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Characterization of Hercynian Gabbroic Complex Massif of Koudiat El Khil Middle Jebilet Morocco Using Magnetic Susceptibility Variation

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Abstract: Measurements of magnetic susceptibility on the gabbroic formations in situ of Koudiat El khil (Middle Jebilet), allows to confirm spatial distribution of the various lithostratigphical facies constituting this hercynian terrane. Measurements were carried out using the portable torch Kapameter according to transverse profiles of the magmatic body. For a best positioning of measurements, without worries to miss any lithological varieties and to work according to a well defined mesh, the equidistant between localities were made using the GPS instrument. Applying this technique in these conditions allows highlighting the presence of a small outcrop of ultrabasic rocks, which was not mapped out during former works. As the value of magnetic susceptibility is a function of the importance of ferromagnetic and paramagnetic minerals in the rocks, measurements obtained reflect well the mineralogical variation and as a result to limit each rock variety. Conciliating this method of magnetic susceptibility with petrographic and geochemical studies could therefore to define five lithofacies. They are ultabasic cummulats, ferro-gabbros, ferro-diorites, isotropic gabbros and aplites. These rocks show average values of the magnetic susceptibility going of 11,2 * 10G^3 IS for the ultrabasic cummulats to 0,31 * 10G^3 IS for the isotropic gabbros. The pegmatitic pockets present within the ferro-gabbros and the isotropic gabbros show very low magnetic susceptibility values with average of 0,17 X 10G^3 IS, testifying the scarcity of magnetic minerals and confirming the mineral abundance of clear minerals such plagioclases. This method of measurement allowed also defining on the field the alteration effect as well as locating these weathering zones and the tectonic structures which are associated. Combining this method with the geochemical data revealed a positive and progressive correlation with FeO * and TiO2 contents going from basic to differentiated terms, owing to the effect a magmatic differentiation which is responsible of diversification of these magmatic rocks.

Key words: Hercynian Gabbroic Complex % Koudiat El Khil % Middle Jebilet% Morocco

INTRODUCTION

Koudiat El Khil is located at 25 km in NW of Marrakech, and at 5Km in the South of the mine of Kettara on the Eastern edge of road connecting Marrakech to Safi (Fig.1 and 2). It is constitued by an assembly of small hills whose altitude does not exceed 500 m and extended on 2 km. At the outcrop, the hills of Koudiat Arhil present a lengthen form warped in its North-East part. Its southern stump presents a sub-meridian direction on approximately 450 m width, while the northerner part is oriented NE-SW with a thickness of a few tens meters. Hills constitute an intrusive magmatic block inside of a thick shistous formation known as “schist of sarhlef”, consequently to the hercynian orogen effect. A late do1eritic seams with meridian direction cut the magmatic unit.

Combination of the petrographic, geochemical and magnetic susceptibility data enables to distinguish in space of the massif, the following magmatic varieties (Fig. 1):

- % Ultrabasites.
- % Isotropic gabbros,
- % Ferro-gabbros,
- % Quartzic ferro-diorites
- % Aplites.

The lithological change between these different rocks is progressive. Both clear contacts and nor apparent boundaries are not observed crossing the intrusion.

Dense and complex network of faults stakes out Koudiat Arhil massif and its surrounding metamorphic

