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The Benguerir meteorite: Report and description of a new Moroccan fall

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Abstract–A meteorite fall was witnessed on November 22, 2004, at 11:45 A.M. (GMT) near the city of Benguerir, Morocco. This is one of the first falls from Morocco to be scientifically described. The total mass of the fall is estimated to be at least 40 and 80 kg. Three impact locations have been identified, two of them in soft ploughed ground and a third on a granite surface, which was apparently broken by the impact. The weight of complete pieces range between approximately 100 g and 10 kg. We have classified the stone as an LL6 ordinary chondrite, based on mineralogy and petrology, with shock grade S3 and alteration W0. The dark fusion crust is perfectly fresh, and a number of samples were collected shortly after the fall by local residents and authorities before rainfall, which occurred a few days later. We show that the magnetic susceptibility of Benguerir is homogeneously high, indicating a constant metal content despite brecciation, in the high range for LL6. The LL6 classification can also be confirmed magnetically, with a specific signature similar to other measured LL6 falls.

INTRODUCTION

Over the last decade, numerous meteorite finds in Morocco have given rise to a problem of nomenclature in relation to their origin, their place of find, and identification.

Many meteorite falls in Morocco, including the two most recent ones, Bensour (Russell et al. 2004) and Oum Dreyga (Russell et al. 2005), have been the subject of uncontrolled searches and collection without any scientific consideration. This has had the effect of creating a series of meteorites with the prefix "Northwest Africa (NWA)" of unknown provenance. Information concerning previous falls have neither been reported nor even collected afterward, so that the few remaining pieces of information cannot be regarded as very reliable. The existence of meteorites as valuable objects is recognized even in the most remote villages of Morocco. It is therefore not surprising that three days after the fall near Benguerir, for example, "Al Ittihad al Ichtiraki," a national newspaper in Arabic whose readership is neither the intelligentsia nor the scientific circles, reported the meteorite fall on its front page. The authors got the information phoned half a day before the arrival of this newspaper in the south of Morocco, where the trade of meteorites is the most active. We reached Benguerir on a Friday morning, four days after the fall.

The Benguerir fall is the first scientific report by a native of Morocco describing the fall and the stone. It was described in the Meteoritical Bulletin No. 89 (Russell et al. 2005). Three impacts were observed and samples were collected from these sites. An estimate of the bulk mass was possible, and the overall direction of the fall was estimated. Reports by a number of eyewitnesses were collected and are summarized in this report. This paper aims at describing this fall and making a comparison with other falls in the same region—within a few hundred kilometers—specifically Bensour and Kilabo, which are also classified as LL6 chondrites.

DESCRIPTION OF THE FALL

On Monday, November 22, 2004, at about 11:45 A.M. GMT, a meteorite fall was witnessed near Benguerir, Morocco (about 50 km north of Marrakesh). The location of the fall (Fig. 1) is to the south of the village of Sebt Brikyine, which is 12.5 km northwest of the city of Benguerir. Additional stones from the same shower have been observed in Si Abdellah and Tnine Bouchane, a few kilometers further west.

