Chapter 3 Geology of the Sectors

3-1 The Eastern Zayda Sector

3-1-1 Distribution of Geological Units

This sector is occupied by the Basement composed mainly of Crystalline Schists and Granites and by the covering rocks such as P-T Red Sandstone Formation, K_{2cm2} Mudstone Formation, K_{2t} Limestone Formation, T_1 Mudstone Formation, T_2 Marl Formation and Q_1 and Q_2 Siltstone Formations.

(1) Basement

1) Crystalline Schists

The Crystalline Schists are distributed in an approximate area of 250 km^2 from the north of Mibladane to Hawli and Sidi Ayyad. Also, some are distributed at Ilarich Azougagh, located along the northeastern marginal zone of the Zayda Granite Body.

In this Sector, the Crystalline Schists are composed mainly of chlorite-sericite schist as well as hornblende schist and sericite-quartz schist. Amphibolite is also distributed.

The chlorite-sericite schist occupies most of the Crystalline Schists in this sector. It is pale green or green in color, and is well-foliated. Main constituent minerals are chlorite and sericite. Veinlets of segregation quartz are contained more abundantly than other schists.

The hornblende schist is observed well in and around a zone of contact with the Zayda Granite Body. It is also found at the west of Hawli. The hornblende schist is green in color and the schistosity develops well. The constituent minerals are mainly chlorite and hornblend with minor amount of sericite.

The sericite-quartz schist is found around the Zayda Granite Body and at the west of Hawli. It is grey or dark grey in color, and the main constituent minerals are sericite and aboundant quartz. In the above-stated areas, thin layers 10 to 20 cm thick of this schist are alternated with chlorite-sericite schist or hornblende schist.

The amphibolite is distributed and observed around the Zayda Granite Body. Lithologically, it is dark green, coarse-grained and massive, and the constituent minerals are mostly hornblende. There is an amphibolite composed of only dark green hornblende about 1 cm in diameter, found at Ilarich Azougagh. This rock is found in lenticular mass about 300 m in major axis.

The Crystalline Schists are, as a whole, distributed forming an oval dome extending in the direction of NE-SW.

2) Granites

The Granites are distributed in an approximate area of 400 km^2 between Zayda and the western limit of the Crystalline Schists area. In this sector, Granites are composed of granite, porphyritic granite, contaminated granite, aplitic granite and dykes.

The granite is distributed occupying more than half part of the Zayda Granite Body area. White to pink, coarse-grained and compact in characteristics, this rock is composed of such main minerals as quartz, plagioclase, potash feldspar and biotite.

The porphyritic granite is distributed predominantly in the zone 1 to 2 km in width from the south of Arib, located at the south of the Zayda Granite Body, to the north of Assaka Ijdiy. Some exposures are also found around Ilarich Azougagh, along the northern margin of the Zayda Granite Body, at Aït Ghiat and around the Paneau-1 to the east of Assaka-n-Tabhirt. The rock shows similar color as the granite and it has characteristically large crystals of orthoclase as phenocrysts, occasionally reaching 4 cm in size. The main constituent minerals are same as those of the granite. (Refer to

Table I-6 No. 1D20)

The contaminated granite is distributed in the area around Ilich Azougagh in the southern part of the Zayda Granite Body and along the contact zone between the Granite Body and the Crystalline Schists. Some are found at Tourtit in the central part of the Zayda Granite Body and around Ilarich Azougagh in the northeastern part of it. This contaminated granite is composed of the granite and the porphyritic granite carrying xenoliths of the Crystalline Schists. In the vicinity of the Sidi Ayyad river about 3 km west of Sidi Ayyad, as well as around Talat n-Ait Sadane about 10 km southwest of Sidi Ayyad, this contaminated granite can be observed as porphyritic granite containing xenoliths of the Crystalline Schists. The main constituent minerals are same as those of the granite. (Refer to Table I-6 No. 1B04)

The granodiorite is distributed around Sidi Ayyad and around Bou Archicha about 3.5 km west of Sidi Ayyad. This rock is dark green in color, compact and rather fine-grained in characteristics. The main constituent minerals are plagioclase, quartz, microcline, biotite, green hornblende etc. (Refer to Table I-6 No. 1K09)

The Aplitic granite is distributed in the area from the Ilich Azougagh Mylonite zone to Zayda, occuping the western half of the Zayda Granite Body, and no distribution of this rock has been recognized in the eastern half of the Granite Body. The aplitic granite is rose-pink in color, massive and rather fine-grained in characteristics. The main constituent minerals are quartz, plagioclase, orthoclase and biotite. Megascopically, biotite is less in amount and alkali-feldspar is more abundant than the above-stated granites. (Refer to Table I-6 No. 1A11 and 1A05) This aplitic rock is distributed as sheet-like body gently dipping (less than 1^{o}) to the northwest as a whole. The thickness is as much as several meters in general but occasionally it reaches about 20 m.

Two or three sheets of this rock are well observed at a cliff along the Moulouya river around Paneau-1. There are other occurrences of this rock as stock-like rock body jutting out of the surface. A stock of this rock found about 2.5 km southeast of Assaka-n-Tabhirt is of the size about 200 m in diameter and about 50 m in height. Several small stocks found in the Tourtit area are of the size about 30 m in diameter. Compared to other granitic rocks, the aplitic rock has greater resistibility against weathering, and due to this fact, this rock is seen to have formed many small hills in the plain from the Ilich Azougagh Mylonite zone to Zayda.

Among the above-stated granites, the aplitic granite is distinguished from others by the difference of the lithofacies that it is rose-pink in color, rather fine-grained and by the difference of the mineral composition that it has less mafic minerals and more alkali-feldspars. The aplitic granite has clear boundary with other rocks, while the granite, the porphyritic granite, the contaminated granite and the granodiorite are Transitional each other to form obscure boundary.

As for the relation of the Granites to the Crystalline Schists, it is certain that the Granites have intruded into the Schists. In the Crystalline Schists close to the boundary, some intrusive bodies like dykes are recognized to be developed along schistosity, while in the Granites near the boundary there are many xenoliths caught by the Granites, which become less in amount in accordance with the distance from the boundary. The same phenomena are observed around Bou Archicha about 4 km west of Sidi Ayyad and around Sidi Said along the Moulouya river.

The dykes distributed in this Sector are aplite, granite porphyry and microgranodiorite.

The dykes of aplite are developed abundantly in the Zayda Granite Body.

They show such lithofacies similar to that of the aplitic granite, but generally, they are rather fine-grained and have less amount of mafic minerals as biotite, compared to the aplitic granite. The dykes of this rock are seen to have intruded with almost vertical inclination. Generally, the dykes are of small scale, and the width is less than 1 m in many cases, but there are some dykes more wide, as seen in the Sidi Ayyad area, where there is a dyke of the width of about 4 m.

There are two sorts of the dykes of granite porphyry. One is the granite porphyry which is light brown, hard and compact with phenocrysts of quartz and plagioclase. This sort of granite porphyry can be found in the following localities; a dyke at Immayn-n-Ait Rahhou, 3 dykes from Assaka-n-Tabhirt over to its east, Paneau-1, and another dyke at the east of Dique about 2 km northeast of Zayda. The direction of the intrusion is NE-SW, with vertical dipping. Generally, the width of the dykes is small except for those found at Dique and at the west of Paneau-1, which are about 4 m wide. In many cases, fracture zones are found along both sides of the dykes, and in places, along these fracture zones there are anomalies of radioactivity.

The other sort of granite porphyry dykes is milky grey and hard, with the phenocrysts of quartz up to several mm in size. Phenocrysts of biotite of the size of about 1 mm are also recognized. The dykes are exposed in the approximate N-S direction of the intrusion at Bou Archicha to the west of Sidi Ayyad and at Tichout Niktane to the southwest of it. No anomalous radioactivity has been recognized on this sort of dykes.

The microgranodiorite is found in the granodiorite which is distributed at Sidi Ayyad, where the dykes are seen to have intruded in the direction of NE-SW, carrying anomalous radioactivity.

Most of the above-stated dykes are seen to have intruded the Granites and to have been covered with the P-T Red Sandstone Formation.

(2) P-T Red Sandstone Formation

The rocks belonging to this formation are scatteringly distributed in small masses in the area where the Basement rocks are found. Also, they are distributed in the plain extending around the Sidi Ayyad river, to the north of the area above mentioned. But, in this plain, exposures are very small as seen at the bottom of rivers, as they are covered with the Quaternary system. There are some distribution more of the rocks of this formation in the graben structure at Assaka Ijdiy in the Ilich Azougagh Mylonite zone.

In this Sector, this formation is composed of arkose sandstone 2 to 3 m thick and overlying reddish brown siltstone beds including thin layers of sandstone, the thickness of which is about 40 m. The arkose sandstone is composed of fragments, 2 to 3 mm in size, of quartz, orthoclase and plagioclase in addition to the fragments of granites, in the granite area, and it is yellowish white in color. In the area occupied by the Crystalline Schists, the formation shows reddish brown color, being composed of fragments of Crystalline Schists as well as those of mica other than quartz and feldspars. The reddish brown siltstone is not bedded and well consolidated but easy to be cracked to form a pattern like beads on abacus. The inserted sandstone is fine-grained sandstone, as thick as 10 cm to 1 m. Partly leached, it shows white color in places.

The arkose sandstones are thinner in the area of the distribution of the Crystalline Schists, than those found in the area where the Granites are distributed. In some places around Hawli, the arkose sandstone is missing. The formation distributed in the area where the Basement rocks are exposed is composed only of the hard arkose sandstone at the base of the formation, due to the erosion of almost all the upper parts composed mainly of the siltstone.

The strike and dip of the formation is almost horizontal in the area to the south of the Moulouya river. Slight inclination of about 5° to the north can be recognized in the area, and in the plain area around the Sidi Ayyad river it is distributed almost horizontally again.

In the area where the Crystalline Schists are distributed around Sidi Ayyad, it is recognized that the dip of this formation is gently to the north at the south of the Sidi Ayyad river while at the north it dips to the south. In this area, there is a depression on the surface of the Basement in the direction coinciding to the present Sidi Ayyad river (E-W), and the thickness of the arkose sandstone is as much as over 10 m in places, at the bottom of the river about 1 km west of Sidi Ayyad.

In the north of the area occupied mainly by the Crystalline Schists at Sidi Ayyad, the rocks of this formation are gently dipping about 5° to 10° to the north.

In the arkose sandstone, ripple mark, sole mark and cross-laminate are often observed. The direction of the paleochannels, which has been estimated from them, is almost north in the area where the Zayda Granite Body is distributed.

(3) K_{2cm2} Mudstone Formation and K_{2t} Limestone Formation

The rocks belonging to these two formations are distributed in small exposures in the Ilich Azougagh Mylonite zone, in a manner that K_{2t} Limestone Formation overlies the K_{2cm2} Mudstone Formation.

The K_{2cm2} Mudstone Formation is composed mainly of soft siltstone, and the thickness is more than 20 m.

The K_{2t} Limestone Formation is composed mainly of limestone with calcarous siltstone, and the thickness is as much as 60 m. In this area, a boat-bottom like structure has been formed by the synclinal structure constituted by these two formations in the graben structure which was formed by the two parallel faults distributed with the approximate interval of 250 m in the Ilich Azougagh Mylonite zone.

(4) Tertiary System

The T_1 Mudstone Formation constitutes basal beds of the Tertiary system in this sector, and is distributed in the north of Zayda and in the northeast of Sidi Ayyad. The beds of this formation are scatteringly distributed in small exposures, covering the P-T Red Sandstone Formation. At the northeast of Sidi Ayyad, it contains basal conglomerate beds 1 to 2 m thick at the base of the formation. The T_1 Mudstone Formation is composed of brown sandstone and siltstone. The conglomerate found around Zayda is rather calcareous.

The T_2 Marl Formation is extensively distribured southward from the point about 4 km southeast of Zayda, covering the Granites and the P-T Red Sandstone Formation at the southwest of the Zayda Granite Body. The formation is composed mainly of white siltstone and yellowish grey marl.

(5) Quaternary System

Q_1 Siltstone Formation is distributed almost horizontally on the hills at Aganbou and at Al Ja'ba about 7 km east-north-east of Zayda. This formation is composed mainly of calcareous conglomerate including pebbles of basalt, medium to coarse-grained sandstone and siltstones. The floats of the calcareous conglomerate are found around Paneau-1, which have been recognized to carry radioactivity.

Q_2 Siltstone Formation is distributed extensively in the plain around the Sidi Ayyad river. It covers the P-T Red Sandstone Formation. This Q_2 Siltstone Formation is composed of grey or grey brown soft siltstone beds, 3 to 4 m in thickness.

3-1-2 Geological Structure

(1) Sedimentary Structure

Most of this Sector is occupied by the Granites, and the sedimentary rocks are distributed in the area surrounding the Granites. The arkose sandstone, at the lowermost of the lowest member of the area, which is the P-T Red Sandstone Formation, occupies the depression on the surface of the Granite Body. The arkose sandstone is covered with reddish brown mudstone beds. The arkose sandstone is seen to have been accumulated only in depressions and so, its continuity is poor. The thickness is no more than several meters. Medium to coarse-grained fluvial deposit as seen in the northwestern part has not been recognized between the arkose sandstone and the mudstone beds. It is thought that the sedimentary environment would have been of quiet mud flat type. Some parts of the arkose sandstone are recognized to form lead ore deposits, which are mined by open-pit method around Zayda, where this relation can be observed well.

The dip of the mudstone beds is almost horizontal in the south of the Moulouya river, while the beds are dipping to the north as gentle as about 5^o in the north of the Moulouya river. In the plain further to the northeast, around the Sidi Ayyad river, the dip of the mudstone beds is horizontal again. Also, around Sidi Ayyad, gentle synclinal structure can be recognized along the Sidi Ayyad river. In the area further north, the mudstone bed is dipping about 10^o to the north along the northern margin of the Basement.

The Jurassic system has not been recognized in this Eastern Sector of Zayda, and it is inferred that this area would have been island-like lands in the Jurassic period.

As for Cretaceous system, it is thought that this system might have been covering this area extensively, as small distributions of the Cretaceous system have been recognized in the graben structure in the Ilarich Azougagh Mylonite zone.

The T_1 Mudstone Formation of the Tertiary system is scatteringly distributed, covering the P-T Red Sandstone Formation. The T_1 Mudstone Formation lies almost horizontal. The T_2 Marl Formation, also covering the P-T Red Sandstone Formation and the southwestern part of the Zayda Granite Body, is distributed almost horizontally.

The Q_1 Siltstone Formation of the Quaternary system is distributed horizontally, covering the P-T Red Sandstone Formation at the small hill found at the east of Zayda. As the floats of the calcareous conglomerate found at the base of the Q_1 Siltstone Formation have been recognized to be present around Paneau-1, it is thought that the layers of this formation would have been overlying the area extensively. The Q_2 Siltstone Formation is distributed horizontally, covering the northern part of the Zayda Granite Body.

(2) Fault Structure

The main faults found in this Eastern Sector of Zayda are, eastwards from the west, Ansagmir Fault, Ilich Azougagh Mylonite zone, Souk et Ajar Fault, Dar Akorar Fault, El Hassir Fault (containing ore deposits) etc., which are respectively in the direction of approximately NE-SW, and are distributed with the interval of 3 to 4 km. In this Sector, faults and fissures of four directions --- E-W, N-S, NE-SW and NW-SE, are developed, apart from those mentioned above.

The Ansagmir fault runs in the granite at the west of the Anzagmir river, which flows northeastward in the central part of this area. This fault is composed of fracture zone, the width of which reaches occasionally

10 m. This fracture zone accompanies many fracture zones, large and small and in the same direction in its vicinity. This fault can be traced from Bou Tsakourt to Immayn-n-Aït Rahhou, accross the Moulouya river. It is hard to trace the southwestern extension of this fault, because another faults and fissures of the general direction of E-W are developed around Bou Tsakourt. The trend of the Ansagmir fault is in the direction of about NNE-SSW in the south of the Moulouya river, while in the direction of NE-SW in the north of the Moulouya river. The dip is almost vertical. At Immayn-n-Aït Rahhou in the north of the Moulouya river, a dyke of granite porphyry is found accompanied in the fracture zone of the width of about 10 m.

The Ilich Azougagh Mylonite zone is found parallel and with the interval of about 4 km east of the Ansagmir fault. This mylonite zone is well exposed around Assaka Ijdiy, good for observation. There are three fracture zones in a belt of the width of about 400 m, which can be observed along the shoreline of the Moulouya river. Especially, the outer two of these three fracture zones are large scaled fractures, the width of which reaches 50 to 60 m. The one in the middle is as wide as about 30 m. These three fracture zones are, as a result of intense mylonitization, composed of partly consolidated mylonite formed through the crushing of the sedimentary rocks as well as granites and of brecciated mylonite constituted by pieces of fractured and deformed granites in addition to soft clays. This mylonite zone can be traced about 5 km northeastward from the point about 2.5 km southwest of Assaka Ijdiy, but it is evident from the result of the analysis of aerophotograph that this mylonite zone would extend further northeasterly to Bou Hamza through Ilarich Azougagh. The interval of the eastern two of the above-stated three fracture zones is 100 to 150 m in the north of the Moulouya river, but, there is a graben structure of boat-bottom like shape, formed in the narrow zone between these two fracture zones about 250 m apart in the south of the Moulouya river. In the southwestern part of this mylonite zone, fissures and faults of the direction of approximately east and west are well developed, and it is hard to trace the southwestern extension of this mylonite zone. In the north of the Moulouya river, it is possible to trace this mylonite zone on the surface up to near Timiloust, but in further northeastern area to Ilarich Azougagh, the observation of the mylonite zone on the surface is impossible due to the covering of the Quaternary system.

The Souk el Ajar fault extends southwestward from the Sidi Ayyad area through Sidi Said. This fault is well exposed along the Nait Saddane valley at the northeast of Sidi Said, but it is covered with surface soil around Sidi Ayyad. The fault runs close to the contact zone between the Crystalline Schists and the Granites, where the fault is a fracture zone with clay about 2 m wide, carrying another two fracture zones of similar scale in the vicinity. By the results of the aero-photograph analysis, the continuity of this fault has been confirmed. It is recognized that this fault cuts the sedimentary units up to the P-T Red Sandstone Formation.

The Dar Akorar fault extends northeasterly passing through Jbel Kou Ali, branching the El Hassir fault, along which lead mineralization is recognized, at Sidi Ayyad area, and it has been confirmed that the fault extends about 13 km to the southwest. Along a small valley about 1 km east of Sidi Ayyad, it is observed that this fault is a fracture zone more than 3 m wide, accompanied by veinlets of barite. The trend is NE-SW and the dip is vertical. The lead-mineralized part of the El Hassir fault, branched from the Dar Akorar fault, is a fracture zone of the width of 1 to 2 m, trending NE-SW with vertical dip, though there are some parts of of this fault showing the dip of 70° to the southeast in its northeastern extension. It is recognized that this fault cuts the beds older than or belonging to Jurassic system.

Among the faults and fissures of E-W direction existing in the area where main faults of NE-SW direction are distributed, it is noted that the Marabout ore vein (Pb) is the mineralized fault or fissure cutting the P-T Red Sandstone Formation.

Also, in the area between Zayda and Ansagmir fault, fracture zones along the Granite porphyry dyke of the NE-SW direction are developed in the granites, in addition to the fracture zones of the same direction but without accompanying such dyke. Some of these fracture zones are recognized to cut the P-T Red Sandstone Formation covering the Granites, but others are seen as slight joint-like fissility of the similar direction in the P-T Red Sandstone Formation. In the area to the east from around Bou Tsakourt in the southern part of the Zayda Granite Body, there are echelon faults of the direction of east and west, which are associated with lead and barite mineralization.

3-1-3 Indications of Mineralization

In the area at the east of Zayda, there are indications of mineralization containing uranium, and heavy metals such as lead and barite.

(1) Indication of mineralization containing radioactive elements

As the indications of mineralization containing radioactive elements, there are indications of vein-like type mineralization along the Moulouya river at the northwest part of the Zayda Granite Body and in the Sidi Ayyad area at the eastern end of the Zayda Granite Body, and those of litho-tectonic type mineralization belonging to the sandstone type mineralization in the Assaka Ijdiy area. In addition to the above, along the north bank of the Moulouya river near Assaka-n-Tabhirt, floats of Quaternary calcareous conglomerate bearing radioactivity have been found, and also anomalous radioactivity has been recognized within the dark-colored precipitates deposited on the surface of the granites and in the river sediments (sands) found along the shore of the Moulouya river. These indications are listed in the Table I-11.

In the area along the Moulouya river in the northwestern part of the surveyed area, more than 15 veins bearing anomalous radioactivity are recognized from Zayda, through Assaka-n-Tabhirt and Paneau-1 of Zayda ore deposit, to Ifzwane. These radioactive anomalies are associated with dykes of granite porphyry and with ferrouginous quartz veins, of the approximate direction of NE-SW. Parts of such ferrouginous quartz veins and the dykes of granite porphyry have fracture zones along their both sides. They are seen to have intruded the granites but are overlain by the P-T Red Sandstone Formation.

In the sidi Ayyad Sector, there are 37 veins, large and small in scale, among which 28 veins show the values of over 300 c/s, by the results of the radioactive measurements. The above-stated 37 veins are roughly divided, according to the directions, into groups of N-S, NE-SW, NW-SE and E-W. The groups of E-W and NE-SW are constituted with barite-quartz veins associated with galena and malachite, which have been recognized to have no anomalous radioactivity except for the F-1 vein. The N-S group is composed of ferrouginous quartz veins developed in the area occupied by the granodiorite and most of the above-stated 28 veins bearing anomalous radioactivity are belonging to this group. In this area, exploration works were carried out from 1953 to 1955 by SOMAREM (Societe Marocaine de Recherches et d'Etudes Minieres), as a part of which diamond drilling, trenching, shaft-sinking etc. were included.

In the Assaka Ijdiy Sector, anomalous radioactivity is associated with the P-T Red Sandstone Formation, K_2cm_2 Mudstone Formation, and K_2t Limestone Formation which are distributed in the graben structure formed by the subsidence of the zone between two parallel faults of the direction of NE-SW with the interval of about 250 m each other. Trenching and diamond drilling were carried out in this area, too, as a part of the exploration works performed by SOMAREM in the past.

Floats of the Quaternary calcareous conglomerate bearing anomalous radioactivity have been found on the north slope of the Moulouya river, about 3.5 km east of Assaka-n-Tabhirt, where no more than several boulders about 1 m in diameter are recognized. It is not certain from where these boulders have been derived.