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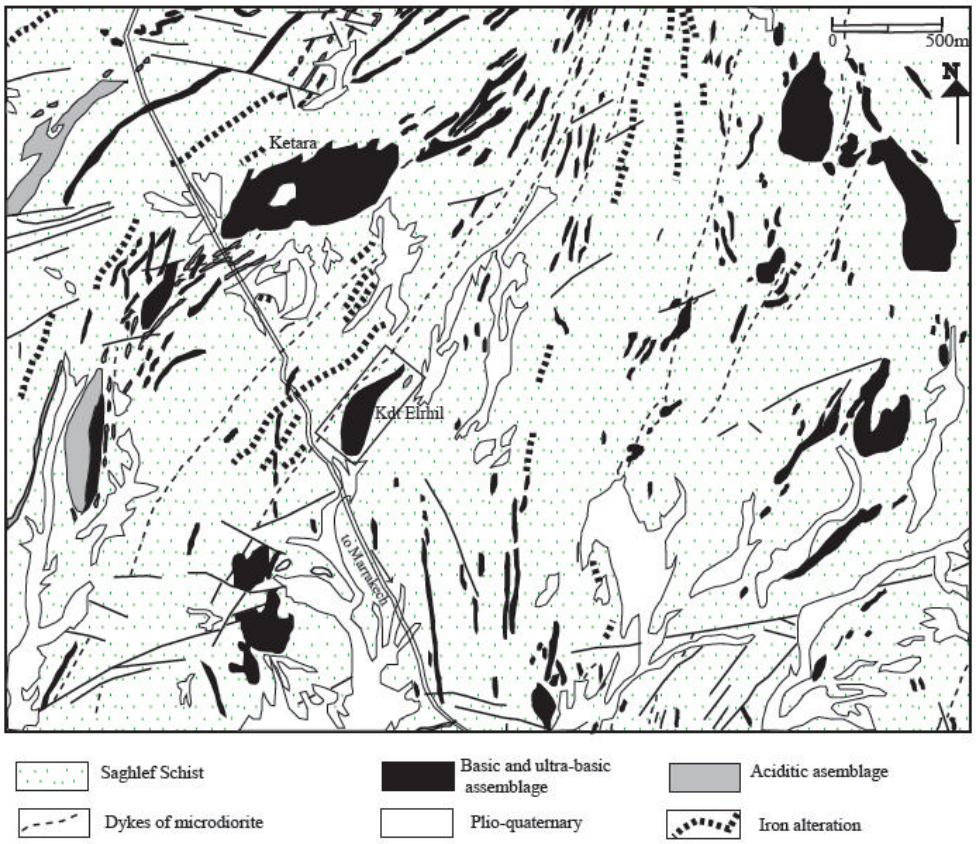

Fig. 1: Map of hercynian terranes of Jbilets centrals Mrocco according to Huveline 1972 modified

Fig. 2: Localization of Koudiat El Khil in the eastern side of the Marrakech Safi road. (Google Earth) with transects of SM measurements

schists. Sometimes faults are discontinuous and intertwined showing various directions. However these faults are frequently oriented N 30 to N 70, with a dip generally towards North-West. They constitute excellent drains to the circulation of the hydrothermal solutions as tested by alteration consequences.

Gabbroic rocks of Koudiat Arhil and its hosted environment are affected by an important schistosity which is subsequently reached again by fracturing events materialized by conjugated plans. Apart from the intrusion, regional schistosity presents N20 direction to N40, while approaching the magmatic body, it tends to shape it.

The studies made in the sector by Zaïm [1], enabled him to show that the magmatic bulk is conformable with bedding hosted rocks and is sited on reversed limb of a dumped anticline. Stratification plane S_0 is sub-meridian with vertical dip or extremely sloped to the West, whereas the schistosity S_1 presents a less significant dip towards the West. Additionally, sedimentary marks allowed to confirm these results and to establish that the polarity of the gabbroic formation is from West to East.

Petrographic Characteristics

Ultra Basic Rocks: This variety of rocks is detected for first time by this work owing to magnetic susceptibility measurements used on the field. It was identified on a small west part of the gabbroic complex (Fig. 5). These rocks are much altered and present a cumulative texture with mainly olivine and infrequent pyroxenes in association of iron oxides.

Gabbroic Rocks: This kind of rocks is divided in disproportionate bulk gabbros between the Western part (tens of meters) and the Eastern edge (a few meters). Among the various rocks constituting the solid mass, gabbroic varieties are clearly most dominant. They occupy more than two third parties of the total surface of the intrusion.

At the border rocks show a fine grain structure, due to fast cooling in contact with schist. To the centre of the massif gabbros present a greenish aspect with coarse grain texture, which locally become pegmatitic with macrocristal individualized minerals of plagioclase and amphibole. In contact with quartzic ferro-diorites gabbroic rocks are considerably dark as iron oxides are abundant. Two major differentiate facies were distinguished regarding to microscopic features: isotropic gabbros and ferro-gabbros. This distinction is confirmed by chemical data.

