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Project: BLOCK STRUCTURE OF THE LITHOSPHERE AND ITS ROLE IN THE GENESIS AND DISTRIBUTION OF METALLIC ORE DEPOSITS

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PROGRESS REPORT

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The Progress Report, presented with this letter, gives a brief review of the main results as of August 31,1987, focused on the principal objective of the project: Testing of a model of block structure of deeper parts of the lithosphere in which the block boundaries guide magmatism and predetermine most favorable areas for the concentration of metals.

August 31, 1987

Respectfully submitted:

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BLOCK STRUCTURE OF THE LITHOSPHERE AND ITS ROLE IN THE GENESIS AND DISTRIBUTION OF METALLIC ORE DEPOSITS

A two-year project funded by the U.S.Agency for International Development. Grant # PDC-5542-G-SS-5073-00

PROGRESS REPORT

Presented: August 31, 1987

The main objectives of the project

Testing of a model of block structure of deeper parts of the lithosphere in which block boundaries guide magmatism and predetermine most favorable areas for the concentration of metals (fig.1).

Morocco provided a special opportunity for testing the above model because:

1 - It is located adjacent to a former junction of three lithospheric plates (North America, Africa and Eurasia), the motion of which could cause movements along intraplate block boundaries, especially in the marginal parts of the plates.

2 - An extensive data base was available in Morocco, including, in particular, a detailed monograph of the geology of Morocco by A.Michard (1976), of mineral deposits of Morocco (Géologie des Gîtes Minéraux Marocains) published by the Service Géologique du Maroc,1980; a comprehensive review of the geotectonic and structural evolution of Morocco by M.Saadi (1980), containing a detailed analysis of structural lineaments; an outstanding gravimetric study by Van den Bosch (1971, 1981); several seismic and magnetic studies (especially those by Ben Sari,1978, and Demnati, 1979), as well as a set of excellent geological and structural geological maps of Morocco on different

scales, published by the Service Géologique du Maroc.

The initial observations and the strategy of the project

The preliminary examination of Van den Bosch's (1971, 1981) isostatic anomaly maps of Morocco, carried out by Jan Kutina, has revealed the presence of two north-south trending boundaries in the deep structure of Morocco.These boundaries, superimposed on Saadi's (1982) mineral deposit map of Morocco have shown that all the most important deposits of Pb-Zn-Ag concentrate to the east and those of Cu to the west of the main N-S trending structural boundary which extends close to the longitude 6°W (fig.2).The same map has shown that:(1) The major silver deposit of Imiter (black dot No.2 in fig.2) occurs, on the scale of fig.2, close to the intersection of the above N-S trending structural boundary and the South Atlas Fault, the latter delineating the High Atlas Mountains on their southern side; (2) The cobalt district of Bou Azzer (marked by the symbol Co in fig.2) occurs close to the southern projection of one of the N-S trending structural boundaries and, farther south, a major concentration of gabbro-dolerite rocks occurs in the Saharan parts of the Anti-Atlas (see the small framed area marked A in fig.2); (3) The South Atlas Fault shows significant changes in its strike, which may be related to the deep structure of Morocco, and, if so, may play a role in the concentration of metals.

The above observations indicated that a detailed study of the isostatic anomaly maps may reveal additional regularities reflecting deep structure of the territory and its role in metallogeny. In this connection, it appeared important to include in the project plan : (1) Additional gravimetric measurements by Moroccan geophysicists, espe-

cially in the southern part of the Anti-Atlas (actually performed by Drs.M.F.Hamouda and A.Bellot of the Service Géologique du Maroc), and to request Dr.T.G.Hildenbrand of the Geophysical Branch of the U.S.Geological Survey, Denver, to receive the Moroccan geophysicists in his laboratory and produce, under a cooperative program, a set of the digital,colored, residual and regional gravity anomaly maps of the project area of Morocco. This kind of maps, first compiled for the territory of the United States by T.G.Hildenbrand and co-workers (publ.1982) proved to be very useful for the study of regional distribution of ore deposits. An example from a metallogenic application of these maps in the western United States was available at the onset of the AID-project, but the paper itself published as late as this year in the Bulletin of the Geological Society of America (Kutina and Hildenbrand, 1987).

The project also benefited from a detailed analysis of structural lineaments performed by Saadi (1971, 1980) which was reviewed, in a comprehensive way, by Saadi and Mahmood (1984) . It was followed by a remote sensing study, performed under the project by Bensaid and Mahmood (1986).

The initial observations with which the project started, have been presented at the 6th International Conference on Basement Tectonics in Santa Fe, New Mexico, September 1985, and published the same year by M.Bensaid, J.Kutina, A.Mahmood and M.Saadi (December 1985).

A brief review of the main results as of August 31,1987, is presented in the next sections.

Examination of the isostatic anomaly map of Morocco

Studies of deep-seated controls of mineralization, carried out in over twenty countries on five continents (Kutina 1986,1973) have indicated that the lithosphere is penetrated by a system of deep-seated fracture zones or structural boundaries, some of them extending down to the base of the lithosphere. According to the above studies, four sets of deep-seated structural boundaries have usually developed, trending essentially N-S, E-W, NW-SE and NE-SW. However, one or two sets of these boundaries are usually much better developed and can be more easily recognized in the surface geology than the other sets, giving an impression that some of the sets of structural boundaries are missing.

Mutual intersection of structural boundaries of different orientation defines lithospheric blocks. Figure 1 is a model showing two sets of deep-seated structural boundaries, delineating blocks of orthogonal shape. For the sake of simplicity, the crust is not distinguished in the illustration, but it should be understood that the presence of many deep-seated structural boundaries is, in the surface geology, masked by the complicated history of geological evolution. Nevertheless repeated movements along the structural boundaries of the 'basement', especially the vertical movements, have caused their upward propagation through the heterogeneous rock complexes of the crust. There exists a voluminous literature about the different ways of manifestation of the deep-seated structural boundaries in the surface geology, and criteria for recognizing them.

Let us imagine that the lithosphere with a block structure shown

in fig.1 is subjected to stresses leading to vertical movements of some of the blocks, it is to uplifting of some and subsiding of others. As the average density of rocks composing the crust is lower than that of the upper mantle material, the vertical movements can bring the denser upper mantle material into shallower depths, so that rock complexes of different density, each belonging to another structural block, may appear side by side at a particular depth level. Counting the erosion and denudation of the uplifted blocks, accumulation of thick sedimentary strata in some slow-subsiding basins, penetration of some blocks by igneous masses etc,, there is a great variety of reasons why the mass distribution in the lithosphere is uneven and why the boundaries of some blocks can be recognized in a gravity map.

According to the Airy model of isostasy, there is a tendency of the blocks to compensate their different "weight" by a different degree of their submerging in the plastic, partially molten material beneath the base of the lithosphere. It was our hope and expectation that the isostatic compensation, reflected in Van den Bosch's isostatic gravity anomaly maps (calculated for different thickness of the lithosphere) will reveal the most important structural boundaries of Morocco by different gravity values of the blocks.

Figure 4 shows one of the isostatic anomaly maps of Van den Bosch, selected for our analysis. We have distinguished, by different patterns, four groups of gravity values in the map, using the darkest pattern for gravity values higher than 50 milligals (reflecting parts of the lithosphere with the greatest participation of rocks of higher density). The course of the Atlas Mountains, separately shown in fig.3, is superimposed on the isostatic anomaly map in fig.4 (shown by heavy full lines)

The course of the Atlas Mountains, in fig.3 shown in the context of the main structural domains of Morocco, essentially reflects the shape of the depression in which sedimentation proceeded in the Mesozoic time. Fig.2 gives the extent of the folded Mesozoic (mostly Jurassic) rocks comprising considerable part of the High Atlas Mts. and the Middle Atlas Mts., and the extent of the Triassic continental red beds in the western part of the High Atlas.