Dark-colored and white precipitates are recognized to have been deposited in the sands (river sediments) along the Moulouya river in the Assaka-n-Tabhirt area and on the surface of granites about 4 km east of it. These precipitates are thought to have been derived from granites found on the north slope of it. Anomalous radioactivity of 400 c/s to 2,000 c/s has been recognized in places within such precipitates, the distribution of which is, however, not extensive.

Of these indications bearing anomalous radioactivity, four main indications of vein-like type mineralization (F-1 vein in the Sidi Ayyad Sector, Paneau-1, G-P and Dique) were selected in addition to the indication at Assaka Ijdiy, and detailed mapping were carried out. The results of such precise mapping are given in the followings.

1) Paneau-1 Block

This Paneau-1 block is the area where the No. 1 ore deposit of Zayda Mine was found. The lead ore deposit has been already mined out, but the anomalous radioactivity has been recognized in the mined-out site. The measurement of the radioactivity has shown the values of 1,000 c/s to 3,000 c/s at several points other than the highest value of 7,000 c/s at a point. These high values of the radioactivity have been recognized in the arkose sandstone directly overlying the granite. They are found scattered in the mined-out site. At the point where the highest value of 7,000 c/s was shown by the measurement of radioactivity, dark-colored precipitates are recognized to be deposited in the arkose sandstone directly overlying the granite. To the northeast and to the southwest of this point, there are points showing values of 300 c/s to 1,000 c/s, obtained by the measurement of radioactivity. To tie these points together, they are located on a line corresponding with an extension of a fracture zone accompanied by ferrouginous quartz veins found in the granite. In this fracture zone, values of 300 c/s to 400 c/s by the measurement of radioactivity are recognized partly. The assay values of the sample collected from the point where highest value of 7,000 c/s has been obtained are as follows; U: 0.061%, Th: under 0.002%, V: 0.003%. There are two more points found in the mined-out sites, showing the value of 3,000 c/s by the measurement of radioactivity. The one is found at the point 400 m towards the southwest of the above-stated anomaly, but no fracture zone has been recognized in the granite in the extension of the distribution of points of anomalous values. The other point is about 260 m west of the point of the highest value of above-stated 7,000 c/s. Around this point, other points showing values of 200 c/s to 500 c/s are distributed in the approximate direction of NE-SW. The assay results of the sample collected from the point showing the value of 3,000 c/s are as follows; U: 0.005%, Th: 0.003%, V: 0.015%.

There is a dyke of granite porphyry in the southwestern part of the mined-out site, accompanied by fracture zones, along which no remarkable anomaly of radioactivity has been recognized on the surface but for a point showing the value of 300 c/s. It has been recognized that this dyke extends to the southwest across the Moulouya river.

2) G-P vein

This G-P vein is about 2 km west of Paneau-1, to the east of Assaka-n-Tabhirt, that is, in the midway of the both places. It is the anomaly of radioactivity associated with a brown and hard dyke of granite porphyry about 4 m in width. The highest value obtained by the measurement of radioactivity is 2,800 c/s, but the anomaly is not extensive. The anomalous area is as small as only 1 m wide and 2 m long, including the points showing the values of 500 c/s to 2,000 c/s around it. The assay results of the sample collected at the point showing the value of 1,500 c/s are U: 0.008% and Th: 0.002%, while those of the sample from the point showing the value of 200 c/s are U: under 0.002% and Th: under 0.002%. In the anomalous area showing the values of 2,000 c/s to 2,800 c/s, yellow uranium mineral (carnotite) has been recognized along minute-fissures in the granite porphyry. Other than the above-stated, there are six points showing the values of 250 c/s to 800 c/s by the measurement of radioactivity as shown in Pl. I-8. However, they are not extensive in scale. The dyke of this granite porphyry is accompanied by fracture zones along both sides. This dyke extends to the southwest across the Moulouya river. The extension to the northeast is covered with arkose sandstone.

3) Assaka-n-Tabhirt

In this area, the survey was carried out for geology and radioactivity, and the results were reported by M. Annich (1977).

This area is underlain by granite, aplitic granite and arkose sandstone covering them. The anomaly of radioactivity is associated with ferrouginous quartz veins developed in the aplitic granite. There are two ferrouginous quartz veins in this area, both of which are as narrow as about 10 cm in width but are extending more than 400 m. The highest value of the measured radioactivity is 13,500 c/s, but the distribution of the anomaly is not extensive on the surface.

4) Dique vein

The area is at the east of the waste-water pond, across the Moulouya river, of the Zayda Mine about 2 km north-north-east of Zayda. The area is occupied by the aplitic granite, and a dyke of the granite porphyry intruding it in addition to the arkose sandstone covering them. The dyke of the granite porphyry is as wide as about 4 m, running in the direction of NNE-SSW. The exposure is over 40 m, though covered partly with surface soil, and the extension of both directions of northeast and southwest is overlain by the arkose sandstone. The anomaly of radioactivity is associated with ferrouginous quartz vein in the same direction of the dyke, contained in the dyke of the granite porphyry. The anomaly is as extensive as 30 cm to 40 cm in width and over 10 m in length, bearing the measured highest value of 3,500 c/s. The assay results of the sample collected from this point are U: 0.071% and Th: under 0.002%.

5) F-1 vein in the Sidi Ayyad Sector

The F-1 vein is about 400 m north of the El Hassir Mine in the northeastern part of the surveyed area. The area surrounding the F-1 vein is occupied by the granodiorite and the Crystalline Schists. This F-1 vein is a dyke of microgranodiorite (scaled 1 to 2 m in width and about 600 m in length) bearing anomalous radioactivity. The trend of the dyke is NE-SW, with the dipping vertical or to 80^{o} to SE. According to R. Alaui (1976), trenching at 10 places (9 places in the detailed surveyed area), shaft-sinking at a place (30 m deep) and diamond drilling of 3 holes were conducted by SOMAREM. The anomalous radioactivity is associated with minute fractures found in the dyke of the microgranodiorite, and with oxidation zone along the boundary between this dyke and the granodiorite. The highest value of the measured radioactivity is 8,000 c/s around the shaft, which is situated at about the central part of the dyke. The scale of the anomaly of radioactivity is largest around this place. The part showing the values more than 300 c/s is as extensive as 50 m. Taking the part showing the values over 500 c/s, the anomaly is as wide as 3 m with the extension of about 30 m. In addition to the above, there are some places showing the values as high as 2,000 c/s to 3,500 c/s towards the northeast of the above-stated shaft, but the scale of the distribution is about 5 cm in width and 1 to 2 m in length in each case. Even if the anomaly of the values of over 300 c/s is taken, the extension is only 15 m to 30 m. The assay results of the sample collected at the point showing the value of 2,500 c/s are U: 0.085% and Th: under 0.002%.

6) Assaka Ijdiy

Assaka Ijdiy is about 15 km east of Zayda. The area is occupied by the granite, the P-T Red Sandstone Formation, the K_2cm_2 Mudstone Formation and the K_2t Limestone Formation. The P-T Red Sandstone Formation, the K_2cm_2 Mudstone Formation and the K_2t Limestone Formation are distributed in the Ilich Azougagh Mylonitec zone on the base of the granite, in the graben structure like a boat-bottom, both sides of which are bounded by faults. This graben structure is in a scale of about 250 m in width and about 1 km in length. On the surface of it, the K_2cm_2 Mudstone Formation and the K_2t Limestone Formation are exposed, and the P-T Red Sandstone Formation is exposed as blocks caught in the eastern fault zone, as well as at the place about 400 m north in the graben, though the exposure is small in scale.

The anomaly of radioactivity on the surface is recognized with the K_2t Limestone Formation along the boundary between this K_2t Limestone Formation and the k_2cm_2 Mudstone Formation. The anomalous zones are distributed in both sides of the graben structure. The zone situated along the east side includes two weak anomalies of the values of 200 c/s to 300 c/s, while along the western zone there are three anomalies ---

an anomaly showing the values of 400 c/s to 2,000 c/s, weak anomaly showing the value of 200 c/s to 350 c/s and another weak anomaly showing the value of 500 c/s. Except for the anomaly showing the value of 2,000 c/s, the distribution of anomalies is not extensive in scale. The anomaly in which the highest value of radioactivity shows 2,000 c/s is about 300 m in length and about 40 m in width. According to H. El Harsi (1976), trenching of 11 places and diamond drilling of 3 holes were carried out, in the past, by SOMAREM. The value of 2,000 c/s has been recognized in an above-stated trench, where it is observed that yellow uranium mineral (which seems to be carnotite) is associated with minute fissures developed in the limestone. The diamond drilling was performed around the axis of the boat-bottom structure to the east of this anomaly, but the drill hole did not reach the Basement Complex and it is said that anomalous radioactivity has not been recognized there, although details are not certain. The assay results of the sample collected at the points of the values from 400 c/s to 2,000 c/s in a trench in the above-stated anomaly are U: 0.005%, Th: under 0.002% and V: 0.008%.

(2) Indications of mineralization containing heavy metals as lead and barite

As the indications of mineralization containing heavy metals such as lead and barite, there are ore deposits of vein-like type in the Sidi Ayyad Sector, in addition to the Zayda sandstone type mine. Here, only the outline of the Zayda mine is given, and the ore deposits in the Sidi Ayyad Sector will be described in the paragraph 3-4 Mibladen-Hawli mine Sector.

Zayda Mine

The Zayda Mine is located at Zayda in the central part of the surveyed area and is operated by SODIM (Société de Development Industrial et Miner). The mine office, mill and incidental facilites are there at about 1 Km northeast of the village of Zayda, though labourer's houses are provided around Zayda.

The ore deposits of this mine was discovered by BRPM in 1958, and the operation started in 1972. The number of workers and the production in 1977 are as follows;

Total number of workers:		321
Production	crude ore:	1,200,000 t/year
	grade:	Pb : 3.60%
	concentrate:	about 40,000 t/year
	grade:	Pb : 69 %, Ag 185 g/t

In the crude ore, 8 to 9% of barite ($BaSO_4$) is contained, which is recovered as byproduct.

The ore bodies ever found are 66. The exploration works have been promoted since 1972, and the ore reserves, which was about 8,200,000t with average grade of Pb 3.2 % at the commencement of the operation, have increased to be about 10,000,000t at present, after adding the newly-discovered 8,000,000t and reducing the mined-out 6,900,000t up to 1977. The main method of exploration works is drilling. The drilling program in 1978 was about 20,000 m, which is to be carried out around the area in the north of Zayda.

The ore deposits are stratiform deposits emplaced in the arkose sandstone at the base of the Permo-Triassic Red Sandstone Formation. The ore is of disseminated type, and it is observed that mainly cerussite, galena,and barite have filled the space amid the grains of quartz and feldspars composing sandstone. The ore minerals are mainly cerussite, galena, barite, but lead-sulphate ore mineral, pyrite,and chalcopyrite are also contained. Rarely, pyromorphite, wulfenite,and fluorite are found. There is no zinc ore mineral.

The area around the mine is occupied mainly by granites and the beds of the P-T Red Sandstone Formation of Permo-Triassic system, unconformably overlying the granites. The arkose sandstone at the base of the P-T Red Sandstone Formation is most thickly developed in paleochannels formed on the surface of the basement. The above-mentioned 66 ore bodies are emplaced in such paleochannels. The thickness is as much as over 2.5 m but occasionally it reaches upto 10 m. Therefore, the scale of single ore body is large in general, as seen of the No. 54 ore body, which is being mined at present. The ore reserve of this single ore body is about 4,700,000 t with the average grade of Pb 3.8% (The thickness of the ore body is about 10 m). These many ore bodies are scatteringly distributed in the area of 20 km by 25 km around Zayda, but through the exploration works, indications of mineralization as well as parts of the orebodies have been caught in the area from the west of Zayda to Bou Mia and also in the northeastern part of Zayda. Thus, the area where ore bodies are distributed will be expanded to over 70 km x 25 km. Favorable results of the further exploration works are expected.

3-2 Bou Mia -- Zayda Sector

The geological units distributed in this Sector are the Bou Mia Granite Body occupying the central part of the surveyed area and the sedimentary rocks represented by the P-T Red Sandstone Formation in addition to the systems younger than that, up to Quaternary system. In the Tarekochid river area, branched from the Moulouya river, flowing in the western part of the area occupied by the above Granite Body, positive survey and exploration works for uranium ore deposits were carried out by BRPM, taking this area as a model exploration area in the period of 1976 and 1977. Through the present survey, an indication of carapace type uranium mineralization has been found about 6 km north of Bou Mia, though small in scale.

3-2-1 Distribution of Geological Units

The central part of this sector is occupied by the granites, the distribution of which is like the letter U, open to the north. There are three sorts of granites --- medium to coarse-grained grey homogeneous granite, porphyritic granite with phenocrysts of orthoclase 1 to 3 cm in sizes,and fine to medium-grained light pink aplitic granite. They are seen to have been intruded by various dykes as granite porphyry, aplite etc. Lithologically, these rocks are same as the granites distributed in the Eastern Sector of Zayda. The granite occupies the most part of this sector, and the porphyritic granite is distributed in a belt about 1 km wide, extending in the direction of northwest from the point about 5 km westsouthwest of Bou Mia. These two rocks are bounded each other with transitional relation. The aplitic granite is distributed mainly in the southwestern part of this sector, though it is locally found in the northwestern part. The aplitic granite is generally in the irregular and massive form in this sector, but in the north of Bou Mia an aplitic granite in the sheet-like form has been recognized. The dyke of the granite porphyry is found at about 3 km westsouthwest of Bou Mia, where it is observed that the trend of this dyke is in the direction of N10^{o}W with almost vertical dip, with the width of 3.5 m, and that the dyke has remarkable phenocysts of quartz about 1.5 mm in sizes. On the surface, brown gossan has been observed and microscopically iron-oxide minerals and remarkable sericitization have been recognized. The result of the measurement of radioactivity has shown that the value of the radioactivity with this aplitic dyke is as high as about 150 c/s, while the value with the surrounding granite is 70 to 90 c/s. Along the boundaries of the both sides of this dyke, zones of marginal facies similar to fine-grained quartz liparite in characteristics are found in the approximate width of 40 cm. Also, in some parts there are inclusions of xenoliths of the crystalline schists which are observed to be contained in the granite, in the vicinity of the area where this dyke is located.

The P-T Red Sandstone Formation is distributed extensively in a zone surrounding the Granite Body. The arkose sandstone at the base of this formation is observed to have been accumulated in the depressions found in places on the surface of the Granite Body. The arkose sandstone is generally coarse-grained but occasionally conglomeratic, and light brown in color, hard and compact in characteristics. Resistant against weathering, this arkose sandstone is found to have been left on the high place, too, which would indicate that the surface of the granite body at the time of the sedimentation of the P-T Red Sandstone Formation was not so different topographically from the surface of it which can be observed at present. In this district, the P-T Red Sandstone Formation is composed of the sedimentary beds of red mudstones directly overlying the arkose sandstone. The thickness of this red mudstone is as much as over 50 m in some places. The β_{P-T} Basalt lavas situated upon the uppermost part of the P-T Red Sandstone Formation are missing in the northern area of Bou Mia, but they are distributed in three sides surrounding Bou Mia, that is, in the northwestern part, in the western part and in the southern part. Along a shore of a river about 2 km west of Tamarout in the southwestern part of the surveyed area, there is an insertion of a coal bed of the thickness of 30 cm, underlying the basalt lavas. It is only at this point in the surveyed area that carbonaceous matter or organic matter was found in the P-T Red Sandstone Formation. But no anomalous radioactivity has been detected there.

The J_1 Limestone Formation succeeding the β_{P-T} Basalt Formation is distributed in almost same area as the βP-T Basalt Formation is developed. The J_1 Limestone Formation is observed well especially in the northwestern part. There is an inserted layer of red sandstone between this limestone formation and the basalt formation. So, a belt of three colors, black of the basalt, reddish brown of the sandstone and white of the limestone, is recognized in the exposure found along the hill side, which makes it so easy to trace the beds that this red sandstone layer has been regarded as a key bed. It is observed that the limestone formation distributed in the area close to the granite body contains sandy parts and parts of alternation of sandstone and limestone, but the limestone becomes the more massive or conglomeratic in places in the further area from the granite body. There are many fossils of corals in this limestone formation.

The Cretaceous K_{2cm} Red Sandstone Formation is distributed particularly in the northern part of this district. The formation is composed of alternation of grey sandstones, mudstones, reddish brown mudstones and marls with insertions of lenticular gypsum. Because the beds of this formation is so colorful, this formation was taken as "poly-color formation" in the field survey.

Overlying the above-stated formation, the K_{2cm} Limestone Formation composed of grey to yellowish grey sandy limestone is distributed. It is observed that this formation contains abundant fossils of bivalves and oisters, particularly in this sector. The beds belonging to this formation are exposed well in the northern part of this sector. There is a pink limestone bed situated about 1.5 m stratigraphically above the base of this K_{2t} Limestone Formation. This pink bed is a local index bed in the northern part of this sector.

The Tertiary system in this sector is found overlying directly the P-T Red Sandstone Formation in the northeastern part, and also overlying the Cretaceous limestones. In the south and in the west of Bou Mia, the Tertiary system is seen extensively developed on the Cretaceous system. It is composed mainly of light brown siltstone and partly of conglomeratic sandstone, with insertions of marls.

The Quaternary system of the Q_1 Siltsone Formation and the Q_2 Siltstone Formation is composed mainly of conglomerate bearing pebbles of limestone, basalt, sandstone and so on. The Quaternary system is distributed mainly in the southern part of this sector. At about 2 km southeast of Bou Mia, there is a distribution of β_{Q2} Basalt lava, which is seen to have formed a nearly round plateau about 2 km in diameter. This basalt lava contains olivine and is black and compact, without affected by any alteration.

3-2-2 Geological Structure

The most characteristic geological structure in this sector is graben structure formed by the faults of the direction of north-south. There are three faults extending north and south, at the points respectively of 1.5 km, 3.0 km and 6.0 km to the west of Bou Mia. (Temporarily they are called BM-1 Fault, BM-2 Fault and BM-3 Fault.) Considering from the geological relationon the profile of east and west, the followings can be said on respective fault;

BM-1 Fault westside uplifted/eastside subsided

BM-2 Fault westside subsided/eastside uplifted

BM-3 Fault westside uplifted/eastside subsided

As for the exposure of these faults, the BM-1 fault is observed in the northern extension and along the national highway, and the BM-2 fault is exposed accompanying mylonitized fracture zone with the width of about 50 m in the central part of the Granite Body, and along the southern end of this fault, overturning of the sedimentary beds can be recognized.

The BM-3 fault has been distinctly recognized to be present there as to its southern half through the geological features. Part of this BM-3 fault is exposed in the sedimentary rocks around the southern end of this fault. The northern extension can be clearly recognized on the aerophotograph. As stated above, the zone with the interval of about 3 km between the BM-2 fault and the BM-3 fault is the subsided zone against the both outer sides, to form U-shape profile. Meanwhile, the joint pattern which were developed secondarily in the Granite Body is observed to be predominantly in the direction of N30°W in the eastern side of the BM-2 fault, while in the western side of the BM-3 fault fractures of the direction of N30°E are well developed on the contrary. Therefore, it is thought that the graben zone between the BM-2 fault and the BM-3 fault would have been pushed out southwards. The general structure in the graben is observed to be gently dipping to the north, and this structure is thought to have provided a favorable way for the dissolution and transportation of uranium. Another graben structure is found in the granite body in the Tarekochid area in the western part. There is a comparatively large fault, to be noted as one of the major fault structures, passing around Boutkhaubaye located between Bou Mia and Karrouchan (This fault is temporarily called to be Boutkhaubaye Fault). The trend of this fault is N50°E and in the area of the southeastern side of the fault, the red mudstone beds are distributed, while basalt layers and Jurassic systems are distributed in the area of the northeastern side of this fault, which is the subsided side against the other side. The northeastern extension of this fault is thought to be joined together with the Yahia-Oufalla fault. The distribution and the structure of the sedimentary rocks in this Sector are, as mentioned above, comparatively monotonous in the southern part and in the western part of this sector, but are limited geologically, by the Boutkhaubaye fault in the northwestern part as above-stated, and furthermore, the northeastern part of the Sector is recognized to have formed a basin-like geological structure zone linking to the area of Itzar, through the subsidence of the northeastern part caused by the BM-3 fault.

The analysis of the geological structure of the area around Bou Mia in the eastern part of this Sector has been performed by the gravity survey carried out as a part of the present survey. By the result of this analysis, there would be a paleochannel on the granites at the north of Bou Mia, while it is estimated that there would be a depression of the surface of the basement about 800m below present surface, in the south of Bou Mia. Also, by the result of the diamond drilling of the hole No. HM-2 carried out at the south of the Bou Mia Granite Body, the granite is distributed at the depth of 526 m in the hole, and it is thought that the inclination of the surface of the granite would be comparatively steep, if the granite caught by the drill hole is continuous to the granite exposed on the present surface. It is difficult to determine whether this inclination represents the surface at the time of the sedimentation of the beds on the granite or the inclination represents the results of the dislocation caused by the faults of the directions of northeast-southwest or east-west, which were active in later period.

3-2-3. Indications of Mineralization

The indications of mineralization found in this sector are mainly those of uranium and lead.

As for the indications of uranium mineralization, there are many anomalies of radioactivity in the Granite Body. Especially, in the western half of the body, where such indications are found to be distributed in many localities, exploration works including diamond drilling were carried out by BRPM in the program called Tarekochid project.

An indication of uranium mineralization has also been found at the northeastern end of the Granite Body in the present survey.

As for the indications of lead mineralization, there are known several exposures of lead ores, but no detailed survey has been carried out yet.

(1) The indications of uranium mineralization.

1) Outcrop along the Lkis river: An indication of uranium mineralization is observed along a fissure found in the granites outcropping on the floor of the Lkis river, which flows southward in the central northern part of this area. The fissure is composed of swelling and pinching lenticular shape several meters long and about 20 cm wide in maximum, extending in the direction of NE-SW. Very small amount of green copper-oxide minerals are found in the swelling parts. By the measurement of radioactivity, the anomalous values of 600 to 2,000 c/s have been detected along such fissures.

   There is another anomaly of radioactivity, showing the value of 5,000 c/s, in the exposure of the granite, located about 800 m north of the above-stated point. It has been recognized that this anomaly is caused by the small scaled concentration of uranium along the joints of the country rock.

2) Graben in a small granite mass at the western end of the area: There

is a graben of the approximate width of 50 m, formed between two parallel faults of the direction of east-north-east, in the central part of a small exposure of granite, about 200 m in east and west, and about 500 m in north and south. An anomaly of radioactivity, which shows the value of 1,500 c/s, representing uranium concentration has been detected in the granite distributed in this graben. Detailed survey will be necessary for the continuity of the mineralization.

