well as dividing the high volcanic areas in the north from the lower more dissected cordillera country to the south, is almost certainly associated with the Carnegie Ridge fracture zone. This is manifested across the Andean chain by the Cañar river gorge which dissects the Cordillera Occidental, the node of Cañar and the Paute river gorge which dissects the Cordillera Real.

The Cañar-Azuay basin extends southwestward towards the E-W aligned valley of the Río Jubones which probably represents a parallel E-W fracture zone normal to the cordilleras. The basin itself is situated in the N-S orientated graben-controlled inter-montane area, and lies in a depression between the two cordilleras.

Pleistocene and Pliocene drainage in the basin can to some extent be traced by the distribution of the fluviatile sediments. Along the foot of the Cordillera Occidental (which bounds the basin on the west) the Turi and Santa Rosa formations have linear facies of boulder beds which probably represent the main river deposits of the ancient equivalents of the Rio Tarqui and upper Rio Azogues. A closer control is seen in the distribution of the Quaternary Llacao volcanics: the old valleys were filled with resistant pyroclastics which remained as intervening ridges and ridge cappings when the streams shifted laterally: a typical example of topographic (volcanic) inversion.

The general drainage pattern of the basin is dendritic. Rock weathering, aided by still active hydrothermal activity, has been intense, and unaltered Tertiary rocks are scarce. This hydrothermal

activity, although controlled largely by the boundary fault contacts of the basin, has led directly to the formation of the travertine deposits, and, indirectly, to some of the clay deposits described below.

2.3 Climate and Vegetation

Altitude is considered to be the primary factor controlling climate in the region. The lower reaches of the Giron river system to the south of the basin proper is warm and semi-arid between Giron and Santa Isabel (1,600 m) with an average annual temperature of between 18°C and 25°C. The Cañar Azuay basin itself where most of the population is concentrated, has an average elevation of about 2,500 m. Average annual temperatures are around 14°C and 15°C and rainfall about 1,000 mm most of which is considered to be precipitated from December to May. The project has found to its disadvantage in certain operations that the weather is perhaps more meaningfully divided into periods of weeks rather than months and that rainfall can continue well on into September. The meteorological station at Cuenca (2562 m) shows an average daily temperature maximum of 20°C and a minimum of 12°C, the daily range of temperature being much greater than the annual. The difference in maximum temperature between the "warmest" and "coldest" months is only about 2°C. Climate also appears to be influenced by the varying degree of exposure to the prevalent easterly winds. The Paute valley which drains the basin to the E seems to be more humid than those leading up from the Pacific coastlands such as the Rio Cañar and the Rio Jubones. This may be an indirect influence of the Humboldt Current. The mountains which surround the basin, especially the Cordillera Occidental to the west, range up to just below the snowline (4,500 m) and are cold, grassy, paramo areas which are usually damp, boggy and uninhabited,

Vegetation is quite sparse over the predominantly clayey and sandy Tertiary sediments of the basin except for lush, seasonally flooded river flats particularly along the Tarqui river area S of Cuenca which provide excellent cattle grazing. Centuries of over-grazing have eliminated the indigenous trees everywhere except in the most inaccessible corners where a few groves of valuable 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 (peach, apple) and ornamental plants have been imported, amongst which the *Eucalyptus* predominates.

3. REGIONAL GEOLOGY

The Cañar-Azuay sedimentary depression is the only true intramontane basin filled by Mesozoic-Cenozoic sediments throughout the length of the Ecuadorian Andes. Minor sedimentary depressions occur further to the south near Loja and although perched, are not truly

intramontane in character. It has been a major structural feature since the pre-Upper Cretaceous in the primitive Andean rise, and was apparently isolated from being a completely marine environment during the Laramide orogeny. Apart from a typical continental facies some of the following Tertiary beds indicate an estuarine environment and it must, therefore, be suspected that some sort of link was maintained between the basin and the sea on and off for a considerable time. The structurally controlled line now occupied by the Jubones River could well have provided this link. Facies types indicate that the area eventually became dry land after the major Cascadian Mio-Pliocene orogeny. Complete severance of the basin from a Pacific drainage probably did not occur until well into the Quaternary when the southern end of the basin was blocked off in the region of the Nudo de Portete by rhyolitic pyroclastics. This damming effect was probably partially or wholly responsible for the development of the Paute Gorge (Tahual Canyon) which is now the only drainage outlet from the basin, and the subsequent shift to an Atlantic (Amazon) discharge.

The Cañar-Azuay basin is bounded on the west side by a section of the Cordillera Occidental which is here represented by the broad Chanchán-Cerro Cajas-Puruvin massif (8). In its upper section it is composed of some thousands of feet of semi-horizontal Tertiary to Quaternary volcanics. These are predominantly pyroclastic, but narrow intercalated lavas have been mapped (9). On the east, the basin is bounded by the narrow Cordillera El Verde which, although capped by recent sedimentary volcanic debris, probably owes its origin to intrusive activity along an Andean graben line.

The Cenozoic sediments that fill the basin and which lie unconformably above the Upper Cretaceous San Marcos Formation have been derived from Mesozoic volcanics and Mesozoic plus Palaeozoic (?) metamorphics that underly the adjacent ranges. Volcanism contributed pyroclastic material during sedimentation and reached a climax in the Pliocene epoch leaving masses of andesitic to rhyolitic pyroclastics and lavas on the cordilleras.

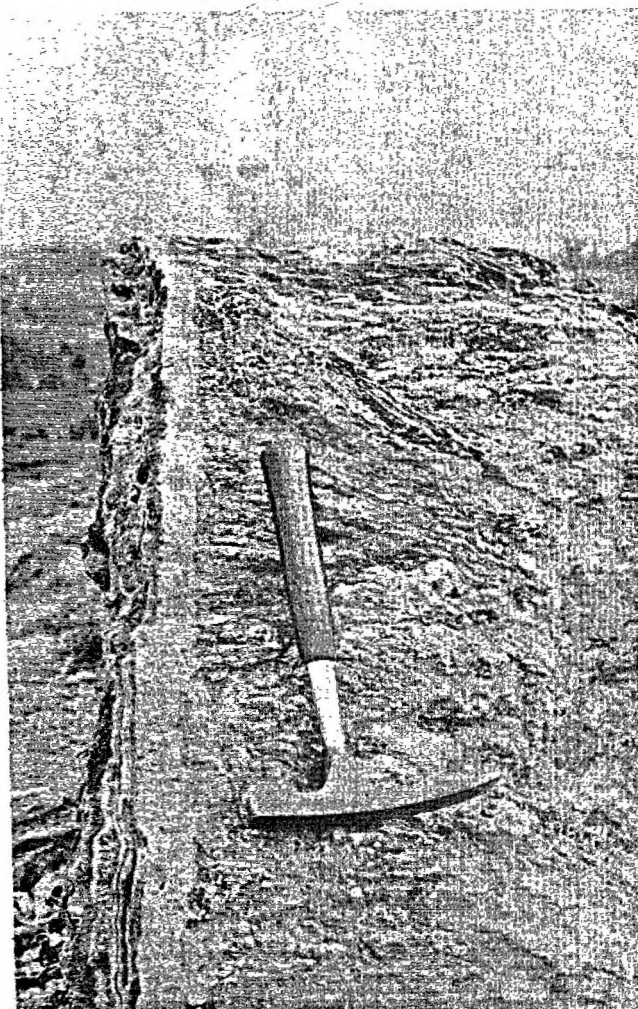
The detailed stratigraphy and bibliography is given by the project in Technical Report No. 1 (7) where an attempt has also been made to correlate the stratigraphy of the Cañar-Azuay basin with other sedimentary belts of the country. The basin has two main structural divisions which trend NE to NNE. The eastern half is moderately to highly folded with a zone of thrust-faulting, whereas the western half is only slightly folded with dips of 5° to 15° being typical. The older rocks are exposed in the eastern half and the younger in the western. Cross structures were mapped in many places, but since these are for the most part older than the northerly trends, their total effect is not always apparent. Boundary faulting on the west side of the basin along the foot of the Cordillera Occidental is indicated by the alignment of travertine deposits. This main belt, orientated N20° - 30°E has been traced for more than 70 km from Baños in the south to El Tambo in the



BAÑOS DE CUENCA

PHOTO I — Principal travertine wall looking north. Note central fissure.

FOTO I — Banco principal de travertino mirando hacia el norte. Nótese fisura central.



BAÑOS DE CUENCA

PHOTO II — Fissure in main wall lined with vertically banded, crystalline Type II travertine. Porous sub-crystalline Type I travertine tufa is layered horizontally forming the outer sections of the wall.

FOTO II — Fisura en el banco principal revestido de travertino de Tipo II bandeado en forma vertical y de textura cristalina. Travertino poroso de Tipo I se encuentra bandeado horizontalmente y forma las partes exteriores del banco.

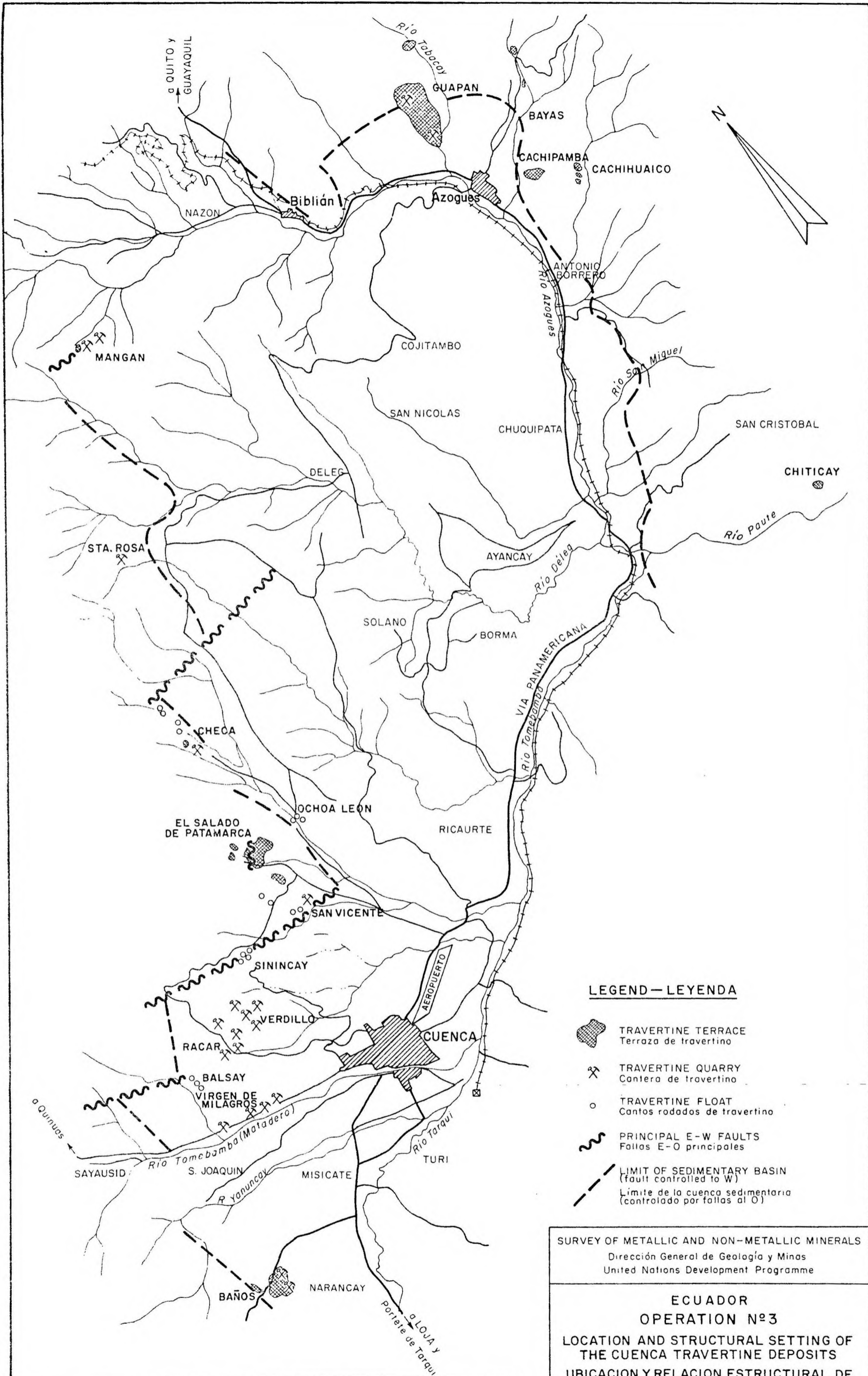
north. The travertine deposits along this belt are related to the intersection of the boundary fault zone with the older but sometimes rejuvenated E-W structures.

PART ONE - TRAVERTINE

4. INTRODUCTION

Quarrying and cutting of "Marbles" for construction, decoration and art objects has been a traditional handicraft since early colonial times in the area of Cuenca. The industry is principally based on the main section of the travertine belt located to the west of Cuenca which extends over 15 km in a north-south direction (Map No.2). In spite of the local availability of travertine, increased imports of Carrara marble during the last decades have motivated a shifting of the industry from Cuenca to Guayaquil and Quito, where imported marble is cheaper and where the demand for marble products is larger. This was causing concern about a possible drain of foreign exchange on the country. In order to reactivate the Cuenca marble industry, the local authorities under the sponsorship of the Centro de Reconversión de Cañar y Azuay (CREA), contemplated improving its technical standards, mainly through better quarrying and through mechanical sawing of the marble slabs at the Parque Industrial of the city.




There is some confusion over the present terminology. The material being quarried at Cuenca is known variously as "mármol", "caliza", "cal", "marga", "cascajo", etc., depending on whether it is used for ornament, lime, or is considered worthless. These terms are geologically incorrect, especially marble, because this connotes an opulence and artistic value that the rock does not enjoy. The word travertine is accurate both scientifically and artistically. It is derived from the Roman town of Tiburtinus, now Tivoli, where deposits of the same origin were quarried to decorate summer villas. Italian travertine is exported all over the world. The material most resembling the original is that which is being burned for cement at Guapán. It has never been used for decorative stone partly because it has only recently been exposed but also because it lacks the bright colours long associated with the other varieties of the Cuenca region. Should any of the material found in the Cañar-Azuay basin be selected for expanded production, it should be promoted under the name of travertine. The travertine is of recent origin and is related to past and present hot spring activity. Apart from its uses as a decorative stone, it is also the basis of the cement industry at Guapán and reserves in the area are considered to be sufficient for several decades to come. A primary step to further industrialization, however, would necessitate a calculation of reserves over selected deposits. Also exploited is an onyx-type travertine which is fashioned into small objects such as ashtrays and fruits: a light green variety comes from Saraguro, Loja Province, and a white variety from Portete, Azuay Province.



NOTE.— Topography compiled and reduced from 1:50 000 sheets, Cuenca, Gualaceo and Azogues of the Instituto Geográfico Militar, Quito.

NOTA.— Topografía compilada y reducida de las hojas a 1:50.000, Cuenca, Gualaceo y Azogues del Instituto Geográfico Militar (I.G.M.), Quito.

LEGEND—LEYENDA

-  TRAVERTINE TERRACE
Terraza de travertino
-  TRAVERTINE QUARRY
Cantera de travertino
-  TRAVERTINE FLOAT
Cantos rodados de travertino
-  PRINCIPAL E-W FAULTS
Fallas E-O principales
-  LIMIT OF SEDIMENTARY BASIN
(fault controlled to W)
Limite de la cuenca sedimentaria
(controlado por fallas al O)

SURVEY OF METALLIC AND NON-METALLIC MINERALS
Dirección General de Geología y Minas
United Nations Development Programme

ECUADOR
OPERATION Nº3
LOCATION AND STRUCTURAL SETTING OF
THE CUENCA TRAVERTINE DEPOSITS
UBICACION Y RELACION ESTRUCTURAL DE
LOS DEPOSITOS DE TRAVERTINO DE CUENCA

1 0 1 2 3 km
SCALE
Escala 1:100 000

MAP Nº2
MAPA Nº2

Previous descriptions of the travertine deposits have been made by Erazo, 1957 (1), Mosquera, 1955, 1957 (2,3), Spindler and Herrera, 1959 (6), and the origin of the deposits has been touched on by Sauer, 1965 (5). With the time available for this work as scheduled by the extremely diversified Plan of Operation, it was not possible to make detailed assessments of all the travertine deposits within the 2,610 km² area of Operation No. 3. The aim, therefore, was to evaluate the known deposits as far as possible and ascertain their geological origin to guide future exploration and development work. A summary of chemical analyses for the Cuenca travertines is given later in Table I.