Isotropic Gabbros: This gabbroic type is the most represented. It constitutes the abundant mass in the western part and a narrow band towards the eastern edge. Its borders present a fine intersertal texture with abundant plagioclase crystals rounded by small spaces filled by clinopyroxene and iron oxides. Elsewhere texture is generally sub-ophitic with dominant plagioclase and clinopyroxene. Plagioclase crystals present two different aspects:

- Frequently lengthened sub-euhedral crystals are macled with feldspar and/or Carlsbad varieties; some of them are zoned.
- Tabular micro-crystals are generally twinned in albite feldspar and not zoned.

As associated minerals actinolitc-and ouralite are present .These amphiboles would come from the alteration of ancient clinopyroxenes. Some small preserved crystals of clinopyroxene are recognized which are associated with actinolite, chlorites and calcite.

The opaque minerals are not abundant. They constitute of small inclusions in mafic minerals or in interstitial position where they tend to surround other mineral phases. Titaniferous oxides are ilmenite kind, recurrently in association with leucoxene.

Towards the centre of the hill gabbros present a pegmatitoidic texture represented by preserved macro-crystals of clinopyroxene with poecilitic aspect including micro-crystals of ilmenite and plagioclase. Rare and interstitial crystals of quartz and apatite are as accessory mineral phases in this type of rocks.

Ferro-Gabbros: Less abundant than the first type, this variety of gabbros is closely linked to the ferro-diorites in several places. Ferro-gabbros are characterized by their green aspect for the reason that they are rich in oxides. Microscopic study show a granular texture with plagioclase and amphiboles associated with titaniferous oxides and apatite.

Preserved plagioclase has a composition of Labrador and andesine. Clinopyroxene is completely transformed into amphibole and chlorite with inclusion of microcrysts of plagioclase and oxides. The opaque minerals are relatively abundant and present different sizes and varied forms. They consist of small granulated pieces or skeletal crystals with more important size.

As for the precedent facies apatite and interstitial quartz are present.

Quartzic Ferro-Diorites: This sort of rocks outcrops on few tens metres square at eastern side of the hill. The pegmatitic texture is represented by primary crysts of plagioclases and amphibole in a quartzo-felsitic ground mass. Composition mineralogical of these rocks

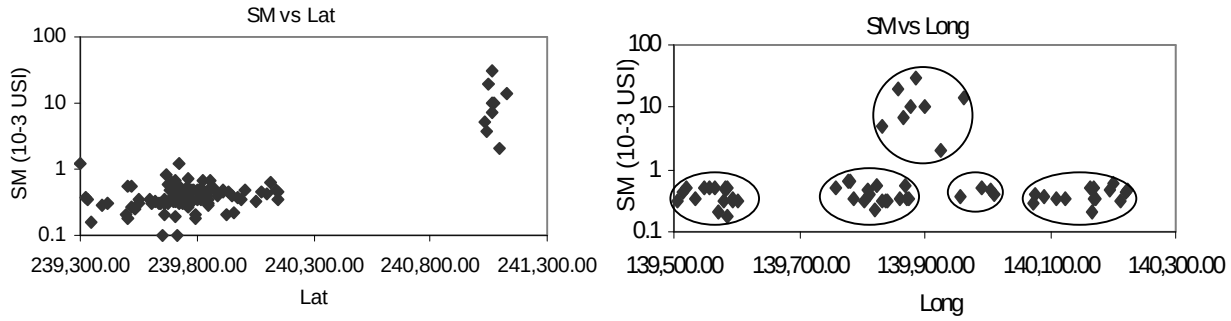

Fig. 3: Variation of magnetic susceptibility according to latitude and longitude in Koudiat Elkhil hills

