RECONNAISSANCE FOR URANIUM IN THE ANTOFAGASTA AREA, PROVINCE OF ANTOFAGASTA, CHILE

By
Paul H. Knowles
William A. Bowes

Mario Serrano C.
Rodolfo Gruenwald S.

April 1961

Division of Raw Materials
Washington, D. C.

and

Instituto de Investigaciones Geológicas
Santiago, Chile
LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

This report has been reproduced directly from the best available copy.

Printed in USA. Price $0.50. Available from the Office of Technical Services, Department of Commerce, Washington 25, D. C.
RECONNAISSANCE FOR URANIUM IN THE
ANTOFAGASTA AREA, PROVINCE OF ANTOFAGASTA, CHILE

By

Paul H. Knowles, William A. Bowes,
Mario Serrano C. and Rodolfo Gruenwald S.

April 1961
Santiago, Chile
## RECONNAISSANCE FOR URANIUM IN THE
### ANTOFAGASTA AREA, PROVINCE OF ANTOFAGASTA, CHILE

### CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>5</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>5</td>
</tr>
<tr>
<td>Geography</td>
<td>7</td>
</tr>
<tr>
<td>Location and accessibility</td>
<td>7</td>
</tr>
<tr>
<td>Topography and climate</td>
<td>7</td>
</tr>
<tr>
<td>Exploration and mining history</td>
<td>9</td>
</tr>
<tr>
<td>Acknowledgements</td>
<td>9</td>
</tr>
<tr>
<td>GENERAL GEOLOGY</td>
<td>9</td>
</tr>
<tr>
<td>Stratified rocks</td>
<td>10</td>
</tr>
<tr>
<td>Intrusive igneous rocks</td>
<td>10</td>
</tr>
<tr>
<td>Structure</td>
<td>10</td>
</tr>
<tr>
<td>RECONNAISSANCE FOR URANIUM</td>
<td>11</td>
</tr>
<tr>
<td>Geologic structures</td>
<td>11</td>
</tr>
<tr>
<td>Stratified rocks</td>
<td>13</td>
</tr>
<tr>
<td>Intrusive igneous rocks</td>
<td>13</td>
</tr>
<tr>
<td>Sierra Gorda district</td>
<td>13</td>
</tr>
<tr>
<td>Other mineralized districts</td>
<td>15</td>
</tr>
<tr>
<td>SUMMARY AND CONCLUSIONS</td>
<td>16</td>
</tr>
<tr>
<td>SELECTED BIBLIOGRAPHY</td>
<td>17</td>
</tr>
</tbody>
</table>

### ILLUSTRATIONS

1. Index map of Antofagasta area, Province of Antofagasta, Chile 6
2. Geologic sketch of the Antofagasta area, Province of Antofagasta, Chile (in pocket) 8
3. Geologic sketch of mines in the Sierra Gorda district, Province of Antofagasta, Chile (in pocket) 8
4. Geologic map of the San Armando mine, Sierra Gorda district, Province of Antofagasta, Chile 8
RECONNAISSANCE FOR URANIUM IN THE
ANTOFAGASTA AREA, PROVINCE OF ANTOFAGASTA, CHILE

TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 1</td>
<td>Radioactivity in the Antofagasta area, Chile</td>
<td>12</td>
</tr>
</tbody>
</table>
RECONNAISSANCE FOR URANIUM IN THE
ANTOFAGASTA AREA, PROVINCE OF ANTOFAGASTA, CHILE

ABSTRACT

The Antofagasta area, in the Province of Antofagasta, Chile, was investigated in September and August 1958 by two field parties of the U. S. Atomic Energy Commission and the Instituto de Investigaciones Geológicas de Chile, who were working under a cooperative agreement between the two governments. The purpose of the investigation was to examine the area for the possible occurrence of commercial deposits of uranium.

Bedrocks of the greater part of the area are Jurassic volcanics and Cretaceous sediments intruded by at least two phases of the Andean diorite complex of Middle Cretaceous age. Small remnants of Tertiary sands and gravels and widespread Quaternary alluvium cover the broad intermontane valleys.

