DETECTION OF ASTROBLEMES WITH THE AID OF SATELLITE PHOTOGRAPHS

L. JAKUCS

The discoveries made in the course of satellite research in connection with the Moon and the inner planets of the solar system bear witness to the fact that the effects of the impacts of comsic bodies (impact genetics) must be regarded as much more general in the forming of the surfaces of the planets than considered by traditional geology. It has been proved that on the surfaces of the Moon, Mercury, Mars and Phobos all of the other surface-forming factors are greatly outweighed by the astroblemes, i. e. the "star-wounds" created by the impacts of cosmic boides, mainly in the form of circular or nearly circular crater-like formations of various sizes.

While our knowledge was confined to the craters of the Moon and was obtained merely by means of telescopic examinations from the Earth, science tended to interret these as the results of volcanic phenomena. However, even then this assumption was not a problem-free one, because of the unusually large dimensions of most of the craters on the Moon. Since then, closer examinations made on the surface of the Moon have disproved the volcain crater theory (now maintained only by journalists), and it has become clear that the impact energies of meteorites and other cosmic masses must the surfaces water and an appreciable atmosphere.

It is obvious that laws which hold for the solar system in its entirety must also hold for the individual parts of the system, including the Earth. Thus, it would not be correct to eliminate research into the effects of cosmic impacts in drawing conclusions as to the development of the surface of the Earth.

The atmosphere and water cover of the Earth provide practically no defence against the impact of meteorites of larger mass, and even small planet-like foreign bodies; they merely "plane away" the resulting larger or smaller impact damage to the crust (destroying them, filling them in, and covering them with sediment formations). If these planation processes did not act on the Earth, then lts surface would be characterized by the cosmic "bomb-craters" formed in such a confused pattern on the Moon, or on Mercury, since these forms have of necessity occurred on the Earth too during the long history of the development of its crust. Hence, the research of astroblemes, partly denuded, partly filled with younger formations or buried by thick covering layers, and even possibly deformed structurally in the orogenetic belts, is today naturally a primary task of the realistic geosciences. One of the far from negligible factors in this is that the ever increasing number of observations indicate that the occurrence of raw materials of mining importnace may be characteristic in the impact areas.

However, the traditional geological research methods were earlier not suitable for the detection of these crater formations, often with gigantic dimensions, on the surface of the Earth. Topographical maps did not help towards this either, as the relief elements of the impact formation did not remain on the surface throughout long geological periods. At the same time, the form to be viewed overall was generally so unusually large that the distance available to the observer was not suffic cient for the system of interrelated signs to be recognized. The spreading of "aerogeology", involving the use of aeroplanes, did yield certain initial results, with the suggestion of the meteoric origin of a number of craters a few hundred metres or even 1–2 km in diameter (the recognition of the Barringer meteor-crater in Arizona, the casting of doubt on the volcanic origin of certain Jurassic–Shale Mountain maar lakes, etc.). However, the decisive discoveries and the recognition of the correlation were permitted only by the synoptic views provided from satellite heights.

The number of formations with impact genetics recognized on the surface of the Earth, including those ranging in size from a few kilometres right up to the giant craters with diameters of several hundred kilometres, has already attained several hundred. These are partially or completely broken down, buried or deformed, but they can always be identified with certainty from the cosmic photographs. At times they are indicated merely by elliptical or ring-shaped layer formations or soil or vegetation changes, since the geosurface forms not renewed by the actual geological and physical geographical processes are very rapidly destroyed in a geological sense. However, if their positions can be successfully located with the aid of the space photographs, detailed on-site research in most ceases (sometimes simply by means of deep drillings) provides other mineralogical, petrological, geological and ge physical proof too of the impact origin of the discerned structure.

In the following we present synoptic pictures of some of the larger terrestrial astroblemes, taken from the photographic material of the satellites APOLLO–9 and LANDSAT I. It must be noted that the existence of these structures was earlier either unknown to science, or (as in the case of the Great Slave Lake) the solution regarding the genesis of the basin was sought in terms of traditional geological factors.

