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Redistribution of ions within the active layer and upper permafrost, Yamal, Russia

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ABSTRACT: A landslide-affected slope was chosen to study the ionic migration in the active layer and upper portion of permafrost. The research was conducted in two stages, in 1994 and 2001. Several boreholes, in dry and wet environments of the shearing surface of a 1989-landslide, were drilled. A background borehole on an undisturbed site was sampled as well. Each sample, collected from the core, underwent a conventional chemical cation-anion analysis. The results showed desalinization of the active layer and upper permafrost, which occurred in 7 years. Different migration rates noted for various salts determine change of ionic composition from marine pattern to continental, because mobile ions are washed away by surface and subsurface runoff, while the less mobile ones are accumulating in the upper portion of the active layer due to capillary rise and at the active layer base on a geochemical barrier.

1 INTRODUCTION

Saline frozen deposits, widely distributed at Yamal Peninsula, leave their prints on every natural and anthropogenic process occurring in the region. A specific type of the tundra vegetation with a "warmer" appearance (high willows, richer biomass compared with zonal vegetation) develop at the sites where the saline deposits are exposed at the surface due to the landslide process. The landslide process removes the upper fresh, often sandy soils down slope and exposes the clayey saline perennially frozen soils (Leibman 1995). The landslide activation and permafrost exposure is accompanied by the vertical migration and horizontal wash away of readily soluble salts (Leibman & Streletskaya 1996; Tentyukov 1998; Ukraintseva et al. 2000).

The objective of the present work is the suggesting a dynamic pattern for the process of ionic migration in a case study on a landslide slope within the coastal-marine plain, Yamal Peninsula, Russia.

2 STUDY AREA

The area under study is located at the interfluve of Se-Yakha and Mordy-Yakha rivers (Fig. 1). The territory is represented by a hilly plain with narrow watersheds and extensive gentle slopes. Marine terraces have the maximum altitude up to 58 m. Narrow valleys of rivers and small creeks, ravines and gullies intensively dissect the territory.

Marine sedimentation prevailed in the area during the Middle and Late Pleistocene. A thick stratum of marine clayey deposits was accumulated in the course of marine transgression (Ershov 1995). The polar basin's water surface continually decreased, and its shoreline moved northwestward. Marine deposits, being turned into a subaerial state, began to freeze up in Late Pleistocene.

Figure 1. Yamal Peninsula, star points to the study area.

The main relief-forming process at the study area as well as at other coastal plains of permafrost zone is thermal denudation on slopes, including cryogenic landslides, thermal erosion, nivation, etc. (French 1996, Kaplina 1975, Leibman et al. 1991, 1997, Lewkowicz 1988, 1990, Zhigarev 1975).

Active natural cryogenic processes typical of the region on study, expose the sediments containing soluble salts, microelements and lenses of brine, and subject them to destruction. That, in the end, affects essentially the chemical composition of sediments as well as superficial and active layer water (Leibman & Streletskaya 1996, Ukraintseva et al. 2000).

3 RESEARCH METHODS

A field study has been carried out in Central Yamal, “Vaskiny Dachi” research station. The site was affected by a landslide event in 1989 (Leibman 1995). Samples were collected from the core of shallow boreholes and their ionic composition tested to analyze redistribution of water-soluble salts, caused by involving of the upper section of permafrost into seasonal thaw as a result of a landslide process.

Several shallow boreholes were drilled in 1994 (Leibman & Streletskaya 1996). Considered are two boreholes located on a shearing surface, borehole #2 at the wet site, in the sediment accumulation zone, and borehole #3 in the dry site, the zone of active erosion, and thus well-drained (Fig. 2a, b).

The same landslide area was under study in summer 2001. Sampling was undertaken in a background borehole #1 on an undisturbed surface to characterize a stable slope without redistribution due to a landslide. Boreholes #2bis and #3bis correspond to old ones #2 at the wet site, and 3 at the dry site, respectively. The results of repeated chemical tests are compared to reveal the dynamics of the ionic migration through a geological section in various landscape-geochemical conditions.

