KINGDOM OF MOROCCO

REPORT ON GEOLOGICAL SURVEY OF THE HAUTE MOULOUYA AREA

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METAL MINING AGENCY

JAPAN INTERNATIONAL COOPERATION AGENCY

GOVERNMENT OF JAPAN

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PHASE I

(VOL. I)

March 1979

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PREFACE

The Government of Japan, in response to the request of the Government of the Kingdom of Morocco,decided to conduct a geological survey for mineral exprolation in the Haute Moulouya area of the Kingdom of Morocco, and commissioned its implementation to the Japan International Cooperation Agency.

The Agency, taking into consideration of the importance of technical nature of the survey work, in turn sought the Metal Mining Agency of Japan for its cooperation to accomplish the task within a period of three years.

This year was for the first phase survey, and as for this current year, a survey team was formed consisting of five (5) members headed by Mr. Junnosuke Oikawa, MESCO, Inc., and sent to the Kingdom of Morocco. The team stayed there for ninety-nine (99) days from September 11, 1978 to December 18, 1978. During the period of its stay, the team, in close collaboration with the Government of the Kingdom of Morocco and its various authorities, was able to complete survey works on schedule.

This report submitted hereby summarized the results of the survey performed for the first-phase survey, and it will be also formed a portion of the final report that will be prepared with regard to the results obtained in the second and the third phases.

We wish to take this opportunity to express our heartfelt gratitude to the Government of the Kingdom of Morocco and the other authorities concerned for their kind cooperation and support extended to the Japanese survey team.

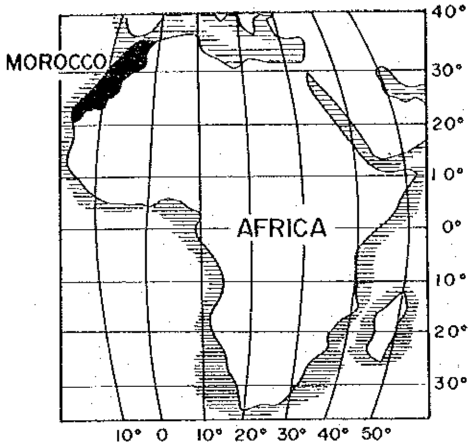
March, 1979

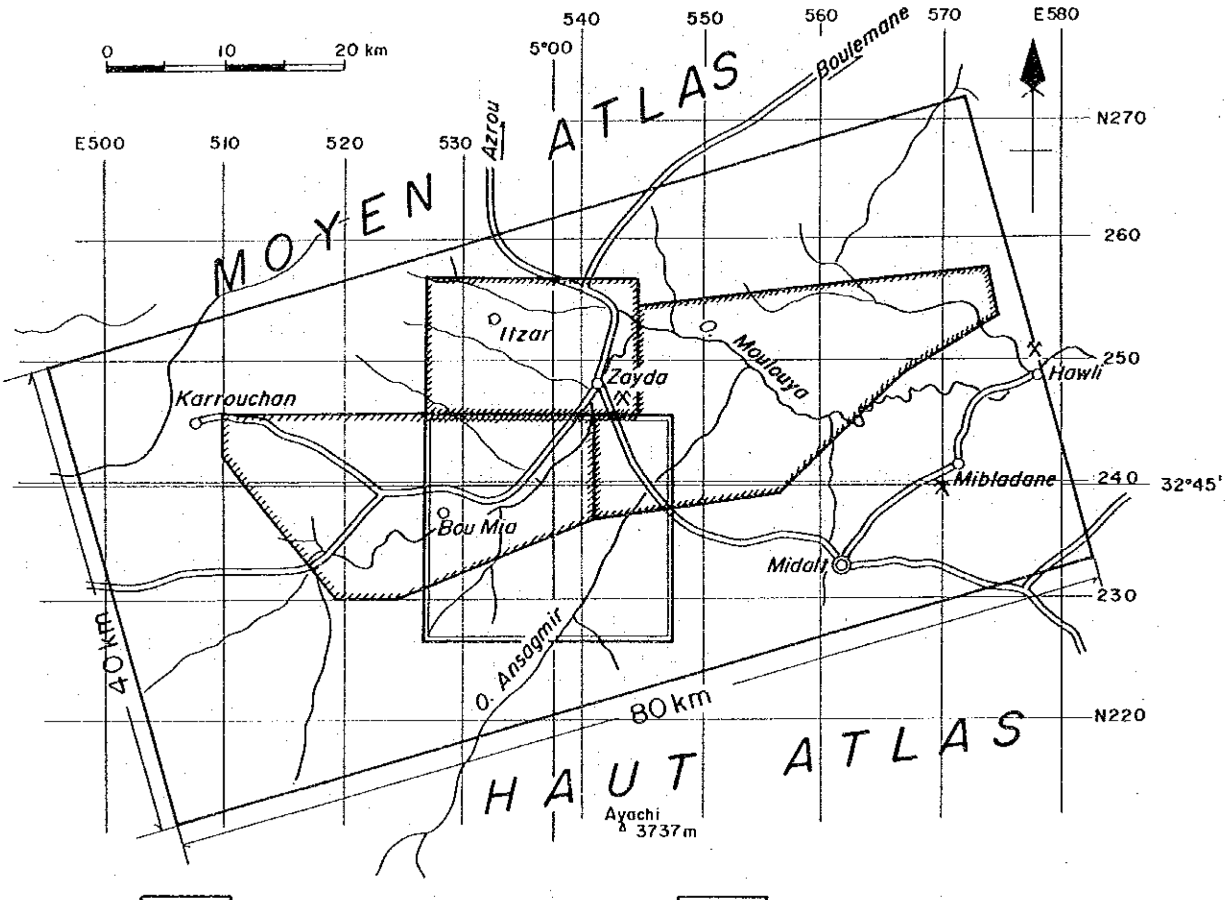
Shinsaku Hogen
President
Japan International Cooperation Agency

Shinsaku Hogen

Masayuki Nishiie
President
Metal Mining Agency of Japan

Masayuki Nishiie





General surveyed area

Gravity surveyed area

Semi-detailed surveyed area

Fig. I - I Location Map of the Surveyed Area

INTEGRATED CONTENTS

ABSTRACT

(1) Purpose: Geological survey and gravity survey were carried out as the first phase of the Basic Geological Survey for the Development of Mineral Resources, in the Haute Moulouya area, the Kingdom of Morocco, for the purpose to extract favorable areas for the emplacement of mineral resources out of the subject area of about 3,200 km^2.

(2) Geology: The country of Morocco is divided into three structural units geologically, that is, northern unit, central unit and southern unit. The present survey area is in the central unit called Atlas Structure Zone.

The survey area is composed of three structural zones, that is, the peneplain zone constituting the basin in the central part, the Moyen Atlas range zone in the northwestern part and the Haut Atlas range zone in the southern part.

In the central part, the Basement Complex are distributed extensively, being divided into two blocks. The Basement is composed of Precambrian System or Paleozoic Crystalline schists and the Granites which intruded at the period of Hercynian orogeny.

Surrounding these two inliers of the Basement, the sediments from Permo-Triassic System to Quaternary System are distributed. In this area, it has been confirmed that the terrestrial red sandstone formation was accumulated extensively in the trough-like inland basin in the Moyen Atlas region in the northwestern part of the surveyed area, during the Permian to early Triassic Period after the formation of the Basement.

At the end of this sedimentation, effusions of Basalt lava were recognized.

In Jurassic Period, marine transgression occured and thick beds of

limestone and dolomite were accumulated, especially in the Haut Atlas trough zone formed in the southern part of the surveyed area. The area occupied by the granites remained island-like lands.

It has been recognized that, in the middle Cretaceous period, remarkable marine transgresion occurred there after small regression. The whole area was under the sea level and limestones were accumulated extensively.

In the Cenozoic Era, both zones of the Haut Atlas range and the Moyen Atlas range were uplifted and deformed by the folding and faulting movement caused by the Tertiary Alpine orogeny. The whole area was upheaved. By the intense faulting movement, many large and small graben structures were formed in the area occupied by the granites in the central part of the survey area. The remarkable faults developed in the present area are the faults of NNE-SSW system found mainly in the central part, those of NE-SW system predominantly recognized in the northwestern and southeastern parts and those of N80°E system observed in the Haut Atlas range zone.

(3) Ore deposits and Indications of Mineralization: There are many indications of mineralization, including lead ore deposits and uranium mineralization in the present surveyed area. The lead ore deposits near Zayda are now operated extensively.

There are three types of lead mineralization found in this surveyed area; one is stratiform sandstone type" contained in the Permo-Triassic arkose sandstone, the other is "stratiform dissemination type" in lower Jurassic limestone and dolomite, and the another is "fissure-filling vein type" contained in the Basement and in the Permo-Triassic system.

There are four types of uranium mineralization found in this surveyed area; the first is vein-like type occurring in the granites, the second is sandstone type contained in the Permo-Triassic Red Sandstone Formation, the third is conglomerate type in the Cenozoic conglomerates, and the last is "carapace" type formed in the oxidation zone on the surface of the granite bodies.

(4) Gravity survey: Through the analysis of the results obtained by the gravity survey carried out with 654 survey points in an approximate area of 400 km^2 in the central southern part of the present surveyed area, the structure of the Basement in this area has been confirmed. Also, the distribution of paleochannels on the Basement has been presumed in the area where the depth of the Basement is comparatively shallow.

(5) Conclusion

1) Following have been confirmed about the lead ore deposits. It is recommended that the most appropriate method of the exploration for this lead ore mineralization should be employed in each case according to each type of the mineralization.

a) As for sandstone type ore deposits, it is important to trace paleochannels where arkose sandstone beds were accumulated, as this type of mineralization is associated with such arkose sandstone found in the granite zone. Apart from the vicinity of Zayda, it can be said that the distribution of lead ore deposits would be expected around the Bou Mia Granite Body.

b) As for stratiform dissemination type ore deposits, it is important to carry out detailed geological survey in and around the area between the two faults, that is, the Amhrou Fault and the Henri Fault, viewing from the fact that this type of mineralization is closely related to the fault structure and the lithofacies of the Jurassic calcareous sediments.

c) As for vein type ore deposits, it can be said that it would be most effective to conduct mapping of the vein structures in detail on each exposure and to carry out exploration at the depths, as it is certain that this type of mineralization has variation as to properties of ores from the surface exposure to the depths, and the fault structures would have played a great role for the formation of ore veins and for the dislocation of them.

2) Most of the indications of uranium mineralization are small in scale in the present surveyed area, but this area is thought favorable for the emplacement of uranium ore deposits, viewing from the following results obtained through the present survey.

a) The granitic rocks, distributed in the central part of the surveyed area, are the appreciable source to supply uranium for the formation of uranium ore deposits. The detrital rocks formed through the weathering and erosion of these rocks for long periods are distributed extensively as terrestrial sediments around the granitic rocks, to form favorable country rocks of the uranium ore deposits.

b) Geological basin structure of gentle inclination was formed around the present central basin, and it can be said that this basin structure would have provided favorable place for the concentration of uranium.

c) There are many indications of vein type uranium mineralization, recognized in the present survey area.

(6) View to Future Program

The following survey works would be recommended as the second phase of the exploration program for the uranium ore deposits.

1) Investigation by diamond drilling for the geological structure around the favorable points obtained from the results of the gravity survey carried out in the first phase of the present survey.

2) Investigation for the geological structure of the Basement by gravity survey in the area north of Bou Mia –– Zayda and in the lowland at the northeast of Zayda, where uranium would be expected to be concentrated, in addition to the investigation of indications at the points of uranium concentration, by Radon etching survey. In each of these two areas, diamond drilling of more than one would be necessary to obtain fundamental data for the analysis of the results of the gravity survey and the Radon etching survey.

3) Investigation through detailed geological survey in the area eastnortheast of Karrouchan, to obtain informations on the indications for the emplacement of uranium mineralization, as well as to comprehend the relation of the geology of this area to that of the north of Bou Mia –– Zayda.

4) Detailed geological survey in the following sectors:
In the northeastern Zayda, and the Sidi Ayyad sector, where indications of vein-like type uranium mineralization have been recognized. In the Assaka Ijdiy sector, where indications of sandstone type uranium mineralization have been recognized.
In the Aït Sa'id sector, where indications of "Carapace" type uranium mineralization and the lead mineralization have been recognized.
Also, investigation by pilot diamond drilling, if possible, in the most favorable area so far extracted.

GENERALS

CONTENTS

Chapter 1 Introduction

1-1. Circumstance and Purpose of the Survey

The Kingdom of Morocco has long history and abundant experiences as to the development of mines. Especially, as seen in the fact that the production of the phosphorous ore in the Kingdom is eminent for the world standard, the Kingdom of Morocco is one of the important nations to produce underground resources. In this country, exploration and development of various mineral resources have been positively carried out by the Bureau de Recherches et de Participacion Minieres (BRPM in short), established in 1928, and works of joint ventures participated by foreign capitals are also active.

In relation to Japan, followings are noted: The government of Japan received a request from BRPM for the cooperation to the geological and structural survey in the Anti-Atlas region situated in the southwestern part of the Kingdom of Morocco. The government of Japan sent missions for the preliminary surveys twice, that is, in February and in October, 1973, and reached an agreement with the government of Morocco as for the survey plan in the above-stated area, in February, 1975. The basic geological survey for the development of mineral resources in this area was commenced in April of 1975, and the survey was carried out for three years until April in 1977. Besides this long term survey, the "follow-up survey" was performed in January of 1978, and views were exchanged as for the progress of the follow-up survey and the demand for future program, between the representatives of the both countries. At the time of this meeting there was a discussion about the survey in the new areas, which had been requested to the government of Japan from the government of Morocco in November of the previous year. Several areas had been listed for the areas to be investigated, but finally the Haute Moulouya area was selected by the preliminary research mission negociating for agreement, which were sent in April to May of 1978. The final agreement of the total program of the survey was reached between the governments of the two countries in August of the same year. The present survey was commenced as the first phase of the above-stated survey program on 11th of September, 1978.

The main purpose of the present survey is to comprehend the geological structure of the whole subject area of about 3,200 km^2, to find out indications of lead and uranium mineralization, to confirm the geological environment for such mineralization to be emplaced and to extract favorable areas where further detailed and effective exploration works would be warranted to be carried out as the second or later steps of this survey program, through the informations thus obtained.

1-2. Outline of the Survey Works

The subject survey area is an approximate area of 3,200 km^2 in the Haute Moulouya region of the central part of the Kingdom of Morocco. As the survey methods, geological survey and geophysical prospecting (gravity survey) have been carried out with the cooperation of BRPM.

1-2-1. Geological Survey

(Preparation)

Prior to the field survey, the geological structure was studied through the investigation with stereoscopic observation of aerophotographs of the region including the subject area, in approximate scale of 1 to 55,000, which had been published by the government of morocco. Also, the rough compilation map of the geology in a scale of 1 to 50,000 to be supplied for the field survey was prepared with combining the results of the above-stated aerophotographic analysis and the information obtained from the compilation of various geological maps and sketches found in the literatures and the reports available.

(Field survey)

The field survey was commenced on 11th of September and completed on 18th of December in 1978. Three survey parties were prepared for the field-works and each survey party was composed of a Japanese geologist, a morrocan assistant and porters. The transportation from the camp to the field was depended on the four-wheel-drive vehicles. The base camp for the indoor-works and fieldworks was set up at the village of Zayda. The density of the reconnaissance routes was decided as the necessity in each area, and the field survey works were carried out according to the program as follows.

(1) Whole area: Reconnaissance routes were established at the intervals of about 10 km, along which the general geological mapping was completed. The important points for geological survey were mapped more detail on precise observations.

(2) Eastern part of Zayda: The interval of the reconnaissance routes was about 2 km. In the approximate area of 400 km^2, the total length over 250 km of the routes was mapped in detail on precise observations.

(3) Bou Mia --- Zayda area: The interval of the reconnaissance routes was about 4 km. In the approximate area of 500 km^2, the total length over 30 km of the routes, thought to be important geologically, was mapped in detail on precise observations.

(4) Northern part of Zayda: The interval of the reconnaissance routes was about 4 km. In the approximate area of 200 km^2, the total length over 60 km of the routes was mapped in detail on precise observations.

(5) Mibladane and Hawli mines: Investigation was carried out into the exposures of the ore deposits and into the working faces, characteristic to each of the two mines.

For the geological mapping along the reconnaissance routes in the fields, the topographical map with the scale of 1 to 50,000 published in 1978 by the Ministry of Agriculture of the Kingdom of Morocco was used in addition to the map of the scale of 1 to 25,000 which was prepared by enlarging the above topographical map. All the results of geological mapping were put in order and recorded on the route map of the scale of 1 to 50,000. Also, a part of the detailed mapping was recorded on the accompanying sketch map, and, in this case, only the number of the sketch map was recorded on the route map.

Concerning the geological observations, granites were described, with attention to grain size, texture, component minerals and their amount, color and the features along the boundary to other rocks, while sedimentary rocks were described, with attention to grain size, main constituent minerals, color, dip and strike, lateral and vertical variation, paleochannel such as cross-laminae, sole mark etc. and indications to show direction of the sedimentation, as well as the existence of carbonaceous material in case of terrestrial layers and the existence and the species of fossils for the correlation in case of limestone. Also, no matter whether it is sedimentary rock or igneous rock, attention was paid to the presence of joint, fissure and fault as well as their forms, shapes and scales on the observation and the mapping. In case some mineralization is associated with them, occurrence and continuance of the ore minerals were investigated and parts of them were mapped in detail. A scintillometer (SPP-2NF type) for the measurement of the radioactivity was always carried by each party of the geological survey along the reconnaissance routes, and radioactivity was recorded.

