A UNIQUE LANDFORM: THE METEORITE CRATER

(A Plea for Wider Recognition in Geography)

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There is an almost general agreement among most students of the surface of the earth, that the meteorite craters represent the most unique landform of our planet (and perhaps of all other planets with a solid surface). Yet, interestingly enough, no textbook in geography deals with this landform sufficiently. What is even more striking that most exts totally ignore it. It appears that most text writers are either not aware of the results of recent research in this direction (mainly by other sciences) or refuse to commit themselves — therefore selecting the ostrich tactics. This is unworthy to our profession and unfair to our students. Present day students are studying in an age when we are able to view our planet from the outside also and not only from the surface which gave a limited horizon.

The term "landform" in the title of course refers to "the shape, form and nature of a specific feature on the surface of the earth" (MONKHOUSE, F. J. 1965. p. 182.), that is also called terrain element, topographic relief or landscape features. It is well recognized that the earth's land surface is composed of a tremendous variety of landforms and known that their variety is endless since no two are exactly alike. The reason for this is due partly to their complex origin but mainly to the dynamic forces affecting them at all times. In spite of the limitless variety generally they are all regarded by most schools as the product of interaction between internal and external forces acting in constant opposition to each other. This is the stage of knowledge reflected by most introductory texts in geography today although this view reflects the knowledge of the early 1950s that is insufficient in the 1970s. It is not only insufficient but it is incorrect and wrong. Wrong because not *all* "... the features of land surfaces are the product of the two sets of forces" (MONKHOUSE, F. J. 1965. p. 48), but there is a third force. That force is *extra-terrestrial.* To date this force has been overlooked and unrecognized by most authors, although it has been active in producing landforms (minor and major) ever since the existence of the earth's crust. This force is the kinetic energy of cosmic bodies that is expressed by the formula $Ke = 1/2\, m. v^2$, meaning that the kinetic energy of a moving body is one half the product of its mass and the square of its speed. Since the mass can range up to the size of minor planets and the cosmic speed is about 16 km/sec it is easy to see that we are talking here about tremendous (at the present time practically unexpressable) amounts of energies. The result of the impact of this kinetic energy is a surface feature what we call the meteorite crater. It is an impact crater that very much looks, like a raindrop created feature in loose dust in miniature, or in real size like an enormous bomb crater. To date, this landform has been most often referred to as "cryptovolcanic" or "pseudovolcanic" structure and has not been recognized by geographers at large as a valid, significant and unique landform.

The reasons for this are perhaps twofold: first, their origin had to be scientifically proven, and second, the old view concerning landform genesis would have need to be changed. Neither is easy and one cannot expect complete acceptance by all. But since the scientific proof for the meteorite crater origin has been established during the past two decades, a more general recognition is overdue and must follow.

Similarly to other modern sciences, geography and geomorphology (the true interpreter of landforms) must be able to accommodate new facts and change their views when old ones become restrictive. It appears that an increasing number of people feel the way as H. Robinson expressed: "... the whole approach to geomorphology is changing and many of the former explanations of features and processes are not only being questioned, but in some cases have been shown to be inaccurate" (ROBINSON, H. 1969. p. 111.). I like to regard the meteorite crater as a good example for pointing out not only that some explanations of features and processes must be re-evaluated, but also that a hitherto neglected landform should be recognized by geographers as well as by the general students of the surface of the earth. Reference to them in the past as "cryptovolcanic" or "pseudovolcanic" features reveals grave superficiality unacceptable anymore today.

It is quite probable that some readers have the impression that to regard the meteorite crater a "neglected landform" is unjustified. The reason for this probably is the fact that the meteorite craters have created fascination to people for a long time already. It is true, but the point here is not a reference to fascination but to scientific recognition. I would even like to suggest that the general awareness of them is largely due not to the meteorite craters on the earth but on the Moon.

