Economical Geology
Of Comoros

Anjouan, Moheili, and Grande Comore Islands

Volume 2

PARS KANI

MINERAL INDUSTRIES RESEARCH & DEVELOPMENT Co.

August 2009

An Overview

1. Introduction

The preliminary geological research in winter 86 that last for 10 days by the geology-managerial team of Pars Kani Company in Comoros evaluated all geological data and mining conditions of this country. The major problem in doing so was the shortage and in many cases the lack of basic information about the geology of the country and mineral potentials including metallic and non-metallic resources. In this process and after having gathered and reviewed all existing data by Pars Kani, the project requirements have been specified, written out, and presented based on geological and mineralization conditions in order to produce and compile a preliminary base geological and mineral exploration map. Therefore, suggested descriptive list of services in form of a contract was prepared and presented to Comoros authorities, which then finalized and signed by both parties on 09 August, 2009.

The timetable of the contract indicates that provided all necessary tools and facilities are available, the project would take six months to be carried out, however, due to some roadblocks the job was accomplished within 12 months, and its outcome is now presented in three sections as it follows:

1- Geological map with scale of 1:50000
2- Preliminary mineral explorations
3- Executive recommendations in mining industry sector

2. Goals

As there had been no fundamental data on mining and geological conditions of the area, the mineral explorations managed by Pars Kani Company in Comors was the very first of such operations that was carried out and reported in Comors. In a nutshell, the purpose of the project based on the defined goals, was to explore, locate and exploit mineral deposits that could lead to increase in national income, job opportunities, economical stability and entering to global mineral markets. The followings have been the main goals of this operation:

- Preparing the base geological map with the scale of 1:50000
- Identifying all promising zones for metallic minerals
- Identifying all promising zones for non-metallic minerals

- Assessing the tonnage of mineral deposits and prioritizing them for additional exploration operations
- Defining PFS designs for the promising zones (Pre Feasibility Study)
- Presenting detailed operation plan based on priorities

The report comes in five sections to cover all of these goals:

1- Section one: geographical and morphological situation and previous studies
2- Section two: general geology
3- Section three: reviewing economical geology
4- Section four: introducing "PES" plans
5- Section five: suggestions

3. Methodology

Methodology applied in some areas where there is lack of information about petrology and basic exploration data was a big issue. In order to make most of the available time and facilities, the following method was applied:

-Collecting all data including geographical, geological, etc. about the studied area (from Madagascar to Mozambique)
-Gathering satellite information and processing them
-Comparing this area with other areas in the world that have similar petrology characteristics
-Choosing to do preliminary sampling in two forms of rocks samples and heavy minerals so as to cover the watershed basin in the whole area
-Checking out all heavy minerals and identifying economical minerals i.e. metallic, non-metallic and precious stones
-Studying heavy minerals and identifying economical minerals including metallic, non-metallic and precious stones
-Studying rock samples and identifying non-metallic resources
-Providing preliminary maps for promising zones based on all inputs and the extension of the area according to integration of all mineral and geological data

All promising mineral areas for metallic and non-metallic resources were identified in order to be worked on later in the second stage of the operation and based on the priorities.

1-Chapter One

1-1-Geographical Situation

Comoros is a series of islands located in the southeast of Africa in Indian Ocean, east of Mozambique and southwest of Madagascar with geographic coordinates of 12°10' southern latitude and 44°10' eastern longitude. Comoros is derived from the Arabic word "Al-Ghamar" meaning "moon".

The capital city is Moroni. The area of the country is 2170 square kilometers which is covered with land. It has 340 kilometers of shoreline with a hot and humid climate which is due to being surrounded by Indian Ocean and proximity to the equator. Its rainy months last from November to May.

The highest point of the country is Karthala Mountain with 2360 meters high and the lowest point is Indian Ocean beach at 0 meter level.

Comoros consists of several active volcanic islands and the main islands are Grand Comoros (1150 square kilometers-the biggest), Anjouan and Moheili.

The country is formed of seven districts which are governed by federal law. Its capital is Moroni located in Grand Comoros Island. Figure 1-1 shows the location of these islands in relation to each other.

Figure 1-1-Comoros islands locations.

1-2-Roads and Communication

The country has 880 kilometers of roadways and four airports. It has 16900 land line phones and 16100 mobile lines, and 20000 people use internet.

1-3-Historical Geography

The primary descendants came from Polinzi islands. The country was conquered by Moslems and the people had a tendency towards Islam. Islam was brought to this place from Persian Gulf by some people including businessmen from Shiraz. France colonized this country from 1843 and it became the official colony of France since 1912 and it was joined to Madagascar (Malagasies) governed by France, however, Comoros called for its economical independence in 1971. The country witnessed unilateral independence by its parliament in 1975. Some western European countries, Saudi Arabia, Iraq and Kuwait started a political and economical relationship with this country in 1979. Comoros which had disconnected from United African Organization after a coup rejoined this organization once again in the same year.

1-4-Human Geography

Comoros has the population of 690948 (revealed in 2006) of which 30% live in the cities (10% in the capital city). Population growth is 30% and the population density is 215 individuals in each square kilometer. Statistics in 1998 showed that the population was 546000 and it is predicted to reach 782000 in 2010. Of this population, 42.7% are less than 14 years old, 54.3% are between 15 and 64 and 3% are more than 65 years old.

Comoros people are from Sakalva, Oimatsaha, Mokoa, Cafre, and Antalote races. The population is mainly African, but there are two groups of immigrants there: one group from Africa shores, Madagascar, Iran, India, and the second group come from Portugal, Netherlands, and France.

98% of the population is Sunis Moslems and 2% are Catholic. The official language is Arabic, but people speak in French and Shikomoro, too.

1-5-Previous Studies

The investigations show that there had been no comprehensive research on providing a geological map and systematic mineral explorations. The studies, however, come in the following as they illustrate the only identifiable minerals are sand, gravel and construction rocks found and exploited in some areas.

1- Class et al, (1998), the process of plum-Lithosphere interactions in the Ocean basins, the case of Grande Comore, Journal of petrology, 39 (5), 881-903

2- Cottorti et al 1999, carbaratite metasomatis in of the oceanic upper mantle: Evidence from clinoPyroxenes and glasses in ultramafic xenoliths of Grande Comore, Indian Ocean journal of petrology, 40 (1), 133-165

3- Flower, R.F.J. 1972, petrology of volcanic rocks form Anjouan, Comoros , Bulletin volcanologique, 36 (1), 238-250

4- Flower, 1973, Trace element distribution in lavas from Anjouan and Grande Comore, western Indian Ocean, chemical geology, 12, 81-98

5- Strong, D.F., 1972, the petrology of the lavas of Grande comore, Journal of petrology, 13(2), 181-218

6- Savin, et al, 2001, Hydrothermal system mapped by CSAMT on karthala volcano/Grande comore Island, journal of applied Geophysics, 48(3), 143-152

7- Emerick C.M. and R.A. Duncan, 1982, Age progressive volcanism in the Comoro Archipelago, western Indian Ocean and implications for Somali plate tectonics. Earth Planet. Sci. Lett. 60: 415-428.

8- Flower M.F.J., 1973, Evolution of basaltic and differentiated lavas from Anjouan, Comoros Archipelago. Contrib. Mineral. Petrol. 38: 237-260.

9- Hajash A. and R.L. Armstrong,1972, Paleomagnetic and radiometric evidence for the ages of the Comoros Island, west central Indian Ocean, Earth Planet. Sci. Lett. 16: 231.

10 - Pavlovsky R. and J. de Saint-Ours, 1953, Etude Géologique de l'Archipelago des Comoros. Service Géologique, Tananarive, Madagascar, 55 pp.

11- U.S. GEOLOGICAL SURVEY MINERALS YEARBOOK—2003

12- U.S. Geological survey minerals yearBook—2005

13-Bachèlery, P. & Coudray, J., 1993, Carte Volcano-Tectonique de la Grande Comore (Ngazidja), Echelle 1:50,000. - Cooperation Francaise, CIRAD, Université de la Reunion.

14- Pavlovsky, R. & Saint-Ours, J. de (1953): Etude Geologique de l Archipelago de Comoros. - Service GeologiqueTananarive, Madagascar, 1-55; Tananarive. Stieltjes, L. (1988): Mayotte (Archipel des Comoros).-

15- Bureau de Recherches Géologiques et Minieàes, Carte Géologiques de la France. Notice Explicative,
1-135: Orleans, including geological map of Mayotte 1:50000; Orleans.

16- The Petroleum Geology and Geophysics of the Mozambique Channel

2-Chapter Two

2-1-General Geology

Comoros is located in the southwest of Africa, north of Madagascar, and the Mozambique Canal. This country consists of a series of mid-oceanic volcanic islands formed due to the action of hot spots in mantle and along the line departing Madagascar from Africa. These islands in a chronological order are Anjouan, Moheili, and Grande Comoros, which have many beauties in the eyes of volcanologists.

Anjouan and Moheili islands have one high peak with a large crater and some secondary craters which have been active in different times. These secondary craters can be divided into two Scoria cones and phreatic eruptions. The lava composition varies from Olivine basaslt, to picrite basalt and as moving towards the end of activity, the volume of Olivine basalt increased. Light green Olivine crystals are the characteristics of these rocks which can be found in different sizes.

The presence of large volume of explosive pyroclastics in form of bomb to pozzolan indicates that the eruption occurred close to water as the sequence of each eruption is explosive at first and then changes to lava flow. Since pyroclastics have been undergone weathering much faster and turned into laterite-bauxite clays specific to tropical areas, they have formed the soil of this land and therefore dense jungles grew on them. This matter has also been very effective in creation of farming lands and coconut gardens in and around explosive craters. Corals in the altitude of 30-50 above the sea level confirm that these islands have been active and increase in height has happened from the beginning.

Grand Comoros Island is important because of its vastness and young age. This island has two main volcanic craters named La Grill and Karthala and it seems to have two main eruption phases. La Grill peak is older and it is more alkaline in composition as its composition leans towards phenolite. La Grill includes mid to thin layers and thin very porous scoria Olivine basalt is which is extended into pyroclastic-pozzolan units. La Grill is a peak formed of very light pozzolan and it has a dense vegetation coverage that has made it the best suitable area for farming. Karthala which is an active volcano is the highest volcanic peak in this island with 2300 meters high. The last eruption of this peak occurred in 2005.

This complex includes pyroclastics and lavas with Olivine-basalt composition which have flowed from main craters as "A A" and secondary craters as "Pa ho ho" in the form of ropy**.** The type and extension of plantation can tell us the age of these lavas as the plantation coverage becomes better as we move from the younger to the older lavas. Karthala crater is a product of stair-like collapse due to many eruptions which have been active in form of scoria eruption, spatter, and Pele's tear-drops eruptions in the first phase, and the second phase formed the lava lake which cut through the southern part of the crater and caused a huge amount of "AA" lava to flow down from north to south. This flow destroyed all the jungles on its way and created a beautiful scene. There is large a depot of sulfur accompanied by sulfur steam on the southern part of this crater, which is a considerable resource on this island.

The northern and western slopes of Karthala have undergone a huge landslide as signs of scoria basalts from La Grill can be seen underneath, which could verify the old age of La Grill eruption.

3-Chapter Three

3-1-Economical Geology

As mentioned in chapter two, this country is formed by rocks and lava which are in the shapes of Olivine basalt and pozzolan layers. Field surveys and analyses indicate the mineral potentials of this country as it follows.

3-1-1-Olivine-bearing Sands

The geological characteristics of this country are in the way that Olivine grains can be seen even with naked-eyes after breaking a rock into pieces. However, the only deposit with economical benefits is located in the Grand Comoros Island. This island is on 11°44'53/1" geographical latitude and 43°27' geographical longitude. This deposit is located in the eastern part of the island about one kilometer from Pidjani village. Figure 3-1 shows the geographical situation of this deposit.

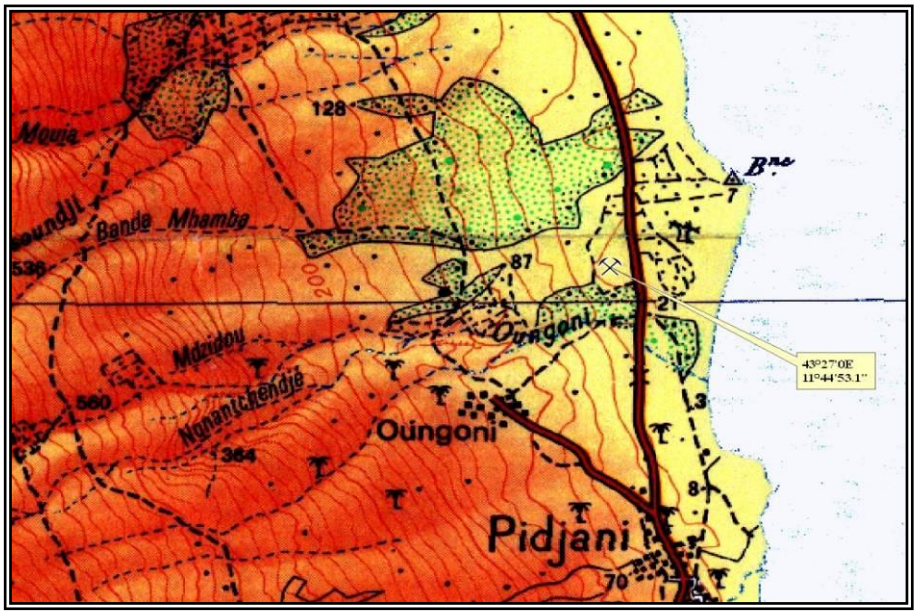


Figure 3-1-Geographic location of potential sandy Olivine deposit.

Geologically, this deposit is part of an alluvial unit that is a sequence of large conglomerate pieces to loose fine-grained sandstone. The amount of Olivine varies a lot, in other words, in some parts of this alluvial that are mainly fine-grained sands (a few millimeters), Olivine content can reach up to 40%, and the Olivine-rich parts are seen in forms of scattered lenses throughout this spread of alluvium. Based on the field surveys and findings the extent of this unit is about two kilometers. The samplings showed that in some

places within this sequence the grade is around 10% which can reach up to 40% and even 50%. Physically, these Olivine grains are semi-angular to circle, and their size varies from one millimeter to few millimeters. More than 90% of these grains come in this size.

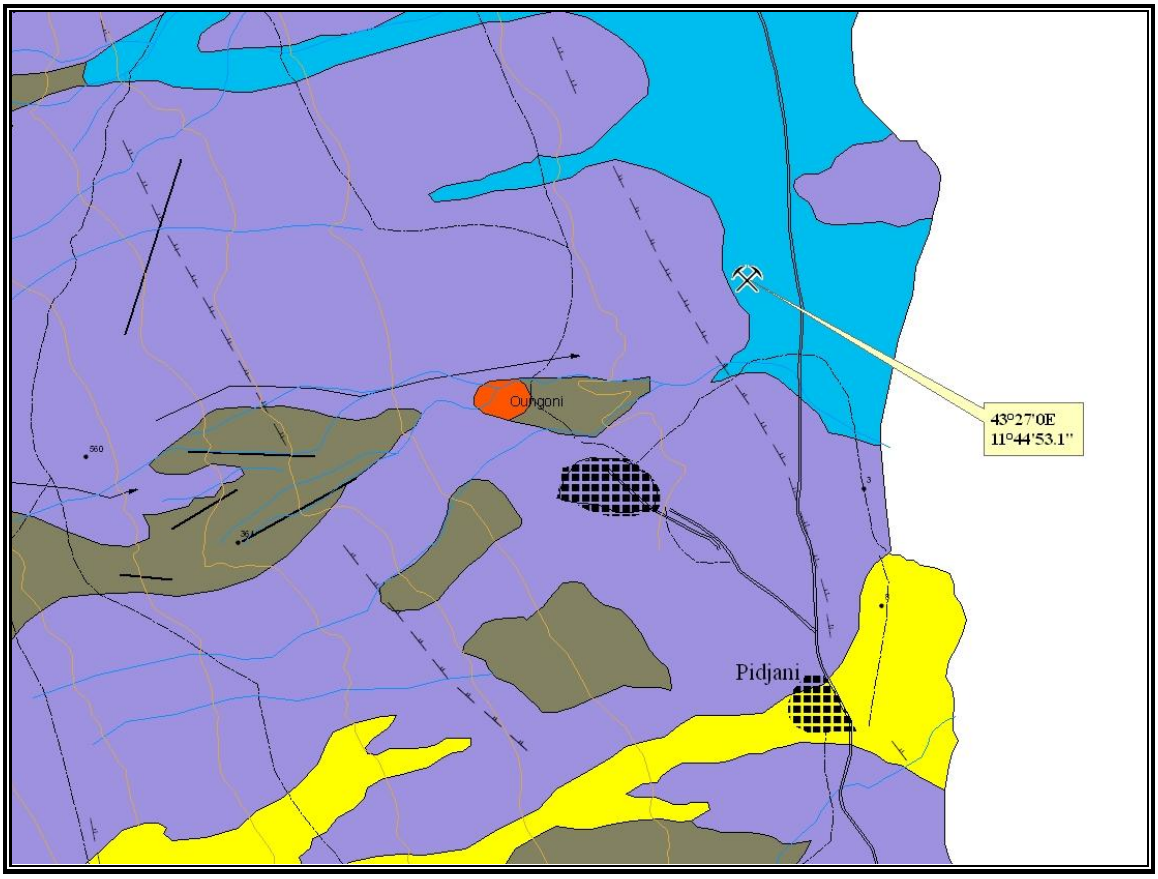


Figure 3-2-location of sandy Olivine deposits on the geological map.

Figure 3-1-A view of sandy Olivine alluvial spread.

Figure 3-2-A view of alluvial sequence of Olivine.

Generally a great share of Olivine of this deposit is of Forsterite type. We should mention here that Olivine (peridotite) is a general term for compounds with the formula (Mg, Fe) $_2$ SiO_4 whose versions rich in Mg is called Forsterite and rich in iron called Fayalite. Of course their composition changes in form of a continuous series. The minerals within this range with the increase in iron are chrusolita, Hyalosideolite, Hortonlite, and Ferro-hortonlite. Magnesium rich Olivine hardness is between 6.5 and 7 and its density is 3.2-4.3 g/c3. The density increases with the increase in the amount of iron. From the point of view of jewelry the best type of it is olive green. In the studied samples different types of Forsterite (honey color), Fayalite (black), and Olivine were found (appendix 1).

In some crystals, some spots of Hematite are found. The crystals are transparent or semi-transparent and in some of them Iddingsitic decomposition is seen. Some crystals have maintained their perfect crystal system. The size of grains varies from 1000 to 1410 microns, and in some parts between 250-350 microns.

Figure 3-3 Varieties of peridotite.

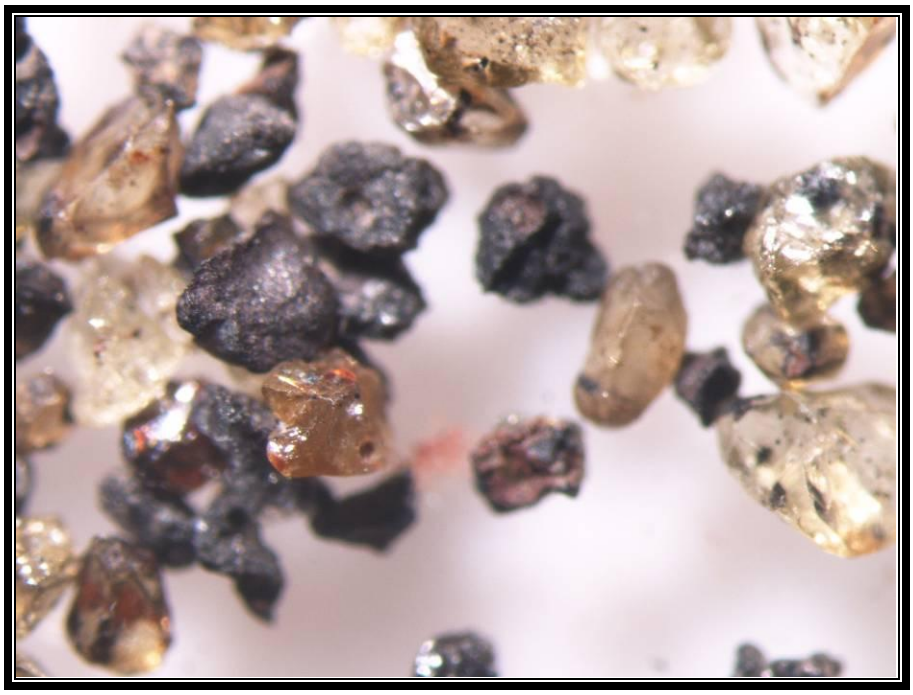


Figure 3-4 Varieties of peridotite.

Figure 3-5 Varieties of peridotite (Olivine, Forsterite, Fayalite).

Figure 3-6 Olivine.

Figure 3-7 Varieties of peridotite (Olivine, Forsterite, Fayalite).

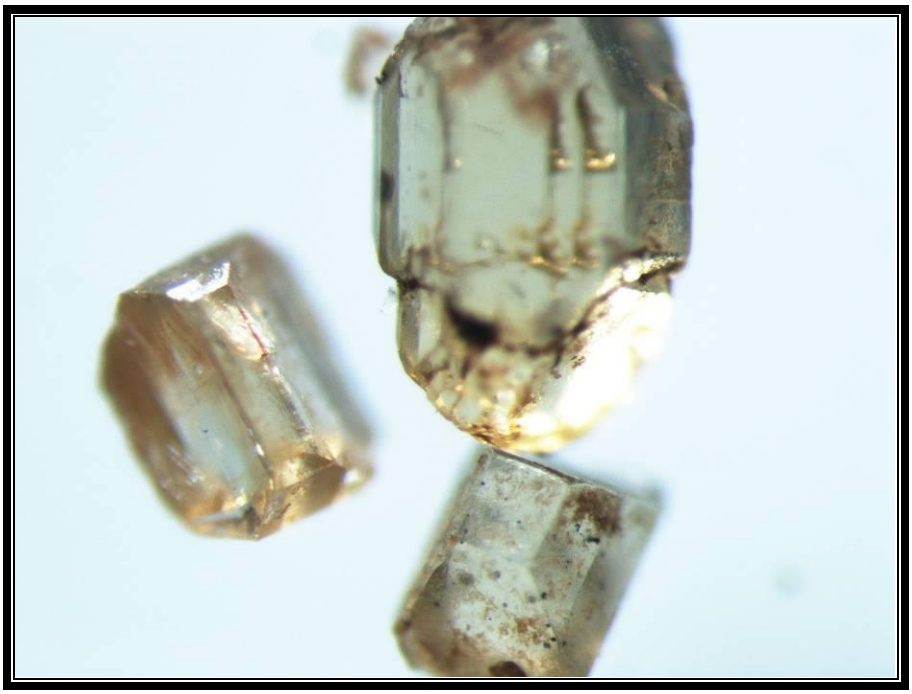


Figure 3-8 Forsterite (peridotite).

Regarding the extent of the alluvium unit in an area that is about 2 kilometers long and 500 meters wide and the thickness of at least 5 meters, the volume of the mineral deposit is at least about 5 million cubic meters. Considering the special weight of the alluvium constituents (Olivine 3.2 4.3) and pieces of rock (about 2 g/cm^3), in the most conservative way, if we assume the specific weight to be 2 g/c^3 (taking into account the alluvium conditions), the minimum tonnage is estimated about 10 million tons.

3-1-2-Spinel

The geological conditions of the country which are the results of frequent volcanic eruptions can potentially be the reasons for formation of precious and semi-precious stones deposits. Some prospecting works have been carried out to investigate the promising lands for Spinel-bearing areas.

Spinels are precious minerals with hardness of 8 and density of 3.5 to 4.1 gr/cm^3 and the chemical formula is $MgAl_2 O_4$. This mineral lacks clear to semi-clear cleavage and it can be found in colors of red (Sapphire Spinel), blue (Ruby Spinel), and green (Spinel chloride), brown and black.

In the following you can find all these places distinctively (Appendix I shows the results of heavy minerals and their weight in details).

3-1-2-1-Grans Comoros Island

Spinel can be seen in this geographical zone with the following specifications in table 3-1

Geographical situation	Sample number
11° 46’ 14.7” 43° 15’ 43.5”	9242
11° 47’ 36/7” 43° 16’ 28”	9243
11° 47’ 55.2” 43° 16’ 32”	9244
11° 49’ 13.7” 43° 17’ 10.1”	9245
11° 48’ 44.8” 43° 27’ 2.6”	9249
11° 43’ 50” 43° 26’ 38.8”	9255
11°46’ 46.6” 43°22’ 29.7”	9258

Table 3-1- Spinel districts in Grande Comoros.

Map 3-3 shows the topography of the situations and map3-4 illustrates all districts on the geological map.

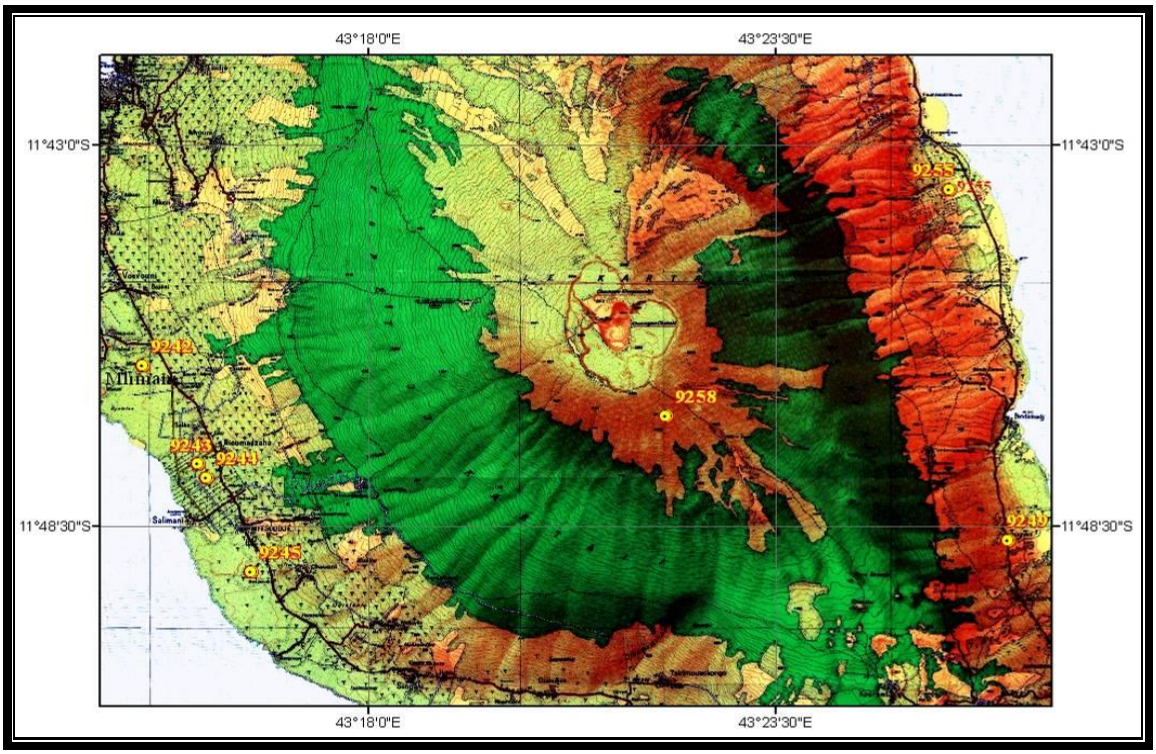
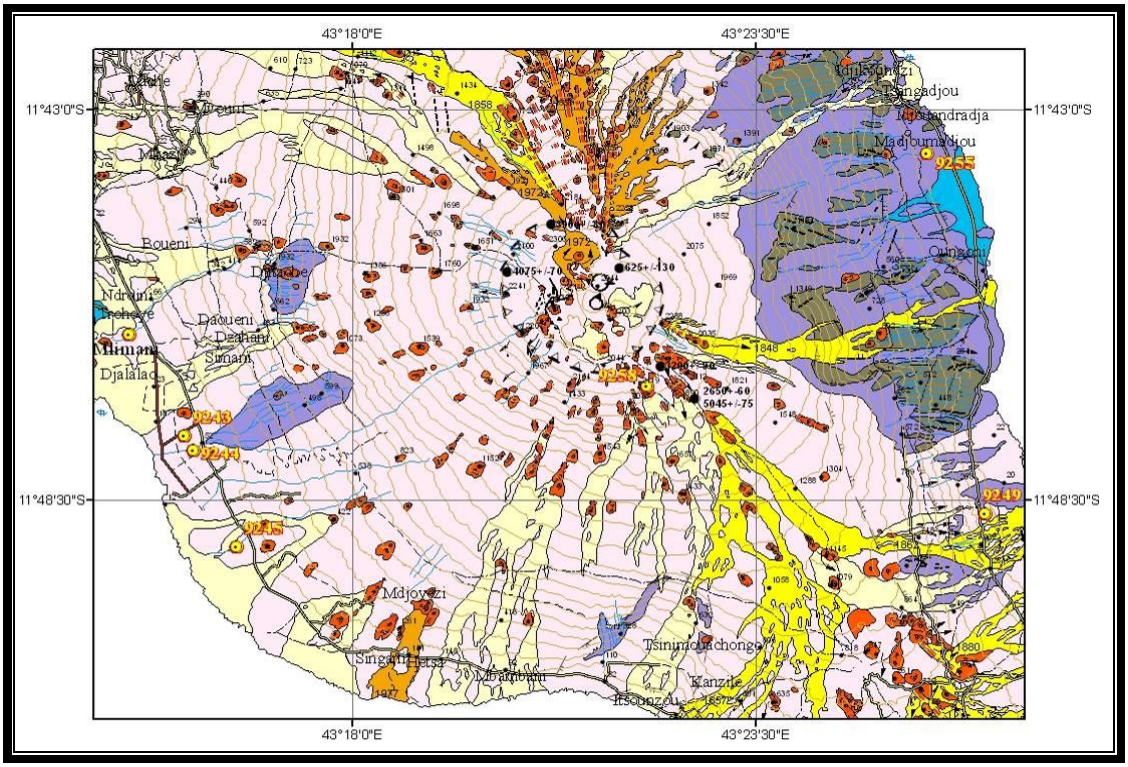


Figure 3-3- Location of the studied area on the topographical map



Map 3-4- Location of the studied area on the geological map.

Sample 9242: the sample is taken from a dried stream with the width of 15 meters. The bed of this stream has rocks in different sizes which are mainly Pyroxene and Olivine basalt. The samples carried 2 Spinel grains with size of 1300 microns and they were semi-angular in shape (Appendix I).

Sample: 9243: the sample was taken from a river alluvium where the bed was covered by basaltic lava with a rough uneven surface. In parts of this basaltic bed Olivine basalt rocks and pieces resulted by erosion are found and based on the studies on this sample there are at least two Spinel particles with the size of 1200 microns (Appendix I).

Sample 9244: the sample was taken from a river with a 20 meter width. The bed was fully Olivine basalt and there had been some pores in it that seems to have formed as gases steamed out of the rocks.

Some deposits were collected in parts of the river. The microscopic studies showed that the area had more than two Spinel particles with size of 1000 microns and they were semi-angular and circle (Appendix I).

Sample 9245: the sample was taken from a fully dried river (at the time of sampling). The bed rocks were Olivine basalt and Pyroxene Olivine basalt in that some grains of Pyroxene could be seen with naked-eyes. Microscopic and heavy mineral studies showed that this sample had at least two Spinel particles with the size of 1400 microns (Appendix I).

Sample 9245: this sample has been taken from a 4 meter-wide River. The bed was formed by old Olivine basaltic lava and they were almost broken. The mineralogical studies showed that there were at least three Spinel particles with the size ranges from 1000 to 14000 microns in the shape of semi-angular and circle (Appendix I).

Sample 9255: the sample was taken from a 15 meter-wide river. The bed included large amount of Olivine basalt blocks. The mineralogical studies showed that there were at least two Spinel particles with the size of 1000 microns (Appendix I).

Sample 9258: the sample was taken from the bed of a volcanic ash flow. There were at least two Spinel particles in the size of 14000 microns and semi-angular. Figures 3-9, 3-10, and 3-10 show the Spinel samples.

