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Geochronology of basalts from the Valley of Lakes, Mongolia, and their correlation with the Cenozoic sedimentary sequence

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Abstract. The Valley of Lakes, Mongolia, is a key region in which to elaborate the geochronology of biostratigraphic horizons of the continental Paleogene and Neogene. Here, basaltic volcanism is developed widely. Basalt flow units are found alternating with and overlying sedimentary strata, while dikes and bosses cut through Paleocene, Oligocene, and Miocene faunal horizons. Analyzing biostratigraphic material in combination with K–Ar dating affords upgrading the biogeochronological subdivision and correlating some of the horizons with the mammalian zonation of Europe. The Valley of Lakes thus becomes the stratotype locality for Cenozoic continental sections in Inner Asia.

The Valley of Lakes is a unique area in Mongolia in two respects. It has broadly developed sequences of the continental Cenozoic sediments with numerous occurrences of Paleogene and Neogene mammalian faunas. Another feature of this area is massive development of basalts that are intercalated with sedimentary strata and that form necks, domes, and dike swarms. This combination of sedimentary and extrusive rocks offers an approach to constructing a stratotypic biochronologic reference scale for this region of Inner Asia (Figures 1, 2) [*Badamgarav et al.,* 1975; *Devyatkin,* 1970, 1981, 1993a, 1993b, 1994; *Vislobokova,* 1996; *Zazhigin and Lopatin,* 2000]. By now, a wealth of works on the Cenozoic geology has been published, and some fifty K–Ar and ^{40}Ar–^{39}Ar basalt ages and magnetostratigraphic measurements from sedimentary and extrusive sequences of this depression have been obtained. Lately, the Mongolian–US and Mongolian–Austrian field teams have been operating there [*Daxner-Höck et al.,* 1997; *Höck et al.,* 1999].

Despite the voluminous scientific data resulting from these exercises, however, a number of issues concerning geochronology of basalts and their relations to the sedimentary sequence of the Paleogene and Neogene, require a certain revision and refinement.

The Valley of Lakes is a major intermontane basin separating the Khangai and the Gobi Altay. It stretches for almost 500 km EW from the Dzabkhan River to Dalan-Dzadgad. The basin is relatively narrow, no more than 30–50 km across. Its northern slope is bounded by the low escarpment of the South Khangai Plateau, and southern, by the sharp tectonic face of the Gobi Altay. The basin is asymmetric, its axis being displaced nearly as far southward as the Gobi Altay foothills. The basin's north slope has keyboard structure, individual blocks of buried Paleozoic basement becoming progressively depressed toward basinal interior. On the south, one finds a series of horst highs formed by pre-Cenozoic basement. The total thickness of Cenozoic deposits in the basin's interior, based on drilling and geophysical data, exceeds 500 m. These deposits and their overlying Quaternary sediments usually lie flat in the basinal interior, while toward the margins they are not infrequently dislocated, especially near recent faults.

The most complete Paleogene and Neogene sequences are encountered in the valleys of rivers running from the South Khangai Plateau, in the northern and central Valley of Lakes, and in the area between the Tuin-Gol River and south foothills of the Ikhe-Argalantu Range. In the southern part of the basin, these sequences are buried beneath Pliocene–Quaternary sediments.

The bulk of the Valley of Lakes basalts are found com-

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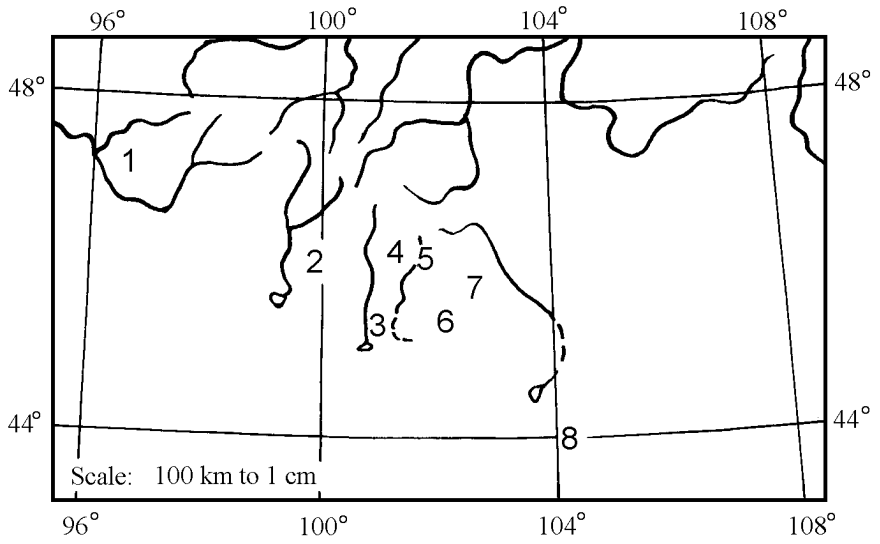

Figure 1. Location scheme of the Valley of Lakes Paleogene and Neogene key sections dated by the K–Ar and ^{40}Ar–^{39}Ar methods. Section numbers, as in Figure 2.

posing numerous stratified plateaus, clustering in an EW-trending belt along the Bayan-Khongor zone of deep faults. The surface of these basaltic plateaus is tilted gently southward, evidently in keeping with the general regional gradient of the topographic surface onto which the lavas were erupted. No significant deformation of basal flow units has been recorded. On the very south (southwest of the Bayan-Khongor fault zone), however, one notes flexural bends of basaltic flow units passing locally into a system of normal faults.

