Space Disasters and Chevron Dunes

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Abstract

This paper describes a method of evaluating the height of tsunami wave through the height of chevron dune created by this wave. It is shown that not only the consistency between axes but between heights of different chevrons on remote from each other sea and ocean shores, may indicate the origin of these dunes from waves called giant tsunami. There was found (using space photographs) chevron on Makran coast of Iran, which together with the previously known chevron on Indian shore of Arabian Sea, as well as sediments in Lower Mesopotamia and in Bay of Chah Bahar, located near the first chevron, form a system that emerged about 5,200 years as a result of a previously unknown impact event – fall of the meteoroid in the northern part of Arabian Sea. Lines of axes of these two chevrons, crossing the Arabian Sea, give coordinates of this falling point.

There were obtained the estimates of parameters of a small asteroid – a celestial body, fall of which has created well known Burckle crater and system of its tsunamigenic chevrons, and the lower limit of the explosion energy, which occurred during this disastrous process, was defined. It is shown that it is on 3 orders of magnitude greater than the energy of the explosion of Tambora volcano in 1815 which has caused «Year without summer» on the whole Earth. Consequently, the climatic consequences of this event were so great that, apparently, this event could not have happened later than the beginning of Younger Dryas (about 12,700 years ago).

Keywords: meteoroid, asteroid, comet, impact, chevrons, explosion, tsunami, Flood

I. Introduction

There are so-called chevron dunes (chevrons) on sea and ocean coasts, which have been created (according to ideas shared by many researchers) by giant tsunami waves formed by earthquakes, volcanic explosions, landslides or falling into the oceans of large celestial bodies. World-wide list of chevrons includes 221 objects [1]. It would be expected that any from chevrons form a peculiar groups, with a common origin. As a first approximation, these groups are determined through azimuths of their longitudinal axes pointing to the direction from which the wave had come.

These azimuths show the direction (bearing) on the source of the wave. And the number of points on which these bearings indicates, is much smaller than the number of chevrons. Despite the fact that in presence of a complex coastline (protrusions, islands, peninsulas, bays and narrow straits) the line of direction of the wave motion can deviate from the radius (more precisely, from the orthodrome on the surface of geoid for big distances), drawn from the source of disturbance, possible deviations are usually not too large and fairly predictable. If desired, in each case, they may be calculated. But, for this it is necessary to know the wavelength, which becomes known only after solution of the problem, so that these studies should be made by using successive approximations. In the case of incidents of high energy the wavelengths are great and diffraction of waves on relatively small relief elements is very little. And there are many chevrons whose axial deviation from orthodrome, conducted from a source of tsunami, is practically absent.

However, the idea about giant tsunamis that have created chevron dunes on the sea shores at past, is meeting with strong objections. In contrast, somebody maintains that the dunes have aeolian (wind) origin (see, for example, [2]), mainly because of that similar structures could be found sometimes inland – a zone of dunes Palouse in the northwest of the United States is used usually as example [3]. Such statements are popular despite the fact that these chevron dunes are often composed of fairly large and heavy particles that could not be elevated with the aid of wind. In addition, the presence in chevrons of marine organisms, as well as «celestial» metals: nickel, chromium and iron, embedded in fossils, quite clearly point to underwater powerful explosions, caused by falls of celestial bodies [4]. In addition, there are evidences that Palouse dune area was created not an air but water flow during the great flood that occurred here according to geological standards recently – at the end of the Pleistocene, and probably has been caused by the melting of glaciers [4].

Large Burckle impact crater has been discovered in the Indian Ocean in one and half thousand kilometers to the southeast of the island of Madagascar at coordinates 30.865° S and 61.365° [5, 6], and on the shores of Madagascar, Africa, Sri Lanka and Australia there is a group of chevron dunes, bearing axes of which are aimed at the location of this crater. So, it is a quite reasonable assumption that these chevrons were created by giant tsunami, arising in the moment of this crater formation because of falling of celestial body. Diameter of the crater is about 29 km and it is located at a depth of 3.8 km, and the meteoroid, falling of which led to formation of the crater and the giant tsunami, should be very great.

It is quite obvious that if not only the azimuths, but the maximum heights of the chevrons, will be linked by functional dependence on the distance to the alleged source of the wave (which is derived from simple and reasonable physical considerations), then this dependence could be a new proof of their origin by water waves, not by wind. The most promising source of this kind is the object or process that created the Burckle crater. There are near three tens of known chevrons, which could be linked to this crater (see [1]). And we could also estimate the parameters of this celestial body that has created Burckle crater, and to understand whether it is possible to consider it a source of the Bible flood that is already done now (see, for example, [6]).

II. Method of determining the wave's height through the maximum chevron's height created by it

Despite the complexity of wave's emergence process during the falling of body in the water, the spread of long gravitational waves on shallow water (that is all movements of tsunami on the ocean) could be described quite simple (see, for example, [7]). Thus, despite the fact that from physical point of view it is always a wave on «shallow water» hereinafter shall distinguish waves «at a depth», that is, when the thickness of the layer of water is close to sea depth in the point of falling, and «shallow» – when the thickness of the water and the wave height are comparable. Since in the absence of the influence of the coasts such wave spreads concentrically on the surface of the water, capturing all make greater circular area of the ocean, and since dissipative energy losses during its motion may be ignored, then at the constant depth the wave height H is inversely proportional to the distance from the center of its origin L (see, for example, [8]):

$$H \sim L^{-1} \qquad (1)$$

If the wave propagates in the channel with a constant width, then for the same reasons

$$H \sim L^{-1/2} \qquad (2)$$

Changing the wave height H from the layer thickness (depth) of water S, in which it extends, as is known, is determined by the formula Airy that also was obtained from energy considerations [7]:

$$H \sim S^{-1/4} \qquad (3)$$

So that, with decreasing the depth of water the height of the wave is increased until it reaches the maximum possible value for shallow water H^* and will not become approximately equal to 3/5 of the depth of the water S^* at this point:

$$H^* = \frac{3}{5} S^* \qquad (4)$$

Then the growth of wave height stops due to the strong turbulent dissipation of energy at the forefront of the wave [9]. Farther, it moves with a constant height, and then at very shallow depths

$$S_{\lim} < \frac{4}{3} H^* \qquad (5)$$

its forefront topples, and this wave disintegrates [7].