In Fig. 1 we may see the Richat Creater discovered in the West African Mauritania, in a photograph taken from APOLLO–9. The elliptical crater basin in the centre of the picture is 55 km in diameter, and as regar*ds* its development and form structure it is completely analogous to the Aristarchus Crater on the Moon. In area A–3 on the photograph a second, much smaller crater may also be seen; this was proba bly formed simultaneously with the Richat structure. The energy arising on the impact of the cosmic mass broke up the horizontally situated rock layers of the Richat depression in such a way that an elliptical structure resulted: if we proceed in any direction from the impact centre towards the rim of the giant crater, the arc-like cuestas of ever younger rock layers follow one another. The outward-sloping declivities of the mountain ring on the rim of the formation consist of dispersed material, amd thus their structures comprise loose debris. On these slopes a weakly developed erosion valley network has been incised, but similar ones could not develop in the inner "rock-amhitheatre" of the crater.

From the above geomorphological facts we may attempt to draw conclusions as to the relative age of the astrobleme. The developed erosion valley network of the the denuded rock desert clearly discernible in the more distant periphery of the crater was formed under subtropical climatic conditions at the end of the Tertiary and at the beginning of the Quaternary. In these valley formations the crater definitely displays younger genetics, since it does not act preformatively or divertingly on the seen valley

Fig. 1. APOLLO—9 satellite photograph of the 55-km diameter Richat Crater to be found in Mauritania in West Africa. This is one of the youngest giant meteorite craters on Earth. A second, much smaller crater is also visible in field A—3; this was probably formed in an analogous manner and synchronously with the Richat structure. It is worthwhile to observe its elliptical layer cuestas, which are situated increasingly higher and are geologically younger on progressing outwards from within the "rock amphitheatre ; the now completely inactive valley systems developed in the bed mountain; and the extending sand desert covering the lower half of the picture. The relation of these difierent soil types to one another permit the chronological fixing of the impact.

systems, and there are practically no water course traces in its interior. Its development may therefore at any event be placed at after the desertification or at the initial period of this, i. e. at the end of the Pleistocene or at the beginning og the Holocene. The presence of the peripheral wadis, on the other hand, justifies that we go back in time at least to the beginning of the Holocene as regards the occurrence of the impact structure.

The sand mass covering the lower half of the picture is undoubtedly the youngest (extending) formation of the area; it nicely illustrates the currently advancing tendency of the sand desert. The photograph depicts very well how the sand cover is gaining ground at the expense of the valleys and the Richat Crater, and then later the bare rock desert interspersed by the valleys.

In the LANDSAT–I photograph in Fig. 2 we see the double, regular circular basin of the Clearwater Lakes in North Quebec, in the vicinity of the Hudson Bay. The literature previously classified these lakes as being of volcanic origin. One of the reasons why this is improbable is that the lake basins were formed in pre-Cambrian