Individual plateaus are made of extrusive basalt sheets comprised of two or three flow units each, resting on a relatively planated basement surface. These are minor volcanic fields ranging in area from 10 km^2 (Bayangin-Teg Plateau) to 600 km^2 (a plateau south of Mt. Bogdo-Ula). As a rule, the fields are made up of several flow units totaling 10 to 40 m in thickness. Individual flow units are 2–5 m thick, basalt sheets being as thick as 60–70 m. The flow units are rather uniform in morphology, with massive interiors, not infrequently with block parting, and vesicular, often ferruginated crusts.

Variations observable in the composition and thickness of extrusive basalt sheets reflect original differences between the Valley of Lakes basaltic fields. This is further supported by the extraordinarily broad range of basaltic flow facies. They were produced by the activity of various volcanic centers, whose relics are found within individual basaltic fields. The largest number of volcanic features in the form of necks occur in the interfluve between the Tuin-Gol and Tatsin-Gol rivers. These necks stretch in a chain elevated above the plain, from the north slope of the Valley of Lakes. We documented the large Dushu-Sharo-Ula dome, over 1 km in diameter, on the east terminus of the Ushuguin-Nuru Range. Apparently, explosive activity at this center was resumed repeatedly. From it, three thick (up to 10 m) basalt flow units with sediments in-between project southward. Further south, they are overlain by Neogene and Quaternary sequences. The upper flow unit is of Neogene age (21±2 Ma), and the two lower ones, of Oligocene age, are interbedded with Shand-Gol Formation redbeds along the Shand-Gol gorge. The upper of these units is dated at 28±1.1 Ma [*Devyatkin,* 1981].

Cenozoic volcanism is also widespread outside the Valley of Lakes: north of it, on the Khangai, and south of it, on the Gobi Altay and in southern Gobi Desert. Here, this volcanism is in continuity with the Mesozoic [*Shuvalov and Nikolaeva,* 1985] effusive cycle. Along the south margin of the Arts-Bogdo Range, one finds necks and extrusive sheets of Paleocene and Eocene age [*Devyatkin,* 1981; *The Geologic...,* 1995; *Yarmolyuk et al.,* 1994]. In the Valley of Lakes (near Bain-Dzak), a section is known to exist where basalts with 51±3 Ma K–Ar age overlie the Upper Paleocene Khashato Formation.

The Cenozoic sedimentary section of the Valley of Lakes is understood well enough [*Badamgarav et al.,* 1975; *Devyatkin,* 1970, 1981; *Vislobokova,* 1996]. From bottom to top, the following formations are recognized here:

(1) The Khashato Formation (Upper Paleocene)—red-colored gravelstones, sands, clays (up to 60 m), erosionally overlying Upper Cretaceous strata near Bain-Dzak (eastern part of the basin). The Formation exhibits primitive mammalian faunas.

(2) The Kholboldzi Formation (Middle–Upper Eocene)—a correlative of the Naran-Bulak Formation in the Trans-Altay Gobi (80–100 m thick)—composed of varicolored clays, sands, shingles, characterized by *Lophialetes, Teleolophus, Rhodopagus, Helates, Eudinoceras,* etc., faunas.

(3) The Ergilin-Dzo Formation (Lower Oligocene) conformably overlies Eocene strata and is represented by light-colored weathered shingles, quartz sands, and clays (up to

50–80 m). At the top, one finds intercalations of red sand and clay. The contact with the Shand-Gol Formation is conformable. In the Valley of Lakes, the Formation is not characterized biostratigraphically. In its stratotype locality, near Ergilin-Dzo, it contains abundant *Bronthoterium* faunas.

(4) The Shand-Gol Formation (Lower–Upper Oligocene) is most widespread in the Valley of Lakes and is comprised of redbed clays, sands, and, at the basinal slopes, of rock debris and gravels of the same color. It comprises a range of facies, mostly proluvial-type, up to 30–50 m thick. The Formation is characterized by *Indricotherium* and *Tsagonomis* faunas [*Devyatkin,* 1981]. In recent years, three successive faunal stages have been recognized [*Vislobokova,* 1996]; assumedly, the base of the Formation may reach down into the Early Oligocene. Detailed biostratigraphic studies at the Paleogene/Neogene boundary, performed by the Austrian–Mongolian field team (IGCP Project 326) have also resolved several stages in the development of Shand-Gol Formation faunas [*Daxner-Höck et al.,* 1997; *Höck et al.,* 1999].

(5) The Loo Formation (Middle–Upper Miocene) is developed along the north slope of the Valley of Lakes and is represented chiefly by sands and gravelstones and, in its upper part, by pinkish and greenish clays with sand lenses totaling up to 25–30 m in thickness. Erosion at the base of the Loo Formation is recorded in all the sections studied. Based on it, the Oligocene/Miocene boundary is drawn. The Loo Formation is characterized by *Anchitherium* and *Mastodon* faunas [*Devyatkin,* 1981; *Zazhigin and Lopatin,* 2000].

