The aeromagnetic map of northern Algeria: Processing and interpretation

F. Asfirane a, A. Galdeano b

a D6partement de G6ologie de l'ENS, 24 rue Lhomond, 75005 Paris, France
b URA CNRS 729, Institut de Physique du Globe de Paris, 4 place Jussieu, 75005 Paris, France

Received 28 September 1993; revised 7 March 1995; accepted 13 March 1995

Abstract

A very precise magnetospectrometric survey of Algeria was flown from 1969 to 1974 by AeroService Corporation. A new compilation of the aeromagnetic data for northern Algeria is presented. To a first order, the map shows a very good correlation between the magnetic anomaly distribution and the main geological trends. The coastal anomalies occur without a break along the foot of the continental shelf and may correspond to an opening phase of the western Mediterranean basin. The onshore magnetic anomalies exhibit a bimodal distribution, consisting of long-wavelength anomalies which may be associated with undulations of the deep basement and of short-wavelength anomalies that correspond to shallower sources that were probably created during an important Triassic volcanic event. The main trends of the two families of anomalies are geometrically well correlated.

1. Introduction

From 1969 to 1974 AeroService Corporation carried out an aeromagnetic survey under the auspices of two Algerian companies, Sonatrach and Sonarem. This survey covered the whole of Algeria with non-uniform density measurements. The main part of the area was surveyed for oil exploration (Sonatrach), but over some parts, in particular the Hoggar and northern Algeria, mineral exploration was the goal (Sonarem).

A new compilation of the aeromagnetic data, concerning only the northern part of Algeria, was authorized by the Haut Commissariat à la Recherche (HCR), the Algerian agency for scientific research management. The available data covers the area roughly bounded by the Moroccan border to the west and the Tunisian border to the east, and spreads out from the Saharian Atlas in the south to Algerian territorial waters in the north. The area surveyed thus covers the Algerian part of the Atlas range. The data were mostly available in rough compilation form.

In this paper, we present the reprocessing and a description of the resulting aeromagnetic map of northern Algeria. One purpose of this work is to link this survey with the Mediterranean one [1,2], with the goal of making the structure of the Algerian margin more comprehensible. We also attempt to interpret the most important magnetic features and to define the geological problems which might be solved using aeromagnetic data.

2. Geological setting

The area studied is located in a part of the North African Alpine chain that is classically subdivided into three domains: the Tell, the pre-Atlas, and the
Atlas proper (Fig. 1). This area corresponds to the deformed margin of the stable African craton: the northern edge of that area suffered its first extension from the Late Triassic up to the Early Cretaceous owing to the opening of the Central Atlantic. Extensional structures originated a complex transform zone (with an overall sinistral sense) that joined the Central Atlantic with Tethys along the present-day coast of North Africa. This led to the opening of restricted oceanic basins [3–5], although more to the south the result was differential subsidence of intracontinental basins.

Therefore, as early as in the Mesozoic the crust of the area was complex. It subsequently became greatly deformed during the Alpine orogeny (during the late Paleogene, but mainly during the Neogene). The result of all this tectonism is the following:

2.1. Thrusting

In the north, bordering the coast, crystalline nappes consisting of continental rock (the Grande and Petite Kabylie) are thrust to the south over the small oceanic basins and over the southern slope of these basins, which formed the Tellian basin. Radiometric dating yields an age for these cores of about 25–80 Ma [6], with a range of between 15 and 19 Ma for the Edough massif [7]. The nappes are composed of Cretaceous and Paleogene flysch (Grande and Petite Kabylie) with Jurassic limestone (external domain) and Palaeozoic metamorphic rocks (internal domain) [6–13] and lie in a reverse position on Jurassic and Cretaceous autochthons. The thrusting of these nappes is associated with a late Eocene deformation event that involved top-to-the-east shearing [14].

The debate surrounding the nappe thrusting in this area is longstanding [15–17], with Mattauer [18] denying the existence of such a process and Durand Delga [19] supporting it. The nappes were initially recognised only in the Grande and Petite Kabilies, but were eventually also located to the south in the Hautes plaines setiféennes and in the Nappe néré-tique constantinoise [20]. The aeromagnetic map (Fig. 3) shows magnetic anomalies (Grande Kabylie

---

![Fig. 1. Structural map of the Algerian Alpine range (after [46]).](image-url)
anomaly, GKA; Petite Kabylie anomaly, PKA; Ba-
bor anomaly, BA) which seem to correspond to the
offsets appearing in the accretion zones [21,1]. Some
authors have interpreted the allochthons as proof of a
mythical Alboran plate which occupied part of the
western Mediterranean [22].

