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# Lithology of mudflow-forming deposits

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***Abstract:*** *In recent years, the number of mudflow- and flood-related accidents has increased. For people living in highland areas and near mountain river beds, mudflows pose a great threat. More exact and reliable prediction requires thorough study of mudflow processes. This article contains analysis of a lithological aspect of mudflow.*

**Keywords:** Lithology, mudflows formation, emergency situations.

## Introduction

Mudflow is formed during transformation of a water flow which becomes saturated with friable fragmental materials [7, 8]. Valley investigations show that friable fragmental materials of various genetic types of quaternary deposits take part in mudflow formation. However each type makes different contribution to the mudflow formation process. So, for example, it was noted that glacial (moraine), colluvial, proluvial deposits take active part in mudflow formation [3-5]. Alluvial and fluvioglacial deposits, as well as rock glacier deposits are far more inert [2]. The key lies in a composition of mudflow-forming deposits.

## Methods

Level of water flow saturation with friable fragmental materials depends on a number of factors which were described and numerically assessed by famous scientists T. Takakhashi, R. Bagnold, A. Kroshkin and Yu. Vinogradov [1, 9]. Based on the results of their investigations, they developed a formula called as Takakhashi–Bagnold equation [11]. This equation is modified relative to $C_Т$ parameter, where $C_Т$ – is a weight concentration of fragmentary materials in a mudflow mixture. The equation is as follows:

$$C_Т = \frac{\rho_0 \times tg\alpha}{(\rho_T - \rho_0)\times(tg\varphi - tg\alpha)} \quad (1)$$

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where $\rho_0$ and $\rho_T$ - density of water and of a solid component of mudflow mass; for practical calculations, $\rho_0$ =1.0 g/cm$^3$; $\rho_T$ =2.65 g/cm$^3$ may be assumed;

$\varphi$ - angle of internal friction of friable fragmental deposits under water;

$\alpha$ - slope of valley floor or mudflow site.

According to this equation, mudflow forming activity of deposits is characterized by $C_T$ parameter which depends on the angle of internal friction $\varphi$. The higher the value of $\varphi$, the bigger the possibility of water flow saturation with fragmentary materials. Angle $\varphi$, in turn, depends on the composition of mudflow forming deposits. Therefore, the connection between $C_T$ and deposits composition is observed through the parameter $\varphi$. However, to characterize such composition, it is necessary to find a parameter. A famous surveyor of mudflow forming soils V.N. Vardugin (1977) established that the presence of clay-silt fractions in deposits even in small amounts (1-2 %) adds specific properties of coherent deposits, for example, transition to a free flowing state and movement in indiscrete mass with some degree of moisture and on the slopes exceeding the angle of internal friction of the mudflow mass. Therefore, the clay-silt fraction of deposits reflects the possibility of their involvement in mudflow formation to the maximum extent.

To assess the impact of silt and clay particles on the angle of internal friction of deposits, field investigations were carried out to define the angle of internal friction of fine earth under water. Particles smaller than 10 mm composing filling material of coarse deposits are considered to be fine earth. It included sand particles from 2 to 0.1 mm, and silt and clay particles smaller than 0.1 mm.

**Results**

Sampling was made in 14 valleys of the northern slope of Kyrgyz ridge. Number of samples: Chon-Kaindy – 59, Dzhardy-Kaindy – 58, Kashkasu – 31, Yantkunush – 31, Tuyuk-Issykatinsky – 50, Isha – 36, Kurortnaya-1 – 15, Kurortnaya-2 – 14, Adygene – 30, Sokuluk (along valley profiles) – 99, Sokuluk (in estuaries) – 163, Sokuluk (additionally in estuaries of dangerous mudflow catchment areas) – 26, Kara-Balta (along valley profiles) – 18, Kara-Balta (estuaries of mudflow catchment areas) – 57, Kegety – 67, Dzhelamysh – 45. In total 799 samples, including 478 with defining an angle of internal friction, in dry and under water conditions. Results are summarized in Table 1.

