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WEATHERING OF THE ADUN-CHELON GRANITE, TRANSBAIKALIA

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Different weathering mechanisms and patterns have been studied in the Late Jurassic Adun-Chelon granites in southeastern Transbaikalia (Dauria) in the course of field work and laboratory analyses. The Adun-Chelon granites have unusual rough surfaces produced by mechanical, chemical and biogenic effects, but especially by frost weathering. Rock-forming minerals behave in different ways during cryogenic weathering: quartz is the most susceptible mineral while feldspar and micas are more stable. The difference between quartz and feldspar in resistance to cryogenic disintegration is responsible for the observed surface roughness.

Granite, grus, cryogenic weathering, micromorphology, quartz, feldspar, Transbaikalia

INTRODUCTION

Modern geosciences often use jointly data of different scales, from satellite images covering vast areas to micrometer and nanometer structures resolvable due to instrumental advances. Permafrost research deals with morphology and textures of primary and secondary minerals, ice inclusions, as well as cryogenic effects in rocks and soils. We study landforms and microstructure of granites in southeastern Transbaikalia and mechanisms of their weathering, in the field and in laboratory.

Weathering is a complex interplay of multiple processes and mechanisms. In the classical interpretation, it can be physical, chemical or biogenic, but the relative contributions of different agents may vary even within a single weathering profile and are hard to constrain. Dissolution may be the key process in both chemical weathering and karst formation. In biogenic weathering, reactions with chemically aggressive life products of organisms are different from biomechanic effects. Mechanic weathering is most often meant as disintegration of an originally monolith rock into angular fragments of block, boulder, debris, grus, sand, and silt sizes, mainly as a result of variations in temperature and moisture (frost [*Popov, 1967*] or cryogenic [*Ershov, 2002*] weathering). The interpretation of cryogenic weathering has changed lately from simple mechanic disintegration by freezing water [*Poltev, 1966*] to complex physicochemical interaction between rock and water in different phase states [*Konishchev, 1981*]. The degree of cryogenic weathering can be estimated quantitatively from grain sizes of eluvium [*Konishchev and Rogov, 1994*]. Quartz turns out to be less resistant to cryogenic effects than feldspar, and its weathering behavior in cold environments is quite different from that in a warm and wet climate [*Rogov, 2011*].

STUDY AREA AND METHODS

The Adun-Chelon granites occur in an undulated terrain on the SW extension of the Kukulbei Range in southeastern Transbaikalia, on the right side of the Borzya River, 25–40 km east-southeast of its inflow into the Onon River (Fig. 1). The granites are erosively exposed at 760–986 m asl and form several tens of outliers (hogbacks) rising from 3–5 to 20–25 m high above smoothly elevated hills. The area is dissected by U-shaped gullies arranged in a quasi-radiated pattern. Denudation in the area appears to continue or resume repeatedly through the neotectonic history. The Adun-Chelon granites are strongly and unevenly deformed. The zones of numerous densely spaced steep fractures are more vulnerable to surface processes and are heavily weathered [*Ananiev et al., 1992; Lukashov, 2013*], while the elevated large and small watersheds are less dissected. The hogbacks produced by selective denudation resemble a herd of grazing animals (Fig. 2), this being the origin of the area name: Adun-Chelon is Mongolian for *a herd of stones*.

The area has been widely known since long ago from reports of prominent scientists: Peter Simon Pallas (1772), Vladimir Vernadsky, and Alexander Fersman. It was mined for gemstones, including black quartz (morion). However, morion mining was stopped because most stones turned out to be of low quality, with abundant microfractures, gas-liquid inclusions, and opacity sites.