The presence of well over 50.000 craters are recognized on the surface of the Moon (ranging up to several hundred miles in diameter) and a good many of them are widely regarded as meteorite craters, yet, how few of us are aware of the presence of similar features on the Earth? Many people are even able to name a few of these craters on the Moon, but on the Earth most likely, none. Or may be the Barringer Crater (Fig. 1) in Arizona, or perhaps the New Quebec Crater (Fig. 2/a), but quite likely no more. What is the reason for this? Is it because the Moon has many and the Earth only a few? Definitely not. It is quite probable that our planet was hit by an even larger number of extra-terrestrial bodies than our satellite was. The real reason for our unawareness of their presence on the Earth is very simple. Until recently selenography in some respect had a distinct advantage over geography. That advantage is mainly due to the fact that ever since Galileo's first telescopic observations in 1609, the major surface features of the Moon have been known, and many of the craters were recognized, while we had only a limited view of the Earth. (In fact the first detailed map of the visible side of the Moon by F. Hevelius, 1647, was a better map than any map of the Earth at that time.) However today we are able to elevate ourselves to have a birds' eye view of our planet making it possible for us to recognize the hitherto unrecognizable features. Naturally the surface of the Moon, being void of any gaseous envelope, lacks the gradational forces displayed so powerfully by our atmosphere on the earth. As a result, instead of having a relatively short period of existence the surface features are preserved and actually we can find the history of the Moon written upon its face. We recognized the bombardment of the Moon by meteoroids, comets, asteroids and even small minor planets a long time ago, and it was only a matter of time that man began to wonder why the same phenomena would not have taken place on the Earth. Especially

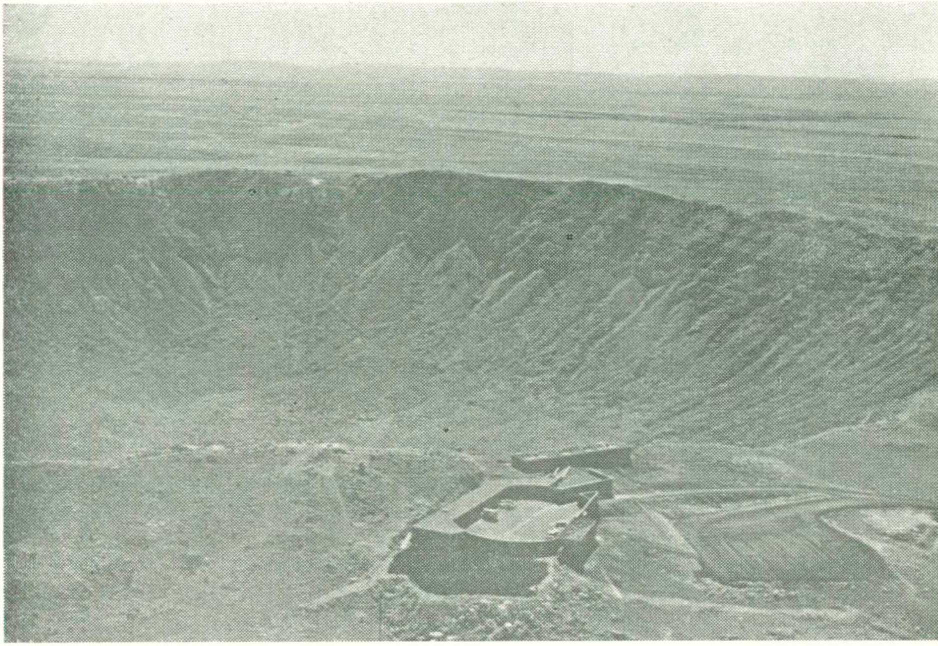

Fig. 1. The classic example of meteorite craters on the Earth is the Barringer crater in Arizona, USA.

considering its larger surface area and larger gravity, actually we may say the recognition of the meteorite craters on the Earth was inspired by the lunar features. (The similarity is shown on Figure 2/a—b.) However, recognition alone is not enough. Their origin must also be scientifically proven.

While the recognition took place at the end of the last century (Gilbert, 1895) the stage for thorough scientific investigations for most of these features was only reached during the last 20 years or so. Canada and the United States have played a leading role in these investigations by initiating the world's first systematic search for ancient meteoric craters, that has been followed by many other nations. As a result of these investigations, the acceptance of impact cratering on the Earth is gaining recognition.