Apart from the microscopic observation of the samples collected from characteristic rocks and especially from non-ordinary rocks, the followings were carried out: Age determination by K-Ar method on 3 samples of the granites; Chemical analysis of the rock composition on 15 samples; Chemical analysis of the metal contents (Pb, Cu, Ba, Au, Ag) of 36 ore samples; Chemical analysis of U, Th and V contents in 43 samples. Also, X-ray microanalysis (XMA) was employed for the determination of the elements associated with uranium on 4 samples to obtain information on the occurrence of uranium minerals.

For the mapping, in addition to the ordinary survey tools, small compasses, measuring tapes, hand level, barometer and etc. were used for the detailed mapping of the place where geological column was to be made as to the sedimentary rocks as well as at the exposures of vein-like ore deposits. No special equipment was necessary for the fieldworks, but some preparation was required as to clothings, because the temperature varies very much; that is, it is very hot in the midday from the middle September to the early October, when the temperature rises over 30°C, while it is very cold after the late November, when the temperature goes down to around 0°C in the morning and the evening. Arrangements of the time for field survey works were necessary, too.

1-2-2. Geophysical Prospecting

The area where the geophysical prospecting was carried out is approximately 400 km^2, about 21 km in east-west and about 19 km in north-south, located at the south of Zayda. The term of the fieldwork required 71 days from 11th of September to 20th of November in 1978, including the conference with BRPM and the days of analysis works in Rabat (7 days). The actual prospecting works were carried out by two Japanese geophysicists, accompanied by morrocan assistants and porters.

(Gravity survey)

Establishing 654 gravity survey stations in the above-mentioned area of 400 km^2, gravity measurement was carried out, with the standard interval of the stations about 500 m. The stations were distributed along the main roads and the branch roads, while other stations stayed for from the remarkable topographic object surveyed by simplified topographic survey with correlation with the topographical map. As the most part of the surveyed area is topographically plain land with less undulation, it was hard in many cases to confirm the position of stations because such roads and structures on the topographical map are poor, although it was easy to move for the works. Therefore, efforts were made to keep the precise positions of the stations by the methods to measure distance and direction, to survey by stadia and to survey on foot, which had not been included in the original program.

(Level survey)

The level survey using automatic level, was carried out for every gravity survey stations. The survey for distance by stadia was also employed for some stations. At the time of the change of seasons, when strong wind blows, the survey was done by holding staffs as short as possible to keep the preciseness of the survey.

(Analysis in Japan)

Isogravity map has been drawn after various correction including the topographic correction by electronic computer. Through filtering analysis and quantitative analysis by simulation calculations the underground geo-structure has been presumed, based on the isogravity map by the corrected density $\rho = 2.5$.

1-2-3. The survey completed by BRPM

BRPM carried out the radiometric survey for the distribution of radio-activity in the granite body in the eastern part of the survey area, the Radon-Etch survey in the central southern part of it, and the diamond drilling (three holes), as the exploration works independently programmed to be performed by BRPM, considering the program and progress of the investigation by Japanese survey team. The result obtained through the radiometric survey was compared with those of the geological survey performed by Japanese survey team.

1-3. Members of the Survey Team

The members of the survey team are as follows;

Leader (Liaison representative)	Junnosuke Oikawa	MESCO, Inc.
General Affairs	Toshiaki Yamamoto	MITI, Japan
	Yutaka Hatano	JICA
	Kazuhiro Chimura	JICA
	Toyo Miyauchi	MMAJ
	Kazunori Kano	MMAJ
	Hisamitsu Moriwaki	MMAJ
Survey Member	Fukio Kayukawa	MESCO, Inc.
	Kazuharu Umezu	"
	Kazuhiko Kinoshita	"
	Shigeji Asaoka	"

MITI, Japan: Ministry of International Trade and Industry

JICA: Japan International Cooperation Agency

MMAJ: Metal Mining Agency of Japan

The Moroccan geologist Mr. M. Annich joined the survey team in the whole schedule of the fieldworks, whose main works were to collect the bulletins and the reports, to compile the geological map together with Japanese members, and to carry out the radiometric survey in the granite zone in the eastern part of the survey area. He also participated in the actual works of the geological survey at times and joined the discussion on the geology etc. Also, Mr. S. Barrakad of BRPM, who is the chief in charge of uranium exploration, and Mr. Shigeru Matsutoya, who had been sent as a specialist from the government of Japan, participated the surveys at times and for general affairs as supporters. Furthermore, to each survey party, a prospector from BRPM joined for fieldworks.

Chapter 2 Outline of the Survey Area

2-1. Topography

The survey area is in the Midalt district of the Ksar es Souk prefecture in the Meknes state. The area is situated in a basin of triangle shape between the Haut Altas range, running almost east-west in the central part of the Kingdom of Morocco, and the Moyen Atlas range which branches from the Haut Atlas range and is extending to the northeast. The survey area is on the peneplain of the altitude from 1,200 to 1,800 m above sea level. (Fig. 1-2)

The Haut Atlas range is the backbone range of Morocco which stretches in the direction of east-north-east from the north of the Agadir port which faces the Atlantic ocean, and extends about total 900 km to Algeria, passing the southern side of the survey area. It is composed of many peaks of the altitude of more than 4,000 m above sea level, delineating the northern limit of the Sahara shield. Meanwhile, the Moyen Atlas range extends in the direction of northeast roughly from Beni Mellal, which is located about 100 km west of the survey area, passing through the northwestern part of the survey area. The range shows the feature of highland of the approximate altitude of 2,000 m above sea level, in the present survey area.

The topographical characteristics of the basin consist of two main plains --- one is the lower plain (whose altitude is 1,200 to 1,600 m above sea level) formed by the alluvial sediments and by the erosion against the rocks composed of the basement to the Tertiary beds, and the other is the upper plain (whose altitude is 1,550 to 1,800 m above sea level) composed of the terraces which have been left at the foot of the mountains through erosion, consisting of the Tertiary and the Quaternary lake sediments covering the above-mentioned older rocks. In the lower plain, the area where

Bou Mia and Zayda Granite Bodies are distributed is seen to have formed such features as round hills comparatively higher than the surrounding areas.

Regarding the water flow, the Moulouya river is running from the west to the east in the central part of the basin, which pours into the Mediterranean Sea after changing the direction to northeast. The river is gently flowing with the banks of gentle slope in the upstream of Zayda, which is located in the central part of the survey area, while the river forms V-shape valley, the banks of which are composed of sharp cliffs of the approximate height of 100 m, in the Crystalline schists zone developed near Hawli, after passing through gentle Zayda Granite zone. In the northwestern part of the survey area, the Serrou river, which runs to the southwest in the central part of the Moyen Atlas range and flows into the Atlantic Ocean is seen to have dissected deeply the sediments of the Karrouchan basin, forming high cliffs locally.

2-2. Climate and Vegetation

As for the climate, there is a great difference between the northern side and the southern side of the Haut Atlas range. In the northern side of the Haut Atlas range, the climate, represented by what is called Mediterranean Sea type climate, is generally mild, except for July and August, when hot wind so-called Sirocco blows in from the Sahara Desert. In winter, there is a certain amount of rainfall accompanied by the approaches of low atmospheric pressures as occured in temperate zone. Meanwhile, in the southern side of the Haut Atlas range, poor in rainfall, arid climate is predominant, and steppe and desert are well developed. The survey area is located in a highland basin between the Haut Atlas range and the Moyen Atlas range, and it is comparatively arid.

The rainfall, the temperature and the humidity of the survey area in average during past 30 years and in 1977 are shown in the Table I-1.

Average annual rainfall reaches 242.6 mm. In the dry season from middle June to middle September, average monthly rainfall is about 7 mm, but in the rainy season from March to middle June, monthly rainfall is 20 to 45 mm in average. In the other months, average monthly rainfall is about 20 mm. Snowfall is seen beginning in late November. The snow disappears in May.

Table I-1 Climate in Midalt area

by Midalt meteorological station

Month	Rainfall m/m	Temperature (°C)						Humidity %
	1949-1977 (year)	1949-1978			1977			1977
		max.	min.	av.	max.	min.	av.	av.
1	12.5	19.5	-10.0	6.4	17.8	-4.7	5.8	64
2	18.9	26.1	- 6.9	7.7	20.1	-2.0	8.9	56
3	24.5	25.5	- 3.1	9.5	23.0	-0.5	11.7	43
4	44.3	27.6	- 3.8	11.3	24.9	-0.3	14.0	46
5	32.9	32.2	- 0.1	15.4	27.7	+1.4	14.4	49
6	25.2	34.6	+ 3.2	19.2	34.6	+3.2	18.3	34
7	6.8	36.7	+10.7	24.4	36.0	+10.4	22.1	42
8	7.0	37.2	+ 7.5	24.0	36.0	+7.5	22.4	33
9	19.3	33.7	+ 2.0	20.7	33.3	+9.0	19.4	50
10	14.2	29.3	- 1.2	14.7	25.4	+3.5	13.5	57
11	23.4	23.8	- 2.1	9.6	24.1	-2.5	10.5	38
12	13.6	21.1	-13.5*	5.9	19.2	-1.8	8.6	62
av.	20.2	-	-	14.1	-	-	14.1	48

Note: -13.5*: minimum temperature in 1957

max : maximum min : minimum av : average

Average annual temperature is 14.1°C. In the dry season, it is very hot and the temperature goes up to over 36°C at the hottest. In the term from November to May, the lowest temperature goes down to lower than 0°C. Especially, from November to February, it is very cold. Thunderstorm is seen locally in the season from June to October.

Regarding the vegetation in the surveyed area there is difference between the plain part of the basin and the hilly part of it. In the plain part, clusters of needle leaf grass of about 50 cm height, particular to arid steppe, grow all over. Trees are observed only in the swampy area along rivers. On the other hand, in the hilly part, trees of pine, ceder etc. grow well and grasses are few.

2-3. Inhabitants and Industry

Main towns in the surveyed area are Midalt (population 56,500 in 1977), Bou Mia (population 36,500 in 1977) and Itzar (population about 30,000 in 1977).

The most predominant race of the inhabitants in the surveyed area is the Berber, followed by the Arab. Foreigners are rather few. Most of them profess Mohammedanism, the state region.

Official language is Arabic, though French is used as associate official language. However, the public language used among the inhabitants is Berber. As for education, primary school (6 year system) is established in every village and efforts are paid for crusade against illiteracy. The educational and cultural center in the surveyed area is the town of Midalt, where middle school (3 year system) and high school (4 year system) have been recently established.

The main industries in this area are agriculture, stock-farming and mining. Agriculture and stock-farming are active mainly in the following two zones; the wheat-cropping agricultural zone from Itzar to Bou Mia area, where Tertiary and Quaternary sediments are well developed, and the pasture zone in the eastern part, which is occupied by Granite and Crystalline schists.

In the agricultural zone, with the acceleration of systematic mechanization to use tractors, it is endeavored to improve the agricultural production mainly of wheat. The ratio of cultivated land to uncultivated one is about 50%. Recently, the lands are cultivated with fruits such as apples, pears, melons and so on, through irrigation.

As for stock-farming, pasturing of sheep is found everywhere, especially around Midalt in the eastern part, and there is domestic industry of textile manufacturing of wools in such area. The number of cattles in this area registered at the Midalt local office in 1977 are as follows; sheep 148,792, goat 45,920, horse 7,787 cow and bull 5,851 and camel 634.

Concerning the mining, the areas of Zayda, Mibladane, Hawli, and Sidi Ayyad are composing one of the largest mining area in the Kingdom of Morocco, where mines mainly of lead ore are developed and operated.

2-4. Transportation

The surveyed area is situated about 230 km southeast of the capital, Rabat. It is about 5 hours drive to the surveyed area by vehicles along the road of about 300 km, through Meknes. Buses are serviced regularly several times in a day between Rabat and Meknes, and between Meknes and Midalt.

From Zayda located in the central part of the surveyed area, there are paved roads forwards the south to Midalt and Mibladane, the north to Itzar and the west to Bou Mia. Furthermore, there are unpaved wide roads good for vehicles around Zayda and Sidi Ayyad. Also, agricultural roads have been developed for these years with the spread of tractors. These roads supply good transportation for jeeps. Thus, the traffic condition is pretty well.

However, in winter, vehicle roads in the mountainous land are often inaccessible for heavy snowfall, and traffic gates are prepared for such cases, in many places. Communication and transportation in the inhabitants are by horse, by ass and often by camel.

Chapter 3 Existing Reports and Articles of Various Surveys and Studies

There are many lead ore deposits distributed in the surveyed area, among which three mines called Mibladane, Hawli and Zayda are in operation at present. Exploration works are pretty active on these mines, and concerning the stratiform dissemination type ore deposits of the Mibladane mine and the stratiform sandstone type ore deposits of the Zayda mine, both of which are belonging to rather special types of ore deposits, there are many survey reports and articles on the speciality of their geology and ore deposits. As for uranium mineralization, this area has been attracted as one of the favorable areas since 1950's, and some explorations including diamond drilling were carried out in this area. Since 1975, a program called Tarekochid project has been in operation on the northwestern part of the area by BRPM, including geological survey and pilot drilling. The informations obtained through this project have been given as the survey report by BRPM.

Among these reports and articles, those which are utilized as references for the present survey are listed at the end of this Chapter. The outlines of the main reports and articles of them are as follows;

Geological structure:

The whole land of Morocco has been comparatively well surveyed geologically, and the geological map of the scale of 1 to 500,000 was completed and published in 1954. There are many reports as for the geological structure of Morocco from old times.

The latest general information is contained in Element de Geologie, Marocaine (A. Michard), which summarized former studies and reports and was published in 1976.

The geohistory of the Haute Moulouya area has been described in various reports, but there seems to be none found as to thorough study or discussion on this theme. Comparatively detailed report including results of survey and experiment of comparison of survey methods concerning geophysical prospecting and geochemical survey, is that of Techno-Export (1976), which is the report of the survey carried out mainly for the purpose of the exploration for lead and other metal ore deposits.

Regarding the sedimentary environments of Permo-Triassic P-T Red Sandstone Formation in this area, which has been marked as the favorable beds for the emplacement of uranium ore deposits, there are an article on the Karrouchan basin by J. Lorentz (1976) and a study report on the terrestrial Triassic Formations in the central Haut Atlas region by A.F. Mattis (1977). By Lorentz, the P-T Red Sandstone Formation, distributed in the northwestern part of the Haute Moulouya area, is composed of the sediments in the inland basin formed as a part of graben-like structure extending in the direction of NE-SW, with the approximate width of 40 km. The thickness of the sediments reaches about 600 m at maximum. The basin is not uniform as for the sediments. In the southeastern part, the sediments are the type of alluvial fan and are composed of coarse-grained detritus which were supplied from the Bou Mia Granite Body, while the northwestern part of the basin is occupied by the comparatively argillaceous materials supplied from the basement of the Paleozoic formations. The area, where Mattis investigated the geology, is called Ourica basin about 300 km south-south-west of the Haute Moulouya area. It is thought that the sediments in the Ourica basin would be same as those found in the basin surveyed by Lorentz, which means both sediments are the products accumulated in the same basin, although direct correlatives are impossible as there is no exposure of the P-T Red Sandstone Formation in the area between the above-stated two basins. In each case, the Basement structure of the basin is thought to have been formed by the group of faults of the approximate direction of NE-SW.

Concerning the mechanism of the sedimentation of limestone, dolomite etc. contained in J_1 Limestone Formation of the Lias Series, the Jurassic System, which is the main horizon of the country rocks for the mineralization at the Mibladane mine, there is a detailed survey report by G. Dagallier (1977). This bed is one of the main members composing the folded Haut Atlas mountain range in the southeastern part of the survey area, and is one of the most important beds related to the mineralization of disseminated lead ore deposits, which were emplaced through replacement by selecting certain lithofacies though horizontal variation of lithofacies of this beds is quite remarkable. G. Dogallier comprehended and elucidatated this remarkable horizontal variation of lithofacies in relation to the difference of the distance against the sea level and to the development of the faults.

About 80 km east of the survey area, there are mineralizations represented by Bou-Sellam ore deposits and Merija ore deposits, both of which are sedimentary copper-lead ore deposits. On the genesis of these ore deposits, there is a study report by J. Cais (1969). The ore deposits are seen to have been formed in the coarse-grained sandstone, which is the sediment accumulated in some paleochannels at the base of the Cretaceous formations. This study report furnishes with much information and is helpful to the present survey in many points, especially on the formation of ore deposits and its relation to the development of the geological structure, although none of such ore deposits similar to the above-mentioned has been found in this survey area.

On the Granites and the Crystalline schists in the Haute Moulouya area, there is a study report by D. Tisserant (1977), who determined, through Rb-Sr analysis method, the absolute age of the samples of the older Granites and the Crystalline schists collected from several localities in Morocco. As the result of this study, it is stated in the report that the period of the Granites and the Crystalline schists would have been approximately 300 m.y. ago.