(6) The Khung-Kure (Lower Pliocene?) Formation is exposed at the southern foothills of the Baga-Bogdo Range and consists of light-colored sands and gravelstones and, in its upper part, of a member of limestone and marl of lacustrine origin. Its exposed thickness is up to 25–30 m. The Formation, in all likelihood, is a correlative of the upper part of the Khirgis-Nur Formation of western Mongolia. It is characterized by *Hipparion* faunas. Its contact with Miocene deposits is not exposed, but, apparently, it is conformable, since these formations are genetically similar, both being fluviolacustrine in origin.

(7) The Tuin-Gol (Upper Pliocene to Eo-Pleistocene?) Formation is spread along the valleys of rivers that run down the Khangai into the Valley of Lakes. It forms an assemblage of high (up to 140 m) alluvium terraces and is composed of brown shingles, gravelstones, sands, and red clays. It is characterized by late *Hipparion* faunas. Outside the valleys of major rivers, such as the Tuin-Gol, Tatsin-Gol, and Baidaragin-Gol, deposits of the Tuin-Gol Formation are encountered on the Southern Khangai Plateau, in topographic lows replicating the past, Late Pliocene drainage network.

Position of Basalts in the Cenozoic Sedimentary Sequence of the Valley of Lakes and Their Geochronology

The Eocene basaltic assemblage is developed in the easternmost Valley of Lakes (in the vicinity of Bulgan) and in the Trans-Altay Gobi, at the foothills of the Arts-Bogdo Range. Here, several K–Ar determinations of this age have been obtained: for the Khatal-Sudal neck, 57±2.8 Ma, and for the Barun-Tabun-Khairkhan neck, cutting through the Upper Cretaceous Nemegetu Formation, 47±2.0 Ma. Of crucial stratigraphic importance is dating the basalt intercalation occurring above the Khashato Formation (Upper Paleocene) 2 km westward of its stratotype locality. This intercalation was already recorded earlier [*Berkey and Morris,* 1927; *Devyatkin,* 1981; *Szalay and McKenna,* 1971]. Basalts (3–5 m thick) rest on multicolored clays and sands, lithologically similar to the Khashat Formation, and are in turn overlain by bright red dense clays of the Shand-Gol Formation. Two age determinations, 51.0±3.0 and 37.0±1.0 Ma, have been obtained from this basalt intercalation [*Devyatkin and Smelov,* 1979]. These ages are at variance with one another, but, at any rate, they constrain the possible upper age limit for the Khashat Formation and the likely lower age limit for the Shand-Gol Formation.

The Oligocene basalt assemblage in the Valley of Lakes is rather widespread. Its map area stretches almost 500 km from the Ongin-Gol River on the east to the Dzabkhan River on the west.

In the vicinity of the Dzabkhan River, 20 km downstream of the town (somon) of Tsagan-Olom, there occurs a large (1.5 km by 1.0 km) composite neck field, made up of dikes and domes of various ages. Fragments of flow units stretching from this field are found intercalated in the Oligocene and Miocene sedimentary sequence. Two flow units are exposed spectacularly in the Dzabkhan riverside bluff, intercalating redbed clays of the Shand-Gol Formation. The flow units have distinct columnar jointing and are as thick as 5 m. The upper flow unit yielded a K–Ar age of 31.1±1.2 Ma. Upsection of this unit, Miocene light-colored quartz sands, shingles, gravelstones, and greenish pink alluvial-type clays occur. These are overlain by a third basalt flow unit, lithologically and structurally similar to the two lower basalt horizons. All three basalt flow units display a significant degree of weathering and abundant calcite inclusions in the form of phenocrysts and veinlets. The fourth and uppermost basalt flow unit with a basal break rests on the third unit, but it is distinguished by its freshness, black coloring, an almost total lack of phenocrysts, and strong vertical jointing. It has yielded a K–Ar date of 16.0±1.0 Ma. This basaltic unit is overlain by gray-colored Quaternary shingles of the Dzabkhan River terrace [*Devyatkin,* 1981].

In the central part of the Valley of Lakes and on the South Khangai Plateau, Oligocene and Miocene basalts are widespread. They make up separate plateaus, in places with neck bodies, stretching from the Baidarik-Gol River eastward. The basalts rest on the planated surface of Paleozoic rocks. The plateaus are composed of flow units whose number differs from center to center (from 3–5 to 15, as at Bayangin-Teg). In the interfluve between the Baidarik-Gol and Tuin-Gol, the Kholbo-Teg neck has yielded a K–Ar date of 18.5±1.0 Ma. This neck cuts through the Shand-Gol Formation redbeds. A flow unit associated with this neck and overlying the same Formation has yielded a K–Ar date of 14.8 Ma [*Devyatkin,* 1981; *Devyatkin and Smelov,* 1979].