Another anomaly of radioactivity showing the values of 8,000 to 10,000 c/s has been recognized in the arkose sandstone left on the slope to the south of the above outcrop of the uranium concentration. It is recognized that this anomaly is caused by the local accumulation of the materials, in the joints of the granites, derived from the upper portion of the granite.

Yellow mineral, which is thought to be carnotite, can be recognized in the anomaly in the above-stated graben as well as in the anomaly found in the arkose sandstone on the slope as mentioned above.

3) Granite Outcrop at Sidi Yahia: There are many anomalies of radioactivity, showing the values up to maximum 3,300 c/s, in the granite distributed around Sidi Yahia, which is located about 6 km east of Karrouchan. However, each of them occupies only small area, and is not extensive. It is thought that these anomalies would be superficial concentration of uranium, which had been dissolved and transported from southeast, on the basement rock, distributed in such area. No difference of lithofacies can be recognized of the granite itself.

4) Aït Saïd outcrop of carapace type uranium mineralization: This is an outcrop of small scaled anomaly of radioactivity exposed at a place about 6 km north of Bou Mia. It is recognized to have been formed in the depression of the underlying aplitic granite, in a horizontal

lenticular body, of the thickness of 30 cm in maximum with the approximate width of 2 m. Megascopically, it is predominantly brown, and it has horizontal stripe pattern composed of Quartz -- iron oxide minerals with the width of each band to be 1 to 2 cm. By the measurement of radioactivity in the field, the value shown in the anomalous part was 1,600 c/s, while the value of radioactivity was 600 c/s with the boulder as big as man's head. The assay result is as followings;

U:0.072%, Th:0.002%, V:0.030%

Also, the result of X-ray microanalysis shows the distinct paragenesis of U and V. (Refer to Table I-9, Sample No. 2A13) The country rock looks like arkose sandstone apparently, but under microscope, it is an aplitic granite in which granophyric texture can be recognized clearly. In the overlying arkose sandstone of the approximate thickness of 2 m, small amounts of galena and barite are found to be contained.

The phenomenon that the surface of granite forms crust like tortoise shell by the weathering (which is called to be carapace) is also observed at Ifazwine located in the upstream of Tarekochid, where the granite has been weathered to the depth of about 30 cm and veins composed of quartz and iron-oxide minerals have been found in the form of banded pattern. Progress of weathering can be recognized along the fissilities in the granite. No relation of this bands to the anomaly of radioactivity can be recognized particularly.

(2) The indications of lead mineralization

1) Indication of sandstone type lead ore mineralization at the north of Bou Mia.

Arkose sandstone containing lead and barite is distributed in several places at about 5 km northwest of Bou Mia. As the topography around these indications is rather complicated, detailed surveys for the topography and the geology are necessary in the first place, for the confirmation of ore reserves and ore grade.

There is a lead-bearing arkose sandstone at about 1 km north of the above indications, overlying the aforesaid indications of carapce type uranium mineralization. Samples were collected vertically to some depth at the points of the interval of every 30 m. The assay results of these samples are as follows. (Refer to Table I-11)

Sample No.	2A07	2A08	2A09	2A10	2A11	2A12
Length collected(cm) vertically	140	100	100	100	100	180
Pb (%)	0.24	4.20	0.19	0.94	1.15	1.40
Ba (%)	4.20	2.40	2.08	0.60	0.96	1.84

The BM-1 fault is located in the east of this area of mineral indications, running in the direction of north-south. As it is recognized that the eastside of this fault would have subsided relatively (westside uplifted), it is possible that the eastern extension of the above lead-bearing arkose sandstone could be found underlying the red mudstone bed.

2) Indication of vein type lead ore mineralization at Tabelkirt. At Tabelkirt of about 9 km southwest of Bou Mia, there is a quartz vein, which carries cerussite, galena and barite, in the granite. This vein is as wide as 30 to 50 cm and the trend is N60^{o} - 70^{o}E, with the dip

of 80° to the north. The western extension of this vein is found to be dislocated about 200 m to the south by the fault of the approximate direction of N-S. The extension is about 400 m, so far observed. By the assay result of the samples collected from the outcrop on the surface, Pb contents are as low as 0.3 to 0.4 % (Refer to Table I-11, Sample No. 2B06, 2B07). However, the mineralization along this vein looks to be comparatively stable, and it would be necessary to carry out exploration works for this ore vein.

3-3. The Northern Zayda Sector

3-3-1. Distribution of Geological Units

The geology in this area are composed of Permo-Triassic system, Jurassic system, Cretaceous system, Tertiary system and Quaternary system.

(1) Permo-Triassic system

The Permo-Triassic system distributed in this sector is composed of P-T Red Sandstone Formation and β_{P-T} Basalt Formation.

P-T Red Sandstone Formation is the lowest formation found in this sector and is distributed from the west to the north of Zayda, in the direction of NE-SW as well as at about 4 km west of Itzar, where exposures of the formation are found in a narrow zone of about 3 km in length along the fault of the approximate direction of NE-SW. The beds are almost horizontal in the area around Zayda, while they are steeply dipping to the northwest with the NE-SW strike, resulting from the drag movement caused by the faults, in the area west of Itzar.

The β_{P-T} Basalt Formation is scatteringly found as thin lava flows of the thickness of 1 to 3 m, at about 9 km north of Zayda, and is also distributed continuously in a narrow zone of about 10 km in length along the fault of the approximate direction of NE-SW, located in the west of Itzar.

The lava flow is distributed almost horizontally in the north of Zayda, but along the fault to the west of Itzar it is dipping more than 30° to the northwest with the strike of NE-SW.

(2) Jurassic system

The Jurassic system in this sector is composed of J_1 Limestone Formation and is distributed in the northwestern part of this sector, where the beds are dipping 10° to 50° to the northwest or southeast with the NE-SW strike, partly by the influence of the movement of faults trending in the direction of NE-SW. Around Aït Lhaj about 5 km northwest of Itzar, small scaled folding structure with the axis of NE-SW direction has been recognized in the J_1 Limestone Formation.

(3) Cretaceous system

The Cretaceous system in this sector is composed of K_2cm Mudstone Formation and K_2t Limestone Formation.

The K_2cm Mudstone Formation is distributed in the west of Zayda to its north, extending in the direction of NE-SW, as well as in the northwestern part. In the area around Zayda, this formation is distributed almost horizontally, covering directly P-T Red Sandstone Formation, but in the northwestern part, the beds of this formation are observed to overlie the J_1 Limestone Formation, with the trend of NE-SW, dipping about 10° to the northwest or to the southeast due to the syncline and the faults of NE-SW system.

The K_2t Limestone Formation is distributed, overlying the K_2cm Mudstone Formation, in the northwest of Zayda, extending in the direction of NE-SW. Some of the beds of this formation are exposed at the bottom of the Bou La'joul valley about 3 km northwest of Itzar. As stated in the paragraph 2-4-2, it is recognized that this formation forms basin structure around Itzar in addition to small synclinal structure. The beds of this formation are inclining to the west at the east of Itzar, to the north in the southern part and to the southeast at the bottom of the Bou La'joul valley.

(4) Tertiary system

The Tertiary system in this sector is composed of T_1 Mudstone Formation, T_2 Marl Formation and T_3 Sandstone Formation.

The T_1 Mudstone Formation is constituted mainly of the thin beds, 1 to 3 m in thickness, of calcareous conglomerate in the area around Zayda, and is distributed scatteringly overlying P-T Red Sandstone Formation and the K_2cm Mudstone Formation. In the area northwest of Zayda, the formation is represented by the brown mudstone beds, about 30 m in thickness, exposing in the direction of NE-SW, covering the K_2t Limestone Formation. Also, in the Aït Lhaj area, located in the northwest of Itzar, this formation is mainly composed of calcareous conglomerate, scatteringly found to overlie the K_2cm Mudstone Formation.

T_2 Marl Formation is distributed around Itzar, extending continuously in a belt of the NE-SW direction. The thickness of this formation in this sector is greatest around Itzar, which is as much as 65m.

The T_3 Sandstone Formation is distributed at the west of Itzar, covering the T_2 Marl Formation. It is almost horizontal and the thickness is as much as 40 m.

(5) Quaternary system

The Quaternary system in this sector is composed of the Q_1 Siltstone Formation and Q_3 River Sediments.

The Q_1 Siltstone Formation is composed mainly of grey calcareous conglomerate in this sector. This formation is distributed in the area around Bou Ifoura Aït Amara located about 10 km north of Zayda, and in the area north of it. The thickness is as much as 1 to 3 m.

The Q_3 River Sediments are distributed in the lowlands such as Taslamt valley, Bou La'joul valley and Bouhafce valley.

3-3-2. Geological Structure

There are two major faults recognized in this sector. They are running in the direction of NE-SW. One is passing through Aït Oufalla located about 5 km north of Itzar, while the other fault is seen to run through Aït Naçar about 7 km west of Itzar.

The fault passing through Aït Oufalla is almost vertical or dipping 80° to the northwest. This fault is observed well along the national road No. P21 and at the bottom of the Bou La'joul valley located about 3 km northwest of Itzar. Especially, along the national road No. P21, it is well observed that this fault cuts and crushes the conglomerate bed belonging to T_3 Sandstone Formation.

The fault running through Aït Nacar is observed as a shear zone at the bottom of the valley in the southwest of this village, where it is confirmed that the northwestern side of this fault has been uplifted relatively to the other side, which is, of course, subsided. It is recognized that the beds distributed in the northwestern side of this fault are inclining to the southeast, while those found in the southeastern side of it are dipping to the northwest. Thus, these beds have formed a synclinal structure, and it is thought that this fault would have been formed along the axis of the synclinal structure.

3-3-3. Indications of mineralization

There is no indication of mineralization ever recognized in this sector. Through the present field survey, no anomalous area has been detected in spite of the effort to find out indication of uranium mineralization by carrying sintillometer for the measurement of radioactivity.

3-4. Mibladane -- Hawli Mine Sector. (Refer to Fig. I-7)

This sector is situated at the northeast of Midalt, in the southeastern

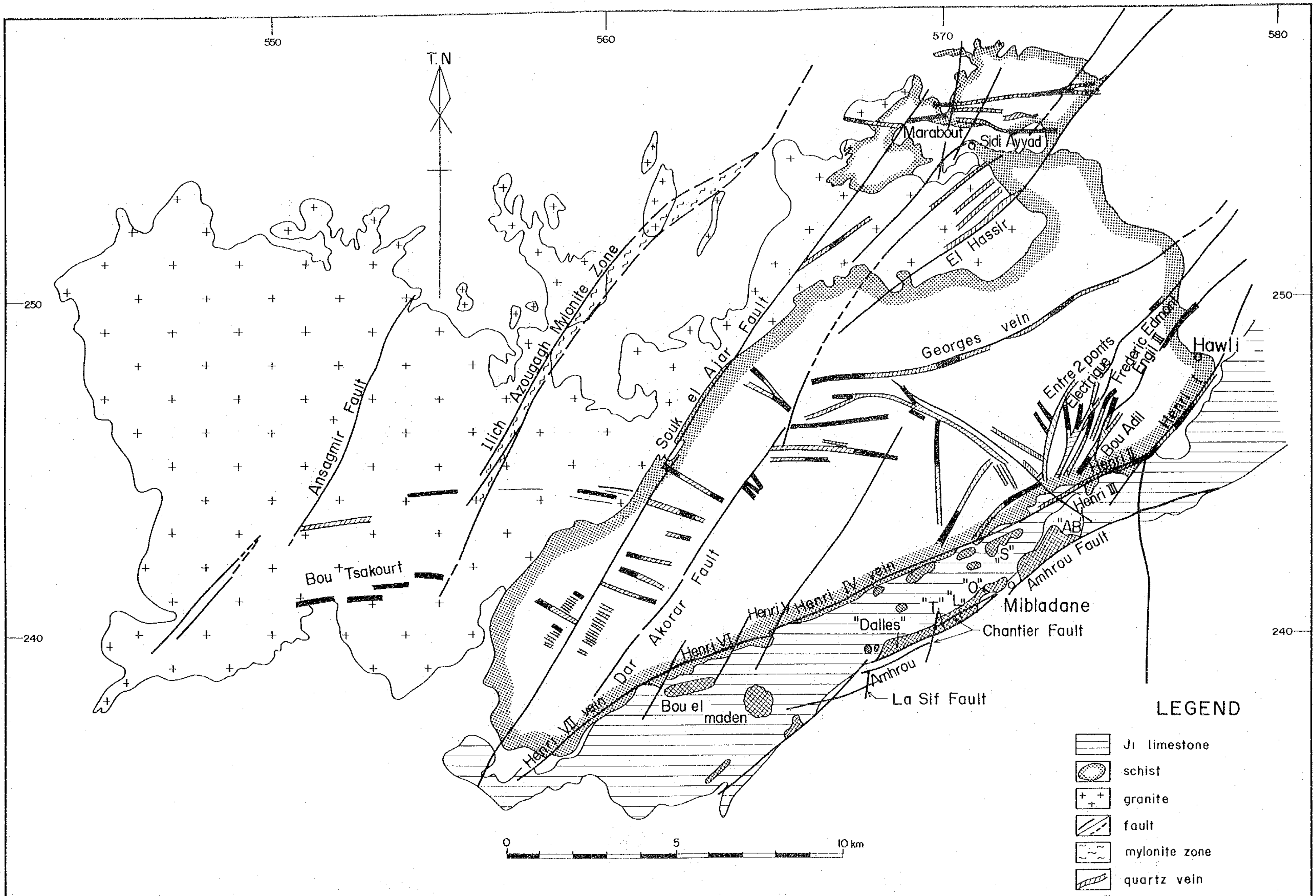


Fig. I-7 Distribution of Pb-Mineralization in Mibladane-Hawli Area part of the surveyed area. The Mibladane mine office is located 13 km northeast of Midalt, and the floatation Plant (treating 600t/day of crude ore) is in operation at present. The Hawli mine also has the mill plant at the point 8 km further northeast of the Mibladane mine office, but this mill plant is not operated now. Exploration works are now being carried out in the Sidi Ayyad sector in the north of Hawli mine. Both mines are producing lead, but the ore deposits of the Mibladane mine are of the stratiform type while those of the Hawli mine are of the vein type.

The present investigations for these mines were carried out in order to make reference for the extraction of favorable areas out of the whole surveyed area through the comprehension of the characteristics of the already-developed ore deposits of these mines. Accordingly, the field investigations were limited to the general observation of the typical working pit of the mines. There are many studies and reports of the geology and the ore deposits of the Mibladane mine, seen in the list of the references because the stratiform ore deposits of the Mibladane mine are rather peculiar and geologically interesting. In this paragraph, merely the outline of these two mines are described.

3-4-1. Mibladane mine

(1) History

The operation of the Mibladane mine was commenced in 1926 and the operation was kept in a small scale until 1948, when the daily treatment of the crude ore became 120 tons. The operation was being expanded and the highest production of 1,400 tons per day was attained in 1957. Decreasing after that, the production of crude ore is 600 tons per day at present. A. Emberger (1965) reported that this mine produced 21,057 tons of lead concentrate in 1962, corresponding to 16 % of the total production of the lead concentrate in Morocco, and the production of this mine became highest in Morocco, outstripping over the head of the Hawli mine. In 1972, the Mibladane mine was still enjoying the top production in Morocco, with the daily treatment of 600 tons of the crude ore, the contents of which was Pb 10 to 12 %.

(2) Geology and ore deposits

The ore deposits are composed of many stratiform orebodies, large and small, and are distributed between the Amhrou fault which extends in the direction of N60°E, passing through Mibladane, and the Henri fault, which is running parallel to the Amhrou fault and is located about 2 to 3 km to the northwest of the above fault. The ore deposits are recognized to be extended as long as about 15 km, that is, about 4 km to the northeast of Mibladane, and about 11 km to the southwest of it. (The Henri fault is called by another name of the Hawli fault and is recognized to carry considerable lead mineralization, part of which used to be worked as Henri vein by the Hawli mine.)

The country rocks of the ore deposits in this area are J_1 Limestone Formation of the middle Lias series of the Jurassic system, composed mainly of limestone and dolomite. Underlying this limestone formation, the sandstone beds of the lower Lias series has been recognized, which is covering the Permo-Triasic system and Basement Complex of Crystalline schists. Overlying the J_1 Limestone Formation, the Toarcian red marl formation and limestone formation are distributed, while in the area southwest of the Amhrou fault the marl formation of the Dogger series has been recognized to be accumulated thick. These Jurassic formations are covered unconformably with the calcareous conglomerate bed of the Cretaceous system.

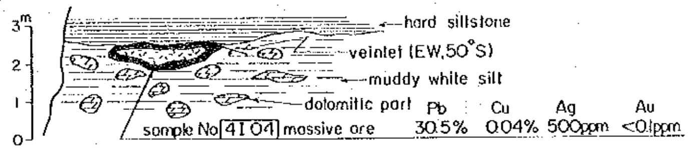
The ore deposits are recognized to have been emplaced in several thin beds 5 to 50 m and 80 to 100 m below the base of the Toarcian red marl formation. The orebodies near the surface have been mined by open pit or by the tunnelling from the open pit workings. The followings are the features of the ore deposits at the workings of "Dallas", "O", "T-Ouest" and at the old workings of "Anc" and "L", which were observed in the present investigation (Refer to Fig. I-8a). That is to say, the ore minerals are galena and barite, and the ore is recognized to be spread laterally in beds of the approximate thickness of 10 cm, dipping gently to the southeast. The beds in which ores are emplaced are comparatively soft marly siltstones, which are overlain by hard and compact calcareous shale and underlain by red or brown massive marly sitstone. In case fine cracks are found in these beds, small amount of galena and barite are recognized in such fissilities, and along the crossing of the fissilities with other fissures, there are some parts where the ores are found to be swelled and massive. Usually, such fissures are small scaled and the extension does not exceed several meters, but in places it is recognized that such fissures have dislocated the overlying shale bed with the distance of 10 to 20 cm.

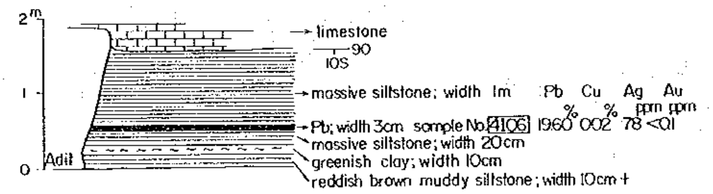
The ore minerals found there are cerussite associated with anglesite, with extremely small quantities of vanadinite and wulfenite.

In the mineralized zone of the Mibladane mine, high grade ores are found around the area along the Amhrou fault, and there are many working pits gathered along the fault. But the area around the Henri fault has also been developed.

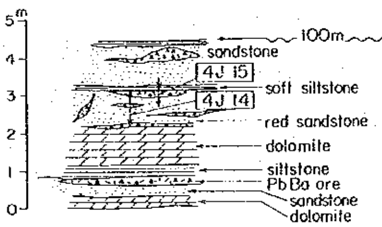
Meanwhile, it has been known that pebbles of ores are contained in the basal conglomerate of the Cretaceous system, which would suggest that the mineralization would have taken place in the Jurassic period. Many models of the mineralization have been proposed as for the ore deposits of the Mibladane mine, including such models as epigenetic telethermal deposits, syngenetic hydrothermal deposits and syngenetic sedimentary deposits. However, sufficient conclusion has not been obtained.

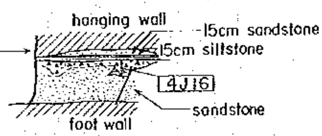
It is thought to be quite useful to carry out the analysis of geological





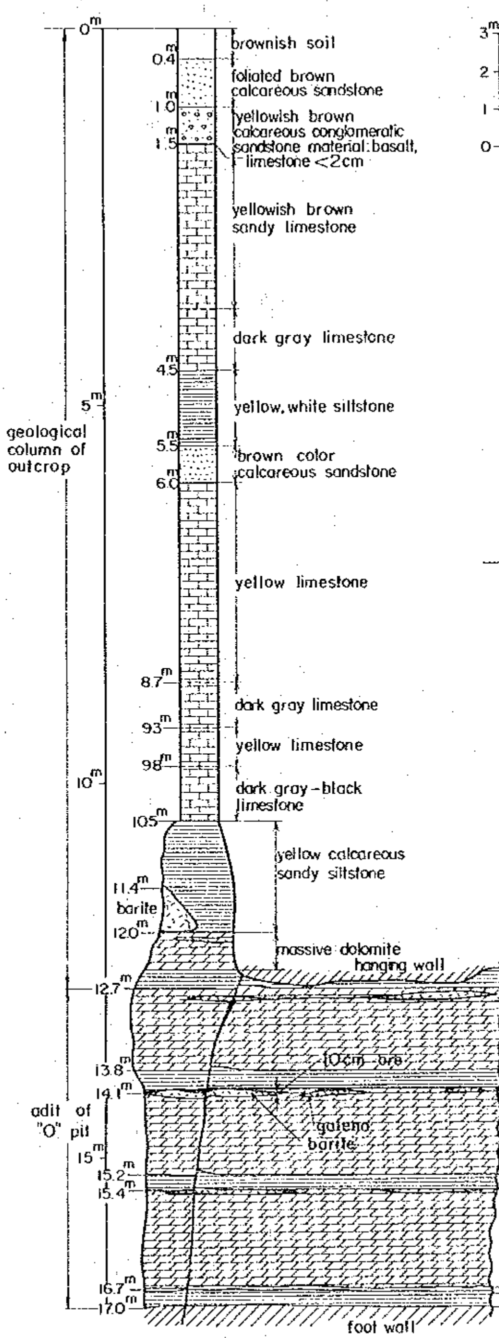
"Bou el Maden" (abandoned)





Sample No.	Pb %	Cu %	Ag ppm	Au ppm
4J 14	5.0	0.02	8	<0.1
4J 15	13.5	0.07	48	<0.1
4J 16	5.4	0.02	24	<0.1

"L" pit (abandoned)



"O" pit

Fig. I-8-(a) Detailed Geological Sketches of Ore Deposits in Mibladane Mine structure in detail in the area between the Amhrou fault and the Henri fault, because the rather intense mineralization has been recognized along such zone where small fissilities are developed along major fault, and because it can be said that there are some beds which would have been selectively mineralized to form country rocks.

3-4-2 Hawli Mine

(1) History

The Hawli mine is opened in 1938 by Société des Mines d'Aouli, which had developed the Mibladane mine. After 38 year's operation, this mine was closed on July 21, 1975. However, since January of 1971, active exploration works have been carried out by BRPM, and additional ore reserves have been obtained. That is, the exploration works of diamond drilling, trenching and tunnelling were carried out in the terms from June of 1971 to December of 1972 and from May of 1973 to December of 1975. At present, tunnelling works for the El Hassir vein and the Marabout vein are being progressed.