5. CONCLUSIONS

- A. A total of 22 travertine deposits, nineteen of which are from the operation area, have been located and examined. Six deposits were mapped, sampled and drilled in some detail. The geological origin of these deposits has been established and 4 inter-related types of travertine have been classified: I. Terrace, II. Vein, III. Eluvial, and IV. Alluvial. All types are related to hot spring activity.
- B. The Terrace deposits are surficial crusts or terraces several meters thick as well as broad, and are composed of very fine-grained calcium carbonate suitable for Portland cement, possibly white cement, fertilizers, sugar refining and other industrial uses. The Vein deposits represent the filling-material of conduits through which the terraces were supplied from depth. These are more coarsely crystalline and banded with different colours and therefore valuable as a source of decorative stone. Although they are the easiest deposits to evaluate and eventually to develop, they remain relatively untouched because of the mechanical problems of extraction. Blocks of the Eluvial and Alluvial types lie scattered in loose detrital material and account for nearly all the present output of ornamental stone from the area. This material is also predominantly colour-banded and is derived from the break-up of the Type II Vein deposits. This colluvial material cannot be mapped or developed systematically and may, therefore, be left to the multitude of pick-and-shovel operators who claim them.
- C. The deposits are distributed around the edge of the Cañar-Azuay basin at, or near, the graben-controlled contacts with the older rocks. At these points there has been easier access to the surface from depth for the carbonate laden waters. It is believed that the carbonate now deposited as secondary travertine, has been derived from basal Cretaceous formations.
- D. The geological evaluation of the travertine deposits will guide future exploration and development work.

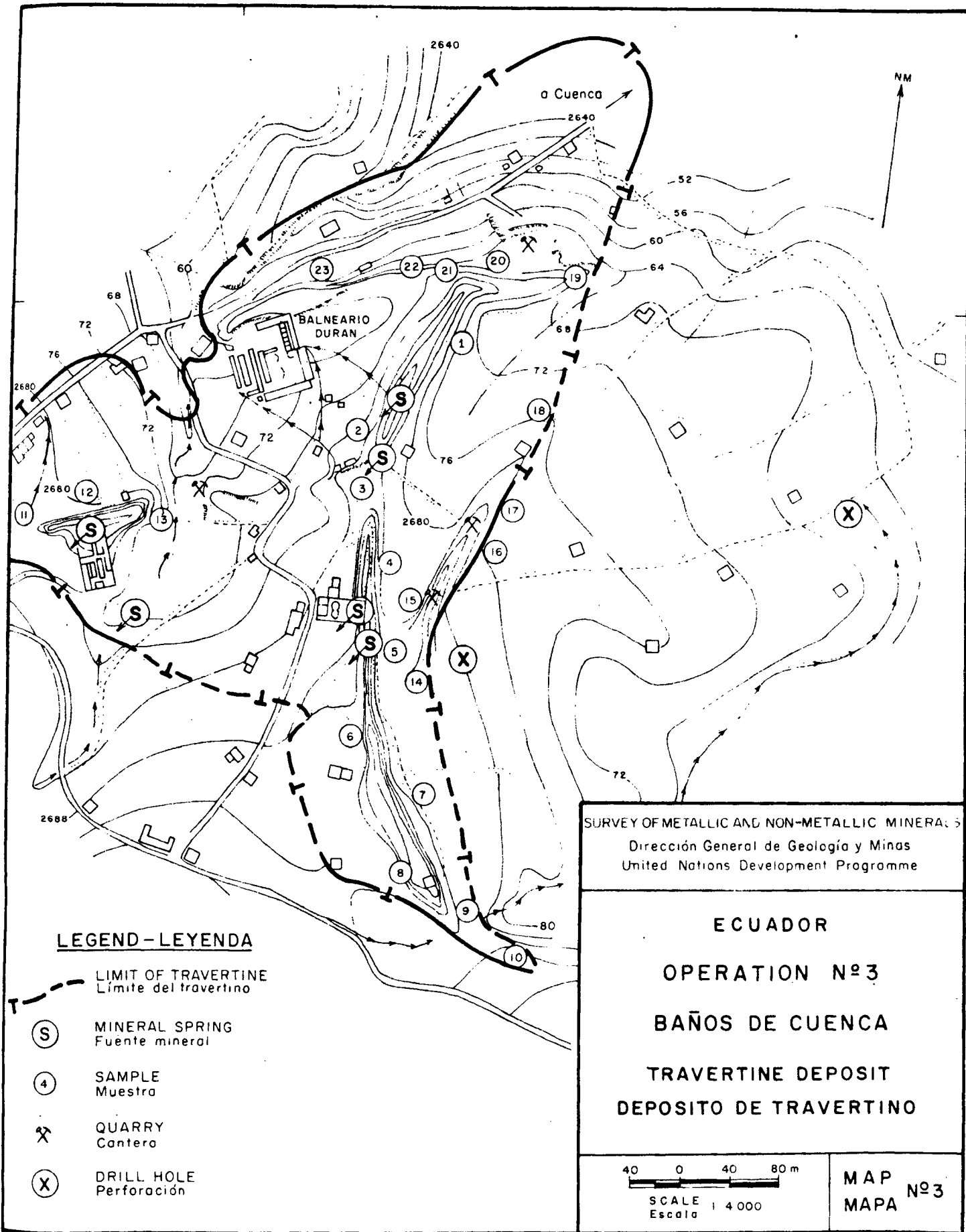
6. RECOMMENDATIONS

- A. Further reconnaissance mapping and prospecting by following up the indicated structural controls, might lead to the discovery of concealed deposits. From the viewpoint of economic development however, the more urgent need is to expand production.
- B. Use of travertine for cement and fertilizer will grow with, or in advance of, the population. Rough estimations of reserves at some of the larger deposits are: Baños de Cuenca, 1,000,000 tons; Salado de Patamarca, 500,000 tons; Guapán, 10,000,000 tons; Cachimamba, 500,000 tons. Exact evaluations must, however, be made at selected sites before development is contemplated. Reserves appear to be sufficient for the medium term future.
- C. The long-worked and disorganized ornamental travertine pits based on Type III and Type IV (eluvial and alluvial) material might provide a steadier and more reliable source of supply by the organization of a local-co-operative. Because of the irregularity of the deposits future reserves will be difficult or even impossible to calculate. There is no doubt that the poor and erratic mining methods, lack of quality control and high transport costs to the principal consumer areas of Guayaquil and Quito are important factors in the preference for imported (Carrara) material.
- D. The colourfully banded travertine which occurs as Type II in the cores and root zones (central fissures) of wall deposits appears to present the best solution for organized and expanded production as future reserves can be fairly accurately calculated. These deposits such as at Baños de Cuenca, San Vicente, Checa and possibly Guapán, have not been previously exploited because of the technical and financial problems involved in mining. Drilling and blasting would possibly damage or destroy much of the valuable core material. Because of their form, they could be exploited methodically, but quarrying and polishing specialists would have to be employed to determine how much of each variety can be supplied. With an assured supply present marble imports could be reduced.
- E. Brief reconnaissance work outside the confines of Operation No.3 has shown that a deposit of white homogenous crystalline limestone (true marble) occurring at Selva Alegre about 50 km to the NNW of Quito might have a considerable impact on the limestone industry.

7. TRAVERTINE DEPOSITS - CUENCA AREA

7.1 Baños de Cuenca

The main deposit of Baños, 2 km by road southwest of Cuenca railroad station, is the thick crust of travertine, roughly a triangle 600-700 m on edge, shown on Map 3. Two small, poorly exposed, terraces are located about 500 m west of the town, where the Río Callaci emerges from the Cordillera Occidental.



LEGEND - LEYENDA

- LIMIT OF TRAVERTINE
Límite del travertino
- MINERAL SPRING
Fuente mineral
- SAMPLE
Muestra
- QUARRY
Cantera
- DRILL HOLE
Perforación

SURVEY OF METALLIC AND NON-METALLIC MINERALS
 Dirección General de Geología y Minas
 United Nations Development Programme

ECUADOR
OPERATION N° 3
BAÑOS DE CUENCA
TRAVERTINE DEPOSIT
DEPOSITO DE TRAVERTINO

40 0 40 80 m
 SCALE 1:4 000
 Escala

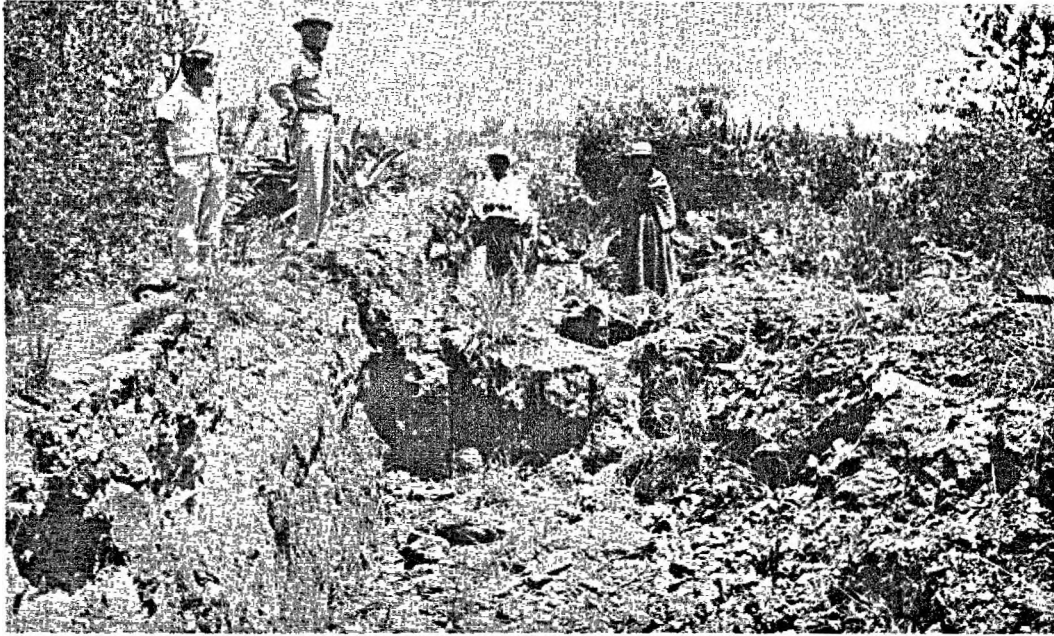
MAP N° 3
MAPA N° 3

Superimposed on the main deposit are four walls, or long linear mounds, easily discernible on the topographic map. The one farthest north starts at the main swimming pool of Balneario Durán and trends N 80° E for about 320 m, and is 12 - 20 m high. Near the east end, CREA (Centro de Reconversión Económica de Azuay) has opened a quarry for lime fertilizer, producing 25 tons of travertine per day at a cost of S/. 60 per ton. The longest wall extends southwards from the quarry for 560 m in a slight arc, striking N 25° E at the northern end, due north in the centre, then S 20° E at the other end (see Photo I). Intersecting the arc near its mid-point is another wall, 200 m long, 25 m broad and 6 m high, striking N 25° E. The fourth wall starts from the Duran steam bath and trends S 78° W across the Quebrada Chin-Chin for roughly 100 m. It is 12 m high where the stream cuts through it and is really a double wall, with a central fosse 3 m wide. Each wall has a fissure running down the middle, and the fosse itself may have been a fissure enlarged by solution. The central fissure is a mere slit 10 - 15 cm wide where hot water is emerging at present, but is a trench with sides 1 - 2 m deep at the south end, where travertine is no longer being deposited.

The fissure is lined with banded, crystalline coloured travertine which therefore has a vertical dip, in contrast to the bulk of the wall, which is sub-crystalline material (white, yellow or drab) either dense or porous (i.e. tufa) and has a sub-horizontal dip. (Photo II). In the short wall on the east edge of the terrace, the central lining is 1 - 5 m thick, and is being mined for ornamental stone (Photo III). No water issues from this wall, and its reduced height suggests that it is being eroded down to its crystalline roots. An intermediate stage is seen in the Chin-Chin wall, where the massive central core, several metres broad, has been exposed by the stream in spite of a thick cover of sub-crystalline material. Warm water still issues from the south flank of the wall, but not from the fissures. From this comparison it is evident that the walls are not merely thicker parts of the travertine terrace, but have vein cores of crystalline material. It is not possible to prove this hypothesis because the land owners objected, with some justification, that drilling might interfere with the hydrothermal plumbing of the spa. Two short Winkie holes were put down on the clay flats east of the terrace in order to determine the possible occurrence of travertine beneath, but only clay was found to depths of 4.3 m and 6.4 m at the points indicated.

Twenty three samples, as located on the map, were cut and analyzed by the laboratory of the Project. The average result given in Table I shows that it is good material for cement and other industrial uses.

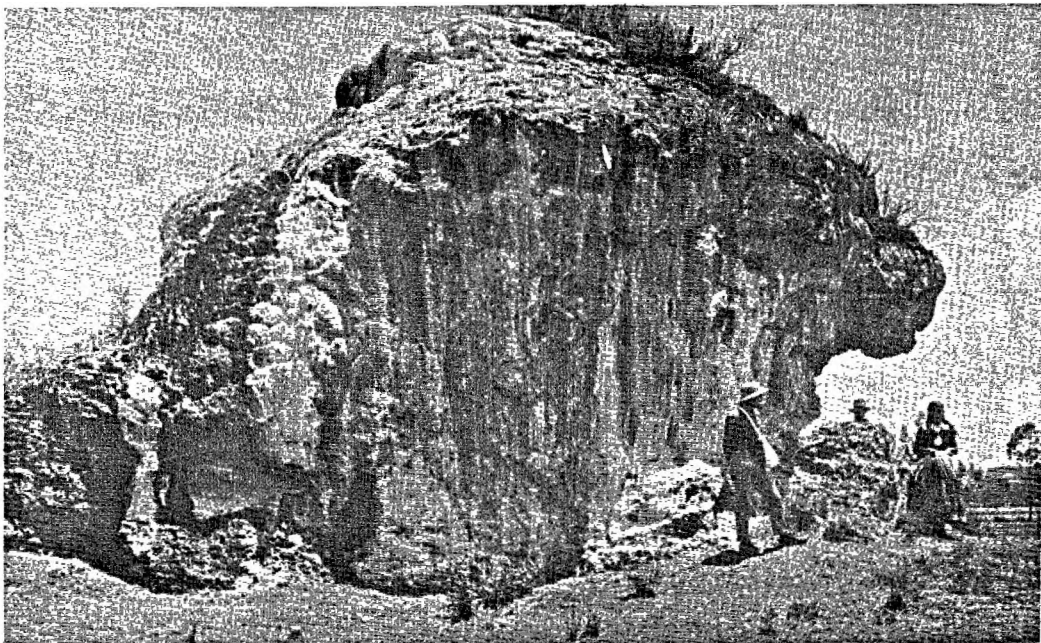
Reserves are difficult to estimate for lack of data on thickness. Sub-crystalline carbonate probably exceeds a million tons, and ornamental stone may well amount to several hundred thousand tons. However, any plans for large-scale mining would have to consider whether the area is not of more value as a spa.



BAÑOS DE CUENCA

PHOTO III — Easternmost wall where core of crystalline Type II travertine is quarried for ornamental stone.

FOTO III — El banco más hacia el este, donde explotan el núcleo de travertino cristalino del Tipo II para piedra decorativa.



EL SALADO DE PATAMARCA

PHOTO IV — Travertine chimney which consists mainly of Type I material. Re-solution cavities are visible.

FOTO IV — Chimenea de travertino que consiste principalmente de material de Tipo I. Son visibles cavidades formadas por disolución posterior a la formación del depósito.

TABLE 1

ANALYTICAL RESULTS OF TRAVERTINES FROM THE CUENCA AREA

Deposit	No. of Samples	CaCO ₃ %	MgCO ₃ %	Al ₂ O ₃ %	Fe ₂ O ₃ %	SiO ₂ %	S%	Total
Baños de Cuenca	23	89.6	1.3	1.5	1.1	2.0	0.2	95.7
Vírgen de Milagros	2	95.7	2.1	0.1	1.2	1.3	0.04	100.4
Racar	1	91.3	1.3	0.5	0.6	0.5	0.07	94.2
Verdillo	1	91.3	0.9	0.5	0.3	0.6	0.09	93.7
Sinancay	1	95.5	2.1	0.4	1.1	0.7	0.1	99.9
San Vicente	1	88.9	3.4	5.4	1.0	0.7	na	99.4
El Salado de Patamarca	5	93.8	2.6	0.1	0.8	1.2	na	98.5
Checa	1	91.6	7.3	0.3	1.8	2.5	0.6	104.1
Sta. Rosa	1	97.9	1.4	0.3	0.6	0.7	0.1	101.0
Mangán	1	89.6	1.6	5.9	1.7	1.2	na	100.0
Guapán	15	87.1	2.4	1.5	1.3	4.8	na	96.5
Cachipamba	23	48.8 ⁺	1.6 ⁺	1.2	1.7	3.9	0.22	na
Cachihuaico	1	88.4	6.8	0.3	1.2	3.9	0.02	100.5
Bayas	2	84.8	2.3	1.0	1.0	3.1	na	92.2
Río Tabacay	2	90.2	3.2	0.7	0.7	2.5	0.03	97.3
Chiticay	1	81.2	3.2	9.5	3.4	1.8	na	99.1
Quinoas	1	96.2	2.0	0.4	0.3	1.0	0.1	100.0
Portete de Tarqui	1	95.7	0.8	2.1	2.1	0.4	0.1	101.2

na - not analyzed

All samples analyzed by the laboratories of the UN Mining Project, Quito, except for Guapán which was analyzed by "Industrias Guapán S.A."

