Journal of volcanology and geothermal research

Journal of Volcanology and Geothermal Research 113 (2002) 319–344

www.elsevier.com/locate/jvolgeores

Holocene-historical volcanism and active faults as natural risk factors for Armenia and adjacent countries

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Received 18 May 2000; accepted 26 June 2001

Abstract

Examples of Holocene-historical volcanism in the territory of Armenia and adjacent areas of Eastern Anatolia and Western Iran are discussed. Holocene-historical activity is proved for the volcanoes of Tskhouk–Karckar, Porak, Vaiyots-Sar, Smbatassar and Ararat. Based on the analysis of remote sensing data, field work, and historical and archeological information, it is demonstrated that there was a considerable number of cases of volcanic activity in Armenia and adjacent regions of Turkey, Syria and Iran during the historical period. The Holocene volcanic centers are situated within pull-apart basin structures and controlled by active faults. Situated in an area prone to many types of natural hazards, Armenia and adjacent countries face high natural risk. The evidence presented shows that volcanic hazard also contributes to the natural risk for these countries.

Keywords: volcano; historical eruption; active fault; Armenia

1. Introduction

The territories of Armenia, adjacent parts of Turkey and NW Iran are areas of vast and intense Quaternary volcanism. There are accounts of Holocene fissure eruptions of Nemrout, Sipan, Tondourek and Ararat volcanoes in Eastern Turkey (Yilmaz et al., 1998; Innocenti et al., 1980), and their relation to neotectonic faults can be demonstrated (Adiyaman et al., 1998; Dewey et al., 1986). Evidence of Holocene volcanism in Armenia has been reported by Balian (1969), Karapetian and Adamian (1973), Azizbekian (1993) and Karakhanian et al. (1997a,b, 1999). Historical volcanic activity in the region is commonly limited to the Nemrout eruption in 1441 and present-day fumarole activity of the Nemrout, Tondourek and Ararat volcanoes (Yilmaz et al., 1998). One goal of this study is to demonstrate that Holocene-historical volcanism is much more widespread in Armenia and adjacent areas of Turkey and Iran than is widely recognized and may be considered a natural risk factor.

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0377-0273/02/$ – see front matter
PII: S0377-0273(01)00264-5

The working technique is based on the analysis of an extensive range of high-resolution satellite images, including those of SPOT, Russian systems, as well as Corona, Landsat-TM, Landsat-7ETM+, and ERS, and air photos of various scales (1:100 000–1:5000). In most of the studied regions, detailed field mapping along with trenching, ^{14}C and archeological dating of samples was done. ^{14}C dating was carried out in the Geology Institute of the Russian Academy of Sciences (GIN) and in Paris Sud University (UPS), and archeological dating was done in the Institute of Archaeology and Ethnography of the Armenian Academy of Sciences.

New evidence from Armenian chronicles and other historical and archeological sources is used extensively. Considering that the historical record in Armenia accounts for not less than 3000 years, and the archeological record spans 10 000–12 000 years (Arménie, 1996), the evidence can therefore cover the entire period of the Holocene. Further, we consider several groups of volcanoes as examples of Holocene-historical volcanism in Armenia, adjacent areas of Eastern Turkey and NW Iran, including Karckar–Tskhouk, Porak, Vayots-Sar, Smbatassar and Ararat (Fig. 1).

2. Tskhouk–Karckar group volcanoes

This group is composed of eight volcanoes elongated meridionally at the NW slope of the large Quaternary volcano Tskhouk (I in Figs. 1 and 2). Volcanoes of the Tskhouk–Karckar group are in the central part of the Siunik volcanic ridge, at an altitude of 3000 m and higher (lat. 35°44′N, long. 46°01′E). The volcanoes rest on thick rhyolites and dacites of the Neogene, and basaltic andesites of the Early and Middle Pleistocene. Well-preserved Holocene lava flows of the Tskhouk–Karckar group are clearly seen in these rocks (Fig. 3).

