

# NON-IMPACT ORIGIN OF THE CRATER FIELD IN THE GILF KEBIR REGION (SW EGYPT)

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## ABSTRACT

The present study is the result of the fieldwork carried out during a geologic expedition in the Gilf Kebir region (SW Egypt), where a large number of crater-like forms are present. It has been suggested that they could be the result of a meteoritic impact (impact breccia, shatter cones and planar fractures in quartz has been identified) or, as alternative hypothesis, a hydrothermal vent complex. From the data collected in the field and the results of the preliminary geological, petrographical and geophysical investigations, we can state that there are no evidences supporting the impact origin of the circular structures in Gilf Kebir region. As alternative hypothesis, an hydrothermal origin is suggested.

## 1. INTRODUCTION

In the South-Western Egyptian desert an impressive number of roughly circular, subordinately elliptical, structures is present, covering more than 30.000 km<sup>2</sup>, East of Gilf Kebir plateau. They range from few tens of meters to more than 1 km in diameter. In 2004 [1] suggested that at least 13 of these structures, located between latitudes 23° 14' N - 23° 32' N and longitudes 23° 17' E – 27° 27' E, could be the result of a meteoritic impact. For this reason in November 2005 an Italian group of researchers has carried out an expedition in the Gilf Kebir region (Fig. 1).

The present study is an attempt to verify the impact hypothesis for the Gilf Kebir Crater Field by interpreting new field, petrographic, structural and geophysical data and possibly to suggest other kinds of origin.

In the eastern part of the Sahara region (Libya, Chad, Sudan and Egypt) several circular structures have been identified in satellite imagery, but only two (Oasis and BP) have been confirmed so far as impact craters. Five more structures (the Arkenu double “crater”, Kebira “crater” and two more large circular structures in northern Chad) need further *in situ* investigations.

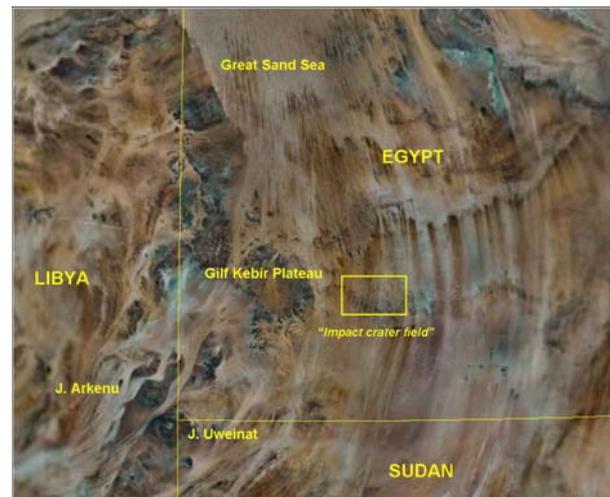


Fig. 1. Satellite image of the South-Western desert of Egypt and Gilf Kebir Crater Field area

## 2. GEOLOGY OF SOUTH-WESTERN EGYPT

The Gilf Kebir is a sandstone plateau about 1000 m high (~300 m above the desert floor) larger than 8,000 km<sup>2</sup> located in the South-West corner of Egypt, near the Libya and Sudan borders. In the investigated area, located East of Gilf Kebir (Fig. 1), the outcropping rocks belongs mainly to the Sabaya Formation (Lower-Upper Cretaceous) with few outcrops ascribed to the Abu Ballas Formation (Lower Cretaceous). Both are mainly arenaceous formations: the former is made by flood-plain sandstones, with interbedded channel deposits and soil horizons; the latter by shallow nearshore marine to coastal siltstones and sandstones, with intercalations of fluvial sandstones [2, 3].