The shape of the Atlas Mountains, as shown in fig.3, indicates that the subsidence, giving rise to the elongated depression, had a tendency to follow a NE-direction, but that it was also controlled by E-W trending structural boundaries. This control is well visible in the changes of the strike of the South Atlas Fault which delineates the former depression on its southern side. This fault zone consists of segments trending ENE to NE (segments A_1, A_2 and C) and those trending E-W (segments B and D). The northern limitation of the High Atlas Mts.also exhibits important changes in its course, of which especially two N-S "steps" (marked by arrows in fig.3) are significant.

The isostatic gravity anomaly map (fig.4) onto which the course of the Atlas Mountains has been transferred, helps to explain the above observations:

1. The E-W trend of the High Atlas Mountains between longitudes about 2°W and 4°30'W correlates with east-west contours in the isostatic map.

2. The change in the course of the southern boundary of the High Atlas Mts.(i.e.the South Atlas Fault) from NE-SW to E-W, as occurring near the longitude 6°W, is related to northern boundary of a major zone of gravity highs which apparently acted as a rigid block, limiting the sedimentary depression on its southern side. The gravity contours of the isostatic map indicate that the above mentioned northern limit-

ation of the zone of gravity highs is part of a major east-west trending structural boundary extending at a latitude close to 31°N, practically from the Atlantic coast eastward (at least as east as 5°W longitude).

The two zones of gravity highs which occur SE of Rabat and SE of Casablanca respectively (fig.4), terminate at a latitude approximately 32°45'N, essentially correlating with northern border of a sedimentary basin shown in the Carte Géologique du Maroc, scale 1:1,000,000, publ. 1985.

Thus, fig.4 shows that a considerable part of the High Atlas Mts., between longitudes 5°30' and 8°W, is characterized by a field of relatively low gravity values, enclosed between zones of higher gravity occurring north of 32°45'N and south of 31°N latitudes.

A rather narro , but over 100 km long zone of gravity highs (> 50 milligals) occurs within the High Atlas Mountains between longitudes 4° and 5°30'W and is not reflected by any larger block of basic rocks in the surface region. This zone of high gravity values may reflect a larger body of basic or ultrabasic rocks beneath the surface, either uplifted as a rigid upper mantle block (similar to the blocks of basic or ultrabasic rocks described in several papers by E.Bonatti and co-workers from the E-W trending fracture zones of the equatorial Atlantic), or an intrusion which did not reach the Earth's surface. The relatively small calco-alcaline massif of Tamazeght, shown by an asterisk in fig.2, correlates with the northern boundary of the above mentioned zone of gravity highs in the High Atlas Mountains.

Besides the above east-west trending structural boundaries, shown by broken lines in fig.4, J.Kutina has distinguished, in the isostatic gravity anomaly map, three N-S trending structural boundaries. Two of

them are reflected as "steps" on the northern boundary of the High Atlas Mountains (one at a longitude close to 7°W, and the other at a longitude west of 8°W).

The recognition of a set of N-S trending boundaries in the deep structure of Morocco is of an extraordinary importance for mineral exploration, because these boundaries intersect with the east-west ones and extend transversely to the orogenic belt of the High Atlas Mountains. The role of these boundaries in metallogeny is described in the next section.

The role of the deep structure of Morocco in the genesis of metallic ore deposits

The metallogeny of Morocco was studied by many scientists. The main results with references are given in the monograph "Géologie des Gîtes Minéraux Marocains, Tome I", published in 1980 by the Service Géologique du Maroc. The relationships between metallogeny and geotectonic evolution of Morocco have been treated by Saadi (1980). The distinguishing of several sets of structural lineaments in Morocco and their comparison with the distribution of mineral occurrences has been done systematically by Saadi (1971, 1980,1982), Saadi and Mahmood (1984), and further extended under the present project by Bensaid and Mahmood (1986).

The purpose of this chapter, which is part of the Progress Report, is to demonstrate (1) the metallogenic role of the block boundaries distinguished in the isostatic anomaly map (fig.4), and (2) to explain how this block structure can be used in exploration for new ore deposits in Morocco.

The isostatic anomaly map (fig.4) reveals two features which are of basic importance for the study of deep controls of mineralization: (1) Intersection of deep-seated structural boundaries of two trends (north-south and east-west), defining lithospheric blocks of orthogonal shape; (2) Intersection of an orogenic area (the High Atlas Mts.) with a set of deep-seated (N-S trending) structural boundaries, extending transversely to the orogen.

The spacing of the three N-S trending structural boundaries, distinguished in the isostatic anomaly map (fig.4), is about 110 km. The two E-W trending boundaries (one extending close to the latitude of 31°N and the other at approximately 32°45'N), intersect with the boundaries trending north-south. There are indications suggesting that another E-W boundary exists at a half distance between the above two, so that the spacing in the E-W set of structural boundaries would be slightly smaller than 100 km.

A similar size of structural blocks has been found in the Precambrian in southern part of the Canadian Shield (the Abitibi area) by Kutina and Fabbri (1972). The lithospheric blocks, distinguished in Morocco reflect, undoubtedly, also a pattern of a block structure in the Precambrian basement, especially when they are manifested in an isostatic anomaly map. In the Abitibi area of the Canadian Shield, Kutina and Fabbri have analyzed the distribution of about 1,500 gold and about 750 copper occurrences. A pronounced tendency of the occurrences of gold and copper (as well as of some other metals) to concentrate near the corners of the lithospheric blocks has been observed. In the case of Morocco, a major cluster of about fifty occurrences and deposits of metals, including the large silver deposit

of Imiter, occurs near the intersection of the N-S trending structural boundary extending close to 6°W longitude and ~~the~~ the E-W trending structural boundary following the 31°N latitude. The other intersections in fig.4 require special study.

Concerning the intersections of the High Atlas Mountains with the set of the N-S trending structural boundaries, the following observations have, so far, been made:

The N-S trending structural boundary distinguished in the isostatic anomaly map at a longitude west of 8°W (fig.4), manifests itself as a "step" on the northern border of the High Atlas Mts. If this boundary extends through the basement beneath the High Atlas Mts., it would intersect the South Atlas Fault which delineates the High Atlas on its southern side. The South Atlas Fault is a deep-seated structural boundary extending from the Atlantic coast at Agadir in an essentially ENE-direction across the whole territory of Morocco. Its intersection with the above mentioned N-S trending boundary would provide suitable channelways for the ascent of magmas and ore forming fluids.

Fig.5 gives a part of A.Demnati's(1979) 'Carte Magnétique du Maroc' with his interpretation of the course of the South Atlas Fault between Agadir and longitude 7°W. The map shows intersection of the South Atlas Fault with three faults of a N-S trend, very well correlating with the longitude of the deep-seated north-south trending structural boundary distinguished in the isostatic map (fig.4). We can observe that the South Atlas Fault changes its strike in the area of its intersection with the three N-S faults: The South Atlas Fault extends essentially northeast between the city of Agadir and the intersection (segment A), and, east of the longitude 8°W, its strike is nearly E-W. This is a typical change in the strike of a major fault occurring at intersection

with a structural boundary extending transversely to the latter. The location of metallic ore deposits and occurrences, transferred to fig.5 from the 'Carte de Gîtes Minéraux du Maroc' (1980) shows a tendency of ore deposits to concentrate in the area of the structural intersection. In particular the Mo-Cu-W stockwork deposit of Azegour, which requires a deep source of magmatic fluids, is characteristic for intersection of deep-seated structural boundaries.