(2) Geology and ore deposits

There are many veins in this Hawli mine area, including Georges, Edmond Engil, Marabout, El Hassir etc. in addition to the Henri ore vein.

The ore veins are the fissure-filling ore deposits along such fissures cutting the Crystalline Schists, the Granites and the P-T Red Sandstone Formation, which are distributed in this area.

The largest ore vein, the Henri vein, extends several kilometers along the Henri fault, running in the N65°E direction. The width of this vein reaches 40 m in maximum so far observed.

The distribution of ore minerals in these veins is as follows in general. (Refer to L. El Maghraoui et al, 1976)

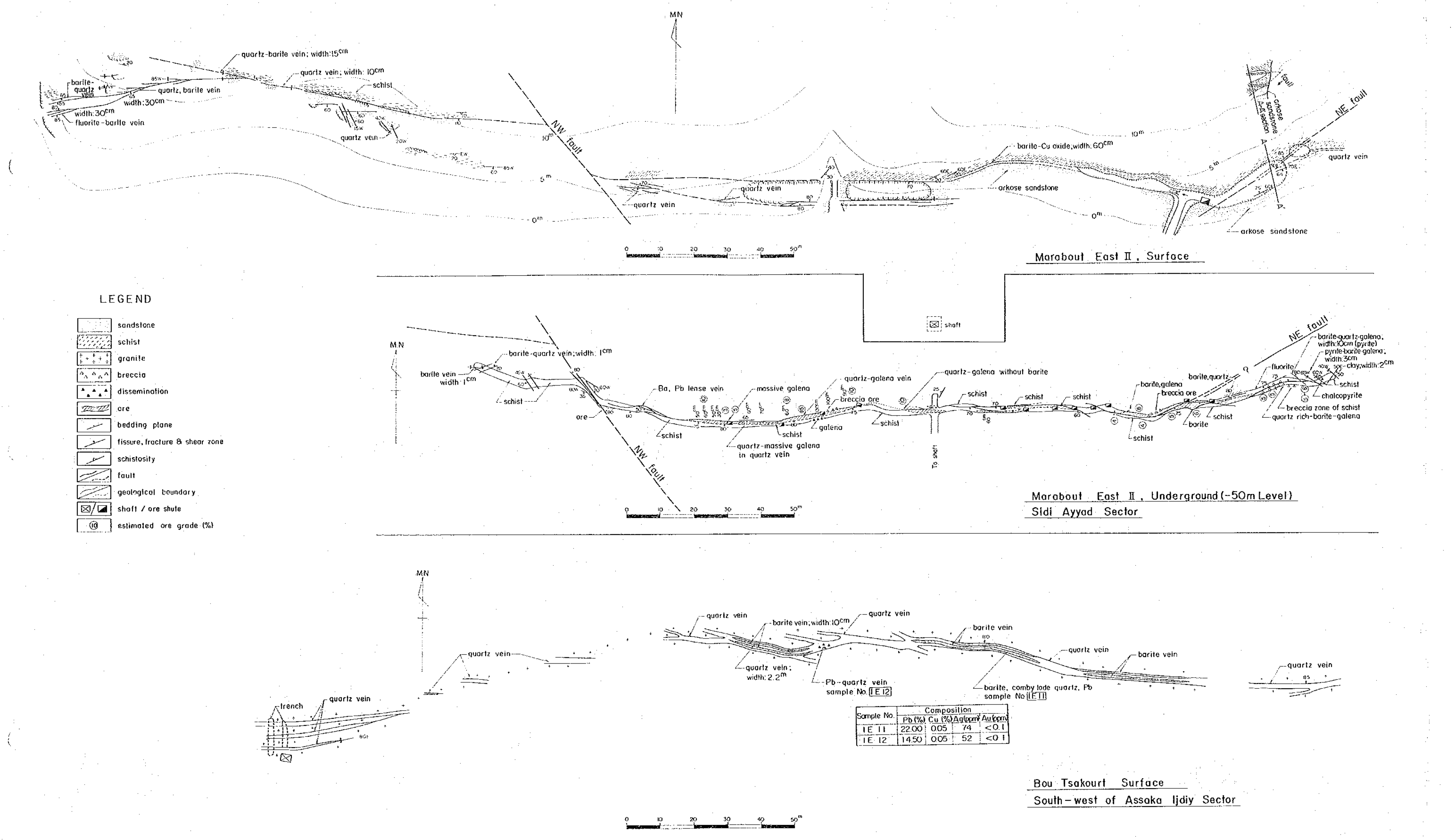
. From the surface to the depth of about 20 m, faults are closed and there is nothing contained.

- The zone from 20 m to 40 m below surface is composed of chalcedonic quartz vein with iron oxide minerals, containing quite small amount of lead.
- The zone from 40 m to 70 m below surface is the area where barite and galena are contained.
- The enriched part of ore minerals in quartz-galena vein is below the above zones. The enriched part reaches to the depth more than 200 m below surface, in case the wall rock of the both sides is composed of the Crystalline Schists.

In the present survey, detailed mapping was carried out on the surface and in the underground of the Marabout East II vein located at the northern end of this area as well as on the surface outcrop of the Bou Tsakart vein located about 14 km northwest of Midalt, which had been selected as examples in order to obtain informations of the geological characteristics of the ore veins. (Refer to Fig. I-8b)

The Marabout East II vein is the lead ore vein, for which exploration works of tunnelling are being carried out by BRPM at present. The general trend is E-W, with the dip of 75° to the south. The width of the vein is 70 cm in average, with the variation of 50 to 150 cm. On the surface, it is confirmed that this vein is extending several hundred meters in the direction of E-W. In the underground, the vein has been traced 80 m to the east and 80 m to the west on the -50 meter level, but the lode has been lost at each end by the dislocation caused by faults, though this has not been mapped in the present survey.

As to ores, dissemination of galena is recognized in the forms of dots or masses in quartz. Along the end of the ore zone, barite and fluorite are associated abundantly.



Sample No.	Composition			
	Pb (%)	Cu (%)	Ag(ppm)	Au(ppm)
IE 11	22.00	0.05	74	<0.1
IE 12	14.50	0.05	52	<0.1

Fig. I-8-(b) Detailed Geological Sketches of the Marabout East II vein and Bou Tsakourt vein

The Bou Tsakart vein is trending in the direction of N70° to 80°E, with the dip vertical or of 75° to the north. The vein is composed of seven small veins distributed in the echelon form. The width of the vein is 2 m in average, and the extension can be traced up to 200 meters. Gangue minerals are quartz and barite.

Along the end of the ore vein, the composition of the vein changes to iron-quartz vein, along which no lead mineral has been recognized on the surface outcrop. It is estimated that this type of vein would carry lead ore mineralization zone at the depth. There are many undeveloped veins of this type, found on the surface.

3-5 Geophysical Prospecting Area.

As to geophysical prospecting, gravity survey was carried out in an area of 400 km^2 in the southern half of the area between the Bou Mia Granite Body and the Zayda Granite Body.

As the surface geology, granites are distributed in the east side and in the west side in the northern part of the area, as stated above, and the P-T Red Sandstone Formation composed of arkose sandstone etc. is distributed around and on the Granite Bodies. The Jurassic system, the Tertiary system and the Quaternary system are developed covering the aboves.

In the P-T Red Sandstone Formation, mudstone beds are overlying directly the arkose sandstone, and no accumulation of medium to coarse-grained sandstone has been recognized. By the results of the diamond drilling, for geological structure, of the hole No. HM-1 performed in the central sothern part of this area as well as that of the hole No. HM-2, performed at a point about 4 km beyond the south-western limit of the area, there is no sediments of medium to coarse-grained sandstone, and the mudstone is thin. In the hole No. HM-1, it is recognized that the mudstone is marly.

The β_{P-T} Basalt Formation accumulated on the uppermost part of the P-T Red Sandstone Formation are well observed continuously on the exposures along the hillside of the terrace topography in the south of Bou Mia. This basalt is intensely chloritized, composed of the accumulation of many layers of lava flow each of which is 1 to 2 m thick. Locally, there are insertions of conglomeratic sandstone, manganese-iron-quartz layer etc.

The basalt layers are not distributed in the eastern half of the area, and though this basalt has been found to exist in the afore-said drill hole No. HM-2, it is not recognized in the drill hole No. HM-1. The J_1 Limestone Formation, overlying the basalt conformably, is also distributed only in the south of Bou Mia, and it is not found in the eastern part of this area. It is thought that the eastern part of the area would have been higher land where such beds as the basalt and the limestone were not accumulated.

The Cretaceous system is not distributed in the southern part of the area, though it is recognized in the northern part.

The Tertiary system is also found in the northern half of the area and is composed of T_1 Mudstone Formation and the T_2 Marl Formation. The beds of the T_1 Mudstone Formation are quite colorful and are mainly soft mudstone, with some insertions of conglomeratic sandstone. The T_2 Marl Formation is composed mainly of grey or yellowish grey marl beds with some inserted layers of limestone. The thickness of the T_1 Mudstone Formation is as much as about 20 m, and that of the T_2 Marl Formation is about 50 m.

The Quaternary system is extensively distributed in the south of the Moulouya river, forming terrace topography. The Q_1 Siltstone Formation is mainly rather soft and massive siltstone in the lower part, though it contains many inserted layers of sands and gravels in the upper part. The Q_2 Siltstone Formation is composed mainly of white or brown soft siltstone. A plateau of basalt lava of the approximate diameter of 3 km is recognized in the east of Bou Mia.

There is no other indication of lead and uranium mineralization in this area than those which are described in the paragraphs as to "The Eastern Zayda Sector"and "Bou Mia -- Zayda Sector".

3-6 Surrounding Sectors

It was decided by the results of the preliminary survey to divide the whole survey area into two different sorts of area, that is, the central part, where semi-detailed surveys would be necessary and the surrounding sectors where only general surveys would be carried out. Thus, the general survey was carried out in the surrounding sectors by establishing the survey routes with the approximate interval of 10 km. As the general geology has been described in the chapter 2 Geology of Surveyed Area, the characteristics of each of these surrounding sectors will be given here.

3-6-1 Northwestern Sector

The Northwestern sector belongs to the Moyen Atlas mountainous belt, whose topography is quite steep. The Srou river, which flows from the northeast to the southwest of this sector, is observed to have formed deep gorge at the approximate altitude of 1,000 m above sea level, while a plateau topography is recognized in the mountainous part at the height of 1,500 m to 2,000 m above sea level.

The rocks distributed in this sector are mainly conglomerate, sandstone and mudstone belonging to the P-T Red Sandstone Formation and βP-T Basalt Formation as well as limestone and marl belonging to the J_1 Limestone Formation of the Lias series. The basement, which is composed mainly of the coarse-grained granite and the crystalline schists mainly of hornblende schist, is exposed about 6 km in length along the Yahia-Oufalla fault close to Sidi Yahia, located about 5 km east of Karrouchan. Also, an exposure of sericite schist has been recognized on the floor of the Marrout river about 13 km northeast of Karrouchan.

The P-T Red Sandstone Formation has coarse-grained sandstone in the lower part and the grain size of the beds becomes finer toward the upper part. The uppermost part is constituted by mudstone. In the northeastern part of this sector, coarse to medium-grained sandstone was accumulated thick while in the southwestern part of it thick mudstone has been recognized.(Fig.I-9) Especially, in the vicinity of the above-stated Marrout, there are frequent inserted layers of conglomeratic arkose sandstone containing cross-laminae, which is thought to be suggesting that the sediments would have been accumulated as delta deposits. The thickness of the medium to coarse-grained sandstone in this area reaches as much as about 150 m. The thick beds of the mudstone are observed well in the area at the downstream of Karrouchan and along the shore of the Srou river in the north. They are comparatively homogeneous and massive, occasionally containing thin layers of fine-grained sandstone. Along the shore of the Srou river, at about 4.5 km southwest of Karrouchan, medium to coarse-grained sandstone is exposed with the approximate thickness of 90 m, underlain by part of conglomeratic coarse-grained arkose sandstone, which would suggest the portion to be close to the basement. The total thickness of the mudstone is over 300 m. Comparatively rapid variation of the lithofacies can be seen in the part between the mudstone and the underlying sandstone. In a valley at Marrout, as above-stated, it is observed that the coarse-grained part becomes thinner gradually toward the northeast. Therefore, there used to be a lenticular sedimentary structure for the accumulation of medium to coarse-grained sandstone, from its vicinity to Karrouchan.

Overlying the red mudstone beds, black or dark green basalt lava flows are seen to have been accumulated with the approximate thickness of 100 m.

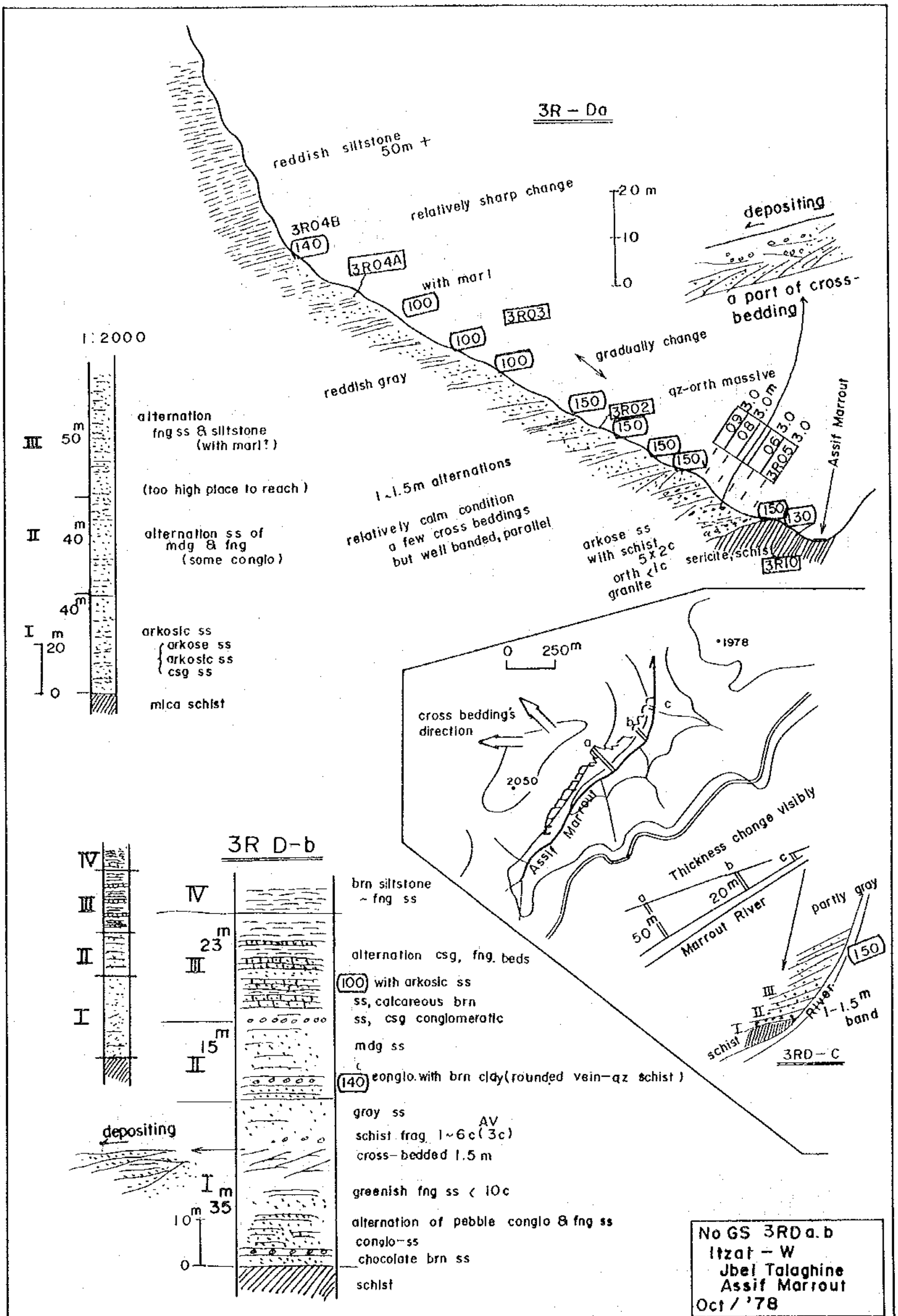


Fig.I-9 Detailed Geological Sketches of P-T Red Sandstone in the North-Western Part

The thickness becomes greater toward the southwest. On the basalt layers, Jurassic limestone formation is overserved to lie conformably. At the base of it, conglomeratic portion can be recognized. Generally, fossils of the fragments of corals are found abundantly in this formation. Resistant against weathering, and due to the development of vertical joints, the limestone is found to form sheer cliffs, and also the topography of platform can be seen in many places where the limestone is distributed.

As for geological structure, the sedimatation of the medium to coarse-grained sandstone regarded as the delta deposits as above-stated is quite characteristic in this area. There are three major fault system in this sector, that is, the faults of N60°E system, those of N45°E system and those of N-S system. These faults are thought to have been formed at the period of the Alpine orogenic movement, except for the Yahia-Oufalla fault, running closely along the boundary of this area to the Bou Mia -- Zayda Sector, which is thought to be a pre-existing fault in the period of the Permo-Triassic period, rejuvenated in the Tertiary period, viewing from the differences of the features of the sediments composed of the P-T Red Sandstone Formation, distributed in each side of the fault. In most cases, the dislocation caused by the faults is upward and downward, and lateral dislocation is usually small. Of course, the distance of such upward and downward dislocation is different with each fault and there are hinge faults. Therefore, sedimentary beds are seen to have been inclined with the angle of up to 30°, in some places. The area of the width of 3 km along the westside of the Yahia-Oufalla fault is a subsides zone like graben, and the sediments are left to be almost horizontal, but in the area further to the northwest, whole of the sedimentary beds are dipping to the northwest. However, in the northeastern part of this area, the level of the basement is high, as seen along the Marrout river, where the exposure of the crystalline schists is at the height of 1,700 m above sea level. This elevation is as high as the hills of the Bou Mia Granite Body.

In this area, no indication of mineralization of either lead or uranium has been recognized, except for the fact that there is a superficial anomalous portion of radioactivity in the granite at Sidi Yahia, which is located at the northwestern end of the area occupied by Bou Mia Granite Body. It is important as to this indication to obtain information whether uranium has been concentrated along the Yahia-Oufalla fault.

Slight amount of copper-oxides has been found along the boundary between the limestone and the basalt distributed at the Aït Brahim village in the upstream of Lkis river in the eastern part of this area. This indication is not continuous. No anomalous radioactivity has been detected. However, as this part, east of Karrouchan, is significant as the area favorable for the emplacement of uranium ore deposits because of the development of medium to coarse grained arkose sandstone, it is desirable to carry out semi-detailed survey in this area.

3-6-2 Northeastern Sector

This sector is situated in the north of the Zayda Granite Body and is composed of the lowland of Tanfit -- Micha -- Sidi Ayyad and the northern half part showing terrace topography formed by the erosion of limestone beds.

In the lowland, βP-T Basalt Formation and the red mudstone beds of the upper part of the P-T Red Sandstone Formation are distributed. The lower part is covered with Quaternary Q_2 Siltstone Formation extensively.

The northern half part is occupied by the J_1 Limestone Formation of Jurassic system, the K_2cm Mudstone Formation of Cretaceous system and the T_1 Mudstone Formation of Tertiary system, which are overlying the above basalt formation. As for the Quaternary system, the Q_1 Siltstone Formation is found partly at the highland and the β_{P-T} Basalt lava flow is distributed along valleys north of Tanfit -- Micha zone.

The J_1 Limestone Formation is distributed from the north of Sidi Ayyad toward the eastern part, and the thickness varies remarkably.

The K_{2cm} Mudstone Formation is distributed with almost uniform thickness. It is recognized that there is a small synclinal structure with the axis of the direction of NWW-SEE around Ifri Ichabar at the north of Sidi Ayyad. This formation is composed of mudstone and marl with various colors like red, grey, yellow etc., characteristically containing inserted layers of gypsum.

The thickness of the T_1 Mudstone Formation is largest around Agzou on the plateau north of Micha, where it is as much as 55 m in thickness, and the thickness is gradually decreasing toward the east and toward the west.

The Q_1 Siltstone Fromation is composed of thin conglomeratic layers in this area, and the β_{Q2} Basalt lava is constituted by thin lava flow, the Length of which is about 5 km.

The geological structure is comparatively monotonous. The beds are mostly horizontal. There is no other major fault than that found at Bou Hamza in the north of Sidi Ayyad, where the northern extension of the Ilich Azougagh Mylonite zone can be recognized.

In this area, no indication of either lead or uranium mineralization has been confirmed. However, it is thought that the possibility for the emplacement of uranium ore deposits would be there as the stable sedimentation zone neighbouring to the northern side of the Zayda Granite Body, where many indications of uranium mineralization have been found.

3-6-3 Southeastern Sector

This sector is located around Midalt and in its east, further south of the Mibladane -- Hawli Mine sector. The area to the south of the Amhrou fault, which passes through Mibladane, down to the Haut Atlas mountainous belt is recognized to have formed a peneplain of the approximate altitude of 1,500 m.

The rocks distributed in this sector are sedimentary rocks from Dogger series to diluvium of the Quaternary system.

The J_{2d1} Mudstone Formation of the Dogger series is distributed in an area about 5 km east of Midalt, with the approximate width of 5 km respectively in north-south and in east-west. Overlying this mudstone formation, the J_{2d2} Limestone Formation is distributed, forming a synclinal structure of the axis of the direction of NE-SW, at about 10 km south of Midalt.

Covering these Jurassic system, the K_{2cm1} Red Mudstone Formation of Cretaceous system is distributed. The lower part of this formation is composed of cognlomerate, containing pebbles of the crystalline schists, milky white quartz, limestone, dolomite etc. with pieces of lead ore. There is various colored mudstone overlying the conglomerate bed. The mudstone contains great amount of gypsum, as is seen in the other areas. The thickness is about 100 m. The K_{2cm2} Mudstone Formation is distributed, covering the colorful mudstone. This mudstone formation is exposed in the lower parts as along the valleys in the eastern part, and is recognized to have formed gentle synclinal and anticlinal structures with overlying K_{2t} Limestone Formation, the axes of which are in the approximate direction of NE-SW.

The T_2 Marl Formation of the Tertiary system is distributed around Midalt and in its west, and it is not found in the southeastern part.