The wavelength λ decreases with the depth:

$$\lambda \sim S^{1/2}, \qquad (6)$$

and this fact should be taken into account when considering the interaction of tsunami wave with elements of coast relief.

As we can assume, chevron dunes are some tangible evidence of ancient tsunamis, but how their height is related to the height of the waves themselves – is not clear. It seems quite evident that if there are no other restrictions, the wave height and the height of sediment layer that is raised and transferred to a new location (including chevron dunes) must have a functional relationship between the energy required to create a layer of sediment and the available energy of wave. In the case when the portion of energy used to create a layer of sediment from available energy is changed a little in the scaling, the functional link may look very simple. In fact, as is well known [7], the wave energy is proportional to the square of its height (at the constancy of rest its sizes):

$$E \sim H^2$$

In that case, while maintaining the geometric similarity, complete (existing) energy of the gravitational wave E_a is proportional to the fourth degree of any size, including height:

$$E_a \sim H^4$$

Exactly the same proportion would be described the relationship between the maximum height of sediment layer, and the energy needed for its formation, but only while maintaining the geometric similarity of this layer. However, experience shows that the shape of the layer of sediments is not remain constant when changing its scale. If the wave height is low, this layer has an almost uniform thickness. However, the sediment layer is becoming more wavy with increasing its height. Strictly speaking, smooth sandy beaches and chevron dunes themselves quite are proof of this assertion. Therefore, the characteristic dimensions and the height of the center of gravity of the dunes while increasing their size will grow more slowly than their maximum height. Consequently, the energy E_r, required for their formation, may be described in the first approximation as follows:

$$E_r \sim h_{max}^{\gamma},$$

where the exponent $\gamma < 4$. In this case, due to the relatively slow changes in the shape of sediment layer, when the layer thickens, the value of γ is unlikely to be markedly lower than 3.

It follows that, at least to a first approximation, the maximum height of the chevron (in the absence of non-energy limits) is associated with a maximum height of the wave as follows:

$$h_{max} = kH^{4/\gamma}, \qquad (7)$$

where k is whilst unknown coefficient of proportionality. Obviously, with such structure of the formula (7) the maximum height of the dune h_{max} may exceeds the height of wave, and this is odds with reality. Therefore it is necessary to introduce an additional, purely geometrical constraint:

$$h_{max} \leq H \qquad (8)$$

This height is called critical. It is determined by the value of the coefficient k and the exponent γ:

$$h_{cr} = H_{cr} = k^{\frac{\gamma}{\gamma-4}}$$

As a result, from the assessments of the heights of the chevrons was found that the exponent $\gamma = 3$ is well suited for further verification. Then

$$h_{max} = kH^{4/3} \qquad (9)$$

and

$$h_{cr} = H_{cr} = k^{-3} \qquad (10)$$

According to the archaeologist Sir Leonard Woolley, the height of wave, which has created a layer of sediment in the ancient city of Ur in Mesopotamian flood («Flood») with a maximum thickness of 3 m, «as it follows from the Bible» had to be 8 meters [10]. Then from (9) the coefficient $k = 3/16 = 0.1875\ m^{-1/3}$, and the critical height of wave in the formation of dunes is $H_{cr} \approx 150$ m. At such heights chevron dunes are compared with the heights of the waves themselves. When the heights of the waves are not so high, chevrons may be 2 – 3 times lower than the wave, and at very small scales these wave-like structures are turning into a fairly even layers of sediments.

III. Selection of chevrons suitable for analysis and verification of calculation method

As mentioned above, at least 30 chevrons could be associated with Burckle crater. However, not all of them are suitable for verification of formulas (9) and (10). In addition to the geometric and energy restrictions on the maximum height of the chevrons there may be many more others. The most obvious limitation of this kind may be banal lack of a suitable particulate material. In addition, chevrons may remain in the shadow of different islands, headlands, and chevrons may be located in the narrow straits or bays. In these circumstances, the formula (1), valid for unlimited ocean, no longer adequately reflect the change of the wave height from the length of its run. And at some parts of the trajectory of wave motion the relationship between its high and long run will be better described by the formula with an exponent less than 1, up to ½ and even lower. Moreover, in such cases, with a significant deviation from the initial direction of the wave could be substantial losses of its energy. If there is closeness of the wavelength and the size of obstacles, there should be considered the effect of diffraction of waves. In all these cases, we lose the ability to properly evaluate the actual wave height, which is necessary for verification of the formulas (9) and (10).

Therefore, chevrons with maximum heights should be used for verification from closely spaced, so this gives some assurance that the lack of bulk material was not in this location. In addition, the chevrons should be situated on the open sufficiently long flat beaches, not in shade of large (comparable with the wavelength) islands. It is clear that the distances from the crater to various chevrons should differ significantly. For chevrons from Burckle group such «standard» exemplars were found of 4: two on the island of Madagascar (the chevrons 156 and 157), one – in Mozambique (Chevron 141) and one – in South Australia (Chevron 198). They are described in Table 1.

Table 1

Object	Latitude (º)	Longitude (º)	L (km)	h_{max} (m)	H_1 (m)	H_2 (m)	H_3 (m)	ε (%)
Burckle	– 30.865	61.365	0	–	–	–	–	–
Chevron 156	– 25.46	45.72	1645	190	190	102	103	0.9
Chevron 157	– 25.22	44.59	1750	182	182	96.8	96.8	0.1
Chevron 141	– 24.13	35.48	2685	115	123	59.4	63.1	6.1
Chevron 198	– 33.87	122.06	5630	60	75.7	32.3	30.1	–7.0
Flood's Meteoroid	21.12	62.79	0	–	–	–	–	–
Konarak	25.47	59.48	590	12.3[*)]	23.1	7.5	7.5	–
Chevron 167	22.78	69.44	710	10	19.7	6.2	6.2	0.0
Ur	30.96	46.10	2200	3.0	8.0	2.0	2.0	–

[*)] – calculated value.