A major feature of the area is the strong system of north- to northeast-trending regional faults with associated faults and fractures.

Significant radioactivity was verified in the Sierra Gorda district about 140 kilometers northeast of Antofagasta. This was noted in three sets of shears in an altered host rock of microgranite and granite.

It is concluded that the Sierra Gorda district warrants at least some additional investigation due to the presence of moderately high radioactivity in strong vein structures cutting a granite which possesses abnormally high background radioactivity.

INTRODUCTION

Through a cooperative agreement between the Governments of the United States and Chile, the Antofagasta area, Province of Antofagasta, Chile, was examined for uranium in August and September 1958 by geologists of the U. S. Atomic Energy Commission (USAEC) and of the Instituto de Investigaciones Geológicas de Chile (IIG).

The Antofagasta area (fig. 1) was selected for reconnaissance on the basis of reliably reported radioactivity in the Sierra Gorda district and the presence of metalliferous deposits associated with intrusive rocks in an area of strong faults and some sedimentary rocks.

The purpose of the investigation was to determine whether commercial deposits of uranium might exist in the area and to ascertain the advisability
Figure 1. Index Map of the Antofagasta area, Province of Antofagasta, Chile
Figura 1. Mapa Indice del area de Antofagasta, Provincia de Antofagasta, Chile.
of more detailed studies. Field instruction in uranium geology for the Chilean geologists is an integral part of the program. Geologic information obtained during this reconnaissance may be used by IIG in its compilation of a geologic map of Chile.

The scope of the work was limited to reconnaissance for the occurrence of uranium, with particular emphasis on potentially favorable structures and lithologic settings. Reported uranium occurrences were visited, and the data obtained were integrated with the areal geology.

Two field parties, each composed of one geologist from the USAEC and one from the IIG, made individual field trips from Antofagasta and Sierra Gorda over a period of two weeks. Traverses were made by light four-wheel-drive vehicles and by foot. A scintillation counter and a Geiger counter were carried by each party. Oblique and vertical photographs were used and all data plotted on a base map (fig. 2) scale 1:375,000. A smaller geologic sketch of the Sierra Gorda district (fig. 3) and a geologic map of the San Armando mine (fig. 4) were also prepared.

Geography

Location and accessibility

The Antofagasta area is in the west-central part of the Province of Antofagasta in northern Chile. The area is roughly a rectangle measuring 138 kilometers north-south by 150 kilometers east-west. It extends from longitude 69°15' W. to the coast and from latitude 22°45' S. to latitude 24°00' S. Antofagasta, in the west-central part of the area, is a major Chilean coastal port (population 79,000). The main north-south highway passes through Antofagasta, and a paved highway extends northeasterly to Calama and Chuquicamata. Numerous secondary roads and trails branch off from the main highways. Daily commercial air service is available to Antofagasta from Santiago. Access railway lines connect Antofagasta and the major salitre mines with the main railway, and a rail line extends northeasterly through Chuquicamata to La Paz, Bolivia.

Topography and climate

The area is one of moderate relief in an early mature stage of erosion. The Coast Range rises abruptly to elevations of 1,500 meters; inland are a series of north- and northeast-trending ranges, with broad open valleys in the central and eastern part of the area. The country is dry and barren of any vegetation except where locally cultivated.

The climate is hot and dry, with rainfall averaging 11 millimeters per year, and frequently several years passing without any rainfall. Fog occasionally occurs in early mornings but is usually dissipated within a few hours.
Figure 4. Geologic sketch of the San Armando mine, Sierra Gorda district, Province of Antofagasta, Chile.

Figure 4. Bosquejo geológico de la mina San Armando, distrito de Sierra Gorda, Provincia de Antofagasta, Chile.
Exploration and mining history

Mining in the Antofagasta area has had a long and varied history. The city of Antofagasta is one of the major ports for the large copper mine at Chuquicamata (200 kilometers northeast of Antofagasta), and has long been an important port for the shipment of salitre. Copper and salitre are the major minerals produced in the area, although considerable silver and some iron and manganese have been produced in the past.

