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Upper Miocene, Pliocene, and Quaternary Stratigraphic Reference Sections of Large Intermontane Depressions in Armenia

Yu. V. Sayadyan

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The representative sections and boreholes of a particular area supplementing each other and constituting an integral reference section are most informative for stratigraphy and paleogeography of recent sediments [14]. This paper presents information on integral reference sections of the large Shirk, Sevan, and Ararat intermontane depressions in the Vorotan–Akeria interfluvium with thickest (up to 2000 m) Upper Miocene, Pliocene, and Quaternary sediments. The author of the present communication studied more than 700 outcrops and cores from approximately 200 boreholes, 120 of which were sampled continuously (up to depth of 700 m). Samples were subsequently subjected to laboratory analyses.

The section of the *Shirak Depression* located in northwestern Armenia is composed of the following units (from the base upward): upper Sarmatian marine clays, sandstones, and limestones (up to 90 m) with *Macra (Sarmatimacra) caspia* Eichw., *M. (S.) bulgarica* Toula, *Pseudomacra poroschini*; Meotian–Pontian volcanic–sedimentary sediments (up to 850 m) with lignite interbeds (up to 50 m) containing ostracodes *Herpetocypris achurjanensis* Bub., *Valvata* sp., and plant remains *Taxus*, *Phragmites*, and *Cercis* [3] in the lower part and volcanic sediments (up to 150 m) with the K–Ar age of 5.15 Ma; lower Pliocene channel alluvium (up to 30 m) defined by lithostratigraphic peculiarities; upper Pliocene lacustrine sediments (up to 550 m) with freshwater molluscan fauna that migrated from the Caspian Sea through rivers and are typical of the early Akchagylian (Borehole 12, 195–115 m): *Cardium dombra* Andrus., *C. radiferum* Andrus., *Micromelania eldarica* Koles., and *Potamides caspius* Andrus. Fauna typical of the late Akchagylian (82–76 m) include *Cardium dombra* Andrus., *C. nikitini* Andrus., *Macra sub-*

caspia Andrus, and pollen of two palynozones (PZ). PZ-1 (188–105 m) includes *Fagus*, *Acer*, *Quercus*, *Juniperus*, *Rosa*. PZ-2 (105–76 m) includes *Pinus*, *Betula*, *Fagus*, *Acer*, *Quercus*. These sediments are overlain by dolerites (up to 70 m) having the K–Ar age of 2.7 Ma and reverse polarity.

Fragments of the Pliocene channel alluvium are recorded on the Dzhadzhur Pass [8]. The lower Neopleistocene is represented by lacustrine sediments (up to 250 m) with mammal remains *Megaloceros* sp.; freshwater mollusks *Dreissena diluvii* Abich (guide taxon for the lower Pleistocene of Armenia), *D. polymorpha* Pall., *D. rostriformis* Desh., and *Micromelania* sp.; freshwater diatom algae (15 species); and pollen of four palynozones: PZ-1 (*Betula*, *Pinus*, Chenopodiaceae); PZ-2 (Chenopodiaceae); PZ-3 (*Quercus*, *Ulnus*, *Betula*); and PZ-4 (*Picea*, *Pinus*, *Betula*, *Quercus*). The middle Neopleistocene lacustrine–alluvial sediments (up to 35 m) yield remains of mammals *Mammuthus trogontherii chosaricus* Dubrovo, *Dicerorhinus kirchbergensis* (= *D. mercki* (Jaeg.)), *Camelus knoblochi* Nehr. [1, 2], and pollen of Chenopodiaceae and Gramineae.

In the section of the *Lake Sevan Depression*, important information was obtained from Boreholes 62 (622 m) and 4 (710 m) drilled in the Masrik Plain and from the Noratuz section scrutinized by Milanovsky [7]. The upper Sarmatian section includes marine clays and sandstones (Borehole 3, 710–560 m) with *Macra (Sarmatimacra) caspia* Eichw., *M. (S.) podolica* Eichw., *M. (S.) timida* Zhizh., *M. (S.) bulgarica* Toula, and plant remains *Laurus*, *Phragmites*, *Ficus*, *Zelkova*, *Citrus*, *Taxus*.

