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Richat and Semsiyat Domes (Mauritania): Not Astroblemes

Abstract: The 38-km-diameter Richat Dome, in central Mauritania, has been widely regarded as a possible astrobleme. Our field examination of the structure and subsequent petrographic study of the critical rock types failed to reveal a single feature attributable to shock processes. We, therefore, dismiss an impact origin for this structure. It must, instead, be endogenic. The same conclusion applies to the much smaller, associated, Semsiyat Dome.

Introduction

In March 1968, we examined two geologic structures of considerable interest to meteoriticists in the Adrar region of central Mauritania, Africa—the Richat and Semsiyat Domes. These structures have been widely regarded as possible astroblemes (ancient meteoritic impact scars) and are listed as such in several bibliographies on this subject (for example, Freeburg, 1966).

Interest in the Richat Dome has been heightened recently by a well-publicized Gemini photo, no. S-65-34670, on which the dissected dome appears as probably the most striking earth structure so far photographed from near space—a giant bullseye vaguely reminiscent of Mare Orientale on the Moon (Pl. 1). A NASA publication on the Gemini results lists it as a suspected impact feature (Anonymous 1967).

The purpose of our expedition was not to achieve any full understanding of Richat Dome, which is a structure of considerable complexity. We did feel, however, that shock metamorphic effects should be readily observable if the Dome were the root structure of a large impact crater. Our purpose was to determine whether or not such shock metamorphic features were present.

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General Geologic Setting of Richat

The Richat Dome was first described by Richard-Mollard (1948; 1952) and further elaborated upon by Monod (1952; 1954). The coordinates of its center are lat 21° 4′ N. and long 11° 22′ W. It forms a circular topographic depression about 38 km in diameter at the edge of a very extensive plateau composed of a flat-lying sedimentary sequence capped by the Chinguetti Sandstone of lower Paleozoic age. The lower part of the sequence, well exposed in the dome, consists of a series of upper Precambrian and lower Paleozoic, miogeosynclinal-facies rocks (carbonates, cherts, sandstones, quartzites, and slightly metamorphosed siliceous shales). As now sectioned by erosion, the dome

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consists of a series of annular rings, like the cut through an onion, with the quartzites forming ring ridges and the softer rocks forming toroidal depressions (which, incidentally, provide easy access to all parts of the structure). The dips of the beds increase toward the center to an average maximum of 20° to 25° (although dips as great as 35° are attained locally). Beyond these maximum values, the dips abruptly decrease as the center is approached. The central "eye" is occupied by a flat-lying limestone and a very subordinate amount of flat-lying meta-arkose. This central "eye" is immediately encircled by a discontinuous, massive ridge of chert and chert breccias, forming the so-called Guelb er Richat.

There has been at least minor igneous activity. Small dolerite dikes or sills outcrop at several locations within the structure. And a rather enigmatic rock type, termed analcimolite (Bardossy and others, 1963) occurs in several areas near the central Guelb. Although there is room for argument here, we interpret these rocks as zeolitized volcanic tuffs.

Radial and tangential faults are present in the outer parts of the structure, but are by no means pervasive. Additionally, in the northern part of the structure, we found a well-developed fault system which is apparently unrelated to the structural doming. Curiously, the system strikes N. 30° E., which is the trend of a straight line joining Richat with two other circular features of uncertain origin—Tenoumer and Temimichat—lying 300 and 400 km to the northeast, respectively.

Evidence Suggestive of Impact

Several lines of evidence have been advanced in favor of a meteoritic origin for Richat:

(1) Highly circular *endogenous* structures of this size are very unusual. With considerable justification, astrogeologists have come to regard all such structures as possible astroblemes until proven otherwise.

(2) The purely vertical uplift occurs in a region of flat-lying sedimentary rocks with few other structural disturbances of undisputed terrestrial origin within several hundred kilometers.

(3) Cailleux and others (1964) point out that the drainage pattern is directed inward rather than outward, as it should be if inherited from an original geomorphic dome. Such a pattern would, however, be expected if Richat were the root structure of a crater.

(4) There are rather extensive outcrops of brecciated cherts and quartzites immediately outside the central "eye." Impact breccias are, of course, a characteristic feature of astroblemes.

