Document symbol:DP/SF/UN/37-SOMALIA

Best copy available

Mineral and Groundwater Survey

SOMALIA

UNITED NATIONS

DEVELOPMENT

PROGRAMME

UNITED NATIONS DEVELOPMENT PROGRAMME

Mineral and Groundwater Survey

SOMALIA

Interim report prepared for the Government of the Somali Republic

by the United Nations, participating and executing agency

for the United Nations Development Programme

UNITED NATIONS
New York, 1970

EXPLANATORY NOTES

The following symbols and abbreviations have been used:

BHQ	banded hematite quartzite
BMQ	banded magnetite quartzite
cps	counts per second
DDH	diamond drillhole
mgal Bouguer	gravity values expressed in milligals
ml	millilitres
TDW	tons dead weight
tds	total dissolved solids

Three dots (. . .) indicate that data are not available.

The dash (—), in a table, [illegible]ates the quantity is nil or negligible.

Reference to "dollars" indicates United States dollars unless otherwise stated.

The designations employed a[illegible]resentation of the material in this publication do not imply th[illegible] of any opinion whatsoever on the part of the Secretariat of the [illegible] Nations concerning the legal status of any country or territory or of its [illegible]orities, or concerning the delimitation of its frontiers.

DP/SF/UN/37–SOMALIA

Preface

In November 1965, the United Nations General Assembly decided to merge two existing development operations—the Expanded Programme of Technical Assistance (established in 1950) and the Special Fund (established in 1959)—into a single entity now known as the United Nations Development Programme (UNDP). The merger was accomplished in January 1966.

The UNDP (established in accordance with resolution 2029 (XX) of the United Nations General Assembly) seeks to advance the development of human and natural resources by conducting, in association with Governments, selected pre-investment and technical assistance projects. Pre-investment projects include resource surveys and feasibility studies to determine where investment is practicable and how it may be made productive; the founding and strengthening of permanent educational institutions designed to promote skills that are fundamental to the development process; and the establishing of research centres to devise new techniques applicable in industry, agriculture and other fields.

Pre-investment projects are initiated at the request of Governments; they have a specific purpose and cover a stipulated period of time. The UNDP normally meets the cost of international personnel, of fellowships for the training of counterpart personnel and of equipment imported from abroad. The Government receiving aid normally contributes goods, supplies and services that can be met from local resources.

The implementation of pre-investment projects is entrusted by the UNDP to one of the agencies of the United Nations family, which in the capacity of executing agency then becomes responsible for the recruitment of international staff, the instruction of local staff and the conduct of work in the field. Upon completion of the project, the executing agency submits a final report describing the work done, evaluating the results and recommending future action.

Since January 1964 the Government of Somalia, with the help of the United Nations and UNDP has been engaged in a mineral and groundwater survey. The interim report records the results of phase I of this collaborative endeavour.

Contents

MAPS (in pocket)

Abstract

In January 1962 the United Nations Special Fund (after January 1966 the United Nations Development Programme) approved the request of the Government of Somalia for an investigation of the occurrence of iron-bearing rocks in the Bur area. Recognition of this and other closely related needs resulted in a Plan of Operation, signed on 22 December 1962, which provided for the development of a Somali geological survey department, and surveys for other minerals and groundwater in addition to the search for iron ore. A total of $US 874,300 was earmarked, of which the Government counterpart contribution was to be the equivalent of $280,000 and the Special Fund contribution was to be $594,300. In June 1966, the total costs were revised to $981,268 of which the Special Fund was to contribute $649,600.

Investigation of the iron occurrences in the Bur area disclosed potential reserves of 170 million tons of ore. Analysis of the ore distribution, ore grade, transportation and beneficiation requirements, however, showed only 33 million tons of marketable reserves which, furthermore, could not be profitably mined. No development of these deposits is recommended for the foreseeable future.

An aerial survey outlined 38 radioactive anomalies within a roughly rectangular area of 10,000 square kilometres in the Bur area. Ground exploration of one, the Alio Ghelle anomaly, found ore bodies of highly albitized rock containing 3.30% ThO_2; 0.12% U_3O_8; and 0.080% Y_2O_3. Simple gravity beneficiation processing gives a concentrate containing 30.0% ThO_2 and 0.83% U_3O_8, with recoveries of 63.3% and 53.2% respectively, which is amenable to leaching and separation. Four additional radioactive anomalies were located on the ground in continuation of Alio Ghelle. Following these finds, the Bur area was given over to concessions and the project withdrew from the area.

A country-wide survey was made for bauxite but only low grade and irregular deposits were found. The prospect of finding bauxite in Somalia is concluded to be poor.

A deposit containing 79 per cent sepiolite was examined, which is unsuitable for highly refined manufacture but may be of industrial use; and it deserves further investigation.

Other minerals of varied economic potential include tin, silver, copper, microcline feldspar, marble, cassiterite, columbo-tantalite, beryl, piezoelectric quartz, galena, molybdenite, bismuthinite, nepheline syenite, gypsum and anhydite. Other minerals in Somalia, either in too low concentration to be of economic interest or not examined in detail, include titanium, manganese, coal, lignite, and oil shale.

The survey for groundwater covered the Bur Galan-Daimir iron-bearing area, the Bur Acaba basin, and the area around Chisimaio. Considerable potential water resources exist in the fissure systems of the basement rocks, in the Jurassic limestones, in accumulations of surface formations and in river underflows. In order to develop sufficient water supplies to meet future needs it is recommended that a permanent Somali groundwater section be established to inventory the resources, assist the Ministry of Works, and to train Somali personnel in groundwater techniques.

A second phase of the project, to carry out additional mineral investigations in the northern provinces and to continue the groundwater survey, was approved by the Governing Council in January 1968. This report covers activities of the first phase only (through February 1969).

Introduction

A. Geographical background

The Somali Republic (Somalia) covers an area of 638,000 sq km comprising both the former British Somaliland and Italian Somaliland. It achieved independence on 1 July 1960. To the west and south lie French Somaliland, Ethiopia and Kenya. To the north and east, its 2,800-km coastline follows the Gulf of Aden and the Indian Ocean (figure 1). The country, 200 km to 300 km wide, is in the shape of the digit 7, with the bar at the north extending 1,000 km westwards and the stem, 1,500 km long, pointing southwards.

To the north and west, hills rise from 1,500 metres to 2,500 metres towards the Ethiopian highland, but the ground drops sharply towards the southeast, where a plateau descends by steps to the sea (figure 2).

The northern two thirds of the country consist mostly of barren sand and rock with little agricultural land. The drainage pattern is typical of arid conditions, with dry stream beds subject to sudden flooding, often losing themselves in local depressions. Temperatures often reach 45°C from May to September, but the winter months are cool. The average annual rainfall is 100 mm.

The southern third of the country is drained by two rivers or *uebis:* the Giuba, which is perennial, and the Scebeli, which is seasonal. Both rise in the Ethiopian hills and flow southwards towards the Indian Ocean. The area contains good potential farmland, especially between the two rivers, but is still largely covered by thick, thorny scrub.

The climatic pattern is well defined. From mid-December to mid-March, the dry *gilal* corresponds to the north-east monsoon. From mid-March to mid-May, the *gu* brings heavy rains and high temperatures. From mid-May to the end of September, the *hagai* corresponds to the south-west monsoon, with a slight rainfall on the southern coastal belt. From October to mid-December, the *der* marks the return of the north-east monsoon, with a second rainy season, less pronounced than the *gu*.

In the south and along the northern oceanic coastal plain, temperatures remain around 30°C, while in the highlands they vary seasonally between 5°C and 40°C. Annual rainfall averages 600 mm in the southern river area.

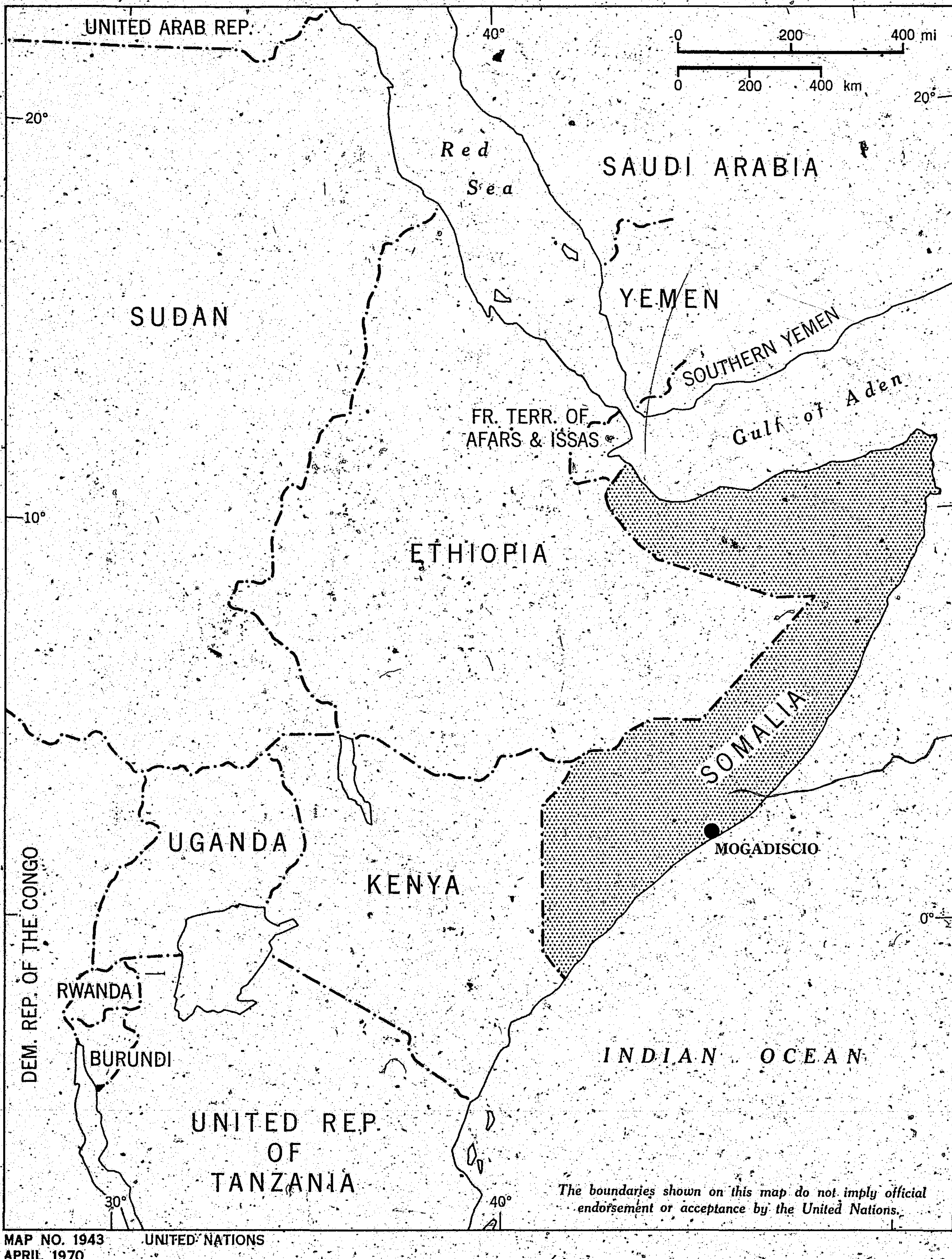


Figure 1. Situation map of Somalia, East Africa

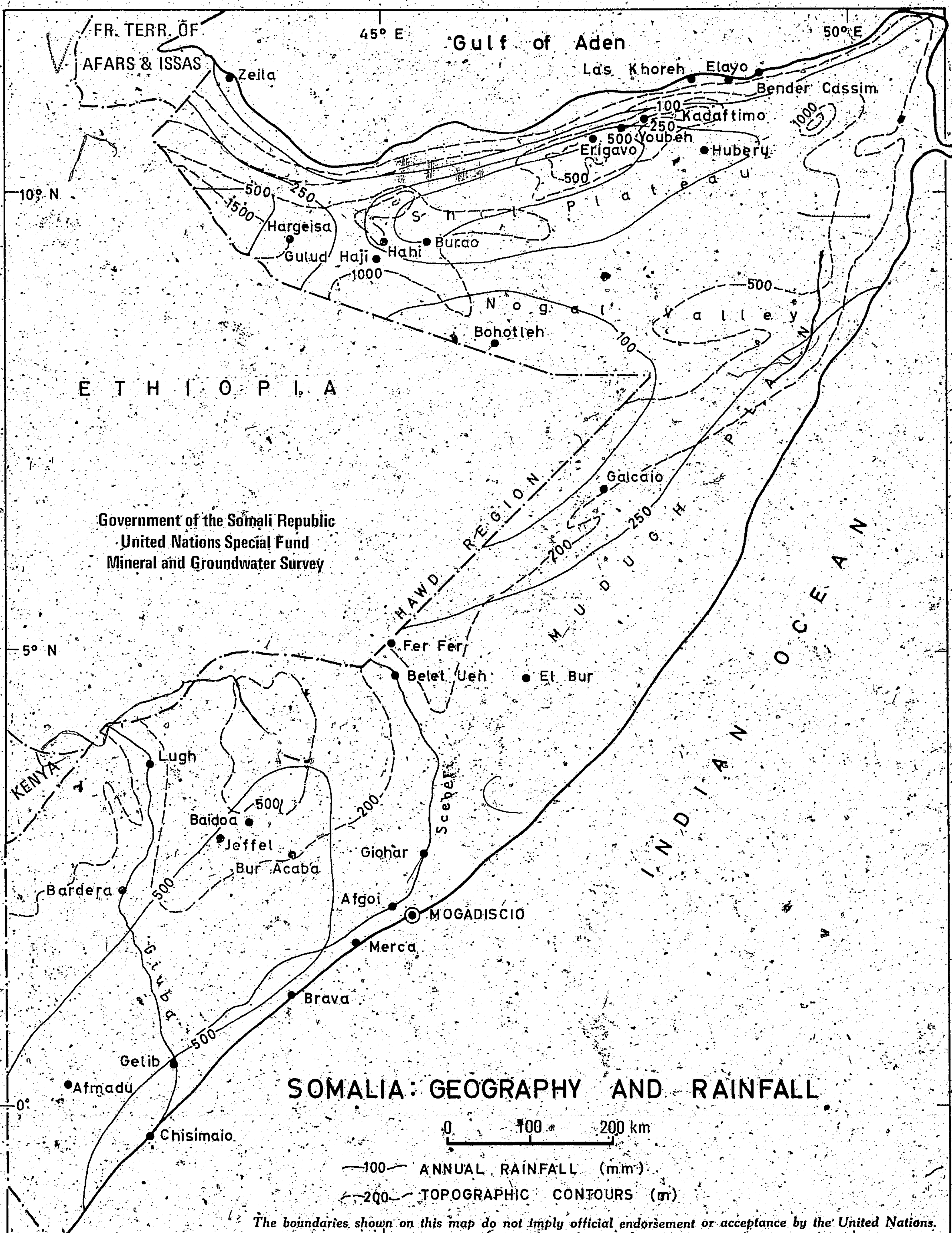


Figure 2. Somalia: geography and rainfall

B. Geology

Somalia constitutes the eastern third of the triangular north-east African structural block which is limited on the north by the Gulf of Aden fault, on the west by the Abyssinian fault trough and on the east by the Indian Ocean (figure 3). Throughout most of the northern part of the country, rock exposures are excellent, there being little or no topsoil, but in the south outcrops are rare, and a thick, featureless, eluvial mantle extends over great distances, covered by dense, thorny scrub.

Rocks of the country fall into three categories:

(*a*) Basement rocks, probably Pre-Cambrian, mostly granite and associations of intrusive and metamorphic rocks;

(*b*) Mesozoic (Jurassic and Cretaceous) and Tertiary sedimentary consolidated rocks;

(*c*) Quaternary dune sands, alluvium, eluvium, and coral reef rock, predominently unconsolidated.

The basement rocks crop out extensively in the north and in the basins of the Giuba and Scebeli rivers. Here they constitute most of the Bur area (plate 1), which is oval in shape and elongated towards the north-east; it lies at 42°45′E, and between 1°30′N and 3°20′N, 100-250 km from Mogadiscio. The basement formations continue westwards into Ethiopia, where they cover large areas. To the east and south-east they have been found in oil wells at depths of 3,000-5,000 metres. In the south-west, these rocks consist mostly of old granites and gneisses. In the north they are represented by granitic pegmatites and by the metamorphosed quartzites, phyllites and schists of the steeply dipping "Inda Add" series. Both in northern and southern Somalia, these basement rocks have been intruded by more recent granites, diorites, small gabbro plugs and quartz porphyries.

These intrusions are believed to be of Jurassic age and to be related to all the mineral occurrences of the country.

The erosional surface of the basement rocks is overlain by Jurassic limestones, marls, sandstones and argillites which are wide-spread in south-west Somalia and which extend into Ethiopia. To the north-east, they disappear under thick formations of the Upper and Lower Cretaceous, themselves overlain by a thick series of Tertiary sandstones, argillites and limestones that have in places been dolomitized and silicified.

Recent (Quaternary) alluvials and dune sands are widespread along the coast of the Indian Ocean and in the central area of former British Somaliland.

C. Previous geological and geographical coverage

Surveys

Northern Somalia

Northern Somalia was extensively studied from the second half of the last century by the former British Geological Survey of the Somaliland Protectorate. Systematic exploration, by Farquharson in 1924, was continued in 1933 by Macfadyen, who published a geological map to a scale of 1:1,000,000 and outlined the geological structure and mineral resources. Between 1952 and 1961, the Geological Survey prepared a 30-sheet map of the area to a scale of 1:125,000 and prospected the main

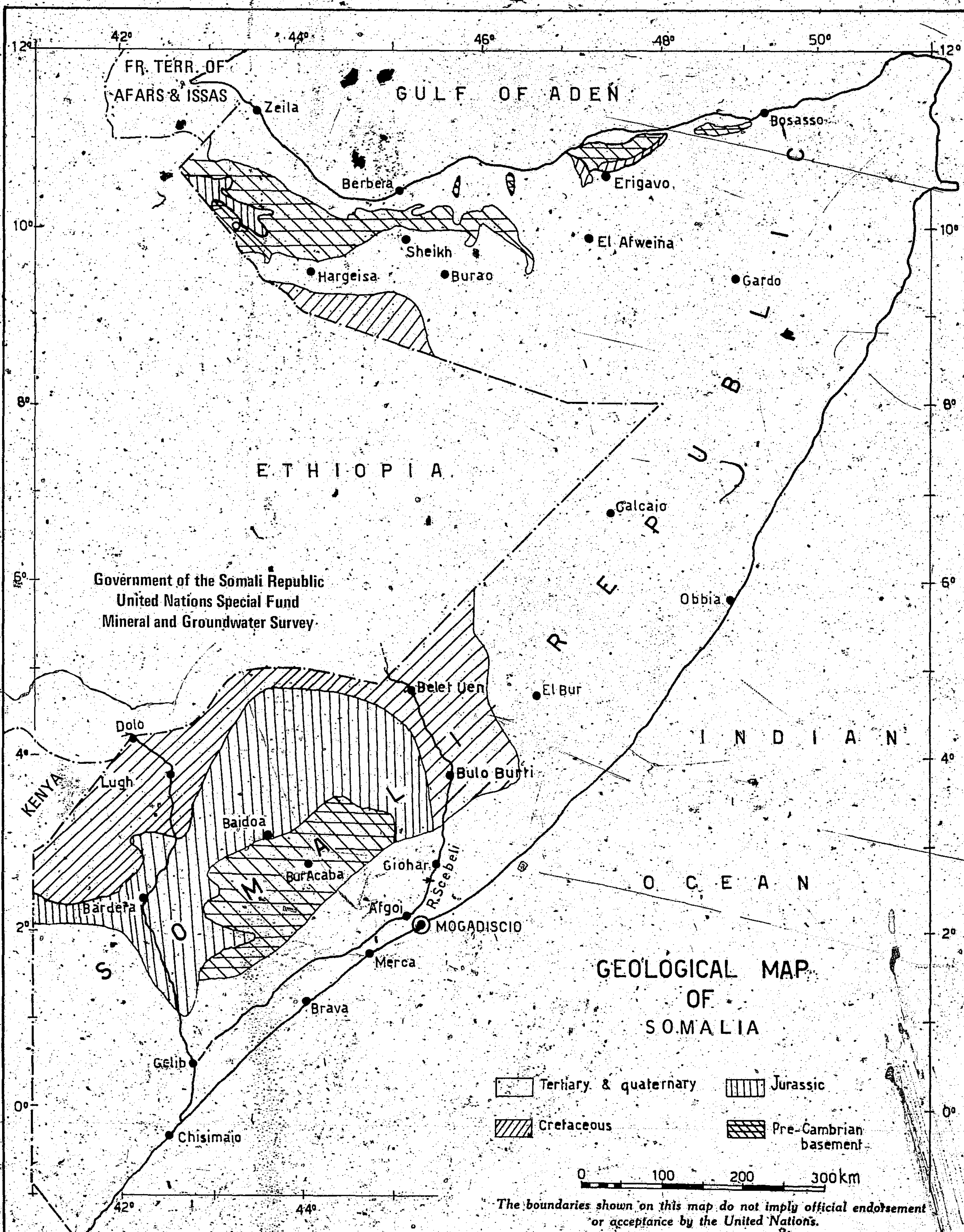


Figure 3. Geological map of Somalia

mineral occurrences. Some of these sheets and their accompanying reports were published, but others were, as of 1968, awaiting publication in the archives of the geological department of Somalia.

The Berbera-Sheikh area and the basic and ultrabasic rocks north-west of Hargeisa were mapped in detail.

The geological structure of the crystalline basement rocks was mapped to a scale of 1:125,000, from a compilation of the 30-sheet geological survey. This map was unpublished as of 1968, and the manuscript contained discrepancies owing to the diverse authorship of the original survey sheets.

In the 1940s, northern Somalia was covered by aerial photographs to a scale of 1:20,000 and 1:42,000, the latter by the United States Air Force. The sedimentary formations were mapped and extensively drilled by various oil companies, and 5,000 km² were thus surveyed and mapped to a scale of 1:50,000 around the Daga Shabell oil showings south-east of Berbera. The central and southern parts of the northern area were surveyed to a scale of 1:250,000.

In 1953, the Somaliland Oil Exploration Company prepared a geological map of the northern area to a scale of 1:1,000,000.

Southern Somalia

Coverage of southern Somalia was less complete. The first geological reports date from the beginning of the twentieth century, but the systematic exploration of Italian Somaliland was carried out within the framework of an over all programme covering the whole of what was then Italian East Africa, with emphasis on Eritrea and Ethiopia.

The basic document for Somalia is Zaccarini's topographical map drawn to a scale of 1:400,000 in 22 sheets, compiled in the 1930s. The geological information is contained in Stefanini's (1933) and Dainelli's (1943) maps to a scale of 1:200,000, and the accompanying reports.

The Bur area was first described by Stefanini in 1916 and was intermittently re-examined in the 1930s. In 1960-1961, it was photographed from the air and interpreted photogeologically by J. Daniels, who prepared a contour map of the main area of basement rocks and of their principal structures. In 1963, an airborne magnetometer survey covered part of the area to a scale of 1:30,000.

Since the second world war, Zaccarini's map has been revised to a scale of 1:500,000 and most of the country has been covered by a photomosaic to a scale of 1:60,000, prepared by the Royal Air Force (R.A.F.), the Food and Agriculture Organization (FAO), and American oil companies.

Certain areas which appeared to be of particular interest for oil exploration or for agricultural and hydrological development were covered by photomosaics to scales of 1:30,000 and 1:50,000, and the R.A.F. photographed certain parts along the Kenyan border to a scale of 1:20,000.

Mineral occurrences

Northern Somalia

Numerous mineral indications (figure 4) were reported in the northern provinces by the British Geological Survey, but they were of only academic interest as long as the country was not equipped with the ports or roads necessary to support a sustained mining development.

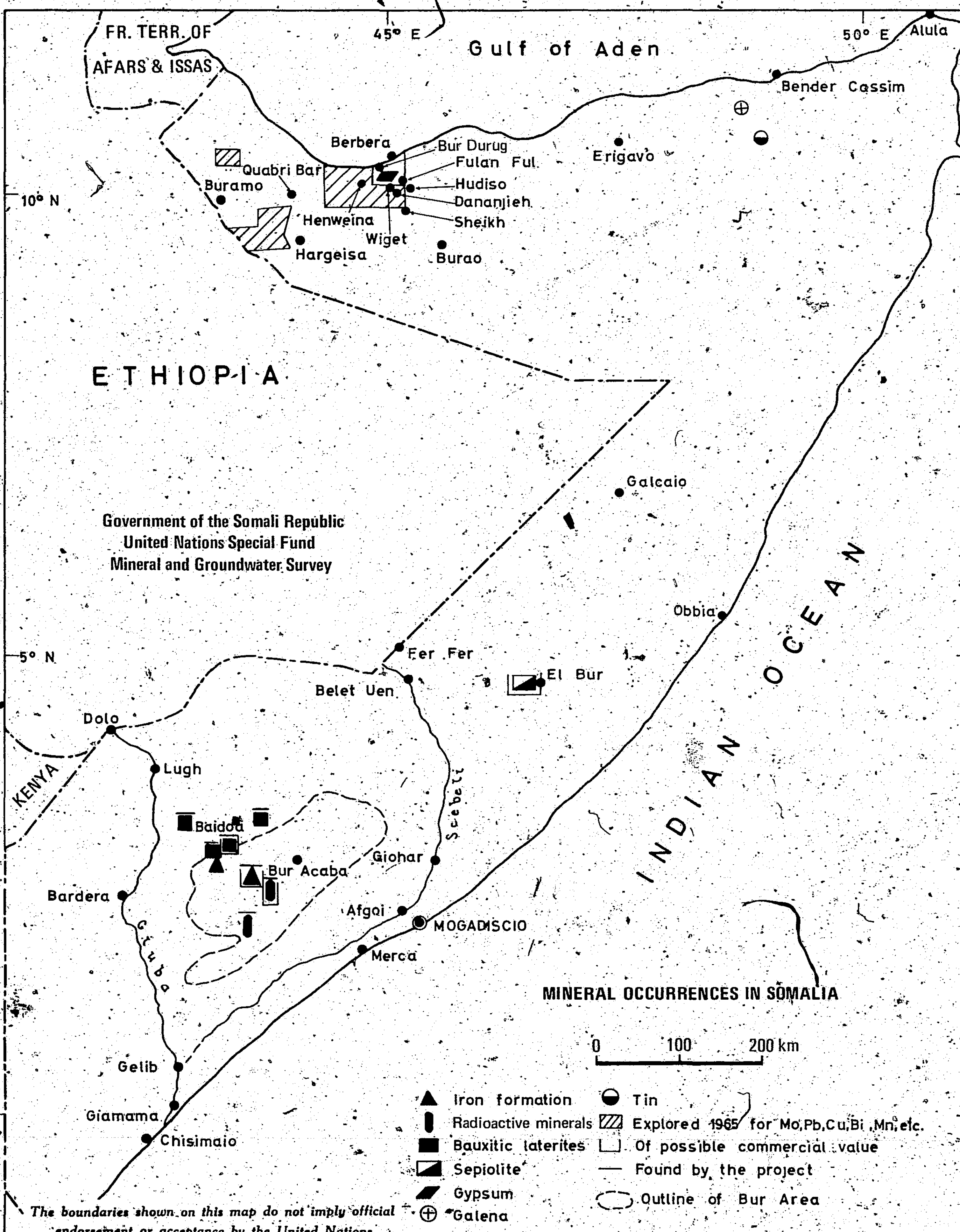


Figure 4. Mineral occurrences in Somalia

Manganese. Reported from Bihen Gaha by Farquharson in 1924, from Aca Dehemid by Gellatly in 1962, and from Hudiso by Hunt in 1948 (localities not shown in figure 4).

Lead. Reported from the Erigavo area by Stock and Greenwood in 1947, and from Fulanful, Wiget and Dananjieh by Pallister in 1959 and Hunt in 1960.

Molybdenite-galena-bismuthinite mineralization. Reported in 1960 from an area south of the Buhl granite intrusion, 40 km north-west of Hargeisa.

Copper (as chalcopyrite and malachite). Reported from several areas, the largest showings being described in 1958 by A. Warden from the Buhl area.

Gypsum-anhydrite. Occurring at Suriah Malebleh, some 15 km south-east of Berbera; partly drilled and sampled in 1959.

Reports also mention nepheline syenites 130 km north-west of Hargeisa and kyanite from the Hudiso area.

Southern Somalia

In the south, apart from oil exploration, the only known mineral occurrences were the ferruginous quartzites in the Bur area, the sepiolite at El Bur and salt from the Obbia pans.

Iron occurrences. First reported by Stefanini in 1916 and re-examined prior to World War II by the Italian Company, "Comina". In 1953, R. Holmes, consultant geologist to the International Mining Company, visited the outcrops and recommended a ground magnetometer survey to look for concealed extensions. In 1961, J. L. Daniels carried out a magnetometric and geological survey of the Bur Galan (map 1 and figure 11) outcrops and estimated them at 300 million tons containing 40 per cent iron. A similar survey on the Culi Culi (map 1) outcrops showed that here the formations were discontinuous.

Sepiolite. Sepiolite has been worked for many years by hand methods, in pits from three to five metres deep, which expose a thickness of some 3.5 metres of sepiolite, including off-grade material (figure 17). At a depth of from one to two metres, the sepiolite is weathered and moist and is therefore easier to dig by primitive methods. It is used by local craftsmen for the manufacture of curios. In 1953, R. Holmes visited the deposit and recommended further study. A private Somali company, Arab Issa and Company, now works some 400 m^2 of the deposits at their southern and northern ends. The sepiolite is cut into cubes measuring half a metre on a side and trucked to Mogadiscio where it is carved into curios and fire bricks. Production is around 15 tons per day. In 1966, interest was expressed in this material by J. Saul, a consulting geologist representing several American, British, and Austrian companies.

Radioactive materials. In recent years, the United States Atomic Energy Commission expressed interest in the exploration for radioactive minerals and provided a Geiger counter and scintillometer for this purpose. Ilmenite-monazite sands were tested at the mouth of the Giuba River as was the Ras Hantara pegmatite area, east of Bender Cassim in the northern [illegible]. Several places in the Bur area gave higher than average readings, b[illegible]nt was found.

Groundwater

Information regarding groundwater [illegible]

In the southern coastal region, [illegible] International Development (AID) drilled for wate[illegible] and sponsored

14 holes to provide the city with water of adequate quality. In the Genale (not shown) area, 147 wells were drilled for the irrigation of banana plantations.

In the Bur area, in 1964, C. Faillace reported on groundwater conditions in the Scebeli River valley and, in 1966, FAO prepared an unpublished report and a map to a scale of 1:200,000 with accompanying cross sections along a line Lugh-Cannana (not shown) to Mogadiscio overlapping onto the adjacent areas of the Bur province.

In the Lower Guiba area, in 1963–1964, the Water Construction Design Institute of the Union of Soviet Socialist Republics carried out a survey of the river section Jamama (Giamama)-Fapole; and the Irrigation Research Institute of the USSR examined the lower reaches of the Giuba River and the Chisimaio area. Their reports constitute the basic documents for the area.

In the northern area, local water resources were surveyed by the British Geological Survey, and in 1966–1967, the Irrigation Research Institute of the USSR, studied the northern slopes of the coastal mountains and plain along the Gulf of Aden with a view to providing water for a fish cannery at Las-Khoreh.

I. Background of the project

A. History

Among the various mineral occurrences which were known in Somalia, the ferruginous quartzites of the Bur area were considered to be the most interesting, and previous reports had recommended that the two principal outcrops, Bur Galan and Daimir be systematically explored.

The Government of the Somali Republic therefore approached the United Nations Special Fund in July 1961, with a request for a project to cover the investigation of the iron-bearing occurrences of the Bur area (figure 5a). This was approved by the Governing Council at its seventh session, and the United Nations was designated as Executing Agency, with the Ministry of Commerce and Industry of the Somali Republic as its counterpart.

Examination of the Government request, however, showed that it was too restrictive. If full use were to be made of the resources necessary to implement the project, it would have to be broadened in scope and area, to complement the bilateral agreement entered into with the USSR to develop the port of Berbera which enhanced the economic interest of the mineral showings of northern Somalia. It should also complement the activities of FAO and of the oil companies which increased the urgency of exploration for groundwater and for mineral wealth throughout the southern area of the Republic.

A revised Plan of Operation was therefore signed on 22 December 1962, with the following broad objectives:

(*a*) To help develop a geological survey department within the framework of the Somali Administration;

(*b*) To carry out, as first priority, a pre-investment survey of the iron-bearing occurrences of the Bur area;

(*c*) To explore for other minerals and for groundwater in the Bur area and elsewhere in Somalia.

The project was further entrusted by the Somali Government with the supervision of the geological work being carried out under bilateral agreements.

A. I. Katskov was appointed Project Manager, and work in the field began in January 1964. The main targets for exploration were selected in the Bur area by photogeology, ground traversing and surface sampling, and followed up by geophysical exploration, pitting, trenching and diamond drilling.

In the course of the geological exploration, potentially valuable pegmatite veins were located in the eastern part of the area, good marbles were reported from several points, and heavy concentrates from around Bur Acaba were found to contain high geochemical values of tin, silver and copper.

Some points of the area were covered by a lateritic mantle containing free alumina hydroxides, and these appeared sufficiently favourable to warrant the examination of the country by an expert who surveyed the whole territory for potential bauxite in the course of the first three months of 1968.

As the survey of the Bur area developed, it became apparent that conditions were promising for other minerals and that the survey should be expanded to cover not only the ferruginous quartzites but also all other mineral occurrences. North-east of the Bur area, the El Bur sepiolites were appraised and found to merit further exploration. It was also realized that the ground exploration of a flat, featureless plain covered by thick topsoil and by high thorny scrub was slow and unrewarding. To be efficient, work had to be preceded by an airborne geophysical survey and by aerial photography.

In November–December 1965, an area of 22,000 km² was surveyed by an airborne magnetometer and scintillometer, coupled with strip photography of the flight paths. This showed up several magnetic anomalies, and also 38 radioactive anomalies contained within an area of some 100 × 100 km.

As a result of the above findings, a revised Plan of Operation was signed on 18 June 1966, providing for an increase in the number of specialists and, in particular, for a photogeologist, a mineralogist and an assayer (see annex I). While the geological and geophysical surveys of Bur Galan and Daimir were being completed and supplemented by pitting, trenching, shallow drilling and sampling, a geophysical team located the Alio Ghelle radioactive anomaly (figure 7) on the ground and began its exploration. By the second half of 1967, the volume of work on the iron-bearing occurrences was sufficient to warrant their economic appraisal in the Bur area and emphasis was transferred to Alio Ghelle.

In the northern provinces, work was initially restricted to a survey of the mineral occurrences, already reported from the Berbera and Hargeisa area, that were easiest of access, but as Somali geologists returned from training under bilateral agreements and as foreign geologists provided under bilateral agreements became available to the project, the scope of work was expanded, and the building of the former British Geological Survey at Hargeisa was equipped as a headquarters.

Occurrences of gypsum, colombo-tantalite, beryl, piezo-electric quartz, cassiterite, industrial feldspar, molybdenite-galena-bismuthinite and chalcopyrite-malachite were examined.

Meanwhile, a consultant and an associate expert reported on the possibilities of groundwater in the Bur Galan-Daimir, Bur Acaba and Chisimaio areas, and in the course of the summer of 1968, exploration for water was extended to the northern provinces by the staff of the project working in conjunction with the Department of Public Works.

By late 1967, the over-all results were sufficiently promising for the Somali Government to submit a request for a phase II continuation project, which was approved by the Governing Council in January 1968. Work still continued on the Alio Ghelle and other radioactive occurrences. Though still insufficient to determine reserves or economics, the findings of the surface exploration, drilling, assaying and beneficiation testing all tended to corroborate the possible existence of a major thorium-uranium field. International interest was aroused, and the United Nations submitted an *ad hoc* report to the Government in May 1968.

The Government asked that this potentially valuable discovery be valorised as soon as possible, and the United Nations Development Programme, therefore, sent to Somalia a senior consultant, an expert in uranium, F. R. Joubin, to assess the situation and eventually to advise the Somali Government in their negotiations with companies tendering for concessions.

Mr. Joubin arrived in Somali on 28 July, and following his discussions and recommendations, the United Nations and the United Nations Development Programme agreed to withdraw from the Bur area and to release it for concessions covering all minerals.

Mr. Joubin, with the assistance of Iqbal Singh, M.B.E., bilateral aid legal adviser to the Prime Minister, also prepared a unified mining code for the Government's consideration and established the basic principles on which the uranium concessions could be negotiated.

At the request of the Government, a technical expert was sent to Somalia to assist in the drafting of the tender documents, and a consultant on mineral concessions, C. Beaton of Canada, advised them in their negotiations. Concessions covering approximately three fourths of the radioactive area have been taken up by Somiren/ENI of Italy, Uranerzgebau of the Federal German Republic, and Western Nuclear of the United States of America. The remaining area was held as a government reserve.

Phase II of the project, which was approved before these events occurred, was modified to confine the mineral investigations to the northern provinces of the Republic, the groundwater survey remaining unchanged. As of February 1969, it was being revised following an agreement signed between the Somali Government and the Somiren/ENI group, for the latter to spend $1,000,000 on exploring the Pre-Cambrian areas of the northern provinces. Three possible forms of United Nations co-operation were examined:

(*a*) For phase II of the project to remain unchanged and for the Italian contribution to be used as the Government counterpart payment for this phase;

(*b*) For the northern provinces to be divided into two geographical areas, one attributed to Somerin/ENI, the other to phase II of the project;

(*c*) For phase II of the project, as such, to be cancelled and for United Nations help to be concentrated on providing personnel of the Operational Executive and Administrative Personnel Programme (OPEX) to staff the Ministry of Mines and the proposed department of geology during the first three to four years of their existence.

B. Training

The project trained the following Somali technical personnel: 1 senior geophysicist; 4 geophysicist operators; 1 draughtsman-surveyor; 1 senior field assistant; 1 field assistant; 1 assistant prospector.

A nuclear staff for the geological department was mainly recruited from Somalia, some having already worked for the former British Geological Survey. These required only refresher courses, but others had no experience in geology or geophysics. Practical courses for geophysicist operators, field assistants in geology and drill foremen were, therefore, organized by the project and were followed in all by 12 drill foremen, 5 geophysicist operators, and 3 field assistants in geology. A number of junior Somali personnel were also trained in the field.

As a result of the above, much of the field work in geophysics, geological surveying and drilling has been entrusted to Somali personnel under the general guidance of United Nations experts.

C. Acknowledgements

The thanks of the project go to the following members of the Somali Government who were closely associated with its operation: His Excellency Mr. Ismail Dualeh Warsama, Minister of Animal Husbandry, Fisheries and Mineral Resources; Mohamed Ahmed Abdilleh, Director General of Animal Husbandry, Fisheries and Mineral Resources; and Mohamed Haji Hussein, Director General of the Ministry of Industry and Commerce and Government Representative.

II. Methods employed

The main initial objective of the project was the exploration of Pre-Cambrian rocks of the Bur area with particular emphasis on the iron formations. In the northern part of the country, work was, of necessity, first limited to a reappraisal of the findings of the British Geological Survey, and because of the distance from the Bur area and of the different local conditions, this required a separate organization. The groundwater survey was entrusted to a specialized team. This co[illegible]tion, which influenced the initial organization and work of the project, was e[illegible]led as experience was acquired, and it was as a result of this development t[illegible] the so far unsuspected radioactive occurrences were found in the Bur area a[illegible] the targets of the project changed.

A. Bur area

Geographical and geomorphological description

The Bur area consists of a flat, featureless, erosional peneplain most of which is covered by an eluvial mantle several metres thick and by dense, high, thorny scrub. The only landmarks are occasional sugar-loaf granite domes, termed *burs*, which commonly occur in clusters. Outcrops are rare, the vegetation impedes access and co-ordinated observation, and the lack of landmarks hinders map reading. The basement peneplain is bordered by Jurassic limestones which also overlie the down-thrown blocks.

The only lines of ready access are roads, impracticable during the rains, and along seasonal stream beds, termed *tugs*, some of which can be followed by car. Roads join Bur Acaba-Iscia Baidoa (Baidoa)-Daimir; Dinsor-Yaq Brava, Bur Acaba-Olontole-Jaq Brava; and Iscia Baidoa-Bur Acaba-Uanle Uen-Mogadiscio. A series of tracks fans out from Bur Acaba. During the rains, all these settlements are cut off.

Within the basement area, two sub-types of relief correspond to the metasediments and to the granitic rocks. Both have features in common which distinguish them from the Mesozoic rocks.

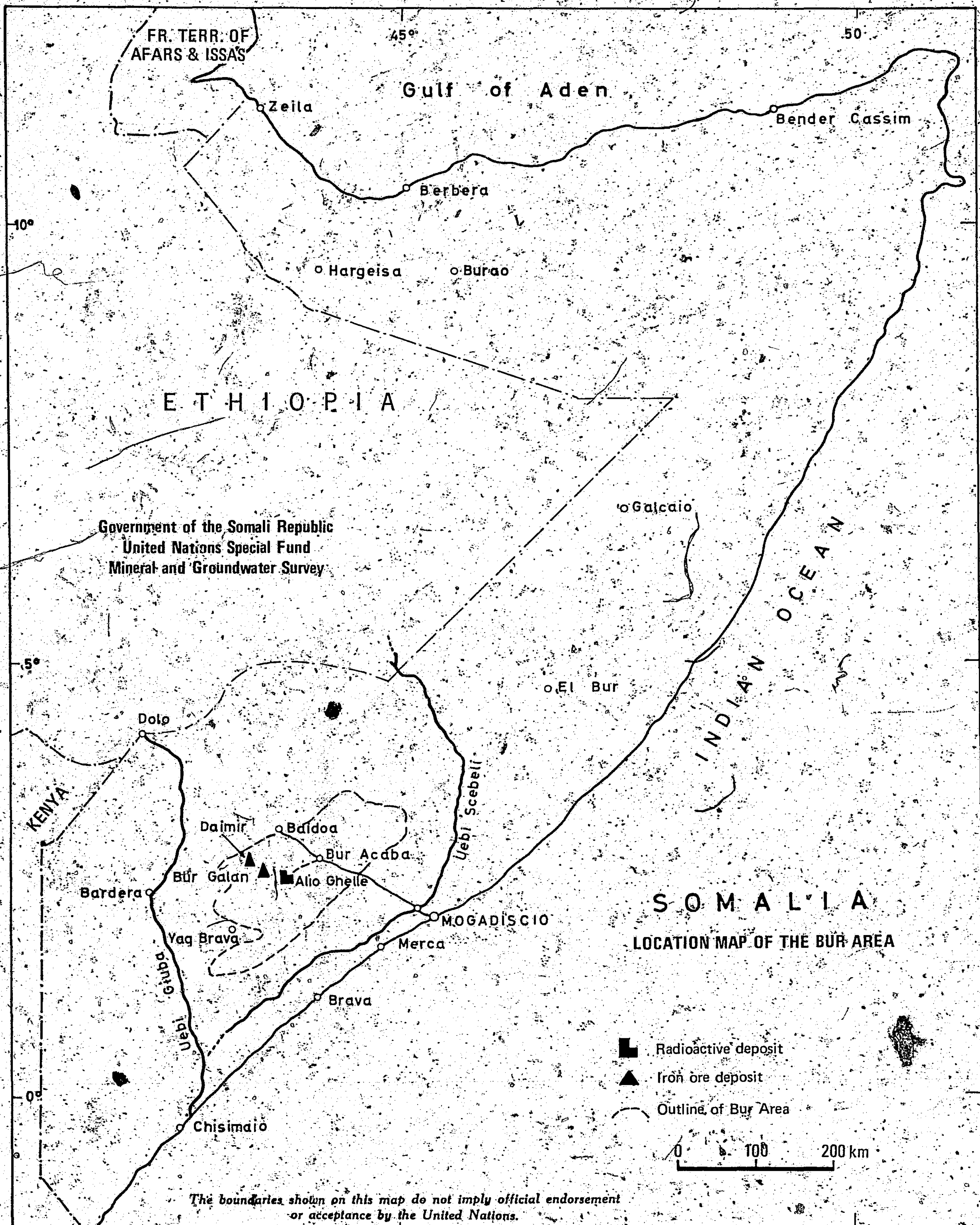


Figure 5a. Location map of the Bur area

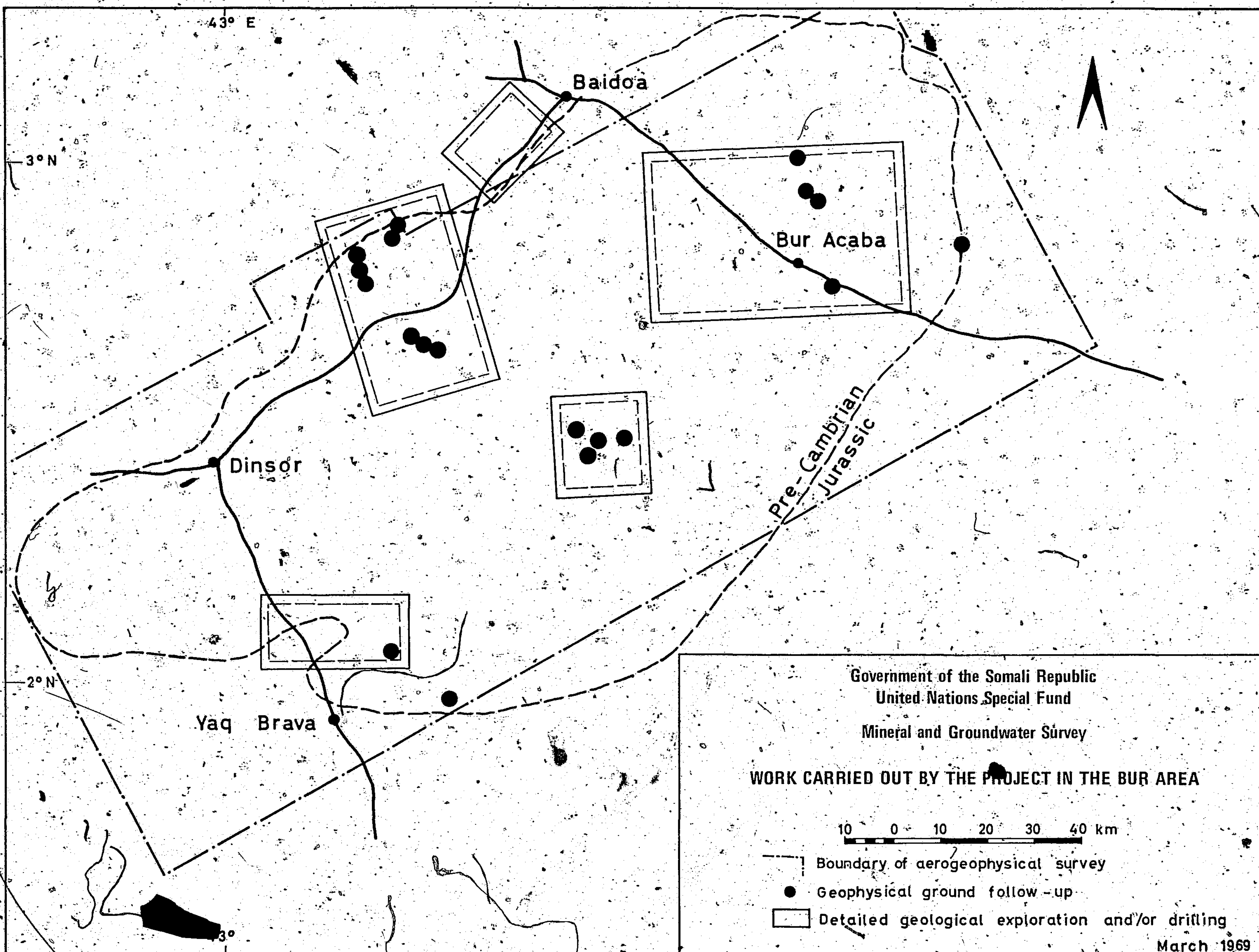


Figure 5b. Work carried out by the project in the Bur area

The principal of these is the drainage pattern which, in both sub-types, is pinnate, with a diagonal pattern superimposed locally. The latter is governed by the interfaces of the metasedimentary beds and commonly follows the planes of schistosity, joints, cleavages, faults and minor shear zones.

In the granitic sub-type, the sugar-loaf domes, or *burs*, constitute a pronounced feature. They are probably the remnants of an eroded peneplain. Major *burs* are rimmed by a rise in ground which is underlain by granito-gneiss.

The areas underlain by metasedimentary rocks are flat and featureless. They slope gently to the south-east following the general tilt of the area. The stream-beds here are too shallow, wide and gently sloping to constitute a morphological feature. They meander over the valley floors, with many minor channels and oxbow lakes.

The quartzites and ferruginous quartzites form low ridges and spurs where their beds are thick. Elsewhere their presence can only be surmised from surface debris. The marbles and the carbonate-silicate rocks give rise to a gentler relief than the quartzites, whilst a slight rise of ground generally occurs around the swarms of quartz veins, which are clearly visible on the aerial photographs.

The Jurassic carbonaceous rocks occur as flat, slightly tilted plateaux cut by the narrow straight valleys of seasonal streams. They cover considerable expanses, especially in the southern and south-eastern parts of the area. Flat and heavily overgrown, their detail is difficult to outline. Although unpromising for mineral exploration, they can be of interest for groundwater research.

Preliminary geological reconnaissance

Field work was preceded by a re-interpretation of all the materials available, and in particular the air photographs and uncontrolled mosaics were used to identify and interrelate the principal geological formations, to establish their mode of occurrence and to obtain an over-all idea of the geological structure of the area.

The most exposed areas visible on the photomosaics were then traversed on foot, generally along stream-beds, where the outcrops were most numerous and access was easiest.

Lithological sampling was carried out, concentrates of heavy minerals were collected from the stream-beds, metallometric samples were taken, and detailed geological sequences were mapped. Work was hampered by difficulties of access and by the lack of identifiable landmarks and of reference points. Individual geological traverses could not be tied in properly, and the topographic maps were unreliable.

Following the results of the airborne geophysical survey, the emphasis of exploration was switched from general geological mapping to the detailed study of the areas of magnetic and radioactive anomaly. Geophysical methods were used in an attempt to determine the structural details of the bedrock below the thick eluvial mantle.

The work became an attempt at the geological interpretation of certain geophysical anomalies, accompanied by regional surveys made to determine relevant structures and to search for other mineralized occurrences.

The over-all results achieved were embodied in a geological map of the Bur area (map 1) to a scale of 1:200,000 with accompanying sheets showing the hydrogeology and morphology. This map was used to identify the uranium anomalies and to interpret the geophysical and geological characteristics of the magnetic anomalies.

Detailed geological exploration

Geological exploration was guided by geophysical surveys, first magnetic on the iron occurrences, then magnetic and radiometric on the radioactive occurrences. Exploration began on the Bur Galan (Bur Dur) and Daimir outcrops, which were already known. The area of interest was first outlined by geophysics and resurveyed when the aeromagnetic maps became available. The thick thorny scrub made access and observation difficult. A base line was cut through the bush along the length of the anomaly, with transverse lines every 200 metres. Directions were determined by alidade, and distances were measured by tape. Where necessary, the lines were extended into the bush by compass and pacing. At Bur Galan, this grid was tied in with a bench mark on the summit of an easily identified granitic *bur* which stood out at the south-eastern end of the outcrops. Dips and strikes were measured by dip needle and compass, but strike readings were only approximate because of strong local magnetic variations. Surface sampling and subsequently pitting, trenching, and shallow drilling were guided by magnetic measurements. At Daimir, the mineralized exposures were surveyed to a scale of 1:2,000; at Bur Galan, to a scale of 1:10,000.

On the radioactive anomalies, geological exploration had to give way to purely geophysical methods, as this featureless area covered by a thick mantle of top soil provided no surface indications as regards the underlying bedrock. The anomalies were located from the aerial geophysical map and the photomosaics by geophysical traversing which subsequently guided all sampling and exploration. Magnetometric surveying was used in an attempt to establish the structural pattern of the basement rocks under the thick surface mantle.

On the El Bur sepiolite deposit, the results of the systematic traversing and of the surface and pit sampling of the Cretaceous and Eocene rocks were embodied in a geological sketch plan of the area (figure 17).

Geophysical methods

Preliminary aerial survey

An aerial survey was first made of the Pre-Cambrian basement formation of the Bur area, with a slight overlap onto the adjacent Jurassic sedimentaries. The characteristics of the survey were as follows:

Equipment: Airborne magnetometer and scintillometer, Doppler navigational control, continuous strip photography of the flight path, over a width of	150 m
Ground clearance	150 m
Line interval (general survey)	1.0 km
Line interval (detailed surveys)*	0.5 km
Intervals between readings	1.0 km
Line direction (general survey)	N 30°W
Line direction (detailed surveys)*	N 25°E and N 60°E
Kilometres flown	23,834
Area covered	22,111 km^2
Scale of maps (composite series)	1:200,000
Number of sheets (composite series)	1
Scale of maps (detailed series)	1:60,000
Number of sheets (detailed series)	19

*Bur Galan, Allo Ghelle, Yaq Brava.

STATISTICS ON GEOPHYSICAL SURVEYING

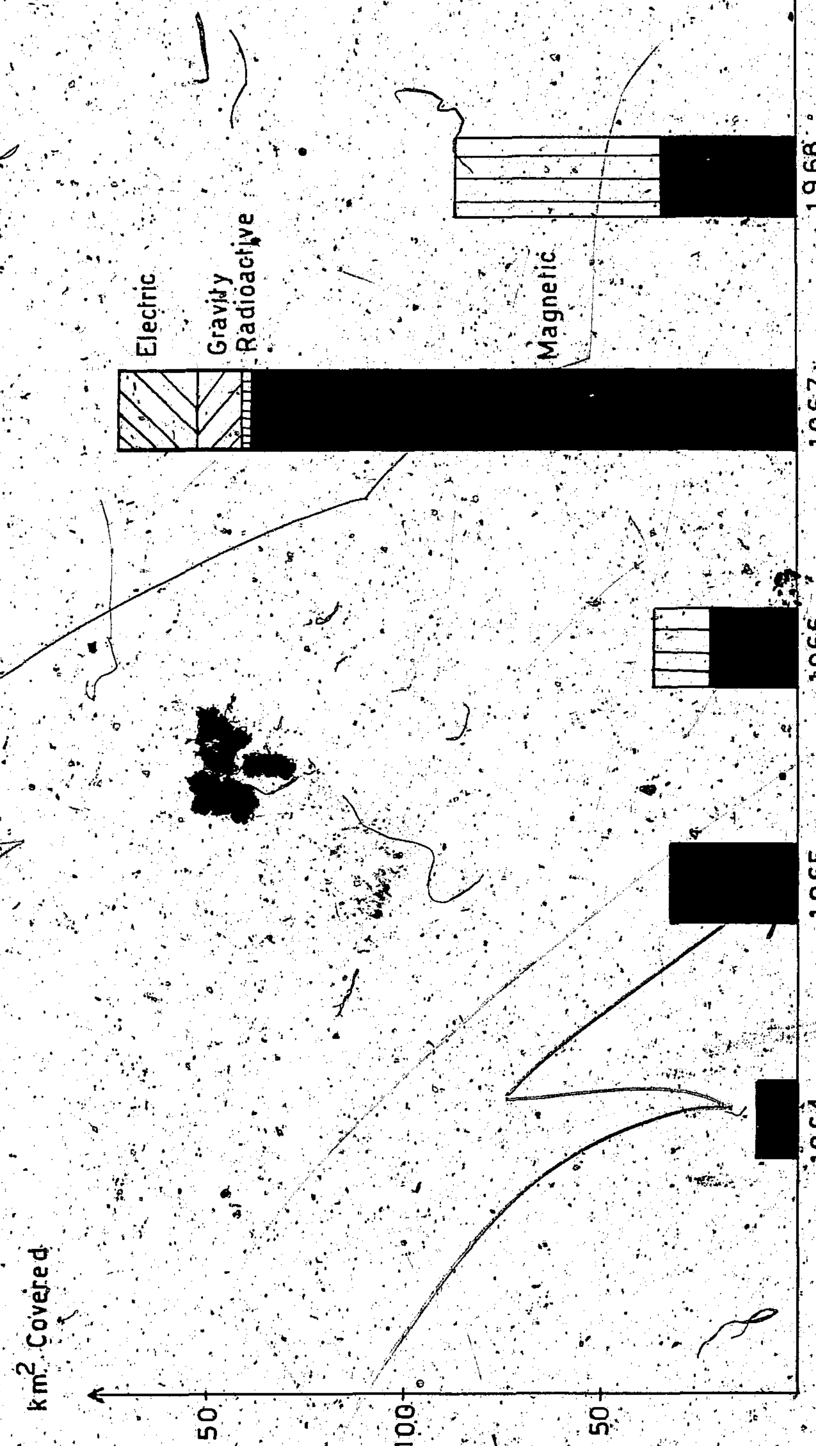


Figure 6. Statistics on geophysical surveying

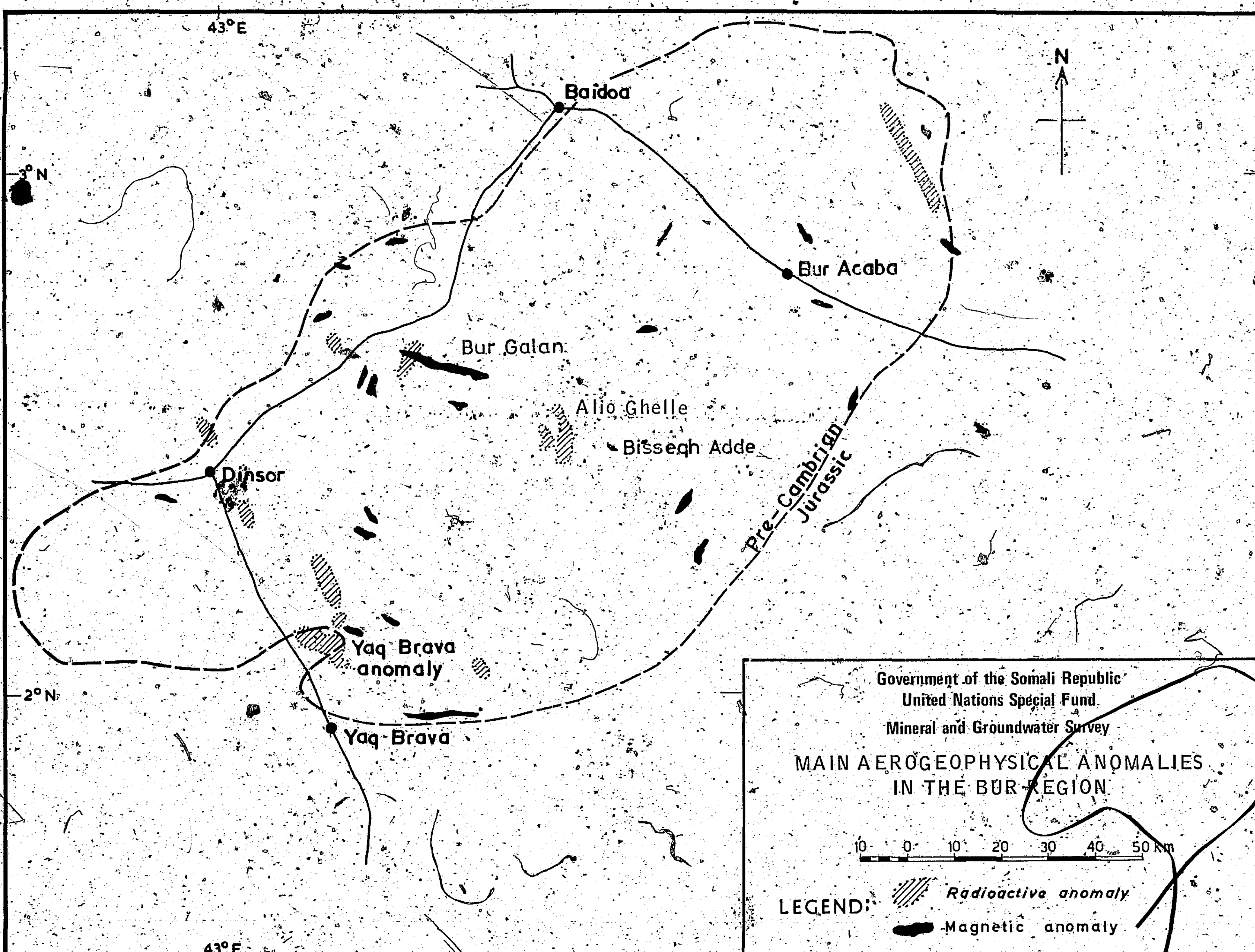


Figure 7. Main aero-geophysical anomalies in the Bur region

The results, which became available by mid-1966, showed not only a series of magnetic anomalies of which 10 were identified as iron formation and 38 were radioactive anomalies. The spacing of the flight-lines and of the readings in relation to ground clearance were such, however, that some anomalies may not have been completely recorded and some may have been missed.

Because of the low magnetic latitude and the highly magnetic properties of the ferruginous quartzites, the corresponding anomalies have a distinct dipole character, and many show a high gradient with a sheetlike structure, giving up to 1,000 gammas at 100 metres altitude, with a minimum to the south and a maximum to the north.

The younger granites have a similar dipole character but with a distance of several dozen kilometres between the two poles. On some sections, the boundary of the Jurassic limestones can be identified because the anomalies die out beyond it.

The radioactive anomalies which lie within a quadrilateral of some 100 km by 100 km are grouped into two main areas with peaks of up to four and six times the background value, surrounded by belts 10 km to 20 km wide, which show twice the background value.

The Alio Ghelle anomaly (map 2) covers an area of approximately 30 km², elongated from east to west, outlined on 4 flight-lines and fading westwards. It is situated 12 km west of Bisseqh Adde village (2°27 N, 43°46 E) and 70 km south-west of Bur Acaba.

The Yaq Brava anomaly was later located on the photomosaics early in 1968.

The results of the aerial survey were difficult to apply because the Doppler navigational control and narrow strip photography had not been preceded by preliminary ground surveying or marking. The only ground plan available consisted in an uncontrolled photomosaic at approximately the same scale. In this featureless, overgrown area, the narrow photostrip was difficult to match up.

Ground geophysics

Because of the thick eluvial mantle and the absence of outcrops, all geological exploration in the Bur area must unavoidably be guided by ground geophysics.

Until 1966, only magnetometric equipment was available, but in 1967 with the arrival of a United Nations geophysicist, additional equipment and trained Somali personnel, the work was expanded: Bur Galan was magnetically resurveyed, gravity was tried out at Dinsor, the Manas bauxites were tested by electric resistivity, and radiometric methods were applied at Alio Ghelle. Magnetic methods are the most useful for general exploration because they can follow the well defined beds of magnetic material contained in the basement rocks and thus provide information regarding structure.

1. *Magnetic methods*. Magnetic traverses were made on the ferruginous quartzites at Bur Galan, Quadia, Bur Coreli and Culi-Culi and repeated when the aeromagnetic maps became available.

Ground readings of 10,000–15,000 gammas, with gradients of 1,000 gammas per metre in the vertical field, were registered. Readings were negative when the total airborne field was positive, and positive when that field was negative. Broad, low-intensity aerial anomalies with amplitudes of 300 to 1,000 gammas were also field-surveyed at Bisseqh Adde, Bur Galeh and around Bur Acada.