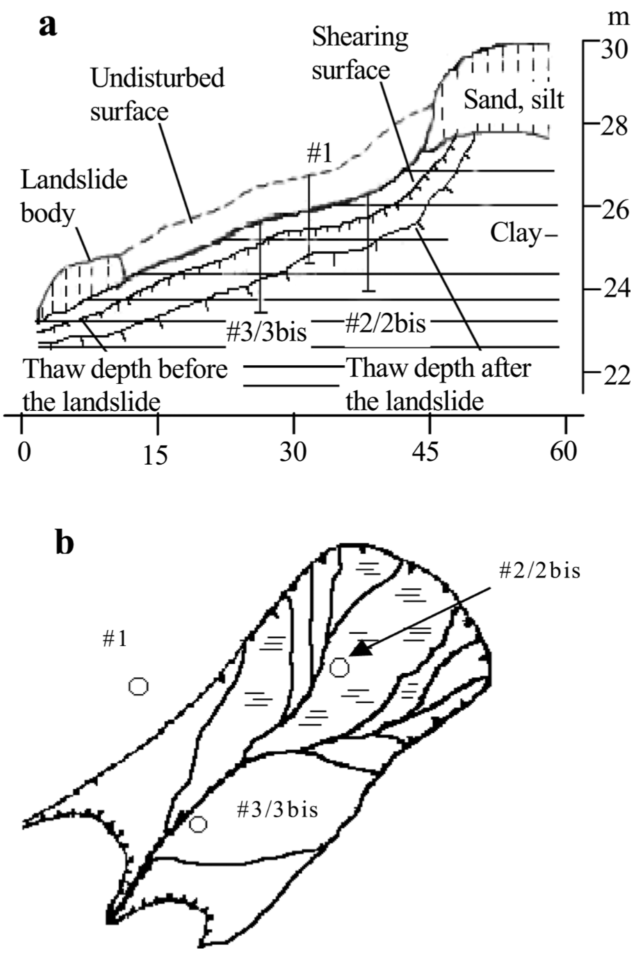

Figure 2. Borehole position: a, profile; b, plan.

4 RESULTS AND DISCUSSION

Background boreholes #1 (2001) characterize the active layer and upper permafrost. It is clear from the diagram (Fig. 3a), that there are two horizons of salinization. Near-surface salinization is due to salt migration upward in winter (Naletova, 1996) and capillary rise in summer (Anisimova, 1981). The second near the active layer base is resulting from the permafrost table accumulating salts as a geochemical barrier (Leibman & Streletskaya 1996).

The soluble salt content in perennially frozen deposits at the depth from about 95 cm downward, is practically similar in all three boreholes (0.6–0.8%). This, probably, proves the similarity of the initial ionic distribution at the landslide and background site before the landslide event.

The active layer of the shearing surface contains as a whole more soluble salts (0.3–0.6%) than the undisturbed area (0.04–0.2%), and the amount of salts increases with the depth (borehole #2, Fig. 3b; and #3, Fig. 3c).

The distribution of soluble salts through the active layer of the shearing surface is rather similar at the dry and wet conditions. Specific pattern is connected with washing away of soluble salts under filtration and accumulation due to capillary rise as well as at the undisturbed site but at a different rate. The main process for the wet site (Fig. 3b) is capillary rise of ions to the surface and evaporation (Anisimova 1981), and then washing away by surface run-off. Intensity of this process is seen from rather low soluble-salt content at the active layer base (<0.5% at 65 cm, Fig. 3b) compared with the dry site (>0.65% at 75 cm, Fig. 3c). In addition, the lower horizon at the active layer base of the wet site, looses its salts due to subsurface runoff over the permafrost table along the post-cryogenic fissured zone where the rate of filtration in clayey ground is abnormally high (Leibman et al. 1993, Naletova 1996).

Comparing ionic composition data for 1994 and 2001, one can see the dynamic pattern for redistribution of ions in the active layer and upper permafrost.

At the wet site of the shearing surface the salt content is much less in 2001 compared with 1994 (Fig. 3b, boreholes #2 and 2bis). Most active desalinization is above