Lead ore deposits:

Lead ore deposits are distributed roughly in two parts of the surveyed area --- one is the Mibladane-Hawli area in the southeastern part and the other is the Zayda in the central part. As for the former area, a survey map of the geology and the ore deposits of the scale of 1 to 5,000 was completed after the long term surveyed by a development company, and furthermore, exploration program has been proposed by R. Bouchta and Gal De Pons (1975), who carried out another survey and investigation.

As for the latter, there are articles by E. Amade (1965) and by J.M. Schmitt (1976).

The lead ore deposits in the Zayda area represented by galena-mineralization in the arkose sandstone at the lowermost part of th e P-T Red Sandstone Formation accumulated in paleochannel around the Granites. As this mineralization is rather particular as for their occurrences, there are many ideas and interpretations on the geology and mineralization of these ore deposits, represented by the two articles by Amade and Schmitt.

It is stated in the study report by Amade that lead would have been supplied through faults and fissures, viewing from the fact that high grade portion of the mineralization is observed upon fissures of the trend of NE-SW and from the comprehension that it is pretty hard to seek the source of great amount of lead in the background of the sedimentary basin.

Meanwhile, the report by Schmitt stated that the source of the lead would have been the background composed of Granites, considering mainly the condition of the sedimentation after weathering and decomposition of Granites, as is the case of the similar type found in France.

It is agreed in the above two interpretations that Pb ions contained in solution would have filled the space amidst the sand grains to develop crystals, before consolidation of arkose sandstone and accummulation of overlying beds.

Uranium ore deposits:

The first systematic geological investigation for uranium mineralization was the survey carried out by SOMAREM (Societé Marocain de Recherches et d'Etude Mineral), which were established as the joint venture of United States of America and France, in 1953. Aero-survey was performed in 1953. In the present survey area, exploration were carried out in the Assaka Ijdiy area, the Sidi Ayyad area, and other areas. However, the investigation by this organization was ceased at the time of the independence of the Kingdom of Morocco, in 1956.

After 1970, J.H. Shepherd, accomplishing the fieldworks as the cooperation survey works of AIEA of the United Nations, supplied the report and the distribution map of all the indications of uranium mineralization ever found in Morocco.

After that, geological investigation of the potentiality to discover uranium ore deposits in the whole land of Morocco was performed in 1974 by A. Durandou, who gave a report including the concrete directions for further exploration. In this report the following four areas were extracted as the favorable areas for the emplacement of uranium ore deposits, where further exploration would be warranted. They are;

(1) Crystalline schist zone in the central Morocco (what is called MESETA area),

(2) Western end of Oranaise plateau (which is Haute Moulouya area),

(3) The area occupied by the Mesozoic terrestrial formations in the central to western Atlas range,

and,

(4) The area underlain by Precambrian or Paleozoic sedimentary rocks in the western part of the Anti-Atlas range.

However, the following five more areas were added, stating as the investigation had not covered the whole area of Morocco;

(1) The area occupied by the covering sedimentary formation in the central Morocco,

(2) The eastern part of the Haut Atlas range,

(3) The area where Cretaceous and Paleozoic sedimentary rocks are distributed in the southern part of Morocco (the boundary area of the Trindouf basin),

(4) The area to the east of the Oranaise plateau,

and,

(5) Rif range.

The report gives the important points required for the survey works common to these areas. Especially, regarding the favorable horizon for the emplacement of uranium ore deposits in the Haute Moulouya area, the following beds were noted;

(1) Permo-Triassic Red Sandstone Formation; it is characteristic that the formation, only distributed from the central to eastern part of the Atlas area, is composed of terrestrial sediments while marine sediments are occupying the Rif area in the southwestern part of it. The formation carries some copper and carbonized plants are contained in the leached zone of the sandstone of this formation. Remarkable variation of lithofacies can be seen from the west to the east.

(2) Jurassic and Cretaceous terrestrial sediments; it is characteristic that the favorable horizons for the emplacement of uranium mineralization are found locally in the upper part of the Lias Series, which are observed to carry some copper. But they are disturbed by tectonic movements and are remarkably influenced by marine transgression.

Since then, survey works for the exploration of uranium mineralization by BRPM have been actively continued. Soon in 1977, a favorable indication of uranium mineralization was discovered in the Wafagga area in the western part of the Haut Atlas area, where diamond drilling is carried out at present. Also, in the Haute Moulouya area, diamond drilling of over 104 holes of its totalling length over 2,860 m was carried out after 1977 in the Tarekochid area in the northwestern part, selected as the pilot area for the exploration. By the report by Guerin et al. (1977), who were in charge of the survey works, small scaled uranium ore deposit was caught at the lower part of the P-T Red Sandstone Formation by the diamond drilling in the Assif Lkis area at the western part of the Bou Mia Granite Body. It is reported that the portion of high grade mineralization lies along the transitional zone of the fine-grained sandstone to the coarse-grained arkose sandstone at the lowermost part of the formation. Also, it is recommended in this report that the area for further exploration should be extended in the direction of north or north-west, as the flowing out of the paleochannel is estimated in such directions in the vicinity area.

Regarding the indications of the vein-like type uranium mineralization distributed in the inner area of the Granite Body, there is a report of the survey carried out in the Assaka-n-Tabhirt area by M. Annich (1977). The Granites are classified into three groups and the measurement of radioactivity was carried out in the grid of 200 m x 100 m, though partly in the grid of 100 m x 50 m.

As for the indications of the vein-like type uranium mineralization located in the Sidi Ayyad area in the eastern part of the survey area, there is a report by R. Alaoui (1976). Also, another indications of uranium mineralization distributed in the small graben structure of the Assaka Ijdiy area in the southeastern part of the survey area, a survey report by H. El Harsi (1976) is there.

Geophysical prospecting:

As the data and the reports of the geophysical prospecting, the followings are known;

Bouguer anomaly map (1/500,000) in the whole land of Morocco.

Report on the gravity survey and on the magnet survey carried out in the Haute Moulouya area (L. Solaini, 1965). Report on the investigation of the geological structure at the depth in the Haute Moulouya area (G. Tchernych, 1977). The area for the present year's survey is located between the Moyen Atlas range and the Haut Atlas range, and belongs to the portion of long wave low gravity in the above-stated regional gravity map. Influence of the geological structure of the surrounding area to the gravity distribution in the survey area can be noted. Such influence is one of the factors to render difficulties for the analysis of the gravity. In the present survey, consideration has been given to obtain analysis results as precise as possible by employing the above-mentioned data and by adding many informations in the surrounding areas for the examination. Also, the core logs of the diamond drilling prepared through the aforesaid investigation of the geological structure at the depth as well as the results of the measurement of rock density have been quite helpful for the quantitative analysis, the density assumption and the analysis of the geological structure below surface.

Names of places:

In this report, the spelling of the names of places has been unified according to the spelling employed on the topographical map of the scale of 1 to 50,000 published in 1978. The followings are the local names which are different from the spelling formerly used in general in the references etc.

Midalt (Midelt)	Zayda (Zeida)
Hawli (Aouli)	Mibladane (Mibladen)
Karrouchan (Kerrouchen)	Itzar (Itzer)
Lkis (Kiss)	Sidi Ayyad (Sidi Ayad)
Ansagmir (Ansegmir)	

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Chapter 4 Conclusion and View to Future Program

4-1. Conclusion

The present survey has been carried out as the first stage of the Basic Geological survey for the Development of Mineral Resources in the Haute Moulouya region of the Kingdom of Morocco. The purpose of the survey is, based on the recommendation of the results of the preliminary survey, to comprehend the geological structure of the whole subject area (about 3,200 km^2) and to obtain as many fundamental data as possible for the grasp of indications of metal mineralization and geological environment favorable for the emplacement of ore deposits of lead and uranium. The surveys carried out were the geological survey for the whole area and the geophysical prospecting (gravity survey) in the central southern part of the approximate area of 400 km^2. The followings are the summary of the analysis results of the above surveys;

(1) Geological structure

The surveyed area is divided into three parts; the central part is structurally stable plain-land of the basin, the northwestern part is mountainous Moyen Atlas Belt and the southern part belongs to Haut Atlas Belt.

The basement rocks of the central part are composed of Precambrian or Paleozoic Crystalline schists and Granite Body which intruded at the period of the Hercynian orogeny. The Granite Body is exposed in the two areas — one is in an area of approximately 25 km x 20 km at the east of Zayda, and the other is of about 10 km x 15 km at the west of Bou Mia. (The former body is called Zayda Granite, while the latter is named Bou Mia Granite). The Granite Body includes many lithofacies as porphyritic granite, aplitic granite, granodiorite and contaminated granite. The granodiorite is distributed at the northeastern end of the central part of the surveyed area.

The aplitic granite is developed at the east of Zayda, as gently dipping dykes or as irregular masses transitional to the surrounding granites. The Schists are classified into chlorite-sericite schist, amphibole schist and quartz-sericite-schist, with the insertions of amphibolite layers. The layers of Schists at the east of Hawli area are composing dome-like folding structure extending to northeast, which occupies an approximate area of 20 km x 10 km. They are metamorphosed to hornfels along the contact with Granite Body, where many dykes of granite porphyry and aplite are seen to have intruded into both the Granites and the Schists.

As for the Zayda Granite and Bou Mia Granite, P-T Red Sandstone Formation composed mainly of arkose sandstone and conglomerate is distributed in the surface depressions on the Granites and in the surrounding areas of the Granites. This P-T Red Sandstone Formation becomes fine-grained as a whole from the lower horizon to the upper, though they form alternation of conglomerate, coarse-grained sandstone and fine-grained sandstone. The uppermost part is mudstone bed. Coarse-grained sandstone is as thick as several meters in the area close to the Granite Body, but the thickness reaches several ten meters in the northwestern part. The total thickness of the P-T Red Sandstone Formation including the mudstone bed is greater in the northwestern part. The P-T Red Sandstone Formation is overlain by the β_{P-T} Basalt Formation extensively.

In an early stage of the accumulation of this P-T Red Sandstone Formation, depression zones like grabens were developed northeasterly in the Moyen Atlas Belt in the northwestern part of this survey area, and in east and west in the Haut Atlas Belt in the southern part. In the northwestern part, Karrouchan sedimentary basin was formed. In the Jurassic period, by the marine transgression, thick limestone beds were accumulated in such grabens, but the area occupied by the Granites was left as islands-like land.

In the Cretaceous period, after temporary marine regression which caused the sedimentation of some red sandstone beds, there was large scaled transgression which brought the accumulation of calcareous beds in the whole area.

In the Cenozoic Era, the entire area was on land and whole beds are composed of terrestrial sediments. Through the middle Tertiary orogenic movement, the upheaval of the Moyen Atlas range and the Haut Atlas range was brought associated with the development of fault structures.

In the central part of the survey area, block-faults are predominant, mainly in the two directions of NNE-SSW and NE-SW. There are upside-down conversions of beds in the area but variations of the inclination of beds are slightly observed. In the Moyen Atlas Belt, more intense block movement would have been accompanied by the variation of inclination of sedimentary layers, while, in the Haut Atlas Belt in the southern part, intense folding movement would have brought some overturned folds of beds.

(2) Lead ore deposits

Many large scaled lead ore deposits are known in the surveyed area, and among them three mines of Zayda, Mibladane and Hawli are in operation at present. The ore deposit at Zayda is stratiform sandstone type associated with arkose sandstone. The ore deposit at Mibladane is disseminated type (partly vein-like) contained layer-like in dolomitic limestone, while that at Hawli is the fault-like fracture filling type.

The main primary minerals are galena, barite, fluorite and quartz, in each of these ore deposits, associated with the secondary minerals such as cerussite etc.

The sandstone type ore deposit at Zayda is composed of such ores in which the spaces among the fragments of quartz and feldspar were filled with galena, barite and fluorite, which would have been supplied in the form of lead-bearing solution from the background land, at the period of the consolidation of the arkose sandstone contained in the P-T Red Sandstone Formation. Therefore, the emplacement of the ore deposits is closely related with the paleochannels where the distribution of arkose sandstone is observed. The Zayda ore deposit is in operation at present with the production of 3000 tons per day by the open pit mining, while the mines of Mibladane and Hawli are operated in small scale with the production of 600 tons per day. The vein at Sidi Ayyad in the northern part of Hawli is now under exploration by tunnelling.

(3) Uranium mineralization

The following four types of indications of uranium mineralization are recognized in the surveyed area;

Vein-like type

Sandstone type

Carapace type

Conglomerate type

The indications of vein-like type mineralization are found as more than 15 veins along the banks of the Moulouya river at the northeast of Zayda. In the present year, detailed mapping was carried out on the main veins. The scales of veins are various, as wide as several cm to 3 meters in maximum and as long as 30 meters to several kilometers. The general trend of these veins is about N 20°E, with quite sheer dipping or vertical. The measurement of radioactivity on the exposures has shown the values up to 13,500 c/s. In such anomalous parts of radioactivity in the vein-like type mineralization, dykes of granite porphyry are observed, in many cases, as wide as 10 cm or several ten cm to occasionally several meters. Sometimes quartz veins containing brown iron-oxide minerals are associated. There are dykes of granite porphyry, which have not been fractured, in the east of the Bou Mia Granite Body. As the measurement of the radioactivity on such dykes sometimes shows high values, it is considered that there are two types of the uranium mineralization --- one is the case that dyke itself contains uranium and the other is the case that the grade of uranium content has been risen by the flow-in of uranium-bearing solution from the surrounding granites into the fractures caused along the dykes at some period after the intrusion of such dykes. As the grade of uranium varies very much at the surface exposures, by the effluence and the reprecipitation of uranium components due to weathering, it is important, for the estimation of the mineralization at the depth, to investigate the distribution of all the veins precisely and to comprehend the characteristics of the structure of each vein as well as the particularity of the mineralization.

The indication of the sandstone type uranium mineralization in Assaka Ijdiy area is located about 12 km north of Midalt. It is thought to be possible as for this indication that the uranium minerals were accumulated and concentrated at the bottom of the boat-like structure, formed by the syncline shape flexure of the Cretaceous limestone beds, in the small scaled graben structure, which had been formed by the depression of the area between the two parallel north-south faults of the lateral interval of about 250 m. This indication of the sandstone type uranium mineralization could be classified into litho-tectonic type. Exploration by the diamond drilling for the part along the boundary between the boat-bottom sedimentary rocks and the underlying granite bodies will be required, but in the first place, it is necessary to confirm in detail the geological structure and the topographical characteristics of the entire area.

As for the sandstone type uranium ore indications, there are roll-front type and peneconcordant type mineralization, which are economically quite significant. However, none of the indications of such types has been discovered in the present surveyed area, though such phenomena as to suggest the existence of the mineralization of the above types have been found at the exposures of the Permo-Triassic Red Sandstone Formation. One of such phenomena is the small scaled leached zone, which is anomalous as to the radioactivity, along the joints and bedding planes contained in the red mudstone beds mainly found around the Granite in the Bou Mia area. Occasionally, the existence of film-like pyrites is recognized in such fissures.

By the diamond drilling carried out in the Tarekochid project by BRPM, peneconcordant type uranium mineralization has been caught, though it is very thin and small in scale. The high grade part of the uranium mineralization is recognized along the boundary of the coarse-grained arkose sandstone bed and fine-grained siltstone layer at the lowest part.

The indication of Carapace type uranium mineralization has been discovered at an outcrop about 7 km north of Bou Mia, through the present survey. In this outcrop, uranium minerals are concentrated along an altered past surface of granite several ten centimeters thick, which had been exposed in the air at the period of Permo-Triassic. This crust is hard and resembles to the shell of animals or plants, like carapace of turtle, where quartz and iron-oxide minerals have been precipitated along cracks parallel to the surface plane. Therefore the crust is called "Carapace". The outcrop is small in scale and is in lenticular shape with its top part depressed, 3 meters long and 30 cm of thickness. The measurement of the radioactivity shows comparatively high values as 1600 c/s at the outcrop and 600 c/s even on a piece sample as big as fist. It is underlain by fresh granite, and in the hanging wall side of it there is lead-bearing arkose sandstone about 2m of thickness. This occurrence of uranium minerals would indicate the bottom of paleochannel formed before the accumulation of arkose sandstone, but variation in the flowing direction is not quite clear.

The indication of conglomerate type uranium mineralization is found as boulders with high values of radioactivity about 1 to 2 m in diameter, derived from Cenozoic conglomerate bed, at the northern bank of the Moulouya river at the northeast of Zayda. The original conglomerate itself has been disappeared by the erosion and the form of the formerly existed uranium deposit is not certain. But, as it is significant that there is such conglomerate type uranium mineralization in this area, exploration for this sort of uranium ore deposits would be necessary.

As for indications of other type of uranium mineralization such as intra-intrusive type, no evidence has been found to show the possibility of the emplacement of this kind of uranium ore deposits, by the results of the radioactivity survey carried out in the granite zone and by the correlation of such data to the geology.

(4) By the gravity survey carried out in an area of 400 km^2 of the central southern part of the present surveyed area, irregularity of the surface of the basement and distribution patterns of the paleochannels have been confirmed in the area to the depth within about 500 m, through the structural analysis of the basement. That is to say, several lines of the paleochannels 5 to 10 km in length have been confirmed from the eastern to northern part of the gravity surveyed area, and furthermore, the existence of deep depression of the depth of 800 to 1,000 m has been recognized in the southwestern part of the area, which indicates step-structure caused possibly by fault-like structure. The paleotopography of the basement rocks is significantly related to the emplacement of lead ore deposits as well as uranium ore indications.

