

GEOLOGY OF THE KHARKHIRAA UUL, MONGOLIAN ALTAI

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INTRODUCTION

During an international expedition in 2000 to study glaciation surrounding the Darhad depression of Khovsgol aimag in north-westernmost Mongolia, an invitation was extended for future geologic collaboration in Mongolia. That goal was realized during the 2003 Keck Geology Consortium project in the Gobi in Dornogov aimag in southeastern Mongolia. About two dozen Mongolian and American professors and students joined in research dealing with petrology, tectonics, and geomorphology (Carson et al., 2004). The success of both the scientific investigation and the cross-cultural communication led to this 2004 Keck Geology Consortium project in the Mongolian Altai of Uvs aimag (Fig. 1).



Figure 1. Map of Mongolia showing location of study area in the eastern Kharkhiraa Uul.

The Kharkhiraa and Turgen Uul are the northeasternmost portion of the Mongolian Altai. The Kharkhiraa Uul rise to maximum elevation of 4037 m. Being near the place on Earth farthest from any ocean, this region has an extremely cold dry climate. For example, at Uvs Nuur, a large saline lake just northeast

of Ulangom, the capital of Uvs aimag, a temperature of -57°C was recorded in 1974.

Base camp (latitude 49.5°N , longitude 91.7°E , elevation 2225 m) was located in the foothills of the Kharkhiraa Uul southwest of Ulangom (Fig. 2). The Burgastai River a few hundred meters north of camp was our water supply. A similar distance east of camp is a placer gold mine; the employees there provided some logistical support (e.g., digging a trench across the fault scarp a few hundred meters west of camp). Two km northwest of camp is a coal mine. Although we slept in personal tents, we had one ger for a kitchen and another for dining and research. All student projects were within one hour's walk and/or drive from base camp. We used two Russian jeeps and two Toyota four-wheel-drive vehicles to study faults in all directions, and to go northwest to the high Kharkhiraa Uul where three students conducted research.

GEOLOGIC SETTING

The mostly Paleozoic rocks (Tomurtogoo, 1999) include marine and continental conglomerate, sandstone, mudstone, limestone, and volcanics, some of which have undergone low-grade metamorphism. Granitic rocks dominate the high peaks. The rocks were folded and faulted as the Chinese and Siberian cratons collided in the Paleozoic and Mesozoic (Misa, 1997). Thrust and right-lateral Cenozoic strike-slip faults dominate the foothills between the Kharkhiraa and Turgen Uul to the west and the Uvs Nuur basin to the east. Their scarps break alluvial fans for many kilometers. These north-south active faults

have normal and thrust components as they bend east and west (Fig. 3). Coal and placer gold mines are worked in the foothills.



Figure 2. View north from base camp across Burgastai River floodplain to Sacred Mountain (elevation, 2664 m).

Long valley glaciers (Fig. 4) radiated from the high peaks in the Pleistocene, and their remnants are still active (Lehmkuhl, 1998). Striated boulders and bedrock indicate that the glaciers were partly warm-based despite the cold climate. During retreats and readvances they left many terminal and lateral moraines from the Late Glacial Maximum until today. These moraines were and/or are ice-cored. Glacier snouts are covered with so much rock debris that they behave like rock glaciers. Thick aufeis (Fig. 5) that accumulates on parts of valley floors during the long cold winters produces cobble pavements. Freeze-thaw of the active layer above the permafrost has contributed to widespread patterned ground, including steps, stripes, circles and polygons. Large sorted polygons are bordered by granitic boulders (Fig. 6). Quaternary climate

fluctuations have led to changes in rates of mass wasting, loess accumulation, and fluvial erosion and deposition. Overgrazing is a major cause of terracettes, mass-wasting, and increased fluvial erosion and deposition. On steep slopes, solifluction, slumps, earthflows, and debris flows are common.