The Daimir and Bur Galan magnetic anomalies were covered by an Askania DF2 Torsion magnetometer grid with readings every 50 metres, narrowed to 10 metres when greater detail was required. This grid served as a basis for the geological survey, and for sampling, pitting, trenching and drilling.

The magnetic field was mapped to a scale of 1:50,000 in an area of 14 km^2 around the Daimir occurrence, and the Bur Galan anomaly was mapped to a scale of 1:10,000.

Magnetic profiles were made every 100 metres with readings every 10 metres in an area of 1 km^2 around the Alio Ghelle radioactive anomaly to determine the trend of the country rocks. With the arrival of the EM-gun in June 1968, this was followed up by a micromagnetic survey comprising 5,000 readings in an area of 2 $\times$ 2 km, and the results were presented on a map to a scale of 1:2,000.

2. *Radiometric methods*. Ground exploration began with the Alio Ghelle aerial anomaly, because it was the first to be identified on the ground and was the easiest of access. The anomaly was covered by a radiometric grid 5 $\times$ 20 metres and 5 $\times$ 10 metres which outlined its contours and local peaks. In all, 4.5 km^2 were finally covered by a radiometric survey to a scale of 1:10,000 which established the general pattern of the radioactivity and found two other high anomalies. This grid pattern was subsequently extended to an alignment 9 km long passing through Alio Ghelle and two more anomalies were recorded.

This survey showed that the high ground anomalies are only a few dozen metres in extent as compared to the wide expanse of the aerial anomalies. It follows, therefore, that all aerially located anomalies must be resurveyed on the ground to locate the origin of the radioactivity.

3. *Electric resistivity*. This was tested along certain profiles at Alio Ghelle and gave an apparent resistivity which varied slightly around 10 ohms along the profiles with certain areas which showed local resistivities 10–20 per cent lower than the average and trending in a westerly direction. A repeat survey during the dry season did not confirm these findings, and it would seem that the extensive clay top soil is a good conductor and masks the electric properties of the bedrock.

4. *Spontaneous polarization*. This was tested on two profiles at Alio Ghelle but showed only slight variations from normal values.

5. *Gravity*. Several readings which were made at various points on the Alio Ghelle anomaly showed a few irregularities but no abnormality in the field. A characteristic feature is a general increase in gradient, up to 0.5 mgal/km, towards the north-east.

Gravity profiles were also made at Bur Galan, Daimir and Bisseqh Adde. At Daimir, peaks of 1.5 mgal Bouguer were registered, but the topographic influence was so strong as to cancel out the geophysical anomalies. The topography was too rugged for the use of gravity methods in detecting iron formations.

Geophysical testing

All drill cores from Alio Ghelle were tested for radioactivity, and graphs were constructed to show the radioactive formations. All trenches and pits were tested by Geiger counter. In most cases, except over the actual occurrences of primary ore, the radioactive intensity, however high it might have been near the surface, diminished downwards. In 1968, the drillholes were logged by means of a scintillometer probe.

Pitting and trenching

At the Daimir iron-bearing occurrence, shallow pits were dug at intervals of 10 to 30 metres along prospecting lines 400 metres apart. Four pit lines were completed on the eastern flank of the occurrence and two on the western flank. Pits were sited according to the results of the ground magnetometer survey, and the geological and geophysical pit sections were tied in with the surface survey. The Bur Galan occurrence was checked by 430 m³ or trenching and by 11 metres of shallow pitting on a similar pattern.

Eighteen pits were sunk, to an average depth of 3 metres and to a maximum depth of 4 metres on the Alio Ghelle radioactive anomaly, to reach the weathered bedrock below the eluvial mantle.

Nine trenches, totalling 1,600 m³ were also dug, averaging 3 metres depth, variable according to the thickness of weathering. Four trenches (project numbers 21, 24, 25, and 26) provided useful information as regards the geological structure and the mode of occurrence of the deposit. The others provided data on the distribution of rock types.

Drilling

Diamond drilling

Drilling on the iron formations was limited to three holes sunk to depths of 41 metres, 13.5 metres, and 29 metres by means of a Winkie drill on the Bur Galan occurrence and to one shallow hole on Daimir.

On the Alio Ghelle radioactive anomaly, the north-eastern peak area was explored by systematic drilling, first along a cross-line to obtain a vertical section across the strike and to obtain some idea of the actual occurrence below the surface mantle, then by a hole offset along the strike, finally to a grid pattern on 50 metres centres, which was not completed, and by an inclined cross-hole.

Although initiated by the project itself, the drilling programme was contracted to the firm of Craelius in 1968.

The results of the programme are summarized in table 1.

Core recovery in unaltered rock was systematically good, but the holes came out of ore along the foot wall and the ore body is not known below a depth of 150 metres. The effects of weathering and oxidation were apparent from the cores.

The holes put down in the centre of the south-western anomaly to obtain a sample of unaltered rock were stopped for technical reasons. One hole was put down on the Airport anomaly (map 2) to a depth of 33 metres and stopped in highly radioactive syenite because work in this area was closed down.

Auger drilling

This method was extensively used on Alio Ghelle to sample the eluvial mantle and to probe the bedrock. A line of holes was put down at 10-metre intervals between DDH 1050/1000 and DDH 1100/1000 to verify an inferred fault which appeared to limit the mineralization. The results were inconclusive.

Trenching and pitting had not been able to find the source of the south-west anomaly. It was therefore covered by 53 auger holes to depths of 7.5–18 metres, laid out on a grid pattern to outline the radioactive rock and to choose a site for diamond-drilling. All soil samples were tested for radioactivity, and this was found

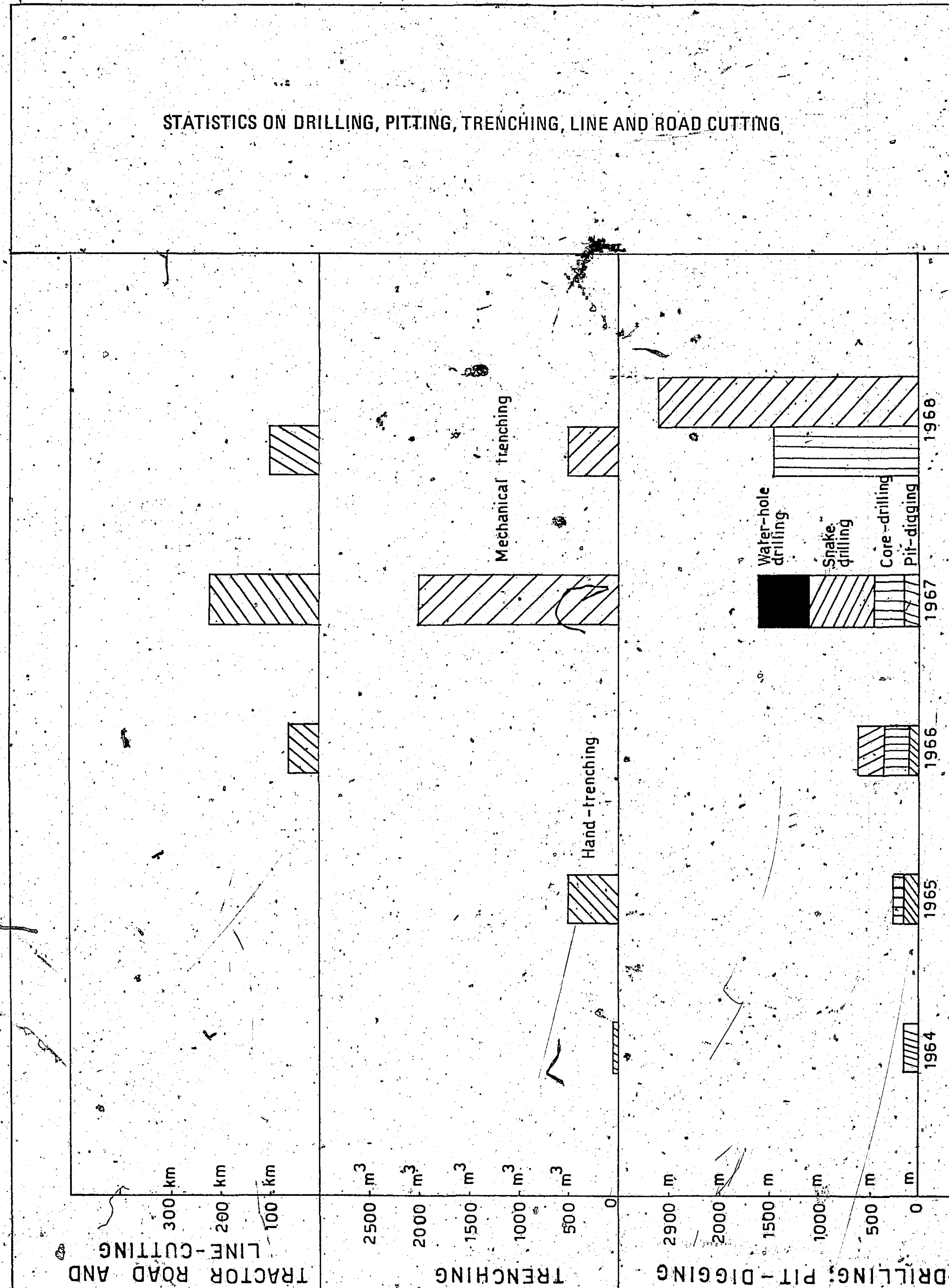


Figure 8. Statistics on drilling, pitting, trenching, line and road cutting

Table 1

DIAMOND DRILLING ON THE ALIO GHELLE RADIOACTIVE DEPOSIT, 1966–1968

*DDH**	*Angle* (*degrees*)	*Depth*	*Mineralization* (*metres*)
Project numbers			
1	90	37.4	0.00–31.00
2	90	121.4	28.00–121.40
3	90	36.0	10.00–17.80
4	90	32.4	—
5	90	64.2	36.50–45.00
6	90	64.0	—
7**	90	32.0	—
8**	90	43.0	0–43
Contractor's numbers (Craelius)			
1050/1000	90	196.75	18–32, 46–140
1100/1000	90	135.75	—
1050/1050	90	151.40	31.10, 100–130
1000/1050	90	194.45	27–37, 109–120
1000/1000	90	241.80	0.00–81.00
1050/950	55 to N 312°W	201.55	68–133
1100/950	55 to W 267°	211.10	100–160

* DDH—Diamond-drillhole.
** On south-west ore body.

to vary considerably from level to level, suggesting that the changes in surface radioactivity are not directly connected with the actual ore body. The underlying rock was highly radioactive.

The Airport anomaly, found early in 1968, was tested by several auger holes put down 20 metres apart along a cross profile. They went down 12 metres to bedrock and showed sharp increases of radioactivity downwards.

The anomalies Anthill, Road, Water Collection and Yaq Brava were similarly explored by auger drilling.

Sampling

The Daimir and Bur Galan ferruginous quartzites were mostly sampled from surface showings and by pitting and trenching. A sample of several kilograms was taken from the pits for beneficiation testing. The drillcores from the three holes on Bur Galan and the one hole on Daimir were also sampled.

At Alio Ghelle, the radioactive surface mantle and underlying bedrock were sampled by pitting, trenching and auger drilling. Twelve pits were put down on the south-west ore body and six on the north-east to an average depth of 3 metres. Nine trenches, totalling 200 metres in length were dug to depths of from 2 to 3.5 metres. Four of these went into bedrock. Along the sides and bottoms of the pits and trenches, 150 samples were taken at one-metre intervals. Twenty-one samples were taken from the cores of DDH 1 between 10.7 and 33 metres and 75 samples from those of DDH 2, between 25 and 121.4 metres.

The cores from DDH 2 were resampled in 2- to 3-metre intervals for assaying abroad.

The El Bur sepiolites were sampled by pitting.

Assaying and testing

The ferruginous quartzites were assayed in the project's own laboratory, and a sample of several kilograms was sent to the Warren Springs Laboratory in the United Kingdom for mineralogical study and preliminary beneficiation tests.

The samples of radioactive material were assayed and tested in the project laboratory and at Columbia University (United States), and a series of duplicate samples from the cores of DDH 2 were sent for assaying and testing to the Warren Springs Laboratory, United Kingdom; the Eldorado Mining and Refining Laboratory, Canada; and the International Atomic Energy Agency, Vienna.

Track cutting and bush clearance

In the thickly overgrown Bur area, the mineral occurrences can only be reached by cutting tracks through the bush, and all exploration must be preceded by line clearance. The main lines of communication opened up by the project are: from the main Baidoa-Dinsor road to Bur Galan; from Bur Galan to Alio Ghelle; and from Alio Ghelle to Bisseqh Adde. In all, approximately 350 km of track were built and line cleared (figure 8). Much of this work was done in 1967 and 1968.

B. NORTHERN PROVINCES

The work of the project in the northern provinces was limited to checking and expanding the findings of the British Geological Survey. Most of it was confined to the Berbera and Hargeisa areas where all localities can be visited by Landrover vehicles along stream-beds and across country.

Reconnaissance traverses were made along the roads and paced traverses on the more promising sites. On the principal mineral occurrences, the overburden was cleared and some pits and trenches dug. The samples of ore and rock were studied mineralogically, the surrounding areas were inspected in detail and small-scale geological maps were prepared. Existing mine workings were also examined.

In the autumn of 1968, the equipment and personnel of the project were moved from the Bur area to the northern provinces. A magnetic and electrical survey covering an area of 1.5 km² was carried out on the Fulanful galena showings (figure 19). A radiometric survey covering an area of 6 × 4 km was carried out in the Bur Durug area. The Burao area was examined hydrogeologically and two localities, Beir, 20 km east of Burao, and Gao, 100 km west of Burao, were chosen for drilling, although the choice of sites had not been made as of January 1969.

III. Geology of the Bur area

A. Stratigraphy

The area explored by the project contains the following rock formations (figures 5a, 9, 10, and map 1):

(*a*) Pre-Cambrian basement crystalline rocks;
(*b*) Intrusives;
(*c*) Overlying Jurassic carbonate sediments;
(*d*) Quaternary and Recent surface accumulations.

The basement rocks can be subdivided lithologically and stratigraphically into a lower series consisting of gneisses, and an upper series consisting of calc-silicate rocks.

Basement rocks, Pre-Cambrian

Lower series

The lower series occurs throughout the area but is most concentrated near the centre. It comprises schist, gneiss, amphibolite, quartzite, and conformable, bedded intrusives.

Most of the lower series consists of medium or fine grained melanocratic to leucocratic and aplitic biotite gneiss containing variable amounts of biotite, potassium feldspar and quartz with accessory sphene and garnet. The gneiss grades locally into biotite schist.

A typical succession along a tributary of the Bur Acaba *tug*, 20 km north-north-west of Bur Acaba, consists of biotite amphibole schist and gneiss with minor interlayers of amphibolite, in beds from 2 to 5 metres thick which trend N–S and dip at angles of 30° to 40°. About 10 km to the north, amphibolite predominates and may even be responsible for the magnetic anomalies in this area.

Southwards, the amphibolite grades into thin alternating beds of sillimanite-biotite gneiss, biotite-amphibole schist and amphibolite.

Westwards from Bur Acaba, the series passes into pink, leucocratic, aplitic granito-gneiss which occurs in beds up to 10 metres thick alternating with beds one metre thick of amphibolite and amphibole schist. The series dips westwards

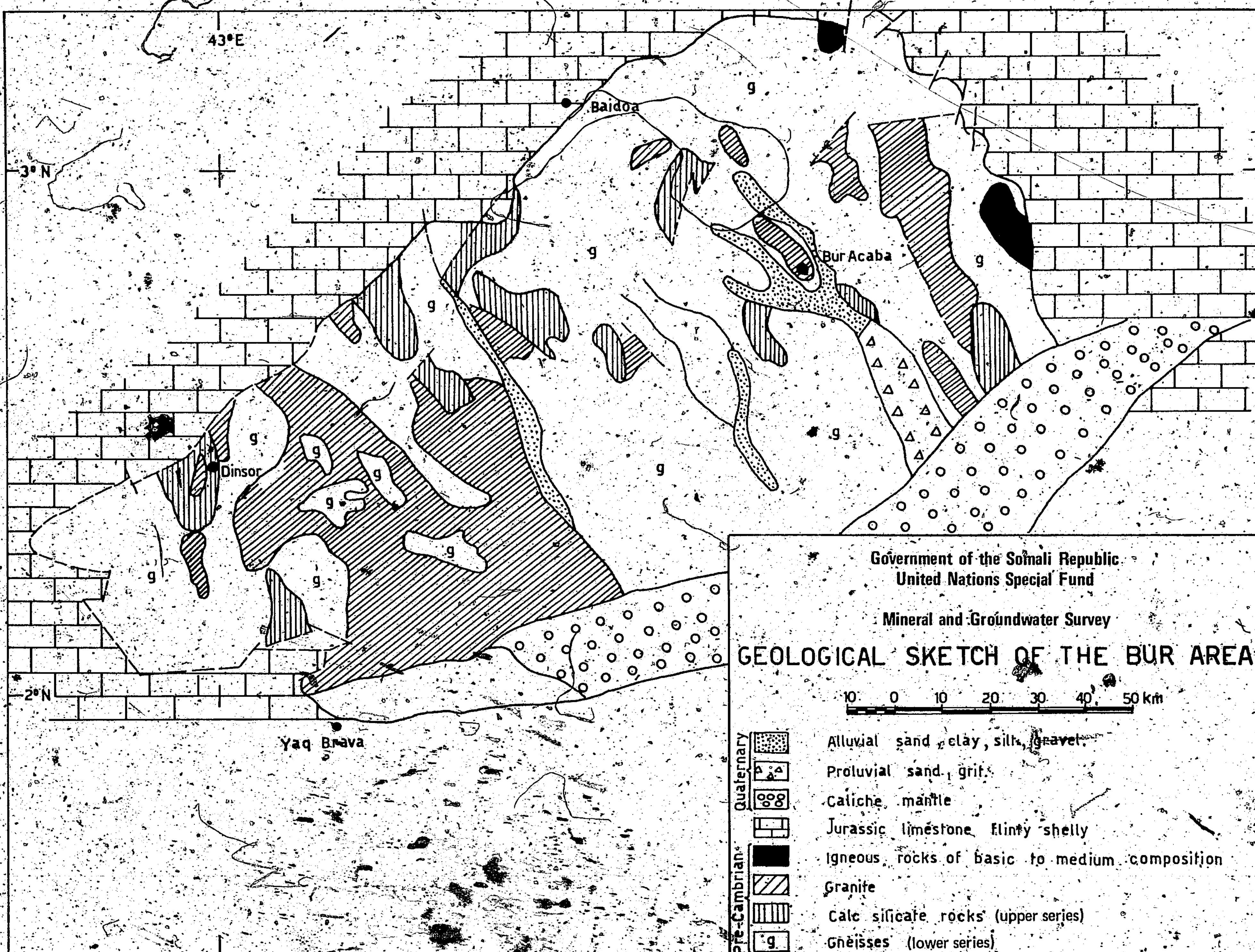


Figure 9. Geological sketch of the Bur area

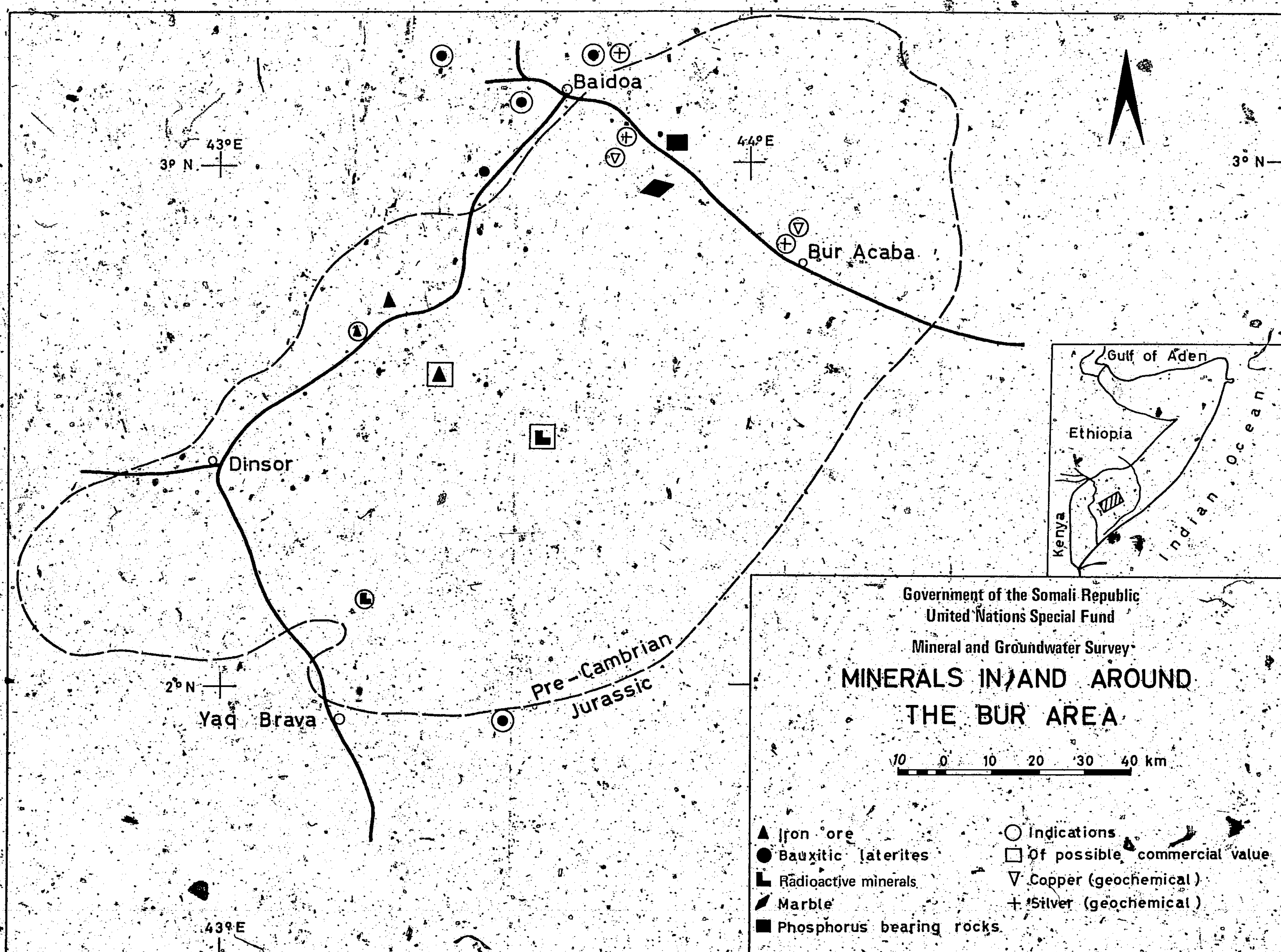


Figure 10. Minerals in and around the Bur area.

at 20°–25°. According to the aerial photographs, further west, the trend of the series is north-west.

In the Lugabaro area, the series is dominated by migmatized granito-gneisses. The rocks of the lower series are probably Middle Proterozoic. There is little information as regards their thickness and it may be several kilometres.

The rocks of the lower series can be identified on aerial photographs by their light colour and finely banded structure. Dark rounded spots, some 250 metres in diameter are hollows which hold rain-water for long periods and are heavily overgrown. They are evenly distributed throughout the area underlain by the lower series, lie some 1-3 km apart and are surrounded by radiating tracks.

Upper series

The upper series is found throughout the Bur area but its relationship with the lower series has not been determined. It comprises numerous rock types which can be subdivided into silicate rocks, calc-silicate rocks and carbonate rocks.

The first two types are dominant.

The geological succession is visible at many points. One outcrop shows amphibole biotite gneisses of the lower series, interbedded by bands of granito-gneiss and conformable aplite dikes and which are continued by cream-coloured medium-grained marbles. Elsewhere, the upper series consists of marble or of calc-silicate rocks interbedded with thin calcite.

At Modu Mode, 25 km north-west of Bur Acaba, the silicified marbles contain 24% P_2O_5. The beds strike N 10°W and dip uniformly at 30°–40°W. They contain bands of pyroxene-garnet rock which resembles skarn and which is mostly found along the contacts between the marble and small granite intrusions. Isolated beds of biotite gneiss, amphibole and amphibole-biotite schist also occur within the rocks of the upper series in this area.

At the south-eastern extremity of the Bur area, the upper series comprise a sequence of gneisses and quartzites estimated to be 2,500 metres thick.

In the western part of the Bur area, the upper series consists mostly of quartzites with the calc-silicate and carbonate rocks conspicuously absent. Its estimated thickness is between 2,000 and 3,000 metres. At Dinsor, Egherta, Bur Galan and elsewhere the country rocks consist of white, fine to medium-grained, clearly banded quartzite with minor interbedding of gneiss and granito-gneiss. Arkosic quartzites crop out along the road between Iscia Baidoa and Dinsor.

The ferruginous quartzites belong to the upper series, although several outcrops were found west of Bur Acaba, within rocks classified as orthogneiss. The relationship between the two is not apparent and aerial magnetometer findings indicate that they persist downwards. The quartzites form low ridges, as at Bur Galan, isometric outcrops from 1 to 15 metres high and covered by boulders, as at Daimir, or accumulations of blocks and debris as in the Quadia area. As measured, the beds range in thickness from a few metres to 40 metres, but true thickness is not known because the beds are severely folded and faulted.

In the central portion of the Bur area, the upper series is intermediate between the east and the west, with quartzite, marble, and their associated rocks equally abundant, and with a pronounced dominance of gneisses similar to those of the lower series.

Near Bur Galan are outcrops of marble and rocks rich in phlogopite, tremolite, scapolite, and apatite. Dolomitic marble and rocks containing pyroxene, feldspar, scapolite, quartz, sphene, spinel, phlogopite, graphite, apatite, and serpentinized forsterite also occur.

Aerial photographs of the areas underlain by the upper series show a coarsely banded pattern of alternate light and dark bands, or else featureless areas. The quartzite ridges and block piles, and marble outcrops give a rugged micro-relief which stands out well on aerial photographs.

Intrusives

Granite

Granite and its associated rocks occur either as large masses or tabular injections conformable with the enclosing metamorphic rocks. Exposures are mostly poor, but the massive granite crop out in places as sugar-loaf domes or *burs*. The largest is in the western part of the area, near the Dinsor-Yaq Brava road. Two main types of granite were identified there: The first, massive, pink to yellow, leucocratic, medium-grained granite; and the second, biotite granite with gneissose structure.

Large xenoliths of gneiss occur within the mass, and the biotite granite seems also to be xenolithic.

In the eastern part of the area, the hill Bur Gulo consists of massive, pink, coarse-grained biotite granite, while numerous small *burs* immediately to the north consist of fine to medium-grained biotite granite which contains up to 20 per cent biotite and large porphyroblasts of microcline.

The Bur Eibi area contains fine to coarse-grained biotite granite and medium to fine-grained granite with large prophyryblasts of microcline. In the Bur Degis area, west of Bur Eibi, the granite is mostly fine-grained and pink to grey. Near Modu Mode village is a small granite boss, typical of those that cannot be seen on aerial photographs. It also contains grano-syenite and syenite which appear to be widely distributed throughout the Bur area. Both contain appreciable amounts of magnetite in grains as large as 2 or 3 centimetres.

The Bur Acaba granite mass was studied in detail. It is oval in shape, trends north-west, and is some 7 km by 4 km in size. Its western contact, some 3.5 km from Bur Acaba, is comformable with the surrounding gneisses and amphibolites and can be followed over a distance of 3 or 4 km. This suggests that the actual *bur* is only a small part of a concealed intrusion, as is probably the case elsewhere.

The following types of granite were identified: medium-grained, friable, biotite granite; fine-grained, hard, aplitic granite; medium-grained leucogranite; and medium-grained, yellow, biotite granodiorite with rare pink microcline porphyroblasts.

The massive varieties are dominant and pegmatoid segregations from one to three metres in size are abundant.

In spite of the variety of granites in the Bur area, they all seem to belong to an old intrusive complex, and no evidence of younger intrusions was seen.

Intermediate and basic rocks

Small little-known bodies of intermediate and basic rocks, probably dikes cutting the metamorphic rocks along fault zones, were discovered while checking the aeromagnetic anomalies.

Coarse-grained plagioclase and hornblende rocks, ranging in composition between diorite and gabbro, were mapped a few kilometres north of Bur Galan. On aeromagnetic anomaly No. 5, a drillhole cut into a dark coarse-grained diorite consisting of plagioclase, biotite and altered hornblende.

The numerous basic rock masses shown on the geological map of the Bur area were inferred from photogeological and geophysical evidence. There is no direct corroboration of their existence, as the area is devoid of outcrops.

Alkalic rocks

The presence of syenite in the granite boss near Modu Mode village has been cited as being widely distributed throughout the Bur area. Drilling has shown this type of rock to be associated with the thorium-uranium mineralization, and to be intrusive in the Pre-Cambrian amphibole gneiss. The mineralogical pattern is complex because of associated injection, albitization, and mineralization of the surrounding rocks. It is described in chapter V dealing with the Bur area radioactive occurrences.

Pegmatites

Pegmatite and aplite dikes are common in the metamorphic rocks and also penetrate the granite masses. The pegmatites usually form lenticular, impersistent bodies from one to five metres thick, interbedded comformably in the surrounding rock and with gradational contacts to the granites. Most of the veins contain a core of quartz from one to two metres thick, surrounded by an outer area of pink pegmatite of variable structure, in places containing microcline crystals as large as 50 cm. Some pegmatites may be younger than the dominant granites: for instance, the white and pink rocks which cut across the surrounding gneisses some 10 km north of Bur Acaba.

Jurassic sediments

These rocks either surround the Bur uplift or lie in tectonic depressions such as that near Yaq Brava. They are referred to as the Hamanli series and consist mostly of limestones which contain clayey or silicified algae, with subordinate amounts of marls and of coquina limestones. The composition of the beds remains constant over great distances. They are subhorizontal, dip gently north near Iscia Baidoa, Daimir and Dinsor and form a plateau slightly tilted away from the Bur uplift.

The thickness of the series in the Bur area is several dozen metres, increasing gradually northwards.

Quaternary accumulations

A continuous eluvial-diluvial mantle of recent origin covers most of the area. On the Jurassic limestones, this mantle consists of 0.5–1 metre of clayey soil, but over the basement rocks its thickness can range from a few decimetres to 20 metres. It consists of brown to brown-grey calcareous clay which passes downwards to a coarse detrital eluvial material. The quartzite terranes are usually free of eluvial cover, while over the schists and amphibolites, the cover reaches maximum thickness. The *tug* valleys are filled with alluvium. The smaller *tugs* have brown sand which is rich in magnetite near the ferruginous quartzite. The valleys of the large *tugs* are up to 2.5 km wide and contain 20 metres to 30 metres of alluvial clay, clayey sand, and gravel. Many of the *tugs* lack a well defined channel in their lower reaches and cover large areas with proluvial accumulations. The Bur Acaba *tug* empties into a broad proluvial plain 20 km south of Harera. The main channel splits into a number of small, temporary stream-beds which, meandering over the plain, have built up a thickness of several dozen metres of clay, sand, and gravel.

Calcareous crusts, or caliche, occur frequently along the limit between the Jurassic plateau and the basement rocks. These caliche crusts may be dense and uniform, porous, variegated or brecciated. From the aerial photographs they appear to be common also in the southern part of the Bur area.

B. TECTONICS

The Bur area falls within the main tectonic unit of the Somali basin which is divided by the Ogaden ridge. It is assumed to constitute an uplift of the basement, in continuation of the Ogaden ridge, and it incorporates several structures.

The structures are typically Pre-Cambrian, and no Alpine folding has been found. Most of the faults cutting the basement rocks are pre-Jurassic, but post-Jurassic faulting occurs along the north-west border of the Bur uplift where there is some evidence of step-fault structure.

The regions where tight linear folding predominates are considered to be anticlinal because they consist mostly of rocks of the lower series. The synclinal zones show isometric folding and blocks of gently dipping strata.

Two major anticlinal zones have thus been outlined, Bur Acaba and Bur Gheluai, separated by a central synclinal zone. The area south-west of Bur Gheluai corresponds to the south-western granite mass.

Bur Acaba anticlinal zone

The Bur Acaba anticlinal zone extends from the village of Duddumal, through Bur Acaba and Manas, to disappear under the Jurassic limestones. The formations of the lower series, which constitute this area, dip at high angles and are compressed into a series of tight linear folds striking WNW-ESE, in accordance with the general regional trend.

A transverse synclinal fold cuts the Bur Acaba anticlinal zone east of the town of Bur Acaba. The structure was not determined but the marbles and calc-silicate rocks examined in relation with the Modu Mode phosphatic occurrence which dip at 30°–40°W, strike E-W some 2 to 4 km to the east.

A typical brachy-anticlinal fold was mapped west of Modu Mode. Its axis trends south-east and the fold plunges in the same direction, showing a periclinal closure near Berdale.

Bur Gheluai anticlinal zone

The Bur Gheluai anticlinal zone contains several SE-NW linear folds with gneisses and schists dipping at various angles from 50° to vertical. This zone terminates between Daimir and Bur Safaranolei in the north-west.

Bur Daien synclinal zone

The Bur Daien synclinal zone covers the north-eastern part of the Bur area and consists of three minor synclinal folds which contain occasional outcrops of rocks of the upper series. All three synclines trend towards the north-west with local deviations. Dips generally average 70° but occasionally are as gentle as 30°.

Central synclinal zone

The central synclinal zone extends from Hararech to Daimir and is characterized by three linear folds with undulating crests and by isometric and brachy-folding. The Daimir syncline which extends toward the NNW, disappears to the north below the Jurassic formations. It contains the Bur Galan and Manas synclinal folds. Faulting and secondary folding produce numerous variations of strike.

C. South-west granite mass

Several elongated granite outcrops appear to merge at depth to form a single large granite inlier. The trend of the gneisses and schists preserved in the roof pendants, and the gneissosity of the granites outline the internal structure of the area. In the east, the rocks trend persistently towards the north-east, in the west they trend north-south, and in the south they trend east-west, outlining a vast structural triangle.

IV. Bur area iron formations

A. General information

Among the several occurrences of ferruginous quartzite, those of Bur Galan and Daimir had long been considered sufficiently important to warrant economic study. The project concentrated its efforts on these, and the other outcrops were only superficially examined.

The Daimir (Dimor) and Bur Galan (Bur Dur) outcrops lie in the centre of the Bur area, between the settlements of Baidoa, Dinsor, and Bur Acaba (figures 9, 10 and 11). They are situated in the densely populated Baidoa administrative district where the principal occupation is camel and goat breeding. Daimir is reached by 10 km of camel track from the Baidoa-Dinsor road, some 50 km south-west of Baidoa, and Bur Galan lies 10 km farther on. The main road continues 215 km to Afgoi (figure 2) and then to Mogadiscio by 25 km of tarmac road. Plans have been made to surface the road.

The country is a featureless plain at elevations between 350 and 400 metres, covered by thorny scrub. A few isolated *burs* break the topographic monotony.

Except for the Guiba River in the west, no perennial streams flow through this territory. Water is drawn from catchment reservoirs and from wells dug around isolated hills. From June to September and from December to March, the water shortage is acute.

A hydroelectric dam with a capacity of 100 megawatts (MW) is projected on the Guiba River 35 km north of Bardera and 150 km from the ironstone occurrences.

B. Regional geology

Daimir and Bur Galan are situated in an area which contains rocks of both the lower and upper basement series and granitic outcrops. The granites are mostly microclinic and leucocratic with small syenitic inclusions and with metadimentary remnants rich in biotite and hornblende. The gneisses which can be seen at Daimir have a pronounced schistosity and are rich in mica and iron minerals. Meta-

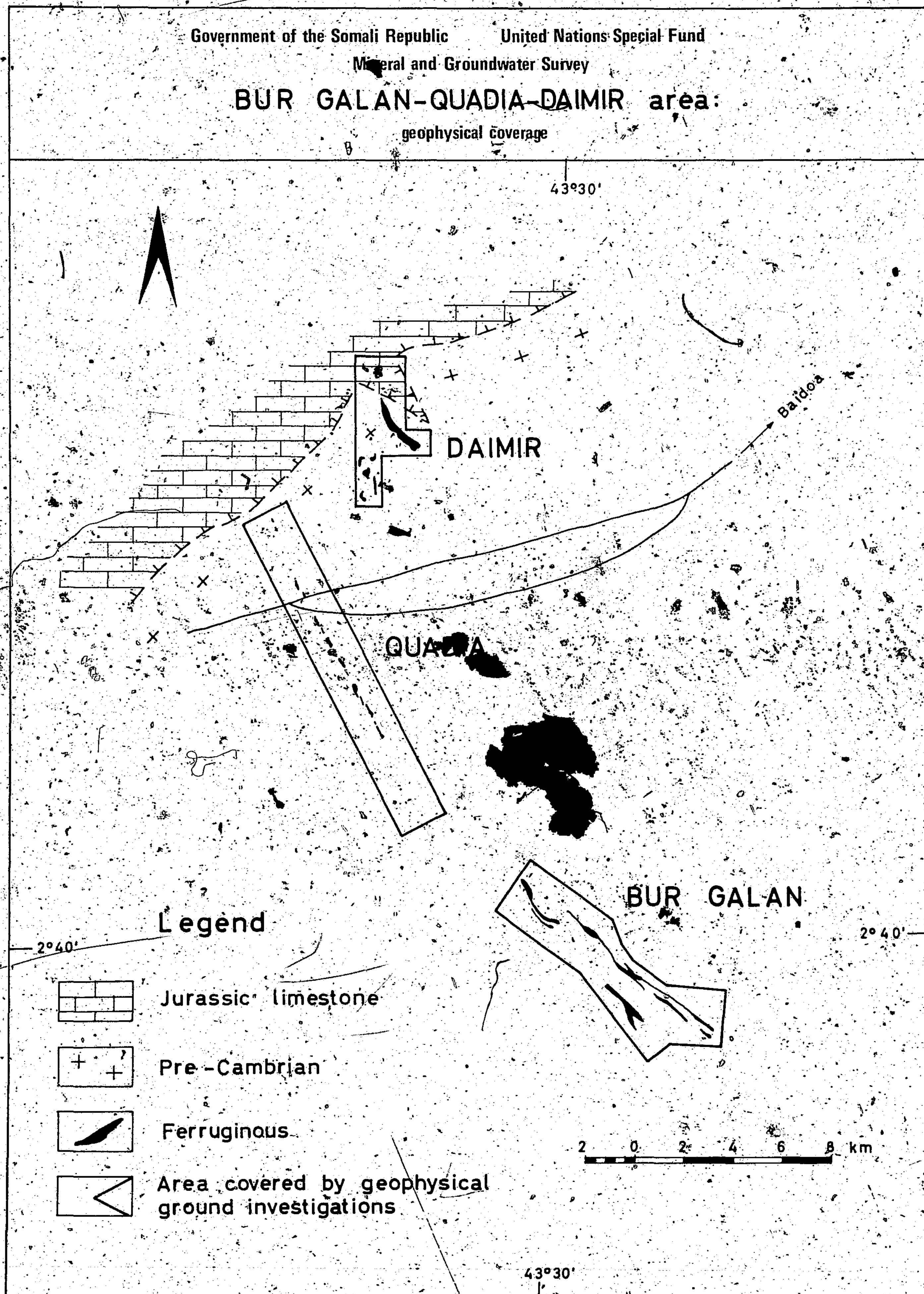


Figure 11. Bur Galan-Quadia-Daimir area: geophysical coverage

carbonates occur frequently with veins of altered carbonaceous and granitic material. Small exposures of gabbro and amphibolite occur along the contact of the granitic rocks and of the ferruginous quartzite around Bur Galan. The ferruginous quartzites which will be described later are widespread throughout the area but occur especially along a main alignment which contains both Bur Galan and Daimir. The adjacent rocks are mostly granito-gneisses with quartz pegmatites.

According to the photogeology, the prevailing structure of the basement rocks is a series of narrow, subparallel folds which strike 55°SE. Fold flexures are gently undulating and show on the photographs as a series of closures, the pattern being repeated at several scales. Younger eruptive rocks also appear to be present in the area. The metamorphic rocks are entirely overlain by reddish brown sand which contains quartz and iron minerals. The granitic rocks are overlain by grey sand low in iron content.

Principal features of iron-bearing occurrences

The outcrops are typical of the numerous occurrences of banded iron formation which exist in all the Pre-Cambrian areas of the world. These rocks are universally termed banded hematite quartzites (BHQ) or banded magnetite quartzites (BMQ) according to the dominant iron-bearing mineral. These abbreviations will be adopted hereunder. Taconites, itabirites and others, are local varieties of these main divisions.

The BHQ outcrops of the Bur area are either linear or isometric. The linear outcrops show the true thickness of the formation and are between 15 and 20 metres wide and several hundred metres long. They strike mostly 310°–330°NW with a steep, generally north-east dip. The strike is locally 50°–60°NE with steep north or south dips.

The isometric outcrops occur as wide, gently dipping folds, often covered by BHQ boulders on the hill-top and with accumulations of quartz at the foot. Local changes of strike are frequent, accompanied by a widening of the outcrop to 50 or 60 metres through duplication by folding. The contact between the BHQ and the gneisses and granites was seen in several trenches and on several outcrops. The BHQ frequently appears to be sheared along the contact, but the exposures were weathered and the observations uncertain.

C. DAIMIR OCCURRENCES

Geology

The ground magnetic survey outlined two anomalies. The eastern one is 3,000 metres long and from 100 to 300 metres wide. It contains large outcrops of BHQ. The western anomaly is more complex and contains three areas of differing magnetic intensity. Exploration was largely confined to the eastern anomaly.

In the eastern anomaly, the BHQ outcrops continue north of the principal occurrence as two parallel bands separated by gneisses. Along its contact with the BHQ, the gneiss is enriched in mica and iron minerals which rapidly disappear with increasing distance. The main band can be followed over a distance of 30 km towards 330°–360°NW, occasionally thickened by folding to as much as 100 metres. The second band consists of a series of isolated outcrops.

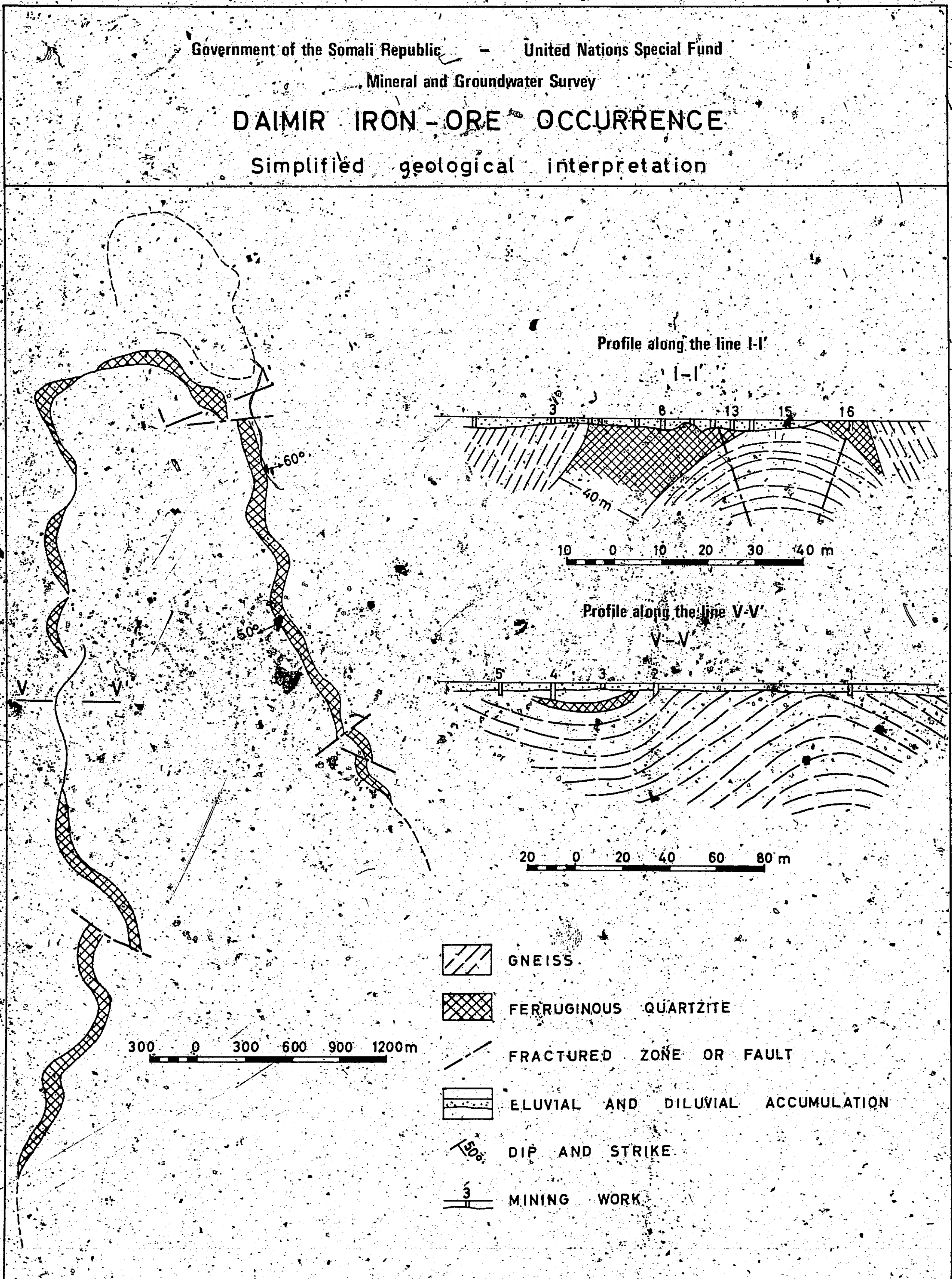


Figure 12. Daimir iron-ore occurrence: simplified geological interpretation

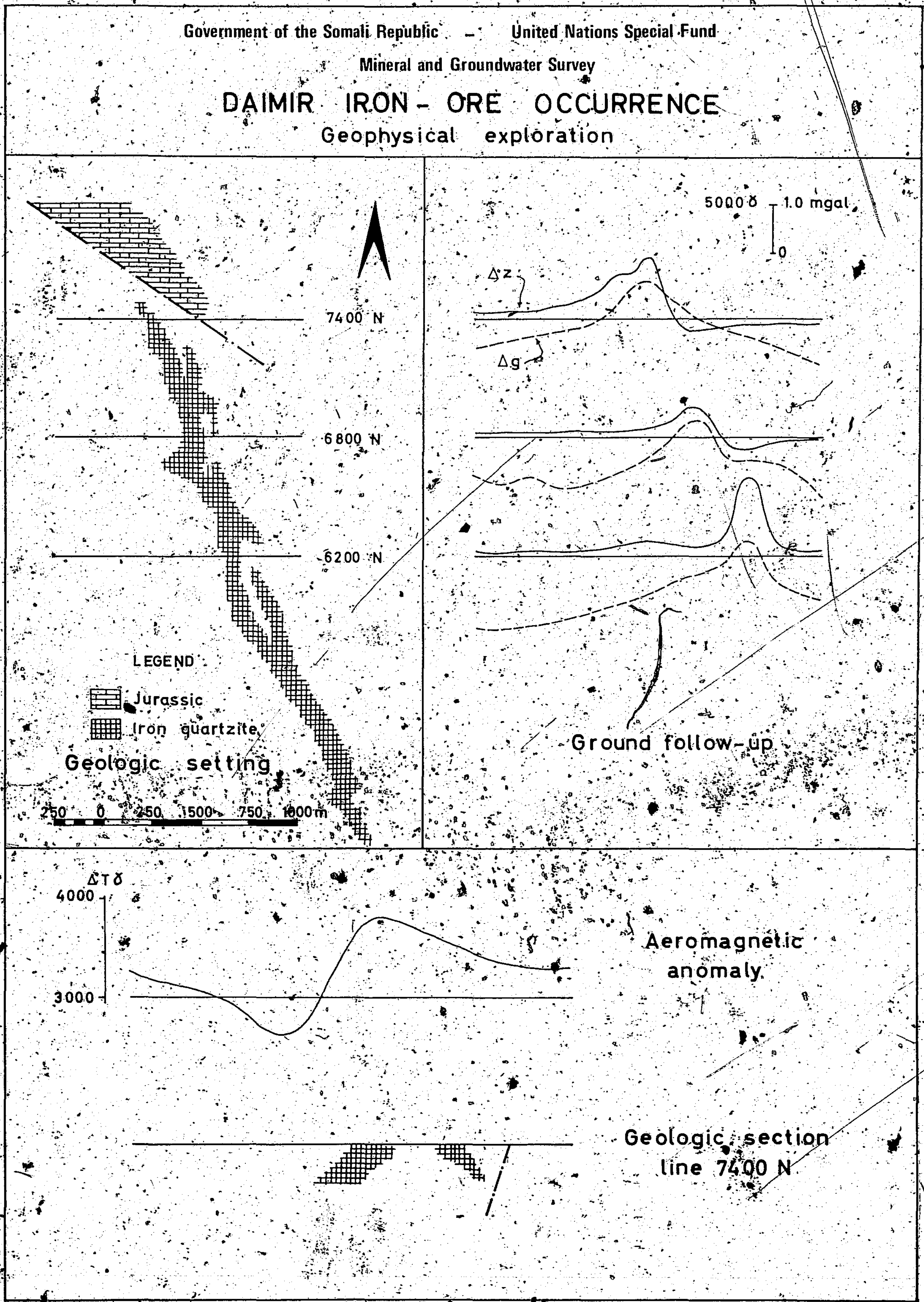


Figure 13. Daimir iron-ore occurrence: geophysical exploration

In the western anomaly, the BHQ is similar to that of the eastern anomaly, but consistent outcrops occur only towards its southern extremity with gentle but variable dips.

The BHQ varies in texture and structure and is strongly folded and faulted. The two occurrences probably lie along the eastern and western flanks of a north-south synclinal fold, possibly accompanied by a gentle overthrust from the south-west. Some fault lines are crossed by quartz-feldspathic veins and the occurrence is probably partially granitized.

The outcrops, some 15–20 metres wide, consist mostly of higher grade BHQ which was more resistant to weathering. According to the geological and geophysical data, the over-all thickness of the formation is around 50 metres, but 20–30 metres of this consists of low grade and less resistant material.

At the base of the formation lie 20–30 metres of well banded quartzite, low in iron. This rock is cream-coloured and contains quartz or chert bands up to one centimetre thick separated by ferruginous bands one to two millimetres thick.

In the middle of the formation, the quartzites are higher grade, the banded structure occasionally disappears, and veinlets and grains of recrystallized quartz from 0.5–1.0 cm in size occur in the rock.

Composition of rock

Magnetite constitutes from 1 to 50 per cent of the rock. It usually occurs in isomorphic or idiomorphic grains, 0.01–2.5 cm in size, or in aggregates 5–8 mm in diameter. It is usually martitized, except for some idiomorphic grains. In some samples, the magnetite is nearly all replaced, and martite accounts for 40–50 per cent of the rock. In others, martite occurs along the edges and fissures of the magnetite grains and accounts for only 2 or 3 per cent of the iron in the rock. Independent grains of hematite can also be found, possibly formed during martitization. Iron hydroxides are rare, generally found along the edges of the martite crystals or as isolated grains up to 0.2 mm in size. Pyrrhotite, pyrite, and chalcopyrite occur sporadically as small isolated grains. Amphibole occurs as pale green grains with polysynthetic twinning. Monoclinic pyroxene, possibly pigeonite, occurs as rare small grains in the quartz. Apatite is rare, sporadic, and occurs as small isolated crystals. Quartz occurs as chert in the banding, or as isolated irregular grains or pseudomorphs up to 8 cm long and 4 cm thick.

In thin sections, the texture of the rock is coarse-grained, granoblastic and sideronitic, with the magnetite or martite developed in the intergranular spaces of the quartz. The structure is mostly banded, occasionally speckled or uniform.

The Daimir occurrences had not previously been sampled. The assays of the 10 samples selected by the project as typical are given in table 2. They show that the iron content of the rock varies between 20 and 23 per cent for the lower grade material, and between 35 and 40 per cent for the higher grade. A small lens of hematite assayed 63.2% Fe.

The recalculation of the assays gives the following theoretical composition (in percentages) for the ore:

Martite	= 20–40	Al^2O^3	= 0.4–0.9
Magnetite	= 10–60 (rare)	CaO + MgO	= up to 1.8
SiO2	= 42–70	P + S	0.1

Table 2

DAIMIR IRON ORE OCCURRENCE: ASSAYS OF SAMPLES

(Percentage)

Sample number	*Location*	Fe	Fe_2O_3	FeO	SiO_2	Al_2O_3	P_2O_5	S	MnO	CaO	MgO	K_2O	Na_2O	L.o.I	H_2O	*Total*
1.	Outcrop line 7400	23.16	31.22	1.44	63.16	0.57	0.08	0.03	0.04	1.72	0.10	0.09	0.09	1.75	0.03	100.29
2.	Trench 8, line 7200	36.3	48.69	2.68	47.34	0.55	0.03	0.02	0.06	0.08	0.15	0.09	0.07	0.34	0.04	100.07
3.	Trench 9	29.3	36.60	4.45	57.23	1.10	0.03	0.03	0.03	0.03	0.12	0.07	0.05	0.56	0.04	100.31
4.	Trench 10	32.8	41.82	4.43	51.72	0.93	0.05	0.03	0.03	0.12	0.17	0.07	0.05	0.56	0.06	100.01
5.	Outcrop line 6400	39.6	51.95	3.83	42.04	0.48	0.12	0.03	0.03	0.12	0.11	0.08	0.07	0.94	0.10	99.87
6.	Rubble line 7200	63.2	87.78	1.86	8.59	0.78	0.04	Tr	0.08	0.02	0.20	0.07	0.04	0.57		100.03
7.	Outcrop line 6000	34.7	43.00	5.75	47.59	0.85	0.09	0.01	0.03	0.43	0.70	0.07	0.04	0.98	0.06	99.59
8.	Outcrop line 5600	19.6	25.55	2.15	70.01	0.86	0.07	0.04	0.05	0.05	0.13	0.07	0.03	0.73	0.07	99.77
9.	Outcrop line 5200	36.0	42.34	7.90	47.16	0.86	0.09	0.04	0.07	0.32	0.32	0.07	0.03	0.90	0.02	100.08
10.	Western alignment	37.8	40.04	12.45	44.89	0.49	0.05	0.02	0.05	0.55	1.03	0.07	0.02	0.48	0.12	100.24

These results correspond with those previously obtained by R. Holmes on 6 samples from the Bur area.

Potential geological reserves

Work is sufficient to give only an order of magnitude of the potential iron ore reserves. Not enough is known of the western occurrence for it to be included in the estimates. The following figures on iron ore reserves can be assumed for the eastern occurrence from the geological and geophysical data obtained:

Length along strike	3,000 metres
Average thickness (including low grade)	50 metres
Assumed extension below mean outcrop level	100 metres
Specific gravity	3.2
Volume	15,000,000 m^3
Tonnage (approximate)	48,000,000

D. BUR GALAN (BUR DUR) IRON OCCURRENCE

Geology

The BHQ formation was followed over a distance of 12.8 km towards 300°–315°NW as a series of isolated hillocks and narrow ridges. The outcrops occur along an interrupted alignment with the actual rock *in situ* occasionally visible, forming close, narrow bands. Towards the centre of the alignment, near the two Bur Galan granite hills, the outcrops are more extensive and form two major bands, one north and one south, separated by gneiss. It was assumed that these two bands represented a single anticlinally folded bed.

The central area of the outcrops is cut by a large fault, nearly parallel to the bedding accompanied by shearing, crushing, and mylonitization. The BHQ itself is jointed, folded and cut by a series of minor faults and by shear zones from one to ten metres wide. The major outcrops are accompanied by thin subparallel lenses which are mostly indicated only by surface debris. The thickness of the beds varies from 10 to 70 metres and their outcrops can be followed along several kilometres with dips of 80°–85° to the SW or NE.

The beds contain intercalations from 4 to 20 metres thick of gneiss, sericite schists and other rocks which were followed on the surface for several hundred metres and were also cut underground.

A lens of coarse marble, 10 to 15 metres wide lies adjacent to the BHQ over a distance of 1,800 metres in the central part of the outcrops.

The north-east and south-east flanks of the occurrence were not explored below ground, and there is little information as regards their structure. The magnetic survey and the rare outcrops suggest the presence of several thick bodies impersistent in length.

Several parallel outcrops of the formation appear to be due to a repetition by folding. Drilling showed that the formation persists at depth.

For purposes of estimating, the occurrence can be divided into three main areas: north-west, 3,200 metres long; central, 5,400 metres long; south-east, 3,200 metres long.

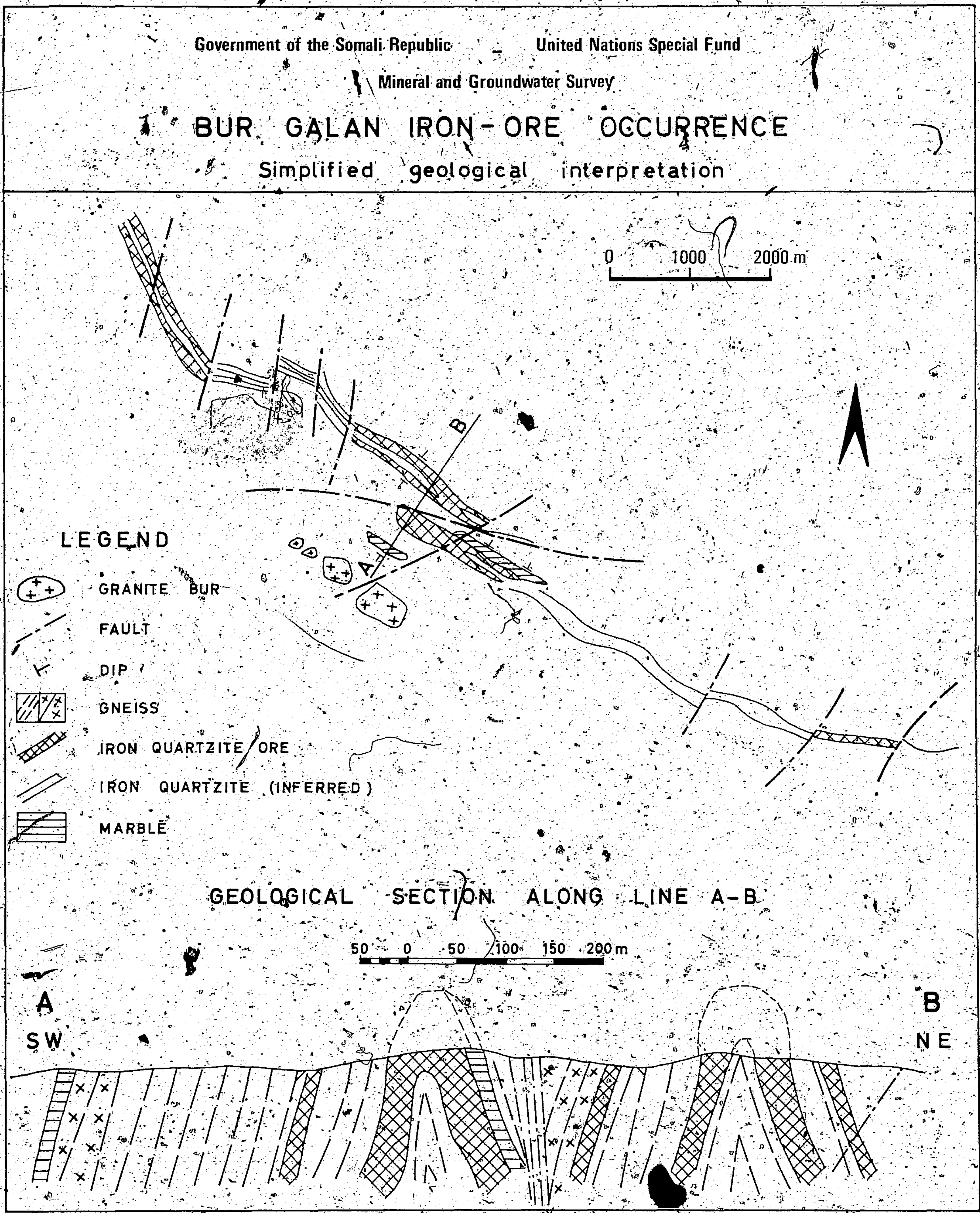


Figure 14. Bur Galan iron-ore occurrence: simplified geological interpretation

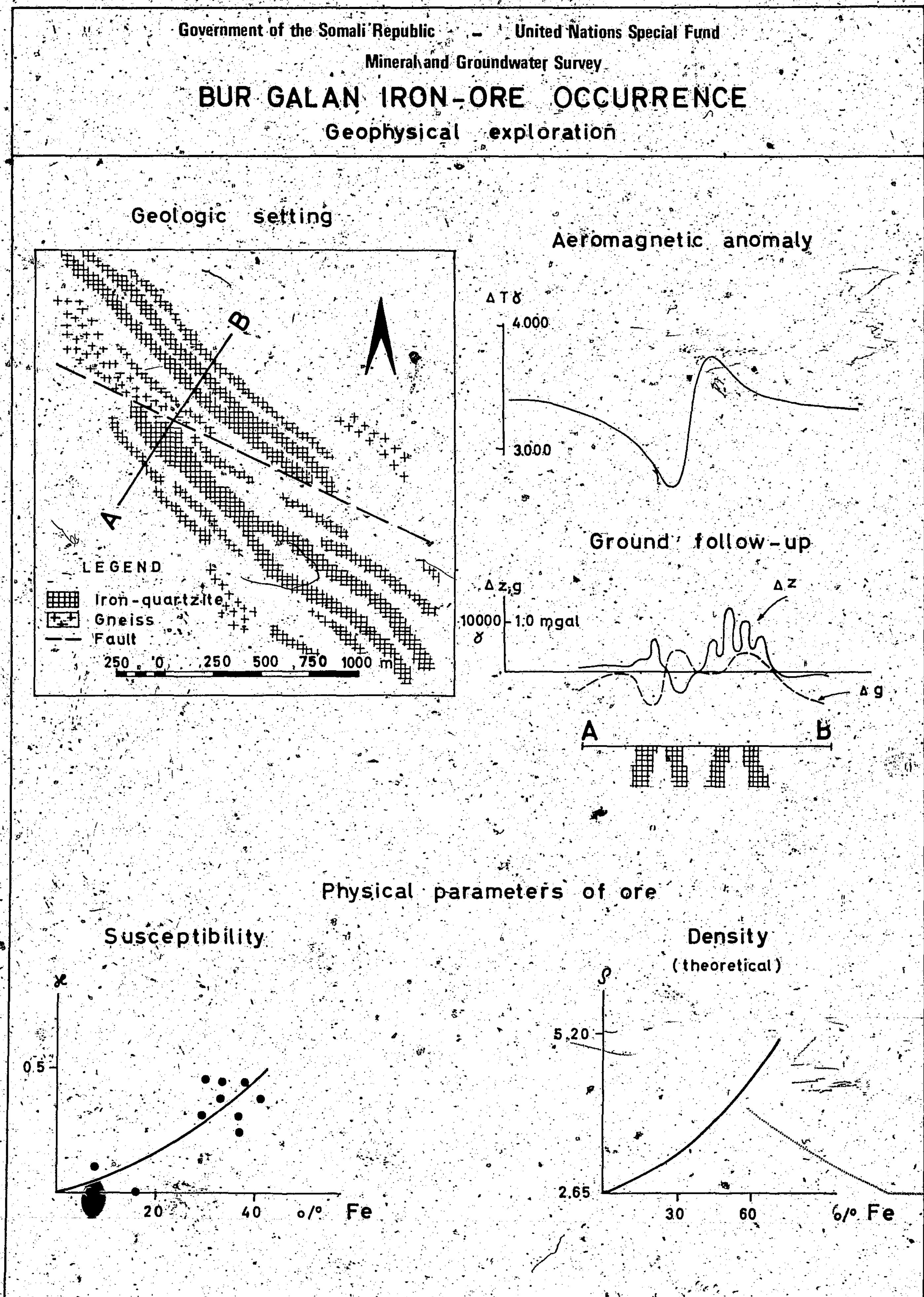


Figure 15. Bur Galan iron ore occurrence: geophysical exploration

Central area

The central area appears to be the most promising of the three. Two major parallel BHQ beds, 300 metres apart, strike north-west along the south-west flank of the occurrence but join and taper off towards the north-west. A similar pattern is found on the north-east flank. Two more beds, 10 to 20 metres thick, lie conformably with the major outcrops and can be followed over a considerable distance. A north-west regional fault cuts the beds accompanied by a series of minor faults which strike east and divide the beds into blocks from 100 to 150 metres long. A bed of coarse marble, 10 to 15 metres thick and 1,800 metres long, lies along the contact of the BHQ, and 25 metres of sericite schist was cut on trenching.

