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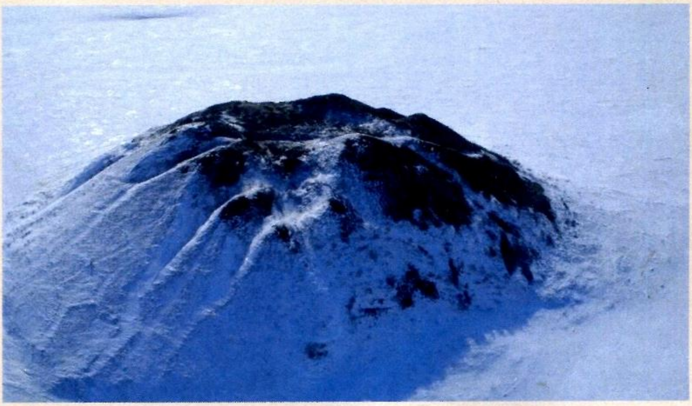
ARCHIMEDEAN FORCE
IN THE FROZEN FINELY-DISPERSED GROUND



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The previously unknown physical essence of the nature of the cryogenic ıeaving forces is uncovered; it is reduced to the manifestation of the action)f Newton's third law with respect to two interacting physical bodies in the 'frozen-thawed system". In this system the thawed ground exerts a force esistance to freezing, which results in the heaving of the frozen ground. Two types of freezing ground systems are distinguished: closed and open)nes. In the closed systems the force resistance of thawed ground to reezing is due to the increasing pressure in it, due to the squeezing excess vater during phase transitions of water into ice. In the open systems the ncrease of pressure in thawed ground is impossible and force resistance to reezing is realized through the Archimedean force, leading to cryogenic ıeaving of frozen finely-dispersed ground in case of a decrease in their lensity while freezing.

Keywords: *force cryogenic heaving, closed and open systems, the fine-lispersed ground, Newton's third law, Archimedes 'force.*

INTRODUCTION

The key moment in the studying of any natural process is to establish he nature of its driving forces, without it neither the full theoretical ubstantiation of the mechanism of its manifestation, nor the correct nterpretation of experimental data and practical recommendations for preventing the negative impact of the process on engineering structures are possible. None of the cryogenic processes have been subjected to such comprehensive and thorough research as frost heaving, due to the physical features of the heaving as the most typical permafrost process, and also to he practical importance of studying this phenomenon for solving different asks of construction on frozen and freezing ground.

But, paradoxically, there are still gaps in the strict physical explanation of the nature of the forces, leading to cryogenic ground heaving. And experts in this field testify to this. Thus, in [*Sarkisyan, Orlov, 1970*] it is said that the forces of heaving are merely **replaced** (highlighted by the author – VM) by reactions of bonds that are equivalent to the strength of the heaving. B.I. Dalmatov declares: "... the reasons for ground heaving are not fully understood, considering which we could make a prediction of this phenomenon ..." [*Dalmatov, 1970*]. "The formulations available in the literature on the heaving of ground reflect external features that appear in the process of heaving, but not the physical essence of this phenomenon" [*Kiselev, 1985, P. 120*]. "The physical essence of the nature of the heaving forces has not yet been discovered theoretically or experimentally" [*Ibid, P. 121*]. Despite the decades since then, the situation has not changed.

The author believes that in order to explain the nature of the forces of cryogenic ground heaving; this process should be considered as a result of the interaction of two physical bodies in the "frozen - thawed" system, which is subordinate to the action of Newton's third law. According to this law, the volume increase of the frozen ground in the system causes force counteraction from the thawed ground. In this case, two types of systems should be allocated – closed and open. In the closed systems the force resistance to freezing is due to the increase of pressure in the unfrozen soil and to the impossibility of pressing out of the system the excess water formed during "the water-ice" phase transition. In the open systems the pressure increase in the thawed ground is impossible. The counteraction from the thawed ground is manifested through pushups frozen soil one in accordance with Archimedes law – due to the decrease in the density during freezing.The author has established the mechanism of this process with the corresponding mathematical description. The validity of this mechanism, proposed to be called "lithostatic", is proved by the author's own experiments, experimental data of other researchers, as well as features of morphology and geographical distribution of natural forms of cryogenic heaving [*Marakhtanov, 1999, 2015, 2016*].