The Precambrian-Lower Paleozoic intrusive and metamorphic rocks, outcropping in the Jebel Uweinat area and in the southern part of the Western Desert and representing the northern part of the African shield, form the basement over which deposition of clastic and carbonate sediments took place through most of the Phanerozoic. The highly-folded metamorphic complex

is intruded by undeformed plutonic bodies (forming the mountains of Jebel Uweinat and Jebel Arkenu in Libya), which, in turn, are penetrated by aplites and pegmatites [4, 3]. In the Jebel Uweinat and Western Gilf Kebir areas also Devonian-Carboniferous sandstones are present [2]; north of the Jebel Uweinat region, igneous rocks are interbedded within the sedimentary section. "Nubia Formation" (or Nubian Sandstones) is a term traditionally used in a broad range of stratigraphic and sedimentological connotations to designate continental sandstones, overlying the Paleozoic basement, of Paleozoic to Mesozoic age in Egypt and other Middle Eastern countries: it can be described as a heterochronous megafacies which can be correlated with different Upper Cretaceous-Lower Tertiary units exposed in the northern sector [4]. In south-western Egypt the Nubia Formation include several units, among which there are Sabaya Formation and Abu Ballas Formation. Volcanic rocks are represented by olivine basalts and dolerites are the most widespread igneous rocks in the area; they occur as plateau, cinder cones, dikes and sills. Their age range between the late Cretaceous and the early Oligocene [4]. Trachyte and phonolite plugs and cones represent much older volcanics (South of the Gilf Kebir area and North-East of Jebel Uweinat): these are probably associated with the late Paleozoic Hercynian movement.

### 3. THE CIRCULAR STRUCTURES OF EASTERN SAHARA

The eastern Sahara (in particular the Western Desert of Egypt, the eastern side of Libya, the northwestern Sudan and the northern Chad) shows the unusual presence of several circular features, with possible different origin. As already mentioned, the region surrounding the Gilf Kebir Plateau, and the top of the Plateau itself, are covered by an impressive number of crater-like forms, some of which associated with Tertiary basalts [2]. The craters interpreted as being originated by impact events by [1] belong to this large group of circular features. Also the plain between Jebel Uweinat and Gilf Kebir is covered by many volcanic crater-like features. Most of these craters have a sandstone rim and are filled with volcanic rocks (e.g. Clayton Craters [5, 6], located about 50 km North-East from Jebel Uweinat), while in some of these only the volcanic rocks are present without rims (e.g. Jebel Peter and Paul). The volcanics generally consist of trachyte and olivine basalts: the trachyte, associated with phonolites, rhyolites and microsyenites are believed to be associated with the Hercynian orogeny which affected the area during the late Paleozoic [7]. Some others of these crater-like features, which don't show volcanic rock exposures, were believed to be cryptoexplosion structures [7]. El-Baz crater (in Egypt), located about 320 km East of Kufra [5, 8], is another circular structure associated to

volcanic events. Also in northern Sudan a group of peculiar circular features (about 130 km East-Southeast of Jebel Uweinat) of unknown origin is present [7]. In the Eastern part of Libya 4 craters are present: Oasis (about 120 km North-Northeast of Kufra) and B.P. (about 80 km North of the Oasis crater), which impact origin has been confirmed [9], and the Arkenu double craters [10], which need further investigations. Moreover, the Kebira crater, on the Libya-Egypt border (about 170 km East-Northeast from Kufra): a 31 km circular structure identified by satellite imagery in March 2006 and suggested to be an impact crater and probably the source of the Libyan Desert Glass [11]; anyway, data collected during our expedition have failed to find any impact evidence in the Kebira crater area. Finally, two new possible impact structures in Chad, also detected by satellite imagery [12].

## 4. RESULTS OF THE INVESTIGATIONS

### 4.1 Study area and fieldwork

We visited 7 of the 13 structures indicated by [1] (GKCF1, 6, 7, 8, 11, 12 and 13) and some others ones in the surrounding areas (Fig. 2). On GKCF1 and 13 has been performed detailed geological survey. From four of these structures (GKCF 1, 7, 11, 13) has been collected rock samples on which petrographic studies has been performed. Geo-electromagnetic field anomalies has been measured using the Very Low Frequency (VLF) method at craters GKCF1 and 13.