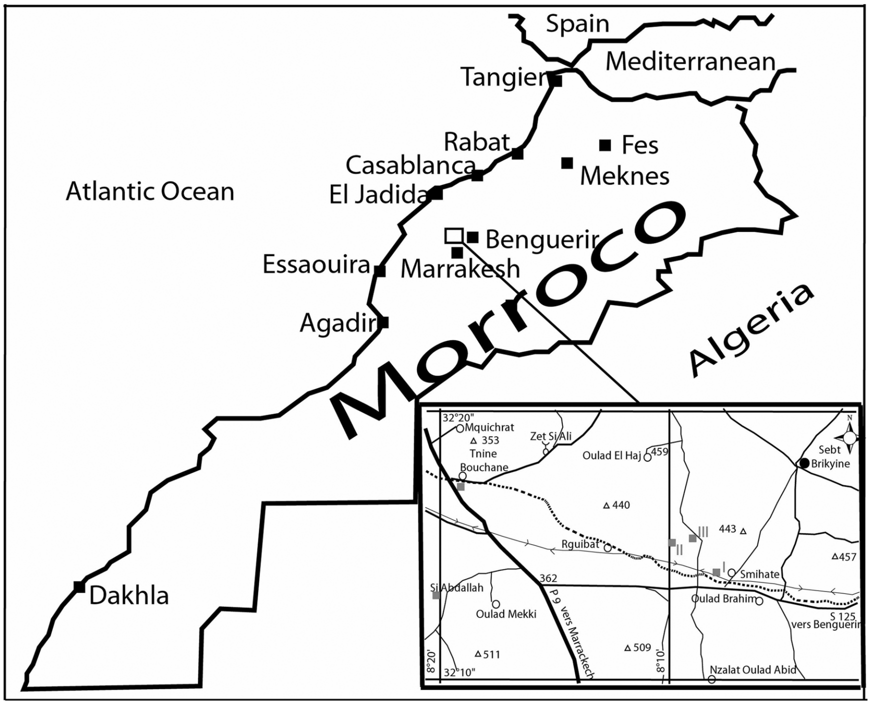

Fig. 1. Maps of Morocco and the fall area. The white rectangle shows the area of the fall near the town of Benguerir. The map of the fall area is from Youssoufia map NI-29-15 1:250.000. Gray squares = major stone recoveries, full features = roads and tracks, discontinuous features = railway, features with arrows = high-voltage line.

Impacts

Three different impacts were observed (Fig. 1):

- Impact I (gray rectangle I): Douar (=hamlet) Lfokra (32°13′52.9″N, 08°08′56.7″W, altitude 398 m), occurred in soft ploughed ground with a diameter of 15 cm and a depth of 10 cm. The small impact crater exhibited a central uplift with raised rims. Eyewitnesses report that the stone broke into two pieces at the time of impact.
- Impact II (gray rectangle II): At Ahl Fouim Sakhra Lourania (32°15′31.2″N, 08°10′51.9″W, altitude 406 m, see Fig. 2), the fall occurred on a granite outcrop (Brikyine granite). Upon landing, the meteorite splintered into many small pieces and dust, some of which remained on the spot for several days. Meteorite fragments were spread about over an area of at least 15 m in diameter. The shocked granite on which the stone impacted was broken apart with pieces thrown up nearly 1.5 m away.
- Impact III (gray rectangle III): At Douar Tnaja, (32°15′43.1″N, 08°09′01.3″W, altitude 416 m), the impact was on soft ploughed ground, with a diameter of about 40 cm and a depth of 20 cm. It also shows a central swell and prominent rims. Witnesses report that there was a single large stone broken on the edges. A grocer in the village weighed a mass to be about 10 kg. Obviously, it was subsequently broken into several pieces. We assume that at least some of the fragments of this meteorite, that are now with the governor and the director of the CNRST (Centre National de Recherche Scientifique et Technique, Rabat, Morocco), are from this stone. Unfortunately, when we returned for the second time on Tuesday, November 30th, the impact at Douar Tnaja was covered with soil, as was the impact at Sakhra Lourania. The third impact had been preserved, except that it started to degrade due to a recent rainfall.

Si Abdellah and Tnine Bouchane: Two stones of 1 and 5 kg were reported later to be found near Si Abdellah and Tnine Bouchane. (See gray rectangles in Fig. 1). Unfortunately, we could not record the exact impact locations of these stones.

According to eyewitness accounts, the fall was from the east to the west extending over about 10 km. As far as we know, attempts to find further samples either eastwards or westwards failed. The total mass of the fall was estimated to be between 40 and 80 kg.

Testimonies from Eyewitnesses

We were able to question two eyewitnesses.

At Douar Lfokra, a young shepherd called Adil heard a thunderous noise followed by shooting-like noises; then he saw an object falling from the sky at high speed. The nearly vertical fall was followed by a dust cloud. He went then to the fall spot where he found two pieces of a black rock with a lead-gray interior. He took it in his hands and brought to his cheek, and reported it was cold.

Fig. 2. The shocked and broken granite plate on which stone II impacted. Note the gray dust derived from the stone upon impact.