This table shows the geographical coordinates of all the enumerated objects and the distance L to the chevrons from group of Burckle (first four dunes), and from the point in the northern part of the Arabian Sea under the name «Flood's Meteoroid» up to two local chevrons and to ruins of Ur – area where archaeological excavations have shown the presence of three-meter layer of sediments. This table contains the value h_{max} – maximum height of chevron or thickness of deposits in Ur, H_1 – maximum height of the tsunami wave in shallow water, defined by the formulas (9), (10) through the height of the chevron. In addition, in Table 1 we can see magnitude H_2 – height of the tsunami wave which would at the same point, but in the open ocean with initial depths (3800 m – for the first group and 3500 m – for the second group of the objects). The first value is the depth in the area of Burckle crater, and the second is the assessment in the Arabian Sea at the specified point. The value H_2 is calculated from the height H_1 of wave in shallow water in the iterative process by the formulas (3) and (4). Further, H_3 is the height of tsunami wave, which is obtained by minimizing of LH_2 using the least squares method that means the recalculation of wave heights by the formula (1). The last column of Table 1 shows the relative difference between the heights H_2 and H_3 of the wave as a percentage, which demonstrates precision of the method for calculating the height of the wave through the height of chevron. Since the values H_2 and H_3 for chevron 157 are virtually identical, so the values H_3 for other cases are the heights of chevrons that were recalculated according to the formula (1) with chevron 157.

The trajectories of waves from Burckle crater to chevrons 156, 157, 141 and 198 are shown in Fig. 1. Even they, strictly speaking, do not fully meet all the requirements to «standard chevrons»: chevrons 156, 157 are located on the island, even though this island of Madagascar is very large. The same island has «propped up» the wave of chevron 141 from north, causing it to turn on the southern tip of the island to north into Mozambique Channel. And Australian shore «propped up» the wave of chevron 198 at the end of its trajectory from the north also. But, as shown by further calculations, the length of the tsunami wave at a depth was about 100 km, and in the shallow water at the Madagascar it was about 30 km (see Eq. (6)), whiles the characteristic transverse size of the island, even in the south, is of about 10 times greater. Therefore, the diffraction of waves in the neighborhood of chevrons 156 and 157 should be insignificant, and with our point of view this island is almost no different from the mainland. While the influence of the boundary conditions at the heights of the waves for chevrons 141 and 198, apparently, explains the difference with the average values of this parameter in some percent (see the last column of Table 1).

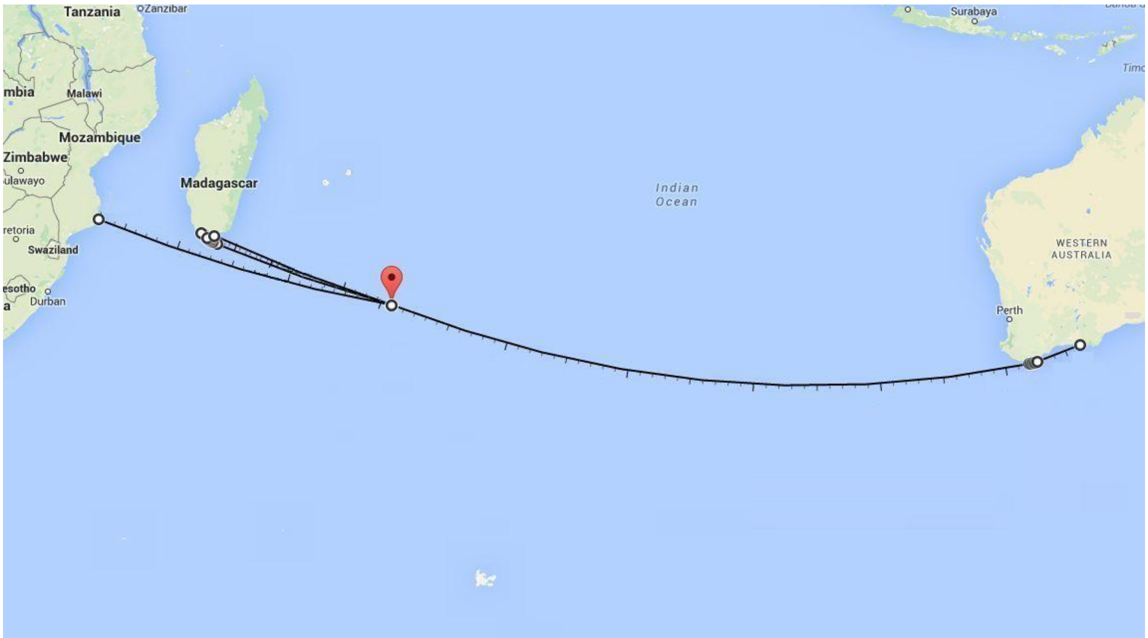

Fig. 1

IV. Formation of a new group of chevrons with the center in the north of the Arabian Sea

Along with well-known chevrons of Madagascar and Australia, which sometimes reach a height of 200 m and more, in the north-eastern Indian coast of the Arabian Sea in Gujarat near the town of Mandvi near the point with coordinates 22.78° N and 69.44° E is the modest chevron 167 with a maximum height of about 10 m. Unlike their more famous counterparts, forming some related group, that chevron is not included in any group, what is evident from the azimuth of the axis that is bearing on the source of its origin. But the bearing points on the northern part of the Arabian Sea, it is precisely on that area, which was considered as a possible area of falling of Flood's Meteoroid – suspected cause of the Biblical «Flood» [11], see Fig. 2.