Fig. 2. The investigated area (numbers from 1 to 13 designate the supposed impact craters).

### 4.2 Local geological setting

In the investigated area, the outcropping lithotypes are made by medium- to coarse-grained, rarely fine-grained, moderately- to poor-sorted quartz-arenites with sub-rounded/sub-angular elements, mainly composed of quartz and minor sedimentary lithic grains (fine-grained

quartz-arenites) (Fig. 3a and 3b). The matrix, when not altered, is made by very fine quartz grains and phyllosilicates (mainly sericite); more commonly the matrix is partially or totally replaced by iron oxides/hydroxides cement and minor ferriferous carbonates. Zircon, tourmaline and muscovite are present as accessory minerals. Quartz grains sometimes show an undulose extinction and often micro-fracturing. Polycrystalline quartz is also present.

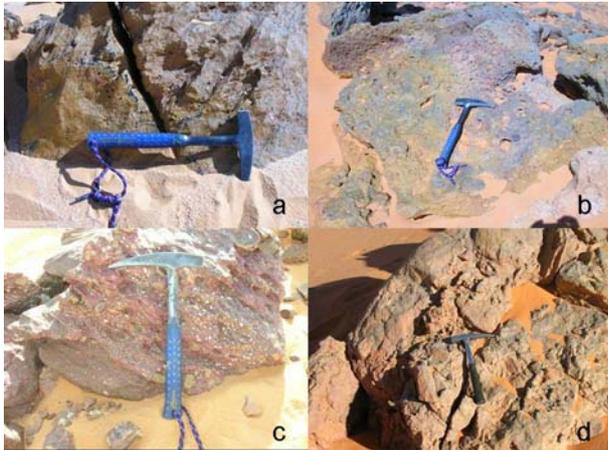


Fig. 3. Bedrock lithologies. a, b: Quartz-arenites; c: micro-conglomerates; d: intraformational breccia (Br1).

In some places the arenites grade to micro-conglomerates with rounded/sub-rounded quartz grains and sedimentary lithic clasts (fine grained quartz-arenites) mm- to cm-sized (Fig. 3c).

Intraformational sedimentary breccias (Br1) are also present; they are made by quartz-arenitic clasts, angular/sub-angular in shape, cm- to dm-sized, rarely up to 20-40 cm (Fig. 3d). Their stratigraphic position is not always clear but they seem to be intercalated with the quartz-arenites.

A different kind of breccias (Br2) outcrop in the inner part of the circular structures but also in the surroundings external parts (Fig. 4). They are made by sub-angular/sub-rounded quartz grains, mm- to cm-sized and by rock fragments (fine- to coarse-grained quartz-arenites and minor siltites), cm- to dm-sized and varying in shape from angular/sub-angular to sub-rounded. In Br2 rare boulders made of Br1 are included. When not altered, the matrix is composed of fine-grained quartz grains and phyllosilicates; often it's totally replaced by iron oxides/hydroxides cement and minor ferriferous carbonates. Zircon and tourmaline are present as accessory minerals. Quartz grains sometimes show an undulose extinction and often micro-fracturing. Polycrystalline quartz is rarely present. This second kind of breccia is often associated with fracture planes.

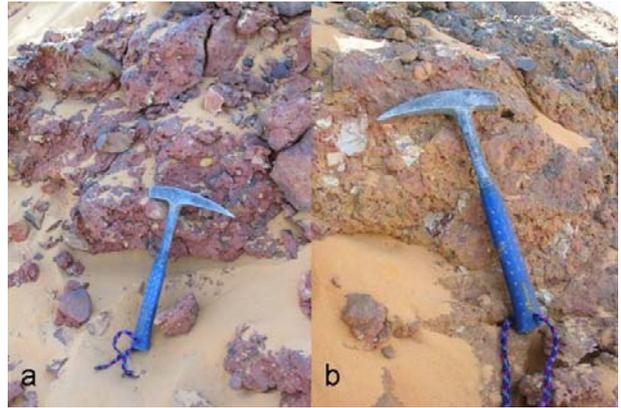


Fig. 4. Breccia Br2 from GKCF1.