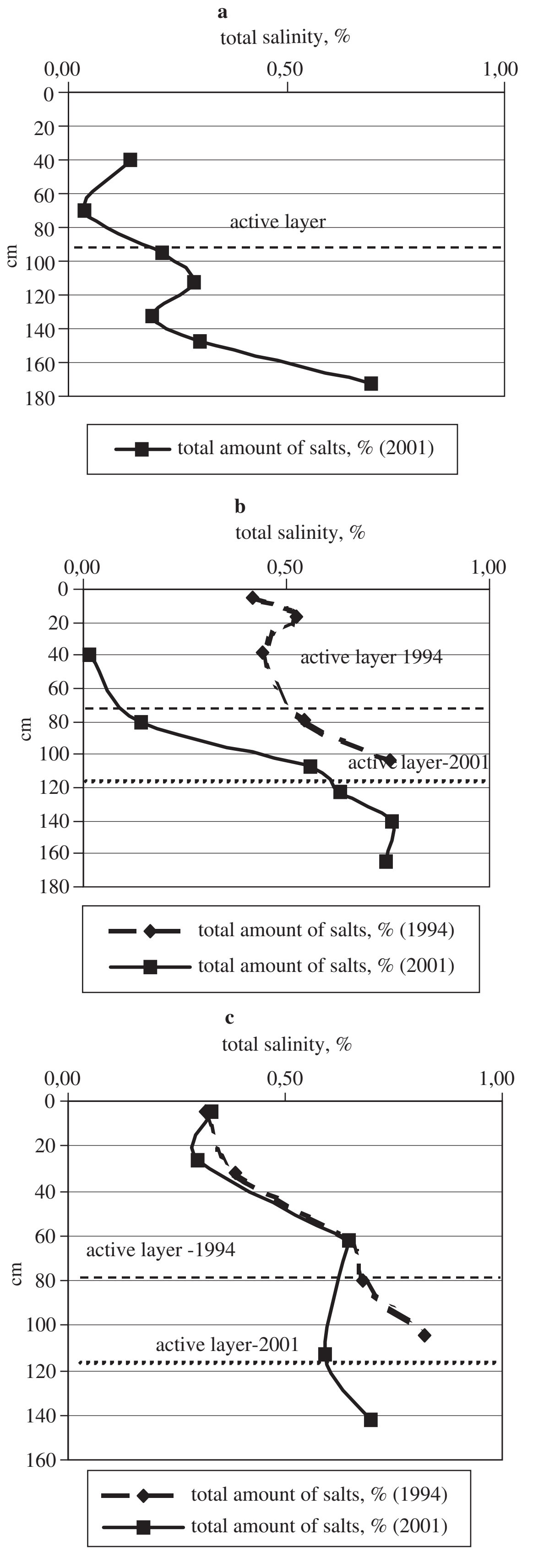

Figure 3. Total content of soluble salts (a dry residue) in the deposits of the active layer and upper permafrost at: a, undisturbed site (borehole 1, 2001); b, wet site of the shearing surface (borehole 2 in 1994 and 2bis in 2001); c, at the dry site of the shearing surface (borehole 3 in 1994 and 3bis in 2001).

the active layer base of 1994. This can be explained by abundant cryostructure formation in the active layer of the wet site, better developed post-cryogenic fissured zone, and thus more intensive run-off. Though there are no samples at the active layer top, it can be surmised that upper accumulation zone (at the depth of 20 cm) in 2001 should be much less pronounced compared with 1994 due to re-vegetation of the surface and preventing of wash out of evaporites.

The dynamics of total salinity at the dry shearing surface (Fig. 3c, borehole #3, 3bis) is characterized by the binomial accumulation pattern. The upper accumulation horizon is less expressed, while the active layer base horizon shows the highest among the study sites content of soluble salts. Most likely this can be explained by an accumulation at geochemical barrier under low run-off in the lack-of-water conditions of the dry site.

Re-distribution of separate ions (mainly anions) is different from total soluble-salt redistribution, depending on the migration ability of anions. Cations are not discussed because the pattern of their distribution with depth does not change qualitatively, though the content of cations decrease. Re-distribution of anions is shown on Figure 4 (bicarbonate-ion), Figure 5 (sulfate-ion), and Figure 6 (chloride-ion).

There is a non-uniform distribution of anions in permafrost at the undisturbed site (Figs. 4a, 5a, 6a) with a peak near the geochemical barrier at the active layer base.

At both sites of the shearing surface (Fig. 4b, c) bicarbonate has minimum content near the surface and in permafrost while in most of the active layer the content of this anion is maximum. Bicarbonate content decreased in 2001 at both sites, as compared with 1994, but at the wet site to a larger degree.