The Meotian section includes the bryozoan *Membranipora* reef (up to 140 m) with *Nitcheina (Membranipora) kirschenewensis* n. sp. overlain by bentonitic clays (up to 25 m) with freshwater mollusks *Dreissena* n. sp. and *Planorbis* sp. [7] and pollen of *Hedera*, *Juniperus*, *Celtis*, *Quercus*, *Fagus*, *Thuja*, and *Pinus*. The

Institute of Geological Sciences, National Academy of Sciences Armenia, pr. Marshala Bagramyana 24a, Yerevan, 375019 Armenia; e-mail: sayad-yuri@rambler.ru

overlying volcanosedimentary sequence contains interbeds of diatom oozes (up to 60 m) with mollusks (*Dreissena* n. sp. and *Limnaea* sp.) and diatoms (24 species) attributed to the Pontian [14].

The lower Pliocene lacustrine–alluvial sediments (boreholes 2 and 4, 622–501 and 560–396 m, respectively) containing interbeds of volcanic tuffs with the K–Ar age of 4.8 Ma and diatom assemblage (45 species) characteristic of the Pliocene [7]. The upper Pliocene lacustrine sediments (boreholes 2 and 4, 501–384 and 396–310 m, respectively) includes *Maetra subcaspia* Andrus., *Avicardium nikitini* Andrus., and *Cerastoderma dombra* Andrus., as well as pollen of *Fagus*, *Tilia*, *Quercus*, *Zelkova*, *Castanea*, *Juglans*, *Punica*, and *Laurocerasus*. Andesites of the Manychar Plateau are dated at 2.5 Ma (K–Ar). Based on lithostratigraphic features, lacustrine sediments in the interval of 282–247 m in Borehole 4 are referred to the Eopleistocene. The pollen spectra characterize three palynozones: PZ-1 with *Quercus*, *Acer*, and Gramineae; PZ-2 with Chenopodiaceae and *Artemisia*; and PZ-3 with *Picea*, *Betula*, *Pinus*, *Quercus*.

The lower Neopleistocene is composed of lacustrine sediments (Borehole 4, 235–188 m) with mollusks *Dreissena diluvii* Abich and *Micromelania caspia* Eichw. and pollen of three palynozones: PZ-1 (*Betula*, *Populus*, *Pinus*, Chenopodiaceae, and Gramineae), PZ-2 (*Artemisia*, Chenopodiaceae), and PZ-3 (*Picea*, *Pinus*, *Betula*, *Carpinus*). The middle Neopleistocene lacustrine sediments are defined using lithostratigraphic criteria. The lower and middle parts of their section are characterized by pollen of the respective PZ-1 (*Pinus*, *Picea*, *Betula*, *Quercus*) and PZ-2 (Chenopodiaceae, *Artemisia*) palynological zones, while the upper part yields diatoms of an oligotrophic basin: *Melosira*, *Fragilaria*, *Navicula*, *Amphora*, and *Diploneis*. The lithostratigraphically defined upper Neopleistocene lacustrine sediments are characterized by the pollen assemblage of *Picea*, *Pinus*, *Betula*, *Populus*, and *Quercus*.

The Holocene lacustrine and boggy sediments are penetrated by boreholes (up to 35 m) and exposed along the Lake Sevan coast. They made it possible to establish 12 cycles of vegetation and climate history [13], lake level fluctuations, and the age of the last eruption of the Aragan Volcano (Gegam Highland) approximately 2000 yr ago based on the geoarcheological method [11, 12].

In the *Ararat Depression*, upper Sarmatian sediments are exposed in the middle courses of the Razdan River, where the stratotype of the Razdan Formation is located. The section is composed of marine clays, marls, sandstones, limestones, coquina, and oil shales (approximately 800 m thick) with *Maetra (Sarmati-mactra) caspia* Eichw., *M. (S.) bulgarica* Toula, and plant remains belonging to the *Ficus*, *Laurus*, *Persea*, *Zelkova*, and other genera [3, 5]. The formation is overlain by sediments of the Vokhhaberda Formation stratotype (up to 500 m) with the lower part composed of tuffaceous siltstones and argillites with Meotian fresh-

water mollusks *Unio flabellatus* Goldf., *U. cf. moldavensis* Hoern., and *U. mactrella* Bog. and upper part consisting of volcanoclastic rocks with the K–Ar age of 5.15 Ma. Pontian and Cimmerian sediments have not been found so far.