Interestingly enough the question of the meteorite craters' recognition has not centered on disbelief in the existence of meteorites (because these have been recognized by the scientific community for about 170 years) but rather on doubts of their size being sufficient to produce large craters. Meteorites were known as very small particles rarely surviving the flight through the atmosphere to land on the ground. However, occasionally, they have been found and some of them proved to be of considerable size. (The largest recorded is almost nine cubic meters and weighs approximately 50 tons.) But even this size could not conceivably form features found on the surface of the earth ranging in size of not only a few hundred feet but up to dozens of miles in diameter. This leads us from the magnitude of meteorites towards that of asteroids and small planets. However with a magnitude of these sizes actually we are not looking anymore at impacts but rather at collisions.

Fig. 2. The New Quebec crater in Canada (above) and the Marinus crater of the Moon (below)

Measuring by human times we may say that major extra-terrestrial objects are only rarely encountered by our planet (perhaps one in every 10.000 years or so) which is fortunate, but as a result their impacts are almost unobservable. But that does not mean that they don't exist. Their imprints are very much present on our Earth.

One of the major reasons for the delayed recognition of meteorites craters is the late realization of the fact that the failure of locating the mass of the meteorite, or at least fragments of it, in a crater or around the rim of the crater is of no proof against the impact origin. It is realized now that the reason for this is in the tremendous energy that is released by the explosion that evaporates, in some cases, the whole cosmic mass.

The explosion creates a depression in the earth's crust, that is a circular basin with elevated rims. To the early observers these features looked like volcanic craters. Hence the term "crater" and classification as a "pseudovolcanic" form. Later it became recognized that the implication of any form of volcanicity is misleading and unfounded. But how could the volcanic explanation be avoided if the only recognized process that supposedly could have produced such a form was volcanicity We have to remember that the "definition" still is, for most earth scientists, that landforms are the products of the internal and gradiational forces. For example, we may quote one of the most frequently used authors in North America on physical geography, A. N. Strahler. He divided the landforms into two main groups: the initial forms "are the original crustal masses raised by internal earth forces and by volcanic eruptions" (and the sequential forms "are the erosional and depositional forms made by agents of denudations" (STRAHLER, A. N. 1966, p. 261.). How do the meteorite craters fit in here? We have to admit that they do not. With all due respect to the eminent author we have to note his total omission. Undoubtedly the meteorite crater is a landform. Also, undoubtedly, it is an "initial form" but its origin has nothing to do with the internal earth forces and volcanic eruptions Not even with the struggle between the opposing forces, because only after genesis are they affected (similarly to every other land surface feature) by the gradational forces.

In the present plea for the wider recognition of meteorite craters as significant and unique landforms, I realize that some facts concerning their origin are perhaps not fully understood yet. But at the same time I also agree with what B. W. SPARKS said: "there are few, if any, landforms, the origin of which are known with certainty. The generally accepted theory is usually only accepted because it explains a large portion of observed facts than its rivals" (1966, p. 261.).

In the first half of the century the impact origin was regarded by some as a possibility. However, today their recognition is based on scientific investigations (topographic, petrographic, gravity, magnetic, seismic, structural and electric) and we have to admit that (while the evidence is unfortunately relatively little known) they are very convincing.

It appears to the author that originally not only the North American, but especially most of the European geographers were also opposed to the impact theory. For illustration it might be the faires (and perhaps also the safest) if I quote an authority under whom I had the honor to study. This prominent member of the Hungarian School, J. CHOLNOKY, expressed his view on the impact crater theory as: "a total humbug and the acceptance of it indicates an inexpressable degree of ignorance... it is a shame that some of our scientists are even considering it seriously" (1942, p. 355.). He said this in 1912 after visiting the then only known meteorite crater in the world, the Barringer Crater in Arizona. And what he said was actually the general view of the time not only in Europe, but everywhere in the world. As a result of that view still even today we can look into any textbook onpphysical geography and we find that the meteorite craters are left out (for example, Gresswell of England, Louis of Germany, Markov of the Soviet Union, Powers, McIntyre, and Strahler of the U.S.A.).