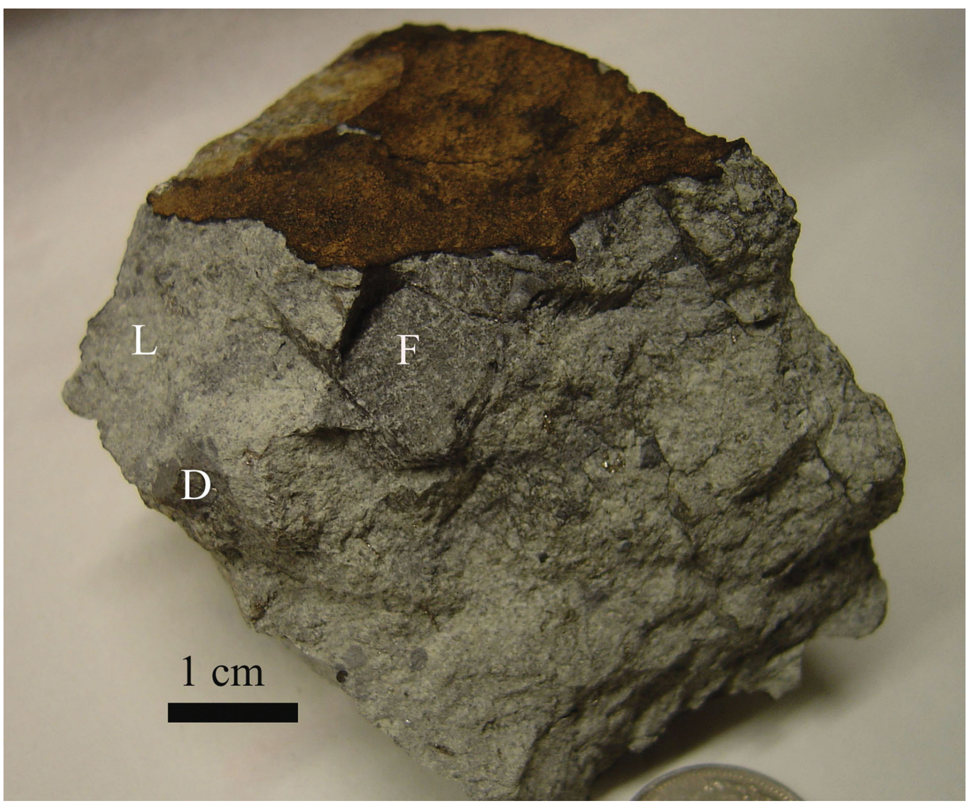

Fig. 3. A 350 g stone in the Hassan II University of Casablanca, Morocco, showing the dark (D) and light (L) clasts, three fracture planes, and a "slickensiding" (F) perpendicular to the fracturing mentioned above.

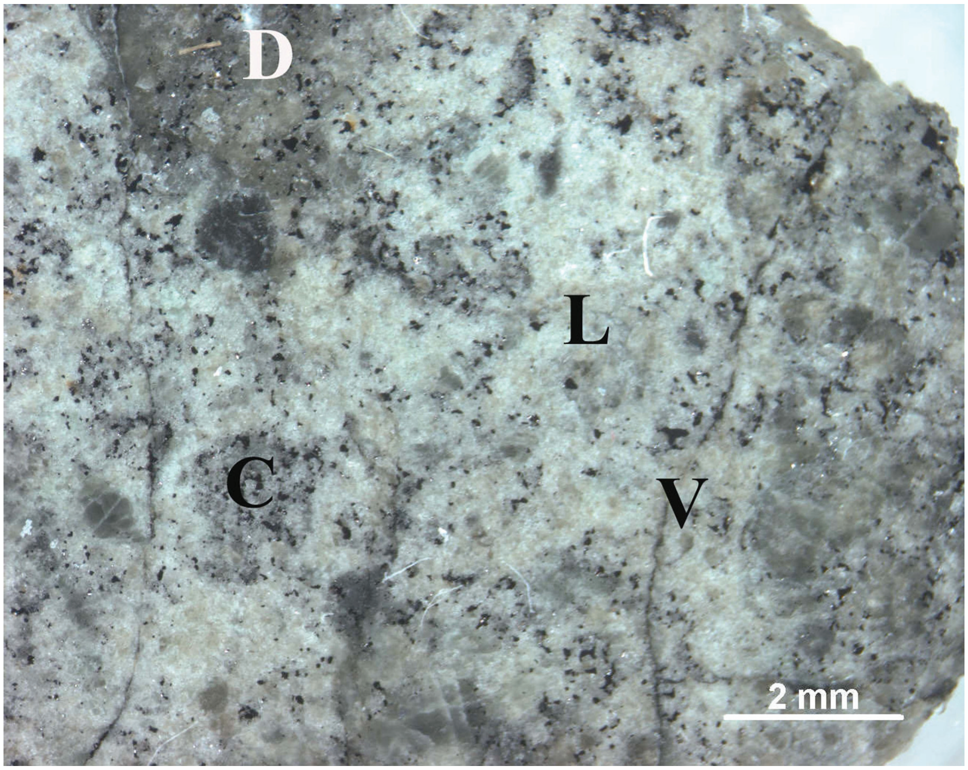

Fig. 4. Polished section showing dark (D) and light (L) clasts, veins filled with metal and sulfides (V), and a preserved chondrule (C).