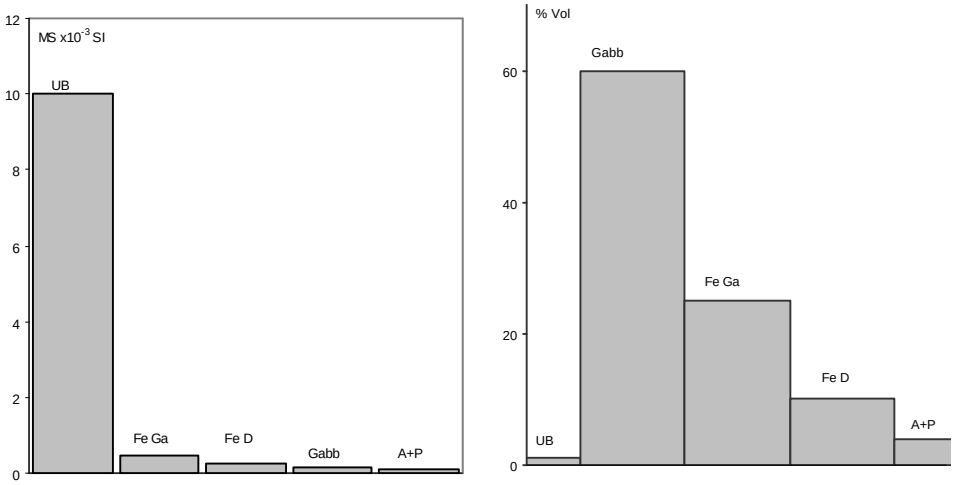

Fig. 4: Illustration of variation of MS and volume for various types of rocks of Koudait El Khil. UB: ultra-basic; Gabb: isotropic Gabbros; Fe Ga: Ferro-gabbros; Fe D: ferro-diorites; A+P: Aplites and pegmatitic pockets

consists of andésine-oligoclase plagioclase, some altered hornblende-actinolitic, amphibole in associations with quartz chlorite and calcite. Titaniferous minerals present a composition of ilmenite.

Aplites: This kind of rocks presents disseminates metric pockets within quartzic ferro-diorites. It appears leucocratic since it rich in quartz and albite and reduced in ferromagnesian minerals. Evolutional passage from quartzic ferro-diorites to sodic aplites is marked by the reduction in the proportions of amphibole at the expense of quartz and albite in symplectitic texture. Green and brown chlorite, calcite, small ilmenite inclusions, zircon and apatite compose a rest of mineral ground mass.

Magnetic Measurements

Field Measuring: The field measurements of the magnetic susceptibility were used by KT 6 kapameter. As the outcrop of gabbroic rocks of Koudiat Elkhil is oriented NE-SW, measures were operated according to transversal profiles (Fig. 2). In order to precise in space each locality of obtained data this work is coupled by GPS informations. Although that magnetic studies is limited where gabbroic rocks present various facies, number of data was accede two hundred. For each measurement locality and petrographic feature of rock is marked. This procedure permits to compile magnetic susceptibility (MS) of every variety of rocks (Fig. 4).

In order to show variation the magnetic susceptibility in space, this factor is represented versus latitude and longitude (Fig. 3). Examination of this variation illustrate that there are two distinguished groups of measurements according in opposition to the latitude. The illustration of magnetic susceptibility versus the longitude provides evidence of five distinguished groups of data giving a global view in space of MS variation. In two cases one group of data exposes high values of MS. It corresponds to the ultra-basic variety of rocks, which are discovered