(5) Cailleux and others (1964) reported the presence of coesite in one of these brecciated quartzites.

(6) Aouelloul, a small crater of undoubted impact origin (Chao and others, 1966a; 1966b) is located 150 km to the southeast.

Results of the Present Investigation

The results of our investigation can be stated as follows: (1) no structural evidence for cryptoexplosive activity, (2) no megascopic evidence of shock metamorphism, and (3) no microscopic evidence of shock metamorphism in the rocks examined. These points are discussed in some detail below.

(1) Impact structures should show evidence of a natural explosive event. Because of the point application of an intensive force, and because shock waves are rapidly damped, an impact structure typically reveals a central "megabreccia" of highly disturbed beds which have been rotated and upthrown, and this distortion rapidly dies out radially outward. Further, astroblemes of this size have a so-called damped-wave aspect, that is a domal center surrounded by a structural depression. At Richat we found no case for the application of any sudden impulsive force. There is no evidence of what might be termed "geologic overkill." There is no megabreccia. No strata are overturned or even vertical. In fact, a flat-lying limestone and meta-arkose occupy the central "eye." Both appear normal in all respects and have not been subjected to any intense tectonism. The structure has the form of a simple dome and lacks any hint of any annular structural depression beyond the uplift. The entire dome is remarkably intact; only minor radial faulting was noted and some outward displacement of beds, which may be ascribable to gravitation slippage after domal uplift. All in all, the tectonic style at Richat best fits a history of slow vertical uplift.

(2) We observed no dikes or pods of injection breccia or pseudotachylite-like material. We did note rare, radial sandstone dikes, which we interpret as sedimentary fillings of open joints.

Of much greater significance is the absence of the conical shock fractures termed *shatter cones*, which have been found in about 20 other putative astroblemes (Dietz, 1968). The fine-grained, homogeneous carbonates and quartzites of Richat should have preserved this type of fracturing especially well. Such rocks are widely exposed within Richat, but our extensive search revealed no sign of this useful field-shock criterion. There is some evidence that shatter coning is related to the development of an elastic precursor shock wave and is formed over a limited range of shock overpressures—roughly from 20 to 80 kb (Johnson and Talbot, 1964). Hence, for large astroblemes shatter coning may be absent from the central eye, but well developed farther out. Shatter coning at the 35-km-diameter, well-exposed La Malbaie (or Charlevoix) structure of Quebec offers an instructive comparison, for it is of a size almost as large as Richat. This shock fracturing is a pervasive aspect of the central regions of this astrobleme; it is found in the central eye and out to ranges of 14 km from ground zero. However, the best development of shatter cones is not at the central point of greatest shock, Mont des Eboulements, but at about 7 km from this central peak where the plastic wave apparently had attenuated to the extent that the combination of strong elastic compression and rapid tensional release was optimal for their formation (Robertson, 1968).

We searched all regions of Richat without finding shatter cones. One horizon of cone-in-cone structure, which has been confused elsewhere with shatter coning (but which actually bears little resemblance), was noted. In view of the excellent outcrop exposures and the pervasive engulfment of the shocked rocks in astroblemes by shatter cones, their total absence is strong evidence against an impact origin for Richat.

(3) The past few years have seen the development of some very useful microscopic criteria indicative of shock metamorphism. Among the most diagnostic are: planar features (fracture sets lying along unusual crystallographic directions) in the mineral grains—shocked quartz, feldspar, and carbonates show these features especially well; optical isotropism of quartz and feldspar (maskelynite) without melting; and kink-banding in mica (Short, 1966). Twenty-eight thin sections of eleven rock types were examined carefully for any such features, and the results were completely negative. The rocks included all those most likely to show such features. Particular attention was paid to the chert and quartzite breccias.

Two of the quartzite breccias were collected from the same general area that Cailleux and others reported as the site of their coesite-bearing, shattered sandstone. Our specimens appear to be simple tectonic breccias, caused by slippage between adjacent rock units during the updoming. They do not correspond to the specimen description given by Cailleux and others. Our specimens consist almost entirely of quartz grains which uniformly display well-rounded nuclei and well-developed overgrowths. The rocks are very clean; there is little or no fine-grained material; the breccia fragments are essentially in place and are identical to the groundmass. The quartz grains are uniformly intact, showing neither random fracturing nor planar features.