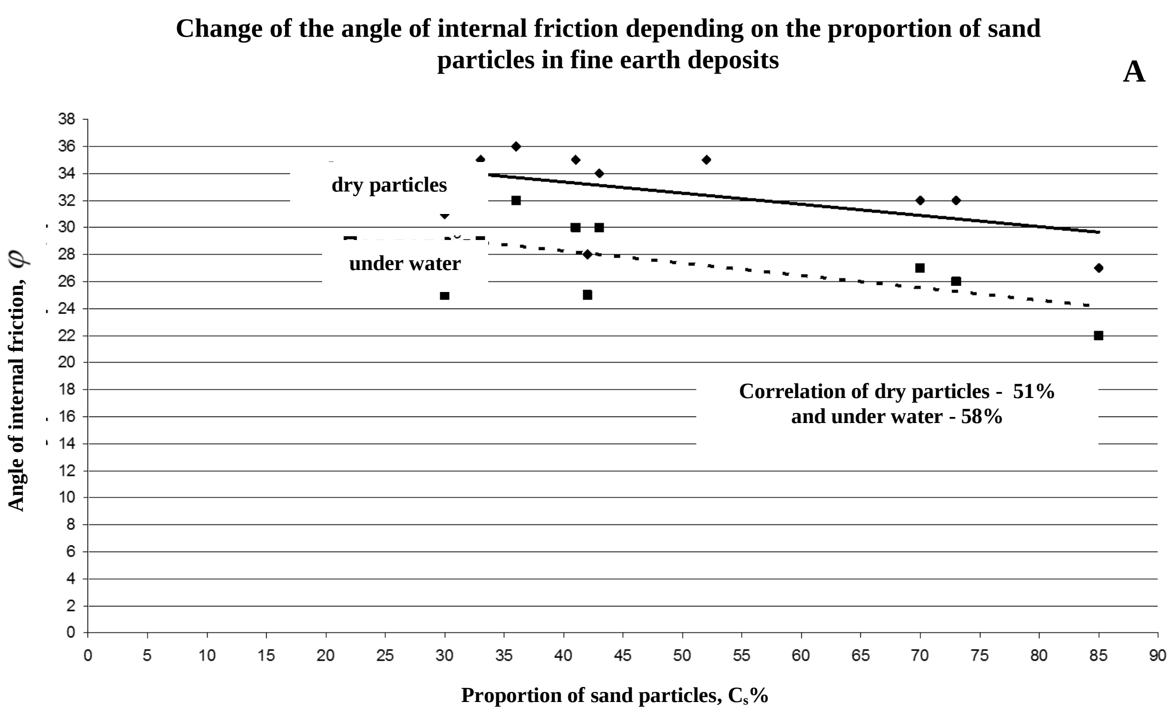
**Table 1.** Results

| Average content % | Holocene alluvium aIV | Mudflow deposits | Mudflow-forming deposits (glacial, mudflow, slope) | Proluvial holocene deposits |
|---|---|---|---|---|
| sand particles | 51 | 40 | 31 | 47 |
| silt and clay particles | 2 | 3 | 5 | 3 |

During the mudflow formation, the number of sand particles increases from 31 to 40 %, then their proportion increases even more when mudflow deposits are scoured with water flows – up to 47 % in proluvium and alluvium.

The number of silt and clay particles decreases when mudflow-forming deposits become mudflow deposits – from 5 to 3 %, then decreases even more when mudflow deposits are scoured with water flows – up to 2 % in alluvium on the valley floor.

Results of field studies are presented in the dependency diagrams (figure 1): $\varphi \sim \varphi \sim f\,(C_s)$ and $\varphi \sim f\,(C_{s/c})$, where $C_s$ and $C_{s/c}$ – is a proportion of sand ($C_s$) and silt-clay ($C_{s/c}$) particles in fine soil.