1. PRIORITY INFORMATION

The first information about the Archimedes' force in freezing fine-dispersed ground is contained in the author's article: Marakhtanov V.P. *Mekhanizm rosta migratsionnykh bugrov pucheniya* [The Mechanism of Growth of Palsas]. *Vestnik Moskovskogo Univ.* [Bulletin of Moscow University], vol. 5. *Geografiya* [Geography], no. 3, 1999. pp. 41– 46 (in Russian).

2. THEORETICAL BASIS

Consider the essence of the problem encountered. According to the conventional concepts, ground frost heaving occurs due to the increase of its volume during the freezing. In this process a characteristic feature is the uplift of the surface of the soil. Question: why is the surface rises, if the increase in the thickness of the freezing layer (the movement of the freezing front) in the opposite direction? An attempt to explain it is given in [*Bykov, Kapterev, 1940*]: “Under natural conditions, the expansion of the soil is possible only upwards, since the broadening to the sides is impeded, generally speaking, by the same tendency to expand the lateral sections of the ground, while the expansion to the downside is impeded by the resistance of the underlying layers with pressure, whereas only the weight of the overlying layers restrains upward movement" (P. 132).

Thus, the layer of frozen soil is repelled from the lower melt layer. Such a view is reflected in the well-known condition of D.R. Mackay [*Mackay, 1979*], wherein the heaving is observed only if the resistance of the thawed ground to the compression Q exceeds the resistance to raising the frozen thickness F:

$$Q > F \qquad (1)$$

In the expression (1), the value of F is composed of the pressure from the weight of frozen soil W and the resistance of frozen soil to deformation forces (bending, tear, shear) U: $F = W + U$. The condition (1) reveals the physical essence of the cryogenic heaving, as a consequence, Newton's third law - the force with which frozen soil pushed up from the molten ground (i.e. the power of cryogenic heave) is equal to the reaction force of the bearing Q which should be at least not less than the resistance force of the lifting of the frozen soil F. These forces act in opposite directions: Q – down, F – up. As follows from condition (1), in order to develop the heaving, the thawed layer underlying the freezing ground must have a sufficient *"rigidity"* exceeding not only the pressure of the weight of the frozen soil W but also its resistance to the deforming forces U.

Such a mechanism of heaving is not universal, if we consider it in application to two different types of freezing ground systems – *closed* and *open*. In closed systems the thawed soil is separated from the external environment waterproof case from all sides. An example of a closed system in nature can be a Pingo (Fig. 1), formed by the freezing of the taliks under lakes [Fundamentals of Geocryology ..., 1959]. Here the waterproof shell is the frozen layer surrounding the freezing of melt of land that lies within the Pingo.

Fig. 1 – Pingo. On the surface of the hill traces of destruction under the influence of high internal pressure . Photo from the Internet.

In the open systems there is no closed waterproof shell around the freezing ground. An example of the open system is palsa (Fig. 2) formed on the freezing sections of bogs, composed of finely-dispersed thawed soils [*Popov, 1967*].

Fig. 2 – Palsa (small growing and 2 large – at the background) on the peat bog. The territory of the Yamovskaya gas field in the north of Western Siberia). The photo of the author.

By the nature of the changes between Q and F in the process of soil freezing, there is a fundamental difference between these types of systems. In closed systems there is nowhere to squeeze the excess water formed during water-ice phase transition, this leads to increased pressure in the thawed earth, and the forces developing at the same time can be quite sufficient to deform the frozen roof or even its break with the outflow fluid mass of soil and water on the surface (Fig. 1). In the closed systems the condition (1) for the development of the heaving is satisfied. Resistance to compression during freezing is ensured not only in the closed natural systems, but also while studying the ground heaving in laboratory conditions. In the laboratory the freezing soil is placed in a vessel with rigid side walls and supported by practically incompressible sand, from where water enters the freezing front. Thus, the expansion of the frozen ground can only be realized up due to the accumulation of ice in it. Consequently, in the laboratory have been studied mainly in closed systems. Note also that in closed systems the cryogenic heave associated with the pressure of growing ice crystals corresponds to the traditional concept. At the same time, *however great the pressure of the ice, its strength effect cannot exceed the compressive force of the thawed ground (or the force of the waterproof shell), i.e., in accordance with Newton's third law, the reaction force of the support.*