The second N-S trending structural boundary distinguished in the isostatic anomaly map, which extends very close to longitude 7°W, is reflected by an impressive "step" on the northern border of the High Atlas Mountains. This boundary is of a special interest to us, because the important concentration of cobalt at Bou Azzer essentially correlates with southern projection of that boundary. As mentioned in the section "The initial observations and the strategy of the project", there is an unusual concentration of gabbro-dolerites in the Saharan part of the Anti-Atlas, correlating with the longitude of the N-S trending structural boundary shown in the isostatic map at close to 7°W. The respective area with the gabbro-dolerite magmatism is shown by a small frame in southern parts of fig.2 and fig.3. We have examined this area (J.Kutina and A.Bennani) in two expeditions and found criteria indicating the presence of a north-south structure at a longitude corresponding to the N-S trending boundary distinguished in the isostatic map. The study of this area, further referred to as the Foum Zguid region, has revealed two interesting targets, one with concentration of nickel and cobalt, and the other with indications of concentration of gold. The results are described in the next section.

The detection, in the isostatic anomaly map, of several deep-seated boundaries of a N-S and an E-W trend, and their mutual intersection, provides a possibility to elaborate a broader plan of mineral exploration, which is beyond the possibilities of the present project. We will call attention to a number of areas of special interest in the final report of our study.

The Foum Zguid region in the Saharan part of the Anti-Atlas and its potential for nickel, cobalt, gold and possibly platinum-group metals

The area here referred to as the Foum Zguid region is shown by a small frame in the southern part of fig.2. It is located in the Saharan part of the Anti-Atlas and its geology is shown in fig.6, simplified from geological maps on the scale of 1:200,000 (quoted in the legend to the illustration). The area is characterized by a great concentration of gabbro-dolerite rocks, marked in black in fig.6. This basic magmatism extends still further eastward for several tens of kilometers, in a rather narrow zone, but the maximum of its concentration (with protrusion towards the north along direction F_2 in fig.6) occurs just in the Foum Zguid region.

In the older literature, still including the geological maps from 1971, used for preparation of fig.6, this basic magmatism of the Foum Zguid region was considered as of Hercynian age. Later, an early Mesozoic age of this magmatism has been recognized, so that the 'Carte Géologique du Maroc', scale 1:1,000,000, of 1985, is classifying this magmatism as of a Liassic age.

From the viewpoint of a broad regional scale, the gabbro-dolerite magmatism of the Foum Zguid region can be considered as product of

an early Mesozoic magmatic reactivation which occurred near the northern border of the West African craton.

On a global scale, a similar magmatic reactivation of Mesozoic age, with a major concentration of gabbro-dolerites, occurred in the Norilsk-Talnakh region, adjacent to the western border of the Siberian platform (close to 90°E longitude), followed by the Yenisei River. A comparison of the Foum Zguid magmatism with that of the Norilsk-Talnkah region is very important, because a major concentration of copper-nickel ores with significant amounts of platinum-group metals occurs in the Norilsk-Talnakh region and is of great economic value.

According to the observations by Vilensky and others, quoted by Smirnov (1976), the most promising areas of the Norilsk district, as regards deposits of copper-nickel sulfide ores, are the thick (more than 100 meters), gently sloping, differentiated lopolith-like intrusions of the alkaline-earth branch of basaltic magma differentiation, which have a small aureole of contact metamorphosed rocks lying beneath a 'screen' of lavas or dolerites.

The isostatic gravity anomaly map (fig.4) has revealed a large zone of gravity highs between Foum Zguid and the 31°N latitude, indicating that rocks of a higher density may substantially participate at some depth beneath the surface. The ultrabasics of the Bou Azzer area, hosting the known concentrations of cobalt, give support to the above idea. Therefore, it is possible that a large body or bodies of basic or ultrabasic intrusives occur beneath parts of the Foum Zguid region and may be "screened" by the gabbro-dolerite rocks, mainly dikes and sills, similarly as in the case of the Norilsk district.

Among the criteria, used in mineral exploration of the Norilsk-Talnakh region, is magmatic differentiation which played an important

role in the concentration of copper, nickel and platinum-group metals.

J.Kutina and A.Bennani, Chief of the Division of Mineral Research, Ministère de l'Energie et des Mines, Rabat, made two expeditions to the Foum Zguid region, searching for signs of magmatic differentiation within the suite of the gabbro-dolerite rocks. The localities where samples have been collected, are marked by no.1 to 16 in fig.6.

Megascopically, three types of intrusives have been distinguished, two of them belonging to the gabbro-dolerite suite of rocks (including a layered type), and the third one being more leucocratic, with relatively higher contents of Al_2O_3 and K_2O, and relatively lower contents of Fe_2O_3 + FeO, MgO and CaO. The rock is hydrothermally altered and a name cannot be assigned to it until its microscopic study is completed and the question resolved whether a part of the potassium has been or has not been added by a superimposed K-metasomatism. In any case, the discovery of this more leucocratic rock is very important as it contains dissemination of pyrrhotite (essentially FeS) and pentlandite - an iron nickel sulfide with a composition usually given as $(Fe,Ni)_9S_8$. An electron microprobe analysis by K.Fredriksson of the Smithsonian Institution has revealed that the pentlandite from our locality contains between 2.3 and 3.3% Co.

The Devonian limestone around the above intrusion is altered, containing an interesting association of minerals with hydrothermal serpentinization of the limestone, with the presence of wollastonite $Ca[SiO_3]$, perovskite $CaTiO_3$ and other minerals, among them a garnet with a very high titanium content (electron microprobe analyses by K.Fredriksson). This contact aureole of the intrusive also contains fine dissemination of minute grains of Ni-Fe-Co sulfide of the pyrite group, The electron microprobe analyses of this sulfide, performed by

J.Nelen in the Smithsonian Institution, gave - quoting the values from three analyses: Ni 37.1 - 38.0 %, Fe 16.2 - 19.2 %, and Co 5.4 - 6.0 %.

In the Norilsk area in Siberia, there has been found a metasomatic leucocratization of the basic rocks and is used as one of important criteria in mineral exploration for the Cu-Ni ores with Pt-group metals (V.S.Sobolev, Ed.,1978). Also, an association of particular minerals in a contact aureole, especially Fe-rich silicates, is considered as a positive sign in the prospection in the Norilsk region.

Our study is still in progress, without final conclusions, but the results seem to be promising and will be, in the final report and publications, accompanied by quantitative chemical and spectrochemical analyses. Our colleagues in the Geochemical Branch of the U.S.Geological Survey are just completing the following kind of analyses of 27 selected samples from the Foum Zguid region:

1. Major components of rocks by inductively coupled argon plasma spectrometry (Mrs.F.Brown)
2. Semiquantitative emission spectrographic analyses of minor and trace elements (D.W.Golightly)
3. Quantitative determination of platinum, palladium, rhodium and gold by atomic absorption spectrometry, following a fire-assay preconcentration of Pt, Pd and Rh. (Norma Rait for the Pt-group metals, and Roosevelt Moore for gold).

Preliminary evaluation of some of the analytical data, as long as they were available, are given in a paper by J.Kutina and A.Bennani, presented at the 7th Internat.Conference on Basement Tectonics, held in Kingston, Ontario, in August 1987. An abstract of the paper is included in this Progress Report. A full evaluation of the analytical

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INTERNATIONAL BASEMENT TECTONICS ASSOCIATION, INC.

46 **THE GABBRO-DOLERITE MAGMATISM OF THE FOUM ZGUID REGION: RELATION TO DEEP STRUCTURE OF MOROCCO AND POSSIBLE POTENTIAL FOR COBALT, NICKEL AND PLATINUM-GROUP METALS**

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The isostatic anomaly map (Van den Bosch, 1971), the magnetic map (Demnati, 1979) and geological criteria are used to define boundaries of major blocks in the deep structure of Morocco. The gabbro-dolerite magmatism of the Foum Zguid region (Saharan part of the Anti Atlas) represents an early Mesozoic tectono-magmatic reactivation of this block structure, occurring near the northern border of the West African craton. The magmatism concentrates between 29°30'and 39°00'N, and 6°30' and 7°15'W, and extends farther east, being controlled by a major latitudinal boundary probably intersecting with a N-S structure of a rift nature which is partly masked by younger tectonics.