Fig. 2

In this regard, revision of large-scale photos of northern shores of the Arabian Sea has been made in Google/Earth system and on the Iranian coast in about of 90 kilometers west of Konarak town at 25.47° N and 59.48° E (see. Fig. 2) typical dunes were found, which are very similar to the chevron 134 in South African or chevron 154 on the southern tip of the Madagascar Island. Everyone can easily make sure in this fact, using Google. Photo of newly found Iranian chevron, which was named Konarak, is presented in Fig. 3

Fig. 3

Lines in Fig. 2, 3 are the bearings to source of tsunami wave, which has created these chevrons. The intersection of bearing lines of Konarak chevron and Indian chevron 167 gives a point of falling of the meteoroid, which is converted from a hypothetical to real object in the moment. It should be noted that these two chevrons are positioned very well to determine the point of incidence (the angle between the bearings lines is very close to direct) and the size of the area of falling is estimated at no more than 0.5°. The coordinates of the nominal point are 21.12° N and 62.79° E. This point is located in the deepwater area of the Arabian Sea in the north of Arabian Depression with a flat bottom and depths in this area of 3 to 4 km [12]. So, the thickness of the water layer at this point was estimated in 3500 m.

Distances from the point of meteoroid's incidence to chevron 167 and to Konarak chevron were measured, and they are equal to 710 km and 590 km respectively (see Fig. 2). The distance in a straight line to Ur city, where three-meter layer of sediments was found [10], is equal to 1990 km. However, tsunami could not spread in a straight line – the Arabian Peninsula Musandam lays on its way. It is known that the wave on the water surface in narrowness at sufficiently large distance from the source forms a rectilinear front of constant height and is moved there with very small losses, even when their depths are small. The wave front is practically normal to the longitudinal axis of the narrowness and its twists don't influence into wave propagation (see, for example, [7, 9]). Therefore, the approximate trajectory of tsunami propagation up to Ur was carried out taking into account these considerations (the ancient coastline of the Persian Gulf was laying near this city). The length of the path of the wave from the point of meteoroid's incidence to Ur was approximately 2200 km (see Fig. 4).

Fig. 4

When the tsunami wave is entering from Arabian Sea into the Gulf of Oman, further into the Strait of Hormuz, and then, into the Persian Gulf, there are factors, which may affect both in one and in the other direction compared to the wave propagation in an unbounded ocean. On the one hand, there are the energy losses along the banks and because of turns of wave trajectory in the vicinity of the Strait of Hormuz, as well as losses due to successive contractions and expansions of the channel. On the other hand, at a distance of several hundred kilometers from the start of the wave its height is determined from the distance not by formula (1), but by something close enough to the formula (2). This means that in «average» the wave energy dispersion practically stops here along its path because of the approximate constancy of the width of the channel. Which of these factors will prevail, we cannot now to say. However we can see that the thickness of sediments in Ur and the height of the chevron on the Indian coast are fully consistent with each other subject to the calculation with the aid of formulas (1), (3), (4), (8) – (10) (see the last two rows of Table 1). And any one of these two calculation points can be added to first four points from table 1 to calculate the standard deviation from data obtained in two different ways.

The standard deviation of these 5 points is only 4.2 % for the range of variation of the maximum thickness of sediments from 3.0 m to 190 m. It is an excellent result, taking into account all attendant circumstances. This means that the method of recalculation of wave height with a maximum height of the chevron works with sufficient accuracy.

V. Influence of sea shores on waves energy and estimation the accuracy of the proposed method

There was a similar situation when tsunami wave has moved through Mozambique Strait (see Fig. 5). As in the Strait of Hormuz, the wave has been deployed by more than 90º, entering the convergent channel and leaving then this sea narrowness. Qualitative difference between these two cases is only in that after leaving from the Strait of Hormuz the wave was moving along fairly narrow Persian Gulf of approximately constant width, but there were almost boundless space of the Indian Ocean on the east for the wave after leaving from Mozambique Strait. This leads to the dispersion of wave energy in an eastern direction, so we can expect that the linear model of recalculation on formula (1) will lead to some overestimation of wave height, and therefore the height of the chevrons on this coast of Africa.