The Adun-Chelon outliers are composed mainly of schists and granites rich in silica and ore minerals. The rocks are strongly weathered and crumbling. The exposed coarse-grained granites are remarkable by rough knobby surfaces (Fig. 3) produced by feldspar crystals, 0.5–1 cm high and up to 2 cm wide. They are especially prominent in overhanging reverse walls

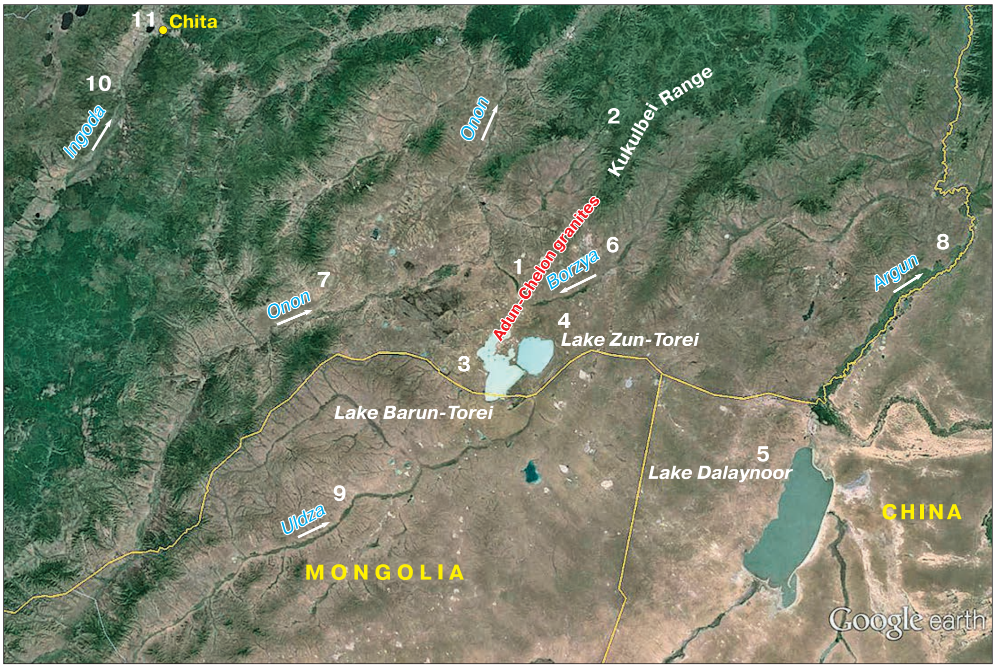

Fig. 1. Study area (GoogleEarth image, www.google.com).

1 – Adun-Chelon granites; 2 – Kukulbei Range; 3 – Lake Barun-Torei; 4 – Lake Zun-Torei; 5 – Lake Dalaynoor; 6 – Borzya River; 7 – Onon River; 8 – Argun River; 9 – Uldza River; 10 – Ingoda River; 11 – Chita.

where no moisture can accumulate and no moss, lichen or alga can grow [*Gurinov et al., 2014*].

The territory is located in the continent interior, in a cold and arid climate, where high erosion rates are maintained by large annual and daily temperature ranges, deficit of winter moisture (less 5 mm of precipitation per month), and very cold winter air temperatures for the middle latitudes reaching –34 °C on average and –50 °C the lowest [*Kachurin, 1950*].

The Adun-Chelon granites were sampled, documented, and analyzed in order to estimate the relative contributions of physical, chemical, and biogenic factors into their weathering and formation of the knobby surfaces. As specific objectives, the study addressed

– the morphology and relative position of minerals (quartz, feldspar, and mica) in granite;

– the role of cryogenic effects in the weathering of crystalline rocks;

– the macro- and micromorphology of rocks subject to weathering in a mountainous permafrost terrain within the mid-latitude zone of southeastern Transbaikalia.

Fig. 2. Adun-Chelon hogbacks. Photograph by A.A. Lukashov.

Fig. 3. Weathered granite surface. Photograph by A.A. Lukashov.

After visual examination, the samples were analyzed on a *Hitachi TM 3000* Scanning Electron Microscope (SEM) with a *Swift 3000* Energy Dispersive Spectrometer (EDS) and a *Nicon Eclipce LV100* Polarizing Microscope (PM).

