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Managing in situ gold concentrations in placers

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Abstract

In studying of the in situ gravitational concentration process part feature for placer, the technological ability to transform the in situ massif placer structure is evident. The two main processes involved in altering the massif in situ have been examined and outlined in detail. The in situ disintegration of massif material results in a new massif gravitational stratification structure. Regularities of the distribution of particles in the array of alluvial gold in situ were obtained. These regularities showed us the possibilities for direct formation of zones with elevated gold concentrations. The disintegration feature separates particles in an aqueous medium and concentrates the full exemption in situ particulate matter within the placer massif. This method will reduce the volume of mining and ore processing and increase profitability.

Keywords: *disintegration, friable massif, gravitation concentration, placer, restructuring.*

1. Introduction

The development of natural placers has technological features for both separate areas and the deposit as a whole. Each field is unique and determines the application of the technological features. These features are very much affected by economic efficiency. The technology is the most effective within standard conditions when the appropriate parameters are the optimal process parameters.

Most placers are alluvial geological objects. The structure of alluvial placer deposits is characterized by unconsolidated sediments of sand and gravel layers consisting of various sizes of sand particles, loam and gold. The fractions of all alluvial sizes from clay to boulders are present in the gold-bearing sand placer deposit as a rule. The contents of the different particle size fractions, including gold particles, are unevenly distributed. Distribution depends on the formation conditions of the deposits. The geological parameters of alluvial placer deposits depend on the intensity of water flow forming the deposit and the initial conditions of the indigenous source.

Two concentration mechanisms of mineral components in alluvial placer deposits are residual and schlich [1, 2]. The same processes are in the secondary areas of high gold concentration of tailings[1, 2, 3]. Residual type gold concentration occurs because of sand and clay component washout and removal by water flow. As a result of this process, the remaining substance is formed with lumpy fractions with free particles of gold remaining in situ.

Schlich concentration occurs due to the accumulation of relatively large particles of useful components (gold particles) in the active layer of sediment. Particles are in vibrational motion in the active layer. Accumulation occurs as a result of the vertical movement of heavy particles displacing lighter particles within the layer.

Both residual and schlich gold concentration in placers can be quite high. Therefore, the gold content can reach and exceed tens to hundreds of grams per cubic meter of sand in some lenses, typically in the bottom layer [1]. The parameters of water flow are altered at different times, which change the sediment layer. Natural geological processes are capable of providing a high level of concentration under certain conditions. Currently, most of these conditions are studied in detail and are widely used as the operating parameters for concentration processes in the extracting apparatus. Well-known characteristics of gold content in a massif indicate that natural geological mechanisms can increase the content exponentially.

Controlled repetition of natural processes can significantly increase cumulative mining efficiency, as indicated by previous studies of gold mining within placer deposits, for example. Industrial-scale gold mining was first applied in alluvial deposits with poor gold content in the Spanish rivers valleys of the Tajo, Duero and Guadiaro Rivers during the Roman Empire [1, 2]. Gold was mined in the so-called Arrugiy with an open pit length of approximately 300, a width of 150 and a depth of 100 meters. Mines were constructed with underground workings and mining support at the bottom of the ore bed. Dams were constructed simultaneously and accumulated water on the surface. When the underground workings were established, the mining support was destroyed, bringing down a large mass of gold rocks and a powerful stream of water, destroying the dam walls. The intense washing water flow containing crushed rocks formed the new placer. An artificially rich placer was created in a confined space with intense and fast alluvial washing of poor gold-bearing rocks in a narrow river valley. Material from the newly created placer was hand washed.

The artificial formation of rich placer deposits can be realized with two primary sequential processes. The first process is a complete disintegration of friable massif that is then conditioned through aquatic suspension. The second process is a gravitational stratification of the alluvial massif. The parameters of stratification and formed sediment strongly depend on the completeness of the disintegration process and a sufficient degree of freedom for the sedimentation particles.

The completeness and rate of disintegration depend on the composition of the massif. The fine clay content in the massif fraction determines the overall capability and power expense needed for disintegration.

Energy disintegration depends on the mechanical connection properties among the particles within the array. Tensile properties of friable massif are determined by severing the van der Waals interactions between the particles [1]. The fracture energy relationship will be greater for the total material volume when the force of a single contact is greater and the overall area is larger. The highest specific energy consumption as a result of disintegration occurs for inherent clay materials.