As already mentioned, the craters have a roughly circular shape, in some cases very poorly evident (as in GKCF12 and 6). The bottom is covered by Quaternary aeolian sands and thus the inner part is not visible. The rim is made by tilted layers of sandstones (as in GKCF13 and 7) (Fig. 5a) or by arc-shaped nearly vertical fracture planes (Fig. 5b), as in GKCF1. These fracture planes characterize not only the “**supposed impact craters**” but are also in isolated structures in its surroundings (Fig. 5c). Iron-oxide mineralizations are often associated with the fracture zones and this is observable not only at the “crater-scale” but also at smaller scale (e.g. cm-sized fractures on the craters floor). Moreover, the fracture planes are frequently associated with breccia bodies (Br2), even though their relationships are not always clear (Fig. 5d). Linear fractures are also present, in and around the crater.

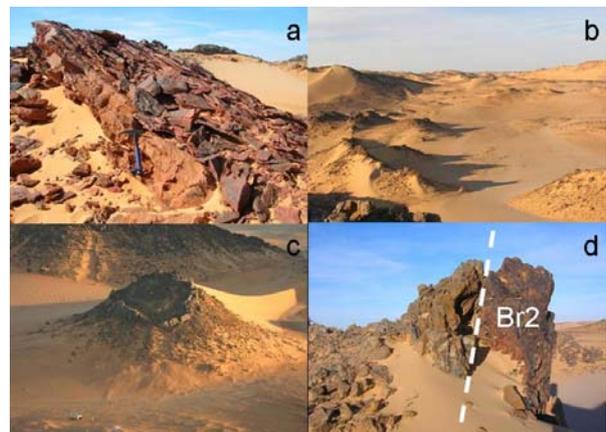


Fig. 5. a: Titled layers of sandstones, crater is on the right (GKCF7); b: Arc-shaped fracture planes (GKCF1); c: Circular structure 1 km S-SE from GKCF13, 50 m in diameter; d: Fracture plane associated with Br2 (crater is on the left) (GKCF1).

### 4.3 Pseudo-shatter cones

Shatter cones are conical striated fracture surfaces unequivocally indicative of meteoritic impacts on Earth. They are generally found in place in rocks below the crater floor, or in the central uplift if present, but they are also observed in isolated rock fragments in breccia units [13].

The surfaces of the outcropping rocks in the crater area are characterized by striations that, in some instances, resemble to shatter cones. From the data collected in the field, it's possible to note that the striations observed seem to be superficial and not pervasive and that they are not fracture surfaces but they occur only on the outcropping surfaces. Moreover, the same striations are visible also on the breccia surfaces (this evidence would be not compatible with an impact origin of the breccia) and on the surfaces of rocks out of the craters area (Fig. 6). Eventually, these features are characterized by directions varying always from N 20° to N 340°, in a rather consistent way with the main winds direction (from North and North-East at present, from North-West until the early Holocene [14]).

From this observations it's more appropriate to consider these pseudo-shatter cones as a result of the wind abrasion effect on the exposed rock surfaces.

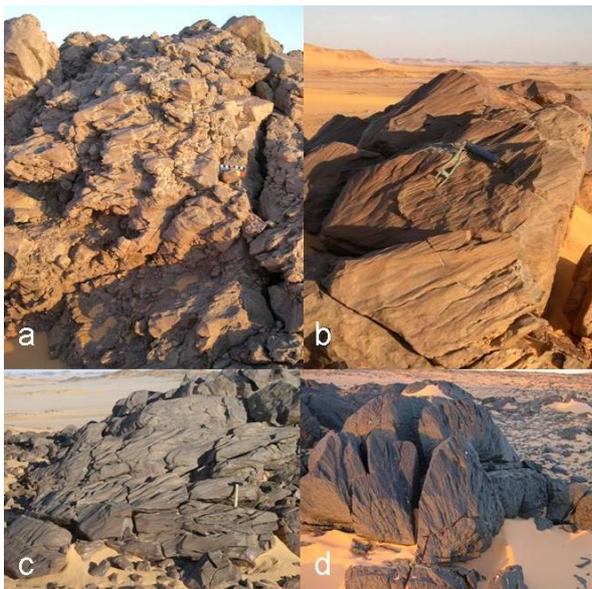


Fig. 6. Pseudo-shatter cones. a: GCKF13; b, c: GCKF1; d: El-Baz volcanic crater.