By the state of preservation, the lava flows are classified into three generations, clearly identifiable in air photos and in the field. Basaltic andesites of the comparatively older Generation 1 are intact only in the western part of the Holocene lava field (Fig. 2). Basaltic andesites of Generation 1 overlie a Late Pleistocene moraine at the eastern coast of Lake Aknalich (Fig. 2). Basaltic andesites of the Holocene Generation 2 form the northern side of the lava field (Figs. 2 and 4). The surface of Generation 2 lava is eroded and covered by a fragmentary soil layer. In contrast, Generation 3 basaltic andesites, forming the central part of the lava field, are not eroded (Fig. 5).

Basaltic andesite eruption centers of the three Holocene generations, and largely of the Pleistocene generation, are inside a large rhombic structure formed by the segments of the Pambak–Sevan active fault (Figs. 2 and 4). This structure is a pull-apart basin bordered in the north and in the south by segments of the main right-lateral strike-slip Pambak–Sevan fault, which have uplifted outer walls. Within the pull-apart, the strike of the Pambak–Sevan fault deflects for 30° changing from W-NW to the meridional. Since the regional compression component is oriented to the N-NE, extension develops inside the pull-apart in a near-meridian direction. The extension is indicated by many parallel normal faults having small strike-slip components and delineating tilted blocks. Lava covers some segments of these faults. Meridional faults of the eastern and western sides of the pull-apart are right-slips with a normal component on their inner walls. Holocene eruption centers of Generations 2 and 3 are aligned in meridian-oriented chains directly in the line of the normal-slip faults of the eastern flank of the pull-apart (Fig. 2). Karakhanian et al. (1997a) describe these structures in detail.

Within the pull-apart depression, there is a thermal spring (III in Fig. 2) with a temperature of 34°C on the surface and 97°C at a depth of 1 km in a boring, which attests to the abnormally high geothermal gradient in the region (6.3°C per 100 m). Many thermal springs with surface temperatures of 60–80°C are found within a radius of 40–50 km (Vorotan, Jermouk, Histissou). Across the pull-apart, petroglyphs, burial kurgans and masonry walls are found in abundance on Pleistocene lava and Holocene flows of Generation 1. Some of their features allow consideration of these objects as evidence of long-term evolution of an Eneolithic culture of hunters and cattle-