+ CaO and MgO

7.2 Virgen de Milagros

The most active travertine quarries in the vicinity of Cuenca are along the old Guayaquil trail from 5 - 7 km west of the railroad station. The piedmont debris covering the slopes grade southward into the thick boulder gravel of the Río Matadero. This material has been worked during the course of many years, probably since Inca times, to extract large round masses of 'marble', leaving pits up to 20 m deep and 100 m long. The belt of workings stretches N85°W, parallel to the river as far as the Río Amarillo, somewhat more than two kilometers. Although the distribution suggests fault control such as that of vein deposits, closer inspection fails to reveal any consistent structure. Travertine blocks from 1 to 10 m in diameter are separated by soil, dark clay, and variegated alteration products; the banding strikes and dips at variable angles with no preferred orientation. Geologic mapping proved futile.

The pick-and-shovel mining is done by landowners, of whom more than a score lay claim. The larger blocks are cut with steel hand saws and the smaller fragments are broken, also by hand, and calcined in one of the nine kilns in the immediate vicinity, using eucalyptus stumps as fuel.

The travertine is crystalline and comes in many combinations of red, pink, white, brown, etc., usually banded. Polished slabs cost upward of \$350 per square meter, depending on the variety.

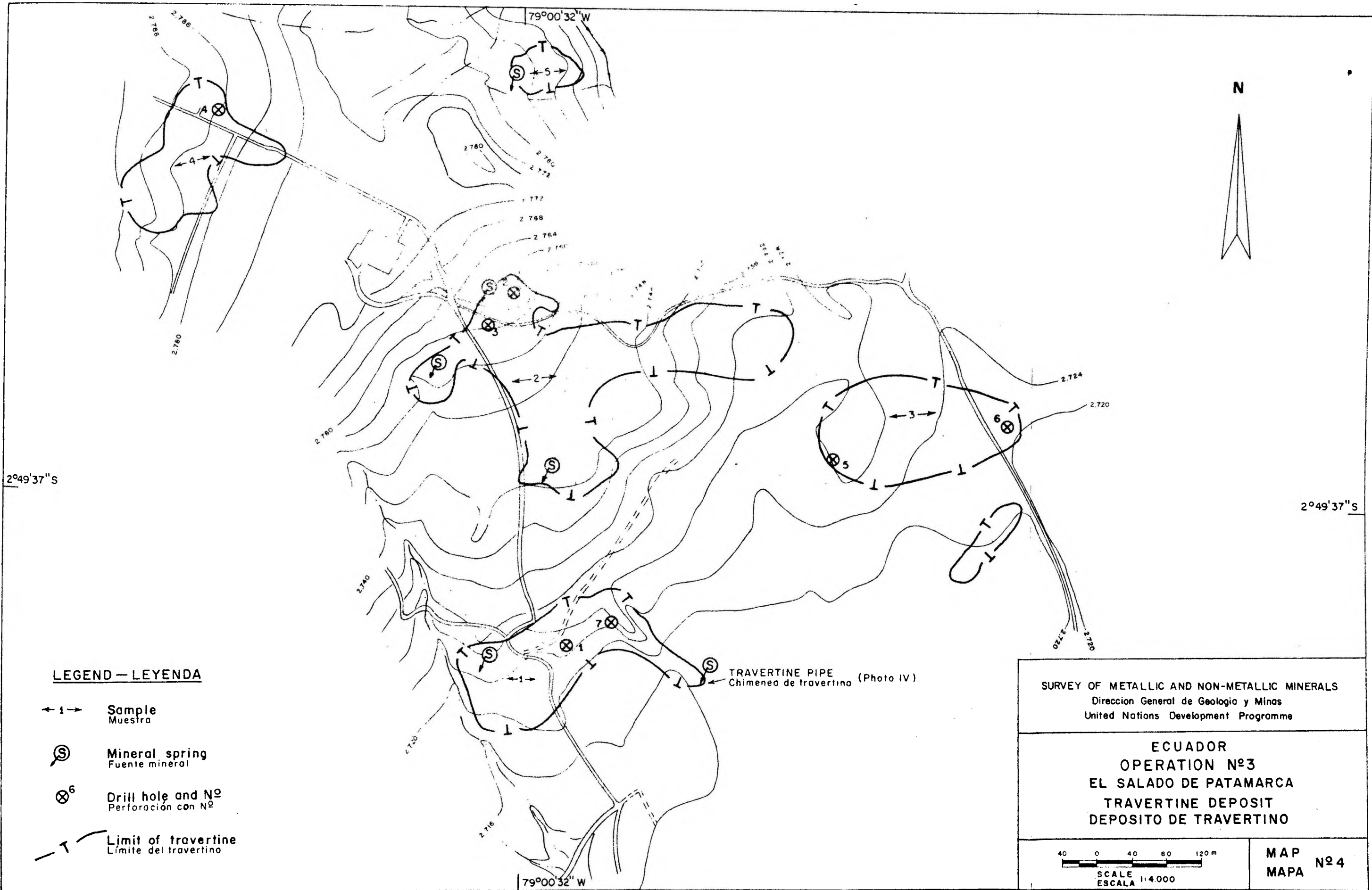
Reserves are difficult to estimate. A respectable tonnage has already been extracted, and the deposit ought to continue with depth, although the original veins were probably lenticular. Drilling to prove tonnage is impractical because the findings cannot be projected, and holes would have to be so closely spaced as to be prohibitively expensive.

7.3 Racar

Numerous, more or less isolated occurrences of travertine have been worked on a small scale for many years in the area 3 to 4 km north of Cuenca called Racar. The piedmont debris varies abruptly in thickness, and at several places the Santa Rosa Formation (7) is exposed even on hilltops. Nevertheless, none of the travertine is in situ, but occurs as detached blocks several metres on edge. Some of the pits are up to 150 m long; others are as much as 15 m deep. Much of the multi-coloured travertine is altered and therefore worthless. The bulk of it is burned on the spot for lime. Blocks of high grade decorative stone are, however, found occasionally.

7.4 Verdillo

A group of open-pit workings are located 7 km northwest of Cuenca station, or about 10 km by road in an area known as Carmen de Verdillo. The main belt of pits is about 100 m wide by 750 m long and trends 35°W; another cluster of small pits half a kilometer to the northeast has a similar trend, but is not as well defined. Although this pattern suggests vein deposits, the



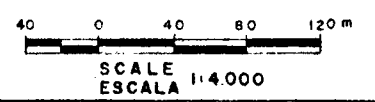
LEGEND — LEYENDA

- ← 1 → Sample
Muestra
- ⊙ Mineral spring
Fuente mineral
- ⊗⁶ Drill hole and N^o
Perforación con N^o
- T - Limit of travertine
Límite del travertino

TRAVERTINE PIPE
Chimenea de travertino (Photo IV)

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 EL SALADO DE PATAMARCA
 TRAVERTINE DEPOSIT
 DEPOSITO DE TRAVERTINO



MAP N^o 4
 MAPA N^o 4

travertine is found only as isolated blocks, with random orientation, completely enclosed in clay and piedmont debris. Outcrops on the steeper slopes show that the area is underlain by the Santa Rosa Formation. The size of the pits (up to 50 m long and 10 m deep), and the dumps, prove that the deposit has been the subject of pick-and-shovel mining for a long time. The blocks, up to 3 m in diameter, composed of white, pink-white, red, brown, etc., crystalline travertine, are sawn into slabs or crushed to make marmolina. No estimate of reserves is possible.

7.5 Sinincay

The stream called Sinincay, which flows past the village of the same name about 7 km by the shortest route north of Cuenca, contains boulders of travertine up to 6 m in diameter along several hundred meters of its course. Travertine float has also been noted at several places north and east of the town, but all this area is covered by piedmont debris or Recent gravel. The contact between the Plio-Pleistocene Santa Rosa Formation and the Mesozoic volcanics, probably an EW fault, is also buried. The villagers may work many months on a single boulder, cutting it into manageable blocks and slabs.

7.6 Ochoa León

The hamlet of this name is situated about 7 km north of Cuenca on the Río Machángara, a major branch of the fluvial network. Blocks of banded red and white travertine big enough to serve as natural supports for the bridge are scattered along the stream bed for about 75 m. The roots of the deposit must be buried under the thick gravel terraces. Apparently no quarrying has been attempted.

7.7 San Vicente

A vein of crystalline, banded red and white travertine 4 m thick, is exposed discontinuously for a length of about 150 m near the chapel of San Vicente, about 9 km by road north of Cuenca. The vein strikes N30°E and dips vertically. Boulders of travertine are abundant in the stream, and the main structural control may be the probable EW fault contact extending to Sinincay (Map No.2) between the Santa Rosa Formation and the Mesozoic volcanics (7). Quarrying has been done on only a small scale, but at the time of examination, only the stream boulders were being worked. The vein is, however, one of the few in the region to be found in place, and warrants attention.

7.8 El Salado de Patamarca

At the foot of the Cordillera Occidental, in the general area of the hamlet called Patamarca, about 12 km by road north of Cuenca, lie several irregular patches of travertine (Maps 2 and 4). Another deposit, 150 by 300 m has been reported to the south, on the Quebrada Chamano, and is shown on Map No.2. The first patch encountered on the road, going northward,

measures about 220 x 100 m, and is bounded on the east by a linear mound 100 m long, 20 m wide, and 3 m high. Like those at Baños, this wall has a vertical fissure down the center, from which juvenile water has issued in the recent past. At present, the water flows out of the top of a mushroom-shaped chimney along the strike projection of the wall, but about 50 m distant (Photo IV). Tepid, slightly saline water, with a distinctly alkaline odor, also bubbles forth vigorously from the northwest end of the patch, and from several other places on the other deposits. Some of these crusts are on steep, dissected slopes, so deposition must have been recent, but since the large mound has caves with stalactites, re-resolution and erosion must have quickly followed once the flow ceased.

A fault, exposed in the Quebrada Patamarca, striking N20°E and dipping 25°SW cuts through the center of the area, bringing the Mesozoic volcanics to the surface from under their relatively thin cover of piedmont clay. That the travertine rests on clay, rather than bedrock, was shown by the six diamond drill holes spotted at random. A summary of these logs is given below:

Resumé of drilling logs

Drillhole S1

0 - 0.60 m	Grey-brown soil.
0.60 - 5.20 m	Light brown, grey and greenish travertine, mostly porous but with some compact crystalline material. Inclusions of volcanic fragments common.
5.20 - 5.42 m	Grey bentonitic clay.

Drillhole S2

0 - 1.67 m	Light brown and grey travertine, rarely compact. Inclusions of volcanic fragments.
1.67 - 3.64 m	Clayey bentonitic soil.
3.64 - 4.55 m	Weathered volcanic material.

Drillhole S3

0 - 0.60 m	Soil.
0.60 - 1.80 m	Dark grey, brown and white travertine generally porous but in places vaguely banded and crystalline.
1.80 - 4.24 m	Grey-brown clay and volcanic material.

Drillhole S4

- 0 - 0.60 m Brown-grey travertine, variably porous with clay (fossil soil) and volcanic inclusions.
- 0.60 - 3.03 m Clayey material - fossil (pre-travertine) soil.

Drillhole S5

- 0 - 1.21 m Porous and semi-crystallized travertine with included volcanic fragments.
- 1.21 - 1.52 m Calcareous soil with volcanic material - rusty dark red.
- 1.52 - 2.72 m Semi-crystalline brown and grey-green travertine.
- 2.72 - 3.40 m Yellow calcareous clay.

Drillhole S6

- 0 - 0.60 m Soil.
- 0.60 - 1.21 m Granular porous travertine.
- 1.21 - 3.33 m Yellow-brown bentonitic clay - calcareous.

The last of the drillholes (S-7) was inclined into the base of the mound, to determine whether it has a core of crystalline banded travertine, as at Baños, but apparently it does not at this point. The drilling indicates that the travertine terraces range in thickness from 0.6 to 1.8 m and are therefore thinner at Patamarca than in other deposits of comparable areal extent.

The total tonnage of this deposit would be on the order of half a million tons. No mining was attempted except to make lime for farm uses.

7.3 Checa

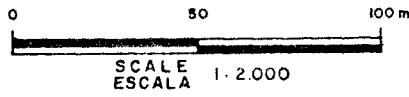
The Checa prospect is located about 200 m west of the town, near the contact of the Mesozoic volcanics with the Santa Rosa Formation. At the south end of the map area, a belt of crystalline travertine 20 m wide strikes N15°W for 150 m. (Map No.5). Several hundreds of meters up the hill sluggish, alkaline springs are depositing sub-crystalline travertine in superficial crusts. At other places between these two deposits, large blocks of crystalline travertine lie partly buried in piedmont debris, and boulders of similar material are strewn along the creek bed for several kilometers to the north. There are, therefore, several nodes of occurrence

78°59'39" W

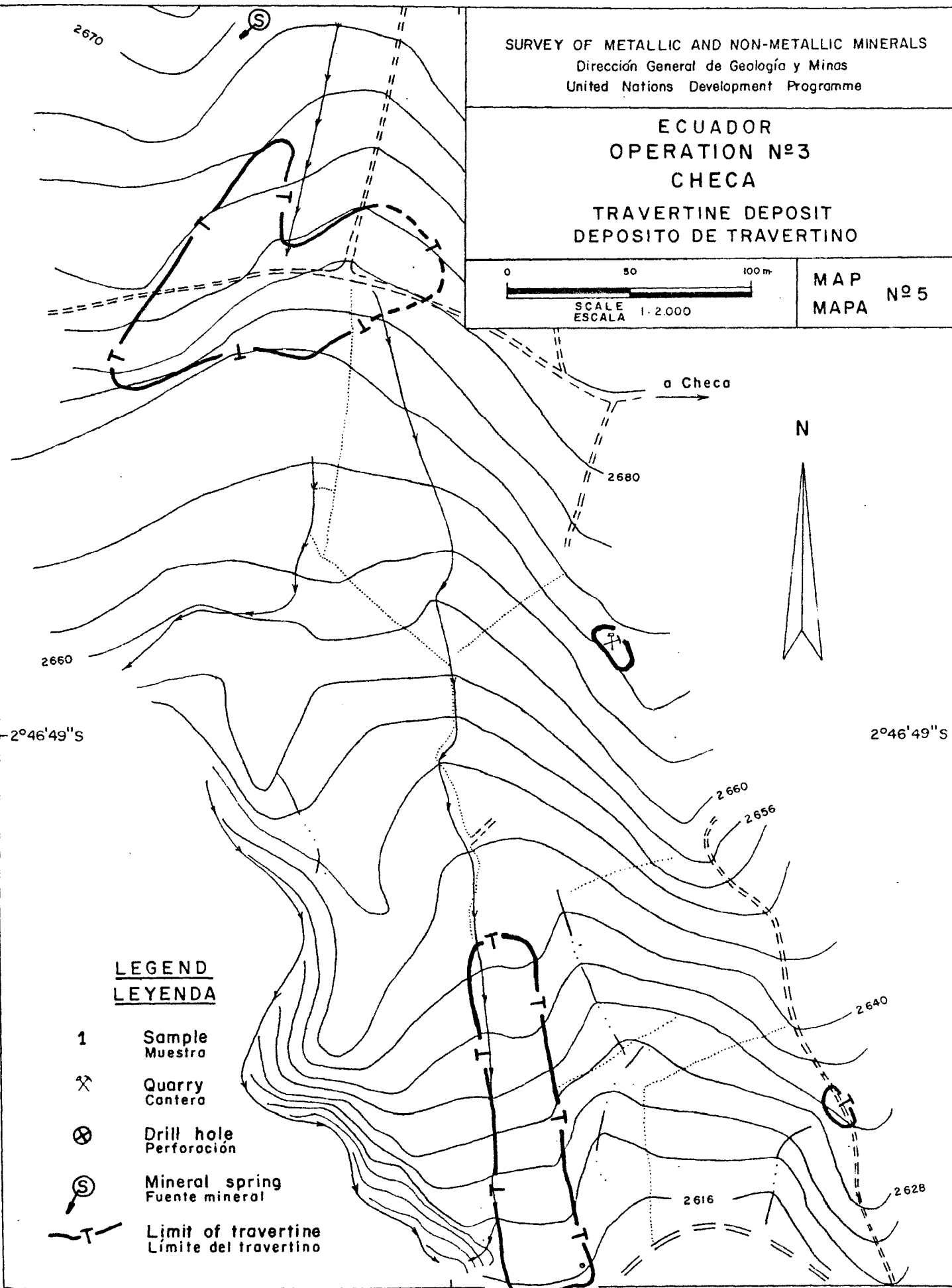
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ECUADOR
OPERATION Nº3
CHECA

TRAVERTINE DEPOSIT
DEPOSITO DE TRAVERTINO



MAP Nº 5
MAPA Nº 5



2°46'49" S

2°46'49" S

LEGEND
LEYENDA

- 1 Sample
Muestra
- ⌘ Quarry
Cantera
- ⊗ Drill hole
Perforación
- Ⓢ Mineral spring
Fuente mineral
- T- Limit of travertine
Limite del travertino

78°59'39" W

in this one area, but only the crystalline material is of economic interest. The original form of the vein is well preserved, and it seems likely that solid travertine lies just below the surface cover of loose blocks. This rock is a banded red-white-grey variety at present mined on a very small scale by the person who dwells on the property. The deposit is one of the very few in which a sizeable tonnage of decorative stone could probably be blocked out.

7.10 Santa Rosa

An occurrence of travertine in the Cordillera Occidental about two hours by trail from a point on the road 3 km north of the village of Santa Rosa was examined in 1966. The steep slope is overgrown with dense brush (ceja de montaña), and it is not clear whether the travertine is in place. A few slabs of white and pink travertine were brought down on mule-back to decorate the local church. The deposit is more than 20 km distant from both Cuenca and Azogues, and so difficult of access as to be of no further interest now.