It is thought that the gravity survey is one of the most effective methods in this area, to be employed in the future program.

(5) In the surveyed area, the explorations for vein-like type uranium mineralization were carried out in the Sidi Ayyad area in 1950's. Also,

in 1976, various surveys and exploration works including geological survey and diamond drilling were performed in the Tarekochid area. However, no favorable results have been obtained through these works so far.

To mention about the general conclusion, obtained by the present survey, concerning the possibility for ore deposits to be emplaced somewhere in this area, it would be possible to expect the existence of uranium ore deposits at the depth in the present surveyed area. Thus, it is recommended to establish exploration program by the appropriate planning in future.

1) Zayda Granite Body and Bou Mia Granite Body distributed in the central part of the surveyed area are favorable as the source to supply uranium (Average assay of uranium contents; 9 ppm of U)

2) Terrestrial detrital rocks were accumulated in a large scale around the granite zone, which had been peneplained through the weathering and erosion in the Permo-Triassic Periods. (Exudation of uranium in long period and the formation of accepting rocks)

3) The central basin has been comparatively stable over the whole geological history, where the fault activity would have been mainly of block-faults to form gentle dip structure and so on. Such structures might have worked effectively for the concentration and the precipitation of uranium minerals.

4) There are many veins containing uranium. These veins would not only warrant further explorations, but also would have been effective as the source to supply uranium to the sandstone type uranium ore deposits.

4-2. View to Future Program

Viewing from the general conclusion obtained through the survey results, the areas where the potentiality is thought to be high enough for uranium ore deposits to have been emplaced, and the expected types of the uranium mineralization are as follows:

(1) Vein-like type mineralization in the northeastern part of Zayda and in the Sidi Ayyad are.

(2) Uranium ore deposits of sandstone type, conglomerate type, carapace type etc. in the basin-like geo-structural zone at the north of Zayda --- Bou Mia.

(3) The same types of uranium mineralization as mentioned above, which were emplaced along paleochannels found in the gravity survey area at the south of Zayda --- Bou Mia. (except for the southern half of the area, where the depth of the distribution of such paleochannels is estimated as much as several hundred meters.)

(4) The same types of uranium mineralization as mentioned above, in the northeastern part of Zayda.

It is certainly said that the potentiality of the emplacement of uranium mineralization might not be little of in the areas such as the southwestern part or the northwestern part of Bou Mia in addition to the above-stated, but it would do well to prepare exploration program in such areas after full consideration of the results of the investigation to be carried out in the above-mentioned four areas.

For the accomplishment of the above works, the following exploration methods are recommended as the program of the second phase;

1) Detailed geological survey of exposures of vein-like ore deposits in the northeastern part of Zayda and in the Sidi Ayyad area. Especially, the survey with pilot drilling is recommended to be carried out in such zones where enriched parts of uranium mineralization would be expected, after the survey for the structural feature and for the distribution of radio-activity.

2) Gravity survey in approximately 400 km^2 from the northwestern to northeastern part of Zayda, for the comprehension of the geological structure of the basement. Determining the distribution of survey points and considering the results of the present survey, it would be desirable to prepare the survey points as many as 900 in total.

3) Radon etching survey in approximately 300 km^2 in the above gravity surveyed area. It is necessary to establish survey points more than 2 per km^2, viewing the estimated sizes of the subject structure of paleochannels. It is desirable to lay about 700 survey points in total. Also, it is necessary for this survey to consider upon the relation of the survey results to the estimated depth of the expected uranium ore deposits and to the locations of faults.

4) It is recommended to extract favorable zones through the consideration on geological structure with the results of the Radon etching survey, which would be recommended to be carried out also in the southern part of Zayda where the geophysical prospecting were carried out.

5) Semi-detailed geological survey is recommended to be carried out for the confirmation of geological structure in the northeastern part of Karrouchan, corresponding to the downstream of the northwestern part of Zayda, where it is necessary to comprehend the geological structure, especially to estimate the sedimentary environment of the Permo-Triassic system.

6) Diamond drilling of more than one hole in each area as the northwest, the northeast and the south of Zayda. The data from this drilling would be very important for the analysis of the results of above-mentioned geophysical prospecting, Radon etching, and geological structure.

7) Geological survey and diamond drilling for the graben structure in the Assaka Ijdiy area.

On the other hand, the followings are noted for the potentiality as for lead ore deposits in the present survey area.

(1) For the Zayda sandstone type lead ore deposits, positive explorations including diamond drilling have been carried out by the present developper, SODIM. But the exploration works have been concentrated to the areas comparatively easy for the development, and investigation works have not been extended fully to such remote areas as Bou Mia or such deep part as more than 100 m. Therefore, mineralized area has not been delineated completely. Zayda type lead ore deposits are closely related to the distribution of paleochannels where arkose sandstones were accumulated, which is common nature with the case of the uranium mineralization. Making full use of the data obtained through the results of the survey for uranium ore, it is recommended to carry out diamond drilling survey after extracting such areas favorable for the emplacement of lead ore deposits.

(2) Mibladane disseminated lead ore deposits are found mainly as the stratiform dissemination emplaced selectively in dolomite layers distributed along the large-scaled fault of the direction of NEE-SWW, passing through the vicinity area of Mibladane. As the same mineralization of disseminated type can be observed along fissures across the stratigraphical structure, it is recognized that such mineralization would have expanded laterally from such mineralized fissures. In another words, it can be said to be important to confirm the tendency of the distribution of fracture zones as well as to follow stratigraphically for the exploration of this type of mineralization. For this purpose, it is necessary to carry out detailed geological survey in the area of 4 km x 15 km, including the above-mentioned large fault.

(3) As for vein type lead ore deposits in the Hawli area, there is the tendency that richly mineralized part could be expected at the depth more than some distance below surface, even if surface indication looks pretty

poor. Considerably good results have been obtained by the underground exploration for the Marabout veins, performed by BRPM at present.

As there are many outcrops of ore veins which have not been explored yet in the vicinity, the potentiality would be high for new ore reserves. However, as these ore veins are the fissure filling type ore deposits which have been cut by other faults to remove the extension of ore veins, it is pretty hard to trace such veins sufficiently. Detailed geological survey including the land survey to plot precisely the positions of the outcrops of the mineralization.

It is necessary for the above-mentioned exploration works for uranium and lead ore deposits to give full sedimentological and tectonic consideration on the topography and the geological structure present or past. However, in addition to the above, it is thought important, for the exploration in this area, to examine mineralogy of the samples collected from surface exposures or from drill cores, in order to ascertain the physical and chemical mechanism of the re-deposition and concentration of uranium minerals, to confirm the positional relation of uranium ore deposits to lead ore deposits of Zayda type, and to estimate the depth of secondary enriched zone of the vein-like type uranium ore deposits, and so on.

PARTICULARS

PART I

Geological Survey

PART I GEOLOGICAL SURVEY

List of Illustrations

List of Tables

(Appendices)

List of Plates

Chapter 1 Geotectonic Units of Morocco and Their Particulars

The country of Morocco is situated at the northwestern end of the African continent, where the geologically oldest rocks are distributed. The most part of the African continent became craton after the Pan African Orogeny, which occurred at the end of pre-Cambrian Age or in early Paleozoic Era. However, the northwestern marginal zone including the land of Morocco was left as mobile zone even after the above orogeny, and the marine transgressions are remarkably recognized in Paleozoic Era, in Mesozoic Era (Triassic period, Lias epoch of Jurassic period and middle Cretaceous period) and in Cenozoic Era (at the end of Miocene epoch), with regressions found in each interval of these transgressions. The most remarkable episode in the geological history of this mobile zone was the intrusion of granites at the period of the Hercynian orogeny in the Paleozoic Era. The granites are closely related to the uranium occurrences as the target of the exploration in this surveyed area.

It has been recognized that the activity of geosynclines and the orogenic movement would have extended step by step from the south of Morocco, which is close to the pre-Cambrian craton, to the Mediterranean Sea in the north, as a whole. Through the characteristics of lithofacies, geological structure and geological history accompanied with such activities or movements, the country of Morocco is divided into three geotectonic units, which are Anti Atlas zone, Atlas zone and Rif zone.

The Anti Atlas zone is occupied mainly by the Anti Atlas Range situated in the central part of Morocco, and is corresponded geologically with the Paleozoic geosynclinal zone extending in the direction of WSW-ENE, which was developed along the northwestern margin of the pre-Cambrian craton. The pre-Cambrian basement is observed to the exposed continuously in a belt from the central part to the northeastern part of the Anti Atlas zone, but the exposures in the southwestern part are rather scattered as inliers of various scales, large and small, like islands. Around them, many beds of Paleozoic sediments are well developed. It is recognized that they have been affected intensely by the Hercynian orogenic movement. In another words, it can be said that the Anti Atlas zone is the Hercynian orogenic belt composed of middle to lower Paleozoic formations, which were developed around the core of the pre-Cambrian basement.

The Atlas zone is situated to the north of the Anti Atlas zone. These two zones are bounded by the South Atlas fault. The Atlas zone is extending in the direction of east-north-east, with the approximate width of 300 km in north and south, from Rabat to Agadir. The zone includes lowland plateau, Meseta, extending in both wings of the Moyen Atlas range, in addition to the both areas occupied by the Haut Atlas range and the Moyen Atlas range. The present survey area belongs to this zone. The Atlas zone is the Mesozoic geosynclinal zone developed on the basement of the pre-Cambrian system and the Paleozoic formations. This geosynclinal zone was uplifted to form land at the period of the Tertiary Alpine orogeny, and it is recognized that there are remarkable differences of the geology and the geological structures between the mountainous part and the Meseta. In the mountainous part, continuous sedimentation is recognized through the Mesozoic Era, while the sedimentation in the present meseta area was intermittent and not prevalent, with the basement exposing extensively. These basement rocks were affected by the Hercynian orogeny and have been folded, metamorphosed and intruded by granites. The present survey area is located in the eastern side of the central part of this Atlas zone, which is in the triangle zone formed by the branching of the Haut Atlas range and the Moyan Atlas range. It is corresponded with the western end of the Meseta oranaise. Around the basement in the survey area, Permo-Triassic terrestrial sediments are distributed. Remarkable marine transgression has been recognized in the Lias epoch of the Jurassic period and in the middle Cretaceous period. Part of the present survey area in the Jurassic period and whole of the area in the Cretaceous period were submerged below sea level. Later, by the intense movement in the Tertiary period caused by the Alpine orogeny, the entire area was uplifted. At the period of the orogenic movement, the geosynclinal zone formed a folded mountain as high as over 3,000 m, while in the meseta area it is only slight deformation that has been recognized.

Rif zone is the area nothernmost of Morocco, where miogeosyncline belt was formed on the basement of the Paleozoic and Mesozoic formations. This miogeosynclinal belt is thought to compose a part of the Alpine orogenic belt found in the southern Europe, viewing from the geo-structural characteristics. This belt is represented by the arcuate folded mountain formed along the shore of the Mediterranean Sea through the repetition of intense thrusting activity from north to south during the period of the Alpine orogeny. Complicated folding structures and fault structures including many overthrusts are recognized notably in this belt. (Fig. I-2)

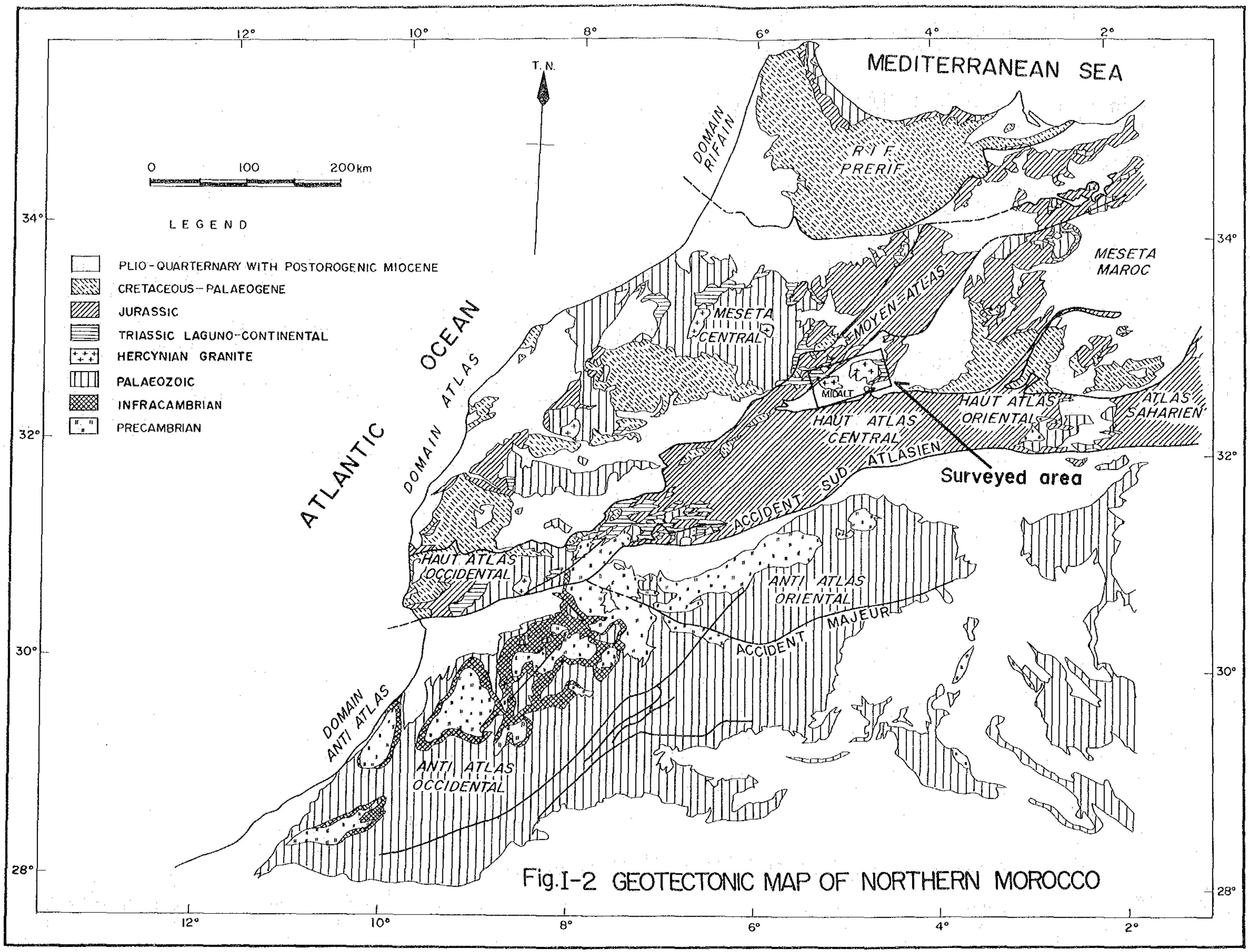


Fig.I-2 GEOTECTONIC MAP OF NORTHERN MOROCCO

Chapter 2 Geology of the Surveyed Area

The rocks distributed in the surveyed area are constituted with the basement composed of Crystalline schists and Granites, and overlying Permo-Triassic Red Sandstone Formation in addition to the sedimentary rocks of Mesozoic Era, and Tertiary and Quaternary Periods and the Quanternary Basalt lava.

The lithology and the stratigraphical relation are illustrated in Schematic Geological Column of the Surveyed Area (Fig. I-3), and the distribution of the rocks and the geological structure are shown in the geological map of the surveyed area (Pl. I-1) and in the geological profiles of the surveyed area (Pl. I-2).

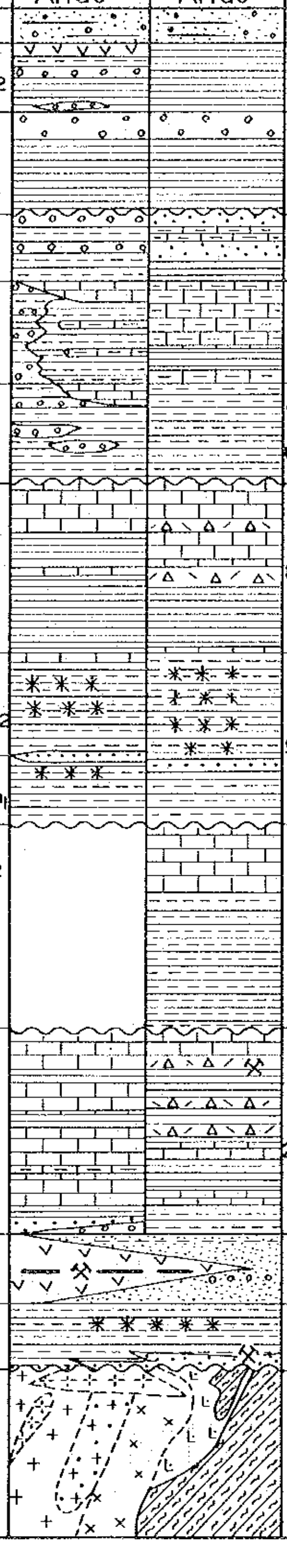
The outline of the geological units, the geological structure, the age of the rocks and the geological history are described here.

It will be appropriate to add that the present survey has been concerned mostly with the lithology and the distribution of radioactivity of the Granites which had been thought to be closely related to uranium and lead resources and to the lithofacies and the sedimentary structures of the terrestrial sedimentary rocks, and that the paleontological consideration (indentification and correlation of fassils) of the sedimentary rocks, the study of which had been in good progress in this country, were according to the conclusions of the publicized literatures and reports.