### 4.4 Geophysical survey

A geophysical survey has been carried out on GCKF1 and 13 to define the subsurface setting of these crater-like structures.

To know the relative thickness of the infilling deposits and then to reconstruct the morphology of the bedrock surface, we measured the geo-electromagnetic field

anomalies using the Very Low Frequency method (VLF) (e.g. [15]) with the ABEM WADI instrument. The electromagnetic anomalies in the inner part of impact craters change with a circular symmetry being the thickness of the infilling deposits different from the centre to the rim of the structures.

Both the investigated structures (GCKF1 and 13) reveal an irregular shape of the electromagnetic anomalies due both to an irregular variation of the thickness of the infill deposits and to the presence of iron-manganese oxide/hydroxide deposits in the basement rocks.

The electromagnetic anomalies measured at GCKF1 (Fig. 7) have a different trend respect to the expected ones: no circular shape anomalies are present and the higher values follow a linear distribution, locally aligned to the main fracture planes, associated with mineralizations.

The values variation measured are also due both to light topographic effects and to the presence of boulders and rock debris.

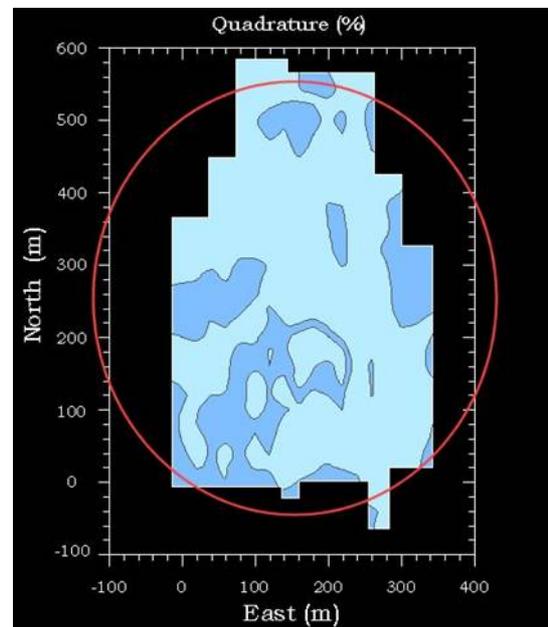


Fig. 7. Elaboration "In Quadrature" of the measured anomalies; dark blue = higher values

## 5. DISCUSSION

It has been suggested that the Gifl Kebir crater field could be the result of a meteoritic impacts [1, 16]. The present study has been carried out in order to confirm or discount the impact origin of these structures, and possibly to suggest a different mechanism for their origin. For this reason this section is organized into topics concerning characteristics commonly used as diagnostic criteria to establish the impact origin of a structure. From the fieldwork and from the preliminary analysis, the following results can be summarized.

- *Target rocks*. They don't show any macroscopic or microscopic shock effects, in particular no planar deformation features (PDF's), no evidence of melting or glass. However, it is worth to note that, in porous sedimentary targets, the shock effects are not always well developed. It's also important to consider that impact structures in sedimentary (porous) targets result in different effects from that in non-porous crystalline targets, even if the same principal types of shock effects occur [17]. On the basis of the observations of shock effects on the Coconino Sandstones at Barringer Meteor Crater it's possible to see a progressive destruction of original texture: at the lowest pressure (< 5 GPa) the porosity is reduced to zero and the minerals are fractured and at moderate pressure (5-13 GPa) fractured quartz coexists with minor amounts of glass and coesite. That's not the case of "target rocks" in Gilf Kebir crater field: the porosity is still present, the quartz grains are only rarely fractured and never deformed, glass is absent.