The situation is different with American geomorphologists. Credit has to be given to Lobeck (the great delineator of landforms) who in 1939 already included in his text a small chapter on "supposed meteorite craters" (LOBECK, A. K. 1939. p. 171.). But he still treated them with caution and suspicion. A. D. HOWARD and L. E. SPOCK (1940, p. 332—345.) deserve even more credit for including the meteorite craters in their landform classification as being of impact origin — but, obviously lacking sufficient scientific proof at that time yet, they have not been taken too seriously and became disregarded by most authors in geography. The classic example of meteoric craters (the Barringer) is mentioned in Von Engeln's book of 1942, yet, in his landform classification that is according to him "forward looking and comprehensive" (VON ENGELN, 1942. p. 69.), they are not included. Strahler in the "Eart Sciences" recognizes them on the moon (STRAHLER, A. N. 1963. pp. 83—86.) but is not very convinced of their presence on the earth. He does not mention them in his later (1966) publication "Physical Geography". W. D. THORNBURY, 1954. p. 515.) is one who among the geomorphic processes includes the extra-terrestrial process, and who took a stand on meteorite craters as being of impact origin. However he discusses them under the title "pseudo-volcanic features" at the very end of his book, almost like a leftover, together with salt plugs, bomb and mine craters. Unfortunately in his book he did not include a landform classification, therefore, his "commitment" may have a shade of doubt. It might be of interes to point out here that the cited geomorphologists are with a basic geological background. If we look into the writings of geomorphologists with a more geographical education, for example, such as Wooldridge or Morgan the omission is obvious (WOOLDRIDGE, S. W. and R. S. MORGAN, 1959.).

The suggestion here is not that geologists on the whole accepted the presence of meteorite craters on the surface of the earth, while the geographers ignored it, because that is not the case. But it appears that the geologically trained geomorphologists had a more open attitude towards this unique landform.

From a survey of geographical literature (limited as it might be) it appears to the author that the meteorite craters as surface features have been neglected by geographers. This landform in some cases may range up to many dozens of miles in diameter. In addition to size is very possible that they may have some mining and recreational possibilities as suggested by DIETZ (1961) and others. Obviously they cannot continue to be overlooked by professional geographers, teachers, and students.

Interestingly enough at the last (22nd) International Geographical Congress (Montreal, 1972) there was only one paper submitted that dealt with the meteorite craters (and in the Congress volume even of that only the abstract was printed) while in the volume of the last 24th International Geological Congress (1972), tha was also held in 1972 in Montreal, a dozen articles dealt with them, obviously indicating the difference in interest. Perhaps it is not unrelated to note that if we look into the "Encyclopedia of Geomorphology" (1968) the meteorite craters are not discussed there, instead a reference is made to "The Encyclopedia of Atmospheric Sciences and Astrogeology". In other words if someone at the present time is interested in this landform or surface feature the explanation of it is not in geography or even in geology but in atmospheric sciences and astrogeology. The point here is not to question the relationship of meteorite craters and astrogeology but to indicate the absence of discussion of a landform in geography.

Today meteorite craters are known and have been studied in many parts of the world such as Canada, U.S.S.R., U.S.A., South Africa, Australia and Europe. The number of the proven ones is around 60 already and the number of the probable and suspected ones are over a hundred. Undoubtedly, as investigations continue, more and more will be recognized on the surface of the Earth. As mentioned earlier it is suspected that their presence in some places may have economic significance in mining and tourism. But their are perhaps even more significant on the buried erosional surfaces. We have every reason to suppose that in earlier geologic times of the Earth cosmic wanderers in the solar system were even more numerous and collisions or impacts were more frequent and of greater intensity than at the present time. Taking this into account the paleo-geographers also have to account on buried erosional surface for the presence of meteorite craters, or rather (as DIETZ, R. S., 1961), named the infilled ancient features) Astroblemes (Fig. 3). The writer has used paleogeographic interpretations for many years in oil exploration and at times pondered over the presence of sub-surface features that would be rather difficult to explain in any other way. It appears that oil production from a Wester Canadian field is related to impact cratering (SAWATZKY, H. B. 1972). The Sudbury Structure of Canada is believed to be more and more the result of a large meteorite impact (FRENCH, B. M. 1972, p. 125) and the huge nickel and copper reserve the result of it. The Vredefort Structure of the South Africa with its gold and diamond accumulations is strongly suggested by some (DIETZ, R. S. 1961) to be of an impact scar. All these are indicators of not only their presence but also their related economic significance.