2-1 Basement Complex

2-1-1 Crystalline schists

The crystalline schists are distributed from the north of Midalt in the southeastern part of the surveyed area to the Sidi Ayyad area in the northeastern part of it, in addition to small exposures found in the



Era	Period	Formation	Thickness M.A.	Thickness H.A.	Description: Moyen Atlas	Description: Haut Atlas
Cenozoic	Quaternary	Q3			Terrace deposit	
		β_{Q2}, Q2	15m ±	30m ±	Basalt (lava), calcareous conglomerate, sandstone, siltstone, calcareous siltstone.	Conglomerate, siltstone, mudstone.
		Q1	25 – 100m	25 – 100m	Conglomerate, siltstone.	
	Tertiary	T3	45m ±	35m +	Calcareous conglomerate, calcareous siltstone, sandstone, marl, reddish brown siltstone-mudstone, sandstone.	
		T2	60m ±	70m	Limestone, yellowish grey siltstone-mudstone, marl, calcareous conglomerate.	Marl, limestone, siltstone.
		T1	40 – 60m ±	15m	Micritic limestone, light brown siltstone conglomeratic sandstone.	Light brown siltstone.
Mesozoic	Upper Cretaceous, Turonian	K2t	80m ±	140m ±	Limestone included molluscas and brachiopodas, calcareous siltstone included molluscas.	Micritic limestone, muddy siltstone, calcareous siltstone, turbidite.
	Upper Cretaceous, Cenomanian	K2cm, K2cm2	50m	90m ±	Limestone included molluscas, calcareous siltstone, poly-colored siltstone intercalated with gypsum beds, sandstone, conglomerate.	Siltstone intercalated with gypsum beds.
		K2cm1		20 – 40m		Alternation of red mudstone, shale, sandstone and limestone.
	Middle Jurassic, Dogger	J2d2		50m		Alternation of limestone and thin shale included shell fossils.
		J2d1		170m ±		Grey mudstone.
	Lower Jurassic, Lias	J1	0 – 250m	230m ±	Limestone included coral fragments, calcareous siltstone, marl, sandstone, conglomerate.	Mibladane Pb-Ba ore deposit. Calcareous to sandy siltstone intercalated with turbidite, limestone, dolomite.
	Permo-Triassic	β_{P-T}	0 – 150m		Basalt (lava), sandstone, conglomerate. Manganese ore bed, coaly shale.	
		P-T	30 – 150m		Red sandstone, arkose sandstone, siltstone, mudstone, partly turbidite, gypsum beds. U. mineralization, Zayda Pb-Ba ore deposit.	
Proterozoic - Paleozoic	Precambrian -Paleozoic	Basement complex			Granite, contaminated granite, porphyritic granite, aplitic granite, granodiorite. Dykes (aplite, granite porphyry). Metamorphic rocks (chlorite-sericite schist, quartz-sericite schist, amphibole schist, amphibolite).	

Fig. I-3 Schematic Geological Column of the Surveyed Area

Karrouchan area in the northwestern part of the surveyed area. In this Karrouchan area, the Crystalline schists are found to be exposed with granites at the Tizi-n'Rechou fall, the mid point of the national road to link Bou Mia. This point is corresponded with the boundary between the Karrouchan basin and the stable zone within basin. In the present year's survey, the Crystalline schists have been found at the bottom of the Marrout river in the basin, about 13 km northeast of Karrouchan. Therefore, it has become evident that the Crystalline schists compose the basement of this area.

The Crystalline shists are generally grey to dark green in color, showing remarkable schistosity. Textures of the original rocks have not been found to be left due to metamorphism. The rocks are composed of chlorite-sericite shist, quartz-sericite schist, amphibole schist and amphibolite. It is presumed that the original rocks of these schists might have been composed of argillaceous rocks, arenaceous rocks and basic igneous rocks, etc. The grains of the constituent minerals of these Schists are as fine as 1 mm in diameter in general, except for parts of amphibolite where crystal grains are as coarse as about 5 mm. Generally, weathering along schistosity has been observed, and therefore the rocks are easily foliated in flat form. Weathered parts show silver grey in color by the presence of flakes of mica, and weathered soil looks reddish brown. The result of the isotopic age determination by Rb-Sr method was reported by D. Tisserant (1977), that the age of the metamorphism of the Schists was upper Devonian to middle Permean periods, which is corresponded with the age of the intrusion of the Granites. Paleontologically, no fossil has been found in the Crystalline schists, and so the age of the original rocks of these Crystalline schists has been left uncertain and is thought Paleozoic or Precamprian Era.

2-1-2 Granites

The Granites in this area are distributed in the two areas, the east of Zayda and the west of Bou Mia. The areas where the Granites are distributed are seen to have formed round hilly land 100 to 200 m higher than the rest of the land in altitude. It has been confirmed by the results of the analysis of the data obtained from the diamond drilling and the geophisical prospecting, carried out in the middle area of the two Granite Bodies, that these two Granite Bodies belong to one unit of Granites.

The Granites are constituted with granite, porphyritic granite, contaminated granite, granodiorite, aplitic granite and hollocrystalline dykes intruding all the above Granites. The characteristics of these rocks are described here.

(1) Granite:

The granite is white or pink in color, coarse-grained equigranular massive rock and occupies the main part of the Granite Body. Porphyritic parts are often observed, where the phenocrysts of orthoclase 4 to 5 mm in grain size are recognized. Rarely it contains small pieces of the Crystalline schists as xenolith. This granite changes to the other kinds of granites gradually.

(2) Porphyritic granite:

This porphyritic granite is distributed in belts, about 1 to 2 km wide, extending as far as several kilometers, in the southern part and in the northern margin of the central part of Zayda Granite Body and in the central part of the Bou Mia Granite Body. It is characteristic that large phenocrysts of orthoclase 2 to 3 cm in diameter are found to be in a configuration arranged to certain direction.

Main constituent minerals are, quartz, orthoclase, plagioclase and biotite like those of the above-mentioned granite.

(3) Contaminated granite:

This contaminated granite is distributed along the contact with the Crystalline schists. Compared to the above granites, this rock is rather dark green in color, and is equigranular massive rock composed of the grains of 2 to 3 mm in size. Generally it contains many xenoliths 1 to 2 m in size, without orientation. Among them, huge xenolith over 100 m in extension is recognized rarely.

The main constituent minerals are like those of the granite, with an addition of small amount of hornblende. The composition of plagioclase is rather rich in Ca, compared to that of the granite.

(4) Granodiorite:

This granodiorite is distributed in the Sidi Ayyad area in the northeastern part of the surveyed area, where it composes the protruding part of the Granites into the Crystalline schists, occupying an area of 6 km in east-west, 3 km in north-south.

The granodiorite is dark green massive compact rock. The constituent minerals are plagioclase, quartz, biotite and hornblende 1 to 2 mm in sizes, which is rather finegrained than the component minerals of the other granites. Quartz is contained very little and it is hard to recognize it megascopically.

This granodiorite also contains many pieces of the Crystalline schists. The relation to the above-stated contaminated granite is transitional.

(5) Aplitic granite:

This aplitic granite is distributed in the area occupied by the granite. It occurs generally in sheet-like form with gentle inclination and it is in stock-like form in places. This aplitic rock is hollo-crystalline and rather fine-grained as a whole, but aggregates of large crystals, several centimeters in sizes, of feldspars, quartz, muscovite, as seen in pegmatite, are recognized here and there.

There is comparatively distinct boundary along the contact zone with the granite, but sometimes transitional relation can be recognized between the two rocks.

The main constituent minerals are quartz, orthoclase, muscovite and biotite. The rock shows leucocratic to pale pinkish color in appearance.

This aplitic granite is corresponded with what are called alkali-granite and graphic granite in accordance with the classification by D. Tisserant (1977).

The results of the consideration on the distribution of both the Zayda Granite Body and the Bou Mia Granite Body are shown in the Fig. I-4. There, the aplitic granite is distributed like bottom-upwarded dish covering each Granite Body, intruding with gentle dipping into the Granite Body itself in the marginal zone. Adding the direction of the aplite dykes and the joints found in the granite to the above, it is likely that they have radial distribution against the structure of concentric circles composed of the aplitic granite.

The boundary of this aplitic granite with the granite is not as clear as that of dykes, and is irregular. It is most appropriate to take up the idea that the aplitic granite is the product of the latest stage of the differentiation of the granite.

The center of the concentric circles is found respectively in each of the Zayda Granite Body and the Bou Mia Granite Body.

As it has been turned out by the radiometric survey that the radioactivity of the aplitic granite is usually higher by 30 to 50 c/s than the other granites, it is important to obtain information on the distribution of this aplitic granite as the source rock for the sedimentary uranium deposits.

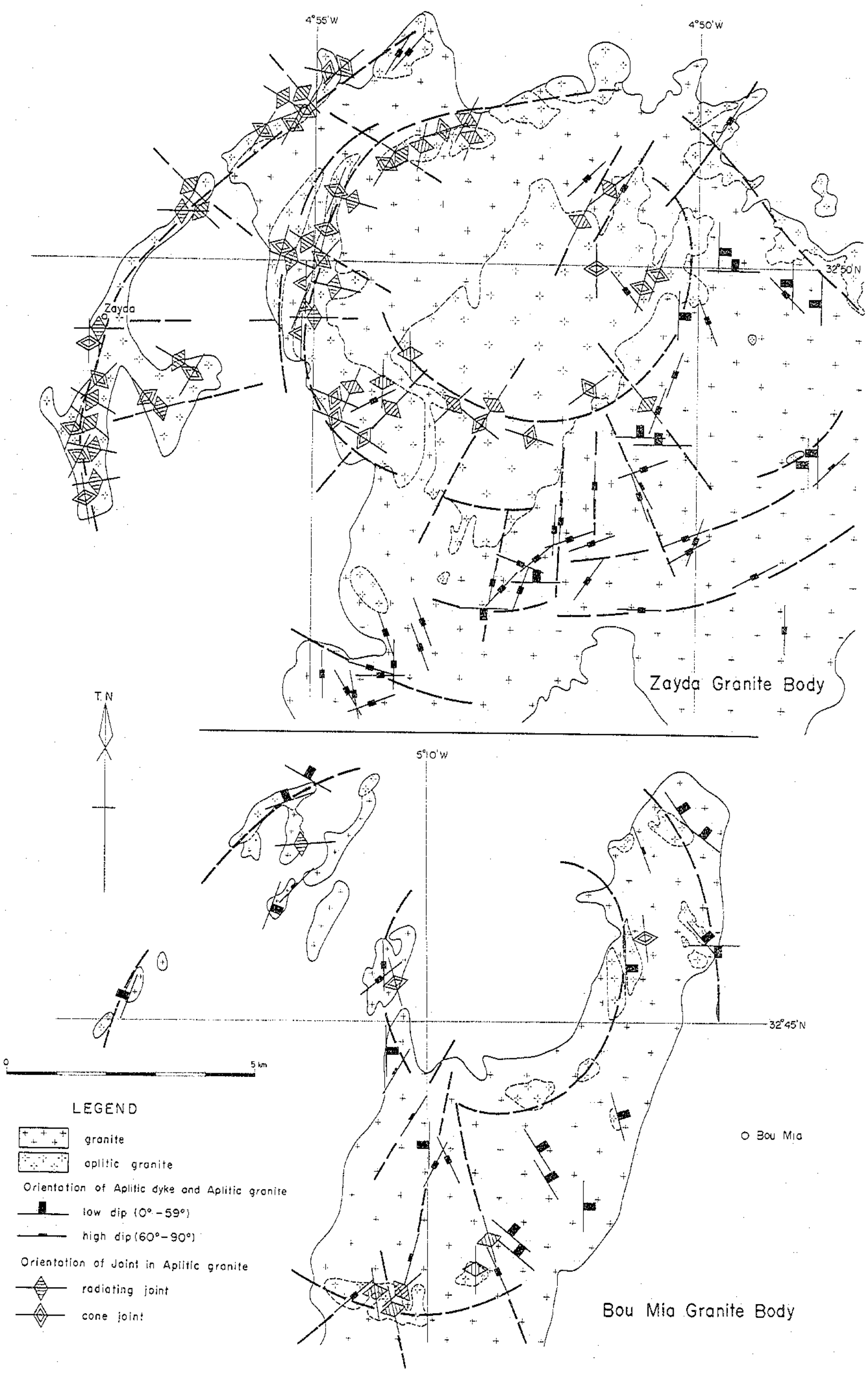


Fig. I-4 Orientation of Joint, Aplite Dyke and Aplitic Granite

(6) Dykes:

As the dykes intruding all the above-mentioned Granites and the Crystalline schists, there are aplite, granite porphyry and micro-granodiorite. As they have not invaded the sedimentary rocks covering the Permo-Triassic beds, these dykes are included into the members composing the basement.

1) Aplite: The aplite dykes are found mostly in the granite zone. Lithologically, it is similar to the aplitic granite, but rather fine-grained. The width of the dykes is various from 50 cm to as much as 4 m. The inclination is almost vertical. It is associated with quartz veins and pegmatites. The radioactivity is not very high, that is, as high as that of the granite (100 c/s ±).

2) Granite porphyry: This rock is also distributed in the Granite zone, as is the case of the aplite dykes, but the dykes of this granite prophyry are not found so many as aplite dykes. The rock is milky white to brown, hard and compact. With the phenocrysts of orthoclase and quartz, the rock has fine to medium-grained hollocrystalline groundmass, composed mainly of quartz, othoclase and plagioclase.

   The dyke of the granite porphyry distributed at the point about 3.5 km southwest of Bou Mia contains the phenocrysts of quartz of about 5 mm in grain size. This dyke, with the width of about 3 m, accompanies fine-grained liparitic marginal facies as wide as about 30 cm along the margins. The radioactivity of this dyke is higher 30 to 50 c/s than that of the surrounding granite.

   As granite porphyry is also found in the indication of uranium mineralization "G-P veins", located about 10 km northeast of Zayda, it is considered that the granite porphyry would have played a significant role for the emplacement of uranium mineralization.

3) Micro-granodiorite: This micro-granodiorite has been found only in the granodiorite zone in the Sidi Ayyad area in the northeast of the surveyed area. The rock is melanocratic fine-grained compact rock, with the main constituent minerals of plagioclase, biotite, hornblende and quartz. In the Sidi Ayyad area, where this micro-granodiorite is distributed, a fracture zone with faults is recognized to be developed along the dyke of this rock accompanying quartz veins. This fracture zone has anomalous radioactivity.

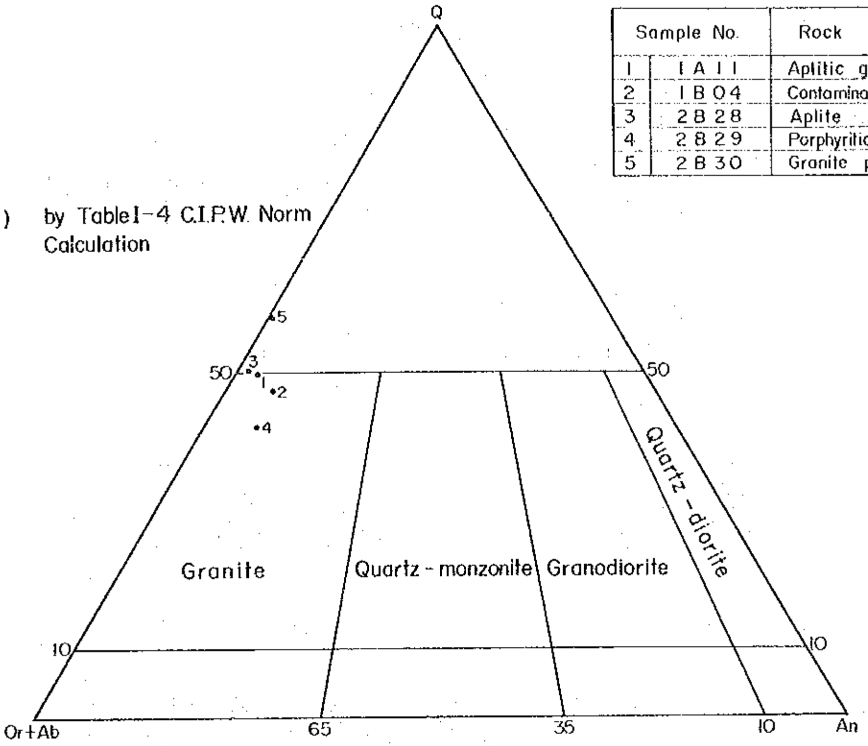
Among the above-mentioned granites including dykes, chemical analysis of the whole rock was peformed on 5 samples, and the main ingredients of SiO_2, K_2O, Na_2O, CaO and Al_2O_3 were analysed on 10 samples and the lithological discussion was held on the information thus obtained. The results of these chemical analysis are shown in the Table I-3. Also, the results of the microscopic determination not only of the igneous rocks but also of the sedimentary rocks are shown in the Table I-6.

After the norm and the mode were calculated, the results were plotted in the triangle diagram, as shown in Fig. I-5, (Norm calculation is shown in Table I-4). It can be seen that the granite and the aplitic granite belong to alkaligranite by the classification, and that what is called granodiorite is plotted at an independent position. In Fig. I-6, in which the variation of $(K_2O + Na_2O)/SiO_2$ was checked, the contaminated granite is plotted in a position between the granodiorite and the granite.