At Douar Tnaja, a shepherd by the name of Abdelaâli heard a thunderous noise followed by shooting. He then saw a projectile coming from the sky in a heavy fog at high speed. It hit the ground with a muffled noise. A cloud of dust ascended, and he heard another shock (probably the impact II) in the direction of the west and a burst a bit further away. Somewhat frightened, he waited for a moment until he went to the spot to see what had occurred. He found a broken stone, black on the outside, light grey on the inside. The corner seemed to be missing. He took the rock in his hands and reported that it was quite cold. He replaced it and returned to inform the local authorities.

Report of the local authorities in Benguerir: The "Chef de Cercle," the local authority leader, reported that on Monday, November 22th, 2004, at 11:45 A.M. a strong thunderous noise was heard (similar to a mine bursting), the window panes of the offices vibrated, and that the whole population was aware of this incident.

Many pieces have been documented:

- One in the office of the governor of the Kelat Sraghna Province. This stone weighs about 4 kg. It seems to be from the Tnaja fall.
- One in the Laboratory of the Gendarmerie Royale which apparently comes from the Douar Lfokra fall. It weighs about 1.2 kg.
- One that the "Chef de Cercle" acting for the local authority, under the advice of the governor, provided for further scientific study. This stone weighs about 350 g and comes probably from the Douar Lfokra fall (Fig. 3). At the same time, two small pieces of a few grams each and even smaller pieces, were given. Their origin is not specified.
- Many small pieces and the two largest ones (about 4 kg and 1.5 kg) in the office of the director of the CNRST in Rabat Morocco.
- Many fragments are with several dealers and collectors.

MACROSCOPICAL DESCRIPTION

The fusion crust is dull black with irregular thickness. Some soils adhere to the crust on the fall side, unlike Bensour (LL6), which remained unspoiled. There are many complete stones completely fusion-crusted from Bensour (Russell et al. 2004), with a few individuals weighting a few grams, but no complete small individuals from Benguerir have yet been reported. We assume that it is difficult to identify these fragments in ploughed fields. For Bensour or Oum Dreyga (Russell et al. 2005), many small individuals have been recovered because of the ease of collecting meteorites from the desert.

The Benguerir stone is weakly magnetic. Bulk stones weigh probably between nearly 10 kg (the Douar Tnaja stone) to nearly 100 gr.

On the largest stone (4 kg, in the governor's possession), one side is smooth and the other exhibits typical regmaglypts. These features are not observed on the other samples.

The sample shown in Fig. 3 seem considerably shocked. There are three planes of fracture. Two are parallel between them and perpendicular to the lengthening of the sample, and the third is perpendicular to the two precedents (thus parallel with the lengthening of the sample) and visible through the crust (see Fig. 3).

Sulfide is observed as clusters a few millimeters in size and veinlets. There are also some druses of sulfides with clear faces.

A few dark clasts of a few centimeters are visible in an otherwise light matrix (see Fig. 3). Chondrules are hardly visible (millimeter to infra-millimetric) (Fig. 4). Millimetric metal grains are observed.

PETROLOGY AND MINERALOGY

To the naked eye, brecciation is visible as on most LL chondrites. Two clast lithologies occur: the first one is light, whereas the other one displays more irregular pieces with dark to very dark aspect (Figs. 3 and 4). A few sparse complete, partial, and relic chondrules are present.

Specific Features of the Two Clast Lithologies

- Opaques (kamacite, taenite, and troilite) are widely dispersed in the dark clasts as small angular grains. In the light clasts, they cluster as large grains (Fig. 5).
- Dense lines of small metal grains underscore the boundaries between the two lithologies, always within the dark one. This suggest a migration of the opaques to boundaries of the dark clasts upon brecciation.
- Silicate crystals are quite large (>100 µm to millimeter-sized) in the light clasts, while their size appears significantly smaller (<100 µm) and more regular (like the opaques) in the dark parts.