RESULTS

It appears reasonable to describe first the surfaces of the weathered Adun-Chelon granites, because the erosion agents commonly propagate from

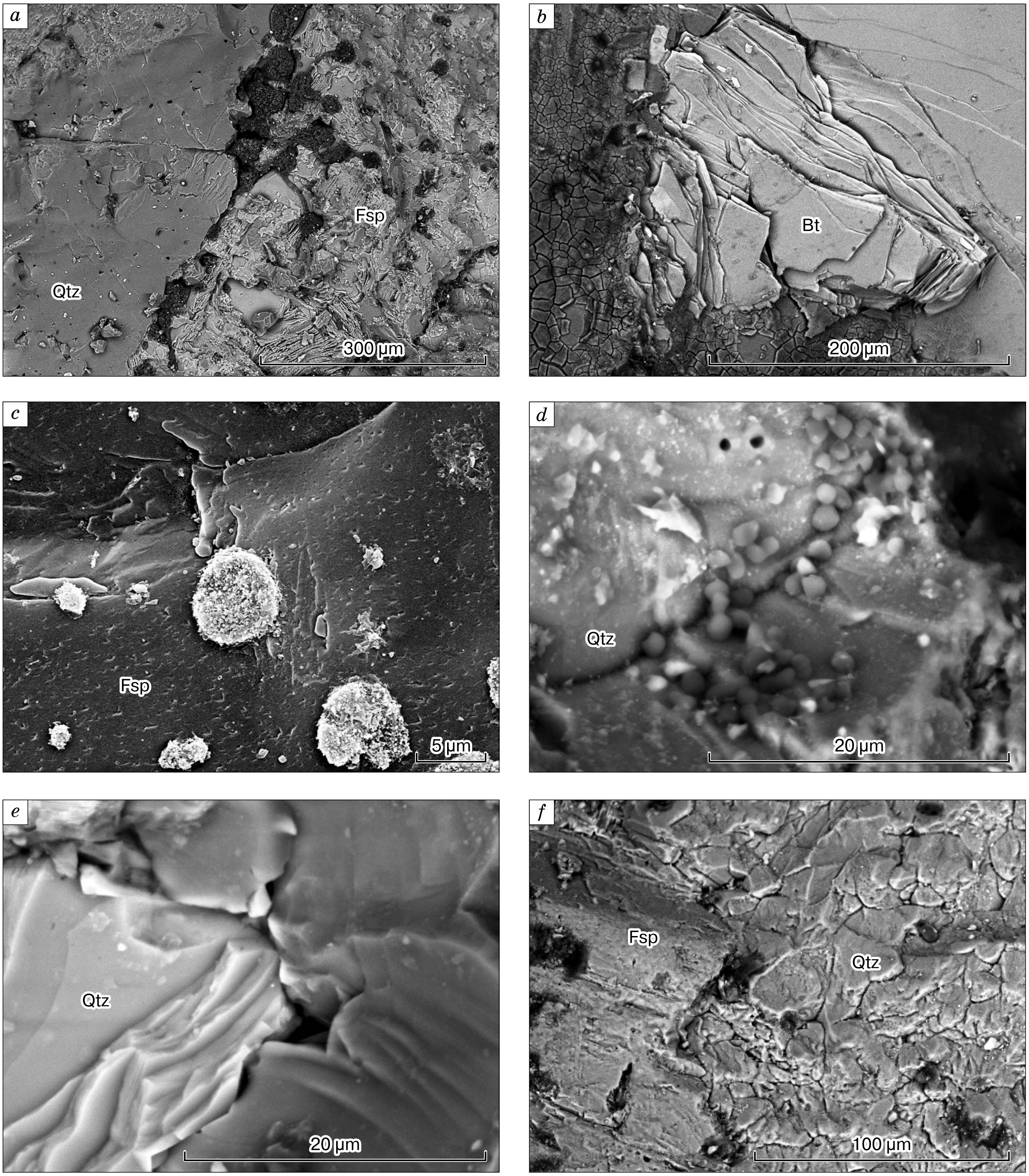

Fig. 4. Granite microstructures.