The results of the isotopic age determination reported by D. Tisserant (1977) have shown the age of the granodiorite to be $(336 \pm 6)x10^6$ years and that of the granite to be $(316 \pm 17)x\ 10^6$ years. The difference is very small between them, but some delicate difference may be suggested on the periods of differentiation and intrusion of these rocks.

a) by Table I-4 C.I.P.W. Norm Calculation

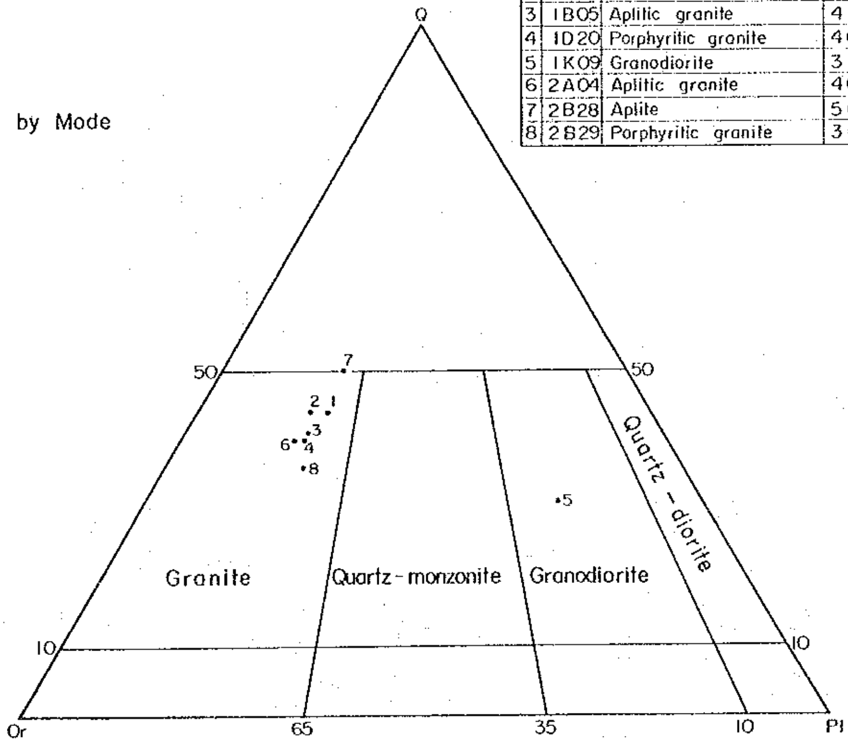
Sample No.		Rock name
1	1 A 1 1	Aplitic granite
2	1 B 0 4	Contaminated granite
3	2 B 2 8	Aplite
4	2 B 2 9	Porphyritic granite
5	2 B 3 0	Granite porphyry



(by U.S.G.S. modal classification scheme)

b) by Mode

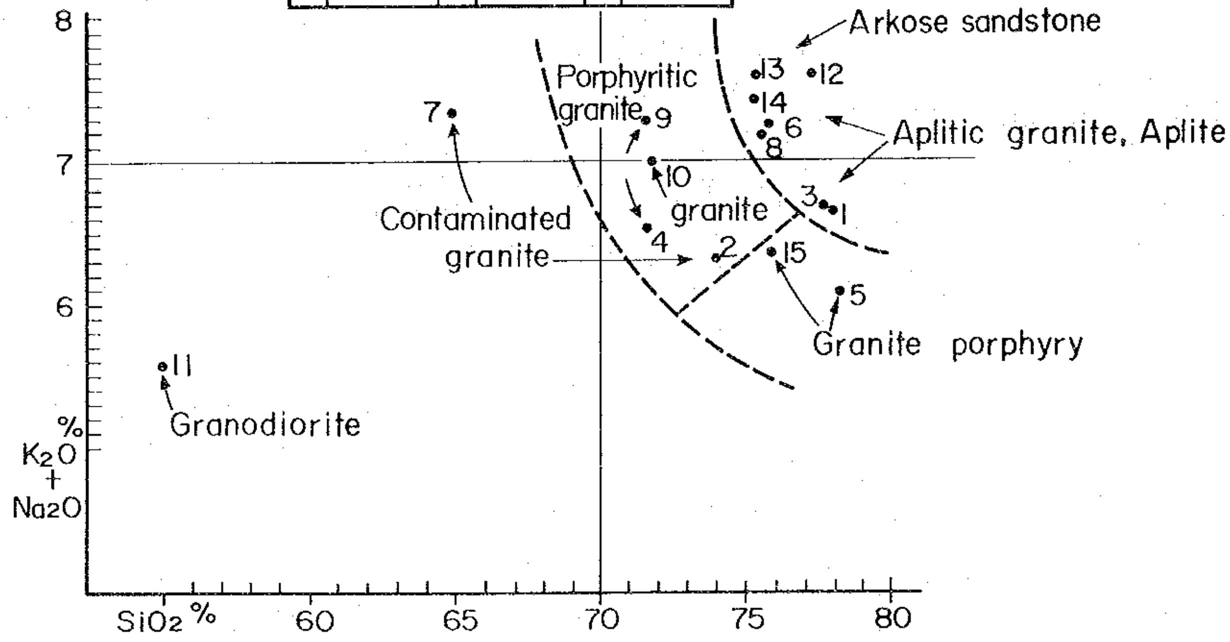
Sample No.		Rock name	Mineral ratio		
			Q	Or	Pl
1	1A11	Aplitic granite	44	40	16
2	1B04	Contaminated granite	44	42	14
3	1B05	Aplitic granite	41	44	15
4	1D20	Porphyritic granite	40	45	15
5	1K09	Granodiorite	31	18	51
6	2A04	Aplitic granite	40	46	14
7	2B28	Aplite	50	35	15
8	2B29	Porphyritic granite	36	47	17



(by the International Union of Geological Sciences modal classification scheme)

Fig. I-5 Classification of Granitic Rocks

Sample No.					
1	1A11	6	1B05	11	1K09
2	1B04	7	1C02	12	2A04
3	2B28	8	1C12	13	2B23
4	2B29	9	1D20	14	2B24
5	2B30	10	1J18	15	2B31



(by Table I-3 Chemical Analysis of Granitic Rocks)

Fig. I-6 Variation of $K_2O + Na_2O / SiO_2$

2-2 Permo-Triassic System

2-2-1 P-T Red Sanstone Formation

(1) Distribution

The P-T Red Sandstone Formation is distributed extensively in the area of Karrouchan basin in the northwest of the surveyed area, in addition to the outcrops found surrounding the Basement Complex in the area where the Basement Complex are exposed in the east of Zayda and in the west of Bou Mia.

(2) Lithology

The P-T Red Sandstone Formation is composed of reddish brown sandy sediments and is divided roughly into three parts from the lowest to the upper, that is, the coarse-grained conglomeratic part composed mainly of arkose sandstone and conglomeratic sandstone, the medium-grained sandy part composed mainly of medium to fine-grained sandstone and the fine-grained muddy part composed mainly of mudstone or siltstone.

The lithology of the coarse-grained conglomeratic part reflects the geology of the background from where the materials of the formation were supplied. In the area where the Granites are distributed, this coarse-grained conglomeratic part is constituted with the fragments of quartz and feldspars with small pieces of granites, while it is composed of fragments of micas with small pieces of Crystalline schists in addition to the fragments of quartz and feldspars in the area where the Crystalline schists are distributed. Usually, grain size is 2 to 3 mm in diameter, but in such part as directly overlying the Basement Complex it is generally coarse-grained, and occasionally pebbles of several centimeters in diameter are contained. In some case, huge cobbles the diameter of which reaches about 1 meter can be found in such part. Generally, it has been well consolidated, and is white to yellowish white in color, and compact in characteristics. Often cross-laminae, ripple mark and sole mark are observed.

The medium-grained sandy part is composed of alternation of reddish brown medium-grained sandstone and fine-grained sandstone with inserted layers of mudstone, conglomerate, marl etc. The constituent grains of the sandstone are mostly quartz, the grain size of which is generally from 1 to 2 mm. Consolidation is pretty well in general. Cross laminae are observed.

Fine grained muddy part is composed mainly of reddish brown siltstone with the insertions of mudstone and marl in places. The siltstone has been consolidated well, but it is easily cracked to form pattern like beads on abacus. There are some parts where gypsum beds are intercalated. Turbidite can be observed in places.

(3) Stratigraphy and structure

The P-T Red Sondstone Formation is seen overlying the Basement Complex unconformably. The stratigraphic succession varies according to the areas. The beds are thick in the Karrouchan basin and the thickness reaches 150 m in maximum, while it is as thin as about 50 m in the plain area (situated between the Moyen Atlas range and the Haut Atlas range) where Bou Mia and Zayda Granite Bodies are occupying most of the area.

In the beds of the formation, partly leached zone by the penetration of the underground water after completion of sedimentation can be observed well. In such leached part, greyish white dots are observed contained in the fresh reddish brown part in places, along joints and bedding planes.

2-2-2 β_{P-T} Basalt Formation

(1) Distribution

This β_{P-T} Basalt Formation is distributed in the area aound the Basement Complex and in the area of the Karrouchan basin. In the area to the east of Zayda, it develops surrounding the P-T Red Sandstone Formation in the southern area and in the eastern to northern area of the Basement

Complex. Around the Bou Mia Granite Body, it exposes surrounding the above sandstone formation in the northwestern to southern area of the Granite Body. This βP-T Basalt Formation is exposed in a zone of comparatively high altitude surrounding hill side, in the area of the Karrouchan basin.

(2) Lithology

The rocks composing the βP-T Basalt Formation are mostly basalt lava, but in some areas, red sandstone is distributed in the area where the basalt lava becomes very thin. Also, in some cases, the basalt lava is underlain by coal bed, and in other cases, the basalt lava has such insertions as thin layers of black shale as well as layers of gypsum and iron-manganese silicate ores.

The basalt lava is dark green in color and hard in characteristics. Partly vesicles are developed well. In places, it is accompanied with oxidation zone of maximum 10 meters in its uppermost part.

Olivine can be observed megascopically. As a whole, the basalt has been chloritized, and in such part as vesicles are developed, they are filled with chlorite and milky quartz.

The red sandstone is the medium-grained sandstone which is composed of the grains derived from this basalt. The black shale is dark in color, and is well consolidated. Its thickness is as small as 5 to 10 cm. The gypsum layer is from 2 to 3 cm in thickness and is developed in the oxidized zone of the basalt lava.

(3) Stratigraphy and structure

The βP-T Basalt Formation directly overlies the P-T Red Sandstone Formation with conformable relation. The thickness varies locally. In the eastern part of the surveyed area, there is a basalt lava with its thickness of about 1 m in the north of Zayda, and after gradually increasing the thickness eastwards, its thickness reaches over 100 m in the east of Hawli. In the western part of the surveyed area, the thickness increases westwards from Bou Mia area to the Karrouchan basin,and it reaches 150 m at the western end.

2-3 Jurassic System

2-3-1 J_1 Limestone Formation

(1) Distribution

In the eastern part of the surveyed area, this J_1 Limestone Formation is distributed inthe southeastern to eastern marginal zone of the Basement Complex located at the east of Zayda. In the western part of it, it is distributed from around the Bou Mia Granite Body to the area of the Karrouchan basin. There are some exposures of this formation along the northern margin of the Haut Atlas range, in the southwestern edge of the surveyed area.

(2) Lithology

This J_1 Limestone Formation is composed mainly of limestone with layers of calcareous siltstone and sandstone. In places, this formation contains red conglomerate and brown mudstone in the lower part. In some cases, turbidite is observed in the calcareous siltstone and mudstone.

The limestone is yellowish white in color and compact in characteristics. Fossils of mollusca are found in the limestone in some areas.
The calcareous siltstone is pale yellowish white in color, and bedding planes are developed well. Most of the sandstones are yellowish red brown and medium-grained sandstone. Consolidation is pretty well. The red conglomerate is composed of sands and pebbles of the basalt. Pebbles are round and 3 to 4 cm in diameter.

(3) Straigraphy and structure

This formation overlies the Permo-Triassic system in conformable relation. The thickness varies locally. This formation is as thick as 120 to 180 m at the north of Midalt in the southeastern to the eastern margin of the Basement Complex in the east of Zayda, and is as thick as 270 m in the east of Hawli. However, the thickness decreases remarkably towards the north and it disappears at the north of Sidi Ayyad. The thickness is about 180 m in maximum in the area from Bou Mia to the Karrouchan basin, while it is 80 to 140 m in the southern area of the Bou Mia Granite Body.

The trend and inclination of the beds of this formation are as follows; In the area from the north of Midalt to Mibladen, the strike is NEE-SWW with the dipping to the south. In the area from the east of Hawli to Sidi Ayyad, it is almost horizontal in general. In the area from Bou Mia to the Karrouchan basin, it is almost horizontal, too, as a whole, but there can be seen some folding structure with the axis of the approximate direction of northeast, in the northwest of Itzar.

In the area along southern side of the Bou Mia Granite body, the dipping is towards the south, while towards the north at the southern end of the surveyed area.

2-3-2 J_2d_1 Mudstone Formation

(1) Distribution

The rocks of J_2d_1 Mudstone Formation are exposed in the southeastern part and at the southern end of the surveyed area, but the distribution is not very extensive. In the southeastern part, this formation is exposed in the east of Mibladane and in the south of Midalt. In the southern end of the surveyed area, they are exposed in the extension of northeast-southwest near the limit of the surveyed area.

(2) Lithology

This formation is composed mainly of mudstone, grey in color. In the upper part of this formation, layers of calcareous shale 10 to 20 cm in thickness are found as insertions. The mudstone is massive and is not bedded. It is easily cracked to form pattern like beads on abacus. In the southeastern part of the surveyed area, grey mudstone is developed well. In the southern end of the surveyed area, corresponding with the south of Bou Mia, reddish brown mudstone as thick as about 10 m is developed in the upper part of this formation.

(3) Stratigraphy and structure

This formation is found overlying the J_1 Limestone Formation with disconformity. The thickness of this formation is over 60 m in the southeastern part and is about 80 m in the southern end of the surveyed area. The strike of the beds of this formation is NE-SW and the dip is as gentle as about 10° to NW or SE. In the southeast of Midalt, an anticline with the axis of the direction of NE-SW is found and the beds are undulating gently.

2-3-3 J_2d_2 Limestone Formation

(1) Distribution

J_2d_2 Limestone Formation is exposed, like the J_2d_1 Mudstone Formation, in the south of Midalt and in the southern end of the surveyed area. The distribution of this formation around Midalt is not so extensive as that of the J_2d_1 Mudstone Formation, and as this formation disappears in the area about 3 km east of Midalt, it is thought that this formation is not distributed in the east of Mibladane.

(2) Lithology

This formation is composed mainly of limestone, but it contains many layers of siltstone, mudstone and marl in the upper part. The limestone is massive, grey and pale brown in color. The siltstone is calcareous, grey and brown in color. The mudstone and the marl are grey.

This formation contains abundant fossils around Midalt. Fossils of mollusca and ammonite (30 cm in size) are found there.

(3) Stratigraphy and structure

This formation is found overlying the J_2d_1 Mudstone Formation with conformity. The thickness is as much as about 60 m in the south of Midalt, and it decreases remarkably eastwards. The strike and dip of the beds of this formation are similar to those of the J_2d_1 Mudstone Formation, and an anticline with axis of approximate direction of NE-SW is seen to have been formed in the south of Midalt.

2-4 Cretaceous System

As the Cretaceous system in this surveyed area, there are K_2cm_1 Red Mudstone Formation, K_2cm_2 Mudstone Formation and K_2cm Mudstone Formation of Cenomanian series. In the southeastern part of the area, the Cenomanian series has been divided into K_2cm_1 Red Mudstone and K_2cm_2 Mudstone Formation, but in the other parts of the surveyed area, the rocks belonging to the Cenomanian series are included into one unit of the K_2cm Mudstone Formation, as it was hard to make sub-division in the present survey.

2-4-1 K_2cm_1 Red Mudstone Formation

(1) Distribution

This formation is distributed in the southeastern part of the surveyed area. It is exposed in the area from about 10 km northwest of Midalt to about 7 km east of Mibladane. Some of K_2cm_1 Red Mudstone Formation is also found at the south of Midalt and about 10 km southwest of Midalt.

(2) Lithology

This formation is composed mainly of reddish brown mudstone, with inserted layers of white or brown fine-grained sandstone. In the upper part of this formation, conglomerate and limestone are contained.

The reddish brown mudstone is lithologically similar to the reddish brown siltsone and mudstone beloging to the P-T Red Sandstone Formation. Cross-beddings are well observed in the fine-grained sandstone. Fossils are rarely found.

(3) Stratigraphy and structure

This formation is found overlying the J_1 Limestone Formation and the J_2d_1 Mudstone Formation with unconformity. The bed is as thick as about 40 m, but the thickness decreases eastwards, and the thickness along the southern bank of the Amghourzif river about 5 km south of Hawli is as much as only 10 m. Generally, the strike of the beds of this formation is in the direction of NEE-SWW, with the dipping 3° to 10° to the north or south, but gentle undulation is observed, caused by the anticline with the axis of the approximate direction of NE-SW found in the southeast of Midalt.