STUDENT PROJECTS

Peter Douglas & Munksaikhan Nurzed

“The Tectonic Implications of the Stratigraphy of the Black Marmot Valley, Kharkhiraa Uul”

The stratigraphy in the vicinity of the Black Marmot Coal Mine makes up part of a poorly studied section of Devonian and Carboniferous rocks overlying the Cambrian to Ordovician Lakes Island Arc Terrane in northwestern Mongolia and may be significant in understanding regional Mid-Paleozoic tectonic history. The stratigraphy of the 8-km² study area is as follows: 1) turbidites with individual beds 0.1-1 m thick; 2) organic-rich, thinly bedded shale; 3) interbedded dolostone, mudstone, and limestone; 4) litharenite to sublitharenite sandstone and conglomerate; 5) quartz-rich conglomerate with interbeds of coal and rhyolite tuff. Basalt flows, ranging from 15 to 50 m thick, occur within units 3 and 4. Hyaloclastites and pillows in the basalt indicate shallow subaqueous eruptions. This stratigraphy represents a transition from a deep marine fan environment through lower energy shallower marine environments to a high-energy fan delta or alluvial fan environment, a series of progressively shallower settings that indicate a local marine regression. The presence of carbonate rocks marks a period of relatively little clastic sedimentation, although thin-section petrography reveals that the limestone contains significant amounts of clastic material. Abundant carbonized macrofossils interpreted as plant debris are preserved in units 1 and 2. Whole-rock basalt XRF and ICP-MS geochemistry indicates a relatively enriched magma source related to subduction, and a Ti/V ratio of 46.10 indicates eruption within a back-arc basin as opposed to an arc

setting. Petrographic analyses of sandstone from units 1 and 4 indicate a provenance rich in volcanic rocks, suggesting proximity to an arc. Both the geochemical and petrologic data suggest that the units described were deposited in a basin flanking an arc, which was most likely formed through back-arc extension.

Jo Nissenbaum

"Paleoenvironment of Carboniferous Conglomerate, Kharkhiraa Uul"

Located in the Black Marmot coal mine area of the northeastern Kharkhiraa Uul, thick Carboniferous conglomerates attest to a depositional environment that fluctuated between marine and terrestrial conditions during a time of rapid uplift and erosion in a proposed back-arc basin. Approximately 35 diverse conglomerate units demonstrate cyclical variance in grain size, fabric, rounding, color, matrix, and cement. Shale, coarse-grained sandstones, coal beds, and welded tuff make up approximately 15 interbeds. The clasts in the conglomerates are mostly quartzite, quartz-sandstone, greenstone, and conglomerate, though a few units have limestone and volcanic clasts as well. Lithologies similar to those in the conglomerates make up the older Paleozoic terrane in this area. The interbedded conglomerate coal/shale sequence suggests an estuarine setting subject to frequent flooding from local highlands.

Laura McCarthy & Tsogtbadrakh Batsaikhan

"Fault-controlled drainage morphology along the Jid Fault, Mongolian Altai"

Successive movements along the Jid fault have controlled drainage patterns in the adjacent basins. The Jid fault is a north-south trending right-lateral strike-slip fault with a vertical component of motion (both normal and reverse) introduced by bends in the fault. Along the southernmost 5 km of the fault, normal movement accompanies the lateral movement. Subsequent down dropping of the eastern block, of which the last event has been preserved as a 1-m scarp, contributed to the formation of a wide basin and resulted in the

damming of south-flowing drainage to create a lake. Approximately 5 km north of the lake a restraining bend in the fault has caused local uplift of the eastern block. This uplift is inferred from the presence of diverted and abandoned stream channels and the apparent beheading of south-flowing drainage. Alluvial fans in the southern drainage basin have experienced stream channel incision and nickpoint migration. Filling of the basin by fan deposition and reduction in catchment area have reduced stream channel gradients and produced marshes and shallow lakes. In the 9-km long basin along the northern section of the fault, strike-slip motion dominates drainage morphology; east-west trending shutter ridges have caused stream capture, abandonment of channels, and lateral displacement of alluvial fans.