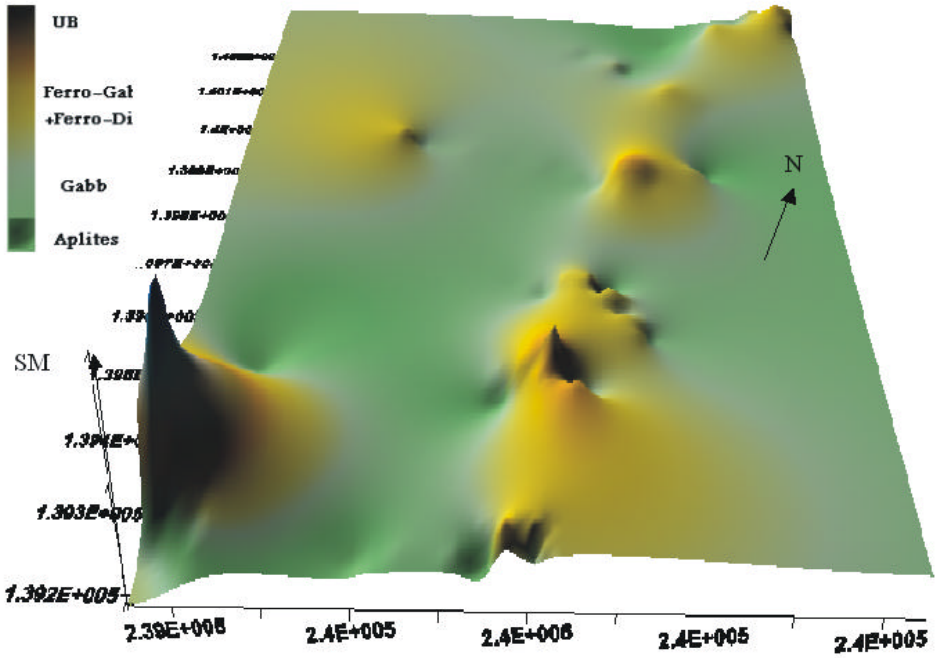

Fig. 5: Spatial variation of MS showing the relationship with magmatic rocks types on the field

for the first time by this physical method. The other three groups of MS data cover all other kinds of magmatic rocks in the massif. They are: ferro-gabbros, ferro-diorites, isotropic gabbros and aplites. To illustrate further this distinction in MS values of these different rocks, SM is reported versus the nature and the representative volume of each kind of rocks in the field (Fig. 4), Fouzi [2] and Aarab [3].

In spite of its small representative volume, ultra-basic rocks show the high values of MS, followed by ferro-gabbros and ferro-diorites while isotropic gabbros are the most abundant are less magnetic. Aplites pegmatitic pockets with very low MS values constitute minor varieties which are closely related to ferro-diorites. Abundance of iron oxides do not reflected the magnetic significance of each rock type, for raison that ilmenite constitutes the principal titanic iron mineral in ferro-gabbros and ferro-diorites. Consequently magnetic behaviour is related to disseminate grains of magnetite difficultly observed by microscope.

In order to illustrate the variation of MS according to the distribution of different types of rocks on the field, this factor is reported versus latitude and longitude (Fig. 5). This representation allows that the ultrabasic rocks which have the highest values are located in South-west of the gabbroic massif. In the second place emerge isotropic gabbros with less picks of Ms sketching out a line oriented N-E. In side of isotropic gabbros appear ferro-gabbros and ferro-diorites. Aplites and pegmatitic facies with depleted values of Ms are represented by depressions or holes. They are related to the two last kinds of rocks.

Thermomagnetic Treatments: Some samples are selected for thermomagnetic analyses. Laboratory investigations of thermomagnetic properties of specimens from gabbroic complex of Koudiat Elkhil have been performed. They were heated between room temperature and 700°C with Argon and cooled to-192°c temperature using Nitrogen liquid in the presence of a magnetic field. Treatments were realized in magnetic laboratory of geology and paleontology of Heidelberg University. Thermomagnetic susceptibility measurements [6 (T)] were made using the Kappabridge KLY-2 apparatus combined with CS-3/CS-L in fields of 300A/m. The volume of analyzed material is around 1 cm^3. Data processing and correction for furnace susceptibility were done using the computer [4].

This technique gives information on the mineral composition of the magnetic phases present in the magnetic fraction of the rock. It looks like standard analytical methods in geochemistry. Each magnetic mineral is characterized by its Curie temperature value. For isotropic Gabbros and ferro-diorites of study area two examples of temperature-dependent low-field susceptibility measurements are shown in Fig. 6.

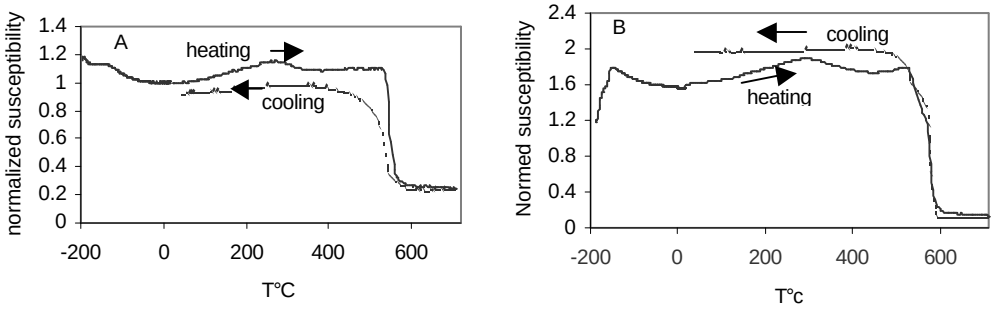

Fig. 6: Thermomagnetic behaviour for two representative samples of isotropic GabbrosJK8 (A) and ferro-diorites JK7(B) of Koudiat El khil massif. Heating: solid line, cooling: dashed line