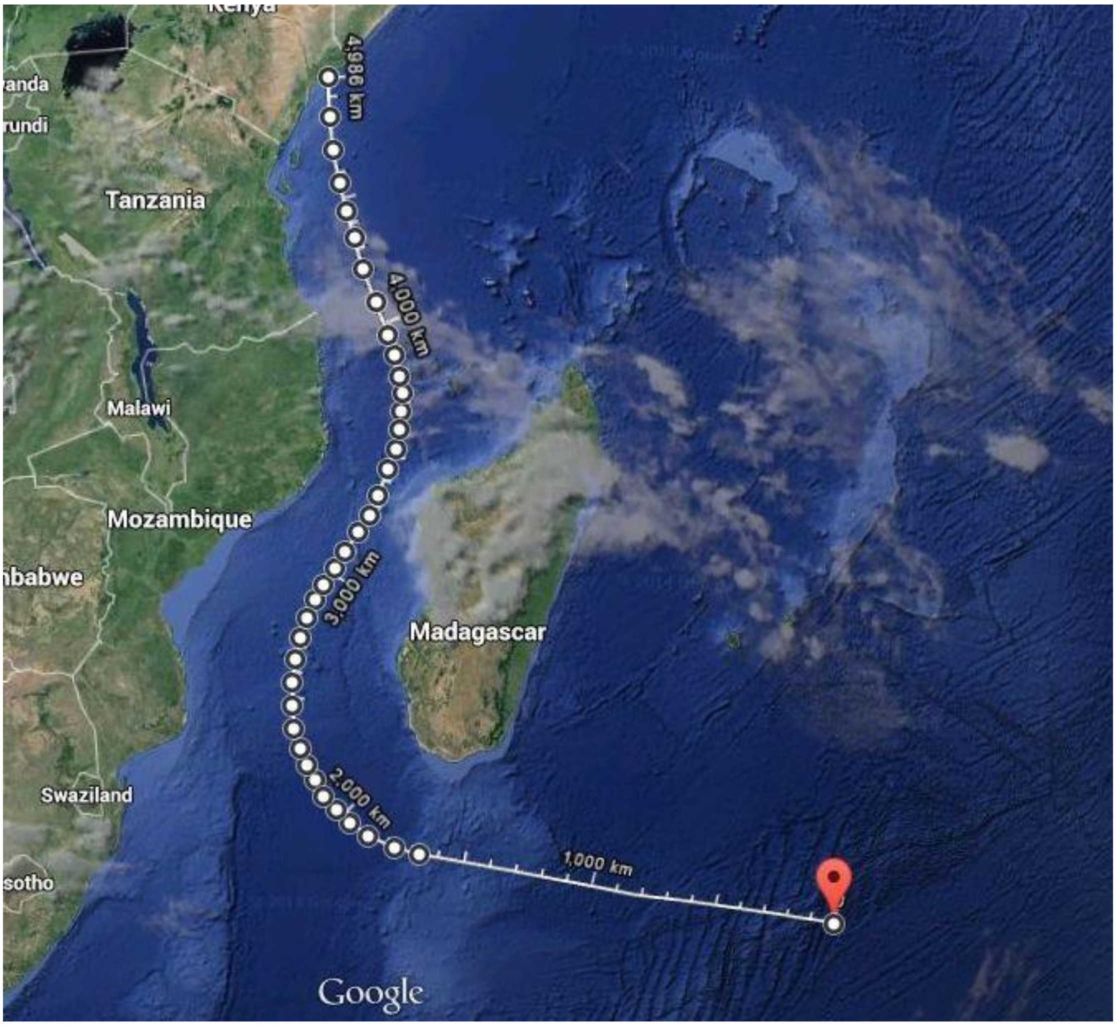

Fig. 5

We can see that so occurs in reality. Table 2 shows the data for chevron 157, for which there is a complete coincidence of wave heights calculated by two different ways, data for chevron 141, which is located at the entrance to the Mozambique Channel, and two new chevrons. One of them is (chevron 143) is at 285 km to the north on a small island in the strait off the African coast, and the second (chevron 144) is far beyond the exit of the strait on ocean beach in Kenya. Its location is depicted by end point of trajectory shown in Fig. 5. Discrepancy between the data for chevron 141 is still acceptable, but there is a progressive revaluation of the wave height with using linear estimation (1) for chevrons 143 and 144. Note that the chevron 143 is located on the island, characteristic dimension of which, normal to the front of the tsunami, is less than the wavelength in this ocean area, and therefore there should be the attenuation of wave due to diffraction, which increases the divergence of estimates in this point. We can see here a progressive divergence of estimates because of the growth of wave's energy dissipation along curved trajectory, which is not compensated by a decrease in dispersion.

Table 2

Object	Latitude (º)	Longitude (º)	L (km)	h_{max} (m)	H_1 (m)	H_2 (m)	H_3 (m)	ε (%)
Burckle	– 30.865	61.365	0	–	–	–	–	–
Chevron 157	– 25.22	44.59	1750	182	182	96.8	96.8	0.1
Chevron 141	– 24.13	35.48	2655	115	123	59.4	63.1	6.1
Chevron 143	– 21.56	35.49	2885	100	111	52.2	58.6	11.7
Chevron 144	– 2.30	40.83	4985	55	70.9	29.8	33.9	12.9

The wave, which has created chevron 144, was moving approximately along the trajectory shown in Fig. 5. This fact follows from the azimuth of axis of this chevron. As seen in Google/Earth, the azimuth is deviated from the meridian not more than 10º. It is not clear, why was not found in those places traces of tsunami that went along the north of the island of Madagascar according more shorter path after the same explosion. Perhaps this is due to the fact that the wave, which has moved to Kenyan shore from the open ocean, was so weakened because of the diffraction on the northern tip of this island, so the wave that came on the Mozambique Channel later turned out to be higher and more powerful and the second wave has erased the traces of the first wave. In addition, the analysis of many chevrons shows that the approach of the tsunami wave at an acute angle to the shoreline is optimal for creating high chevrons, if the height of the area is growing rapidly with distance from the coast.

We can conclude that tsunami wave during the passage across sea narrowness can lose quite noticeable part, but not large share of its energy. And upon further movement through the channel of approximately constant width, the influence of these losses can be offset by diminishing of dispersion of the energy in the direction normal to trajectory. So, there is no too surprising that the wave of Flood's Meteoroid, according to calculations, would be the same height after passing along a curved path, like when moving for the same distance in the boundless ocean.

VI. Dimensioning of meteoroid that could create Burckle crater and chevrons of its group

So, it is now possible to determine height of the tsunami wave, which arose after formation of Burckle crater. Considering that the crater was formed by the impact and explosion of the meteoroid, we may define the possible parameters of this celestial body. For this, as in other studies by author of this kind, the interactive program applies for calculation of falling and fracture of meteoroid [8, 13]. Four parameters, characterizing this meteoroid, should be set in this case: diameter D, average density of the substance of impactor ρ_i, speed v and angle of entry into the atmosphere δ. Furthermore, it should specify the thickness of the water layer S that should be pierced before hitting of the ocean bottom. We have two independent parameters that determine the solution of the problem: the diameter of the crater and the height of the tsunami wave at some known distance from the point of impact. Because of the inverse linear function of the wave height from the length of its path in the boundless ocean, any number of conditions for the wave height gives only one boundary condition for the solution of this problem (as opposed to boundary conditions concerning to maximum overpressure on air shock wave – such conditions may be used as much as necessary because of their non-linearity).

Therefore, for an unambiguous calculation lacks two parameters characterizing the process. However, to analyze of its potential characteristics can be used typical values of the three options of meteoroids, such as: iron-nickel (ρ_i = 7850 kg/m^3), silica (ρ_i = 3200 kg/m^3) and the snow-ice core or fragment of the comet's nucleus (ρ_i = 500 kg/m^3). Then there is only one unknown parameter – velocity, but it can be variated within reasonable limits, and we can see what happens as a result.

In addressing the specific task of evaluating the characteristics of the celestial body, falling of which creates (or could create) Burckle crater and associated group of chevrons, we have the following input and output data: the density of the meteoroid ρ_i – are appointed 3 options mentioned above, the speed of falling v – varies, the thickness of water layer is equal to the depth of the ocean water at the location of the Burckle crater – S = 3800 m, the diameter of the crater d = 29.0 km, the height of the tsunami wave at the depth at a distance of 1750 km – H_3 = 96.8 m (see Table 1). The density of the target material (the ocean floor) is standard for this algorithm – 2750 kg/m^3 [13]. The purpose of the calculation – for assigned speed of meteoroid into the Earth's atmosphere v to calculate the angle of entry δ, the diameter D, the mass m and the energy of impact and explosion of the meteoroid E_e. The last parameter determines the scale of the whole disastrous process which will determine its influence on the environment.