John Mischler & Tsolmon Gonchig

"Geomorphology and structure of the Jid Fault, Mongolian Altai"

The Jid fault is a 60-km-long right-lateral strike-slip fault. A 15-km long section of the fault between N49°27'32.6", E91°43'25.1" and N49°21'35.1", E91°47'61.4" appears to be almost pure right-lateral strike-slip to the north with a thrust component introduced further south as the fault changes orientation from trending north-south to northwest-southeast. At this change in orientation, the fault splits into three north-south splays. The westernmost segment appears to be mostly right-lateral strike-slip while the middle segment has a normal component of motion. The eastern segment follows an anticlinal ridge and has a thrust component. The three parallel fault strands probably form a flower structure of numerous fault strands narrowing into a single oblique strike-slip fault at depth. Well-preserved earthquake ruptures take the form of alternating tension cracks and pressure ridges that represent failure of the top few meters of soil cover in response to strike-slip motion at depth. Extension fractures in areas where the fault has a substantial thrust component are caused by collapse of the scarp.



Figure 3. View south-southeast along the Jid fault. The Jid Mountains are on the upthrown western side of this right-lateral strike-slip fault.

Laura Smith & Sarahatsetseg Puredorg

“Structure and Holocene slip of the Jid Fault, Mongolia Altai”

The NNW-SSE-trending Jid fault is a right-lateral strike-slip fault. From N49°33'8.3", E91°43'26.2" to N49°27'32.7", E91°43'24.9" the fault changes from a high-angle normal fault in the northern 3 km to a high-angle reverse fault in the southern 7 km; the fault is upthrown to the west. A trench at the southern end of the studied section showed clays against bedrock with the contact dipping steeply west, supporting reverse motion. Oblique normal motion along the northern 3 km of the fault is supported by an abrupt change in orientation to NNE-SSW; in deep alluvium here there are earthquake ruptures away from the base of the range. Small grabens at the base of scarps are present along the northernmost km; a trench in an alluvial fan exposed silt against colluvium, with the contact dipping 80° east, indicating normal motion at this point. The Jid fault is active and capable of generating earthquakes as large as 7-7.5 M. Alluvial fans average 15 m

horizontal offset and 5 m vertical offset. Assuming that the fans were most recently active during the last glacial maximum about 15 ka, the estimated slip rate is about 1 mm/year. With an average slip of 3 m, at least 5 earthquakes should have occurred since 15 ka.

Martin Bevis & Enkhbayar Dandar

“Glaciation of Ugwi Yamaa Valley, Kharkhiraa Uul”

The glacier in the compound cirque at the head of the Ugwi Yamaa (UY) Valley flowed about 7 km northeast to become a tributary to the much larger glacier in the valley of the Kharkhiraa River. The moraines were deposited from after the Last Glacial Maximum (LGM) to the Little Ice Age (LIA). The maximum extent of ice in Kharkhiraa Uul is recorded by drift about 16 km to the east on a Tertiary erosion surface. The oldest recognizable lateral moraines of the UY glacier crown valley sides and probably record a retreat from the LGM position. One of these moraines extends into the Kharkhiraa Valley,



Figure 4. Glacier complex at head of Ugwi Yamaa Valey, northeastern Kharkhiraa Uul. Note icefalls, hanging glaciers, lateral and medial moraines.

on top of drift deposited by the Kharkhiraa glacier during retreat from its LGM position far down this valley. At the mouth of the UY Valley, the stream has cut a gorge through a 20-m-high terminal moraine and 20 m of bedrock. Terminal and lateral moraines record both back and down wasting of the ice; it is difficult to determine which moraines indicate pauses in recession versus readvance. The lateral moraines were and/or are ice-cored and have been modified by mass wasting and streams; landslides, solifluction lobes, and alluvial fans are common. Striated bedrock and boulders show that the UY glacier was at least in part warm-based despite extremely low temperatures indicated by nearby permafrost. The present complex of hanging, cirque, and valley glaciers is characterized by medial and lateral moraines. Active ice is retreating from a gigantic LIA ice-cored terminal moraine that shows collapse where the UY River flows under it. Fine-grained sediment in the collapsed area suggests that a lake forms upvalley of the LIA moraine when the UY River is temporarily dammed.