The energy costs can be estimated based on the bond types between particles. Water in the array can be in tightly bound, loosely bound and free states (Fig. 1) [1]. A layer is located adjacent to the particle surface in the tightly bound water layer. The properties of that layer are similar to those of a solid body (thickness of 1–3 molecules) and a somatic layer that has certain mobility (thickness of 10–20 molecules). Loosely bound water forms a film on top of the tightly bound water. The presence of loosely bound water is determined by the excess humidity of rocks above their maximum water absorption, which is different from the water content of a film of water in friable arrays. For example, the water content of sands is 1–7% that of sandy loam is 9–13%, that of loam is 15–23%, and that of clay is 25–40%.

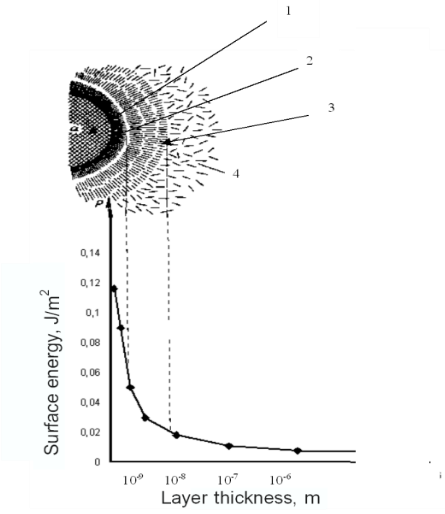

Fig. 1. The structure of water films on the particle surface. (1) particle, (2) firmly bound water, (3) loosely bound water; 4- free water

The strength of aggregates provides contact between the particles within the region of the layer with firmly bound water. Particle connection within the layer of loosely bound water will determine relative mobility. The contact of adjacent particles within the shell layer of free water will lead to complete independence from the system. The number and nature of individual contacts determine the coupling strength value, which does not depend on the strength properties of the mixture elements. When the sizes of mineral particles in the clay rocks are smaller, their relative surface area and strength bound into a single unit are greater. The kinetic energy of the contact through a layer of tightly bound water corresponds to the heat level of a wet surface (116.10^{-3} J/ m^2) [9] (Fig. 2a).

The complete absence of a surface tension connection between the particles is achieved when the particles are located outside the distance of the double layers of tightly bound water and loosely bound water (Fig. 2c) (a state of absolute disintegration).

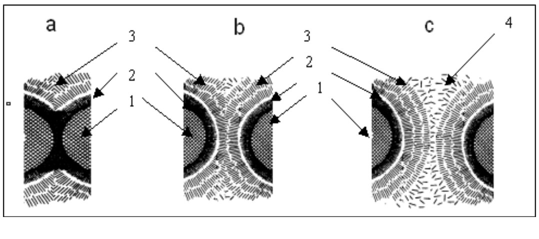

Fig. 2. Schematics of the possible links of clay particles within water film. (1) particle, (2) firmly bound water, (3) loosely bound water; (4) free water

Achieving the absolute disintegration of the clay is not always necessary for some technological washing line materials. The aim for stratification is to achieve complete liberation of the mineral particle surface for all links.

The intensity of treatment provides an initial breaking of the links. The duration of treatment is necessary to maintain a state in which the particles of the array are supplied with free water without constraint.

However, the interaction of mineral particles with the water is a slow technological process characterized by swelling and soaking. The physical essence of the swelling process involves the initial hydration of the outer layer of the particles with free water. Particles of the inner layers of the array can be hydrated only through the diffusion of water from the outer area. The rate of natural self-disintegration of the clay material is very slow and is generally unsuitable for technological purposes. This process occurs at a rate from several tens of millimeters per hour to a few millimeters a day (thickness of the layer is less than 0.5 meters) for different clay soils types that have no forced removal of disintegrated outer layers. The value of water saturation in the array does not occur for thicknesses greater than 0.5 meters unless an external impact is applied (mechanical and vibro-acoustic).

There are two ways in the formation of sediment in the conditions where the particles in the slurry are not linked: precipitation with vertical gravity separation; schlich separation in the turbulent flow.