North-west area

Two continuous beds in the north-west area are as thick as 50 metres, tapering off towards the ends. They strike between 300° and 340°W and are dislocated by faulting. The regional fault which cuts the formation in the central area here lies towards the south.

South-east area

The BHQ in the south-east area outcrops on a hill and is continued to the north-west and the south-east by a series of exposures and patches of surface debris. The beds were followed by a magnetic survey which outlined two consistent features trending north-west and a doubtful feature 610 metres long. The width of these anomalies is between 15 and 30 metres. Magnetometric measurements of thickness are, however, unreliable because of the sharp changes in the magnetic properties of the quartzites, and the trenching and drilling were insufficient to determine the actual thickness of the beds.

The formation is cut by faults trending eastwards, but the regional fault here passes to the north.

Composition of rock

The Bur Galan quartzites were not assayed but were examined microscopically and were found to be similar in composition with those of Daimir and to correspond with the results obtained by Daniels in 1961.

Three samples which were sent to the Romanian Mining Research Institute had the following mineral composition (in percentage of sample):

	Sample number		
	1	*2*	*3*
Martite	50–55	56	60
Magnetite	2–3	5–10	2–3
Limonite	3	3	1–2
Quartz	40	40	35
Clay	Tr.	Tr.	Tr.
Insol. (Ti, Zr)	Tr.	Tr.	Tr.

Potential geological reserves

Estimates of the iron ore reserves at Bur Galan were derived as follows. Measuring the areas of the BHQ formations from the geological map to a scale of 1:10,000, assuming a 100-metre extension in depth, and calculating by blocks, discounting the outcrops, one obtains:

Central area	78,000,000 tons
North-west area	35,000,000 tons
South-east area	6,000,000 tons
TOTAL	119,000,000 tons

A closer estimate of the central area, where the outcrops are more consistent, gives:

Total length	4,000 meters
Assumed width	50 metres
Assumed depth	100 metres
Specific gravity	3.2
Volume	20,000,000 m^3
Tonnage	64 million

E. BENEFICIATION

Iron-stone containing 30%–40% Fe and 35%–50% SiO^2 cannot be marketed or even used economically in a local blast furnace. A 365-kg composite trench sample was, therefore, sent to the Warren Springs Laboratories, United Kingdom, for preliminary beneficiation testing. Gravity methods and magnetic separation on a laboratory and small pilot plant scale gave a marketable concentrate containing 60%–67% Fe, 0.02% P, 1% SiO^2 and less than 0.1% CaO for an iron recovery of slightly more than 80 per cent.

Trench samples are always weathered and are not representative of the ore at depth. In particular, the tests gave good liberation of the magnetite and martite particles at relatively coarse crushing, and this will probably not be the case for the deeper rock lying below the zone of weathering.

F. FEASIBILITY OF MINING

Occurrences of iron formation similar to those in Somalia have been studied in many places throughout the Pre-Cambrian areas of the world. The economics are well known and have frequently been described. Local mining conditions can, therefore, safely be assessed even after a relatively superficial examination.

Marketable reserves

The potential geological reserves between Daimir and Bur Galan have been estimated at 167 million tons. Of these, only 48 million tons at Daimir and 64 million tons at Bur Galan, or a total of 112 million tons, occur with outcrop widths of 50 metres, sufficient for mining by open pit methods to the depth of 100 metres postulated for the reserves.

These thicker areas are said to contain along their foot-wall some 20 to 30 metres of BHQ which averages only 20–23% Fe. This material will not be economical to beneficiate, especially under local conditions. The formations are also said to be variable in thickness and to be interbedded with sericite schist and with other waste materials. The reserves of potentially economic material recoverable from the open pits as described above will, at most, amount to 65 per cent of the geological reserves these pits contain.

To be marketable, under present conditions, the grade of the final product must be around 65% Fe, obtained from a run of mine material which averages 36.3% Fe between Bur Galan and Daimir.

The preliminary beneficiation tests, carried out on weathered material particularly amenable to concentration and at a grade higher than the average, gave satisfactory concentrates for an iron recovery of 80 per cent. This figure can be assumed as representing a maximum estimate of recovery and it means that 2.25 tons of material will have to be mined to produce one ton of marketable concentrates.

The figures on reserves can be summarized as follows (in millions of tons):

	Geological reserves	*Potentially mineable reserves*	*Economically mineable reserves*	*Reserves of marketable product*
Daimir	48	48	31	14
Bur Galan	119	64	41	19
	167	112	72	33

Assuming that the two other areas of BHQ, which were not explored but are said to be similar and to contain similar reserves, the total marketable potential of the Bur area can be assessed at around 65 million tons of concentrates.

The probability of finding further economically mineable tonnages at depth, or on other outcrops, is very slight because:

(*a*) BHQ is everywhere more resistant to weathering than the surrounding basement rocks. Any occurrence of appreciable thickness, therefore, stands out as a hillock or knob. Daimir and Bur Galan are no exception and the fact that there are no other conspicuous outcrops is a very unfavourable indication;

(*b*) The BHQ formations are known to be roof pendants of upper basement sediments within the rocks of the lower basement series. The linear outcrops are discontinuous and between 15 and 20 metres wide at their maximum. It is doubtful whether such outcrops persist to any considerable depths;

(*c*) Iron ore is a low priced commodity which cannot carry a heavy investment per ton of reserves or high operating costs. The Daimir and Bur Galan outcrops cover a "potential geological area" of 525,000 m^2 which contains only 65 million tons of marketable concentrates to an assumed depth of 100 metres. This means that they contain 1.24 tons of concentrates per square metre of area and per metre of depth. The average thickness of the iron formation is said to be between 15 and 20 metres. Assuming that it could be mined by open pit to a depth double its width and that it is consistently high grade, then an extra length of 1,300 metres would have to be mined to produce an increase of 1 million tons of marketable reserves. This would be economically quite unrealistic;

(*d*) Underground mining cannot be considered because it requires costly preliminary preparation and highly skilled personnel difficult to recruit; and the production rates per unit of area are far lower than for an open pit.

Mining and beneficiation

Because of the shape of the ore bodies, the two open pits would go down in the shape of narrow "V"s with a total length of 7,000 metres. As the pit walls are made of compact gneiss, we can assume that they would stand at an angle as steep as 57° without collapsing.

The specific gravity of the ore is 3.2. That of the compact gneiss is estimated to be 2.75. Beneficiation tests have shown that 2.25 tons of ore at the average grade of 3.3% Fe would be required to produce 1 ton of concentrate.

Assuming that an ideal pit has been designed in which a productive face 30 metres wide can be mixed without taking any waste other than that necessary to keep the pit walls at the required angle, the combined characteristics of the two pits taken jointly will be:

	Cumulative			
Depth of pit bottom (metres)	*Total marketable reserves (millions of tons)*	*Production, run of mine (tons per metre pit length)*	*Waste/ore ratio*	*Total tons to be mined per ton of concentrate*
10	3.3	950	0.203	2.71
20	6.6	1,920	0.408	3.17
30	9.9	2,880	0.613	3.63
40	13.2	3,840	0.818	4.09
50	16.5	4,800	1.022	4.55
60	19.8	5,760	1.227	5.01
70	23.1	6,720	1.432	5.47
80	26.4	7,680	1.637	5.93
90	29.7	8,640	1.842	6.40
100	33.0	9,600	2.046	6.85

Supposing that the total mineralized width of 50 metres is mined, the reserves of run of mine will be increased by 40 million tons, but the average grade will drop to 29.2% Fe, and the marketable tonnage will only increase by 8 million tons. The tonnage of run of mine to be taken from the pit per ton of concentrate will increase by 22 per cent. As against this, the volumetric waste-to-ore ratio of the pit will decrease; but the specific gravity of the poorer ore will be lower and can be assumed as 3.0. The reduction of waste-to-ore ratio by weight will be around 36 per cent. The pit operation will, therefore, be about 14 per cent to the good, but this will be offset by having to put an extra 22 per cent of material through the beneficiating plant.

Therefore there will be, at best, nothing to gain in widening the pit to the full width of the BHQ as regards production costs, and the gain in reserves will be insufficient to influence the financial aspects of the operation.

The arguments need, therefore, only be developed for the case of mining the higher grade material alone.

Thirty-three million tons of marketable reserves are insignificant when compared to the minimum reserves which were required to justify the financing of other iron ore mines. Marketable reserves of modest mining operations are around 250 million tons for Lamco (Liberia), 150 million tons for Miferma (Mauritania) while the reserves of Brazil, Australia, India, Labrador, Krivoi Rog (USSR), and Mesabi (United States) are counted in thousands of millions of tons. No advantage can be gained, therefore, by mining to a smaller depth and by sacrificing reserves to obtain an improved mining-to-concentration ratio. The financial charges would be too heavy for the operation to be even considered.

This means that, in round figures, for every 1 ton of concentrates produced, 7 tons of material will have to be mined as from the start of the pit.

A 1 million ton per year marketable production will, therefore, require moving 7 million tons of material, or for a 300-day working year approximately 24,000 tons a day, or from 2 pits 12,000 tons per pit, or in round figures, 4,000 m^3. The average width of the pit would be around 80 metres in ore and waste, assuming benches to be 10 metres high, and the whole pit would have to advance at a rate of 5 metres per day. Assuming always the ideal pit and an ideal solution to the problem of moving the ore out of the pit, this is technically not inconceivable, but is so optimistic that any thought of improving on this production figure is more than doubtful.

A pit recently developed to mine a narrow high-grade orebody lying in conditions somewhat similar to those in Somalia and requiring to move some 5 million tons of material per year cost $4.00 per annual ton moved from the mine, including primary crushing and conveying to plant, but with all the necessary ancillary facilities already available. The 7-million-ton-per-year pits required to mine Daimir and Bur Galan can, therefore, be conservatively estimated at $20 million at least.

The technique, investment and operating costs of beneficiation vary widely with the material treated and require extensive preliminary testing and estimating. Recent estimates made for a hematite-magnetite material which will require less crushing than that of Daimir-Bur Galan gave an investment figure of $10 per annual ton produced, exclusive of ancillary equipment. The Somali beneficiation plant would, therefore, cost at least $10 million.

Pelletizing would probably be carried out at the port and here again, a minimum investment of $10 per annual ton can be estimated, provided that 35 kWh and 200,000 kilocalories per ton of pellets are already available.

The total cost of the mining development would, therefore, amount to at least $50 million including pelletizing, and $40 million without pelletizing.

Transport

The investments and operating costs for transport are entirely dependent on local conditions and cannot be estimated without a thorough preliminary civil engineering survey. The present assessment assumes that transport conditions are good, that civil engineering is limited, and that the load travels downhill through flat country.

The distance from the Bur Galan-Daimir area to the nearest developed port, Mogadiscio, is 350 km. The yearly transport of concentrates will, therefore, amount to 350 million tons/km, with little return freight except for the few thousand tons of supplies to the mine. Practically the whole cost of the operation would be chargeable to the iron ore.

Three methods of transport can be envisaged; truck, pipeline, and railway. Trucking and railing will provide an infrastructure which can be used for the transport of other goods, the pipeline would be specialized in the transport of iron ore concentrates only.

Trucks

The cost of building the Afgoi-Bur Dur road has been estimated at $20,000 per kilometre for one designed to withstand heavy transport.

Road transport is cheapest when done in heavy units. For long-distance operations on a public highway, we can assume the use of 35-ton tractor-trailer units operating at an average speed of 70 km/hr. The round trip can then be estimated at 10 hours on the road plus two hours at terminals for loading, unloading and servicing.

Assuming a round-the-year operation, each unit would carry 25,000 tons per year, and 40 operational units would be required. Five tractors and 10 trailers should be provided as stand-bys for maintenance and repair. The cost of such a fleet would be approximately $3.5 million.

To the above must be added the cost of workshops, of road maintenance equipment, of stocks of tires and spares, and housing of personnel. This can be estimated at a further $5 million.

The total investment for road transport will, therefore, amount to:

Road construction	$ 7,000,000
Rolling stock	3,500,000
Ancillary equipment	5,000,000
	$15,500,000

Road transport for bulk materials is costly to operate, especially where there is no return freight. Tire consumption is high and heavy-duty tires are expensive. For a continuous operation, each transport would require at least three crews, working 12 hours on, 24 hours off.

For examples elsewhere, long-distance haulage of this type can be estimated to cost between $0.015 and $0.07 per useful ton/kilometre. Assuming $0.015 per ton/kilometre, the transport cost per ton from the mine to Mogadiscio would amount to $5.25.

Pipeline

The pipeline method of transport is relatively new and has not been tried out over distances as long as those foreseen in Somalia. The longest mineral pipeline at present in operation is at the Savage River mine in Tasmania and is some 80 km long.

According to published information, the investment and operating costs for a pipeline over long distances are similar to those for a cheap railway operation, and the pipeline is justified mainly when obstacles impede railway construction and operation.

The investment for a 1-million-ton-per-year pipeline in Somalia, including the intermediate pumping stations, is estimated to be around $15 million and the operating cost about $1.50 per ton carried.

Railway

Recent construction costs for mineral railways, built to carry several million tons per year, have varied between $60,000 and $182,000 per kilometre of completed track, according to the amount of civil engineering involved.

For the volume of transport foreseen in Somalia, and the type of ground to be crossed, the track could be of lighter construction than that covered by the above figures, but it must be sufficiently robust to withstand regular heavy transport without risks of interruption.

Relying on the figure of $20,000 per kilometre given for road construction, a figure of $30,000 per kilometre is the minimum which can be assumed for the railway. Including the terminal siding and installations, this corresponds to a total expenditure of $11 million.

The tonnage to be carried is modest and can be handled by relatively light rolling stock suited to the characteristics of the track. Two trains a day, each way, each carrying some 1,100 tons would be sufficient on the basis of a round-the-year operation. Including stand-by equipment and some general purpose cars, the cost of the rolling stock is estimated at around $3 million.

To keep the railway operational, a workshop would be needed to maintain the diesel and electrical equipment, true the wheels and repair the bodies. A wrecker crane would be needed to ensure that the track is kept clear. Spares for rolling stock and track maintenance would have to be provided. It is reasonable to assume an investment of $6 million to cover these operational items and other necessary equipment.

The over-all equipment on the railway would, therefore, amount to $20 million. This corresponds to $0.057 per annual ton per kilometre, which is high. This is because the traffic would be small and the capacity of the railway far from saturation.

Over-all operating costs on high-capacity specialized mineral railways can be as low as $0.003 per ton/kilometre. Assuming that in Somalia the operating costs would amount to $0.005 per ton/kilometre, the transport per ton from mine to port would cost $1.75.

Port facilities

If iron ore is to be exported at competitive freight rates elsewhere than to the countries which are the immediate neighbours of Somalia, sea transport would have to be assured in ore carriers of, at least, 50,000 tons dead weight (TDW). For short hauls ore carriers of 15,000–20,000 TDW could be envisaged.

The cost of port construction to a given depth cannot be estimated before the characteristics of the sea bed have been established. For mineral ports built during the past decade, the sea work alone has varied between $2 million and $25 million. We must assume, therefore, that an adequate port would be already available in Somalia.

The port would have to be equipped with a specialized ore quay, land unloading equipment, a stocking area, sea loading equipment, a small specialized workshop, a small sampling installation, and an assaying laboratory. The over-all cost of such an installation is estimated at $2 million.

Economics

Alternative investments and financial charges

According to the method of transport adopted, the alternative solutions presented above can be costed as follows (in millions of dollars):

	Road	*Pipeline*	*Railway*
Mine	50	50	50
Transport	15	15	20
Port	2	2	2
	67	67	72

Initial stocks, operating capital, first year of operation:

	Rail	*Pipeline*	*Railway*
	3	3	3
	70	70	75

Assuming that the capital is paid off over 20 years at a 5 per cent interest, the corresponding yearly financial charges (in millions of dollars, round figures) would amount to:

Road	*Pipeline*	*Railway*
1.87	1.87	2

The corresponding yearly repayments would amount to:

Road	*Pipeline*	*Railway*
5.37	5.37	5.75

Assuming that road or railway construction is done out of public funds and that the investment ascribable to the mine is limited to the specialized equipment required, the above figures can be modified as follows (in millions of dollars):

	Road	*Pipeline*	*Railway*
Investment	60	70	62
Yearly financial charge	1.6	1.87	1.66
Total yearly repayment	4.6	5.37	4.96

The solution by truck can, therefore, be eliminated because the financial advantages it may represent will be offset by far higher operating costs.

The solution by pipeline is apparently the cheapest, but technically it is still the least assured, and it cannot be used for any other purpose than for the transport of iron ore.

The railway appears, therefore, to be the most economical and assured solution, as has already been abundantly proved elsewhere, especially where railway construction is simple and the haul is downhill or through flat country. This solution will, therefore, be adopted to establish operating costs.

Operating costs

As for the investments, operating costs have been assessed from similar operations elsewhere, in all cases on mines with far greater reserves and far easier pits than would be the case in Somalia, enabling the use of more powerful equipment which is cheaper to operate per ton handled; so that overheads and financial charges can be spread over a greater production tonnage and larger reserves.

In March 1966, a trade publication, the *Engineering and Mining Journal*, published the operating costs for seven mines situated in the United States and Canada, producing pellets from ores similar to those in Somalia.

In all cases, the reserves are many times greater than those of the Somali ore bodies, so that the pits can be bigger and easier to mine, larger equipment can be used, and overheads and financial charges can be spread over far greater tonnages.

Some of these mines are, moreover, situated in highly industrialized areas and benefit from power, workshops, and handling facilities which already exist.

These costs can be summarized as follows:

Mine	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Grade of run of mine ore (% Fe)	30.0	30.0	34.0	33.0	39.0	37.0	31.0
Grade of pellets (% Fe)	62.0	61.0	63.0	60.0	63.0	65.0	65.0
Production capacity (millions of t/y)	10.3	10.7	3.6	1.3	2.4	5.5	9.0
Concentrating ratio	3.1	3.0	2.6	2.1	2.0	2.2	2.5
Investment ($ per t/y)	42.5	31.3	27.8	28.4	31.2	46.4	50.0
Operating costs ($) per ton of pellets							
Mining	1.98	1.62	0.96	1.05	1.40	1.07	1.73
Crushing and concentrating	2.60	2.49	2.47	3.40	3.10	1.55	1.70
Pelletizing	1.15	1.15	1.25	1.40	1.40	1.59	1.70
Loading, stockpiling, handling	0.37	0.54	0.05	0.05	0.05	0.15	0.15
Mine overheads	*0.45*	*0.40*	*0.45*	*0.45*	*0.45*	*0.50*	*0.50*
Sub-total, operating costs ($)	6.55	6.20	5.18	6.25	6.60	4.86	6.35
Financial charges	*3.33*	*2.46*	*2.17*	*2.19*	*2.44*	*3.06*	*4.25*
Total cost at railhead mine ($)	9.88	8.66	7.35	8.44	9.04	7.92	10.60

Based on the above costs, and on examples taken elsewhere with conditions more like those in Somalia, and applying these to the Somalian ore bodies as defined, the following minimum costs can be established for the Somalia ores (in dollars):

	Per ton (concentrates or pellets)
Movement of ore and waste in pit, \$0.35 × 7 tons	2.45
Crushing, conveying, stockpiling, pit overheads, \$0.25 × 2.25 tons	0.56
General services, camp, management, \$0.30 × 2.25 tons	0.68
Total pit expenses	3.69
Concentration at 2.25/1 ratio	2.75
Pelletizing for a 1 million tons/year plant	1.25
Total per ton pellets at mine	8.69
Rail transport, 350 km at \$0.005 per ton/km	1.75
Port stocks and shipment	0.50
Total operating costs f.o.b. vessel	10.94
Repayment and servicing of capital at 5 per cent over 20 years	5.75
Total f.o.b. cost	16.69
In round figures	16.70

Assuming that the ore is not pelletized but is shipped as a concentrate, the investment would be reduced by \$10 million, yearly repayments would be reduced by approximately \$0.75 per ton, and the cost of pelletizing would be economized. Concentrates could, therefore, be shipped at an f.o.b. cost of \$14.70.

Assuming further that railway construction was paid for out of public funds, the yearly financial repayments would be reduced by approximately \$0.80 and the f.o.b. costs would be: pellets, \$15.90; concentrates, \$13.90.

Markets and f.o.b. prices

The c.i.f. (cost, insurance and freight) price of iron ores, pellets and concentrates delivered to Rotterdam can be taken as representative of delivered world market prices. At the end of 1968, these prices stood at $14.00 for a high-quality pellet or concentrate containing 65% Fe, and at $8.50 for a concentrate of the same grade. From these prices, the cost of sea transport must be deducted and, for a 50,000-ton ship from Mogadiscio to Rotterdam, not including the Suez Canal charges, this can be assessed at $3.00, Mogadiscio-Rotterdam. The f.o.b. price which the products can be expected to command in Somalia will, therefore, be around $11.00 for pellets and $5.50 for concentrates. This will correspond to a loss per ton of $4.90 and $8.40 respectively, assuming the railway to be financed from public funds, far too great to be covered by any conceivable improvement in the operation.

Assuming that requirements of iron ore will arise in the countries neighbouring Somalia, which are not equipped to take ships of 50,000 T.D.W., the ore will have to be carried in ships of 15,000–20,000 T.D.W. For a distance of 1,000–1,500 miles in such ships, the freight will also amount to around $3.00 per ton, especially as small ships are far more difficult to charter than big ones. The delivered ore will, therefore, come to a c.i.f. cost of, at least, $18.90 for pellets and $16.90 for concentrates.

At this cost, they will be uncompetitive with the ores which are being mined or developed in Egypt or Saudi Arabia, or with the high-grade iron ore reserves of eastern Zambia to be delivered to the coast once the Zambia-Tanzania rail link has been built.

Assuming further that Somalia purchases its own 20,000 ton ore-carrier and is equipped to service it, this carrier would carry the total production a distance of 1,500 miles in 50 voyages and will spend each year some 200 days at sea and 100 days in port, either loading or unloading, plus 65 days idle. The yearly cost of the operation can be estimated at $1 million, or $1 per ton of ore, not including the overhead and land items involved. The ore would be delivered at a c.i.f. cost of $16.90–$14.90 and will still remain uncompetitive.

Conclusion

The banded hematite-quartzites and banded magnetite quartzites (BHQ and BMQ) of Somalia cannot be considered as economic to mine in the foreseeable future, and no further work should be undertaken on them.

The geophysical study of the Bur area suggests, however, that some broader, relatively intense anomalies may be connected with greenstones which contain magnetite and which may be hidden under the surface mantle.

In the present, undeveloped condition of the area, and with the present low iron ore prices which are expected to persist during the next decade, such deposits will not be economic to mine. But, if the uranium and other industries are successfully developed and provide an economic infrastructure for the area, and if iron ore prices rise as they are expected to do in the long [illegible] some of the mines currently in operation have become depleted, these [illegible] be investigated by a few drillholes as such materials, if suffic[illegible]fully mined elsewhere.

It is not recommended that such work be [illegible]e, especially as such magnetic anomalies may si[illegible] of the basement rocks and devoid of any economic [illegible]

V. Bur area radioactive occurrences

A. General geology

Country rocks

The aerial geophysical survey outlined 38 radioactive anomalies situated within a quadrilateral some 100 × 100 km in size and consisting mostly of dark, fine-grained, foliated gneisses, containing hornblende, biotite, oligoclase, potassium feldspar and quartz. Occasionally, the biotite is lacking, and in some places there occur narrow beds of a true, medium grained meta-amphibolite which appears to be the most favoured rock as regards the radioactive mineralization. Locally the gneisses change by progressive enrichment to a massive, aplitic rock consisting mostly of feldspar.

All the country rocks are strongly granitized and migmatized, and the "lit-par-lit" injection of the gneisses, and even of the amphibolites, produces stringers 3–5 metres thick and like distances apart. Over large areas, the original rock can only be recognized because of the persistent orientation of the biotite.

The granites are either pink, friable, medium to coarse grained microcline granites, or tough, grey, massive plagiogranites.

Syenites have been cut in the drillholes on the radioactive occurrences as veins several metres thick.

The rocks are usually unaltered at a depth of 8 to 10 metres below the surface, but alteration has also been encountered in the drillholes at a depth of 100 metres.

The tight folding, the geological environment, and the high degree of metamorphism suggest that all these rocks belong to the lower series of the Pre-Cambrian.

Vein rocks

Pegmatitic rocks

Tabular bodies of pegmatite occur conformably with the enclosing rocks and are usually surrounded by a halo enriched in pink microcline. They are pink, coarse grained, and blocky and contain up to 50 per cent microcline, quartz, and minor amounts of plagioclase and biotite.

Light grey veins of feldspathic work, from 0.2 to 1.5 metres thick, cut across the formations within the areas of the radioactive occurrences. They consist of 49–50 per cent oligoclase, 30–40 per cent quartz, and up to 20 per cent biotite and hornblende. Their relationship with the pegmatites is not known.

Albitites

Within and around the radioactive deposits, occur tabular bodies and veinlets of a reddish brown or pinkish equigranular coarse to fine-grained rock. It consists mostly of albite with antiperthitic intergrowths of microcline, of quartz, and of subordinate amounts of biotite, calcite, and thorite.

Thorite is the principal mineral of the radioactive occurrences and the albitites are closely related generically to the mineralization.

Calcite

The rocks within the deposits are cut by conformable and transverse veinlets of calcite, 0.2–2.0 cm thick, containing barytes and, commonly, thorite.

Surface mantle

The whole area is overlain by a clayey and arenaceous eluvial mantle, up to 15 metres thick, which entirely covers the country rock. Within the anomalous areas outlined by the aerial survey, this mantle contains radioactive minerals weathered out of the primary deposits and dispersed around them. The mineralogical examination of samples taken from the mantle gave up to 40 per cent thorite in the heavy electromagnetic fraction. This explains the wide extent of the aerial anomalies as compared with the restricted areas of high radioactivity which they contain and which correspond to the primary ore lying below the surface mantle.

In some places, the surface mantle is strongly carbonatized and below these, the gneisses contain irregular, vein-like pockets of finely grained calcite from 0.8 to 1.0 metre in extent which pinch out abruptly at depth or veins of fine to medium-grained loosely coherent calcite which lie either conformably with or across the strike of the gneisses. These occurrences appear to be exogenetic.

B. Radioactive anomalies

Definition

For the purposes of the aerial survey, anomalous radioactivity was defined as that which gave recordings over 1.5 times the background value.

Twenty-six such anomalies with readings of 1.5 to 2.0 times the background value were registered on single flight lines while 12 anomalies with readings of 1.8 to 6.6 times the background value were registered on several flight lines.

It must be repeated that this inventory may be incomplete as the relationship between the ground clearance and the flight line distance was such that some anomalies may not have been fully registered while others may have been missed outright.

Among the anomalies registered, that of Alio Ghelle, situated 12 km to west of Bisseqh Adde village, covers an area of some 30 square kilometres. It was indicated on 9 flight lines and gave readings of up to 4.8 times the background value.

The Yaq Brava anomaly, situated between Dinsor and Yaq Brava village, was identified on 20 flight lines, including cross lines and gave readings up to 6.6 times the background value.

Most of the information given in this chapter derives from the study of the Alio Ghelle anomaly which was the first to be identified on the ground and was the easiest of access. For these reasons, it was the one chosen to begin detailed ground exploration.

Results on Alio Ghelle have, however, been so consistent that it can be hoped that the findings will be applicable to the Bur area as a whole.

Geology of radioactive anomalies

Alio Ghelle area

The ground and underground surveys at Alio Ghelle suggest that the primary ore body generates twin, roughly oval, surface anomalies with their centres of maximum radioactivity approximately 170 metres apart, lying along a line trending N 42° E. The anomalies are elongated in this direction.

The maximum dimensions of the south-western anomaly are 160 × 40 metres, and of the north-eastern anomaly 140 × 100 metres. Between the two lies an area of low radioactivity some 40–50 metres wide.

Drilling showed that these anomalies correspond to two tabular or lenticular bodies which may possibly be up to 50 metres thick, accompanied by satellite lenses a few metres thick and which all strike approximately N 315° W conformably with the country rocks.

The dips in the north-eastern anomaly average between 30° and 40° towards N 40° E, but the range of dip is from 10° to 80°.

In the south-western anomaly which has been far less explored, the dips average 25° towards the south-west, symmetrical to the above. From the results of auger drilling, the ore body which corresponds to this anomaly is apparently T-shaped lying at the crossing of two shear zones, one parallel to the main axis of the occurrence, the other at right angles to it. The two anomalies thus constitute an anticlinal structure with the low-grade, intermediate zone lying along its axis which trends NW-SE.

This anticline constitutes the western branch of a local anticlinorium which trends NW-SE, the two branches joining into a single anticline towards the north. This structure can be interpreted from the aerial photography but was not verified on the ground.

The waste zone, lying along the foot-wall of the radioactive bodies, consists of fine-grained biotite and amphibolite gneisses while the hanging wall consists of schist, amphibolite and gneiss. The radioactive ore bodies lie at the contact between the two, in an area of intense albitization.

The radioactive rocks consist mostly of "albitites" and to a lesser degree of granito-gneiss, amphibolite and biotite schist cut by veins of syenite. The bulk of these rocks contain over 50 per cent albite.

The structure is complicated by minor folding along parallel axes distributed from 5–10 metres apart, and by *en enchelon* folding, plication and drag folding. Variations of dip encountered in the trenches suggest that a minor anticlinal fold cuts across the general direction of strike.

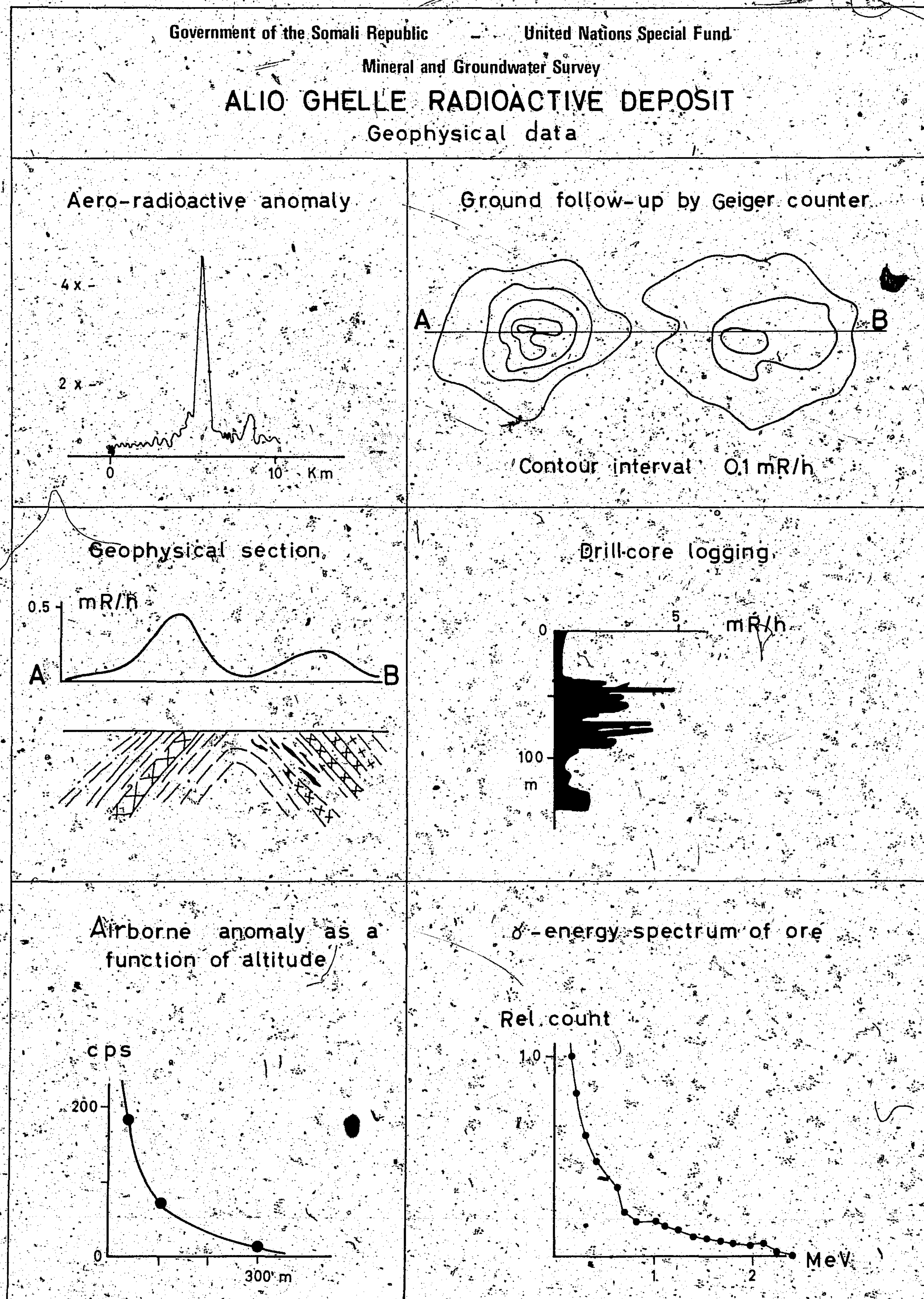


Figure 16. Alio Ghelle radioactive deposit: geophysical data

No clear evidence of major faulting was found, but from the evidence collected in two trenches and from the cores of DDH 2 at a depth of 115 metres, as well as from photogeological interpretations, a shear zone trending ESE passes just north of the ore body. Its displacement may be of the order of 2,000–3,000 metres, the southern block being displaced towards the west. The interruption of mineralization of the north-eastern ore body, between DDH 1050/1000 and DDH 1100/1000, 50 metres to the north-east, may also be ascribable to a fault.

The rocks are cut by a system of joints which strike east and north and dip at a steep angle. The strike direction of east is that of the presumed shear zone, and north is the direction of the many calcite veins which occur in the gneisses.

Once a tentative geological interpretation of the Alio Ghelle occurrence had been made, work was expanded to include the adjacent area, and 4 km² were covered by detailed magnetometric and spectrometric grids.

These surveys found two more anomalies, one situated 500 metres north of the main occurrence which gave readings of 150 cps (counts per second) and was called "Northern", the other situated 400 metres south-east of the main occurrence, which gave readings of 700 cps and was called "Ant-hill".

Anomaly Ant-hill was tested by auger drilling, and the first hole cut into decomposed, highly radioactive rock. Subsequent holes followed the radioactive formation over a length of 90 metres and a width of 10–12 metres with readings up to 3,000 cps. The heavy fraction derived from the samples was tested in Leningrad and gave 20 per cent thorite, 1 per cent uranophane and a few limonite aggregates coated with pitchblende. The proportion of radioactive minerals was higher than would have been expected from the somewhat low surface readings, and the value of surface measurements must, therefore, be rejected in future as a guide to the value of the underlying primary occurrence.

All four anomalies fell within the 50 cps radioactive contour which appears to form a continuous elongated band trending in the direction of the main axis of the Alio Ghelle occurrence. The extensions of this band were, therefore, explored by widely spaced traversing along existing roads, and it was identified, as had been predicted, at two points of easy access where it was between 100 and 200 metres wide and gave three times the background values.

A 10-km line was, therefore, bulldozed through the bush, and a detailed exploration of this alignment disclosed two more anomalous maxima which were called "Airport" and "Road", situated 3 km and 8 km south of Alio Ghelle respectively. Anomaly Airport covers an area of 700 × 200 metres above 75 cps and contains three maxima with readings up to 350 cps. A series of auger holes, set along cross profiles, showed that the radioactivity increased sharply downwards, and the samples collected in the bedrock below 3 to 12 metres of surface mantle contained independent uranium minerals. Anomaly Road covers an area of 200 × 300 metres with readings up to 150 cps. Photogeology suggests that it corresponds to the meeting of several faults.

A further anomaly, termed "Water Collection" was located 3 km east of Alio Ghelle. It is 3,000 metres long and about 300 metres wide, covered by a radioactive grid 20 × 200 metres, it gave uniform readings around 150 cps. Five auger holes reached bedrock under 1.5–12 metres of mantle formations. The bedrock gave readings up to 500 cps.

Most of these anomalies trend parallel to a straight line drawn through anomalies Airport, Ant-hill, and Alio Ghelle SW while certain of the structural features which govern their primary occurrences all lie on parallel alignments.

It would seem, therefore, that these anomalies are the surface manifestation of a continuous band of radioactive rocks which extends from anomaly Alio Ghelle to anomaly Road over a distance of 8,000 metres. The individual occurrences would lie *en echelon* along this band. Such an interpretation has already found a measure of confirmation from the detailed radiometric survey, which was begun on the alignment cleared along the radioactive band.

Attempts at outlining the surface geology and at determining fault lines by an electro-magnetic grid and by pitting were unsuccessful; for the first method, because the clayey and lateritic mantle provides an effective electro-magnetic screen; for the second, because the uniformity of the migmatized gneisses and of the amphibolites which constitute the rocks in the area precludes any interpretation as regards their mode of occurrence.

Yaq Brava anomaly

The Yaq Brava anomaly was located on the ground, after a reinterpretation of data from the aerial survey which covered an area of some 1,250 km², based on the findings at Alio Ghelle. The area was covered by a radiometric grid 200 × 10 metres and 200 × 20 metres.

This outlined three zones at more than 110 cps which appear to be confined to a fault contact between Jurassic rocks and basement rocks and to be related to magnetic anomalies at 3,600 gammas attributable to ferruginous quartzite.

The primary ore bodies were not located possibly because large areas are overlain by zircon and monazite sands up to 10 metres thick.

C. MINERALOGY

Sources of information

Mineralogical information is derived principally from the cores of diamond drillholes (DDH) 1 and 2 put down on the north-eastern anomaly of Alio Ghelle which was covered by a partly completed systematic drilling grid.

This information refers only to the top 120 metres of the ore bodies where the effect of weathering is noticeable. The nature of the ore at depth below the zone of weathering is not known.

The information regarding the south-western anomaly at Alio Ghelle is derived from auger drillholes and trenches cut through the surface mantle and through the top of the underlying ore. One vertical drillhole, put down in the centre of the anomaly, was stopped at a depth of 40 metres for technical reasons. It showed a pattern of mineralization similar to that found on the north-eastern anomaly. Work on the other anomalies is confined to the sampling of the mantle and of the immediately subjacent bedrock.

Mineral samples were sent to the "Institute of Pre-Cambrian and Absolute Age" (USSR). The number of samples was insufficient to obtain definite figures, but the most probable absolute age put forward for the mineralization is 90 million years.

Principal radioactive minerals

The Alio Ghelle ore body is essentially a thorite deposit, related to syenitic rocks intruded into the Pre-Cambrian amphibole-bearing gneisses, and closely associated to the hydrothermal albitization and microclinization of the syenitic dikes and especially of their contact areas with the surrounding gneisses. As such, it fits a common pattern which can be considered as one of the main genetic peculiarities of known thorite deposits.

Thorite (thorium silicate) is the main radioactive mineral of the ore, evenly scattered throughout the albitized gneisses at their contact with the dikes and bodies of syenitic rock. The existence of small amounts of coffinite closely intergrown with uranothorite was reported by the Institute of Geological Sciences (London), pitchblende and uraninite were also identified.

It seems clear, however, that the small quantities of uranium, scandium and rare earths which exist in the ore occur mostly as thorite admixtures.

Thorium

Thorite. The primary mineral of the ore is thorite. It is yellow-brown to red-brown in colour, rarely black, anisotropic, and occurs in spherulites of concentric or radiated fibrous structure, frequently around such grains of the primary rocks as monazite, zircon, and apatite.

Most of spherulites are between 0.1 mm and 0.2 mm in diameter, but some are as small as 0.001 mm. They occur independently or in aggregates.

Thorite replaces albite, and it is noticeable that albite formed after microcline is more easily replaced than albite formed after plagioclase. Its relation with the other minerals of the ore show that these were formed later, and there is indirect evidence to suggest that the thorium mineralization is post-Jurassic.

Other thorium minerals. The identification of the individual minerals present in the botryoidal masses of thorite by optical methods is not possible owing to the very small size of the crystals. X-ray analysis suggests the presence of thorogummite, but it has not been identified with certainty.

Similarly, the spectral analysis of the thorite shows the presence of small amounts of uranium, yttrium, ytterbium, gadolinium, scandium, and iron, but in quantities too small for the mineral to be classified as uranothorite or ferrothorite.

Other minerals, such as samarskite, clarkeite and curite may also be present in the thorite spherulites but in amounts below the limits of sensitifity of X-ray identification.

Uranium

The uranium content was determined both spectrometrically and by wet assay. It was found to be independent of that of thorium, suggesting the presence of separate uranium minerals.

Pitchblende, as a black opaque mineral with a semi-metallic lustre, was identified as forming spherulitic inclusions from 0.001 to 0.02 mm in diameter within quartz aggregates in the cores of DDH 2, between 117.2 and 120.8 metres.

Pitchblende, or possibly another black uranium mineral was found by analysis at Columbia University (United States) forming inclusions and veinlets in samples from around 49 metres in DDH 2.

Uranothorite and coffinite, $USi(O,OH)_4$, were identified in a core sample analysed at Warren Springs Laboratory (United Kingdom). The uranothorite forms mainly large areas which appear to be pseudomorphs after amphibole. They are mostly nucleated on a coffinite grain and can be considerably stained by hematite.

Yttrium

Independent yttrium minerals have not been identified with certainty. Doubtful xenotime was reported from a sample containing 2% Y taken at a depth of 49.2 metres in DDH 2. Doubtful thalenite as brown translucent crystals was also reported. It seems that the yttrium is present mostly as an isomorphic admixture in thorite and sphene.

Europium-ytterbium-scandium

The presence of these metals was detected by spectrometric analysis, but the corresponding minerals have not been identified, and their contents have not been determined with certainty.

It must be repeated that so far all the samples which have been analysed come from the zone of weathering where some of the primary radioactive minerals may have been leached out.

Paragenesis

The following paragenetic sequence was established by the project mineralogist:

Paragenetic sequence		*Corresponding minerals*
1. Biotite schist and gneiss	Pre-Cambrian basement complex	Oligoclase, microcline, quartz, biotite, amphibole, apatite, zircon, sphene, magnetite, ilmenite, orthite
2. Granitic impregnation, including late pegmatites	Pre-Cambrian basement complex	
3. Albitization, accompanied by alteration of the ferromagnesian minerals and rubefaction of the feldspars		Albite, calcite, sericite, riebeckite
4. Fracturing, penetration of hydrothermal solutions; post-Jurassic		Calcite, *thorite*, quartz, zircon, apatite, hematite
5. Minor fracturing, penetration of siliceous solutions and sulphides		Goethite, pyrites, marcasite, chalcopyrite, galena
6. Carbonate replacement		Sphalerite, *uraninite, pitchblende* (?), baryte, sphene
7. Oxydation and secondary alteration		Montmorillonite, chlorite, stilpnomelane, calcite, leucoxene, goethite, limonite, marcasite, *a secondary uranium mineral* (?)

D. Results of analysis

The samples analysed came from between 10.7 and 33 metres in DDH 1 and from between 25 to 28.5 metres and 33.4 to 121.4 metres in DDH 2.

The first lot, consisting of 21 samples, each of approximately 0.5 metre length, was analysed in the project's laboratory.

The second lot consisted of 73 samples of approximately one metre length, and 2 of 11 metres and 6 metres length respectively. Of these, 34 samples, from between 25 and 81 metres, were analysed in the Project's laboratory.

A third lot of 38 samples was then prepared from the cores of DDH 2 between 25 and 121.4 metres.

Sample 39 was a weighted composite of samples 1 to 38, and sample 40 was a weighted composite of samples 16 to 21 which covered the depths between 65 and 80 metres and were believed to have a higher U_3O_8 content.

This series of samples was sent for analysis to the Institute of Geological Sciences (IGS), London, and to the Eldorado Mining and Refining Co. Limited, Ottawa. Composite samples 39 and 40 were also sent to the laboratory of the International Atomic Energy Agency (IAEA), Vienna.

The results of this sampling (in percentages) are as follows:

	ThO_2	U_3O_8	Y_2O_3
IGS, London			
Weighted average samples 1–38	3.29	0.111	0.085
Composite sample 39	3.30	0.120	0.080
E.M. & R., Ottawa			
Weighted average samples 1–38	3.10	0.117	.....
Composite sample 39	3.49	0.133	.....
IAEA, Vienna			
Composite sample 39	2.94	0.098	.....
Over-all average	3.22	0.116	0.082

The figures for the presumed higher grade section between 65 and 80 metres were as follows:

	ThO_2	U_3O_8	Y_2O_3
IGS, London			
Weighted average, samples 16–21	3.84	0.149	0.097
Composite sample 40	3.50	0.130	0.090
E.M. & R., Ottawa			
Samples 16–21	3.49	0.143	.....
Composite sample 40	3.43	0.122	.....
IAEA, Vienna			
Composite sample 40	3.52	0.107	.....
Over-all average	3.56	0.130	0.093

The comparison of the above results with those obtained in the project's laboratory can be made on the weighted averages of samples 16 to 34, 37 and 38. It is as follows:

	ThO_2	U_3O_8	Y_2O_3
IGS, London	3.46	0.121	0.092
E.M. & R., Ottawa	3.31	0.144	.....
Average	3.38	0.132	(0.092)
Project laboratory	2.37	0.13	0.32

In order to establish a scale for rapid field guidance as regards the values of samples and drillholes, the cores which were assayed were also subjected to radiometric measurement. It was found that 130 milli-Roentgens per hour on the core approximates the average value of the deposit, 3.30% ThO_2, 0.12% U_3O_8, and 0.08% Y_2O_3.

The statistical analysis of the results for ThO_2 and U_3O_8, obtained at IGS, London, and E.M. & R., Ottawa, is as follows:

	Number of samples	*Average content % (Probability 0.95)*	*Dispersion*	*Standard deviation*	*Criterion**
ThO_2					
IGS, London	40	3.3 ± 0.4	1.92	1.39	
E.M. & R., Ottawa					
1st analyst	40	2.7 ± 0.4	1.70	1.30	$1.67 < 1.96$
2nd analyst	39	2.7 ± 0.4	1.64	1.28	
U_3O_8					
IGS, London	40	0.11 ± 0.02	0.0035	0.059	
E.M. & R., Ottawa					
1st analyst	40	0.12 ± 0.02	0.0027	0.052	$0.08 < 1.96$
2nd analyst	39	0.12 ± 0.02	0.0031	0.056	

*Student criterion.

The average yttrium content is 0.08 per cent, but its distribution is probably far more complicated than that of uranium because of small amounts of monazite in the ore.

The statistical analysis of uranium distribution in the general sample population from DDH 2 indicates two separate populations of uranium content in the upper horizons of the mineralized zone. The first population which has an average content of U_3O_8 within 0.13–0.14 per cent conforms with the normal law of distribution. The second population which represents about 25 per cent of the samples from DDH 2 has an average content around 0.04 per cent and probably represents those parts of the mineralized zone from which uranium has been partially removed by weathering along the fissures and near the surface.

The $ThO_2U_3O_8$ ratio for the depth explored is 26.6, but at this depth, the deposit is still within the zone of weathering, and given the high mobility of uranium, it is quite possible that a higher uranium content will be found in the deeper parts of the ore body.

E. Beneficiation and recovery

On the basis of existing information, Alio Ghellè and probably the other anomalies must be considered as rich thorium deposits with a relatively low uranium content present as an admixture with the thorium minerals and with contents in rare earth which are too small to be significant from the economic point of view.

Economic evaluations must, therefore, be based for the time being on the recovery of uranium alone, and take into account that, for every ton of U_3O_8 extracted, some 30 tons of ThO_2 will also be produced.

The composite samples 39 and 40 which were sent to IGS, London, were submitted to preliminary beneficiation tests at the Warren Springs Laboratories (United Kingdom).

They contained respectively (in percentages):

Samples	U_3O_8	ThO_2	Y_2O_3
39	0.105	± 3	<0.1
40	0.115	± 4	<0.1

Preliminary leaching tests on the composite sample showed that the ore contained an alkali equivalent of 8% CO_3Ca. Treatment of the material as received, 28 per cent minus-200 mesh, by boiling 50 g of ore for 6 hours with 50 ml of 4N solution of H_2SO_4, extracted only 24 per cent of the uranium. Grinding the ore to 100 per cent minus-200 mesh increased the leaching efficiency to 42 per cent, and to 81 per cent when the solution-to-ore ratio was doubled.

Boiling 50 g of the minus-200 mesh ore for 6 hours with 50 ml aliquots of HNO_3 at solution normalities of 1.6, 3.2 and 4.8, gave extractions of uranium of, respectively, 1.4, 29 and 41 per cent. Doubling the volume of 4N, HNO_3 increased the extraction to 72 per cent. The best results correspond either to a usage of 0.6 ton of 70% HNO_3 per ton of ore, or for the maximum extraction efficiency of 81 per cent which was achieved, 0.4 ton of H_2SO_4 per ton of ore.

Direct leaching of these ores is thus impracticable because of their high alkali content.

Preconcentration tests were, therefore, carried out. The sample, as received, contained 43 per cent plus-72 mesh material. This was finely ground to complete the liberation of the thorite and recombined with the original minus-72 mesh fraction. The final material tested contained 44 per cent minus-200 mesh.

A sample of 1.61 g of this material was treated on a laboratory-size shaking table which gave a concentrated fraction of 7 per cent, a tailings fraction of 71 per cent, and a slimes loss of 22 per cent in relation to the feed.

The distribution results (in percentages) were as follows:

	Assay		*Distribution*	
	ThO_2	U_3O_8	ThO_2	U_3O_8
Table feed	3.3	0.11	100	100
Concentrate	30.0	0.83	63.3	53.2
Tailings	1.5	0.06	32.2	39.0
Slimes (calculated)	(0.7)	(0.04)	4.5	7.8

Careful grinding of the ore will certainly reduce the loss of values in the table tails and slimes, and a concentration ratio of about 8 to 1 is indicated.

It seems, therefore, that although the direct leaching of the ore would be uneconomic, a very rich thorium concentrate around 30.0 per cent ThO_2 and containing 0.83 per cent U_3O_8 can be obtained by a simple process of gravity separation, and, once done, there would be no technical problem to leach and separate thorium and uranium salts from the rich thorite concentrate.

F. Conclusions

From the data available, no reliable estimate can be made of the potential reserves at Alio Ghelle and, therefore, the Bur area as a whole. In fact, the information collected refers only to the weathered zone of one deposit and may not reflect conditions at greater depth or, possibly, even elsewhere.

It can, however, be said that the exploration, which covered part of one of the better anomalies but not necessarily of the best, and which had been chosen for reasons of convenience rather than geological considerations, provided consistently corroborative evidence which conforms to a pattern already known on other deposits of this type.

Under an eluvial mantle which dispersed the aeroradiometric readings, points of high anomaly were found to coincide with radioactive ore bodies situated in highly albitized rocks situated at the contact of syenitic intrusions with the surrounding gneisses.

The structure of the individual occurrences was found to extend along a preferential direction and a radioactive alignment, 3,000 metres long, was determined.

Amenability testing of the weathered ore, possibly impoverished in uranium, showed that there was no technical impediment to achieving satisfactory recoveries of uranium after simple gravity preconcentration.

The general geology of this part of the Bur area is uniform with a repetition of rock types and structures. There is, therefore, every reason to hope that the 37 other anomalies discovered by the aerial survey will conform to the same type as that at Alio Ghelle.

An interesting possibility is opened up by the absolute age determination of the radioactive minerals. If it is confirmed to be 90 million years old, there is no reason why the mineralization should be limited to Pre-Cambrian basement rock, and other valuable elements may also be present in the sedimentary rocks.

IV. Other minerals of the southern area

A. Bauxite

Lateritic rocks of bauxitic aspect were found by one of the project geologists near Manas in the north-west of the Bur area, covering over 15 km^2 and going down to a depth of 11 metres. The first assays were encouraging, and an expert, B. Mikhailov, was requested to carry out an over-all exploration for bauxites in Somalia, to consist of a re-interpretation of the available data; an examination of the findings reported; and a country-wide investigation of the mantle formations.

From the point of view of bauxite geology, Somalia forms a single unit with Kenya and Ethiopia and can be divided into areas of plains and mountains.

Plains area

South-west Somalia

The area is covered by a Neogene-Quaternary arenaceous mantle, above Jurassic and Cretaceous carbonate rocks which are commonly covered by caliche and accompanied by gypsum. The valleys contain sediments of loam and loess. The more rugged coastal area, south-west of Chisimaio, contains occasional limestones and old ocean terraces.

Four traverses in this area failed to find bauxite.

Central area

The geomorphology of this area is varied, and it is covered by 1,500 km of traverses.

In the eastern part of the area, on the left bank of the Scebeli River, occur numerous flat-topped remnants of a palaeopeneplain which consists of Cretaceous sands, clays and limestones.

These remnants are capped by 5–15 metres of lateritic crust containing goethite, hematite, manganese, quartz, clay, and occasional aluminous hydrates. Such deposits indicate past lateritization, but they are small in thickness and extent and are not of economic value.

The northern part of the area is covered by a vast, subhorizontal Jurassic plateau with frequent, Neogene-Quaternary, basaltic intrusions occurring occasionally as small tabular masses. The combination of basalts and of carbonate sediments is favourable for the formation of bauxite, and this area was, therefore, examined in detail. The basalt outcrops are well exposed, covered at most by 15–30 cm of loam containing brown ferruginous concretions.

West of the Bur Acaba occurs a basalt hill some 10–15 metres high, 300 metres long, and 100–150 metres wide. The contact between the basalt and the limestone was examined. The top of the occurrence is fissured and covered by a ferruginous capping from 0.5–0.6 metre thick within which there are no aluminous hydrates.

The Jurassic limestone is well exposed and is normally altered to caliche, with evidence of karst formation. The selective dissolution is very irregular and is not more than one metre deep. The surface depressions in two areas, north-west of Baidoa and Manas (map 1), are filled with a ferruginous pisolithic soil.

The Manas occurrence was drilled. Jurassic clays and limestones were penetrated at a depth of 14.1 metres and the hole was stopped at 22 metres. The upper sequence consisted of brown and yellow ochrous clays, gravels, and loams, containing several horizons of ferruginous concretions.

The samples from Manas were tested microscopically, thermally, by X-ray and by spectral methods. Thin sections showed ferruginous oolites embedded in a colloform cement with finely crystallized carbonates and rare quartz grains. The rock contained carbonate veinlets from one to three millimetres thick.

Thermal analysis gave endothermic reactions at 140°–145°C, 350°–385°C, 520°–530°C, 800°–830°C, and an exothermic reaction at 930°–960°C.

These temperatures correspond to the elimination of the hydroscopic moisture from the colloform, to the reaction of goethite, hydrogoethite, and gibbsite, to the reaction of the foliated silicates of the clay groups and to the reaction of calcite.

The X-ray analysis showed the colloform to be goethitic with occasional kaolinite, gibbsite, hematite, calcite, and quartz.

Four samples analysed in the United Kingdom and the USSR gave (in percentages):

	SiO_2	TiO_2	Fe_2O_3	Al_2O_3	*Loss on ignition*	N_2O
1.	12.11	1.07	47.25	17.02	11.73	1.17
2.	18.30	0.96	45.26	17.41	14.37	1.03
3.	14.50	0.77	37.09	13.32	13.00	0.86
4.	30.76	1.21	29.74	17.64	13.12	1.76

These results were confirmed by the spectral analysis of five other samples.

In the western part of the area, on the right bank of the Giuba River, occur numerous flat-topped remnants of Cretaceous sediments, arenaceous and containing gypsum. Their weathering produces only caliche.

The eastern part of the central area contains, therefore, only a thin lateritic cap which covers the remains of an old peneplain. Greater thicknesses of lateritic material correspond to accumulations of ferruginous sediments which contain some uncombined aluminous hydrates at certain levels (Manas, Baidoa). They probably represent the remnants of a lateritic crust which was formed outside the limits of the area studied and was transported to its present site. The existence of economic accumulations of bauxite in these formations is very doubtful.

Bur area

The Bur area represents a young levelled surface covered by a mantle of loam interrupted by frequent outcrops of basement amphibolites, granitoids, schists and other rocks. The surface covering consists of red-brown quartz sand, commonly accompanied by caliche, and with loam and sand in the river valleys. Bauxite is not to be expected in this area.

Northern plains area

The northern plains area is mountainous or hilly and contains numerous limestone and gypsum outcrops with rare, flat-topped hills, separated by sandy and clayey proluvial sediments.

This juvenile relief is unsuitable for the formation of lateritic or bauxitic deposits, especially in an arid climate.

Mountainous area

Mountains extend through the northern part of the country, along the Gulf of Aden, and consist of a complex of Pre-Cambrian to Recent rocks.

The exposures are good and the presence of bauxite would be easy to recognize, not only in the mantle but also in the underlying Mesozoic, Palaeozoic and Neogene rocks.

Mesozoic and Cenozoic sediments

The Jurassic, Cretaceous, Paleogene and Neogene rocks are mostly carbonates and frequently contain gypsum. Their deposition occurred in arid, marine and lagoon conditions which preclude the formation of bauxite.

Rare sandy and clayey formations related to continental episodes in the Mesozoic-Cenozoic sequence could be potentially bauxitic. One such succession was seen south-east of Alula, in the extreme north-east of Somalia. It consists of a ferruginous sequence 200 metres thick containing polymict, sandy and red-coloured rocks with thin intercalations of limestones and sandstones in limy sediments. At its base occur 40 metres of sandy and clayey rock with a thin interbedding of grey siltstones and argillites containing rare plant debris, and beds of limestone and dolomite with lenses from 0.4 to 0.5 metre thick of brown coal.

No evidence of chemical weathering suggestive of bauxite formation was seen.

Neogene and Quaternary mantle

The terrain is rugged and not suited to the formation of eluvium. The climate is arid, and weathering is accompanied by disintegration and transport towards proluvial fans. The country rocks are slightly altered or covered by a desert patina.

In the course of 400 km of traverses, no bauxitic or lateritic surface materials were seen.

No bauxites occur in the mountainous area.

Conclusions

These conclusions are valid not only for Somalia but for all of tropical East Africa:

(a) The findings at Manas include a redeposited lateritic crust which contained free aluminous hydroxides;

(b) The lateritic crusts and surface brown ores found during the investigation show that the climate was formerly suitable for lateritic weathering, possibly during one of the pluvial periods of the Early or Middle Quaternary which have been reported from the area of the Great Lakes (United States);

(*c*) A more detailed geochemical and mineralogical study of the materials collected could provide information as regards the original formation which supplied the free alumina which could then be identified by further exploration, probably outside Somalia;

(*d*) There appear to be prospects of finding bauxites in some areas of East Africa and particularly in the areas of lateritization. The influencing factors would be: a past and present rainfall of more than 1,500 mm/year; the terrain dissected into peneplains and plateaux; the presence of country rocks rich in Al_2O_3 and poor in SiO_2.

(*e*) Such an environment would also be promising for silicate Co-Ni ores, Mn ores, Fe ores, eluvial gold and diamond and nests of quartz veins. Geochemical exploration for these would be indicated.

B. El Bur sepiolite

Sepiolite, or meerschaum, is a hydrated magnesium silicate of the approximate formula: $2\ MgO \cdot 3\ SiO_2 \cdot 2\ H_2O$

Deposits of this material are relatively few, the principal ones being: Eski Shebir (Turkey), Vallecas (Spain), Amboseli (Kenya and Tanzania) and a number of small occurrences in England, France, the USSR, and the United States.

The best meerschaum has long been used for the manufacture of high-quality tobacco pipes, and in recent years other grades have found a use in the chemical, electrical and ceramics industries because of their absorbant, adsorbant, filtering, moulding, and refractory qualities.

Situated 370 km north of Mogadiscio and 6 km to 10 km north-west of the town of El Bur in the northern part of Mudug Province, the El Bur deposit is one of the largest known.

Geology

The area consists of Eocene limestones which principally contain interbedded gypsum, anhydrite, and clay. Towards the south-west, these formations grade into Cretaceous sandstones and limestones.

The sepiolite occurs as a subhorizontal bed within limestones which crop out west of the deposit. No clear contact between the sepiolite and the limestone was seen but the occurrence is confined to a single deposit aligned north-south.

The mineralized area of the flat-lying sepiolite is an area some 1.5 × 6 km, or 9 km². The deposits are overlain by a thin mantle of overburden and overgrown by bush, containing occasional dazzling white sepiolite debris outcrops or pit dumps. Towards the east, the sepiolite and the limestone are overlain by clays and siltstones which may fill in a surface depression.

The genesis of the deposit has not been established. It could be either a syngenetic sedimentary formation, persistent along the strike, or a series of discontinuous metasomatic lenses, similar to the deposits of Turkey and Tanzania.