More to the south the basin is today imbricated
into several allochthonous units (the Tellian nappes),
which arrived to rest on the High Plateaus. These
nappes branch in the older part of the belt (zone of
intracontinental subduction) on the large thrust zone
which lies beneath the crystalline allochthonous
Kabyllies.

The High Plateaus can be divided into two zones.
The southern part is characterised by a thick Mesozoi-
succession [11] and large structures comprising
depth Cretaceous basins. The northern part includes a
thinner Mesozoic succession and is generally more
tectonised than the southern part; the relief of the
northern part is accordingly imposing.

The Alpine orogeny was late to reach the southern
branch of the High Plateaus, where it formed the
Saharan Atlas, the main part of the chain that is
made up of large step folds. The range is oriented ca.
N60°E [23]. This domain is bounded to the south by
the South Atlas fault, a large suture which is gener-
ally assumed to be the northern edge of the Saharan
Platform, which belongs to the present stable African
plate. Little is known about the manner in which this
southern fold-and-thrust belt roots into the crust.

Finally, it is important to note that, coeval with
the Alpine orogeny, the opening of the western
Mediterranean took place [24,25]. This caused 'ex-
trusion' of the earlier, inner Alpine structures
(Kabylie nappes) [26].

As a consequence of all these events, the crust of

---

**Fig. 2. Distribution of the two types of data used. The area shaded grey is covered by digital records, whereas the diagonally shaded area suffers from a lack of magnetic tapes. We therefore used numerical information from the digitization of fifteen contour maps. The boundaries of the panels correspond to the directions of the flight paths.**
northern Algeria looks not like classical continental crust but like oceanic crust in the first phase of opening.

2.2. Volcanism

Volcanism may be responsible for smaller scale heterogeneity in the Algeria crust.

Two main periods of volcanic activity may be observed: The older is related to the rifting period and is dated as being of mainly Late Triassic to Early Jurassic age, as in other regions of North Africa (particularly Morocco) [4]. In North Algeria there is some evidence of volcanic outcrops, especially along the coast and in the western provinces. Basalt and pillow lavas are observed at Cap Djinet. To the east, in the Cap de Bougaroun region, basalts occur interbedded with sedimentary layers and ultrabasic rocks are present [27]. Volcanic structures are also observed west of Algiers [28] and along the coast, from Morocco to Oran. Boreholes in the western High Plateaus area have revealed basaltic volcanic rocks [29]. In addition, flood basalts also occur in Algeria. These are clearly observed in each Triassic outcrop in the High Plateaus zone [30], and have also been recognised in the Saharan domain. Evidence of volcanism is present in Morocco near the Algerian border, along the structures that follow the northern edge of the High Plateaus [31].

The tectonic evolution of the study area from Triassic to the Miocene is constrained by the motion of Africa; Iberia and Sardinia [11]. Some authors believe that North Africa is bound to the north by a steeply dipping lithospheric subduction zone [32,1,33], although Wildi [11] believes that there is no subduction of oceanic crust, even though Miocene calc-alkaline volcanic rocks have been observed in Algiers [28]. It is not easy to relate this volcanism with subduction, although if we are to believe that such a process took place it would be very young and probably of post-Miocene age.

3. Reprocessing the magnetic data

The survey is composed of tracks and perpendicular tielines flown using UTM coordinates. Most of the area was surveyed in a general manner (spacing of 10 km between profiles), but, as mentioned earlier, the northern part was surveyed for mineral investigation, and here the spacing was reduced to 2 km between tracks and 5 km between tielines.

The survey of northern Algeria, which is where we shall concentrate our discussion, was divided into blocks along NNW–SSE profiles perpendicular to the general strike of the major basement structures (Fig. 2). The survey was carried out with a constant ground clearance of 150 m [34] and the sampling distance along profiles was about 50 m (which represents about 4,600,000 data). However, HCR, the owners of the data, require us to use only a subset of these data. Thus, an average on ten recorded values was retained, reducing to about 460,000 the number of data points (called ‘pick points’ in the following discussion).