2. Materials and Methods

The aim of this paper was to develop a framework to study the in situ formation of the rich parts of a massif. Theoretical data and laboratory experimental results were used to generate conceptual and numerical models of artificial directional array transformation processes. Gold-bearing sands from two placer deposits (“Samson” and “Udereysky”) were used in laboratory experiments. Alluvial deposits Udereysky and Samson located in the southeastern part of the Yenisei gold belt. The deposits are located in the Lower Angara, Motyginsky District, Krasnoyarsk Territory. A primary ore of Udereysky deposit confined to quartz-gold-sulfide type containing gold and antimony. A primary ore of Samson deposit mineralization confined to the weathering crust. Distribution graphs of particle sizes in gold-bearing sands of these placers are shown in Figure 3. The average contents within these placers are similar and approximately 2 grams per cubic meter. Gold-bearing sand material of the Samson deposits appears to be clay. Clay material is kaolin. The average size of the clay particles is 3-5 microns. The average size of the gold particles is 0.01 mm. Materials of other deposits contained more sand (70%) than clay (20%). The average particle size of gold is 0.06 mm.

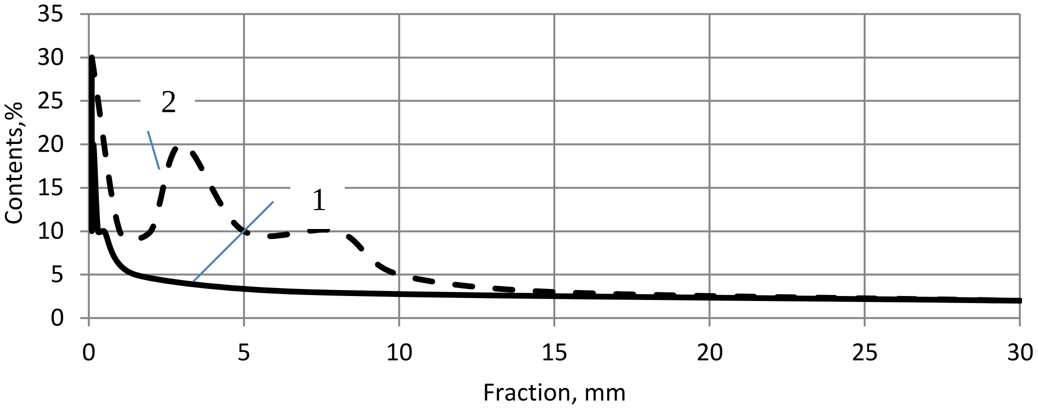

Fig. 3. Granulometric composition of gold-bearing sands of placers: (1) deposit "Samson" and (2) deposit "Udereysky"

Two experimental setups were used for this research. Experimental acoustic installation was equipped with a working chamber in the form of a rectangular-shaped tray of hard plastic with an open surface and a length of 4 meters. The end wall tray is made of soft plastic, which is in contact with the source of the shock-acoustic oscillations. This experimental set simulates in situ restructuring due to the vibrational motions of the particles in an array by transmitting acoustic waves within a low frequency range [1]. The material in the chamber was exposed to the acoustic effects of varying intensity (amplitude of the pressure range from 0.1 to 1.0 MPa). Such a pressure amplitude in the sandy-clay fraction array destroys the water bonds between particles and forces the particles to oscillate within the array [1]. Oscillatory movement of the particles in a portion of the array redistributed the particles: heavy particles moved into the lower layers of the array, while the lighter particles moved to the upper [1]. The radiated wavelength was 100 s^{-1}, and the oscillation frequency varied from 5 to 25 Hz. The intensity of the vibrational amplitude along the length of the tray was measured by sensors. The distribution of particle size and the metal content adjustment layer were analyzed using sieve analysis and schlich testing.

The second experimental setup employs a full-scale long tray with vertical uprights to the full height of the tray. The design of the tray allows vertical racks to be set in differing orders and density of up to 70% of the cross-sectional area of the tray. The uprights are of different sectional shapes. The angle of inclination of the tray can change. The distribution of particle size as a function of tray length was analyzed using sieve analysis at end of each experiment.

Research data on these experimental set-ups allow an assessment of the applicability of in situ gold concentration and yields process parameters.

3. Results and Discussion

The assessment of the distributions of mineral particles of various sizes and free gold particles with height in the sediment was carried out for laboratory experiments on the sand of real placer deposits.