7.11 Mangán

This deposit is in the same belt as those near Cuenca, but in the Province of Cañar, about 15 km by road from Azogues and occurs on the property (hacienda) of a Sr. Roberto Palacios. A distinct fault can be traced from where it makes a niche in a topographic saddle downhill S85°E under the belt of travertine deposits to the farmhouse. The west end of the belt has several patches of porous tufa ('deer-horn rock') 50 to 100 m broad and about a meter thick. The east end has detached blocks of white and pale green crystalline travertine in soil and piedmont debris. About six sacks of crushed material are sent daily to Cuenca to be used in marmolina mosaics. Near the center of the belt a large block of travertine has veins of ruby-red carbonate, possibly aragonite with siderite pigmentation.

7.12 Guapán

The Guapán travertine deposit is in a class by itself with respect to size. The travertine terrace on the slope below the hamlet of Guapán, about 3 km north of Azogues, is some 1500 m long, 500 m wide, and according to early company drilling, about 14 m thick. The government-owned cement company has been extracting about 500 tons a day in recent years, and CREA has been producing about 20 tons of fertilizer lime per day since early 1967. No mapping or sampling was done during the present investigation; and in the end it was not possible to obtain more information on tonnage than that cited in many preliminary reports which estimate a reserve of about ten million metric tons. Local records show this material to run: CaCO₃, 93.5%; MgCO₃, 4.2%; Al₂O₃, 0.6%; Fe₂O₃, 0.5%; SiO₂, 1.6%. An analysis kindly furnished by CREA shows, for their travertine, CaCO₃, 84.9%; MgCO₃, 8.8%; insoluble residue, 3.02%, combined oxides 0.4%. The average of 15 samples taken by the project is given in Table I. This quarry, at the foot of the deposit

along the Río Tabacay, has uncovered a prehistoric burial site. The bodies were interred in caves, crouched in the embryonic position typical of many Andean cultures. The bones show partial to complete replacement by travertine. The non-fossilized snail shells and fragments of pottery may afford a means of dating the deposit, which at this point is about 4 m thick.

Hot, gaseous springs are pouring out a considerable volume of mineral water near the top of the hill. Some of it issues from a fracture, several hundred meters long, which strikes N60°W and passes under the chapel. A travertine wall up to 3 m high has accumulated along parts of its course, and in places the fissure is lined with crystalline material.

The bulk of the deposit is sub-crystalline, dense, massive travertine, but the material mined in the cement company quarry also includes thick layers of a variety not found elsewhere. It is very fine-grained, somewhat vuggy, and has alternating yellow, light brown, and light grey bands. It differs markedly from the brilliant-hued 'marble' elsewhere in the region, and more closely resembles Italian travertine. The possibilities of using this material as decorative stone are being investigated.

7.13 Cachipamba

The slope of the hill immediately east of Azogues, called 'salt flat' in Quechua, has an irregular travertine terrace 650 m long by 50 to 250 m wide. (Map No.6). A line of sluggish, cold, algae-filled springs trend N45°W, across the top of the deposit, and may have some connection with the old mercury mines from which the town of Azogues derives its name. Deposition seems to be very slow at present, and parts of the crust have been eroded or re-dissolved into a spongy tufa. Nevertheless, thicknesses of 4 to 5 m are typical around the edge and in the five Winkie drillholes that were completed.

Resumé of Drilling Logs

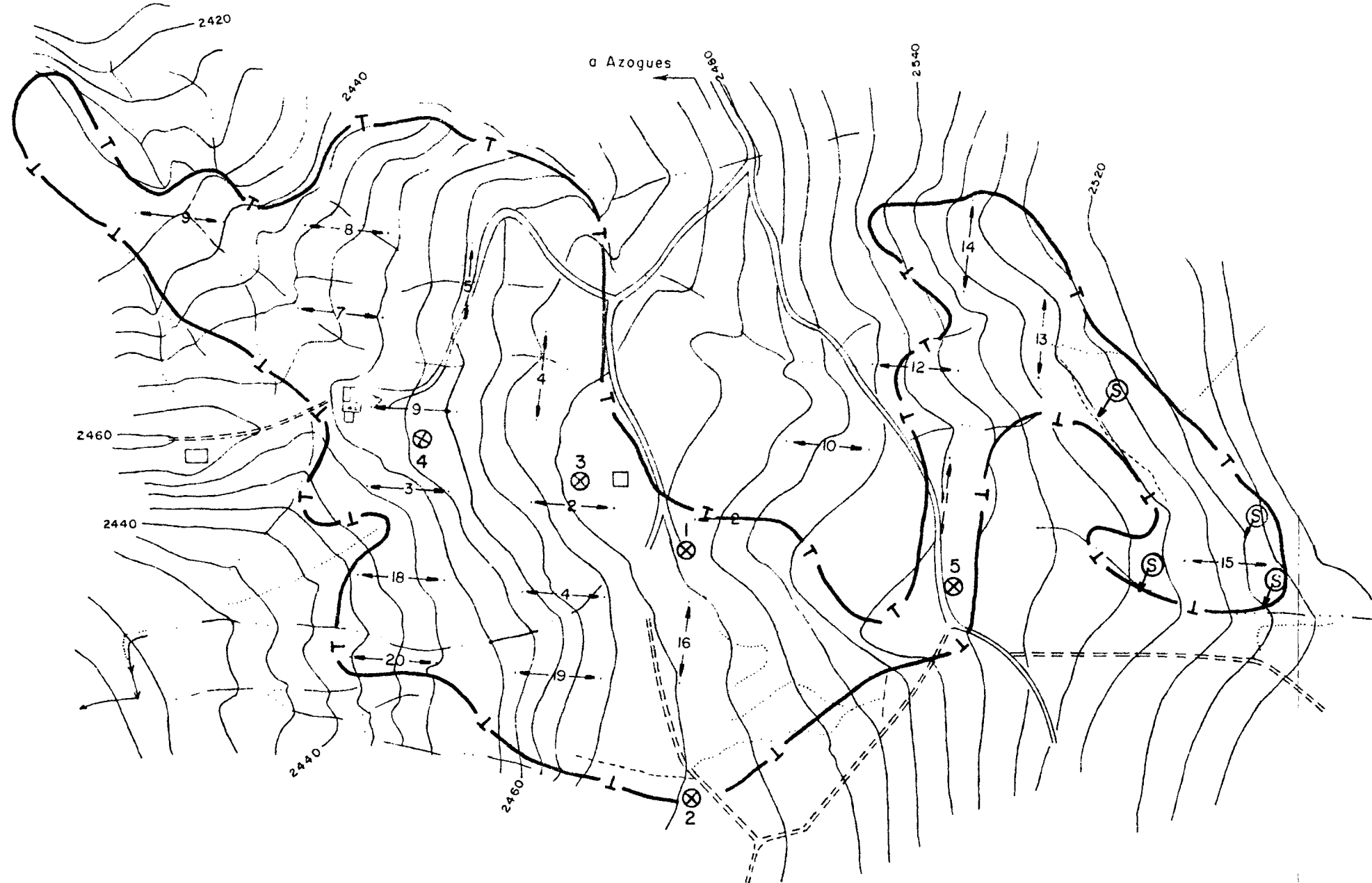
<u>Drillhole 1</u>		<u>Drillhole 2</u>	
.0 - 6.1 m	travertine	.0 - 3.5 m	travertine
6.1 - 6.15 m	clay	3.5 - 6.1 m	clay
6.15 - 8.5 m	travertine		
8.5 - 9.2 m	clay		
9.2 - 9.5 m	sand		

78°49'13"N

78°49'13"N

2°45'41"S

2°45'41"S

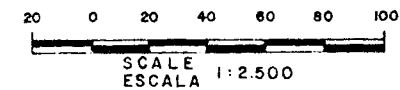


LEGEND — LEYENDA

- Limit of travertine
Limite del travertino
- Mineral spring
Fuente mineral
- Sample
Muestra
- Quarry
Cantera
- Drill hole
Perforación

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ECUADOR
 OPERATION Nº 5
 CACHIPAMBA
 TRAVERTINE DEPOSIT
 DEPOSITO DE TRAVERTINO



MAP Nº 6
 MAPA Nº 6

Drillhole 3

.0 - 3.45 m travertine (poor recovery)
3.45 - 4.3 m clay

Drillhole 4

.0 6.85 m travertine
6.85 - 7.0 m clay

Drillhole 5

.0 - 4.0 m travertine
4.0 - 4.1 m clay

With overburden being negligible, the deposit was sampled on a 40 m grid, and assay results are given in Table I. Parts of the deposit exposed along the road contain silica and ochre, and other parts have been leached by weathering processes.

It should be pointed out that the sulphur content is much higher than at any other prospect in the region, which is excessive for fertilizer, and possibly objectionable for cement. However, several thousand tons of lime have been produced from kilns on the property. Reserves probably total more than half a million tons, excluding obviously low grade areas.

7.14 Cachihuaico

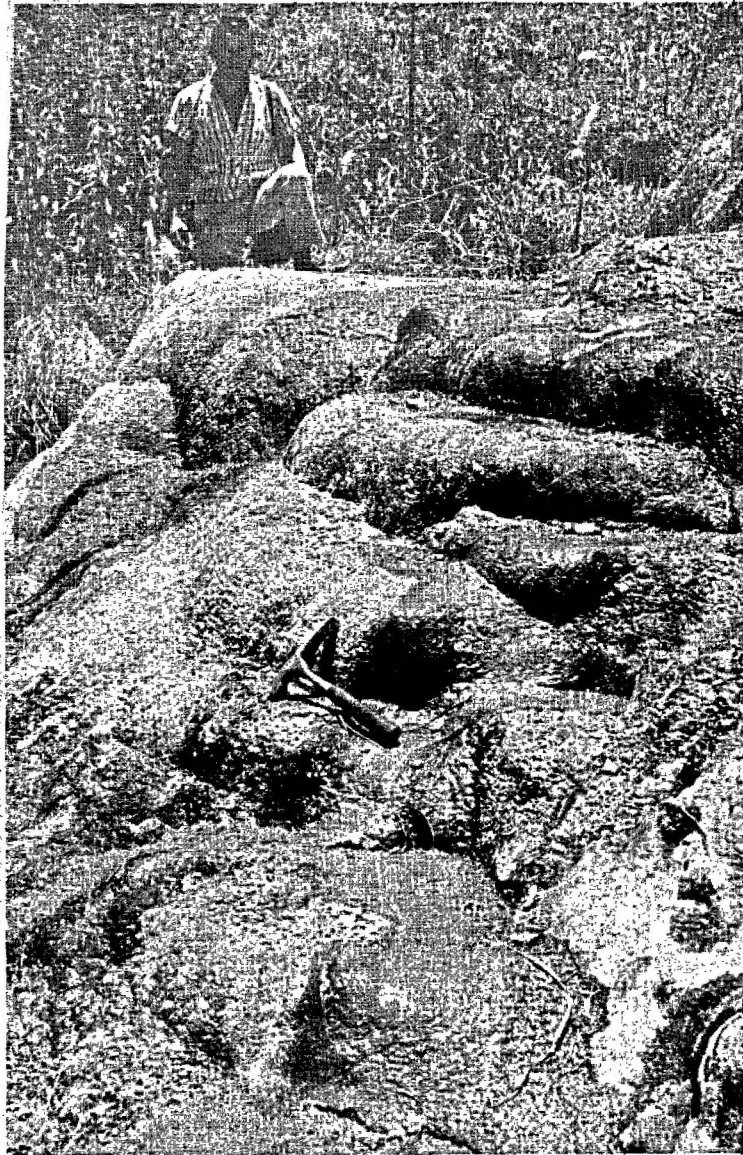
The stream bordering the village of Luis Cordero deeply incised into argillites and volcanics of the Jadan Series (7), is called Cachihuaico, or 'salt creek' in Quechua. Several patches of sub-crystalline travertine, under deposition from cold springs, were noted about half a kilometer south of the school. They are estimated to have the following dimensions: 50x200 m; 20x50 m; 20x100 m; and 50x100 m; being strung out for somewhat less than a kilometer along the west side of the canyon. Reserves are small and the location is difficult, although only about 6 km east of Azogues.

7.15 Bayas

The road to Taday passes along the flank of the volcanic hill called Abuga, and about 5 km north of Azogues, makes a hairpin turn at the Quebrada Shirincay (also called Quebrada Cachihuaico) where terraces of newly formed travertine are conspicuous (Photo V). Though relatively small (about 50 x 100 m) the terraces are probably several meters thick. Another patch was noted about 500 m downstream, and the villagers say that a larger deposit occurs several kilometers upstream.

7.16 Río Tabacay

The upper parts of the Tabacay canyon is cut into black argillites and volcanics of the Jadan Series. The travertine deposit about 3 km north of Azogues is plastered against the steep west side of a slope for a



BAYAS

PHOTO V — Typical terrace deposit of Type I travertine developed on a steep slope.

FOTO V — Típico depósito de terraza formado por travertino de Tipo I desarrollado sobre un talúd.

distance of about 150 m and a breadth of about 75 m. Cold, gaseous water issues from the top and at several levels along the south edge. The material is dense and sub-crystalline. Reserves probably amount to about half a million tons, and accessibility is good.

7.17 Chiticay

An apparently isolated deposit was found on the north side of the Río Paute canyon about 200 m above the road on the farm of Sr. Cordero, and about seven kilometers east of the Descanso road junction. The travertine replaces greenstone in a vertical shear zone striking N10°E, at the contact with black slates and argillites. It also forms two irregular patches about 10 m² on the steep slope. Thick brush and talus obscure the continuity, but the extent is probably small, and the thickness only about one or two meters. The thicker parts have a dense, grey, sub-crystalline carbonate; the thinner have white spongy layers.

7.18 Quinoas

Word of travertine in the Cordillera Occidental about 34 km west of Cuenca was investigated in 1967. A terrace about 20 m on edge was found at a source of gaseous water. The travertine is very fine-grained, colloform and grey-white. The deposit is apparently too small and remote to be of further interest.

7.19 Portete de Tarqui

An occurrence of travertine was examined along the headwaters of the Río Tarqui 26 km southwest of Cuenca at the farm of Sr. Carlos Salazar. It is situated along the west side of the Quebrada Salada, about a kilometer south of the road to Girón. The stream is named from the salty, gaseous, cold springs along its upper banks.

Altered volcanics offer few outcrops and all the workings, abandoned around 1960, are caved-in. Judging from the distribution of the pits and the float, the deposit probably consists of lenticular veins, or eluvial blocks, strung out for about 200 m in a NNW direction parallel to the creek.

The travertine is pure white, with very faint banding but a distinct radiating fibrous habit, which suggests aragonite. Reserves are probably very small.

8. NOTES ON OTHER DEPOSITS

8.1 Saraguro

Pale green, yellow and white travertine, comes from small quarries about 2 km northeast of Saraguro, Loja Province, along the Río Paquishapa 100 to 500 m north of the road. The deposit has been described by Mosquera(2) and by Spindler and Herrera (6). It comprises several veins 0.2 to 2m

thick and 15 to 35 m long, strung out across rhyolite flows and pyroclastics. Reserves are considered small.

Similar travertine, found in many souvenir shops, is said to come from Santa Isabel, about 80 km SW of Cuenca, but a diligent search and inquiry leads to the conclusion that the source is Saraguro, and that no travertine is found at Santa Isabel.

8.2 Loja

An occurrence of travertine was examined at 'Hacienda' Tenería, 11 km by road NW of Loja. Several patches, the largest about 30 x 30 m, are strung out for about a hundred meters in a direction N45°E along the foot of the mountain. The springs are sluggish with a strong alkaline odour and rusty colour. Three abandoned kilns worked material that seems to be low grade, ferruginous, and contaminated with fragments from the underlying metamorphics. Reserves are small. Most of the lime used around Loja comes from thin beds of marl in the Cenozoic shales.

8.3 El Tambo

In the course of triangulating an extension of the base map, the topographer came across a deposit of travertine, apparently a terrace several hectares broad, after field work for this report had been completed. It is said to be located several kilometers SE of El Tambo, along the northern edge of the Cañar-Azuay Basin.

8.4 Selva Alegre

Although this area lies completely divorced from the Project's operation area, occurring to the west of Otavalo in the north of the country, a short reconnaissance was undertaken to visit this true marble (metamorphic limestone) occurrence in an attempt to ascertain its importance in relation to the future marble industry of the country.

The deposit crops out on the lower western slopes of the heavily forested Cordillera Occidental about 50 km NNW of Quito at an approximate altitude of 1,500 m.

The marble is white, homogeneous and evenly crystallized. The western side of the deposit appears to be more homogenous whereas on the east, where the marble is in contact with andesitic intrusives, it is considerably affected by contact effects such as dolomitization and pyritization.