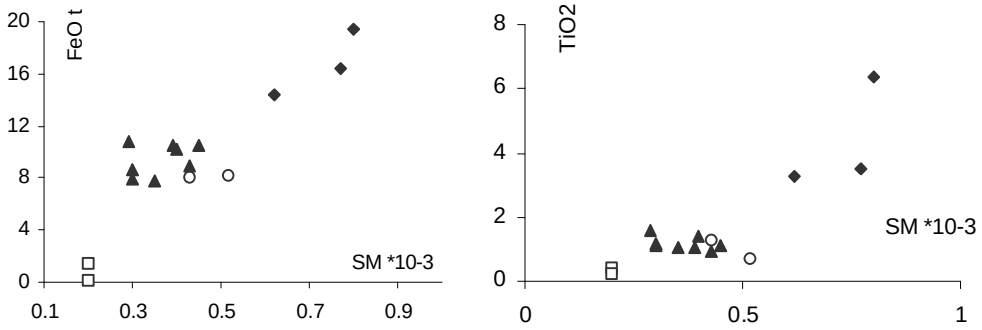

Fig. 7: Variation of magnetic susceptibility versus iron and titanium in various varieties of rocks of Koudiat ElKhil. Ferro-gabbros (lozenges); Ferro-diorites (circles), isotropic Gabbros (triangles); and Aplites (squares)

Sample JK8 (Fig.6A), shows reversible behaviour during the heating-cooling cycle, indicating that no secondary mineral phase has been produced during heating. The most usually occurring Curie points are between 570 °C and 590 °C, indicating the presence of magnetite in the two cases (Fig. 6AandB). However sample JK 7 proves a variable increase and an asymmetric shape of [6(T)] curve, with more magnetic susceptibility values for cooling part. In each investigation, most of the susceptibility is lost after 580°C indicating that magnetite is the main carrier. Higher than 580°C, the heating curves show the presence of hematite, but with a small contribution.

Magnetic Susceptibility and Geochemistry Relationship: In order to illustrate that magnetic susceptibility is closely related to iron content in gabbroic rocks; chemical data performed by Faouzi [2] for theses rocks are reported versus MS values of each rock types. It is required to indicate that ultra-basic rocks are not yet be analysed because they did not be discovered by this author.

A linear evolution of MS is well marked from aplites until ferro-gabbros. As it was revealed above in Figure 4, except for ultra-basic rocks, ferro-gabbros are the second kind of rockd which are magnetic. Whereas ferro-diorites present fewer iron component, followed by isotropic gabbros slightly less magnetic, so they expose both a comparable MS importance. We would like to point out that the designate of ferro-gabbros and ferro-diorites was done regarding to the importance of opaque minerals using microscope by Fouzi [2]. Microprobe analytic data of these crystals reveal composition of ilmenite. Hence abundance of this mineral contributes significantly on the magnetic susceptibility. This explains a relationship between titanium, which is important (until 6.5%) and MS variation Fig.7. This correlation is moreover equivalent to that of iron element for rocks varieties.

CONCLUSION

The magnetic susceptibility study performed on the hercynian gabbroic complex of Koudiat El Khil permitted for the first time to point out presence of a new lithofacies of ultra-basic-rocks. Secondly a new map of magnetic susceptibility based on the field measurements was done. The study allows having a spatial distribution of various rocks types according to magnetic susceptibility variation

trough the hill of gabbroic massif. In general five different types of susceptibility values are presented. They are identified as a result of a combination of magnetic susceptibility, petrographicl and geochemical data. The magnetic susceptibility it is a method of non expensive, fast, and easy to handle especially when it id associated with the GPS data. It could be a new tool for mapping on the field particularly for the composite solid massifs like that which is the subject of this study.

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