The largest mineral production of the area covered in this report has come from the salitre mines in the desert areas, about 60 kilometers east of Antofagasta. Only a few of the former numerous mines are still in operation, although improved techniques and uses encourage some of the salitre mines to continue exploitation.

Many copper deposits have been worked in the coast-range mountains. Copper mines currently in operation are at Mantos Blancos, 40 kilometers northeast of Antofagasta; the Bella Esperanza mine, near Sierra Gorda; the Porvenir mine, in the Desesperada district, 40 kilometers north of Antofagasta; and the Merino mine, 30 kilometers north of Baquedano. Considerable copper and some silver have been produced in the past from the Sierra Gorda district; the Valenzuela district, 20 kilometers north of Baquedano; the Lomas Bayas district, 30 kilometers southeast of Baquedano; and the Caleta Coloso district, 20 kilometers south of Antofagasta. Occasionally individual miners attempt small-scale mining of these older properties.

Considerable silver was produced from the Caracoles district at the turn of the century, but the mines are now inactive.

Manganese is being intermittently produced about 10 kilometers southeast of Baquedano.

The Corporación de Fomento de la Producción in Antofagasta is currently attempting to develop a cement industry, using the large deposits of coquina in the area between Mejillones and Antofagasta.

Acknowledgements

The writers acknowledge the kind assistance of the following persons and organizations in Antofagasta who supplied valuable map information, guidance, and personal knowledge of the area: Sr. Encina of the Corporación de Fomento de la Producción; Sr. Juan Muñoz of the Caja de Crédito Minero; Sr. S. Rovano of the Departamento de Minas y Petróleo; Sr. Fritz Hinzler of the University of Chile; Sr. J. Bakovic of the Sociedad Minera de Quetena Ltda; and Sr. A. Kazazian of the Sociedad Minera Sierra Gorda.

GENERAL GEOLOGY

The most prominent geologic features of the Antofagasta area are the strong north- and north-northeast-trending faults with associated northeasterly
tension faults. This system is widespread, extending from Taltal (south of the Antofagasta area) northerly through the area east of Tocopilla to Salar Grande.

Stratified rocks

The predominant rocks of the Antofagasta area are Jurassic volcanics, which have been dated by Brüggen (1950) on the basis of sediments stratigraphically below the volcanics in the Caleta Coloso district. The volcanics are at least 3,000 meters thick and crop out at most of the higher elevations. The rocks are massive and composed of andesite flows and breccias, andesitic conglomerate, and porphyritic andesite hypabyssal rocks. The andesitic conglomerate is composed of rounded to subrounded, unscrted pebbles and boulders (one inch to three feet in diameter) cemented by a matrix of other andesitic material. Many of the copper deposits occur in older andesitic volcanics.

A sedimentary sequence of Early Cretaceous age (Neocomian) occurs in the southwest part of the area near Caleta Coloso (Brüggen, 1934, p. 96). The section, more than 1,000 meters thick, is composed of red conglomerate, red calcareous sandstone, gray calcareous sandstone, calcareous shale, and sandy limestone.

Small remnants of upper Tertiary calcareous sand and coquina occurring in the valley between Antofagasta and Mejillones have been included on figure 2 with the widespread Quaternary alluvium. The alluvium is composed of eolian and fluvial sands, gravels, and fanglomerates which cover the intermontane valleys. Salitre deposits are associated with these surficial rocks.

Intrusive igneous rocks

The Andean diorite complex of Middle Cretaceous age crops out in various localities; however the larger masses are in the northwest part of the area. The trends of the plutons vary from north to north-northeast. The igneous complex in the central and eastern part of the area clearly intrudes the older volcanics; in the west the stratigraphic relationship is not as clear, and the igneous rock may be older than Cretaceous.

The intrusive, in general, is a medium-grained, equigranular rock varying from granite to tonalite. In the Sierra Gorda area the acidic phase is later than the tonalite. The intrusive complex in the Quebrada Mejillones, east of Mejillones, contains'large dikes which strike north and dip 70° E.