In the southeastern part, the Q_1 Siltstone Formation and the Q_2 Siltstone Formation of the Quaternary system are covering the lowland zone from Sariyt to Bougma. As a whole, notable geological structure of the intense movement such as fualt-structure has not been recognized other than gentle syncline and anticline structure.

Lead ore deposits are distributed only in the area north-western side of the Amhrou fault, and no lead ore mineralization has been found in the Cretaceous system or in the Dogger series distributed in the south-eastern side of the fault. No indication of uranium mineralization has been discovered.

3-6-4 Southwestern Sector

The southwestern sector is extensively covered with the Q_1 Siltstone Formation, except for the parts of the hillfoot of the Haut Atlas mountainous belt, where the J_1 Limestone Formation, the J_2d_1 Mudstone Formation and the J_2d_2 Limestone Formation of the Jurassic system are exposed. The Jurassic system is seen to have been folded complicatedly with steep dipping. Major fault structures are seen in the directions of N70°W system, N80°E system and N20°E system. It is necessary to investigate extensively, even in the area beyond the limit of this sector, because the exposures of the older rocks are found quite limitedly, than the Quaternary system, in this sector.

An indication of lead ore mineralization has been recognized in a exposure of the J_1 Limestone Formation, located at the south-south-east of Bou Mia, along the hillfoot of the Haut Atlas range. There are veinlets of the trend of N55°E, with the dip of 40° to the southeast.

No indication of uranium mineralization has been found.

Chapter 4 Mineral Resources

4-1 Lead Ore Deposits

4-1-1 Distribution and Relation to Geology

The lead ore deposits are distributed around the Zayda Mine located roughly in the center of the surveyed area, around Mibladane in the south-eastern part and around Hawli in the eastern part in this surveyed area. The geology and the ore deposits are described in the paragraphs of 3-1 The Eastern-Zayda Sector as well as of 3-4 Mibladane -- Hawli Mine Sector. The ore deposits are classified into three types, and the characteristics of each type of the ore deposits are given as follows;

Characteristics of Lead Ore Deposits

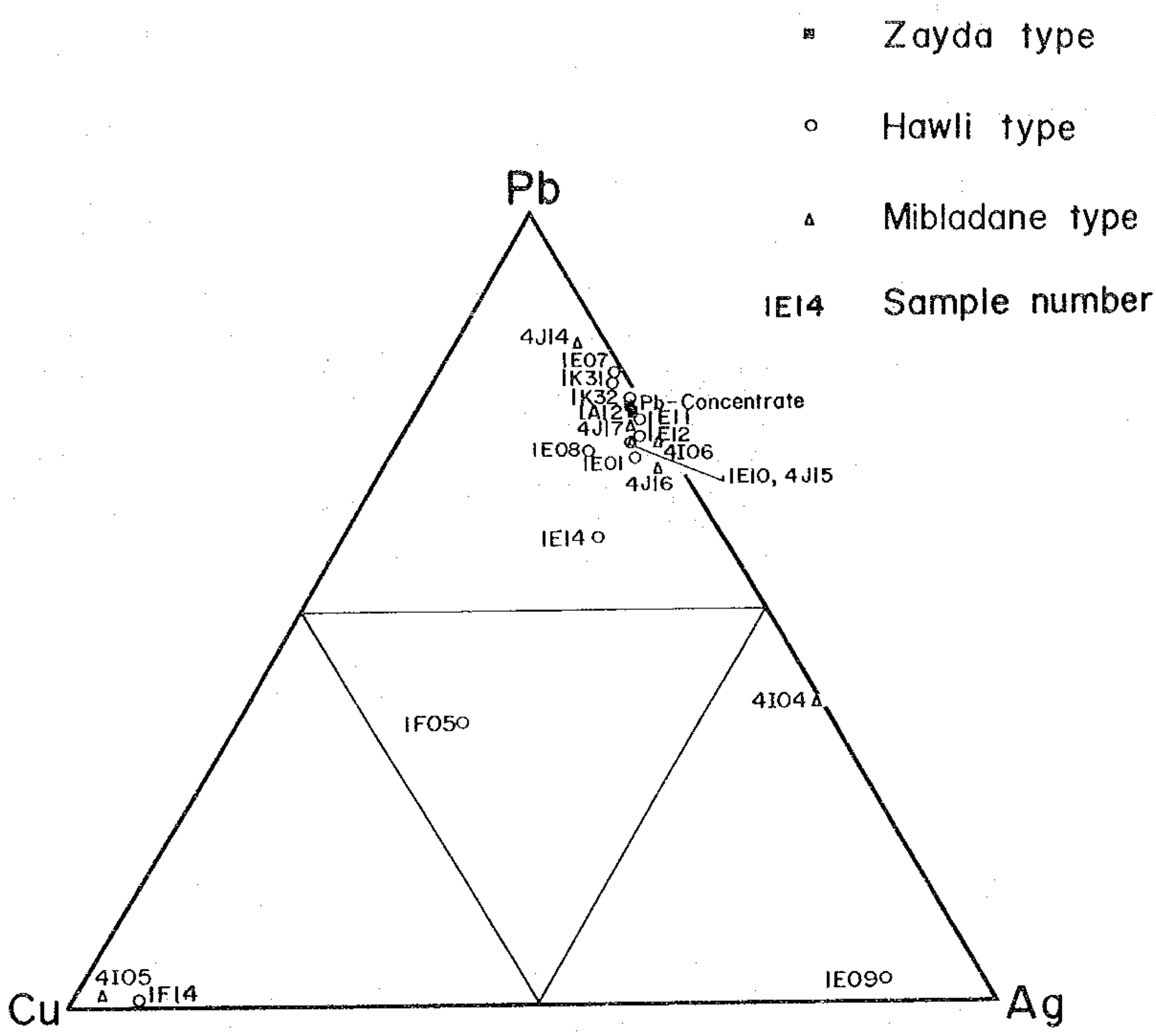
1. Type	Sandstone type	Stratiform dissemination type	Vein type
2. Distribution	Around the granites, mainly around Zayda	Around Mibladane, in the southeastern part	In the area where the Basement complex are distributed; mainly around Hawli
3. Name of the main ore deposits	Paneau-1, 19, 54	Dalles, T, Bou El Maden	Henri, Georges, Marabout
4. Scale of the ore deposits	Thickness: 2.5-10 m Area: 30,000-400,000 km^2 Number of orebodies: 66+ Ore Reserve: 16,000,000 tons Average grade: Pb 3%	Several layers of ore horizons, each of which is 5 to 50 cm thick, are found in the sediments of the thickness of 10 to 20 m. Area: 140,000 to 520,000 m^2 Number of orebodies: 12+	Width of veins: 0.5 to 40 m Extension: several hundred meters to several kilometers Depth: 100 to 200 m
5. Country Rocks	Arkose sandstone at the lowermost part of the P-T Red Sandstone Formation	Limestone at the lower part of the Jurassic system; dolomite, marl, and partly conglomerate of the middle Cretaceous system.	Crystalline schists, granites and red sandstone.
6. Ore minerals	Galena, cerussite, barite and very small amount of fluorite. (Silver is contained in galena)	Galena, cerussite, barite, small amount of Wulfenite, vanadinite. (No fluorite) (Silver is contained in galena)	Galena, cerussite, barite, quartz, fluorite, and very small amount of wulfenite. (Silver and bismuth are contained in galena)
7. Genesis of ore deposits	Epigenetic	Epigenetic and syngenetic	Epigenetic

Using the assay results of the samples collected in the present survey from the ore deposits of these three types, ratios of Pb-Cu-Ag contents were calculated and plotted in a triangle diagram. The ratios are gathered around a point, and therefore it has been concluded that there is no difference of the ore deposits of these three types as for the ratios of the contents of the three metals (Fig. I-10). However, as found in the above table, some differences are recognized among the three types of ore deposits as seen in the facts that the galena of the vein type contains bismuth, which is not contained in the other types of mineralization and that fluorite is not associated as gangue minerals in the stratiform dissemination type of ore deposits. Also, chronologically the ore deposits of the sandstone type are emplaced in arkose sandstone of the Permo-Triassic system and are thought to have been formed almost contemporaneous with the country rocks, while the ore deposits of the stratiform dissemination type is emplaced in the Jurassic system. Acccordingly, there have been studied in detail on the mechanism of the formation of these ore deposits by many geologists, but no unified elucidation, which gives satisfaction to the interpretation of the genesis of the three types of ore deposits at the same time, has been obtained. It would be necessary to make program for exploration works, considering various possibilities of the genesis of the ore deposits, at the recent stage.

4-1-2 Favorable Areas for the Emplacement of Lead Ore Deposits and the Survey Methods

(1) Sandstone type lead ore deposits:

The developed ore bodies around Zayda are recognized to be associated with arkose sandstone of the Permo-Triassic system, formed along paleochannels on the granite body. The distance to the limit, within which lead ores might be crystallized, along the paleochannels from the granite body



π : Percentages of the above each value are calculated as followings,
Pb : 100x Pb% /S , Cu : 100x Cu %x10/S , Ag : 100xAg ppm x0.1 /S
S = (Pb%+ Cu%x10+ Ag ppmx0.1)

Fig. I - 10 π (Pb - Cu - Ag) of Pb Ore Deposits in the Surveyed Area has not been confirmed. It is important to detect paleochannels and to trace them. For the investigation of paleo-topography of the basement, gravity survey is effective in addition to detailed geological survey. Also, as there is an example (Amade, 1965), showing the correlative relation between the distribution of fissures found in the basement and the distribution of such blocks containing high grade ore of more than Pb 2% caught in the survey for the distribution of the grade of ore in the mineralized arkose sandstone, and so this relation should be noted in the exploration works.

(2) Stratiform dissemination type lead ore deposits:

The ore deposits are distributed in the Jurassic calcareous beds in a zone between the Henri fault and the Amhrou fault, which runs passing through Mibladane. Also, the certain mineralized horizons have been confirmed. As to the emplacement of the ore deposits, it is known that there are ore deposits which are thought to have been formed contemporaneously with the enclosing sedimentary rocks, but it is more often observed that ores are swelling and pinching along small fissures across the stratiform ore deposits. Accordingly, it is important in this area to carry out structure analysis including the investigation for the distribution of foldings and faults, small or large, without mentioning the importance of detailed geological survey.

(3) Vein type lead ore deposits:

Large scaled ore deposits of the vein type have been developed and the major parts of them have been mined out already. However, there are moderate scaled ore deposits of the vein type left undeveloped, and they would warrant further exploration works at the depth, through making full use of the informations on the tendency of the zonal distribution of ore minerals etc., obtained with the already-developed ore veins. These ore veins were formed in the Mesozoic Era, and were frequently cut and dislocated by the later fault movements. Therefore, it is necessary to carry out the exploration works as effective as possible, through outcrop survey and underground detailed geological mapping, etc.

4-2 Uranium Ore Deposits

4-2-1 Distribution of Radioactivity and Relation to Geology

The distribution of radioactivity in the basement rocks and overlying sedimentary rocks, and the geology of the indications of anomalous radioactivity in this surveyed area are as follows.

(1) The measured values of radioactivity in the area occupied by the basement rocks, and the correlation to geology (Refer to Pl. I-7).

The regional surveys of the measurement of radioactivity carried out by BRPM up to present time in this survey area are listed as follows. They are composed mainly of the measurement of radioactivity along the routes in rivers and valleys. (Using the instrument SPP-2NF for measurement).

Year	District	Area	Interval of survey points
1976	Sidi Ayyad	50 km^2	300 - 500 m
1977	Bou Mia -- Karrouchan	350 km^2	50 - 300 m
1978	Zayda-East	400 km^2	150 - 300 m

Compiling the results of these regional surveys, the values of radioactivity at each survey point were divided into three ranks of, under 150 c/s, 150 to 200 c/s and over 200 c/s, and then the distribution map was prepared, in the process of the present analysis. The correlation was carried out between the above distribution map of three ranks of radioactivity and the distribution map of the lithofacies of the basement rocks ascertained in the geological survey in the present year (Pl. I-7). As the result of the above correlation, it has been confirmed that the area showing comparatively high values of more than 150 c/s of radioactivity is corresponding roughly to the area where the granites are distributed, though extending outside of such area in some places, and that the area of such high values are scatteringly distributed in the area where the crystalline schists are developed. No remarkable correlation has been recognized between the difference of lithofacies of the granites and the area of such high values of radioactivity. It can be said that the topographically undulated parts such as along the shores of the Moulouya River and the Ansagmir river are to coincide the area of the comparatively high values of radioactivity of over 150 c/s. The points of the comparatively high values scatteringly distributed in the area occupied by the crystalline schists are corresponded to the points where the relief is quite shear. It is thought that the main reason for the high values of radioactivity to be distributed in such places of steep relief would be the accumulation of radioactive materials in such places as topographically rugged country with many cracks as is the case along river shores, derived from the basement zone, especially from the topographical hight of the granite bodies.

Meanwhile, in the present geological survey, SPP-2NF Sintilometer was carried in each survey party and the measurement was performed with the geological mapping. According to the result of this measurement of radioactivity, the values of the granites are generally 50 c/s to 170 c/s (average value is about 105 c/s), except for the aplitic granite, which shows the value of 80 c/s ot 200 c/s (average value is about 135 c/s), a little higher than those of the other rocks.

The values of radioactivity with dykes are partly high, as aforestated.

(2) Assay results of uranium and thorium contained in the granites

According to the assay results of the samples of the granites, the contents of uranium are U: less than 0.002%, but the thorium contents in the aplitic granite are Th: 0.003 to 0.004%, which are a little higher than the other granites showing the values of less than 0.002%. More precise chemical analysis of uranium was carried out with one granite sample and two aplitic granite samples. (Sample No. 1A11, 1B05 and 1J18) The result shows that the uranium contents of two samples of the aplitic granite are both U: 8 ppm, while the content of uranium in the granite is U: 12 ppm. It is no need to mention as fresh samples as possible were prepared.

By M. Annich (1977), uranium cotents of the granites around Zayda are reported to be as follows; porphyritic granite U_3O_8: 65 ppm, fine to medium granite U_3O_8: 43 ppm. The values shown in this results are extremely high, compared with the above-mentioned assay results. It is thought that the samples collected on the surface of the granites would show two cases such as the increase of contents under local secondary enrichment and the decrease of contents under dissolution of uranium. It can be taken as granted that the similarity of the three assay results mentioned above would suggest that the contents of uranium in the granites in the present surveyed area are at least more than 8 ppm. The uranium contents of over 8 ppm can be taken to be comparatively high values as to those in granite. (Generally the uranium contents in granites are said to be 2 to 5 ppm.)

As for thorium, the thorium contents in the aplitic granite are a little higher than those in the other granites. One of the reasons why the values of the measurement of radioactivity in the aplitic granite are higher than those in the other rocks would be this difference of the contents of thorium. (Due to the fewness of the assay results, there is, still possibility that actual uranium content is a little high.)

(3) Values of the measurement of radioactivity with the sedimentary rocks

The radioactivity survey carried out by BRPM in 1978 covered the total area of about 700 km^2, in which the approximate area of 300 km^2 is corresponded with the area occupied by the sedimentary rocks at the west of Zayda. The values are less than 150 c/s with the Permo-Triassic system and whole of the younger members, except for the values concerning the area close to the granites.

The values measured through the present survey are as follows;

The P-T Red Sandstone Formation:	30 to 110 c/s (average about 80 c/s)
The β_{P-T} basalt Formation:	30 to 100 c/s (average about 50 c/s)
The Jurassic system and the younger Formations:	
	20 to 80 c/s (average about 30 to 40 c/s)

Although the values of the P-T Red Sandstone Formation are a little higher than the others, the assay results are showing that the contents of uranium and thorium are respectively less than 0.002%.

(4) Distribution of indications of uranium mineralization and the geology

The points of anomalous radioactivity ascertain through the present survey in this year are at 22 localities. (Refer to Table I-12)
The assay results of the samples collected from all of these anomalous points shows the uranium contents of over 0.004% of uranium (the highest value is 0.188%), while the values of thorium is less than 0.002%.
Therefore it has been clarified by the assay results that the anomaly of radioactivity is due to uranium mineralization. (Refer to Table I-13)
Furthermore, there is an indication of uranium mineralization confirmed by the diamond drilling carried out by BRPM in the Tarekochid area, at the west of Bou Mia. The followings are the interpretation on such indications of uranium mineralization by the most modern method of the classification (F.J. Dahlkamp).

Classification of Uranium Occurrences, after F. J. Dahlkamp

Type	
Vein-like type	Six main categories of economic uranium deposits
Sandstone type	
Conglomerate type	
Hydrothermal veins	
Intraintrusive type	
Calcrete type	
Others (Black shales, phosphorite, etc.)	

Among the above types of uranium mineralization, indications of uranium mineralization which are thought to be corresponding with those of vein-like type, sandstone type and conglomerate type are found in this surveyed area, in addition to particular occurrences of uranium of "carapace type", which is proper to this area. No other type of indications of uranium mineralization has been found in the present surveyed area.

1) Indications of vein-like type uranium mineralization:

The indications of this vein-like type are most prevalent in this surveyed area, and there are many indications of the vein-like type uranium mineralization distributed along the banks of the Houte Moulouya river at the northeast of Zayda, and in the area around Sidi Ayyad. Dykes of granite porphyry and microgranodiorite which intruded the granites have been fractured along the dykes themselves, and uranium derived from the surroundings were deposited in the fractured zone. On the surface outcrops, secondary fissure-filling veins composed of brown material like iron-quartz have been formed. The width of a vein is from 5 cm to about 1 m, and the portions with anomalous radioactivity are recognized to be distributed intermittently with the interval of several meters. In some places, the value is as high as 13,500 c/s. The extension of a fracture zone is 30 m to 1 km. A vein found in the Sidi Ayyad area has been traced and the extension is confirmed to be as far as 600 m. By the X-ray Micro-Analysis examination, it is recognized that the ferrouginous quartz has uranium minerals such as carnotite〔 $K_2(UO_2)_2(V_2O_8)\cdot 3H_2O$ 〕 and Becquerelite〔 $CaO\cdot 6UO_3\cdot 11H_2O$ 〕. And, carnotite occurs with fervanite 〔 $2Fe_2O_3\cdot 2V_2O_5\cdot 5H_2O$ 〕. (Ref. Table I-9)

2) Indications of sandstone type uranium mineralization:

The sandstone type mineralization includes further divisions of roll-front type, pene-concordant type and tecto-lithologic type.

a) Indications of roll-front type: An indication of uranium mineralization has been caught by the diamond drilling for profile survey of the drill hole No. 6 to No. 9 carried out by BRPM as a part of the Tarekochid project, though the mineralization is thin and small-scaled. The mineralized bed, caught in a profile including the drill hole No. 6, is positioned at the approximate depth of 60 m with the extension of over 800 m from the drill hole No. 5 to No. 12 in the direction of NE-SW. The average thickness is 30 cm and the average grade of uranium is about 400 ppm U_3O_8. The horizon of the high grade mineralization is situated between the arkose sandstone on the basement granites and the overlying mudstone beds. It is thought that this mineralized horizon represents a sort of small scaled roll-front type mineralization, where uranium deposition took place by the underground water passing through the coarse-grained part of the country rocks.

b) Indication of tecto-lithologic type uranium mineralization: The indications of uranium mineralization found in the graben structure at Assaka Ijdiy at the north-north-west of Midalt are described in detail in the paragraph 3-1 Eastern Sector of Zayda. No actual example of ore deposits has been confirmed yet. If any, it is thought that uranium would have been reserved along the fractured fault zones and in the red sandstone layers at the bottom of the graben.

Indication of peneconcordant type uranium mineralization has not been recognized through the present surface survey, but it is observed that the leached portions of the red mudstone beds would show the anomalous values of radioactivity of 200 to 400 c/s. Slight amounts of pyrites are recognized in such leached part, and this would be thought to make one of the indications for a possibility that major scaled bedded uranium mineralization could be formed in such leached portions. For the comparison of the mineral compositions of the leached part and the unleached part of the mudstone, X-ray diffraction test was carried out, but no notable difference has been recognized between them (Table I-14).

3) Indications of conglomerate type uranium mineralization:

Floats of the Quaternary conglomerate are scatteringly found around the Paneau-1 at the northeast of Zayda. These floats have high values of radioactivity (about 1,500 c/s). The pebbles are constituted by various rocks such as limestone, granitic rocks, quartz, basalt and so on. As no specific fragment has high uranium content, it is thought that uranium transported from outside would have been fixed in the matrix of the conglomerate during the period of the formation of this conglomerate. Nothing but floats of the conglomerate has been confirmed, and no original bed of conglomerate is recognized to be left at present.

4) Indications of Carapace type uranium mieralization:

As this type of uranium mineralization is unique to this surveyed area and it is not found in the above-stated classification by Dahlcamp, the temporary name is given here.

It is known as to the granite bodies in this surveyed area that there is a pehnomenon to show the surface of the granite bodies was exposed in the period of Mesozoic Era, forming the oxidized zone of the thickness of about 30 cm by intense weathering. As the appearance is like tortoise-shell (carapace in French), it is called to be carapace, which is observed typically at a place close to Ifzwane in the upstream of Tarekochid. The Ait Sa'id indication of uranium mineralization found at a point about 6 km north of Bou Mia through the present survey is the mineralization inside the carapace. The value of the measured radioactivity is 1,600 c/s, and the assay results are as follows; U: 0.072%, Th: less than 0.002% and V: 0.030%. The indication is small in scale. The thickness is 30 cm and the width is 3 m. Extension is uncertain. By the results of the X-ray micro-analysis (XMA) of the samples collected from this indication of uranium mineralization, performed to obtain the information of associated elements, it has been confirmed that uranium is associated with vanadium (Tables I-7 and I-9). By the examination, it can be said to be carnotite and may be tyuyamunite [$Ca(UO_2)_2(V_2O_8)\cdot 5H_2O$], however, it needs to continue farther mineralogical study.

4-2-2 Favorable Areas for the Emplacement of Uranium Deposits and Survey Methods

(1) Geohistorical consideration (Fig. I-11)

For the estimation of the favorable area for the emplacement of uranium ore deposits in this surveyed area, it is necessary to give full consideration on the behavior of uranium and on the geological events listed as follows.

1) During the period of the Hercynian orogeny, there was an intrusion of granitic rocks with a little high content of uranium.