The age and composition of the rocks, especially the contents of Mg, Fe, Cr, Co, Ni and Zr show similarities which some basic rocks of the Norilsk region, Siberia, cited by Fedorenko et al. (1983).

Two samples of the most common gabbro-dolerite rocks from the Foum Zguid area, analyzed by Norma Rait, U.S.G.S. (A.A. with fire assay preconcentration.) gave 7.0 and 11 ppb Pd, 5.5 and 8.1 ppb Pt, and < 0.5 ppb Rh. A serpentinized Devonian limestone from a contact with basic intrusives (near Ikailoula Range) gave 19 ppm Co and 79 ppm Ni (D.W. Golightly), partly coming from a disseminated Ni-Fe-Co sulfide mineral containing about 39% Ni and 5% Co (electron microprobe analysis by K. Fredriksson and J. Helen, Smithsonian Institution).

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results will be published jointly with our colleagues of the U.S.Geological Survey and with Dr.Kurt Fredriksson of the Smithsonian Institution.

The location of the above intrusive with dissemination of pyrrhotite and pentlandite and the Ni-Fe-Co sulfide in its contact aureole, is shown on fig.6 (locality No.8 , marked Ni,Co, close to the southwestern tip of the Hamsailikh anticline).

Another, very interesting observation has been made in the area of the northeastern tip of the Hamsailikh anticline, where the axis of the anticline (followed by a fault) changes its strike, turning from a northeastern direction essentially towards the north (shown by line F_1 in fig.6). In the area of locations Nos.3,4, and 5 (fig.6) the Ordovician quartzites are penetrated by quartz veins, some very rich in limonite. In the foothills of the Amsailikh Range we have observed, with A.Bennani, a great accumulation of opalite, a low-temperature form of $SiO_2 \cdot nH_2O$, very similar to the opalites from some low-grade gold deposits in northern Nevada. As it is well known, some of the low-grade gold occurrences in northern Nevada turned to be important deposits of gold, due to an enormous amount of the low-grade ore and the possibility of mining it by open pit operations.

The first four samples of the opalite, quartz and opalite breccia from the northeastern tip of the Hamsailikh Range, which have been analyzed by atomic absorption, have shown detectable gold in the values between 0.02 and 0.06 ppm Au. Although these values are very low, they represent anomalous concentration of gold. For comparison, I am quoting the contents of Au detected in the opalites from the Jasperoid Peaks in Pershing County, Nevada, given in my first reports on this gold

target, studied under W.A.Bowes,Inc. The gold contents were in two ranges of values: 0.05 - 0.08 ppm, and 0.15 - 0.64 ppm Au. On the basis of these contents and additional study, the locality has been drilled and became a very promising target for gold (results to be published by W.A.Bowes and J.Kutina, in preparation). The gold contents determined in the first four samples from the Hamsailikh Range are in the order comparable with the lower group of gold values from the Jasperoid Peaks. Taking into account that only four samples from the Hamsailikh Range were analyzed and all have shown detectable gold, the locality deserves further attention. We are planning a more detailed examination and sampling of this locality during the next expedition.

The structural setting of the localities with anomalous gold contents in the opalites (the northeastern tip of the Hamsailikh Range) is very favorable for opening fractures in the quartzites, because of the change in the direction of the anticlinal axis. This change may be caused by movements along a deep-seated N-S trending structural boundary, extending into the Foum Zguid region from the north.

Remote sensing studies performed under the project

According to the original plan of the AID-funded project, the Moroccan geologists were supposed to come to the United States, get acquainted with the state-of-the-art of remote sensing studies and get Landsat images covering the entire area of the project or of Morocco. This has been accomplished by the visit of Dr.Mohammed Bensaid, Director of the Geological Survey of Morocco, and Dr.Ahmed Mahmood, Professor at the École Nationale de l'Industrie Minérale in Rabat.

Dr.Bensaid and Dr.Mahmood attended a special course offered by William D.Carter, President of Globex, Inc. Reston, Virginia (former staff

member of the EROS Office, U.S.Geological Survey). Later, Dr.Mahmood attended an advanced course in remote sensing in San Francisco, given by Drs.Lawrence Rowan of the USGS and Dr.A.Goetz of the Jet Propulsion Laboratory.

The Moroccan geologists have received, through the AID-project, a set of Landsat images of Morocco and have used them in their remore sensing study of a part of the project area. The study has revealed significant data about structural lineaments of the region , presented at a COSPAR conference in Toulouse in France and submitted for publication (M.Bensaid and A.Mahmood: The use of Landsat imagery in structural studies in Middle Morocco. In press, 1986).

The experience from this study and from the training courses in the United States will be used in a follow-up of the project in Morocco, and also in lecturing remote sensing at the École Nationale de l'Industrie Minérale in Rabat.

Geophysical study - Compilation of residual gravity anomaly maps and other gravimetric maps of Morocco

As explained on pages 3-4 of this Progress Report, it appeared very important for the study of deep controls of mineralization to compile, for the Moroccan territory, a set of colored, digital residual and regional gravity anomaly maps, using the methodology and computer technique developed in the Geophysical Branch of the U.S.Geological Survey by Dr.T.G.Hildenbrand and co-workers.

The preparation of the gravity data of Morocco, including additional gravity measurements in the Saharan part of the Anti-Atlas has, unfortunately, required more time than we have planned in the project. Nevertheless, the necessary data have been prepared, and the following

maps produced in the Geophysical Branch of the U.S.Geological Survey in Denver, in August 1987, under a cooperative program between Dr.T.G. Hildenbrand and the Moroccan geophysicists Drs.A.Bellot and M.F.Hamouda of the Geological Survey of Morocco:

Color edition on the scale of 1:2,000,000

1. Residual and regional gravity anomaly maps with a cut-off wavelengths of 250 km;
2. Residual and regional gravity anomaly maps with a cut-off wavelengths of 100 km;
3. Horizontal gradient magnitude map;
4. First vertical derivative map;
5. Color shaded relief of the first vertical derivative;
6. Bouguer gravity anomaly map unfiltered;

On the scale of 1:1,000,000

7. Bouguer gravity anomaly contour map (in black and white);
8. Horizontal gradient magnitude map (in color)

It is planned to publish the 1:2,000,000 color maps in the U.S.Geological Survey, Denver, and to consider publication of the 1:1,000,000 maps in Rabat, Morocco.

The compilation of the above maps is an extremely valuable component of the project and has been planned to provide an additional basis for the study of deep structure of Morocco and derivation of new targets for mineral exploration. The maps were supposed to be prepared before the end of 1986 and followed by J.Kutina's study of the maps, with derivation of new target areas for mineral exploration, their examination in the field and final evaluation before August 15,1987. Due to an about nine month delay in preparation of the maps, and their availability as late as in the middle of August 1987, Kutina's study of the maps, field examination

of targets, and final evaluation will have to be performed during the five-month period allowed by AID for compilation of the final report. The last expedition to Moroco has been correspondingly postponed to allow time for examination of the maps.

A preliminary study of the maps indicate that they will be of a great help in defining new target areas for mineral exploration.

Publications based on the AID-funded project

1. Papers published or submitted and accepted for publication

1. M.Bensaid, J.Kutina, A.Mahmood and M.Saadi: Structural evolution of Morocco and new ideas on basement controls of mineralization. Global Tectonics and Metallogeny, Vol.3, No.1, p.59-69, December 1985.

2. J.Kutina: Criteria indicating a block structure of the upper mantle and its role in metallogeny. Abstract in: Terra cognita, Vol.6,No.3, p.498. Full text accepted for publication in the Proceedings of the 7th IAGOD symposium held in Luleå, Sweden, August 1986 (to be published by the Schweizerbartsche Verlagsbuchhandlung in Stuttgart).