In open systems the excess water is freely distributed in the thawed earth. Thus, there are no physical preconditions for increasing the pressure inside is not frozen ground, which is under the frozen layer. On the contrary, as the thickness of the frozen layer increases, the possibility of the development of cryogenic heaving, from the point of view of compliance with conditions (1) decreases. Fig. 3. illustrates the fundamental frequency values of *Q* and F in different systems. To the right of the intersection of the graphs of *Q* and *F* in closed systems cryogenic heaving begins, and in the open, should be discontinued.

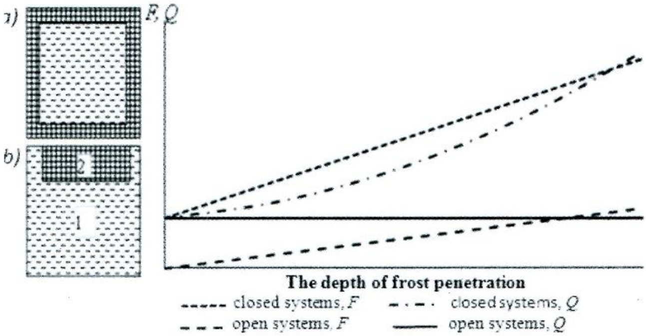

Fig. 3 – Dynamics of Q and F values in the closed (a) and the open (b) ground systems. 1 – thawed ground, 2 – frozen ground.

The absence of pressure buildup in the thawed ground, freezing under the conditions of the open system, is confirmed by experimental data from [*Orlov, 1962*]. The measured pressure in the thawed zone did not exceed 0.03 MPa, and in the areas adjacent to the freezing front it dropped to practically 0. Analyzing the obtained data, V.O. Orlov comes to the conclusion that "... the layer of thawed ground below the freezing front cannot be regarded as a zone of plastic deformation that is under a uniformly distributed load, which is a function of the thickness of the freezing layer" [*Orlov, 1962, P. 124*].

Both general theoretical considerations and factual data show that in the open ground systems the condition (1) for the development of the cryogenic heaving does not "work". What power forces the surface of frozen soil to rise up here?

Let's try to find the answer to this question by analyzing changes in the freezing of such property of the soil, as density. A feature of the physical phenomena accompanying the process of freezing shallow soils (sandy loam, loam, clay) capable of swelling is the reduction of density when it freezes. There are at least three possible reasons for the decrease in density . The first is the removal from the pore spaces of frozen soil excess water equal to the difference between the increase in the pore water during its transition into ice, and a portion of the pores unfilled with water. Secondly, in the frozen ground of micro and macro voids can be formed, a decrease in its density [Bulls Kapterev, 1940]. The third reason (much more effective than the previous) is the formation of ice migration, the share of which in the frozen volume of rock can be tens of percent [Popov, 1967]. In this case, the difference in density between melt and frozen soil is of the same order.

Thus, when a finely-dispersed ground freezes under the conditions of the open system, a frozen body with a lower density is formed in comparison with the thawed ground surrounding this body. It can be assumed that it generates a buoyant force, which tends to push this frozen body out of the thawed ground upwards. This assumption does not seem improbable if one takes into account that in nature the difference in the densities of rocks is caused, for example, by the phenomenon of diapirism [*Khain, Lomidze, 1995*].