Calculations were carried out for everything possible range of speeds of falling for bodies from solar system onto the Earth – from 11 to 72.5 km/s. First, with a constant step Δv = 6.0 km/s from the initial value of v = 11 km/s to the value of 71 km/s parameters were calculated of iron-nickel impactor, able to create a crater like Burckle and its system of chevrons, which were analyzed in section III of this paper. Then, similar calculations were performed for silicate impactor. It was found that the impactor sizes throughout the range of parameters are so large that the Earth's atmosphere already has virtually no effect on its interaction with our planet. Therefore the meteoroids have reached the water surface as a whole, without destroying into pieces (see [13]), and the impact energy is within the accuracy of the algorithm coincides with the kinetic energy of the meteoroid in the vicinity of the Earth. Furthermore, it has been found that there is a limit falling speed of silicate asteroid at which the solution of the problem exists, and this speed is lower than the maximum speed of falling to the Earth for heavenly bodies of the Solar system. Therefore, the calculations with a constant step of velocity can be made only for the speed up to 59 km/s.

Results of stepwise calculations are presented in Fig. 6, which shows the dependence of entry angles δ_a – for iron-nickel impactor and for silicate – δ_c (in degrees) from the velocity v, and the energy of impact and explosion E_a and E_c, respectively (in teraton of TNT, 1 Tt = 10^{12} t = 10^6 Mt).

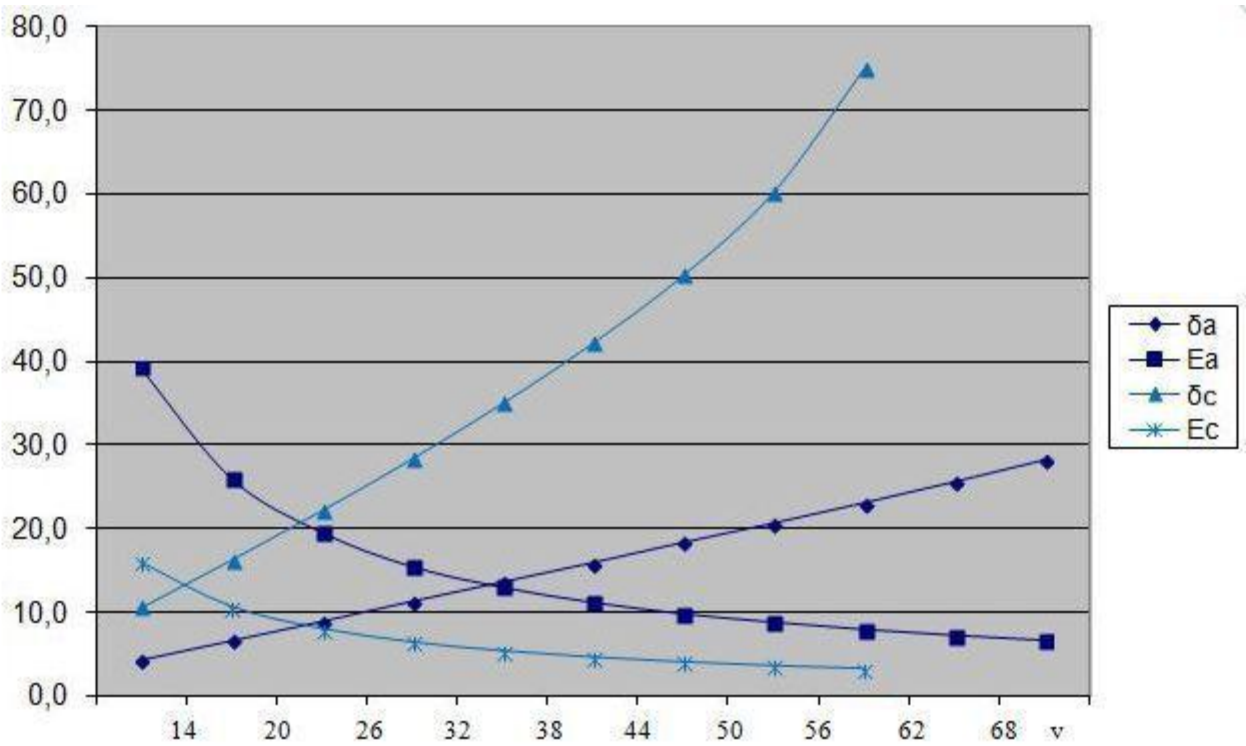

Fig. 6

With the speed is over about 60 km/s, then the entry angle δ_c of silicate meteoroid reaches the limit 90º, and for higher speeds, this problem has no solution. As the result of calculations it was found that the diameters of the two considered meteoroids almost coincide at the same speed – D = f_1(v) that was not quite obvious a priori. Furthermore, there is a linear dependence between the inverse diameter D^{-1} has and the velocity v:

$$D = \frac{1000}{0.115 + 0.0101(v - 11.0)}, \tag{11}$$

where the diameter of meteoroid is measured in m and the speed – in km/s. The standard deviation of calculation results and data from the formula (11) was only 0.21 %.

Given the structure of formulas describing cratering in interactive program [8], more predictable (see [13]) was that the set of parameters $\rho_i \sin\delta$ is the function of speed also – $\rho_i \sin\delta = f_2(v)$. This function f_2 is linear on the velocity with a standard deviation of 0.18 % in all, and, therefore, for the entry angles satisfying the solution of the problem is the following approximation:

$$\delta = \arcsin\left[\frac{589 + 52(v - 11.0)}{\rho_i}\right], \tag{12}$$

where the density of impactor ρ_i is measured in kg/m^3.