Mineralized zones tend to be localized in or near the contacts of the Andean diorite complex with the older volcanics.

Structure

The western part of the Antofagasta area is characterized by extensive fault-block structures. The major regional faults trend north and north-northeast, with related tension faults trending northeast.
The regional faults were observed on aerial photographs and then ground checked. The major structure is a normal fault which enters the coast about 15 kilometers north of Taltal (200 kilometers south of Antofagasta). It trends northerly through La Negra and Salar del Carmen (fig. 2), about 10 kilometers east of Antofagasta; thence north-northeast along the east side of Sierra Miranda, Sierra Valenzuela, and Cerro Quimurco; and finally north through the Cerros de Buey Muerto, ultimately passing about 35 kilometers east of Tocopilla (170 kilometers north of Antofagasta). The west side is down dropped. Bruggen (1950, p. 97, 311) recognized a portion of this fault about 10 kilometers east of Antofagasta and referred to it as a "recent fault." It is proposed by the authors to name this the Salar del Carmen fault.

Parallel and subparallel faults are noted near the major fault; several fan out or "horsetail" from the main fault. Tension faults trending northeast have been developed and, as a rule, are more heavily mineralized than the Salar del Carmen fault and adjacent regional faults. Where observed the regional faults show more of a dip-slip movement, while the tension faults show only brecciation and vein filling.

Any fault pattern that may exist in the eastern part of the area is obscured by extensive alluvium. There is a strong suggestion of a fault extending northeasterly parallel to the highway extending through Baequedano and Sierra Gorda.

Along the coast the volcanics dip to the northwest and west, while the sediments near Caleta Coloso dip southerly. From the coast eastward the strata are broken into a complex system of fault blocks and the dips vary considerably.

RECONNAISSANCE FOR URANIUM

Geologic features and geographic localities investigated for uranium in the Antofagasta area were: (1) geologic structures; (2) stratified rocks; (3) intrusive rocks; and (4) the Sierra Gorda, Lomas Bayas, Valenzuela, and Naguayan districts.

The radioactivity in milliroentgens per hour (mr/hr) of the various rock units in the Antofagasta area and of mineralized structures within those units is given in table 1.

Geologic structures

The regional faults and tension fractures in the area were examined for uranium because of their persistence and the fact that many have been mineralized with other elements.

Northeast-trending tension fractures in the Tocopilla area (200 kilometers north of Antofagasta) were radioactive and may have structural characteristics similar to those in the Antofagasta area. These fractures are probably related to the Salar del Carmen fault and associated subparallel faults.
Table 1. Radioactivity in the Antofagasta area, Chile.

<table>
<thead>
<tr>
<th>Rock units</th>
<th>Background in rock units (mr/hr)</th>
<th>Radioactivity in mineralized structures (mr/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>Maximum</td>
</tr>
<tr>
<td>General background of area</td>
<td>0.015</td>
<td></td>
</tr>
<tr>
<td>Granodiorite and granite</td>
<td>0.03</td>
<td>0.09</td>
</tr>
<tr>
<td>(Sierra Gorda)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tonalite (Sierra Gorda)</td>
<td>0.025</td>
<td>0.06</td>
</tr>
<tr>
<td>Volcanics (&quot;&quot;&quot;)</td>
<td>0.015</td>
<td>0.02</td>
</tr>
<tr>
<td>Diorite (Lomas Bayas)</td>
<td>0.020</td>
<td>0.03</td>
</tr>
<tr>
<td>Volcanics (&quot;&quot;&quot;)</td>
<td>0.020</td>
<td>0.025</td>
</tr>
<tr>
<td>Diorite (Northeastern)</td>
<td>0.012</td>
<td>0.020</td>
</tr>
<tr>
<td>Volcanics (&quot;&quot;&quot;)</td>
<td>0.009</td>
<td>0.012</td>
</tr>
<tr>
<td>Sediments (Caleta Coloso)</td>
<td>0.010</td>
<td>0.015</td>
</tr>
<tr>
<td>Diorite (&quot;&quot;&quot;)</td>
<td>0.008</td>
<td>0.010</td>
</tr>
<tr>
<td>Volcanics (&quot;&quot;&quot;)</td>
<td>0.010</td>
<td>0.015</td>
</tr>
<tr>
<td>&quot;&quot; Antofagasta</td>
<td>0.009</td>
<td>0.010</td>
</tr>
<tr>
<td>Alluvium, including salitre</td>
<td>0.010</td>
<td>0.015</td>
</tr>
</tbody>
</table>
None of the faults or fractures examined in the western part of the area were significantly radioactive. The average radioactivity was 0.015 mr/hr, with a maximum of 0.040 mr/hr.