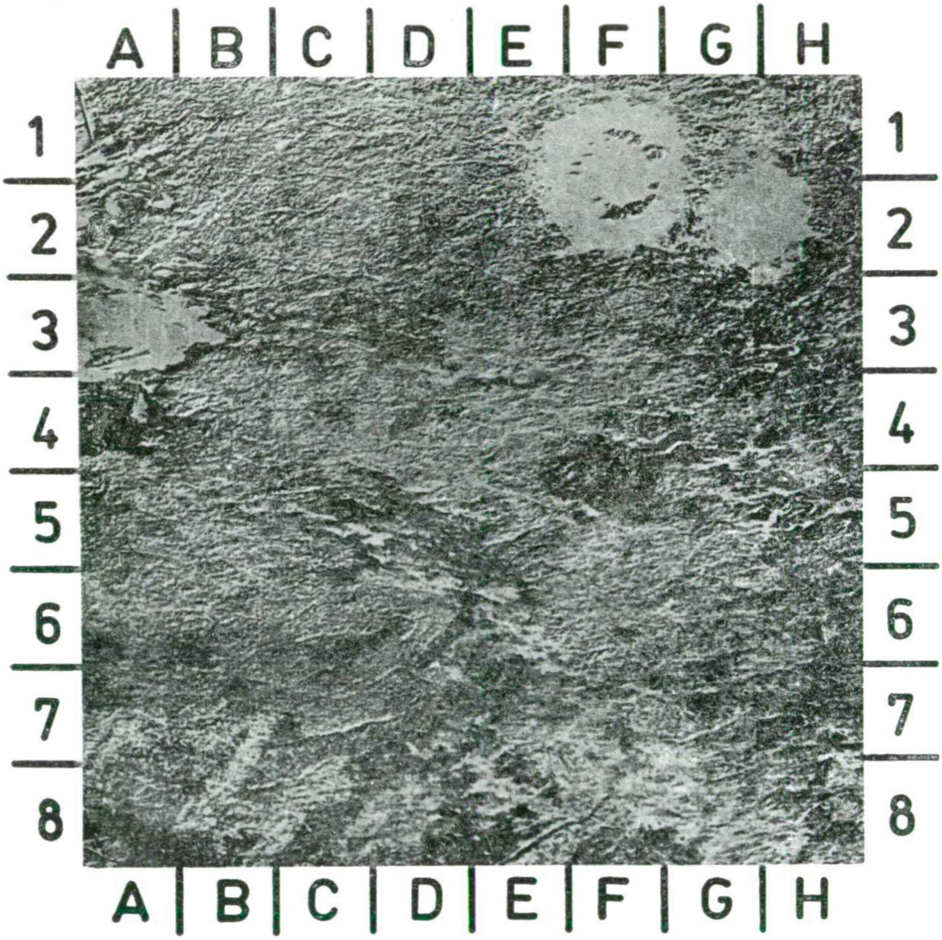

Fig. 2. The regular, circular crater basins of the Clearwater Lakes in North Quebec have now been proved to have an impact origin. The western lake basin is 30 km in diameter and possesses a ring-shaped island, while there is a central unde rwater rock cliff in the middle of the basin of the 20-km eastern lake. Numerous double-ringed meteor craters with central cliffs and with analogous genetics and morphologies are known on the Moon.

granite, and no traces at all of Recent volvanic activity occur even in the distant periphery.

Otherwise, it is certainly not chance that most of the meteorite craters on Earth may be found on the surface of the ancient Canadian apron. The cause of this is that even today the surface here consists of an ancient crust which for long periods in the history of the Earth was an uncovered and continental terrian; indeed, even that thin, loose covering layer which had been deposited on it in the course of the Pleistocene. Hence, on the ancient surface of the Canadian apron all those impact forms were able to integrate which formed on it from the geological antiquity right up to the present day, and which are buried at varioys depths in layers of various ages at other places where deposits accumulated on one another in these same periods.

The western Clearwater Lake is about 30 km in diameter, and also includes a ring-shaped island; the material of this reminiscent of strongly debris-like volcanic agglomeration, but the debris of the granite of the table is also represented in its rock material. The earlier explanations attempted to interpret this phenomenon in a fairly forced way, by the collapsing-in of a volcanic caldera. Today the genetics are no longer in doubt: numerous double-ringed impact craters similar to this are known on the Moon, without the least trace of volcanism. And even if volcanic material can actually be detected in the inside of the crater, in this case too it can only be a question of post-genetic volcanism caused by the crater formation.

The bed morphology of the eastern Clearwater Lake, with a diameter of about 20 km, is also of interest. At the centre of the steep-sided circular basin (this is not seen because of the water and ice cover) a strongly crushed underwater cliff is to be found, the rock material of which is foreign to the region; in every respect, this cliff is analogous to the well-known central cliffs of large meteor craters on the Moon, Mercury and Mars. Its material may possibly be the remnants of the mass itself which impacted and underwent destruction.