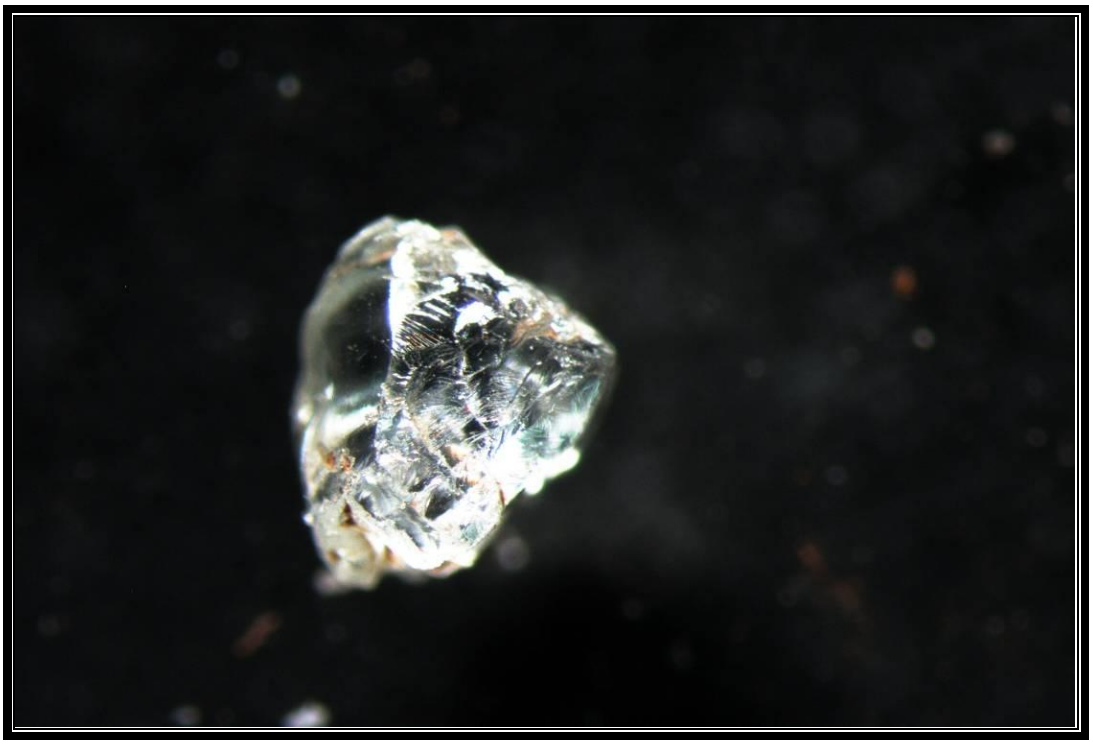


Figure 3-9-Spinel.

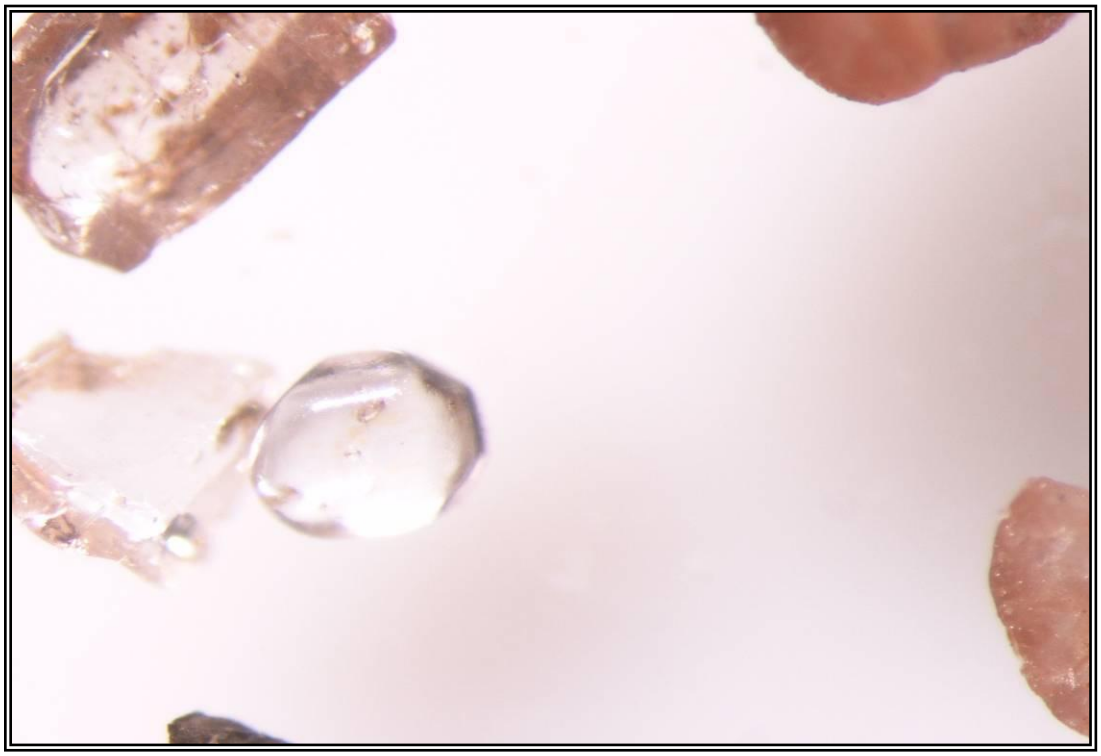


Figure 3-10- Spinel.

3-1-2-2- Anjouan Island

This district had some Spinels with in the following specifications (Table 3-2).

Sample number	Geographical coordinates
9207	12° 11´ ″22.6 44° 24´ 53.3
9206	12° 11´ 9.9 44 ° 24´ 38.9″
9208	12° 12 1.7 44° 25 41.5″
9209	12° 12´ 5.7 44° ´25 36.3
9211	12° 12´ 53/7″ 46° 26 43.4″
9212	12° 12´ 57.3″ 44° 27´ 1.3
9217	12° ´10 56.1 44° 22 ´55.5
9218	12° 11´ 8.2 44° 12´ 13.1
9220	12° 11´ 32.6 44° 21´ 28.7
9223	12° ´11 9.5 44° 28 ´ 59.5″
9224	12° 13´40″ 44° 13´15″
9227	12° ´16 56.4″ 44° 24´ 15.8″
9230	12° 21´ 54.9 44° ´31 13.4

Maps in 3-5 and 3-6 show the location of these districts on topographical and geological maps.

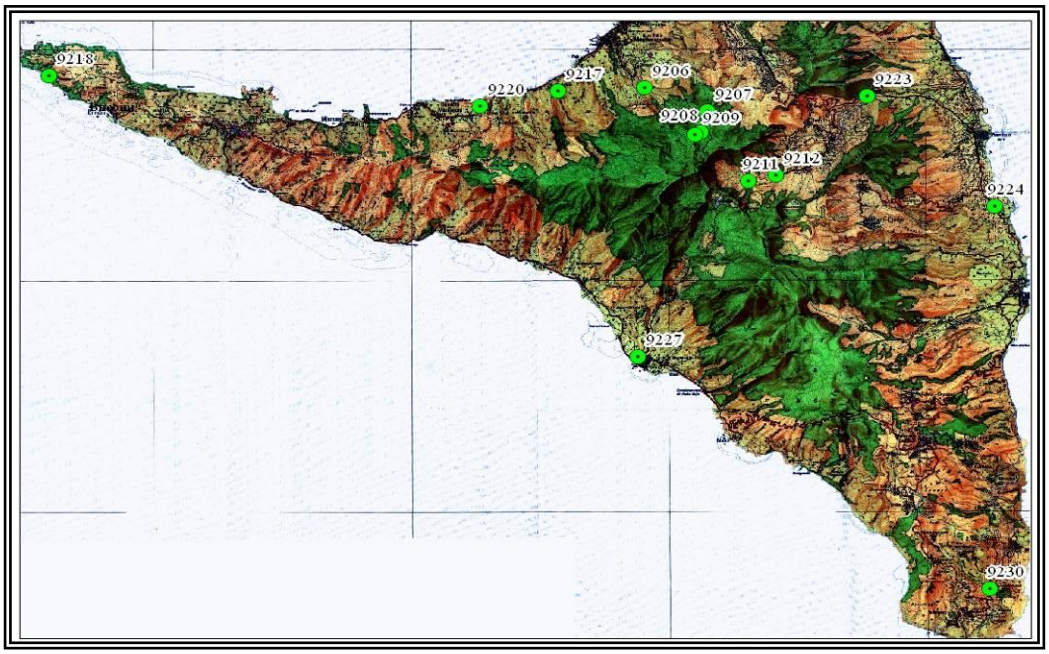


Figure 3-5-Location of these districts on topographical map

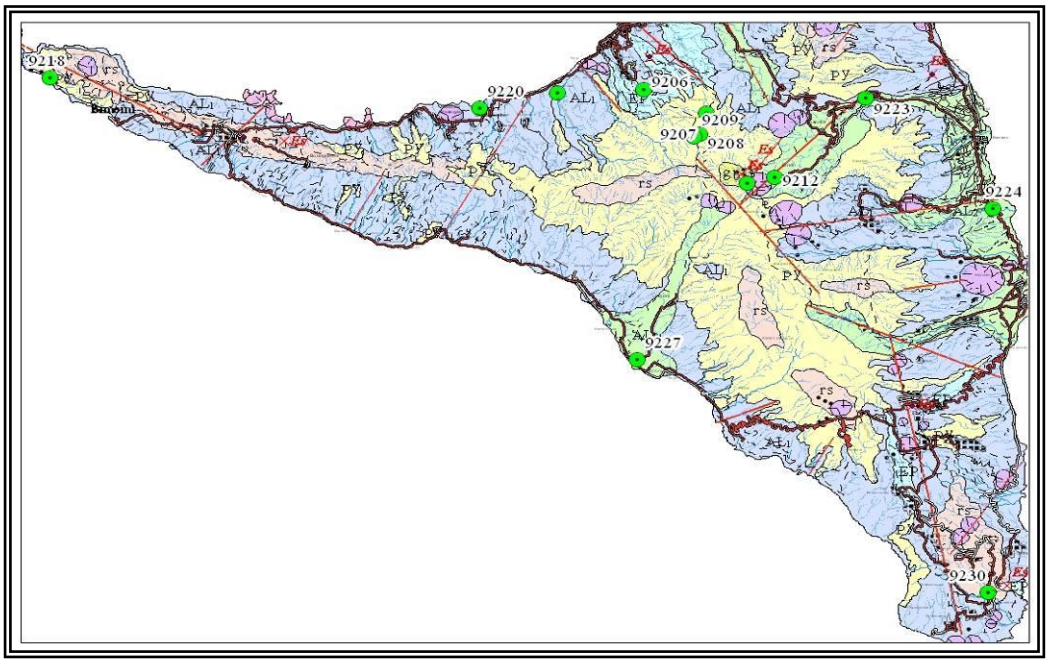


Figure 3-6- Location of these districts on geographical map

Sample 9206: This sample has been taken from a stream with basalt bed rock. Mineral studies showed that there were at least two Spinel particles here with the size of 1200 microns (Appendix I).

Sample 9207: This sample has been taken from broken pozzolan units. This district includes layers of pozzolans. Therefore, in order to understand the mineralization in this area, mineralogical studies were conducted in which at least two Spinel particles were observed with the size of 1000 microns (appendix I).

Sample 9208: this sample has been taken from water channel covered by clay. The altitude was 941 meters and it was all covered by trees and bushes. The researches in the area indicated that it had some Spinels.

Sample 9209: this sample has been taken from narrow water channel. In this part the bed layers are altered and they have changed into clay. Spinel could be spotted there too (Appendix I).

Sample 9211: this sample has been taken at the altitude of 531 meters from a water channel with yellow color water (iron hydroxide). The area was covered by basalt and alluvial deposits including rock parts and clay minerals. Researched showed that this area had Spinel particles in size of 1200 microns (Appendix I).

Sample 9217: the sample came from an altitude of 22 meters from the bed wide water channel formed with basalt and pyroclastic rocks. The studies indicated the presence of Spinel particles in the deposits of this water channel (Appendix I).

Sample 9218: this sample came from the main water channel with the width of 20 meters, and bed consists of Olivine basalt and pyroclastic rocks. The sample showed 8 Spinel particles (Appendix I).

Sample 9220: this sample has been taken from water channel with the width of 15 meters including basalt, pyroclastic rocks. The investigations showed that this area, too, had some Spinel particles (Appendix I).

Sample 9223: this sample has been taken from an area with lot of falls. The studies indicated that this area, or should we say this route, is a promising district for Spinel and titanium deposits (Appendix I).

Sample 9224: this sample has been taken from the bed of a water channel with the width of 15 meters covered by basalt and alluvial deposits. The studies indicated the presence of Spinel particles in this area (Appendix I).

Sample 9227: the sample was taken from the alluvial deposits of a water channel covered by Olivine basalt. Mineralogical studies of heavy minerals pointed to the presence of Spinel particles in these alluvial deposits.

Sample 9230: the sample was taken from the alluvial deposits of a water channel that runs through volcanogenic unit. The studies confirmed the presence of Spinel particle in this district.

3-1-2-3- Moheili Island

Spinel particles were found in parts of this island with the following specifications (table 3-3)

Table 3-3- Spinel district in Moheili Island.

Sample number	Geographical coordinates
9274	12° 17´ 26.3" 43° 44´ 54"
9275	12° 18´ 28.4" 43° ´46 47/7"
9276	12° 18´ 32.3" 43° ´46 46.6"
9280	12° 22´ 4" 43° 46´ 57.2"
9281	12° 21´ 52.3" 43° 46´ 9.9"
9282	12° ´21 15.9″ 43° 44´ 44.4″
9284	12° 21´ 18.6" 43° ´43 39.6″
9285	12° ´20 57" 43° 41 55.2"
9287	12° 19´ 39.3" 43° ´40 9.4"
9288	12° ´16 37.6" 43° 43 54.1"
9289	12° 15 58.6" 43° 41´ 42.5"
9290	12° 15´ 27.6" 43° ´40 22.2"

Sample number	Geographical coordinates
9292	12° 17´ 14" 44° 37 55.1"
9293	12° 18´ 12.2" 43° 38´ 17.5"
9294	12° 18´ 12.2" 43° 38 17.5"
9295	12° ´22 22.2" 43 ° 50´ 27"
9297	12° 20 26.2" 43° 50´ 30.6"

Topographical and geological maps are shown in the following photos 3-7 and 3-8.

Figure 3-7-topographical situation.

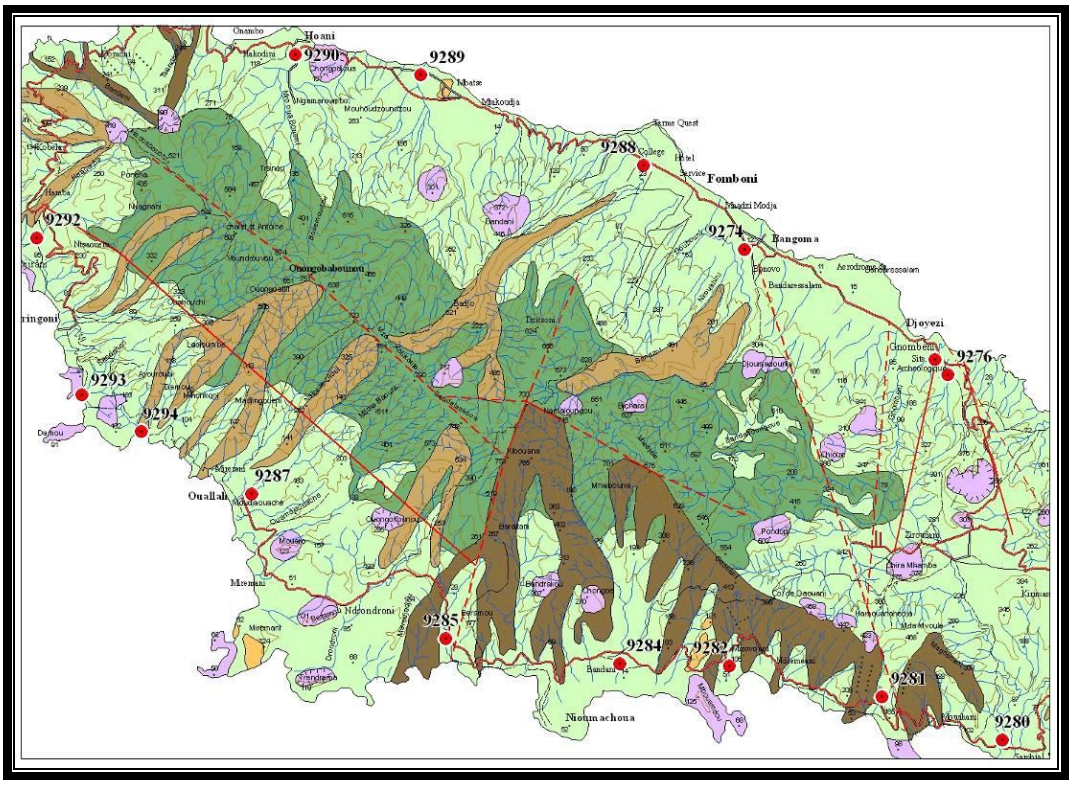


Figure 3-8- Geological situation.

Sample number 9274: this sample has been obtained from a river with thee width of about 30 meters with medium to large rocks with composition of Olivine basalt and pyroclastic rocks. In some areas of the water channel bed rocks and rubble rocks have become argillic. In the sample taken from this water channel two Spinel particles with the size of about 1400 microns were found. (Appendix 1)

Sample number 9275: this sample was obtained from a river with the width of about 10 meters with rich vegetation coverage. The bed rock of this river is Olivine basalt and it is full of water. On the basis of heavy mineral studies the existence of Spinel particles in the alluvium of this river became certain. (Appendix 1)

Sample number 9275: this sample was obtained from the bed of a river with the width of about 15 meters and the composition of Olivine basalt. On the basis of heavy mineral studies, at least two Spinel particles were observed in this sample. (Appendix I)

Sample number 9280: this sample was obtained from the bed of a water channel with the width of about 8 meters, and the bed consists of clay in which Olivine basalt rocks exist. There were at least 8 types of Spinel particles found in this sample based on the heavy mineral studies. (Appendix I)

Sample number 9281: this sample was obtained from the bed of a water channel with the width of about 5 meters, and the bed is rocky with composition of Olivine basalt. About 8 Spinel particles were found in the studies carried out. (Appendix I)

Sample number 9282: in this area basalt and Pyroxene basalt rocks cover the bed of a river with the width of about 10 meters. The samples taken from this area show the existence of Spinelparticles with the size of about 1400 microns. (Appendix I)

Sample number 9284: this sample has been taken from a river with the width of about 20 meters and the bed consists of Olivine basalt. In this sample more than 8 Spinelparticles with the size of about 1400 microns were found. (Appendix I)

Sample number 9285: in this area too, the visible rock unit consists of Olivine basalt rocks, which are seen within the bed rock with the same composition and the results of the studies point to the existence of spinelparticles in this sample.

Sample numbers 9287, 9288, and 9290: in these areas which are placed within a complex, the rock composition is Olivine basalt as well as the sediments resulted due to erosion of these basalts, and in some parts the signs of Kaolinization are seen in a limited fashion. In this sample too, particles of Spinelcan be seen during mineralogical studies. (Appendix I)

Sample numbers 9292, 0203, 0204, 9295, and 9297: these areas also belong to a uniform Olivine basalt rock complex, and the whole bed rock consists of Olivine basalt, slightly altered Olivine basalt and sediments resulted due to the erosion of rocks. In these areas too, the mineralogical studies confirm the presence of Spinelparticles.

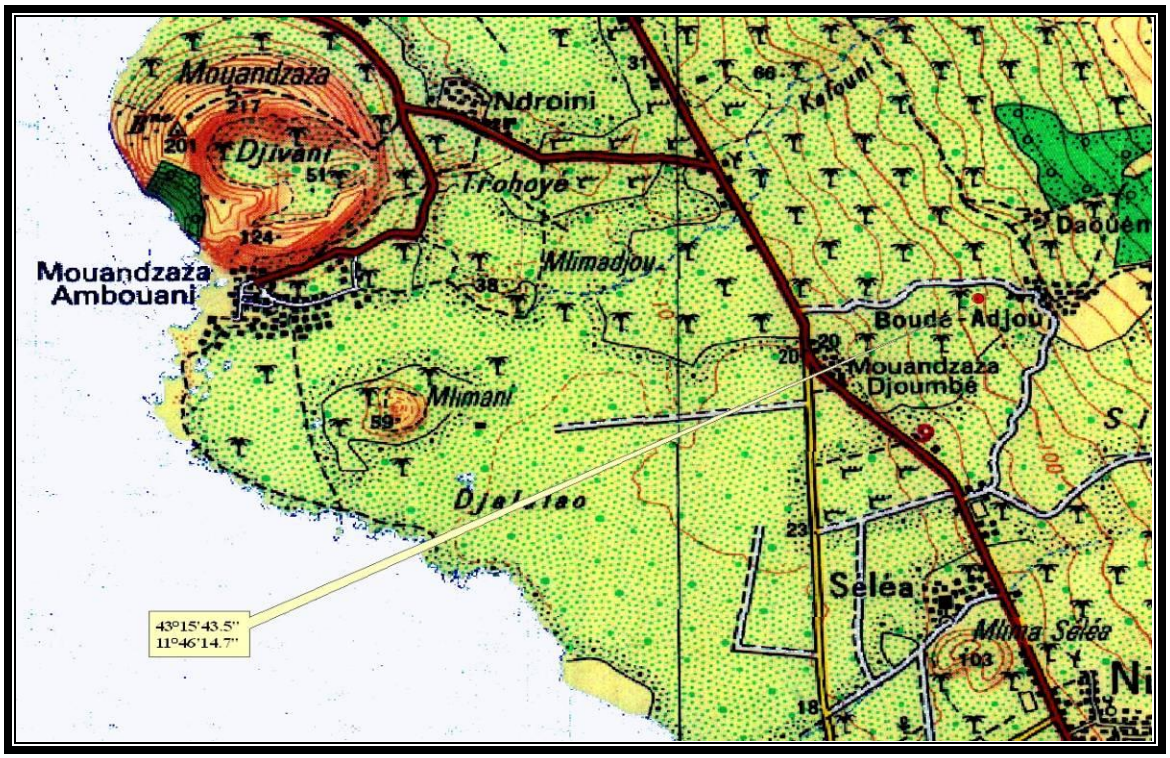
Aforementioned results of studies on exploration of Spinelin these areas show that this country is well suited for Spinelmineralization, and therefore detailed studies about these deposit and the exploitation methods need to be considered in the future supplementary project.

3-1-3 Corundum Eldises

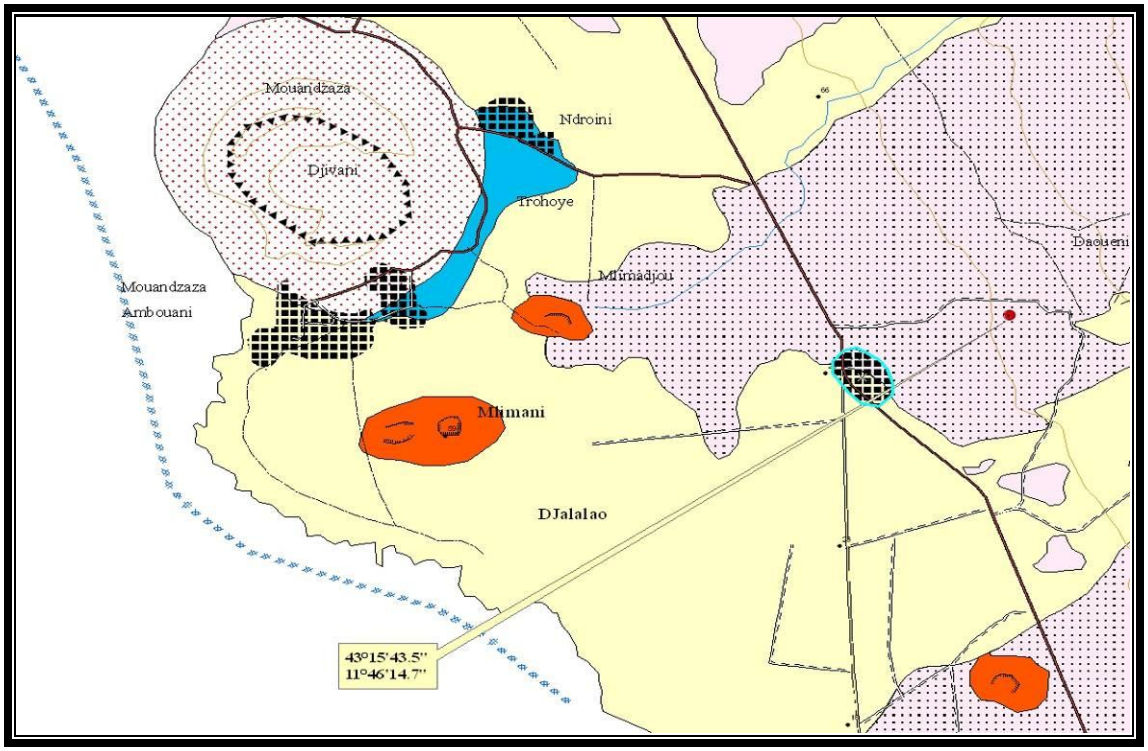
Corundum, with the chemical composition of AL2 O3 is among the precious minerals which have the hardness of 9 and density of 4.02 gr/cm^3. Its broken surface features as conchoidal, transparent to semi-transparent look. This mineral has been used as a precious stone from the ancient times to this date. Corundum is usually found in unsaturated silicate igneous rocks, however it is sometimes found in metamorphosis rocks as well. Different types of Corundum are seen in colors white, gray to black, dark purple, yellow, green, red, blue (Sapphire).

3-1-3-1 Grande Island of Comore:

In the explorations carried out in the grand island of Comors, this mineral was found only in an area with the latitude of 11° 46' 14.7" and the longitude of 43° 15' 43.5". This area has been shown in the topographical and geological maps 3-9 and 3-10.



Map 3-9 Geographic location of the area on the topographical map.



Map 3-10 Geographical location of the area on the geological map.

The sample from this area has been taken from alluvial deposits in a water channel with a width of 10 meters, which consist of Pyroxene, Olivine basalt rocks. During the study in this area, some particles of Corundum with the colors of white and pink were found. The size of them is about 1400 microns and their shape is semi-angular. A view of this mineral is seen in figure 12-3.

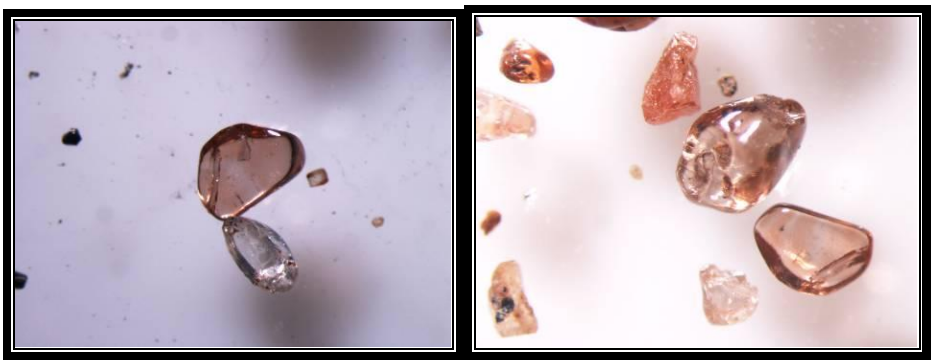


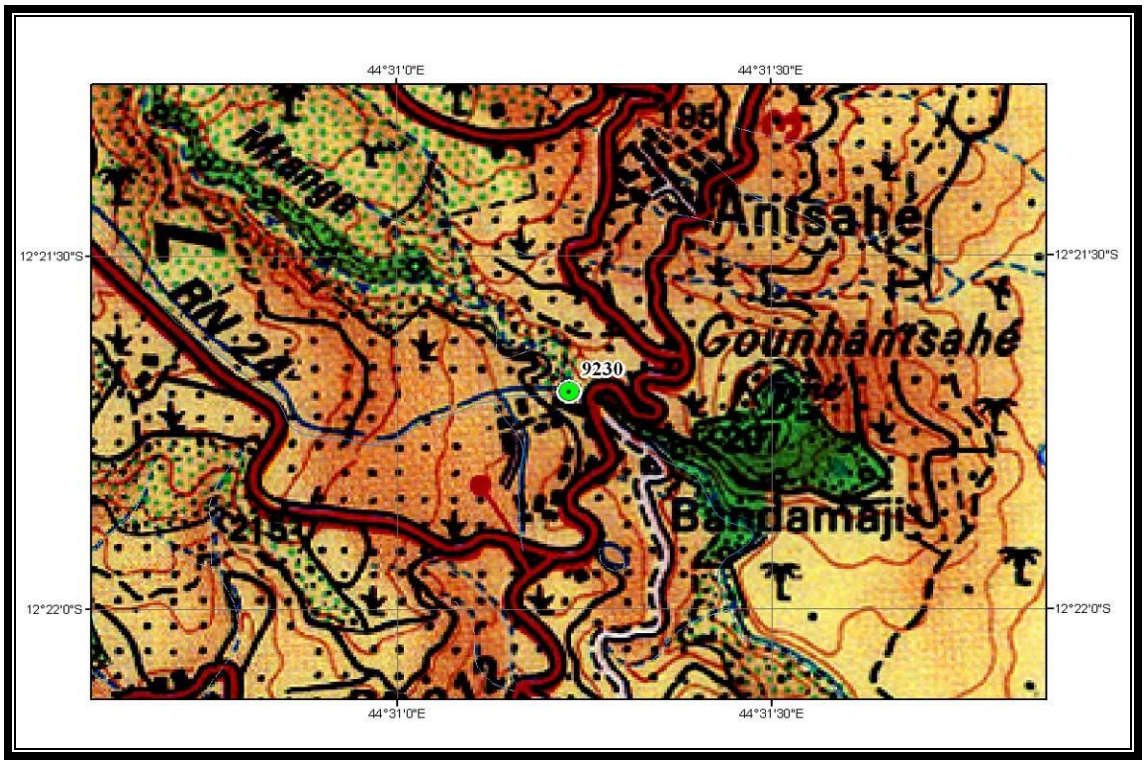
Figure 3-12 Microscopic view of Corundum particles.

3-1-3-2 Anjouan Island

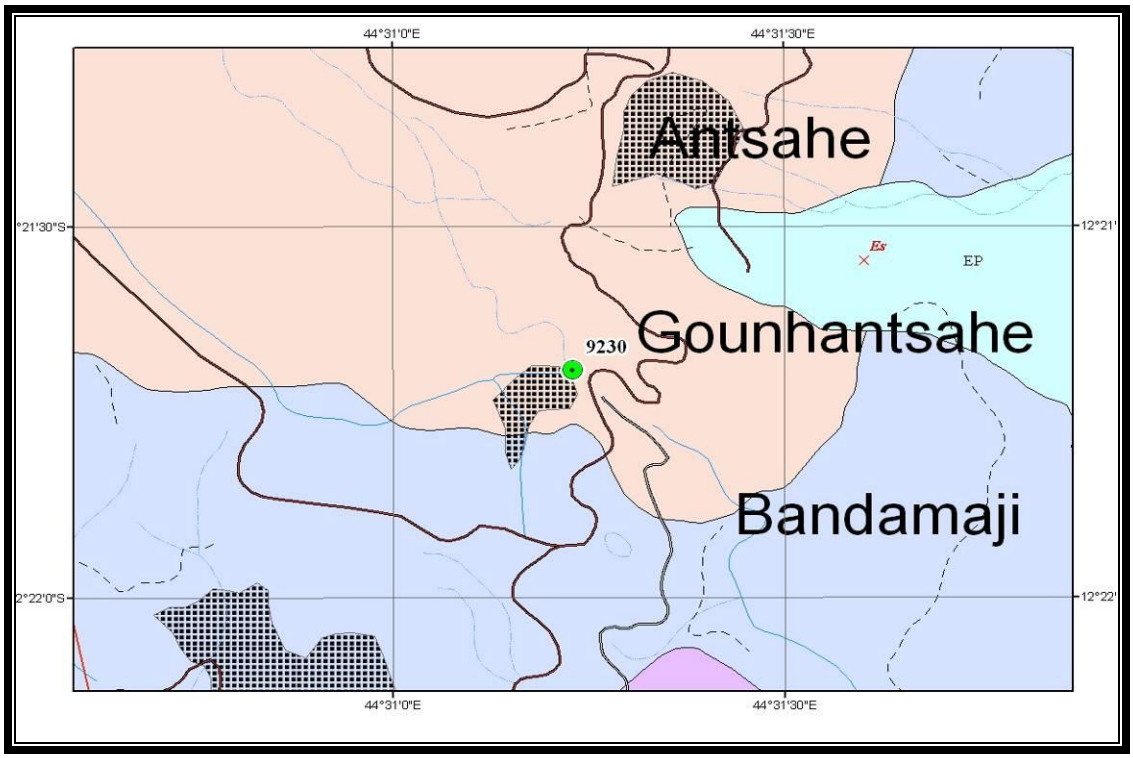
Based on the geological studies and field surveys on this island, the presence of this precious mineral became certain in two areas and the geographical and geological locations of these two areas are shown in the maps 3-11 and 3-12.