Mineralogy

In its natural state, the El Bur sepiolite is massive, tenacious, smooth to the touch, yellowish or grey-white when dry, grey when moist. Its hardness index is 2–2.5;

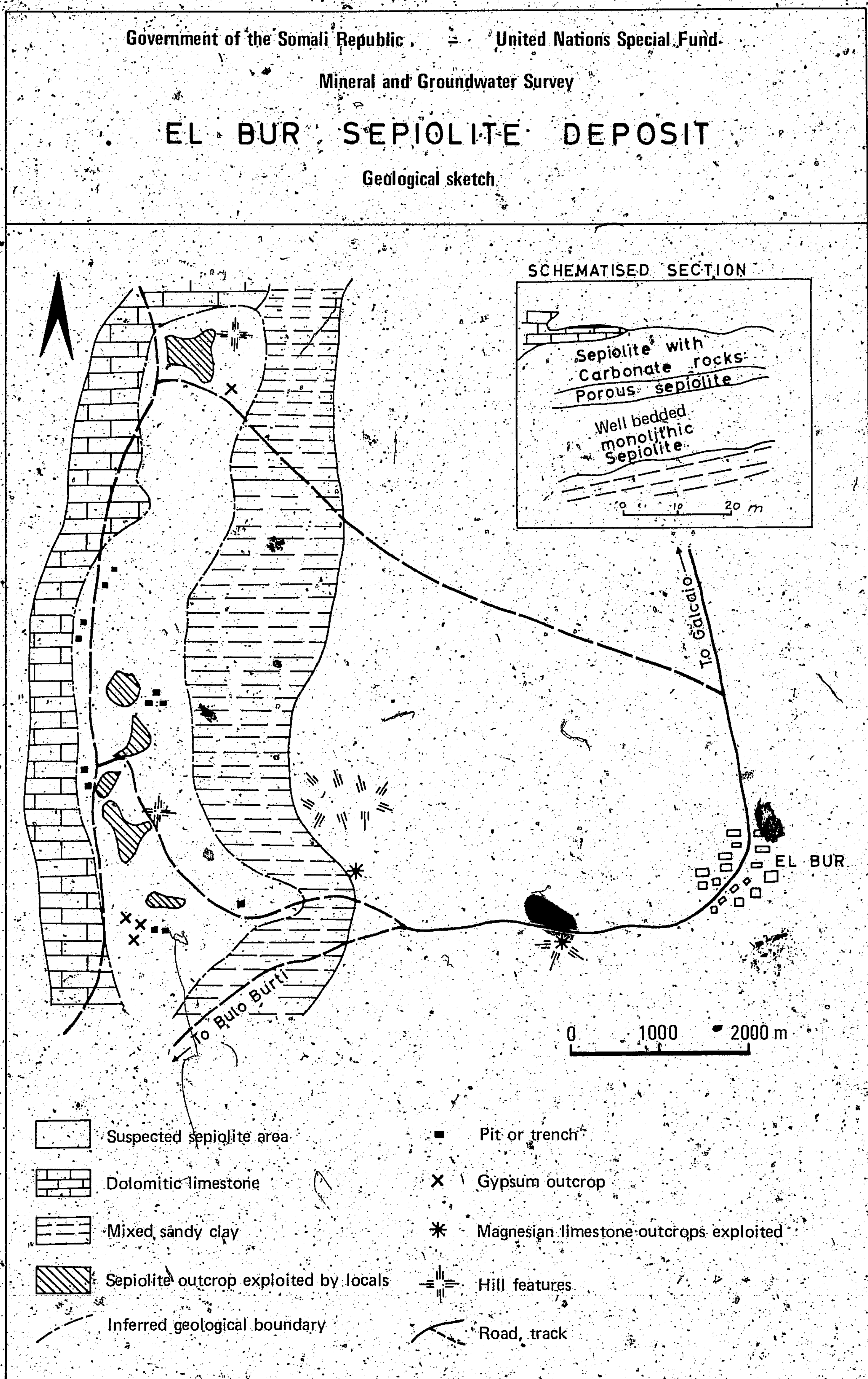


Figure 17. El Bur sepiolite deposit: geological sketch

and its specific gravity is 2–2.2 in its natural state, but drops to 0.83 when dry because of the high porosity.

Thin sections and the electron microscope show a compact tangled fibrous mass which encloses detrital grains of quartz of feldspar and of gypsum.

The material from El Bur contains 79 per cent sepiolite as against 88 per cent for samples from Tanzania. The principal impurity is evaporites, mainly halites, and the material is comparable to the "baruty" meerschaum of Tanzania, unfit for pipe manufacture but suitable for carving into curios and for such industrial purposes as fire bricks.

C. Other minerals of the Bur area

Geochemical exploration

The results of the geochemical and metallometric tests carried out on stream sediments in the course of the general geological exploration were insufficient to support quantitative assessments.

It is important to note, however, that the heavy concentrates from the Bur Acaba area tested very high in silver, copper, and cassiterite; assessed in conjunction with the geology of the area, they merit further investigation.

Marble

Large outcrops of marble of good quality and of various colours, suitable for building and ornamental purposes, were found in the following areas: 3–4 km south of Modu Mode village; 9 km north-north-west of Bur Acaba; in the Dinsor area; in the Bur Galan area.

Their description is given in the technical reports (see References, section C, No. 7, L. Bryzgalov, 1967) which accompany the geological map of the Bur area.

Pegmatites

Numerous pegmatite veins, several metres thick and persistent along the strike, were found in the eastern part of the Bur area. Preliminary tests showed that their feldspars would be suitable for the manufacture of ceramics.

Titanium—manganese

In the Bur Acaba area, traces of titanium and manganese were found in certain of the rock formations but were not considered to be sufficient to justify further exploration.

Phosphate-bearing rocks

In the Modu Mode area, some 25 km west of Bur Acaba, the marbles which contain a considerable admixture of silicates, gave an analysis 24% P_2O_5. This corresponds to a content of approximately 53 per cent of tricalcic phosphate of lime which would not be economic to mine.

VII. Minerals of the northern area

The former Geological Survey of British Somaliland found manganese, copper, lead, molybdenum-lead-bismuth, cassiterite, fluorite, barytes, industrial feldspar, industrial quartz, mica, asbestos, talc, highly aluminous minerals, kaolin, glass sand, corundum, and gypsum (figure 4). These were of only academic interest for a long time because of poor transport facilities and the lack of a port of sufficient capacity for mineral traffic. Under a bilateral agreement with the USSR, the port of Berbera has been developed with the following characteristics:

Anchorage is within the lagoon of a coral reef which parallels the coast. Access to the open sea is towards the WSW and the anchorage is fully protected except for a few days of westerly winds.

The water in the centre of the lagoon is from 10–20 metres deep, and the quay is sited with 9.7 metres of water alongside which can easily be deepened to 11 metres.

The quay is 320 metres long, 126 metres wide and connected to the shore by 545 metres of pier. Handling is done by two five-ton grab-cranes. Anticipated traffic is 180,000 tons per year and can be expanded without difficulty to 400,000 tons per year.

The Government has started to grant mining claims on some of the deposits. A reappraisal of the area is, therefore, urgent.

A. Manganese

A line of rock outcrops, 6 km long, extending near Hudiso towards 310°–320° W, contains scattered indications of manganese. Its strike conforms to that of adjacent rocks and changes abruptly.

The ore occurs as a series of isolated lenses from 0.3–3 metres thick and 2 metres long which pinch out at shallow depth. The mineralization varies from nearly pure, highly oxidized rhodonite to quartz with a few scattered grains of manganiferous garnet and of magnetite, particularly dense along the contacts with the enclosing biotite and biotite-muscovite schists.

No large bodies of high grade material were found, and the average content ranged from 10 to 15% Mn. Assays made in 1954, which reported contents of 7%–

39.7% Mn, must have come from small high grade pockets. Several similar occurrences were examined in the Sheikh area with equally disappointing results. These manganese occurrences must be considered as not economic.

B. Lead

Dananjieh

Galena occurs at Dananjieh in silicified rocks and calcite veins related to a fault zone. The formation strikes 240°W and dips steeply to the north. The mineralized band varies in width from five to six metres and is 150 metres long.

The galena occurs in grains of two or three millimetres in size, or in aggregates up to a centimetre in diameter, in the quartz veins which are associated with quartz-fluorite veins containing barytes and rare apatite.

Several generations of galena-quartz veins can be recognized.

Wiget

A fault zone at Wiget, 5–6 metres wide can be followed over a length of 50 metres towards 20°–30°E in quartz-carbonate hornfels.

The zone consists of quartz-calcite hornfels impregnated with galena, pyrites, chalcopyrites (rare) and malachite.

The mineralization is most intense in the southern part of this zone but is limited to a few mineral grains in the north.

Fulanful

At Fulanful is the most important of the lead occurrences. The ore is related to a quartz carbonate hornfels within a fault zone containing marmoric limestone. The galena occurs in numerous quartz-carbonate veinlets, a few centimetres thick and several metres long, but no evidence was seen of dissemination in the adjacent limestones. It was covered by a magnetometric and electric survey which showed a strong magnetic anomaly.

Conclusions

No mineralization was observed in the limestones lying within the fault zones. It seems, therefore, that the galena is pre-Mesozoic and that the fault zone was revived later.

This seems to be confirmed by the absolute age of four samples of galena from Fulanful which was determined as 900 million years. It is unlikely, therefore, that any large metasomatic deposits will be found in the Mesozoic rocks, but fissure deposits can well occur within the fault zones, and these should be investigated by electro profiling and geological exploration along their strike.

C. Molybdenite-galena-bismuthinite

South of the Buhl granites, 40 km north-west of Hargeisa, molybdenite, galena, and bismuthinite are found in quartz and quartz-pegmatite veins which occur over a large area of schist, amphibolite, gneiss, granite, syenite, and gabbros. The most important vein is from one to fifteen metres thick and 150 metres long. It is sur-

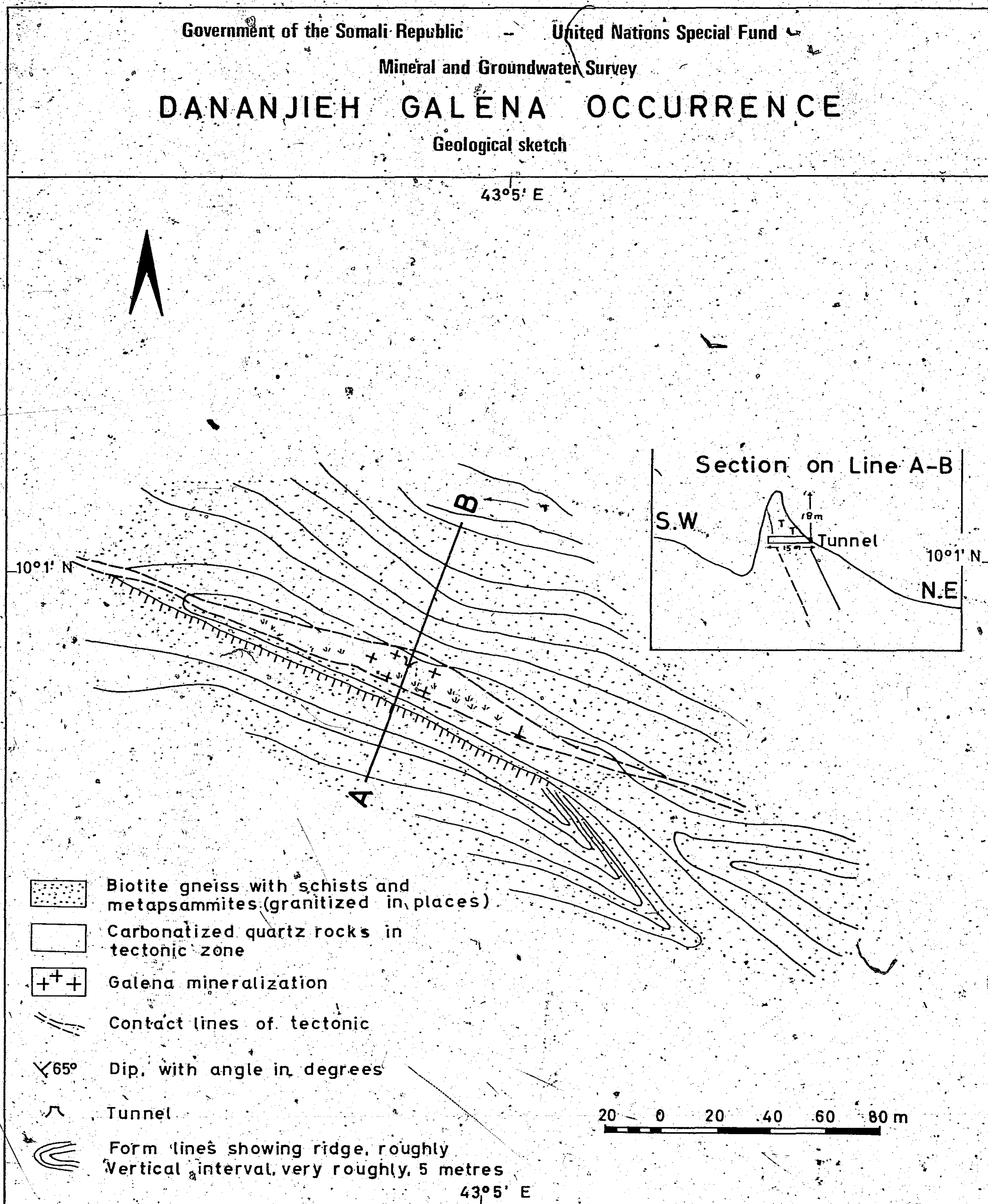


Figure 18. Dananjieh Galena occurrence: geological sketch

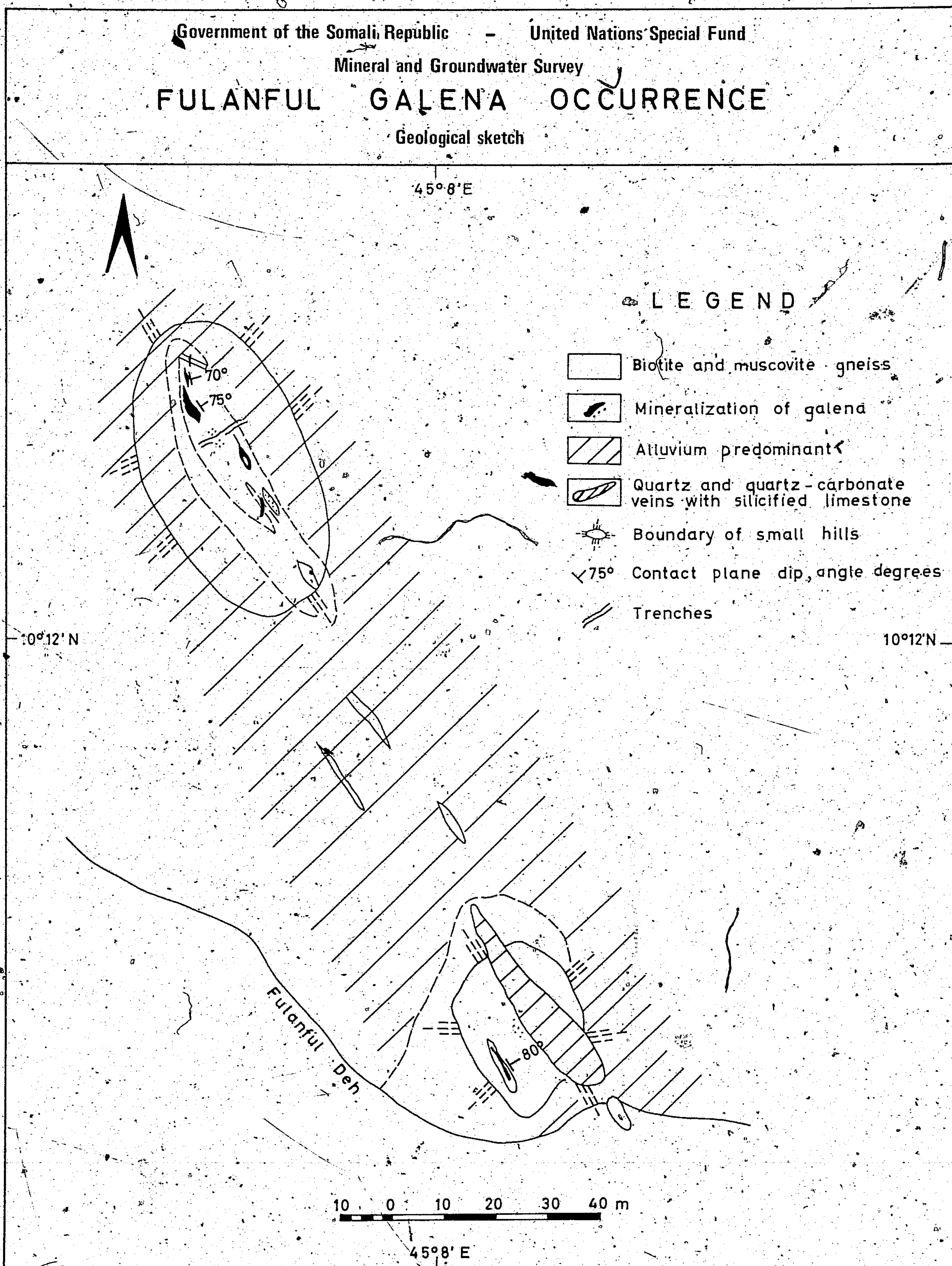


Figure 19. Fulanful Galena occurrence: geological sketch

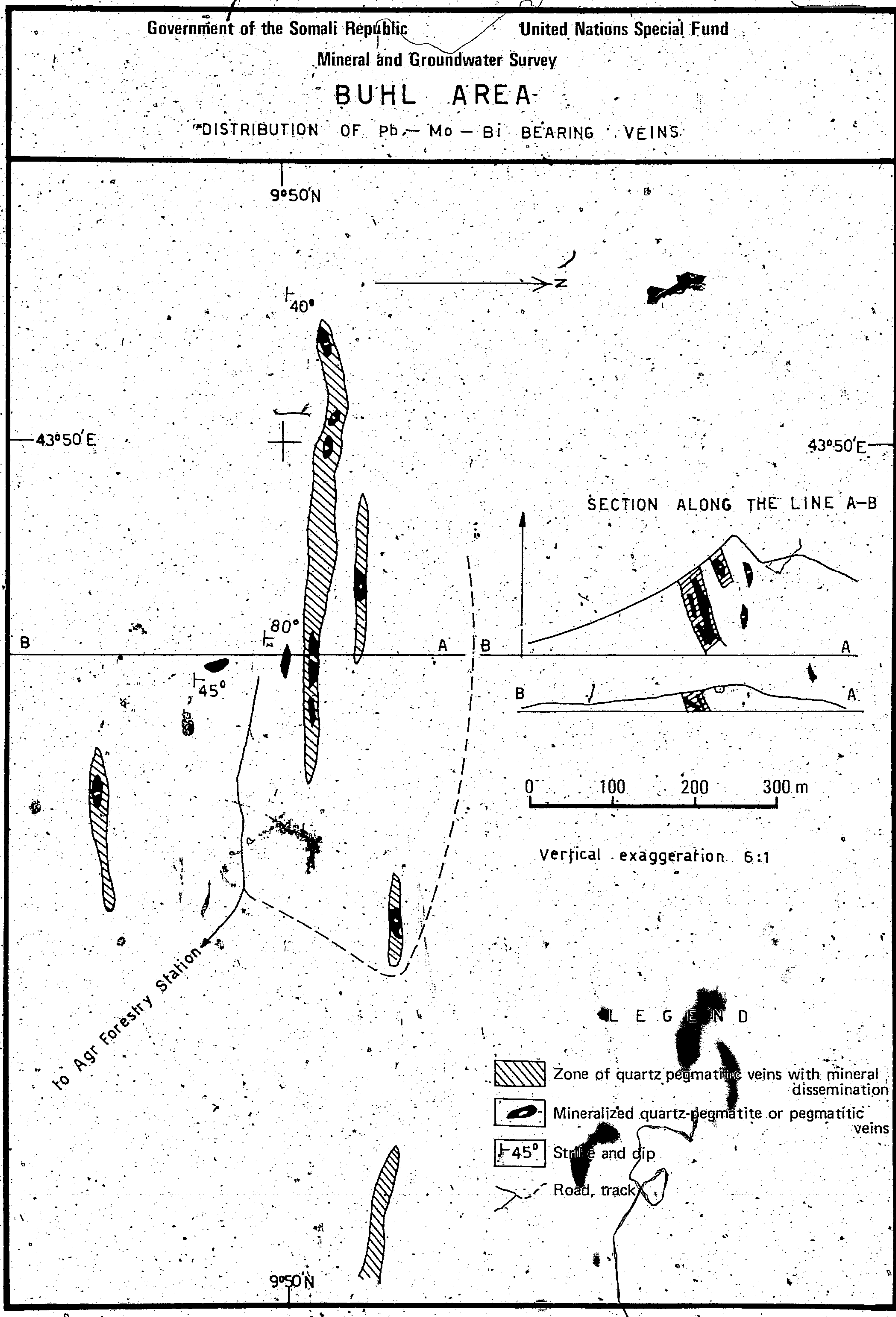


Figure 20. Buhl area: distribution of Pb-Mo-Bi bearing veins

rounded by a number of satellite veins. Their general strike is 75°–100°E and they dip towards the north at angles of 75° to 85°.

The molybdenite occurs as flakes from five to six millimetres in size, thickly distributed in the marginal zones. The galena-bismuthinite occurs as common columnar accumulations of crystals from one to three centimetres in cross sections. Their assay gave 0.16% Pb; 0.45% Bi; and 0.89% Mo. The occurrence in itself is too small to be of economic significance, but it is related to a syenite mass which may well reveal further mineralization, and it merits exploration.

D. Copper

The malachite and azurite which were reported in the past from several places, occur as coatings within the joints of arkosic quartzites and amphibolites. No ore concentrations were seen and the coatings are variable in extent and in many places absent. These minerals appear to have no economic significance.

E. Pegmatites and quartz

Swarms of pegmatite veins occur near the village of Henweina, at Quabri Bar and south of Hammas village. Several new veins were found. At Henweina and Quabri Bar, these veins contain beryl and columbotantalite which are worked by local contractors, using hand methods. At Hammas, individual veins 30–40 metres long and 15–30 metres wide contain industrial feldspars in considerable quantities but of doubtful quality as well as good quality quartz, as yet not assayed but apparently containing 96–98% SiO_2, with good piezo-electric properties. Some veins contain cassiterite. A radiometric survey covering 6 × 4 km in the Bur Durug area revealed a radioactive anomaly. The area appears to contain a promising pegmatite field.

F. Nepheline syenite

An intrusive mass covers 36 km², 130 km north-west of Hargeisa. It consists of syenite and nepheline syenite. The latter have an Al_2O_3 content up to 27 per cent but average 20 per cent.

Under present conditions these rocks cannot be considered as constituting an economic source of alumina, but their existence must be noted for future reference, should change of local conditions warrant re-examination.

G. Kyanite

Kyanite is common, the principal occurrence being at Damal in the Hudiso area. Muscovite-kyanite schists form beds up to 15 metres thick and up to 100 metres long. Those visited have been estimated to contain 130,000 tons of kyanite, and the area holds promise of other occurrences.

H. Coastal sands

Several areas of sand were studied and the reserves contained in the three largest sites were assessed at: monazite, 900 tons; zircon, 240 tons; rutile, 20 tons.

Several new narrow coastal strips have been found, but the thickness of the mineralized sands nowhere exceeds 0.5 metre, and no economic deposits were found.

The east coast of Berbera is very little known and should be explored for possible economic deposits.

I. Gypsum-anhydrite

A deposit of gypsum and anhydrite occurs near Suriah Malableh, 15 km south-east of Berbera. They crop out in a cliff face some 100–150 metres high which is exposed along the bank of a seasonal river bed over a distance of 7,000 metres. The rock consists of massive fine-grained gypsum containing veinlets and pockets of anhydrite. It is interbedded with marls and conformably overlain by limestones.

The formation dips at approximately 30° from the river-bed. Part of the deposit was sampled by the British Geological Survey who put down three drillholes, cut several trenches and drove a few small adits. The area sampled is estimated to contain 5,000,000 tons of rock at +80 per cent gypsum, and 1,874,000 tons of rock at +85 per cent anhydrite.

The base of the outcrop lies some 20–25 metres above sea level, the ground between it and Berbera is flat and could easily be reached by ropeway, road or small railway, probably with a 30 per cent economy on distance.

This deposit was not investigated by the project but, with the opening up of the port of Berbera, its exploration and sampling must be completed to prove additional tonnages and possible outlets must be investigated, in particular, as a source of supply of sulphuric acid for the potential Somalian uranium industry, and as a building material for internal use.

J. Coal, lignite, oil shales

These were superficially examined and a provisional opinion as regards their economic value is given in the technical reports of the project.

K. Building materials

At the request of the Ministry of Industry and Commerce, a search was made for materials to supply a proposed cement factory in the Berbera area.

Large deposits of clay of satisfactory quality were found.

VIII. Groundwater survey

A. CONDITIONS OF OCCURRENCE OF GROUNDWATER

Three main factors must be considered in the search for groundwater: the topography and morphology which divide a territory into watersheds, each with its drainage pattern and groundwater basins; the climate, and principally the rainfall and evaporation; and the geology which governs the ratio of infiltration and the capacity of underground storage and flow.

The problem is to outline and evaluate the corresponding resources, to define their safe exploitation and to secure their proper replenishment.

Quality and distribution of groundwater in Somalia

Fresh groundwater can be found in: (*a*) the coastal zone, by direct infiltration of rainfall into the dunes; (*b*) inland, by direct infiltration into some "perched aquifers"; (*c*) the vicinity of the main rivers and irrigation canals.

Groundwaters are brackish or salty in: (*a*) the proximity of the coast, or when indiscriminately over-pumped in the flood plains; (*b*) the areas west of the Giuba and east of the Scebeli rivers (more than 2,000 ppm chlorides); (*c*) the evaporation areas where the high temperatures of shallow groundwaters exceed 34°C, which therefore normally contain a high concentration of dissolved salts.

In the coastal area, several fresh water "bodies", or "lenses", of different shapes and sizes were found to "float" in a general brackish media.

Oil wells have found fresh water in Mesozoic sediments at depths exceeding 3,000 metres.

B. GROUNDWATER PROVINCES: POTENTIAL RESOURCES

Various authors have divided Somalia into sundry systems of groundwater provinces. Briefly described, the principal units are as follows:

Southern coastal region

In the coastal region, south of the Banta-Gialalassi faults, upper Tertiary sands and coquina constitute the main aquifers, and the waterlevel is in places nearly

100 metres below ground level. Test holes put down by the United States Agency for International Development (USAID), 40 km from Mogadiscio, gave outputs of 40 m³ hour, with a very small drawdown. A programme of 14 boreholes has been sponsored by USAID to provide water for Mogadiscio, the capital city of Somalia where the waters now being distributed are strongly corrosive.

A total of 147 wells, of which 106 were productive, were drilled in the Genale area for the irrigation of banana plantations. Their outputs range from 70 to 140 m^3/hour, and their specific capacity from 5 to 20 m^3/hour/metre.

Bur area

Several surface depressions in this Pre-Cambrian crystalline area, such as the one near Bur Acaba, are filled with unconsolidated arenaceous sediments which are as thick as 36 metres. These sediments contain fresh water which is replenished by the infiltration of rainfall and run-off.

The water-bearing potential of the fracture zones in the bedrock has not yet been studied. The area is covered with thick bush which hinders field observation and renders difficult the interpretation of aerial photographs.

Southern inland region

The main geological formations in this area are massive karstic limestones with interbedded marls of Jurassic age, and upper Jurassic and Cretaceous limestone deposits of moderate thickness containing gypsum, in which scattered wells have been dug by hand.

The best aquifer is represented by the Jesoma (Nubian) sandstones, east of the Scebeli River. West of the Giuba River, the aquifers were not explored.

The waters of the Jurassic rocks are fresh or slightly brackish. They are quite fresh in the recharge areas, west of the Scebeli. Most water found in Cretaceous rocks contain sulphates, but locally the water in the Cretaceous limestones is fresh.

Lower Giuba River area

The hydrogeological surveys carried out in the Giuba River section between Giamama and Fapole village by the Water Constructions Design Institute of the USSR, and on the lower reaches of the Giuba River, and in the Chisimaio area, by a crew from the Irrigation Research Institute of the USSR, constitute a major contribution to the knowledge of the groundwater resources of the Somali Republic.

Large expanses of the area along the lower Giuba River are covered by thick sequences of Mesozoic and Cenozoic sediments, consisting predominantly of Paleogene limestones, siltstones, sandstones, gypsum and clays. The sequence is up to 2,000 metres thick.

The Pliocene and Quaternary series also include other types of sediments, commonly unconsolidated, reef limestones, marine terraces, fixed and mobile dune sands, eluvial formations, and alluvial accumulations built up by rivers and temporary streams. No information is available regarding the water-bearing properties of the Jurassic, Cretaceous and Palaeogene sediments.

The hydrogeological and geophysical exploration which was carried out by the Water Constructions Design and the Irrigation Research Institute (USSR) led to the following conclusions:

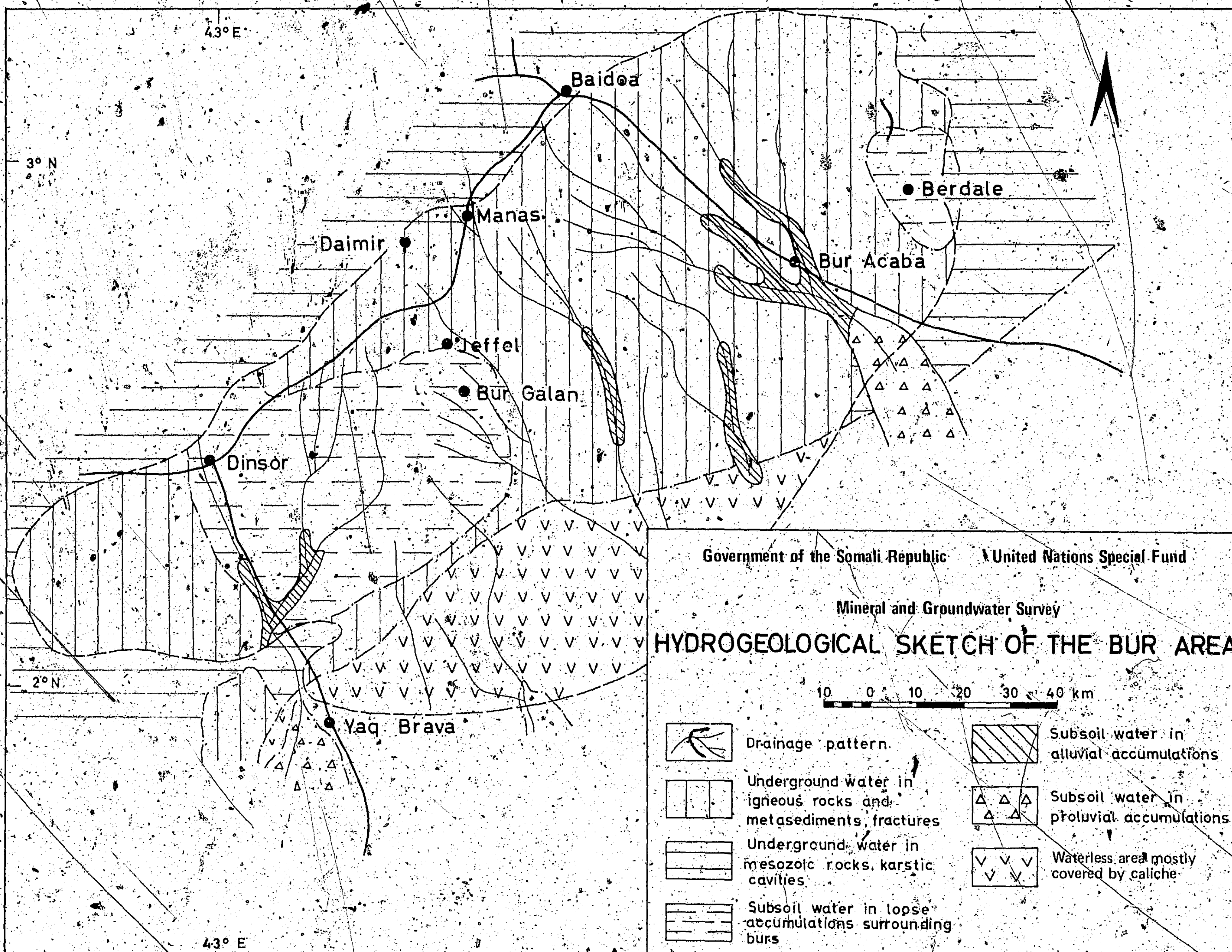


Figure 21. Hydrogeological sketch of the Bur area

(*a*) That wind-laid dune sands, widespread in the coastal area, contain fresh water lenses in certain places, floating on brackish water. The fresh water can be used for a local water supply, but the maximum available is two or three cubic metres per day per well;

(*b*) That while the loam and clay fillings in the lower reaches of the Giuba valley are impermeable, fine-grained alluvial sands are to be found locally and they constitute, in these few localities, the only fresh fresh-water aquifers hydraulically linked with the river.

Wells were drilled in such areas in 1965 to provide water for the Chisimaio meat-packing plant. They yielded up to 10 m^3 of fresh water per day, with a total dissolved solids content of less than 1,000 ppm. The feasibility of using the water in the alluvial sediments of the lower reaches of the Giuba River for domestic and other purposes was determined in the course of this investigation.

Mudugh plain

The Mudugh plain has no significant drainage, and its groundwater resources are almost unknown. Lower Eocene sediments, mostly limestones, containing anhydrite and gypsum, cover large areas, and their waters are commonly highly mineralized.

Shallow depressions occur on the surface of the plain, and these constitute the centre of small endoreic basins; local water resources are available at shallow depth where these depressions contain significant sandy deposits. The possibility of finding deeper artesian waters is not excluded.

The depression called the "Nogal Valley", where many streams terminate, follows the axis of an anticline and contains the greatest density of wells which decreases towards the north.

Shol plateau

The Shol plateau extends from the Nogal Valley to the northern mountains. It consists mostly of middle and upper Eocene sediments; limestone, marl, anhydrite, gypsum. Annual rainfall is less than 200 mm, and evaporation is more than 2 metres per year. The region contains no perennial lakes or streams. Some valleys, or depressions, contain limited water resources; a few springs were seen in the foothills and in the vicinity of the coast. In many places, the groundwater is highly mineralized and contains magnesium sulphate. Few wells have been sunk to depths greater than 100 metres. The Shol plateau is, in the broad sense of the term, a "waterless area."

There might be a possibility of finding fresh artesian water at depths as great as 700 metres in the Jesoma sandstones.

Northern mountains and adjacent areas

The northern mountainous region receives, over much of its surface, except on the summits, only 75–100 mm of rainfall a year, and the main water resources consist in the underflow within the alluvium of some river-beds. The populated centres of the plateau area, such as Hargeisa, Guled Haji, Halo Berato and Burao are supplied from such alluvial reservoirs. The waters are locally mineralized (sodium, magnesium, sulphates, and bicarbonates). Some rivers on the northern slopes, flowing towards the Gulf of Aden, have a perennial flow fed by small springs occurring at the level of the basement rock exposures. Several hot and thermo-mineral springs are found in these areas.

Due to the difficulties of access, only a limited number of holes have been drilled in the northern provinces.

The Hawd region is considered waterless, with the exception of a few temporary shallow lakes. It can be assumed that below the Tertiary sediments, the Nubian sandstones may retain artesian waters.

Northern slopes of the El Madd Massif and the coastal plain, Gulf of Aden

In 1966 and 1967 a crew from the Irrigation Research Institute (USSR) carried out a hydrogeological survey to determine the feasibility of a water supply for the Las Khoreh fish cannery on the Gulf of Aden.

The area surveyed, which had a radius of 25 km around Las Khoreh, contains limestones, sandstones, gritstones, and conglomerates of the Miocene Dubar series. Quaternary formations were represented by Recent beach sands, wind-blown dune accumulations and diluvial-proluvial and alluvial-proluvial sediments on the foot-hill plain and in the major valleys of the mountainous region.

This work established that the geological formations hold large amounts of groundwater which are commonly mineralized up to 4,800 ppm while the waters confined to the proluvial fans of the major valleys are only mineralized up to 3,000 ppm. Wells drilled in the Saba and Damalei valleys for instance, gave on pumping tests up to 3 litres per second of water with mineralizations of 1,500 to 2,000 ppm. If one considers the replenishment of groundwater storage by the precipitations falling on the mountains during most of the year, the water reserves of the alluvial-proluvial accumulations on the northern slopes of the El Madd massif must be considerable. Such groundwater however, which circulates within fractured rocks, is quickly mineralized by the dissolution of salts in these rocks.

C. Hydrogeological surveys carried out by the project

The Plan of Operation stipulated that hydrogeological surveys be carried out, that groundwater conditions and availabilities be examined, and that feasibility studies be carried out. Hydrogeological exploration, therefore, covered the areas of the Daimir and Bur Galan iron ore deposits, part of the north-western region of the project area, the Bur Acaba area and in the vicinity of Chisimaio in southern Somalia.

Daimir-Bur Galan area

Hydrogeological studies were made in the northern part of the Bur area (figure 21) and of the Jurassic plateau which limits it to the north, to determine the ground-water conditions around the Daimir and Bur Galan ferruginous quartzites and to estimate the groundwater reserves and availabilities for a potential mining operation. Several springs provide yields adequate for present requirements, and the area suffers no shortage of water, but the problem of water supply will arise, if any mining or other industry is developed, and this survey is, therefore, relevant to the present exploration for uranium.

The Daimir and Bur Galan ferruginous quartzites occur in the northern part of the Bur region, some 60–70 km south-west of the town of Baidoa, near the Baidoa-Dinsor road. This area is between the Scebeli and Giuba rivers.

According to the records of the meteorological station at Baidoa, the annual rainfall from 1955 to 1965 averaged 561.4 mm, ranging from 309.3 mm in 1955 to 951.7 mm in 1961. Monthly precipitations are even more variable. The average annual rainfall at Bur Acaba, 70 km south of Baidoa recorded 408.2 mm for the same period. All precipitations occur in April-May and October-November.

Geology

In the past, the hydrogeology of the Bur area as a whole, and especially of the area which is under consideration, had not been specifically studied and was almost unknown. The groundwater régime had not been studied at all.

The basement rocks of the area consist of gneiss, schist, and amphibolite, intruded by granite and by haloes of granito-gneiss. They are capped by a mantle of weathered rock and of diluvial and alluvial formations of varied thickness.

The basement rocks are overlain in the north by Jurassic limestones, marls and sandstones, and immediately overlain by the limestones of the Hamanlei series. These limestones form an escarpment which runs roughly along the line of Daimir spring—Manas spring—Baidoa town, and locally it may be several dozen metres high, for instance, in the vicinity of the Daimir spring. The limestones dip gently towards the north-west and are overlain by soft marls which form a flat plateau.

The Jurassic rocks in this area constitute the southern limb of a large, gently folded syncline which extends northwards into Ethiopia.

Eluvial-diluvial and alluvial-proluvial formations cap the basement rocks and have great hydrogeological importance. The eluvial-diluvial formations consist of grey and brown loam, and of sandy loam containing fragments of the basement rocks. The alluvial-proluvial sediments consist of red-brown, unevenly calibrated sand which merges into the general surface sequence. These sediments can be several metres thick.

The weathering of the basement rocks also produces unconsolidated materials which accumulate locally into deposits of considerable thickness.

Hydrogeology

The hydrogeological and hydrological survey carried out in the northern part of the Bur area, outlined the groundwater potential and the hydrogeological characteristics of the individual rock formations. The following hydrogeological units were distinguished; basement rocks, limestones of Jurassic age, alluvial-proluvial sandy sediments, and unconsolidated formations of the weathered zone of the basement.

In the massive and solid basement rocks which themselves constitute a poor aquifer, groundwater availability is limited to fault and shear zones. These rocks can be considered as barren over most of the area.

Jurassic limestones contain the best reservoirs in the area surveyed. Several fresh-water springs occur at their contact with the basement rocks. The springs give yields ranging from a few litres per second up to as much as 25 litres/sec. Although the survey was made in the dry season, the Manas spring gave 13.2 to 13.5 litres/sec., the Daimir spring 2.5 litres/sec., and the Baidoa spring around 25 litres/sec. No data are available regarding the seasonal variations of these springs, but the above measurements can be considered as being close to the minimum.

The waters from a certain number of sources (not shown in figures) were sampled and analysed. The total dissolved solids contained are as follows (in ppm):

Mesera well:	454
Manas spring:	1,192
Audinle well:	989
Daimir spring:	861
Baidoa well:	929

The only water with total dissolved solids (tds) less than 500 ppm was obtained from the Mesera well.

Water in the Hamanlei limestone is characterized by a high content of chlorine ions with HCO_3 second in abundance. The hardness of the water is considerable, and it has a high content of sulphate ions.

The survey of the Jurassic limestones indicates that these rocks may hold a permanent groundwater body which can constitute a potential water supply.

Alluvial-proluvial sediments, which extend as north-south bands over the basement area, can store significant reserves of groundwater, particularly where the alluvium is thickest. Such a site was found in a typical Dainune well 24 km southeast of Baidoa, near the road to Bur Acaba. Still larger reserves of groundwater can be found in alluvium fed by the waters from shear and fault zones; catchment drains were located in grey irregular sands, of probable alluvial origin, at the foot of Bur Galan.

It was assumed in the past that groundwater replenishment near the *burs* was due to the shallow penetration of run-off into their surface, but it can also be assumed that groundwater exists in the alluvial-proluvial sediments near the *burs*, and that the surface run-off coming from the exposed *burs* provides only an additional replenishment of these reserves.

A rough calculation of the possible run-off from the surface of Bur Galan hill was made as follows: The wells are situated in a valley which cuts across Bur Galan. The area of the slope of the south-eastern hill which overhangs this valley is 180,000 m², and that of the north-western hill, 90,000 m². The total catchment area is therefore 270,000 m².

Only heavy and abundant rains result in run-off, and minor rainfalls are immediately evaporated by the heated rock surfaces. Only some 20 per cent of the total rainfall can, therefore, be expected to reach the area of wells at the foot of Bur Galan.

According to the Baidoa meteorological station, the average annual rainfall in this area is 574 mm, and the total water input into the catchment of the wells can be estimated as: $0.574 \times 0.2 \times 270{,}000 = 30{,}996$ m³.

The valley between the hills has an area of approximately 50,000 m². The above input will, therefore, correspond to a sheet of water 0.6 metre thick over the whole area. As the groundwater lies only 1.5–2 metres below the surface, this volume of water would evaporate following capillary rise. In the years of drought, surface run-off is negligible, but the water level in the wells remains practically constant. Surface run-off from the *bur* cannot be, therefore, the only source of replenishment of the groundwater.

The available information indicates that all the precipitations which fall over the area of basement rocks (figure 3) must be considered as the main source of replenishment of the groundwaters in the Bur area. The shallow erosion pattern in the northern part of the area suggests that most of the precipitations go to recharge the reserves of groundwater, and that the rainfall fills not only the depressions which contains loose materials and the dry stream valleys but also the shear zones in the basement rocks. The remaining surface waters are drained off along the seasonal streams to the central and south-eastern parts of the Bur area where the stream-beds are deep and well-developed.

The alluvial sediments in the northern part of the Bur area contain fresh groundwater with a total of dissolved solids of 480–530 ppm. Water in the *balehs* near Bur Galan is more highly mineralized with tds of 840 ppm, the chlorine ion dominating.

Survey of existing water supply

In the areas underlain by Jurassic limestones, groundwater is recovered from natural wells, dug wells and springs. The wells equipped with pumps driven by internal engines yield from 0.5 litre/sec. to 1.5 litres/sec. A ten-hour pumping shift can supply from 40 to 120 m³ of water per night from one well.

In the town of Baidoa, four boreholes and two dug wells tap groundwater from Jurassic limestones (map 1). At the Manas spring and in the settlement of Berdale, groundwater is recovered from Jurassic limestones in concrete-cased wells 3 metres in diameter which deliver their output to a concrete watering trough.

In the area of the Pre-Cambrian basement rocks, the installations for water supply are far simpler. The wells tap the groundwaters of the alluvial-proluvial sediments and of the shear zones. They are usually circular and are cased with wood. The daily outputs of these wells can be 10 m³.

Conclusions and recommendations

The preliminary hydrogeological surveys have shown that considerable groundwater is available in the Daimir-Bur area. Its exploitation requires further surveying, accompanied by drilling.

The reserves of water are, nevertheless, not very great and domestic supplies and industrial supplies must therefore be considered separately.

Domestic water supply. Domestic water supply can be covered by extracting the groundwater from the Jurassic limestones or from the alluvial-proluvial sediments in the area of the Jeffel wells. Assuming a daily domestic consumption of 100 litres per capita, 200 m³ or 2.3 litres/sec. of water would be necessary to supply a settlement of 2,000 inhabitants. This quantity of water can be obtained from the Daimir and Manas springs.

The water contained in the alluvial-proluvial sediments in the area of the Jeffel wells constitutes a promising domestic reserve. The final selection of the source should be preceded by an annual cycle of observations on the Manas and Daimir springs and by detailed topographical mapping and water testing.

A hydrogeological survey to a scale of 1:25,000 should be made of the area of the Jeffel wells and should be accompanied by drilling to measure the thickness of the aquifer, the changes in chemical composition of the water across its section and the permeability of the rocks.

Industrial water supply. The problem of supplying water for industry is far more difficult and present estimates of requirements are only approximate. Assuming that four cubic metres of water are required to treat one ton of ore, and that re-use of water is impossible, the water requirements for a 2,000 ton-per-day mine is

8,000 m³ day or 22 litres/sec. Such quantities of water are not known to be available in the area.

The discovery of such amounts of water will require very considerable exploration which should follow two directions:

(a) *Exploration for groundwater in the area of the Jurassic limestones:* The best site would be between the Manas and Daimir springs, and as close to the point of use. After site selection, at least three wells as deep as 150 metres should be drilled and tested;

(b) *Study of the run-off of temporary streams:* Observations should be made over a period of two years on the surface run-offs of two or three stream-beds. If the discharge of these temporary streams is found to be adequate, sites suitable for the construction of storage dams must be selected and surveyed.

Bur Acaba area

The town of Bur Acaba is situated 200 km north-west of Mogadiscio, between the Scebeli and Guiba rivers. The area is a featureless terrain sloping gently south-east and covered by sparse bushy vegetation. Frequent temporary streams, or *tugs*, flow south-east, the Bur Acaba tug being the largest. The monotony of this flat plain is broken only by a high granite hill, the Bur Acaba, and by a number of small granite outcrops.

As elsewhere between the two rivers, there are two rainy seasons in the area. Rainfall, as measured over a number of years at Bur Acaba, averages 527 mm per year. Most falls during the two rainy seasons, but there are occasional showers during the dry seasons.

Existing water resources

The water supply of the town of Bur Acaba and of the nearby villages comes from surface waters collected in small reservoirs, or *balehs*, which hold from 300–1,500 m³ each. The *balehs* fill up twice a year during the rainy seasons, but the water lasts for only 2 months after rains, and the reservoirs are dry for 3–3½ months of each year.

Wells have been sunk into the Recent unconsolidated formations which fill surface depressions around Bur Acaba, but a more permanent and dependable supply is provided by the fissure water from the shear zones in the basement rocks. The wells which tap these fissure waters give the highest yields and have been dug and equipped with more care.

At the town of Bur Acaba there is also a well, 15 metres deep and 0.95 metre in diameter which is equipped with a diesel pump.

Provided that the water reservoirs are filled twice a year, and assuming that the evaporation ratio does not exceed 0.8 cm per day, the total water presently available at Bur Acaba amounts to some 75,000 m³/year. As against this, the annual water requirements for domestic purposes and for watering livestock are estimated at 128,000 m³/year. There is, therefore, a deficiency of 53,000 m³/year, or some 145,000 litres of water per day.

In the dry years, replenishment of the reservoirs is partial if at all, and the area suffers from an acute shortage of water. Requirements will increase further when the Afgoi-Baidoa motor-road is opened.

Because of this situation, and considering that the prospects were good of finding appreciable reserves of groundwater in the Recent sediments which fill the depres-

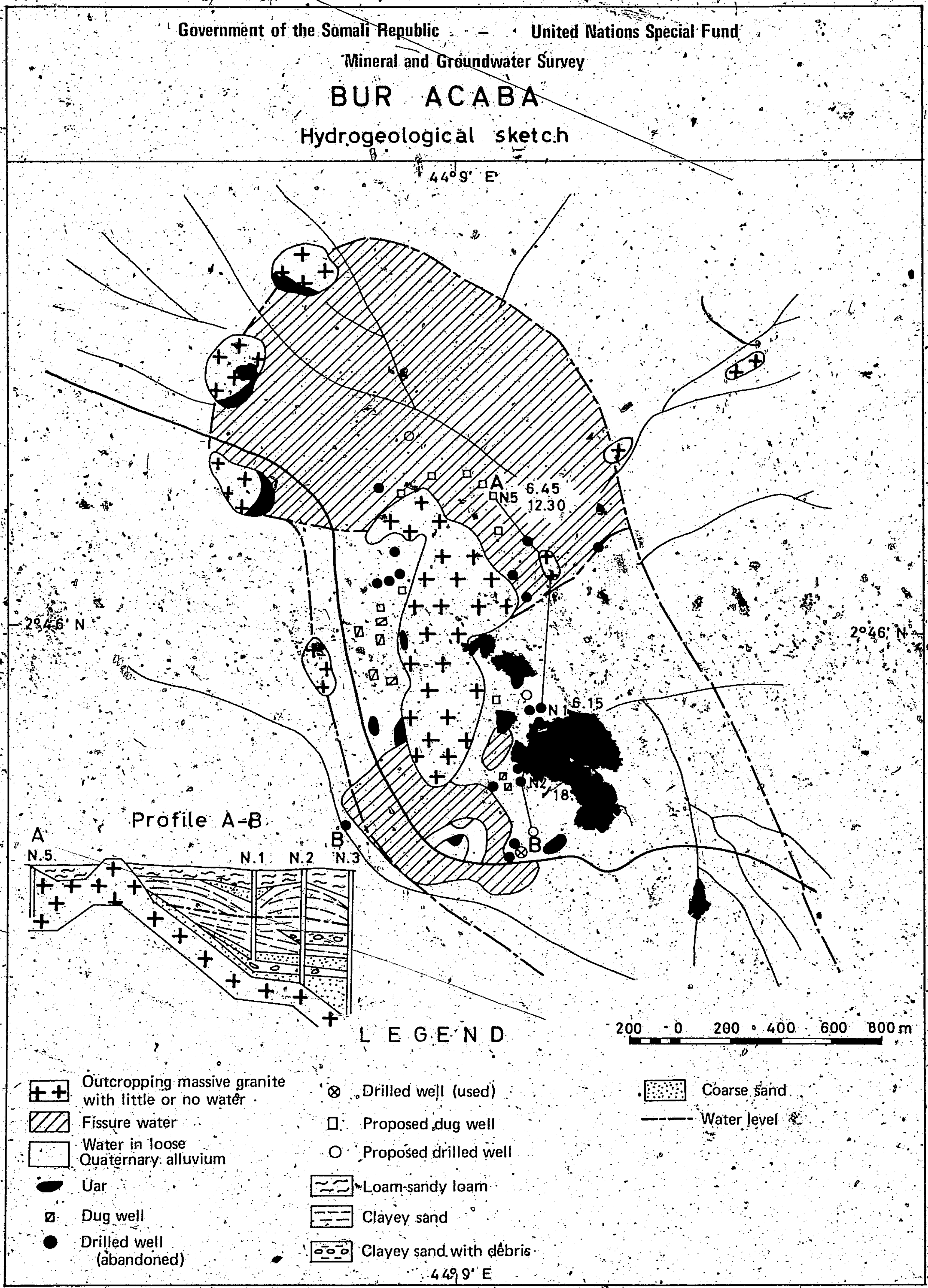


Figure 22. Bur Acaba: Hydrogeological sketch

sion of Bur Acaba, the project undertook a limited hydrogeological survey to understand the groundwater conditions and to find water supplies. This survey also covered part of the Bur Acaba *tug* valley, several kilometres east of the town.

Hydrogeology

The town of Bur Acaba is situated in the centre of a shallow surface depression which is floored with Recent unconsolidated sediments and underlain by crystalline basement rocks, mostly granites and granito-gneisses. A 200-metre granite hill, or *bur*, rises sharply in the middle of this depression. A number of small *burs* and granite outcrops occur in the vicinity, particularly to the north-west of the principal hill.

The geological succession within the Bur Acaba depression varies locally, but can be summarized as follows: the top part of the sequence, 2–5 metres thick, consists of brown clays, loams, and sandy loams which commonly constitute an impermeable cover. This capping prevents all infiltration from the surface into the underlying permeable sediments. The aquifers are, therefore, productive only in such areas as are underlain by shallow basement rocks, either outcropping, or capped by a thin mantle of coarse eluvium. The basement rocks are mostly fractured and faulted. The mantle of clayey sediments is in places as thick as 12 metres.

These clayey and loamy accumulations are usually underlain by fine-grained clayey sand containing debris and blocks of hard rock at different levels. The beds of clayey sand alternate with the coarser material which is free of clay and of other fine particles and provide permeable, if impersistent, aquifers.

There is a difference in water availability between the upper and lower portions of this water-bearing succession, though no obvious difference in composition was noticed. In wells 12–13 metres deep, the water-table usually established itself between 6.45 and 6.50 metres below the surface, but on deepening the wells to 15 or 17 metres, it dropped to between 7.5 and 9 metres. This could be due to the presence of a semi-permeable level within the water-bearing sequence.

The maximum thickness of the unconsolidated sediments measured in a borehole was 27 metres. The hole did not reach the hard rock, and the true thickness of the sequence is not known. This well was test pumped and gave a discharge of 6.5 m^3/hour.

The extent of the water-bearing formation is not known, and therefore the catchment area cannot be defined.

A second source of groundwater in the Bur Acaba area is the fissures in the basement rocks. This water is tapped by wells in the northern part of Bur Acaba sunk directly into the sheared granito-gneiss between 50 and 100 metres north of the foot of Bur Acaba hill. The production of the shear zone is appreciable, and the wells give a high yield. The water-table was not depressed by a bailing test. No detailed investigation of this water could be made because of the lack of equipment for hard-rock drilling. Water of this type appears to provide a more dependable source of supply than the water contained in the unconsolidated sediments of the alteration zone of the basement rocks.

Water in the alluvial accumulations of the big *tug* valleys provides another source of supply in the area. Such water-bearing sediments were drilled in the flood-plain of the Bur Acaba *tug*. They consist of fine-grained clayey sands, from 10 to 15 metres thick, underlain by clays and capped by brown loam. Great variations can be foreseen in the composition of this sequence along the meandering streams, and it is unlikely that the general flow of groundwater along the whole *tug* will be found. It is more probable that the large-grained, well-classified, water-bearing sediments form limited lenses which are confined to the meanders of the river where this type of better classified material is usually deposited. Because of their predominantly fine-grained structure and their considerable content in clayey materials, only a low yield of water can therefore be expected from the alluvial accumulations.

Drilling

All drilling was done by auger drills. The layout of the holes is shown on the hydrogeological sketch (figure 22). Boulders of hard rock were abundant in the sequence, and some wells had to be abandoned and redrilled a few metres away.

Some 20 wells, totalling 250 linear metres, were drilled. Of these, only nine cut the water-bearing formation, some only partially. Well No. 3a, the deepest, had to be abandoned because of mechanical failure at a depth of 27 metres, and a second No. 3 well was put down near it to a depth of 23 metres. The depth of the other wells ranged from 8 to 17 metres. Well No. 3 was test pumped, equipped with a filter and handed over to local authorities for use.

On chemical analysis, the quality of the water proved suitable for both domestic use and watering of livestock.

Summary and recommendations

The hydrogeological studies carried out around Bur Acaba clarified the groundwater conditions in the area. The areas of distribution of the three types of groundwater were outlined and their capabilities established. Several wells which tapped groundwater were drilled and the most successful of these was test pumped, equipped, and delivered for use.

As regards the feasibility of an adequate water supply in the area, it can now be affirmed that the water deficiency, assessed at 145 m^3/day, can be covered by making use of the three known types of groundwater.

Water in the alluvial accumulations of the Bur Acaba *tug* can provide limited supplies but if larger amounts of water are required, a dam would be preferable to a great number of wells.

Chisimaio area

At the request of Sayed Habib Ahmed, the UNDP Resident Representative in the Somali Republic, a hydrogeological survey was carried out in the Chisimaio area to help the Livestock Development Agency of FAO develop a water supply for livestock holding grounds. A reconnaissance hydrogeological survey was made and subsequent drilling was supervised by a United Nations expert.

Hydrogeology

The reconnaissance of this area revealed that all the wells, drilled and dug mainly along the Chisimaio-Afmadu road, gave brackish water which is nevertheless used for watering livestock. All of them, except those situated in the tug valleys, extract the groundwater from Tertiary sandy-clayey sediments.

A yellow-grey fissured and cavernous limestone, probably of Tertiary age, crops out at a distance of from 10 to 12 kms from the coast. It trends north-east and dips an angle of about 3° towards the north-west. The width of this limestone band is about 1 km on the outcrop, but its true thickness is unknown. This limestone is overlain by a sandy sequence. Assuming that the limestone outcrop constitutes the recharge area of a related aquifer, and taking into account its relatively small distance from the sites selected for the water wells, it was assumed that the water of the aquifer would be fresh or only slightly brackish.

Drilling showed two aquifers in the area. The piezometric level of the upper one is at depth of 50 metres. The corresponding water-bearing succession consists of grey quartz sands some 94 metres thick, underlain at a depth of 149 metres by a layer of dark plastic clay some 7 metres thick. The water of the upper aquifer is mineralized, up to 4,000 ppm. The lower aquifer, 34 metres thick, consists of inequigranular grey sand, which encloses clayey interbedding some 10 cm thick, particularly abundant in the lower part of the sequece. It is underlain at a depth of 185.5 metres by dark clay with thin intercalations of dark, fine-grained sands.

When the lower aquifer was reached, the water table in the well rose from a depth of 50 metres to 14.5 metres, showing that a confined aquifer had been encountered. Water from the lower aquifer proved, on chemical analysis, to be only slightly mineralized, containing no more than 200 ppm. The upper brackish aquifer was cased off, and the well equipped with a filter and delivered for use, as was also a second, 12 km north-east of the first.

Summary and conclusions

As a result of the hydrogeological survey, two water wells were drilled and delivered for use, covering the water requirements of the area for domestic purposes and for watering livestock. The information obtained leads to the conclusion that considerable amounts of fresh water can be obtained from the lower aquifer in the area. If more water is required, deeper wells will have to be drilled to tap the water confined in the limestone aquifer. If industrial water requirements arise, and if brackish water is acceptable, it can be obtained by drilling to a depth of 50 metres to tap the upper aquifer.

Northern provinces

In the course of 1968, the objectives of groundwater exploration were changed to the northern territories to help the Public Works Department select drilling sites and water sections. Six groundwater areas were selected: Hahi, Elayo, Huberu, Kadaftimo, Youbeh, and Behotleh. These were examined first by photogeology, then by geoelectrical depth probing. At Behotleh, 105 micromagnetic stations were made to try and detect a supposed fault. Drilling sites were selected at all the locations, and drilling commended.

During November and December 1968, at the request of the Government, the hydrogeology of the Burao area was examined to provide water for local use. Two potential drilling areas were selected, one to provide water for Beir, 20 km east of Burao, the other to provide water for Gao, 100 km west of Burao. By the end of 1968 the actual drilling sites had not been selected, and the possibility of drilling within Burao township itself was being investigated.

IX. Geological Survey Department of Somalia

The work of the project has shown that Somalia's potential mineral and groundwater resources are such that they may play an important part in the economic expansion of the country, and now that the port of Berbera has been deepened and other ports are projected in the southern part of the country, the time has come for these resources to be developed. As the economy expands, other developments will become possible and other requirements will arise.

A full inventory of a country's mineral wealth cannot be made in the short time available to a United Nations project, and such an inventory, to be kept up to date, [redacted]uires specialized techniques, a thorough knowledge of past results, and, in a co[redacted] where exploration is difficult over large areas, a well organized supporting s[redacted]e.

Mining, a[redacted]tural, and civil engineering enterprises will unavoidably be preceded by a nu[redacted]ber of academic studies, regional investigations and preliminary surveys, many of them marginal and even unproductive, which are beyond the scope of any private company and must be carried out by the Government. Similarly, the development of the water resources will require the systematic investigation of all the country's geological formations, classified into hydrological, morphological, and meteorological units and examined in conjunction with regional requirements and the problems of civil engineering.

A piecemeal approach to such an investigation can only be justified in the early stages of development when major deficiencies must be made good; otherwise, some requirements will be satisfied to the detriment of others.

A complete groundwater survey is too long an operation to be completed within the time allotted to a United Nations project and it also will demand constant readjustments as requirements become more complex. A time will also come when not only the search for new waters must be considered but the problems of their distribution and of the pollution of existing waters by waste.

With the advent of the mineral and agricultural developments foreseen in Somalia, the problem of water exploration has become urgent.

If the country is to benefit fully from the impetus provided by the United Nations project, it must form an organization to take over the work of mineral and groundwater exploration when the project withdraws. This need would be fulfilled by the creation of a national geological survey, working under the aegis of a technical ministry acting as advisor, or as executing agent, for the Government. This department would also provide an outlet for the nation's youth trained in earth sciences; it would stimulate national interest in mineral exploration and provide an organization to which individuals and companies already working in Somalia, or who may be attracted to Somalia, can turn for information and advice.

This need has not escaped the attention of the Government of Somalia which has given the project its full co-operation in long-term planning and has taken measures to ensure that a nucleus of young Somali engineers be trained in the earth sciences. Nine Somali geologists, geophysicists and surveyors were trained abroad under bilateral aid agreements, and since their return, they have been working with the project. A surveyor and a geologist have benefited by United Nations scholarships, while twenty young Somalis have been trained by the project as field geophysicists, geologists and drillers.

Moreover, the former headquarters of the British Geological Survey at Hargeisa has been re-opened and is being used as a base for the exploration of Northern Somalia. When the project (phase II) becomes operational, the building will accommodate the project personnel and give space for a laboratory, library and store, as well as cartographic and conference rooms. A new building is being completed in Mogadiscio to house the national geological survey. It will consist of two stories with a seven-room ground floor and a nine-room first floor. The layout of the building is shown on figure 23.

In 1968, a proposal, summarized below, was submitted by the project to the Government for the staffing of the geological survey department.

Explanatory note on the recommended establishment of a geological survey

Somalia is one of the few countries in Africa where very little work has been done in the past towards systematic geological and mineralogical study of the country; as a result, there are many basic difficulties in carrying out exploration for minerals and groundwater which may have an important effect on the rapid economic development of the country.

The systematic geological mapping of the country should, therefore, be started as soon as possible as well as the collection and completion of all available data resulting from the work of private companies in the field of oil exploration and other geological and hydrogeological work. The geological map is the basis for mineral exploration. At least two geologists are required for the geological mapping unit in the early stages. One of these geologists may specialize in photogeology.

Mineral exploration calls for the application of modern techniques such as photogeology, mineralogy, petrography, geochemistry, geophysics and special diamond drilling for core recovery. For this purpose, the estimated minimum number of posts required for the initial stage of the geological survey (covering a period of about five years) has been indicated in the respective units. Not all these posts can be filled immediately, but steps should be taken to find and train Somali personnel for them. Additional students should be encouraged to undergo the required studies and practical training.