The absence of planar features does not preclude the presence of coesite in these rocks since the minimum shock pressure necessary to produce planar features is about 50 kb, while coesite may form at pressures as low as about 20 kb (Short, 1966). However, at 20 kb shatter cones should form in the rocks, and the quartz grains should show extensive shattering.

The central nest of chert breccia is a remarkable aspect of Richat, and its origin would seem to be rather critical to the Richat problem. These breccias are highly variable over very short distances, principally with respect to the size and crystallinity of the chert fragments, the crystallinity of the groundmass chert, and the amount of quartz in the groundmass. All contain detrital quartz grains in the cherty groundmass. Some have only a trifle, some so much that the groundmass appears to be a quartzite in hand specimen. Rarely, both extremes may be found in the same thin section. No fractures or planar features are present in the quartz. All of these chert breccias are polymict breccias in the sense that the angular fragments are clearly different from the groundmass and cannot be derived from it, even though there is evidence of in-place fracturing for some fragments (some pieces could be fitted back together). They, therefore, *cannot* be tectonic breccias. Texturally, it appears that the quartz in the groundmass is being replaced by chalcedony. The groundmass shows no evidence of fracturing, grinding, or other disturbance, which suggests it had not lithified at the time of brecciation. On the basis of our examination, we suggest tentatively that these rocks may be pseudobreccias in the sense that they assumed their present configuration prior to complete lithification, perhaps as a result of the lithification process itself, which would involve the differential shrinkage of lenses and pods of pure silica gel in a mass of silica gel and quartz. But aside from speculation about the true origin of these chert breccias, and more to the point of this investigation, we are certain that these breccias are not shock breccias of the type formed by cosmic impacts.

Summary and Conclusions

During our careful field and laboratory examination of rocks exposed in the Richat Dome, we failed to find any of the features which should have been present, if the dome were the root structure of an impact crater. Other than for the minor presence of problematical rhyolite tuffs, there is neither evidence for explosive activity nor the application of any shock imprint.

It may be argued that Richat is a deep root structure of an impact crater and that all evidence of impact metamorphism has been removed by erosion. However, the amount of erosion this theory would require is excessive. Available data indicate that rather severe shock effects can be expected beneath an impact crater to depths which are about one-fifth the crater diameter (Baldwin, 1963). Less severe effects, such as shatter-coning, would extend even deeper. Thus, for a feature the size of Richat, we would expect to find evidence of shock to a depth of at least 10 km below the original surface. Removal of all shock features, then, requires at least 10 km of erosion of an area which has shown exceptional crustal stability, such as the flat-lying, undisturbed Precambrian and Paleozoic sediments, for half a billion years. Clearly there has been no significant tectonism or uplift, or both, since the formation of the dome. And since the maximum uparching of the dome can be no more than 3 to 4 km (Cailleux and others, 1964), it appears to be the upper limit to the amount of rock removed by subsequent erosion.

We conclude that the total lack of shock metamorphic effects is significant and that Richat is *not* an astrobleme, but is endogenous in origin. We note that both Richard-Mollard and Monod assigned an endogenic origin to Richat. The latter regarded it as a probable laccolith, but another possibility is that it is structural in response, for example, to tumescence of the upper mantle. Geophysical surveys might do much to explain its origin. Regional gravity and magnetic anomalies for the region have been assembled by Rechenmann (1965–1966), and these show no unusual anomalies. However, the critical control lines in the Adrar region may have skirted Richat only.

What of the other arguments favoring an impact origin? Except for the reported coesite, we regard them as either circumstantial or specious, or both. An endogenous origin for a large, highly circular dome requiring the application of purely vertical forces, in an area conspicuously lacking in any other tectonic features, is unusual, but is not impossible. The centripetal drainage pattern is not superimposed. It has clearly developed subsequent to peneplanation and is entirely normal for the present topographic configuration. The proximity of an undisputed meteorite crater—Aouelloul—has no significance, because the two events are quite unrelated in time. Aouelloul is a slightly eroded, bowl-shaped depression with a raised rim. It is probably Quaternary in age. Richat is an ancient geologic structure which has been peneplaned and then resculptured to its present configuration, which displays 100 m, or so, of local relief.