Formula (12) implies the existence of the maximum speed of the object v_{lim} (when δ = 90º):

$$v_{lim} = 11.0 + \frac{\rho_i - 589}{52}, \tag{13}$$

and the lower the density, the lower this speed. According to (13) v_{lim} = 150.6 km/s for iron-nickel meteoroid, v_{lim} = 61.2 km/s for silicate object, and v_{lim} = 9.3 km/s for comet's nucleus with density of 500 kg/m^3. And this value of speed is lower than the minimum velocity, at which the celestial bodies fall to the Earth – $v_{min} \approx$ 11 km/s (the escape velocity on the surface of the Earth is 11.2 km/s, but at the entrance of object from west the rotational speed of the Earth is subtracted from rated speed and it may be reduced by about 0.4 km/s during the entrance with very flat trajectory near equator). If the density of the impactor is equal to the density, for example, Itokawa asteroid ($\rho_i \approx$ 1900 kg/m^3) [14], the v_{lim} = 36.2 km/s.

Thus, the fall of the comet, in principle, could not form a Burckle crater. This is due to the fact that the object of such low density much more effectively creates tsunami than crater in a solid crust of the Earth, and the balance of these active influences on the hydro- and lithosphere as part of the problem cannot be achieved on some real speed. This balance can only exist, when density ρi > 589 kg/m^3.

Further calculations showed that for all values of the density in the range

$$500\ \mathrm{kg/m^3} \le \rho_i \le 7850\ \mathrm{kg/m^3}$$

the obtained from expressions (11), (12) values of velocity v and entry angle δ differ typically from the calculated with the aid of program [8] not more than ± 5 m/s and ± 0.05º m respectively. So instead of numerical calculations to determine the parameters of the Burckle impactor at a given entry speed for any reasonable value of its density is sufficient to use the approximate expressions (11), (12). The mass of the object and the energy of explosion are easily determined by the formulas

$$m = \frac{\pi \rho_i D^3}{6}, \qquad (14)$$

$$E_e = \frac{mv^2}{2} \qquad (15)$$

In order to convert the energy of impact and explosion of the impactor from SI units into megaton or teraton of TNT, is enough to divide the result by $4.18 \cdot 10^{15}$ J/Mt or $4.18 \cdot 10^{21}$ J/Tt, respectively.

The results of calculations of certain representative embodiments of the Burckle meteoroid are shown in table 3. The first 3 rows of the table correspond to utmost speed of entry v_{lim}. This speed for iron-nickel meteoroid MB-lim-1 is much higher than the maximum speed of celestial bodies from Solar System. The small difference between the results of numerical calculations and estimations by formula (13) is because the Earth's atmosphere affects the movement of dense but not too large meteoroid at this high speed, resulting its destruction in the air, and dissipation of about 0.01 Gt energy (in TNT) before the impact and explosion. For maximum speed of entry of Solar System objects (MB-1-max option) v_{max} = 72.5 km/s, entry angle δ is less than 29º, mass of the impactor increases by the order, and energy – more than 2 times in comparison with the utmost speed option of meteoroid. Version of the iron-nickel meteoroid MB-1-min with minimum speed has an absolutely unimaginable size and mass for such celestial bodies. For a better understanding of the scale of considered impactors we may compare their with 67P/Churyumov-Gerasimenko comet, mass of which is almost exactly equal to 10 Gt [15].

Table 3

var	v (km/s)	δ (º)	ρ_i (kg/m^3)	D (m)	m (Gt)	E_e (Tt)
MB-1-lim	151.8	90.0	7850	656	1.16	3.18/3.19
MB-2-lim	61.2	90.0	3200	1607	6.95	3.11
MB-3-lim	9.3	90.0	500	10280	284	2.94
MB-1-min	11.0	4.30	7850	8715	2720	39.3
MB-2-min	11.0	10.6	3200	8715	1110	16.0
MB-1-mid	41.0	15.9	7850	2390	56.1	11.3
MB-2-mid	41.0	42.2	3200	2390	22.9	4.59
MB-1-max	72.5	28.8	7850	1360	10.3	6.49

However, any variants of iron-nickel impactor seem to the author of this work not compatible with our ideas about the structure of the solar system. So-called «metal» asteroids of spectral M class are known, of course. However, their average density is much lower than the values used for iron-nickel version of the impactor, and they are pretty close to the density of its silicate version [16]. Among real iron-nickel celestial objects, Arizona meteorite is known as the largest with a diameter of about 40 m and mass of about 0.3 Mt [17], which is almost 200 thousand times smaller than average variant MB-1-mid of Burckle impactor. Therefore, it should be assumed that the iron-nickel impactor capable to create the Burckle crater and its system of chevrons cannot exist in reality, like a comet. All these geological structures could only be created by carbon, silicate or «metal» asteroid with the average density of about from 1800 to 3500 kg/m^3.

As follows from system of equations (11) – (15), minimum energy of impact and explosion of the asteroid needed to create Burckle crater and its chevrons is 2.93 Tt TNT (at v = 11.0 km/s, δ = 90°, ρ_i = 589 kg/m3). This is the lower limit of the energy for this process. We also note that the maximum size of the crater in the water after the fall of the impactor in all variants of calculation is very close to 50 km. If we consider this crater in the water as a half-wave dipole oscillator, the length of tsunami wave at the depth can be estimated as mentioned above in section III, in 100 km.

The size of Burckle impactor is great, and it should be greater, the lower the speed of its entry into the Earth's atmosphere. Therefore, the asteroids that are the closest to the Earth can apparently be excluded from this consideration. In such circumstances, the most likely objects could be from main asteroid belt or groups of Trojan asteroids [18] ejected due to gravitational effects of Jupiter or other giant planets to elongated orbits with a perihelion less than 1 AU. If the aphelion of asteroid was not changed much, then, for Jupiter Trojans its greatest value may be close to 5.5 AU. The minimum value of the perihelion of all known asteroids has Phaeton [19], and it is around 0.14 AU. If the extreme values are 5.5 AU for aphelion and 0.125 AU for perihelion, the entry speed of the object in the Earth's atmosphere should be about of 40 km/s. If the asteroid has «dropped» off the bottom border of the main asteroid belt, its aphelion is only slightly more than 2 AU. Then the speed of its entry into Earth's atmosphere will be equal to about 12 km/s for perihelion about of 1.0 AU. Thus, the entry speeds of asteroids between 12 and 40 km/s is the speed range, which should be considered in addressing this problem.