The geographic location of these two districts is shown in table below:

Geographic location	Sample Number
12° 21´ 54.9" 44° 31´ 13.4"	9230
12° 22´ 43.9" 44° 30´ 4"	9231



Map 3-11 Geographic location of Corundum indexes in the topographical map



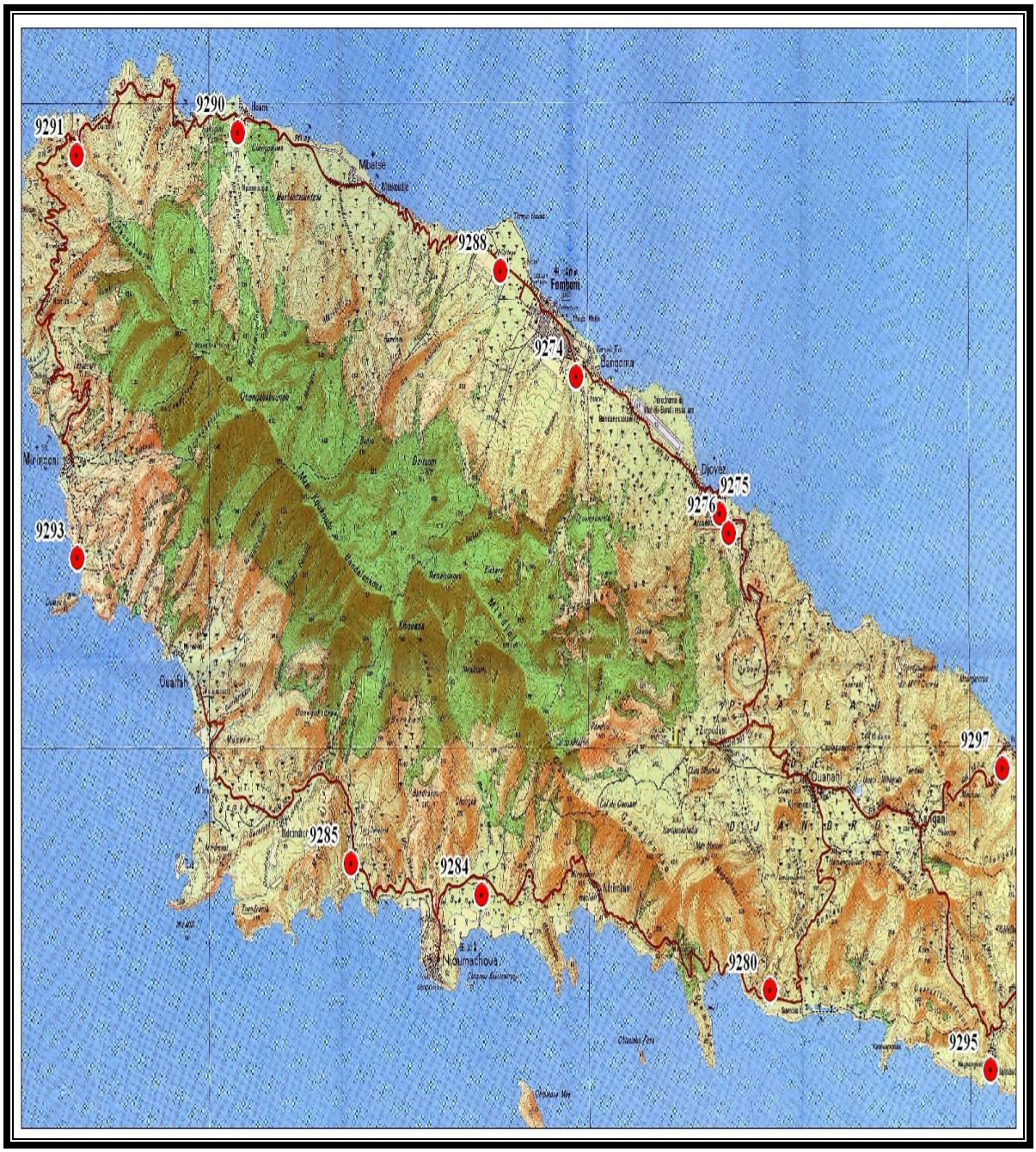
Map 3-12 Locations of these two districts on the geological map

Sample number 9230: in this area volcanoclastic rocks are widespread and cover a large part of the area. The study sample taken from the alluviums of this rock unit has been studied. The most important point in this area is the presence of Corundum and Spinelat the same place, and both minerals are considered as gemstones. Corundum particles in this area are round to semi-angular and their size is about 1300 microns. (Appendix I)

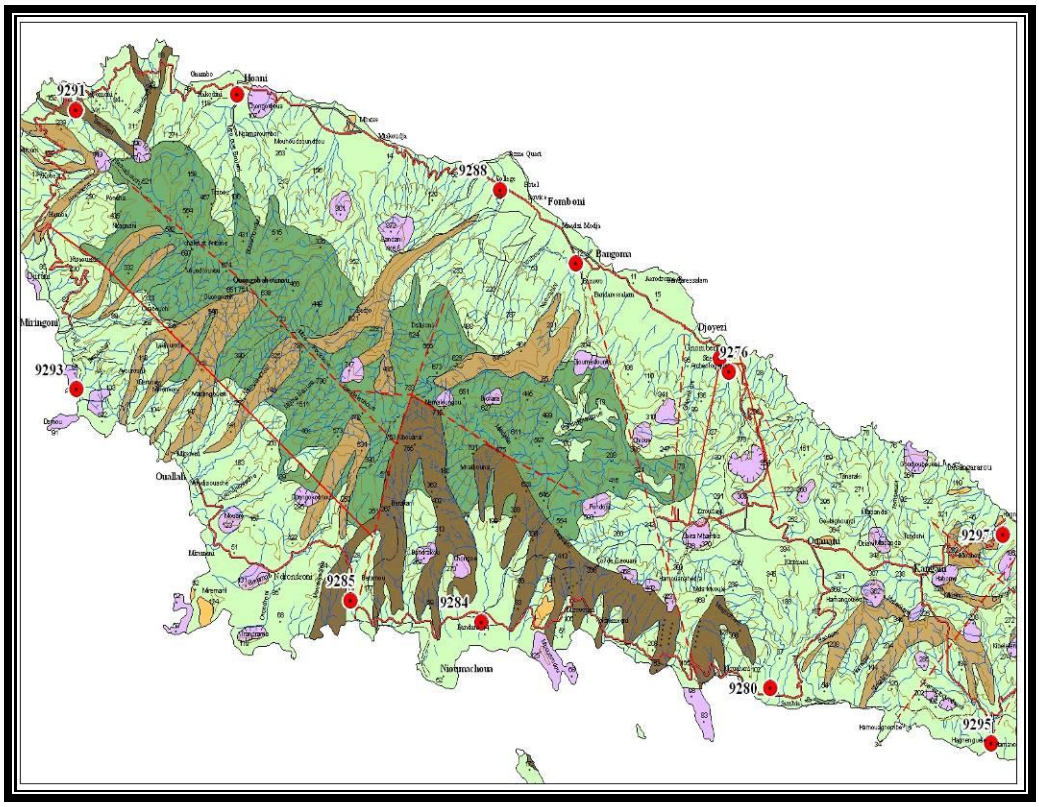
Sample number 9231: this sample has been taken from a river with the approximate width of 20 meters which is covered by Olivine basalt and pyroclastic rocks, and alluviums resulted due to their erosion. In this area too, there are round to semi angular particles and their size is about 1300 microns. (Appendix I)

3-1-3-3 Moheili Island

In this island Corundum particles have the highest distribution and have been spotted in 11 places. The geographic locations of these places are shown in the geological map no. 3-14.



Map 3-13 Location of Corundum-bearing places on the topographical map



Map 3-14 Geographic locations of Corundum-bearing places on the geological map

The geographic coordinates of these places are shown in table 3-4.

Table 3-4 Geographic coordinates of Corundum-bearing places in Moheili Island

Geographic coordinates	Sample Number
12° 17´ 26.3" 43° 44´ 54 "	9274
12° 18´ 28.4" 43° 46´ 47.7"	9275
12 ° 18´ 28.4" 43 ° 46´ 47.7"	9276
12 ° 22´ 4" 43 ° 46´ 57.2"	9280

Table 3-4 continued- Geographic coordinates of Corundum-bearing places in Moheili Island

Geographic coordinates	Sample Number
12 ° 21 ´ 18.6" 43 ° 43´ 39.6"	9284
12 ° 20´ 57" 43 ° ´41 55.2"	9285
12° ´16 37.6" 43° 43´ 54.1"	9288
12 ° 15 ´ 27.6" 43 ° 40´ 22.2"	9290
12 ° 15 ´ 43.3" 43 ° 38´ 19.1"	9291
12° 18´ 12.2" 43° 38´ 17.5"	9293
12° 18´ 48.5" 43° 38 ´ 36.8"	9295
12° 20 ´ 26.2" 43° ´50 30.6"	9297

Sample number 9274: this sample has been taken from the alluvium sediments of a river with the width of about 30 meters and with a bed consists of large to medium size rocks with composition of Olivine basalt and pyroclastic rocks. Some Corundum particles with the size of about 1400 microns were observed.

Sample number 9275: this part of the river which has been almost fully covered with vegetation was taken up. The bottom rock of this area is Olivine basalt. It should be mentioned that in this area Corundum particles are seen along with Spinel. (Appendix)

Sample number 9276: this sample has been taken from a river with the approximate width of 15 meters and its whole bed is covered by Olivine basalt. In this area particles of Corundum with the size of 1200 microns are seen along with Spinel. (Appendix I)

Sample number 9280: this sample has been taken from the alluvium sediments of a river with the width of about 8 meters which is made of clay deposits and Olivine basalt rocks. Based on the mineralogical studies, several Corundum particles with the size of 1000 to 1400 microns were found. (Appendix I)

Sample number 9284: this sample has been taken from the alluvium within a water channel with the width of about 20 meters and its bed consists of alluviums and rock units of Olivine basalt. The coexistence of Corundum and Spinelparticles also adds to the importance of mineralization in this area. (Appendix I)

Sample number 9285: this sample has been taken from the main river with the width of 15 meters. The bed of this river is covered with Olivine basalt rocks. In this area too, the Corundum and Spinel particles are seen together. And the size of the particles is between 1200 and 1400 microns.

Sample number 9288: this sample has been taken from the alluvial unit of a river with the width of 30 meters, which its bed is mostly covered by Olivine basalt rock unit. Through heavy mineral studies in this area, several particles of Corundum with round and semi angular shapes with the size of about 1400 microns were observed. (Appendix I)

Sample number 9290: this sample has been taken from the alluvial unit of a river with the width of about 10 meters in which large to medium Olivine basalt rocks are observed. In this area too, Corundum particles are observed along with Spinel. (Appendix I)

Sample number 9293: this sample has been taken from the alluviums at the bed of a river with the width of about 12 meters which has been covered Olivine and Pyroxene basalt rocks. The mineralogical studies in this area show the presence of Corundum particles along with Spinel.

Sample number 9295: this sample has been taken from the Olivine basalt unit within the alluviums at the bed of a river with the width of about 8 meters. The mineralogical studies in this area show the presence of Corundum particles along with Spinel. (Appendix I)

Sample number 9297: this sample has been taken from the bed of a running river with the width of about 15 meters and its bed is covered with Olivine basalt rocks. According to the results from mineralogical studies the presence of Corundum particles along with round to semi angular Spinel particles with the size of about 1300 microns has been confirmed. (Appendix I)

3-1-4 Pozzolan deposits

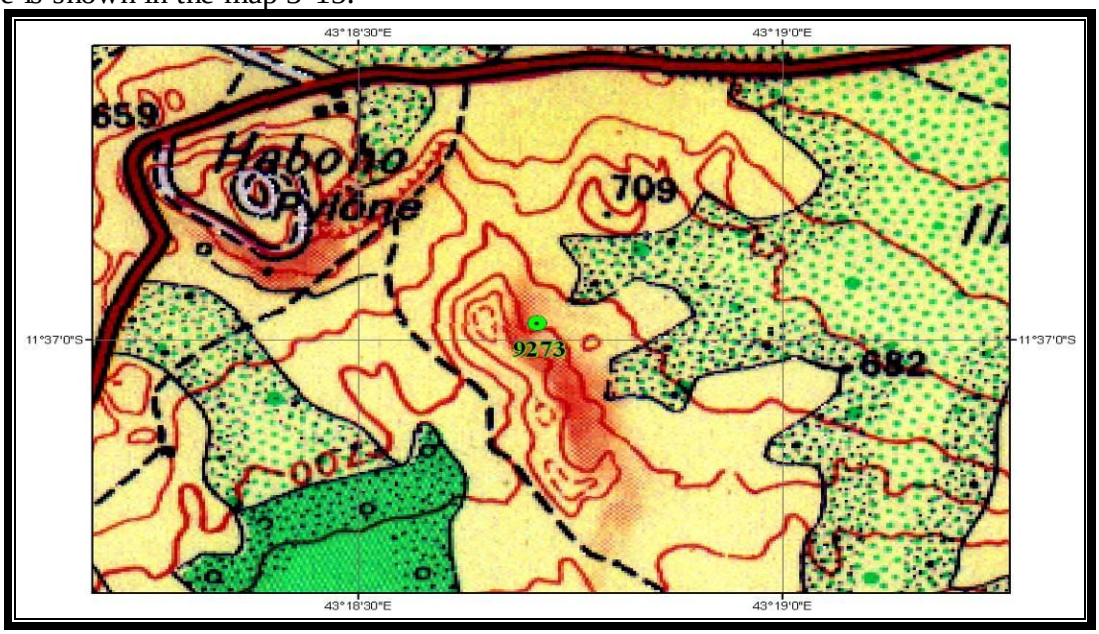
Regarding the petrologic structure of Comores which is totally the product of volcanic activities, the presence of numerous resources of the pozzolan resulted from the eruptions,

and sometimes the volcano ashes, is observed. In other words the pozzolan units formed by volcanic eruptions are the source of pyroclastic and flow deposits, and have large volume of gas and solid materials which create eruption columns as tall as thousands of meters. With the increase of the volume of the materials in eruption column, some of them flow down the slope of the volcano. These flow materials contain plenty of pozzolan, ash particles and sometime lava pieces. As time goes by these materials transform into clay minerals due to physical and chemical weathering process. Therefore only young deposits that belong to Tertiary and Quaternary could create valuable mineral deposits around young volcanoes. Considering the geological conditions of this country, the extension of pozzolan units is noticeable, and generally it can be said that large parts of the outcrops and rock units forming these islands are made from pozzolan. Regarding the importance of pozzolan deposits and in order to study their quality for the purpose of their application in producing construction materials, sampling was performed on the most qualified outcrops in this area and various analyses, and the results of these studies and analyses are presented as it follows:

3-1-4-1 Grande Comores

3-1-4-1-1 Area I

One of the most important places in which the spread of pozzolan units is so noticeable is Itsoundzu with latitude of 11° 36' 58.5" and longitude of 43° 18' 42.6". The location of this place is shown in the map 3-15.



Map 3-Map 3-15 Geographic location of pozzolan deposit in area I.

In this area pozzolan deposit is spread as at least 50 meters in diameter and 20 meters height. As far as physical appearance this deposit is seen in form of completely loose grains with the least amount of soil (clay minerals).

In figures 3-13 and 3-14 a view of the extension of this unit is shown.

Figure 3-13 A view of the extension of the pozzolan unit.

Figure 3-14 A close view of the extension of pozzolan unit in area I

Table 3-5 Results of chemical analysis

Sample Number	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Cl	L.O.I
9273	41.7	16.43	14.05	10.60	8.40	-	0.63	0.55	n.d	6.57

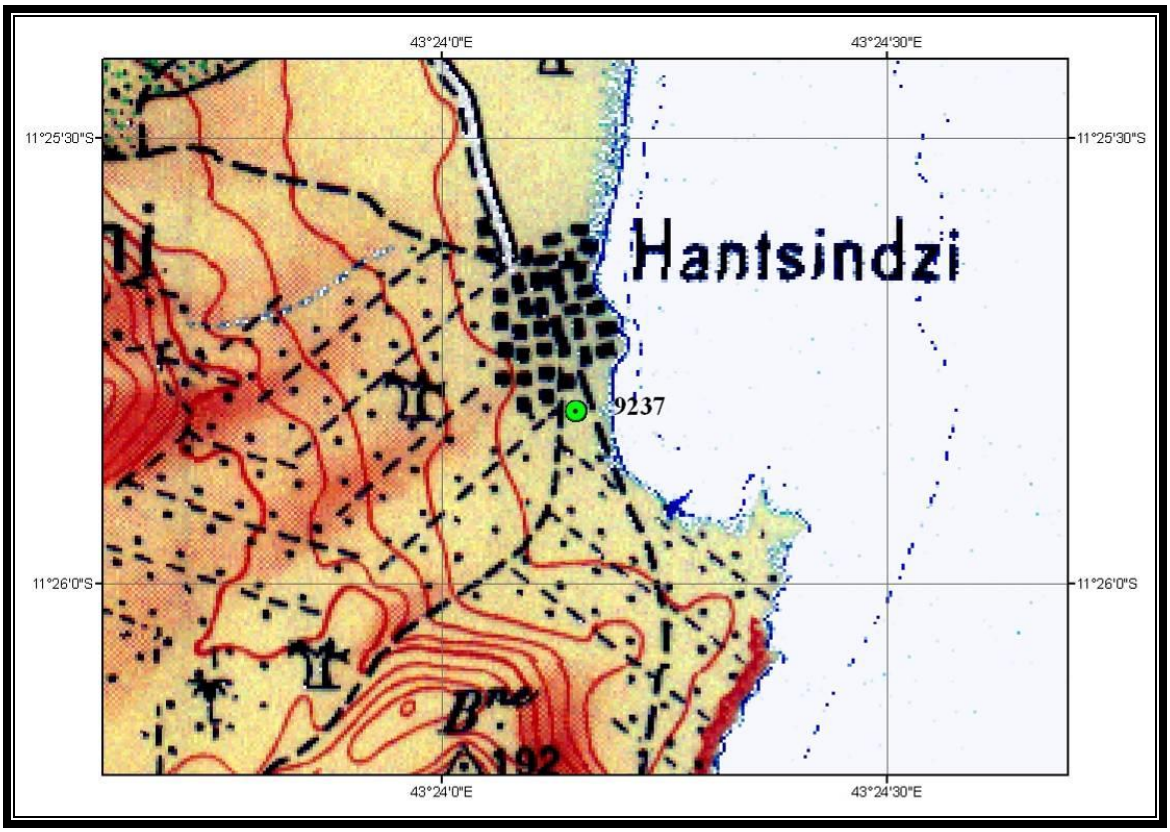
One sample was taken from this area for finding the percentage of elements and cement test, which the results are presented in the table below:

Table 3-6 Results of pozzolan activity test

Pozzolan activity		
Sample number	7 days	28 days
9273	%73.5	%75.6

3-1-4-1-2 Area II

Another location in which pozzolan units are widespread is Chezani area located in the latitude of 11° 25' 48.1" and longitude of 43° 24' 12.1". The location of this area is shown in map 3-16.



Map 3-16 Geographic location of area II

In this area thick layers of pozzolan as tall as around 300 meters are seen, which spread in an area with 200 meters in diameter.

A view of this area has been shown in figure 3-15.

Figure 3-15 A view of the spread of this unit

A sample was taken from this area for finding the percentage of elements and cement test, which the result of this analysis is shown in table 3-7.

Table 3-7 the results of the chemical test

Sample number	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Cl	L.O.I
9237	44.70	16.90	13.30	12.00	6.25	n.d	2.60	2.10	n.d	2.99

Table 3-8 Result of pozzolan activity test

Pozzolan activity		
9237	7 days	28 days
	%78.2	%83.3

3-1-4-1-3 Area III

In this area, pozzolan unit is widespread and is seen in an area of hundreds of meters with the height of about 20 meters. From geographical point of view this area is located in Ossoudjou area with the latitude of 11° 28' 48. 7.6" and longitude of 43° 19' 48.4". The geographical location of this area is shown in map 3-17.

Map 3-17 Geographic location of the spread of pozzolan

A sample was taken from this area to determine the percentage of elements and also for cements test, and the results are presented below.

Table 3-9 Chemical composition of pozzolan of area III

Sample number	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Cl	L.O.I
9265	43.90	18.87	13.50	7.50	5.30	n.d	0.66	0.08	n.d	10.10

Table 3-10 Results of pozzolan activity test

Pozzolan activity		
9265	7 days	28 days
	%70.4	%66.4

This unit is shown in figures 3-16 and 3-17

Figure 3-16

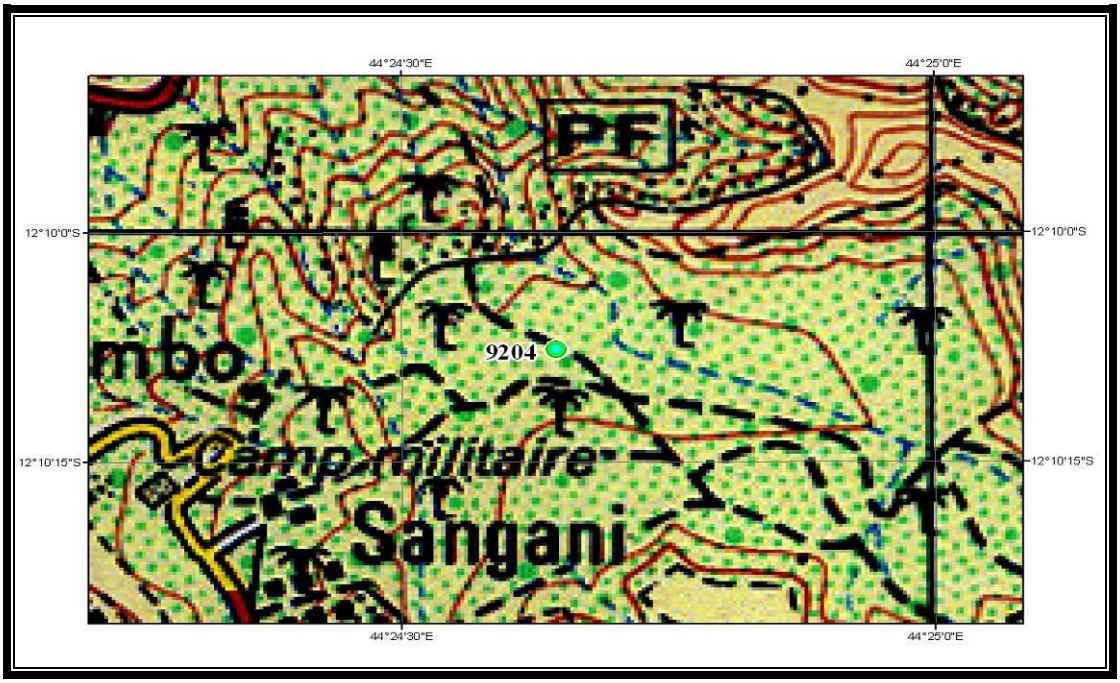
Figure 3-17

3-1-4-2 Anjouan Island

In this area the pozzolan unit is quite widespread and is seen in different areas. The details of two areas of spread of this substance are presented below:

3-1-4-2-1 Area I

This area is located in Sanyani district with the latitude of 12° 10' 41.5" and longitude of 44° 24' 15.5". The geographic location of this area is shown in map 3-18.



Map 3-18 geographic location of area I

The extension of this area is more than 100 meters and its thickness reaches up to 10 meters. A view of this deposit is shown in figure 3-18.

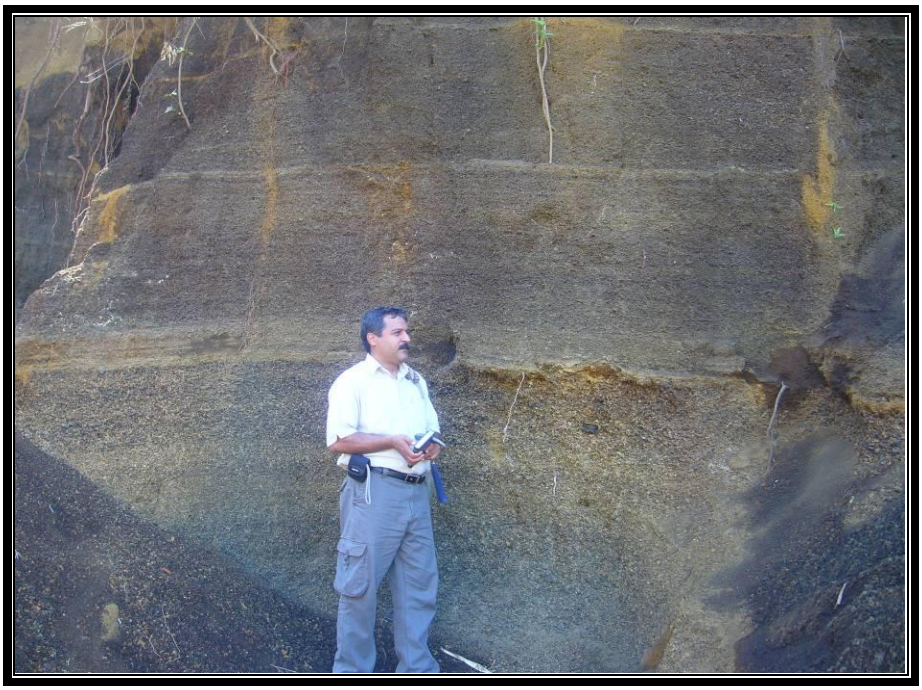


Figure 3-18 A view of the extension of this pozzolan unit

To determine the chemical composition of this deposit and to test it for its possible use in cement industry, a sample was selected and tested, and the related result is presented in table 3-10:

Table 3-10 Results of chemical analysis of pozzolan in area I - Anjouan Island

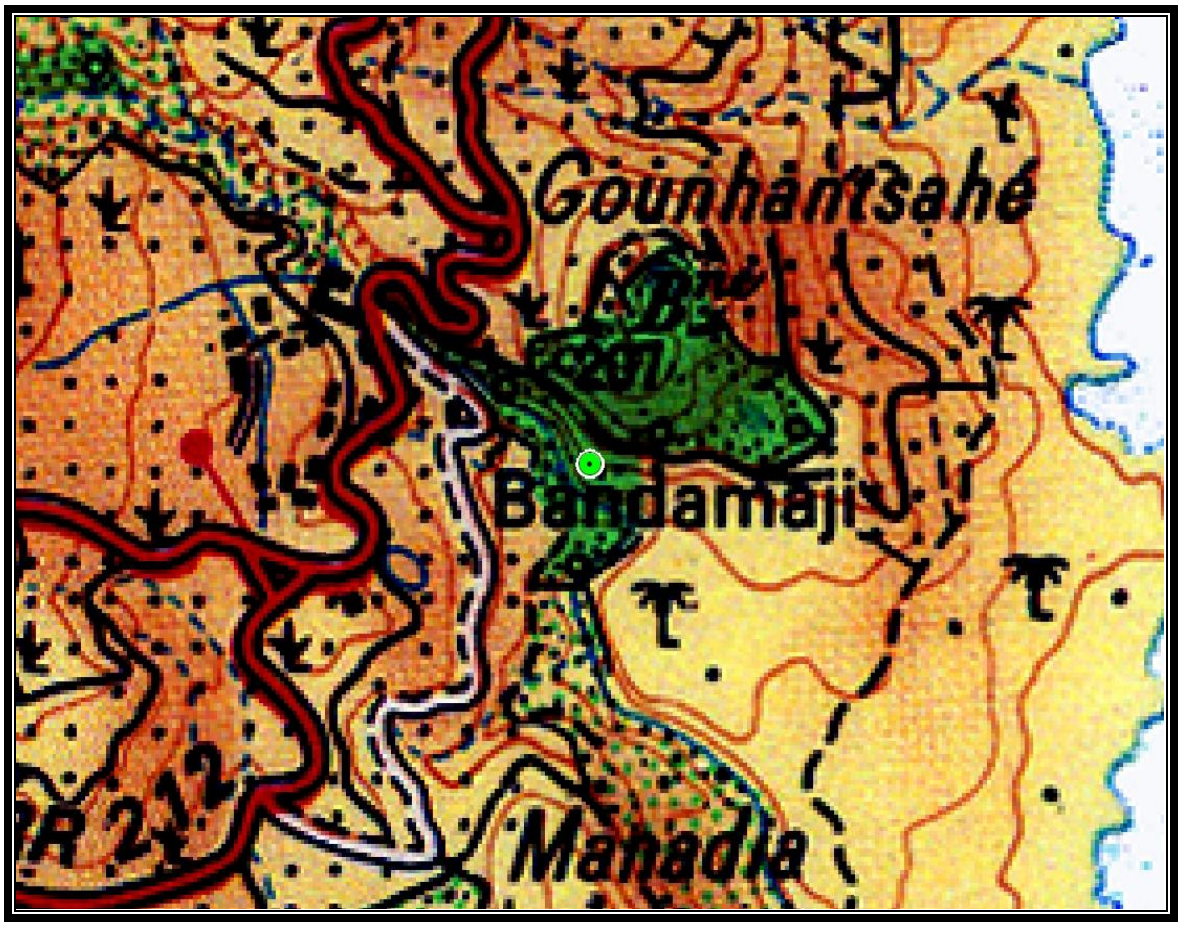
Sample number	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Cl	L.O.I
9204	45.00	20.30	14.30	9.12	5.40	n.d	1.53	0.72	n.d	4.63

Table 3-11 results of pozzolan activity test in Anjouan Island, area I

Pozzolan activity		
9204	7 days	28 days
	%57.8	%80.2

3-1-4-2-2 area II

This area is located in the very far southwest end of Mtango Island, with the latitude of 12° 21' 50.3" and longitude of 44° 31' 27. The location of this area is shown in map 3-19.



Map 3-19 Geographic location of pozzolan in area II in Anjouan Island

In this area pozzolan unit is spread around 400 meters with a thickness of 50 meters, and the local people manually granulate these materials and use them to produce concrete for construction needs. 20 workers work in this area.

A view of this deposit is shown in figure 3-19

Figure 3-19 A view of pozzolan deposit in area II

Considering the results of the analyses, the above mentioned samples chemically fall in pozzolan category, but in terms of pozzolan behavior and hydraulic specifications, they have only been able to meet the minimum requirements in ASTMC311 standard test (pozzolan activity), and since it couldn't satisfactory pass the test related to hydraulic index and resistance against hydrated lime, they are not considered as high quality pozzolan, and therefore in percentages higher than 15% one cannot expect a suitable cement product that are mixed and produced with this material.

3-1-5 Laterite Bauxite deposits

In tropical climate, the product of alteration of rocks containing aluminum silicate is mixture of aluminum and iron hydrates, silica and some other impurities generally called laterite. Due to this alteration silicates minerals decompose and their silica and iron content are departed, and alkaline metals are washed away in form of solutions thus aluminum content or grade increases and laterite bauxite is formed. For formation of such deposits the conditions below must be in place.

- Tropical climate (good level of moisture and temperature between 18 and 24 degrees Celsius)

- Aluminum silicate rocks suitable for decomposition in tropical climate such as different types of basalts, syenite, clay and clay schists.
- Chemical and biochemical factors
- Presence of suitable topography so dissolved substances can either drain into ground or flow down.

In other words, laterite bauxite deposit is a form of laterite with high aluminum content whose impurities are washed away due to weathering and the end result contains high content of aluminum. For such deposits to form plenty of rain, high temperature, suitable topographic surface and good drainage is required to flush solutions out of laterite and bauxite rocks.

In such deposits not only aluminum minerals but also nickel, cobalt and iron minerals are formed, which their amount depends on the rocks underneath the laterite unit.