The reduction of crossline errors was done by AeroService in 1974, who produced magnetic tapes containing the records of the magnetic field, the geographic locations, and altitude measurements. Digital records are thus available for most of the study area, although some tapes were missing and only paper maps could be processed in their place (Fig. 2). The recorded magnetic data were computed from the observed total magnetic field corrected by AeroService by subtracting an unknown regional field and adding a constant of about 30,000 nT. However, the resulting reduced field bore a strong regional N–S gradient which differs greatly from that estimated above the adjacent Mediterranean area (Alboran Sea [35] and southern Mediterranean [1]). To estimate this regional trend we approximate it with a polynomial surface of low degree computed by the least mean square method (see [36] for details). After a number of attempts we chose a polynomial of degree 2, which represents the correction between the regional field computed by AeroService and, we hope, a better estimated normal field. Removing this trend provides a mean value of the anomalous magnetic field equal to zero, which is physically correct [37].

4. Main magnetic features of the anomaly map

The obtained anomalous field was interpolated on a regular grid from the data picked along the profiles
by bidimensional interpolation (UNIRAS version 6.3A). The dimension of the grid cell is 2 x 2 km and the result is shown in Fig. 3. The interpolation function is smooth between two given pick points (about 0.5 km along profiles separated by roughly 2 km). So, as the anomalous field may contain higher frequencies in the flight line direction, some regions may be slightly perturbed by possible aliasing phenomena. However, such phenomena will be attenuated by the upward continuation computed in the following section.

At first glance it appears that the major trends of the magnetic structures (Fig. 3) are well correlated to the tectonic trend of the Atlas range. The trends of the main structures are generally inherited from Triassic tectonic features, as may be observed in the western half of the map, particularly in the High Plateaus region west of Algiers. An important anomaly of about 150 nT and here named the High Plateaus anomaly (HPA in Fig. 3) is observed from \( X = -1^\circ, \ Y = 32^\circ30' \) to \( X = 6^\circ, \ Y = 36^\circ \). This anomaly is comparable in terms of amplitude and size to that of the Paris Basin [38], which is one of the most important magnetic anomalies in southwestern Europe. This HPA anomaly is probably linked with the complex system of magnetic anomalies which extends far to the west into Morocco and follows the High Atlas range [31]. To the east of Algeria the trend of the HPA changes and becomes E-W in the vicinity of Monts du Hodna (anomaly MHA). It is difficult to know whether MHA is really the magnetic continuation of the HPA system or if, alternatively, we are observing two (or possibly three) different magnetic anomalies which have been formed along the same tectonic structure. In short, soft attenuation to the east and lumping into an anomaly system near the border with Tunisia is noticeable.

Although HPA and MHA probably correspond to deep magnetic structures they are modulated by the superimposition of the effect of shallower structures. This is particularly evident along the northern edge of the HPA, in the Chott-Ech-Chergui (CECA) and Monts de Saida and Monts de Tlemcen regions. These short-wavelength anomalies are associated with Triassic volcanic structures that have been observed at the surface and in shallow drill samples [29].

In the eastern part of the map, the main trend of the anomalies is approximately NW–SE (Aures anomaly, AA in Fig. 3) and is well correlated with the Aures, a well-known range that has been described by several geologists (e.g., [39]). This region marks a big change in the behaviour of the North African Alpine range and it is notable that the features of the anomalous magnetic field also show different behaviour compared to those in the main part of study area (e.g., lower amplitude and no large anomalies).

A large anomaly (SASA) lies along the southern edge of the map and exhibits, like HPA, two main trends, NE–SW in the western and central part and E–W in the eastern part. This anomaly closely follows the well-known South Atlas Suture, which separates the Atlas range from the Saharan Platform. However, only a rough description of the SASA is possible because the southern part of anomaly is not covered by the available data.

5. Upward continuation and northward extension of the map

The magnetic anomalies along the coast are not well described by the Algerian survey. However, previous magnetic surveys flown over the western Mediterranean and compiled by Galdeano and Rossignol [35] do allow us a better description. By connecting the two datasets the entire anomaly (positive and negative parts) can be seen perfectly. To do this it is preferable to have all data at the same altitude. As is well known, the downward continuation of potential fields is very unstable in the presence of proximal sources, and this is exactly the case with the High Plateaus magnetic anomalies. We therefore decided to make the combined map at 3000 m above mean sea level. This altitude is sufficient to lie above all relief (and magnetic sources) and changes little the information obtained on the large magnetic structures.