The average density of sufficiently large asteroids is considerably lower than the density of the small pieces of such materials because the porosity. Therefore for silicate asteroids characteristic density is close rather to 2000 kg/m^3, and for «metal» – to 3000 – 4000 kg/m^3. Therefore, we now consider the entry speed of impactors in the range of 12 – 40 km/s with the density of 3500 and 1800 kg/m^3. Their characteristics are shown in Table 4. Critical entry speed is 34.3 km/s for objects with lower density, so this value is the maximal for them. According to [13], the number of objects larger than MB-4-1 and MB-5-1 options is in 10 – 15 times less than the number of objects larger than MB-4-3 and MB-5-3 options. So that the options of Burckle impactor with speeds of about 12 km/s and somewhat higher are very unlikely. Incidentally, MB-5-1 option is in mass nearly to 50 comets 67P/Churyumov-Gerasimenko together, and MB-4-1 is almost 100.

Table 4

var	v (km/s)	δ (º)	ρ_i (kg/m^3)	D (m)	m (Gt)	E_e (Tt)
MB-4-1	12.0	10.55	3500	7995	936	16.1
MB-4-2	20.0	17.6	3500	4855	210	10.1
MB-4-3	40.0	36.8	3500	2450	27.0	5.17
MB-5-1	12.0	20.85	1800	7995	481	8.29
MB-5-2	16.0	28.15	1800	6040	208	6.37
MB-5-3	34.3	90.0	1800	2855	21.9	3.09
MB-Ph	35.7	69.5	2000	2745	21.6	3.30

Much more likely impactors with entry speeds into Earth's atmosphere in the range, the boundaries of which are determined by options MB-4-2, MB-5-2 and MB-4-3, MB-5-3. And after this conclusion, there has arisen the idea to take a closer look at Phaethon asteroid with its highly elongated orbit. Despite not very high aphelion, which is 2.4 AU, its entry speed is near 35.7 km/s that is rather close to the limit speed corresponding to its average density of 2000 kg/m^3. Therefore, an object of this type is quite close to the impactor with the minimum energy of the process. Its parameters are shown in the last row in Table 4 called MB-Ph. The explosion energy of this impactor‘s option is on 12 % above the absolute minimum, and, surprisingly, such an asteroid, only in 6 times greater by mass, not only exist in reality, but occasionally approaches quite close to the Earth [19]. The smaller the object size, the more often they are found in the solar system, and therefore, a mini-Phaeton with mass in two 667P/Churyumov-Gerasimenko comet is the most likely option of impactor that has created Burckle crater and system of its chevrons. Investigation of the structure of Burckle crater can allow unambiguously estimating the angle of entry of the impactor, the energy of its explosion and the characteristics of its trajectory.

VII. Discussion of results

Thus, the results of this study make it possible to move from a purely empirical material – maximal height of various chevron dunes to assessment of parameters of the impactor caused a wave, which has formed these dunes. After analyzing of chevrons of Burckle group there began to take shape the contours of a celestial body that has created this crater. More carefully examining of this crater may to allow clarifying the characteristics of this celestial body.

It was assumed earlier, for example, that the Burckle crater was created by comet in May-June 2807 BC, a fall of which led to «a strong explosion (with 100 – 200 gigatons in TNT)» [20]. However, not speculative thinking of representatives of the Institute of Computational Mathematics but computations make possible to assert that, in principle, comet could not simultaneously creates a Burckle crater and all system of chevrons. The energy of this process turned out to be, at least, one and half ten times greater than previously imagined. Well, of course, such great disaster, for at least at 3 orders of magnitude larger than the explosion of the volcano Tambora [21] should not have happened in 2807 BC, because that the dendrochronological data do not allocate this year and its immediate surroundings. Therefore, «in terms of trees» any, even the smallest disaster, so vividly and colorfully described in [20], did not happen, as opposed to, for example, from 3201 BC.

In contrast to this, all complex of collected and received data shows that the Mesopotamian flood, or, in other words, the Bible «World Flood», namely submersion of this lowland of first terrestrial civilization under the water, was the result of falling debris of the comet much more modest size into the northern part of the Arabian Sea [10]. And two chevrons, including previously unknown, as well as sediments at the bottom of Chah Bahar bay, which age has been determined, approximately in 5.3 thousand years [22], but not only sediments in Lower Mesopotamia, became tangible evidence of so famous disaster. In more detail the information about it may be found in [11]. And the energy released in the fall of the asteroid that created Burckle crater, is too great to this event could be linked with the Bible Flood.

Conclusions

1. The proposed method allows determining the height of tsunami wave through the height of chevron dune, which is created by this wave.

2. Information about wave height gives, in the presence of other information, the ability to evaluate the basic parameters of the impactor, which has caused this wave.

3. If we use not only azimuths, but and the heights of chevrons, we may prove that they have the origin from a single center of water wave propagation, not from wind.

4. A significant number (more than 200) of high chevron dunes, often linked into a certain groups with some impact craters, is proof that there were significant disasters in our planet during Holocene, caused by falling of large celestial bodies into the oceans.

5. Formerly known chevron, located on Indian shore of Arabian Sea in of Gujarat, and chevron, which has been found now on Makran coast of Iran, along with sediments in Lower Mesopotamia and in Iran's bay Chah Bahar form a group of geological structures associated with the falling of meteoroid in northern Arabian Sea that was a cause of Mesopotamia flood (famous the Biblical «World» Flood).

6. The celestial body, fall of which into the Indian Ocean has resulted to Burckle crater and to its chevron system could only be an asteroid, the size of which is most likely to constitute 2.7 – 5 km, and the energy of the explosion more than 3 Tt of TNT.

7. This energy is almost 3 orders of magnitude more than energy of the explosion of Tambora volcano in 1815 that caused «Year without summer» in the whole Earth, so the consequences of asteroid's fall should to lead to a strong climate change, apparently, at least no less than the beginning of the Younger Dryas (about 12,700 years ago). Therefore, there is no reason to link the falling of Burckle asteroid with later dates.

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