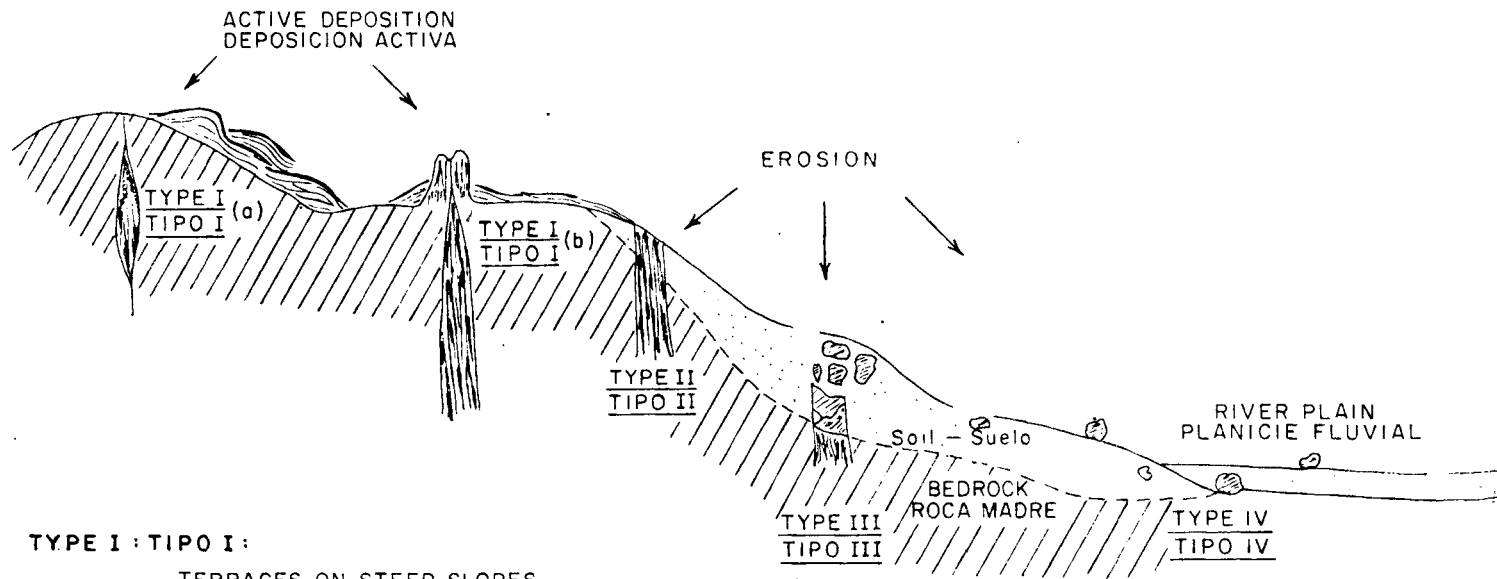
Although no laboratory tests were carried out, the Selva Alegre material appears to compare favourably with second quality Carrara marble as far as constructional ornamentation is concerned. The deposit could assume some importance.

9. DISCUSSION

The Baños springs are pouring out a steady stream of boiling water. The salinity seems to be slight, but souvenir pottery immersed overnight takes on a perceptible coat of calcium carbonate, and after several days glistens with tiny calcite crystals. Given time, the thick walls and extensive crusts can be accounted for in the same way. Baños, Guapán, Patamarca, Cachipamba, Cachihuaico, Tabacay, Bayas, Chiticay, Quinoas and the northern part of Checa all have mineral springs. Where the waters issue on a steep slope, terraces are built up; where it comes out on level ground, linear mounds or walls are also developed. The travertine in the terraces is amorphous or finely crystalline, white, grey or drab in colour, and compact to spongy in texture. The other type of travertine is coarse-crystalline, brightly coloured and usually banded. The chemical analyses presented in Table I show that both types are essentially calcium carbonate (calcite and / or the meta-stable aragonite), with very minor magnesium carbonate, and, to give the colours, traces of siderite, hematite, etc. The coarsely crystalline variety, predominant at Virgen de Milagros, Verdillo, Racar, Sinincay, San Vicente, Ochoa León, Checa, Santa Rosa and in some of the outlying prospects, is not found in terraces, and except possibly for Portete de Tarqui, is not associated with active mineral springs. The workings from which this 'marble' comes are deep pits, aligned in belts, which suggests that they are, or were, veins. Nevertheless, the two varieties of travertine are interrelated, as can be seen at Baños. The coarse-grained travertine lines the fissures from which the waters are discharged; it has vertical banding formed by slow crystallization at depth. The amorphous, spongy travertines, with their horizontal layering, was precipitated rapidly, on the surface. Thus the walls, or linear mounds, are built of fine-grained material, but have cores of the colourful coarsely crystalline banded rock.

The apparent differences in physical form of the various deposits is only an expression of weathering (see Figure 1). Guapán and Baños, the largest deposits, have hot springs. The other terraces have tepid or cold springs and the remainder none at all. As soon as deposition slows down, the carbonate, very soluble in the rainy climate, begins to dissolve more rapidly than it is replaced. Fissures widen into channels, caves develop inside the walls, and patches of spongy material appear in the crusts. Soon all the surficial, or finely crystalline amorphous travertine disappears, leaving only the root of the core. This is the stage seen at Checa, San Vicente, the eastern edge of Baños, and possibly at Portete de Tarqui. Further erosion, plus repeated movement along the fissure, breaks the vein up into large more or less detached blocks, but preserving a linear distribution. These are mined at Virgen de Milagros, Racar and Verdillo. Finally, as the destruction nears completion, only scattered boulders are left for the patient miners to pick apart.

HYPOTHETICAL PROFILE OF TRAVERTINE DEPOSITS
 PERFIL HIPOTETICO DE LOS DEPOSITOS DE TRAVERTINO



TYPE I : TIPO I :

- a) TERRACES ON STEEP SLOPES
Terrazas desarrolladas sobre taludes
- b) WALLS ON FLATS; CORES INTACT
Bancos desarrollados sobre llanos; núcleos intactos

TYPE II : TIPO II :

VEIN ; Veto

TYPE III : TIPO III

ELUVIAL ; Eluvial

TYPE IV : TIPO IV

ALLUVIAL ; Aluvial

**SUGGESTED FORMATION OF
 TYPES OF TRAVERTINE DEPOSITS**

**FORMACION SUGERIDA DE TIPOS
 DE DEPOSITOS DE TRAVERTINO**

FIG. 1

Thus four types of travertine can be distinguished: I) Terrace, II) Vein, III) Eluvial, and IV) Alluvial. Although interrelated, each type presents a different problem for economic development. Type I, Terrace deposits are essentially composed of amorphous, finely or semi-crystalline spongy travertine whereas Types II-IV are predominantly crystalline, banded material and have provided all the known 'marble' of the area.

To clear up any remaining doubt about the origin of the mármol, (marble) and caliza (limestone) of the region, it should be emphasized that none of the deposits is of sedimentary or metamorphic origin, as implied by the colloquial use of these terms. Limestone does occur, (but is not mined), as beds up to 2 m thick in the Cretaceous rocks beneath the basin, and it is presumably from the leaching of these older rocks that the hot springs have derived their carbonic acid. Map 2 shows that the travertine deposits of the Cuenca-Azogues area are distributed around the edge of the basin, on or near the contact with older rocks. None is found in the central part, where any carbonate-bearing waters would have been diluted in a longer ascent. This pattern, together with evidence that the deposits are localized at fault junctions, ought to assist further exploration.

The terrace deposits of finely crystalline travertine, are of prime interest for industrial and agricultural uses. Of wide areal extent, easy accessibility, with little or no overburden, they offer a large, cheap supply of high grade calcium carbonate for existing cement, fertilizer, sugar refining, as well as possible chemical or metallurgical needs in the future.

Portland cement is produced at Guapán, by calcining the travertine and blending in local shale and gypsum. Good deposits of kaolin have now been developed in the same area (Part Two, Clays), opening up the possibility of making white cement, which has a high unit value and can be exported under suitable conditions. Fertilizer lime is being produced by CREA at Guapán and Baños, and its use will expand steadily as local farmers see its advantages.

Mapping, sampling, and drilling for the present report indicate reserves of the Terrace-type of deposit to supplement the known tonnage at Guapán, which in itself is thought to be good for many decades.

Most of the travertine used as ornamental stone comes from Virgen de Milagros, Verdillo, and other quarries near Cuenca of the Eluvial (Type III) deposits. It is very difficult to estimate how much of this material has been extracted since the erection of Huayna Capac's palace, and it is even more hazardous to say how much remains, because the occurrence of eluvial blocks cannot be predicted by geologic mapping nor confirmed by drilling. The pick-and-shovel miners just keep digging until they find a block, then cut it into slabs, calcining the refuse.

They sell the polished 'marble' at prices ranging from \$350 (US\$ 17.50) per square meter. But because of many variations in colour, banding, texture and other properties, there is no standard supply. The Alluvial (Type IV) shows even more variations, since the scattered boulders may have come from several different veins. The main advantage of the eluvial and alluvial deposits has been their amenability to primitive mining.

The coloured and banded vein-root or vein-core type of deposit offers another possibility. Encased in sub-crystalline travertine walls or bedrock these deposits have hardly been scratched because of the extraction problem. Drilling and blasting could damage much of the material and so another form of mechanical extraction involving cutting would have to be contemplated. On the other hand, being in situ, they can be mapped and developed systematically by private enterprise or a Government institution.

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PART TWO - CLAYS

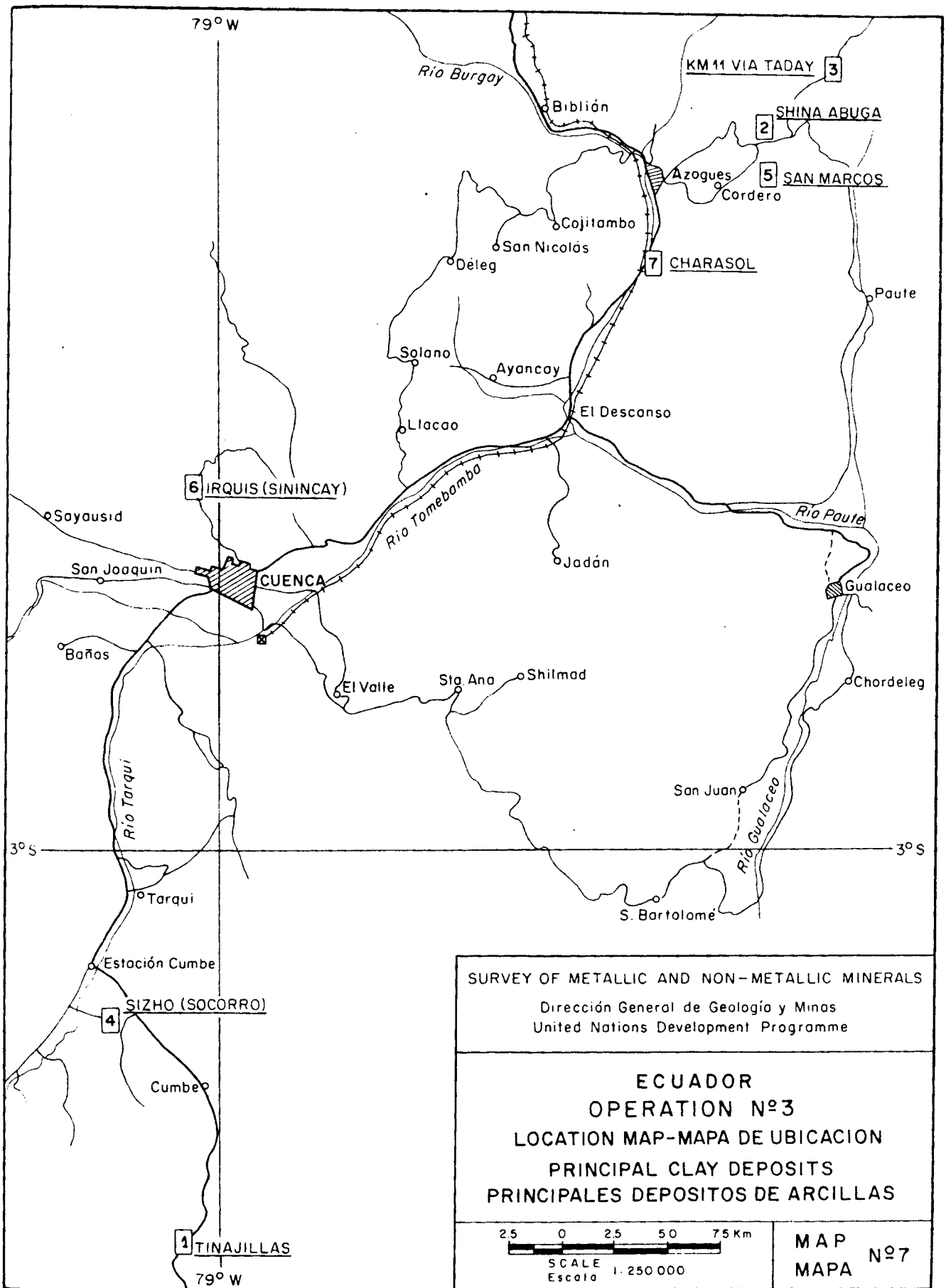
11. INTRODUCTION

With increasing industrial development in the country a greater demand will be made on raw material reserves. In the non-metallic category it is not difficult to imagine that clays will become increasingly important as industrial demands expand, new industries are developed and export markets are investigated. A complete study of clay deposits from discovery, through geological evaluation, mining feasibility and methods to laboratory tests and their industrial applications will be required.

The United Nations assisted project was exploratory in nature, and under the terms of the Plan of Operation work was necessarily confined to the primary areas of study: exploration and preliminary evaluation. Operation No.3, effected over the pre-selected area of Cuenca was therefore limited to geological mapping of the deposits, an estimation of possible reserves and basic laboratory identification by X-ray diffraction so that clay-types could be classified according to their mineralogy. The best was made of the tools available. The clays could not be classified according to their potential industrial uses, as this would have involved the establishment of a specialized laboratory for testing such properties as plasticity, green strength, shrinkage, porosity, deformation temperature, vitrification range, bloating characteristics, etc.. The establishment of an industrial materials testing unit would be a logical step for Government to pursue.

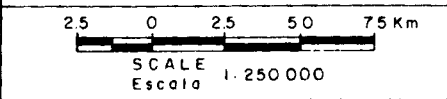
In the exploitation of clay deposits some important areas are mining methods, quality control and transport. Presently only primitive methods are employed for the extraction of clay, and this includes washing and settling on site for which purpose an adequate water supply is required. Where deposits are close to permanent streams this should present no problem, and where drainage or borehole water is not readily available the storage of rainwater has been suggested as a last-ditch solution. In most cases the clay deposits described in this report are easily accessible by road, and transport to the industrial consumer in Cuenca is fairly cheap and straight forward.

Quality control which secures the delivery of a standard product to the factory is also, vitally important. Clays vary in their properties and the blending of clays, sometimes with other ingredients, is required to supply products to meet individual requirements. The complete process from mining to blending is often best controlled by the factory; a situation which is not by any means standard in the Cuenca area.



SURVEY OF METALLIC AND NON-METALLIC MINERALS
 Dirección General de Geología y Minas
 United Nations Development Programme

ECUADOR
OPERATION N°3
LOCATION MAP-MAPA DE UBICACION
PRINCIPAL CLAY DEPOSITS
PRINCIPALES DEPOSITOS DE ARCILLAS



MAP N°7
MAPA N°7

The clay deposits have previously been reported on by Mangez and Mosquera, 1959 (1) and a Japanese technical aid mission, 1958 (2) who concluded that the clays in this area had little technical or economic importance. Much of the descriptive work in the present report is based on investigations made by Government counterpart geologist Núñez del Arco (2).

12. CONCLUSIONS

1. Six kaolin deposits were studied in some detail from the Cuenca (Cañar-Azuay) area with estimated total reserves of about 200,000 metric tons excluding the Shiña Abuga deposit where several million tons can probably be proved by further detailed work.
2. A bentonite deposit was delineated at Charasol and over the surveyed area of 13 hectares an estimated reserve of 500,000 metric tons is readily accessible. The structural and topographic position of the bentonite horizon presents excellent conditions for strip mining. The principal constituent of the bentonite is a calcium-montmorillonite and therefore the material would not be applicable to the petroleum drilling-fluid industry. Further tests however showed that the bentonite might make a high grade foundry clay. Its application in the cement, purifier and pesticide industries should also be studied.
3. Kaolin is presently being won on varying scales from most of the described deposits and is being used in the ceramic industries especially in the developing pottery center at Cuenca. The highest quality material comes from Shiña Abuga and consists principally of kaolinite, quartz and cristabolite, with minor amounts of illite, montmorillonite and plagioclase. A higher standard of quality control particularly at the quarry sites would seem to be warranted so that standard products are readily available to industry.
4. Apart from their use in the ceramic industry, an investigation should be made of the application of the kaolin clays in such fields as soap, paints, cosmetics, fertilizers and insulators.
5. The kaolin deposits are generally encountered beneath an acid humus-rich soil and are developed over volcanic rocks. The formation of the clays by decomposition of the volcanics is attributed to the action of humic acids or hydrothermal activity or a combination of these two processes. The general distribution of the deposits around the margins of the Cañar-Azuay sedimentary basin where hydrothermal activity is responsible for the development of the travertines suggests that this late stage volcanic process has played an important role. These observations should aid the extension of clay prospection activities.