The force pushing the frozen ground from thawed really is the Archimedean force, whose action in the water and air environment are well known and, for example, be considered in the design of ships and aircraft. In respect to soils, the author has not encountered a practical account of the force of Archimedes in them, with the exception of provisions governing the construction of pipelines [*SNiP 2.05.06-85*]. There in the footnote to paragraph 8.14, it is said that "when designing pipelines in areas of transitions, consisting of soil, which can shift to liquid-plastic state, when determining the buoyant force is the density of water, density of liquefied soil, to take" (that is, in fact, the calculation of Archimedean force in the ground). The mechanism of cryogenic heaving associated with the influence of Archimedes, taking into account the physical properties of the environment in which this mechanism is manifested, can be called "mitostaticheskim".

3. THE ESSENCE OF DISCOVERY

The essence of the discovery lies in establishing the operation of the Archimedes law in a ground environment represented by finely-dispersed moist soils (clays, loams, sandy loams) that freeze under the conditions of the open system. The frozen ground formed in this way, in the case of a lower density than the thawed ground, is heaved from the latter under the influence of the Archimedean force. A similar mechanism is suggested to be called lithostatic. Below there are main positions of the lithostatic mechanism [*Marakhtanov, 2016*].

1. In nature the winter freezing of the soil is characterized by spatio-temporal heterogeneity due to the heterogeneity of the factors determining

the freezing conditions (mainly snow and soil-vegetation cover).

As a consequence, in the initial freezing period separate frozen masses are formed, surrounded by thawed ground and freezing as an open system.

2. On the massifs formed in finely-dispersed (clays, loam, sandy loam) moist soils, the buoyancy (Archimedean) force F_e acts, equal:

$$F_e = g\rho_t V \qquad (2),$$

where ρ_t – thawed ground density, V – volume of frozen massif, g – acceleration of gravity.

3. If the density of the frozen ground ρ_f is less than the density of thawed one ρ_t, the buoyancy force can cause the floating frozen mass to rise from the thawed ground under the action of the upward part of the buoyancy force equal to the difference F_e and the weight of the frozen massif W. This difference can be defined as the driving force of the heaving F_{dr}:

$$F_{dr} = F_e - W = g\rho_t V - g\rho_f V = gV(\rho_t - \rho_f) \qquad (3)$$

4. Moving up frozen array can be difficult, since the shear strength along the lateral surface of the FR, as well as additional external loads on the array L. hence, for. beginning cryogenic heaving of soil you need the following inequality is satisfied:

$$F_{dr} > F_r + L \qquad (4)$$

This inequality can be made as an array of further freezes, its volume increases and increases F_{dr} in accordance with the formula (3). An additional effect may be the increase in the content of ice in the mountains, which leads to a decrease in its density ρ_f.

5. Since the beginning of floating (heaving), the volume of the frozen massif V is divided into two parts: thrown out from the thawed ground (above-ground) V_a and immersed in the thawed ground (underground) V_u ($V = V_a + V_u$). At the same time, as the freezing process continues, the system "frozen ground - thawed ground" at any time tends to the position of *static equilibrium* corresponding to the condition:

$$F_e = W + F_r + L \quad (5),$$

where F_e – Archimedian force acting on the underground part of the frozen massif V_u.

Equality (5) can be reduced to the following form:

$$g(\rho_t - \rho_f)V_u = g\rho_f V_a + F_r + L \quad (6)$$

The left-hand side of equality (6) is F_{dr}, acting on the underground part of the frozen massif, and the product $\rho_f g V_a$ is the weight of the above-ground part of the frozen massif W_a. As the freezing process continues, the volumes of the underground V_u and the aboveground V_a parts of the massif are constantly increasing, which corresponds to all new positions of static equilibrium and constant heaving of the frozen massif. In this case, the massif, due to its inertia, always lags somewhat behind the static equilibrium position. But as soon as the freezing ends, this position is reached.

6. If at some point to prevent the rise of the frozen massif (heave), and freezing continues, the static equilibrium is disturbed, which corresponds to a breach of the equality (6). The right part of it remains constant, and the left part (the driving force) increases in proportion to the increase V_u. This growth is not compensated by the increase in the weight of the above-ground part of the massif in formula (6), since the massif is

"locked". The force that tends to move up stable array – is the force of cryogenic heaving F_{kh}, which is calculated by the formula:

$$F_{kh} = g(\rho_t - \rho_f)\Delta V - F_r \quad (7),$$

where ΔV – increment of the volume of the frozen part of the massif or (that is the same) of the entire massif from the moment of its stop.