The continuation at 3000 m for the Mediterranean surveys was previously carried out by one of us to contribute to a data compilation supervised by UNESCO (‘Geophysical Mapping of the Mediterranean Sea’). This latter project did not include the magnetism part, and therefore the upward continuation of
the Algerian map at the chosen altitude must now be computed. The difficulty is that these data are not located on a horizontal surface but were acquired at constant clearance above the ground. To perform the upward continuation it is essential to use a specific technique. We chose the method described by Bhattacharyya and Chan [40] and the corresponding computation is carried out using a program published by Ciminale and Loddo [41].

However, now another problem arises: The true altitude of the observed points remains unknown. Indeed, the magnetic tapes contain only the ground altitude (i.e., the clearance). The availability and digitisation of precise topographic maps represents an insurmountable problem. However, in synthetic tests we find that small variations in the topography have little influence on the final result at an altitude of 3000 m. We therefore simply use the altitude given by the ETOPO_5 model [42]. This model is very smooth (5 × 5 min) compared to the real topography, but it is precise enough if we consider that the flight path could not be exactly parallel to the topography. As the upward continuation acts as a short-wavelength filter, the aliasing effect due to the interpolation is strongly attenuated. Comparison between the previous map (Fig. 3) and the map computed at 3000 m (Fig. 4) shows how much the upward continuation attenuates the observed short wavelength. In contrast, the anomalies linked to the deep sources (of long wavelength) are only slightly modified.

In addition to the previously described anomalies on land, we can also clearly distinguish a suite of well-defined anomalies offshore along the coast. These anomalies benefited greatly from the combination of the two datasets. When we observed the two magnetic maps separately (northern Algeria and the western Mediterranean) before combination, we were unable to foresee continuity of the anomalies located on either side of the Algerian coast. However, combining the two maps allowed us to observe a surprising continuity along the coast. The alignment is different from that observed in the deep Mediterranean where anomalies have been attributed to oceanic crust [1,43]. Neither alignment characteristic of the northern side of the Mediterranean, where only isolated groups of anomalies can be observed along the coast at the foot of the continental slope [35].

6. Some other classical transformations

In order to interpret the anomalies in terms of geological structures, several transformed maps were computed using convolution filtering [44].

First, the anomalies were reduced to the pole [45]. This operation, which moves the anomalies to the top of their sources, necessitates information on the magnetization direction. Since the Eocene the earth's magnetic field has had a direction close to the present one. Therefore, in many cases around the Mediterranean basin, the formation of which is recent, the in-situ direction of the remanent magnetization will not differ from the induced direction. In addition, it is also possible that the most recent tectonism overprinted the main part of the original magnetization when it had a different direction. Throughout the region, the major tectonic features are of Alpine age, and it is very difficult to distinguish a remanent magnetization with a direction that is very different from that of the normal field. For example, paleomagnetic measurements carried out on samples from Morocco (in a region located near the Algerian border) have shown that the behaviour of the magnetization is generally equivalent to an induced magnetization [31]. Thus, the assumed magnetization vector is parallel to the normal field, with the parameters $D = -4.0^\circ$, $I = 50.5^\circ$ (where $D$ is the declination and $I$ the inclination of the magnetic vectors). Fig. 5 shows the resulting transformed map. Towards the southern edge of the map a single circular anomaly is observed. This is a good example to demonstrate that the operation of reduction to the pole has been well computed: the positive anomaly is circular as a simple, localized dipolar anomaly, but the associated negative part, which is clearly visible in Fig. 4, is modified and bows into the positive anomaly, as it should do in theory.