2) The granites were eroded in the Permean to Triassic period, and uranium flow into the Karrouchan basin with the clastic sediments. The formation of ore deposits occurred partly on the way of paleochannels,

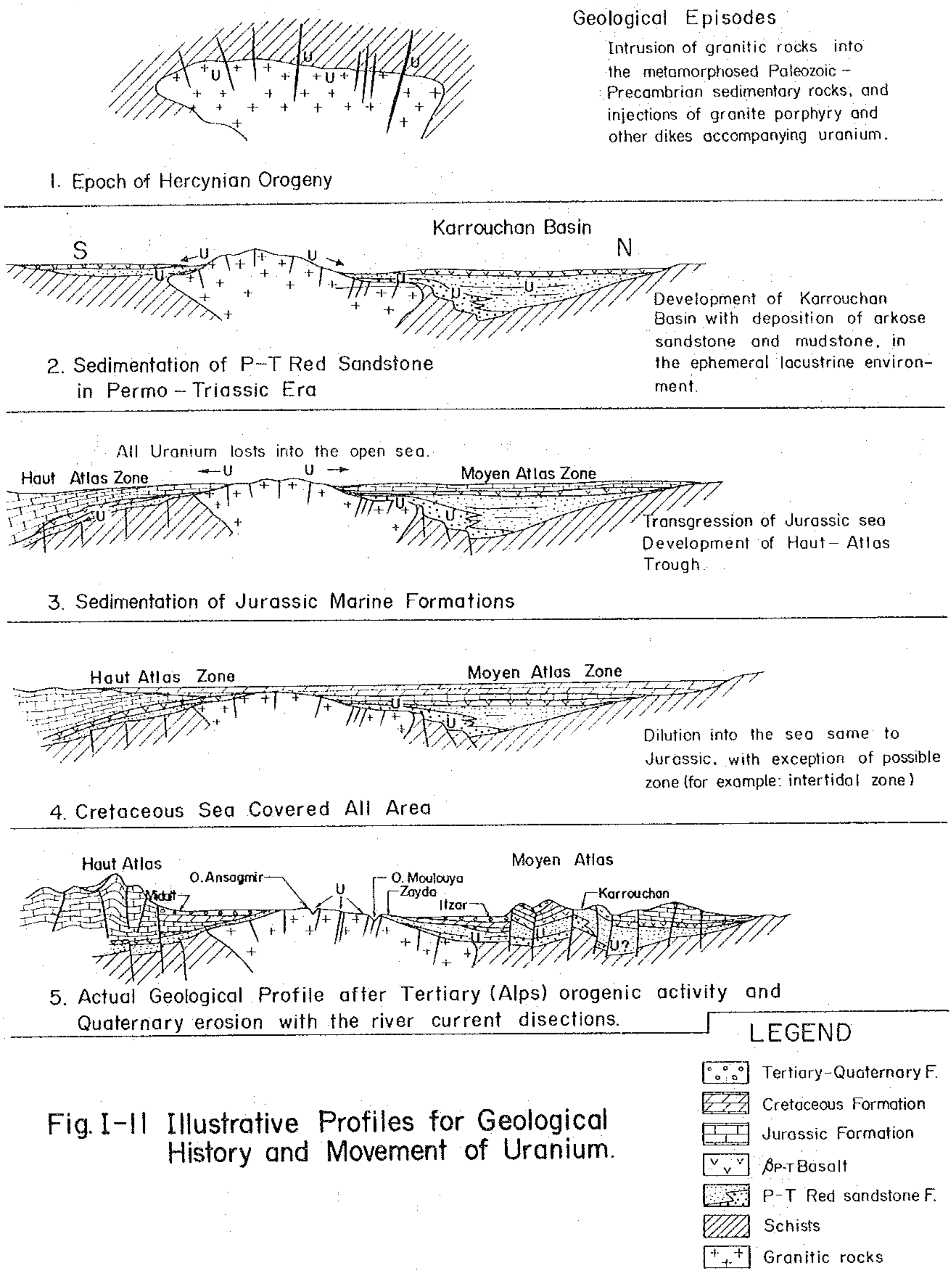


Fig. I-11 Illustrative Profiles for Geological History and Movement of Uranium.

but most of uranium were transported to the mouth of channels to the basin, where ore deposits were formed, or otherwise uranium was scattered.

3) There is no indication of uranium mineralization in the Jurassic system and in the Cretaceous system, including the beds formed through the marine regression.

4) The relation of the Karrouchan basin and the granite zone was cut and separated by the Tertiary orogenic movement, and a new basin was formed along the hillfoot of the southern side of the Moyen Atlas belt. However, as the inland lakes were formed in this basin, the granites were positioned below water level, and therefore the granites were not eroded during this period. There was no mobilization of uranium.

5) At the beginning of the Quaternary period, the inland lakes disappeared and the erosion of the granites and the dissolution of uranium took place again. Although part of the uranium were concentrated along the fissures to form vein-like type uranium deposits through the process of fissure-filling, most of the uranium have been transported out of this area by flowing into the Moulouya River running through the central part of the granite zone.

As above, the formation of uranium ore deposits would be restricted to the Permo-Triassic period and to the Quaternary period.

(2) Favorable areas for the emplacement of uranium ore deposits and survey methods

As the conclusion of the above-mentioned eviences and elucidations, the following areas will be extracted as the favorable areas for the emplacement of uranium ore deposits in the present surveyed area.

The survey methods are given together (Fig. I-12).

1) The area for geophysical prospecting of the first year:

By the results of the gravity survey, the distribution of paleochannels

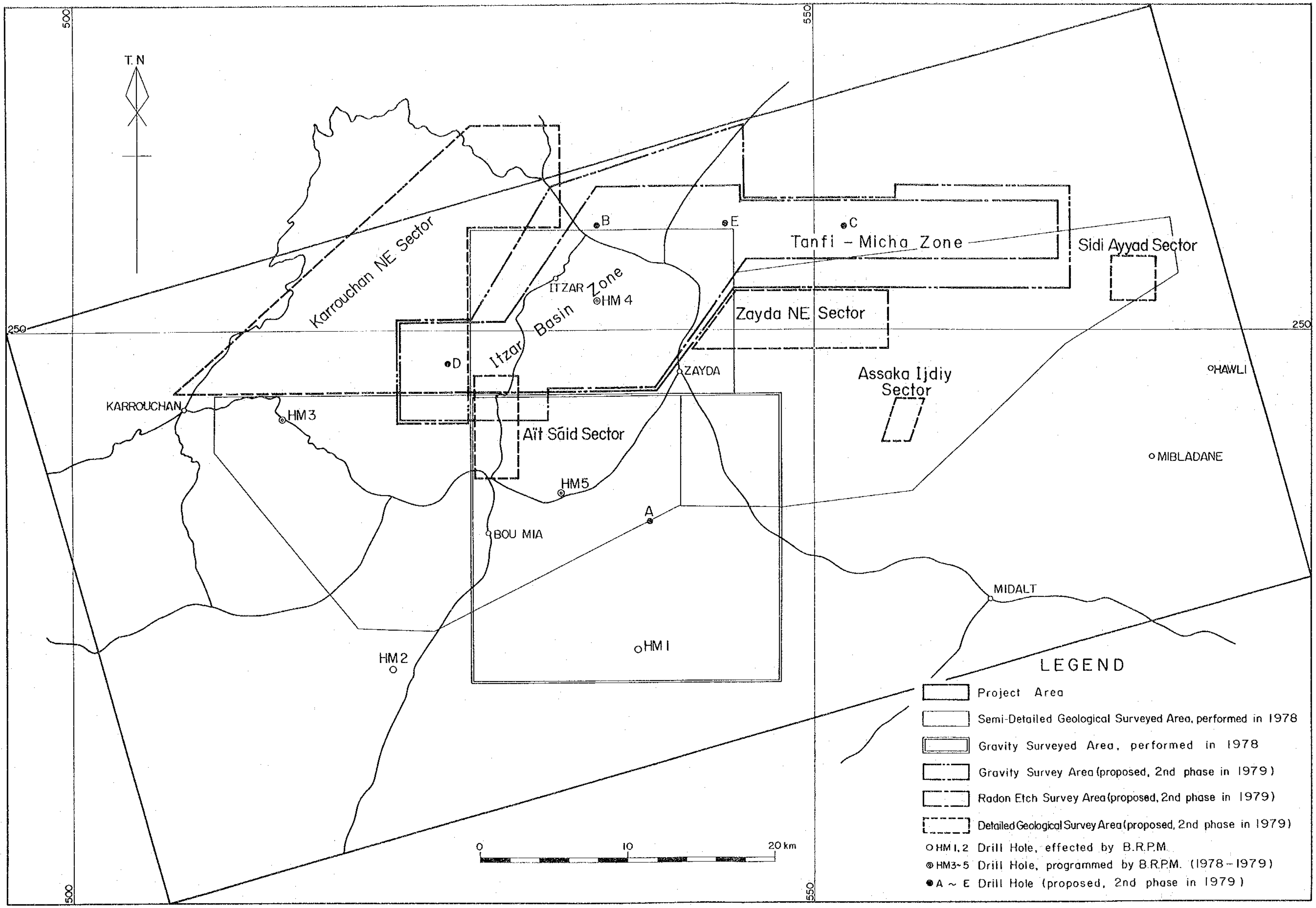


Fig. I-12 Proposed Exploration Programme for the 2nd Phase, 1979 has been estimated. Uranium ore deposits of sandstone type and conglomerate type might be present there.

It is desirable to carry out exploration by diamond drilling for the estimated paleochannels of the distance of more than several kilometers from the area where the granites are distributed.

2) The area of approximately 400 km^2, including "Itzar basin zone" at the north of Zayda - Bou Mia, and Tanfit - Micha zone at the northeast of Zayda: The northwestern part of this area is limited by the Yahia - Oufalla Fault and the geological structure like basin has been formed. The Tanfit - - Micha zone is very stable zone geo-structurally, inclining gently toward the north from the area where the indications of vein-like type uranium mineralization such as Assaka Tabhirt and Paneau-1 are found. Uranium concentration in the Quaternary peirod will be expected in addition to Permo-Triassic uranium ore deposits. Also, at the western end of this area, there is a graben structure inclining toward the north, formed in the central part of the Bou Mia Granite Body. This graben structure is thought to be prividing favorable place for uranium concentration. For the investigation in this area, geophysical prospecting is necessary for the information of the geo-structure of the basement, and to obtain the fundamental data, for the analysis of the results of the geophysical prospecting, it is necessary to carry out investigation by diamond drilling for geological structure, of more than one hole in each of the Itzar basin zone and the Tanfit -- Micha zone.

It is thought that the existence of reducing environment is one of the most important factors for the formation of ore deposits through the precipitation of uranium dissolved in moving water. It is hard to estimate, by the analysis of geo-structure only, the distribution of uranium ore deposits, which would have been formed through the combination of various factors such as above-said reducing environment. Meanwhile, there is an effective method using radon gas for the exploration of uranium ore deposits. This method is to estimate the presence of orebodies or the extension of the known orebodies by measuring the quantity of radon rising from orebodies, by exposing it on special films. (Tentatively this method is called to be Radon Etch.) As the presence of faults, the penetration in rocks, the thickness of rocks, the climate etc. will given much influence to this Radon Etch method, it is necessary to take full care of the analysis of the results. But, it is thought that this method is one of the most effective methods to estimate the distribution of ore deposits. Most of this area is flat like plain topographically, and the inclination of sediments in gentle. Therefore, it is thought that this area is suitable for the Radon Etch method to be employed. It is desirable to carry out the Radon Etch in an approximate area of 300 km^2, where the depth of orebodies is estimated not to be deep by the results of the above-stated geophysical prospecting. It is necessary to establish the density of the survey points to be at least 2 points per square kilometers.

3) Northeast of Zayda and the Sidi Ayyad area where indications of vein-like type uranium mineralization are distributed: The values of the measured redioactivity on the surface of the indications of vein-like type uranium mineralization are irregular due to weathering. Therefore, to obtain informations on the mineralization of the inside of the ore vein, there is no other way of exploration than tunnelling. For this reason, it is necessary to map in detail all the indications of vein-like type mineralization so far found, and to give full consideration on the structure of the veins and the features of the mineralization along the veins, for the selection of such veins as to deserve further exploration and for the

determination of the locations of the tunnelling. The detailed survey will be necessary in an area of 48 km^2 in the northeast of Zayda and in the Sidi Ayyad area of 9 km^2.

4) The area of 204 Km^2 in the northeast of Karrouchan: It has been estimated from the results of the first year's geological survey that this area would be corresponding with the mouth for the flowing out of detrital rocks, derived from the zone of the Zayda -- Bou Mia granite bodies. As the surveyes performed in this area are only general surveys, it is necessary to carry out semidetailed geological survey in this area to confirm the geological-structure more precisely, for the discovery of indications of uranium mineralization and for the informations helpful for the analysis of the geological-structure of the Itzar basin zone in the southeastern part of this area.

5) The Ait Sa'id area of 21 Km^2 : Indications of carapace type uranium mineralization have been found in this area. But in its eastern extension, there is a major fault of the direction of north-south. As the east side of this fault has been subsided,the distribution of the mineralized zones is not certain. The lead-bearing arkose sandstone is distributed there. Detailed geological survey is necessary for the exploration of uranium and lead.

6) The Assaka Ijdiy area of 6 km^2 : It is reported that the drill holes did not reach the bottom of the Cretaceous system, although diamond drilling of three holes was carried out at the top of the hill, for the geological structure of the Cretaceous system, which is recognized to have been subsided, in a form of synclinal structure in the graben. There are anomalies of radioactivity along both sides of the hillfoot, and the concentration of uranium would be expected. Therefore, it is thought that this area would warrant further exploration. For the most appropriate program for the investigation by diamond drilling, it is desirable to carry out detailed geological survey.

PARTICULARS

PART II

Geophysical Survey

PART II GEOPHYSICAL SURVEY

List of Illustrations

List of Tables

(Appendices)

List of Plates (1 : 500,000)

Chapter 1 General Description of Survey

1-1 Summary

1-1-1 Purpose

This report is about gravity measurements and their interpretation in Haute Moulouya, the Kingdom of Morocco. Main purposes of the survey are to gain basic data necessary to realize the subterranean geological structure -- mainly structure of a basement -- of district under survey and understand geological environments and the likely deposits of, mainly, lead and uranium ores.

1-1-2 Location and Scope

The district under survey is in a steppe surrounded by the mountains of Moyen Atlas and Haut Atlas in the central part of the Kingdom of Morocco and, administratively, included in the county of Midalt.

This district, as indicated in Fig. II-1 (Location of Gravity Survey), is on the southern side of Zayda and covers about 400 km^2 ranging lat. 32°38' - 32°49' N and long. 4°54' - 5°07'W.

1-1-3 Period

The period of the field survey and analysis in Japan were as follows:

Gravity survey	September 16 - November 6, 1978
Leveling	September 16 - November 11, 1978
Field analysis	November 7 - November 15, 1978
Total period of field survey	September 11 - November 20, 1978
Analysis in Japan	November 21, 1978 - March 20, 1979

1-2 Outline of Topography and Geology

1-2-1 Topography

The surveyed area is in a basin between the mountains of Moyen

Atlas and Haut Atlas. The Moyen Atlas mountains are peneplain-like with altitude of about 2,000m and run in the direction of NE-SW. The Haut Atlas mountains have peaks of over 3,000m in elevation and run in the direction of NEE-SWW.

The surveyed area is generally of gentle hills, except for the northern and northwestern parts where some mountains of about 1,800m in elevation are. There, the elevation which is some 1,700m in the southwestern part gradually decreases in the northeastern direction and becomes about 1,500m in the vicinity of Zayda in the northern part of the area. Thus, topography is generally flat. A Quaternary lava plateau being southeast of Bou Mia shows characteristic topography.

The Moulouya river running from the western part of the surveyed area to the north is the trunk of the local river system. On the south side of the river, rivers form valleys in the direction of N-S or NNE-SSW, as Ansagmir river, while on the north side, Bouhafce river, Agarsif river and other rivers form valleys in the direction of NW-SE.

There are no indications of great erosion or terrace developments in the surveyed area.

1-2-2 Outline of Geology

The outline of geology of the surveyed area is as follows: (Fig. II-7, Table II-6)

In the northwestern and northeastern parts of the surveyed area, there are outcrops of so-called Bou Mia Granite Body and Zayda Granite Body which are believed to form a basement of the area.

This basement is covered -- from bottom upward -- with Permo-Triassic P-T Red Sandstone Formation and βP-T Basalt Formation, Jurassic Lias J_1 Limestone Formation, Cretaceous Cenomanian K_{2cm} Mudstone Formation and Turonian K_{2t} Limestone Formation, Tertiary T_1 Mudstone Formation, T_2

Marl Formation and T_3 Sandstone Formation, and Quaternary Q_1 Siltstone Formation, Q_2 Siltstone Formation, βQ_2 Basalt lava, etc. All formations are generally flat.

In the northern to western parts of the surveyed area, Permo-Triassic, Jurassic and Cretaceous formations are distributed about the fringes of both Granite Bodies. Particularly a N-S fault is developed on the eastern fringe of the Bou Mia Granite Body. Adjoining the fault, the Permo-Triassic and Jurassic formations distributed near Bou Mia are believed to

The Tertiary and Quaternary formations are distributed over these relatively old sediments.

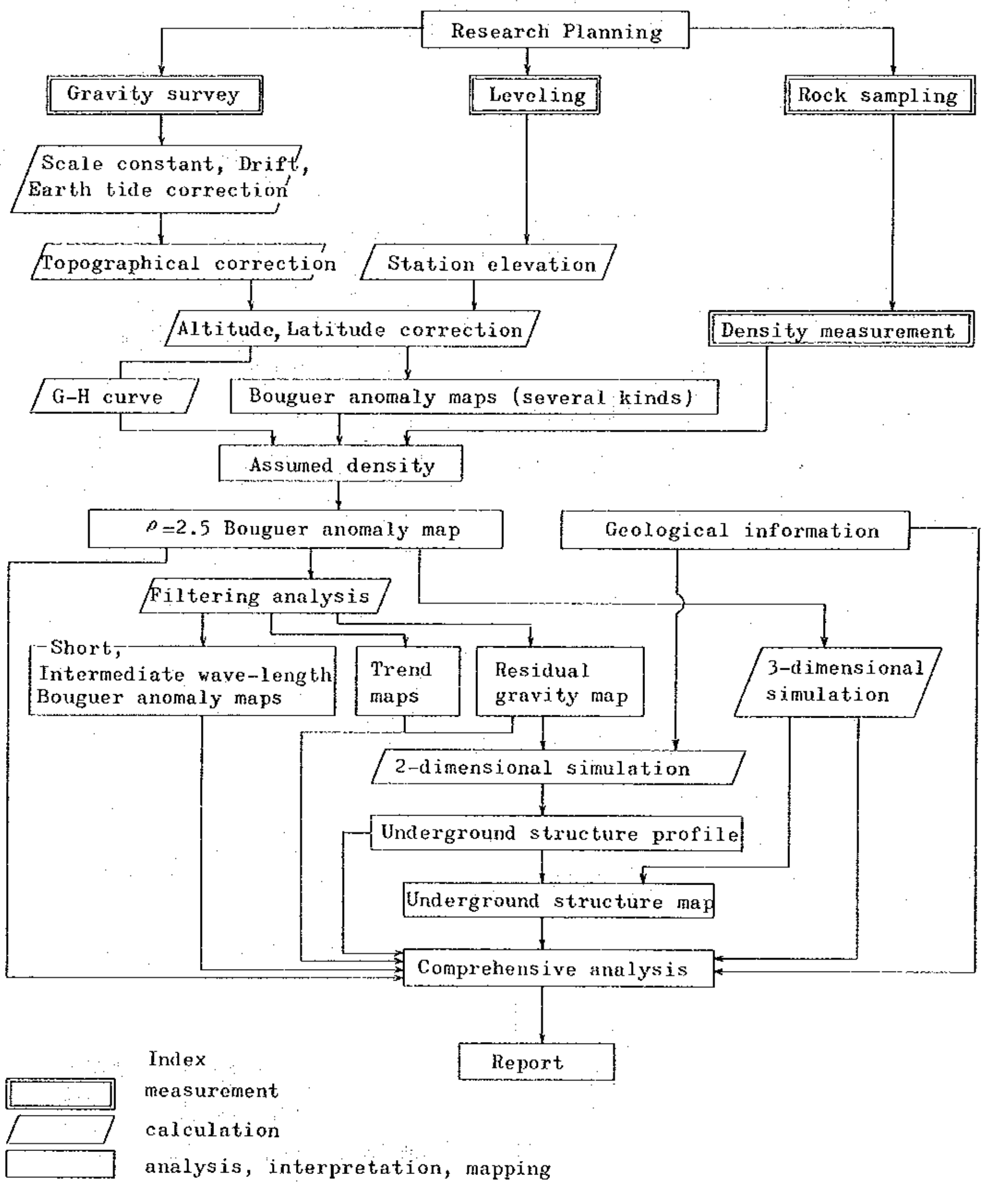
The Tertiary formations covers the northern half of the surveyed area, and the Quaternary formations covers the southern half.

In the southeast of Bou Mia, the Quaternary βQ_2 Basalt lava is within about 6 Km^2 . It is also distributed in a form of a dome about 6 to 8 Km west-northwest of Zayda.

Chapter 2 Gravity Survey

This chapter is about measurements, data reduction and analysis of this gravity survey. All procedures from field survey to report preparation are indicated in Table II-1 (Flow Chart of Gravity Survey).

Table II—1 Flow chart of Gravity survey



2-1 Gravity Observation

2-1-1 Gravity Meter

Gravity values were measured by the gravity meter G-366, product of La Coste & Romberg Co. This gravity meter has a reading scale of 0 to 7,000 and can measure gravity values ranging from 0 mgal to about 7,300 mgal.

The gravity value conversion table for this gravity meter is partially shown in Table II-2.

Table II-2 Scale Constant Expressed Milligal for La Coste & Romberg
(Model of Gravity Meter; G-366)

Counter Reading	Value in Milligal	Factor for Interval
2300	2431.83	1.05771
2400	2537.60	1.05779
2500	2643.38	1.05787
2600	2749.17	1.05796
2700	2854.96	1.05805
2800	2960.77	1.05813
2900	3066.58	1.05821
3000	3172.40	1.05829

2-1-2 Gravity Stations

Details of the stations used in this gravity survey are as follows:

Survey area	Approx. 400 km^2
Station-to-station interval	Approx. 500 m
Number of stations	654 stations

The gravity stations were numbered by their localities as follows:

Sub-base stations	No. 2001 - 2004	4 stations
Main road	No. 1 - 190	190 stations

Central area	No. 301 - 400	100 stations
Southeastern area	No. 401 - 488	88 stations
Northeastern area	No. 501 - 549	49 stations
Northwestern area	No. 601 - 698	98 stations
Western area	No. 701 - 738	38 stations
Southwestern area	No. 801 - 887	87 stations
Total		654 stations

Two observations were carried out for each sub-base station.