It has not yet proved possible to determine the age of the Clearwater Lakes. The inland ice cover of the Pleistocene was active above lake basins that had shore-lines of the lakes, but even more so by the phenomenon clearly to be seen in the photoggraph,that the surface of the cyclic island corolla of the western lake basin also displays itself the traces of glacial exaration. The impact therefore occurred before the Quaternary. To date, however, no other age-indicating datum or sediment has emerged from the depths of the lakes, and thus, as regards the time of the formation, the possibilities remain open from the beginning of the ancient period right up to the end of the Tertiary.

Similarly in Canada, in Central Eastern Quebec, we find the ring-shaped basin (66 km in diameter) of the Manicouagan Lake, the LANDSAT photograph of which is shown in Fig. 3. In the knowledge of the analogies with the lunar craters, we must consider that this structure too exhibits impact genetics, not only because there are no volcanic craters with such a large diameter on Earth, but also because its dimensions correspond perfectly to the average diameters of the meteor craters on the Moon and Mars.

The bedrock of the island occupying the centere of the corolla-shaped lake basin is the same as the pre-Cambrian crystalline rock that is characteristic everywhere in the entire region. Mesozoic vulcanites and sediments are also to be found on the surface of the island, however, which indicates that the crater already existed in the geohistorical middle age and functioned at that time as a local sediment-collecting