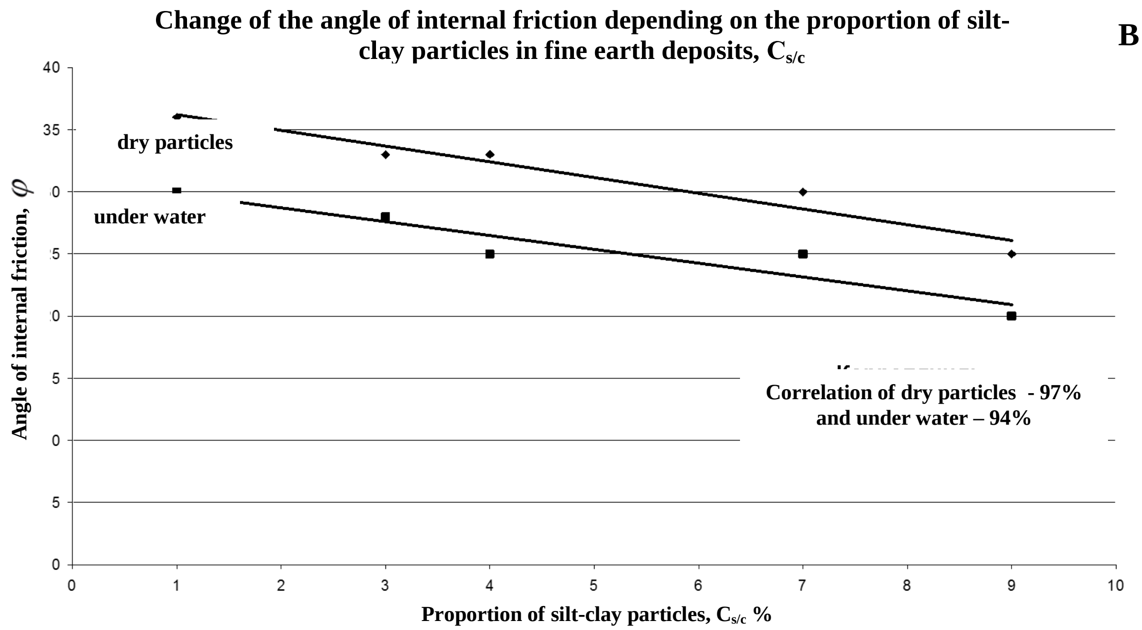



**Figure 1.** Diagrams of dependency of the angle of internal friction on the proportion of sand, silt and clay particles in fine earth of mudflow-forming deposits

The diagrams show clear dependency of the angle of internal friction on the proportion of silt and clay particles in fine earth. Especially a tight connection is observed between an angle of internal friction $\varphi$ and $C_{s/c}$, where correlation coefficient is 94-97.5 %. Therefore, it can be suggested that mudflow activity of the deposits greatly depends on the proportion of silt and clay particles in their fine earth.

However, such dependency is limited. The observations over mudflows in Tian Shan valleys show that a mudflow forming activity of the deposits (with increasing proportion of silt and clay particles) increases to some extent after which it begins to decrease. With high proportion (more than 30 %, see table 2) of silt and clay particles in fine earth, the deposits will not form mudflows. The most striking instance of this property of friable fragmental deposits is the absence of mudflows in the areas of development of the Paleogene-Neogene rocks. In the course of rock decay and breaking, friable fragmental deposits are formed with high content of silt and clay particles which only form suspended streams with density up to 1.4 g/cm$^3$. At the top of the Paleogene-Neogene rock section there are coarse deposits of so called Sharpyldak suite of upper Pliocene-lower Pleistocene age. The content of silt and clay particles in fine earth of such suite deposits is within the limits of mudflow formation, and therefore there, are traces of typical mudflows observed in the area of development of the Sharpyldak deposits. On the other hand, if the number of silt and clay particles in deposit fine earth is small, i.e. below the lower limit of mudflow formation, the mudflow forming activity of such deposits will drop sharply. So, colluvial-type coarse deposits, “rock stream” or “rock glacier” deposits are scarcely involved in mudflow formation. If a mudflow encounters a “rock glacier”, it will strike against it as if it were a dyke, deviate to an opposite side of valley, then go round it and move on.