Of utmost importance to geochronologic dating of Oligocene and Miocene sedimentary deposits and of bios-

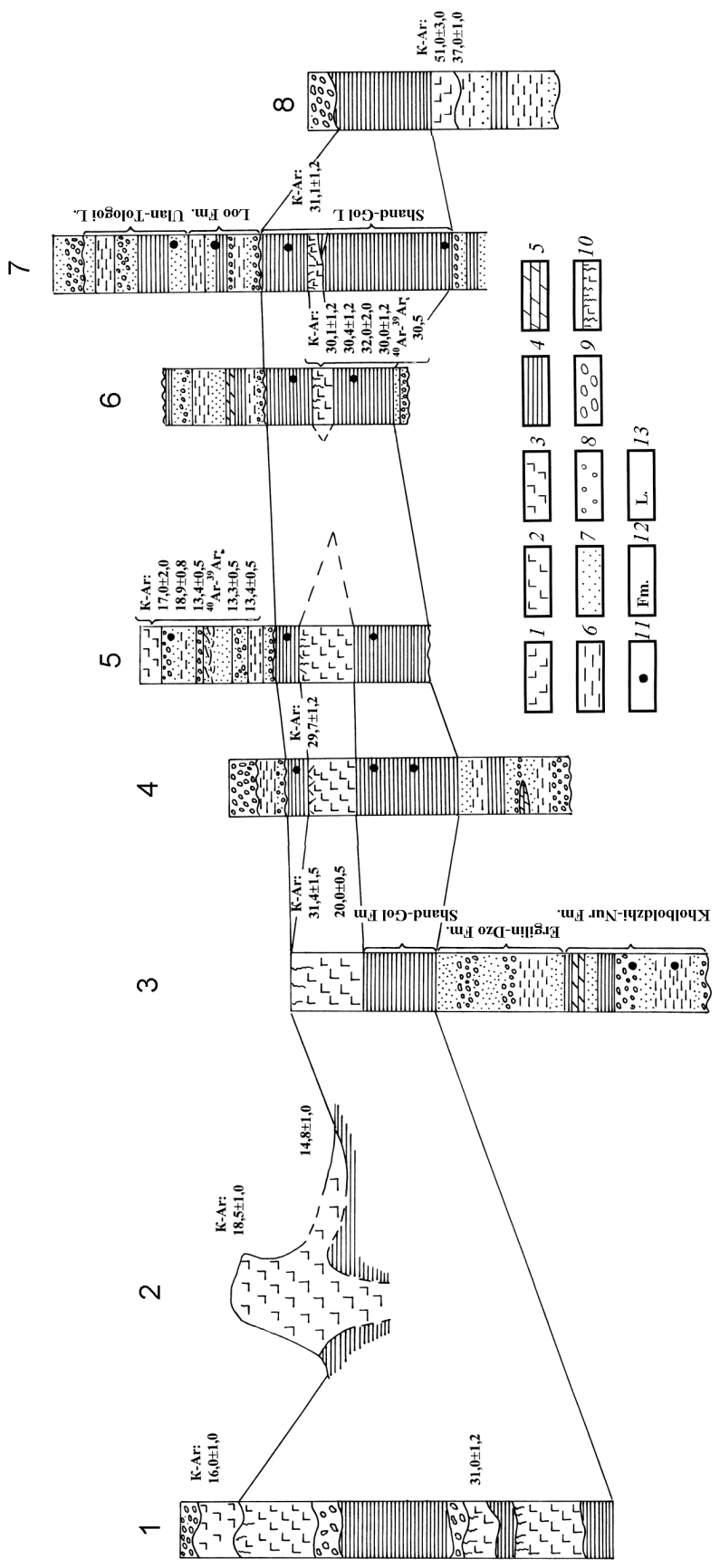

Figure 2. Valley of Lakes Paleogene and Neogene key sections dated by the K-Ar and ^{40}Ar-^{39}Ar methods (from west to east). Symbols: 1 - Eocene basalt, 2 - Oligocene basalt, 3 - Miocene basalt, 4 - Shand-Gol Formation, redbed clay, 5 - Loo Formation, marl, 6 - clay, 7 - sand, 8 - gravelstone, 9 - cobblestone, 10 - weathered basalt, 11 - mammalian finds, 12 - Formation, 13 –Lo– Locality. Sections: 1 – Dzabkhan, 2 – Kholbo-Teg, 3 – Khunuk, 4 – Tatsin-Gol (right side), 5 – Tatsin-Gol (left side), 6 – Tatal-Gol, 7 – Shand-Gol-Loo-Ulan-Tologoi, 8 – Khashato.

Table 1. Radiometric (K–Ar) age determinations of basalts from the Valley of Lakes

Laboratory no.	Field no.	% K	^{40}Ar (rad) cm^3/g	% Ar (rad)	Age, m.y.
3113	9301	1.39	1.706×10^{-6}	36.8	31.4±1.5
3114	9304	2.67	1.246×10^{-6}	66.1	12.0±0.5
3115	9305	1.64	1.906×10^{-6}	81.9	29.7±1.2
3116	9307	1.55	1.890×10^{-6}	86.0	31.1±1.2
3117	9306	2.42	2.887×10^{-6}	87.5	30.4±1.2
3118	9302	2.37	1.235×10^{-6}	72	13.4±0.5
			1.232×10^{-6}		13.3±0.5