3. M.Bensaid and A.Mahmood: The use of Landsat imagery in structural studies of Middle Morocco. Proceedings of the COSPAR conference in Toulouse, France, 1986 (accepted for publication).

4. J.Kutina and A.Bennani: The gabbro-dolerite magmatism of the Foum Zguid region: Relation to deep structure of Morocco and possible potential for cobalt, nickel and platinum-group metals. 7th Internat.Conference on Basement Tectonics, Kingston, Ontario, August 1987. Abstract in the 'Program with Abstracts', p.47. Full text under preparation for the Proceedings of the Conference.

2. Papers in preparation without a definite title

1. A geochemical study of the basic magmatism of the Foum Zguid region in Morocco. By J.Kutina, A.Bennani, K.Fredriksson and a group of scientists of the Geochemical Branch of the U.S.Geological Survey (D.W.Golightly, F.Brown, Norma Rait and Roosevelt Moore).

2. Residual and regional gravity anomaly maps and other gravimetric maps of Morocco by T.G.Hildenbrand, M.F.Hamouda and A.Bellot.

3. Changes in the strike of the South Atlas Fault in Morocco, related to a set of intersecting, deep-seated structural boundaries. Metallogenic implications. By J.Kutina with co-authors.

4. A comprehensive paper reviewing the main results of the project. Compiled by participants of the project, geologists and geophysicists, edited by Principal Investigators M.Bensaid and J.Kutina.

It is probable, that additional publications will result from the project studies.

Acknowledgements

We would like to express our sincere thanks to the U.S.Agency for International Development, in particular Dr. Asher and Dr.M.Rechcigl in the Office of the Science Advisor in Washington,D.C., and the AID Mission in Rabat, in particular Dr.Robert Kahn, for the support we have received and their keen interest in our project work.

Our gratitude also belongs to Mr.Josiah Royce, Coordinator, Mineral Activities, U.S.Trade and Development Program, for numerous discussions and valuable advice.

The Geological Survey of Marocco in cooperation with the Geological Offices in Marrakech and Ouarzazate have facilitated our two expeditions to the Saharan part of the Anti-Atlas. We would like to express our sincere thanks for the most valuable assistance they have provided this project.

References to papers quoted in this Progress Report will be included in the Final Report.

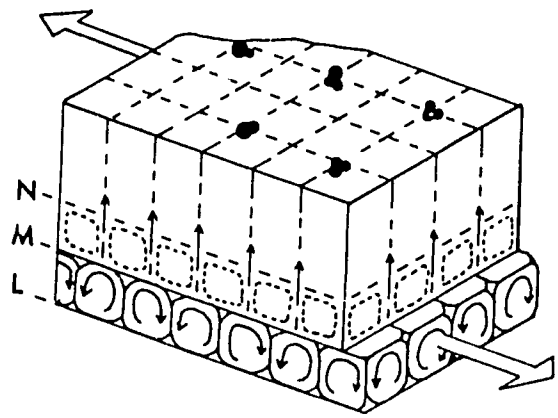


Fig.1. Model of block structure of the lithosphere showing melting proceeding preferentially along boundaries of blocks at the base of the lithosphere, finally leading to separation of a layer of convective cells. The arrows indicate the ascent of magmas and the path of ore forming fluids. The full dots show location of intrusive/volcanic centers and associated ore deposits. From Kutina, 1983.

The project is testing the above model in the territory of Morocco. The isostatic gravity anomaly map reveals structural boundaries compatible with the above model - see figure 4. Moreover, the sedimentary depression now reflected in the shape of the High Atlas Mts., was controlled, to a considerable degree, by deep-seated structural boundaries of the lithosphere of Morocco. Explanation in the text.

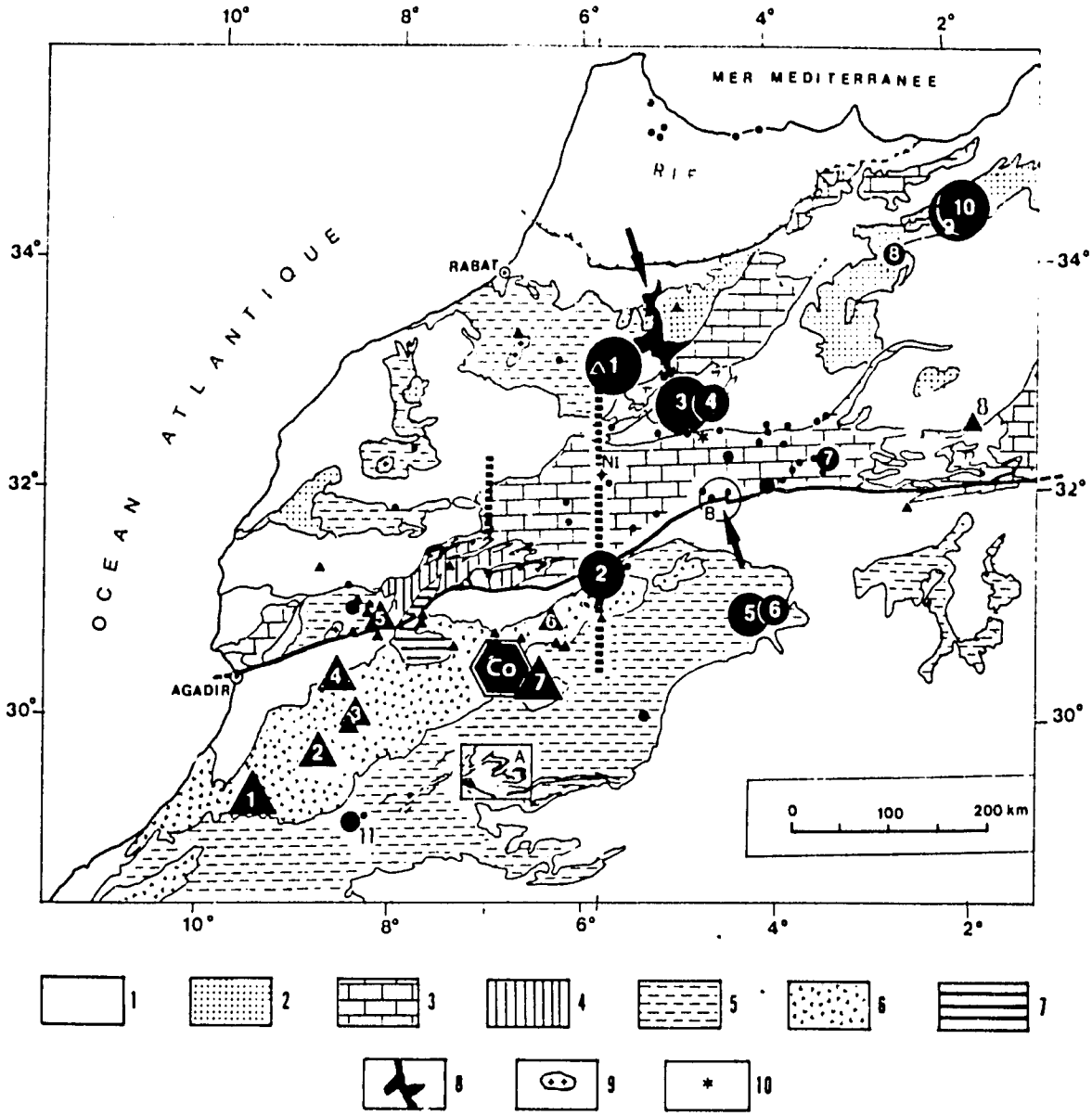


Fig. 2. Geologic scheme of the project area showing the distribution of the main deposits of lead, zinc and silver (black dots), copper (black triangles) and the location of the cobalt district of Bou-Azzer (Co).