7. Depending on the configuration of the frozen massif, it is possible to determine the height of its pushed out part (the force of heaving) h_b, corresponding to the static equilibrium condition. For clarity, we will present Figure 4 that shows a frozen massif in the form of a cylinder in a static equilibrium position with no load ($L = 0$).

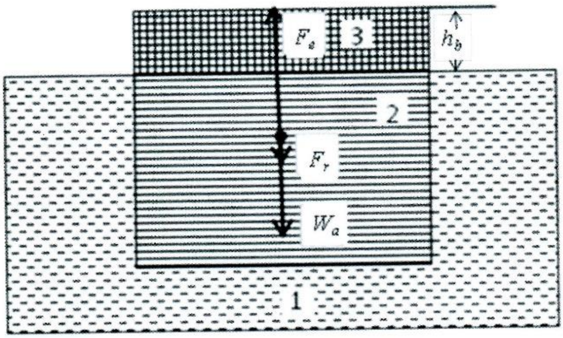

Fig. 4 – Frozen massif in the position of static equilibrium and the forces acting on it. Legend: 1 – thawed ground; 2 – underground part of the frozen massif; 3 – aboveground part of the frozen massif; W_a – the weigh of the aboveground part of the frozen massif; F_r – shearing resistance; F – Archimedean force ($F_e = W_a + F_r$)

If the massif has the form of a cylinder (including the wrong one or a parallelepiped, the expression (6) is written as:

$$g(\rho_t - \rho_f)S(H - h_b) = g\rho_f S h_b + F_r + L \quad (8),$$

where S is the area of the array, H is the thickness of the array (depth of freezing).

Hence, in the absence of an external load on the frozen massif ($L = 0$):

$$h_b = H\left(1 - \frac{\rho_f}{\rho_t}\right) - \frac{F_r}{g\rho_t S} \qquad (9),$$

under load:

$$h_b = H\left(1 - \frac{\rho_f}{\rho_t}\right) - \frac{F_r + L}{g\rho_t S} \qquad (10).$$

The parameters $\frac{F_c}{g\rho_m S}$ and $\frac{F_c + L}{g\rho_m S}$ in formulas (9) and (10) are equal to the possible decrease in the height of heaving of the frozen massif (Δh_b) due to the action of the shearing force and the load on the massif.

8. The geometric parameters of a frozen massif in the form of a cylinder or a parallelepiped, H and S, considered above can be used to calculate the force of heaving F_{kh}. For this in Formula (7), ΔV is replaced by $S\Delta H$, where ΔH is equal to the depth of frost penetration from the stop of the array. From here:

$$F_{kh} = g(\rho_t - \rho_f)S\Delta H - F_r \qquad (11).$$

4. SOME PROOFS OF DISCOVERY RELIABILITY

4.1. Author's experience

To prove the action of the lithostatic mechanism, the author performed experiments where experimental and calculated data were compared. First, a series of experiments was carried out with specially prepared frozen cylinders to verify the validity of formulas (9) and (10).

Then the experiment was performed, where the force of heaving of the freezing massif of irregular shape from the thawed ground was measured, when it is impossible to ascend from the very beginning of freezing, i.e. the validity of formula (7) was verified. These experiments are detailed in [*Marakhtanov, 2016*]. Here are the main results.

4.1.1. The confirmation of the validity of formula (9)

Two identical in form and size of the cylinder (ice cylinder with the density ρ_f = 0,92 g/cm^3, and ice-soil cylinder with a density of ρ_f = 1.4 g/cm^3), having a height H = 5.5 cm, immersed fully in the loam with a soft plastic consistency with a density of ρ_t =1.87 g/cm^3 and a temperature of about 0 °C, after which they surfaced Two identical in form and size of the cylinder (ice cylinder with the density ρf = 0,92 g/cm3 and ice-soil cylinder with a density of ρf = 1.4 g/cm3), having a height H = 5.5 cm, immersed fully in the loam with a soft plastic consistency with a density of ρt =1.87 g/cm3 and a temperature of about 0 °C, after which they surfaced in a few minutes. The ice cylinder up to a height of 2.8 cm, and the ice-soil cylinder of 1.2 cm. Theoretical lifting height Hb is determined according to the formula (9) with Fr = 0, respectively, 2.8 cm and 1.4 cm, the discrepancy between the heights of the ice-soil cylinder can be explained by the influence of his Fr.