2-4-2 K_2cm_2 Mudstone Formation

(1) Distribution

This formation is, as is the case of the K_2cm_1 Mudstone Formation, distributed mainly in the southeastern part of the surveyed area. Also, in the Ilich Azougagh Mylonite zone, small exposures of this formation are found overlying the P-T Red Sandstone Formation.

(2) Lithology

This formation is various in color, and is composed of soft mudstone and siltstone, with some gypsum layers. The mudstone and the siltstone are in many colors as brown, yellow, green or white. The gypsum layers are developed, in places, with the thickness of about 1 m. In cases, the gypsum is found in such occurrence as networks cutting beds.

(3) Stratigraphy and structure

This formation is found overlying the K_2cm_1 Red Mudstone Formation with conformity, and is as thick as over 70 m in the south of Mibladane, but the thickness decreases southeastwards.

The general trend of the beds of this formation is NEE-SWW, with the dipping about 10° to the north or to the south. There is a folding structure with the axis of approximate direction of NE-SW or NNE-SSW in the south-eastern end of the surveyed area, where gentle undulation of the beds can be observed, caused by this folding structure.

2-4-3 K_2cm Mudstone Formation

(1) Distribution

K_2cm Mudstone Formation is distributed extensively in the area to the north of the Basement Complex found at the east of Zayda and the west of Bou Mia. It is also found along the southwestern side of the Bou Mia Granite Body. In the area of the Karrouchan basin, this formation is distributed in the northwestern area of Itzar.

(2) Lithology

This formation is colorful like the K_2cm_2 Mudstone Formation, and is composed mainly of soft siltstone with red sandstone, marl and limestone, accompanied by gypsum layers.

The siltstone is constituted with the alternation of various colored leyers such as those of green, reddish brown, yellow and white colors. Gypsum layers are found developed in places.

The sandstone is mostly medium to fine-grained red or brown sandstone, but occasionally it composes thin layers of yellow or white, fine-grained sandstone.

The limestone is yellowish white or light red in color, and is argillaceous. Usually thin layers of the limestone of 1 to 4 m in thickness are found inserted in the siltstone or in the sandstone.

(3) Stratigraphy and structure

This formation is found overlying Permo-Triassic and Jurassic systems with disconformity. This formation is as thick as 60 m in the north of the Bou Mia Granite Body, but the thickness decreases eastwards to be as much as 40 m. In the west of the Bou Mia Granite Body, the thickness is about 45 m. The beds are distributed almost horizontally, but in the north-western area of Itzar, a syncline formed with the fault movement has been found, where the trend of the strata is NE-SW, with the dipping of 10^{o} to 30^{o} to the northwest and to the southeast.

The characteristic of this formation is that it is composed of colorful sandy or silty sediments associated with gypsum, and it is considered that most of this formation is corresponded with the K_2cm_2 Mudstone Formation.

2-4-4 K2t Limestone Formation

(1) Distribution

K2t Limestone Formation is distributed in the area from several kilometers northeast of Itzar to the north of the Bou Mia Granite Body. It is also found at the southeastern end of the surveyed area and at the southwest of the Bou Mia Granite Body. There are some exposures of this formation in the Ilich Azougagh Mylonite zone, in the Assaka Ijdiy area.

(2) Lithology

This formation is composed mainly of calcareous siltstone with limestone, locally with inserted layers of sandstone.

The calcareous siltstone is generally white or yellowish white in color, hard and compact in characteristics. It is well bedded.
It is characteristic of this formation that, as for the limestone, there are yellowish white limestone and white or yellowish micritic limestone.
The sandstone is yellow, silty, fine-grained sandstone. In places, there are muddy turbidite including nodules or breccias of limestone.
Generally, this formation contains fossils of mollusca.

(3) Stratigraphy and structure

This formation is found overlying the K_2cm_2 Mudstone Formation with conformity, and is as thick as 80 m around Itzar and 135 m in the southeastern part of the surveyed area.

The beds of this formation are lying almost horizontally. There is a small scaled syncline with the axis of the N-S direction at the place about 7 km west of Zayda. Generally, it is observed that the beds of this formation are forming basin structure, inclining gently (about 3^{o}) toward the vicinity of Itzar.

In the southeastern part, there are folding structures with the axis of the approximate NE-SW direction, where the trend of the beds is NE-SW, with the dipping about 10^{o} towards northwest or southeast.

2-5 Cenozoic Group

According to E. Amade (1958), the Cenozoic group in this surveyed area is constituted with the Quaternary system and the Tertiary system, which is composed of lacustrine sediment of Miocene to Pliocene Epoch (or Pontian Stage to Pliocene Epoch ?).

Viewing the whole surveyed area generally, the Tertiary system is found overlying the Basement Complex unconformably, lying almost horizontally but quite gently dipping toward the center of the basin from the Moyen Atlas range in the northern part of the surveyed area.

It can be said that the Quaternary system is distributed everywhere in the surveyed area, but, as a whole, it lies quite gently dipping toward the center of the basin from the southern Haut Atlas range.

The higher plains, forming the encircling part of the basin in the surveyed area, are composed of the Tertiary system and the Quaternary diluvial sediments, while alluvial sediments are deposited in the lowland and the drainage area of rivers in the southern part of the basin.

2-5-1 Tertiary System

The Tertiary system distributed in the surveyed area is, from the lowest, divided into T_1 Mudstone Formation, T_2 Marl Formation and T_3 Sandstone Formation.

(1) T_1 Mudstone Formation

1) Distribution

The T_1 Mudstone Formation is distributed in the western part of the surveyed area and along the southern side of the Moyen Atlas Range, at the north of Itzar. The southern limit of the distribution of this formation is about 10 km south of Zayda.

2) Lithology

This formation is composed mainly of reddish brown, rather soft mudstone without beddings, but in the northern part, micritic limestone layer of about 15 m thickness in maximum is developed, in the uppermost part of this formation. Occasionally, the rocks of this formation look grey, and along the Moyen Atlas range many inserted layers of conglomeratic sandstone are seen. The pebbles contained in this conglomeratic sandstone are limestone, siltstone, basalt and so on.

3) Stratigraphy and structure

The thickness of this Mudstone Formation is about 60 m in the western part, about 40 m in the northern part and about 15 m in the central part of the basin.

This formation overlies all the lower formations with unconformity, but no basal conglomerate has been observed to have been developed.

(2) T_2 Marl Formation

1) Distribution

The T_2 Marl Formation is distributed in almost the same area of the distribution of the above T_1 Mudstone Formation, but in addition to it, the distribution is extended into the basin, that is, to the south of Midalt in the southeastern part of the surveyed area.

2) Lithology

T_2 Marl Formation is composed mainly of hard marl which has grey or yellowish grey silty matrix containing abundant calcareous grains several centimeters in diameter, and is partly with layers of siltstone and limestone. Along the Moyen Atlas range at the north of Itzar, the formation is changes to conglomerate.

3) Stratigraphy and structure

The thickness is about 60 m in the northern part, and about 70 m in the central part of the basin. The beds are almost horizontal and no disturbance of the beds has been recognized. But there is a small-scaled anticlinal structure with the axis of the direction of N-S direction in the southwestern part of Midalt. In the micritic limestone located about 2 km southeast of Itzar, fossils or braquiopode have been found. The relation to the underlying T_1 Mudstone Formation is conformity.

(3) T_3 Sandstone Formation

1) Distribution

This formation is distributed along the foot of the Moyen Atlas range at the north of Itzar, and also on Mt. Miydalt located between Zayda and Midalt.

2) Lithology

This formation is composed mainly of grey or yellowish grey, hard and often well-bedded siltstone, sandstone and mudstone. Along the hill-foot of the Moyen Atlas range, calcareous conglomerate beds are inserted in this formation.

3) Stratigraphy and structure

This formation covers conformably the underlying T_2 Marl Formation, the thickness is about 45 m.

2-5-2 Quaternary System

The Quaternary system distributed in the surveyed area is divided, from the lowest, into Q_1 Siltstone Formation (Diluvial), Q_2 Siltstone Formation (Alluvial) and Q_3 River Sediments.

(1) Q_1 Siltstone Formation

1) Distribution

This formation is extensively distributed occupying large area in the southern part of the surveyed area, at the hill-foot of northern side of the Hault Atlas range. Also, it is distributed in small scales along the hill-foot of the Moyen Atlas range in the northern part of the surveyed area.

2) Lithology

The lower part of this formation is composed of colorful siltstone such as pale yellow, green, brown and so on. The upper part, about 20 m thickness, is composed of the alternation of conglomerate and siltstone. But, in the area near hill foot, lower part contains many sandstone and conglomerate and, in places, is composed of sand and gravel beds.

3) Stratigraphy and structure

The maximum thickness is thought to be about 100 m, viewing from the outcrops. It is known from the data of the already-completed diamond drilling that the thickness of this formation is about 150 m in the south of Bou Mia. The relation to all the underlying rocks is unconformity.

(2) Q_2 Siltstone Formation

1) Distribution

Q_2 Siltstone Formation is distributed in the low land in the central part of the basin, forming alluvial plains in the east of Bou Mia, in the northeastern part of Assaka-n-Tabhirt and in the west of Midalt.

2) Lithology

This formation is composed mainly of white or brown weakly-bedded silt. Conglomerate beds which are rarely developed as insertions are like concrete, cemented with calcareous materials.

3) Stratigraphy and structure

The thickness of this formation is about 20 m generally. The relation to all the underlying rocks except Q_1 Siltstone Formation is unconformity.

(3) Q_3 River Sediments

These sediments are distributed along all the rivers in the basin. It is composed of siltstone, sandstone and conglomerate, which are the youngest sediments.

2-6 Effusive Rocks

As effusive rocks, there are Permo-Triassic basalt lava and β_{Q2} Basalt lava belonging to the Quaternary system.

As the outline of the basalt lava correlated to the Permo-Triassic system is stated in 2-2 β_{P-T} Basalt Formation, only the description on the β_{Q2} Basalt lava is given here.

(1) Distribution

The β_{Q2} Basalt lava is found as lava flows at the exposures about 20 km north-north-east of Zayda in the surveyed area. The center of the effusion is situated in the Moyen Atlas range at the north of it, and the above exposure is corresponded with the southern end of the lava flow which is seen extended about 10 km. There is a round lava dome about 1 km in diameter, at the place about 5 km northeast of Zayda. Also, the Basalt lavas are found scatteringly as round hills several hundred meters in diameter on the topographical highs located about 7 km southwest of Zayda. The similar sort of basalt lavas about 3 km in diameter can be found at the place about 3 km east of Bou Mia. In addition, small-scaled distribution of Basalt lava has been recognized at the north of the Bou Mia Granite Body.

(2) Lithology

The βQ_2 Basalt is generally dark-colored, fine-grained and compact in characteristics, and vesicles are developed well. It is partly vitreous. Sometimes olivine can be observed megascopically.

(3) Stratigraphy and structure

Covering the Q_2 Siltstone Formation, this Basalt lava flew out before the formation of the present river sediments. Pebbles on the surface were caught and taken into the lava when it was flowing out. It is partly brecciated. Along the margin of the lava dome, the thickness of the flow decreases and the lava flow contains abundant vesicles there. Finally, what can be found on the surface are only pebbles of lava with several centimeters. Many faults are found in the area where this basalt lava is distributed at the north of Bou Mia. The lava plateau at the east of Bou Mia, the ring-shaped lava dome at the southwest of Zayda, and the lava flow at the southwest of Zayda, and the flows of lava at the northeast of Zayda are seen to be roughly arranged along a line of the direction of N 30°E.

2-7. Geological Structure (Refer to PL. I-4)

The geological structure in the survey area is composed of the Basement extensively occupying the central part of the surveyed area and the sedimentary rocks including the P-T Red Sandstone Formation and other later sediments which covers the Basement, in addition to groups of faults dislocating and deforming the above-stated rocks.

2-7-1. Structure of the Basement and the Covering Sedimentary Rocks

The Basement Rocks are composed of the Crystalline Schists and the Granites, which were affected by the Hercynian orogenic movement.

The Granites are extensively exposed in the area of 400 km^2 in the east of Zayda and in the area of 300 km^2 in the west of Bou Mia, in the surveyed area. It is estimated from the results of the geophysical prospecting that, as for the Granites, the two Granite Bodies would be belonging to one oval shape unit including these two bodies, extending in the direction of N 75^{o}E, approximate size being 30 km in north-south and 60 km in east-west.

The beds of the P-T Red Sandstone Formation were accumulated in and around depressions formed by weathering on the surface of the Basement Rocks. The region including the areas occupied by this P-T Red Sandstone Formation is situated in the southeastern end of an inland-basin called Karrouchan basin zone, which was formed at the northwest of the surveyed area in the Permean to Triassic period.

It is said as a result of regional geological study (H. Lorenz, 1976) that the Karrouchan basin has non-symmetric structure, as the sudden depression is recognized in the south-eastern part of the trough-like basin extending in the direction of NE-SW.

In the area at the northeast of Karrouchan, where the area used to be low-land, there are accumulations of thick beds of arkose or coarse-grained sandstone belonging to the P-T Red Sandstone Formation, the source material of which were supplied from the areas of Zayda and Bou Mia Granite Bodies.

The direction of sedimentation in the southeastern part of Zayda is from south to north, according to the geological evidences as cross-laminae, sole mark etc. observed in the present survey in addition to the study of paleochannels in the vicinity of Zayda (J.M. Schmitt).

On the contrary, in the area to the south of Zayda --- Bou Mia, it is not arkose sandstone but mudstone and marl that have been caught by the diamond drilling of the hole No. HM-1, and HM-2, and no fluvial or fan deposits have been found in this area, although details of the sedimentary structure are not certain mainly because of the covering of the younger sedimentary rocks.

The P-T Red Sandstone Formation has basalt lava flows on its uppermost part in general, which are distributed in quite an extensive areas by several effusion. Though there is no covering of the basalt lava in the area where the plateaus of comparatively high level had been formed on the basement, the horizontal accumulation of this basalt lava, due to its remarkable fluidity, provides an important key bed in the present surveyed area.

The Jurasic limestone beds, which overlie the above-mentioned formation are seen occupying parts of the afore-said Karrouchan basin, too. Another thick limestones were also accumulated in accordance with the subsidence of the younger graben formed in the Haut Atlas region in the southern part of the surveyed area. But, in this period, some parts of the Basement would have been left as lands in the form of a island with a elongation of NE-SW direction including the Zayda Granite Body. There is no covering of the Jurasic sediments.

There was another marine regression after that, but by the new transgression in the middle Cretaceous period, the entire area was placed below water level.

The Cretaceous system has little been found in the areas of the Moyen Atlas range and the Haut Atlas range, but is distributed around the Basement in the basin area in the central part of the surveyed area. The Cretaceous system has been found continuously to be lying almost horizontally or with gentle dipping on the slope of the hill composed of the Basement, that is, the distribution is seen extensively at the north of Zayda - Bou Mia, in the Midalt area, in the southwestern part of the surveyed area and in the western part of it. At the north of Zayda -Bou Mia, the Cretaceous system has been found to be in the form of gentle syncline structure around the town of Itzar, while gentle undulation accompanied by three synclinal axes of the direction of NE-SW can be recognized in the Midalt area.

The Tertiary system is generally found to be developed in the form of almost horizontal monotonous sediments in the basin, except for the area in the Moyen Atlas range at the northwest of Itzar, where the Tertiary system is recognized to compose synclinal structure. As a whole, the system is constituted with the beds thick and conglomeratic in the north while silty or marly in the south.

On the contray to the above-stated Tertiary system, Quaternary sediments are developed thick in the area along the hillfoot of the Haut Atlas range in the southern part of the surveyed area.

2-7-2. Fault Structure

The granites gave contact metamorphism to the Crystalline Schist at the time of their intrusion. It is thought that the oval-shape granite body occupying most of the surveyed area has formed a sort of craton, including the surrounding zone of the width of several hundred meters or several kilometers.

Along the approximate limit of this craton-like Basement Rock Body, the following three groups of faults are developed.

(1) The fault of the direction of NE-SW running through Sidi Yahia, located about 4 km east of Karrouchan in the northwestern part of the surveyed area, and Aït Oufalla, located about 6 km north of Itzar. (This fault is

temporarily called to be Yahia - Oufalla Fault hereunder)

(2) The fault of the direction of N80°E, which corresponds with the southern limit of the surveyed area, that is, northern limit of the Haut Atlas range zone. (This fault is temporarily called to be Haut Atlas Northside Fault.)

(3) The Amhrou fault, the direction of which is N50°E, passing through Mibladane in the southeastern part of the surveyed area.

These faults are parallel to the following trough structures distributed around the central Basement Rock Body --- that is, the trough structure of the Permo-Triassic period in the Moyen Atlas range zone the trough structure developed in the Haut Atlas range zone in the Mesozoic age, and that branched from the latter to the direction of northeast. The Yahia-Oufalla fault and the Haut Atlas Northside fault were formed at the period of the Tertiary Alpine orogeny, along the main tectonically-weak zone in the Basement Rocks.