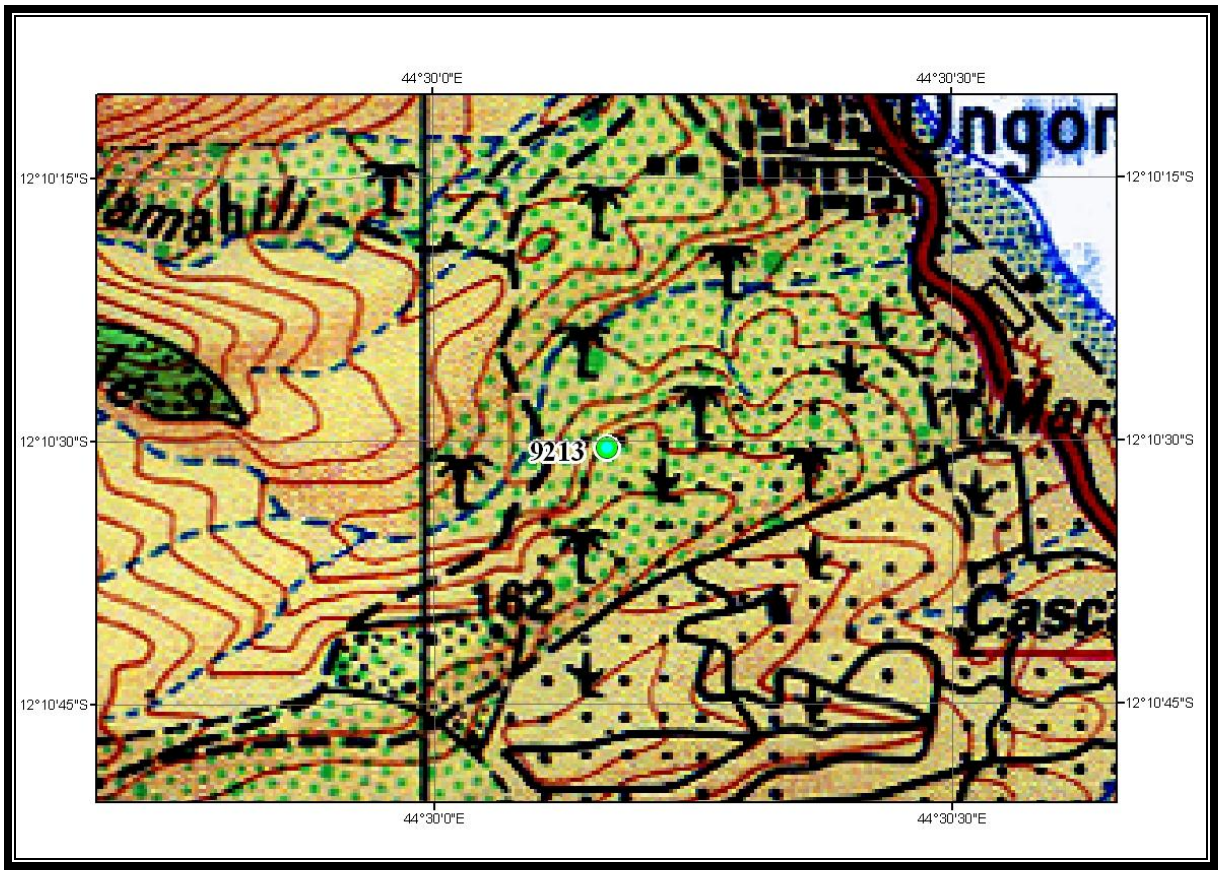
Bauxite minerals without iron are rare because iron minerals exist in most of the source of such deposits in tropical regions that undergo weathering process and lead to formation of laterite bauxite deposits with high iron content.

In such deposits other elements are also found such as Gallium and Titanium. Of course no method has yet been introduced to extract Titanium content from such deposits.

Comores Islands with regards to their petrologic conditions that are discussed in chapter 2 are mostly made of basalts, and considering the climate condition of these islands, the possibility of existence of laterite bauxite deposits was taken in to consideration. On this basis and according to the prepared exploration program, the promising areas were studied and only in Anjouan Island one noticeable laterite bauxite deposit was found.

3-1-5-1 Bauxite laterite deposits of Anjouan Island

Geographically this area is located 300 meters east of Ongoni village at latitude of 12° 10' 29.5" and longitude of 44° 30' 15.8” and its location is shown in map 3-20.



Map 3-20 Location of bauxite laterite deposits in Ongoni

Based on field surveys carried out in this area, at the surface this deposit stretches out at least 300 meters in different directions and its height reaches up to 50 meters. A view of this reserve is shown in figures 3-20 and 3-21.

Figure 3-20 A view of the deposit in north of Ongoni

Figure 3-21 Another view of the spread of bauxite laterite deposit

To analyze and realize the forming chemicals and minerals of this deposit, two samples were tested with XRF and XRD methods, and their results are presented below:

Table 3-12 Results of chemical analysis of bauxite laterite samples

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	S	LOI	P_2O_5	MnO
9213	33.90	31.77	16.22	1.10	0.12	0.40	0.16	0.09	0.08	15.30	0.24	0.19

Table 3-13 Results of mineralogical analysis with XRD method

Mineral composition respectively	Sample number
Magnetite+Hematite+Mica+Illite+Kaolinite+Serptin group Minerals	9213

Based on average global grade of Al_2O_3, the least exploitable Al_2O_3 is 30 percent. In primary analysis this deposit contains the acceptable minimum grade of aluminum oxide. On the other hand the field surveys have shown some other outcrops north of Hanjoho (about 5 kilometers to the north of Ongoni); therefore its tonnage can be very noticeable. In order to calculate the definitive amount of tonnage as well as to study the percentage change of Al_2O_3 in various outcrops, a detailed exploration work seems to be necessary. Nevertheless the estimation of deposit tonnage around Ongony village is around 11 million tons with Al_2O_3 grade of 30%.

3-1-6 Red laterite soil deposits

Such deposits are born when the existing iron and aluminum content rocks that are rich in is mafic minerals are oxidized and a layer of red minerals with rather small knot texture is formed that is called laterite. This process is mainly seen in tropical regions. In warm and humid regions heating and drying processes alternately occur. Occurrence of such processes is very suitable for oxidization of iron. In such areas iron and aluminum oxides, and clay minerals are usually seen together, but sodium, calcium, magnesium and potassium leave the environment because of the moisture.

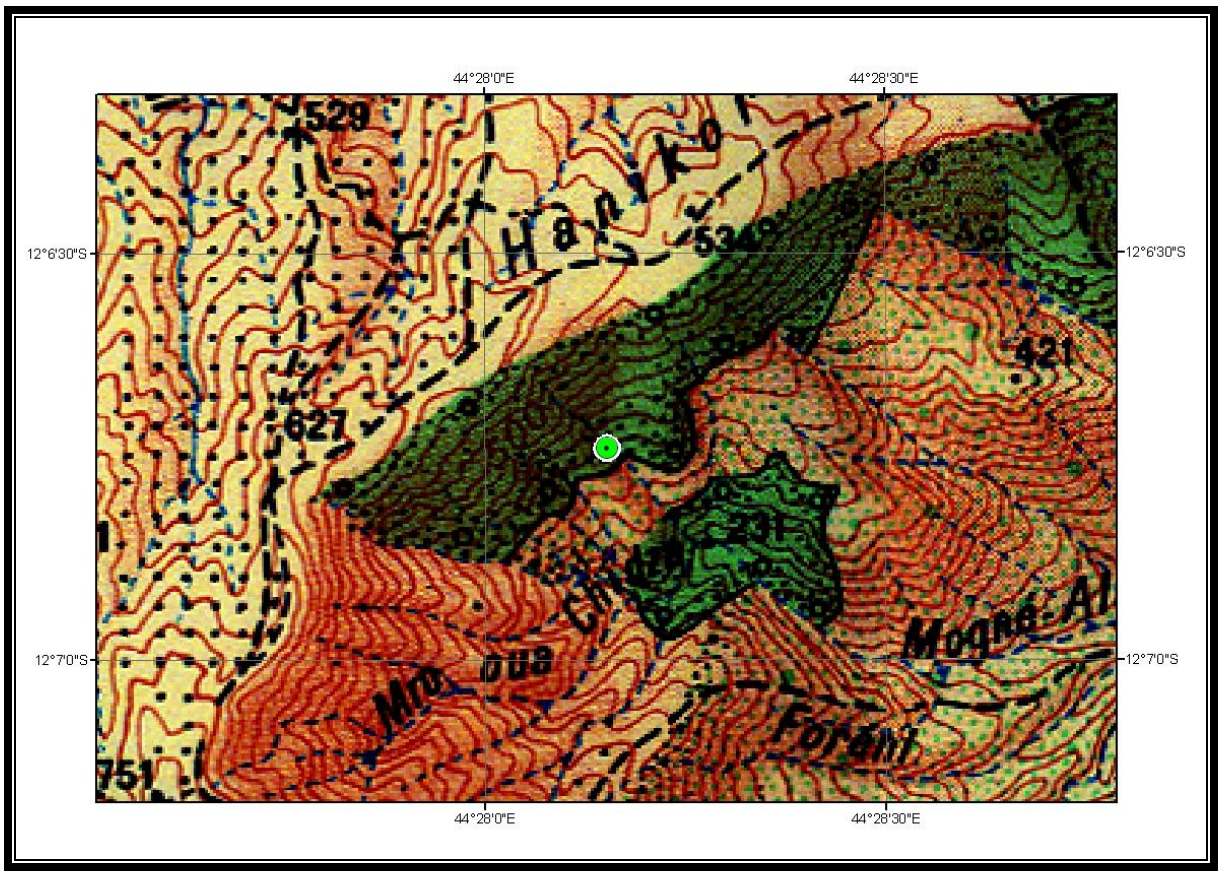
Based on exploration studies red soils are seen in the forms of strips and/or small to large lenses in different parts of these three islands. The spread of this unit is very significant in Anjouan Island. Considering the petrological and stratigraphical studies carried out in this island, this unit in form of a strip runs from the east part of the island and stretches to the middle parts. Based on field surverys and macroscopic studies of the samples, this unit is mainly formed of red clay soils resulted from alteration of pyroclastic and basalts, which

despite their remarkable extent, they generally are not worthy of mining and just being used as farming soil. This unit is also found in other places in the island such as in central, southwestern and northern parts which have been marked as (rs) on the map. In all areas, this unit is generally the product of alteration of pyroclastic deposits and basalt rocks. In Moheili Island this unit is found in a very limited and scattered manner in Ouahani, Mbaste, Miremanl, and west of Mirovini. Based on the studies, these deposits have no value in terms of red laterite soils and are used only as farming soil. In Grand Comores Island there is almost no deposit of red soil similar to those found in Anjouan and Moheili islands.

According to the studies the only significant laterite red soil deposits are located in Anjouan Island, and their specifications are presented below.

3-1-6-1 Laterite red soil deposit in northeastern of Hajoho

This deposit is located in northeastern part of the island, 4 kilometers northeast of Hajoho at the altitude of 520 meters. Its geographic coordinates are latitude of 12° 06' 44.4" and longitude of 44° 28' 9.2". The geographic location of these deposits is shown in map 3-21.



Map 3-21- geographical location of laterite red soil deposit

According to field survey these deposits have been formed within a crater formed by flung basalt rocks. Around this crater, the spread of red soils is seen which usually used as farming lands. The diameter of the crater is 700 meters, and per field observation its northern part seems to be less tall than the other parts and this could be the result of the function of an eastern-western fault. In this area and at the southern part of the deposit, the height of the red soil deposit reaches up to 10 meters. But in the northern part and lower parts the red laterite soil is covered by a layer of red clay soils and jungle trees. According to the studies, the least area of spread of the red laterite soil is 40 thousand square meters. In figures 3-22 and 3-23 the spread of these deposits is shown.

Figure 3-22- A view of the spread of red laterite soil

Figure 3-23- A view of the spread of red laterite soil in northern part

Considering the least area of the spread of the deposit and the least value for specific weight of the red laterite soil (2.5 g/cm^3) , the tonnage of this deposit is estimated around 1 million tons. To analyze the chemical composition and the types of present minerals two samples were studied, and the results are presented in table 3-14.

Table 3-14- Results of XRF and XRD test for determining chemical composition and types of minerals

	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	S	LOI	P_2O_5	MnO
XRF	15.30	27.80	32.02	5.63	0.04	0.37	0.06	0.02	0.16	17.83	0.21	0.05
XRD	Hematite + Mica Illite											

Comparing this deposit to other deposits of the world (with the average grade of 30-35% of iron oxide), this deposit with grade of 32% of iron oxide is well worthy of additional and detailed exploration studies.

3-1-7 Ilmenite indices

The most important resources of titanium in the world reside in placery, marine and basic igneous deposits. From mining point of view, economical deposits of titanium are those deposits which have more than 10 percent of TiO_2 in primary mines and more than 10 percent ilmenite or 1.5 percent rotile in placery deposits. According to studies carried out in the area, a total number of 4 titanium-bearing locations have been found; 2 of which exist in Moheili Island and the other 2 in Anjouan Island. These indices and their specifications are explained below.

3-1-7-1 Anjouan Island

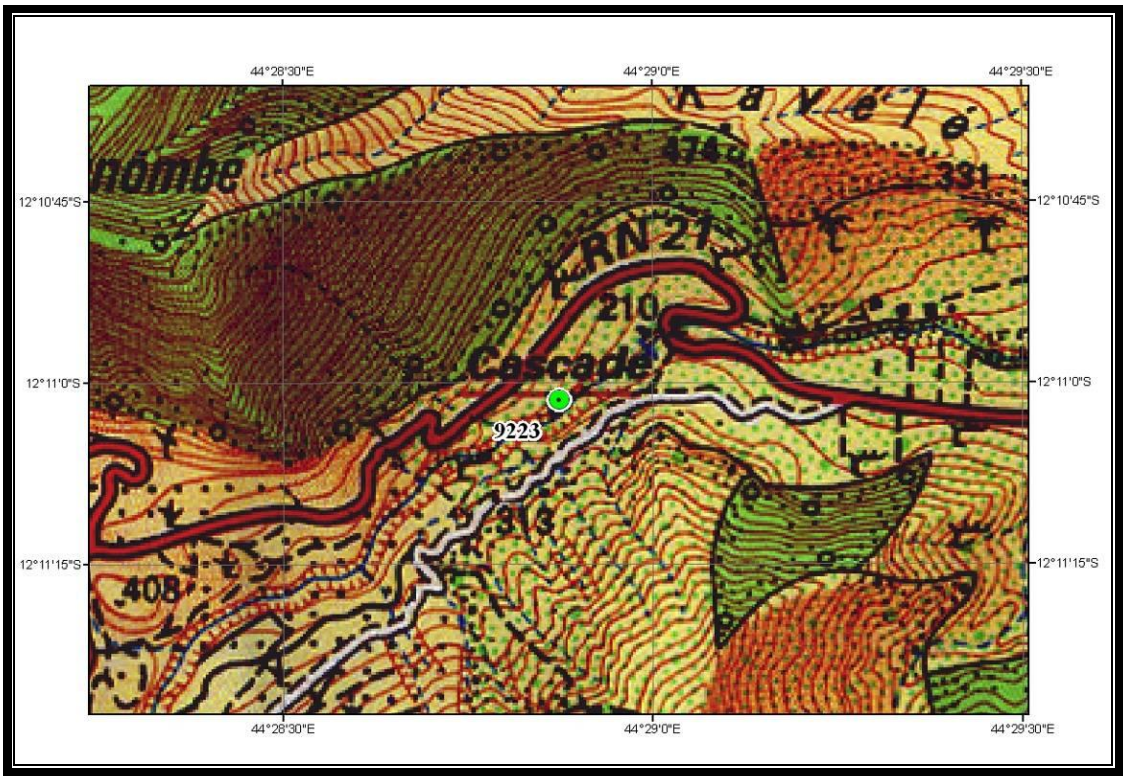
3-1-7-1-1 Area I deposit

This area exists along a main running river that originates from the central heights of the island overlooking the city of Dindi. According to the studied carried out in the area, there is gabbro body with two kilometers in diameter at the source of this river. Mineralogical studies on this gabbro show the presence of ilmenite within the matrix of the rock along with other opaque minerals.

According to these studies and in the first look this gabbros body was determined to be the primary fertile deposit because of its titanium content. A view from this gabbro body is shown in figure 3-24. Based on thin section studies the mineral paragenesis includes: Pyroxene, Olivine, Bioitite, Plagioclase, Rutile and opaque minerals.

Figure 3-24- A view of titanium-bearing gabbro body

Along the path of the river within the Cascade area with geographic coordinates of latitude of 12° 11' 9.5" and longitude of 44° 28' 59.5", a heavy mineral sample was taken for mineralogical studies as well as studying the concentration of titanium-bearing minerals. The studies revealed 24 percent ileminte and 35 percent titanomagnetite (sample number 9223 appendix I). Map 3-23 shows the location of the sample taken from this area, and in figure 3-25 a view of sampling location is shown.



Map 3-23- The location of the sample taken from this area

Figure 3-25 – A view from the sampling location and the morphology of the area

Regarding the fact that the path of the river is very steep and practically there is no possibility of formation of alluviums containing titanium, the further surveys and studies were focused on the river delta around its entry point to Indian Ocean.

This place is located in the latitude of 12° 10' 47.4" and longitude of 44° 30' 47.2", it is the joining point of the river and the ocean. In this area, the thickness of titanium-bearing alluviums is at least 10 meters and its spread is about 250000 square meters. In terms of grains, regarding the high slope of river it is made of big rocks in size of few centimeters and fine grain alluviums in size of millimeters which alternatively cover each other in some parts of this area. There are place in this delta where fine grain sands are extracted for use in concrete production. Regarding the thickness of sediments and their spread and taking into consideration the specific weight of 2 g/cm^3, the estimate of the tonnage is about 5 million tons with the grade of 20 percent. In figures 3-26 and 3-27 the ilmenite and titanomagnetite grains found in the samples are shown.

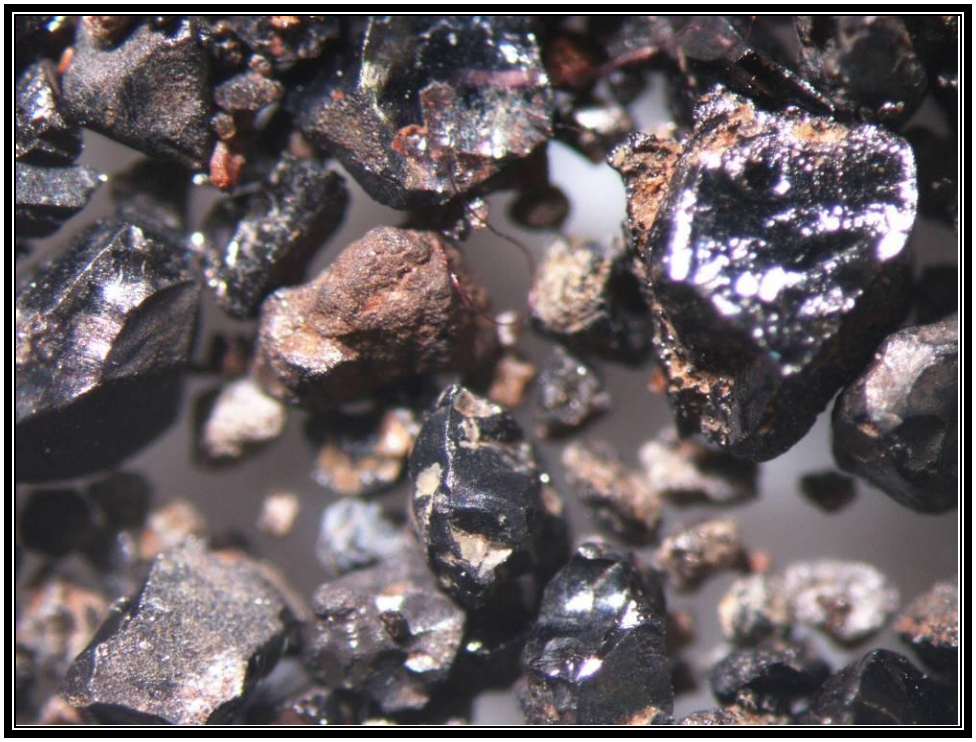


Figure 3-26 – A view of ilmenite and titanomagnetite grains found in the samples

Figure 3-27 – Another view of the ilmenite and titanomagnetite grains found in the samples

3-1-7-1-2 Area II index

This area is located in the southeastern end of the island in Solapouani. The geographic coordinates of this area are latitude of 12° 22' 43.9" and longitude of 44° 30' 04". The mineralogical studies in this area have shown a maximum of 6 percent of titanomagnetite, and with regards to lack of ilmenite minerals, this area is introduced only as an index.

3-1-7-2 Moheili Island

3-1-7-2-1 Area I index

This area is located at the latitude of 12° 18' 32.3" and longitude of 43° 46' 46.6", in the south east of Djoyezi. Based on heavy metal studies in this area, some signs of titanium-bearing minerals have been found (ilmenite, titanomagnetite). Considering the percentage of the minerals (sample 9276 appendix I), this area is introduced only as a mineral index.

3-1-7-2-2 Area II index

This area is located at the latitude of 12° 18' 48.5" and longitude of 43° 38' 36.8", in the west of the Djiranl area island. The results of the heavy mineral studies in this area also showed signs of titanium-bearing minerals (ilmenite, titanomagnetite) (sample 92945, appendix I).

3-1-8 sulfur deposits

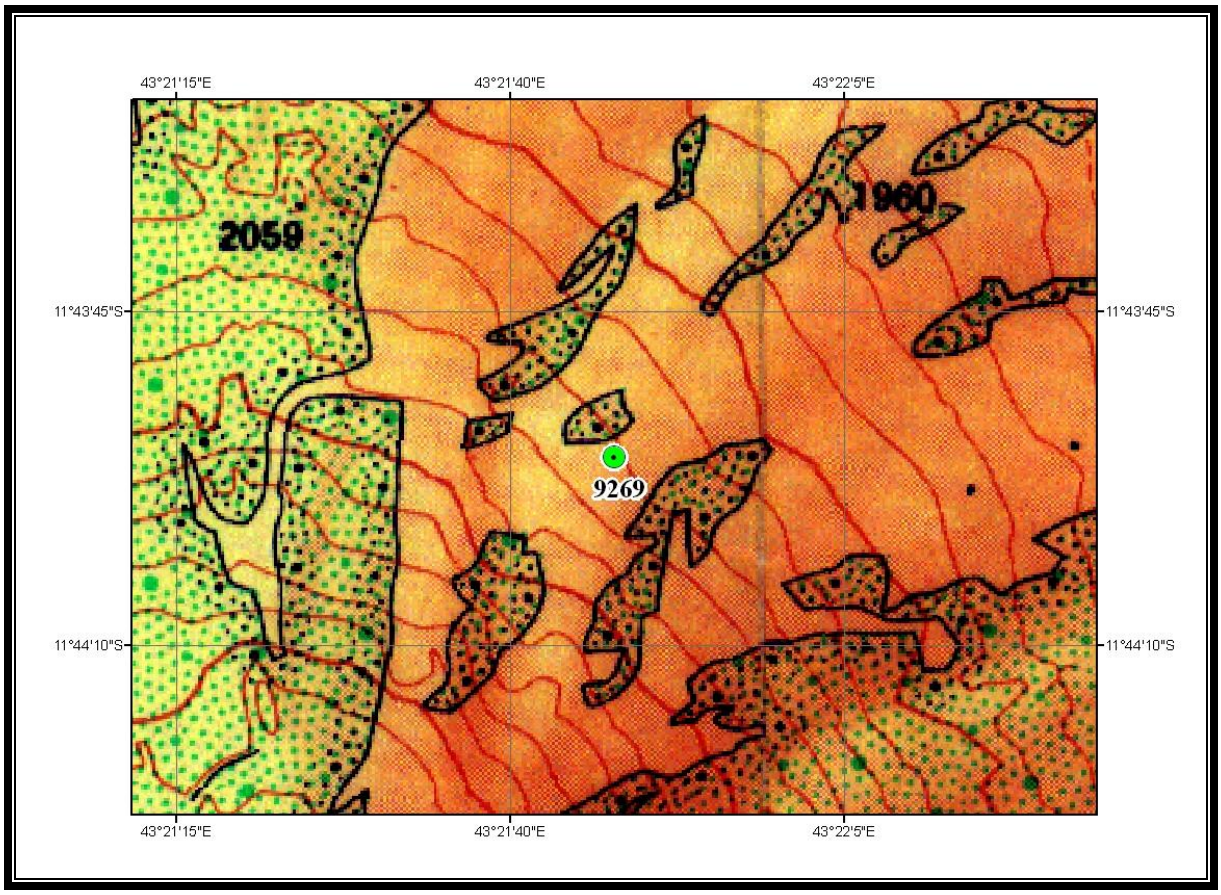
Until the beginning of the twentieth century almost all of the sulfur of the world was obtained through mining of volcanic deposits, and its production was limited to sulfur containing countries like Japan, Turkey, Mexico, Italy and South America. Nowadays, the sulfur mines resulted from deposits produced by evaporation, crude oil refinement process, sweetening of sour gas and volcanic deposits are the source for producing sulfur. Among these sources, the volcanic deposits are only used locally due to their limitation and mining difficulties, and therefore play no role in international trade.

However, during geological studies in Comores Island only one pure sulfur deposit was found which exists in Grand Comores Island.

3-1-8-1 Grand Comores Island

3-1-8-1-1 Sulfur deposit on northern slope of Karthala volcano

This deposit is located at the latitude of 11° 43' 55.9" and longitude of 43° 21' 47.8", at the altitude of 2091 meters above the sea level (on northern slope of Karthala volcano. From geological point of view, the area is mostly covered with young lavas with very rough surface and there is practically no vegetation coverage in the area. Due to the situation of the area and activities of volcano the ground in the area is very warm and water steam along with sulfur gases come out through the cracks in rocks. In north to south direction and within a distance of about 200 meters there are 4 holes along one line which are covered by sulfur crystals. Due to the situation of the area, activeness of the volcano and placement of sulfur crystals in cracks, this deposit could stretch down to deeper parts. However due to being difficult to pass through the area (map 3-24), access to area is practically very hard and on the other hand due to activeness of the volcano and presence of gases and sulfur containing steams, one cannot call it deposit. To find the percentage of its sulfur content, a sample from this area was taken and tested, and the results are presented in table 3-15.



Map 3-24 - Geographic location of sulfur-bearing area

In figures 3-28 and 3-29 the spread of the sulfur-bearing area is shown.

Figure 3-28 – A view of sulfur-bearing area

Figure 3-29 – A view of sulfur-bearing holes

Table 3-15 results of sulfur analysis

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	S	LOI	P_2O_5
9269	16.15	0.50	0.63	2.19	0.46	0.29	0.05	0.26	71.82	7.1	0.07

3-1-9 Clay deposits

Usual clay or clay soil is a type soil with small grains (1:256 millimeters) and it is shapeable enough for molding, which consists of clay, illite and chlorite minerals, a little kaolin and smectite, along with some calcite, quartz and unaltered feldspar minerals, pieces of mica, hydro mica and amorphous minerals called alumina which they themselves are the product erosion and chemical decomposition of silicate rocks.

The percentage of the elements and the substances forming the clay depend on the source rock composition, the length of route of transportation, and the climatic and topographic conditions of the area. Some of the impurities of the clay give it unique color as Fe_2O_3 content makes it red, limonite makes it yellowish bright brown and organic chemicals give it a gray color.

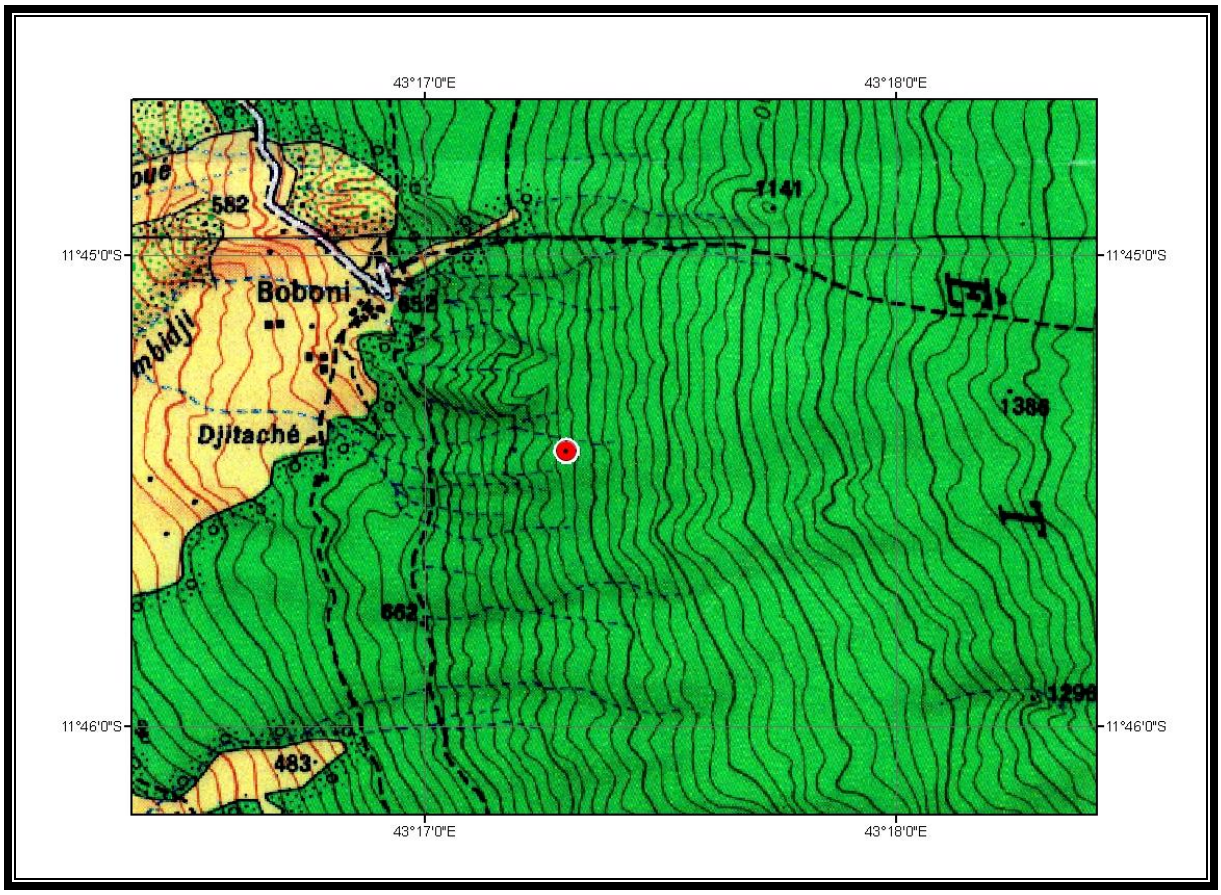
Here and in course of economical geological studies of Comores, its clay deposits were also paid attention to and studied. Considering the rock and geological conditions of this set of islands and also their young age, formation of clay deposit has only occurred in some areas which are geologically older. On this basis, the concentration of clay soils is higher in two islands of Anjouan and Moheili which are older than Grande Comores in terms of the formation time. Below the most important clay-bearing areas of this country are explained as it follows.

3-1-9-1 Grande Comores Island

The spread of clay is limited in this island but, regarding their chemical composition, their application in production of brick and other clay products is possible. On this basis clay resources were studied in three places on this island.

3-1-9-1-1 Area I

This deposit is located at the latitude of 11° 45' 25" and longitude of 43° 17' 18", in Bobini area. Its location is shown in map 3-25.



Map 3-25 – Geographic location of the deposit in area I

In this area volcanic lavas of Pyroxene- Olivine basalt cover all the area. A clay layer with width of about 3 meters and length of about 100 meters is the product of erosion and alteration of volcanic units but alteration and erosion processes have not been fully finished and therefore clay minerals are seen only in the form of a thin layer on the rock units. Due to the presence of iron, the clay of this area is seen in red color. The result of chemical analysis of the clay is presented in table 3-16.