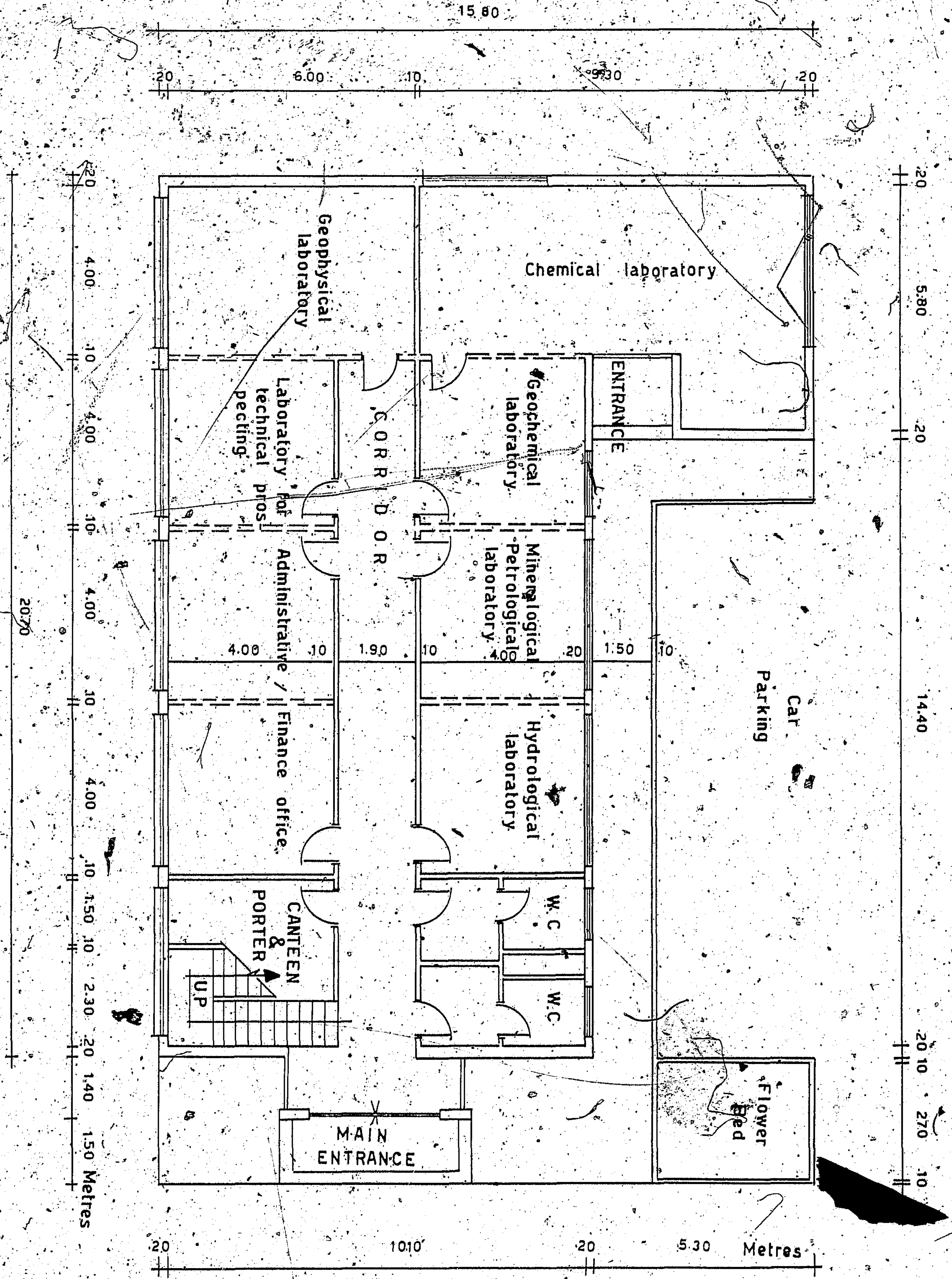


Figure 23a. Somali Geological Survey Building, Mogadiscio: Ground floor plan

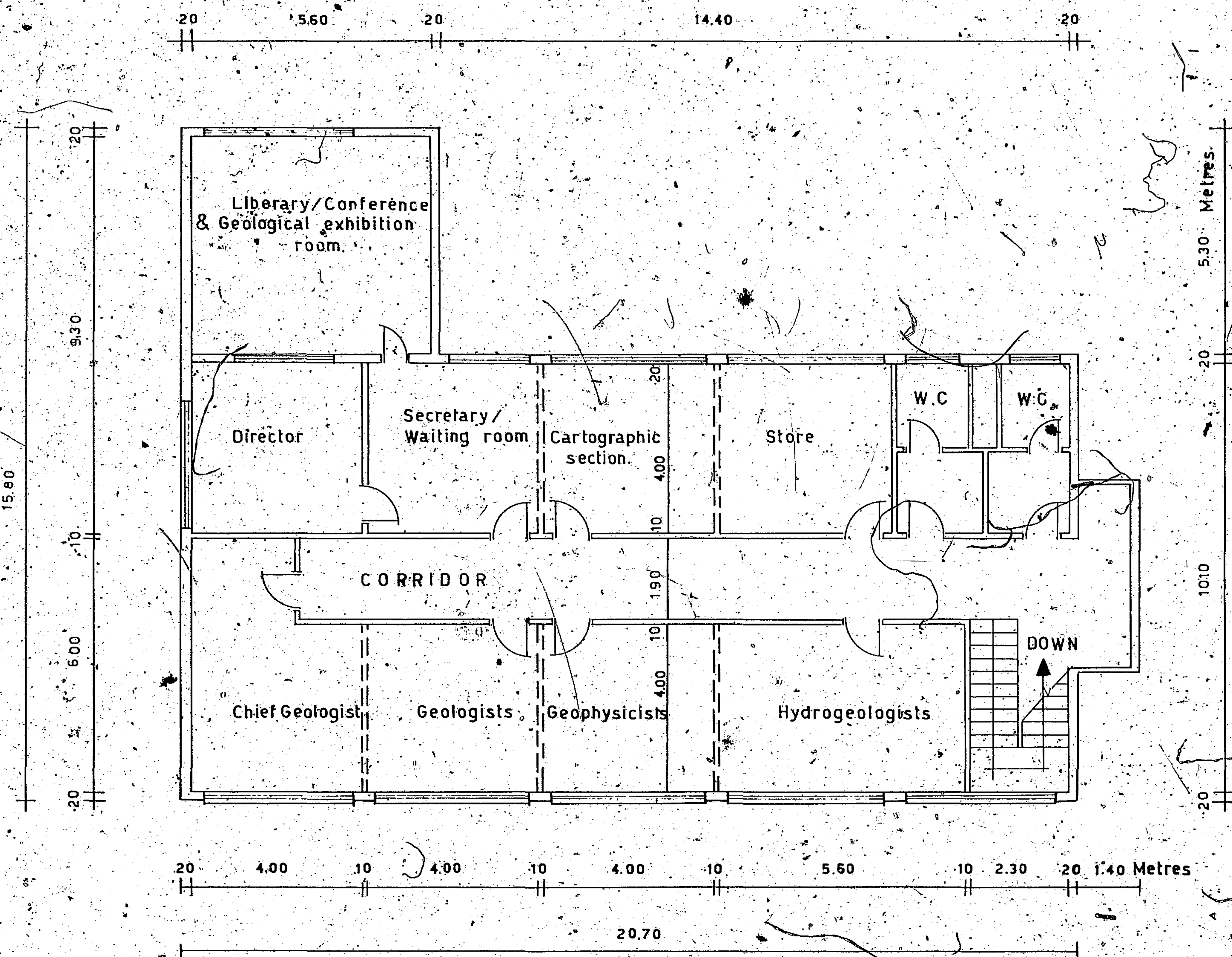


Figure 23b. First floor plan

Needless to say that Somalia, as its economy develops and the population grows, will need more and more water. A well-equipped groundwater unit in the geological survey department is badly needed. A specialist in engineering geology should be trained for public works construction needs (roads, bridges and dams).

Particular care should be given to the formation of an adequate drilling unit needed particularly for checking mineral discoveries and prospecting, and also for reconnaissance and test drilling and pumping for groundwater. Drilling of producing wells will, of course, be the responsibility of the Ministry of Public Works.

A map preparation unit is very important for the drafting and preparation for printing of the geological maps, diagrams and sections, and the illustration of geological maps, diagrams and sections, and the illustration of geological publications. (Complementary support and training assistance from the cartographic and topographic centre would, of course, be needed.)

In view of the difficulties of logistical support in a country of distances with limited communication facilities, a field servicing unit is desirable. Surveyors are required for field topographic work, particularly for such work as gravity measurements, and also for drilling operations. (Complementary support and training assistance from the cartographic and topographic centre would, of course, be envisaged as well.)

The planned administrative and accounts unit represents the minimum needed for the normal housekeeping functions and for typing and secretarial services. The fledgling survey will also draw upon the advice and assistance, centralized accounting, and personnel management services of the Ministry.

A library and documentation unit is particularly important for the conservation of archives and the collection of documentation on local and regional geology of Somalia and neighbouring countries.

A small museum forming part of the library and documentation unit will play an important role in the collection of characteristic samples of country rocks and minerals essential for the professional training of young geologists and technical aides, and for public information. The museum will also ensure the preservation of drilling cores and geochemical and geological samples collected during the field expeditions.

Finally, a properly functioning workshop is needed if project field operations and especially drilling are to be efficiently carried out, and if professional staff time is not to be wasted and mobility reduced for lack of properly serviced drills and vehicles. Similarly, proper maintenance of valuable laboratory and technical instrumentation is important, and an instruments technician should be specially trained for this.

The proposals outlined above and in the tentative organization chart and establishment listing shown in annex III are considered optimum requirements having regard to the magnitude of the task and its importance for the development of the country's mineral resources (including groundwater). It is hoped that this target can be achieved over the first five-year period of the establishment of the survey, although at the outset (say the first two or three years) only about 60–70 per cent of the professional posts may be filled. It is understood that some nine Somali geologists have already returned, academically qualified after studies abroad, and that at least four more will return in the near future; and additional personnel are undergoing training abroad in this field. It is important that full use be made of this valuable and expensive training for the betterment of the country.

X. Conclusions and recommendations

A. Conclusions

Bur area

Geological coverage

The Bur area was explored by aerial geophysics, by photogeology and by a wide network of geological, geochemical and geophysical traverses.

Lithological sequences were sampled and classified, structures were analysed, geochemical and metallometric samples were tested and rock types were determined chemically and mineralogically. This was completed by the detailed surface and underground exploration of certain of the iron-bearing and radioactive areas.

The work was hindered by the presence of a thick mantle of soils which concealed the rock outcrops, by the dense vegetation, by the absence of landmarks in a flat, monotonous area, and by the lack of good topographical control.

The results were reported to the Government embodied in a regional geological map, drawn to a scale of 1,200,000 (map 1) and supplemented by reports and two separate maps showing the hydrology and morphology of the area. Much of the interpretation was done on geophysical and geological evidence only, which it is recommended should be verified later, and the absence of a proper triangulation has undoubtedly led to a certain amount of topographic distortion. In spite of this, the geological map is sufficient to constitute the basic document for future mineral and groundwater exploration, for agricultural developments and for civil engineering.

Evaluation of iron-bearing formations

Among the iron-bearing outcrops already known, and the anomalies located by the aerial survey, those at Bur Galan-Daimir, and others situated in an unnamed area 60 km to the south, were considered to be the most important.

Previous experts have recommended the exploration of Bur Galan-Daimir as being the best, and as being typical of the other ore showings; they were also the easiest of access, and were therefore chosen for the project's initial exploration.

The outcrops of ferruginous quartzites were followed over a distance of 43 km by geological and geophysical methods, and they were found to consist of discontinuous beds of banded magnetite and hematite quartzites similar to those which occur in areas of upper Pre-Cambrian rocks throughout the world.

The average width of these outcrops is between 15 and 20 metres. The formation dips steeply and is complicated by faulting and folding, which in places produce a local widening to 50 metres through duplication of the beds.

The persistence of these narrow bands to any considerable depth is doubtful as, in other parts of the world, they are roof pendants of upper Pre-Cambrian in the rocks of the lower Pre-Cambrian, and either pinch out rapidly at depth or grade into granite.

The deposits at Daimif and Bur Galan are two such occurrences of widening by duplication. They were explored in detail by systematic geophysical and geological surveying, by pitting, trenching, and some shallow diamond-drilling.

Out of a maximum thickness of 50 metres, some 20 metres lying along the footwall consist of quartzites containing only 20–25% Fe, which can be rejected immediately as being of too low a grade for beneficiation under local conditions, whilst the remaining 30 metres contain between 30% Fe and 40% Fe, with an average content probably around 32% Fe to 33% Fe, possibly as high as 36% Fe.

Surface samples of this material, enriched by weathering to 40.6% Fe and more easy to beneficiate than will be the deeper lying rock, were sent to Warren Springs Laboratories (United Kingdom) for a mineralogical examination and preliminary beneficiation testing. These tests showed that a concentrate containing 60–67% Fe could technically be obtained for an 80 per cent iron recovery.

The over-all geological reserves of these outcrops were assessed at 170 million tons of ore, down to a hypothetical depth of 100 metres. Of this amount, 112 million tons were at thickness which could potentially be mined.

Taking into account the low-grade material which must be excluded and the waste interlyers reported as occurring in the ore, these potentially mineable reserves must be reduced further to 72 million tons.

To obtain a 65% Fe concentrate, at an 80% Fe recovery, starting with an ore containing on average 36% Fe, 2.25 tons of ore will have to be mined to produce one ton of concentrate. The mineable reserves of 72 million tons will thus be reduced to 33 million tons of marketable reserves.

Assuming that the unexplored area 60 km to the south contains similar reserves, the total iron ore potential of the Bur region amounts to some 65 million tons.

An analysis of mining conditions shows that, taking into account the waste/ore ratio in the pits and the concentrating ratio in the plant, 7 tons of material will have to be handled to produce a ton of concentrates. An operation producing more than 1 million tons per year of marketable product would not be technically feasible.

Conditions of transport and of shipment were also examined, and assuming that a suitable port already existed in Somalia, and by comparison with other mines, the following *minimum* figures of investments and costs were established:

Investment (In millions of dollars)

Mine and beneficiation, including pelletizing	50
Railway	20
Port ore-handling facilities	2
Stocks, operating capital, etc.	3
	75

Costs per ton (In dollars)

Pit expenses	3.70
Concentration	2.75
Pelletizing	1.25
Rail transport	1.75
Port	0.50
Servicing of capital	5.75
Total: f.o.b. pellets	16.70
f.o.b. concentrates	14.70

If part of the transport investment were to be paid out of public funds, these f.o.b. costs could be reduced to $15.90 and $13.90 respectively.

As against this, the price, including insurance and freight, of similar products now being delivered at Rotterdam, which can be taken as representative of world market prices, is $14.00 for pellets and $8.50 for concentrates. From these prices, the cost of freight must be deducted.

Calculating on distance alone and on availability of shipping, freights from Mogadiscio to a European, North American, or Japanese port in a ship of over 50,000 tons of dead weight, or in a ship of 15,000–20,000 tons dead weight for a 1500-mile haul to a neighbouring country, can be assessed at a minimum of $3.00 per ton.

The most that Somalia [illegible] expect to receive for its iron ores, f.o.b. port, would be therefore $11.00 for pellets and $5.50 for concentrates.

The operation would therefore run at a loss of $4.90 to $8.40 per ton produced, far too big to be compensated by any improvement in estimating.

It is concluded, therefore, that the iron ore deposits in Somalia are not economic to mine and will not be so in the foreseeable future.

Geophysical exploration also outlined several broad, low-grade anomalies, which were not investigated. It was suspected that they might correspond to greenstones containing magnetite, such as are successfully mined elsewhere. This is not impossible, but it is more probable that they correspond only to local but insignificant complexities in the basement rock.

No exploration of them is recommended at present. They could be investigated by a few drillholes in the future, after more immediate objectives in the area have been achieved.

Evaluation of radioactive occurrences

The aerial survey outlined 38 radioactive anomalies which gave over 1.5 times the background readings, lying in an area some 100 km by 100 km. The relationship between ground clearance and flight-line distances was such that this inventory may be incomplete. The Alio Ghelle anomaly was chosen for initial exploration, though it was not the best, because it was the first to be located on the ground and was the one of easiest access.

Ground exploration showed that the wide anomalies registered on the flight-lines corresponded to a dispersal of radioactive minerals throughout the surface mantle and that such areas contained peaks of higher radioactivity which corresponded to the bodies of primary ore hidden below this mantle.

Thus, the Alio Ghelle occurrence consisted of twin anomalies, each generated by a separate ore body, elongated along a NE-SW axis and lying with their centres some 170 metres apart, separated by a barren zone.

Surface and underground exploration showed that the actual ore bodies consisted of sheets or lenses of highly albitized rock, containing 3.30% ThO_2; 0.12% U_3O_8; and 0.080% Y_2O_3. The north-eastern anomaly, which is the most extensive, was surface tested by pitting, trenching and auger drilling and was followed down to a depth of 120 metres by 14 diamond drillholes, first laid down according to geophysical and geological considerations, then on a grid pattern which was not completed. The south-western anomaly was extensively surface tested but only one diamond drillhole was put down, and this was stopped at 40 metres for technical reasons. All openings were continuously tested by Geiger counter or scintillometer probe.

The cores from DDH1 and DDH2 were assayed in the project's own laboratory and duplicate samples of the mineralized cores were sent for check assays to the Institute of Geological Sciences, London, and to the Eldorado Mining and Refining Company, Ottawa, Canada.

Various samples were sent for mineralogical determination to Columbia University, New York, and to the All-Union Geological Institute, Leningrad, USSR.

Warren Springs Laboratories (United Kingdom) carried out preliminary concentration and beneficiation tests on the samples sent to the Institute of Geological Sciences, London. They found that the run of mine ore could not be treated economically by acid leaching because of its high content in alkalis, but that a simple gravity process gave a concentrate containing 30.0% ThO_2 and 0.83% U_3O_8 with recoveries of 63.3 per cent and 53.2 per cent respectively, which was amenable to leaching and separation. The figures would be certainly improved on an industrial scale and especially with finer grinding.

All results of exploration and testing have so far bee[illegible]vergent and the mineralization can now be defined as consisting principa[illegible] thorite, containing admixtures of uranium, yttrium, ytterbium, and possibly scandium and europium. Independent uranium minerals were also identified as were doubtful xenotime and thalenite.

The present ThO_2 U_3O_8 ratio is 26.6, but all the samples examined so far come from the zone of weathering and it is probable that many of the primary uranium minerals have been leached out at these levels in the ore body.

The statistical analysis of the assay results shows that they fall into two populations, one with an average content of U_3O_8 within 0.13–0.14 per cent which conforms with the normal law of distribution, the other, representing 25 per cent of the samples, containing an average 0.04 per cent and corresponding probably to areas from which uranium has been leached out, along fissures or near the surface.

Once the principal characteristics of Alio Ghelle had been established, the survey was expanded to cover the neighbouring area. It revealed two more anomalies, Northern, lying 500 metres north of the main occurrence, and Ant-hill, lying 400 metres to the south-west. All four anomalies fell within a 50 cps contour which trended south-west. Its extension was therefore explored in the direction and two more anomalies were found, Airport and Road, respectively 3 km and 8 km to the south. All these anomalies were surface-tested, and they appear to conform with the pattern already established at Alio Ghelle.

Anomalies Ant-hill, Alio Ghelle, and Road all lie on one alignment, 8,000 metres long. This alignment was cleared of bush over a distance of 10 km and a detailed radiometric survey was started. A continuous radioactive band, at least 3,000 metres long, lies 3 km east of Alio Ghelle and was called the "Water Collection" anomaly.

The structural controls which govern the mineralization were not established, though there are indications of shearing and faulting.

The Yaq Brava anomaly, which was the most important indicated by the aerial survey, was identified on the ground, following a reinterpretation of the aerial findings over a surface of 1,250 km, in the light of the information obtained from the study of Alio Ghelle. It appears to correspond to a fault line along the contact between the basement and Jurassic rocks and had so far eluded discovery. The primary ore remains to be found.

The work carried out by the project was restricted to the weathered zone of one orebody among many and to the area immediately surrounding it. It is premature to speak of possible, or even potential reserves, but all the results achieved so far have systematically tended to confirm the presence of a widespread thorium-uranium mineralization which corresponds to the pattern known in other parts of the world.

The information obtained on one anomaly enabled the project to expand its exploration and to find four other anomalies and a continuous radioactive band 3,000 metres long.

Applied to the reinterpretation of a completely different part of the Bur Area, this information enabled the project to locate other anomalies which had until then eluded them.

Such consistent results, considered in conjunction with the uniformity of the basement formations in the Bur Area, lead one to expect that the pattern of the Alio Ghelle occurrence will be repeated on the other anomalies and that these will be of similar interest.

Other minerals

Tin, silver and copper are represented by high values found during the geochemical exploration of the Bur Acaba area. These indications were not followed up, and their origin is not known. They merit further investigation.

Pegmatite veins are numerous in the eastern part of the Bur area. Some are several metres thick and appear to persist along the strike. The microcline feldspar they contain is chemically suitable for a ceramics industry.

Marbles, varicoloured and of good quality, occur in large outcrops, 3 km south of Modu Mode village, 9 km north north-west of Bur Acaba, in the Dinsor area and in the Bur Galan area. They will become of interest once the area has been opened up.

On the negative side, the titanium and manganese showings in the Bur Acaba area and the phosphorous-bearing rocks around Modu Mode are too insignificant to warrant further exploration.

Bur sepiolite

The sepiolite being mined on a small scale at Bur, occurs in a flat-lying outcrop which covers an area of 1.5 × 6.0 km. It is thickly overgrown. The deposit was provisionally mapped and sampled. The material appears to contain on average of 79 per cent sepiolite as against 89 per cent for similar material from Tanzania. It therefore appears unsuitable for highly refined manufactures but undoubtedly has some industrial use.

Bauxite

The whole country was divided into geological, morphological and climatic units, and each was surveyed and assessed on its own merits by a specialist in bauxite. No indications were found in any of the areas of rocks and conditions suitable for the formation of bauxite. The surface accumulations, which contain free aluminous hydrates, near Manas in the north-west part of the Bur area, consist of bauxitic-lateritic materials which obviously originated, geologically, elsewhere, and were redeposited. They are too low grade and irregular to be economic. There is thus no expectation of finding bauxite in Somalia, but a search may be fruitful in neighbouring countries.

Northern territories

Work, so far, has consisted of a re-appraisal of the findings of the former British Geological Survey, principally in the Berbera and Hargeisa areas.

The Pre-Cambrian formations contain fields of pegmatite veins and quartz veins bearing cassiterite, columbo-tantalite, beryl, piezoelectric quartz, and industrial feldspars. Some of these veins are mined by hand methods.

Veins of galena occur in the Erigavo district, at Fulanful, Wiget, and Dananjieh and may be the manifestation of more extensive fissure deposits.

Associated molybdenite-bismuthinite-galena mineralization occurs south of the Buhl massif, 40 km north-west of Hargeisa. This intrusion contains alkalic rocks which may well correspond to larger occurrences.

Nepheline syenites occur 80 km north-west of Hargeisa and kyanite is found in the Hudiso area.

Gypsum occurs as a large hillside outcrop, 15 km south of Berbera. It is of easy access and has been provisionally sampled by the former British Geological Survey who estimated the existence of 5 million tons of rock containing over 80 per cent gypsum and 1.8 million tons of rock containing over 85 per cent anhydrite.

This deposit could become an important source of building material, and of sulphuric acid for the potential Somali uranium industry, but it requires further investigation.

Coal, lignite and oil shale have also been reported from the northern provinces.

As against this, all the showings of chalcopyrite, malachite and azurite which had been previously reported and were visited, were found to correspond to insignificant occurrences or to "paint" along fissure walls. None of them merited further investigation.

Groundwater survey

The survey for groundwater was limited to the Bur Galan-Daimir iron bearing area, the Bur Acaba basin and the Chisimaio area.

Bur Galan-Daimir area

This contains several springs adequate for present requirements but insufficient for industrial purposes. The best potential aquifer in the area is the Jurassic limestone, whose contact with the basement formation is marked by several fresh-water springs. The survey suggests that this may constitute a persistent aquifer, but this opinion must be confirmed by further investigation and drilling.

Within the area of basement rocks, water is confined to fault and shear zones which feed subsurface depressions, filled with considerable thicknesses of unconsolidated formations, from which the water can be extracted. These should be identified.

Bur Acaba area

Three water-bearing features can be identified:

(*a*) Fissure zones in the basement rocks that largely underlie the area and which are covered by an eluvial mantle from which water can be locally extracted;

(*b*) The mantle itself which, under 2 to 5 metres of impermeable claybed, contains alternate beds of clayey sands and of coarse detrital materials. These can be up to 27 metres thick, and they constitute an impersistent aquifer;

(*c*) The alluvial accumulations in the dry river (*tug*) valleys and in their flood plains. The accumulations of water are here apparently confined to lenses or fans of coarse-grained, well classified sediments.

These findings were confirmed by drilling several wells and laying out the data on a hydrogeological map to a scale of 1:10,000. This showed up a subsurface depression which apparently contains a considerable volume of groundwater.

The total water available at present in the area is estimated at 75,000 m^3/year, as against an estimated requirement of 128,000 m^3/year, principally for agricultural purposes. This constitutes a deficit of 145 m^3/day.

The survey shows that, if the potential water resources of the basement rocks, of the eluvial mantle and the alluvial fans, were all properly mobilized, the present deficit could be made good. Such work would probably have to include the building of earth dams.

Chisimaio area

All the wells along the Chisimaio-Afmadu road, except those dug in alluvials, give water containing on an average 40,000 ppm total dissolved solids. This is drawn from Tertiary sands and clays, probably fed by a bed of fissured and cavernous limestones which outcrop 10–12 km from the coast, trend north-east and dip at about 3° to the north-west.

Drilling showed that, in fact, there were two aquifers. The piezometric level of the upper is at a depth of 54 metres and this relatively shallow aquifer consists of 94 metres of quartz sand, underlain at a depth of 149 metres by 7 metres of plastic clay.

The lower aquifer, which is confined, is constituted by 34 metres of grey sands, underlain at a depth of 185.5 metres by dark clay. When the lower aquifer was reached, the water level in the well rose from a depth of 50 metres to 14.5 metres.

The water from this aquifer contains 2,000 ppm of totally dissolved solids.

Two water wells were drilled, cased off and delivered for use. Any appreciable increase in the water supply will probably have to come from the limestone aquifer, of which the exploration is recommended.

Northern provinces

Water exploration was recently started in the northern region.

B. Recommendations

Bur area

At the request of the Somali Government, and upon the recommendation of F. R. Joubin, consultant to UNDP, this area has been relinquished by the United Nations project and opened to mining concessions.

United Nations activity as regards this area is limited to an advisory capacity, aimed at assisting the Government in its negotiations with private companies and in establishing a unified mining code for Somalia.

The following recommendations may, however, be of use.

1. *Iron ore occurrences.* No further exploration for iron ore is recommended in the foreseeable future.

2. *Radioactive occurrences.* The following points regarding the exploration carried out by the United Nations project should be borne in mind:

   (*a*) The aerial inventory of the anomalies may be incomplete;

   (*b*) The intensity and area of the aerial anomalies cannot be taken as an indication of the value of the underlying, hidden, primary ore body;

   (*c*) All the data so far collected refer to the zone of weathering;

   (*d*) The structural controls of the mineralization remain to be found;

   (*e*) Results so far achieved all seem to indicate that the conditions governing the Alio Ghelle occurrence may be typical of the Bur area as a whole.

3. *Tin, silver, copper.* The high geochemical values encountered in the Bur Acaba area undoubtedly merit following up as soon as opportunity permits.

4. *Pegmatites, building materials.* These will be of interest primarily to a future ceramics industry and a future building industry. They can have no economic value until the area is provided with adequate transport and industrial facilities. No immediate investigation of these occurrences need be undertaken.

Bur sepiolite

If the Bur sepiolite deposits are to be developed on a large scale, considerable further knowledge is required as regards their grade, geology, thickness and lateral extent. In particular, systematic sampling should outline such areas of better grade material as may exist.

The following course of action is therefore recommended:

(*a*) Put down 15 diamond drillholes on a systematic grid measuring 2,000 × 750 metres to a presumed average depth of 30 metres;

(*b*) Make mineralogical and chemical analysis of the cores;

(*c*) Carry out systematic pitting and trenching on a wide grid according to the findings of the drilling;

(*d*) Take bulk samples of the pits and trenches for industrial testing.

Bauxite

No further exploration for bauxite is recommende[illegible]

Minerals of the northern provinces

In spite of all the work which has been done, [illegible] occurrences in the area is insufficient to warrant an [illegible] value.

Mining methods have been too elementary to give any indication as to what industrial conditions would be like.

Drilling in this area has been restricted to three holes on the Suriah Malableh gypsum deposit and to four holes on the Fulanful and Danajieh galena occurrences. None of the other deposits have ever been explored at depth and there is no knowledge as regards metallogenesis.

When the area was explored by the British Geological Survey and during the first years of exploration by the project, the uranium deposits of the Bur Area were still unsuspected and no particular attention was paid to the search for radioactive minerals in the northern provinces. The geological exploration has shown, however, that a number of points of similarity exist between the rock formations in these two Pre-Cambrian areas and the search for radioactive materials in the northern territories should no longer be neglected.

With the development of the port of Berbera to take boats of 9-metre draft, with the possibility of deepening to 11 metres, the mineral exploration of the northern provinces assumes a new urgency, and the following course of action is recommended:

(*a*) Limit exploration initially to the areas of basement rocks and intrusives;

(*b*) Cover these areas by an airborne geophysical survey to complete and supplement the existing geological coverage;

(*c*) Follow up by geological, geochemical and geophysical surveys, starting with the most promising areas, particularly directed towards the search for radioactive minerals and for cassiterite;

(*d*) Expand this survey to cover the areas of pegmatites and gneisses surrounding the Buhl intrusion, to search for molybdenum, tin, berylium, copper, lead, tantalum, mica, feldspar and quartz;

(*e*) Sample promising mineralized occurrences and map them;

(*f*) Probe the most promising occurrences at depth by geophysical methods and follow this up by diamond drilling and/or tunnelling;

(*g*) Independently of the above, re-assess the Suriah Malableh gypsum deposit and make a feasibility study. Re-assess the occurrences of fuels and of building materials in the light of the potential economic development of the area.

Groundwater

The United Nations survey was limited to three circumscribed areas and carried out by only two specialists.

Nevertheless, it showed that present requirements and foreseeable future domestic requirements could be met by mobilizing known resources. It also showed that there were considerable potential water resources within the country, in the fissure systems of the basement rocks, in the Jurassic limestones, in the accumulations of surface formations and in river underflows.

It did not have the time or the means to follow up these indications or to establish where reserves of water sufficient for industrial purposes were to be found.

Lack of water can be nearly as great a handicap to mining development as would be an inadequacy of the ore; and water is essential for agricultural development. With the possibilities now emerging in Somalia, this problem has become one of urgency which can only become increasingly acute.

It is, therefore, strongly recommended that a permanent groundwater section be established within the geological department and that it be entrusted with the following three primary functions: (*a*) to inventory the country's resources in groundwater; (*b*) to assist the Ministry of Works in its water activities; (*c*) to train Somali personnel in groundwater techniques.

REFERENCES

Unpublished reports prepared by the project or by the Somali Geological Survey are available at the *Geological Survey Department, P.O. Box 744, Mogadiscio, Somalia.*

A. *Minerals*

Azzaroli, A. C. *and* G. Mapla. Carta geologica della penisola Somala (1:400,000). Roma, 1960.

Dainelli, G. Carta geologica dell' Africa Orientale (1:2,000,000). Reale Accademia d'Italia. Centro Studi dell'Africa Orientale. Roma, 1953.

Dainelli, G. Geologia dell'Africa Orientale. Vol. I, bibliografia. Reale Accademia d'Italia. Centro Studi dell'Africa Orientale. Roma, 1943. 464 p.

Daniels, J. L. Photogeological study of the Bur region, Somali Republic. Overseas Geology and Mineral Resources. (4) 9:427–437. 1965.

Farquharson, R. A. First report on the geology and mineral resources of British Somaliland. London, Waterlow and Sons Ltd., 1924. 53 p., map (1:1,000,000).

Gellatly, D. C. Carbonatites of the Darkainle Nefeline syenite complex. University of Leeds. 8th Ann. Rept. (1961–1962).

Geological Survey Department, Somaliland Protectorate. Ann. Repts. (April/March). 1952–1953, 13 p., mimeograph; 1953–1954, 11 p., mimeograph; 1954–1955, 16 p., mimeograph; 1955–1956, 31 p., mimeograph; 1956–1957, 13 p., mimeograph; 1957–1958, (Hargeisa, Government Press, 1958) 18 p.; 1958–1959 (Hargeisa, Government Press, 1959) 22 p.; 1959–1960 (Hargeisa, Government Press, 1960) 27 p.; 1960–1961 (Hargeisa, London, Crown Agents, 1962) 17 p.

Holmes, R. J. The mineral deposits of Somalia. Bibliography. World Mining Consultants, 1953. 54 p.
Mimeograph.

Somaliland Oil Exploration Co., Ltd. A geological reconnaissance of the sedimentary deposits of the Protectorate of British Somaliland. London, Crown Agents, 1954. 42 p., map (1:1,000,000).

B. *Groundwater* (in chronological order)

1. MacFadyen, W. A. Water supply and geology of parts of British Somaliland. 1955. 183 p.
Mimeograph.

2. Hunt, J. A. A general survey of the Somaliland Protectorate, 1944–1950. London, Crown Agents, 1951. 203 p.

3. Corfitzen, M. E. *and* G. Kinzy. Preliminary report on Somalia agricultural projects. Rome, E.C.A., 1950.

4. Usoni, L. *and* G. Parisini. Relazione sulle possibilità idriche del sottosuolo della Somalia. Roma, Ministry for Africa, 1951.

5. Ahrens, T. P. A reconnaissance groundwater survey of Somalia. East Africa. Roma, Comitato Interministeriale per la Ricostruzione, 1951. 270 p. 4 maps.

6. Wilson, G. Groundwater geology in Somalia. Mogadiscio, 1958.

7. Faillace, C. Surface and underground water resources of the Shebli valley. Mogadiscio, 1964.
   Contains detailed bibliography.

8. Food and Agriculture Organization. Agriculture and water survey, Somali Republic. June, 1966. Final report.

9. Konoplyantsev, A. A. Groundwater conditions in the area of Daimir and Bur Galan ferruginous quartzite deposits. Mogadiscio, 1966.
   Unpublished.

C. *Technical reports prepared for the Government of Somalia as part of the Mineral and Groundwater Survey* (in chronological order)

1. Report on prospecting and re-interpretive operations in the northern provinces of the Somali Republic during the period of March-October, 1965. By E. Malyutin, economic geologist, 1965. 28 p., maps, bibliography.

2. Report on sepiolite/meerschaum in the Somali Republic. By A. I. Katskov *and* E. S. Sherr, associate expert, 1966. 24 p., bibliography.

3. Report on the geology of the Bur area. By A.V. Ilyin, photogeologist, 1967.
   Explanatory note to the geological map of the BUR area (1:200,000).

4. Interpretation and operational report of the airborne magnetometer and scintillation counter survey in the Somali Republic. By C. E. Curtis *and* R. K. Harman (Canadian Aero Survey), 1967.

5. Report on the geology of the iron ore deposits of Daimir and Bur Dur. By A. I. Katskov, Project Manager, 1967.
   Preliminary exploration results.

6. Report on the results of the hydrogeological work carried out in the Bur Acaba area in the Somali Republic. By V. A. Strukov, associate expert, 1967.

7. Report on the results of the geological prospecting operations carried out in 1966 on the Modu Mode apatite occurrence (phosphorus). By L. Bryzgalov, economic geologist, 1967. 27 p., map.

8. Report on the iron ore deposits of Daimir and Bur Dur, Bur area, Somali Republic. Romanian Mining Design Institute, 1967.
   Preliminary feasibility report.

9. Report on the geology of the Alio Ghelle thorium/uranium deposit. By N. I. Nefedov, mineralogist/petrologist *and* V. S. Lartsev, associate expert, 1968. 40 p., map and vertical section (1:1,000).

10. Report on the beneficiation of Somali iron ore. By T. J. Hickey *and* K. J. Henley (Warren Spring Laboratory), 1968. Ministry of Technology.

11. Report on the prospect of finding bauxites in tropical East Africa (Somali Republic). By B. M. Mikhailov, economic geologist, 1968.

12. Report on the uranium-thorium-rare earth deposits of the Alio Ghelle ore field in the Somali Republic. By A. I. Katskov, Project Manager *and* V. S. Lartsev, associate expert, 1969. 129 p., 17 maps and diagrams, 8 photographs.

D. *Target reports prepared by the Geological Survey Department, Somaliland Protectorate*

Daniels, J. L. Report on the geology of the Borama and parts of the Hargeisa districts. Quarter degree sheets No. 2, 8, 12, 20, 21, 32, 33, 44.
Typescript.

Greenwood, J. E. G. W. Report on the geology of the Las Khoreh-Elayu area, Erigavo district. Quarter degree sheets No. 5, 6 (1:125,000). London, Crown Agents, 1960. 36 p., appendix: The cassiterite deposits of the Dalan area. By J. A. B. Stuart.

Hunt, John A. Gypsum and anhydrite in the Somaliland Protectorate. Hargeisa, 1954. 4 p.
Mimeograph.

______. Report on the geology of the Adadleh area, Hargeisa and Berbera districts. Quarter degree sheet No. 35 (1:125,000). London, Crown Agents, 1958. 16 p.

______. Report on the geology of the Berbera-Shiekh area, Berbera and Burao districts. Quarter degree sheets No. 24, 36 (1:125,000). London, Crown Agents, 1960. 27 p.

Mason, J. E. (revised by A. J. Warden) Report on the geology of the area north of Hargeisa and Laferug, Hargeisa and Berbera districts. Quarter degree sheets No. 22, 23, 34 (1:125,000). London, Crown Agents, 1960. 34 p.

Pallister, J. W. Mineral resources of Somaliland Protectorate. Overseas Geology and Mineral Resources, 7(2):154–165.

E. *Unpublished reports* (typescripts)

Daniels, J. L. A magnetic and geological survey of the iron ore and associated rocks at Culi-Culi south of Bur Acaba. c. 1954 (JLD/25 and JW/18).

______. A magnetic and geological survey of the iron ore and associated rocks of the Bur Galan region, near Baidoa. c. 1954 (JLD/24).

______. A preliminary note on the molybdenite occurrence at Darkainle, near Dobo, Borama district. 1959 (JLD/15).

______. A short report on an occurrence of beryl and slightly radioactive columbite in pegmatites in the Waran Weis and Theb valleys, 45 NNW of Hargeisa. 4 p., map. 1958 (JLD/4).

______. Minerals and rocks of possible economic significance from Hargeisa and Borama districts. 11 p., maps. 1959 (JLD/14).

Gellatly, D. C. A short note on the Afka Dehemid talc deposits. n.d. (DCG/10).

______. The cassiterite deposits of Dalan, near Elayu, Erigavo district. 19 p., map. 1961 (DCG/12).

______. The geology of the area around Dalan, near Elayu, Erigavo district. n.d. (DCG/7).

———. The geology of the area around Manja Yihan, Bosaso district. n.d. (DCG/8).

Pallister, J. W. Suria Malableh gypsum-anhydrite deposit, Berbera district: estimate of reserves. 10 p., map. 1958 (JWP/8).

———. *and* A. J. Warden. Core-drilling on Suria Malableh gypsum-anhydrite deposit, Berbera district. 14 p., map. 1959 (JWP/11 and AJW/10).

Warden, A. J. A short report on the copper mineralization at Buhl, Hargeisa district. 8 p., maps. 1958 (AJW/8).

———. Geological report on the Suria Malableh gypsum/anhydrite deposit. 10 p., maps. 1957 (AJW/4).

ANNEXES

Annex I

PROJECTS COSTS

(According to Plan of Operation as revised 18 June 1966)

	Categories	*Totals*
1. *Staff*		
Special Fund contribution	$343,600	
Government contribution	196,668	$540,268
2. *Fellowships*		
Special Fund contribution		10,000
3. *Equipment and supplies*		
Special Fund contribution	$ 90,400	
Government contribution	65,000	155,400
4. *Sub-contracts*		
Special Fund contribution		195,000
5. *Sundry*		
Special Fund contribution	$ 20,600	
Government contribution	60,000	80,600
		$981,268

Annex II

PERSONNEL AND SCHOLARSHIPS

A. Personnel

International experts

A. I. Katskov	Project Manager	Jan 1964–present
E. I. Malyutin	Economic geologist	Nov 1964–Jan 1965
M. G. Dolgikh	Driller, prospector	Nov 1964–Jan 1968
Ph. Saprykin	Assayer	April 1966–March 1968
L. Bryzgalov	Economic geologist	Sept 1966–Jan 1968
A. V. Ilyin	Photogeoligst	March 1966–March 1967
E. I. Nefedov	Mineralogist, petrographer	Sept 1966–Jan 1968
B. M. Mikhailov	Economic geologist	Jan 1968–March 1968

Short-term consultants

A. A. Konopliantsev	Hydrogeologist	July	1966–Oct 1966
J. Cameron	Economic geologist	Jan	1967–May 1967

Bilateral aid associate experts

V. S. Lartsev	July	1966–March 1968
E. S. Sherr	Jan	1964–May 1967
B. Ingre	Jan	1967–March 1968
P. J. Bakker	Feb	1967–March 1968
V. A. Strukov	July	1966–July 1967

Government counterpart personnel, trained on bilateral aid

M. Y. Awalsh	Geologist	Jan	1965–present
A. S. Osman	Geophysicist	Jan	1967–present
M. S. Mursal	Geologist	April	1967–present
H. A. Farah	Petroleum geologist	Aug	1967–present
I. H. Adan	Mining geologist	Aug	1967–present
M. S. Abdi	Geologist	Aug	1967–present
A. M. Abdullah	Geologist	Aug	1967–present
A. H. Laran	Geologist	Aug	1967–present
M. S. Nur	Geologist	Aug	1967–present

A Somali national, Mr. H. A. Abdullah, was appointed by the United Nations on 1 January 1964 as Administrative and Financial Officer of the project.

B. Scholarships

Mr. Ibrahim Ali Essa, a draughtsman, returned from a scholarship overseas in August 1967.

Mr. Ahmed Mohamed Behi, a geologist, left for a scholarship at an American university in September 1967.

Annex III

GEOLOGICAL SURVEY DEPARTMENT, SOMALIA

A. Organization chart

(A3) Director

Geological section
- (A) Chief geologist and deputy director, 1
  - Geological mapping unit: (A) Senior geologist, 1; (A) Geologist, 1; (B/C) Geological aide, 1
  - Economic geology mineral exploration unit: (A) Senior economic geologist, 1; (A) Geologist, 2-4; (A) Mineralogist petrologist, 1; (B/C) Geological aides, 2-4
  - Groundwater eng. geology unit: (A) Senior hydrogeologist, 1; (A) Hydrogeologist, 1; Engineering geologist, 1
  - Geophysical unit: (A) Geophysicist, 1; (B/C) Geophysical operators, 4-6
  - Geochemistry unit: (A) Senior geochemist, 1; (A) Geochemist, 1-2; (B) Geochemical aides, 2-4
  - Drilling unit: (A) Drilling* engineer, 1; (C9) Drillers, 3; (C) Drilling aides, 3
  - Field service unit: (B7) Field supt., 1; (C) Field assts., 4; (D) Fieldmen, 30; (C) Surveyors, 2

Laboratory unit
- (A) Chief chemist, 1
- (B) Laboratory technicians, 2
- (C) Laboratory aides, 2

Map preparation unit
- (B7) Head draftsman, 1
- (B) Draftsman, 1
- (C) Draftsman, 1

Administration section
- Administrative accounts unit: (B7) Administrative officer, 1; (C) Accounts clerk, 1-2; (C) Stores clerk, 1; (C) Clerk / typists, 4-6; (D) Messengers, 4
- Library documentation unit: (B/C) Librarian museum supt. 1; (C) Library documentation clerk, 1; (C) Museum clerk, 1
- Workshop: (B) Workshop supt., 1; (C) Instrument technician, 1; (C) Auto drill mechanics, 2-3; (C) Blacksmith, 1

B. Staff

Rating	Post	Number of positions	Rating	Post	Number of positions	Rating	Post	Number of positions
A3	Director	1	B	Laboratory technicians	2	C	Accounts clerks	2
A	Geologists	9	B	Geochemical aides	2	C	Stores clerk	1
A	Geophysicist	1	B	Workshop superintendent	1	C	Clerk typists	6
A	Geochemist	1	B/C	Geophysical operators	6	C	Librarians and documentation clerk	1
A	Chemist	1	B/C	Geological aides	5	C	Museum clerk	1
A	Hydrogeologists	2	B/C	Librarian and museum superintendent	1	C	Instrument technican	1
A	Drilling engineer	1	C9	Drillers	3	C	Auto and drill mechanics	3
A	Mineralogist/petrologist	1	C	Laboratory aides	2	C	Blacksmith	1
B7	Draftsman	1	C	Draftsman	1	D	Fieldmen	30
B7	Administrative officer	1	C	Drilling aides	3	D	Messengers	4
B7	Field superintendent	1	C	Field assistants	4			
B	Draftsman	1	C	Surveyors	2		Total	103

Summary: A3, 1; A, 16; B7, 3; B, 6; B/C, 12; C, 31; D, 34

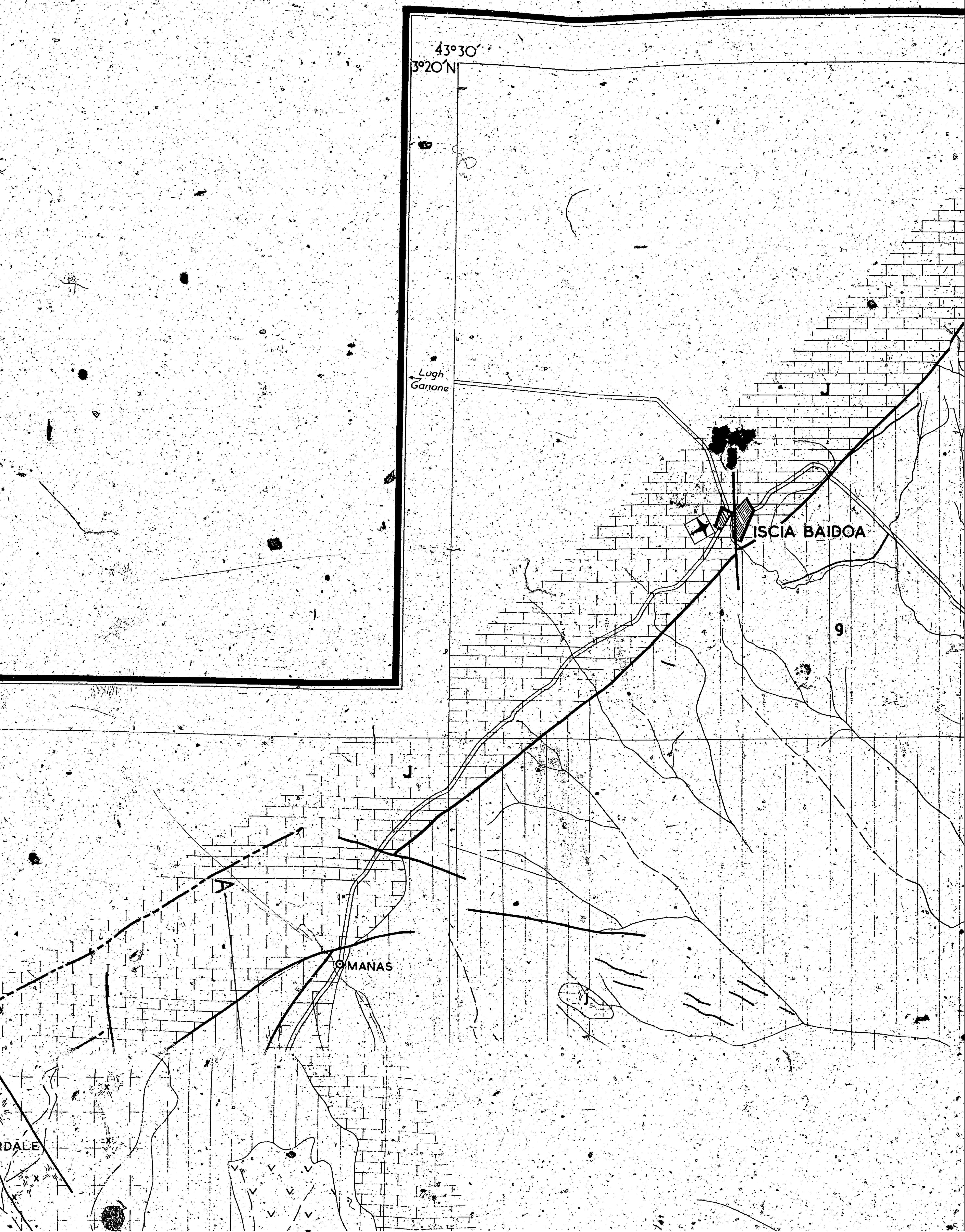
* Chief driller or drill foreman with B7 rating may suffice in the early years

STRATIGRAPHICAL COLUMN

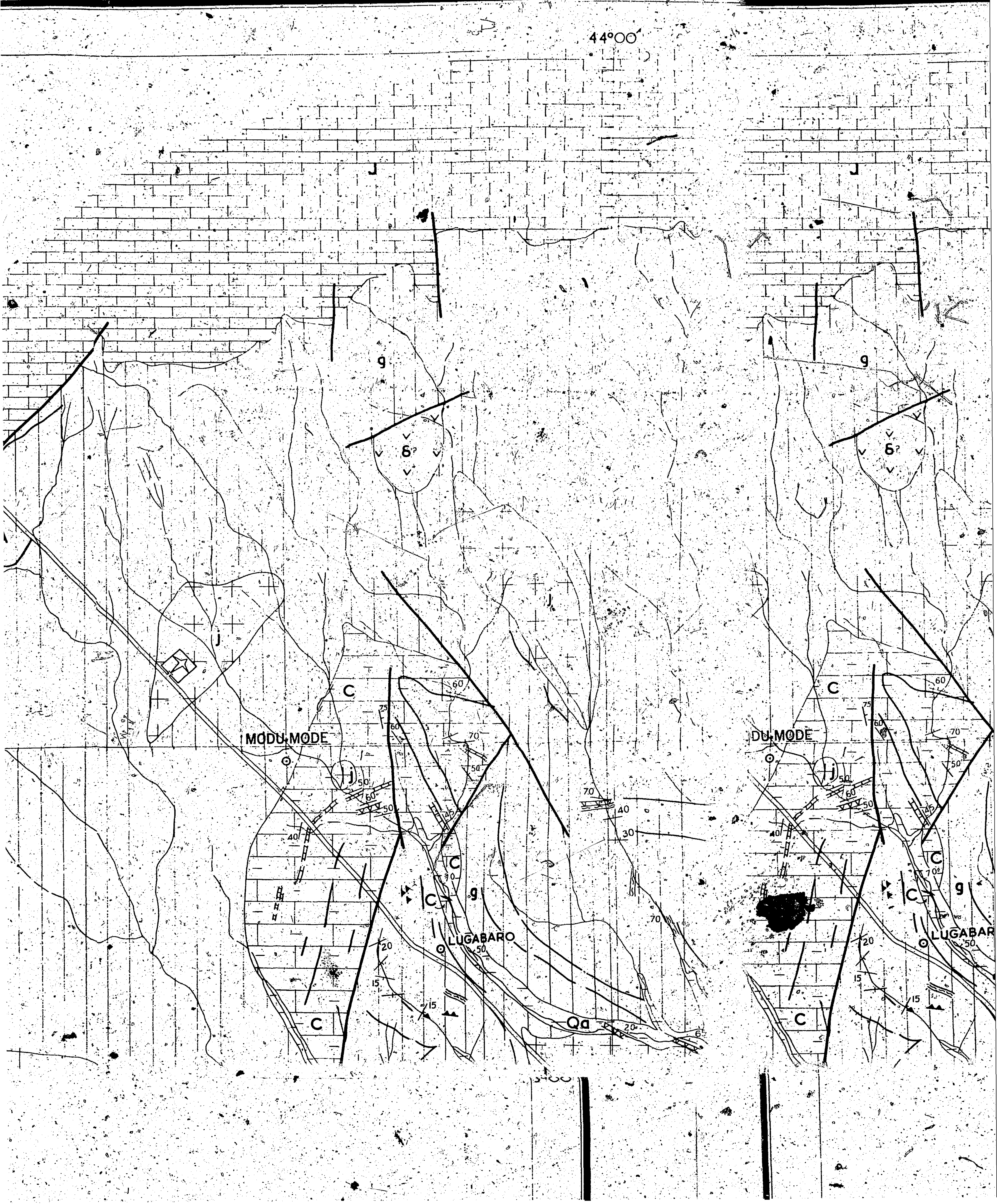
GROUP	SYSTEM	SERIES	INDEX	SECTION	THICKNESS IN METRES	DESCRIPTION
	JURASSIC		J	Si	500	White to yellowish-grey limestone. Thin to medium bedded, plated, Shelly limestone and algal limestone. Silicified, dolomitized and gypseous varieties. Occasional chalcedony inclusions. Remains of gastropoda and brachiopoda
-CAMBRIAN (BASEMENT)		CALC-SILICATE SERIES (UPPER)	C	P, Mn, Ti, Mg, J	2,500	Biotite gneiss and schists. Marble - white, pink and rose, micro to coarse grained Quartzites - milky white, greyish and violet. Rhodonite(?) marble. Sphene-bearing calc-silicate rocks. Dolomitic marble. Iron quartzite. Quartzite and gneissose $CaCO_3$
		SS SERIES (LOWER)		j	THOUSANDS	Grey biotite gneiss. Thinly foliated, dark grey, amphibole schists. Iron quartzite. Amphibolite - thinly foliated to massive. Black, massive, amphibolite.


43°00'
3°00'
BUR EIBI
BERDALE

1 : 200,000

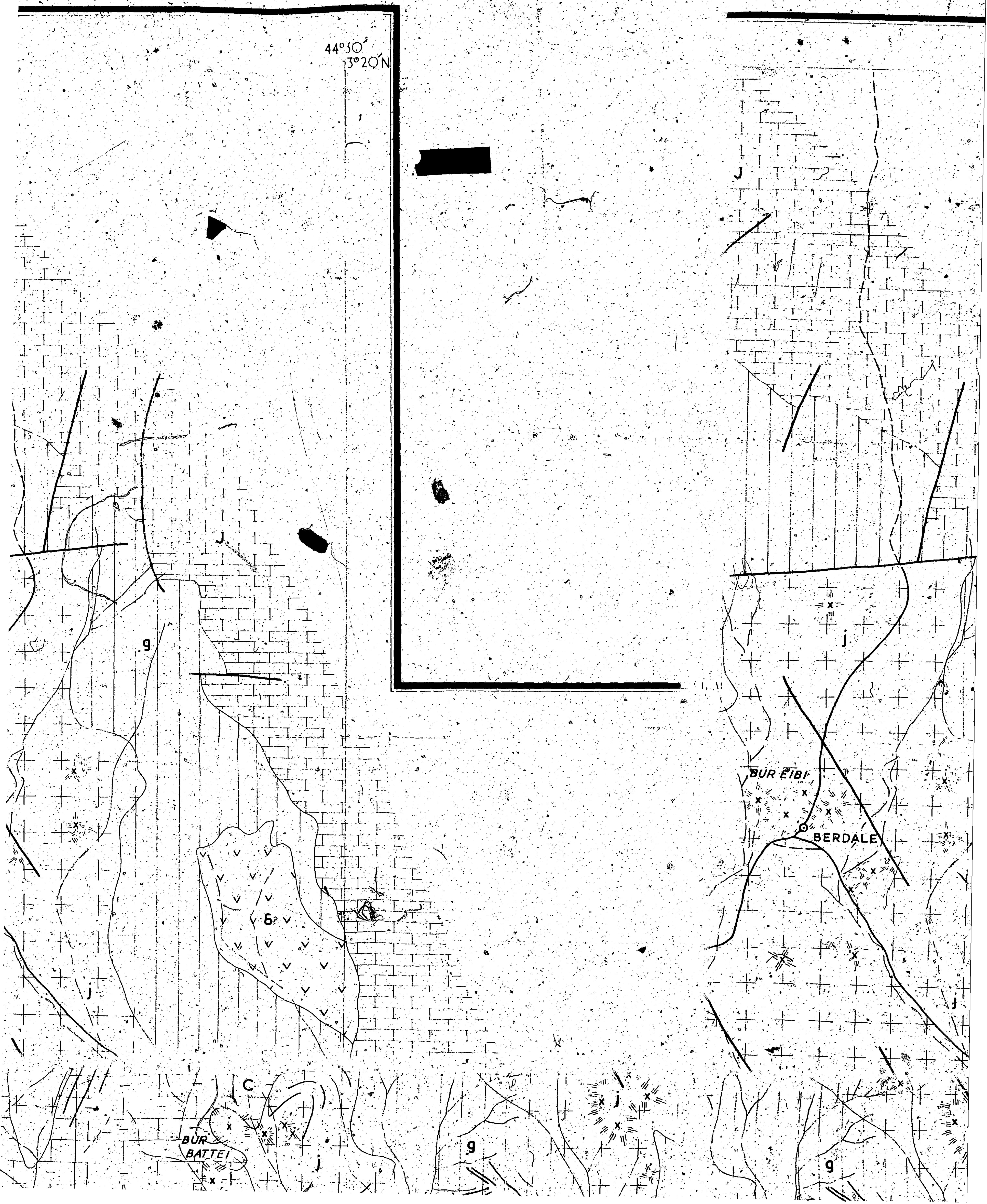


OF THE BU OF TH

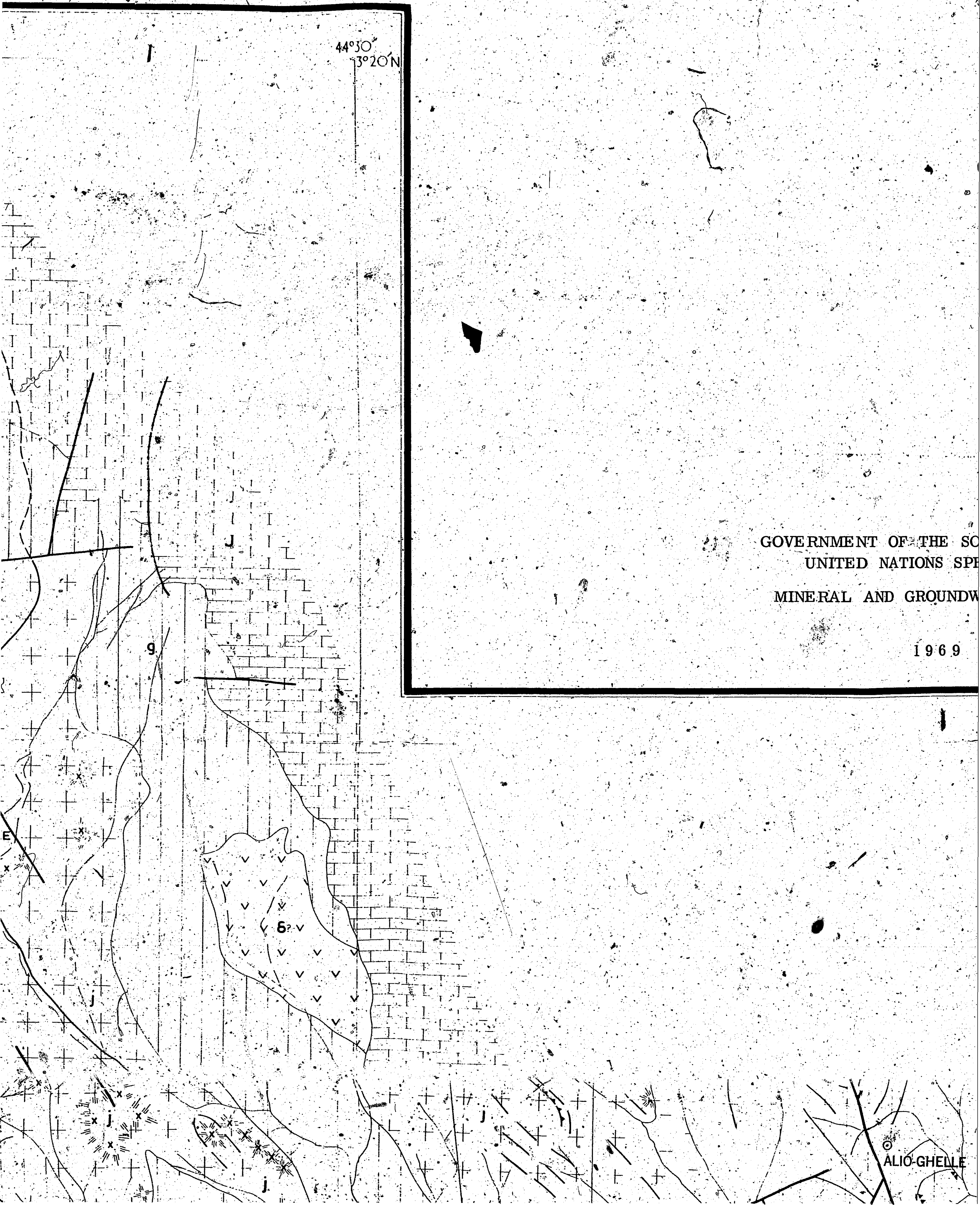


THE BUR AREA SON

SOMALI REPUBLIC



SOMALI REPUBLIC

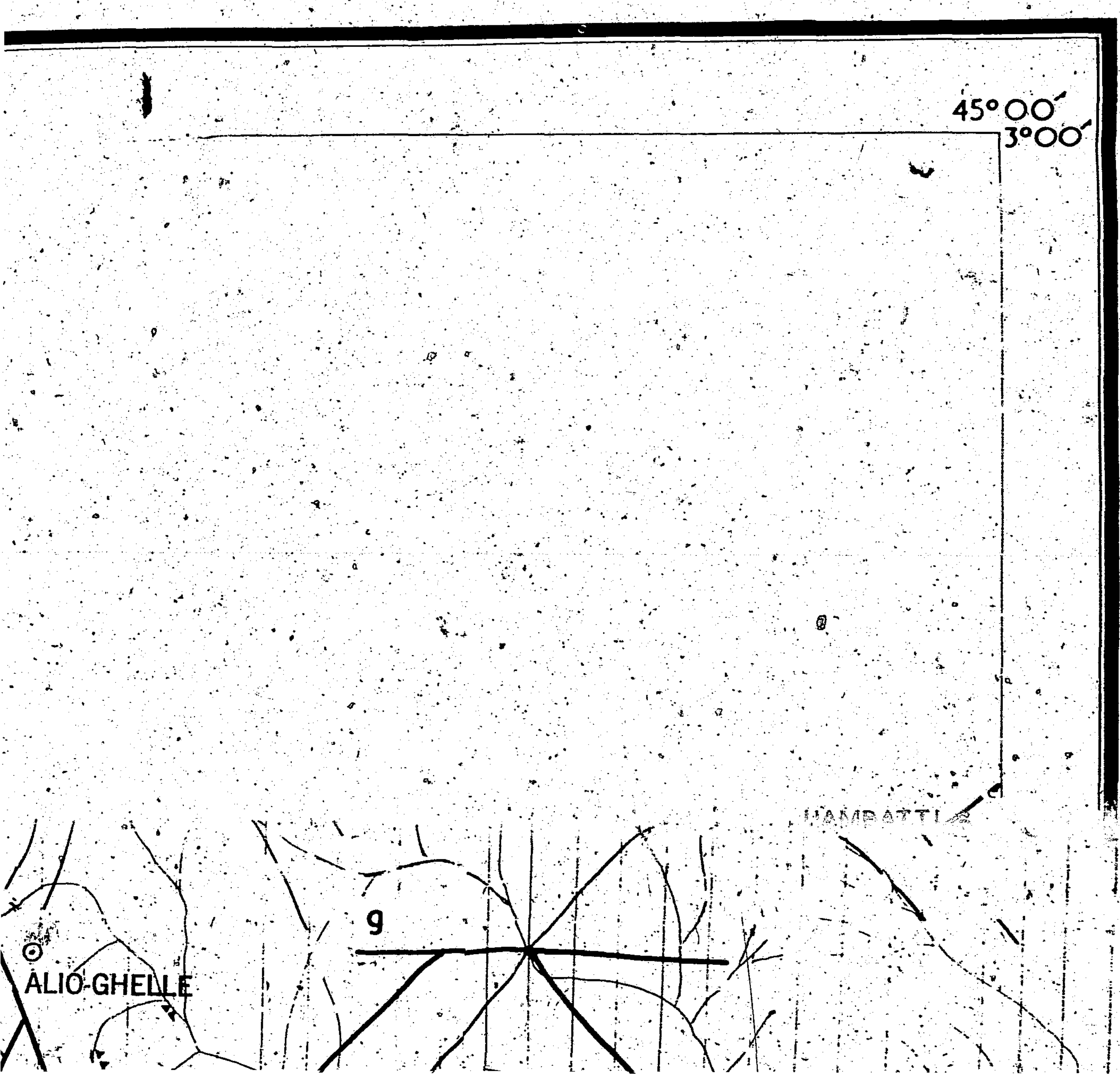


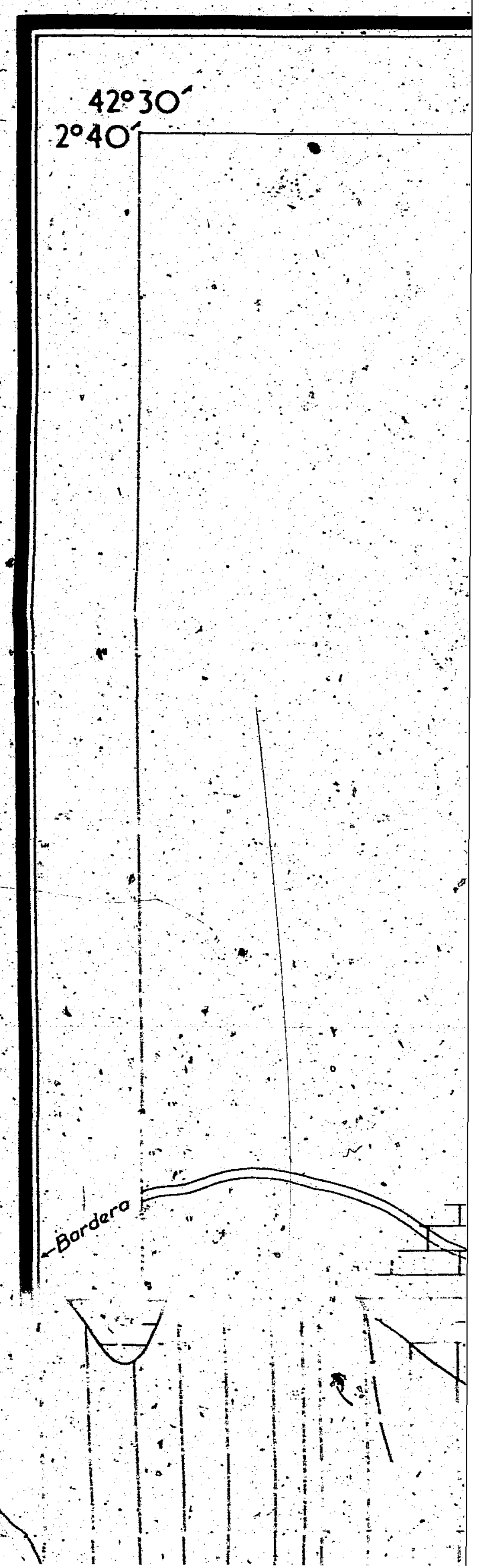
PRE - CAMBRIAN

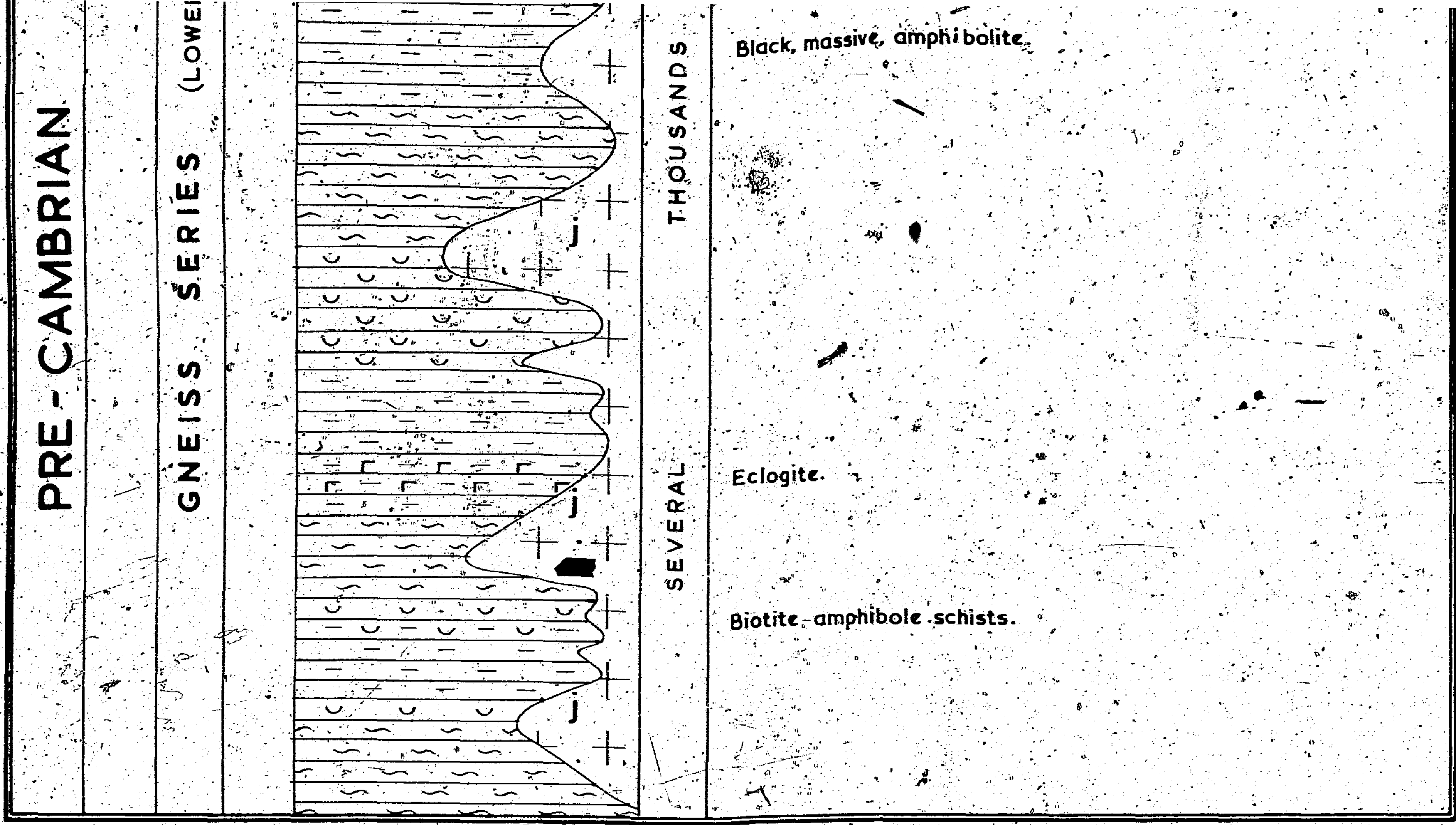
T OF THE SOMALI REPUBLIC
NATIONS SPECIAL FUND