Processing the material of placer deposits in a vibro-acoustic laboratory setup (Fig. 4) revealed that the massif structure is converted for radiation with pressure amplitude greater than 0.2 MPa within the frequency range of 15 to 25 Hz. Four specific areas have been allocated. The sizes of these areas vary according to radiation intensity, but their presence was noted in all experiments. The first zone closest to the source (a) is a zone of intense mixing and becomes noticeable in the first seconds of processing. The second zone (b) is a transition zone and is not an area of intensive stirring of the massif material. The third zone (c) is the zone of forming and compacting sediment, where the material of this zone is characterized by dense packing and water displacement to the surface (above the sediment). The fourth zone (d) is an area without changes in the structure of the sediment compared to the initial zone.

The redistribution metal content was noted in zones a, b and d. Restructuring is inherent only in zone c. The process of structure redistribution occurs along with the process of sediment compaction [13]. The redistribution of particles ends when the sediment becomes fully compact. The primary process of in situ material restructuring occurs in zone c (Fig. 4). The dependence of layer thickness with high content metal on the processing cost energy magnitudes was obtained from restructuring the material array on acoustic laboratory installation (Fig. 5). These results characterize used materials only. However, this principal relation may be applied to restructuring the absolute majority of the placer deposits, which involves alluvial formation. The resulting dependence of decreased productive sand layers is characterized by the direct dependence on material disintegration. Energy loads of approximately 1.5 kW • h /m^3 provide a fourfold reduction in the volume of the starting material.

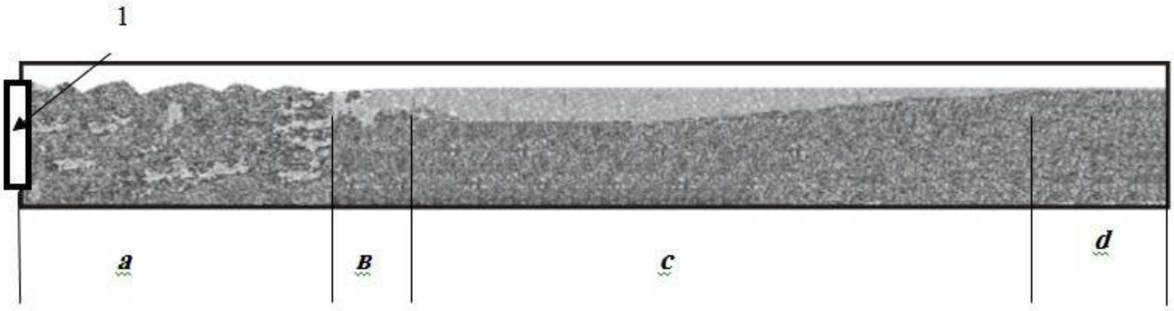

Fig. 4. Laboratory setup for acoustic wave array processing.
(1) acoustic source; a) mixing zone; b) the transition zone; c) zone of sediment compaction; d) unchanged zone

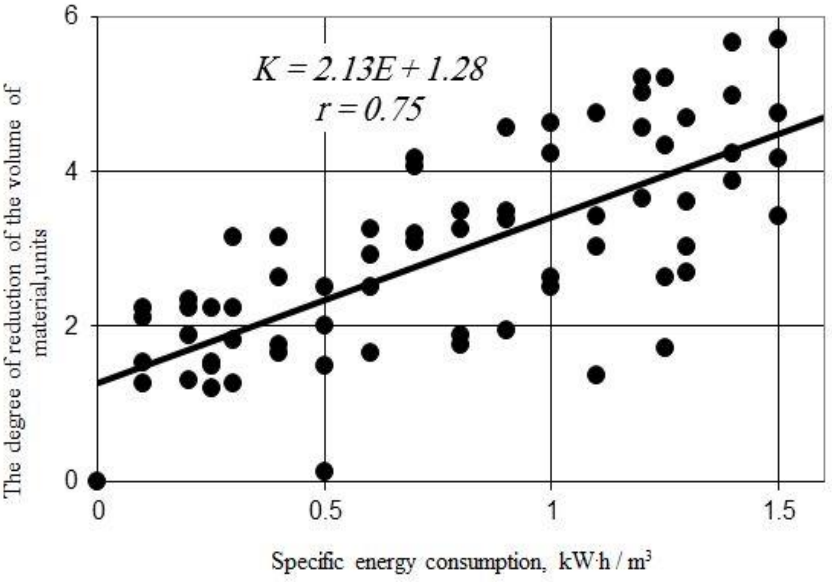

Fig. 5. The dependence of the reduction of the productive layer of gold-bearing sands on energy capacity