Table 3-16- Results of chemical analysis of clay deposit in area I of Grande Comoros

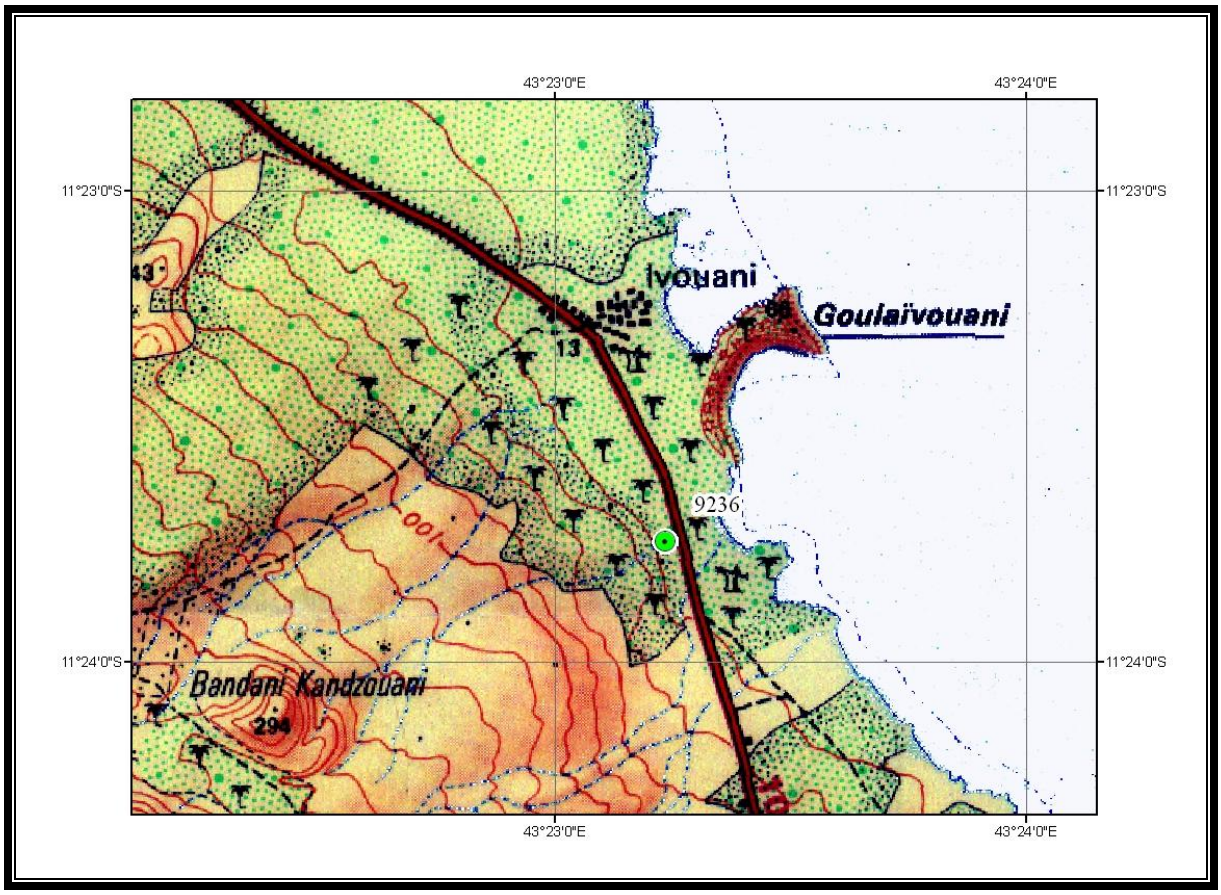
Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	S	LOI	P_2O_5	MnO
9203	31.80	19.09	15.09	2.76	4.43	3.52	0.98	0.42	0.08	20.85	0.36	0.16

In figure 3-30 A view of the spread and placement of this unit is shown.

Figure 3-30 – A view of the spread of the clay unit of area I of Grand Comoros

3-1-9-1-2 Area II

This deposit is located at the latitude of 11° 23' 43.9" and longitude of 43° 23' 13.7", in northeastern part of Grande Comores Island. The geographic location of this area is shown in map 3-26.



Map 3-26 – Geographic location of clay deposit in area II of Grand Comores

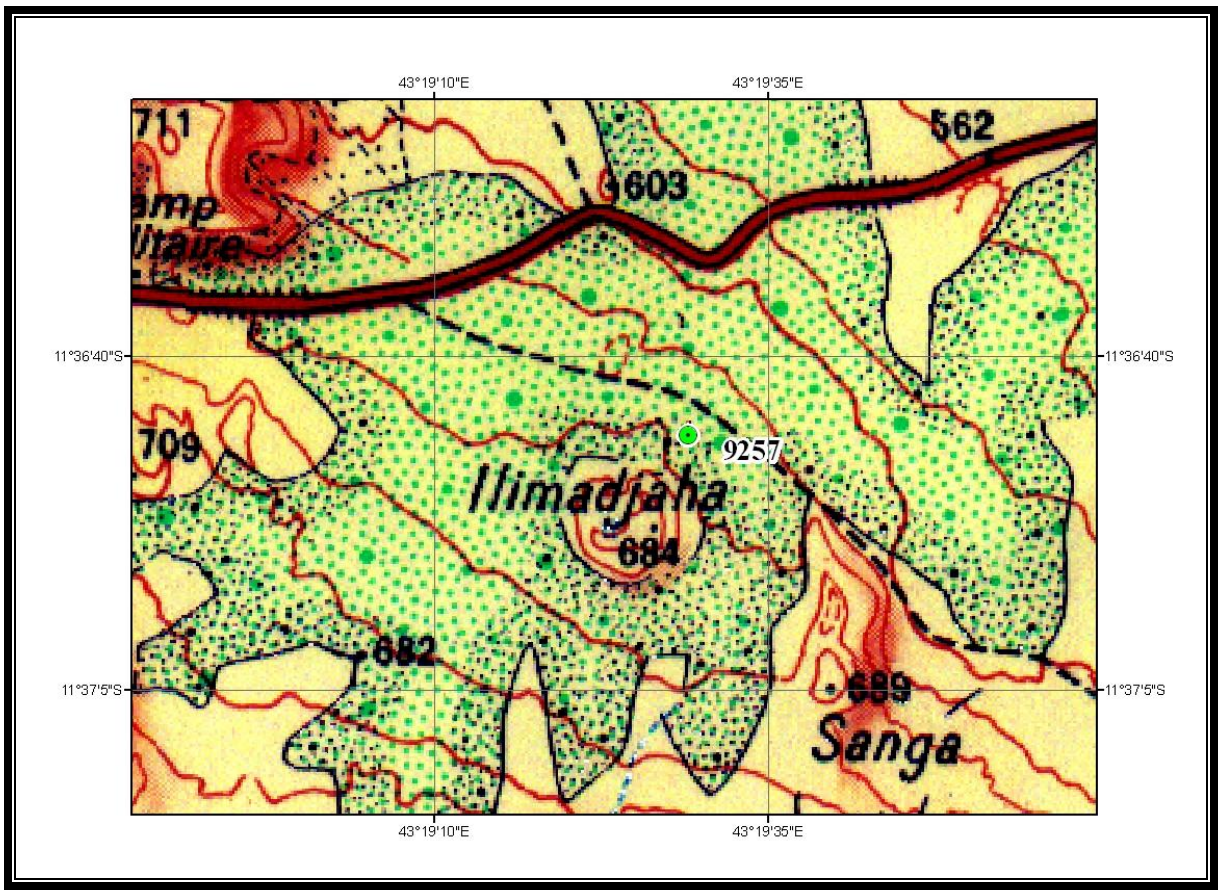
In this area there is a crater with a collection of volcanoclastic rocks which in some parts have turned to clay minerals due to alteration process. The spread of clay unit in this area is about 40000 square meters which has variable thickness in different places with an average of 10 meters. The approximate tonnage of this deposit is about 1 million tons. The result of the chemical analysis of this deposit comes in shown in table 3-17.

Table 3-17 – Results of chemical analysis of the clay sample from area II of Grand Konuru

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	S	LOI	P_2O_5	MnO
9236	40.83	14.48	14.25	2.23	2.39	0.22	0.15	0.03	<0.02	14.79	0.12	0.17

3-1-9-1-3 Area III

This deposit is located at the latitude of 11° 36' 45.9" and longitude of 43° 19' 29", in western part of the island and in Isoundzu area. In map 3-27 the geographic location of the deposit is shown.



Map 3-27 – Geographic location of clay deposit in area III of Grande Comores

This area is fully covered with Olivine basalt and pyroclastic rocks which have turned into clay minerals in some areas as result of alteration. From the tonnage point of view this area is noticeable. It spreads over an area with the length of about 1000 meters and width of 500 meters and its height exceeds 50 meters. The approximate amount of tonnage is about 60 million tons. In table 3-18 the average numbers from chemical analysis of this sample is presented in table below.

Table 3-18 Average numbers from chemical analysis of clay deposit in area III of Grande Comores

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	S	LOI	P_2O_5	MnO
9257	25.76	16.98	15.68	2.86	3.95	6.34	0.36	0.14	0.07	26.60	0.04	0.17

3-1-9-2- Anjouan Island

In this area red clay soil shows extensive spread and covers a large part of western, central, northeastern and southeastern parts. All of these red clays are the product of alteration on Olivine basalt units and pyroclastic rocks. The areas covered by red clay are used as farming lands. However based on observations, clay deposit in area I was studied and analyzed.

3-1-9-2-1 – Area I

This deposit is located at the latitude of 12° 11' 48.9" and longitude of 44° 16' 43.9", in northern part of the island in Maoueni area. In map 3-28 the geographic location of this area is shown. Rock units of this area include Olivine basalt, which have transformed to red clay due to alteration.

Map 3-28 – Geographic location of clay deposit in area I of Anjouan

The spread of this unit in this area is noticeable. Its length is about 500 meters, its width about 400 meters and its thickness is more than 10 meters. The result of chemical analysis is shown in table 3-19.

Table 3-19 – Results of chemical analysis of clay deposit in area I of Anjouan

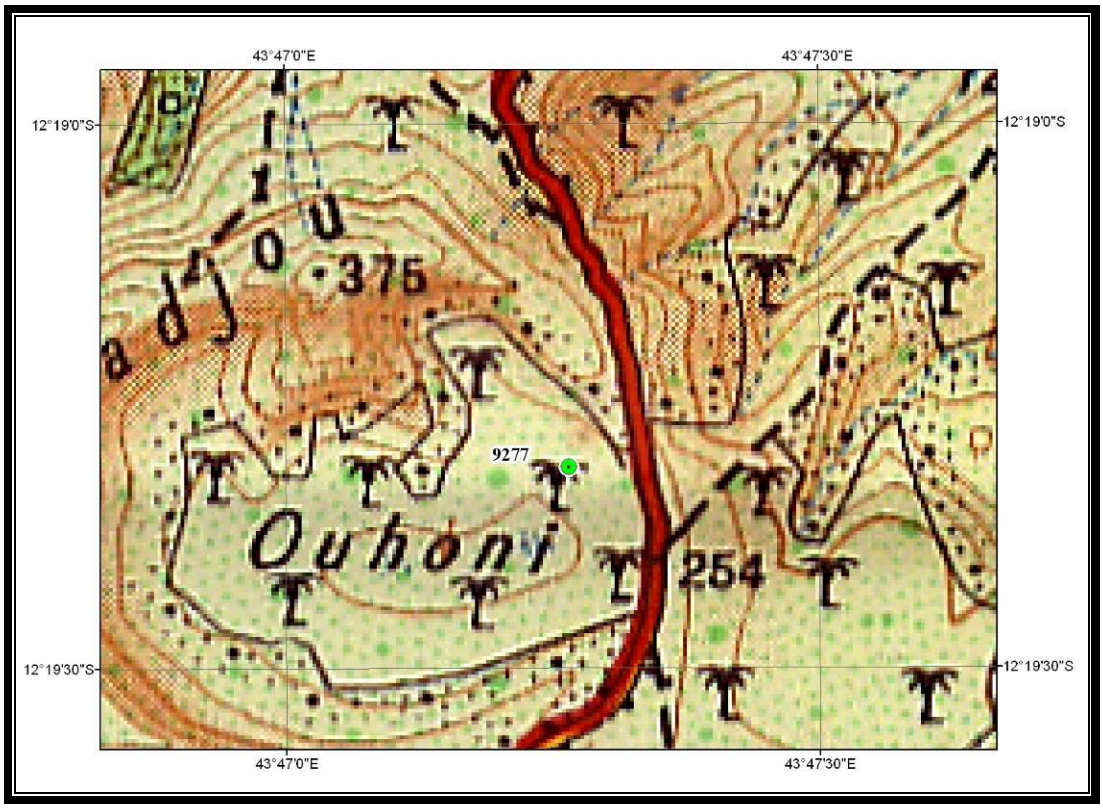
Sample number	SiO2	Al2O3	Fe2O3	TiO2	CaO	MgO	Na2O	K2O	S	I.O.I	P2O5	MnO
9229	38.53	18.17	17.10	3.83	2.60	2.68	0.76	0.87	0.02	14.12	0.92	0.18

3-1-9-3 Moheili Island

In this area the extension of clay spread is noticeable, but it is mostly used as farming lands. In parts that are described below, it is clearly seen that all rock units have transformed to clay soil as a result of alteration. Here three main clay-bearing areas are discussed.

3-1-9-3-1 – Area I

This deposit is located at the latitude of 12° 19' 18.9" and longitude of 43° 47' 16", in northeast of the island in Ouhoni area. The deposit in this area is the product of erosion and alteration of rock units with the composition of Olivine basalt and pyroclastics of older craters. In map 3-29 the location of this area is shown.



Map 3-29 – Geographic location of clay deposit in area I of Moheili

The spread of this unit is noticeable in way that its length is about 600 meters, its width is about 400 meters and it has a thickness of at least 20 meters as seen on the cut-through wall on the road side. The results of the chemical analysis are shown in table 3-20.

Table 3-20 – Results of chemical analysis of clay deposit in area I of Moheili

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	S	I.O.I	P_2O_5	MnO
9277	15.85	27.14	29.76	5.62	0.20	0.48	0.11	0.04	0.08	19.28	0.59	0.16

A view of this deposit is shown in figure 3-31.

Figure 3-31 – A view of the spread of this clay deposit

3-1-9-3-2 – Area II

This deposit is located at the latitude of 12° 20' 46.5" and longitude of 43° 41' 7.6", in southwestern pat of the island in Ndrondroni area. In this area also, a clay deposit with the area of 500×600 meters and observable thickness of at least 8 meters formed due to the alteration of Olivine basalt rock units and pyroclastics. The geographic location of this area is shown in map 3-30.

Map 3-30 – Geographic location of clay deposit in location II of Moheili

The results of the chemical analysis of this deposit are presented in table 3-21.

Table 3-21 – Results of chemical analysis of clay deposit in area II of Moheili

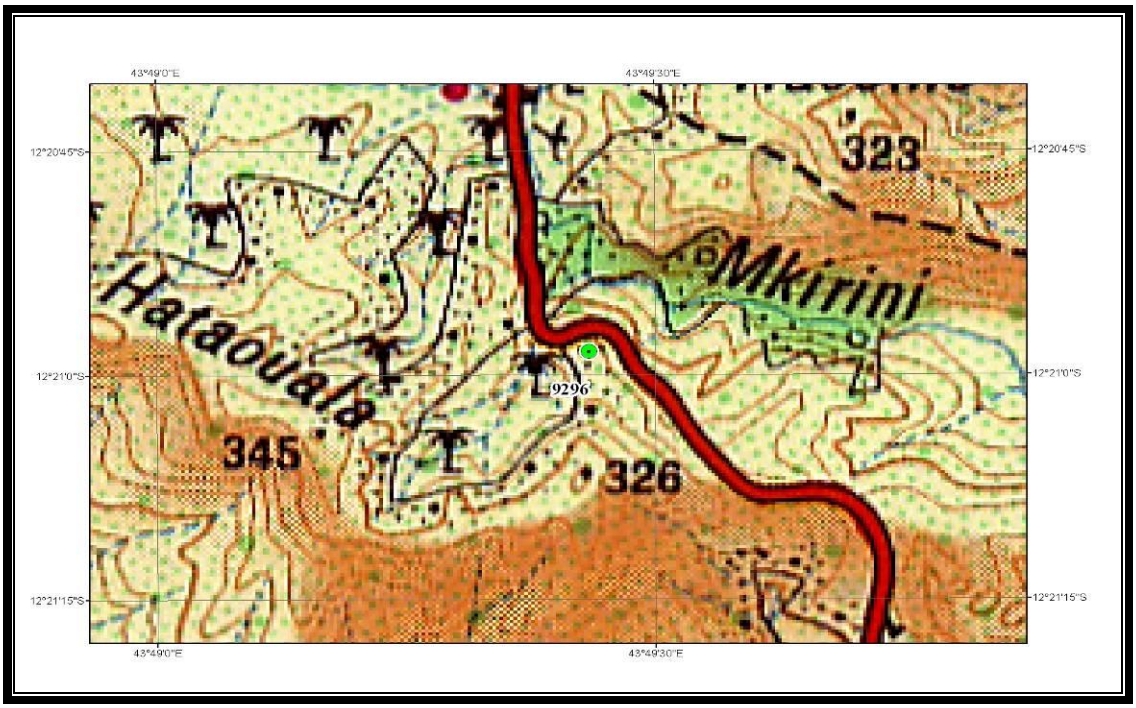
Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	S	I.O.I	P_2O_5	MnO
9286	28.32	23.87	22.46	4.90	0.32	1.28	0.08	0.02	0.03	17.18	0.90	0.20

A view of the spread of this deposit is shown in figure 3-32.

Figure 3-32 –A view of the spread of clay units in area II

3-1-9-3-3 – Area III

This deposit is located at the latitude of 112° 20' 58.2" and longitude of 43° 49' 26.2", in eastern part of the island, south Ouanai. In this area the clay deposit is the product of erosion and alteration of Olivine basalt and pyroclastic units which spread over an area of several kilometers. Based on field surveys, this area has gray to lemon and red clays which indicates the presence of organic substances and iron oxides in them. Large part of the area is used as farming land. The location of the area is shown in map 3-31.



Map 3-31- Geographic location of the clay deposit in area III of Moheili

In table 3-22 the results of chemical analysis on the sample taken from this clay deposit is shown.

Table 3-22 – Results of chemical analysis of clay deposit in area III

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	S	I.O.I	P_2O_5	MnO
9296	22.62	24.82	28.19	4.79	0.04	0.21	0.08	0.01	0.18	17.87	0.98	0.03

According to results of field studies and analyses carried out on the clay deposit of this country, the followings are concluded:

1- In regards to their use in production of brick and baked clay: the clay used in this industry must have specific specifications which consist of:
   a- The amount of Al_2O_3 must be near 15 percent (less than 17 percent and more than 12 percent). If the amount is more or less than these numbers, the raw brick cracks at the time of drying and breaks during baking.
   b- Amount of sulfate ion in clay must be less than 0.8 percent.
   c- Amount of calcite must be less than 30 weight percentage.
   d- Amount of NaCl and KCl all together must be less than 0.2 percent.

Therefore, based on the analyses, only the clay deposits in areas II and III of Grand Comores can potentially be used to produce high quality bricks.

2- For producing fireproof clays, since the amount of Fe_2O_3 in all clay deposits of this country is high (between about 15 and 30 percent), and the variation range of them must be 2.4 percent at most, despite the very good percentage of Al_2O_3 and other ingredients, unfortunately these clays are not directly usable for fire clay industries.

The variation range of chemical composition for fire clays is shown in table 3-23.

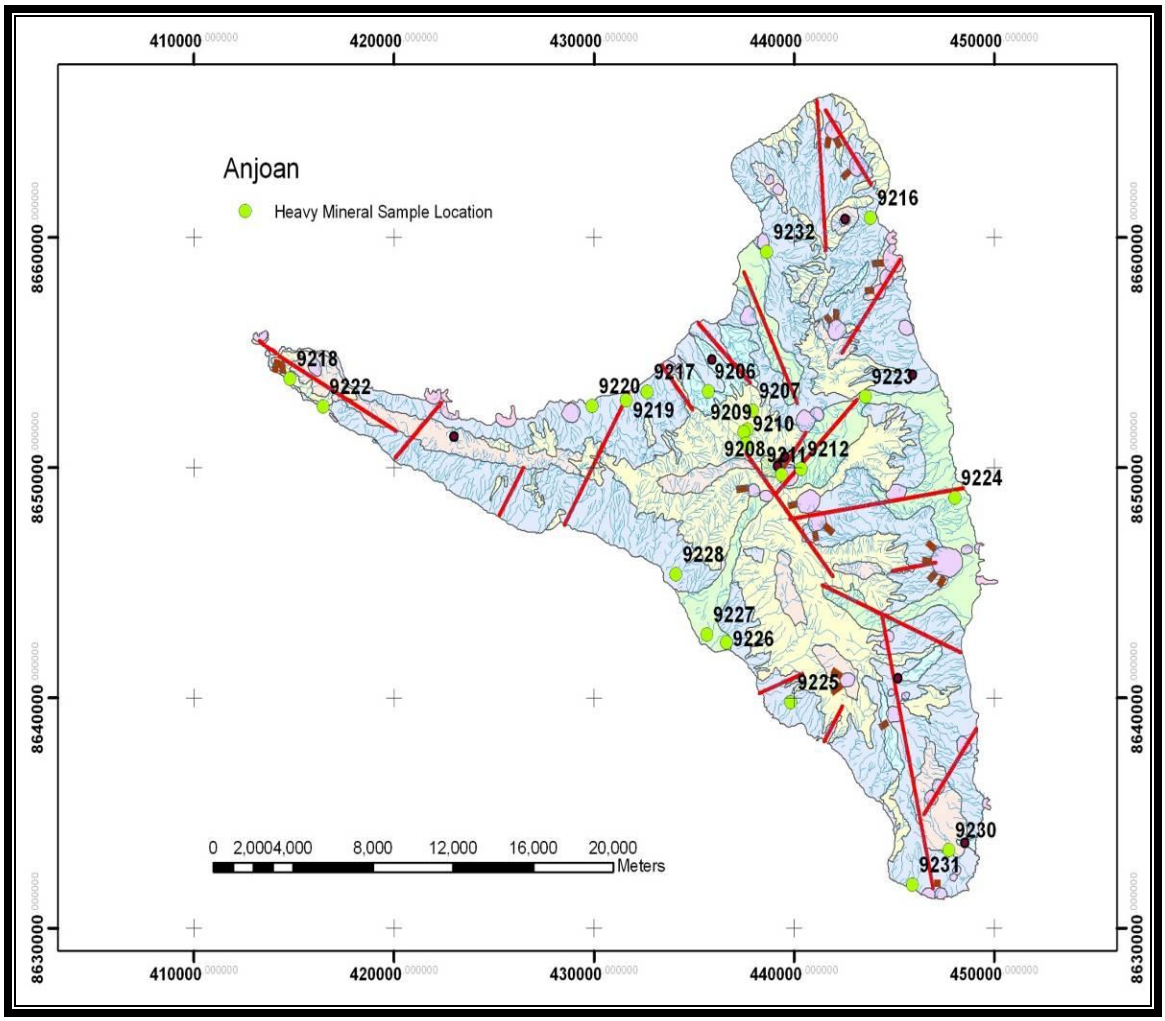
Table 3-23- Variation range of chemical composition of fire clays

Chemical	Maximum (percent)	Minimum (percent)
SiO_2	58	42
Al_2O_3	38	23
Fe_2O_3	1.7	0.4
FeO	0.7	0.2
FeS_2	0.5	-
MgO	1	0.1
CaO	0.8	0.4
Na_2O	0.5	0.05
K_2O	1.9	0.05
$(H_2O)+$	13.5	8
$(H_2O)-$	5	1
TiO_2	2.5	1
P_2O_5	0.5	0.1
organic substances	0.25	0.01

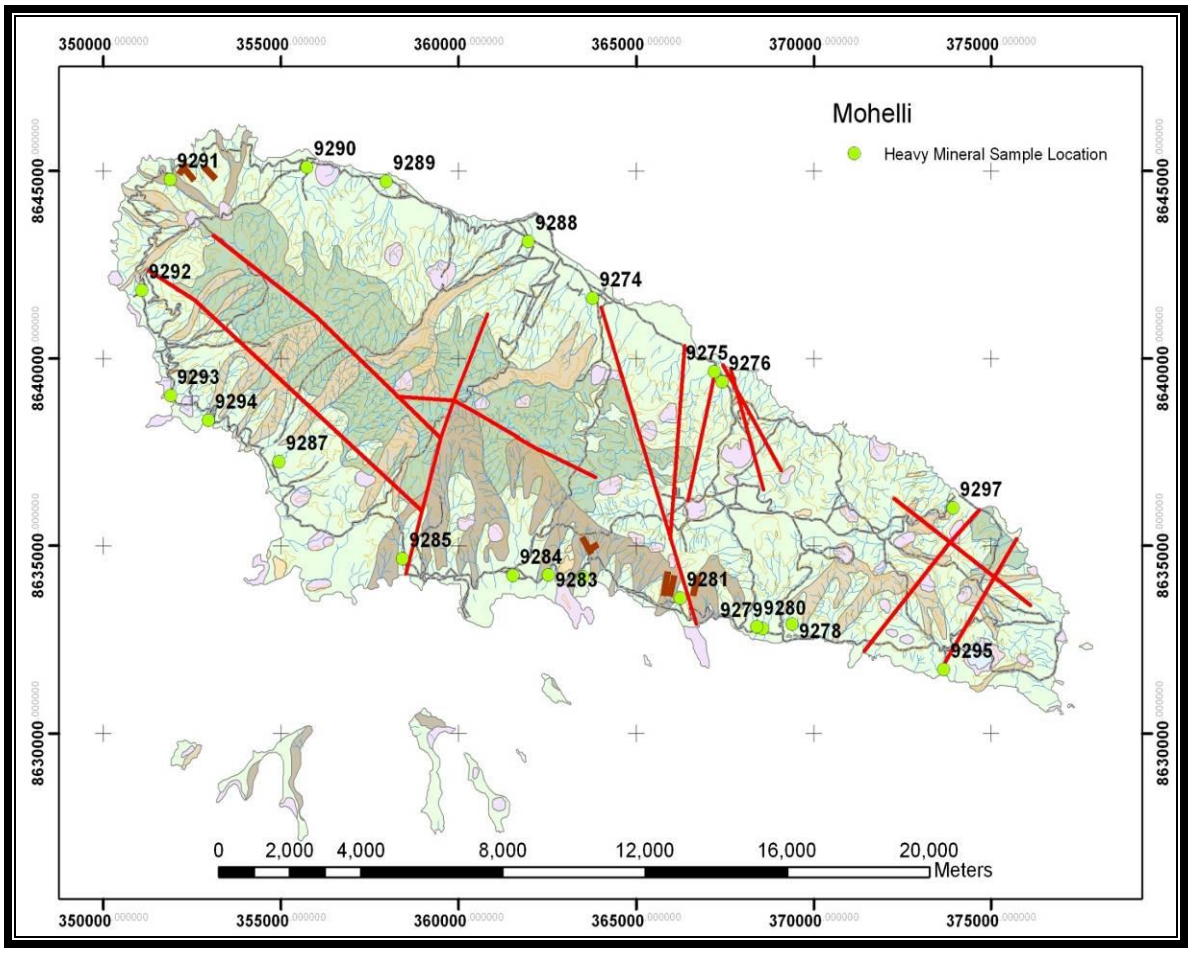
3-1-10 – Heavy minerals

3-1-10-1 – Sampling of heavy minerals

72 samples of heavy minerals were taken from all over the area during this stage of the work, and the locations of sampling are shown in maps below.



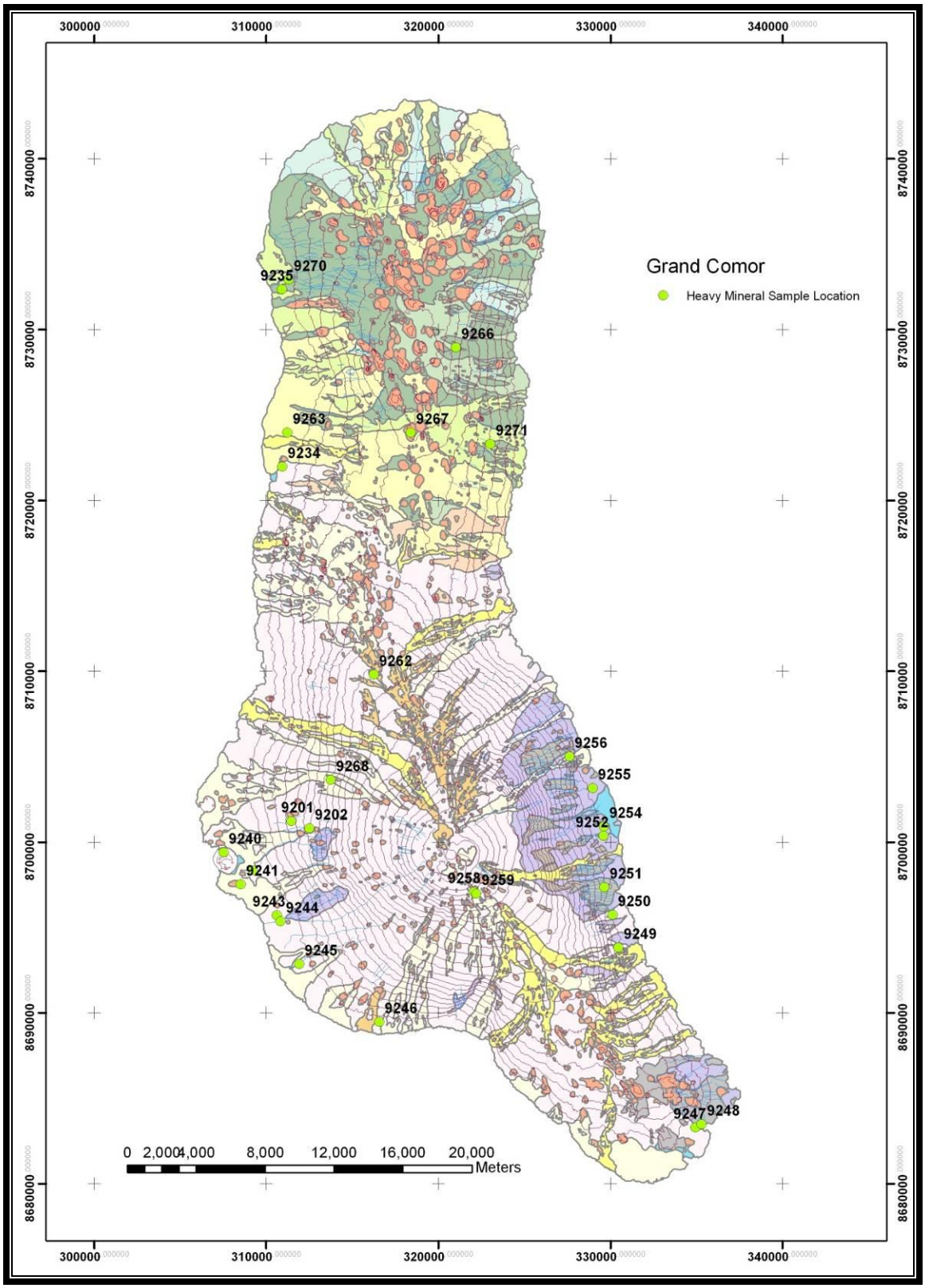
Map 3-32 – Locations of heavy mineral sampling in Anjouan Island



Map 3-33 – Location of heavy mineral sampling in Moheili Island

3-1-10-2 – Some points about the method of sampling and preparation of heavy mineral samples

For heavy mineral sampling, large rivers with large watershed area are more suitable because the low number of samples would have the least effects on the results. Heavy mineral samples are taken from places where the concentration is more probable. In these areas sand grains are more abundant and mostly form in places where the river slope decreases. The possibility of accumulation of these materials decreases in highlands, snow levels and also areas where chemical erosion is more active.



Map 3-34- Heavy mineral sampling locations in Grande Comore Island

The more the density in sampling, produces the higher accuracy of the results, and also the number specified in list of services document of the contract is a function of the area that each sample has under its coverage and it is normal to see increase in number of samples where the area of watershed is larger. Another factor which affects the number of heavy mineral samples per area unit is the litho logy of geological units and with more variety in rock units would require more samples to be taken. It is safe to assume that one heavy mineral sample is enough for each watershed area with one or few square kilometers.

The weight of the heavy mineral sample is determined by the goal of the study, and generally that amount of deposit is taken of which 4 liters of sample would be left after being sifted with -20 to +80 mashes. The mud in samples washed out in the first phase and the volume of sample is recorded before and after mud-washing. The next step is panning the samples. In the next stage the remaining part of the sample is exposed to two magnets with standard magnetic intensity and divided into three parts of strong magnetic, weak magnetic and non magnetic, and the volume of each part is recorded. From these three parts the non magnetic part is sent for bromoform process in order to separate heavy and non heavy parts. After the above stages are completed, each part is studied and the percentage of the intended variable in that part is determined. At the end of the process and using these percentages and the initial volume of sample used in each stage, the amount of each heavy mineral is calculated in PPM or percentage. It is obvious that considering the preparation process the calculated amounts do not represent the actual amount in the water channel and the real numbers are less than the recorded numbers.