Shock Features

Several features are clear evidence of shock. Numerous veinlets are filled with sulfide (mostly) and minor metal (Fig. 6). They randomly cross-cut both dark and light lithologies (Fig. 4). Numerous silicates appear cloudy due to the occurrence of fine metal and sulfide droplets. A few melt pockets exhibit small silicate phenocrysts with opaque spherules. Troilite is locally deformed by stress (Fig. 7) and is polycrystalline within the aforementioned veinlets. All silicates and chromites are heavily fractured (Fig. 6). A mild etching with nital (nital = alcohol + 2% HNO_3) reveal deformed Neumann bands in kamacite. Accordingly, we assigned a shock grade S3 (Stöffler et al. 1991).

CHEMICAL ANALYSIS

Microprobe analyses were performed on the Cameca SX100 and Cameca SX 50 microprobe Université Pierre et Marie Curie Paris VI. Analysis of major mineral phases are presented in Table 1. The analyses are homogenous in accordance with the classification on type VI of an LL ordinary chondrite (Fa 30.5% ± 1%, Fs 25.3% ± 1%, Ab 83.0%, An 10.6%, Or 6.4%) (Jarosewich 1990).

Table 1. Representative composition of major and minor mineral phases of the Benguerir meteorite by microprobe analyses on Cameca SX100 Université Pierre et Marie Curie Paris VI (service de microsonde électronique UPMC).

	Olivine	OPX	CPX
Analyses	350	293	215
SiO_2	37.37	52.28	54.25
Al_2O_3	0.01	0.16	0.44
MgO	34.60	27.03	16.27
FeO	27.32	17.18	6.04
MnO	0.40	0.33	0.21
CaO	0.03	1.85	20.99
Na_2O	0.00	0.09	0.46
K_2O	0.00	0.03	0.00
TiO_2	0.01	0.20	0.48
Cr_2O_3	0.00	0.03	0.77
P_2O_5	0.00	0.04	0.06
Total	99.76	99.44	99.96
	$Fa_{30,54}$	$Fs_{25,36}$	$Fs_{9,74}$
		$En_{71,13}$	$En_{46,80}$
		$Wo_{3,49}$	$Wo_{43,44}$

Table 2.

Meteorite	$\log\chi$	s.d.	P	$\log M_{rs}$
Appley Bridge	3.50		1.14	
Bensour	3.71	0.06	1.22	2.5
Douar Mghila	4.04			2.55
Dhurmsala	4.27	0.08	1.45	2.45
Galim a	4.28		1.29	
Jelica	3.61	0.14	1.28	2.16
Kilabo	3.67	0.05	1.09	2.46
Manbhoom	3.63	0.06	1.08	2.13
Oued El Hadjar	4.11	0.01	1.16	2.80
Segowlie	4.37		1.13	
Saint-Mesmin	4.18	0.10	1.36	2.51
Saint-Séverin	4.02	0.07	1.26	2.78
Benguerir	4.36	0.01	1.24	2.51

A comparison of olivine and orthopyroxene analysis between the other LL6 recent falls in this area of Africa, such as Bensour (Russell et al. 2004)(Algeria/Morocco, February 11, 2002, Fa 31.6, Fs 24.3) and Kilabo (Russell et al. 2003) (Nigeria, July 21, 2002, Fa 31.1, Fs 27.1), shows small differences between these LL6 chondrites (Cole and Sipiera 2003).

MAGNETIC PROPERTIES

Magnetic properties were measured on several fragments to fit this new fall into the magnetic classification scheme of

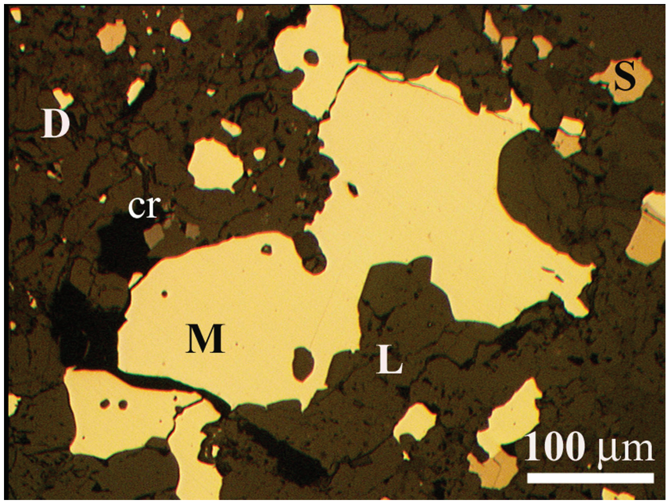

Fig. 5. A large grain of metal in a light clast. Silicates are fractured. M = metal, S = sulfide, D = dark clast, L = light clast, cr = chromite.