The geology is simplified from Saadi's (1982a) 'Carte Structurale du Maroc', the ore deposits are after Saadi's (1982b) 'Carte Minière et Energetique du Maroc'.

The two N-S trending lineaments are structural boundaries distinguished by J. Kutina in Van den Bosch's (1971) isostatic map, reproduced in fig. 4. Note that all of the most important deposits of Pb-Zn-Ag concentrate to the east, and those of Cu to the west of the N-S trending structural boundary which extends close to longitude 6°W.

The rectangular inset A, shown south of the cobalt district of Bou-Azzer, is an area with great accumulation of dolerite sills and dikes.

The area B (open circle) shows the intersection of the South Atlasic Fault with a lineament which is proposed to extend transversely to the High Atlas Mountains (marked by two arrows). The area B may be of special metallogenic interest.

Legend to geology: 1—Neogene and Quaternary; 2—Tabular Jurassic cover; 3—Folded Mesozoic (mostly Jurassic); 4—Triassic continental red beds; 5—Undifferentiated Paleozoic; 6—Undifferentiated Precambrian of the Anti-Atlas; 7—Precambrian granites of the High- and Anti-Atlas; 8—Doleritic dykes of Liassic age (mainly in the Anti-Atlas); 9—Hercynian granites; 10—Calco-alcaline massif of Tamazeght (High Atlas).

Pb-Zn-Ag deposits (shown by black dots): 1—Jbel Aouam Pb-Zn (Ag); 2—Imiter Ag; 3—Zeida Pb-Zn (Ba); 4—Aouli and Mibladen Pb-Zn; 5—Tadaout Pb-Zn; 6—M'Fis Pb-Zn; 7—Bou-Dahar Pb-Zn; 8—Sidi-Lahcen Pb-(Ag); 9—O. Mekta Pb-Zn; 10—Bou-Beker Pb-Zn; 11—Addana Pb-(Ag).

Cu deposits (shown by black triangles): 1—Ouansimi; 2—Tazalaght; 3—Talat-n'Ouamane; 4—Asif-Imider; 5—Tanfit; 6—Bou-Skour; 7—Bleida; 8—Jbel Klakh.

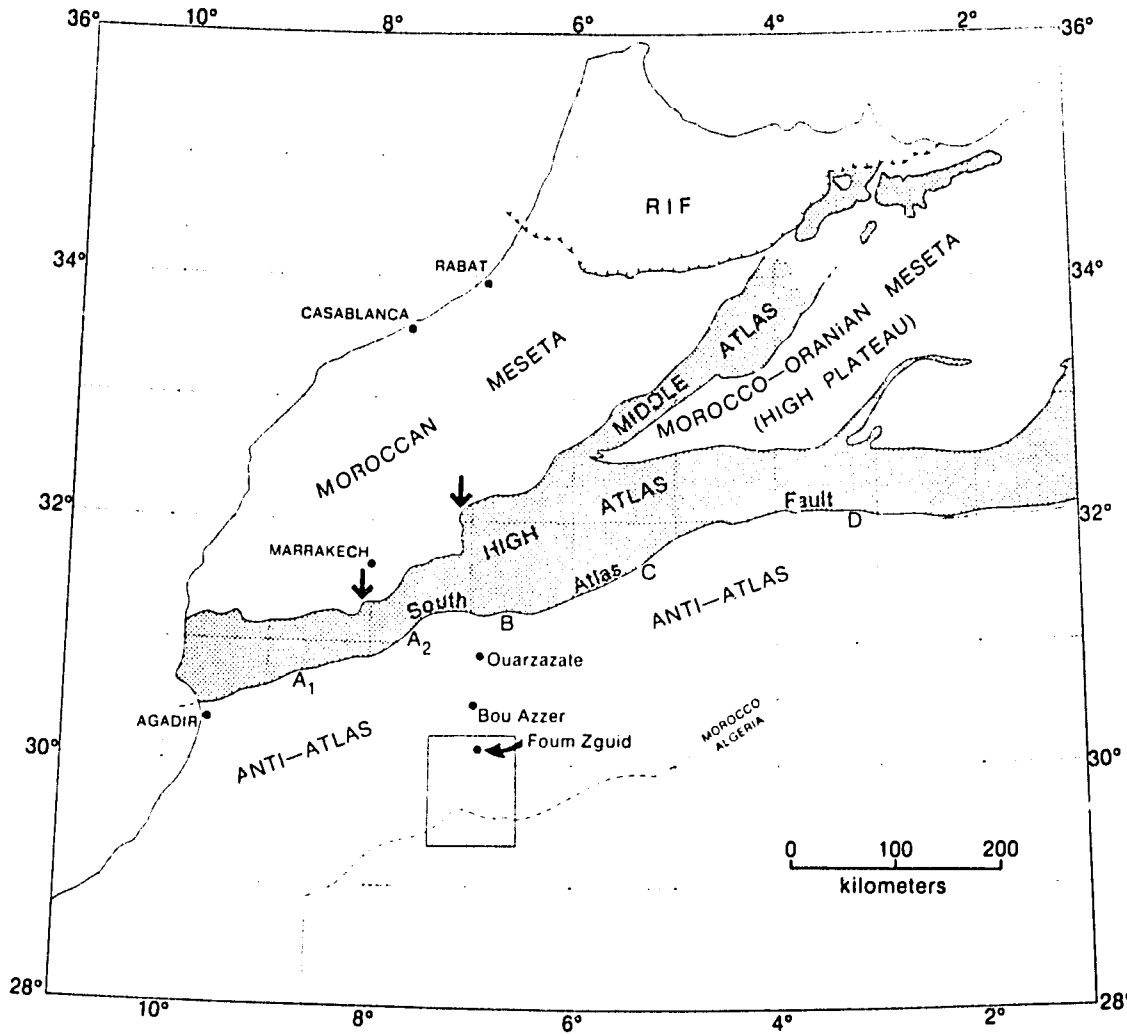
For greater detail, see 'Géologie des Gîtes Minéraux Marocains' (1980).

Reproduced from Bensaid et al., 1985 (under this project).

Fig.3. The four principal structural-geological domains of Morocco: 1. Meseta (the Moroccan meseta and the Moroccan-Oranian meseta), 2. Atlas Mountains, 3. Anti-Atlas, and 4. Rif. (Adopted from Michard,1976, and Saadi,1980,1982). The course of the Atlas Mountains is after Saadi's (1982) map. Note the changes in the strike of the South Atlas Fault (the east-west segments B and D and the northeast segments A_1, A_2, and C, and the morphological "steps" on the northern boundary of the Atlas Mountains, marked by arrows).

The Foum Zguid region in the Saharan part of the Anti-Atlas (inside the small frame corresponding to Figure 6),was found potential for concentration of nickel, cobalt, and gold (this paper).

The Moroccan-Algerian boundary is approximate, for illustrative purposes only, adopted from the New International Atlas Atlas published by Rand McNally and Co., Chicago,1983, sheet 'Northwestern Africa', distinguishing between the "indefinite or undefined and disputed defacto segments of the boundaries". The boundary within the Foum Zguid region (small frame) is according to the course of Oued Dra in Figure 6.


36°
10°
8°
6°
4°
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36°
34°
34°
32°
32°
30°
30°
28°
28°
10°
8°
6°
4°
2°
RIF
RABAT
CASABLANCA
MOROCCAN
MESETA
MIDDLE
ATLAS
MOROCCO—ORANIAN MESETA
(HIGH PLATEAU)
HIGH
ATLAS
Fault
D
MARRAKECH
South
Atlas
C
B
ANTI—ATLAS
A2
A1
Ouarzazate
AGADIR
Bou Azzer
Foum Zguid
MOROCCO
ALGERIA
ANTI—ATLAS
0
100
200
kilometers

Figure 3.