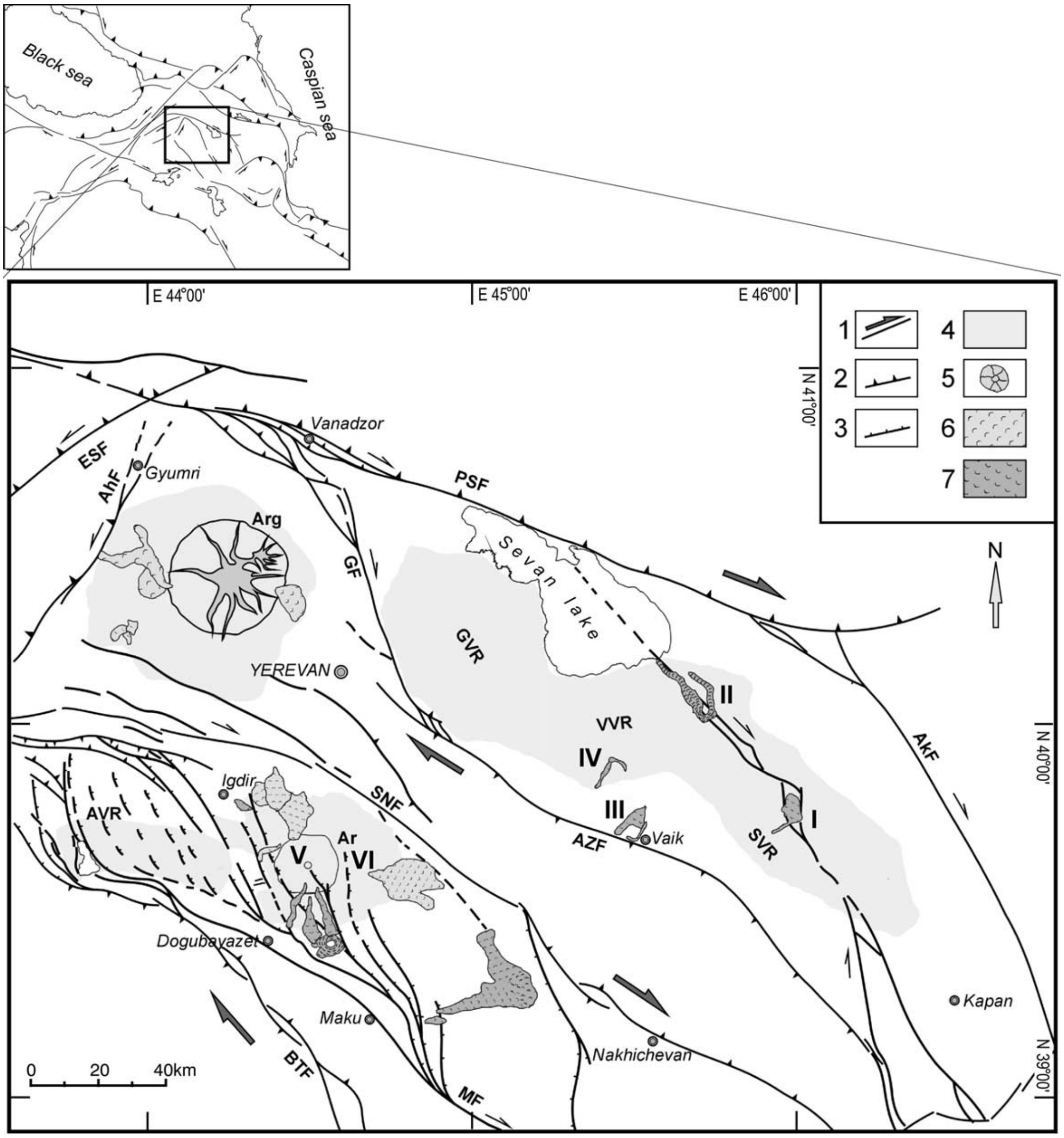

Fig. 1. Active faults and young volcanism in Armenia and adjacent areas. 1, Active strike-slip faults; 2, reverse faults and thrusts; 3, normal faults; 4, volcanic areas; 5, large volcanoes; 6, pre-Holocene lava flows; 7, Holocene lava flows. Digits in the figure: I, Tskhouk–Karckar group volcanoes; II, Porak group volcanoes; III, Vaiyots-Sar; IV, Smbatassar; V, Ararat; VI, Touzhik. Volcanic areas: GVR, Ghegham volcanic ridge; VVR, Vardeniss volcanic ridge; SVR, Siunik volcanic ridge; AVR, Agri-Dag volcanic ridge; Arg, Aragats stratovolcano; Ar, Ararat stratovolcano. Active faults: PSF, Pambak–Sevan Fault; AKF, Akery Fault; AhF, Akhourian Fault; ESF, Zheltorechensk–Sarykamis Fault; GR, Garni Fault; AZF, Areni–Zanghezour Fault; SNF, Sardarapat–Nakhichevan Fault; BTF, Balikghel–North-Tabriz Fault.