tratigraphic horizons identified within them are basaltic horizons exposed in a number of sections between the Tuin-Gol and Shand-Gol rivers. From this area, some ten K–Ar age determinations have been obtained from basalts occurring both in the Oligocene strata of the Shand-Gol Formation and in the overlying Miocene strata of the Loo Formation [*Badamgarav et al.,* 1975; *Devyatkin and Smelov,* 1979; *Gabuniya et al.,* 1975; *Mellet,* 1968]. A synopsis of geochronologic data for basalts of Mongolia and the Valley of Lakes is given, in particular, in [*Devyatkin,* 1981]. In recent years, new radiometric data have appeared that require further refinement of the geochronology of basalts of this area and their stratigraphic position in the Cenozoic sedimentary sequence. Seven new K–Ar dates have been obtained in Hungary at the Institute of Nuclear Research by Dr K. Balogh from samples provided by E. V. Devyatkin and A. Dudich (Geologic Institute of Hungary), collected on a field trip under IGCP Project 326 in 1993 (Table 1). At Salzburg University, Austria, 30 radiometric (^{40}Ar/^{39}Ar) dates were obtained on basalts from Oligocene and Miocene deposits [*Daxner-Höck et al.,* 1997; *Höck et al.,* 1999].

Comments on the position of K–Ar dates in the Paleogene and Neogene stratigraphy:

(1) 9301 (Elegen)—basalts overlying the Shand-Gol Formation on the western slope of the Elegen valley. The former date, 20±0.5 Ma [*Devyatkin and Smelov,* 1979], must be disregarded.

(2) 9304 (Delkh locality). Along the foothills of the Ushuguin-Nuru Range, from the Tatsin-Gol River eastward, there stretches a basaltic horizon tilted (up to 45°) southward. It occurs in the Shand-Gol Formation, and we interpret it as an effusive intercalation conformable to the tilt of the Formation itself. The 12.0±0.5 Ma date suggests that this is a dike of the Miocene assemblage, emplaced conformably among Oligocene strata. This dating requires additional studies of the geologic setting of the dike itself and further age determinations along the entire length of the dike.

(3) 9305 (Shand-Gol Formation, left-side slope). Here, a basalt intercalation occurs in the Shand-Gol Formation, with faunas below and above this flow unit. It has yielded several age determinations: 32.0±2.0 [*Mellet,* 1968], 31±2.0 [*Gabuniya et al.,* 1975]. *Daxner-Höck et al.* [1997] cite an ^{40}Ar/^{39}Ar date of 30.5 Ma from the same flow unit, conceding, however, that this horizon may be 32–33 m.y. old.

From the same flow unit, we obtained a K–Ar age of 30.4±1.2 Ma. This flow unit has thus been dated in the same section at four laboratories, the obtained values fitting in a rather narrow range of 30–32 Ma. The Tatal-Gol area is a key locality in which to date the lower half of the Shand-Gol Formation. Hence, in the Oligocene two geochronologic levels of basalts are identified:

(1) The lower (principal) basalt horizon, in the range 30–32 Ma (Tatal-Gol, Dzabkhan, Tsagan-Obo, Khunuk).

(2) The upper basalt horizon, in the range 26–28 Ma (Tatal-Gol, Tarmelin-Churem).

Basalt dates from the top of the Shand-Gol Formation, 24–25 Ma [*Devyatkin,* 1981, p. 107], require verification and cannot at the present be taken into account while constraining the age of this formation.

The youngest basaltic assemblage from the Valley of Lakes is most widespread on the Ushugiin-Nuru Range, between the Tatsin-Gol River and the town (somon) of Guchin-Us. It makes the surface of the range and, in its foothills, it overlies Miocene strata of the Loo Formation. Outlying Miocene basaltic fields and necks stretch as far west as the Baidarig-Gol River. On the left side of the Tatsin-Gol River, several K–Ar age determinations in the range 17.0±2.0 to 19.0 Ma are available from basalts above the Loo Formation [*Devyatkin,* 1981, p. 107; *Gabuniya et al.,* 1975]. From a basalt flow unit on the left side of the Tatsin-Gol River, K. Balogh obtained two K–Ar dates, 13.4±0.5 and 13.3±0.5 Ma. The same basaltic horizon has yielded ^{40}Ar–^{39}Ar dates of 13.0±0.25 Ma [*Daxner-Höck et al.,* 1997; *Höck et al.,* 1999], which gives a very good fit of age determinations for this basalt horizon, so that it should be attributed to the upper–Middle Miocene.

Stratigraphic Position of Vertebrate Faunas in the Cenozoic Sedimentary Sequence of the Valley of Lakes and Their Geochronology

The oldest faunal assemblage in the Valley of Lakes has been reported from the Khashato Formation. It is from this locality that the finds of primitive mammals of the genera *Prodinoceras, Penacolophus, Paleostylops, Pseudictops* (?), etc., have been obtained, which permit attributing this assemblage to the Upper Paleocene [*Devyatkin,* 1981,

p. 26]. Earlier still, 2 km west of the stratotype locality of the Khashato Formation, *Berkey and Morris* [1927] detected a basalt horizon occurring at the top of this formation. It yielded a K–Ar date of 51±3.0 Ma [*Gabuniya et al.,* 1975]. A second dating of these basalts gave a different value, 37±1.0 Ma [*Devyatkin and Smelov,* 1979]. One way or another, Khashato deposits predate these values. The Upper Paleocene deposits are overlain by redbed clays of the Shand-Gol Formation, resting on basalts.