Other than the above-stated fault-structures distributed in the marginal zone of the surveyed area, there are many faults developed in the approximate direction of N30°E in the central part occupied by the Basement. These faults, including the Souk El Ajar fault, are distributed in parallel pattern with the interval of 3 to 4 km, extending over ten kilometers. Among them, the Ilich Azougagh Mylonitized fault zone is a fracture zone with the approximate width of 400 m. This zone is accompanied by the graben-like depression filled with Cretaceous sedimentary beds, at the southern end of the zone. Therefore, it is thought to be suggested that the period of the formation of this fault zone is post-Cretaceous, probably at the time of the Alpine orogeny. The direction concerning these faults changes gradually from N30°E to almost N-S in the area occupied by the Bou Mia Granite Body in the western part of the surveyed area. They are seen to have cut the Cretaceous sedimentary beds, too. However, the relation of these faults to the Tertiary system is not obvious.

Most of the faults are found to have dislocated the beds upward and downward, forming graben and horst structures. Lateral dislocation by these faults has seldom been found though observed rarely. If any, it is seen with the faults of the direction of N30°E or N-S in general, where the western blocks are dislocated southward (correlatively the eastern blocks northward), so far observed.

The directions of the structure in the Basement Rocks are represented by the dykes of granite porphyry closely related to the uranium mineralization as well as by the trend of ore veins such as quartz-galena-barite ore veins.

Among the dykes, those distributed in the northeastern part of Zayda are of the direction of N20°-40°E, and the dykes of granite porphyry located about 3 km at the southwest of Bou Mia are of the direction of N10°W. As the intrusion of these dykes is roughly at the same period of the formation of the Granites, it is thought that the dykes would have intruded along tectonically-weak zone formed during the cooling of the granite body.

Meanwhile, there are many ore veins of the approximate direction of east-west as seen with those distributed at Sidi Ayyad and in the southern part of the Zayda Granite Body, in addition to the ore veins which were formed by filling fissures of the approximate direction of N50°E, as shown by the above-stated group (3), represently by the Henri ore vein in the eastern part of the surveyed area. It is recognized that both of these fissures are cut and dislocated by the faults of the directions of N30°E to N-S.

The fault and fissure systems in the present surveyed area are very much complicated due to several tectonic movements from Hercynian orogeny to Alpine orogenic movement, though rough classification would be possible as tried in the above-stated way.

2-7-3. Structure to be noted for the Exploration

(1) The followings are the geological structures related to uranium ore deposits, to which attention should be paid.

1) Source rock and terrestrial sedimentary rocks. The Granite Body, as the source rock of uranium, is distributed in comparatively extensive areas. Around the Granite Body, there is an sedimentation of the P-T Red Sandstone Formation including arkose sandstone, with gentle inclination. Especially the distribution of this formation is found along the north of both of the Zayda and the Bou Mia Granite Bodies and also at the west of Bou Mia.

2) Basin structure. The beds of the P-T Red Sandstone Formation would have been deposited toward the Karrouchan basin in the northwestern part of the surveyed area, and it is thought that the uranium would have been transported, associated with the materials of these sedimentary beds. Through the orogenic movement, which occurred in the region of the Moyen Atlas range at the period of the Alpine orogeny, the northwestern side of the Yahia-Oufalla fault was uplifted to higher position than the other southeastern side. Caused by this movement, a basin structure appeared in a zone from Bou Islikhane, at the north of the Bou Mia Granite Body, to Itzar. This basin structure (which is temporarily called to be Itzar Basin Zone) is structurally significant as it would have played a role to concentrate uranium in the red sandstone, and also it is expected that the basin, due to its closed structure, would have provided a reducing environment required for the fixation of uranium. In addition to the above-mentioned, it is estimated by the gravity survey that there is another basin structure formed on the basement. This basin is located about 6 km south of Bou Mia. Around there the existence of paleochannels on the basement

has been inferred, in the direction for the materials to be flowing into the basin.

3) Graben Structure. Concerning the indication of the uranium mineralization along the Ilich Azougagh Mylonite zone in the Zayda Granite Body in the Assdka Idijy sector, it is possible to expect that the concentration of uranium would have occurred in the graben structure formed between the two parallel faults, as afore-stated. In the western part of the Bou Mia Granite Body, actual existence of anomalous part of radioactivity has been recognized in a small graben found in the Granite Body.

Of the graben structures, that found in the Bou Islikahne area is conspicuous, where gentle dipping synclinal structure has been recognized in the graben formed between two parallel faults with the approximate interval of 4 km in east-west. The axis of this syncline plunges to the north and the entire graben looks to form confluence into the afore-stated Itzar Basin Zone.

4) Vein-like Structure. The vein-like structure containing indications of anomalies of radioactivity can be found abundantly in the Sidi Ayyad sector and in the area to the northeast of Zayda. The trends of these vein-like structure are predominantly N20°-40°E. The fracture zones are recognized to have been filled with brown iron-quartz, occasionally with dykes of granite porphyry and microgranodiorite.

In such dykes, uranium is contained originally a little, and therefore, it is thought that the uranium would have been deposited along fractures, concetrating from such dykes itself and the vicinity, after the faulting movement to form such fractures along the dike rock. Then, it would be possible to expect enrichment of uranium at the depth.

The above-stated facts are the structures of comparatively large scale. The favorable structures for the concentration of uranium may be in many cases, for example; combination of the structure of surface of the Basement with the sedimentary rock's structure, etc. Detailed examination of the geological structures would be necessary in each case, and every area.

(2) As for the lead ore deposits, the geological structure for the attention to be paid is different in each of the types of the lead mineralization; Zayda type, Mibladane type and Hawli type.

For the confirmation of the geological structure concerning the Zayda type ore deposits, it is necessary to ascertain paleochannels or to clarify paleogeographic structure as location for the sedimentation of arkose sandstone at the base of the P–T Red Sandstone Formation. Therefore, the sedimentary structures of the Red Sandstone Formation around the Zayda and the Bou Mia Granite Bodies are important. The problems are similar to those of the geological structures for the emplacement of the uranium, as aforestated, and so, the favorable area for the uranium mineralization is the area to be noted as favorable area for the lead mineralization. The difference is that lead ores would have been precipitated in such zone near to the granite body, while uranium would have been transported far from the granite body.

As for the Mibladane type mineralization, detailed geological survey is necessary for the confirmation of the geological structure, as the localization of ore deposits is thought to be controled by the fault structure and by the folding structure to form minute fissilities as well as by the distribution of the beds from Jurassic Lias series to Cretaceous Cenomanian series.

The Hawli type lead ore mineralization is represented by the group of veins including Henri ore vein as the main vein. The Marbout vein in the

Sidi Ayyad sector is under exploration at present. They are the ore deposits formed by filling faulting fissures. They are frequently dislocated by later faults. Detailed geological investigations on the surface and the underground are necessary.

2-8. Age of Rocks and Geological History

2-8-1. Results of Age Determination of Rocks

Isotopic analysis for age determination by K-Ar method was carried out on three rock samples collected from such parts of different lithofacies of the granite body distributed in the central part of the surveyed area. (Refer to Table I-5) The results are as follows;

Sample No.	Rock	Area where samples were collected	Age(m.y.)
1B04	granite	east of Zayda	307 ± 11
2B29	porphyritic granite	west of Bou Mia	306 ± 11
1A11	aplitic granite	east of Zayda	300 ± 11

Meanwhile, age determination was attempted by D. Tisserant (1977) by Rb-Sr method on the samples of the basement rocks collected at the standard points in the country of Morocco, and among the results of this age determination, the isotopic ages of such rocks as those concerning this surveyed area have been reported as follows;

Rock	Age(m.y.)
granodiorite	336 ± 17
alkalic granite	316 ± 6
calc-alkalic granite	309 ± 5

Rock	Age (m.y.)
graphic granite	294 ± 4
aplitic granite	303 ± 9
pegmatite	298 ± 9

The rock called "alkalic granite" in the Tisserant report coincides with granite in the present report, and "calc-alkalic granite" and"graphic granite" are corresponded to "aplitic granite" in this report.

The above-mentioned results of the age determination would indicate chronologically that the age of these rocks are corresponded with the Hercynian orogeny in the later Carboniferous period of the Paleozoic Era. It is interesting for the consideration of the formation of whole of the granitic rocks that the result of the age determination is suggesting the intrusion of the granodiorite, which is distributed at the northeastern end of the Zayda Granite Body, is the earliest of the intrusions of all the granitic rocks.

Also, the results of the age determination of the samples of the β_{P-T} Basalt Formation, positioned geologically at the uppermost part of the Permo-Triassic system, which was carried out by Geochron Laboratory, have been reported by J. Lorentz (1976). Followings are the results;

	Whole Rock analysis	Plagioclase analysis
Sample 1	192 (m.y.)	199 ± 21 (m.y.)
Sample 2	192 (m.y.)	213 ± 24 (m.y.)
Sample 3	166 (m.y.)	179 ± 11 (m.y.)

The above results of the age determination indicate the age of later Triassic period. Accordingly, it is possible to correlate the geological age of the

P-T Red Sandstone Formation to Permo-Triassic period.

As for paleontological age determination, there is a fact that the end of Triassic period has been indicated with the red sandstone by the result of pollen analysis (A.F. Mattis, 1977) contained in the red sandstone formation distributed in the Ourika Basin, which is about 300 km southwest of the present surveyed area and has similar geological environment, although there is no discovery of any fossil helpful for the correlation of ages in the P-T Red Sandstone Formation distributed in the present surveyed area.

As for Jurassic sediments, *Hesperithyris renieri*, which is indicating middle Lias epoch, has been identified, in the fossil enclosure containing gastropods and bivalves, situated about 30 to 40 m below the ore horizon around the Mibladane mine. Also, in its overlying beds, fossils of brachiopods such as *Rhynchonella aff. meridionalis Desl.*, *Rhynchonella batalleri Dub.* and *Terebratula vari. Rou.*, indicating Toarcian age of the upper Lias epoch, have been identified. In addition, in the Dogger series unconformably overlying the above sediments, there is a bed containing pelecypoda fossil of *Posidonomya alpina* as well as spicules of echinoids and fragments of *Belemnites* (R. Felenc, Colloque, 1965), and there are many comparatively detailed study as to the corelation of Mesozoic formations.

2-8-2. Geological History

As for the Basement rocks, the age of the intrusion of the Granites is indicated, as mentioned above, to have been in the later Carboniferous period of the Paleozoic Era (at the period of the Hercynian orogeny), but the age of the Crystalline Schists, which were intruded by the above granites, has been left uncertain. Concerning the intrusion of Granites, the granodiorite distributed at the northeastern end of the Zayda Granite Body was consolidated in the earliest stage, by the results of the isotopic age determination as stated above, and after that it is estimated that the granite and the aplitic granite were consolidated in this order, though age gap would have been very little. The aplitic granite is occasionally of irregular form, but in general it is distributed as a sheet in a shape like an upsidedown dish in the western half of the Zayda Granite Body. It is thought that the material of alkalic composition would have been gathered together as sheets in an upper part of the rock body of the granite in the process of the cooling after the intrusion of the granites. The arkose sandstone at the base of the P-T Red Sandstone Formation is distributed in the area up to the hillside of the hilly land composed of the Granite Body, which shows that this aplitic granite body was exposed on the surface as extensive as it was weathered and eroded out. By the result of the measurement of radioactivity, the aplitic granite distributed in this area has a little higher value of the radioactivity compared to that of the other granitic rocks. The dykes, which intruded the granite body after the consolidation are distributed mainly in the northeastern part of Zayda and in the Sidi Ayyad sector, where, it is regarded, the marginal zone of the Granite Body is exposed. The dykes are less found and if any, they are inferior toward the central part of the Granite Body, and therefore, it is thought that the fissure system found in the Granite Body would have been formed during the consolidation period.

The detrital sediments formed through the weathering and the erosion of the Basement rocks were accumulated under the continental environment, and arkose sandstone containing much of iron oxide minerals was formed in the depressions and along the rivers on the Basement. In the Permo-Triassic periods, when the above sedimentation would have taken place, a trough-like sedimentary basin called Karrouchan basin was formed, as an inland basin, in the direction of NE-SW, in the northwestern part of the surveyed area. (At the almost same time, the Ourika basin was formed about 300 km southwest of this basin. The Ourika basin also has structural trend of NE-SW system and the Karrouchan basin is situated on the northeastern extension of the above trending. There is no exposure of the P-T Red Sandstone Formation in the area between the two basins and therefore, the continuity has not been confirmed, but it is recognized that the two basins are related geo-structurally.) The width of the Karrouchan basin in NW-SE is approximately 40 km. The particularity of this basin is seen in the fact that the basin has non-symmetric basin structure, caused by the sudden subsidence of the southeastern part of it. In this southeastern part, great amount of detrital sediments derived from the granite body were accumulated, while pieces of the crystalline schists and the sediments of the lithofacies composed mainly of micas are occupying the northwestern part of the basin, on the contrary. The grain size of the sandstone changes gradually from coarse to fine, according to the horizontal position, upward from the bottom, and in the uppermost part of it, the sediments are found to be mudstone, which is seen to cover whole of the area. In the northeastern part of the Karrouchan basin, coarse to medium-grained sandstone beds are observed to be as thick as more than 100 m in some places, but along the zone around the Zayda and the Bou Mia Granite Bodies, mudstone bed has been found to be directly overlying the arkose sandstone. The mudstone is overlain extensively by the β_{P-T} Basalt Formation, the age of which has been determined to be later Triassic period. As pillow lava structure, which is an evidence that the lava flow out in water, has been found very little of this basalt lava, and thin layers of gypsum and conglomeratic insertions can be observed, it is estimated that in the basin there would have been a little lacustrine water at the time or that the basin was under the condition to form small local lakes seasonally. After the effusion of the basalt lava, marine transgression of the Lias epoch of the Jurassic period occurred. The invasion of marine water came to this surveyed area from the direction of eastnortheast, and further extended to the points about 200 km southeast of the area. As the central part of the present surveyed area was constituting high plateau, no sedimentation of Jurassic sediments has been recognized, and the Jurassic beds found around this area are composed of shallow-water sediments such as marls, shales and limestones containing abundant fossils of corals. However, in the Haut Atlas range zone in the southern part of the surveyed area, a deep trough of the direction of NEE-SWW was developed, and particularly in the Dogger epoch, dark grey mudstones showing abyssal lithofacies were accumulated in the central part of the trough.

In the Turonian epoch of the late Cretaceous period, there was another large scaled marine transgression in the area around present surveyed area, and the entire area including the area occupied by the Basement rocks was submerged below sea level. The beds of the K_2t Limestone Formation was thus accumulated. In the Cenomanian epoch just before the above period, the K_2cm Mudstone Formation composed of red mudstone, grey sandstone and dark grey mudstone was accumulated in the surveyed area. This Formation is distributed everywhere in the surveyed area, and it has comparatively large amound of gypsum layers as insertions. Therefore, it is estimated that the sedimentary environment of the member would have been of shallow lucastrine sedimentation type, characterized by the repetition of the dry condition and the submerged conditions. There are abundant fossils of bivalves and gastropods contained in the K_2t Limestone Formation. Especially, these fossils are found abundantly in such beds of this Formation as distributed around the granite bodies. Although it is recognized that there would have been geological episodes such as marine transgression and regression as well as the development of troughs in the north and the south, in the sedimentation of the beds belonging to Permo-Triassic system to Cretaceous system, the sediments were accumulated in comparatively stable condition without accompanying violent movement such as tilting etc., as a whole, and therefore large scaled unconformity has seldom been recognized along the boundaries of the formations. It is between Jurassic system and Cretaceous system in the Haut Atlas range zone in the southeastern part of the surveyed area that the unconformity has been recognized. I. Evans (1976) reported the study results that the movement was kept in the sedimentary basin during the period of the formation of the Jurassic system.

The largest movement, by which the above-mentioned frames of the geology were affected, was the Alpine orogeny in the Miocene epoch of the Tertiary period. The entire country of Morocco was uplifted to form land, and to say about the effect of the orogeny in this surveyed area, both zones of the Haut Atlas range and the Moyen Atlas range were upheaved and deformed through faulting and folding by the pressure in the direction of north-south. A fault system of the direction of nearly N30^{o}E was developed in the basement area of the central part.

As mentioned in the paragraph 2-7 Geological Structure, many faults accompanying dislocation mainly of upward and downward were formed apart from the Yahia -- Oufalla fault in the Moyen Atlas range zone, and in some part, the elevation of the basement became higher than that of the central Zayda area. The Haut Atlas range zone was affected by the more intense movement and some overturned faults are recognized. At present, this zone is seen to have constituted mountainous belt of the altitude of more than 3,000 m. During such orogeny in the Tertiary period, the area in and around this surveyed area became an inland basin through the uplifting of the surrounding areas, and siltstones, marls, and conglomeratic sandstone were accumulated.

The same things can be said roughly with the Quaternary sediments, but it is thought that it shows the precedence of the upheaval of the Moyen

Atlas range to that of the Haut Atlas range that the Tertiary conglomeratic sediments are greater in thickness in the northern part and are rather fine-grained in the southern part.

The Tertiary sediments are composed mainly of the material derived from the surrounding areas, and any sedimentary bed of the detrital rocks derived through the weathering of the granite mass has not been found yet. This fact is indicating that, after the sedimentation of Jurassic system, the Tertiary system and the later sediments were accumulated without erosion of the granite mass, and that it would not have been before Quaternary period that the basement rocks appeared on the surface to be exposed.

The effusive rocks of the β_{Q2} Basalt lava are seen to have been directly overlying the Granites. It is observed that these effusive rocks are in the form of lava flow, and that their distribution would have been controled by the present topography, and therefore it is evident that the activity of this extrusion was quite recent.