4.1.2. The confirmation of the validity of formula (10)

The experiment was performed under conditions of a variable external load on the surface of an ice cylinder having the following parameters: diameter 9.5 cm, height 6.1 cm, volume 432 cm^3, weight 4 N, density ρ_f = 0,92 g/cm^3. A cargo weighing 3.07 N was placed on the surface of the cylinder. The cylinder along with the cargo was submerged flush to the melted loam of a fluid-plastic consistency with density ρ_t = 1,86 g/cm^3 and then left to itself. After stopping the floating of the cylinder, its height was measured, and then the load was reduced to 1.96 N. As a result of the decrease in the load, ascent began again. In the course of the experiment, such an operation was performed at six load stages (until its complete removal). Experimental data in comparison with the calculated data for $F_r = 0$ are presented in Table 1.

Table 1 – Results of the experiment with variable load on the surface of the cylinder.

The time from the start of the experiment, min.	Weight, g	Load, N	The height of the ascent, cm	
			the actual	the estimated when $F_r = 0$
30	313,0	3,07	0,6	0,7
80	200,0	1,96	1,5	1,6
120	150,0	1,47	1,9	2,0
133	100,0	0,98	2,3	2,3
155	50,0	0,49	2,7	2,7
200	0,0	0	3,1	3,1

4.1.3. The confirmation of the validity of formula (7)

The experiment was conducted using the original installation [Marakhtanov, 2016], where the array of frozen soil, surrounded by unfrozen soil with a temperature of about 0 °C, was obtained. For experience took the clay liquid consistency, with a density ρ_t = 1.82 g/cm^3.

Force of cryogenic heaving was measured weights with the platform results of the experiment are presented in table 2.

Table 2 – Results of experiment to measure the forces of frost heavir an open system

The time from the start of the experiment, hours min.	The air temperature, °C	The readings of scales, g	The force of heaving, N
15 hours. 30 min.	−15	0	0
17 hours. 15 min.	−16	28,9	0,283
18 hours. 00 min.	−16	36,4	0,356
19 hours. 00 min.*.	−17	58,1	0,57

* The end of the experience

The volume of the frozen massif ΔV, extracted from the surroun thawed ground after the end of the experiment is 161 cm^3, the ma 232.5 g, the density ρ_f = 1,44 g/cm^3. With such parameters, the calcula according to formula (7) with $F_r = 0$ gives the value of the heaving f Fps = 0.60 N that exceeds the measured heaving force by only 0.03 N Table 2). Probably, this difference is connected with the accurac determining the experimental parameters, as well as with the resistanc shearing of the lateral surface of the frozen ground by contact with thawed ground F_r, which was not taken into account in the calculation.

4.2. The confirmation of the validity of formula (11) by experimental data of V.O. Orlov

Experimental data of V.O. Orlov were obtained in the study of normal forces of frost heaving of finely-dispersed soils near Igarka in 1 at the experimental site No. 2 [*Orlov, 1962*]. A detailed description of experimental procedure, the data obtained and their interpretation by the author are presented in [*Marakhtanov, 2016*]. Here it is expedient to present the main results. On the experimental site No. 2, the bulging force of the frozen massif with S = 132 m2, density ρ_f = 1,71 t/m^3 was measured from the thawed loam with a density ρ_t = 1,85 t/m^3 of a fluid-like consistency. Table 3 shows the values of the actual heaving forces estimated by V.O. Orlov, in comparison with the results of calculations using formula (11) with $F_r = 0$.