13. RECOMMENDATIONS

1. Further development of the ceramic industry and industrial expansion into other fields where clays are employed must be preceded by specialized laboratory testing to determine their relevant industrial applications. Once this has been done and likely areas have been outlined, then the deposits should be surveyed in detail to determine reserves and development methods. Obviously, where more than one clay type is found in the same area such as at Taday - km 11, detailed sampling, laboratory testing and evaluation must proceed simultaneously.
2. To aid economic development in the clay industry Government should investigate the best method of establishing a materials testing laboratory. This would be available to guide potential consumers in their selection of materials.
3. The fact that good quality clays are found and may continue to be found well outside the Cuenca area, (the lacustrine kaolinite (halloysite) - gibbsite deposit at Puyo serves as a good example), should be taken into account during development studies.

14. A NOTE ON THE INDUSTRIAL USES OF CLAYS IN ECUADOR

The ceramic industry has been established in Ecuador since colonial times. Tableware produced at Latacunga some 80 km south of Quito was quite famous in the nineteenth century. For this, kaolin from the nearby Pujilí deposit was employed. At Cuenca, the centre of the project's area of exploration, a ceramic industry has been established for many years and is growing in importance quite rapidly.

Clays now have a vast number of industrial applications and naturally these have so far not all been exploited in Ecuador. The principal local application has been in the ceramic industry, and there are four factories in operation. These are the Cerámica Ecuatoriana de Riobamba, Cerámica Moderna (Cermod) de Cuenca, the Cerámica Modelo de Cuenca and the Escuela de Cerámica de Azogues. The latter ceramic school is a rather primitive installation and works just with local primary materials whilst the factories use both local and imported materials. Local clays are obtained from Shifia Abuja, Iruquis, San Marcos and Charasol (Cañar-Azuay area); Aurora, Lourdes and Maldonado (Chimborazo Province); Masma and Las Guardias (Bolívar Province); Puyo (Napo Province) and from Pujilí (Cotopaxi Province). For the Cañar-Azuay area the limestone is obtained from the travertine deposits described in Part One and gypsum is screened on a cottage industry basis from the Loyola Formation (4)

which is the upper member of the Azogues Group. Quartz is obtained from Tixán some 30 km to the north of Cuenca in Chimborazo Province. Imported raw materials include ball-clay from England, clays from Colombia and enamels from Mexico.

The Cermod factory in Cuenca was established on a small scale, but gradually expanded and was converted into a pilot plant for personnel training and some experimenting with the local clays. This pilot plant was so successful that the factory was modernized to produce whiteware and ornamental pieces. At the time of the project's investigations in 1966-67, 15,000 pieces were being produced monthly with a labour force of 50. The plant now only produces ornamental pieces, and a new factory, Cerámica Modelo de Cuenca, manufactures whiteware, employing 80 labourers and producing 10,000 pieces monthly. This new plant has a small laboratory for testing the physico-chemical properties of the raw materials.

The ceramic factory at Riobamba, approximately 160 km south of Quito and 140 km to the north of Cuenca, employs 140 workers and manufactures glazed tiles, sanitary materials and whiteware. Annual production of finished pieces amounts to about 3,000 metric tons per year. Laboratory tests carried out here include determination of oxide content, granulometry, humidity, water absorption and porosity.

The whitest and purest clays are required for the manufacture of domestic and sanitary articles. Other types of clays, or mixture of clays, find application in the preparation of roofing tiles, bricks, adobe, terra cotta, stoneware, sewer pipes, paving bricks and of course in cement manufacture. These articles are all being produced on varying scales within Ecuador.

Another important use of clays is in the petroleum industry where they are applied in both the discovery and recovery processes. In view of the recent petroleum discoveries in the Oriente, or Amazon Basin region of the country, there is obviously a potential market for clays if the right types can be found locally. Presently all drilling fluid materials are being imported. Apart from barite, the principal ingredient of drilling mud is bentonite with specific swelling properties. The bentonite outlined at Charasol to the north of Cuenca was found to be unsuitable, but as will be shown later it could well find application in the foundry industry.

Apart from applications in the ceramic, petroleum and metallurgical (foundry clays) industries, clays are also used in paint manufacture and the textile, pharmaceutical, pesticide and fertilizer industries where they can be applied for clarifying, emulsifying or as fillers. With the intended development of such industries in Ecuador detailed laboratory studies of local clays will have to be made to establish standard requirements for each particular industry which would then enable them to be classified according to application.

15. PRINCIPAL KAOLIN DEPOSITS STUDIED

15.1 General Remarks

Detailed work was limited to six kaolin deposits in the Cuenca, or Cañar-Azuay area, and these were found to have certain common characteristics: all are found at an approximate altitude of 3,000 m on a fairly mature landscape; the thickness of the kaolin layer is usually between 1 m to 2 m; the kaolin layer occurs below a 2 m to 8 m thick, dark coloured, humic soil horizon and all the deposits are developed on volcanic rocks.

The deposits have been formed by the alteration in situ of Quaternary volcanic rocks which range in composition from basalts to rhyodacites. In nearly all cases this alteration has been caused by hydrothermal effects associated with the later stages of volcanic activity which is still evident by the thermal springs responsible for the formation of the travertine deposits described in the first section of this report. Additional alteration of the volcanics may have been caused by the breaking-down action of humic acids.

Kaolin reserves were estimated from hand auger holes which were drilled on variously spaced grids and X-ray diffraction determinations which were sometimes confirmed by chemical analyses showed that varying amounts of halloysite, quartz, cristabolite, plagioclase and illite are generally present in addition to kaolinite.

Some data on the deposits is included into Table II, and details are given in the reports on individual deposits which follow. The location of the deposits is shown on Map No.7, and chemical analyses of clays from selected areas are tabulated in Table III.

15.2 Tinajillas

The Tinajillas kaolin deposit lies 41 km to the south of Cuenca on the Panamerican highway at an altitude of about 3,000 m on high páramo country associated with the Nudo de Portete. The kaolin which forms a lense-shaped body varies in thickness from 1 m to about 10 m and is developed over porphyritic acidic volcanics (rhyolitic) typical over a large extension in this area. The deposit is developed immediately beneath a thick capping of black soil.

Over 100 sample holes auger drilled on a 25 m grid over a total extension of 5.33 hectares showed that an amount of at least 350,000 m³ could be mined easily from near surface: a conservative reserve estimate of 700,000 metric tons (Map No.8). Although there is no nearby supply of permanent water, the high area is subject to a fairly heavy rainfall and it is thought possible that sufficient rainwater reserves could be built up for exploitation of the deposit. The cost of trucking to Cuenca would be in the region of S/25(\$5,00) per ton.

TABLE II

DATA SUMMARY OF THE CUENCA KAOLIN DEPOSITS

Deposit	Developed from: (rock-type)	Thickness	Area m ²	Overburden	Mineralogy (in order of importance)	Reserve estimate	
Tinajillas	Porphyritic rhyolitic volcanics	1m-10m	56,000	Humus-up to several m	Cristobalite Kaolinite Halloysite Quartz Illite	700,000 m tons	Accessible by road,
Shiña	dacites	1m -	4,500,000	Humus-up	Kaolinite	several	Used extensively by ceramic industry = good quality Accessible by road
Abuga	latites	several metres		to several m	Halloysite Quartz Cristobalite Montmorillonite	million m tons	
Taday km 11	pyroclastics	2m	18,000	Humus 2m-3m	n.d. (firing tests carried out)	75,000 m tons	Accessible by road, some good quality material used in ceramics.
Socorro	sedimentary tuffs	0-5m 1.5m	13,000	n.d.	n.d. (firing tests carried out)	26,000 m tons	Near road access - generally poor quality.
San Marcos	andesites tuffs	n.d.	n.d.	n.d.	Kaolinite Quartz Cristobalite Illite Plagioclase	n.d.	No direct road access, used for manufacturing of ceramic tiles.
Irquis	intra montane valley fill	1m-2m	large extension	Humus 0.5m	Kaolinite Illite Quartz Montmorillonite Plagioclase	n.d.	Partial road access, fairly poor quality used for making bricks and roof tiles.

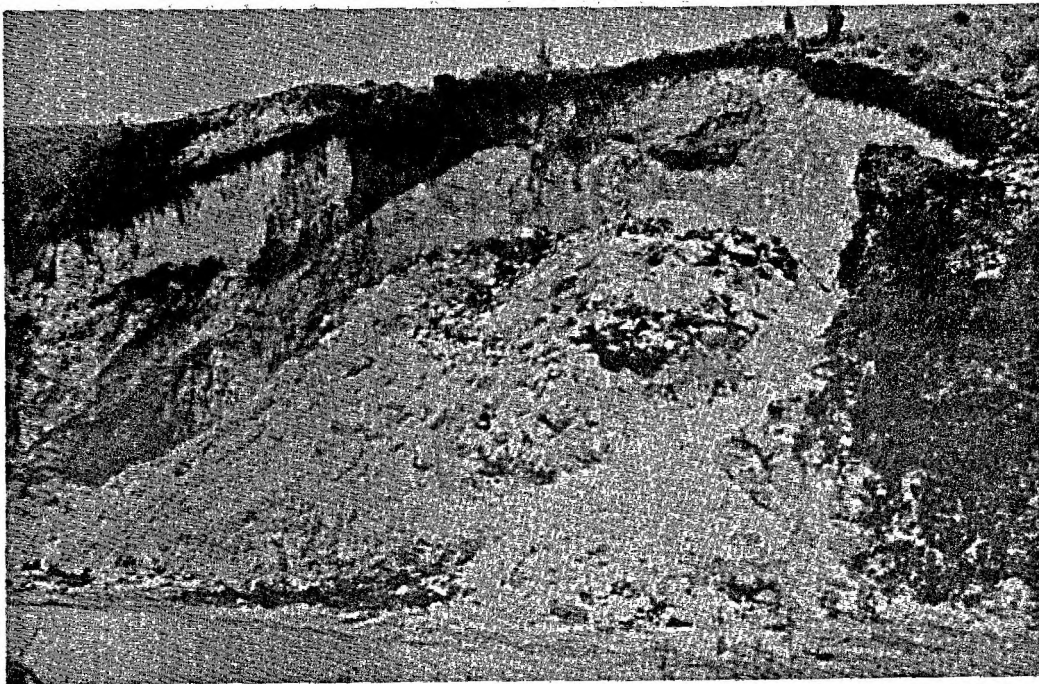
n.d. - not determined



TINAJILLAS

PHOTO VI — Well developed kaolin horizon directly beneath humus layer.

FOTO VI — Horizonte de caolín inmediatamente bajo la capa de humus.



TINAJILLAS

PHOTO VII — Rudimentary methods of exploitation with lack of planning and technical control lead to contamination of the kaolin and inefficient production.

FOTO VII — Métodos rudimentarios de explotación combinado con la falta de programación y control técnico, resulta en la contaminación del caolín y una producción ineficaz.

Six representative samples were examined by X-ray diffractometry and it was found that the following mineral species were present in order of importance: cristobalite, kaolinite, quartz, illite and feldspar (See Table II). There is a tendency for hydration and transformation of the kaolinite to halloysite which is an effect of weathering and which decreases with depth. The clay is white to yellowish white in colour, of granular texture, and has low plasticity.

The maximum depth of investigations by drilling was 7 m and before further development work on this area is programmed it is suggested that the depth extension as well as the variation in clay-type with depth is examined in detail to obtain an accurate picture of reserves.

15.3 Shiña Abuga (Mina Mercedes)

In size, and to a certain extent in quality, this is the most important deposit in the Cuenca area. It is located about 7.5 km NE of the town of Azogues along the road to Taday and indeed was discovered during road construction. Altitude is about 3,000 m which gives the area a temperate to rather chilly climate with a daily temperature range averaging 5°C to 11°C. Rainfall is between 1000 mm and 1200 mm per year. The discovery of this deposit is one of the principal reasons why the ceramic industry was developed in the Cuenca area, and the clay from Shiña Abuga is still the principal raw material being used by local industry.

The kaolin deposit is again lenticular in shape and is developed over dacites and latites which have suffered extensive cross faulting. Kaolinization may have resulted from hydrothermal activity associated with the nearby extinct volcano, Abuga, and been aided by activity along the fault lines. Similar to the Tinajillas deposit, the kaolin immediately underlies a thick development of acid, black, humus-rich soil. Humic acids may also have contributed to the development of the kaolin.

A topographic survey on a scale of 1:2,000 was made of the deposit (Map No. 3) and this was used as a basis for the construction of a 50 m spaced sampling grid. The mineralogical variation of the kaolin over this grid is summarized in Table IV. Within the area of the deposit 35 holes were augered to maximum depths of 8 m and 10 additional prospecting holes were drilled outside the area covered by the grid. Channel samples were also taken across the exposure provided by the present quarry. This work showed that the area of kaolinization covers about 4,500,000 m² (4.5 km²) and that several million tons of material are, therefore, readily available. Nearby permanent water is available for mining operations and transport to Cuenca would be in the region of \$100 (\$4.00) per ton. The permanent gravelled road to Taday traverses the deposit.



FIELD SAMPLE Nº	LABORATORY
Nº DE MUESTRA DE CAMPO	REGISTRATION Nº Nº LABORATORIO
● LL	— 1737 (6m)
○ P1 ^{IV}	— 1764 (5m)
○ P1 ^{IV}	— 1768 (12m)
○ P1 ^{IV}	— 1769 (14m)
○ P2	— 1772 (3m)
○ P2	— 1775 (7m)
○ P3	— 1795 (1m)
○ P3	— 1798 (4m)
○ P3'	— 1802a(5m)
○ P3''	— 1806a(4m)
○ P3 ^{IV}	— 1812a(2m)
○ P5	— 1837a(3m)
○ P6	— 1843a(4m)
○ P7'	— 1847a(4m)

α Azoques
7.5 Km

LEGEND — LEYENDA

- SAMPLES — Muestras:**
- GRID Red
 - ROAD Carretera
 - QUARRY FACE Frente de la cantera
 - CONTOURS AT 10m INTERVALS Curvas de nivel con intervalos de 10m

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

ECUADOR
OPERATION Nº3
SHIÑA ABUGA
KAOLIN DEPOSIT
DEPOSITO DE CAOLIN

SCALE 1:2,000
Escala

MAP Nº9
MAPA Nº9

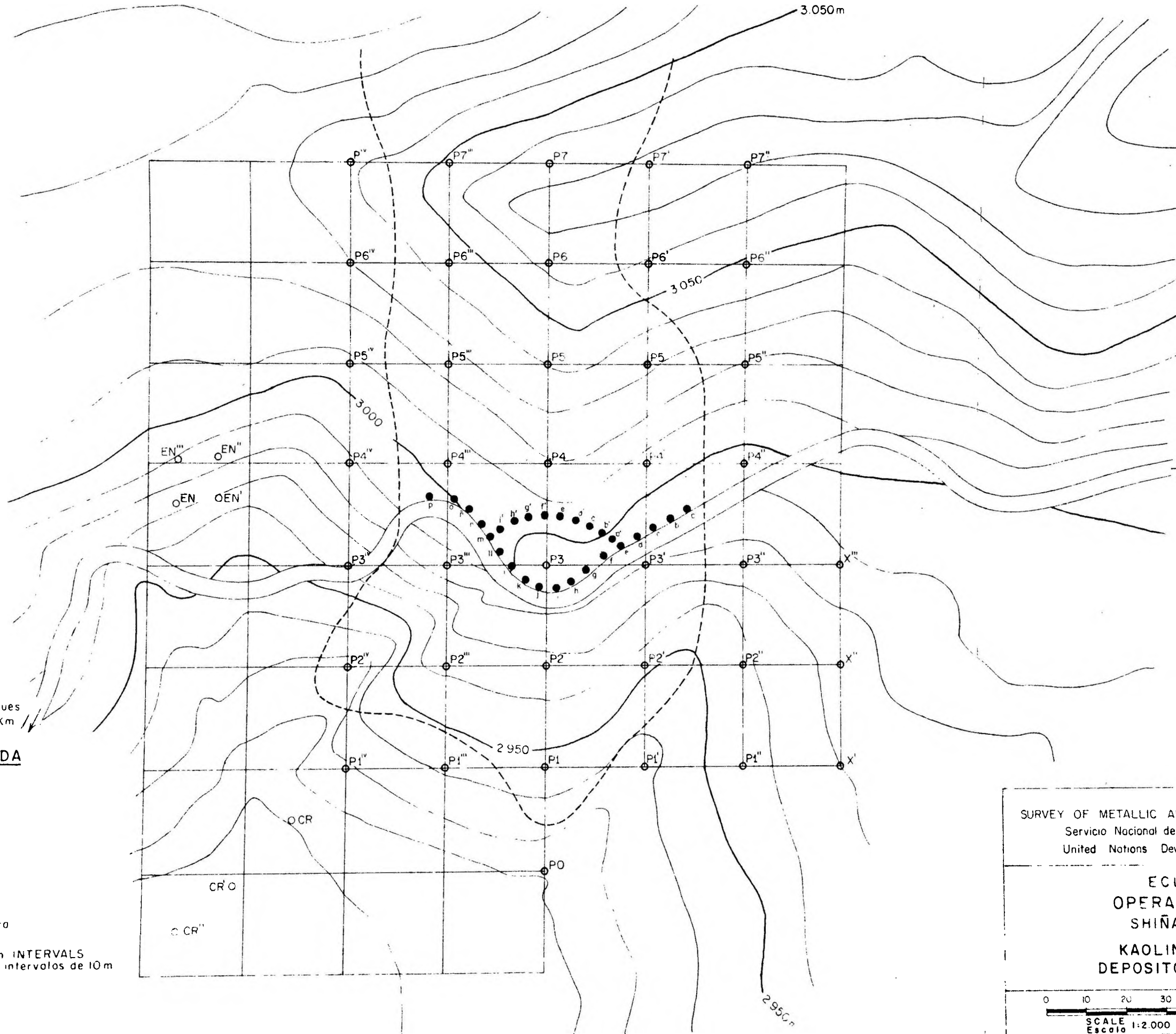


TABLE III

ANALYTICAL RESULTS OF CLAYS FROM THE CUENCA AREA

Deposits	SiO ₂ %	Al ₂ O ₃ %	Fe ₂ O ₃ %	CaO%	MgO%	Na ₂ O%	K ₂ O%
Shiña Abuga (1)	67.02	24.04	0.02	0.24 (2)	0.32	na	na
Shiña Abuga (3)	56.27	26.81	4.6	0.42	2.03	na	na
Taday km 11 (3)	59.14	23.50	3.50	0.70	1.41	na	na
San Marcos (4)+	58.77	25.93	6.00	na	na	na	na
Irquis (#)	62.00 (4)	22.00 (4)	1.90 (2)	na	0.47 (2)	na	1.63 (2)
Charasol (1)	71.60	15.12	4.00	-	1.01	na	na
Charasol (4)	69.74	16.60	2.84	1.01	3.00	0.15 (4)	0.29 (4)

1. Analysis by Fábrica de Cemento Guapán C.A, Azogues
2. Analysis by Servicio Nacional de Geología y Minería, Quito
3. Analysis by "Cermod", Cuenca
4. Analysis by Cerámica de Riobamba, Riobamba (+ average of 6 samples)

Average of 3 samples

na Not analysed



SOCORRO — SIZHO

PHOTO VIII — Prospection pit. Note typical kaolinized Quaternary tuffs in distance.