The reduction of the sediment productive layer and increasing its content depends on treatment energy quantity. The trend of this dependence is linear and is likely the result of the energy required to break the bonds between the particles. Higher contents can be achieved in the layer by the formation of a precipitate with a greater amount of metal particles that are not bound to clay and sand particles. Smaller size of the gold particles within the sand and clay of gold-bearing sand is higher than total surface area, and more energy will be required to prevent particles from bonding.

The energy values required for disintegration are different, and the changes may be significant. First, the energy values depend on the type of communication at the contact between the particles (Figs. 1 and 2). The interaction force between particles within the shell of tightly bound water (trend 1, Fig. 6) is much higher bond strength than that of the shell of loosely bound water (trend 2, Fig. 6). Maximum energy (~400 kJ/m^3) is required to disintegrate the clay with particle sizes of approximately 1-3 microns.

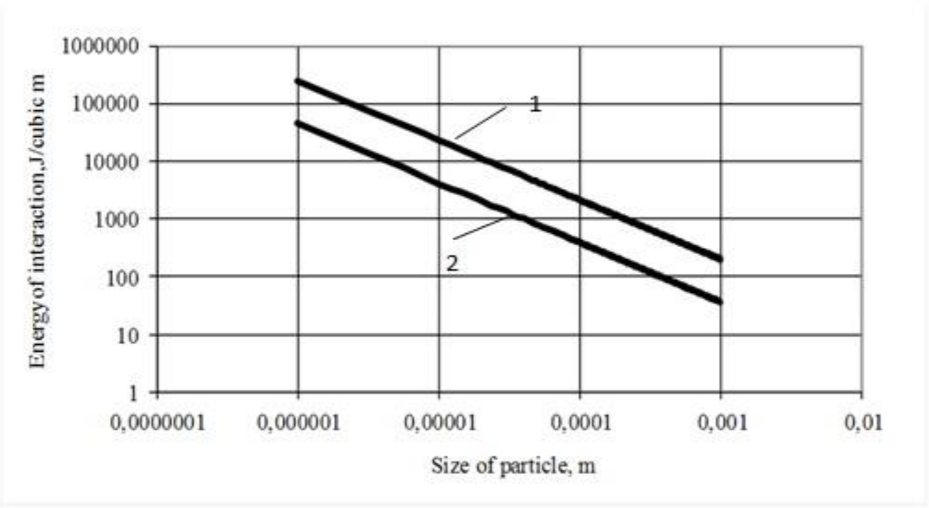

Fig. 6. The dependence of energy consumption of total disintegration on particle size

Such energy costs characterize the aggregate (tightly bound) state of the clay (Fig. 2). The disintegration energy of similar size clay particles is significantly reduced (approximately 80 kJ/m^3) (trend 2, Fig. 6) for the initial state at the level of loosely bound links between particles in pulp. The energy disintegration difference between tightly bound and loosely bound levels is essential. The transition from tightly bound to loosely bound levels occurs automatically when the particle bonds have access to free water. Water molecules are adsorbed into the space between the particles when possible, which is called soaking and is characterized by an increasing level of massif humidity. Soaking is a natural process and occurs slowly regardless of forced disintegration [10], but it does not occur without available free water. Forcibly destroyed connections between the particles without free water can be immediately restored with minimal restructuring when the load of disintegration is stopped. Clay materials are thixotropic; hence, disintegration and restructuring of clay materials is possible with free water only.

The experimental value of the energy of disintegration is in excess of the theoretical data partly because the destruction of particle connections is repeated many times due to the thixotropic nature of the bonds among clay particles in aggregates. The large experimental value can also be explained by the reduced efficiency coefficient value of the experimental setup source as a result of reflection fluctuations that occur during the passage of acoustic waves from the generator through the membrane into the working chamber of the experimental setup.

The next step for restructuring placer massifs is through an analogue of the Roman Arugiy [1]. If the deposit contains excess natural terrain relief (terraced placers), the whole or a portion of the massif can be replaced in the tray with vertical partitions to the lower valley area or a lower area inside the deposit. The height difference can be formed artificially in the deposit contour if there are no natural height differences in the relief field.