a: lichen at grain boundaries between quartz (Qtz) and feldspar (Fsp); *b*: iron-oxide film at biotite grain boundary (Bt); *c*: colloidal material on feldspar surfaces; *d*: opal globules on quartz surfaces; *e*: fracture in quartz across a void of liquid-gas inclusion; *f*: typical surfaces of quartz and feldspar.

the surface inward. The granites are covered by an almost invisible discontinuous lichen coat. According to microscopy, it consists of a thin (fractions of a millimeter) crust or separate thallus structures connected by their hypha filaments (Fig. 4, *a*). The section of the lichen coat shows a typical layered structure, with rhizines growing along fractures inside granite. The lichens enclose abundant clay- or colloidal-size mineral particles in which chemical analyses reveal various adsorbed elements from biophiles of the substrate (such as P) to impurities (up to 1.5 % Ni, 2.7 % Ti, 3.5 % Ag); there is also some sulfur, though it may be fatal for lichen when reaches certain concentrations. Lichens mainly occupy microfractures between mineral grains or cover feldspar and mica grains, but almost never grow on quartz. Possibly, they fail to anchor in quartz either because it lacks nutrients or because its surface renews frequently. In general, lichens play a significant role in biogenic weathering of granites, which apparently begins with activity of bacteria often found in fractures and other defects (though avoiding quartz).

Biogenic weathering of the Adun-Chelon granites develops jointly with chemical changes in minerals. There are visible brownish veneers or ochreous stains of iron oxides on sample surfaces, on fracture planes, and along microfractures. Dry films of colloidal iron often accompany biotite particles (Fig. 4, *b*) indicating that iron may come from dissolution of biotite. Besides the colloidal films, iron occurs as fine spherical concretions, 1 to 10 μm on rock surfaces and up to 20 μm within the lichen coat, or it makes part of siderite concretions reaching a size of 100 μm.

Feldspar in the Adun-Chelon granites is mainly plagioclase. Breakage across cleavage planes exposes sets of sharp platelets, while 10 to 50 μm clots on cleavage-parallel planes trace precipitation of colloids. The clots have different morphologies depending on size: the smallest ones look like irregular flakes, larger ones are rings or ring segments, and the largest clots are spherical (Fig. 4, *c*). Although being chemically stable, quartz bears signature of dissolution and precipitation of silica as 1–3 μm opal globules (Fig. 4, *d*).

The Adun-Chelon granite samples are heavily deformed, with networks of microfractures splitting them into 0.25–0.50 cm^3 blocks. Microscopy shows the fractures to follow the boundaries of grains and aggregates, especially between quartz and feldspar. Such microfractures may result from temperature variations and different thermal properties of rock-forming minerals. The largest grains have iron-stained surfaces and are coated with lichen, which reduces the mechanic strength of granite. Smaller microfractures of another kind are localized in grains of biotite, feldspar, and quartz. Those in mica and feldspar follow the cleavage and possibly result from thermal stress or are wedged apart and further widened by ice, especially in mica. Almost all microfractures in quartz are of cryogenic origin, produced by ice that forms in closed or (most often) open voids of gas-liquid inclusions (Fig. 4, *e*) [*Rogov, 2000*]. The voids are tens of micrometer wide and the thickness of fractures is within 1 μm. These very fractures deteriorate the gem quality of morion splitting its grains into 10–50 μm blocks (see a fractured quartz grain next to a much less deformed grain of feldspar in Fig. 4, *f*).