To assess a mudflow-forming capacity of the deposits of various genetic types, a field study of their composition was carried out in Aksai river valley (Ala-Archa river basin on the northern slope of the Kyrgyz ridge). The mudflow-forming capacity of deposits was assessed based on the density of mudflows formed by them. The density of mudflow mass within the flow was determined using the following formula:

$$\rho_C = (1 - C_T)\rho_o + C_T \rho_T \quad (2)$$

Symbols are the same as in the formula (1).

Table 2 contains the results of calculations of parameters $C_T$ and $\rho_c$ by formulas (1) and (2) for mudflow forming deposits of various genetic stratigraphic sequences. The value of $tg\alpha$ is set equal to an average slope of the Aksai mudflow site – 0.27 [6]. A proportion of silt and clay particles, as well as an angle of internal friction $\varphi$ of the deposits of various genetic types are given in the table as average values of samples taken from mudflow forming deposits in the Northern Tian Shan valleys.

**Table 2.** Results of calculations by formulas (1) and (2)

| No. | Genetic stratigraphic sequence | Number of samples | Average content of silt and clay particles, % | Average value of the angle of internal friction, deg. | Possible concentration of mudflows | Density of mudflows, g/cm$^3$ |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 1 | alluvium $Q_{IV}$ | 30 | 4.7 | 34 | 0.41 | 1.68 |
| 2 | alluvium $Q_{III}$ | 30 | 8.9 | 29 | 0.58 | 1.96 |
| 3 | alluvium-proluvium $Q_{IV}$ | 36 | 5.8 | 32 | 0.47 | 1.78 |
| 4 | alluvium-proluvium $Q_{III}$ | 30 | 4.6 | 34 | 0.41 | 1.68 |
| 5 | colluvium $Q_{IV}$ | 50 | 6.9 | 30 | 0.53 | 1.87 |
| 6 | deluvium $Q_{IV}$ | 38 | 5.8 | 32 | 0.47 | 1.78 |
| 7 | glacial $Q_{IV}$ | 60 | 9.4 | 28 | 0.63 | 2.04 |
| 8 | glacial $Q_{III}$ | 30 | 24.1 | 24 | 0.91 | 2.50 |
| 9 | glacial $Q_{II}$ | 30 | 23.9 | 24 | 0.91 | 2.50 |
| 10 | colluvium-glacial $Q_{IV}$ | 30 | 8.5 | 29 | 0.58 | 1.96 |
| 11 | proluvial $Q_{III-IV}$ | 30 | 15.8 | 25 | 0.82 | 2.35 |

Values of mudflow forming parameters given in table 2 provide clear evidence that mudflows with high, almost ultimate density (2.50 g/cm$^3$) appear when Middle-upper quarternary glacial deposits are scoured. Content of silt and clay particles in their fine earth exceeds 20 %. Recent glacial and proluvial deposits (2.04-2.35 g/cm$^3$) play less active role in mudflow formation. Colluvium-glacial and Upper quarternary alluvial deposits are even less active. Their activity is near to that of colluvial deposits (1.87-1.96 g/cm$^3$). At last, the least mudflow activity is typical of alluvial-proluvial, recent alluvial and deluvial deposits. Density of mudflow suspension upon scouring of such deposits will be 1.68-1.78 g/cm$^3$.

According to “Guidelines for mudflow runoff stations and hydrographic parties” (1990), mountain flood streams, in terms of density, fall into following types: 1) suspended – with density from 1100 kg/m$^3$ to 1400 kg/m$^3$; 2) mud – with density from 1.4 to 1.8 kg/dm$^3$; 3) debris – with density from 1.8 to 2.5 kg/dm$^3$.

As table 2 shows, debris flows may be formed in valleys with glacial sequence deposits. Proluvial deposits also can form mudflows with density exceeding 2 kg/dm$^3$, but such proluvial deposits represent derived glacial sequences.