The possibility of principle manageable gravitation restructuring was studied experimentally in the second experimental setup (Fig. 7).

The pulp flow in a channel with vertical partitions causes material sedimentation when passing through frequently changing zones of high and low dynamic pressure generated by flow around partitions. The intensive deposition process occurs at the boundaries of the dynamic pressure drop partitions [2]. The dependence of the grain size on the differential pressure (dynamic flow pressure to the baffle) was precipitated (Fig. 8) experimentally. The heavy and large particles form the bottom layer in close proximity to the baffles immediately behind. Pulp flow through the partitions produces turbulence. Turbulent flow results in a permanent oscillatory motion of the sediment particles and promotes mass transfer in the layer. Denser and heavier particles with greater inertia are less prone to removal in the aquatic environment and are located in the front of the tray. Lighter and smaller particles snatched from the sediment were carried by the flow and moved downstream to the next partition.

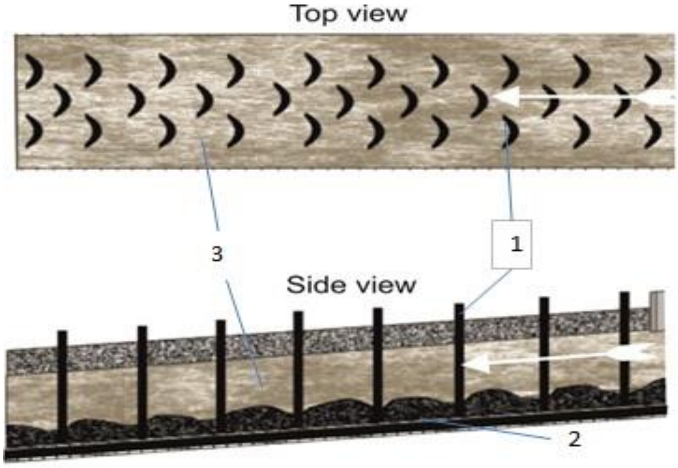

Fig. 7. Experimental tray with vertical partitions
(1) vertical partitions, (2) sediment, (3) pulp flow