The Upper Pliocene is represented by the Nurnus Formation of lacustrine sediments (up to 20 m) exposed in the middle courses of the Razdan River, where they host remains of mammals *Dicerorhinus etruscus* (Falc.), *Equus* cf. *stenonis*, *Hipparion* sp. [4] and upper Pliocene diatoms (57 species) [9]. The sediments are overlain by reversibly magnetized dolerites 2.47 Ma old (K–Ar). The Eopleistocene is represented by the 170- to 180-m-high Nubarashen terrace composed of channel alluvium (up to 30 m) of the paleo-Araks river [10], while the lower–middle Neopleistocene is composed of lacustrine and lacustrine–alluvial sediments of the Ararat Formation divided into two subformations. The lower (early Neopleistocene) subformation (up to 200 m) includes mollusks *Dreissena diluvii* Abich, *D. polymorpha* Pall., and pollen of *Juglans*, *Betula verrucosa*. The upper (middle Neopleistocene) subformation (up to 60 m) includes vertebrate remains *Mam-mathus trogontherii chosaricus* Dubrovo, *Paleolox-odon antiquus* (Falc.) [1, 2], and pollen of *Pinus*, *Betula*, and *Alnus*.

In the *Vorotan–Akeria interfluvial depressions*, Miocene sediments are not established so far. The basal part of the Pliocene section is composed of volcanosedimentary rocks (up to 500 m) dated by the K–Ar method at 3.0 Ma. Higher in the section, these sediments are replaced by the lacustrine Sisian Formation (up to 450 m), which is overlain by basaltic flows constituting the Erablur Plateau (K–Ar age 2.5 Ma). The lacustrine sediments enclose plant remains, pollen, and diatoms characterizing six cycles in vegetation development of the study region (from the base to top): turf-gramineous steppe, coniferous–broad-leaved forests, Chenopodiaceae–*Artemisia*–Gramineae steppes, broad-leaved forests, *Artemisia*–Chenopodiaceae steppes, broad- and narrow-leaved forests.

The Eopleistocene represented by the Gorisa Formation of volcanoclastic rocks is divided into two subformations. The lower subformation (up to 250 m, 1.5 Ma based on the K–Ar method) is overlain by the Noravan lacustrine beds (up to 30 m). The upper subformation (up to 150 m) with benthic and planktonic diatoms (26 species) is overlain by the Tatev lacustrine beds (up to 150 m) with pollen characterizing three palynozones: PZ-1 with *Quercus*, *Alnus*, *Betula*, Gramineae, Malvaceae; PZ-2 hosting Compositae, Chenopodiaceae, *Artemisia*; and PZ-3 containing *Quercus*, *Corilus*, *Ulmus*, *Carpinus*, *Betula*.

The lower Neopleistocene corresponds to the Aknash lacustrine beds with basaltic flows 0.7 Ma old (K–Ar) at the base. The beds yield diatoms (15 species) and pollen of four palynozones: PZ-1 (Chenopodiaceae, *Artemisia*, *Ephedra*); PZ-2 (*Quercus*, *Betula*, *Fagus*,

Chenopodiaceae, *Artemisia*); PZ-3 (Chenopodiaceae, *Artemisia*); and PZ-4 (*Picea*, *Pinus*, *Betula*). The middle Neopleistocene includes the Angekhakot lacustrine beds defined by lithostratigraphic criteria. They contain diatoms (36 species) and pollen of three zones: PZ-1 (Chenopodiaceae, *Artemisia*); PZ-2 (*Betula*, *Picea*, *Pinus*, *Quercus*); and PZ-3 (Chenopodiaceae, *Artemisia*). The upper Neopleistocene is represented by sediments constituting terraces V–III of the Araks, Vorotan, and Akera river systems. The Holocene is represented by sediments of terraces II and I and floodplains [10].

Thus, in the late Sarmatian, the present-day Sevan, Ararat, and Shirak intermontane depressions were flooded by waters of the Eastern Paratethys. Significant reduction of the Paratethys in the Meotian and Pontian [6] resulted in its retreat with the formation of a large lake. In the early Pliocene, the region was subjected to erosion. During the late Pliocene–middle Neopleistocene, all large intermontane depressions were occupied by lakes, among which only the Sevan Depression retained the synonymous lake until now. In some parts of the region, local tectonic and paleoclimatic events influenced and refined the general development trend. However, these details (often essential) are beyond the scope of this work.

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