Three other transformed maps were also computed. In order to maintain only the long-wavelength anomalies, the anomalous field was continued upward at an altitude of 20 km (Fig. 6). In this case, the short-wavelength structures must be accentuated either by the use of vertical derivatives or by constructing shaded maps. After a number of attempts it appeared that the shaded map is, in our case, the best way to bring out the short-wavelength anomalies. These transformations, combined with the reduction
Fig. 4. Magnetic map continued upward to a height of 3000 m. The magnetic data for the southwestern Mediterranean were added and joined to the Algerian map in order to obtain the best description of the magnetic anomalies along the coast.
Fig. 5. Reduced-to-the-pole magnetic map. The assumed parameters are $-4.0^\circ$ for the declination and $50.5^\circ$ for the inclination. The box bounds a particular anomaly that is enlarged in the inset (see text for explanation). The two lines on the western side of the map show the position of two profiles used in Fig. 9.
Fig. 6. Upward continuation at 23 km of the reduced-to-the-pole magnetic map. This map shows smooth anomalies corresponding mainly to deep magnetic structures.
to the pole, allow us to define more easily the magnetized bodies. Finally, the distribution of the magnetization can be estimated with a "pseudoinversion". This computation is based on an equivalent horizontal layer with a given thickness at a given depth. The resulting model does not correspond to reality because, as is usually the case in continental areas, the magnetized bodies cannot be reduced to a horizontal layer. The utility of this equivalent source distribution is that the duality of magnetic anomalies composed of negative and positive parts disappears and the negative zones that are found bear an intrinsic signature. The computed pseudoinversion was obtained by considering a thickness of 1 km and a depth of 2 km. The parameters of these values are not particularly important: only the relative value of the computed magnetization is significant.

7. Comments on the transformed maps

The northward displacement of the reduced-to-the-pole anomalies is noticeable for the long-wavelength anomalies and is particularly observable on the anomaly HPA (Fig. 5). The observed displacement is very important because the study area is at a relatively low latitude (between 32°N and 38°N) and the direction of the earth's magnetic field is relatively far from the vertical. In addition, the HPA anomaly seems shortened in the N–S direction after reduction to the pole and its new location is located just below the set of short-wavelength anomalies. These short-wavelength anomalies (CECA), in contrast, have only been slightly moved and have kept significant amplitudes, forming a better defined NE–SW alignment. The reduction to the pole seems to better reorganize the anomalies located above the Chott-Ech-Chergui area. This is due to the fact that the anomalies are probably located along faults but at different depths. Therefore, they appear aligned in the reduced to the pole map but not in the original map where the effect of inclination (variable for each depth and/or for each wavelength) destroys the pleasing pattern. The short-wavelength anomalies correspond to basaltic rocks. Indications of magmatism have indeed been noted in the Chott-Ech-Chergui region, where boreholes reveal the presence of Triassic basaltic layers of about 50 m in thickness at a depth ranging from 600 to 1300 m [46]. These short-wavelength anomalies extend far to the west, into Morocco [35].

In the central part of the map, south of Algiers, the long-wavelength MHA (100 km) extends eastward to Chott-El-Hodna. As mentioned above, a real difficulty is to determine whether the anomalies HPA and MHA correspond to a single one which has been affected by several tectonic phases or whether they correspond to different anomalies. Unfortunately, the reduction to the pole does not provide additional information on this problem. It seems that the two anomalies correspond to a single E–W structure, the eastern end of which could have resulted from Alpine tectonism.

No important anomalies are visible in the northeastern part of the reduced-to-the-pole map (Fig. 5). To the east, near the Tunisian frontier, two anomalies with an amplitude of less than 50 nT are clear; these have orientations of roughly NNW–SSE and N–S, in a region where grabens are located [47]. The boundary between the two anomalies corresponds to the fault described by Guiraud [46] and Zerdazi [47]. There is no structural information concerning the transition between these anomalies and the large E–W trending MHA anomaly.

To the north, the anomalies lying along the Algerian coast are now pushed to the north (Fig. 5). Almost all the anomalies are now located in the sea; only part of the important Gulf of Bougie anomaly (GBA) and part of the Cap de Bougaroun anomaly (CBA) still lie onshore. The anomalies along the coast may be associated with the first phases of the opening of the Algero-Provencal basin. Along the coast we observe that the anomalies are segmented (GBA, CBA and CDA (the Cap Djinet anomaly)). We believe that the main anomalies are cut by several faults that are probably oriented NE–SW. The calc-alkaline volcanism identified in Algiers, at Cap Djinet (Grandes Kabylies) and in Tenes toward the west [28], is probably of Miocene age. At first glance, the anomalies which are still visible on the continent at Bejaia (GBA) and Cap de Bougaroun (CBA) seem to be associated with granitic rocks or with the basic Kabylie basement. However, these anomalies are too intense to be associated with outcropping granitic rocks (and note that the volume of basaltic rocks described in these regions is too low).
Fig. 7. Shaded view of the magnetic map at 3000 m (see Fig. 4). We can distinguish low-level magnetic anomalies which are linked to the shallow geological structures.
even if they were to bear highly magnetized diorite [20]. We therefore strongly suspect the existence of highly magnetized sources beneath the granitic outcrops. The relative distance between the magnetic anomalies lying along the coast is not identical on either side (west and east) of Algiers Bay. If we assume that the magnetic anomalies are related to continental basement, this phenomenon would indicate that the geological units associated with the Kabylies are not in a normal position relative to the coast. This would accord with the hypothesis that the origin of the Kabylies is "ultra"-African (Fig. 5).