Positions of gravity stations were decided by referring to roads, rivers, structures and topographical features on topographical maps. Where reliable topographical features for determination of a station position were lacking, positions for such stations were determined with help of stadia survey using automatic levels, distance measurement by chain measuring and pacing, and bearing measurement using compass.

2-1-3 Standard of Gravity Values

The gravity value of 979,154.65 mgal at the gravity base station B-7 which was established during the geophysical prospection (Prospection Geophysique par Procede de Gravimetrie et Magnetometrie Dans les Bassins de la Moyenne Moulouya de la Haute Moulouya et D'itzer Engil, Solaini L. 1965) was used as the gravity standard of this survey.

A base station No. 2000 was first set up in front of a hotel in Zayda as for closed observations and a base station No. 3000 was later set up in front of the residence of members about one kilometer southeast of Zayda. Fig. II-2 shows a relation of these base stations.

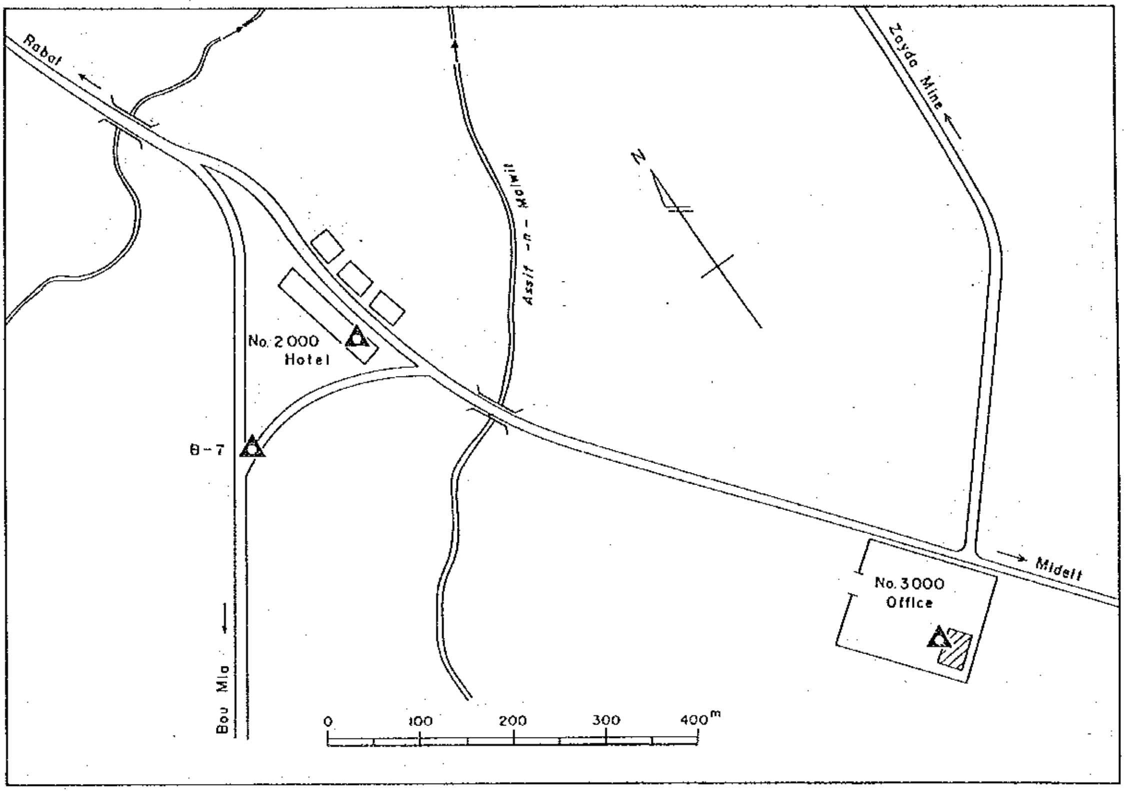


Fig. II-2 Location of Base Stations for Gravity Surveys

The gravity values at base stations No. 2000 and No. 3000 were determined by closing observations in two round trips from the gravity standard station B-7. Also, closing observation with another gravity base station B-8, located about 7 km north of Itzar, was carried out to confirm the gravity value at the gravity standard station B-7. The results of these closing observations are shown in Table II-3.

The gravity values at the two base stations, No. 2000 and No. 3000, were set as 979,155.410 mgal and 979,152.892 mgal respectively, which are the mean values of the two closed observations at the respective stations. They were used as the basic gravity values for everyday closing observations.

Fig. II-3 (Sketches of Gravity Base Stations) and Fig. II-4 (Sketches of Sub-base Stations) illustrating the gravity standard stations and four sub-base stations are at the end of this report.

2-1-4 Leveling

Levelings were performed using two B-2 automatic levels, products of Sokkisha Co. Elevation 1,458.78 m at the gravity standard station B-7 was used as the elevation standard.

As indicated in Fig. II-5 (Network of Leveling Survey) at the end of this report, survey was performed by closed routes insofar as possible so as to increase accuracy.

The closing errors for each route, in the appended survey calculating table, completely satisfy the following specifications:

closing error: $\varepsilon \leqq 100\sqrt{D}$ mm (D: distance of closed route in km)

Elevations of every stations are shown in Pl. II-1 (Locations of Gravity Stations and Their Altitudes).

2-2 Corrections of Gravity Values

Observed gravity values are affected by many factors, such as time, location, elevation, and relative topography, etc. at each station. In order to correct these factors and to get gravity values under the same condition, the following corrections were performed. These corrections were carried out by an electronic computer.

2-2-1 Drift Correction

It is usual to show different gravity values compared to the gravity value which is measured a few hours before, even if earth tide correction is done for both values. This typical error of a gravity value is called drift of a gravity meter and its variation rate can be corrected by assuming that it varies linearly to time.

In the gravity calculation tables of the appendices, drift rates per day and per hour completely satisfy the specification of the survey, within 0.2 mgal/day. Especially, the average drift rate was about 0.04 mgal/day for the whole survey period except at the beginning of the survey; thus the measurement was very precise.

2-2-2 Earth Tide Correction

Earth tide correction is to eliminate influence of location change of the moon and the sun affecting on gravity observation. Influence of the sun and the moon varies with time, latitude, and elevation of an observation station. By applying this correction, an accuracy of observation can be improved, because drift correction can be detected as a simple closing error.

Earth tide correction value (Δg) is as follows:

$$\Delta g = 1.2 \left[\frac{3}{2} \gamma_0 \cdot \frac{M}{E} \cdot \frac{a}{r^3} \cdot \rho^2 \{ \cos^2 \phi \cdot \cos^2 \delta \cdot \cos 2\theta + \sin 2\phi \cdot \sin 2\delta \cdot \cos\theta + 3.0 (\frac{1}{3} - \sin^2 \phi)(\frac{1}{3} - \sin^2 \delta) \} \right]$$

where

γ_0 = 978.049 (1 + 0.0052884 $\sin^2\phi$ − 0.0000059 $\sin^2 2\phi$) gal

ϕ : latitude of the station

δ : astronomical declination

θ : astronomical hour angle

ρ : mean radius of the earth (6370.28 Km)

r : distance from the earth's center to the sphere

sun: 1.496 x 10^8 Km

moon: 384405 Km

a : distance from the earth's center to the station

= 6378.388 (0.99832 + 1.6835 x 10^3 cos 2ϕ − 3.5 x 10^6 cos 4ϕ)

+ elevation at the station (Km)

$\frac{M}{E}$: mass ratio of the sphere and the earth

(sun:332958; moon:0.0123)

2-2-3 Topographical Correction

Topographical correction is a correction to eliminate influence to a gravity value of irregularities of surrounding topography. Topographical maps are divided by grids of an equal spacing and the elevations at the center of each grid are read to know relative undulation among observation stations. Gravity values affected by each block separated by grids are summed up to get a topographical correction value of a concerned observation station.

Topographical influence by a block separated by grids becomes bigger as distance of a block to a station is nearer and becomes smaller as distance to a station is further. Based on this phenomena, highly precise topographical correction was carried out for an area near to a station, while rough correction was carried out for a remote area.

Scales of topographical maps, ranges of correction and grid spacings for each correction are as follows:

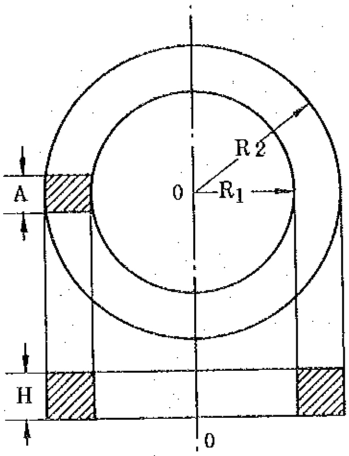
	Far	Middle	Near	Adjacent Area
Scale of Map	1/100,000	1/50,000	1/50,000	
Correction range (N - S)	120 Km	24 Km	4 Km	20 m radius
Correction range (E - W)	120 Km	24 Km	4 Km	20 m radius
Grid spacing	4000 m	1000 m	250 m	

Relations between grids and stations are shown in Fig. II-6 (Grids of Topographical Correction) at the end of this report.

Each correction calculations are done by an electronic computer. Following Kane's formula is used for each correction in Far, Middle, and Near areas.

Kane's formula is

$$g = 2G\rho A^2 \left(R_2 - R_1 + \sqrt{R_1^2 + H^2} - \sqrt{R_2^2 + H^2} \right) / \left(R_2^2 - R_1^2 \right)$$



g : topographical correction value

G : gravitational constant

ρ : density

R_1 : distance from the station to inside of grid

R_2 : distance from the station to outside of grid

A : length of correction block

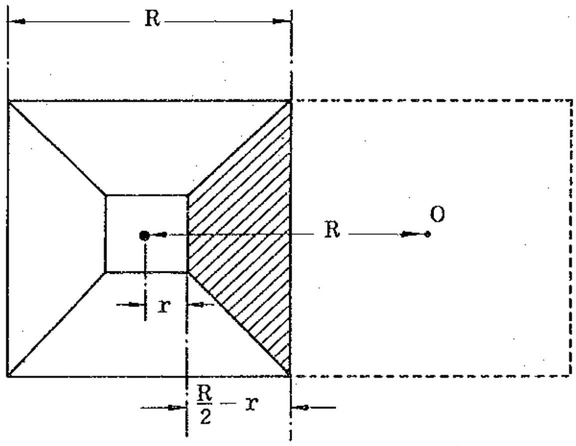
H : height of correction block

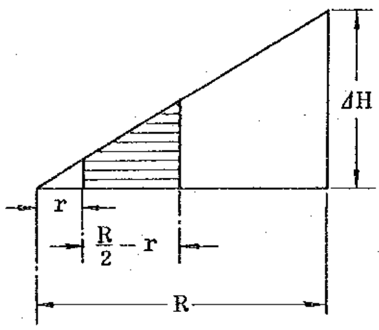
However, correction of a block including a station can be calculated by assuming a head cut pyramid which is drawn by connecting elevations of adjacent blocks and the station (center) elevation with straight lines and eliminating an area within 20 m from the station. This relation is shown in the following schematic diagram:

R : adjacent grid distance (250 m)

r : adjacent correction range (20m)

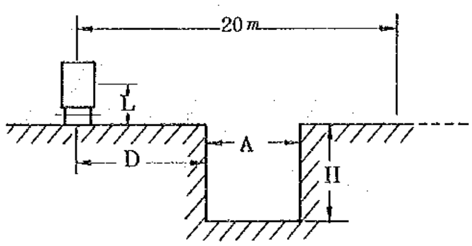
ΔH : elevation difference between blocks





For adjacent correction within 20 m from the station, cross section was drawn and correction value was calculated by the following formula:

$$\Delta g = 2G\rho H\left(\tan^{-1}\frac{2(D+A)}{H+2L} - \tan^{-1}\frac{2D}{H+2L}\right)$$



Δg : correction value for adjacent topography

G : gravitational constant

ρ : density

L : gravity meter height (0.2 m)

2-2-4 Altitude Correction

An altitude correction includes a free air correction which is a correction of gravity value due to simple elevation difference and a Bouguer correction due to attraction of underground rock density.

A free air correction value Δg_1 is calculated by the following formula using the mean vertical gravity gradient of the earth's surface.

$$\Delta g_1 = g_0 \left\{ 1 - \frac{R^2}{(R+H)^2} \right\} = \frac{2 g_0 HR + g_0 H^2}{(R+H)^2} \simeq \frac{2 g_0}{R} H \fallingdotseq 0.3086 \text{Hmgal}$$

where

g_0 : gravity value at geoid

R : mean radius of the earth (m)

H : elevation of a station (m)

A Bouguer correction Δg_2 is calculated by the following formula, providing that an infinite slab having a thickness H and a density ρ exists between the geoid and the earth's surface.

$$\Delta g_2 = -2 \pi G \rho H \fallingdotseq -0.0419 \rho \cdot H \text{ mgal}$$

where

G : gravitational constant

ρ : density

H : elevation of a station (m)

A free air correction and a Bouguer correction are functions of elevation of a station. Therefore, they can be added together into the following formula:

$$\Delta g_1 + \Delta g_2 = (0.3086 - 0.0419 \rho) H \text{ mgal}$$

and called an altitude correction.

2-2-5 Latitude Correction

Shape of the earth is not perfectly spherical but an oblate spheroid and a gravity value on the surface of the earth is minimum around the equator and becomes maximum at both poles due to oblate shape and centrifugal force of rotation of the earth. The international gravity formula gives the standard gravity value S.V. as follows:

$$S.V. = 978,049 \ (1 + 0.0052884 \sin^2\phi - 0.0000059 \sin^2 2\phi) \ \text{mgal}$$

This also gives a correction of latitude ϕ of each station.

2-3 Method of Analysis

In the following paragraphs analytical process of the survey will be explained, by using a Bouguer anomaly map which was drawn by using previously mentioned corrections on observed gravity values.

2-3-1 Density Measurements of Rock Samples

A gravity anomaly reflects a density contrast in underground. Therefore, it is necessary to find average densities of rocks and density distributions of layers in the surveyed area in order to analyse underground structure from gravity anomalies.

In this survey, density measurements were carried out on 97 rock samples collected. We also studied the results of density measurements of rock samples from a deep structure in Haute Moulouya area. (La Structure en Profondeur de la Region de la Haute Moulouya D'apres les Donnees Geophysiques, Tchernysh G. 1977)

These results are listed in Table II-4 (Densities of Rock Samples), Fig. II-7 (Geological Map and Locality of Rock Samples), and Fig. II-8 (Result of Density Measurement of Boring Core) and are consolidated in Table II-5 (Distribution of Rock Densities) for comparison with representative formations in the surveyed area. These tables and figures are at the end of this report.

For density measurements, rock samples were soaked in water then wiped off excessive water in order to obtain condition where rock samples were in the field. Samples treated by the above-mentioned way are measured. Rock density was calculated from the following formula:

$$\text{Density:} \quad \rho = \frac{Wa}{Wa - Ww} \qquad \begin{array}{ll} Wa: & \text{weight in air} \\ Ww: & \text{weight in water} \end{array}$$

Special attention was paid while collecting rock samples. Only fresh rock samples were carefully collected and the samples were collected from every formation in the surveyed area. An average density of each formation does not necessarily represent the formation density itself but a general tendency of density difference is considered to be obtained.

The followings may be considered from the results of density measurements of rock samples. The names and marks of geological formations used in the charts are based on the classification used in the geological survey of the current year.

(a) The densities of all rock samples range widely from 1.81 to 3.05. Particularly, the rock densities of Quaternary, and Tertiary vary greatly, reflecting the difference of density due to their characters and types. Whereas, the densities of rocks in Mesozoic and older system are similar: this is particularly the case of Granites.

(b) The average density of 2.78 for Quaternary $\beta Q2$ Basalt lava and the average density of 2.60 for Granites which forms a basement in the surveyed area are considered to be in the high density group. The former is very close basalt lava and has a great density but is thought to occur only locally and thin; thus it is unlikely to affect greatly gravity distribution.

(c) Meanwhile, Granites which forms the local geological basement of the area shows a high average density of about 2.60 including aplitic and xenolithic types and is presumed mainly to account for high gravity anomalies in the gravity maps.

(d) As low density group, the Quaternary sediments with an average density of 2.33 (except Quaternary Basalt lava) and Tertiary formations with an average density of 2.36 are low density groups. The Upper Cretaceous, Jurassic,and Permo-Triassic with average densities of 2.49, 2.40,and 2.48, respectively, are groups with medium to low densities.

(e) When they are regarded as one group with low density of an average density of about 2.40, it is possible to presume a double-layer structure with a density difference of about 0.2 between these and the granite basement.

2-3-2 Assumption of Density

Assumption of density in the gravity calculation greatly affects the result of gravity survey. Results of density measurements of rock samples shown in Table II-4, indicate rock density near the ground surface between 1.81 and 3.05, but it is not appropriate to determine an average density of the rocks, only from measured density values of rock samples collected from the surface of the ground, because a density of a rock changes its density depending on its depth.

Therefore, in this gravity survey, the followings were studied to determine density for gravimetric corrections.

(a) Bouguer anomaly maps were prepared with varying density to six different values (ρ= 2.00, 2.30, 2.40, 2.50, 2.67, 2.80) which are essential for topographical correction and altitude correction. Based on five Bouguer anomaly maps prepared, correlation between shape of gravity distribution and topography for each map were examined. It was considered to be proper to adopt Bouguer anomaly maps based on a density between ρ = 2.30 and ρ = 2.50.

(b) Average densities of rock samples from each formation, which are thought to represent rocks of the surveyed area, are given as follows: .

Sedimentary rocks	Quaternary	$\rho = 2.33$
	Tertiary	$\rho = 2.36$
	Upper Cretaceous	$\rho = 2.49$
	Lower Jurassic	$\rho = 2.40$
	Permo-Triassic	$\rho = 2.48$
Basement Complex	Granites	$\rho = 2.60$
	Crystalline Schists	$\rho = 2.80$
	(According to B R P M data)	
Average density of all rock samples		$\rho = 2.49$

(c) As indicated in Fig. II-9 (Gravimetric Value-Elevation Curve) at the end of this report, G-H relationship charts were prepared, using the relationship between station elevations and gravity values, and the following densities by areas were obtained from them.

Main road (entire; stations No. 1-190)	$\rho = 2.25$
Southeastern area (stations No. 401-488)	$\rho = 2.42$
Northwestern area (stations No. 601-698)	$\rho = 2.63$
Southwestern area (stations No. 801-887)	$\rho = 2.53$

It is considered from these results that a corrected density of $\rho = 2.30$ to $\rho = 2.60$ is appropriate.

By reffering to the above results, we decided to use a Bouguer amonaly map based on a corrected density of $\rho = 2.5$ for further analysis.

2-3-3 Trend Analysis

Shown in detail in Chapter 3, the Bouguer anomaly map used in this survey shows a remarkable long wave-length trend due, mainly, to isostasy and a large-scale geological structure and it is extremely difficult directly to compare the gravity distribution in the map and the geological structure. Therefore, trend analysis was carried out to eliminate this trend.

The Bouguer anomaly map ($\rho = 2.50$) was divided into grids at intervals of 500 m and the gravity values at each grid point were read. These gravity values at grid points were regarded as a function, G (X, Y), of grid-point positions (X, Y), and a trend of the second order Z_2 (X, Y) and a trend of the third order Z_3 (X, Y) were obtained by the least square method. These were patternized as a trend map of the second order and a trend map of the third order. Further, a residual gravity map of the second order was prepared by subtracting gravity values on the trend map of the second order from the gravity values at each grid point.

The calculating formulae were as follows:

Trend of second order: $Z_2 (X, Y) = -94.247 - 0.40763 X - 1.07528 Y + 0.00352X^2 + 0.01142X \cdot Y + 0.00851Y^3$

Trend of third order: $Z_3 (X, Y) = -90.450 - 0.60956X - 1.10651Y + 0.00405X^2 + 0.02470X \cdot Y - 0.00019X \cdot Y^2 + 0.00014Y^3$

Residual value of second order $= G (X, Y) - Z_2 (X, Y)$

2-3-4 Wave-length Analysis

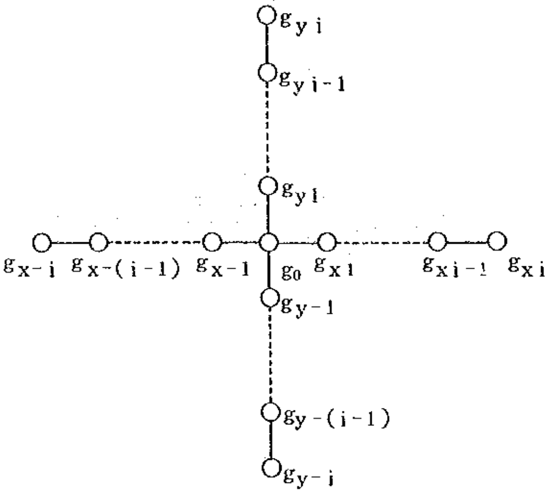
Wave-length gravity values were filtered by the running average method to detect gravity anomalies of several wave-lengths in a Bouguer anomaly map.

Wave-length gravity values for three types: noise, normal and local, by wave-lengths, were calculated, using grid-point gravity values from the Bouguer anomaly map by the following formulae:

$$\text{Noise} = g_0 - \frac{1}{6} \sum_{i=-1}^{1} (g_{xi} + g_{yi})$$

$$\text{Normal} = \frac{1}{6} \sum_{i=-1}^{1} (g_{xi} + g_{yi}) - \frac{1}{14} \sum_{i=-3}^{3} (g_{xi} + g_{yi})$$

$$\text{Local} = \frac{1}{14} \sum_{i=-3}^{3} (g_{xi} + g_{yi}) - \frac{1}{30} \sum_{i=-7}^{7} (g_{xi} + g_{yi})$$



In this survey, "noise" values for detecting short wave-lengths and "normal" values for detecting intermediate wave-lengths were employed; they were patternized as a "Short wave-length Bouguer anomaly map" and a "Intermediate wave-length Bouguer anomaly map".

2-3-5 Two-Dimensional Analysis

Estimating an underground structure that corresponds to gravity anomaly, two-dimensional simulation calculations on three sections were carried out using residual gravity values of the third order. The results of simulation are drawn as underground structure profiles.

An underground structure model is represented by several polygons and their densities. Gravity values on the surface of the ground induced by the underground structure model were calculated. Then calculated gravity values were compared with gravity values read every 250 m on a residual profile. Then, if the coordinate points composing polygons and their densities are regarded as variables,and if these variables are changed, a density structure was obtained by calculating gravity values of a density structure model until section gravity values coincided with caluclated gravity values by least square fitting.

To calculate gravity values of a density structure model, Talwani's method were employed.