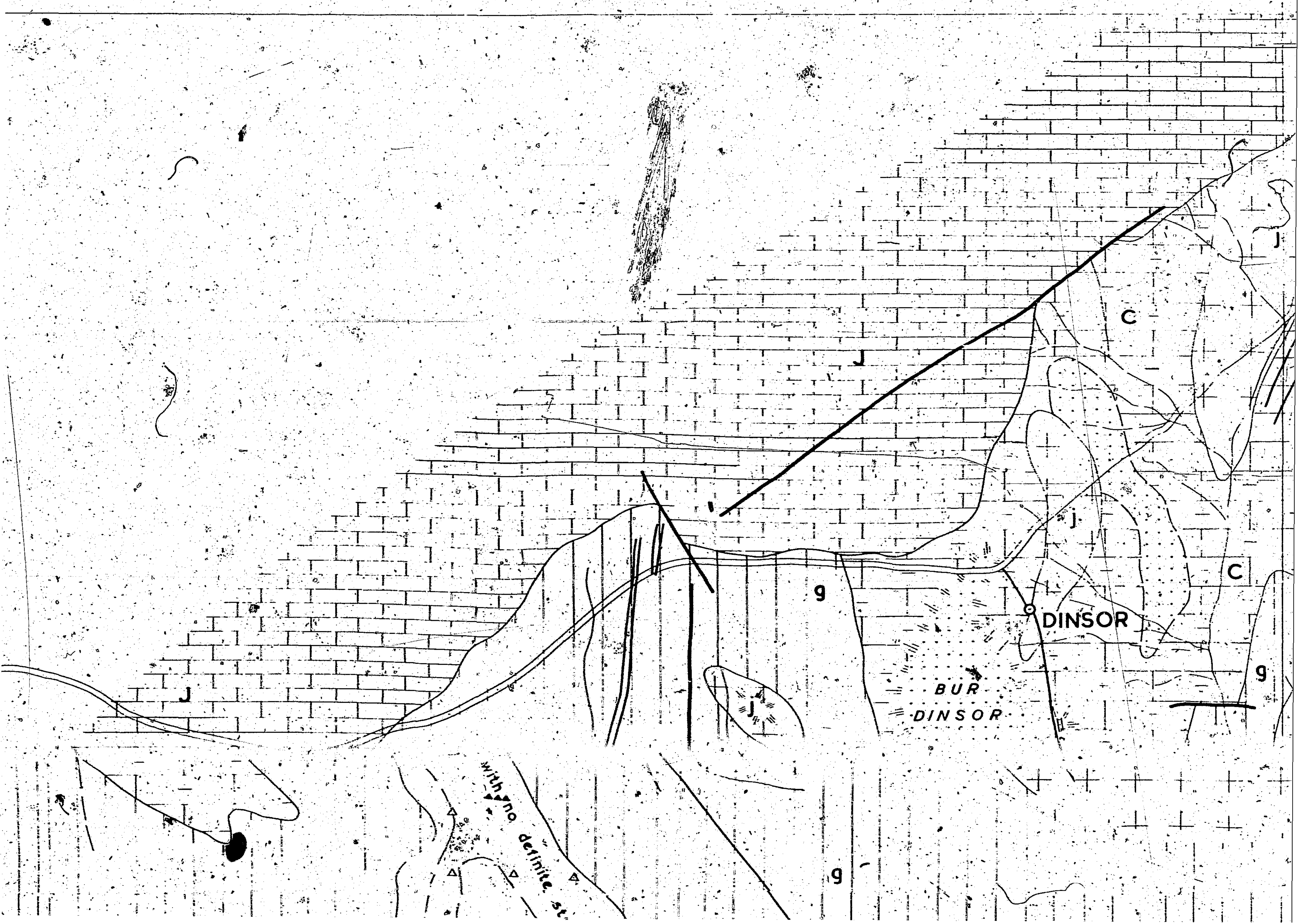
ND GROUNDWATER SURVEY

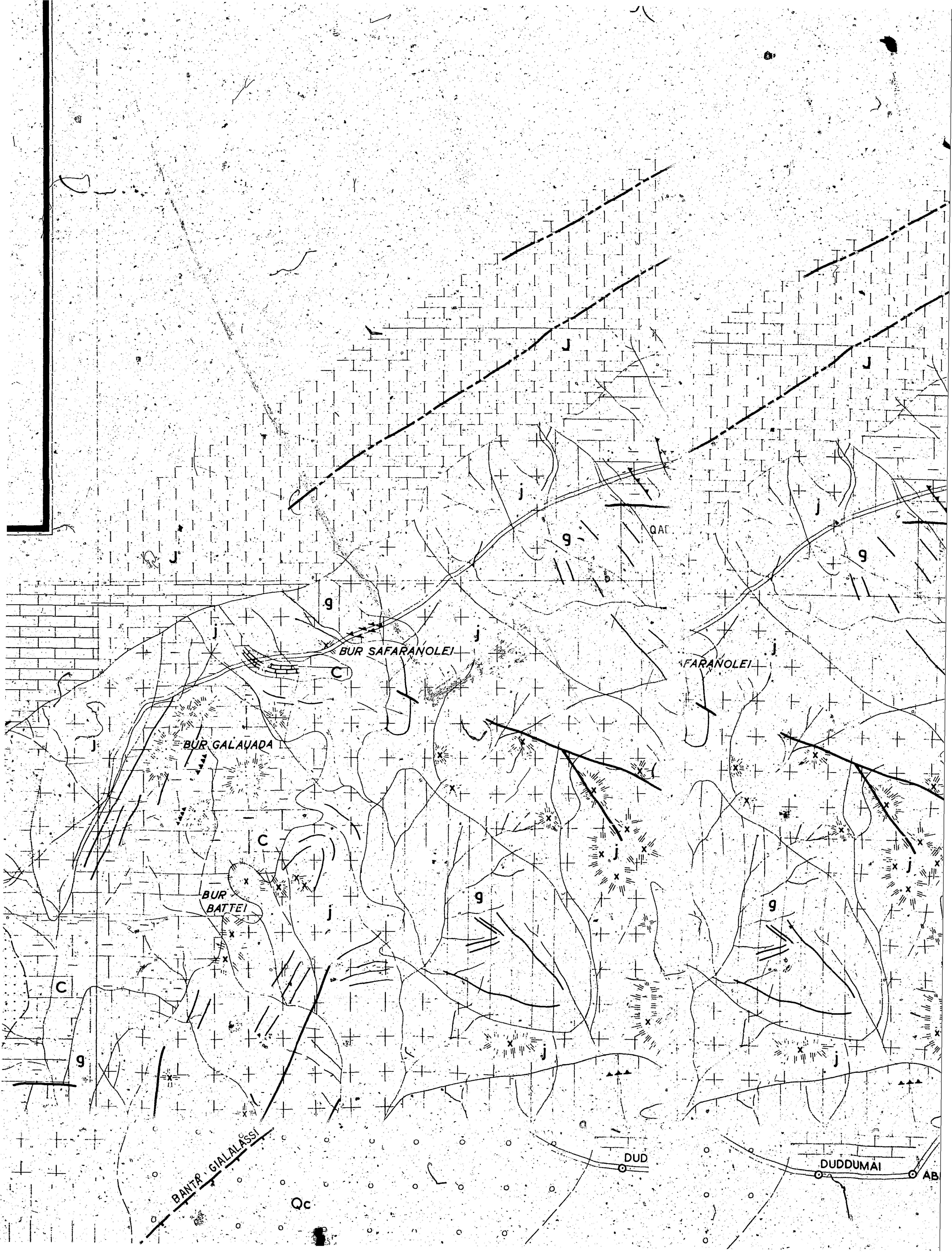
1969



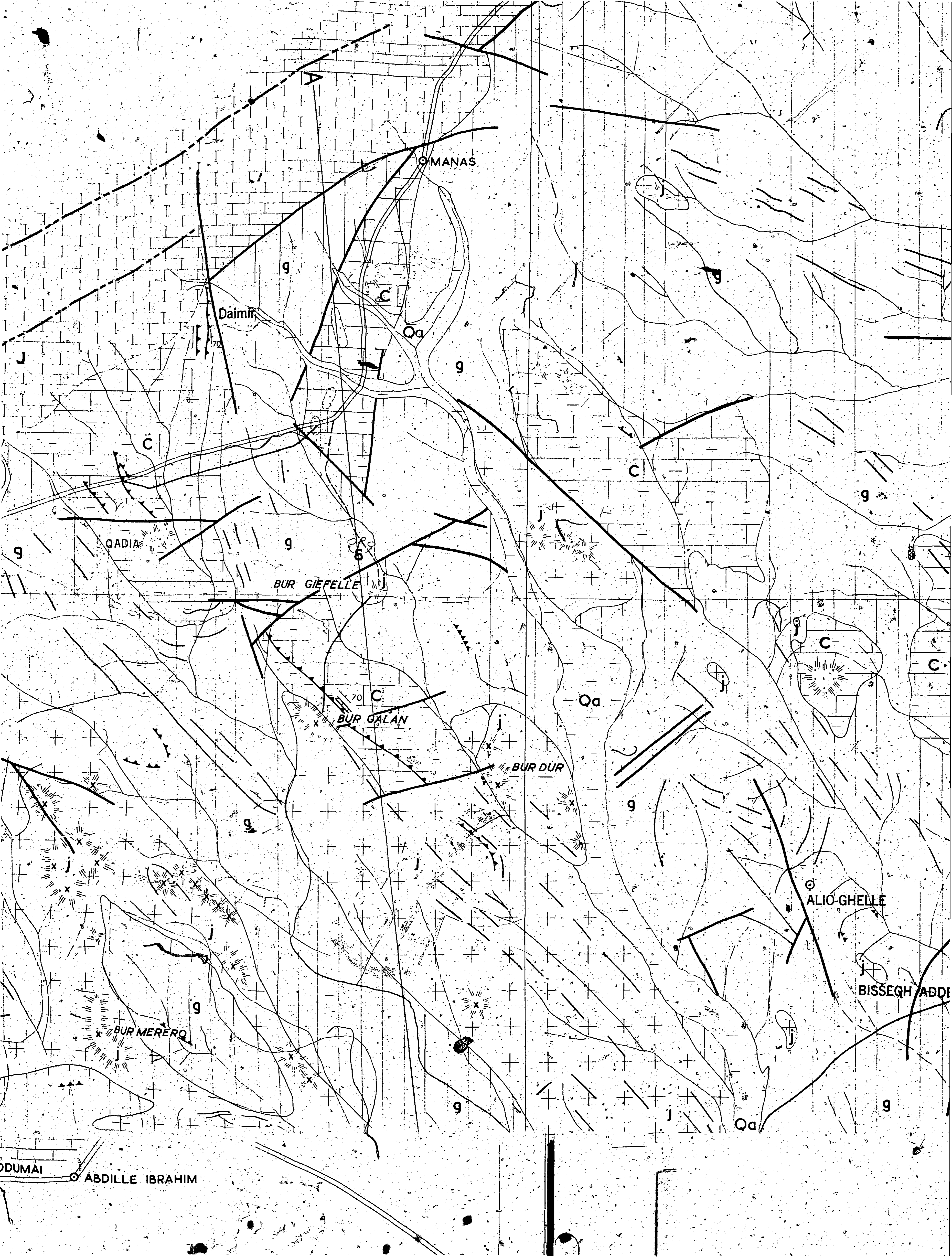



PRE-CAMBRIAN
GNEISS SERIES (LOWE
SEVERAL THOUSANDS
Black, massive, amphibolite.
Eclogite.
Biotite-amphibole schists.
j

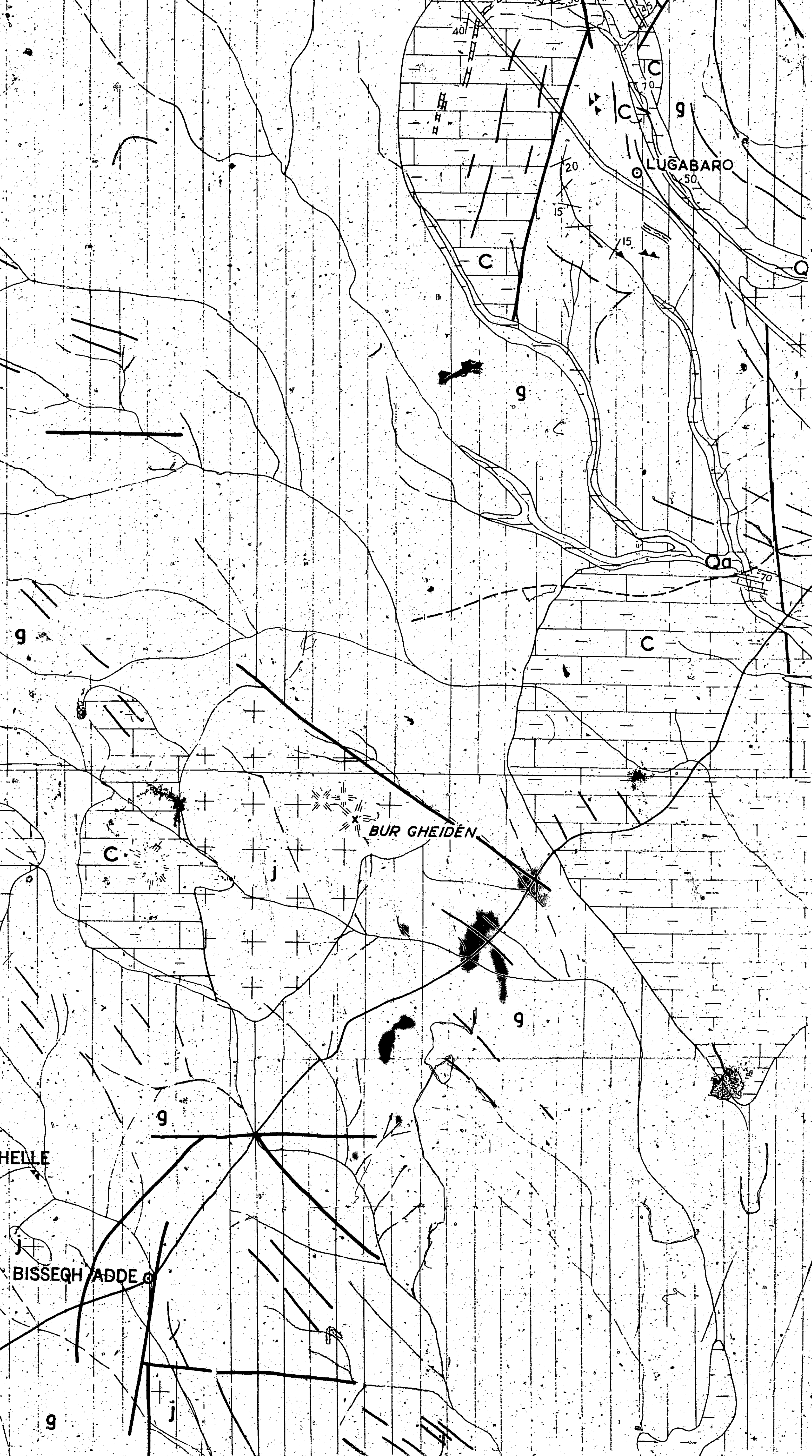

J
C
j
g
DINSOR
BUR DINSOR
with no definite st



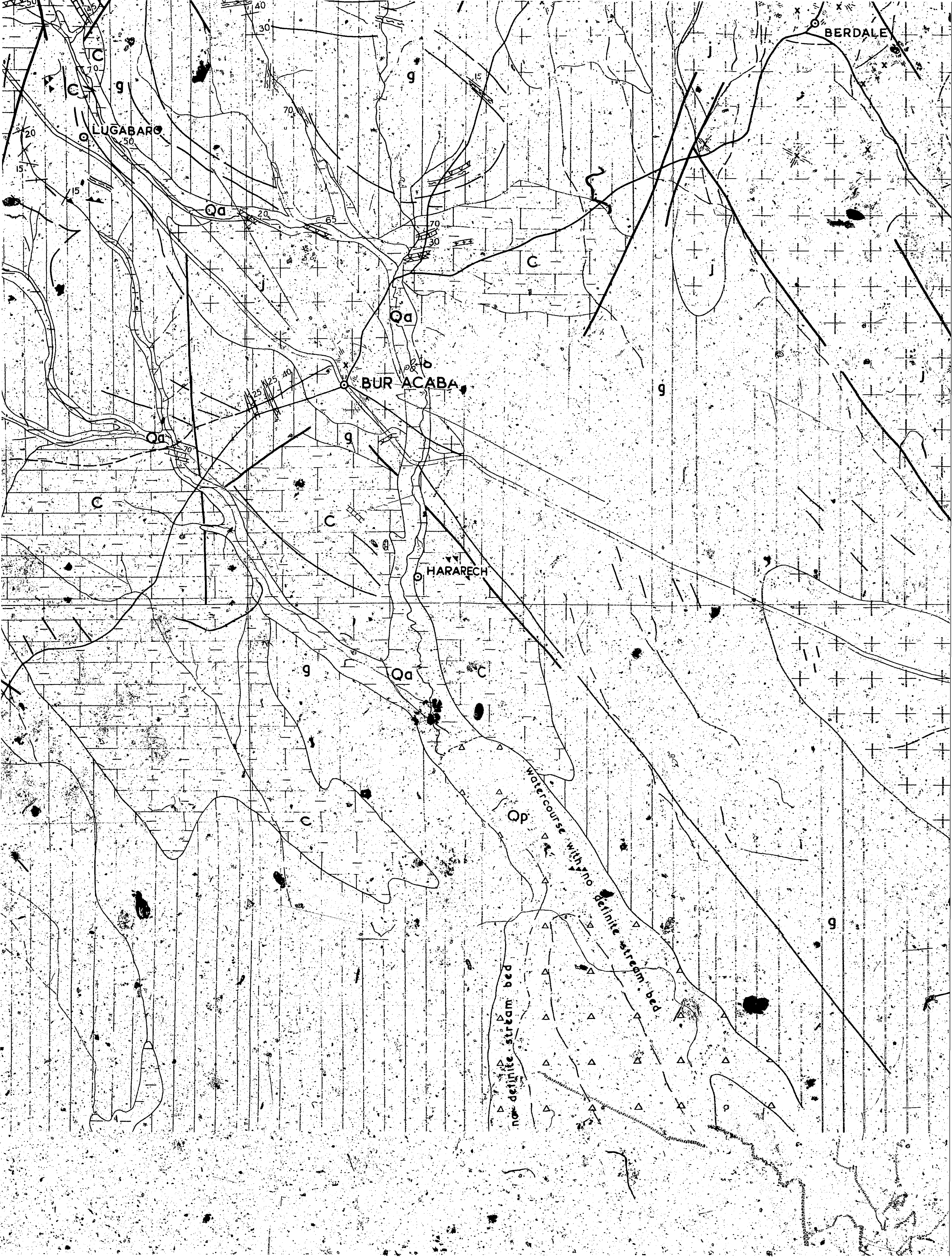
J
J
j
g
J
g
j
BUR SAFARANOLEI
C
SAFARANOLEI
BUR GALAUADA
C
BUR
BATTEI
C
g
DUD
DUDDUMAI
BANTR GIALALASSI
Qc



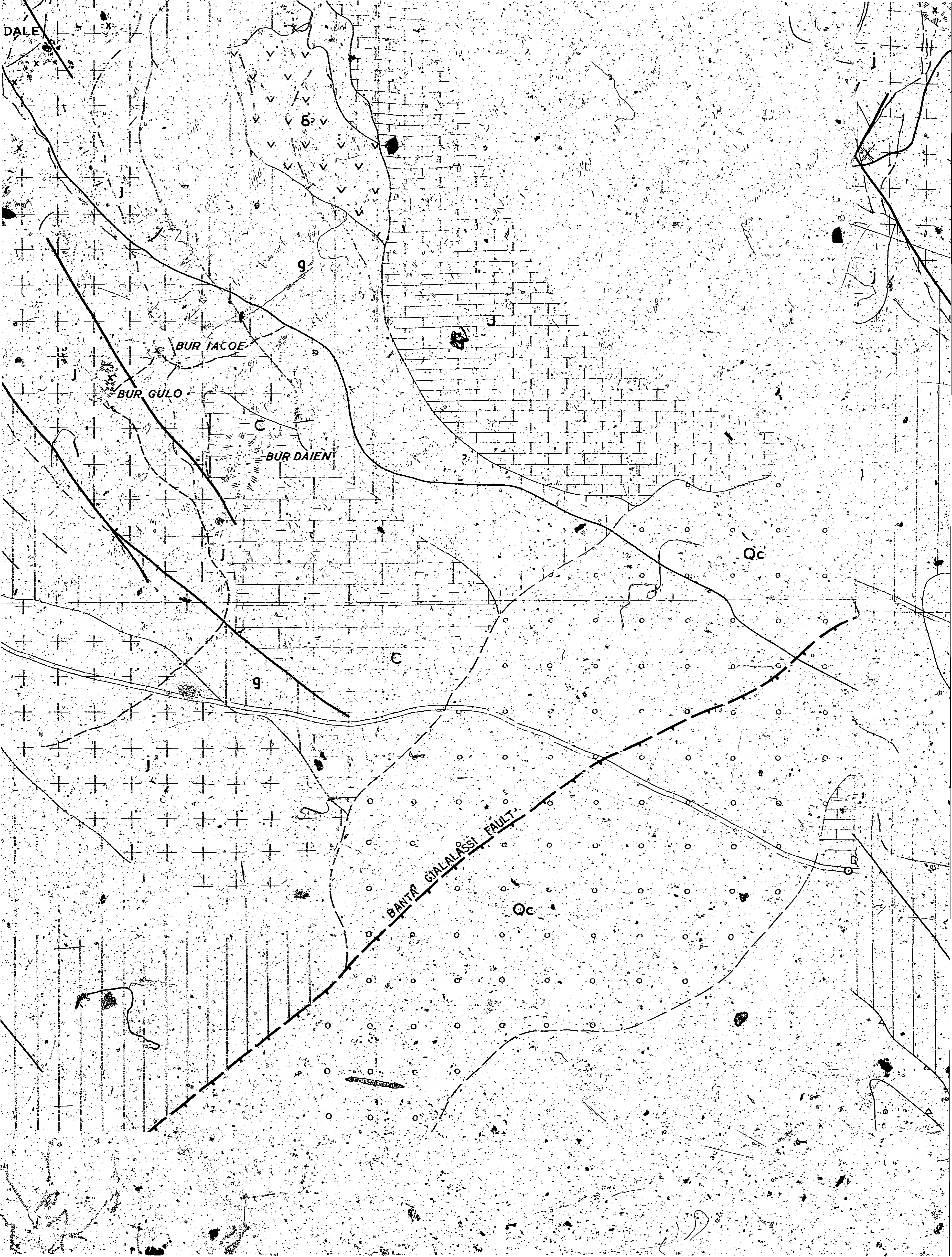
A
MANAS
Daimir
J
C
g
Qa
QADIA
BUR GIEFELLE
j
BUR GALAN
BUR DUR
ALIO GHELLE
BISSEGH ADDE
BUR MERERO
ODUMAI
ABDILLE IBRAHIM

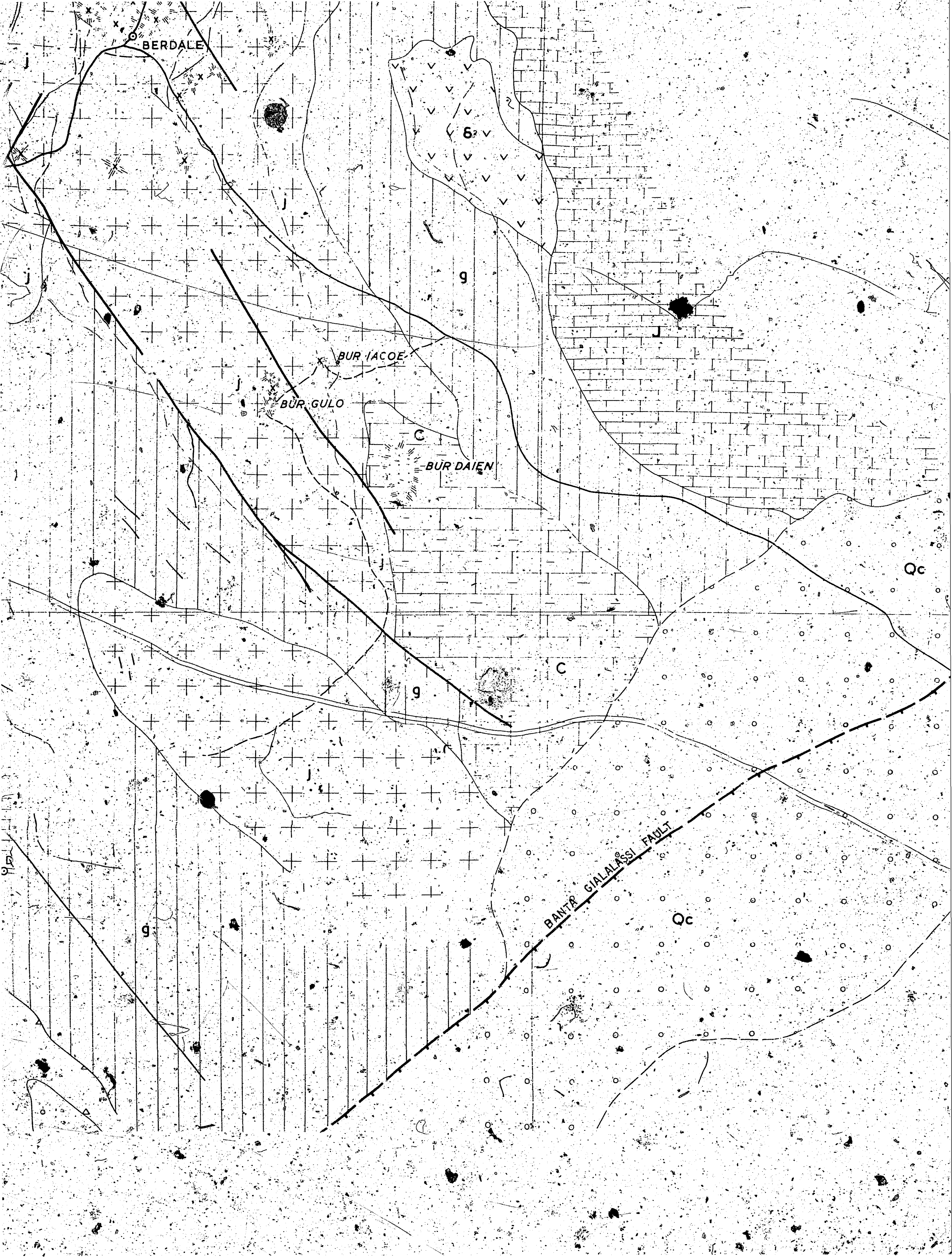


C
g
LUGABARO
Q
Qa
BUR GHEIDEN
j
HELLE
BISSEGH ADDE

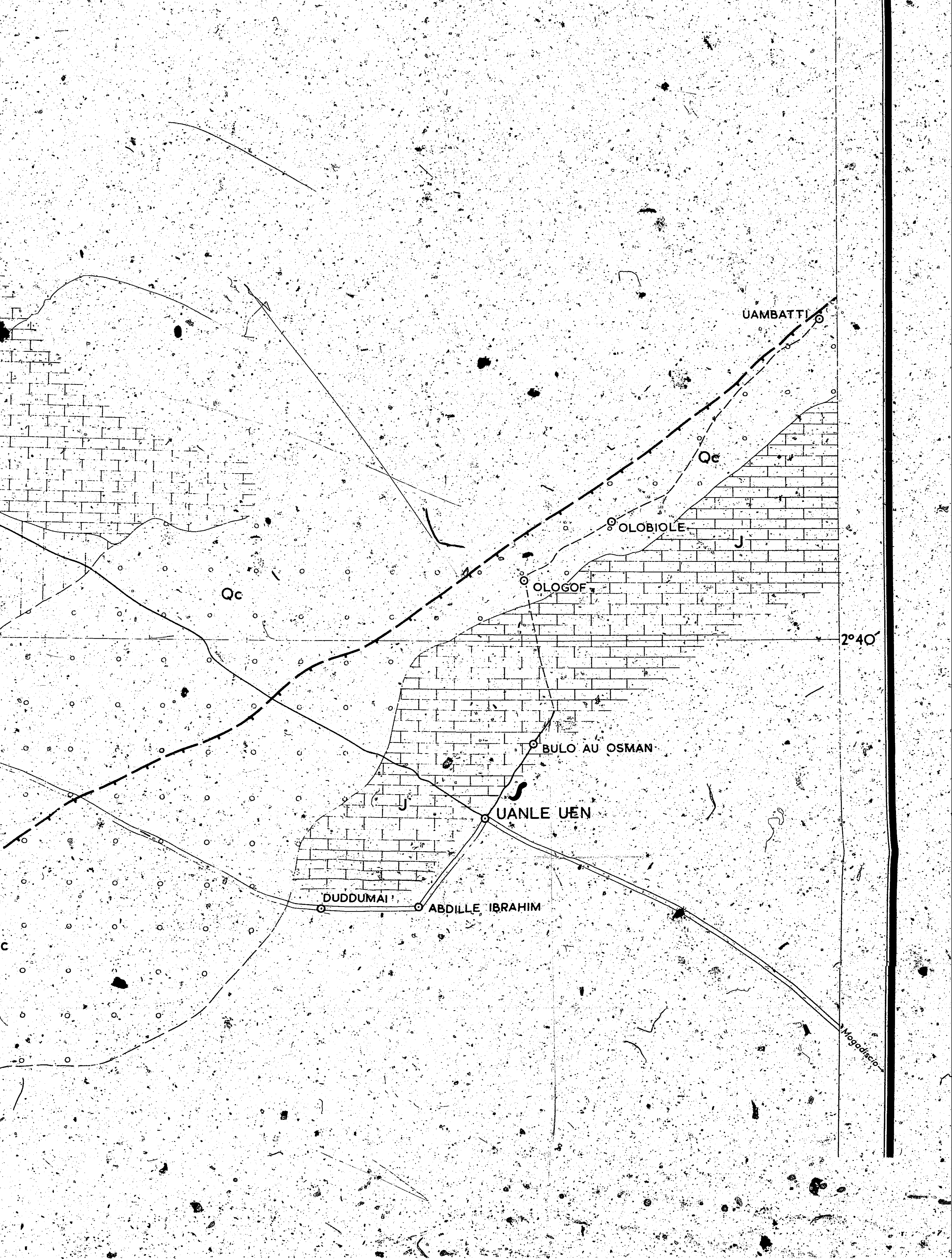


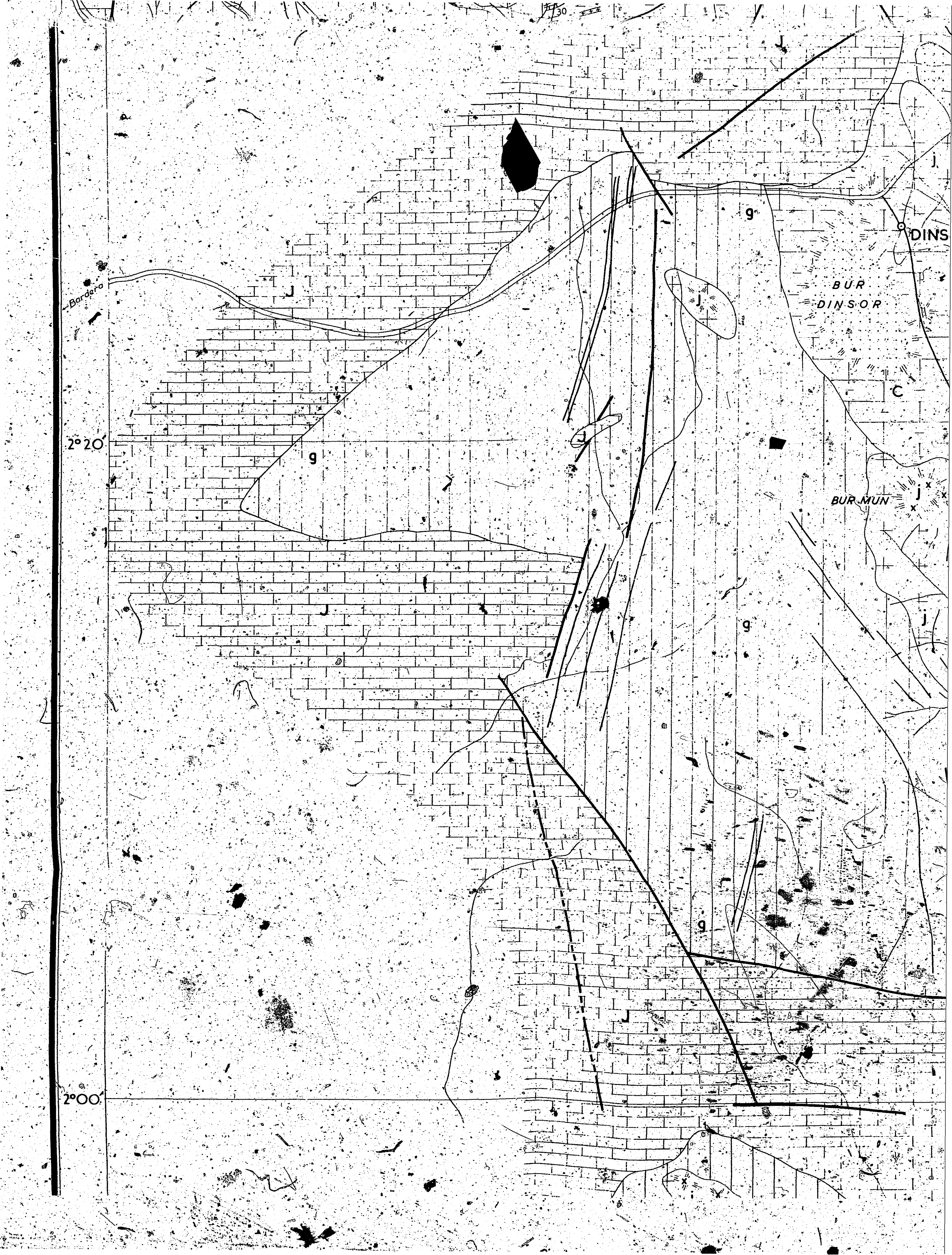
BERDALE
LUGABARO
BUR ACABA
HARARECH
Qa
Qp
C
g
j
watercourse with no definite stream bed
no definite stream bed


DALE
BUR IACOE
BUR GULO
BUR DAIEN
BANTA GIALALASSI FAULT
Qc
Qc
C
C
g
g
j
j
j
j
j
j
δ

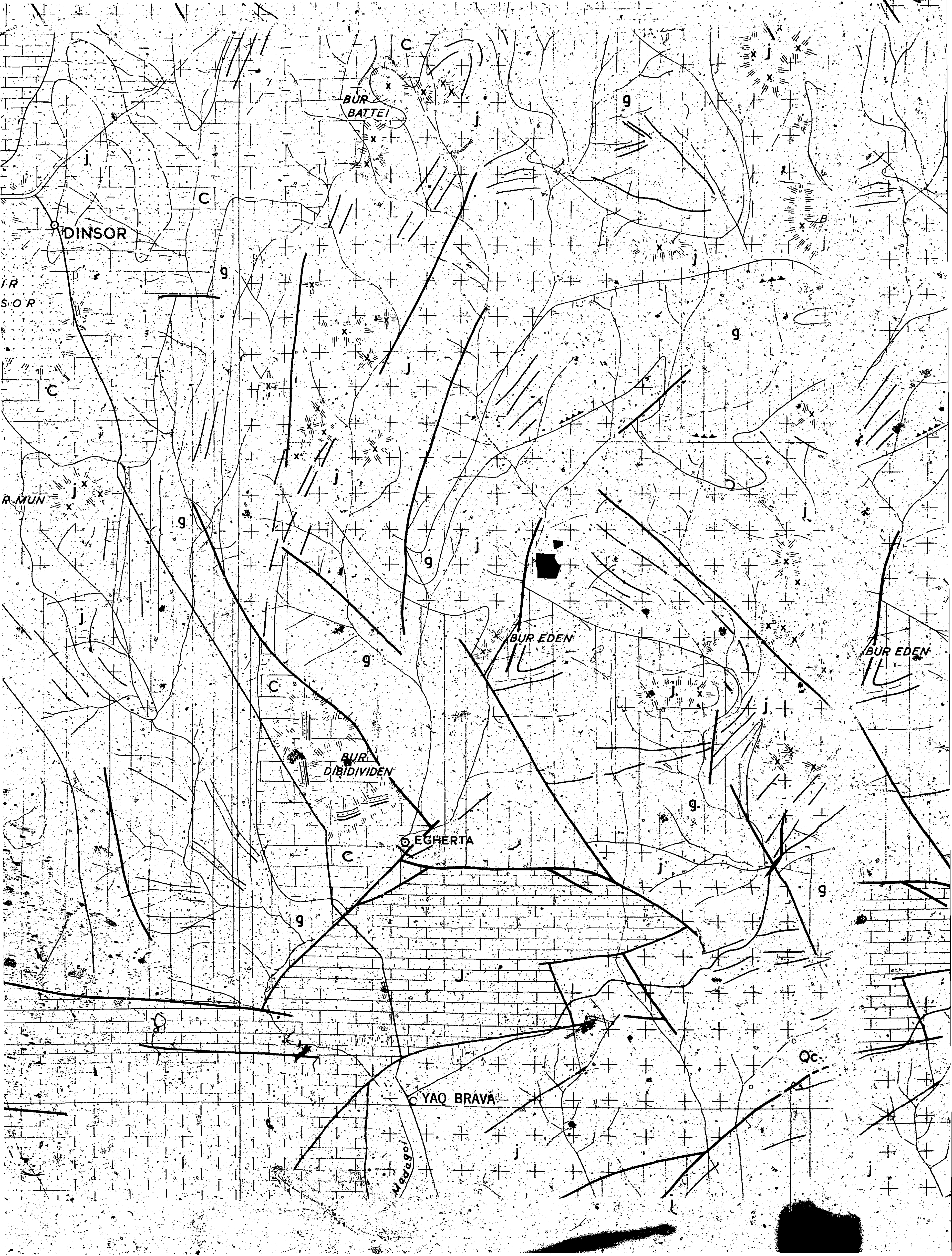


BERDALE
j
j
j
j
j
δ
g
J
BUR IACOE
BUR GULO
C
BUR DAIEN
C
g
g
Qc
Qc
BANTA GIALALASSI FAULT

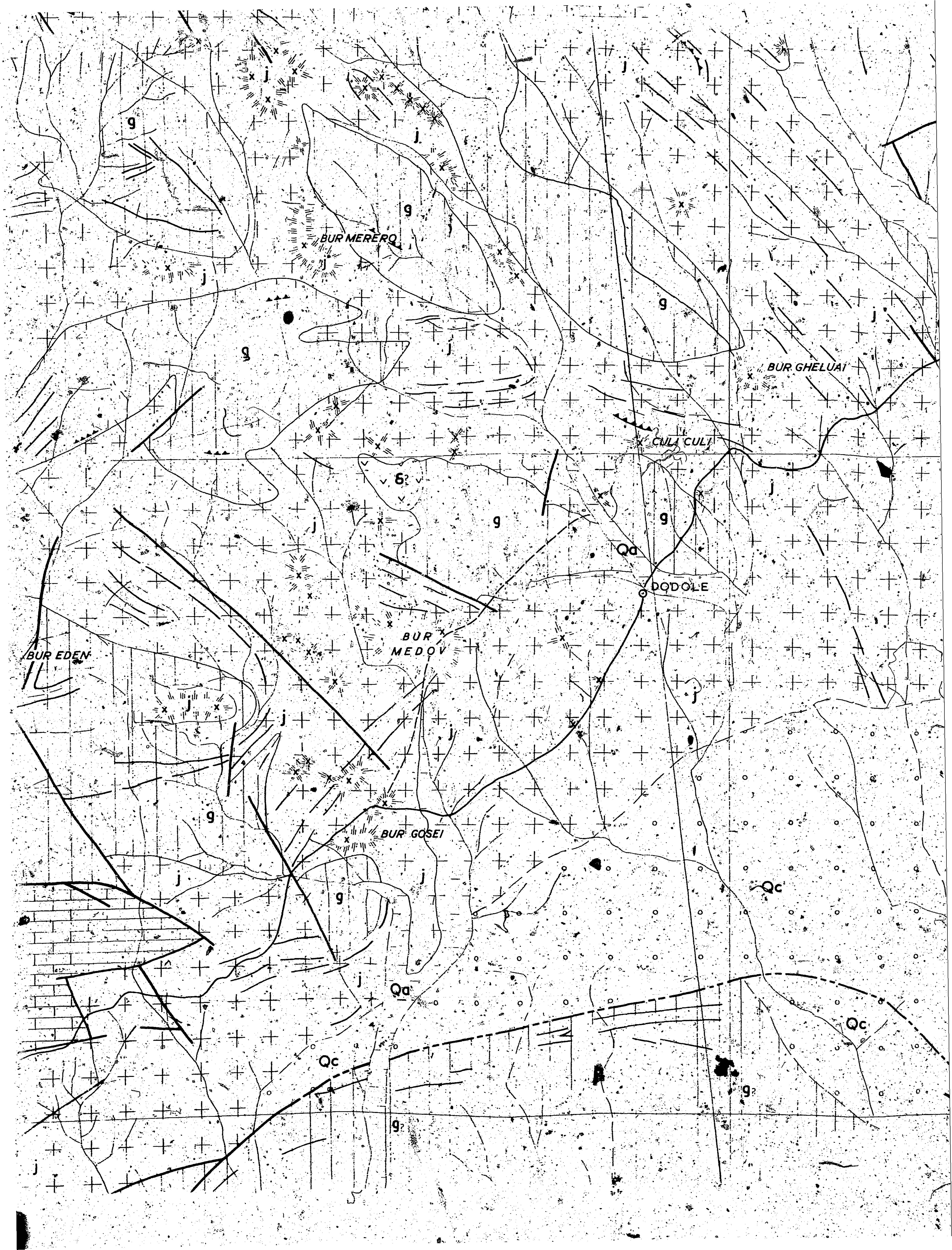

UAMBATTI
Qc
OLOBIOLE
J
OLOGOF
Qc
2°40'
BULO AU OSMAN
J
UANLE UEN
DUDDUMAI
ABDILLE IBRAHIM
Mogadiscio
c



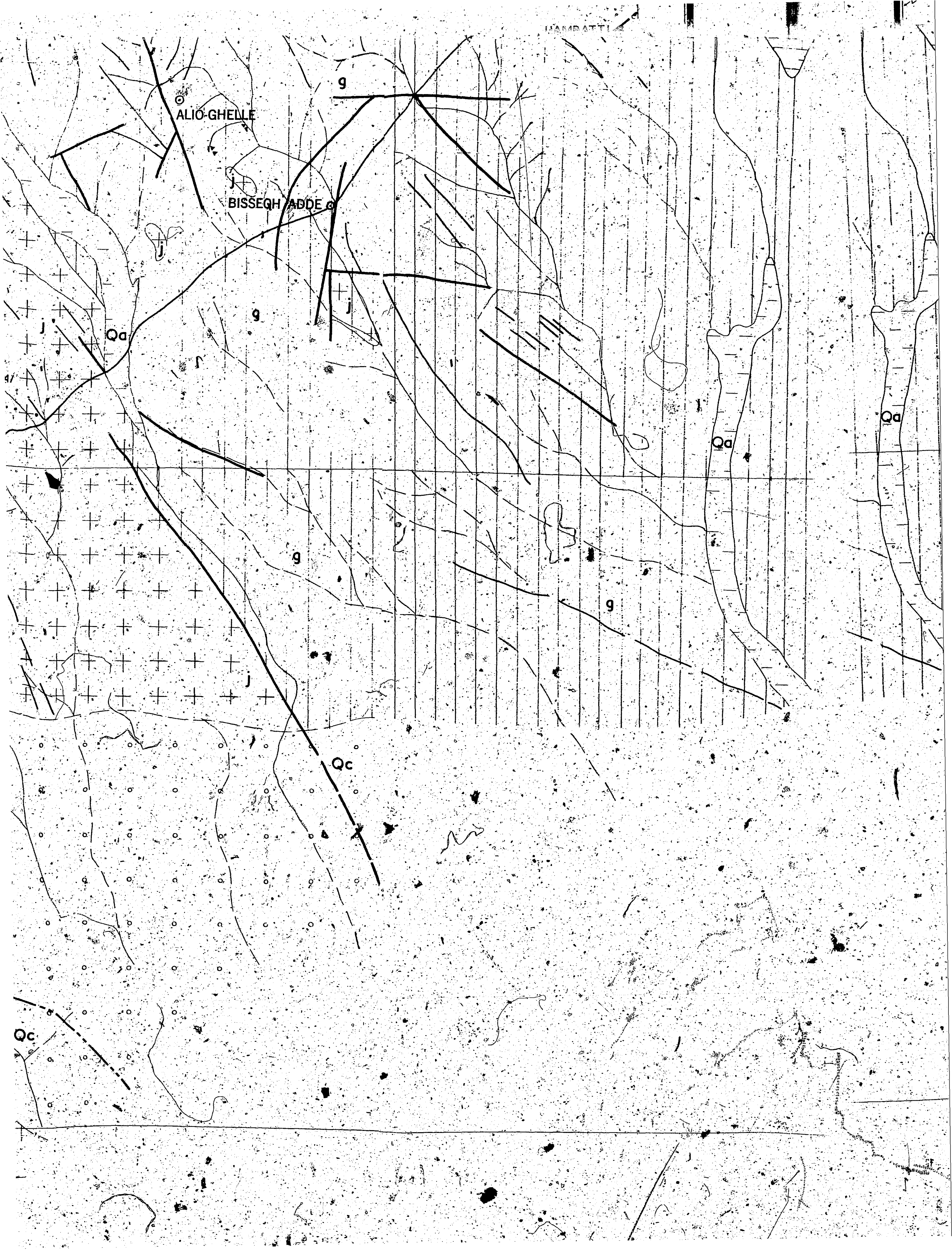
30
J
j
g
DINS
Bardera
J
BUR
DINSOR
J
C
2°20'
g
J
j
BUR MUN
J
g
j
g
J
2°00'



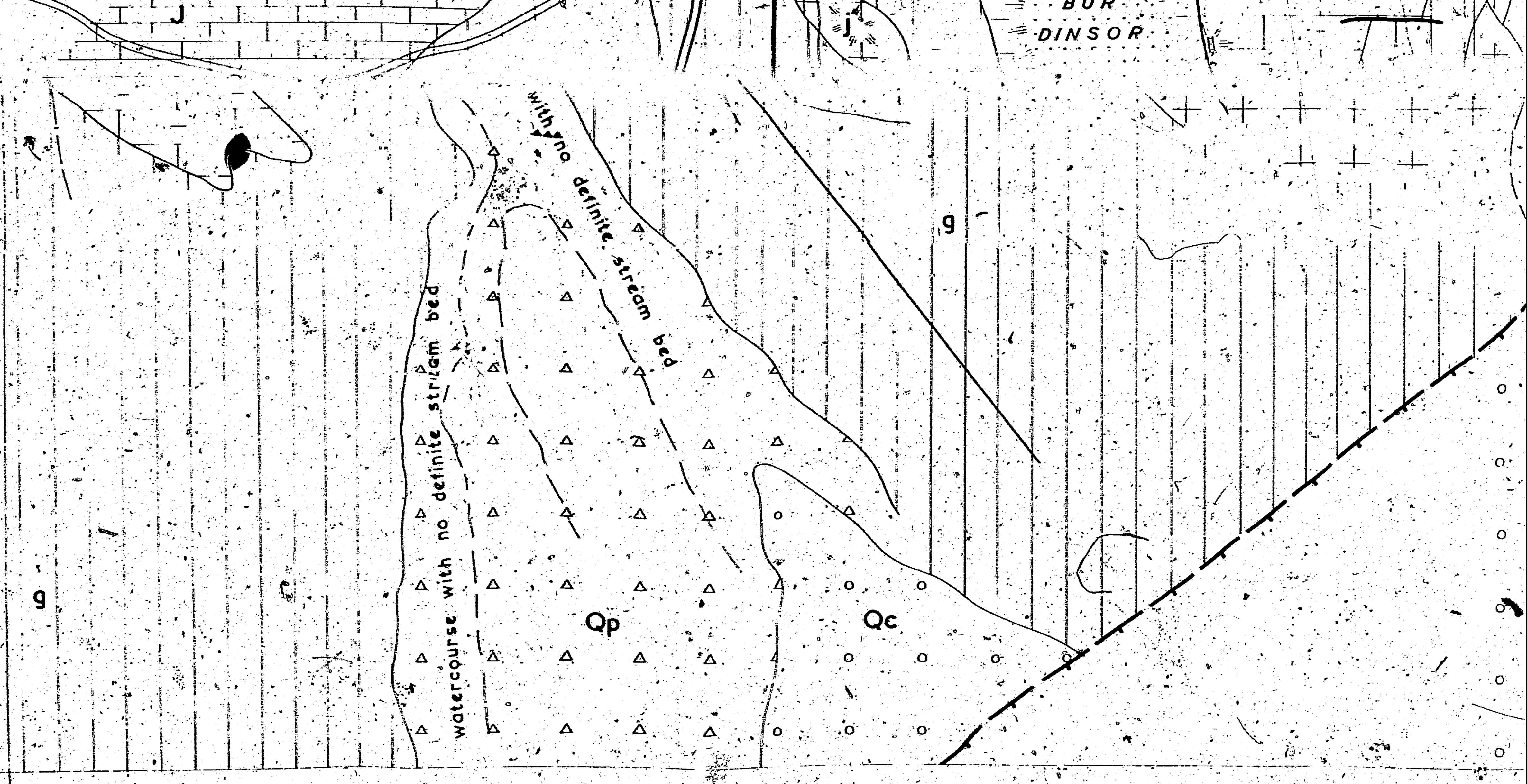
BUR BATTEI
DINSOR
R MUN
BUR EDEN
BUR EDEN
BUR DIBIDIVIDEN
EGHERTA
YAQ BRAVA
Madagoi
Qc



BUR MERERO
BUR GHELUAI
CULI CULI
DODOLE
BUR MEDOV
BUR EDEN
BUR GOSEI
Qa
Qc
g
j



ALIO-GHELLE
BISSEQH ADDE
g
j
Qa
Qc



L E G E

QUATERNARY

Qa — ALLUVIAL SAND, CLAY, SILT, GRAVEL

Qp — PROLUVIAL ... GRIT, SILT

Qc — CALICHE MANTLE; HARD CALCAREOUS ROCKS (CALCAREOUS CRUST)

JURASSIC

J — LIMESTONE: ARGILLACEOUS, FLINTY, SHELLY

PRE-CAMPRIAN BASEMENT COMPLEX

δ? — IGNEOUS ROCKS OF MEDIUM TO BASIC COMPOSITION (MOSTLY INFERRED BY PHOTO-INTERPRETATION)

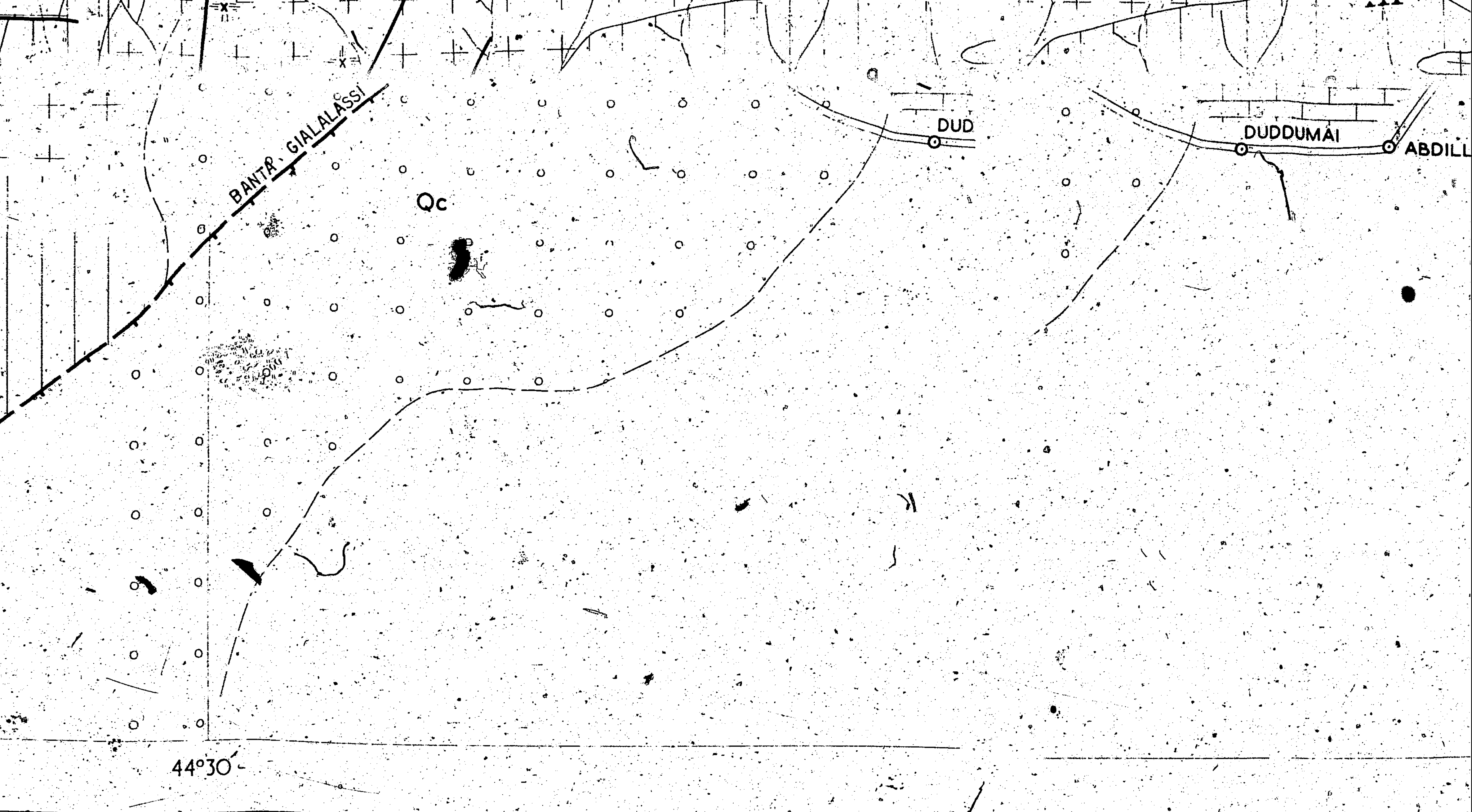
j — GRANITE: PINK TO YELLOWISH, MEDIUM TO COARSE-GRAINED, MICROCLINE-BIOTITE TO LEUCOGRANITE, SMALL-GRAINED GRANULITIC GRANITE (ALASKITE)

C — CALC-SILICATE ROCKS. UPPER SERIES. QUARTZITE - MILKY WHITE, GNEISS, SCHIST, MARBLE, SILICATE MARBLE, CALCI (CARBONATE-BEARING ROCKS OF COMPLEX COMPOSITION); IRON QUARTZITE, GRANITE INJECTIONS

g — GNEISS, LOWER SERIES. GNEISS, SCHIST, AMPHIBOLITE - HEAVILY IMPREGNATED WITH PEGMATITE, APLITE, GRANULITIC GRANITE

LITHOLOGICAL SYMBOLS

x x — GRANITE MONADNOCK



...END

GEOLOGICAL SYMBOLS SYMBOLS

GEOLOGICAL BOUNDARY

CONTACT, INFERRED

CONTACT, APPROXIMATE

FAULT

FAULT, INFERRED, IN THE BASEMENT UNDER JURASSIBASEMENT UNDER JURASSIC SEDIMENTS (AERO-MAGNETIC MAP)