Two K–Ar dates on basalts were obtained by *Shuvalov and Nikolaeva* [1985] south of the Valley of Lakes near the town (somon) of Khurmen. Here, Paleocene strata are overlain by a basaltic horizon dated at 53±8.0 Ma, while basalts that underlie these deposits are dated at 61±8.0 Ma. However, the lack of faunas from the sequence and wide geochronologic scatter (±8.0 m.y.) preclude using these data in full measure.

A younger horizon of Paleogene deposits in the Valley of Lakes has been established by us under the name of the Kholboldzi Formation, a counterpart of the Khaichin Formation in the Trans-Altay Gobi. These strata are dominated by varicolored clays, silts, sands, and shingle intercalations of fluviolacustrine type. In places, one finds fragments of red-colored paleosols with horizons of carbonate concretions. These deposits total at least 80–100 m in thickness. They are overlain by bright white-colored Oligocene sands and shingles of the Ergilin-Dzo Formation. The Valley of Lakes exhibits three faunally dated sections of the Kholboldzhi-Nur Formation: on the left side of the Tuin-Gol River (opposite the town (somon) of Bogdo) and in the vicinity of Mankhen-Teg (20 km northward), in the northern foothills of the Ushuguny Nuru Range, at the base of the "sub–Shand-Gol" part of the Paleogene sequence, faunally barren sections of the Kholboldzhi-Nur Formation are documented (near Builyasutuin).

Mammalian faunas from the Kholboldzhi-Nur Formation are represented by a pantodont–tapiroid assemblage [*Devyatkin,* 1981] with *Breviodon–Lophialetes* as characteristic representatives. This assemblage correlates well with that of the Khaichin Formation in the Trans-Altay Gobi and the Irdyn-Manga and Shara-Murun Formations, China. The age of the faunas and their enclosing strata is constrained to the Middle to lower–Upper Eocene [*Belyaeva et al.,* 1975; *Reshetov,* 1979]. No direct relationships between sedimentary sequences of the Kholboldzi Formation and the Valley of Lakes basalts are observable.

The overlying Ergilin-Dzo Formation is composed of white oligomict sands and shingles and erosionally (?) rests on Eocene strata. In the Valley of Lakes, it is not dated faunally, but in terms of its stratigraphic position and lithology it matches the stratotype established in southeastern Mongolia [*Berkey and Morris,* 1927; *Devyatkin,* 1981; *Osborn,* 1925; *Yanovskaya et al.,* 1977]. The lower part of this Formation (Khubsugul beds with *Protembolotherium efremovi*) belongs to the Upper Eocene. The upper part of the Formation (Ergilin-Dzo Formation proper with *Brontops gobiensis* and *Embolotherium ergiliense*) is attributed to the Lower Oligocene by Dashzeveg. However, basaltic radiometric ages from the base of the overlying Shand-Gol Formation (30–32 Ma) in the Valley of Lakes along with faunas from this level, as analyzed by [*Vislobokova,* 1996], suggest lowering the age of the upper horizons of the Ergilin-Dzo Formation to the Upper Eocene. Lithologically, the Shand-Gol Formation grades upward into the Ergilin-Dzo Formation through an interlayering of white sands and red clays. The correlative of the Ergilin-Dzo Formation in the Valley of Lakes has been renamed into "the Tsagan-Obo Formation" [*Höck et al.,* 1999]. In recent years, detailed biostratigraphic studies in the Oligocene and Miocene of the Valley of Lakes have been conducted [*Daxner-Höck et al.,* 1997; *Höck et al.,* 1999; *Vislobokova,* 1996; *Zazhigin and Lopatin,* 2000]. Besides obtaining radiometric ages from basalts, an opportunity arose to refine absolute ages of the resolved faunal horizons (assemblages). In the Shand-Gol Formation, *Vislobokova* [1996] established three faunal stages (assemblages). Formerly, these faunas were considered to form a single entity, albeit potentially divisible into horizons of different ages [*Devyatkin,* 1981, p. 49; *Shevyreva,* 1976]. The earliest assemblage (with *Lophiomeryx angarae, L. gobiae,* and *Enmeryx culminis*) has been reported from the base of the Formation beneath basalts dated at 30–32 Ma. These faunas are similar to the assemblage from the Lower Oligocene Ergilin-Dzo Formation of Mongolia and from the Urtyn-Obo Formation of China. In Europe, the correlative of this stage is Zone MP21, dated at 33.1 Ma. The lower boundary of the Zone is dated at 33.7 Ma and coincides with the Eocene–Oligocene transition. Therefore, the lower part of the Shand-Gol Formation must belong to the Lower Oligocene.

The second faunal stage (assemblage) of the Shand-Gol Formation, with *Lophiomeryx* cf. *mouchelini* and *Eumeryx imbellins,* has been obtained from its middle part, at the level of 30–32 Ma basalts and a little higher [*Vislobokova,* 1996]. In the Valley of Lakes, this assemblage is represented by the majority of occurrences. In Inner Mongolia, this stage corresponds to the level of the Ulantatal occurrence. This stage correlates with Zones MP22–23 of Europe. For Zone MP23, an age of 30.5 Ma has been cited [*Leveque,* 1993]. At this level, Assemblage B is established, which is also attributed to the Lower Oligocene [*Daxner-Höck et al.,* 1997].