3-1-10-3 – Key factors in distribution of halos in heavy minerals

The key factors in distribution halos in heavy minerals from origin towards bottom are:

a- Composition and largeness of the mineral deposit in the origin area,
b- Chemical environment governing the origin and transport condition, which could cause the level of resistance and distance of transportation to vary for different minerals.
c- Mechanical specifications of minerals and mechanical changes during transportation and sedimentation. Some minerals are resistant to mechanical erosion but some are not and would break.

Some of these factors depend on the climatic and geomorphologic conditions of the environment. This is why the transportation distances reported for different minerals are different. For example, for gold and wolframite halos as long as tens of kilometers have been recorded. In cases where outcrop is small or topographic slope in water channel is mild, these distances are significantly reduced, and it is possible that the trace of the minerals decreases so much that in the first few kilometers of the path these minerals are not recordable in the water channel. In such cases this possibility exists that in the first kilometer of the path the content of some heavy minerals decreases by 90 percent.

3-1-10-4 – Analyzing data of heavy minerals in Comoro

3-1-10-4-1- Drawing histogram for heavy mineral variables

The histogram of the distribution of different variables was analyzed in this part. For most of the variables, and regarding the fact that in most of the samples no amount has been recorded, determination of distribution and path of change of data are not possible and the value of histogram are not the same regarding the number of valid data in each of them.

Table 3-24 – Number of recorded data for each variable

Mineral Name	Number	Mineral Name	Number
MAGNETITE	72	LEUCOXENE	7
TITANOMAGN	54	SPHENE	2
GOETHITE	3	CINNABAR	4
HEMATITE	51	GOLD	1
LIMONITE	57	GALENA	7
PYRITE_OXI	9	OCHER	16
PYROXENE	44	MARMATITE	1
AMPHIBOLE	15	PYRITE	10
EPIDOT	2	PYRITE__LI	1
GARNET	2	CORUNDUM	15
PERIDOTS	72	SPINEL	39
ILMENITE	25	MARTITE	7
OLIGISTE	5	MIMETITE	1
CHROMITE	17	PYROLUSITE	2
BIOTITE	4	NATIVE_LEAD	3
CHLORITE	6	NATIVE_COP	4
STAUROTIDE	3	CUPRITE	7
ZIRCON	59	MALACHITE	3
APATITE	41	LITHARGE	2
CELESTINE	1	DEBRIES	1
BARITE	5	RUTILE	9

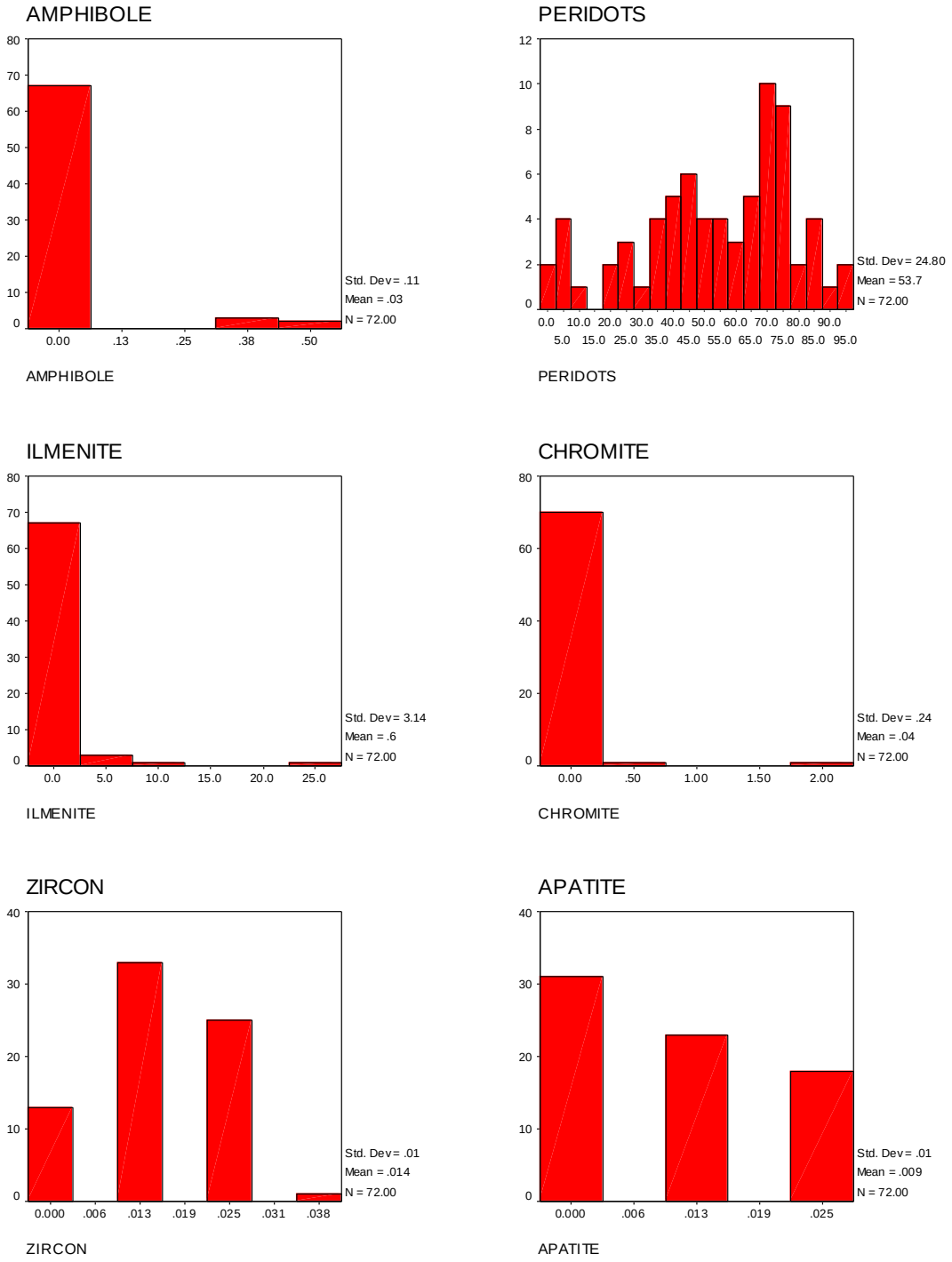


Figure 3-33 – Histogram of abundance of amphibol, peridotite, chromite, ilmenite, zircon and apatite minerals

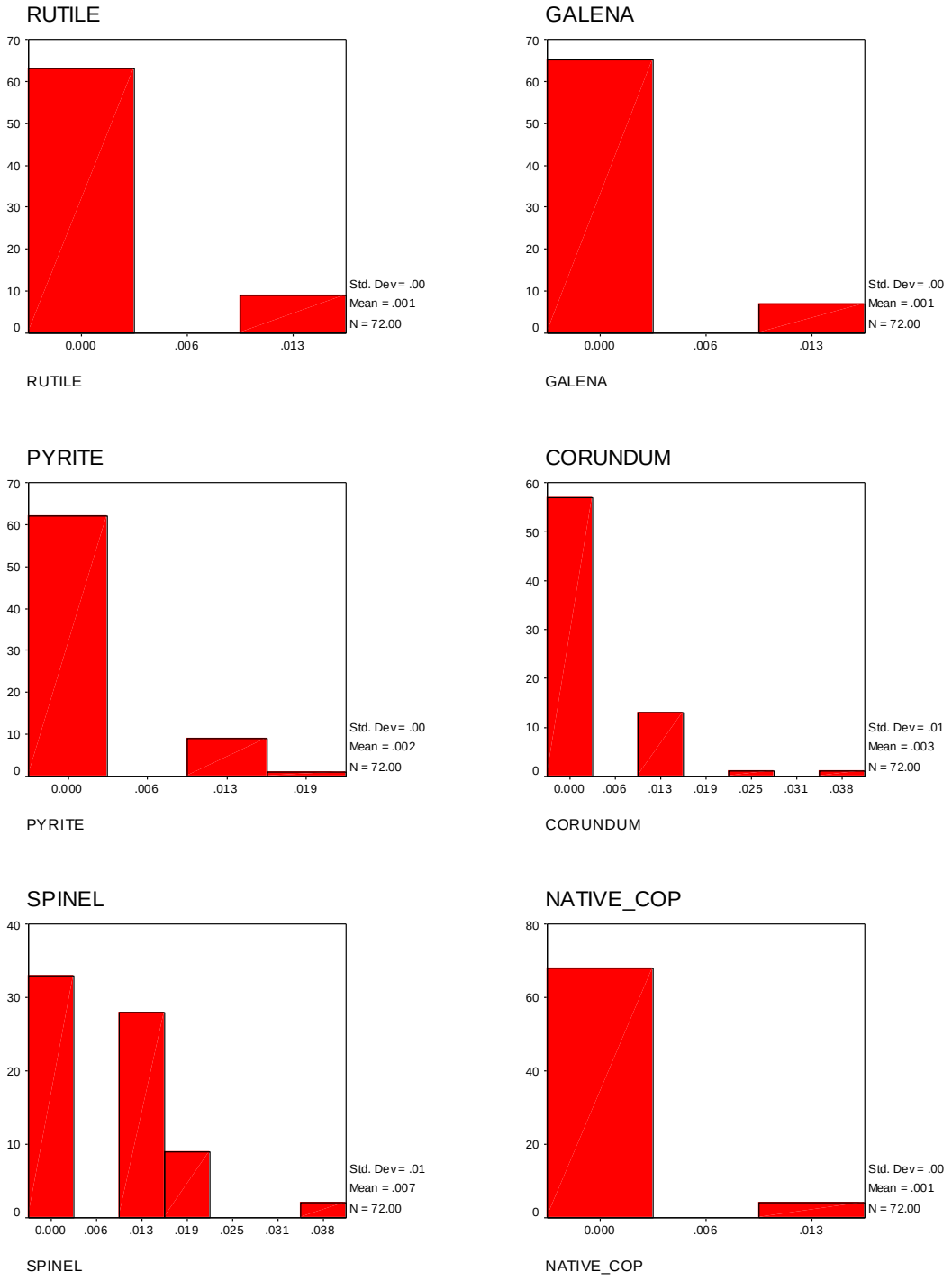


Figure 3-34 – Histogram of abundance of rutile, galena, pyrite, corundum, spinel minerals, and native copper

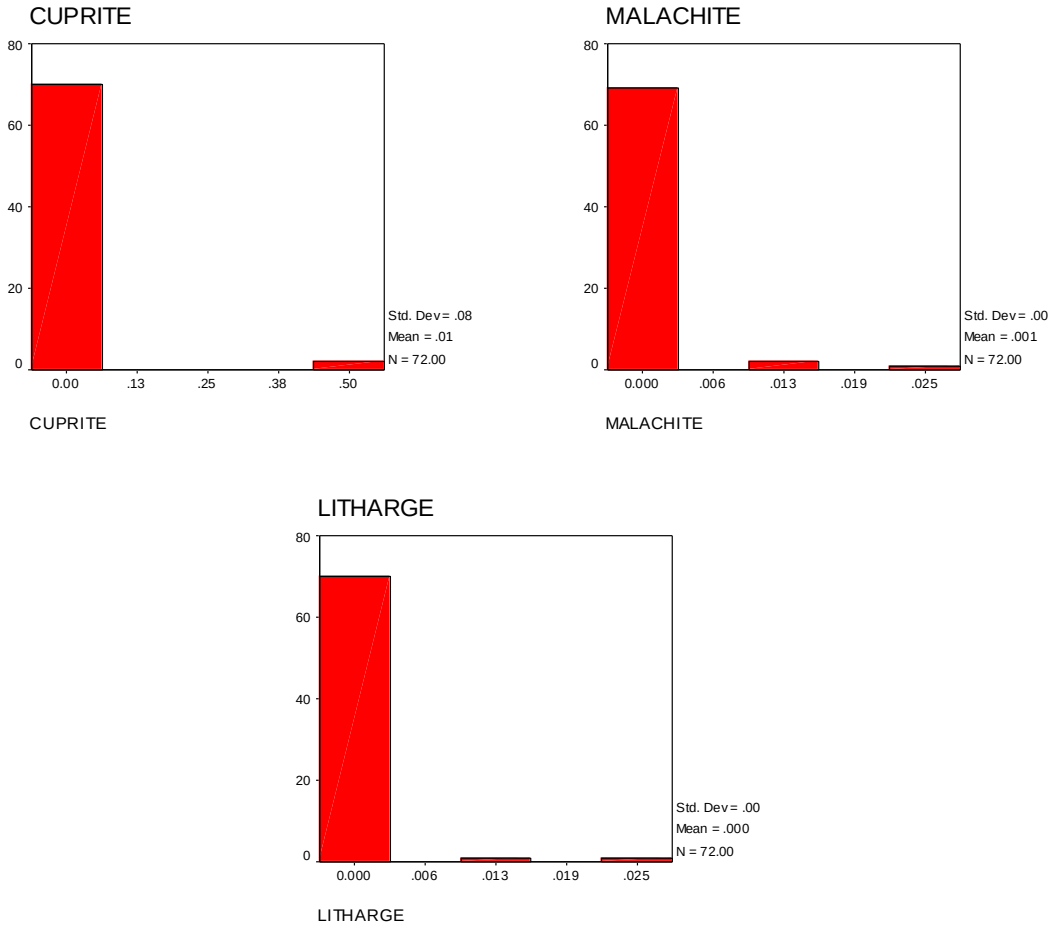


Figure 3-35 – Histogram of abundance of cuprite, malachite, and litharge minerals

3-1-10-4-2 – Analysis of the cluster of variables of heavy minerals

This method can be helpful for better understanding of the relation between different variables of heavy minerals because it shows the paragenetic relationship between the variables of heavy minerals. To determine such relationship between different variables and to choose the most suitable ones some variables have been analyzed with cluster method in order to prepare the ditribution map of the heavy minerals.

By comparing dendrogram of data against bimodal dendrogram of recorded variables (0 and 1), it is observed that the bimodal method has a more meaningful grouping and displays parageneses much better. Thus this method was used for cluster analysis. This dendrogram has a weak symmetry due to weakness of paragenetic relationship and lack of data. The results of this analysis are shown in a dendrogram in figure 3-36.

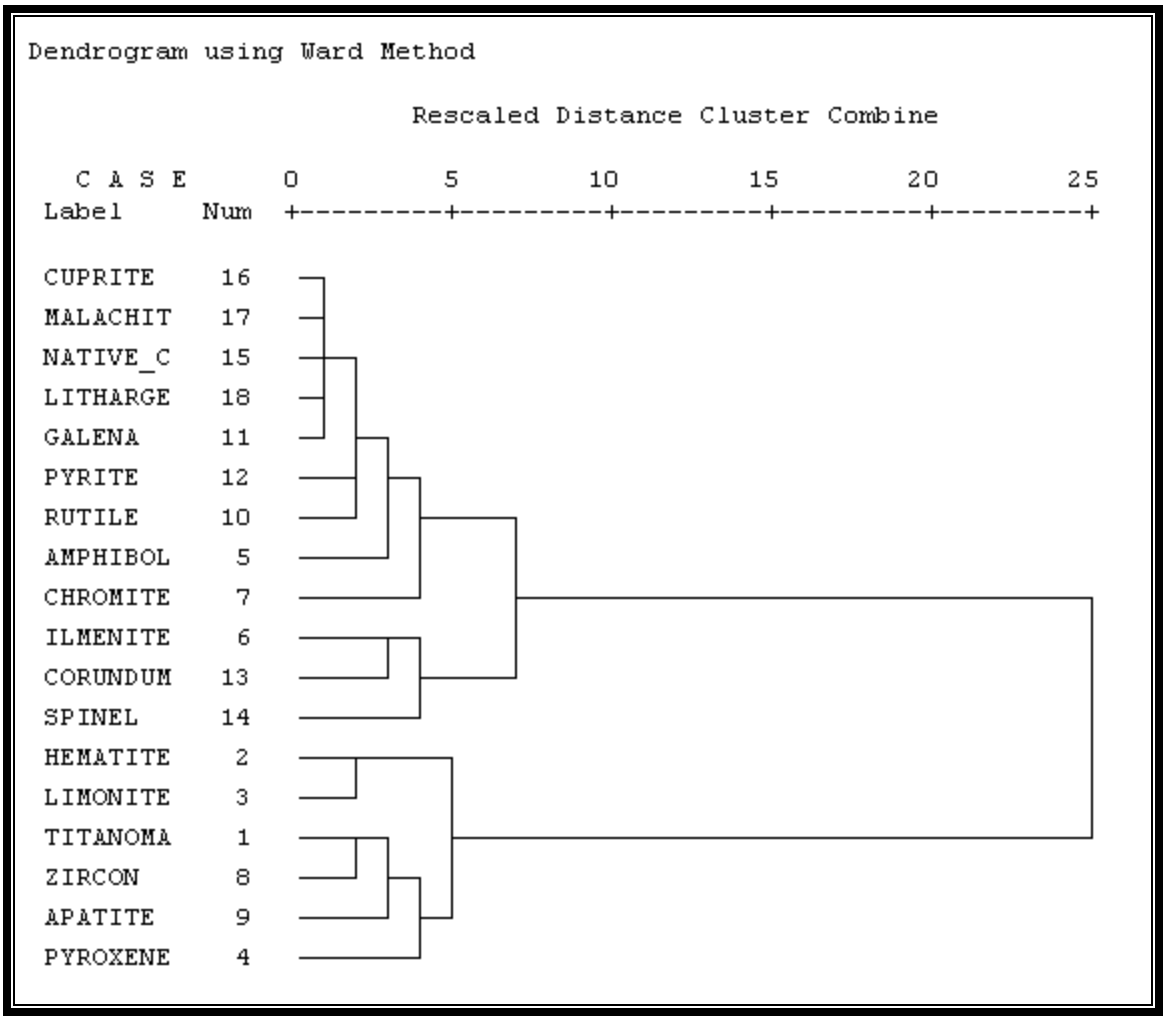


Figure 3-36 – Bimodal cluster analysis (0 and 1) of recorded variables in data from heavy minerals (Comores)

In dendrogram drawn for data of heavy minerals in Comores, it can be seen that the data have been separated from each other into two main groups. Among the metallic minerals the group of cuprite, malachite, native copper, lithargite, and galen are connected to each other with very strong relation. Iron containing minerals such as hematite and limonite are in the opposite group and the interesting point is that amphibole has closer relationship with copper and lead minerals and pyroxene is closer to the group of iron-bearing minerals.

Among other groups that have good relation with each other we can mention spinel corundum group and ilmenite. The other group includes apatite, zircon and titanomagnetite.

3-1-10-5 – Introducing promising spots

Looking at the results from analysis of heavy mineral, in some points considerable amounts of different variables have been recorded. Variables such as lead-bearing, copper-bearing minerals and mercury and gold seem to be promising. Considering the recorded amounts,

promising areas are divided into three priorities of 1, 2 and 3, and the parameters specific to priorities 1 and 2 are described below.

Priority 1

Sample 9226: The place of taking this sample is in Anjouan Island with the latitude of 12 ^{o} 17' 2.9" and longitude of 44 ^{o} 24' 53" (map 3-37). An interesting point in this sample is recording of 4.56ppm of gold in this sample which is accompanied with some amount of pyrite.

Sample 9223: this sample was found in Anjouan Island with the geographical longitude of 44 ^{o} 28' 59.5" and latitude of 12 ^{o} 11' 9.5" (map 3-37). Total amount of lead minerals in this sample is 6.05 ppm and copper 0.89 ppm. Mercury is present in this sample in form of cinnabar mineral with the amount of 2.06 ppm, and considering the presence of galena and pyrite, we are probably dealing with a hydrothermal process in this part which has produced these numbers in this sample.

Samples 9274 and 9275: These two samples were found in Moheili Island in two adjacent water channels. The geographic coordinates of sample 9274 are "43 ^{o} 44' 54" longitude and 12 ^{o} 17' 26.3" latitude. Sample 9275 is located in longitude of 43 ^{o} 46' 47.7" and latitude of 12 ^{o} 18' 28.4" (map 3-36). In these two samples a high amount of copper minerals in form of cuprite with the amount 44.84 ppm in the first sample and 31.39 ppm in the second sample. In these two samples, no signs of other minerals are observed and even the mount of pyrite mineral was not at a recordable level, which this requires further studies. However, regarding the fact that considerable amounts of copper are seen in these two samples, this part seems to be promising and worthy of more exploration works.

Priority 2

Sample 9218: This sample has been taken in Anjouan Island in the longitude of 44 ^{o} 12' 13.1" and latitude of 12 ^{o} 11' 8.2" (map 3-37). Copper mineral with the amount of 7.92 ppm and lead minerals with the amount of 2.4 ppm are found in this sample. Some amount of pyrite has also been registered in this sample.

Sample 9206: This sample has been taken in the Anjouan Island with the longitude of 44 ^{o} 24' 38.9" and latitude of 12 ^{o} 11' 9.9" (map 3-37). The amount of lead minerals for this sample is 2.37 ppm and pyrite is also found in it.

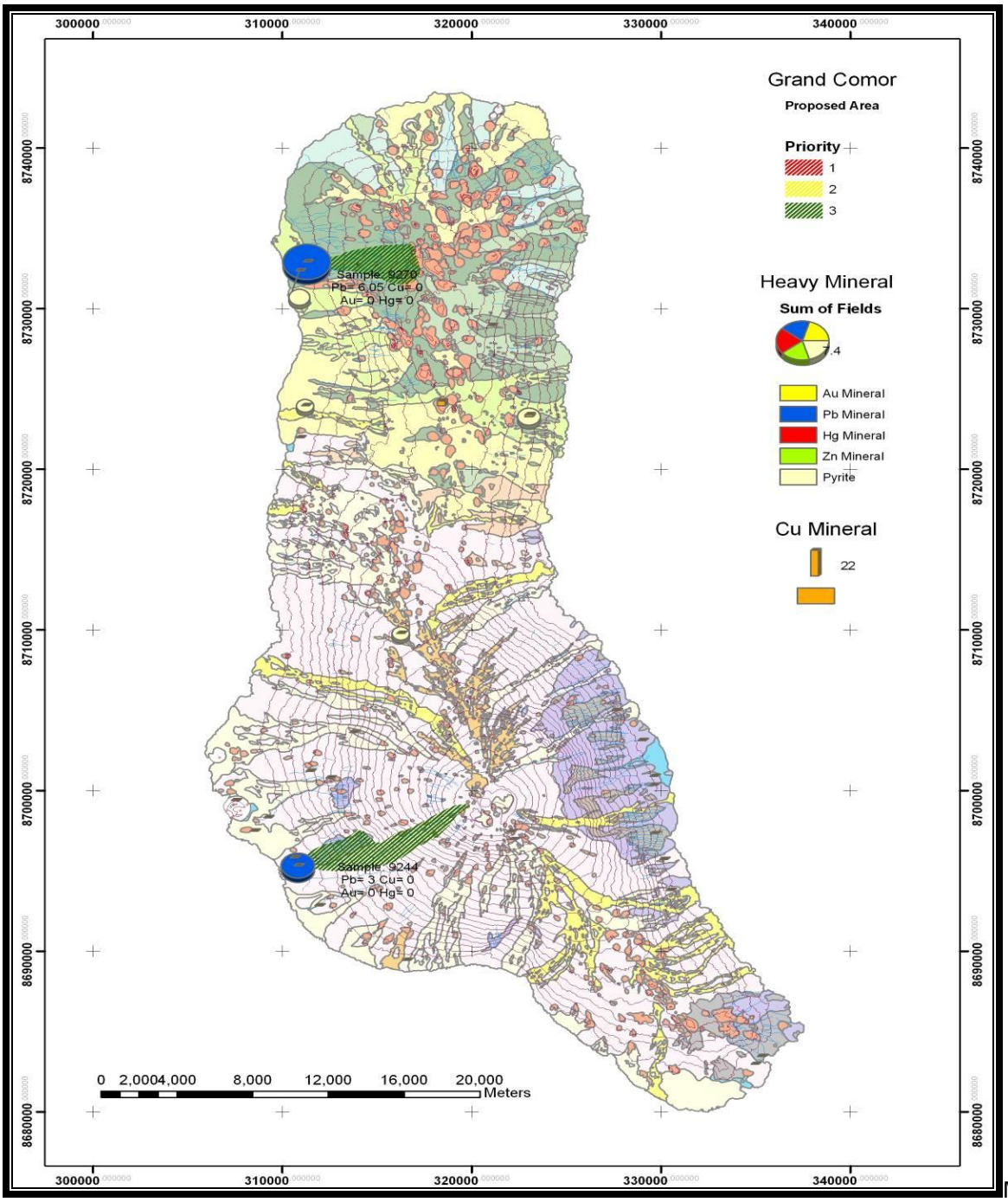
Sample 9289: The taking place of this sample is in the geographic coordinates of 43 ^{o} 41' 42.5" longitude and 12 ^{o} 15' 58.6" latitude located in Moheili Island (map 3-36). This sample has the highest amount of lead mineral as much as 9.11 ppm and it is placed near samples 9274 and 9275 (which have priority 1) and lithologically is similar to these two samples.

Sample 9283: This sample has been taken from the geographical longitude of 43 ^{o} 44' 14.6" and latitude of 12 ^{o} 21' 19.4 "and it is located in Moheili Island (map 3-36). An interesting point about this sample is togetherness of galena and cinnabar minerals which increases the possibility of hydrothermal activities.

3-1-10-6 Suggestion

Regarding the result of heavy mineral analysis on these samples, the following points are suggested:

1- In areas with the priority of 1 and some spots with the priority of 2 a regular grid of geochemical samples with the water channel method is to be defined and through taking samples with higher density, the identity of the recorded amounts in the heavy minerals and places with anomalies to be determined with more accuracy.
2- In the next stage it is suggested that the anomalies that possibly are recorded in stage 1 a thorough study and analysis is carried out by preparing geological and mineral map as well as litho-geochemical samples in a regular grid.



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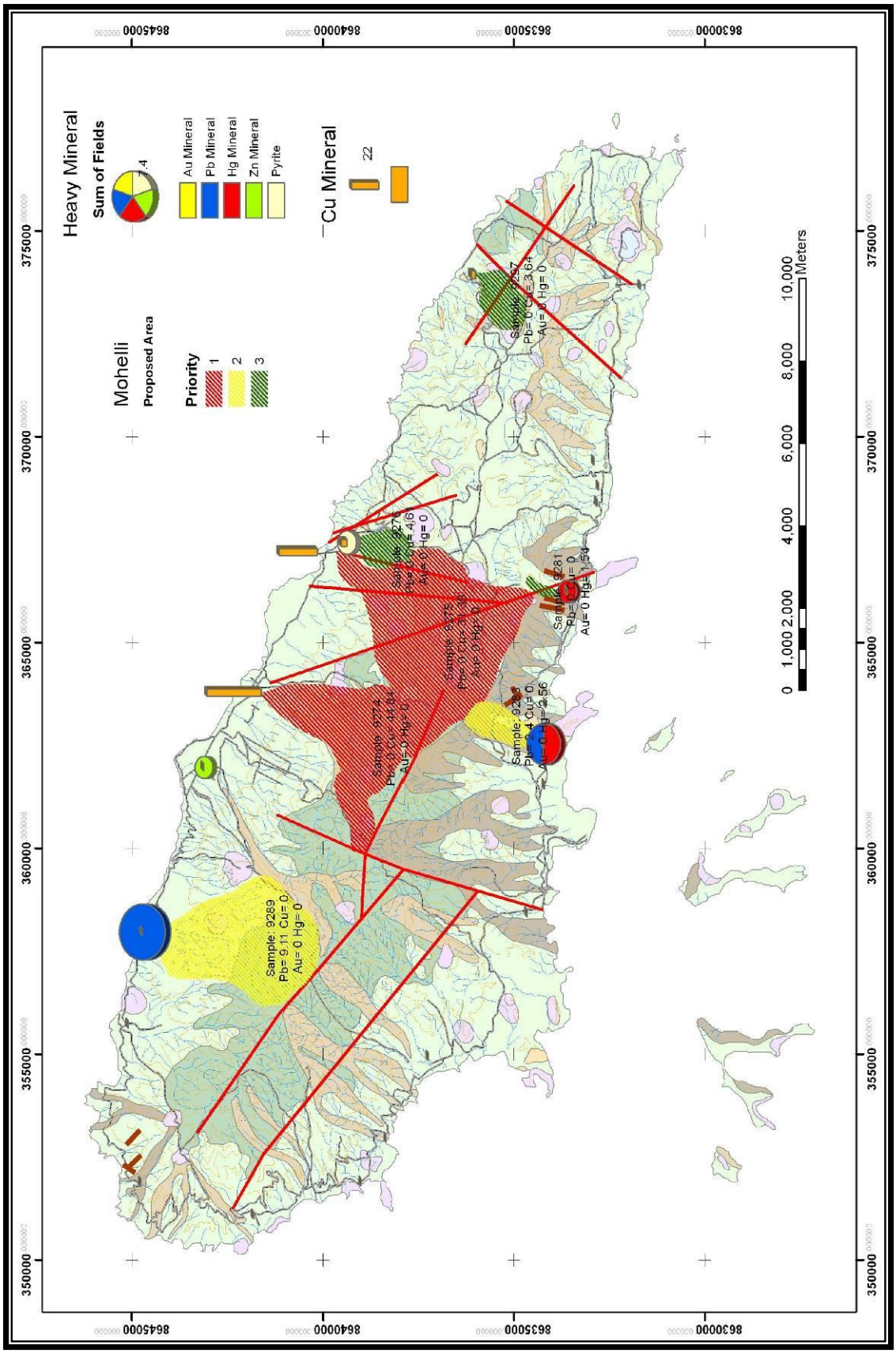
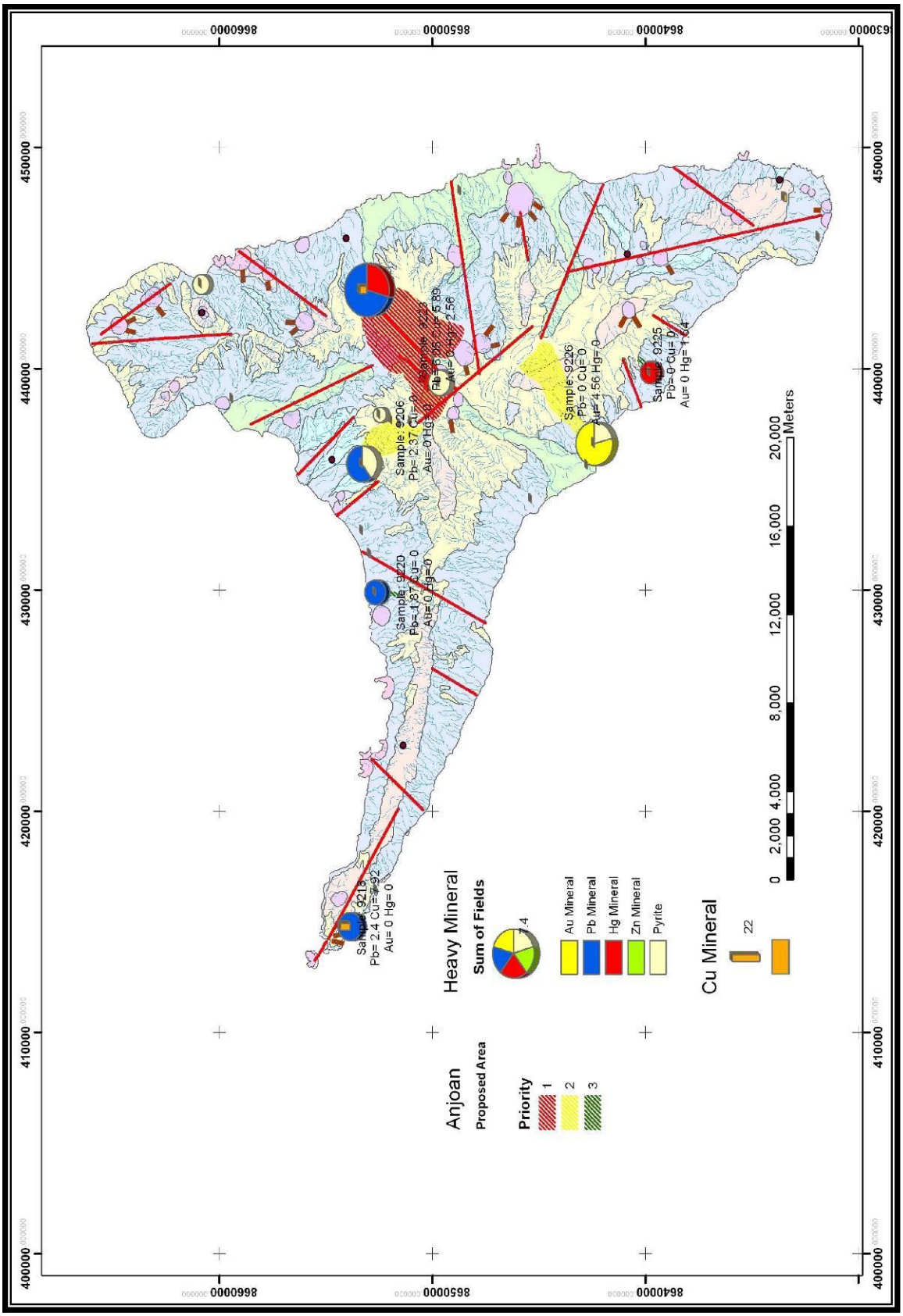
Map 3-35 – Promising points for heavy mineral samples (Grande Comore)



Map 3-36- Promising points of heavy mineral samples (Moheili)



Map 3-37 – Promising points of heavy mineral samples Anjouan Island

4- Chapter Four

4-1- Economical-technical justification preplans

Regarding the content of chapter 3 about the explanation of the mineral deposits of this country, the most important presentable plans in mineral industries sector are explained and introduces as such:

1- plan for production of Olivine from Olivine-bearing alluviums
2- plan for production of red laterite soil
3- pozzolan production plan
4- laterite bauxites production plan

4-1-1 – The plan for the production of Olivine from Olivine-bearing units in Grand Comores

4-1-1-1 Introduction

The composition of Olivine can be introduced through CaO-MgO-FeO-SiO_2 system. The most common minerals in this system are the solid solution of forestrite (Mg_2SiO_4) fayalite (Fe_2SiO_4) series. Neither of these two final members is found in abundance in nature. Therefore the Olivine mineral is always a combination of these two members. Magnesium rich olivines which are called forestrite, is of great importance in industry, especially in refractories and metallurgy. Olivines with more than ten percent of fayalite, and less than 80 percent of forestrite do not have industrial application.