The upward continued map (Fig. 6), where all the short-wavelength anomalies linked to shallow sources are removed, shows an alternation of positive and negative long-wavelength anomalies that are probably associated with deep-seated bodies (e.g., HPA and MHA). The analyzed anomalies have a width of about 200 km and an amplitude of about 50 nT.

South of Biskra, the amplitude of the anomalies increases considerably and becomes greater than 100 nT. This large increment may be partially due to the edge effect of the map. The anomalies of this group located about 34.5°N, 5°E seem to consist of several isolated bodies (see Fig. 7), although on the upward continued map (Fig. 6) we can only distinguish a single anomaly. The anomalies probably correspond to a single deep origin which has been perturbed by deep faulting. On the northeastern border of the SASA, in the Biskra region (Fig. 5), there are short-wavelength anomalies with relatively high amplitudes. Apparently, the situation is similar to that observed in the CECA area. In the same manner these short-wavelength anomalies are probably associated with Triassic volcanic structures that may be related to the volcanic layers found in boreholes at Hassi-Messaoud (to the south) and at Hassi-R'Mel (to the southwest) [48].

The negative anomalies located north of the South Atlas suture also have very high amplitudes (SAA). The large SASA does partially contribute to this negative zone by invoking variable depth to the top of the magnetic basement. The negative anomaly located above the Saharian Atlas range of course corresponds to deep geological basement. Indeed, the thickness of the sediments is at least of 8 km and decreases to 1.5 km on the High Plateaus [46] where large positive anomalies are observed. To the east, on the edge of the MHA, the reduced-to-the-pole magnetic anomaly (Fig. 5a) and the magnetization map (Fig. 8) are negative and the geological basement seems to be deeper, probably lying at a depth of 6 km [47]. There appears to be a good correlation between the long-wavelength magnetic anomalies and the topography of the geological basement.

The short-wavelength anomalies are brought out on the shaded map (Fig. 7), where the signal is better represented in the western part. We observe lineament L1 with significant amplitudes and associated with the short-wavelength CECA, and lineament L2 with smaller amplitudes and probably corresponding to a fault system in the El-Asnam region. This region corresponds to a zone of crustal weakness. In the eastern part, where the signal is less significant, we see alignment L3, which parallels the coast. This alignment corresponds to the faults identified by Vila [20].

8. Modelling

Using the various transformed maps, we conclude that for western and central Algeria two groups of magnetic anomalies can be distinguished—long wavelength and short wavelength. The short-wavelength anomalies are associated with shallow sources which correspond to volcanic rocks (basalt) with high magnetization (amplitude of about 350 nT). These rocks are probably of Triassic age, as is the case for the rocks located south of Biskra where samples have been dated [46]. The long-wavelength anomalies are more difficult to interpret. Irrespective of whether the anomalies have their origin in the Precambrian basement or in Triassic intrusions [48], determination of the magnetization intensity and the geometry (e.g., mean depth and distribution) of the two types of magnetized bodies is no easy task. The magnetic behaviour of the deep basement is not well understood, despite the numerous studies carried out
Fig. 9. Anomaly profiles 1 (left) and 2 (right) selected from the map reduced to the pole (see Fig. 6). (Top) The magnetic basement is modelled for only long-wavelength anomalies with two different values for the magnetization intensity (1 and 0.6 A/m). The resulting computed values are compared with the measured data ( ). The two models seem to be equivalent. (Bottom) The short- and long-wavelength anomalies are plotted in grey. Beneath the basement, models computed for long-wavelength anomalies with a magnetization of 1 A/m need the addition of small basaltic bodies (magnetization intensity of 1.5 A/m). The resulting magnetic field is drawn above, as a grey line.
over the last 10 years, although we can reasonably assume that the magnetization of these types of rocks is not very high (i.e., perhaps several A/m, but not 10 A/m). The Saharan Atlas region is a sedimentary basin, the depth of which can be estimated at about 8–10 km (although in the case of folded formations the depth is more than 10 km).