The accumulation zone for sulfate-ion at geochemical barrier is most expressed at the wet site (Fig. 5b) where maximum is noted at the active layer base of the relevant year. Remarkable is abrupt increase of sulfate content at the surface of the dry site (Fig. 5c). This is explained by several reasons: (1) capillary rise of soluble salts is more active at the dry site, (2) chlorides are the most mobile and first washed away, and (3) the content of bicarbonates is low from the beginning. Thus, sulfates are the main component of evaporites on the surface of the dry site.

The total content of chloride-ion is the highest among other anions due to marine type of initial salinization in the study deposits. The main distribution pattern is persistent decrease with depth up to the active layer base. But there is a specific feature within the active layer of the wet site. Here at a depth about 20 cm other anions have maximum in 1994 (Figs. 4b, 5b), while chloride content shows minimum (Fig. 6b). Unfortunately there is no data at this depth for 2001.

Chloride content does not change much in 2001 compared with 1994 in permafrost, but there is rather a high difference in 1994 and 2001 at the active layer of the wet site (Fig. 6b) or near the surface at the dry one (Fig. 6c). Thus, geochemical barrier at the active layer base for this anion is not efficient. Capillary rise is, probably, the main factor of redistribution for chloride.

As demonstrated by the field study, the change in content of cations and anions between 1994 and 2001

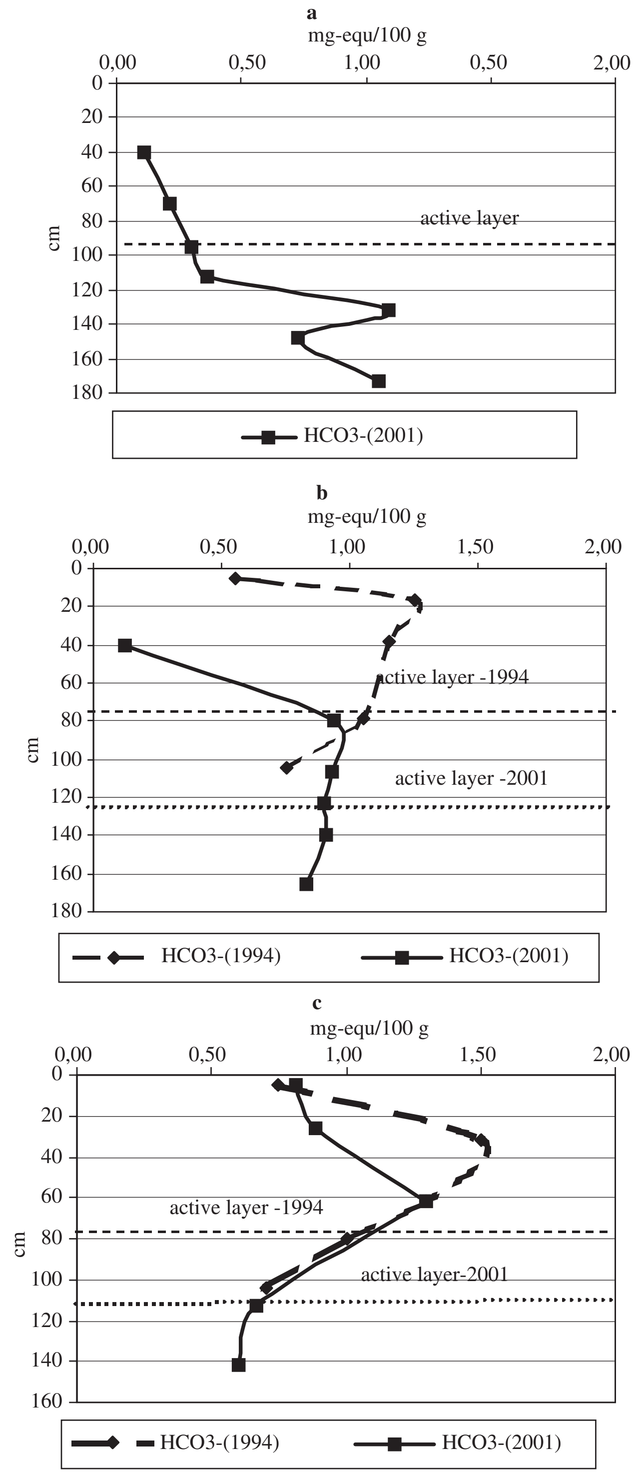

Figure 4. Content of bicarbonate-ion in the deposits of the active layer and upper permafrost at: a, undisturbed site (borehole 1, 2001); b, wet site of the shearing surface (borehole 2 in 1994 and 2bis in 2001); c, at the dry site of the shearing surface (borehole 3 in 1994 and 3bis in 2001).