## Conclusion

Therefore, in terms of a mudflow forming activity of friable fragmental deposits, mountain and piedmont valleys are divided into three groups:

1. Valleys where all three types of mudflows might be formed. These are mountain valleys with recent glaciation or outlier of former glaciation, thick mass of moraine deposits in the upper reaches. These are first- and second-order large mountain valleys. Here, the mudflows might be formed due to the outburst of mountain lakes and intraglacial basins, as well as the heavy rains which additionally humidify mudflow-forming deposits with snow-melt waters.
2. Valleys where the first and second types of flows may be formed. These are third- and fourth-order mountain valleys with traces of former glaciation in the upper reaches. This group also includes some piedmont valleys with a thick mass of the Sharpyldak suite coarse deposits lying in the upper reaches. As was said earlier, lithological composition of such deposits facilitates formation of the second-type mudflows. In these valleys, mudflows might be formed due to heavy rains additionally humidifying deposits with snow-melt waters.
3. Valleys where only suspended streams are formed. These are piedmont valleys with their sides and floors made of Paleogene-Neogene shaled-out deposits. High content of clay particles inhibits formation of high-density mudflows. Under heavy rains, shaled-out deposits are easily scoured and form the suspended streams.

## References

[1] Vinogradov, Y.B., 1980. Etudes on mudflows. Hydrometeoisdat. 144 pp., (in Russian).

[2] Gerasimov, Y.B., Dikih, A.N., 1977. Features of erosive activity of glacial mudflows in the areas of developed ancient moraine deposits. In Dynamics and regime of modern and ancient glaciation of Tien Shan. Frunze: Ilim, pp. 131-139, (in Russian).

[3] Yerokhin, S.A., 1992. Report on results of the engineering-geological study of dams on high-mountain lakes with high risk of mudflows in Kirgizia in 1988-1992. Funds of Gosgeolagenstva (State geological agency) of KR. Bishkek, 289 pp. (in Russian).

[4] Yerokhin, S.A., 2008. Engineering-geological study of dams on high-mountain lakes with high risk of mudflows on the territory of the Talas, Naryn, Chui and Issyk-Kul regions of the Kyrgyz Republic. Report of the engineering-geological party of Kyrgyz complex hydrogeological expedition based on the work in 2000-2008. Funds of Gosgeolagenstva (State geological agency) of KR. Bishkek, pp. 174, 192, (in Russian).

[5] Yerokhin, S.A., 2000. Engineering-geological study of dams (of moraine-glacial complexes) on high-mountain lakes with high risk of mudflows, of mudflow hotspots, and mountain valleys with high risk of mudflows in Kirgizia. Report on the works conducted in 1991-2000. . Funds of Gosgeolagenstva (State geological agency) of KR. Bishkek, pp. 131, 151, (in Russian).

[6] Yerokhin, S.A., Dikih, A.N., 2003. Assessment of hazards of mudflow and flood in the Ala-Archa National Park. Izvestia (news) of the National Academy of Science of the Kyrgyz Republic. Ilim, 4. Bishkek, pp. 130-139, (in Russian).

[7] Yerokhin, S.A., Mangeldina, N.G. and Zaginayev, V.V., 2010. Assessment of mudflow hazards in mountain valleys in Kyrgyzstan and prediction of mudflow activities in 2010. Monitoring, prediction of hazardous processes and events on the territory of the Kyrgyz Republic. Issue number seven with modifications and additions. Ministry of Emergency Situations of the Kyrgyz Republic. pp. 594-606, (in Russian).

[8] Yerokhin, S.A., Zaginayev, V.V., 2011. Prediction of mudflows and freshets in Kyrgyzstan in 2011. Monitoring, prediction of hazardous processes and events on the territory of the Kyrgyz Republic. Issue number eight with modifications and additions. Ministry of Emergency Situations of the Kyrgyz Republic. pp. 601-604, (in Russian).

[9] Kroshkin, A.N., 1959. Conditions of mudflow formation and some of its estimations on the Ala-Archa river. Institute of energy and water resources of Kirgiz SSR, Issue 5 (VIII), Frunze, (in Russian).

[10] Accounts Chamber of KR 22-102:2001. The procedure to identify zones of freshet and mudflow damage as a result of breakthrough of mountain lakes on the territory of the Kyrgyz Republic, (in Russian).

[11] Stepanov, B.S., 1985. Transport-shear and shear-erosive mudflow processes. Mudflow streams. Collection 9, Hydrometeoizdat, Moscow, pp. 3-16, (in Russian).