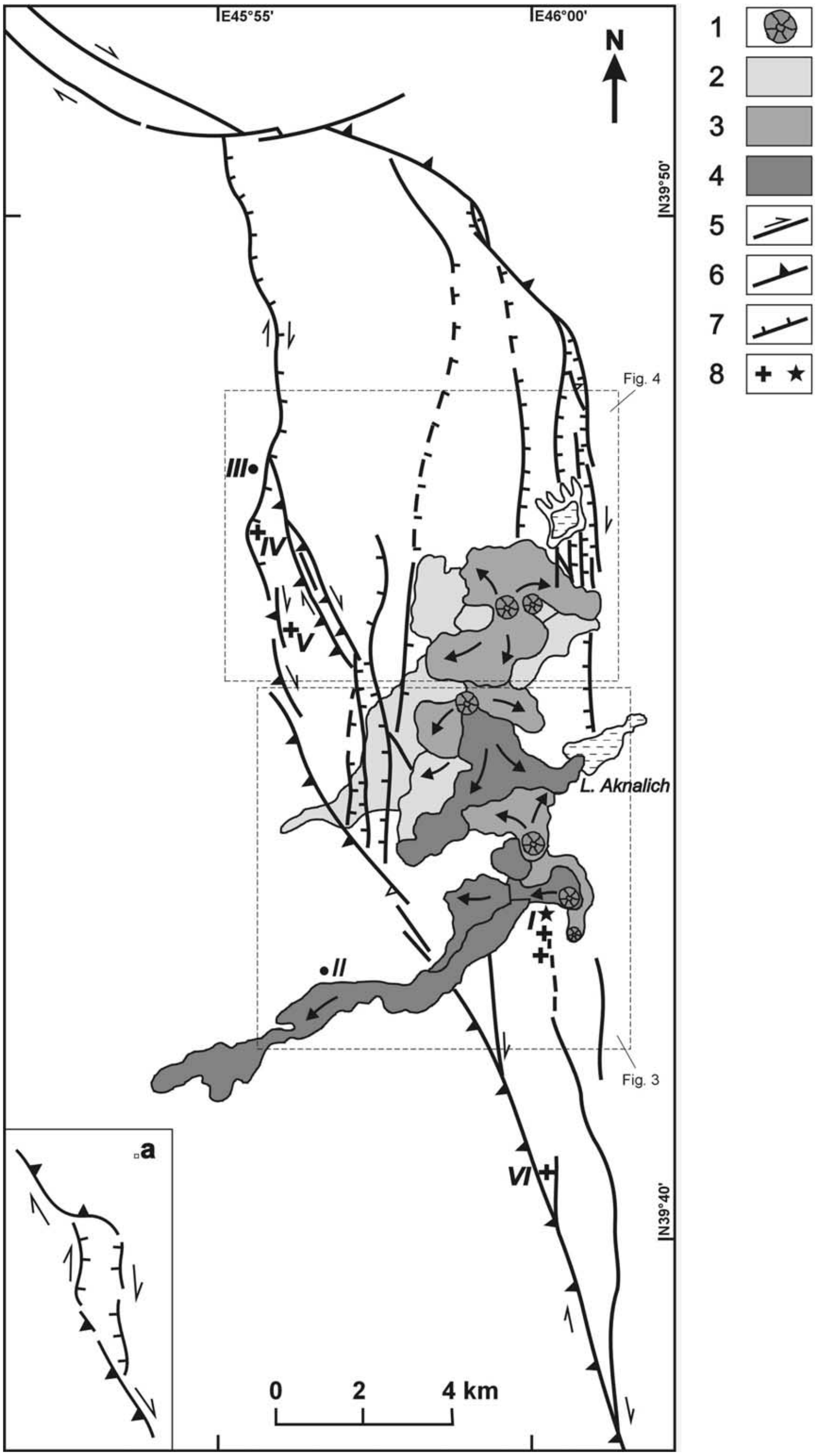

Fig. 2. Sunik pull-apart basin with the Tskhouk–Karckar group volcanoes. 1, Volcanoes; 2, Generation 1 Holocene lava; 3, Generation 2 lava; 4, Generation 3 Holocene lavas; 5, strike-slip faults; 6, reverse faults; 7, normal faults; 8, petroglyph fields and ancient structures. (a) Conceptual geodynamic model of the Sunik pull-apart basin.