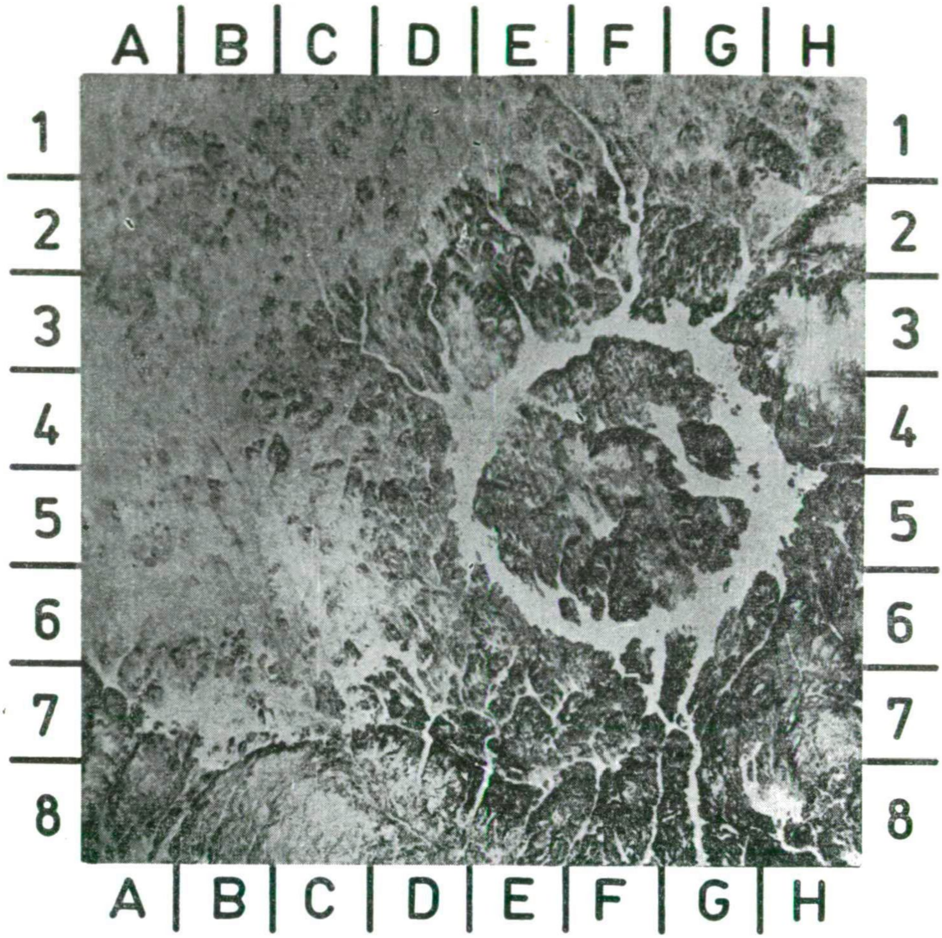

Fig. 3. A LANDSAT photograph of the Manicousagan Lake in Central Eastern Quebec. The ring-shaped basin, with a diameter of 66 km, is one of the most ancient giant meteor craters on the Canadian apron. The large island standing out at the centre of the structure was elevated in the course of post-genetic isostatic movements of the crust under the crater, also inducing weak volcanism; in the Mesozoic, however, the entire structure still functioned as a local sediment-collecting basin. The water level of the lake has now been raised; a hydroelectric power plant is operating in fild G—8.

basin. The later relative elevation of its central part presumably occurred because of isostatic reasons, for the mass loss of the crust thinning caused by maes impacts not breaking through the crust results in significant negative gravitational anomalies in the area of the crater.

Such an ancient origin of the Manicouagan Lake is otherwise also proved by the orientation of the valley systems incised into the crystalline bed mountain. The crater lake appears to be of importance in determining the directions of even the oldest waters courses, and its presence must therefore be reckoned with from the beginning of the denudation cycle of the table. On the basis of a number of morphological characteristics, it is almost certain that in this case we are concerned at any event with a much older formation than the previously considered Clearwater Lakes.

It should be mentioned that in all three crater lake satellite photographs the lake surface (differently from normal) is quite light. The reason for this phenomenon is that the lakes are frozen over, as ice (unlike water) does not absorb the light rays an therefore reflects white. Otherwise, the Manicougan Lake is operated as an artificially built-up water strogare, with the aid of the dam system perceptible in area G-8 of the satellite picture.

In the following photographs we shall be considering areas where the meteoric crater formation itself can no longer be seen, but the impact genetics are nevertheless strongly suggested indirectly. In the first case we shall examine the traces of the old cosmic impacts on a denudation terrain consisting of old rocks and not covered young deposits, while the second case involves an accumulation area covered by young sediments.

Figure 4 is a satellite photograph of a detail of the South African Transvaal. The picture clearly shows the arc-like chains built up from the alternations of the volcanic and sedimentary rock provinces of the Transvaal Mountain system, and also (in CD–12) the elliptical formation, consisting of alkaline granites, of the Pilanesberg intrusion. J. Grootenboer and R. B. Hargraves, who have been carrying out research of a geological nature in this area, have described the traces of several extremely large-scale cosmic impacts in the region of the mountain system (e.g. the huge Vredefort concameration lying to the south of the limits of the photograph). Of these, however, the form element to be seen in the satellite picture gives cause for a characteristic interpreation, since we are concerned here essentially with a basin-like elliptical granite formation, which encompasses antecedent basic and ultrabasic rocks.

When the geological formation sequence and correlations are examined, the synchronism of the occurrences of the various formations can definitely be excluded, even from the satellite picture. It is not even probable that the granite formation already existed in the activization period of the volcanism,for in this case the spatial arrangement of the vulcanites would conform to the limiting contours of the rock mass. Even on the plication of the mountain structure visible in the picture, however, the granite was not in its present position. This circumstance is proved among others by the fact that its presence does not induce any dislocation at all in the plication traverse lines of the mountain structure. The granite of the Pilanesberg must therefore be regarded as post-orogenetic in the genetic sense that the impacting mass not only gave rise to a crater basin, but also promoted the isostatic penetration of the granitic magma by means of the produced deep-acting crust fractures and significant local negative gravitational anomaly.