In the northeastern part of the area radioactivity up to 4.0 mr/hr was noted in the faults of the Sierra Gorda district (fig. 1).

Stratified rocks

Near Caleta Coloso at least 1,000 meters of Neocomian marine calcareous sandstone and shale lie conformably on older volcanics of probable Jurassic age. The sediments are intruded by the Andean diorite complex that extends along the coast to the west. A strong northwest-trending fault cuts the area, and 5 kilometers to the east is the major north-trending Salar del Carmen fault. No significant radioactivity was noted in this sedimentary sequence, the average reading being 0.010 mr/hr, with a maximum of 0.015 mr/hr.

Much of the Antofagasta area is underlain by Jurassic volcanics which are traversed by numerous faults and veins. Observation of the volcanics and related veins revealed no significant radioactive anomalies.

Intrusive igneous rocks

Numerous Andean diorite intrusives occur in the Antofagasta area. Many of the metallized zones are near the contacts between intrusive and volcanic rocks - the veins usually being in diorite, granodiorite, granite, or related rocks of the Andean diorite complex. With the exception of the Sierra Gorda district, none of the veins examined in this complex showed any radioactive anomalies.

West of the Salar del Carmen fault numerous basaltic dikes intrude both the diorite complex and the older volcanics. The highest radioactivity in or near these dikes was 0.009 mr/hr.

Sierra Gorda district

The Sierra Gorda district (fig. 3) is north of the highway to Calama and Chuquicamata, 130 kilometers northeast of Antofagasta. Sierra Gorda is one of the stations on the Antofagasta - La Paz, Bolivia, railroad. The district was originally opened for copper at the principal Catalina mine, now inactive and flooded. Radioactivity was noted within the past few years and brought to the attention of the authors by Juan Bakovic and A. Kazazian of Antofagasta.

Jurassic volcanics have been intruded by the Andean diorite complex. The composition of this intrusive varies from tonalite to leucogranite, with the more acidic phases occurring later than the tonalite.

At the San Armando mine (fig. 4) the radioactivity occurs in three sets of shears: two major and one minor, with probably smaller shears.
paralleling the major sets. One major shear strikes N. 10° W. and dips vertically, while the other strikes N. 65° W. and dips about 70° SW. The minor shear strikes N. 40° E. and dips 54° NW. The major shear striking N. 10° W. appears to be the last movement in sequence of faulting. The host rock of leucogranite is highly altered. The radioactivity is confined largely to the gouge on both hanging walls and foot walls, with the higher concentrations (a maximum of 2.4 mr/hr) generally at intersections of the minor set of shears with the two major sets. On the major set where there is no obvious intersection, however, a very localized reading up to 4.0 mr/hr was noted on the east drift (fig. 4).

The major shears tend to feather out into a horsetail system, but the main brecciated zone is from 1 to 5 meters wide and is exposed in the workings a distance of about 20 meters for each major set. The minor shear has a width of about a half meter and is exposed for 15 meters.

Minerals from the San Armando mine were identified by X-ray analysis as metazeunerite, atacamite and quartz. In an open trench about 15 meters southeast of the shaft of the San Armando a reading of 1.5 mr/hr was obtained in the surface caliche. A yellow, secondary uranium mineral was visible.

At the San Armando Norte an irregular, tourmalinized zone of brecciation registered up to 0.35 mr/hr at a depth of 2 meters.