FOTO VIII — Pozo de exploración. Nótese al fondo tobas Cuaternarias caolinizadas típicas.

Shiña Abuga was previously investigated by Mangez and Mosquera, 1959 (1) and mention is made of a previous study by B.F. Wallis in 1958 for the Banco de Fomento in which it is stated that the deposit was studied by drilling to depths of 200 m which provided a reserve estimate of 4,200,000 metric tons.

Over 20% of the samples taken were subjected to investigation by X-ray methods and some of these were selected for chemical analyses. Detailed results which are presented in Tables III and IV show that the principal minerals are kaolinite, halloysite, quartz, and cristobalite. The increase of hydration and subsequent lowering of the crystallinity of the kaolinite appears to occur where there are lower percentages of plagioclase and orthoclase.

Chemical analyses indicate that the kaolin content averages about 55% and that excess silica as either quartz or cristobalite averages approximately 30%.

15.4 Taday - km 11

This deposit lies beyond that at Shiña Abuga, about 11 km to the NE of Azogues on the Taday road at an altitude of 3,150 m. A deep ravine limits the deposit on its western side and on the surface it is covered by a humus layer varying between 2 m and 8 m in thickness. The underlying kaolin which in this case may have been developed purely as a result of decomposition by humic acids and aided by meteorization occurs as a 1 m thick band. The clay is developed from Quaternary pyroclastics.

About 2.5 hectares were examined by augering over a 20 m spaced grid and this allowed the definition of the clay horizon over an area of 1.25 hectares in which two grades of serviceable kaolin were distinguished. Firing tests (1,145°C) on these materials were carried out by the Cermod factory in Cuenca and showed that one type of high quality clay gave a very pure white colour. This clay zone has an average thickness of 2 m and extends over an area of 6,342 m² so giving an estimated reserve of about 25,000 metric tons. The second type, also of quite good quality burnt to an even light cream colour. The reserves of this clay are estimated to be in the order of 50,000 metric tons. The better quality kaolin is usually found on the southern side of the deposit at a depth from surface of between 4 m and 10 m.

15.5 Socorro

About 25 km to the south of Cuenca along the Panamerican highway a small subsidiary road runs westward into the eastern inter-montane foothill front of the Cordillera Occidental. The small hamlet of Socorro lies here at an altitude of 2,900 m, and the kaolin deposit is situated just outside the village. Quaternary tuffs, intercalated

TABLE IV

MINERALOGICAL VARIATIONS IN AREA AND DEPTH OF THE SHIÑA ABUGA KAOLIN

Spacing	Sample No. (+)	DEPTH FROM SURFACE								
		1m	2m	3m	4m	5m	6m	7m	12m	14 m
S	1764, 68, 69					cr, pl, ka			ka, qz, cr	ka, qz, cr
50m	1772, 75			qz, cr, ha, pl				cr, qz, ha		
50m	1795, 98(1)	ha, pl, cr			pl, cr, ha					
100 m	1837a			cr, qz, ka						
50m	1843a				cr, ha, qz					
50m	1847a				ha, qz					
N										
W	1812a		pl, il, ha, cr							
75m	1737							ka, qz, cr, il		
25m	1795, 98(1)				pl, cr, ha					
50m	1802a					qz, cr, ka, pl				
50m	1806a				ha, cr, qz					
E										

Samples are from axial profiles of grid located centrally with respect to the quarry and extending 150m N of the quarry face (Sample 1847a), 150m S of the face (Samples 1764, 68, 69) and 25m W and E of the face respectively (samples 1812a and 1806 a).

X-ray determinations by C. Faure, Expert Mineralogist, UN Mining Project, Quito.

ha=halloysite; ka=kaolinite; pl=plagioclase; qz=quartz; cr=cristobalite; il=illite. Predominant minerals only are shown in order of importance.

(+) Denotes laboratory registry number. For sample locations see Map 9.

within volcanic-rich fluviatile material including coarse conglomerate horizons, have probably been altered by incipient thermal activity combined with heavy meteorization. The effects of hydrothermal alteration around the boundary area of the Cañar-Azuay basin should not be underestimated. In the general area of Tarqui and Portete massive sections of the Turi and Tarqui Formations are exposed which are completely kaolinized and even include the boulder constituents of the massive conglomerate horizons which until picked with a hammer appear to be fresh material (5). The so-formed clay is generally white, but has low plasticity, high porosity and a fine-grained texture in which abundant quartz grains are noted as well as sporadic flakes of ferromagnesian minerals.

An auger drilling programme was carried out on a 20 m spaced grid over an area of 1.3 hectares. Results show that the main clay horizon has a thickness of between 0.5 m and 1.5 m with possible reserves of 26,000 metric tons. Some firing tests were carried out by Cermod, but the general quality of the material was found to be too low for use in the ceramic industry.

15.6 San Marcos (Guintul)

The San Marcos kaolin deposit is located 11 km to the southwest of Guintul school to the north-east of the hamlet of San Marcos about 4.5 km to the east of Azogues at an altitude of 3,000 m. The deposit is cut-off to the north by the Infiernillo creek and similarly delimited to the south by the Yanacocha creek. The major clay horizon has been developed by hydrothermal alteration of andesites and tuffs and has a dip of 22° to the north-west.

A N-S baseline was laid out traversing the deposit and auger holes were drilled at 50 m intervals along this line. Samples were examined by X-ray diffractometry and showed that principal mineral constituents are kaolinite, quartz, cristobalite and illite in descending order of importance.

Due to the structural position of the deposit no estimate could be made of the reserves or the thickness of the principal clay horizon. Presently the clay is being mined by pick and shovel, transported by mule-back to San Marcos and from there carried to the consumer by truck via Azogues. Material from San Marcos is used principally by the ceramic factory at Riobamba in the manufacture of glazed tiles. It is estimated that some 3,000 m³ have already been won from the deposit. The clay of a light grey colour, shows excellent plasticity. More extensive and deeper drilling would have to be carried out to establish a reserve figure. If further work then shows this deposit to be of some significance communications will obviously have to be improved.

15.7 Irquis (Sinincay)

The Irquis clays occur in an area of valley-fill to the west and north-west of Cuenca where they are exploited by the local villagers for the manufacture of bricks and roofing tiles. The main horizon, about 1 m to 2 m thick is superficial and lies directly beneath a 0.5 m soil capping which is extensively cultivated and therefore hindered a complete study.

The material is white to light-grey and cream, has poor plasticity and is fairly granular in texture. X-ray diffraction tests on three representative samples showed the principal mineralogy to be kaolinite, quartz and illite.

16. THE BENTONITE DEPOSIT OF CHARASOL

16.1 General description and geological setting

The Charasol bentonite deposit is a well marked stratigraphical component of the Guapán Formation (4) which outcrops near the village known as Borrero on most topographical maps, but which is locally called Charasol. The village lies astride a paved section of the Pan-american highway 3 km to the south of Azogues, about 25 km to the north-east of Cuenca at an altitude of 2,400 m. The climate is temperate with average maximum and minimum daily temperatures in the order of 24°C and 10°C respectively. Rainfall is about 700 mm per year and generally falls between the months of December and May although the climate is rather changeable.

The principal structural feature of the area is the gently folded Azogues syncline, the approximate N-S aligned axis of which in this area is occupied by the Azogues river which flows to the south and drains the northern section of the Cañar-Azuay basin. The river valley is up to a kilometer wide at Charasol and the gentle slopes of the eastern flanks are controlled by the dip of the shales of the Guapán Formation of between 12° and 15° to the NW. The bentonite occurs as an intercalated lense within the Guapán Formation and outcrops on this dip slope immediately to the east of the road where about 10,000 m³ are exposed by erosion along the Guabaná creek. Conditions for strip-mining are excellent.

The underlying sandstones of the Azogues Formation crop out upslope to the east where they form conspicuous hog-back features. The Guapán Formation (? Oligocene), the upper member of the Azogues Group, is basically a shale unit about 100 m thick in the Azogues area but which lenses out entirely to the south(4). The typical rock is a finely laminated, fissile, heavily weathered paper shale which is bleached and coated with yellow limonite on the surface. The lense of Charasol

bentonite probably represents a fine volcanic ash layed down under shallow lacustrine conditions typical of this period of development of the sedimentary basin. Gypsum partings within the shales are common and it also occurs as fracture fillings and partings within the bentonite. A well defined gypsum horizon about 60 m above the contact with the sandstones of the Azogues Formation considerable aided prospection work and the definition of the bentonite horizon. It is very possible that the same bentonite horizon also occurs as sub-outcrop on the easterly dipping western side of the Azogues syncline to the west of the Azogues river.

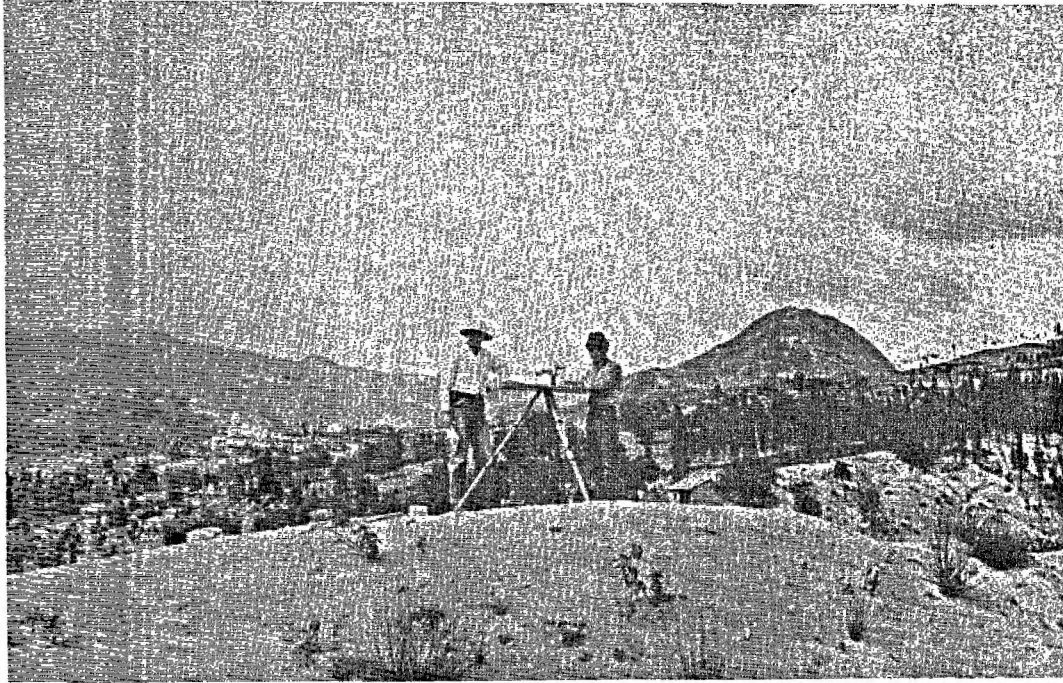
16.2 Work performed

A geological map was prepared on a 1:2,000 scale over an area of 24 km² to demarcate the outcrop of the Guapán Formation in the Charasol-Azogues area. Based on the results of this work a NS-EW orientated grid with 50 m spacing was surveyed in to the east of the village; the outcrop of bentonite being almost centrally located with respect to the grid (Map No.10). Auger drilling was carried out on grid intersections to depths which varied from 0.5 m to 20.50 m. Altogether 120 such holes were drilled with a total length of 650 m. This work resulted in the evaluation of the bentonite horizon over an area of 16 hectares (0.16 km²) where it was found to vary in depth between 0.50 m and 7.0 m. The overlying paper-shales have been eroded away in the area of outcrop and towards the west form an overburden up to 18 m in thickness. It is in this direction (down dip) that the upper surface of the bentonite plunges quite steeply and where evaluatory work was not continued. Isopacs were constructed for the bentonite as well as the shale overburden and it was calculated that for the area drilled, reserves are about 500,000 metric tons with an overburden of just over 2,000,000 metric tons (2). A stripping ratio of about 4:1 is therefore indicated.

16.3 The bentonite

The Charasol bentonite, when wet, has high plasticity and adhesiveness, and when dry is evenly compact with a tendency to part or fracture in a conchoidal manner. Colour is usually off-white through cream lead-grey to a light khaki and in drilling this was found to vary both laterally and vertically without, macroscopically, affecting the general homogenous texture. On drying, the clay tends to desaggregate into small spherical fragments and on weathering it forms cauliflower like structures which can be used as a prospecting guide.

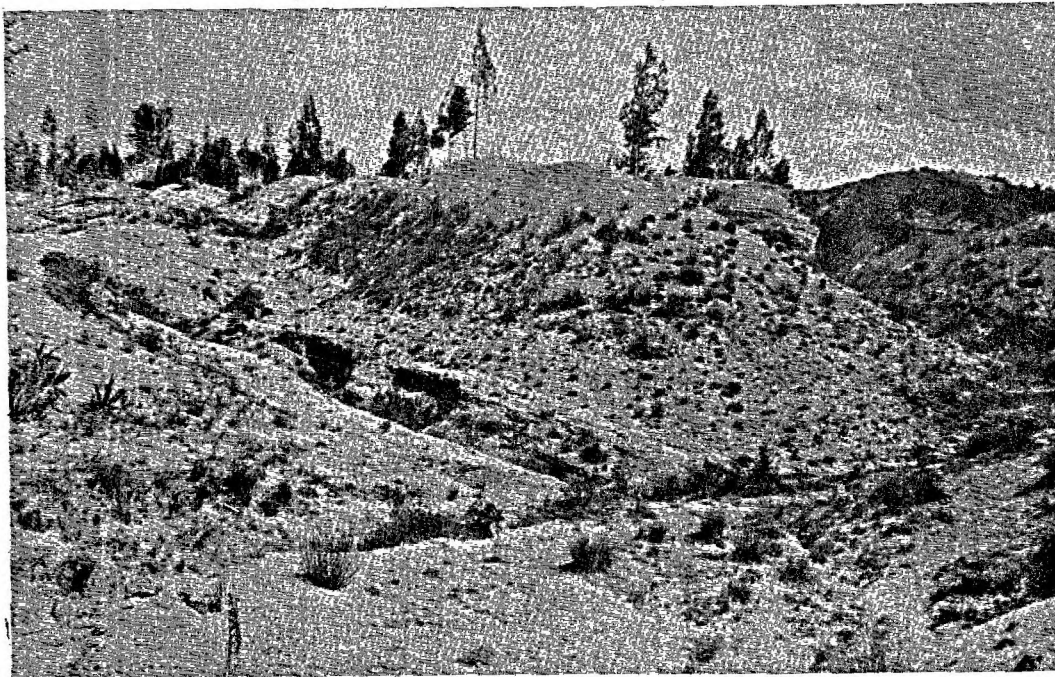
X-ray diffraction studies showed that the principal mineral is montmorillonite and that minor quantities of illite, cristabolite and quartz are always present. Selected representative samples were subjected to chemical analyses and the results are summarized in Table III. From this chemical data it can be estimated that 50% of the bentonite is composed of montmorillonite and about 40% by quartz and/or cristabolite. This rather contradicts X-ray information.



CHARASOL

PHOTO IX — Bentonite outcrop with the extinct and worn down Abuga volcano at far right.

FOTO IX — Afloramiento de bentonita, y a la derecha al fondo el extinto y erosionado volcán Abuga.



CHARASOL

PHOTO X — Outcrop of bentonite bed (grey) overlying the lower shale horizon (white) of the Guapán Formation.