Relative age dating suggests that the moraines downvalley of the ice-cored terminal moraine are recessional from the LGM.

Will Gallin & Molor Erdenebat

"Patterned Ground in the Kharkhiraa Uul"

Three types of patterned ground exist on gentle slopes in the Kharkhiraa Uul. Stone-bordered polygons and cobble mounds are on drift at an elevation of 3000 m. Earth hummocks lie both there and also in lower (2200 m) unglaciated valleys. Regularly spaced stone-bordered polygons have diameters of 5-8 m and up to 35 cm of relief; cobble mounds range from 0.5 to 2 m in diameter and have up to 25 cm of relief. Both exhibit evidence of frost heaving and creep of coarse granite clasts. Sediment in stone-bordered polygons is well sorted whereas cobble mound sediment is generally poorly sorted. Earth hummock diameters are mostly less than 0.5 m (with exceptions up to 1.5 m); they are generally 15-20 cm high (but as much as 47 cm). Evidence indicates formation of earth hummocks through a process involving

seasonal growth and decay of ice lenses in silty soil. Stone-bordered polygons are quite deformed on the slopes of old lateral moraines.

Pat Kailey

“Slope Instability in the Eastern Kharkhiraa Uul”

The slopes of the eastern Kharkhiraa Mountains are currently undergoing a period of dramatic instability triggered by climate change, increased runoff from mining operations, and/or overgrazing. Ten-to-twenty-degree vegetated slopes with large accumulations of colluvium fed by talus upslope are the most susceptible to failure. Earthflows are 10-20 m wide with convex, vegetated toes 1 m high undergoing solifluction. Debris flows characterized by natural levees travel from steep slopes to valley floors. Many slopes and valleys exhibit multiple generations of mass wasting. Peat beds (up to 10 cm thick) alternating with loess, alluvium, and/or colluvium indicate cycles of stability-instability. The maximum and minimum ages of the peat beds are 1930 and

850 radiocarbon years B.P., respectively. These dates suggest shifts in environment during the last two millennia from either climate change and/or increased stress on the steppe from human habitation.

Nicholas Swanson-Hysell

“Aufeis in the Kharkhiraa Uul”

At an elevation of ~2900 m in the glaciated Ugwi Yamaa Valley (N49°34.63', E091° 27.23'), aufeis covered an area of ~60,500 m² in mid-July, 2004. This laminated ice sheet developed on a braided stream channel that is constricted by a small canyon below the sheet. The aufeis had a maximum thickness of 4.3 m. One 2.15 m section of the ice had 90 laminations while another section of 2.35 m had 64. There are three different types of ice: equidimensional crystals, candle ice, and plate ice. Equidimensional crystals dominate ranging from 3-12 mm. Candle ice, vertically oriented cylindrical ice, occurred both in beds (1-5 cm thick) and in lenses. The candle ice lenses have flat bottoms and convex tops, and can be as thick as 35 cm resulting in candle ice of that length. The plates of ice are



Figure 5. Aufeis along the Ugwi Yamaa River. The aufeis is about 1 m thick and extends about 0.8 km along the valley floor.

amalgamations of crystals that clip downstream at angles between 40° and 65°. Between July 21 and 29, 2004, the stream was blocked by the ice and eroded a cut bank 3.90 m high. Evidence of similar past erosional events indicates that auffs played an important role in widening the channel. Alluvial clasts under auffs have responded to the load by preferentially aligning so that their flat surfaces create an alpine sub-auff cobble pavement.

MAJOR SCIENTIFIC ACCOMPLISHMENTS

Bedrock

The northeastern Kharkhira Uul contain a wide variety of continental and marine sedimentary rocks, some with scarce fossils: conglomerate, sandstone, mudstone, dolomite and limestone. In places, these rocks have experienced low-grade metamorphism to become phyllites. Locally massively-cored lava flows, pillow lavas, hyaloclastites, and tuffs are associated with the sedimentary

rocks. The high mountains are dominated by at least three granitic plutons, with gneiss and migmatite in places.