The third faunal stage (assemblage) has been obtained from the upper half of the Shand-Gol Formation, and it might correspond to the upper basaltic horizon, dated at 26–28 Ma, and to the overlying strata of *Vislobokova* [1996]. It is divided into two parts: (a) with *Lophiomeryx* cf. *chalaniati, Eumeryx* sp. and (b) with *Amphitragulus* cf. *querey, Dremotherium* cf. *guthi,* corresponding to the mammalian Zones MP24–28 and MP29–30 of Europe. For Zone MP28, a 24.5 Ma date, and for Zone MP30, a 22.5 Ma date are available [*Leveque,* 1993]. The Austrian workers recognize Assemblages C and D in the upper half of the Shand-Gol Formation. In China, this biostratigraphic level corresponds to the Taben-Bulak and Shargaltain-Tal faunas. The second half of the Shand-Gol Formation belongs to the Upper Oligocene.

The Miocene strata of the Loo Formation erosionally overly redbed clays of the Oligocene. Currently, they are known to display three faunal occurrences; the Ulan-Tologoi and Loo were studied repeatedly by the Soviet–Mongolian Geological and Paleontological Expeditions. The third occurrence was discovered during the 1993 Field Symposium

on the Oligocene–Miocene boundary at Builyasutuin-Gol in the southern foothills of the Ushugiin-Nuru Range. In recent years, it was studied by the Austrian–Mongolian field team [*Daxner-Höck et al.,* 1997]. The faunal assemblages of these localities are likely to occupy different stratigraphic levels in the Miocene. Overall, the Ulan-Tologoi faunas were attributed to the Middle Miocene [*Devyatkin,* 1981]. According to *Zazhigin and Lopatin* [2000], the presence of the genera *Alloptox, Democricetodon,* and *Megacricetodon* suggests that this occurrence is older than Zone MN4; i.e., it might belong to the upper–Lower Miocene. The find of the rodent *Ansomys orientalis* Qiu renders this level close to the Xihun faunas, China, whereas the similarity of the *Democricetodon* and *Megacricetodon* hamsters from the Loo Formation to those from the Akzharsky Formation, Kazakhstan, points to near synchroneity of these stratigraphic levels. Provided the zonal correlation to the European mammalian zonation is valid, the Ulan-Tologoi faunas fit in the 17–18 Ma age interval.

The Builyasutuin-Khuduk faunas (Assemblage E) contain *Scinridae* indet., *Democricetodon* sp., *Allocricetus* ? sp., *Lophocricetus* cf. *gansus, Paralactaga* sp., *Rodentia* indet. [*Daxner-Höck et al.,* 1997, p. 171]. These faunas belong to the Upper Miocene and, according to these workers, they occur above the third basaltic horizon, with K–Ar age of 13.0 Ma. Note, however, the lack of direct geologic links between the Builyasutuin-Khuduk (VIK-A) section and the third basaltic horizon, the distance between them being ca. 20 km. Furthermore, on the geologic map attached to the paper, the Builyasutuin-Khuduk (VIK-A) occurrence is plotted in the outcrop area of Oligocene strata of the Shand-Gol Formation. Another oddity is that the basaltic horizon dated at 26 Ma has been placed in the TAR-A section of the Miocene Loo Formation (p. 166). If one accepts the proposed positioning of the VIK section above 13 Ma, the faunal assemblage of this level may correspond to the upper–Middle to Upper Miocene. Paucity of detailed biostratigraphic data, however, as yet prevents its precise biostratigraphic positioning and, accordingly, its zonal correlation. The upper half of the Loo Formation might correspond to the lower part of the Oshin Formation of western Mongolia [*Devyatkin,* 1981], which contains an assemblage of rodents and leporines similar to the Tungur faunas of China [*Qiu,* 1990]. If so, it can be dated to the second half of the Middle Miocene [*Zazhigin and Lopatin,* 2000].

In the Valley of Lakes, upsection of the Loo Formation there occurs the Khung-Kure Formation, a counterpart of the Khirgis-Nur Formation of western Mongolia [*Devyatkin,* 1981]. It is represented by two members, sandy and marly, totaling up to 80 m in thickness. The sand member is known to contain a Pliocene mammalian assemblage: *Gazella* sp., *Camelus* (?) sp., *Hipparion* sp., *Castor* sp., *Rhinocerotidae, Mastodontidae, Struthiolithus* sp. [*Berkey and Morris,* 1927]. From our collection in this locality, *Prosiphnens* sp., *Sinocastor* cf. *anderssoni, Hipparion* cf. *mongolicum* were also determined in the 1970s. Inasmuch as the base of the Khung-Kure Formation is not exposed, nothing can be ascertained concerning its contact with the Miocene portion of the Valley of Lakes section (the Loo Formation), which provides the only constraint on its age. Based on magnetostratigraphic data, the Khung-Kure Formation likely belongs to the Gilbert Zone and, partly, to Zone 5; i.e., it can be dated between 3.3 and 5.2 Ma [*Devyatkin,* 1994].

The uppermost part of the Neogene section of the Valley of Lakes is represented by the Tuin-Gol Formation, forming the highest terrace (up to 120 m) along the valleys of the Tuin-Gol, Tatsin-Gol, and Narin-Gol rivers. Deposits of this age are comprised of sands and loams [*Devyatkin,* 1981]. In different localities, these strata have yielded Upper Pliocene mammalian faunas including *Hipparion houfeneuse* (as determined by V. I. Zhegallo), *Serridentinus florences, Pentolophodon* cf. *sinensis, Dicerorhinus* cf. *etruscus, Hipparion* ex gr. *elegans, Chilotherium* sp., and *Phinocerathidae.* H. F. Osborn [*Berkey and Morris,* 1927] also cited a find of *Equus* sp.