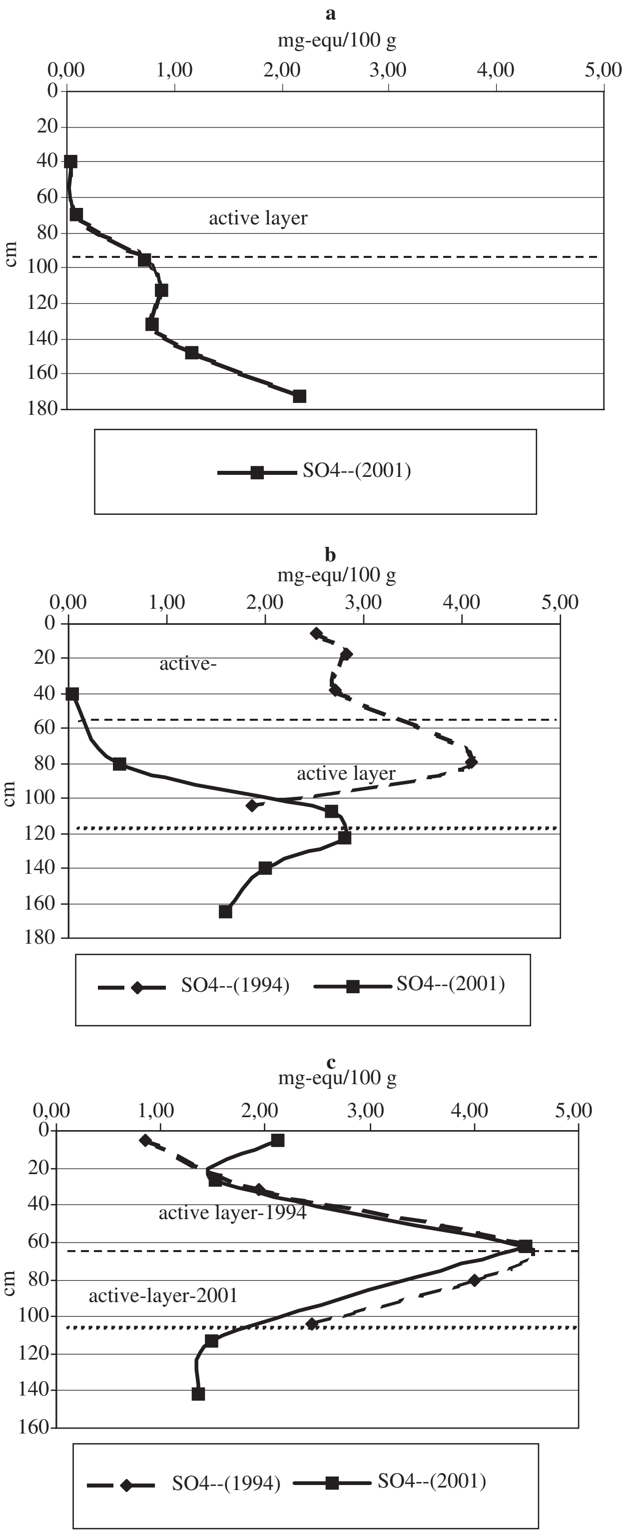

Figure 5. Content of sulfate-ion in the deposits of the active layer and upper permafrost at: a, undisturbed site (borehole 1, 2001); b, wet site of the shearing surface (borehole 2 in 1994 and 2bis in 2001); c, at the dry site of the shearing surface (borehole 3 in 1994 and 3bis in 2001).

follows migration rates of various ions. At undisturbed surface all anions have the same distribution pattern with maximum in the zone of maximum seasonal thaw depth (geochemical barrier), at the shearing surface this regularity is broken by re-distribution of chloride-ion. This ion due to a high migration rate moves fast from permafrost into the active layer and is washed away by surface and active layer runoff. Sulfate and bicarbonate form a second zone of accumulation at the depth of 20–30 cm. This zone is most expressed at the dry site and more actively reducing at the wet one due to a higher runoff. Chloride marks this zone by a reduced rate of washing away.