We have not yet attempted to separate coesite from the brecciated quartzites. We hope to do so in the near future. But even if coesite is present, we see no reason to change our conclusions. The complete absence of even minor grain fracturing in the quartz breccias compels us to reject a shock wave origin for that coesite. Coesite is stable at pressures of 20 kb or so, and it is possible that local intergrain stress concentrations may exceed this figure in certain tectonic environments which are characterized by strong shear stresses. Alternately, pressures lower than 20 kb may suffice to produce coesite in high-stress environments. Recent experiments have shown, in fact, that coesite can be synthesized metastably at confining pressures as low as 5 kb in samples which are simultaneously subjected to high-strain rates (Green, 1968). Should the presence of coesite in these rocks be confirmed, we would regard it as the first documented occurrence of this mineral resulting from normal, near-surface endogenous processes.

Semsiyat Dome

The flat-lying beds of the Mauritanian Adrar are disturbed by another dome, Semsiyat, 50 km west southwest of Richat's center, at lat 21° 0′ N. and long 11° 50′ W. Only 5 km across, it is much smaller than Richat, but of the same tectonic style, so that it may be fairly regarded as a *petit frére* of this great dome. Although it shows clearly from the air, it is barely perceptible on the ground. The quaquaversal dips of the annular beds are too low to measure in the field. The dome occurs on a flat plateau and the structure itself has a relief of only a few meters. The central "eye" is slightly depressed as is an outer "race track."

The direct evidence bearing on the origin of this structure is not nearly as clear-cut, as is the case for Richat. Primarily, this is due to the very poor exposures and the greater effect of weathering on those rocks which are exposed. There are, for example, no outcrops at all in the central "eye." During a one-day field reconnaissance, we found no shatter cones nor did we see any other structures or rock types suggestive of shock processes. A few pieces of badly weathered chert breccia were found as float in the central "eye." No quartzite breccias were found. There was no microscopic evidence of shock metamorphism in the quartzites we examined.

Taken alone, the evidence is far from conclusive. Nevertheless, the close structural similarity and areal proximity to Richat leads us to believe, in the absence of any evidence to the contrary, that the origins of the two structures are closely related. We conclude, therefore, that Semsiyat is also endogenous in origin and is not an impact feature.

Relationship to Three Modern (?) Meteorite Craters

French workers have tended to associate the Richat and Semsiyat domes with three modern (only slightly eroded) craters of central Mauritania—Aouelloul, Tenoumer, and Temimichat-Gallaman—which are aligned along a trend of N. 30° E. and over a distance of 500 km. This trend also passes just west of Semsiyat and skirts the eastern side of Richat. There can be no common time of genesis of these two groups of features, as Richat and Semsiyat are clearly ancient peneplaned and exhumed structures of at least pre-Neogene age. One may still argue that they all are endogenic and developed along a common fault line, but we are inclined to believe that the presence of Richat and Semsiyat along this lineation is fortuitous. Because of its impact glass, Aouelloul seems certainly to be a meteorite crater, and we suspected that Tenoumer and Temimichat-Gallaman may possibly be as well, although associated meteorites are unknown. Their lineation is suggestive of a possible triple impact event. Monod and Pomerol (1966) suggested that Tenoumer is a volcanic crater based upon associated lava dikes. However, a sample of this "lava" obtained by us at Dakar from the Bureau for Research in Geology and Mines has been the subject of restudy by Bevan French, who has found shocked inclusion of country rock of the type commonly associated with impact craters. Hence, this "lava" appears to be an impactite which tends to identify Tenoumer as a meteorite crater (B. French, personal commun.).

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Gemini photo no. S-65-34670

GEMINI IV PHOTO OF THE 38-KM-DIAMETER RICHAT DOME OF MAURITANIA FROM NEAR SPACE

The much smaller Semsiyat Dome can be seen halfway between the capsule nose and the Richat Dome at about the 4:30 o'clock position.

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Notes