In order to gain some insight into the arrangement of the magnetic structures, a 2D model is computed for the western part of the map where the deep structures are reasonably cylindrically shaped (i.e., elongate). This modeling, which uses the classical Talwani [49] method, was carried out in two steps. First, the long-wavelength anomalies were modeled from two profiles selected from the upward continued map (Fig. 9a,b; top panels). For a 0.6 A/m magnetization intensity the magnetic basement (surface between two homogeneous media) exhibits large variations in depth (about 25 km from top to bottom). These variations seem too large (Fig. 9a,b; bottom panels) to be real and the magnetization must be increased in order to reduce the slant of the basement topography. Therefore, we take 1 A/m and this allows us to obtain a shallower basement and smoother variations in topography with the same amplitude of observed magnetic anomalies. The model obtained in this case closely fits the observed data (Fig. 9a,b; top panels). The depth of the sedimentary basin is about 12 km, which is an acceptable solution (according to Guiraud [46] there are at least 8 km of sediments in the Saharan Atlas). This modeling therefore allows us to represent the basement topography which was inherited from the Hercynian tectonism and which is responsible for the long-wavelength anomalies.

Because it is not really correct to compute models for short-wavelength anomalies only, the final models were computed considering the total signal (short- and long-wavelength anomalies). A model with varying depth to the basement is represented, in which, on the basis of borehole data [29], some basaltic rocks are placed near the surface prior to computation of 2D models. Both models (Fig. 9c,d) are satisfactory, the negative lobes observed on the two profiles corresponding to the deepening of the basement and the short-wavelength anomalies with marked amplitudes corresponding to basic rocks located near the surface and inserted in the sedimentary rocks. The magnetization of the basement is 1 A/m and the basaltic rocks have a magnetization intensity of 1.5 A/m. The basaltic rocks probably have the same origin as the volcanic rocks observed far to the south. These rocks are the result of magma intrusions that marked the extension phase which created the fault system during the Triassic.

9. Conclusion

We have shown a very pleasing correlation between the anomalous magnetic field and the most relevant geological features of northern Algeria. Joining the northern Algerian with the western Mediterranean data shows a surprising continuity of the anomalies along the coast. These anomalies are associated with the initial oceanic opening of the Algero-Provencal basin.

A reduction to the pole was carried out to accurately correlate the aeromagnetic map with the geological structures. This transformation noticeably moved to the north the long-wavelength anomalies. Only a small part of these anomalies corresponds to sources located onshore. The pattern of the anomalies along the coast does not correspond to those usually observed in oceanic domains. The discontinuities in the anomaly system located in the Kabylies are interpreted as resulting from the faulting of a single magnetized body.

Two groups of anomalies are observed in the continental domain. The short-wavelength anomalies are probably associated with Triassic magma intrusions caused by extension. The long-wavelength anomalies may be associated with the basement topography inherited from the Hercynian tectonism. This implies that the basement is probably more magnetized than generally expected (0.6 A/m). Such a highly magnetized basement is also observed in Europe where the source geometry is known from seismic studies [38,50]. This interpretation of highly magnetized basement is supported by various workers active in northern Algerian geology (Andrieux, Frizon de Lamotte, Guiraud and Caby, pers. commun.), although such high magnetization may also be explained by invoking large Triassic magma intrusions rather than magnetization of the basement (Burg, pers. commun.). On the basis of magnetic
data alone, we are unable to distinguish between the two hypotheses. Having said this, however, the significant variation in the basement topography in the Atlas domain may be the result of a large fault zone (cf. Fig. 9c). In this case, the magnetic anomalies could be the magnetic expression of the accretion of blocks located north of the South Atlas fault.

Acknowledgements

We are grateful to the staff of the Haut Commissariat à la Recherche (HCR) and of the Centre de Recherche et d'Exploitation des Materiaux (CREM), and in particular to M. Mokadam and Z. Benchik, whose intervention was essential in obtaining the magnetic data for northern Algeria. We also thank J. Andrieux, D. Frizon de Lamotte, R. Guiraud, R. Caby, J.P. Burg and R. Bayer for discussion. In addition, we thank too Y. Ricard and the anonymous reviewers for their enlightening comment. This is IPGP contribution 1396 NS. [PTI

References


blastomylonitique dans le nord de la Petite Kabylie (Algérie).


[42] Fichier mondial de topographie ETOPO_5.