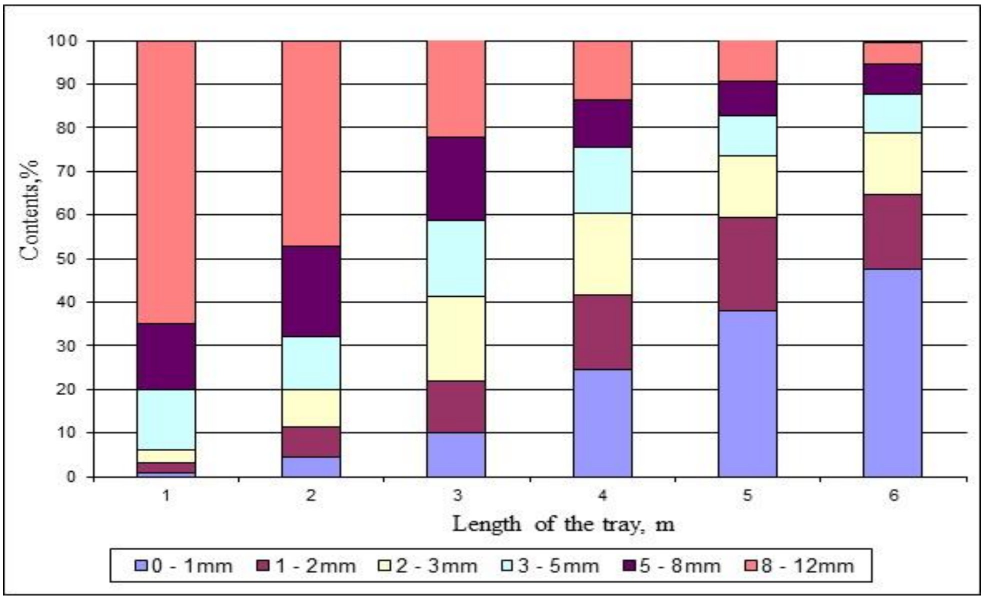

Fig. 8. Distribution particle size along the length of the tray

A full series of experiments was completed in this experimental setup. The angle of inclination of the tray was varied from 2 to 10 degrees. The ratio of the sand to the water in the pulp ranges from 1:1 to 1:15. The sand particle size distribution along the length of the tray varied depending on the ratio of the sand in the pulp and the inclination angle of the tray. The particle distributions are presented in Figure 8 for an angle of inclination of 6 degrees and a ratio of sand to water in the pulp of 1:2. The primary characteristic of the distribution remains fundamentally the same for all parameters. The distribution of the gold content in the tray was assayed in each experiment. The overall distribution patterns were in accordance with the hydraulic size parameters [2, 3, 4]. This distribution pattern indicates the possibility of the division of fractions using this method. Converting a massif in situ by restructuring the tray (the gutter) can reduce the amount of gold-bearing sand by 10- to 12-fold for the described deposits, in agreement with hydraulic size.

Assessments of the distribution of mineral particles of various sizes and particles of free gold as a function of height in the sediment were modeled mathematically based on laboratory experimental results of sand within real placer deposits. These assessments were made according to the adjustment of known dependencies and experimental data for a particular material particle size. The model considers the dependence of clay fraction sedimentation (only for gold-bearing sands with a clay content less than 20%). The model indicates that a two-meter productive layer can be formed from the five-meter height of the initial productive layer of sand as a result of the disintegration of the alluvial deposits array and the free deposition of particles. The gold distribution has linear characteristics. A higher concentration of gold in situ can be obtained only through vertical vibrations of particles when the sediment is not completely compact. Studies confirmed that the high natural irregularity of the metal content in the productive sand layer is characterized by unstable sedimentation conditions. Structural variation ranges from 20 to 60% for stable conditions of sediment formation (Fig. 5). The experimental data of the repeated formation of alluvial sediments suggest that the concentration can be increased to 5-8 times that of the initial concentration of the array.

4. Conclusions

The nature of contact mechanisms between particles in an array and the energy values of these contacts has produced methods of restructuring in placers. The experimental results in this paper confirm the correctness of the proposed solutions. The presented materials from experimental investigations of the formation of a new array are obtained through two methods: (1) the in situ restructuring of the array using acoustic waves to treat the massif layer without moving and (2) alluvial material array conversion through transportation to another location using natural schlich concentration. The principal possibility of restructuring the placer array was demonstrated through experimental results and theoretical modeling. Both experimental study options conducted on the real placers of the material show possible methods of technological solutions for fields in which conditions allow in situ restructuring of the array. The results of experimental modeling substantiate the possibilities of managing the restructuring process of the array. Both research methods of gravitational vertical separation and schlich separation in turbulent flow are comparable in terms of possible gold concentration in the sediment. Both methods can provide a high degree of concentration of gold in the sediment. The method of schlich separation is easier to use because it does not require costly and specialized equipment, however, this method requires a space for the restructuring. The method of vertical gravity separation allows you to work with large amounts of arrays with special vibroacoustic equipment. This method does not require additional space in the restructuring process. Only restructuring the array allows a reduction in the height (or volume of production and processing) of productive formation by up to 4- to 8-fold. Technological solutions can ensure the removal of most burdens along with the pulp in the process of massif preparation.

The samples of material of two real placers were used for experimental investigation. Regularities of the distribution of particles in the array of alluvial gold in situ were obtained.

These regularities showed us the possibilities for direct formation of zones with elevated gold concentrations. These regularities are common to all placers. Experimental dependencies of these investigations reflect general natural gravity regularities behavior of particles of different density in the slurry to flow conditions and wave processing. In addition, at the part of massif with properties that do not fit the concept of the deposit you can create in situ the placer with definite form, category and gold content. Additionally, restructuring the array in situ allows the removal of the harmful clay fraction from the gold-bearing sands during array preparation increases the level of extraction for enrichment and minimizes water consumption. A significant decline in production and ore-dressing will enhance economic efficiency. The decrease in production at the same value of the metal (gold) can provide significant pollution reduction in some cases because smaller waste volumes will be placed in sailings and tailings. Such an approach can serve as a basis for a series of new technological solutions. The methods of placer restructuring will require the development of special equipment and methods. The methods and experimental setups discussed in this article can serve as a prototype for new equipment. The development approach for preparing placers with in situ massif structure transformation may be crucial not only for natural placers but also for the development of man-made objects, the reclamation of waste products and the creation of new deposits.

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