At the Salvadora mine, about 2 kilometers west of the San Armando mine, moderately high radioactivity was noted in a highly fractured and oxidized surface mantle of granitic rock, which had an average radioactivity of 0.140 mr/hr (locally up to 1.5 mr/hr). Radioactivity in the sheared and altered granite exposed at greater depth in the workings averaged 0.15 mr/hr, with a maximum of 0.25 mr/hr. The prominent shears strike N. 35° W. and dip vertically, but are exposed only a few meters within the open pit. The mineralized mantle is about 10 meters thick and covers the entire area at the edge of the irregular open pit. There are no visible uranium minerals, although large amounts of secondary copper minerals are present, as well as salitre and some gypsum.

The Catalina mine was inaccessible, but it was reported that about 100 meters deep some radioactivity had been encountered. The maximum radioactivity of the dumps surrounding the mine was 0.10 mr/hr.

At the Casey, Jr. prospect, about 500 meters north of the Catalina mine, a shear zone up to 2 meters wide was noted; it registered up to 0.20 mr/hr. The vein strikes N. 50° W. and dips 50° SW. The hanging wall is microleucogranite, and the footwall is a tourmalinized breccia similar to the host rock at the San Armando Norte.

On the basis of crosscutting relations, there have been at least two intrusive stages in the Sierra Gorda district. An early diorite (tonalite)
phase had an average radioactivity of 0.04 mr/hr and a maximum of 0.06 mr/hr; a later, more acidic phase of aplite, microgranite, microleucogranite, and microgranodiorite had an average radioactivity of 0.05 mr/hr and a maximum of 0.09 mr/hr, exclusive of the mineralized structures. The older volcanics had an average radioactivity of 0.02 mr/hr, with some copper- and silver-mineralized structures having an average radioactivity of 0.03 mr/hr and a maximum of 0.07 mr/hr (in a copper prospect 3 kilometers northeast from Catalina).

In the northern part of the district (fig. 3) a vein in a granitic host rock containing massive hematite had a maximum radioactivity of 0.05 mr/hr. Farther north a small vein in a tonalite host containing galena and silver had the same maximum radioactivity. A vein containing galena was reported to occur a few kilometers west of the Catalina mine.

Mineral zoning is noted in the south-central portion of the district where radioactive deposits are enveloped by a concentric periphery of copper deposits and, in turn, two lead deposits on the outer northern and western rims. A hematite deposit occurs near the lead deposit and one of the copper deposits.

The Bella Esperanza mine, the main mine feeding the Planta Aconcagua 5 kilometers southeast of the railroad station of Sierra Gorda, averaged 0.07 mr/hr, with a maximum of 0.10 mr/hr. The host rock is a porphyritic granite.

Other mineralized districts

The Lomas Bayas district, about 35 kilometers southeast of Baquedano, contains east-trending copper and silver veins in a host of diorite near the contact of the intrusive with the older volcanics. The average radioactivity of the veins was 0.03 mr/hr, with a maximum of 0.04 mr/hr. No major regional structure seems to be present in or near this district.

The Valenzuela district, about 20 kilometers north of Baquedano, is an old mining district in which copper mineralization occurs in several parallel veins in a host of older volcanics. The average radioactivity of the veins was 0.006 mr/hr and a maximum, 0.010 mr/hr. The Merino mine, a currently active copper producer 20 kilometers to the north-northeast, had similarly low radioactivity. The active Mantos Blancos copper mine, halfway between Baquedano and Antofagasta, is comparable geologically and radiometrically to the Valenzuela district.

The Naguayan district, an old copper district 50 kilometers northeast from Antofagasta, contains mineralized zones in a host of older volcanics within 2 kilometers of a granitic intrusion. The veins bear copper and iron minerals in a gangue of quartz and gypsum. The average radioactivity was 0.010 mr/hr and the maximum, 0.012 mr/hr. A few kilometers to the southeast is the now active Porvenir mine with similar geology and a similar level of radioactivity. These veins probably represent mineralized structures in the tension fault system of the area.
Near Caleta Coloso small abandoned copper mines occur in both the intrusive complex and the older volcanics near the contact of the two rocks. This district is a few kilometers west of the Salar del Carmen fault. The average radioactivity in the mineralized structures was 0.009 mr/hr and the maximum, 0.020 mr/hr.