L. KING (1967) wrote that: "It was necessary for the author to see as much of the Earth's surface as possible, yet not to interpret it in terms of preconceived philosophies; often to sit passively upon hills just letting the scenery "soak in" and teach the „beholder". This kind of stand against "preconceived philosophies" is encouraging when we seek to find order, system and possible explanations amidsthe topographic features. There is no more question about the existence of the meteorite craters on the Earth. They do exist and have to be dealt with in geography. In order to do this we have to recognize that:

1) Meteorite craters are unique because they were formed by a process not similar to the genesis of any other landform.
2) The meteorite craters are produced by the impact and the accompanying explosion of extra-terrestrial masses.
3) The resemblance of meteorite craters to volcanic craters is only superficial.
4) The possibility for meteorite crater formations on the surface of the Earth existed since the first crust was formed.
5) Their presence can also be suspected on buried erosional surfaces.

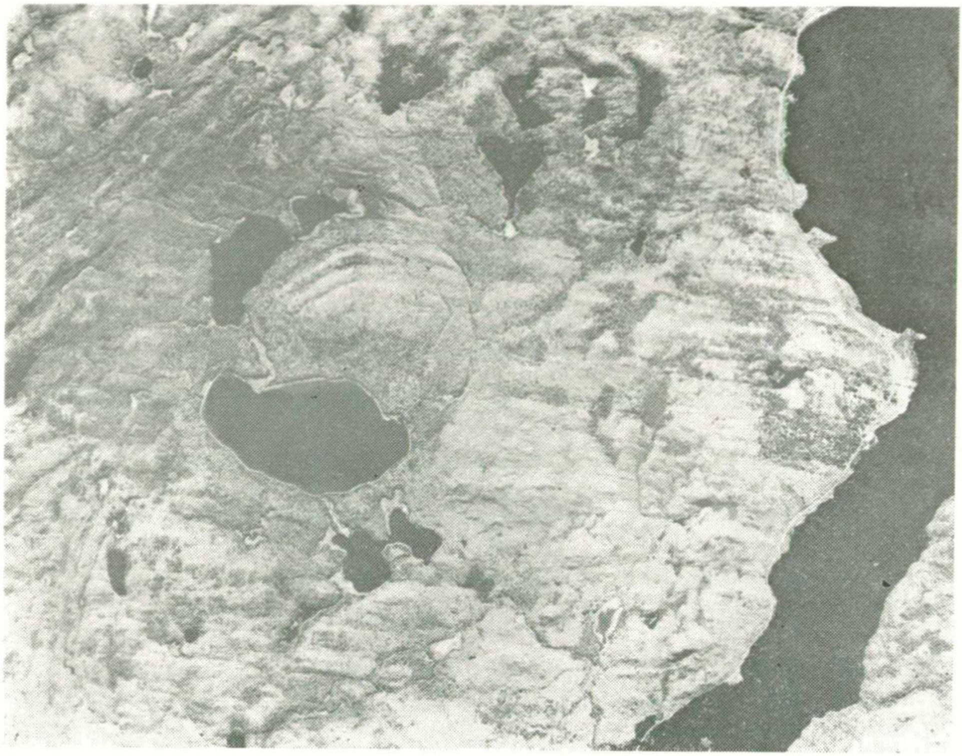

Fig. 3. The partially exhumated Brent crater (Ontario. Canada) is a good example of the astroblemes

6) The presence of meteorite craters on the surface of the Earth (and their range in size) is qualifying them from both minor and major landforms. It is necessary to regard them as extra-terrestrial (cosmogenic) landforms, which were not produced by tectonic, volcanic or gradational forces, but by cosmic forces.

On these grounds, it is proposed that they should be included in the classification of landforms in the:

a) surface forming processes (internal-external and *cosmic*),
b) classification of basins; on the basis of origin, form and size,
c) classification of lakes (besides the most important categories produced by erosion, deposition, earth movements, volcanic activity),
d) form and structure modifying forces of rocks (besides tectonics and weathering).

Until these are not recognized by geographers and included in our textbooks on physical geography, or in any other text on the earth sciences, at least as possibilities, our competence is questionable and the students of geography have every right to say that the book we make them to buy is 20 years out of date.

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