A general regressive stratigraphic sequence in an orogenic setting is preserved in the Late Paleozoic terrane of the field area. Unusual associations of conglomerate and coal shale, plus turbidites bearing coal fragments, contribute to an unusual picture, the closest contemporary analogy of which might be a river plain/estuary/bay environment flanked closely by volcanic mountains as in coastal Japan today.

Asymmetrical folding of Paleozoic strata suggests multiple deformation events. Fold limbs on the eastern edges of synclines are nearly vertical, while the opposite limbs of these folds dip gently. Hinges are nearly chevron in form, and hinge traces bend from NE-SW to NW-SE across distances of only a few hundred meters. Numerous large “parasitic” folds lie within the larger, kilometer-wide folds that cross the best area of exposure, near the Black Marmot coal mine.



Figure 6. Sorted polygons at an elevation of 3000 m. The stone borders are granitic blocks.

The foothills of the mountains are host to operating coal (Carboniferous) and placer gold mines, with potential for gold in the bedrock.

The Jid fault

A right-lateral strike-slip fault (named the Jid fault by Bayasgalan et al., 2004) runs north-south for 60 km in the eastern Kharkhiraa Uul of the Mongolian Altai. The Altai Mountains contain seismically active faults that have generated numerous recorded earthquakes of magnitude > 7 . Identifying active structures such as the Jid fault has implications for estimates of seismic hazard and for understanding the regional tectonics.

The fault shows indications of recent movements at scales ranging from drainage re-organisation at the kilometre scale, to ground deformations likely to result from movements during a single earthquake. From the scale of the ruptures and the observed length of roughly 60 km, the most recent earthquake may have had a magnitude of about 7.5. In addition, numerous horizontal offsets of about 10-15 m and vertical scarps of < 5 m in the youngest alluvial deposits show the likely cumulative Holocene movement. The fault has many excellent examples of features associated with oblique-slip active faults, including stream displacements, pull-apart basins, shutter ridges, and river piracy.

Along most of the Jid fault trace there is a slight vertical component of motion. The vertical component is introduced by bending along the fault and is normal in some places, and reverse in others. Parts of the fault show structural complexity at the surface with numerous parallel strands having both normal and reverse components of motion. The complexities probably form a 'flower structure' in cross-section.

Assuming that the last period of alluvial fan deposition was at the last glacial maximum (approximately 10-15 ka ago), the horizontal offsets of 10-15 m would imply roughly 1 mm/yr of strike-slip motion. If the fault fails in magnitude 7.5 earthquakes with 3 m of slip in each, the average time between events will be about 3,000 years.

Surficial processes

During overall retreat from the Late Glacial Maximum to the present, glaciers left many terminal, recessional, and lateral moraines recording times when the ice readvanced and/or was in equilibrium. Striated bedrock and boulders indicate that the glacier in the Ugwi Yamaa Valley was at least in part warm-based; a huge ice-cored terminal moraine there dates from the Little Ice Age.

Slope instability is wide spread: debris flows reach valley floors; earthflows and steep slopes are undergoing solifluction. Sediments in stream cuts provide evidence for alternating stability (organic-rich and loess soils) and instability (alluvium and colluvium).

A wide variety of sorted and non-sorted patterned ground exists: steps or terracettes (directly and indirectly influenced by overgrazing), stripes, stone-bordered polygons, circles (with apparent mud eruptions), contraction polygons in turf, and earth hummocks in wet, fine-grained soil.

In addition to the growth of segregated ice in a periglacial environment, the uplift of the centers of circles and polygons in patterned ground may be due to fine-grained sediment from spring dust storms filling low-temperature and desiccation cracks.

Thick winter aufeis persists through the summer and locally strongly influences valley floor morphology, causing cobble pavement beneath it and enhanced stream erosion and mass-wasting at its sides.

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