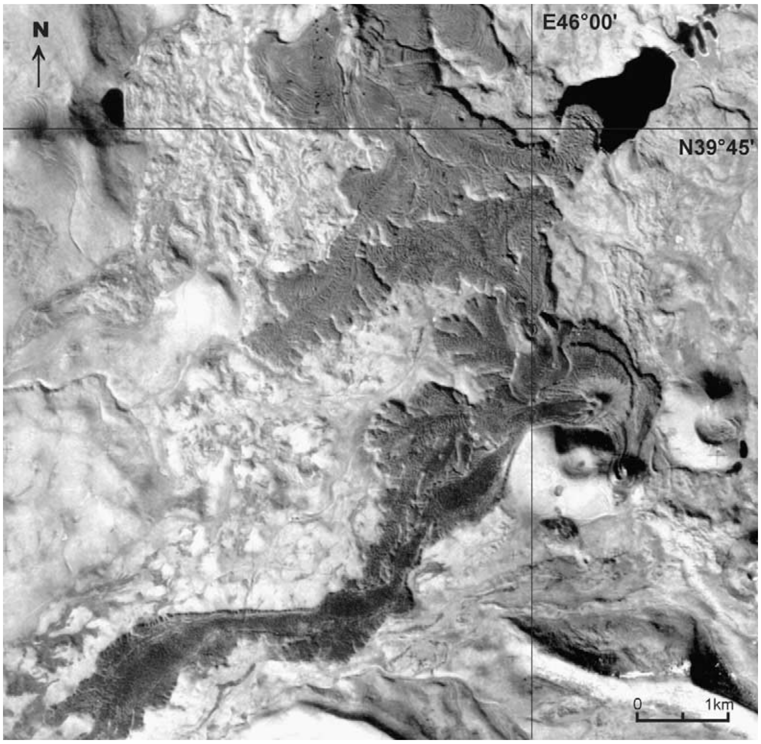

Fig. 3. Air photo of lava flows for the Tskhouk–Karckar group volcanoes (the southern part, see Fig. 1).

breeders. Apparently, microclimate, favorable relief, and thermal and fresh-water resources in the pull-apart were convenient for the development of that culture.

However, there are no petroglyphs and old structures on the Holocene lava of Generations 2 and 3. In the south of the Holocene lava field (I in Fig. 2), Generation 3 Holocene lava directly overlies a petroglyph (Fig. 6). By ^{14}C dating, the age of the petroglyphs is late 4th–early 3rd millennium BC (Karakhanian and Saphian, 1970; Karakhanian et al., 1999). Therefore, the lower limit age for the lava of Generations 2 and 3 should be younger than late 4th–early 3rd millennium BC.

The upper limit age for the eruption of Generation 3 lava is estimated by the dating of a sample taken from a burial place near the north flank of the Generation 3 lava flow (II in Fig. 2). Blocks of Generation 3 Holocene lava flow were used to build a kurgan over the grave. The blocks rested on a man-made layer of piled loam, containing obsidian tools, bones and primitive ceramics. The loam layer also filled the space in the grave. ^{14}C dating of the loam (GIN-9603) established the age at 4720 ± 140 years BP. Therefore, Generation 3 lava was erupted early in the 3rd millennium BC. Considering the intact condition of Generation 2 lavas, they can be 200–300 years older.

Despite the convenience of the pull-apart basin for cattle breeding and defense, no traces there indicate the later presence of human beings until the period of cattle-breeding settlements of the 17th–18th centuries AD.

Intense strike-slip motions in the main zone of the Pambak–Sevan fault at a rate of 5–6 mm/yr (Trifonov et al., 1994) transform into extension and subsidence at the pull-apart site. The slip rate decreases north-to-south along the NE boundary of the pull-apart, but increases on its SW flank. In sum, slip rate on both sides of the pull-apart basin remains equal to the total slip rate along the Pambak–Sevan fault.