Table 3 – Actual and calculated values of the punching force of a frozen massif

Increase of capacity of the frozen array *ΔH*, m	The actual power (on the indicator), KN	The estimated heaving force $F_{пуч.}$, KN
0,36	69,0	69,9
0,61	109,8	118,4

In the last row of the table. 3, the calculated force exceeds the force by almost 9%, which can explain the exclusion from the calculation of the resistance force FR through the side surface of the array.This force has grown, in accordance with the increase in the area of the side surface in the process of freezing array.

4.3.The explanation of the rounded form of natural aboral formations by means of formula (11)

Replacing in the formula (11) the resistance to heaving F_r by the product $F_{rs}P\Delta H$, where F_{rs} is the specific shearing force per unit area of the lateral surface of the frozen massif, *P* is the perimeter of the massif, and dividing the right and left parts of formula (11) by the increment value volume with $S\Delta H$, we obtain:

$$\frac{F_{kh}}{S\Delta H} = g(\rho_t - \rho_f) - F_{rs}\frac{P}{S} \quad (12)$$

The left-hand side of the equation (12) can be designated as the specific force of the heave, equal to the bulging force per unit of the volume of the frozen mass. The right side of the equation, and hence the specific shear strength, is maximal at the minimum value of the ratio of the perimeter P to the area S. As it is known, from all geometric figures this ratio is minimal for a circle. Thus, for the process of heaving in the open system, *the circular form of the frozen permafrost is most energetically favored*. Planned roundness is characteristic of all, without exception, abyssal formations, developing in natural conditions. Naturally, the shape of an ideal circle is possible only if the values of the parameters ρ_t, ρ_f and F_{rs}., included in the formula (12), are spatially unchanged, which in nature does not usually exist and some irregularity is observed. Nevertheless, the tendency to maintain a circular shape is always present.

4.4. The correspondence of the heights of the natural palsa formed under the conditions of an open system, the static equilibrium condition determined by formula (6)

Proceeding from the static equilibrium condition (6) at $F_r = 0$, the author derived an approximate formula for determining the height of the palsa h, which has an elevated form close to the spherical segment, and the underground one to the cylinder [*Marakhtanov, 1999*]:

$$h \approx 2(H - h_p)\frac{\rho_t - \rho_f}{2\rho_t - \rho_f} \quad (13),$$

where hp is the thickness of peat on the Palsa. According to this formula, heights of 7 palsas were calculated, the actual data of which are contained in [Evseev, 1976]. The results of calculations in comparison with the actual data are given in Table 4.

Table 4 – Estimated and actual heights of palsa

№ palsa	Settings of palsa				Height of palsa h, m	
	H, m	H_p, m	P_t, t/m³	P_f, t/m³	the estimated	the actual
20-PA	8	0	2,0	1,85	1,1	1,0
59-3A	9,5	0	2,0	1,81	1,6	1,5
6-ST	9	1,4	2,01	1,77	1,6	1,7
9-PA	10	2,2	1,94	1,65	2,0	2,0
17-PA	8	0	2,0	1,61	2,6	2,5
50-3A	10	0,5	2,0	1,60	3,2	3,0
283	11	1,25	2,0	1,53	3,7	3,5

5. THE FIELD OF SCIENTIFIC AND PRACTICAL IMPORTANCE

The scientific value of the discovery lies in the possibility of a rigorous physical explanation of the formation conditions, morphology, geographic distribution and evolution of cryogenic heaving form (seasonal and year-round) in Northern latitudes [Marakhtanov, 1999, 2015]. The practical significance lies in the application of the obtained formulas to calculate the force effects on soil freezing, which leads to deformation of the foundations of buildings and structures and determining the magnitude of deformation. An example is given in [Marakhtanov, 2016]. In addition, it is possible to calculate the forces acting on the "warm" pipelines laid in the Northern swamps with alternating thawed and frozen areas prone to

;welling, where the traditional methods of calculation, in principle, mpossible to apply.

6. FORMULA OF DISCOVERY

t is theoretically established and experimentally validated previously ınknown phenomenon of the action of Archimedean forces in freezing ›pen system "frozen - thawed earth", composed of finely-dispersed moist ;oil, resulting in vertical upward movement of frozen soil agglomerates vith the formation of forms of cryogenic heaving.

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