A very close analysis of the satellite photograph, however, also raises the possibility that in the case examinded it is perhaps not a question of an intrusion, but simply that the granite present in the bed mountain position is merely exposed by the impact crater basin, as a concequence of the mechanical removal of the younger formations on it. At any rate, a fact giving much food for thought and supporting this latter conception is that on the granite block itself, and on its entire surface too, it is possible to observe certain inner cyclic formations; these are usually signs counted as primary form characteristics of impact crater formation, in the cases of both terrestrial and lunar astroblemes.

Fig. 4. A LANDSAT photograph of the Pilanesberg structure (in DC—12) in the South African Transvaal mountain system. The circular alkaline granite basin, which also exhibits a certain ring-shaped structure in its surface relief, is in stratifaction discordance with the mountain contours in its environment (which consist mainly of vulcanites and sedimentary, carbonate rocks); it is therefore a post-orogenic formation. There are two possible altrnatives for its formation: (a) The impact crater formation, with deep-acting crust rupture, and the resulting large negative gravitational anomaly promoted the isostatic intrusion of the granitic magma. (b) The granite lying in the bed mountain position was simply only laid bare by the crater basin, by means of the mechanical removal of the younger formations on it.

In the LANDSAT picture to be seen in Fig. 5 we may examine the remnants and traces of the Brazilian Araguainha meteorite crater. This interesting buried structure has been known for only a few years. It is to be found on the 17th degree of latitude South and the 53rd degree of longitude West, and has a diameter of 40 km. Its name originates from a town of the same name built on the banks of the Araguainha, one of the largerst tributaries of the Amazon. The area is part of the "Campos", or under a different name the tropical savannah, which is covered by grass and shrubs, and in isolated places by woods.

The present relief has retained nothing of the one-time crater. Merely a small cone-like elevation stands out at the geometric centre of a large circular structure perceptible only from the satellite photograph. This hill was earlier condidered to be an old small volcano, for rock fragments suggestive of volcanic activity were found in its environment. In 1973, however, the American researcher Dietz also found pre-

Fig. 5. A LANDSAT-I photograph of the traces visible on the surface of the Araguainha Crater in Brazil. The buried structure, outlined mainly by the different vegetation types and the different soil natures, lies about 650 km west of the state of Mato Grosso, on the 17th degree of latitude South and the 53rd degree of longitude West. Similar structures have also been detected elsewhere in the prehistoric wildrenesses of Brazil with the aid of satellite photographs. The impact origin of the Araguainha Crater has since been successfully confirmed by means of deep drillings and mineralogical-petrological analyses.

Cambrian rock fragnents, sandstone and shale in addition to the volcanic material in the soil of the region. His findings were later confirmed by the microscopic petrographic analyses of B. M. FRENCH, and it thus became indisputable that the rock fragments in question originate from the bedrock under the thick soil layer covering the area. The two dark-coloured ring-bands to be seen in the picture give rise to the impression that the Araguainha structure might be a double-ringed astrobleme, whereas in reality it is not this; the centric circles merely disclose the differences in vegetation, depending on the differences in the nature of the soil, in the otherwise plain terrain.

The satellite photograph of the north-eastern arm of the Canadian Great Slave Lake (see Fig. 6) is extremely interesting and promises to give rise to much discussion in the future. The earlier mosaic-geological maps and aerial photographs did not reveal such substantial large-structural features as stand out on the present synoptic photographs, and which appear to be genetic characteristics of fundamental importance.

One such noteworthy circumstance is the fact (not interpretable via traditional geological arguments) that the archaic rock-structural outlines, well prepared by the ice and typical of the surface structure of the entire region, vary in the northerm and mainly the western immediate shore-contour of the lake basin, and the semicircular lake basin is delineated by a uniform, narrow, contact rock-band with a resistance to abrasion different from that of its environment. The most striking feature in this fact is that the closely-fitting shore chain consists of the same proterozic plicated crystalline rocks as the areas more distant from the lake basin, and the glacial exaration has nevertheless behaved selectively in favour of the shore band. All this can only be explained in that the rocks of the shore contour were made more resistant to abrasion by some process: a process (possibly syngenetic) connected with the formation of the lake basin.