Thin sections of the granite samples viewed under cross-polarized light show more evidence of cryogenic weathering. Quartz breaks down both along the fractures that cut across inclusions and from the surface (Fig. 5, *a*, *b*). These results corroborate the idea of V.N. Konishchev [*Konishchev, 1981; Konishchev*

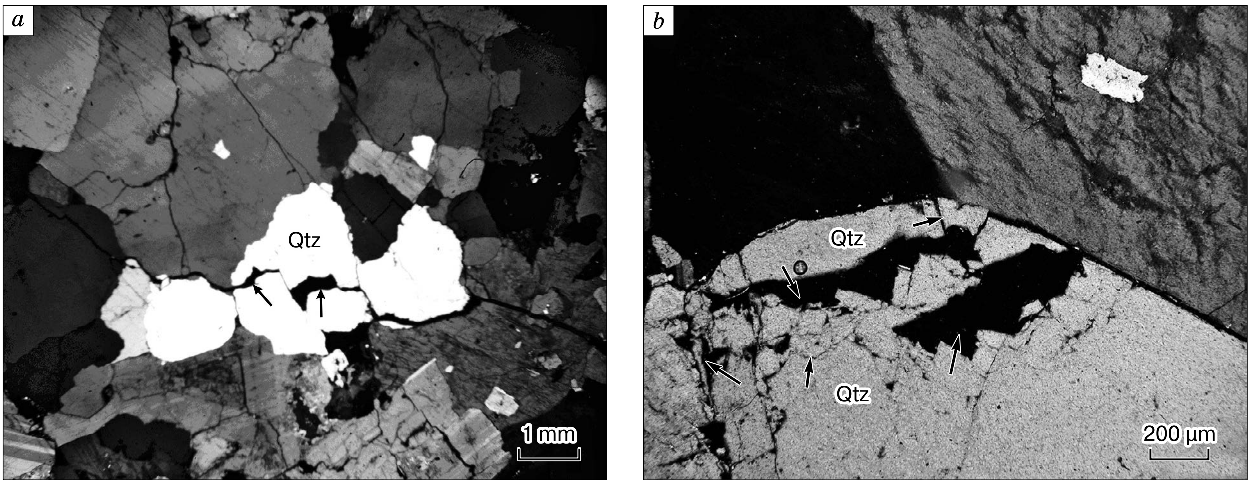

Fig. 5. Thin sections of Adun-Chelon granites.

a: fractures in quartz (Qtz) across voids of gas-liquid inclusions (shown by arrows); *b*: breaking off quartz grain surfaces.

Fig. 6. An example of cavernous weathering (tafoni): granite in Wright Valley, Victoria Land, Antarctica. Photograph by Mike Weiss (www.rossea).

and Rogov, 1994] that quartz is more susceptible to frost effects than feldspar. As a consequence of fracturing along grain boundaries combined with their bacterial colonization and wedging apart by ice, the quartz grains break off leaving the prominent feldspar grains. Thus, it is the difference in susceptibility of quartz and feldspar to cryogenic disintegration that is responsible for the observed knobby surfaces.

The weathering mechanisms influence the hogback shapes. In a dry and cold continental climate, feldspar is more resistant to thermal stress and frost effects than other minerals. However, it becomes subject to hydrolysis in the presence of moisture (e.g., in hollows or at contact with soil), which produces leaching pools and causes undercutting. Weathered rocks become rotten and crumbling even in relatively monolith bedrock and thus vulnerable to other surface processes.

The excessive and preferential fracturing of quartz minerals rather than feldspars in cryogenic weathering was also inferred by *French and Guglielmin* [*2000*] who described cavernous weathering phenomena ('tafoni') on the granitic and gneissic metasedimentary rock produced by frost and wind in the Northern Foothills region of Antarctica (Fig. 6). The Adun-Chelon granites likewise exhibit cavernous weathering, though the role of frost in its origin is to be specified.

CONCLUSIONS

1. The Adun-Chelon granites are exposed to biogenic, chemical, and thermal weathering, but their features are mostly due to cryogenic weathering.

2. Rock-forming minerals behave in different ways during cryogenic weathering. Quartz breaks off as ice forms in gas-liquid inclusions, while feldspar and biotite, in which ice follows cleavage planes, become foliated but keep their volume and stay in the rock longer than quartz.

3. The difference in susceptibility of quartz and feldspar to cryogenic disintegration is responsible for the observed knobby surfaces of the Adun-Chelon granites and their wind erosion.

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