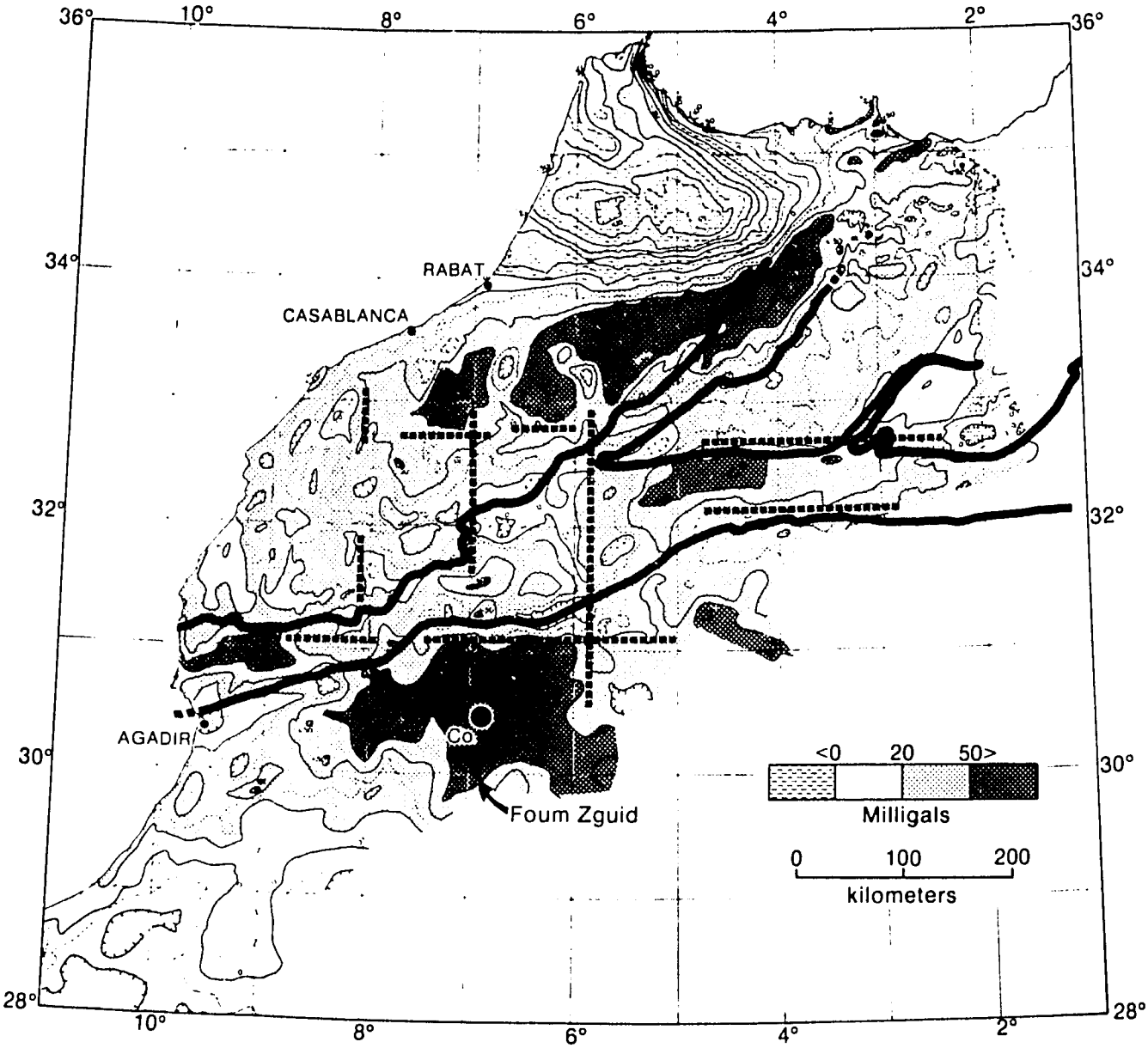


Figure 4. The isostatic anomaly map of Morocco, adopted from Van den Bosch (1981). D=2.67; Airy-Venin Meinesz hypothesis, T = 30 km, R = 0 km, 10 mgals contours.

The course of the Atlas Mountains (heavy full lines), superimposed on the isostatic map, are from Saadi's (1982) "Carte Structurale du Maroc", scale 1:2,000,000.

The N-S and E-W trending boundaries of lithospheric blocks, marked by heavy broken lines are distinguished by Jan Kutina (this paper). The location of the cobalt district of Bou Azzer is shown by a heavy dot, marked Co.

Compiled by J.Kutina, 1987. Explanation in the text.

Figure 5.

A cluster of ore deposits SW of Marrakech, Morocco, developed in places where the South Atlas fault intersects with a set of N-S trending faults.

The South Atlas fault, extending east-north-easterly from Agadir, is shown by a major magnetic lineament (with segments A and B of different strike), on the background of isobath contours giving the depth and indicating the structure of the crystalline basement. More detailed explanation is in the text.

The interpretation of magnetic data and the isobath contours are after A.Demnati's (1979) 'Carte Magnétique du Maroc', sheet Marrakech; the location and relative size of mineral deposits are after the 'Carte Géologique du Maroc' (1985), and the types of mineral deposits are distinguished after the 'Carte de Gîtes Minéraux du Maroc' (1980). The areas enclosed by circles Nos.1 and 2 are local targets defined by J.Kutina inside the broader area of intersection, understood as potential for concentration of metals at least as north as the Mo-Cu-W stockwork deposit near Azegour.

Compiled by Jan Kutina, September 1986.