For what concerns the shocked quartz, possibly identified in sandstones and breccias by [1, 16], it's important to say that the identification of PDF's based solely on petrographic techniques is now considered inadequate for positive identification of shock metamorphism. Visual identification of shock metamorphic features in the optical microscope can be somewhat ambiguous and controversial. SEM (or TEM) is the optimal tool for visual characterization and unequivocal identification of shock features. However, it's important to say that PDF's in porous target, compared to non-porous rocks, are generally rare [17]. Anyway the deformation features found in quartz grains in these rocks are significantly different from PDF's in impactites and possibly the result of "normal" tectonic processes.

Eventually, it's important to note that shocked quartz grains occur not only in parautochthonous target rocks of the crater floor, or in allochthonous lithologies, such as breccias or impact melt rocks, but also in various types of proximal and distal ejecta: the presence of shocked quartz grains in a clastic sedimentary rock (without any others impact evidence) can result from the erosion of a distant impact structure.

- *Breccias*. Interpreted as impact breccia by [1]. From the data collected in the field it's possible to say that there's the presence of two kind of breccia. Br1 is a sedimentary intraformational breccia; Br2, which has a more complex setting, a general discordant relationship with the bedrock and which is associated to the fracture planes on the craters rim, is likely genetically linked to the origin of the circular structures. They don't show any microscopic shock effects, no PDF's, no shock minerals, and no evidence of glass or melting. It's worthy to note that some impact breccias are melt-free

and with distinctive shock effects only rarely observed in the fragments ("impact lithic breccias"). This kind of breccia is often associated, horizontally and/or vertically, with units containing melts or shocked minerals and so the exact identification of the lithic breccia is possible. But that's not the case for Br2.

- *Pseudo-shatter cones*. The presence of shatter cones is considered an unequivocal fingerprints of meteoritic impacts on Earth. Other structures have similar morphology, for example natural percussion marks, slickensides, wind abrasion structures and cone-in-cone structures. As already mentioned, they are generally found in place in rocks below the crater floor, in the central uplift or in isolated rock fragments in breccia units [13]. The axes of shatter cones are generally described as pointing toward the shock wave source area but many cases of non-radial orientation are known [18]. From the analysis *in situ* and from the univocal direction of the striation, we can conclude that the pseudo-shatter cones are originated, very likely, by wind erosion.

- *Circular morphology*. The circular shape that is characteristic of the supposed impact craters is identifiable (both in the field and in satellite imagery) in many other structures in the surroundings. In the impact origin hypothesis these structures would be part of an impressive crater field made by thousands of craters with an extension of thousands of km<sup>2</sup>. Moreover some of these structures are associated with basalts. The common morphology of all these structures and their huge numbers (together with the absence of impact evidences) lead to take into account the fact that all these features have a common origin and that a meteoritic impact is a very implausible hypothesis.

## 6. CONCLUSIONS

On the basis of our fieldwork and preliminary investigations, we can state that there are no clear and unequivocal evidence supporting the impact origin of the circular structures in Gilf Kebir region; until substantial evidence is provided, it's necessary to identify the origin of the craters in others endogenic geological processes.

The presence of such an extended field of circular structures, linked to a widespread volcanic activity in the surroundings and to the evidence of an intense fluid circulation in the craters, lead to take in consideration a hydrothermal origin for these structures (one of the hypotheses suggested also by [16]). The hydrothermal venting could account for the origin of such an extended field of nearly circular forms: what we actually see could be the result of an eroded hydrothermal vent complex. In this case the brecciation could be fluid-induced, probably for the fluctuations in pore fluids

pressure. These hydrothermal fluids could also have enriched with iron oxide during their way to the surface, crossing oxidized sediments or paleo-soils. The pre-existing sets of fractures planes could have driven partly the fluids circulation and also the development of the structures.