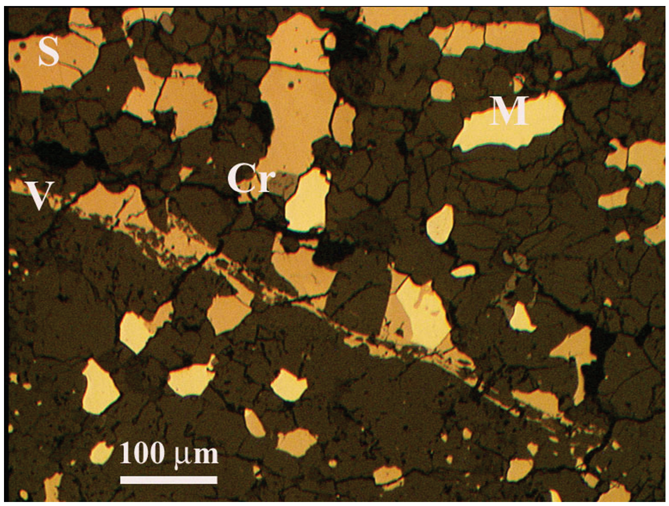

Fig. 6. A veinlet (V) filled with sulfide (S). Silicates and chromite (Cr) are heavily fractured. M = metal.

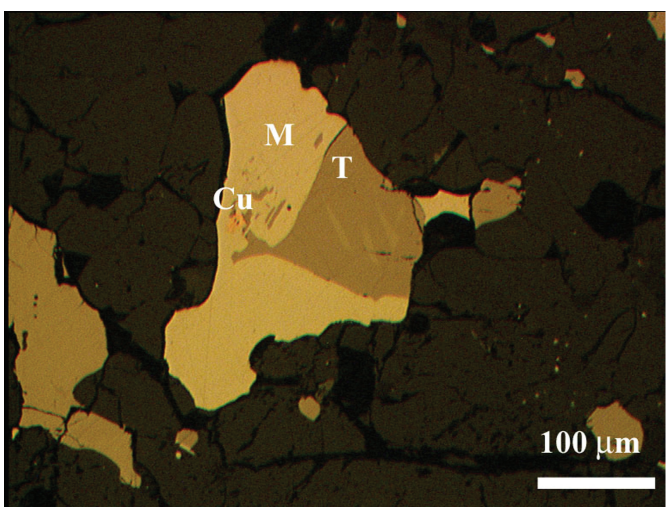

Fig. 7. Troilite (T) locally deformed by stress. M = metal, Cu = a grain of native copper.

Rochette et al. (2003), and compare it in particular with the recent regional LL6 falls, Bensour and Kilabo. Magnetic susceptibility (χ in 10^{-9} m^3/kg) was determined using a KLY2 bridge for small fragments as well as the SM30 contact susceptibility probe for a 347 g piece (Gattacceca et al. 2004). The Benguerir pieces exhibited a very homogeneous logχ of 4.36 ± 0.01, showing a constant metal content at the cm^3 level, despite brecciation. Log is in the high range for LL6 (3.96 ± 0.36, see Table 2), comparable to Segowlie but very distinct from Bensour or Kilabo (see respective s.d.), which are among the LL6 poorest in metal. Note that Segowlie, previously known as an L6, has been reclassified as an LL6 by Rochette et al. (2003), based on petrographic and microprobe analysis. A magnetic anisotropy ratio *P* of 1.24, reflecting the preferred orientation of metal (Gattacceca et al. 2005), is in the middle range for LL6 (1.22 ± 0.11). Saturation remanence (M_{rs} in 10^{-3} Am^2/kg; see Rochette et al. 2003) gives a logM_{rs} of 2.51, in the middle LL6 range: 2.54 ± 0.12). This suggests a rather homogeneous content of the remanence-bearing mineral tetrataenite among LL6, with respect to a variable taenite/kamacite content revealed by susceptibility.

The LL6 classification can thus also be confirmed magnetically, with a clearly specific signature with respect to other measured LL6 falls.

CONCLUSION

The Benguerir meteorite is an observed fall that occurred on November 22, 2004, at 11:45 A.M. (GMT). This is the first Moroccan complete scientific report describing the fall and the stone. The meteorite was identified in a very short time (three weeks). It has been classified as an LL6 ordinary chondrite, with a shock grade S3 and weathering W0. The fusion crust is fresh. Benguerir has been compared to Bensour and Kilabo and shows clear specificities, particularly on the metal content determined by magnetic susceptibility.

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