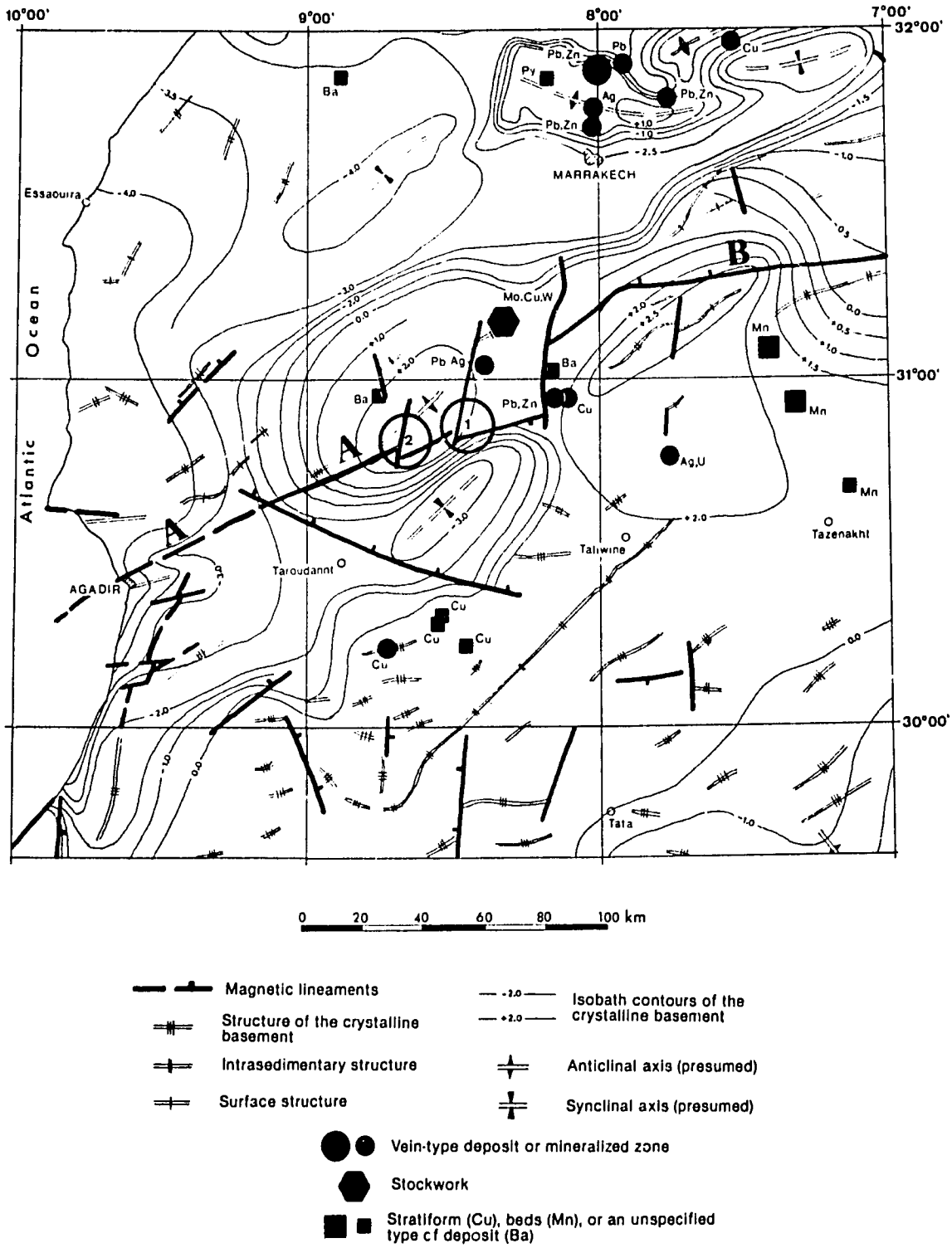

10°00'
9°00'
8°00'
7°00'
32°00'
31°00'
30°00'
Atlantic Ocean
Essaouira
AGADIR
MARRAKECH
Taroudannt
Taliwine
Tazenakht
Tata
Mo.Cu.W
Pb Ag
Pb,Zn
Pb
Py
Ag
Cu
Ba
Mn
Ag,U
A
B
0 20 40 60 80 100 km
Magnetic lineaments
Structure of the crystalline basement
Intrasedimentary structure
Surface structure
Isobath contours of the crystalline basement
Anticlinal axis (presumed)
Synclinal axis (presumed)
Vein-type deposit or mineralized zone
Stockwork
Stratiform (Cu), beds (Mn), or an unspecified type of deposit (Ba)

Figure 5.

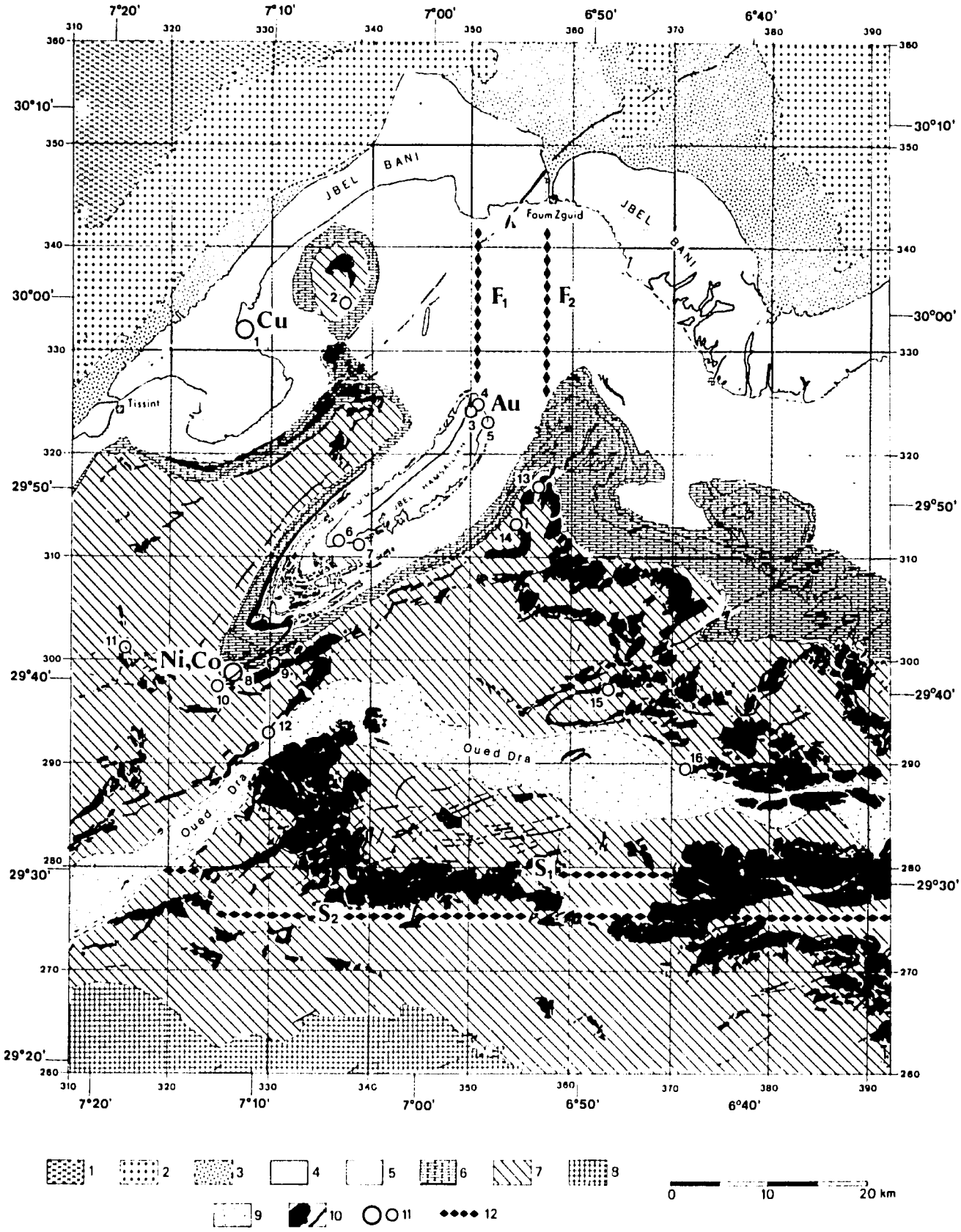
Figure 6

Geological map of the Foum Zguid region, Saharan part of the Anti-Atlas, Morocco, showing a locality with concentration of nickel and cobalt (No.8, Ni,Co) and an area with opalites containing anomalous contents of gold (Nos.3,4 and 5), discovered under the AID-funded project by J.Kutina and A.Bennani.

The geology is after the "Carte Géologique des Plaines du Dra au sud de l'Anti-Atlas Central" and the "Carte Géologique de l'Anti-Atlas Central et de la zone synclinale de Ouarzazate", both on the scale 1:200,000 , published by the Service Géologique du Maroc in 1971 and 1970 respectively.

Legend. 1 - Precambrian (Infracambrian); 2 - Lower Cambrian; 3 - Middle Cambrian; 4 - Ordovician; 5 - Silurian, partly covered by Quaternary sediments; 6 - Lower Devonian; 7 - Middle and Upper Devonian; 8 - Carboniferous; 9 - Quaternary sediments of Oued Dra; 10 - Gabbros and dolerites of Liassic age; 11 - Localities of samples collected by J.Kutina and A.Bennani in 1986 and 1987; 12 - E-W trending structural boundaries (S_1 and S_2) in the southern part of the map, and possible positions of north-south trending, deep-seated structural boundaries (F_1 and F_2) in the northern part of the map, proposed by J.Kutina (this paper).

Compiled by Jan Kutina, 1987.


7°20'
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30°00'
29°50'
29°40'
29°30'
29°20'
JBEL BANI
Foum Zguid
Tissint
Cu
Au
Ni,Co
F1
F2
S1
S2
Oued Dra
0
10
20 km

Figure 6