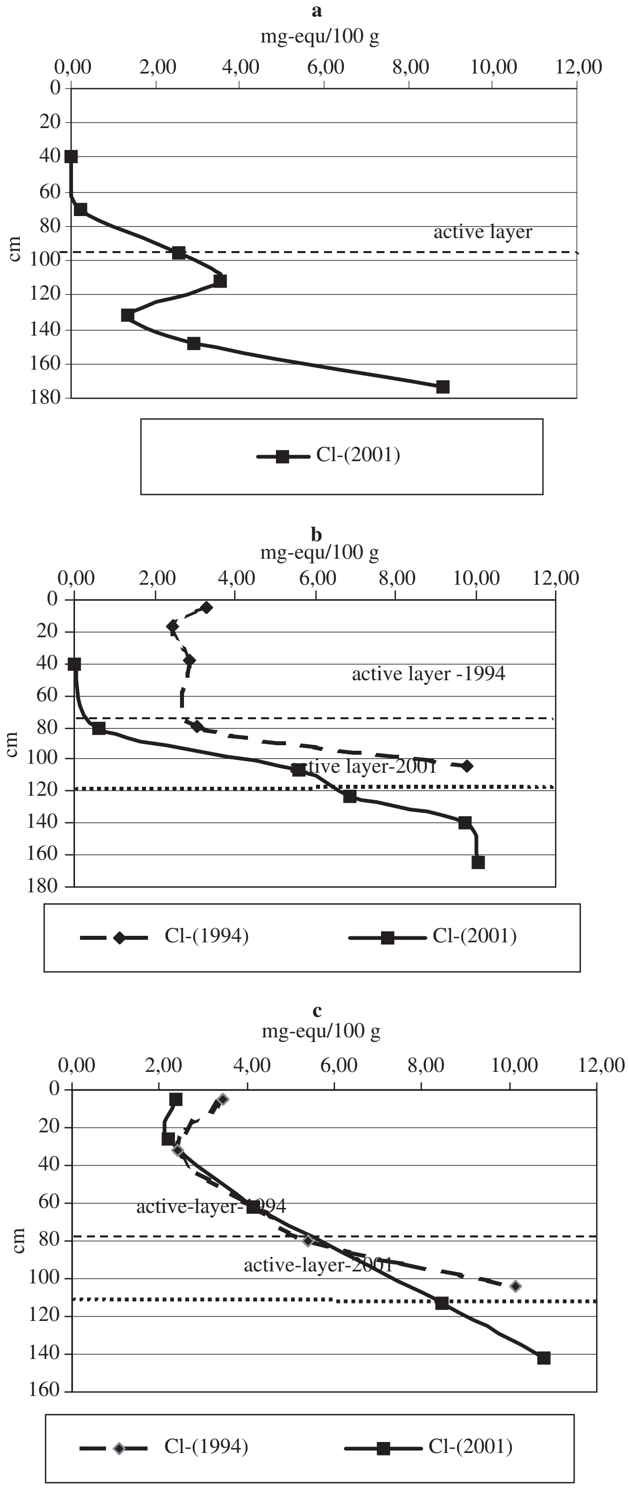

Figure 6. Content of chloride-ion in the deposits of the active layer and upper permafrost at: a, undisturbed site (borehole 1, 2001); b, wet site of the shearing surface (borehole 2 in 1994 and 2bis in 2001); c, at the dry site of the shearing surface (borehole 3 in 1994 and 3bis in 2001).

5 CONCLUSIONS

Sampling and ionic analyses of active layer and upper permafrost deposits at a landslide-affected slope show the following.

1 Shearing surface compared with undisturbed slope is characterized by reduced content of soluble salts in both active layer and upper portion of permafrost, thus landslide process causes desalinization of near-surface saline marine deposits.
2 Different rates and dynamical pattern of ion redistribution at the wet and dry sites of the shearing surface depend on the migration rates of ions in combination with water filtration and movement rates.
3 Since 1994, in 7 years, two zones of accumulation were formed in the new active layer. One at the geochemical barrier of the active layer base is effective only for bicarbonate and sulfate ions, while the upper one in addition to other anions, is feebly distinct for chloride as well.
4 The initially marine type of salinization in perennially frozen deposits involved in the seasonal thaw after the landslide event turns into continental due to a high rate of washing away chloride-ion.

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