FAULT: SUPPOSEDLY BORDERING THE BASEMENT UPRDERING THE BASEMENT UPLIFT FROM THE SOUTH-EAST

TREND LINES: (METAMORPHIC ROCKS); IC ROCKS);
SCHISTOSITY-GNEISSOSITY LINES: (IGNEOUS ROCKS) LINES: (IGNEOUS ROCKS)

MARBLE, CALCIPHYRE

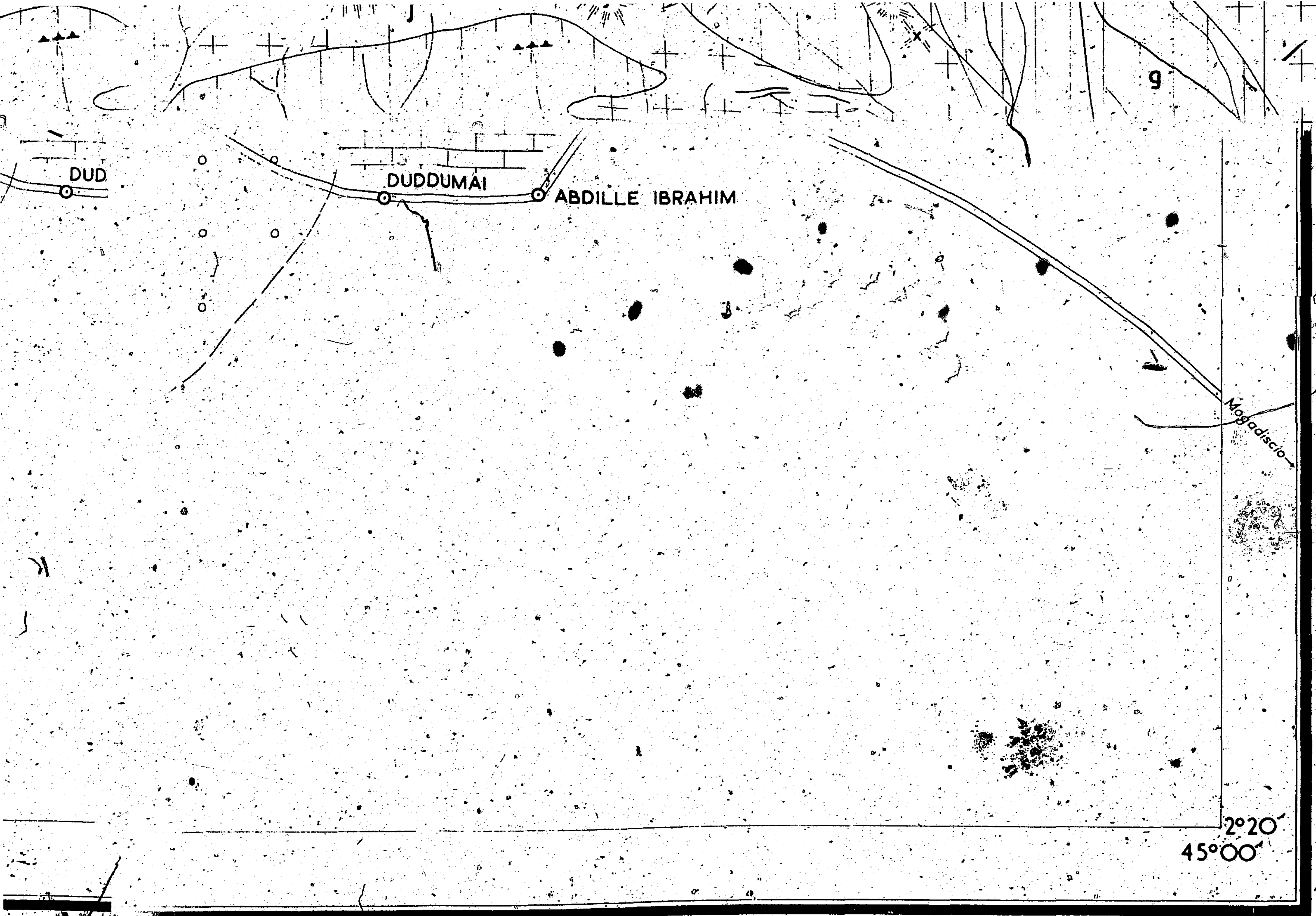
15 STRIKE AND DIP

APLITE,

A B GEOLOGICAL CROSS SECTION ON

TOPOGRAPHICAL SYMBOLS SYMBOLS

ROADS PRINCIPAL



Map 1

S SYMBOLS

? JURASSIC BASEMENT UNDER JURASSIC SEDIMENTS

MENT UPL DERING THE BASEMENT UPLIFT FROM

IIC ROCKS);

ROCKS) LINES (IGNEOUS ROCKS)

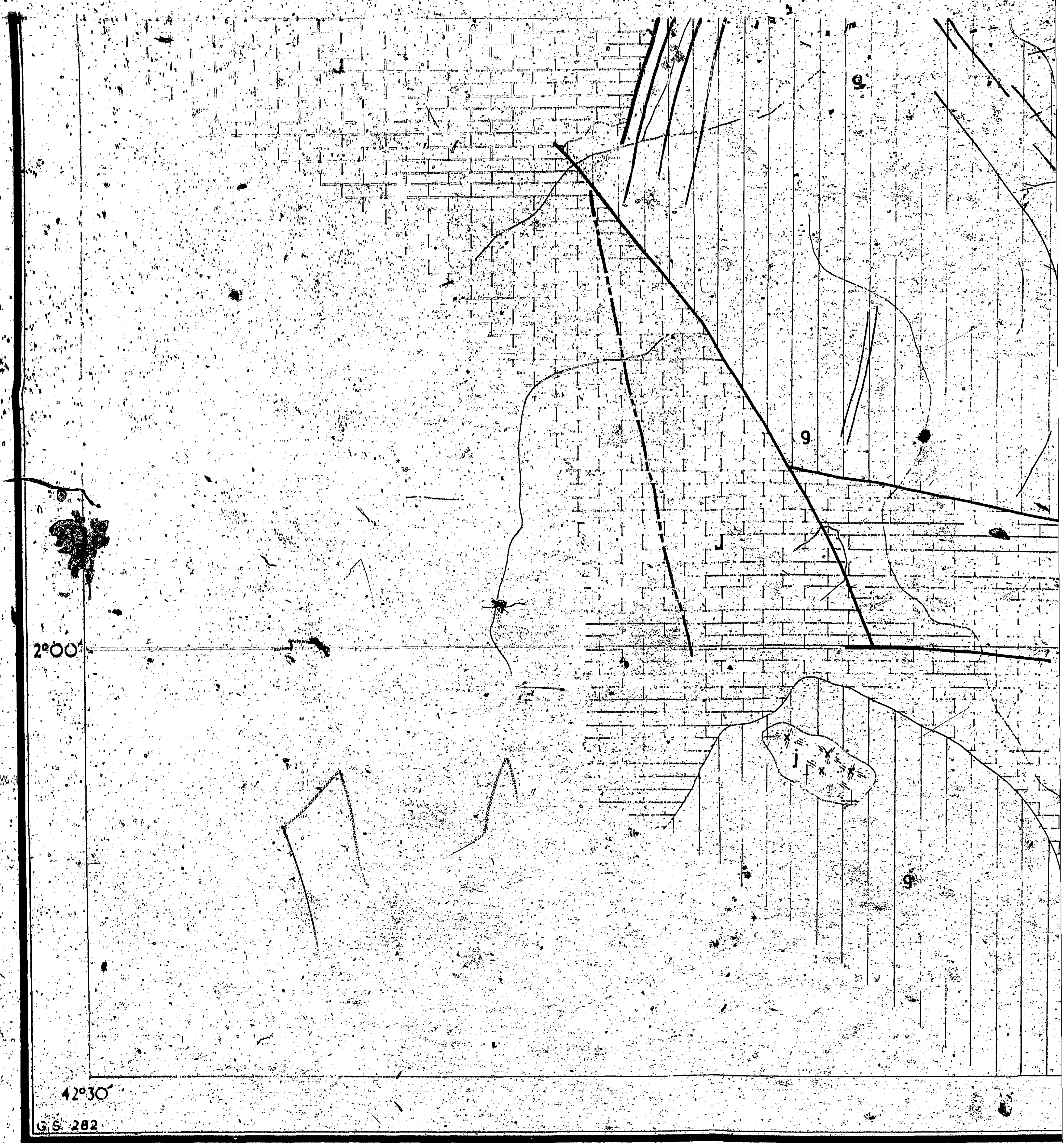
BASE MAP COMPILED FROM:

1. Uncontrolled mosaics, constructed by Hunting Surveys Ltd., Scale - 1: 60,000. 1964

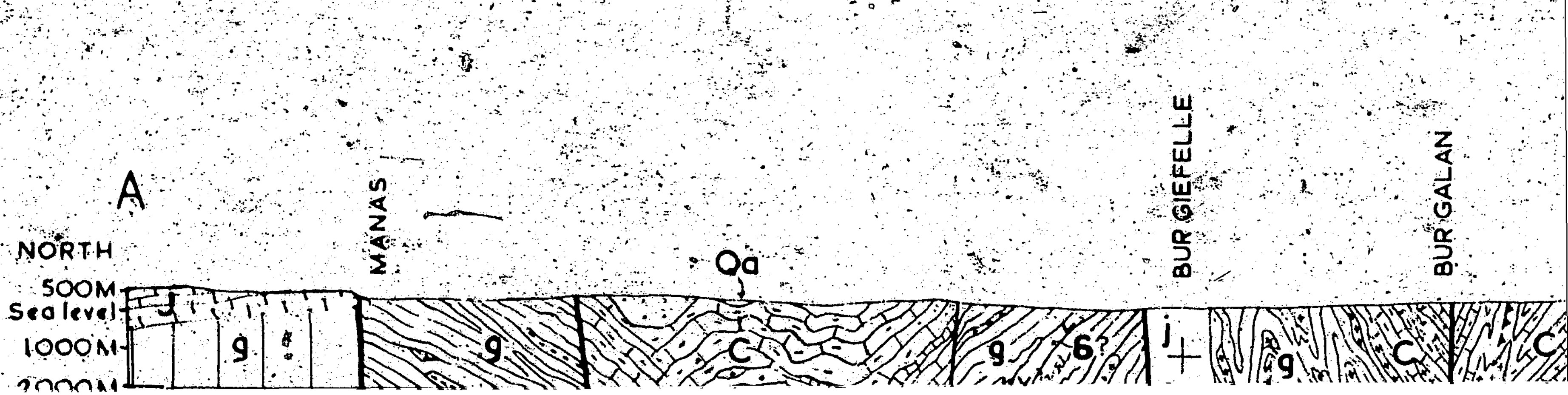
2. Uncontrolled mosaics, constructed by Aero Exploration, Frankfurt/M; Scale - 1: 30,000. 1965

3. G. S. G. S. 4355, Sheet NA 38/1, Fourth Edition.

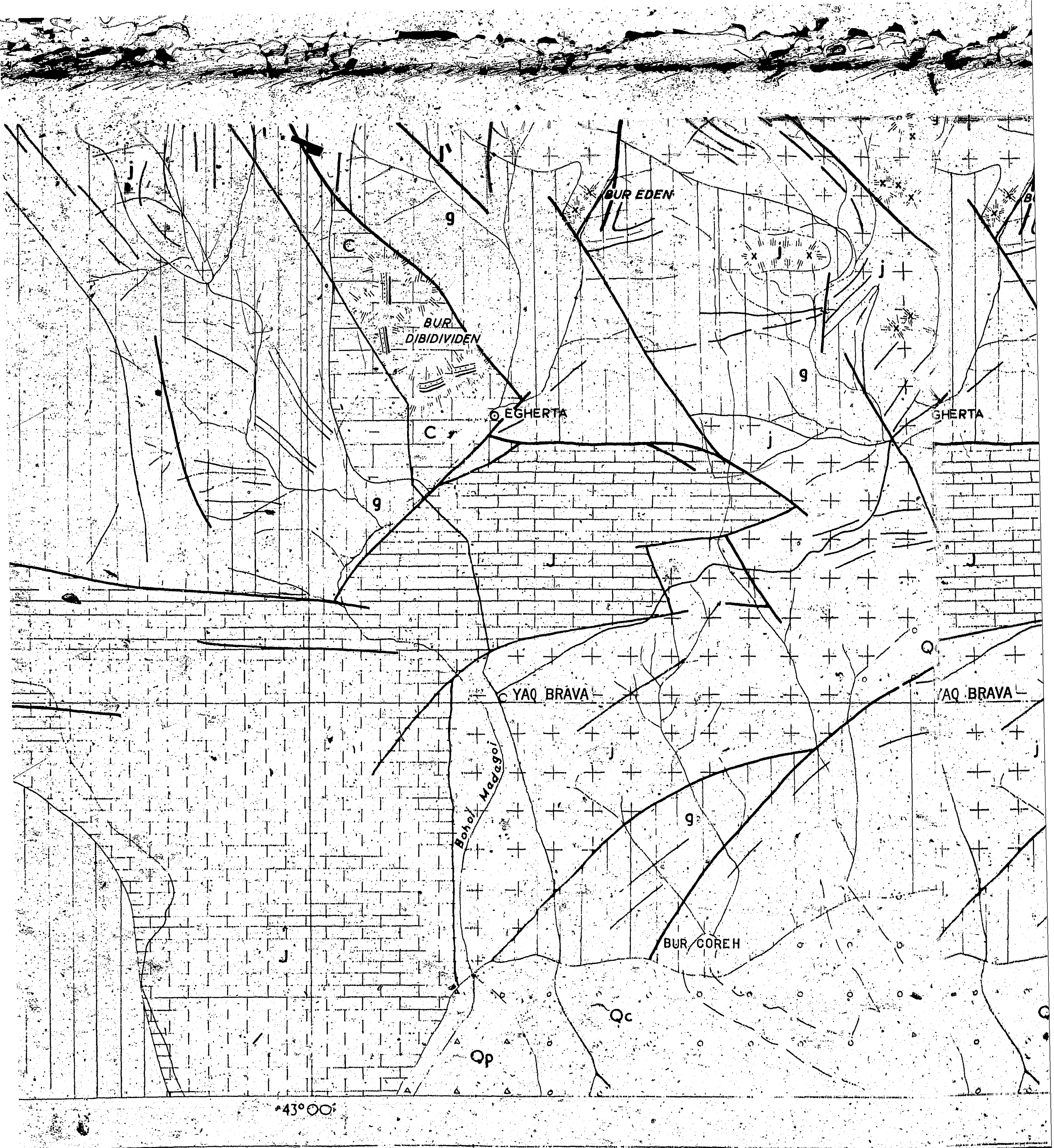
SYMBOLS



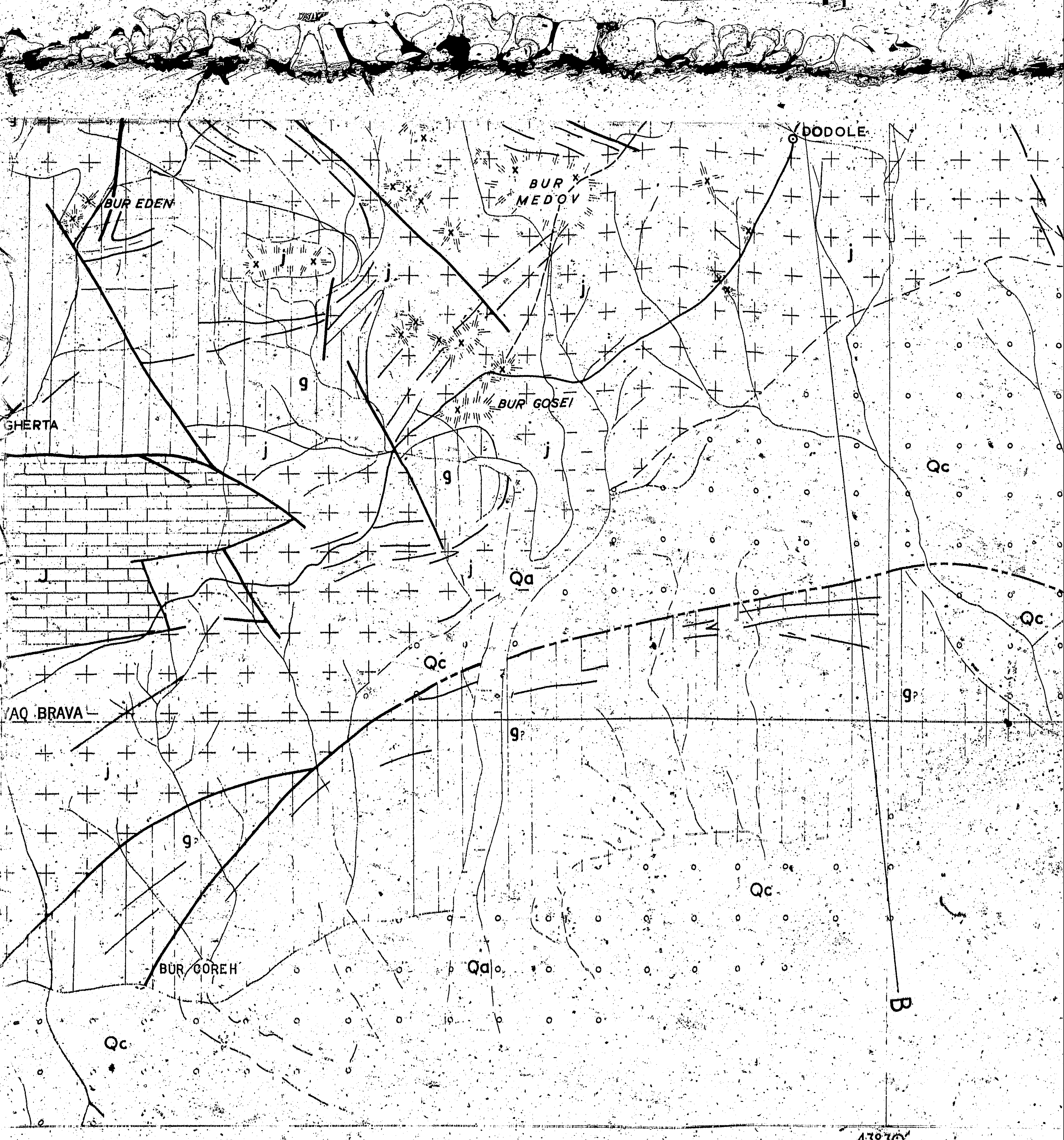
J
g
J
j
g
2°00'
42°30'
G.S. 282



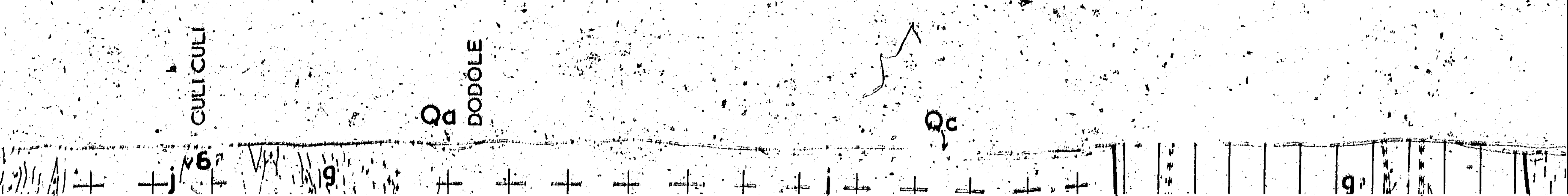
A
NORTH
MANAS
BUR GIEFELLE
BUR GALAN
Qa
500M
Sea level
1000M
g
C
j

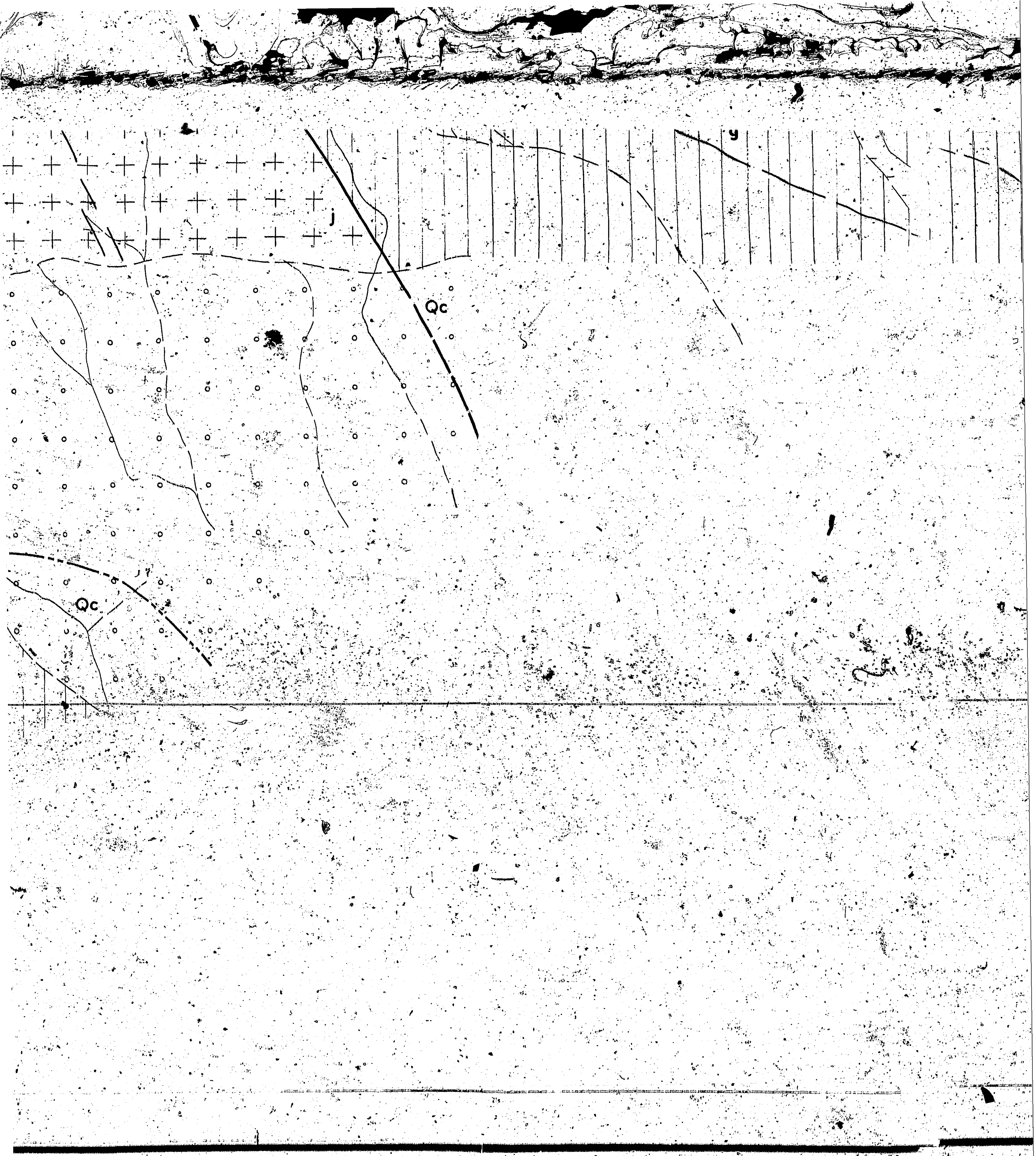


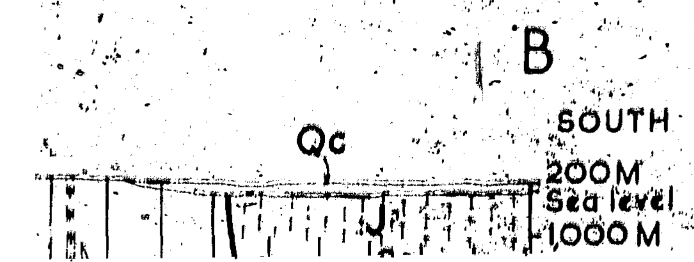
GEOLOGICAL CROSS SECTION A - B SEC

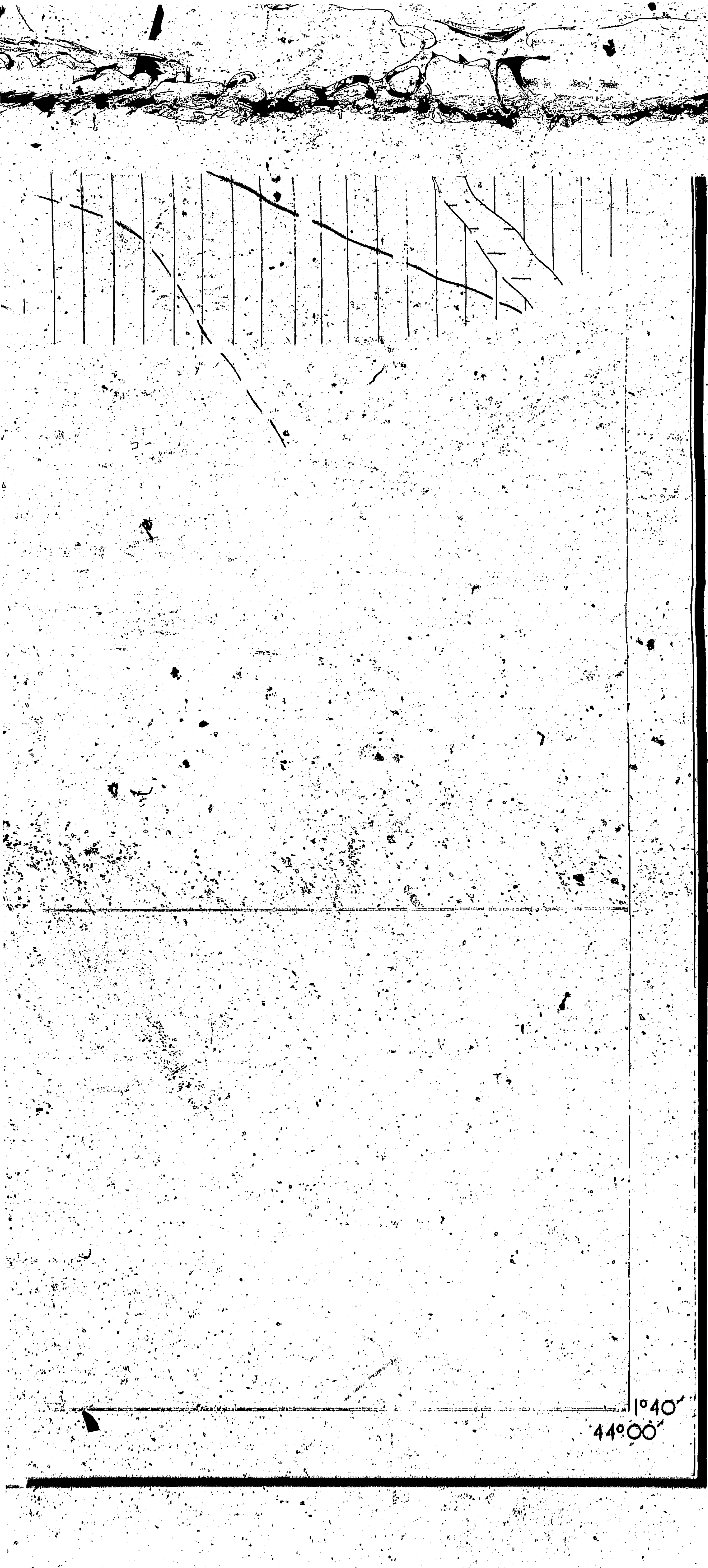

DODOLE
BUR MEDOV
BUR EDEN
j
g
GHERTA
BUR GOSEI
Qa
Qc
VAQ BRAVA
g?
BUR COREH
B
43°30'

SECTION A-B


CULI CULI
DODOLE
Qa
Qc
j
g


y
j
Qc
Qc


B
SOUTH
Qc
200M
Sea level
1000 M



QUATERNARY	Qa	ALLUVIAL SAND, CLAY, SILT, GRAVEL
	Qp	PROLUVIAL SAND, GRIT, SILT
	Qc	CALICHE MANTLE; HARD CALCAREOUS ROCKS
JURASSIC	J	LIMESTONE: ARGILLACEOUS, FLINTY, SHELLY
PRE-CAMPRIAN BASEMENT COMPLEX	δ?	IGNEOUS ROCKS OF MEDIUM TO BASIC COMPOSITI
	j	GRANITE: PINK TO YELLOWISH, MEDIUM TO COARSE-G SMALL-GRAINED GRANULITIC GRANITE (ALASKITE)
	C	CALC-SILICATE ROCKS, UPPER SERIES. QUARTZIT (CARBONATE-BEARING ROCKS OF COMPLEX COM
	g	GNEISS, LOWER SERIES. GNEISS, SCHIST, AMPHI GRANULITIC GRANITE

LITHOLOGICAL SYMBOL

- GRANITE MONADNOCK
- a: QUARTZITE MONADNOCKS; b: AREA OF SU
- a / b / c — IRON QUARTZITE BANDS: a: OBSERVED; b: INFE INTERPRETATION. c: INFERRED BY PHOTOGEOLO
- MARBLE, SILICATE MARBLE AND CALCIPHYRE
- GNEISS BANDS
- AMPHIBOLITE BEDS
- QUARTZITE BEDS
- GRANITE, APLITE, PEGMATITE (SEE GEOLOGICA

miles 4

GRAVEL

AREOUS ROCKS (CALCAREOUS CRUST)

FLINTY, SHELLY

ASIC COMPOSITION (MOSTLY INFERRED BY PHOTO-INTERPRETATION)

IUM TO COARSE-GRAINED, MICROCLINE-BIOTITE TO LEUCOGRANITE,
ITE (ALASKITE)

RIES. QUARTZITE - MILKY WHITE, GNEISS, SCHIST, MARBLE, SILICATE MARBLE, CALCIPHYRE
COMPLEX COMPOSITION); IRON QUARTZITE, GRANITE INJECTIONS.

SCHIST, AMPHIBOLITE - HEAVILY IMPREGNATED WITH PEGMATITE, APLITE,

SYMBOLS

AREA OF SUPPOSED QUARTZITE

RVED; b: INFERRED, BOTH BY AEROMAGNETIC SURVEY AND PHOTOGEOLOGICAL
Y PHOTOGEOLOGICAL INTERPRETATION.

CALCIPHYRE BANDS

SEE GEOLOGICAL CROSS SECTION)

GEOLOGI

GEOLOGICAL BOU

CONTACT, INFERR

CONTACT, APPR KS (CALCAR

FAULT

LY

FAULT, INFERRED
(AERO-MAGNETIC

FAULT: SUPPOS TION (MOST
THE SOUTH-EAST

TREND LINES: (M -GRAINED, MI
SCHISTOSITY - GNE

STRIKE AND DIP ITE - MILKY
MPOSITION);

A B GEOLOGICAL CRO PHIBOLITE -

TOPOGRAPHI LS

ROAD, PRINCIPAL

ROAD, OTHER

SUPPOSED

TRACK

NFERRED, BC
LOGICAL IN

PRINCIPAL TOWN

OTHER SETTLEME RE BANDS

WATERCOURSES

AERODROME

LANDING STRIP

OGICAL CROS

HUNTING'S MOSAI

(REDUCED FROM ORIGINAL COMPILATION)

miles 4 0 4 8 12 16

...KS (CALCAREOUS CRUST)

...LY

...TION (MOSTLY INFERRED BY PHOTO-INTERPRETATION)

...-GRAINED, MICROCLINE-BIOTITE TO LEUCOGRANITE,

...ITE - MILKY WHITE, GNEISS, SCHIST, MARBLE, SILICATE MARBLE, CALCIPHYRE
...MPOSITION); IRON QUARTZITE, GRANITE INJECTIONS

...PHIBOLITE - HEAVILY IMPREGNATED WITH PEGMATITE, APLITE,

...LS

SUPPOSED QUARTZITE

...NFERRED, BOTH BY AEROMAGNETIC SURVEY AND PHOTOGEOLOGICAL
...LOGICAL INTERPRETATION.

...RE BANDS

...OGICAL CROSS SECTION)

GEOLOGICAL SYMBOL...

GEOLOGICAL BOUNDARY

CONTACT, INFERRED

CONTACT ; APPROXIMATE

FAULT

FAULT, INFERRED, IN THE BASEMENT UNDER...
(AERO-MAGNETIC MAP)

FAULT: SUPPOSEDLY BORDERING THE BASE...
THE SOUTH-EAST

TREND LINES: (METAMORPHIC ROCKS);
SCHISTOSITY - GNEISSOSITY LINES: (IGNEOUS...

STRIKE AND DIP

A—B GEOLOGICAL CROSS SECTION

TOPOGRAPHICAL SYMBOLS

ROAD, PRINCIPAL

ROAD, OTHER

TRACK

PRINCIPAL TOWN

OTHER SETTLEMENTS

WATERCOURSES

AERODROME

LANDING STRIP

HUNTING'S MOSAIC EDGES

(REDUCED FROM ORIGINAL COMPILATION)

4 0 4 8 12 16 20 miles

SYMBOLS

SEMENT UNDER JURASSIC SEDIMENTS

ING THE BASEMENT UPLIFT FROM

ROCKS);
ES: (IGNEOUS ROCKS)

BASE MAP COMPILED FROM:

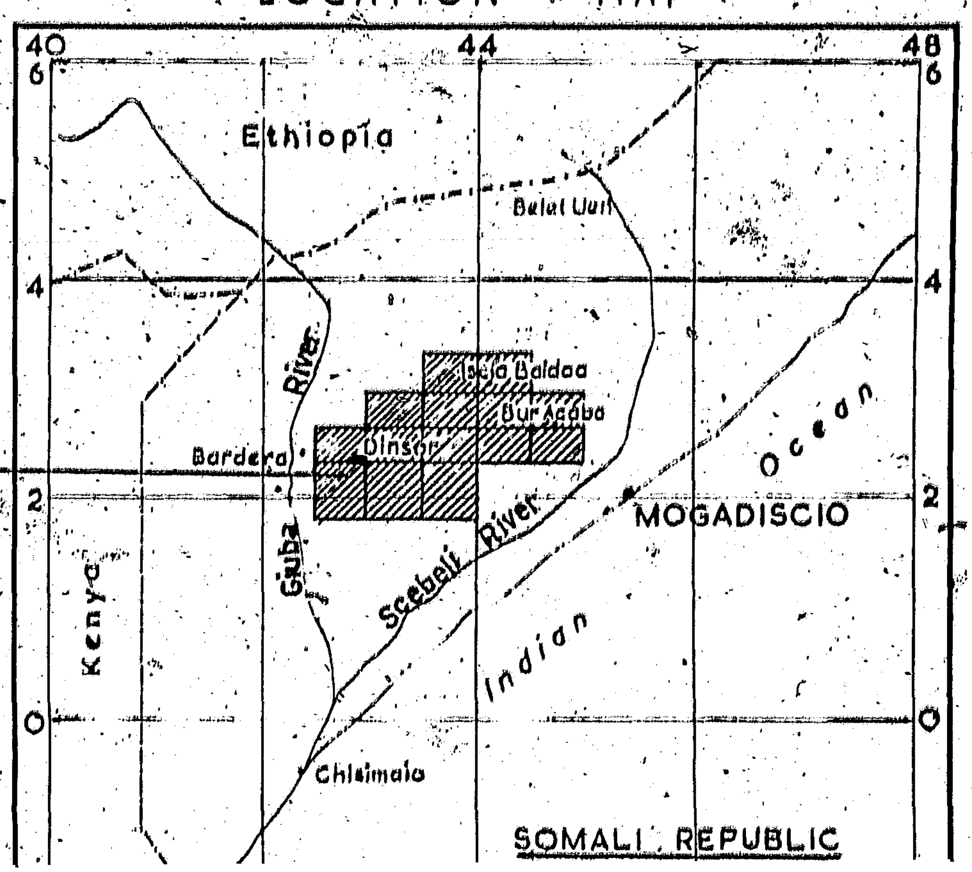
1. Uncontrolled mosaics, constructed by Hunting Surveys Ltd., Scale - 1:60,000. 1964

2. Uncontrolled mosaics, constructed by Aero Exploration, Frankfurt/M.; Scale - 1:30,000. 1965

3. G.S.G.S. 4355, Sheet NA 38/I, Fourth Edition.

MBOLS

LOCATION MAP



Subdivisional lines separate individual sheets scaled at 1:60,000

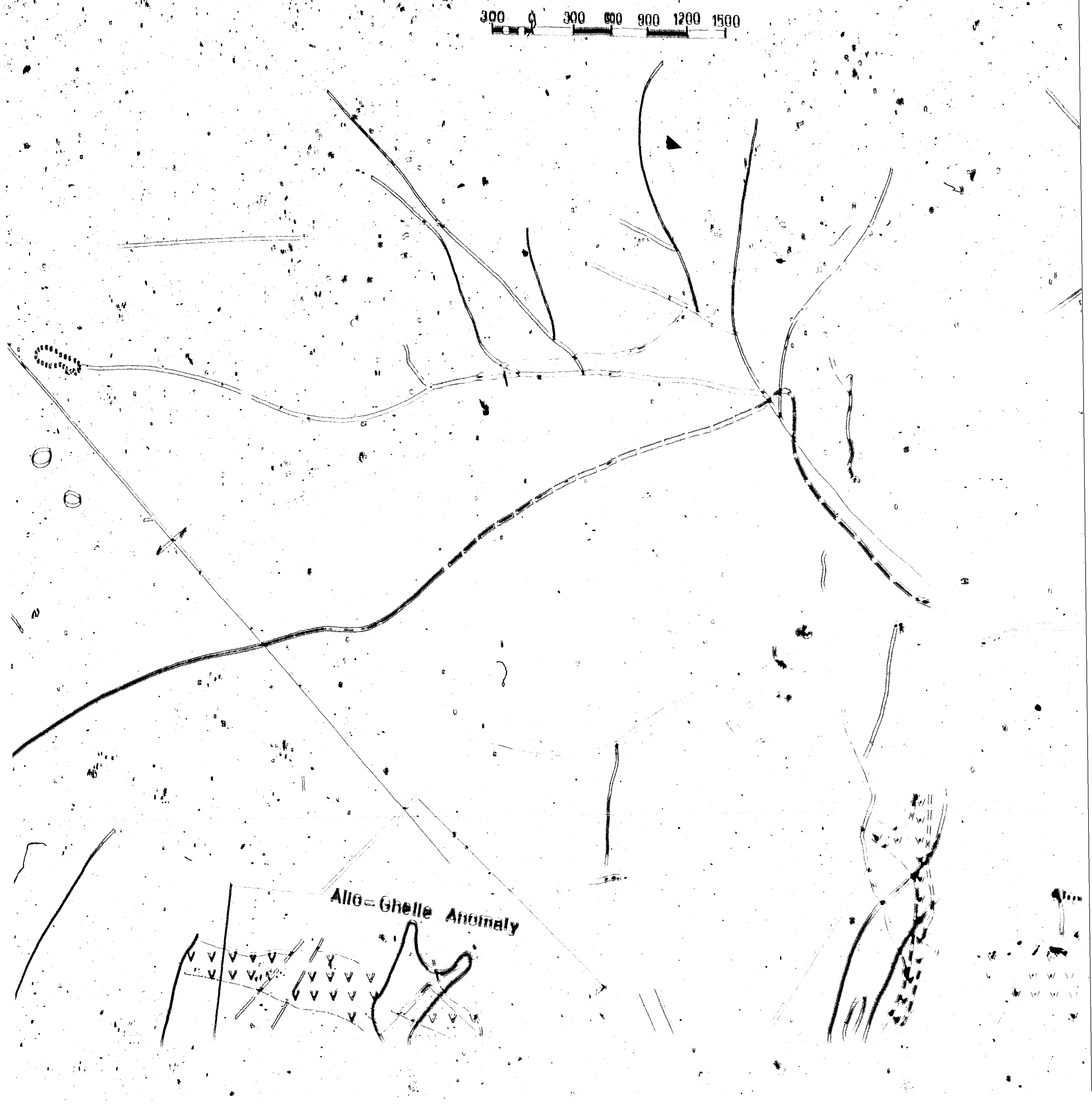
GOVERNMENT OF THE SOMALI REPUBLIC — UNITED NATIONS SP[?] GOVERNMEN

MINERAL AND GROUNDWATER SURVEY

ALIO GHELLE

PRINCIPAL ANOMALIES AND GEOLOGICAL INDICATIONS

Scale in Metres



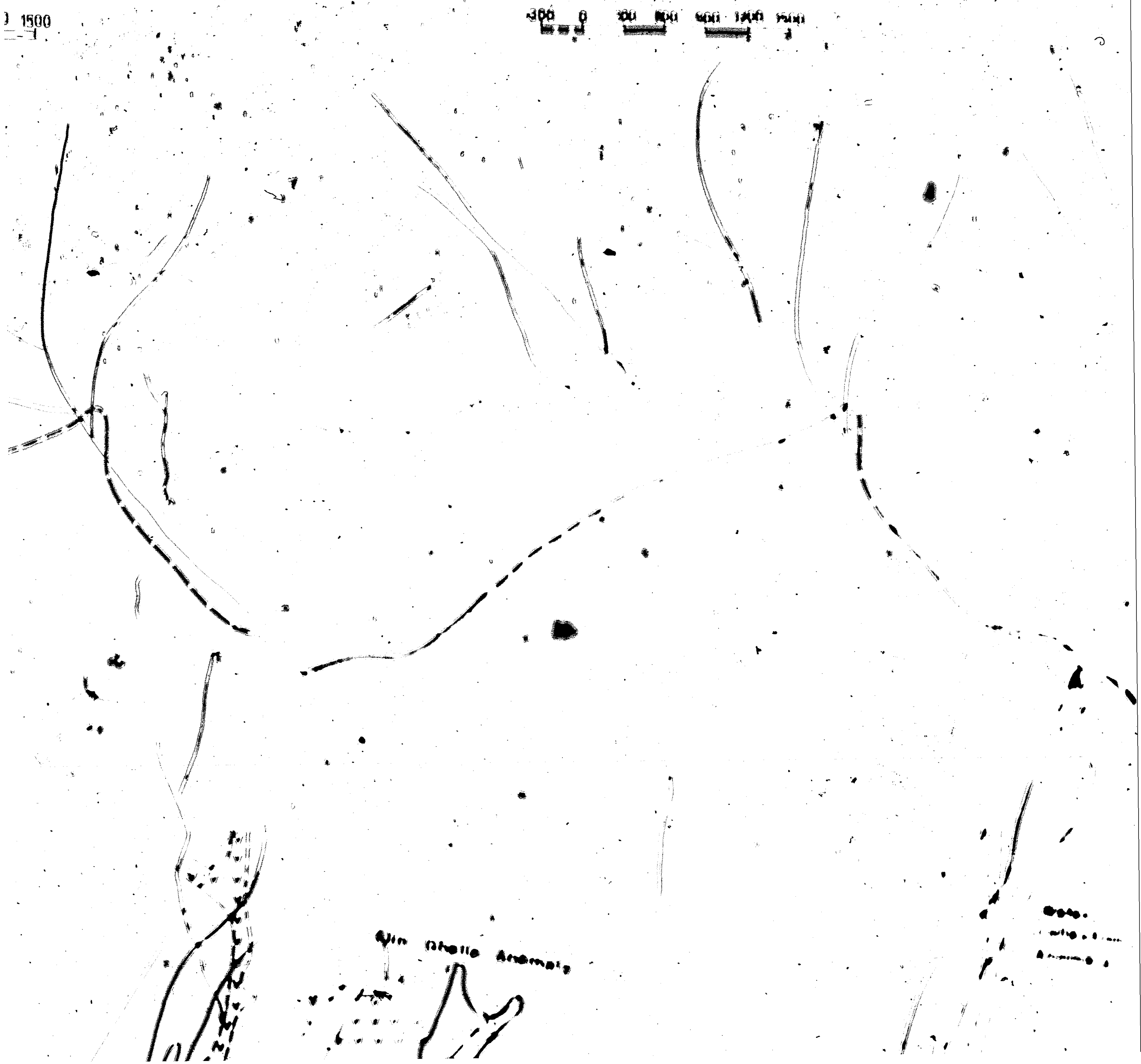
GOVERNMENT OF THE SOMALI REPUBLIC — UNITED NATIONS SPECIAL FUND

MINERAL AND GROUNDWATER SURVEY

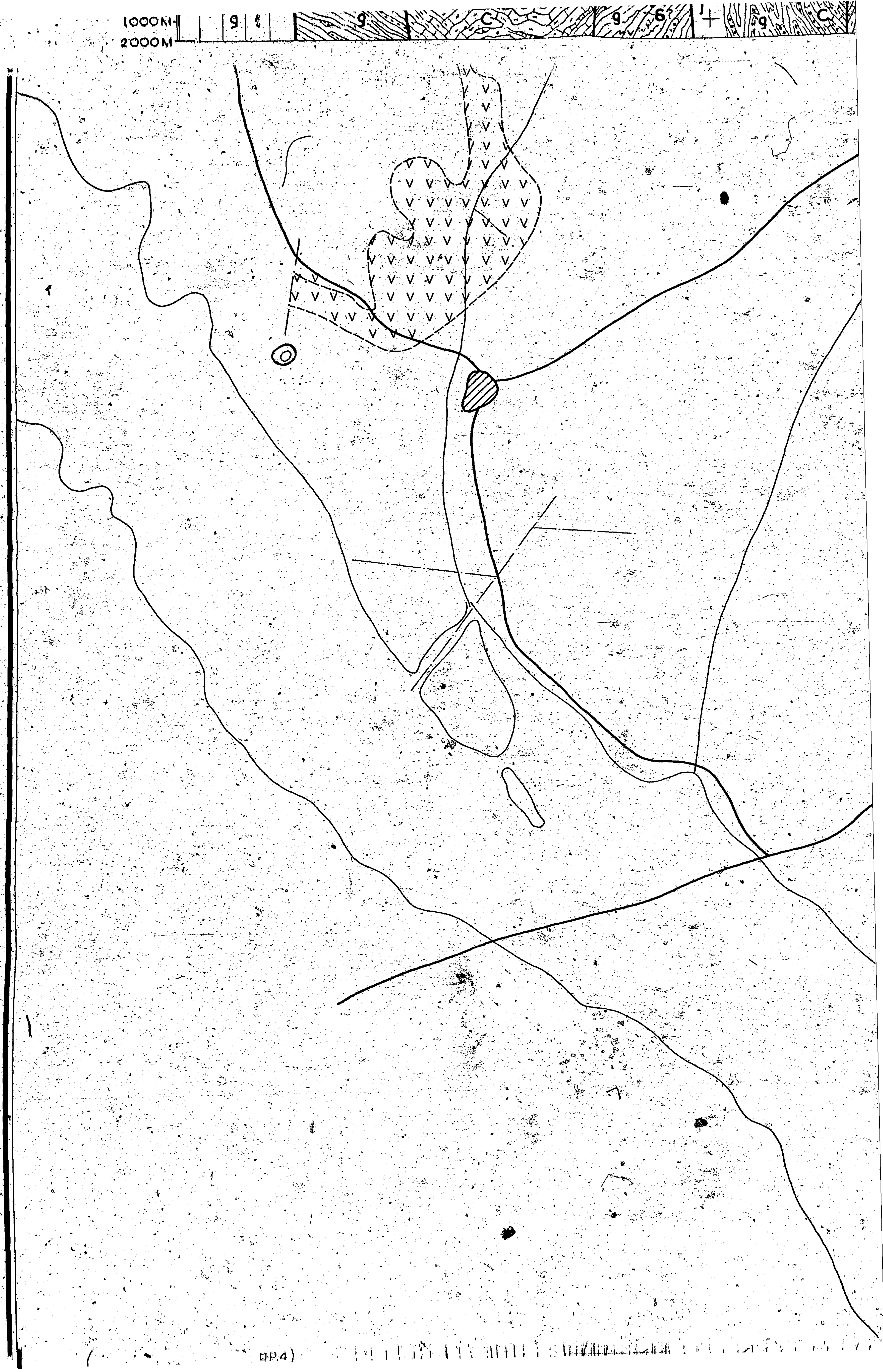
ALIO GHELLE

PRINCIPAL ANOMALIES AND GEOLOGICAL INDICATIONS

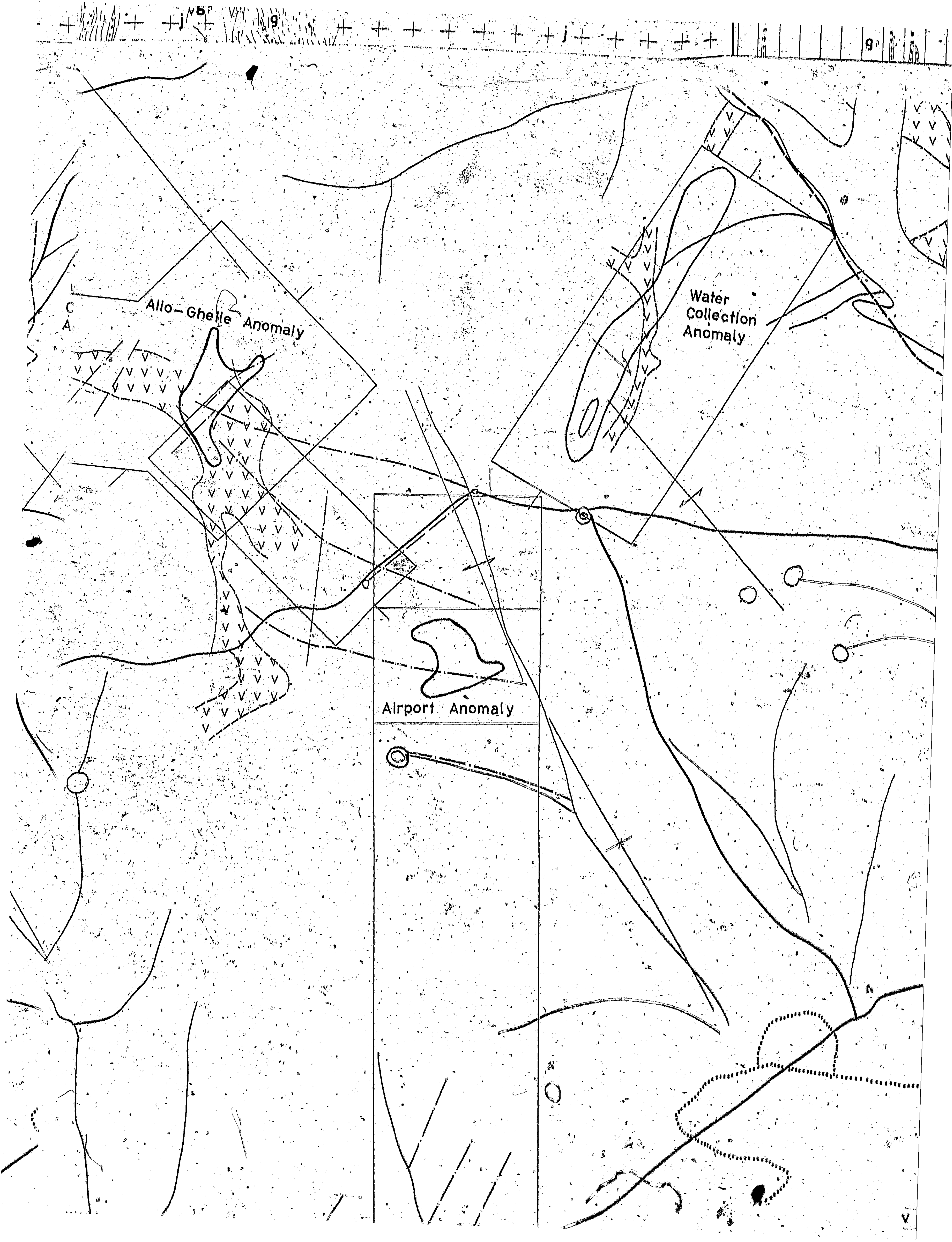
Scale in Metres



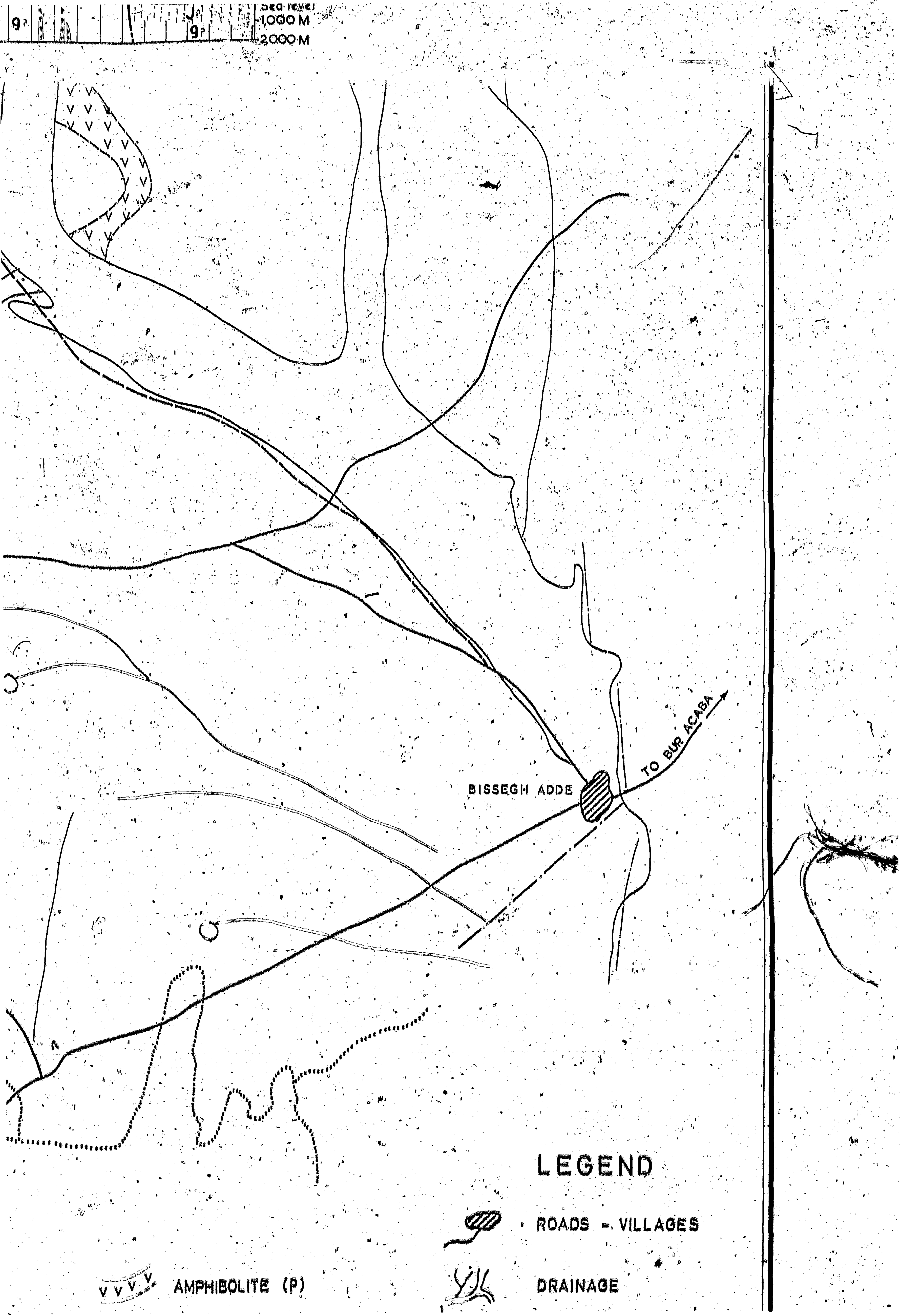
ECIAL FUND


1000M
2000M


Alio-Ghelle Anomaly
Airport Anomaly

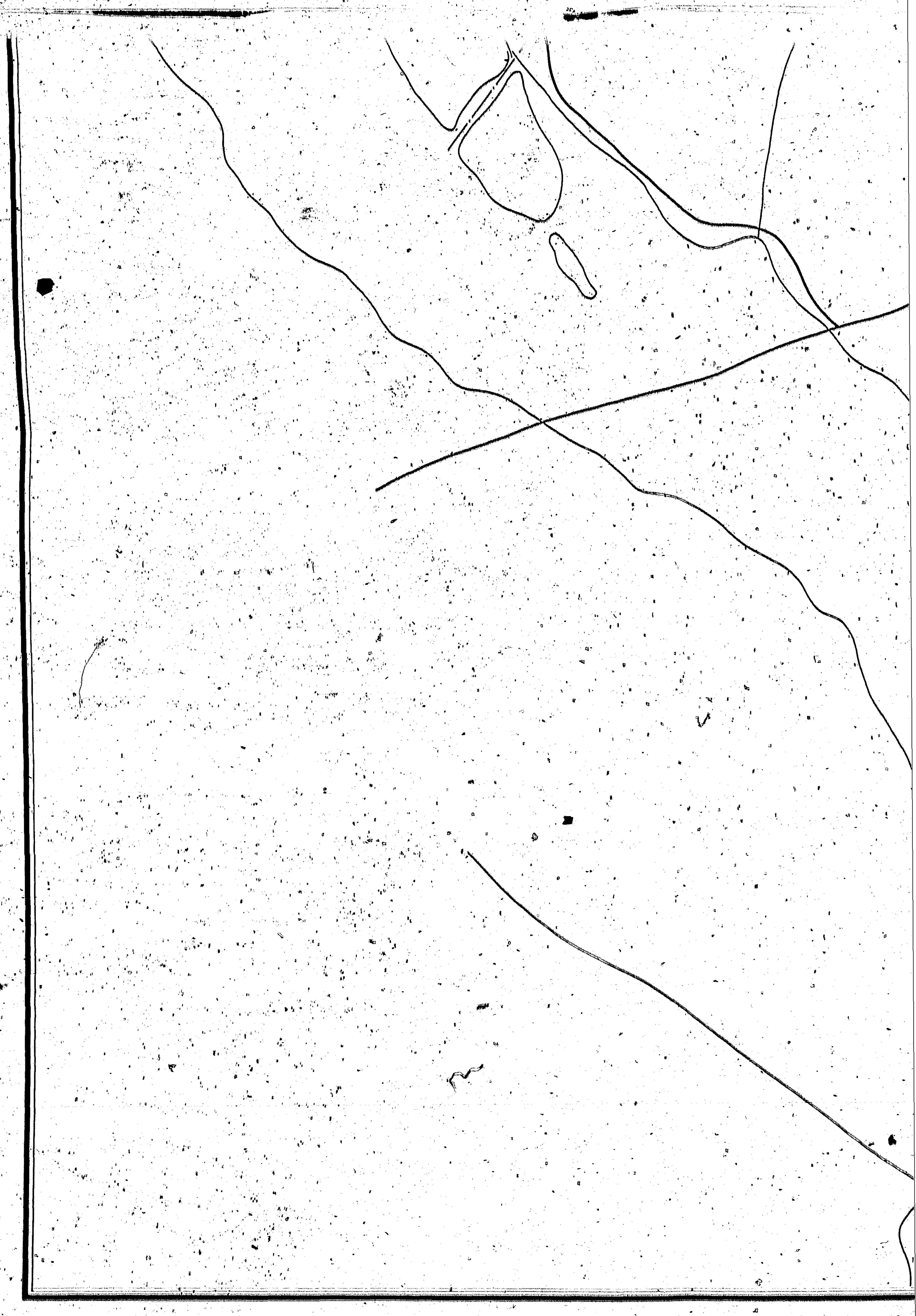


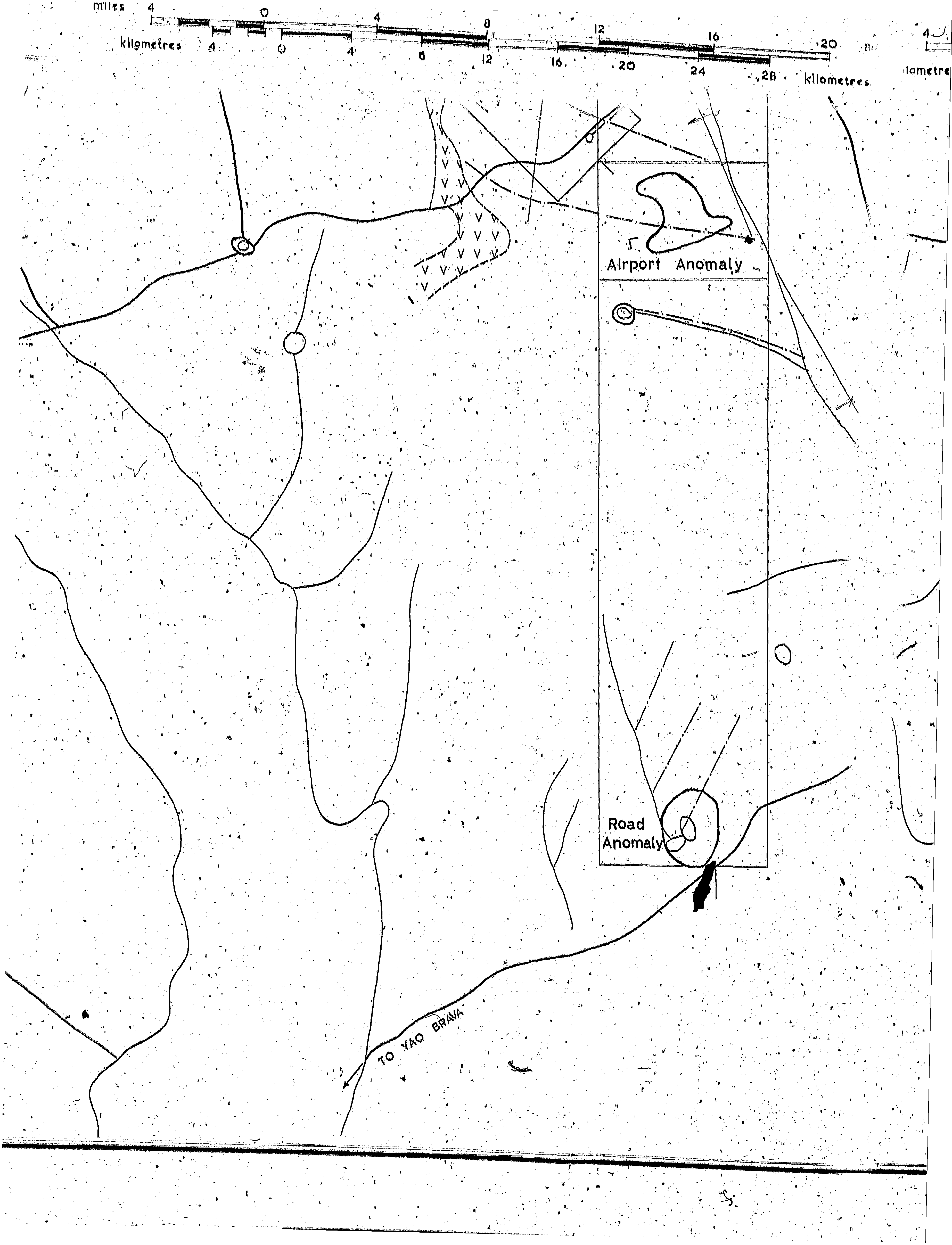
Allo-Ghelle Anomaly
Water Collection Anomaly
Airport Anomaly