4-1-2 – The purpose of the exploration

The purpose of preparation of this preplan is the preliminary study of the possibility of investment on processing and production of Olivine sand and approximate profit estimation of this project with having the international market in mind. In general view, the pluses of the production of such product can be summarized as:

- presence of large deposits of Olivine-bearing sands in Comores, especially in Grand Comores island
- easy processing of Olivine from sand
- international market and its limited producers regarding the various use of Olivine
- attention to this mineral as jewelry and precious stones

4-1-3 – Introducing the Product

According to the mineralogical studies carried out, Olivine deposits in Grand Konuru are mainly from the forestrite type. The chemical composition of this mineral from the theoretical

perspective includes 57.1 percent MgO and 42.9 percent SiO_2, but such composition is hardly found and it can contain impurities of Ca, Mn, and especially Fe. The crystallization system of this mineral is orthorhombic. Its color is green to lemon yellow and transparent, and it has glassy look.

4-1-4 – Origin

Olivine has come to existence in different geological environments, and the most important of which are:

- Ultramaphic rocks, especially those ultramaphic rocks in ophiolitic complexeswhich are knwon as Apline peridotites.
- As nodules in basalts and kimberlits
- As single crystals in alkaline and acid rocks
- In basic and ultra basic volcanic rocks
- Special serpantinite masses which have been attacked by intrusive acid bodies (tonalite). In these cases the serpentine minerals have turned to Olivine.
- Metamorphed carbonate rocks, specially metamorphed dolomites, and magnesium skarns.
- Crystallization of Olivines rich in iron and special Fayalite as result of local metamorphism of iron rich deposits (ironstone).
- Moon stones, specially Spinel-bearing troctolites contain Olivine

Among aforementioned environments, only dunite bodies along with Alpine peridotites, and dunites with alkaline complexes and their foothill alluviums are considerable in terms of concentration of forestrite. Some magnesium skarns and metamorphed iron rich deposits contain considerable amounts of forestrite and fayalite. Sometimes Olivines are extracted from skarns, which are as precious as gems.

4-1-5 – Application

4-1-5-1 – Refractory substances for blast furnace

About 77 percent of the total amount of the produced Olivine in the world is consumed in production of substances for protection of the body of the metal melting furnaces. The benefits of using Olivine in this section include high thermal stability, insignificant volume changes, resistance against alkaline slags and not having dusting pollution.

4-1-5-2 – Foundry Sand

About 15 percent of the total amount of the Olivine produces worldwide is used as foundry sand in metallurgy industries. The reasons of superiority of Olivine over quartz in foundry sand are not having dusting pollution, being environment friendly, higher melting point and consequently higher thermal stability.

Olivine sands are mostly used in molding aluminum, brass, magnesium, and magnesium-bearing steels.

4-1-5-3 – Refractories

Olivine, as series of minerals formed from isomorphs of two final rounds of forestrite and fayalite, has two melting points at the two ends of this series as high as 1890 degrees Celsius in the forestrite term and 1205 degrees in fayalite. Since the refraction characteristic of Olivine depends to some extent on the amount of forestrite solution, the best relation for realization of this goal, is the molecular ratio of SiO_2 to MgO to be one to two, but in Olivine, due to the conditions of the environment of formation, this forestrite ratio does not even exist in the pure forestrite type.

In the application of Olivine as refractory (which must be forestrite), there is always some amount of iron too, which turns into magnetite in the heating process. Therefore some SiO_2 is released, and since there is no metal ion in its access, it enters into the MgO composition and forms a kind of pyroxene mineral with low melting point. Thus in the process of roasting the refractory, while flushing out Fe, it is attempted to maintain the ratio of two MgO to one SiO_2 and forstrite with high melting temperature is created instead of pyroxene. For this purpose, the lack of MgO is compensated by adding pure magnesia to the mixture until reaching to the ideal formula.

4-1-5-4 – Heat Storage Blocks

About 2 percent of the total amount of Olivine produced worldwide is consumed for the production of heat storage blocks, and the reason of using Olivine in their production, is low thermal transmission coefficient and high melting point. These characteristics cause such blocks to show resistance against high temperatures and prevent the escape and waste of heat.

4-1-5-5 - Abrasive Substances

About 1.4 percent of the total amount of produced Olivine is consumed for the production of abrasive substances, the reason of which is rather high hardness (6.5 to 7) and high specific

weight (3.27 to 4.37). Of course the use of this mineral as abrasive substance is so limited in comparison with other mineral used in this sector and the reason that is the final cost and environmental issues.

4-1-5-6 – Other Limited Applications

About 2.6 percent of the total amount of global Olivine production is used in the followings:

- as fertilizer, since Olivine is a rich source of magnesium it is used to enrich farming soil
- as a source of magnesium for extraction of magnesium
- in sand blasting, specially for dulling glass, Olivine particles are used with other abrasive substances
- all types of Olivine with suitable colors are used in jewelry industries
- Olivine is mostly used in metal melting industries.

4-1-6 – Market Studies

4-1-6-1 – Global Productions

- Norway

The production of Olivine in Norway is about 3.5 million tons a year which is extracted from the dunite masses in the Fjodane complex (in the south of Alesuns in Summerc-Nordfjord in west of the country). These sediments are largest deposits in the world which have 2000 tons of Olivine in an area of 6 square kilometers. The minerals in this dunite mass include 92% percent Olivine, 5% pyroxene and serpentine, 1.5% chlorite and 1% spinel. The mineral composition of Olivine is 94% forestrite, and 6% fayalite.

- Japan

Japan is the second biggest producer of Olivine after Norway with the production of about 2 million tons per year. Olivine is mainly extracted from the serpentine sediments in Hormon Hill in Hokaido which is used in steel and metallurgy industries.

- Italy

The Nuova Crves Srl is an Olivine deposit near Turin in north of Italy. 75 kilometers of this deposit has more that 100 tons of deposit with 95-97 percent Olivine. From Olivine production of this country about 40% is used in refractories and metal melting, 25% in metallurgy, 20 percent in abrasive substances, 10 percent bituminous productions

especially color and ceramics, and 5% in road construction and the other 10% is used in other industries.

- Spain

In La Coruna state in Galicia in northwest of Spain, about 700000 tons of Olivine is produced each year from Olivine dunite groups which are mostly used in refractory industries.

- Turkey

150 thousand tons of Olivine is produced annually in this country. The main producer is the Beykrom Mining Inc. factory, in Beyseechir, Konya with the production capacity of 150000 tons per year. This Olivine is mostly used in steel industries, refracroties, sand blasting, and metallurgy, and the smaller grains are used in other industries.

- China

Olivine production in Henan state in central china is situated within forestrite deposits, in southwest of Henan in village of Xixia, west of Nagying in village of Yubian. The mineral deposit is almost as big as 7.5 * 1.1 kilometers with total tonnage of more than 100 million tons and mineral deposit tonnage of 9 million tons. The Olivine global production numbers are presented in table 4-1.

Table 4-1 – Global production of Olivine (1000 tons)

Country	Production
Australia	80
Austria	20
Brazil	350
China	350-500
Italy	100
Japan	2000
Mexico	150
Norway	3500

South Korea	500
Spain	700
Taiwan	400
Turkey	150
United States	100
Total	8050

4-1-6-2 – Global prices of Olivine based on different applications

- Ex-Works Faundary: 60-110 $/t (bulk), 77-125$/t (bags)
- Aggregate: 50-78$/t (bulk)
- Drygraded, refractory aggregate: 72-80$/t (bags)
- Foundary and blasting sand: 78-84$/t (bags)
- Sand for tundish: 100-110$/t (bags)

On this basis the average price of every ton of Olivine is 100 dollars.

4-1-7 – Processing procedure

Regarding the situation of the Olivine deposits in Grand Comores Island, the best and most appropriate way for processing and production of Olivine is through gravitational separation method, in other words considering Olivine grains being loose in sand and the difference of specific weight of Olivine and other minerals and rock pieces, the processing of Olivine can be carried out using these two factors and physical and gravitational methods.

In this process there are a few stages that are explained as it follows:

1- Mining and transport of the sediments to the feeder sift stage
Regarding the fact that Olivine-bearing deposits are broken and crashed due to the natural factors, and they are seen as loose sediments, therefore there is actually no crashing stage in the processing of the Olivine and only Olivine-bearing alluviums are transported by loader to feeders for dumping onto sifts.

2- Sifting stage
In this stage, the primary mineral load is granulated and categorized into three groups with size of 0 to 3 millimeters, 3 to 6 millimeters and 6 to 10 millimeters.

3- Separation Stage

The output of 0 to 3 millimeters in wet environment is poured on the table in two steps and Olivine separation is carried out based on the specific weight. Product with size of 3 to 6 millimeters is fed into spiral and product with size of 6 to 10 millimeters is separated using jeek. The suggested processing procedure is shown in figure 4-1.

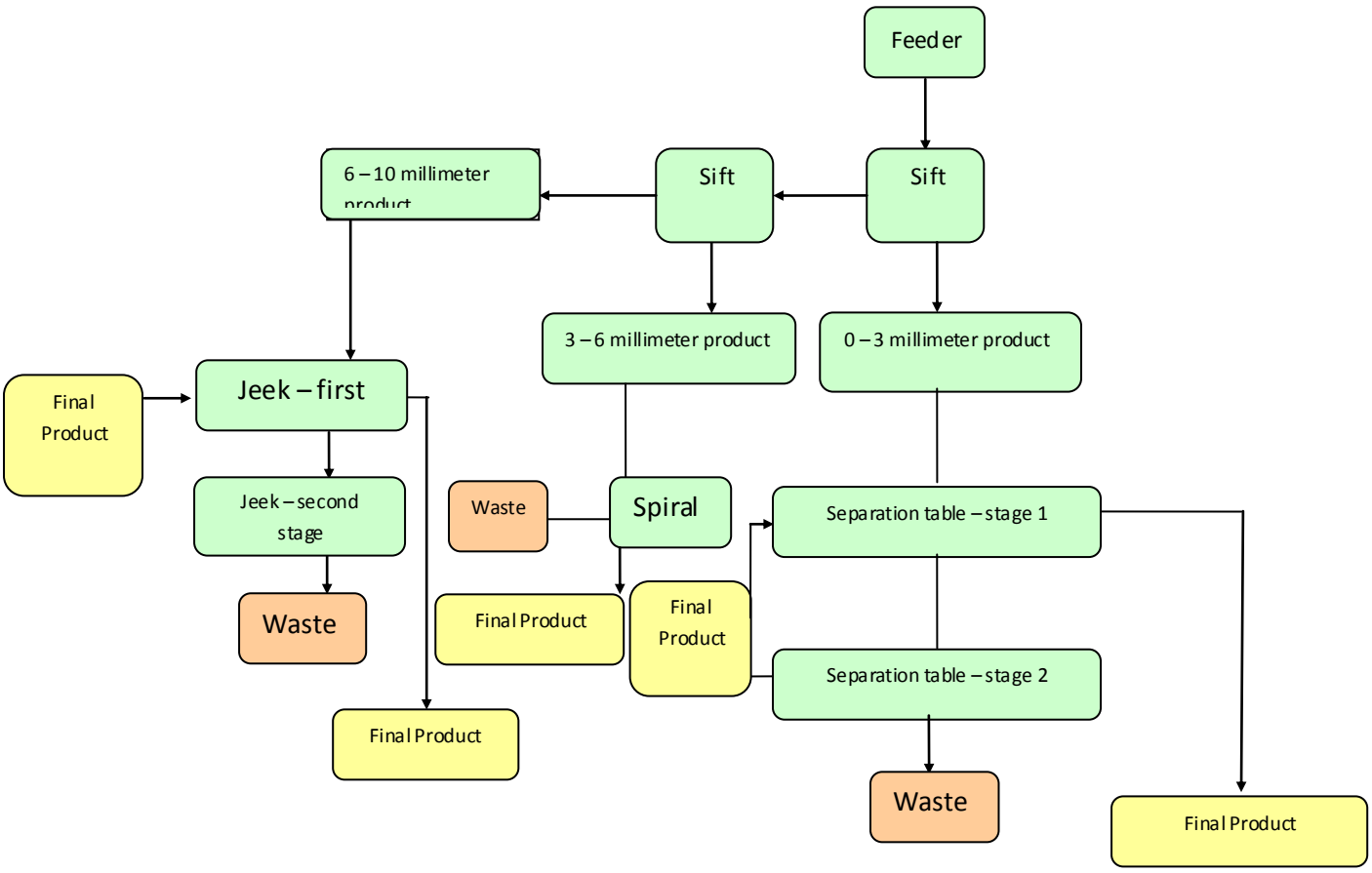


Figure 4-1 A schematic view of the processing procedure for Olivine sands

4-1-8 – The capacity of the plan

Regarding the present mineral reserves and also minimum and maximum amount of global production (between 20 and 3500 thousand tons) it is suggested that in the first stage this unit is designed to operate with capacity of 250 thousand tons a year (830 tons a day, 300 working days each year), which considering the average grade of at least 25 percent olivine, its annual production will be about 62 thousand tons a year, and in the case the product sets foot in the global market, the production capacity could increase up to 500 thousand tons of input soil per year.

4-1-9 – Economics indexes

- The amount of fixed capital about 5.5 million dollars

- Supplementary exploration studies; 0.25 million dollars

- The amount of capital in circulation about 0.3 million dollars

- Production costs about 1.7 million dollars

- The sales price per ton, averagely 60 dollars (to cover the risks of the project the price has been assumed 40 dollars less than global price).

- Annual sales about 3.72 million dollars

- Gross profit about 2 million dollars

- Return On Investment (ROI) rate about 32 percent

- Capital return period about 37 months

4-2 –Red laterite soil production from red soil deposits of Anjouan Island

4-2-1 – Introduction

Iron oxide is the first mineral that human made use of directly as a colorful mineral without processing it. Iron oxides having different ratios of water, in different shapes as network water and crystallization water, offer a wide range of colors of yellow and lemon, to crimson red and blackish dark brown. These oxides may be black and metallic color in normal condition, and show clearly their jewelry color in form of powdered.

Ancient people with artistic vision and instinct used these materials in drawings and therefore founded the first cultural step rocks in application of these pigments. Later on,

this substance was used not only for its artistic application but also for being not toxic, cheap and abundant in many other industries.

After paint and ceramic industries were born, these pigments found a significant place in these industries to the extent that at the present time paint and ceramic industries are among the most important consumers of colored soils.

4-2-2 – Product specifications

4-2-2-1 – Introducing this product including general and technical specs

The word pigment is from a Latin word and describes a substance that creates the feeling of color. By passage of time this word was also used for describing adornment and decoration of colorful objects. In middle ages this word became popular for various color extracts and today it is frequently used even in biology texts.

Based on the current standards, (DIN, ISO, A.S.T.M), the word pigment means small particles that are not dissolvable in a mediating substance, and due to its characteristics such as magnetic, protective, pigmentic, mechanical sturdiness and metal surfaces protection against corrosion , it has many use and applications.

Unlike soluble organic colors, pigments are hardly dissolved in solvents and glues, and only create a heterogenic mixture in form of scattered particles.

Colorful soils are a combination of iron oxides in form of hematite, limonite, and magnetite together with impurities like silica, alumina, manganese oxide, titanium, magnesium and…

Hematite (Fe_2O_3) with the color of red, H_2O limonite (FeOOH) with the colors of yellow to brown and with trade names of Ochre, Umber, Sienna and magnetite (Fe_3O_4) with the color of black are the major minerals forming red and yellow soils.

Iron oxides are produced in natural and synthetic ways. The major methods for the production of synthetic iron oxide include thermal decomposition of iron salts, revival of organic compounds using iron and sedimentation of iron salts.

On the other hand, the use of biotechnological methods of producing red and transparent yellow iron oxide pigments is developing. The raw material in this process is the waste materials or filings including 40 to 100 percent iron. These pigments have a color range of yellow, red; brown to black that are associated with the forming minerals, percent and type of impurities.

Iron oxides are dissolved in acids, but not in water, alcohol and ethers and their density varies in a range of 4.9 to 5.3 g/ c3.

Iron oxides are the most abundant pigment minerals found in nature. As a general rule, iron is stable in form of Fe3 in normal oxygen. Regarding the amount of water that this oxide absorbs in form of molecular or crystalline water, it creates a wide range of colors from blackish brown to crimson red and yellow.

4-2-2-2 – General characteristics of colored soils

Iron oxide pigments are categorized into the following groups in term of color:

a- yellow pigments of iron oxide:

Yellow iron pigments are yellow ochre and raw sienna which are made of limonite, goethite, lepidocrocite minerals. Raw sienna contains hydrated iron silicates and about one percent magnesium oxide. The amount of iron oxide in raw sienna is more than yellow ochre and has a more coloring power. The name sienna has been taken from a region in Italy with the same name.

b- red iron oxide pigments:

These pigments are produced in two ways of natural and synthetic and the natural red soil can be said to be formed mainly from hematite minerals. Beside hematite mineral, the natural origins of this pigment are calcinated pyrite or siderite, dehydration of hydrated iron oxides and oxidization of magnetite.

Red soil deposits exist in many countries of the world and the most important of which is the red soil deposit in Hormoz Island in Iran and red soil of Spain. In some countries which lack red soil deposits with acceptable grade, the mixture of synthetic and natural red soil is used.

c- Brown pigments of iron oxide:

The natural types of this pigment including burned sienna, raw umber; burned umber, burned sienna are produced by calcination of raw sienna. In this process, the limonite present in raw sienna loses its crystalline water. Umber is a mixture of hydrated iron oxides and magnesium oxide together with clay minerals. The color of this pigment tends toward green and the shade of the color depends on the ratio of iron and magnesium content. This pigment is used in semi transparent oil and for creation of wood pattern and adornments.

4-2-3 – Applications of the product

Iron oxides due to being non toxic and environment friendly have a wide range of applications which are mentioned below:

- Coatings such as oil, polish, color, magnetic tapes cover and …

Due to the abundance of industrial covers in the markets, to cite them one by one is not possible as coatings and covers are different in terms of granulation and percentage of pigments, and therefore the application.

- Building materials such as cement, mortar, concrete and so on…

To color cement, mortar and asbestos materials and some other building materials, iron oxides are used.

- Pigments

It is used to give color to ceramics, glass, paper, plastic, rubber, textiles and… the most important of which are:

A – Ceramic industry:

One of the most important applications of red soils is in production of ceramic colors. These colors are used as fire proof colors in ceramics industries. These materials are added to the raw materials or placed on them as decorative patterns and then heated.

B – Glass industry:

Hematite is used as the additive to the raw material of glass, or the red soil is added to the raw material to color them.

Pure iron oxide powder is used as polishing material in glass manufacturing and finishing precious metals. The presence of red soil in glass also prevents ultraviolet rays to pass through.

C – Magnetic tapes:

Magnetic ferric oxide with grade of at least 98 percent is used as color in making covers for magnetic tapes. Magnetic ferric oxide is rarely found in the nature and is often produced with synthetic method.

D – Paper industries:

To create stable colors against the sunlight, this pigment is added to the papers (especially in wallpapers).

E – Cosmetics products:

Red soil is also consumed in cosmetics industries. In this case the used red soil must contain less than 3 ppm arsenic, 10 ppm lead and 3 ppm mercury.

To use iron oxide as catalyst, granulation at nano level is needed. Thus the cost of producing catalysts from iron oxide is much higher than the other applications.

4-2-4 – Global market

Based on the international statistics the amount of production of iron oxide pigments in the year of 2007 was 826000 tons (table 4-2), from which 22 percent has been used in making covers, 15 percent in color industries, 10 percent chemical industries, and 13 percent in other usages.

	Country	2005	2006	2007
1	Austria	4000	4000	4000
2	Brazil	2000	2000	2000
3	Cyprus, umber	12000	12000	12000
4	France	2500	2791	2800
6	Germany	4000	4000	4000
7	Guatemala	11268	7341	7000
8	Honduras	17000	17000	17000
9	India, ocher	360000	360000	360000
10	Iran	2500	2600	2600
11	Italy	500	500	500
12	Lithuania	-	4	4
13	Pakistan, ocher	5500	5500	6000
14	Paraguay, ocher	250	250	250
15	SouthAfrica	510	590	532
16	Spain, ocher	140000	140000	140000
17	Turkey	280000	206000	260000
18	United Kingdom, Iron Oxides and hydroxide	12000	8913	8000
Total		854028	773489	826686

Table 4-2 – Global production of red pigment (tons) – source USGS

4-2-5 – Alternative material

Regarding the unique characteristics of natural iron oxides and hydroxides in production of various types of colored soil needed for different industries, it is necessary to use them in producing pigments. In other words, iron oxides and hydroxides, after

being extracted and processed and crushed into different sizes, are among the minerals that have various pigmentic characteristics and variety of colors and are used in different industries.

This characteristic is not present in other industrial minerals unless special chemical methods are utilized in production which is not economical due to high production costs. Therefore iron oxides and hydroxides have practically no substitute in the industries as pigments.

4-2-6 – Global price of the product

According to the latest statistics, the price of different types of colored soils is presented in table 4-3:

Table 4-3 – price of different types of colored soils

Year	Type of pigment	Average price (dollars for ton)
2005	Natural iron oxide with bright color	825
	Natural iron oxide with dark color	750
2006	Natural iron oxide with bright color	849
	Natural iron oxide with dark color	762
2007	Natural iron oxide with bright color	893
	Natural iron oxide with dark color	805

According to these statistics, the global price of synthetic black iron oxide pigments is 1.02 dollars per kilogram and the price of yellow iron oxide is between 1.20 to 1.30 dollars per kilogram.

4-2-7 – Capacity of the plan

As was explained in the third chapter, the best red soil reserve in this country is in Anjouan Island whose reserves is estimated about 1 million tons (chapter 3, part 3-6-1). On this basis, the amount of annual production is estimated around 4000 tons of processed soil with grade higher than 75%. And regarding the 32 percent of average grade of this deposit the annual exploitation rate is to be around 15000 tons.

4-2-8 – Technical considerations

As was mentioned in the previous parts, the red and yellow soils (mineral pigments) have multiple applications and in each application, the physical and chemical characteristics of the product are different. Therefore the production of product with certain characteristics is only possible through some special processes to be applied on the raw material.

In following, all of the processes used in production of colored soils (iron oxide) are discussed.

4-2-8-1 – Methods of processing and production of pigment from iron oxides

To process of iron oxides and produce different types of pigments, there are multiple methods. Choosing the suitable method varies for various types of raw materials and production units, and depends on the following factors:

- Type of intended product

The type of intended product also has a considerable effect on the processing method of unit. For example if the intended color for input limonite is brownish yellow there is no need for calcination process on the concentrate produced by processing unit. But if the color of intended product is reddish brown, calcinations must certainly be used.

Here different methods used in enriching iron oxides and the application limitations of each of them are explained:

- permanent magnetic roll (permoll)

This method is used for input materials with coarse granulation and high magnetic state. The input load to this apparatus is dry. Important guidelines in tuning this apparatus include:

- rotation speed Vpm
- placement angle (θ˚)
- thickness of the layer of material (mm)
- input tonnage (ton/hrs)

The grain size limitation for this method is usually between 0.5 to 3 millimeters.

- wet high magnetic separator

This method is used for grains with low magnetic state or small grains (range of below 0.5 millimeter to about 75 microns). The field intensity needed for limonite is 4000 to 23900 and for hematite is 1805 to 2050 Gauss.

- flotation

This method is suitable for grains with low or very low magnetic state, and grain size ranges from 0.3 to below 0.075 millimeters. To prevent the problem of slime in flotation process (smooth problems in flotation include slime transition with hydraulic transition and the cover phenomenon) the grains between 10 to 20 microns are usually taken out of the system.

Flotation process is chosen considering the type of input substance especially in terms of granulation and type of surface characteristics of grains. The suggested processing method for this deposit is explained below.

Rock breaking unit

Rock breaking unit is a cylindrical rock breaker which is located on a path closed with double sifts with the opening size of 3 and 5 millimeters. The product of rock breaking unit is the output of sifting with the sizes of 0.5 to 3 millimeters and below 0.5 millimeters.

Milling and separation unit (increasing grades)

The output load of the rock breaking unit is divided to two categories of 0.5 – 3 and below 0.5 millimeters. If the input load has the capability of separation with magnetic separator, the 0.5 – 3 millimeter grains are sent to this unit, and gains less than 0.5 millimeter in size are sent to a more powerful magnetic separator unit with high intensity. It is possible that grains less than 0.8 millimeters in size are entered into the flotation unit.

Now if we cannot create a suitable concentrate with the magnetic separator method, then the output grain is directed to milling unit from the rock breaking unit and after obtaining appropriate grain size (below 0.5 millimeter or less), the material is processed in magnetic separation or flotation parts. Since the technological test has not been carried out on the input substance, it is much safer to consider a combination of aforementioned methods.

a- 50 percent of the output load of the rock breaker unit is milled until the grain size reaches to 0.5 millimeters or less.
b- The 3 – 0.5 millimeter particles from the output of rock braking unit can be processed through magnetic separator.

c- Grains with sizes less than 0.5 millimeters to 0.8 millimeters are processed using the high intensity magnetic separator.
d- Grains less than 0.8 millimeters in size are transferred to flotation after dessliming.

Milling and enrichment machineries unit

- Ball mill
- Classifier
- dessliming hydro silicon
- High intensity magnetic separator
- Flotation machinery including:
- Preparation container
- Flotation cells (rougher, cleaner, scavenger)
- Filter

Powder making unit

Powder making unit consists of a Ball mill (which works dry) and is in a closed way of air with silicon. In this system, the product is determined in terms of grains by setting the times of circle in system (time in the mill).

The power of the mill has been chosen in a way to be able to powder 100 percent of the product into size of less than 40 microns and 50 percent of it into size of less than 20 microns.

Packaging unit

This unit includes the following machines:

1- hopper
2- packing machine

Control and sampling the product

To determine changes and control important characteristics such as color, percent of oil absorption, dissolution in water and… a sample is taken from the output and is studied by XRD, chemical analysis, and microscopic studies.

4-2-9 – Economics indexes

- Fixed capital about 3.5 million dollars

- Supplementary exploration studies, 0.25 million dollars

- Capital in circulation about 0.5 million dollars

- Production costs about 1.5 million dollars

- Sales price in tons, averagely 700 dollars (to cover the risks of projects the price is considered 200 dollars below the global price)

- Annual sales about 2.8 million dollars

- Gross profit about 1.3 million dollars

- Return On Investment (ROI) rate about 30 percent

- Capital return period 37 months

4-3 – Pozzolan production plan from the numerous deposits of Comore

4-3-1 – Introduction

Pozzolan has been in use since very long time ago due to lightweight and ease of use. The use of this material in Europe goes back to 2300 years B.C. in ancient Rome cathedrals, palaces and houses were made with pozzolan cement. Approximately wherever there is access to pozzolan, this material is used for building walls and ceilings. With advance of technology and studies on this mineral, it has been used in different industries more than ever and its importance has been increasingly recognized day by day. This substance is the focus of attention of all countries in the world, even those without pozzolan deposits, due to unique application in building structures. For example in 1997, in the course of a study, some amount of this substance was transported to Vietnam from Philippine and was used in construction of houses. Due to the very good response of this material in such extremely hot climate in south of Vietnam, the export of this mineral from Philippine to Vietnam began then and still continues.

Moving in direction of increasing economical growth and industrial development requires transformation in industry sector and changing it into a stable sector.

Since the world in the future is a world full of rivalry, expansion of markets, emergence and popularity of high-end technologies, expansion of business units, the requirement for success in this part is to fully use all capacities and opportunities, and to understand and analyze new global and regional situations and to learn the ways to determine the sustainable and economically stable growth. In other words, it necessitates the creation of an economy which can respond to population needs such as creating jobs

and income, production growth, and supplying and the other hand rivalry in international markets.

Here mines and mineral industries have a special place in production section and creation of added value as in some cases a processed product is sold several times the price of raw material in market.

For this purpose, regarding the raw material at hand, production and calibration of mineral grains for usage in different sections such as finishing metal pieces, decolorizing clothes, cement, agriculture, heat and noise isolators, and above all the production of light building materials can be considered among the investment pluses.

With this justification, study and research about producing different types of processed pozzolan pebbles with variety of applications especially in production of different types of light-weight building materials is of great importance.

4-3-2 – Introducing the product

Pozzolan consists of substances that does not have cohesive characteristic, but if it is of active type when mixed with lime in room temperature and in presence of water, it would behave as cohesive. In other words pozzolans are substances with high silica and alumina content and are made of very fine and amorphous particles, and therefore they have a high special surface and show cohesive characteristics in environment having water and calcium hydroxide.

Pozzolans are divided into two groups of natural and synthetic:

1- Natural pozolans include volcano ashes which pour out of craters due to the eruption and deposit in water and/or land. Due to fast cooling process the forming minerals of this volcanic product does not have enough time to crystallize and therefore materialize as amorphous vitreous product.
2- Synthetic pozzolans include smelter slags, clay and baked shale, and ashes left from burning coal, which have an amorphous vitreous phase due to rapid warming and cooling and are very similar to natural pozzolans regarding the physical and chemical characteristics. Today, in industrialized countries, synthetic pozzolan is used as additive to Portland cements.

4-3-3 – General characteristics

Characteristics such as, low specific weight, cellular structure, lightweight, heat and sound isolation and high abrasive ability has caused this substance to be applicable in industries. Various mineral pebbles are different in terms of application, and the size of particles usually varies from clod, large, medium, small, and very small. The size of mineral pebbles used in abrasives varies from mesh 6 (for cleaning) to mesh 300 (for polishing). Also mineral pebbles used in abrasives must have pores with thin walls, in form of grains with

nearly cubic shape, uniform composition and free from impurities. To better understand the grain arrangement of the rock parts of the mineral pebbles, special studies need to be carried out on each deposit. Characteristics such as specific weight, durability, elasticity coefficient, resistance against fire, noise isolation and low head conductivity coefficient have caused this mineral to have a wide range of applications in different sectors of industry.

4-3-4 – Application

Mineral pebbles have been recognized as a lightweight mineral and used in construction since the time of ancient Rome. Main application of this product is in construction, concrete production, road surface cover, outside view of buildings, repair, building and maintenance of roads and also as supplement and additive to all types of mortars This substance has currently various industrial applications which are explained below.