The second noteworthy circumstance is the huge lineament well visible in the picture, which can be followed in a straight line from mosaic H-1 of the picture to the edge B-8, and which is part of one of the largest structural forms ot the Canadian apron, the McDonald break-system. It can clearly be assessed that the break resulted not only in a vertical movement, but also in a very significant horizontal table separation, in the course of which the eastern half of the already existing lake basin was forced tectonically away from the western semi-basin. That is, the straight eastern shore of the examined area of the Great Slave Lake is not syngenetic with the lake basin itself, but is the block-rim of a later plate-tectonic movement foreign to the process deepening the basin.

The third very thought-provoking phenomenon is the concordance in from of the shore-arc of the lake basin and the traverse directions of the island-arcs in the lake. This can be interpreted most simply in that the island-arcs earlier formed part of the semicircular shore, and then broke away from this and (on the action of the horizontal block movements along the McDonald break-system) occupied their position at the centre of the present lake (remaining somewhat behind the crust section moving away in the north-eastern direction). That the relative movement of the provinces along the break (forming the left and right halves of the picture) did in fact take place in the directions indicated by the arrows is clearly proved by the scissor-like opening of the line of the north-western lake shore and the island-arcs.

Fig. 6. A LANDSAT photograph of the north-eastern arm of the Great Slave Lake in North West Canada. The lake basin is genetically the smaller half of a bisected giant meteor crater (its original diameter was about 210 km). The missing part of the basin was shifted tectonically along the McDonald break-system which cuts across the photograph in the SW-NE direction; it now lies a position about 180—200 km to the south, and as the southern bight of the central depression of the Great Slave Lake it has been filled in by the talus of the inflowing Slave Rivere. Much geomorphological and geological evidence has been established as to the abovfl-outlined genetics of the lake structure. This evidence is described in detail in the text.

However, we wish to point out another circumstance too: besides the apparent petrographic identity, the rock material of the large-arc island bands has developed the same high resistance to abrasions as the crystalline rocks of the western shore of the lake basin. This too strengthens the conclusion that the island-arc could at one time have been the shore contour of the lake basin.

Finally, it should be noted that the McDonald break-system consists of a cluster of several straight break-planes running parallel to one another. This is well visible in the photograph, e.g. in fields H-12 and BC-8. It stands to reason, therefore, that the narrow concordant island and peninsular bands connected with the eastern shore line of the lake basin and partially merging into this are the rippling products of the friction belt between the main break-planes, and can be regarded as quasi-"macroscopic friction breccias".

On the basis of the given arguments, the north-eastern arm of the Great Slave Lake is regarded as a semi-basin with impact genetics. The formation of the originally naturally circular giant crater preceded one of the final periods of activity of the McDonald break-line passing through it, in which the crust tables including the crater basin underwent a significant shift in plane compered to one another. This movement resulted in the breaking away from each other of the two semi-basins of the lake, and in their separation along the break. Although the "half-lake" to be seen in the picture remained geomorphologically in the course of the subsequent geological periods, it shifted about 180–200 km in position, in a north-eastern direction, compared to the eastern half of the crater basin. Since then, the eastern semi-basin of the crater has become filled in, since the Slave River has deposited its enormous lacunian alluvial delta in it.

Even in spite of the fairly deformed and broken-up state of the astroblene, we assume that the age of the cosmic impact giving rise to it is not too ancient. At any event, at the bottom of the basin there are only Quaternary lacunian sediments and quite young (probably similarly Quaternary or Ternary-end) vulcanites, in a horizontal stratification, while immediately below them the drilling samples show the crystalline and metamorphous bed mountain of the Canadian apron. It is very probable, therefore, that the horizontal crust shifts in accordance with the McDonald break-line are plate-tectonic symptoms, occurring in a quite young stage, and possibly still active at present.