Seismogenic surface ruptures of Holocene age

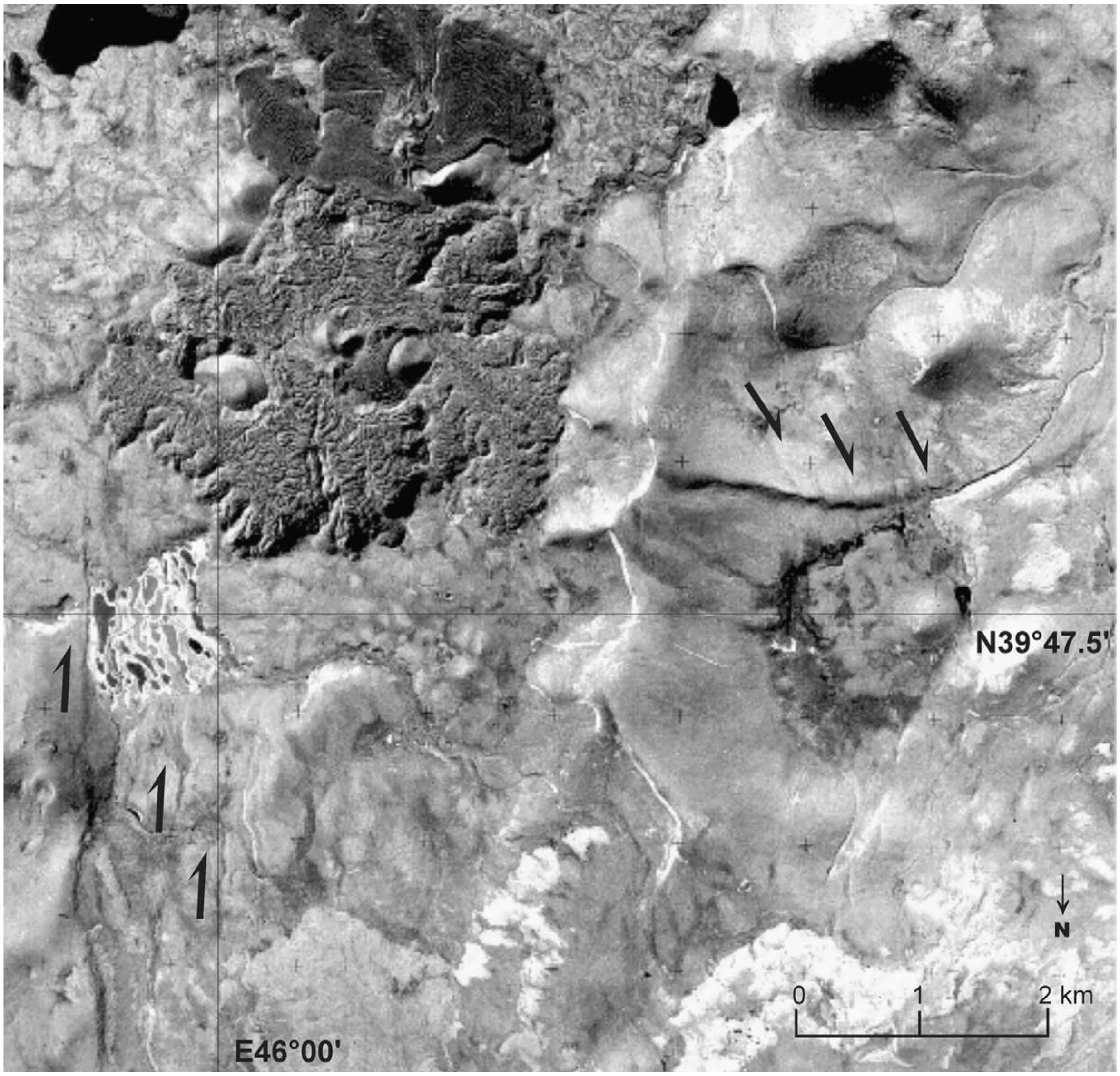

Fig. 4. Air photo of Holocene lava flows from the Tskhouk–Karckar group volcanoes (the southern part, see Fig. 1). The arrows indicate right strike-slip faults, forming the borders of the Sunik pull-apart basin.