The maximum radioactivity at the manganese mine near Baquedano was 0.010 mr/hr.

The Caracoles district, an old silver district 40 kilometers southeast of Sierra Gorda, was not included in this reconnaissance, but none of the several samples checked for radioactivity exceeded 0.010 mr/hr.

SUMMARY AND CONCLUSIONS

Based on reconnaissance in the Antofagasta area, it is concluded that the Sierra Gorda district warrants at least some additional investigation due to the presence of moderately high radioactivity in strong vein structures cutting a granite which possesses abnormally high background radioactivity.

The following observations have been made in this district:

1. There were two periods of intrusion: (a) an early tonalite phase; and (b) a later microgranite to microgranodiorite phase. Nearly all veins in the later phase, whether small or large, vary greatly in the level of radioactivity. Ore minerals are atacamite, malachite and metazeunerite in a gangue of quartz. The wall rocks are highly argillized. Northern Chile has a thick zone of oxidization which may explain the lack of primary uranium minerals in the shallow depths of exploration. The older intruded rocks of the district are andesite volcanics which contain copper-mineralized veins virtually devoid of any significant radioactivity.

2. Radioactive minerals in the Sierra Gorda area are found more frequently in a host of the later acidic intrusions than in the older andesitic volcanics.

3. Radioactivity increases in the overburden above the San Armando and San Salvador mines; such an increase may serve as a guide in locating other structures in the area.

4. On the basis of structure, mineral associations, and alteration of wall rock, it is concluded that hydrothermal solutions were the source of the mineralization of the Sierra Gorda district and were related to the later acidic phase of intrusion. Fault zones and host rock localized the deposition of the ore minerals.
5. Although no apparently significant radioactive anomalies were noted in the mineralized zones of the tension faults, it is believed possible that greater radioactivity may occur at depth, such as is evident from recent studies of similar, and possibly related, structures about 200 kilometers to the north in the Tocopilla area.

A comprehensive study of the Sierra Gorda district would be needed to properly evaluate its uranium potential. This should include the following:

1. Preparation of a geologic map (scale: 1:10,000) to cover the general area shown in figure 3, with particular emphasis on intrusive rock contacts, lithologic variation within the intrusives, and study of all structures within the intrusive and in other rocks.

2. Preparation of detailed geologic maps of all pertinent prospects in the above area (scale: 1:250), with emphasis on rock types, mineral suites, structure, and variations in radioactivity.

3. Development of zoning relationships between the various mineral occurrences.

4. Making a radiometric grid survey over the extensive alluvium.

5. Diamond drilling of two holes at the San Armando and Salvardora mines. Each hole should be drilled to intersect the major vein system at depth - probably about 100 meters.

The above geologic work could aid in outlining those places most favorable for physical exploration.

In the northern and northwestern parts of the Antofagasta area radiometric examination is indicated for some of the deeper workings of the mines associated with tension faults. This examination should include the Porvenir and Merino mines as well as some of the mines in the Naguayan district. Of special interest would be those mines located in an intrusive host rock.

SELECTED BIBLIOGRAPHY

Brüggen, Juan, 1934, Las formaciones de sal y petróleo de la Puna de Atacama: Santiago, Bol. Minas y Petróleo, v. 4, no. 32, p. 105-122.


, 1950, Fundamentos de la geología de Chile: Chile, Instituto Geográfico Militar, 374 p.


Hinsler, Fritz W., 1958, Unpublished report of Laboratorio de Fisica Nuclear, Universidad de Chile.


Figure 3. Geologic sketch of mines in the Sierra Gorda District, Province of Antofagasta, Chile

Figure 3. Bosquejo Geológico de las minas en el Distrito de Sierra Gorda, Provincia de Antofagasta, Chile