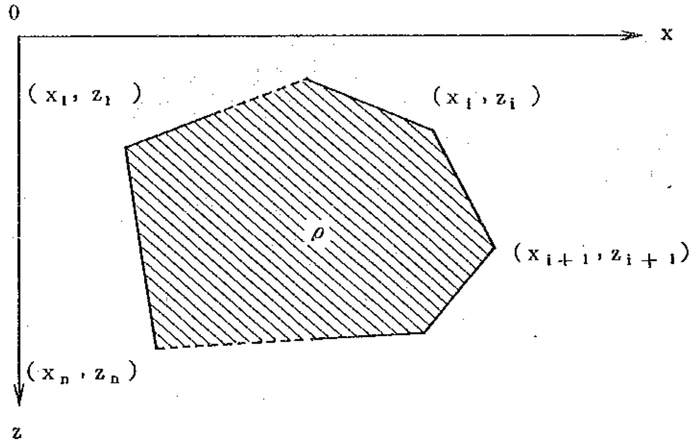
A vertical component (gv) of gravity value at point (O), induced by a polygon (infinitely long to the direction perpendicular to this paper) with density ρ on the figure, is given by the following formula:

$$gv = 2\rho G \sum_{i=1}^{n} \int_{z_i}^{z_{i+1}} \int_{\infty}^{X} \frac{z}{x^2+z^2} \, dx \cdot dz$$

where

ρ : density

G : gravitational constant



As designing an initial structure model is important in simulation, a multi-layer structure was initially assumed by using informations of geological distributions on the ground surface and basing on the two-layer structure. Densities of each model structure were taken from Table II-5 (Distribution of Rock Densities) and Fig. II-8 (Result of Density Measurement of Boring Core). The initial values of densities of each layer were calculated by using following general figures:

$\rho = 2.40$	Quaternary, Tertiary, Upper Cretaceous, Lower Jurassic, Permo-Triassic
$\rho = 2.55$	High-density basalt zone of Permo-Triassic
$\rho = 2.60$	Granites
$\rho = 2.80$	Crystalline Schists

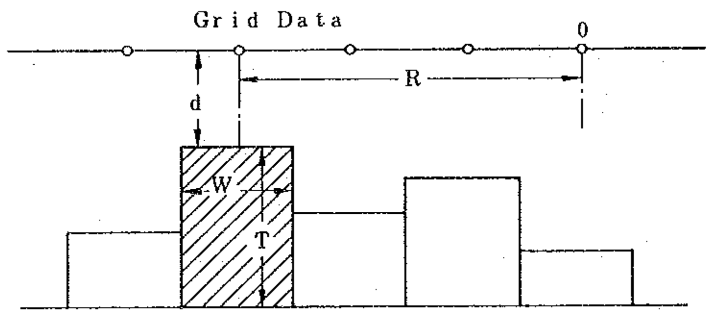
Residual gravity values of the second order were used for all quantitative analysis involved in this survey.

2-3-6 Three-dimensional Analysis

The residual gravity map of the second order described in "2-3-3 Trend Analysis" was studied and gravity values at grid points, intervals of 500 m were read. These residual gravity values at grid points were used for three-dimensional simulation of a two-layer structure.

This simulation was carried out assuming an underground structure to be a two-layer structure and density difference between an upper (first) layer and a lower (second) layer to be roughly $\Delta\rho = 0.2\ g/cm^3$ obtained from rock sample density measurements. To calculate gravity values of a given model, the second layer is divided into square prisms with 500 m square and varying thickness of each prism by the least square method, and calculated gravity values were made to coincide with gravity values at every grid point.

The formulae for the calculation and the schematic diagram are as follows:



If three-dimensional prisms are placed, being their centers at each grid point as shown in the figure, a vertical component of gravity value at grid point (0) due to a prism shown by oblique lines in the figure is expressed in the following formula:

$$\Delta g \simeq G\rho W^2 \left\{ \frac{1}{\sqrt{R^2 + d^2}} - \frac{1}{\sqrt{R_2 + (T + d)^2}} \right\}$$

However, the following formula is used only for the prism, right under the grid point (0).

$$\Delta g_0 \simeq 2\pi G\rho\left\{T-\sqrt{(T+d)^2+\frac{W^2}{\pi}}+\sqrt{d^2+\frac{W^2}{\pi}}\right\}$$

where

G: Gravitational constant

ρ: Prism density ($\Delta\rho = 0.2$)

W: Prism width = grid interval

d: Depth from the ground surface

R: Distance between a grid, where a concerned prism is, and a grid of measurement

T: Prism height from the standard surface

The calculation was carried out repeatedly until the total sum of gravitational attraction from whole prisms, which is a gravity anomaly value at a grid point (0), coincides with a residual gravity value at the same point (0) by varying depth (d) of every prism.

The results were on an underground structure map where a surface of the second layer is indicated by contour lines and also geological interpretations are added.

2-3-7 Explanation of the Tables of Gravity Calculations

All correction calculations were carried out by the electronic computer model FACOM M160-AD. Computer outputs are compiled in the appendices.

(1) Earth Tide Correction and Drift Correction

This table deals with gravity values at each measuring station reduced from observation value by using each correction such as earth tide, drift, instrument height and by converting to gravity standard value. On this table the following items are described from left to right.

Y M D	year, month, day of observation performed
NO	station number
TIME	day, hour, minute

READING	observed value
INST. H	instrument height (cm)
X FACT.	observed gravity value (mgal)
ETCOR	earth tide correction (mgal)
INST. COR	instrument height correction (mgal)
+ COR	corrected value (mgal)
DRIFTCOR	drift correction (mgal)
GRVTY DIF.	difference from standard gravity value at the base station (mgal)
GRVTY VAL.	gravity value (gal)

(2) Topographical Correction

This table indicates Far, Middle, Near, and adjacent topographical correction values and total values at every station. On the table the followings are described in the order of left to right.

STATION-NO	station number
LATITUDE (Y)	N-S distance (m)
LONGITUDE (X)	E-W distance (m)
ALTITUDE	station altitude (m)
FAR	far topographical correction value (mgal)
MIDDLE	middle topographical correction value (mgal)
NEAR	near topographical correction value (mgal)
CLOSE-1, -2	adjacent topographical correction value (mgal)
SEA	sea water topographical correction value (mgal)
LAKE	lake water topographical correction value (mgal)
TOTAL	total topographical correction value (mgal)

Here, density of $\rho = 2.0$ g/cm^3 was taken as a general density of the ground for calculation.

(3) Altitude Correction and Latitude Correction

In this table Bouguer anomaly value is calculated and altitude correction, topographical correction, and latitude correction are also included. On the table the followings are described in the order of left to right:

STATION-NO	station number
LATITUDE (Y)	N-S distance (m)
LONGITUDE (X)	E-W distance (m)
ALTITUDE	station altitude (m)
G.V.-S.V.	gravity value corrected latitude correction (mgal)
2.00 ~ 2.80	Bouguer anomaly values calculated by using six different densities (mgal)

Chapter 3 Survey Results

The following charts have been prepared on the basis of this gravity survey:

Pl. II-1 Locations of Gravity Stations and Their Altitudes

Pl. II-2 Bouguer Anomaly Map (Corrected density: $\rho = 2.5$)

Pl. II-3 Residual Gravity Map in Polynomial of Second Order

Pl. II-4 Short Wave-Length Bouguer Anomaly Map

Pl. II-5 Intermediate Wave-Length Bouguer Anomaly Map

Pl. II-6 Contour Line Map of Depth of Basement Rock from Ground Surface

Pl. II-7 Profile of Underground Structure A-B

Pl. II-8 Profile of Underground Structure C-D

Pl. II-9 Profile of Underground Structure E-F

Pl. II-10 Interpreted Map of Underground Structure

This chapter discusses the gravity distribution in the gravity maps of Pl. II-2 to Pl. II-5.

Pl. II-6 to Pl. II-10 are discussed in Chapter 5 in conjunction with geological structure.

Fig. II-10 (Bouguer Anomaly Map on Haute Moulouya Area), Fig. II-11 (Regional Gravity Trend in Polynomial of Second Order) and Fig. II-12 (Regional Gravity Trend in Polynomial of Third Order) which were prepared as reference material prior to the preparation of the "Residual Gravity Map in Polynomial of Second Order" are at the end of this report and these are also discussed.

3-1 Bouguer Anomaly Map

3-1-1 General Features

Pl. II-2 is a Bouguer anomaly map using $\rho = 2.5$ as a reduction density. Bouguer anomaly values within the surveyed area were between -107 mgal and -129 mgal, thus indicating great negative anomalies. Since this surveyed area is in a highland such as Moyen Atlas and Haut Atlas mountains, these negative anomalies seem to be due to the so-called isostasy, theory that a Mohorovicic boundary surface is deeper under a large mass of high mountains.

As can be seen from Fig. II-10 at the end of this report showing the general gravity distribution and topography around the surveyed area, the surveyed area is between the Moyen Atlas and Haut Atlas mountains of 2,000m to over 3,000m and forms a large mountainous area, as a whole. Since the gravity distribution in Fig. II-10 is reducted by a reduction density of $\rho = 2.67$, the minimum Bouguer anomaly value is expressed by a much smaller figure of under -140 mgal. Bouguer values ranging from -75 mgal to -140 mgal are shown but in the Mediterranean coast to the north and in the Atlantic coast to the northwest, the average of Bouguer anomaly values is about 0 mgal.

The correlation between elevation and Bouguer anomaly verifies the existence of isostasy. Similar examples have been observed in the Rocky mountains in North America, the Andes mountains in South America, and the Tibet plateau in Asia.

In the gravity distribution in Pl. II-2 (Bouguer Anomaly Map) the most characteristic feature is semiarced isogal lines throughout the surveyed area. The gravity distribution is rather monotonous as gravity values gradually increase in the northern, northeastern and eastern directions from the center of low-gravity anomaly being south of Bou Mia in the southwestern part of the surveyed area.

Perhaps, the characteristic feature of the gravity distribution is not only because of the structure of the granite basement in the surveyed area but also of the geological structure of the Moyen Atlas and Haut Atlas mountains running in the approximate NE-SW and NEE-SWW directions in north and south of the area. High-density rocks -- mainly Precambrian Crystalline Schists -- are widely distributed under these mountains. Granites, which is the basement of the area and have lower density than the above-mentioned high-density rocks, intruded between two mountain ranges. The gravity gradient of the NNW-SSE direction caused by the relation of two different densities dominates the gravity distribution. In the gravity distribution in Fig. II-10, high anomaly in the vicinities of both mountain ranges and low anomaly along the Moulouya river are known to exist in parallel in the NEE-SWW direction, thus attesting the above-mentioned fact.

Generally from the view point of gravity gradients, a gradient of about 0.8 mgal/km exists almost uniformly in the NE-SW direction passing through the center of the surveyed area. This seems to be reflected the structure of the Granites. In the N-S or NW-SE direction a steep gravity gradient of about 1.2 mgal/km is developed and gravity anomaly in this direction is largely presumed to be the effect of the above-mentioned geological structure.

As seen above, long-wave gravity trends including influences from outside of the surveyed area are found in the gravity distribution of the Bouguer anomaly map.

3-1-2 Local Features

There are no closed gravity anomaly in the Bouguer anomaly map. All gravity anomalies are expressed by the direction of isogal lines and by their curves. So, local gravity anomaly and paleochannel system on the basement can be assumed by tracing the continuity of the curves in the isogal lines. Since, however, a semiarced trend is developed throughout the surveyed area, as stated above, only conspicuous gravity anomalies will be discussed hereunder, leaving the details for discussion in "3-3 Residual Gravity Map in Polynomial of the Second Order".

(a) Short wave-length gravity anomalies have been found mainly in the northern half of the surveyed area. Because short wave-length anomalies are generally reflections of shallow structures, this fact suggests shallowness of the basement or complication of the geological structure near the ground surface.

Further, these gravity anomalies tend to be in a line of the N-S direction.

(b) A low-gravity anomaly continuing for about 10 km in the N-S direction clearly exists at southeast of Zayda. The isogal lines extend approximately E-W on the west side (northern part of the surveyed area) of the low anomaly and N-S on its southeast side (eastern part of the surveyed area).

It can be seen from these facts that these low-gravity anomalies exist above the undulations of the underground structure. Thus they show structural lines in the Bouguer anomaly map.

(c) A low-gravity anomaly continuing in the N-S direction exists about 8 km NNE of Bou Mia while another low-gravity anomaly running in the E-W direction is about 15 km south of Zayda. In parallel with these, there are jut-outs of high-gravity anomalies in both area, but low-gravity anomalies are dominant.

3-2 Regional Gravity Trend Maps

As stated already, this survey gravity trend analysis was carried out as well as quantitative analysis using the "Residual Gravity Map in Polynomial of Second Order" in order to eliminate the extensive gravity trend appearing in the Bouguer anomaly map. However, this trend reflects factors not only outside the surveyed area but also the basement structure of the surveyed area. If, trend analysis is performed, it might eliminate also gravity anomalies, too due to the basement structure in the surveyed area.

Therefore, the accuracy of analysis in the surveyed area was improved by compiling and preparing gravity maps for the area and its vicinities prior to the analysis, using the gravity map in Fig. II-10 and existing geophysical data (Solaini L. 1965), and analysing by means of a wide range of data.

3-2-1 Gravity Trend Map of the Second Order

Fig. II-11 is the gravity trend map of the second order (see Fig. II-11 at the end of this report). It is a regional gravity distribution in the Bouguer anomaly map mathematically approximated to a curved surface. It well indicates an overall gravity trend because local anomalies are eliminated.

Fig. II-11 shows a line of a low-gravity anomaly in the NE-SW direction and a tendency of the lineament is to decrease and disappear in the southwest direction with a linear gradient of about 0.5 mgal/km. Further, gravity gradient rise in the northern and southeastern directions clearly reflects trends in Fig. II-10, particularly those of outside the surveyed area.

3-2-2 Gravity Trend Map of the Third Order

Fig. II-12 at the end of this report is a trend map of the third order. Though the third order trends are generally similar to those in the trend map of the second order, they express a somewhat more complicated curved surface. In it, a line of low-gravity anomaly, which was linear in the trend map of the second order, bends toward the north and, moreover, the gravity gradient along this line is steep near the center of the surveyed area. Also outside the surveyed area, trends are curvilinear, compared with linear trends in the trend map of the second order, and the gravity gradient increases furthermore.

These phenomena are due to the fact that approximate curved surfaces follow Fig. II-10 - Regional Gravity Map - according to the advance of orders; thus they are a natural outcome. However, this map is not as desirable as the trend map of the second order because it shows not only trends out of the surveyed area but also basement structures in this area.

3-3 Residual Gravity Map in Polynomial of the Second Order

A residual gravity map is a Bouguer anomaly map where a gravity trend is subtracted. In it, regional gravity distribution is put aside and the local gravity distribution is detected. The higher order of polynomial, the smaller gravity anomalies are emphasized.

In deciding which residual gravity map should be used for analysis, residual gravity maps of both the second order and the third order were prepared and comparatively studied. As the result, the residual gravity map of the second order believed quantitatively to express better the structure of the basement granite was selected and used for quantitative analysis of two and three-dimensional simulation calculations.

The characteristics of the gravity distribution in the residual gravity map of the second order (see Pl. II-3) are described below.

The maximum and minimum residual values in the residual gravity map of the second order are approximately +2.7 mgal and -4.3 mgal, respectively, the difference being about 7 mgal. The positive part of residual values and the negative part thereof occupy roughly the same square measure and positionally are clearly divided into two areas by the isogal line of ±0. In other words, the low-gravity anomaly zone developed in the southwestern part of the surveyed area and the high-gravity anomaly zone surrounding the low-gravity anomaly zone make a sharp contrast.

Closed gravity contours showing gravity anomalies, which were not confirmed by the Bouguer anomaly map, occurred sporadically. Besides, small gravity anomalies are seen as accentuated isogal-line curve, thus presenting a complicated situation.

The details of the gravity distribution in the residual gravity map of the second order are as follows:

(a) Areas over +2 mgal are conspicuous high-gravity anomalies. Such anomalies are sporadically about 7 km north of Bou Mia, the south side of Zayda and the east to southeast of Zayda. They indicate that the basement granite is distributed near the ground surface.

(b) High-gravity anomaly zones in the E-W and N-S directions are in the northern and the eastern parts of the surveyed area. A saddle-like basement structure is presumed to be extended to each direction.

(c) An approximately 10 km belt of low-gravity anomaly continues in nearly N-S direction as if to separate the high-gravity anomalies into two parts. This low-gravity anomaly is accentuated in this map, compared with the Bouguer anomaly map which also show it.

(d) A low-gravity anomaly with the smallest residual value of -4.3 mgal is about 6 km south of Bou Mia. With this low-gravity anomaly as the lowest, a prominent low-gravity area of some 60 km^2 encircled by an isogal line of -3 mgal lies in the vicinity.

This low-gravity area is encircled by close isogal lines of -1 mgal to -3 mgal -- which seems to suggest that the basement structure is like a basin.

(e) The general conditions of the basement can be assessed by tracing an area, where isogal lines are dense, by assuming it as a density boundary surface where the basement sinks as a fault.

First, three fault-like structures can be assumed along the high-gravity anomaly zone mentioned in (a) and (b). There are in the NNE-SSW direction north of Bou Mia, in the NWW-SEE direction and more or less parallel with the Agarsif river, and in the NNE-SSW direction and about 2 km west of the Ansagmir river to the south of Zayda.

Then, as the second step fault-like structures are presumed to exist near an area with dense isogal lines of -1 mgal to -3 mgal mentioned in (d). Finally a basin-like structure in the depth may found.

(f) Many closed gravity anomalies and short-wave gravity anomalies are seen in the prominent high-gravity anomaly zones in the northern and eastern parts of the surveyed area. If curve in low-gravity anomalies is to be noted as possible reflection of paleochannel system on the basement, there is the tendency that the direction in which this curve continues is orthogonal to the direction of the isogal lines. Further, in the northern part of the surveyed area it is in the N-S direction while in the eastern part it is in the E-W direction and orthogonal to the axis of the saddle-like structure described in (b).

As stated above, gravity distributions appearing in the residual gravity map of the second order can be appropriately considered to reflect the structure of the basement.

3-4 Filtered Bouguer Anomaly Maps

Filtered Bouguer Anomaly Maps are analytical maps to select any wave-length of gravity anomalies in a Bouguer anomaly map.

The short wave-length Bouguer anomaly map to show short wave-lengths mainly indicates only effects near the ground surface while the intermediate wave-length Bouguer anomaly map to show intermediate wave-lengths expresses the structure at the intermediate depth, but gravity anomalies reflecting structures near the ground surface and deep underground are excluded.

3-4-1 Short Wave-Length Bouguer Anomaly Map

Pl. II-4 is a short wave-length Bouguer anomaly map. Gravity anomalies of short wave-length occur everywhere in the surveyed area. These are believed not only to reflect gravity anomalies at shallow depths of underground but also to express topographical effects and density changes in the same layer.

General gravity distribution and the direction of the distribution shown in a short wave-length Bouguer anomaly map generally agrees with what is shown in the intermediate wave-length Bouguer anomaly map, which is described later. To avoid repetition, therefore, description of them is omitted here. Short wave-length Bouguer anomaly map will serve future detailed surveys as useful reference material if they are used comparatively with ore indications.

3-4-2 Intermediate Wave-Length Bouguer Anomaly Map

Pl. II-5 is an intermediate wave-length Bouguer anomaly map. Gravity distribution in an intermediate wave-length Bouguer anomaly map comprises areas where shape or arrangement of gravity anomalies show a specific direction and areas where there is no direction in shape or arrangement.

Positive gravity anomalies and negative gravity anomalies lie alternately in the NW-SE direction and in parallel with the Agarsif river and the Almagh river north of Bou Mia. Particularly, high anomalies are on both rivers and low anomalies lie parallely on the southwest side of the rivers. This relation may suggest that topographically low parts correspond to positive anomalies while topographically high parts correspond to negative anomalies. At the same time, it is believed to reflect a basement structure in the NW-SE direction. Similarly, a positive anomaly is arranged in the NNE-SSW direction along the Ansagmir river and, to the north, a negative anomaly is more than 10 km in parallel with the positive anomaly.

No remarkable directivity is present in other areas but, where a basin

-like structure exists southeast of Bou Mia, as described in explaining the Bouguer anomaly map, negative anomalies occupy a large portion, which implies the existence of depression in the whole area. Though positive anomaly exists in part of this basin-like structure, this may, from the depth characteristic of the intermediate wave-length Bouguer anomaly map, represent density changes above the surface of the basement.

In this chapter, gravity distribution and the surface geology are compared, then a quantitative study is made by two-dimensional cross-section analysis and three-dimensional analysis and underground structure in the surveyed area is estimated, based on the gravity survey.

The following table is a summary of important stratal ages, rock names and distribution areas used in the following discussions. In it, the classification of stratal names and rock names is based on the geological survey conducted this year.

Table II-6 Classification of Geological Distributions

Geological Unit		Geological Unit and Mark	Lithology	Area of Distribution
Cenozoic	Quaternary	(Q_1, Q_2, Q_3)	terrace deposit, conglomerate, siltstone, mudstone	These formations cover the southern half of the surveyed area. River sediments are around main rivers.
		(β_{Q2})	basalt lava	Basalt lava is in the southeast of Bou Mia and the west-southwest of Zayda.
	Tertiary	(T_1, T_2)	marl, limestone, siltstone, conglomerate, sandstone	These formations cover mainly the northern half of the surveyed area.
Mesozoic	Upper Cretaceous	Turonian (K_{2t})	micritic limestone, muddy siltstone, turbidite, calcareous siltstone	This formation is in the northwest end of the surveyed area.
		Cenomanian (K_{2cm})	limestone, gypsum bed, calcareous siltstone, poly-colored siltstone	This formation is in the northern side of Agarsif river, the north-western part of the surveyed area.
	Lower Jurassic	Lias (J_1)	limestone, siltstone, marl, sandstone, conglomerate, turbidite, dolomite	This formation is only in a small area in the south of Bou Mia.
	Permo-Triassic	(β_{P-T})	basalt lava, sandstone, conglomerate	This formation is only in a small area in the south of Bou Mia adjoying the J_1 formation.
		(P-T)	red sandstone, arkose sandstone, siltstone, mudstone	This formation is mainly in the vicinity of the basement granites.
Proterozoic ~ Paleozoic	Paleozoic ~ Precambrian	Basement Complex (Gr)	granite	There are outcrops of Zayda Granite Body in the east of Zayda and Bou Mia Granite Body in the northwest of Bou Mia. The Bou Mia Granite Body is along N-S faults.