In its stratotype locality, the lower part of the Tuin-Gol Formation is normally magnetized and may belong to the Gauss epoch—i.e., it might be older than 2.5 Ma.

To summarize, ten biostratigraphic levels from the Upper Paleocene to Pliocene inclusive, are currently resolved in the Valley of Lakes. These levels have their matching faunal assemblages. Six basaltic horizons are established, interbedded with sedimentary sequences at geochronologic levels of 37–51 Ma (below and above the Khashat Formation), of 29.7–32.0 and 28.5 Ma (inside the Shand-Gol Formation), and of 13.3–18.9 Ma (inside and above the Loo Formation). Based on faunal data, controlled by K–Ar and ^{40}Ar–^{39}Ar age determinations, correlation is made with the continental mammalian zones of Europe within the Oligocene and Lower Miocene (Figure 3).

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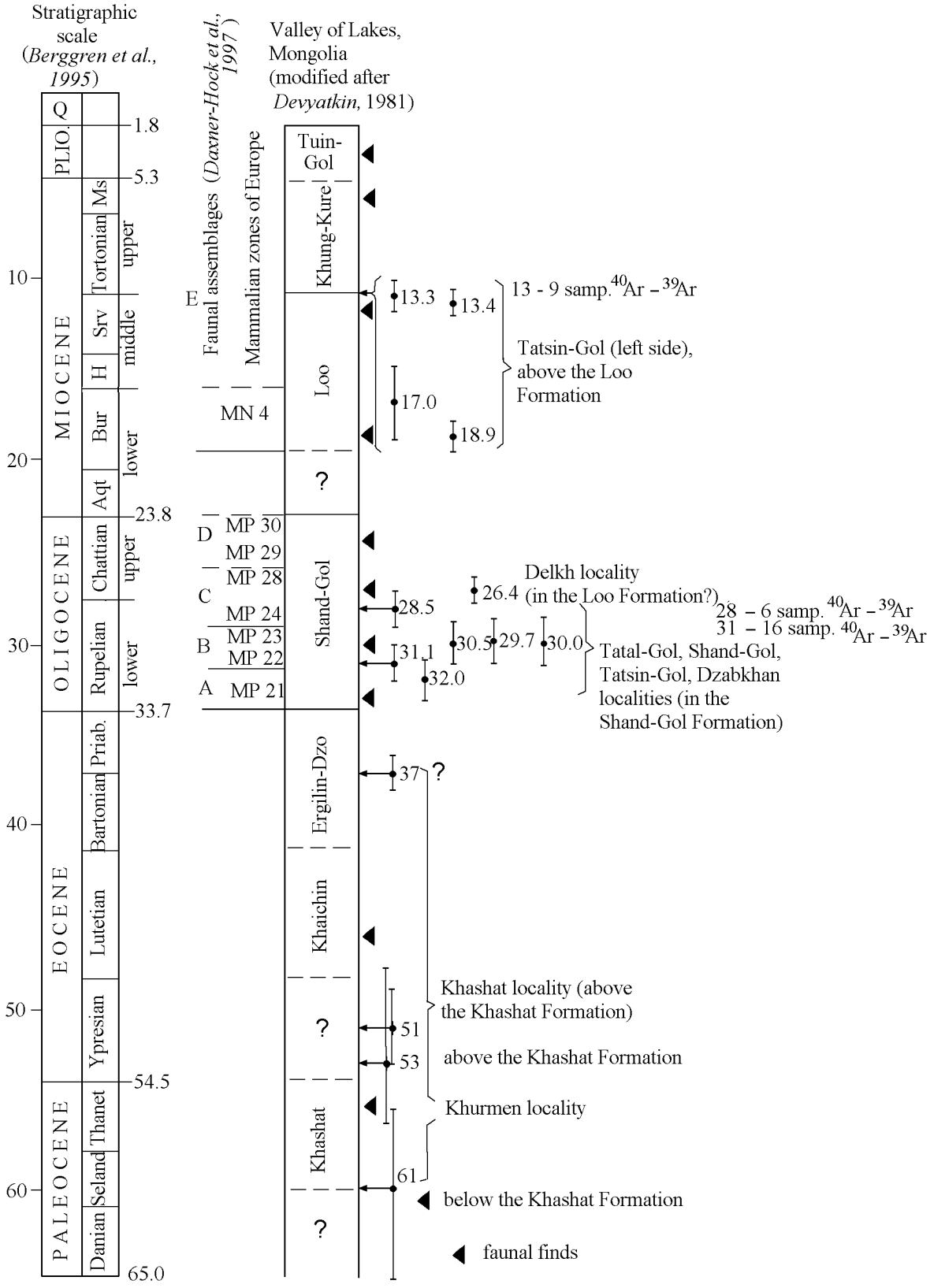

Figure 2. Position of mammalian assemblages and K–Ar and ^{40}Ar–^{39}Ar basalt dates (Ma) in the Valley of Lakes composite section.

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