4-3-4-1- construction

Lightweight blocks

Lightweight cement blocks weigh more than 20 and less than 50 pounds in 100 square feet. A square yard of this product, depending on the amount of used cement, weighs between 1250 and 1350 pounds. These blocks are made of mixture of pieces of pozzolan with ordinary cement. Since cement does not fill all the holes inside pumice, its volumetric weight is much less than ordinary blocks. In addition to its light weight, these blocks are superior to the ordinary blocks for the following reasons:

- better heat isolation
- more unified in color and texture, and therefore the structure does not need thick cover
- easier to cut and also easier to be installed with screws and nails
- more elastic resistance

Different applications of pozzolan and mineral pebbles in general in construction projects:

1- filler in building floors and roofs
2- use in mortar filled behind the wall surface (like stone facade…)
3- various cementing of outside view of builings
4- filling the space between soil and concrete (like foundation concrete, bridge pillars, tunnel and dams walls, underground canals ceilings)
5- building different types of lightweight concrete with acceptable resistance
6- repair and maintenance of concrete blocks
7- isolation of underwater pipes at the bottom of rivers and seas
8- pre-fabricated panels of building facades
9- various types of lightweight bricks in different sizes

- Fire proof covers

Fireproof covers which are mostly used as protective covers in large structures such as gas and water pipelines, electricity lines, telephone lines and similar cases. This product has high prices and therefore it is only used in critical projects. Recent studies have shown that covers made of pozzolan are very resistant to fire and their final cost is much lower compared with other similar products. The analysis of fireproof covers in structures is performed through determining the required thickness to resist fire in certain time intervals.

4-3-4-2 – Polishing

Pozzolan is used in polishing surfaces with a high sensitivity and which must be smooth and flat (like cathode light bulbs, optical parts such as lens and prisms, glass and mirror, electrical circuit wafers and also for wood, marble, television screen and silverwares).

In all of the above items, based on degree of abrasiveness and level of roughness of the polished surface, sand blast method is used, in which pozzolan particles with different sizes are blasted at the given surface using pressured air (figure 4-2)

4-3-4-3 – Agriculture

This substance has a wide range of application in hydroponics agriculture and the use of pumice in this type of agriculture increases the capabilities of planting and efficiency. Also grains with size of (5 – 10 m) are used to improve poor soil as well as to improve drainage and irrigation because it causes moisture to remain in soil. It is also used in flower nourishing, ventilation of all game fields, ventilation of golf courses, and fertilizer for poor soils and creation of kiwi fruit groves. Pumice is also used in arid regions and places where there is a need for growing vegetation in special places (greenhouses, creation of green spaces on the underground concrete canals and farming in arid areas) as the bottom layer of soil, and its important characteristics include:

Figure 4-2 – Application of mineral pebbles in polishing industries

1- retaining water and gradual release of water into soil
2- decreasing soil pressure
3- optimizing use of soil volume
4- increasing mineral characteristics and strength of soil due to mineral content at special level and percent

This substance is used in agriculture and greenhouse soil for absorption and retaining water. About the use of mineral pebble in agriculture, comprehensive studies have been carried out, and the results of which are presented below:

- Mineral pebble has a rather high water absorption capability, and once saturated, it can be used as water source for plants.
- Decreasing the frequency of watering
- Ventilation of soil around the root in ordinary soils happens normally at the beginning of the cultivation, but as time goes by the soil becomes dense and compact and therefore ventilation does not happen as desired. But with use of mineral pebbles and considering their high porosity and the spaces among grains, ventilation takes place easily.

From other applications of these substances, one can mention the production of toothpaste, different cleaners, additives to painting oil, polishing substances, shoe polish, plastic, synthetic resin, flexible covers, water filters, matches, welding electrodes, chemical transmitters, road covers to strengthen the soil, abrasives in soap and other cleaners, for sloping roofs and building floors (particles smaller than 40 millimeters).

In table 4-4 the different applications of mineral pebbles are shown.

Grain size	Applicatioen	Consumr
Large Large Medium Very small Large Large medium Very small Very small Small Very small Small	Non slippery covers Noise isolators, colors Mixed paint Wideners Strainers Chemical transmitters Sulfur for lighters and matches Cleaners and polishers Metal plating Finishers	Paint industries Chemical industries Finishing plastics and metals
Very small Medium Very small Small	Cleaning stone clichés Hand soaps Glass cleaners Toothpaste	Cleaners
Medium Small	Cleaners Polishing rough surfaces	Abrasives
Very small Very small Small Very small	Processing of TV screen Polishing glass Bevelling Finishing cut glasses	Glass and mirror
Very small Very small large	Filler Circuit wafer cleaner Additive and soil change	Other industries: Ceramics Electrical industries Agriculture

Table 4-4 – Different applications of mineral pebbles in industry

On the other hand, at the present time, mineral pebbles are important alternative for sand in wastewater and heavy wastewater refining pools. The use of pebble last three times longer than sand.

Additionally, regarding the lightness of pebbles, emptying the refining pools is easier.

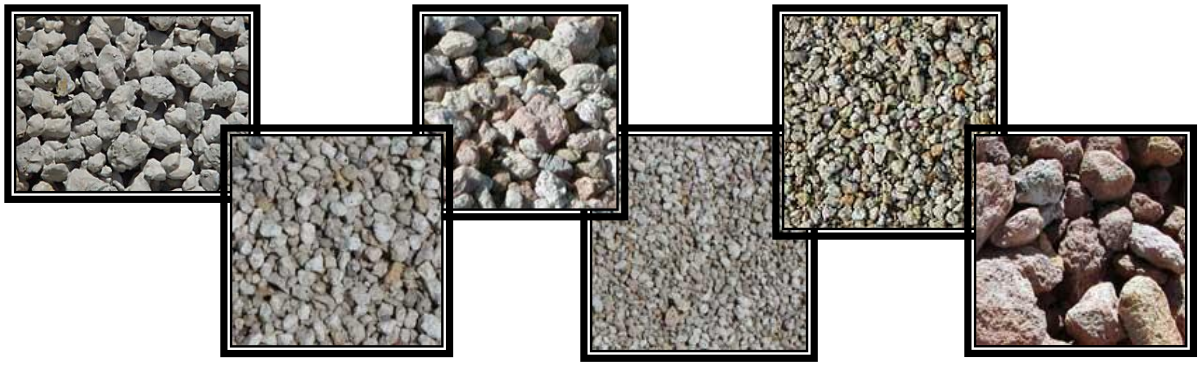


Figure 4-3 – a view of the grains of the mineral pebbles

4-3-5 – Alternative material

Regarding other materials with more or less similar physical and chemical characteristics, some substances can certainly replace one another. This replacement depends on the location of mine, its value and processing method and transportation of product to consumers. In this area some light masses like perlite, expanded shale, and volcanic slags and swollen clays can replace mineral pebbles as pieces used in concrete. Also for pozzolan cement, some substances like tall furnace slags, diatomite opally cherts, ashed clay clods are good replacement. For road construction, materials like crushed rock and sand can replace mineral pebbles.

For abrasive application, materials like garnet, silicic sand, tripoly, diatomite, aluminum oxide and silicium carbide can be used instead of pumice.

However, although there are alternatives for most mineral pebbles, its production is yet favorable due to abundant deposits, easy and low-cost exploitation, ease of processing and product popularity.

4-3-6 – Global market

Countries producing mineral pebbles and their production are shown mentioned in the tables 4-5 and 4-6. From 1993 to 2007, Italy has had the highest production volume

among the countries of the world with 5 million tons of annual production. Among European countries, the use mineral pebbles especially in construction is so common, and a little share of their production is exported. The United States, in spite of high volume of production, is one of major importers of this product.

4-3-6-1 – Global reserves

The countries located along the strip of young volcanoes are the major producers of mineral pebbles, among which the following countries can be cited:

- Existing reserves in the volcanic structure of Italy plays a significant role in the economy of this country. Volcanic formations of Aegenien and Tiran which are parallel to each other are among the important mineral pebble deposits of this country. The most important area is in Lipari Island, from different part of which mineral pebbles are extracted.
- Greece with historical background in production and extraction of this material is considered one of the biggest producers. The importance deposits of this country are in Ylai and Thra Islands.
- Germany has also a long history in the production of mineral pebbles, and its most important deposits exist in Rein area. Since such reserves in Germany are decreasing, this country has turned to importing this mineral especially from Greece.
- In the United States due to the presence of many volcanic systems in west, a high percentage of production of this product is taken place in western states such as California, Idaho, New Mexico, and Oregon.
- The volcanic activities in Iceland have created hundreds of meters of volcanic substances under its ices. These substances are called Plagonite in Iceland. Due to the delayed cooling of these materials under the ice sheet, therefore their pores have not closed completely and thus their porosity percent is higher than other places, and their weight is lighter. The most important mine resides in south of Iceland and it is the product of activities of Mouheda volcano, which has about 20 million cubic meters of deposit.
- There are important deposits in New Zeeland and in southern Island of Rotorua Taupo area.
- England is also among the countries with high amounts of mineral pebbles which is comparable with Italy and Greece in terms of production.

Pozzolan production volume and trend in the world

The average production of mineral pebbles in this period (1996 - 2007) is shown in table 4-5.

Table 4-5 – Amount of global production of mineral pebbles in years 1996 – 2007 (thousand tons)

2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996	Year
17500	17700	16600	16200	15600	12000	11600	11500	11200	11100	10800	11400	World

The production numbers of major producers has been shown in table 4-6.

Table 4-6 – global production of mineral pebbles in years 1999- 2007 (thousand tons)

2007	2006	2005	2004	2003	2002	2001	2000	1999	Year Country
4750	4750	4750	4650	4600	4600	4600	5100	5100	**Italy**
2250	2250	2233	2140	2150	1600	1700	1650	1200	**Greece**
1500	1300	1200	1181	884	-	-	-	-	**Iran**
1270	1490	870	956	920	697	643	583	577	**U. S.**
1000	1035	895	820	754	650	600	480	450	**Turkey**
17500	17700	16600	16200	15600	12000	11600	11500	11200	**Whole world**

The average price of mineral pebbles, based on the type of application is presented in the following table:

Table 4-7 – Average global price of mineral pebbles based on their industrial applications (dollars per ton)

2007	2006	2005	2004	2003	Abrasives
228.42	216.38	312.36	202.59	215	Production of lightweight blocks
21.42	43.05	26.88	37. 83	37	Additives to concrete
16.30	14.23	24.73	37.83	28	Agriculture
146	158	112	149	110	Laundry and discoloring

32.04	53.32	39.38	49.03	40	Other

4-3-7 – Capacity of the plan

Regarding the volcanic structure of Comore and extreme extension of this mineral material, it can certainly be said that these reserves are endless. Production and processing of this material can be considered as one of the priorities in investment this country. According to what has been described thus far, the capacity of the plan is considered to be around 100 thousand tons per year.

4-3-8 – Technical studies and surveys

The most important parameter in production of the mineral pebbles is the grain size, in a way that each grain size has its own unique application in the industry. About the production and processing of different types of mineral pebbles two points must be taken into consideration:

a- Elimination of impurities and improvement of chemical quality of the product.
b- Granulation

Part (a) has less importance compared to part (b), and it is usually totally eliminated in mineral processing plants. The most important factor in determination of application of mineral pebbles is their granulation, in a way that the most part of investment is on crushing, milling, granulation and creation of various grades of the product. In other words, the pivotal point in designing production and processing plants is on crushing and granulation processes. Figure 4-4 shows an introductory flow diagram of processing line for mineral pebbles.

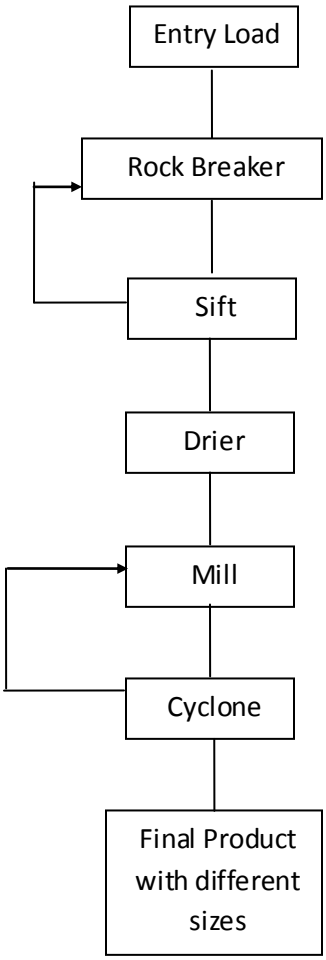


Figure 4-4 – Introductory flow diagram of processing line of mineral pebbles

The extracted pebble from the mine is stored in input load depot, and is entered into rock breaking feeder using loader from there. The selected rock breaker in this stage is cylinderical and is placed in a path closed with two installed sifts.

To obtain products with size smaller than 1.2 millimeters, the output of rock breaker is fed into the mill.

All substances lose their moisture first in a rotating dryer, and then entered into mill using installed elevators.

The chosen mill is of ball type and works in dry environment. This mill is placed in closed path with air cyclone. It is also to mention that the other grain sizes are also obtainable through tuning the mill and cyclone production line.

The output product of the mill is transported to special silos using special elevators, and is packed into 50 to 300 kilogram bags using installed packager.

4-3-9 – Economical indexes

- The amount of fixed capital about 8 million dollars
- Supplementary exploration studies; 0.25 million dollars
- The amount of capital in circulation about 0.2 million dollars
- Production costs about 2 million dollars
- Sales prices per ton, averagely 60 dollars (to cover the project risk the price has been considered 30 dollars less than the global prices)
- Annual sales about 6 million dollars
- Gross profit about 4 million dollars
- Return On Investment (ROI) rate about 46 percent
- Capital return period about 25 months

4-4 – Plan of laterite bauxite production from Ongoni reserves

4-4-1 – introduction

The word bauxite was used for the first time by a French researcher named Berthier for naming a mineral taken from Le Baux in Frances. Bauxite does not have a history longer than that, because due to being hard to melt and high reduction conditions it had no place in the preliminary technologies, and was produced as a mineral product when the metal smelting technology on the verge of industrial revolution realized its characteristics and benefits.

After the discovery of aluminum as an element with very useful characteristics on the one hand and its abundance in nature on the other, a wide search began for its production and processing. Also high resistance of aluminum oxide to fire expanded the researches on the bauxite deposits worldwide. Thus the large reserves in Australia and Guinea were

discovered, and on the other karstic horizons of the world were exposed to exploitation. It is used as aluminum ore if it has suitable physico-chemical conditions otherwise used for fireproof mineral product.

4-4-2 – The purpose of the plan

Regarding the laterite bauxite reserves in Anjouan Island, the following purposes are in mind:

- thorough and precise exploration on laterite bauxite reserves
- extraction and granulation of bauxite
- stepping foot in global mineral markets

4-4-3 – Characteristics of the product

Bauxite is a raw mineral made of one or more aluminum oxides as the main rock forming minerals along with some metal oxides and minerals as well as secondary minerals. Therefore bauxites must be considered as rock and not mineral, since they are formed by a combination of different minerals.

From the viewpoint of genesis, bauxites are very complicated. Thus it can be named for different aspects. The most important names that reflect the specification and genesis of bauxites are:

- Gibbsite bauxite: the most abundant (24 percent) aluminum-bearing bauxite whose main primary mineral is gibbsite.
- Bohemia bauxite: stands in second place after gibbsite bauxite with 23 percent abundance.
- Diasporic bauxite: the third type of bauxite in terms of abundance with diaspora as its primary mineral.

Bohemia-gibbsite bauxites and diasporic- bohemia bauxites are in the next places with 15 and 14 percent of aluminum content.

- Hematite-goethite bauxite: is the most abundant type of iron-bearing bauxite (42 percent.)
- Hematite bauxite: with 23 percent it stands in the second place among all iron-bearing bauxites.
- Kaolinite bauxite: is the most abundant type of bauxite with silicate origin.
- Lautrite bauxite: is only found in platforms and alumino-silicate rocks.
- Karestic bauxite: is found in active tectonic areas; on carbonate rocks.

4-4-4 – Genetic setting

The favorite condition for formation of bauxite is:

1- Presence of rocks rich in aluminum
2- Permeability of rocks or clays for flushing out silica down and around underground water reserves.
3- Tropical or semi-tropical climate with plenty of rainfall, and alternation of dry and wet periods.
4- A higher rate of weathering compared to weathering needed to form other materials.
5- Topographic domes to confine water channels and fluctuation of underground water level.
6- Good amount of time
7- Presence of vegetation when vegetation might be a factor through helping humic acids. Bauxites are made from clay or any type of rocks which contain aluminum. These rocks mainly include granite, nepheline syenite, anorthosite, phenolite, basalt, andesite, dolerite, gabbro, horenfles, schist, slate, kaolinite sandstone, siltstone, and shale. But the important point is that in formation of bauxite, the intensity and duration of lateritization and bauxitization processes are more important than the high aluminum content in the source rock. For example, wide reserves in western coast of Cope York Peninsula in Australia have been made from kaolithic sands with less than 4 percent of aluminum. The decomposition of the source rocks and their resulting bauxites explain the chemical changes at the time of bauxitization; therefore due to the variable chemical composition of the source rocks and progress of weathering in one area bauxites deposits have formed.

4-4-5 – Extraction

Since most the bauxite deposits form create flat layers near the surface, strip-mining methods are usually used for exploitation. Although in some parts of the world, like Arkansas in the U.S., France, Greece, Hungary and Kazakhstan, underground methods are used for bauxites in deeper places.

About 90 percent of world's bauxites are mined with open-pit method. Burden removing is carried out in most open-pit bauxite deposits. The thickness of the burden can reach up to 70 meters, and depending on the hardness of the burden, earth-removing or explosion methods can be used. The usual methods of underground mining of bauxite deposits, based on the location of the deposit, include top slicing, sublevel stopping, block caving, shrinkage stopping, longwall, and room and pillar mining.

4-4-6 – Application

Cement industries

The SiO_2 grade in bauxite suitable for cement industries should not be more than 6 percent, otherwise the cohesive power of cement reduces severely. The presence of iron is not only harmless but also increases the hardness of cement, and it can also help lower melting

point in cement production process. However, the very high content of iron in cement affects its refractory characteristics.

Bauxite is used in production of cement with high alumina. Cement with high alumina contains alumino-silicate instead of calcium aluminate, and has special applications in construction. This type of cement reaches its maximum resistance after 24 hours and is very stable against erosive factors such as chemicals.

- metallurgy

Bauxite is the only economical aluminum mineral rock, and the highest desirable grade in bauxite exploration is the metallurgical grade.

Lower grade of alumina in bauxite desirable for metallurgy is evaluated based on factors such as mining, transportation and processing costs, taxation, geographical location of the alumina plant geographical location in relation with bauxite sources and other raw materials used in alumina refinement and accessibility and alternative costs or higher grades of bauxite resources. The internal relation of some or all of these factors can make the application of bauxite possible even with 25% of, similar to what is seen in west of Australia.

Presence of iron minerals in hematite form is not harmful to bauxite and is economically acceptable up to 25 percent.

- chemical industries

Bauxite used in chemical industries must have the lowest level of iron and alumina dissolvable in sulfuric acid.

One of the most important uses of bauxite in chemical industries is the production of alum $Al_2 (SO_4)_3.18H_2O$ from alumina for the urban water treatment.

- steel industries

In steel industries, to control the viscosity of the slag, bauxite in grain size of 10 to 50 millimeters, less than 7 percent of SiO_2, more than 55 percent of alumina and low moisture can be applied.

- refractories

Bauxites with low metallurgical purity and in some cases with high kaolinite minerals are used as refractory. Bauxite used in refractory industries must have very low content of alkaline and earth alkaline element.

- abrasives

Since bauxite with abrasive capability has hosted a high tolerance of iron, thus bauxites with iron impurities can be used for abrasion purposes. Besides, TiO_2 can increase the

roughness of abrasive bauxite. Calcinations of bauxite can be used in production of abrasives.

- road construction

Due to hardness and durability of calcinations of bauxite, it is used as top cover for roads, and its grains with layers of asphalt are very durable and are not worn out. Calcination of bauxite grains must be between 1.67 and 3.30 millimeters and calcination process must be carried out at high temperature.

- welding

In underwater welding, to prevent water from penetrating into welding area, calcinations bauxites can be used. One of the important points is to consider the amount of water content in calcinations bauxite.

- oil production

One of the important methods for increasing the output of oil wells is through the use of hydraulic cracks in wells. The substances used in this industry are called propellant. For this purpose quartz sands and substances with high hardness are used. In very deep depth, one of the substances used in large quantities is calcinations bauxite. For this purpose, the material is turned into particles smaller than 12 microns, and then it is shaped as ball and stabilized under high temperature. This way, hard and condensed balls are produced. This action is called clod building. To obtain more permeability, these particles are sifted and particles with 6 to 80 meshes are selected for use.

4-4-7 – Global market

In year 2006 the global production of bauxite was 196 million tons, which increased to 205 million tons in 2008. Exploitation of bauxite deposits has been reported in 25 countries, from which the greatest producers of bauxite are Australia, Guinea, Brazil, Jamaica, and China, which these five countries are accounted for about 70 percent of the total global production.

Major deposits used in non-metallurgic industries are limited to few countries. Bauxite with abrasive characteristics is produced in Australia, China, Greece, Guinea, Guyana, and Italy; and bauxites with refractory characteristic are produced in Brazil, China and Guyana.

The amount of bauxite produced between years 2005 to 2008 has been shown in table 4-8.

Table 4-8 –Bauxite production between years 2005 and 2008 (thousand metric tons)

2008	2007	2006	2005	Country name
63000	62400	61400	60000	Australia
25000	24800	21000	19800	Brazil
23000	30000	20000	18000	China
2200	2220	2000	2450	Greece
18000	18000	15200	15000	Guinea
1600	1600	1500	1500	Guyana
20000	1900	13000	1200	India
15000	14600	13000	12000	Jamaica
4800	4800	4900	4800	Kazakhstan
6400	6400	7200	6400	Russia
4500	4900	4800	4580	Surinam
5900	5900	6000	5900	Venezuela
30	30			Vietnam
6800	7150	4820	6420	Other
205000	202000	177000	169000	**Total sum**

4-4-8 – Global prices

According to studies performed in global trade the price of each ton of bauxite varies depending on the grain size, alumina content, and volume of order, amount and type of impurities. However the average global price for each ton is 27 dollars per ton.

4-4-9 – Production capacity

Regarding the probable deposits of laterite bauxite in Anjouan Island (chapter three, part 3-3-1) which is estimated about 11 million tons; the most suitable economical development strategy and development policy can be based on these reserves as a main

relative advantage point. In addition to institutionalization of mining and employment, this policy can help export development considering domestic pluses and advantages. For this purpose and in the first step, it seems that the goals of the mining section to reach plans for producing 500 thousand tons of bauxite, and also to stepping foot in global market are reasonable.

4-4-10 – Production process

It is obvious that the best type of bauxite is the type that has the highest level of Al_2O_3, on the other hand since bauxite has multiple applications, and different industries need bauxites with different characteristic for their products, this mineral must be processed in different stages and to meet the needs and goals defined by the industry.

Processing or quality of bauxite depends directly on the percentage of alumina, meaning the higher the alumina, the more the quality and the less alumina, the less desirable it becomes. Generally in enriching bauxite attention must be paid to the following points:

- Impurities whose percentage must not be more or less than a given level; for example, the iron content in bauxite used in refractory must not be more than a certain amount.
- Impurities that are harmful in some industries and are not of importance to others like silica or iron impurities.
- Size of particles and grains, degree of refractory, amount of aluminum, quartz, iron oxide and titan are among the important factors for application of bauxite in different industries.

It is obvious that the level of impurities are different in different mines, thus the processing and elimination methods are different too. Bauxite enriching includes separating impurities such as silica, alkaline minerals and intact rock pieces and things as such, which can be carried out in two methods of dry and wet.

4-4-11- Common processing methods

There are various ways for processing bauxite which are chosen according to the mineral type and specification of the final product. The common method of processing bauxite is explained below.

- crushing stage

In this stage the extracted minerals are crushed in one or two rock breaking stages and, after going through magnetic apparatus, the material enters the mill in a closed path.

- grain setting stage

If the extracted bauxite has all the desired specs defined by the buyers, after granulation process and without having done the separation and purification, the product is delivered to the customers.

Of course in some cases, during crushing and granulation, accumulation of a set of impurities especially hard silicate minerals like quartz or soft minerals with large and small grains happens, which in this case crushing and granulating processes help bauxite and other impurities become effectively separated.

- gravitational separation stage

This method is usually used for separation of iron-bearing minerals and other silicate impurities accompanying bauxite.

Different equipments needed for preparation of gravitational concentrate can be used, but regarding the efficiency, desired grade and type of input load especially from the point of view of distribution of impurities in the sample and freedom degree of this mineral, the type of gravitational apparatus varies.

One of the important factors in choosing gravitational method is the amount of mid-range particles. In most production units several gravitational separator units are used to increase grade and output. In this plan application of hydro-cyclone and classifier is considered and recommended.

- magnetic separation

This method is used for separating iron oxides. The possibility of using magnetic apparatus for iron oxide separation becomes known once such apparatus is used. The diagram of the process is shown in figure 4-5.

4-4-12 – Economical index

- The amount of fixed about 15 million dollars

- Supplementary exploration studies; 0.25 million dollars

- The amount of capital in circulation about 1 million dollars

- Production costs about 4.2 million dollars

- Sales price for per ton, averagely 20 dollars (to cover the existing risks the price is offered 7 dollars less than the global price)

- Unit production capacity about 500 thousand tons per year

- Amount of annual sales about 10 million dollars

- Gross profit about 5.8 million dollars
- Return On Investment (ROI) rate about 37 percent
- Period return capital about 33 months

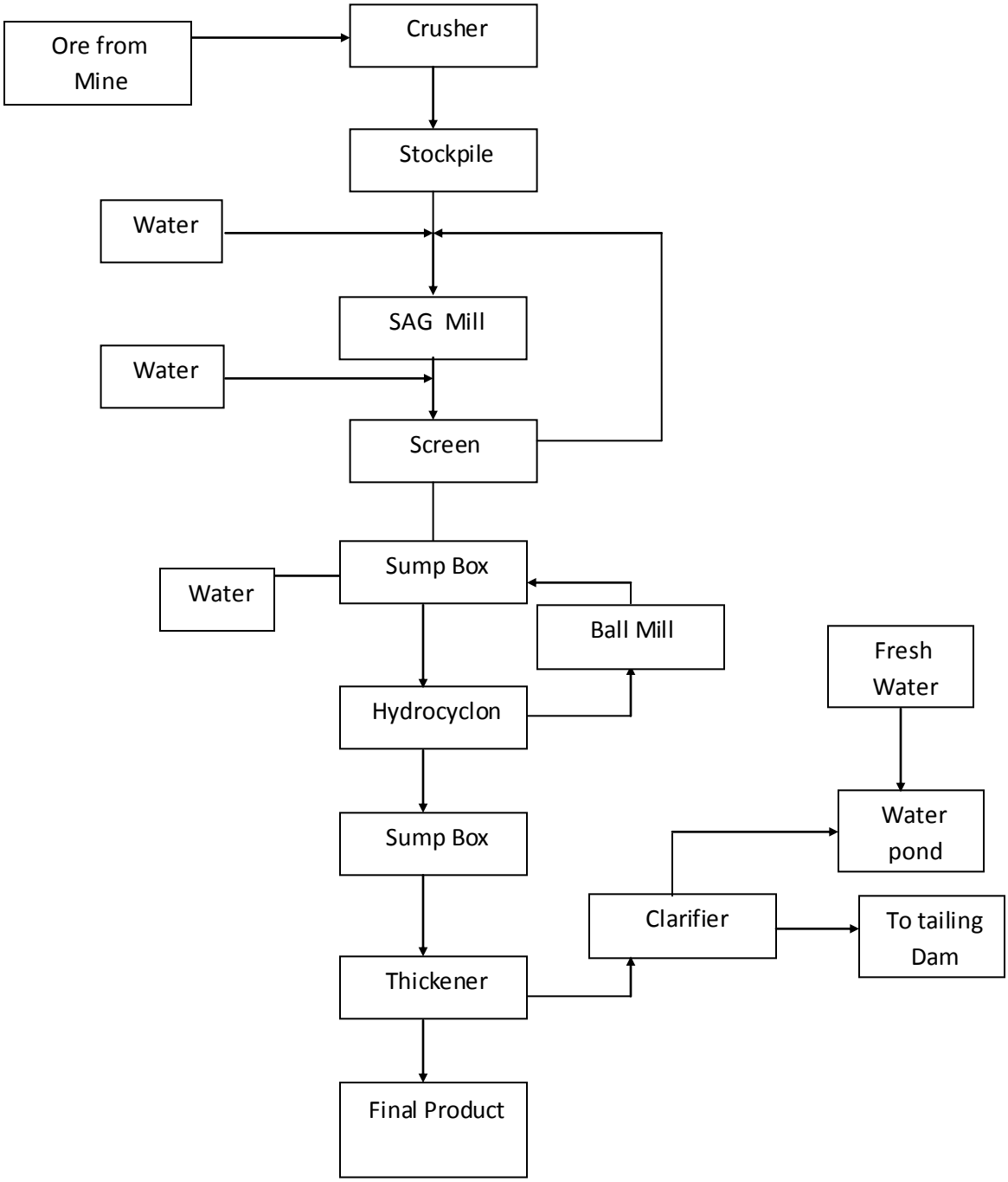


Figure 4-5 – Flow diagram of processing of laterite bauxite

5- Chapter five

5-1- Ideas and suggestions

According to what has been described in this report so far the following points can be reminded:

- Regarding the maps, geological and preliminary mineral exploration maps for both metallic and non-metallic minerals of Comore Archipelago have been prepared and compiled, and several districts of metallic and mostly non-metallic mineralization have been identified and marked.
- For the first time the rock units of this country have been petrologically studied, and the mineralization condition has also been studied and analyzed.

On this basis and also based on the predicative indexes of mineralization in this country, practical suggestions for continuation of exploratory programs are hereby recommended.

In this country, 9 mineral reserves and indexes with different perspectives have been determined, on which exploration works are suggested to be performed. The criterion in selection of these areas has been explained in chapter 3.

We divide these areas to three groups on the basis of level of importance.

- Totally promising deposits with economical perspective (requires detailed geological studies)
- Promising (second priority in course of detailed geological studies)
- Somewhat promising (third priority in course of detailed geological studies)

The major part of aforementioned suggestions and ideas is to study the geological issues and the appropriate methodology. In other words, these suggestions indicate what needs be done to study the interesting and promising districts (from mineralization point of view) and the scale of such exploratory studies. It is obvious that during geological studies, special plans are presented with regards to each district and the type of minerals.

1- Carrying out detailed studies on identified mineral deposits with great potential (totally promising) will cover:

1-1 – laterite red soil in Anjouan
1-2 - laterite bauxite in Anjouan
1-3 – olivine-bearing sands in Grand Comore
1-4 – pozzolan deposits in Grand Comore
1-5 – clay deposits in Grand Comore

The suggested services for the detailed geological studies are as it follows:

- preparing geological map with scale of 1:20000 with use of satellite images
- designing sampling network and taking rock and stream samples
- preparation and study of the samples
- digging trenches and holes based on the results from studying samples and underground studies
- sampling from trenches and holes and determining grade changes in mineral content
- calculating the tonnage of deposits on the basis of preformed studies
- compiling report and analysis of geological data in the scale of 1:10000

2- carrying out geochemical studies on the identified promising mineral deposits in prospecting stage include:

- titanium-bearing sands of Anjouan Island
- gold index in Anjouan Island

The suggested services for geochemical studies are as it follows (scale of 1:25000):

- designing of optimal sampling networks in watersheds
- taking geochemical and rock samples from water channels
- preparation of samples
- analysis of samples
- separation of collections of different samples based on upper-hand rock
- determination of level of sensitivity of the matrix based on the rock types
- data analysis
- analyses
- network estimation of amount of enrichment index
- control of anomalies
- taking heavy mineral samples
- study of heavy mineral samples to determine their level of abundance

Study of variability of density of cracks and their continuation

Analysis and compilation of all geological (petrology and fractures) and geochemical data, heavy mineral, mineralized samples, alteration and… to model the anomalies and to introduce promising areas and finally to prepare subjective maps indicating mineralization.

3- carrying out introductory geochemical studies on potential mineral deposits (somewhat promising) include:

- Lead and copper index in Anjouan Island
- Lead and Mercury Index in Moheili Island

The suggested services for the introductory geochemical studies are as it follows (scale 1:50000):

- designing of optimal sampling network in watersheds
- taking geochemical samples from water channels
- preparation of samples
- analysis of samples
- separation of collections of different samples based on upper hand stone
- determination of level of sensitivity of the matrix based on the rock types
- data analysis
- analysis
- network estimation of amount of enrichment index
- control of anomalies
- analysis and accumulation of all the geological data, geochemical data and… to model anomalies, and introduce promising areas and eventually offering topical maps indicating mineralizing.

Analysis and compilation of all geological (petrology and fractures) and geochemical data, to model the anomalies and to introduce promising areas and finally to prepare subjective maps indicating mineralization.