are found on some of the pull-apart faults (IV, V and VI in Fig. 2). The ruptures are identified by scarp steps of varying steepness that indicate pulses of motion in alternation with scarp erosion periods (Wallace, 1977). Other seismicity indicators are stepwise alternation of extension ditches and compression ridges (typical for seismogenic slips), distinct dams of temporary watercourses, as well as a clear colluvial wedge revealed in the trench. The slip rate on the SW flank fault (1 mm/yr) is much less than the average total slip rate on the main Pambak–Sevan fault (5–6 mm/yr) and suggests high seismic potential of the pull-apart and a considerable contribution of strong seismicity to the total motion on the pull-apart faults. Seismogenic ruptures can be traced on the lava of Holocene Generations 1 and 2, but are lacking on Generation 3 Holocene lava.

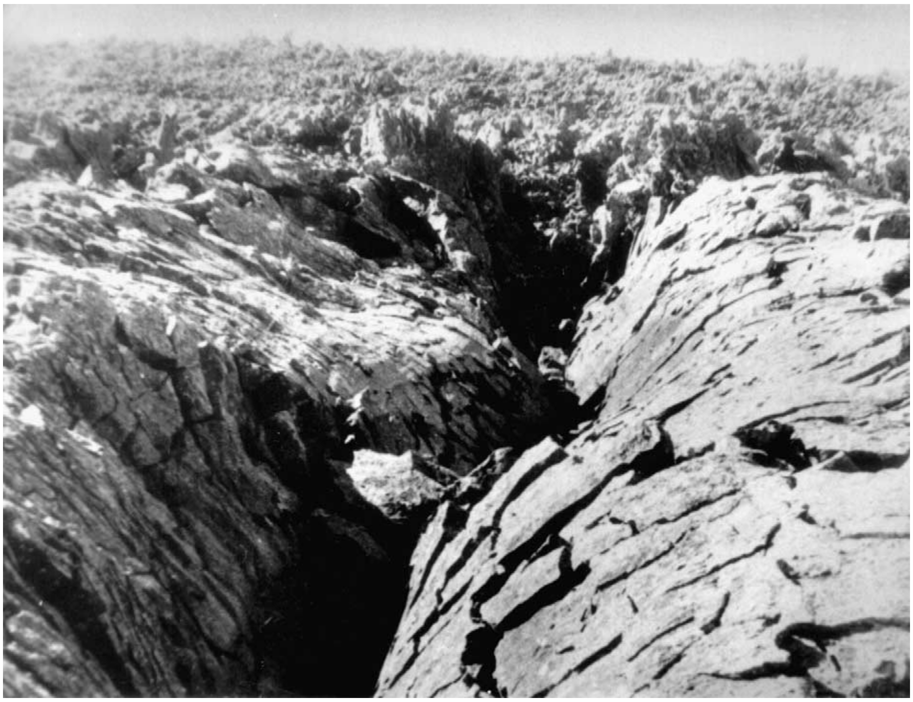

Fig. 5. Holocene lava flows of Generation 3 of the Tskhouk–Karckar group volcano, view from the southeast near Site 4 in Fig. 3.

Findings of petroglyphs upturned and broken by seismic motion on the seismogenic fault scarp suggest that the petroglyphs had been created before the last earthquake occurred. The earthquake is dated to the 3rd millennium BC (Karakhanian et al., 1997a, 1999), i.e., about the age of the Generation 3 Holocene lava eruption. Early in the 3rd millennium, the volcanic eruption of Generation 3 lava and the strong earthquake eliminated the Eneolithic culture in that region. The area was re-developed only in the Middle Ages.

3. Porak group volcanoes

The volcanoes are at the SE coast of Lake Sevan, on the northern slope of the Vardeniss volcanic ridge, at an altitude of 2800 m (lat. 40°01′N, long. 45°47′E) (II in Fig. 1). The group consists of the central Middle Pleistocene Porak volcano with 10 parasitic cones and Holocene fissure eruption centers (Figs. 7 and 8). Thermal sources of Jermouk and Histissou (65°C) are 15–20 km away from the Porak volcano. The Porak volcano is 37 km to the NW of the Tskhouk–Karckar volcano group described in Section 2. There are two large lava flows, up to 21 km long, that start from the group of Holocene ejecta near the Porak volcano and spread to the north and northwest. All Holocene vents of these lava flows are elongated in the NW direction and flanked by Pambak–Sevan active fault segments.