However, even this hypothesis is not fully satisfactory: probably these complex and peculiar features are the result of the interaction between different geological processes. At present, this hypothesis cannot be completely constrained: further investigations are necessary. Anyway, the lacking of clear evidences of a meteoritic impact and the geological framework of the investigated area, lead us to confirm the hydrothermal-volcanic hypothesis.

Eventually, as a general indication, it's important to emphasize that the analysis of satellite imagery is a fundamental tool for looking for impact craters, but has to be considered only as a preliminary step.

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### REFERENCES

1. Paillou Ph., et al. Discovery of the largest impact crater field on Earth in the Gifl Kebir region, Egypt, *C.R. Geoscience*, 336, 1491-1500, 2004.
2. Klitzsch E., et al. Geologic Map of Egypt 1:500000, The Egyptian General Petroleum Corporation, Cairo, Egypt, 1987.
3. Said R., *The Geology of Egypt*, A. A. Balkema Publishers, Rotterdam, Netherlands, 1990.
4. Issawi B., Geology of the southwestern desert of Egypt, in *Desert landforms of southwest Egypt: a basis for comparison with Mars*, 57-66, F. El-Baz and T.A. Maxwell Eds., National Air and Space Museum, Washington DC, 1982.
5. El-Baz F., The "Uweinat Deset" of Egypt, Libya and Sudan: a fertile field for planetary comparisons of crater forms, *Desert landforms of southwest Egypt: a basis for comparison with Mars*, 251-253, F. El-Baz and T.A. Maxwell Eds., National Air and Space Museum, Washington DC, 1982.
6. Clayton P.A., The western side of the Gifl Kebir, *Geographical J.*, 81, 254-259, 1933.
7. El-Baz F. and Issawi B., Crater forms in the Uweinat region, in *Desert landforms of southwest Egypt: a basis for comparison with Mars*, 79-89, F. El-Baz and T.A. Maxwell Eds., National Air and Space Museum, Washington DC, 1982.
8. Barakat A., El-Baz crater: basaltic intrusion versus meteoritic impact crater, *Annals of Geological Survey of Egypt*, XXIV, 167-177, 1994.
9. Abate B., et al., B.P. and Oasis impact structures, Libya: preliminary petrographic and geochemical studies, and relation to Libyan Desert Glass, *Conference Paper, 28th Annual Lunar and Planetary Science Conference*, 1997.
10. Paillou Ph., et al., Discovery of a double impact crater in Libya: The astrobleme of Arkenu, *C.R. Geoscience*, 335, 1059-1069, 2003.
11. El-Baz F. and Ghoneim E., Largest crater in the great Sahara discovered by Boston University scientists. <http://www.bu.edu/phpbin/news/releases/display.php?id=1073>.
12. González E. and Alonso S., Evidence of two new possible impact structures in Chad: separate impacts, binary asteroids or Aorounga impact chain?, *Lockne Workshop, Abstract Volume*, 2006.
13. French B.M., *Traces of catastrophe: a handbook of shock-metamorphic effects in terrestrial meteorite impact structures*, LPI Contribution N. 954, Lunar and Planetary Institute, Houston, 1998.
14. Brookes I.A., Geomorphic indicators of Holocene winds in Egypt's Western Desert, *Geomorphology*, 56, 155-166, 2003.
15. Reynolds J.M., *An Introduction to applied and environmental geophysics*, Ed. Wiley, New York 1997.
16. Paillou Ph., et al. An extended field of crater structures in Egypt: observations and hypotheses, *LPSC XXXVII*, Abs. #1286, 2006.
17. Grieve R.A.F., et al., Shock metamorphism of quartz in nature and experiment: II. Significance in geoscience, *Met. Plan. Sci.*, 31, 6-35, 1996.
18. Baratoux D. and Melosh H.J., The formation of shatter cones by shock wave interference during impacting, *Earth Plan. Sci.*, 216, 43-54, 2003.