Sea level
1000 M
2000 M
BISSEGH ADDE
TO BUR ACABA
LEGEND
ROADS - VILLAGES
AMPHIBOLITE (P)
DRAINAGE

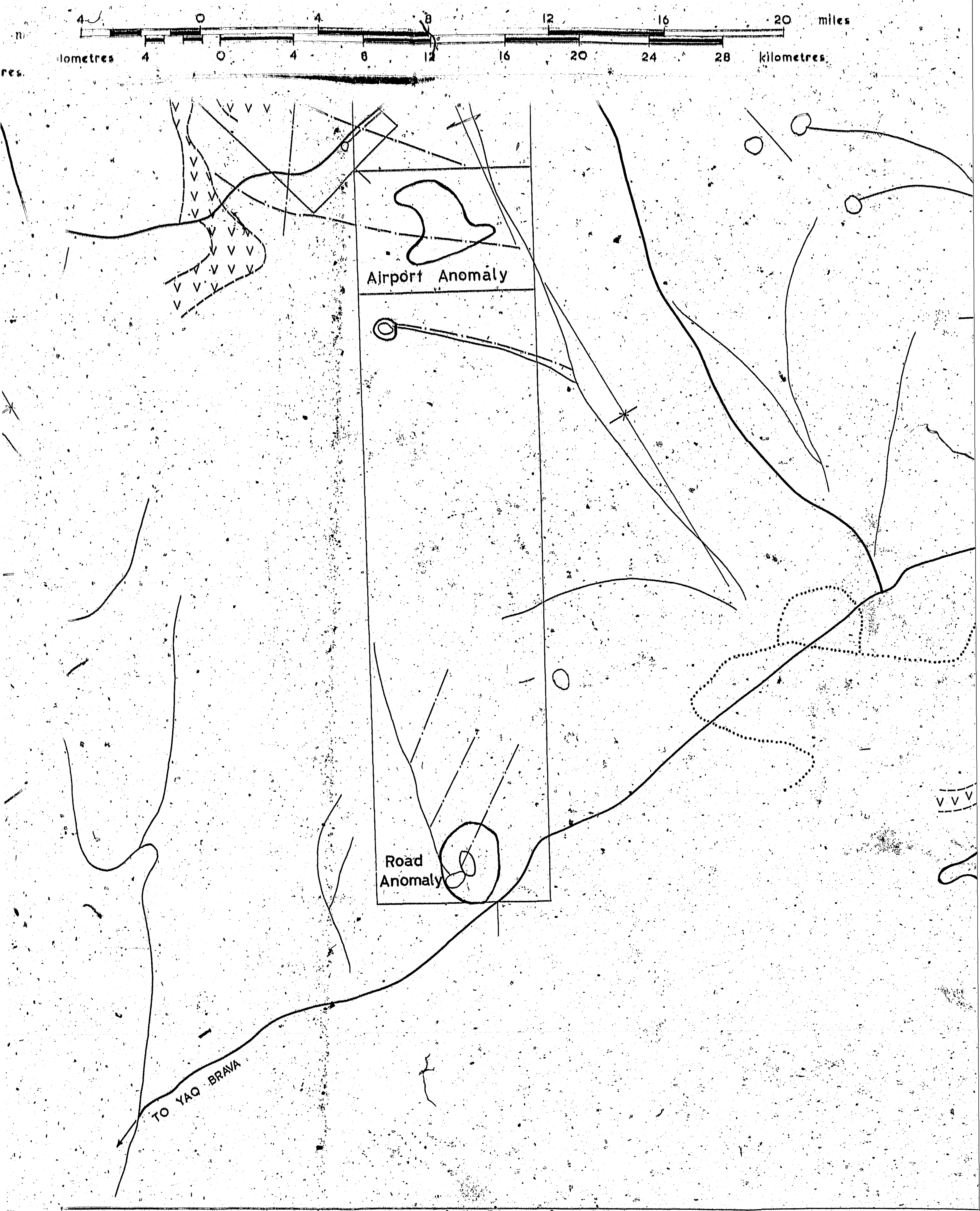
miles

Compiled by:
U.N. Photogeologist - A. ILYIN

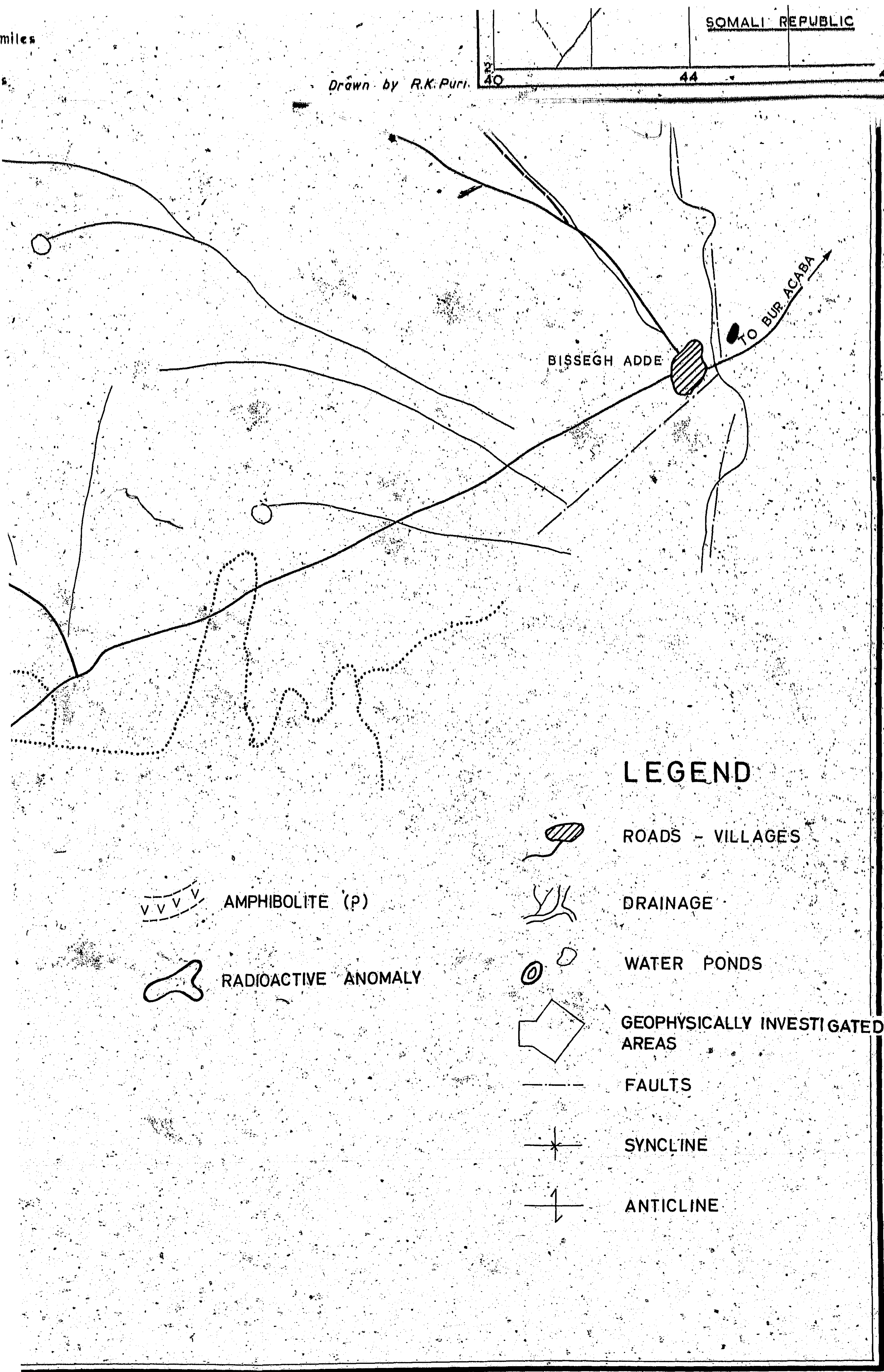




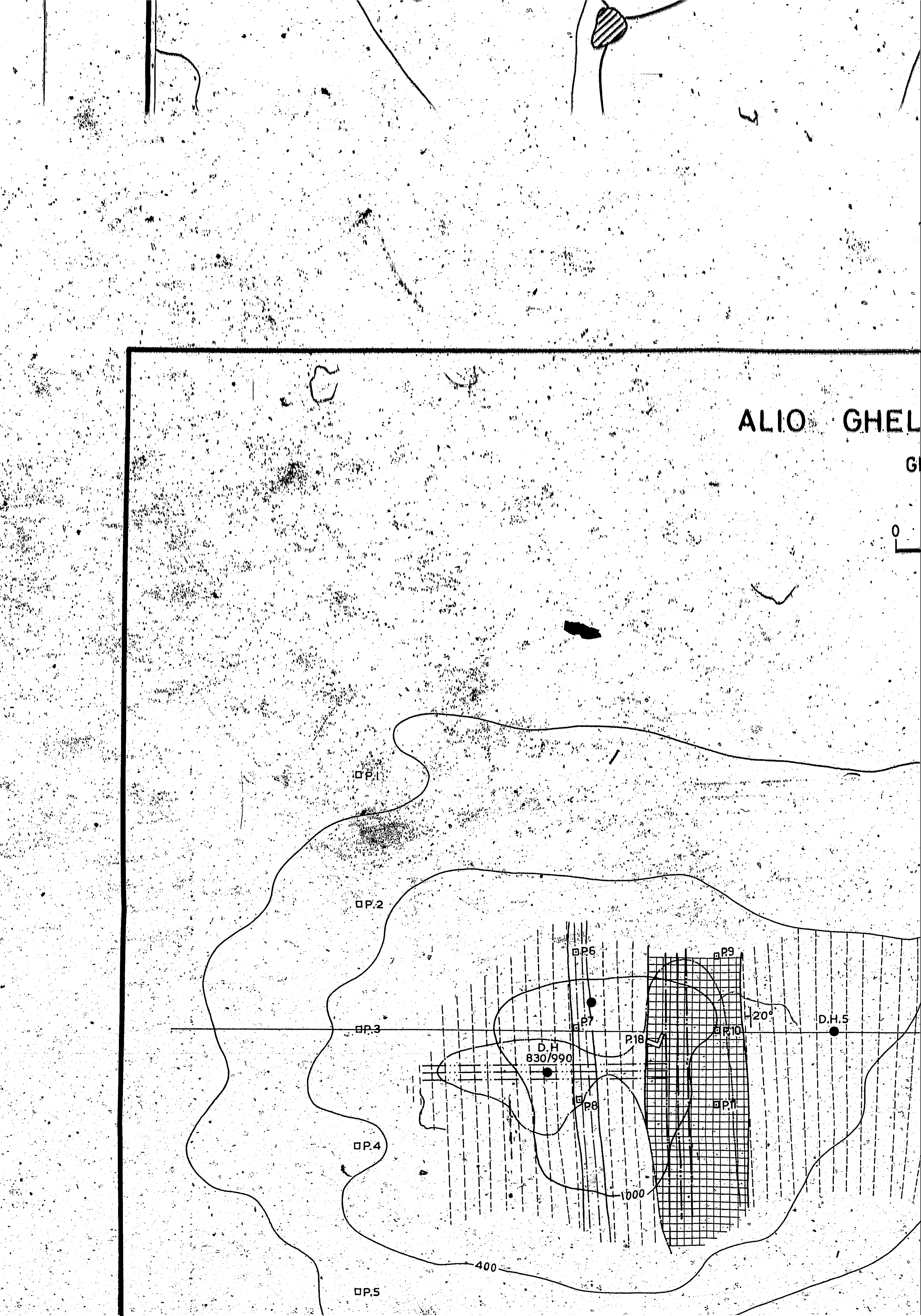
miles
4
0
4
8
12
16
20
kilometres
4
0
4
8
12
16
20
24
28
kilometres
Airport Anomaly
Road Anomaly
TO YAQ BRAVA



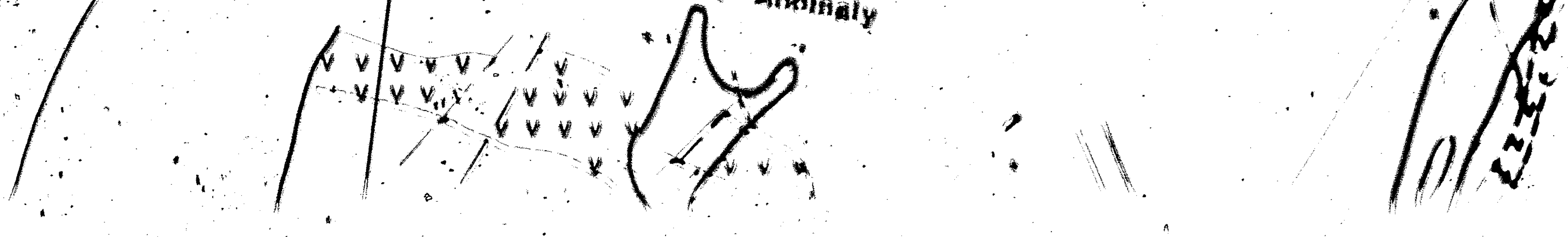
4 0 4 8 12 16 20 miles
lometres 4 0 4 8 12 16 20 24 28 kilometres
res.
Airport Anomaly
Road Anomaly
TO YAQ BRAVA


miles
Drawn by R.K.Puri
SOMALI REPUBLIC
2
40
44
2
48
BISSEGH ADDE
TO BUR ACABA
LEGEND
ROADS - VILLAGES
DRAINAGE
WATER PONDS
GEOPHYSICALLY INVESTIGATED AREAS
FAULTS
SYNCLINE
ANTICLINE
AMPHIBOLITE (P)
RADIOACTIVE ANOMALY

Map 2

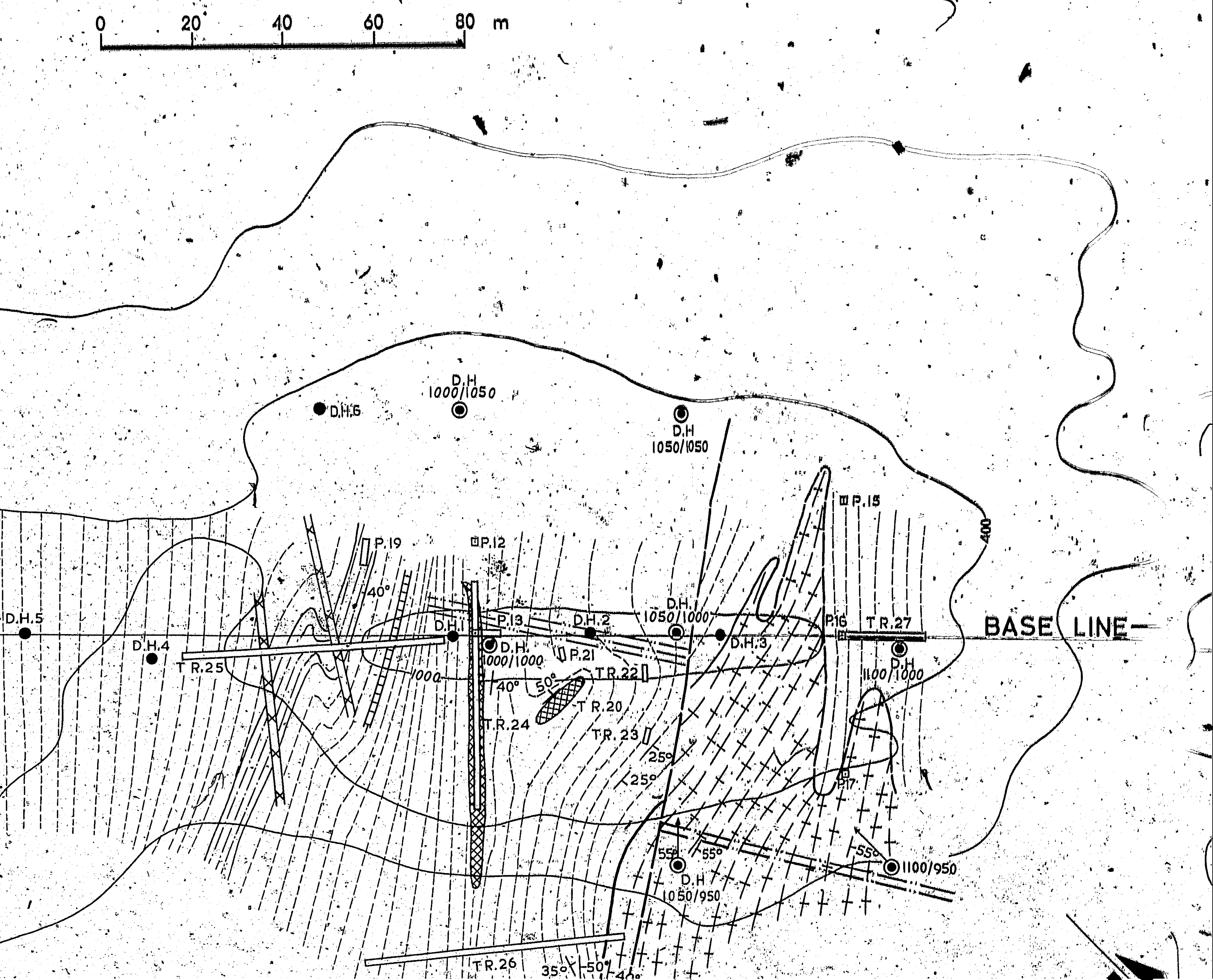


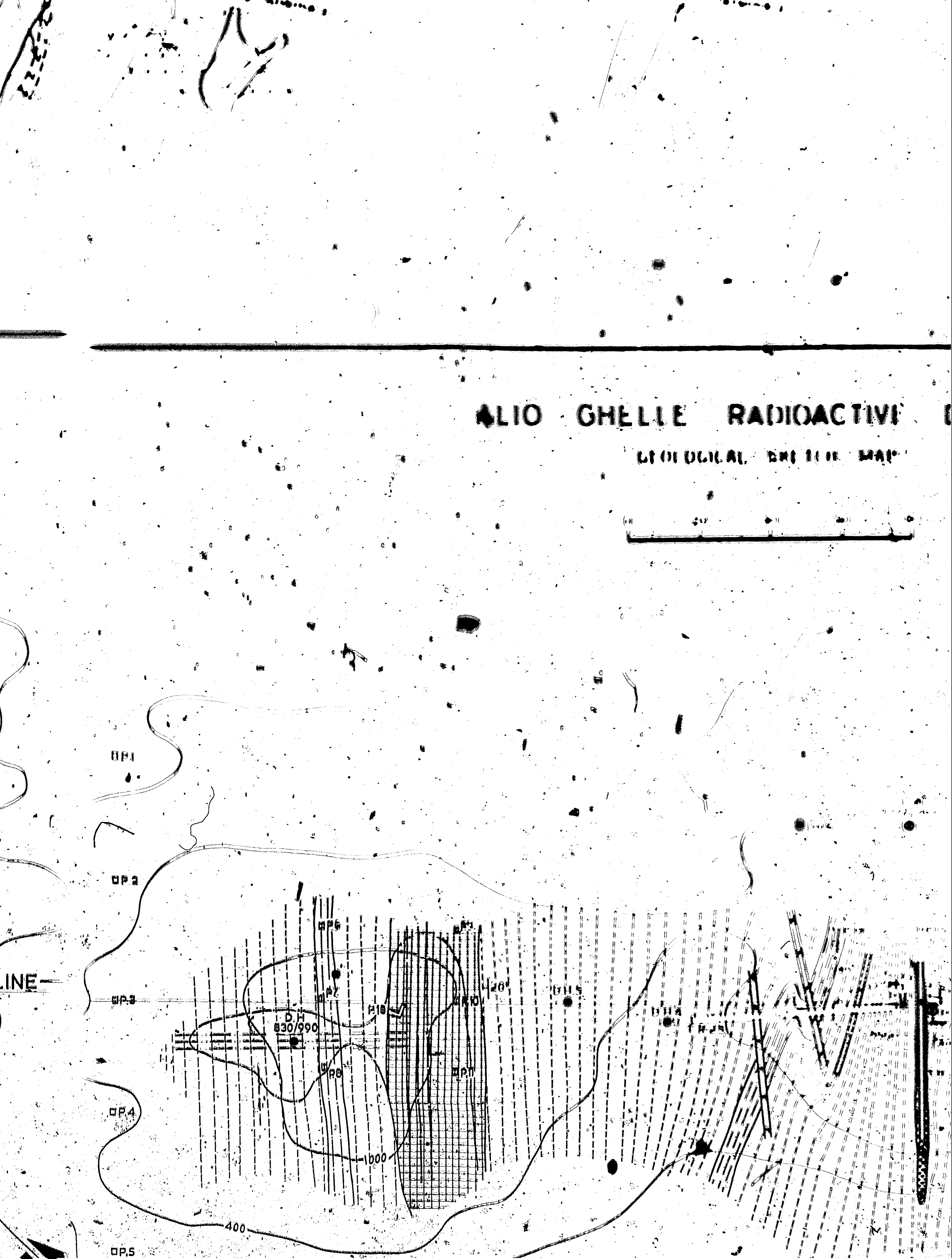
ALIO GHEL
P.1
P.2
P.3
P.4
P.5
P.6
P.7
P.8
P.9
P.10
P.11
P.18
D.H
830/990
D.H.5
20°
1000
400



GHELLE RADIOACTIVE DEPOSIT

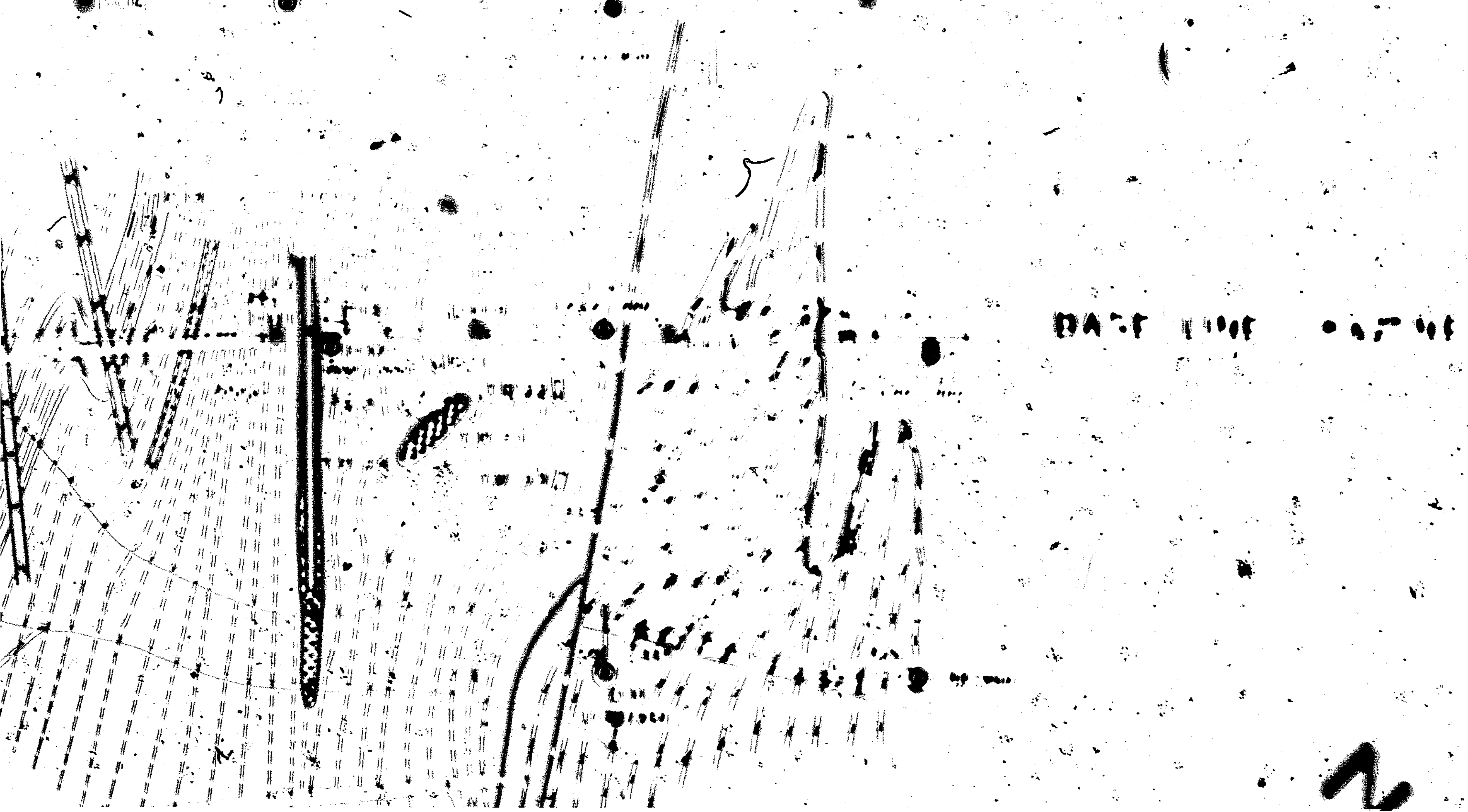
GEOLOGICAL SKETCH MAP

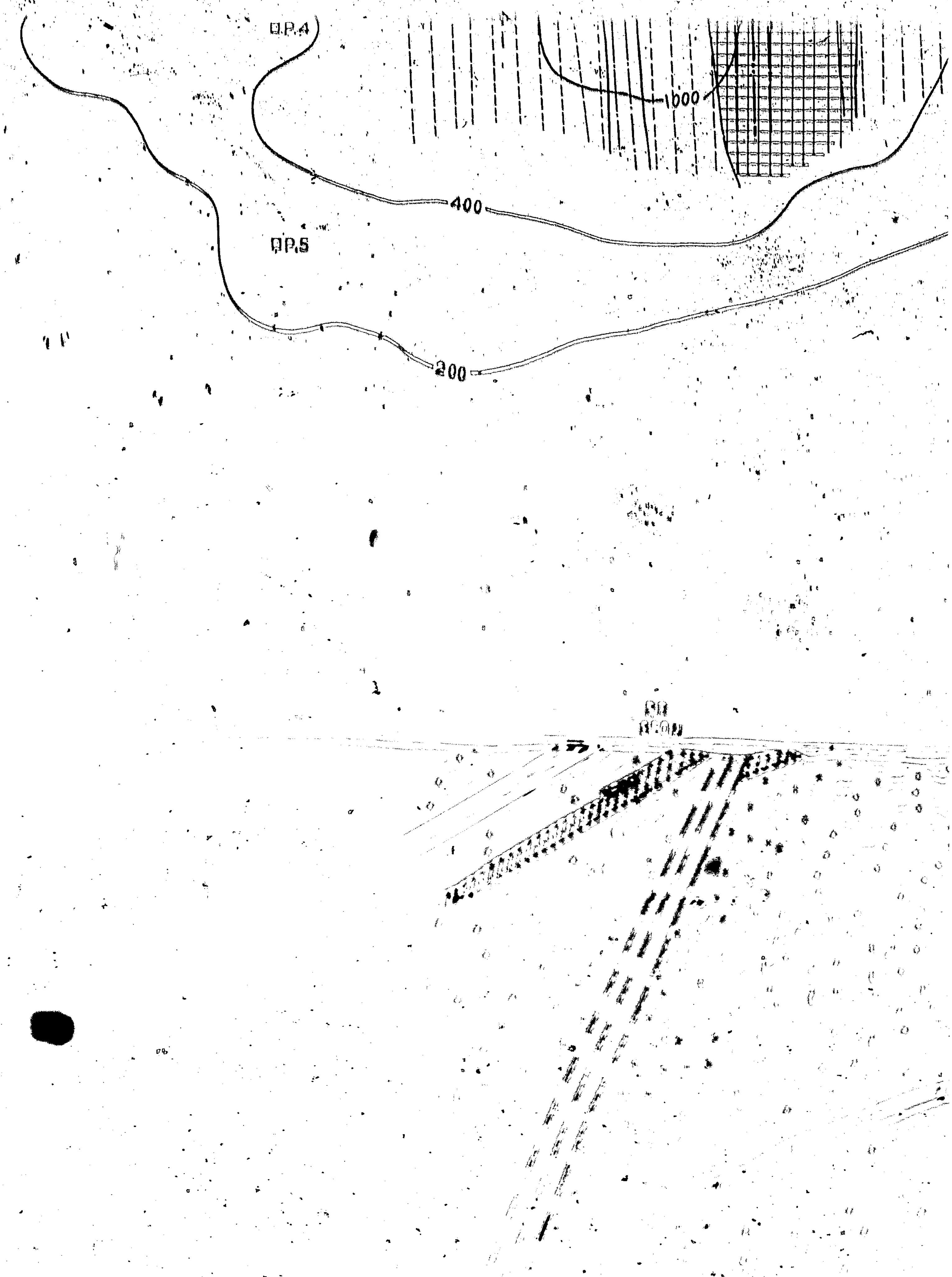


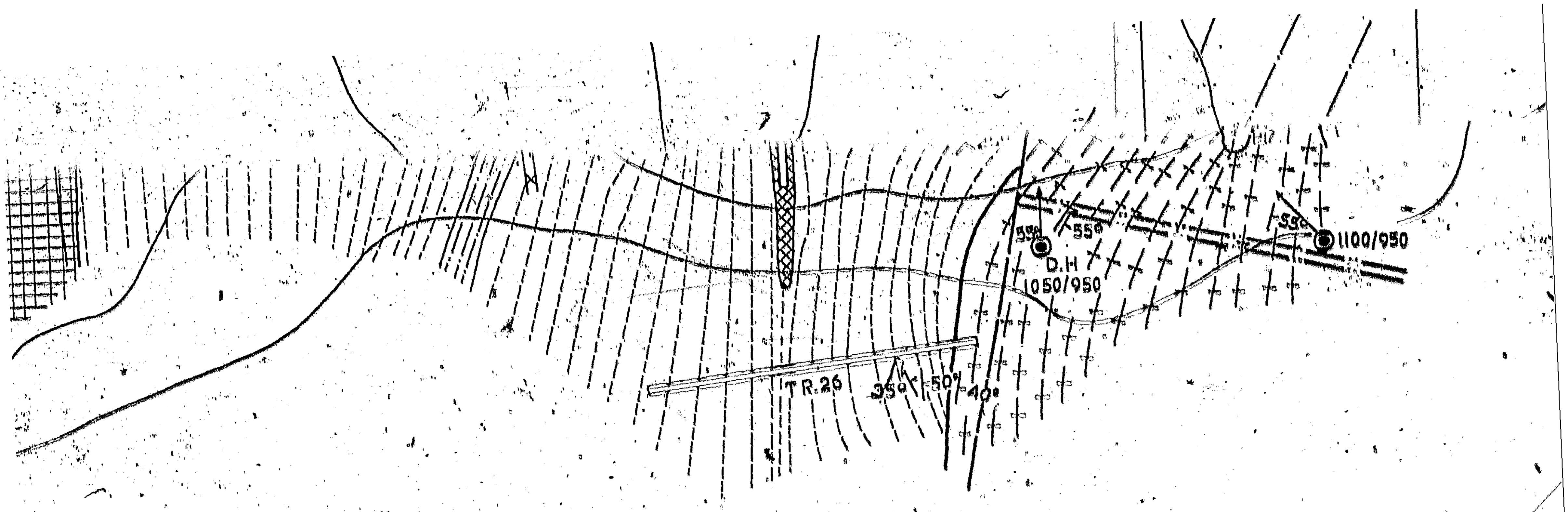


ALIO GHELLE RADIOACTIVE
GEOLOGICAL SKETCH MAP
LINE
D.H
830/990
1000
400

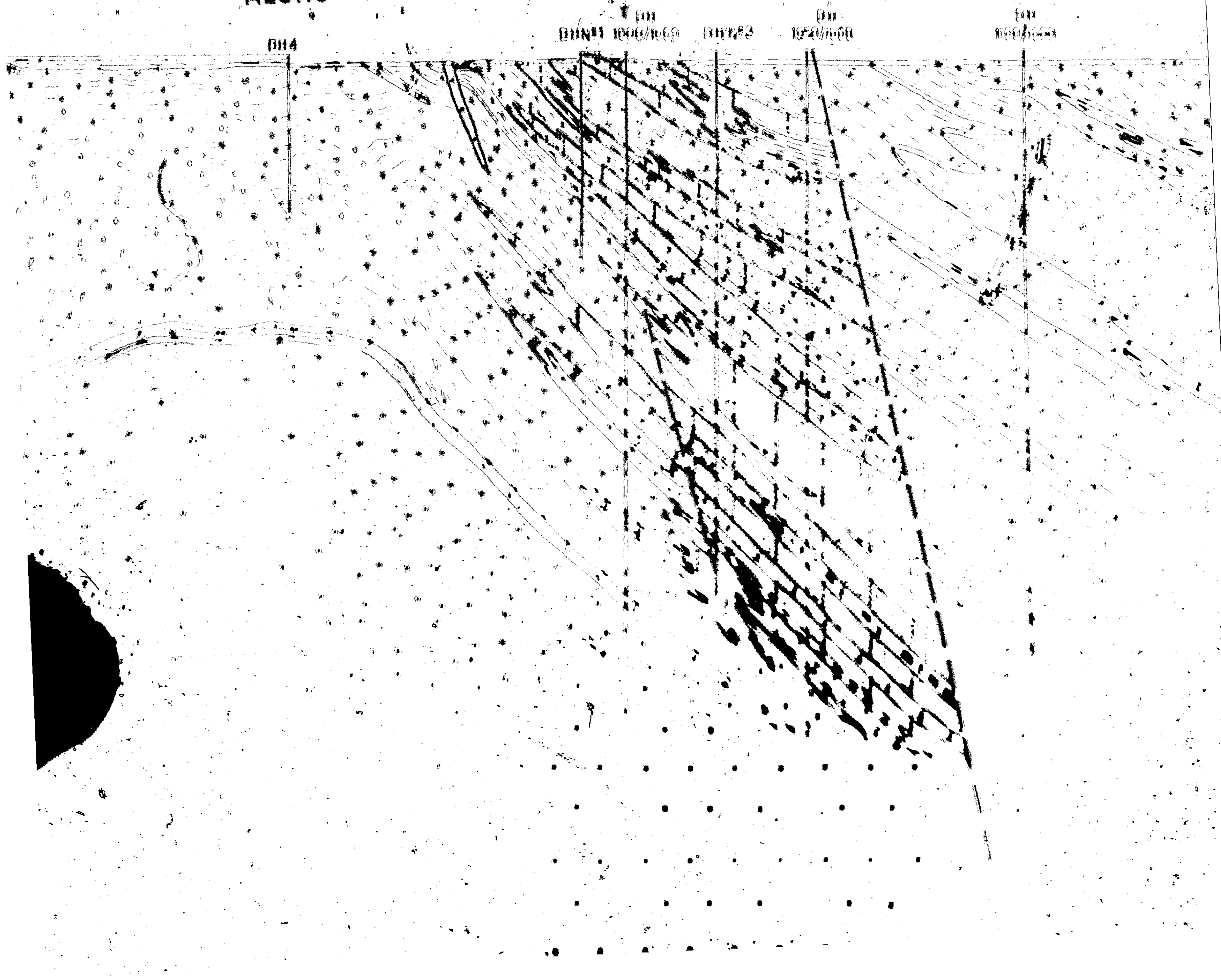
ADIOACTIVE DEPOSIT

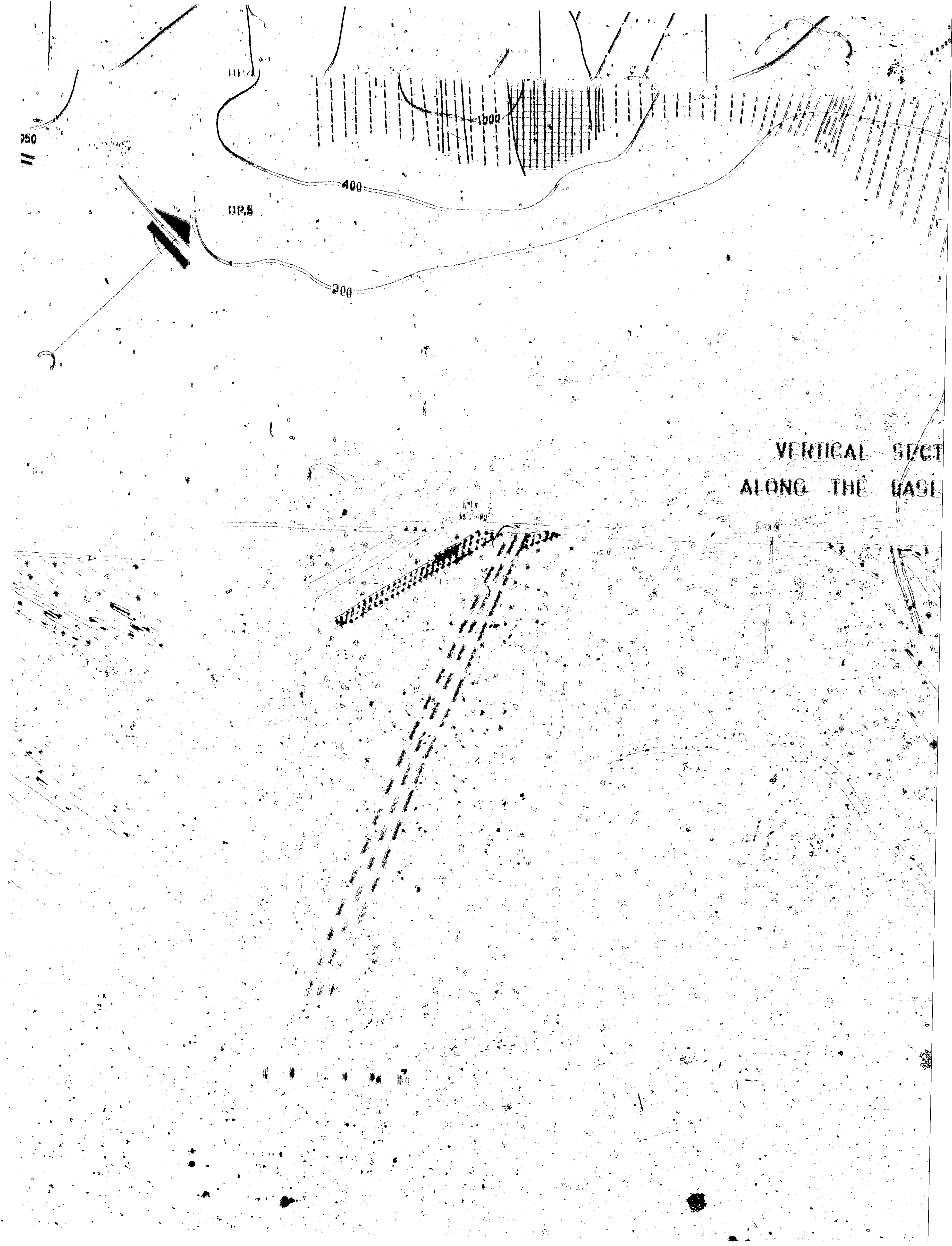



OP.4
1000
400
OP.5
200

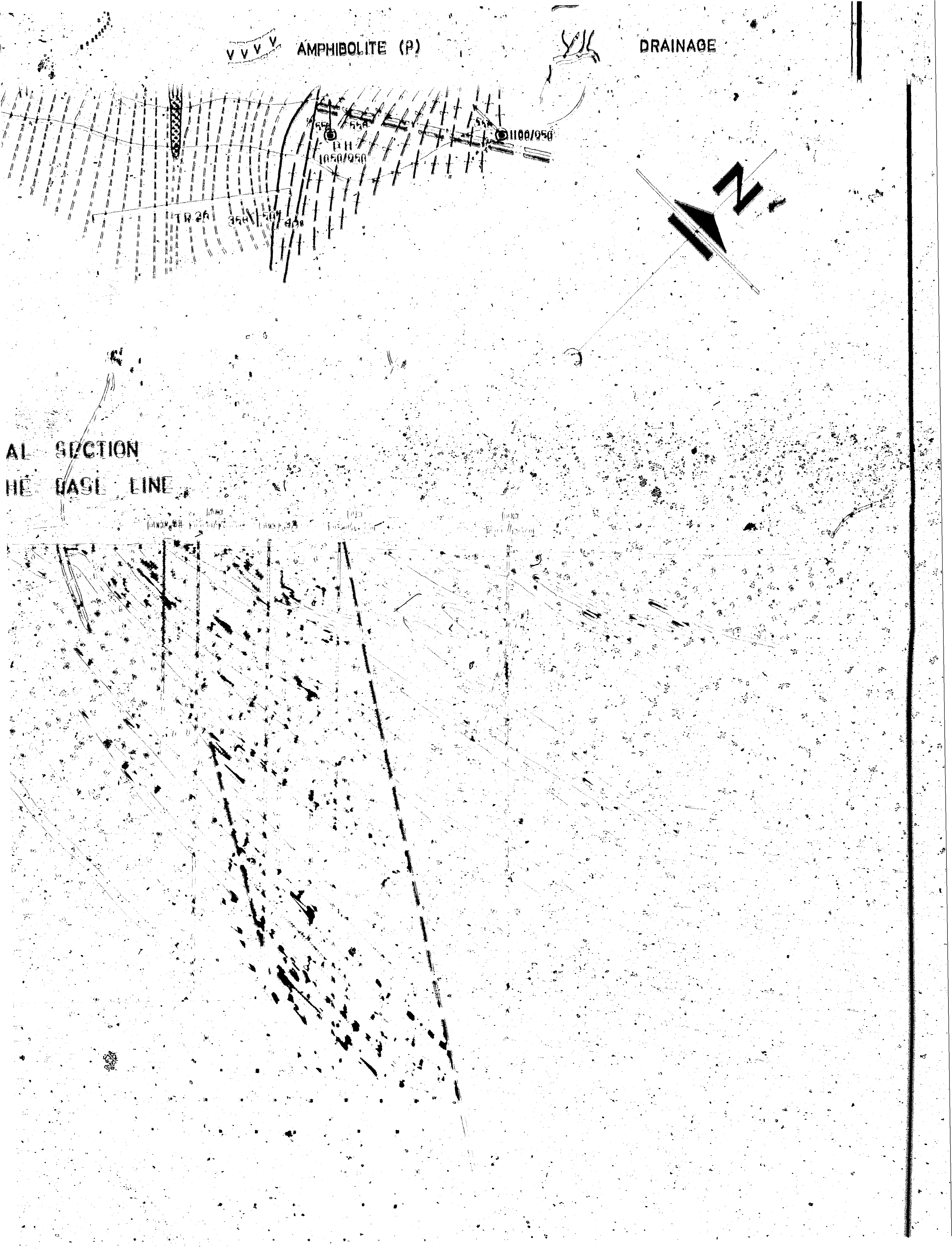


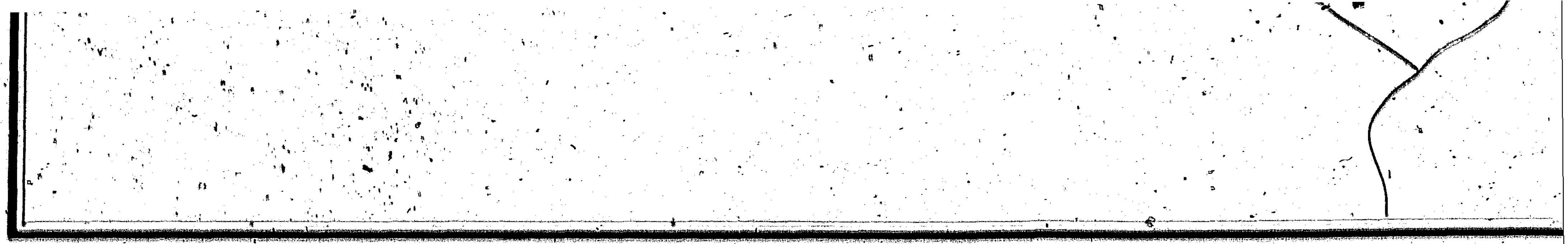
VERTICAL SECTION
ALONG THE BASE LINE





1600
400
200
VERTICAL SECT
ALONG THE BASI


AMPHIBOLITE (P)
DRAINAGE
B H
1050/950
1100/950
N
AL SECTION
HE BASE LINE

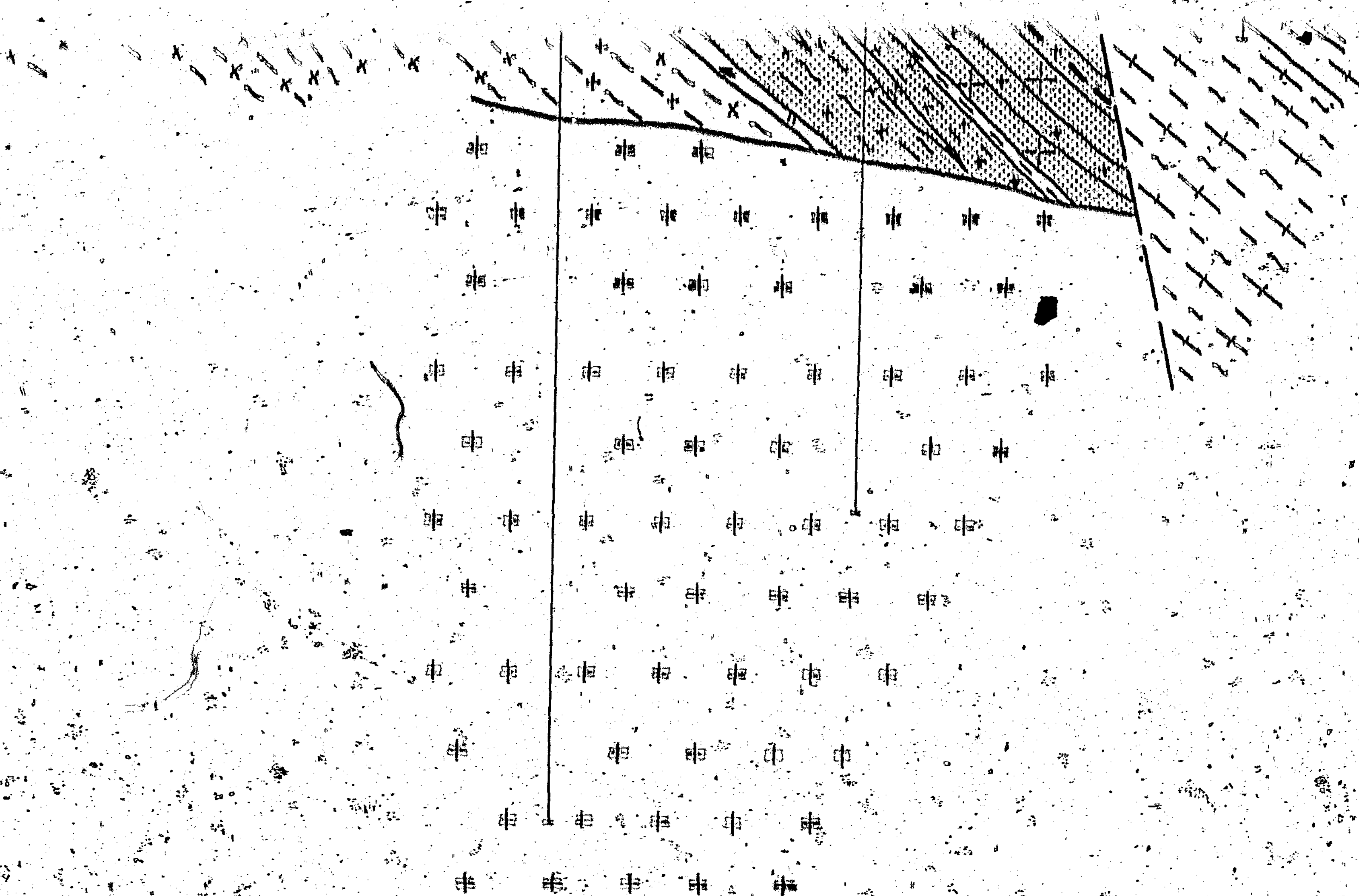


LEGEND

- GNEISSOSITY IN SCHISTS AND GNEISSES
- BIOTITE – AMPHIBOLITIC, SMALL – GRAINED PLAGIOGNEISS WITH COLOURLESS PLAGIOCLASE AND QUARTZ
- GREYISH – PINK GNEISSOSE GRANITE
- AMPHIBOLITE BED
- BED OF TREMOLITE SCHIST (VERTICAL SECTION).
- VEIN OF MICROCLINIC PEGMATITE
- COARSE – GRAINED ALBITITE
- VEIN OF WHITE QUARTZ – PLAGIOCLASIC, COARSE – GRAINED ROCK
- GREYISH – PINK, SMALL TO COARSE – GRAINED SYENITE
- RED – BROWN SANDY LOAM
- FAULT
- SHEAR ZONE GOVERNING MINERALIZATION
- CONTOUR OF THE SW ORE BODY
- METASOMATIC ALBITIZATION
- [illegible]

DRILLHOLES

- DRILLED BY PROJECT
- DRILLED BY [illegible]
- a) VERTICAL
- b) INCLINED
- CONTOUR OF SURFACE RADIOACTIVITY, COUNTS PER SECOND



LEGEND

ISSOSITY IN SCHISTS AND GNEISSES

ITE – AMPHIBOLITIC, SMALL – GRAINED PLAGIOGNEISS
F COLOURLESS PLAGIOCLASE AND QUARTZ

YISH – PINK GNEISSOSE GRANITE

IIBOLITE BED

OF TREMOLITE SCHIST (VERTICAL SECTION)

OF MICROCLINIC PEGMATITE

IE – GRAINED ALBITITE

OF WHITE QUARTZ – PLAGIOCLASIC, COARSE – GRAINED ROCK

ISH – PINK, SMALL TO COARSE – GRAINED SYENITE

BROWN SANDY LOAM

T

AR ZONE GOVERNING MINERALIZATION

OUR OF THE SW ORE BODY

ASOMATIC ALBITIZATION

AND STRIKE

HOLES

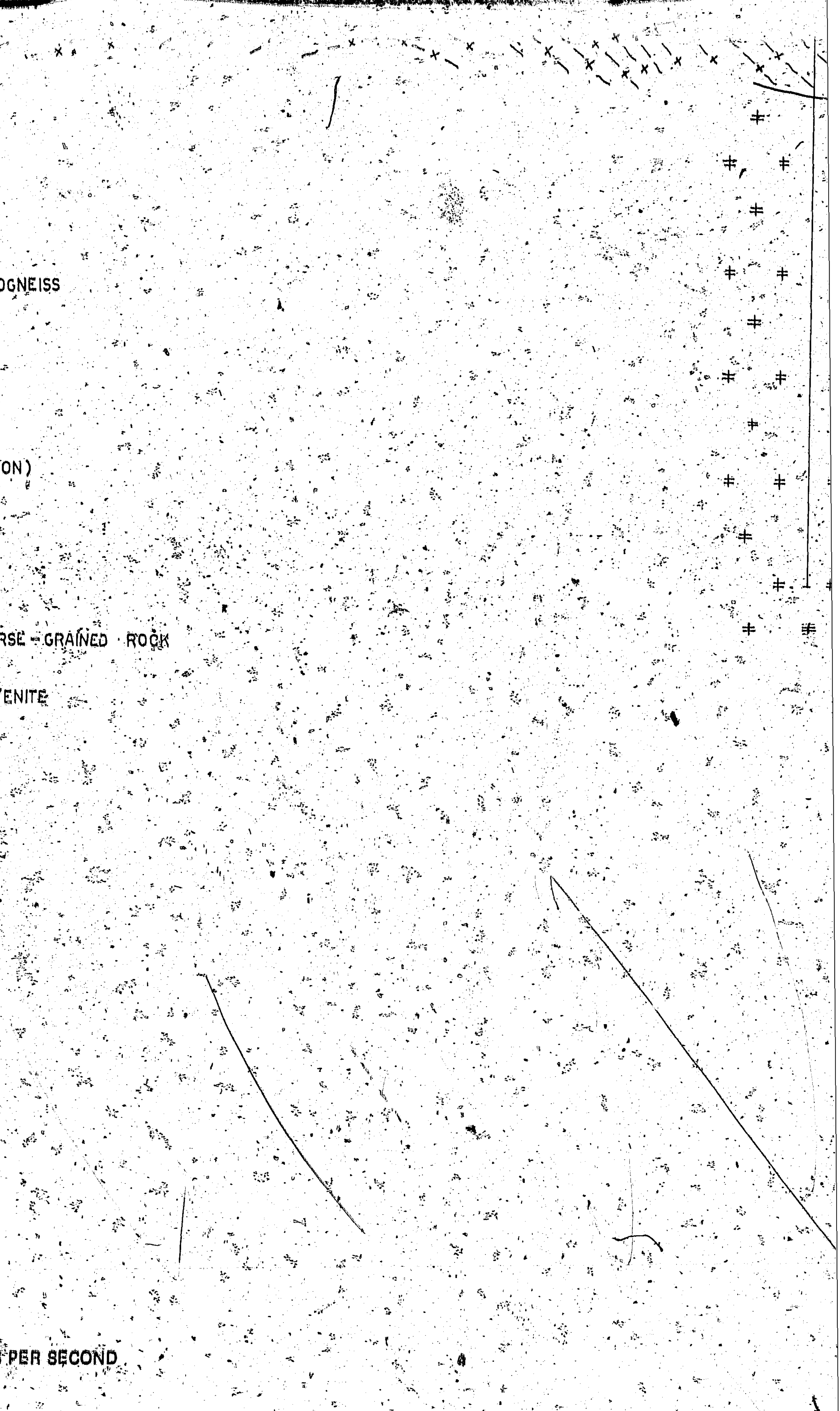
LED BY PROJECT

LED BY CONTRACTOR CRAELIUS

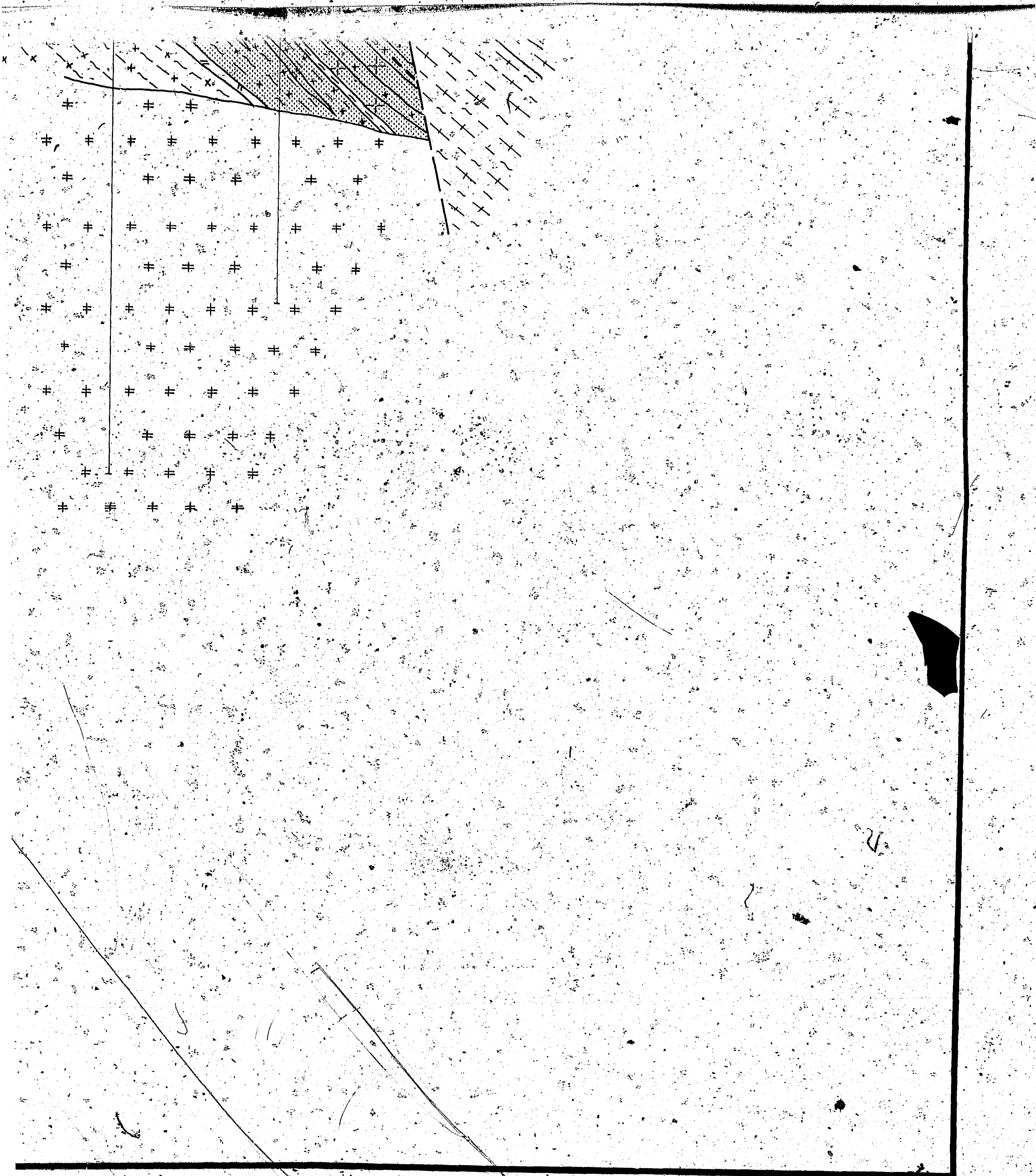
ICAL

NED

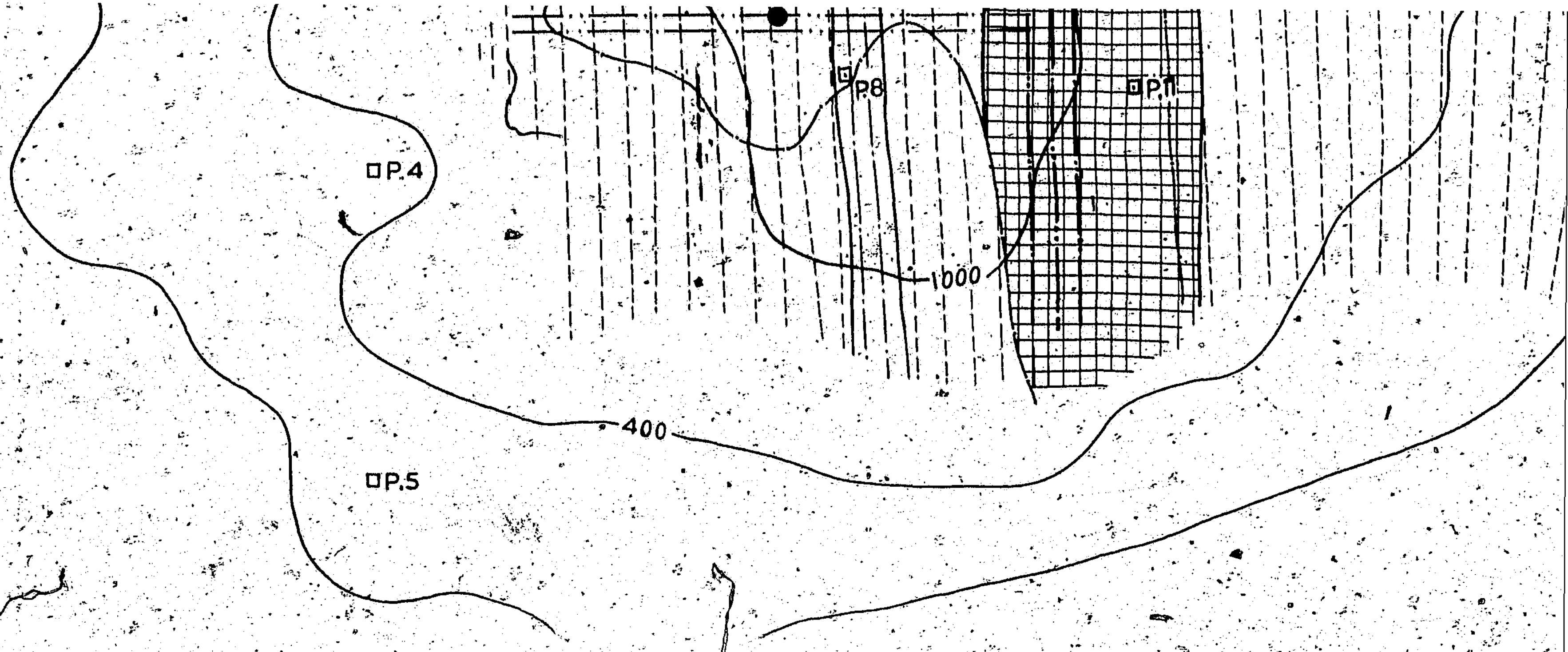
OUR OF SURFACE RADIOACTIVITY, COUNTS PER SECOND

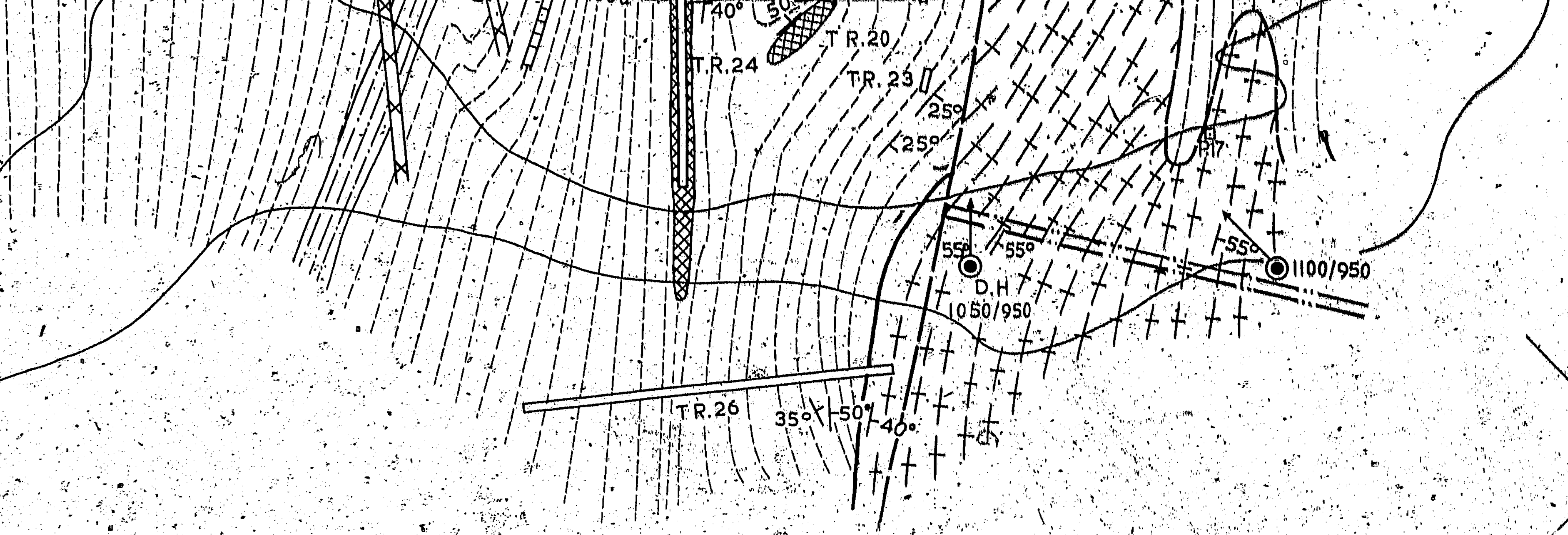


Map 2



Map 3


P8
P.11
P.4
1000
400
P.5



40°
T.R.20
T.R.24
T.R.23
25°
25°
17
55°
55°
55°
D.H
1050/950
1100/950
T.R.26
35°
50°
40°

THE END