FOTO X — Afloramiento de la cama de bentonita (gris) que se ve encima de las lutitas inferiores de la Formación Guapán (blanco).

The bentonite was submitted for API standard tests to determine its possible usefulness as a drilling mud and also tested for its application as a foundry clay. Results of the drilling mud tests given in Tables V and VI indicate that it is a calcium type bentonite with little swelling characteristics and would therefore not make it acceptable as a drilling-mud clay. Preliminary work carried out by the American Colloid Company+ shows that the Charasol material "has good green compression strengths compared to our southern bentonite and the pH value, dry compression strength and hot compression strengths are similar in characteristics to our White Springs calcium type bentonite". It may therefore prove to be an excellent foundry clay. Other possible applications of bentonite are as follows:

- mixing with Portland Cement (about 2 lbs. per bag) can improve workability, lessen the aggregate segregation, and considerably enhance the impermeability of the concrete.
- in the pesticide industry bentonites are used as carrier-diluents and have a vital bearing on the potency and efficiency of dusts and sprays which may contain only between 1% and 20% of active ingredients. The bentonite as a pesticide carrier ensures evenness in deposition over sprayed surfaces (plants, etc.) and aids the adhesive properties so that the pesticide is not washed off by heavy rainfall or dispersed in high winds. It should be noted that Ecuador is one of the world's leading producers of Pyrethrum (after Kenya and Tanzania).
- as decolourizers and deodorizers of mineral vegetal and animal oils, bentonites are used in the beverage industry which has grown rapidly within Ecuador over the last few years (beer, fruit juices, etc.). Bentonite becomes flocculated, settles, and improves the clarity of the beverage.

With prospective industrial development in all these fields a more detailed investigation is warranted in the Charasol area to extend reserves and examine mining economics and methods. A complete market survey could be carried out by relevant Government departments.

Note + - The American Colloid Company, Skokie, Illinois 60007, U.S.A. Thanks are extended to Mr. Clyde Sanders of the above company for his kind co-operation in this matter.

TABLE V

DRILLING MUD TESTS ON A BENTONITE SAMPLE FROM CHARASOL

(by Texas Petroleum Company)

1.	Wet Screen Analysis Residue on U.S. Sieve No.200:	3.0%
2.	Moisture	11.0%
	Apparent Viscosity(Cp.):	3.25
3.	Fann Reading: Plastic Viscosity (Cp.):	2.0
	Yield point (Lb/100 sq.ft.):	2.5
	Gel:	1-1
4.	Filtrate (c.c.) at 100 psi. & 30 min:	26.0
5.	Filter Cake (In.):	4/32
6.	Specific gravity:	2.45
7.	pH:	7.1
8.	Yield (bbl. of 15 Cp. mud per ton of material):	25
9.	Bencidine reaction:	Positive
10.	The suspension properties are not good because a part of material precipitates, even when the mud is agitated.	
11.	The material may not be hydrated in water.	

Note: These tests were carried out by Texas Petroleum Company, Colombian Division, Velasquez, with the following comments:

"The tests were made according to Section 3 of API Standard 13A, Fourth Edition; March 1966.

Due to the low yield of 15 centipoise mud from this material, 25 barrels per ton, it must be classified as "Low grade clay". After some of the 15 centipoise mud made from it was allowed to stand 24 hrs., it was found that a high proportion settled out. This indicates the presence of considerable non-mud making material. When the subject sample was viewed under the microscope and moistened the solid grains did not show any swelling tendency but remained of about the same size and the grains could be seen very easily. This could be indicating that a great portion of the solids do not swell or are insoluble in water. On the other hand, when Wyoming Bentonite was subjected to the same process, immediate clay swelling was observed and the whole mass was very uniform. In this case individual bentonite particles could not be distinguished. The sample has a specific gravity of 2.45 versus 2.3 to 2.4 for bentonite (see page 190 "Composition and Properties of Oil Well Drilling Fluids", by Rogers).

All these factors indicate that this material is unsuitable for use in drilling operations".

TABLE VI

DRILLING MUD TESTS ON A BENTONITE SAMPLE FROM CHARASOL

(by Anglo Ecuadorian Oilfields Ltd.)

1. Visual Inspection. The sample appeared to consist of a mixture of dark brown, good looking bentonitic type clay and also some dark grey clay which appeared sandier and less suitable for mud making. The whole of the sample was ground to the required grain size and the remainder of the analysis proceeded on this ground sample.
2. Sand Content (i) Charasol sample = 3.5%
 (ii) A.P.I. maxm. = 2.0%
3. Yield 15 c.p. mud (i) Charasol sample = 20 bbl per ton
 (ii) A.P.I. minm. = 90 bbl per ton
4. Filtration 15 c.p. mud (i) Charasol sample in fresh water = 40 cc.
 (ii) Charasol sample in formation water = 70 cc.
 (iii) A.P.I. maxm. = 15 cc.

TABLE VII

TESTS ON BENTONITE SAMPLES FROM CHARASOL

(by UN Mining Project - Quito)

	<u>I</u>	<u>II</u>
1. Water content	47.00%	27.50%
2. Sand content	2.50%	1.25%
3. Mud density (6% concentration)	8.59 Lb/gal.	8.58 Lb/gal.
4. Marsh Viscosity	26.30 sec.	26.40 sec.
5. Plastic Viscosity	2.50 Cps.	2.50 Cps.
6. Yield Point	1.50 Lb/100 ft ²	1.50 Lb/100 ft ²

17. NOTES ON OTHER DEPOSITS

The following deposits were not examined in any detail, either due to their inaccessibility or poor quality. The subsequent notes are given to help complete the clay inventory of the Cañar-Azuay area.

17.1 Cushin (Bolo)

Kaolinized tuffs are found 40 km to the south-east of Cuenca on a farm belonging to Sr. Teodoro Crespo of Cuenca. A dirt road links the deposit with the Panamerican highway near Cumbe.

17.2 Baños de Cuenca

A good quality white kaolin is found 5 km to the west of Baños about 15 km to the west of Cuenca. Presently the material is brought into Baños by mule for transport to Cuenca, but worked only on a very small scale.

17.3 Taday (Mendez)

About 21 km on the road from Azogues to Taday a poor quality clay which is contaminated by iron-oxides is found on a plateau area of the páramo.

17.4 The Taday pyrophyllite deposit

A deposit of pyrophyllite (a clay mineral similar in physical properties to talc and muscovite) occurs to the south of the village of Taday to the north-east of Azogues, but can only be reached after a 2-hour mule journey. The occurrence is associated with metamorphic rocks and lies at an altitude of about 4,000 m. The pyrophyllite is pearly white, laminar, crumbles easily and soapy to the touch. Pyrophyllite finds application as an insulator in the electrical industry, refractories, and can also be used as a substitute for talc in the manufacture of talcum.

Additional Note

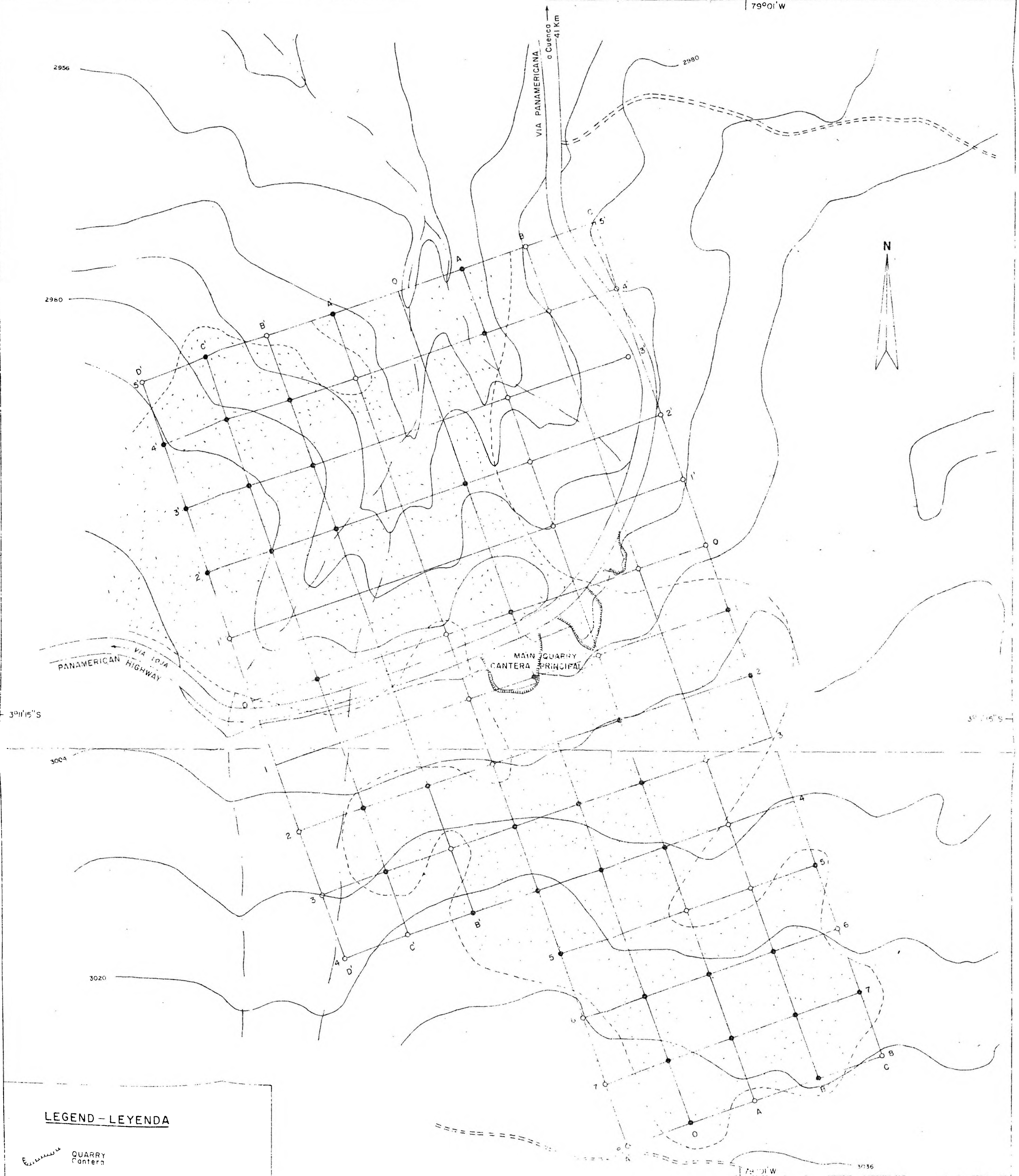
The Masma and Maldonado clays of Bolívar and Chimborazo Provinces, outside the project's study area, are rich in illite and come close to "ball-clays" in their characteristics. These types of clays are essential for the preparation of whiteware pastes and have so far not been located in the Cuenca area where it appears that principal potteries are being established.

18. REFERENCES






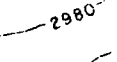
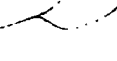
1. MANGEZ, G. and MOSQUERA, C., 1959. Reseña sobre el yacimiento de caolín de Azogues y los lavaderos auríferos de Sigsig-Aillón. Archives of the Dirección General de Geología y Minas, Quito. Unpublished report of Bureau de Recherches Geologiques et Minieres, France (Mission en Equateur), 8 pp.
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79°01'W

VIA PANAMERICANA
a Cuenco - 41 Km

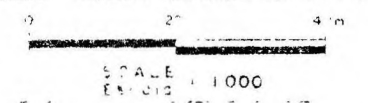


LEGEND - LEYENDA

-  QUARRY
Cantera
-  AUGER HOLE
Pozo taladrado
-  - POOR KAOLINIZATION
Caulinización pobre
-  - GOOD KAOLINIZATION, WITH SAMPLE NO
Caulinización buena, con N° de muestra
-  AREA OF STRONG KAOLINIZATION
Área de fuerte caulinización
-  2980 - CONTOURS AT 8m INTERVALS
Curvas de nivel con intervalos de 8m
-  CREEK
Quebrada

SURVEY OF METALLIC AND NON-METALLIC MINERALS
Dirección General de Geología y Minas
United Nations Development Programme

**EQUADOR
OPERATION Nº3
TINAJILLAS
KAOLIN DEPOSIT
DEPOSITO DE CAOLIN**



MAP Nº8
MAPA Nº8

78°48'30" W

78°48'20" W

SURVEY OF METALLIC AND NON - METALLIC MINERALS
Dirección General de Geología y Minas
United Nations Development Programme

ECUADOR
OPERACION N° 3
CHARASOL
BENTONITE DEPOSIT









INVESTIGACION DE MINERALES METALICOS Y NO-METALICOS
Dirección General de Geología y Minas
Programa de las Naciones Unidas para el Desarrollo

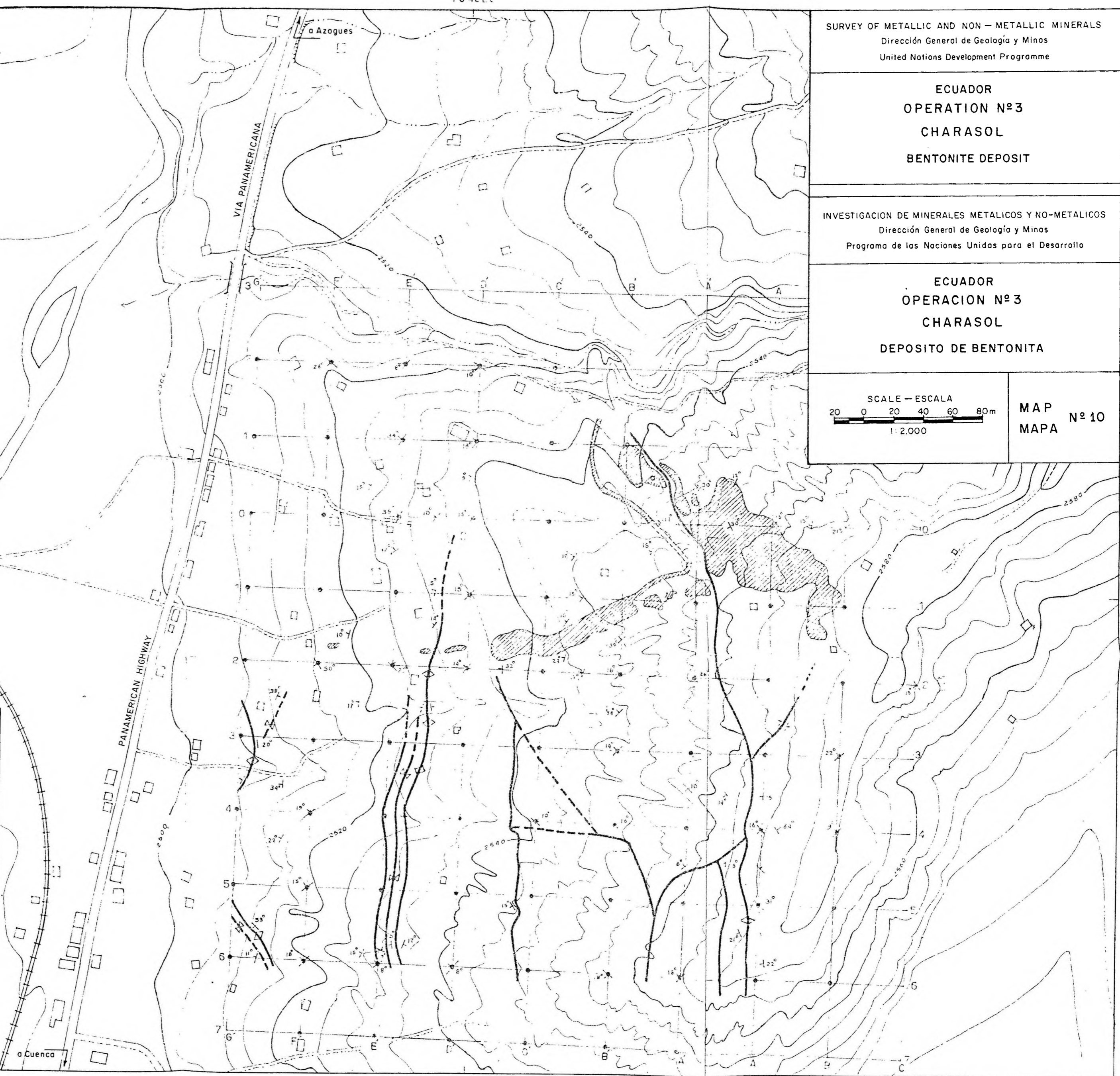
ECUADOR
OPERACION N° 3
CHARASOL
DEPOSITO DE BENTONITA

SCALE - ESCALA
20 0 20 40 60 80m
1:2,000

MAP N° 10
MAPA

LEGEND - LEYENDA

-  SAMPLING GRID WITH AUGER SAMPLE POINT
Red de muestreo con punto muestreado o taladro
-  BENTONITE OUTCROP
Afloramiento de bentonita
-  FAULT
Falla
-  ANTICLINE
Anticlinal
-  SYNCLINE
Sinclinal
-  STRIKE AND DIP
Rumbo con buzamiento
-  CONTOURS AT 5m INTERVALS
Curvas de nivel con intervalos de 5m
-  CREEK
Quebrada



2465

2465

78°48'20" W