At the site of the Porak volcano group, the Pambak–Sevan active fault is distributed in two en echelon right-stepping segments, which determine extension inside the structure they edge. At the northern termination, the northeasternmost fault branch bisects the top of the Middle Pleistocene Khonarassar volcano (I in Figs. 7 and 8). The Khonarassar volcano cone is displaced along the fault for 800 m to the right (Trifonov et al., 1994). The NE and SW fault branches are 2 km apart. Both have uplifted outer walls and are linked in the south flank with shorter right-slip

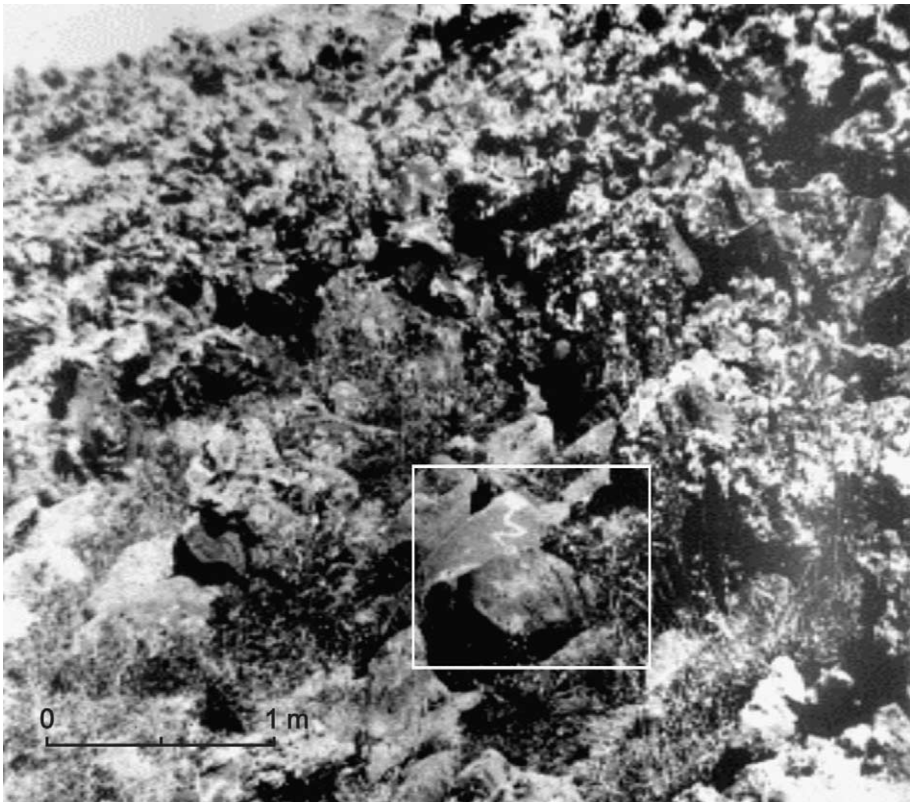

Fig. 6. Holocene lava flows of Generation 3 in the Tskhouk–Karckar group volcanoes that overlie a 1.2×0.7-m block carved with a *snake* petroglyph dated late 4th–early 3rd millennium BC.

and normal faults. Therefore, there is a typical structure of a narrow and elongated pull-apart with a central graben depression accommodating Porak volcano and Holocene lava vents.

Based on geological mapping, it is possible to distinguish between the three generations of Holocene basaltic andesite lava flows. The first is the earliest Holocene generation that formed two flows of lava stretching northward into the regions of the Karchahpiur (the western flow) and Akounk (the eastern flow) villages (Fig. 8). Fragmentary soil layer covers the surface of Generation 1 lava, while this lava in turn overlies Late Pleistocene deposits of Lake Sevan. The Holocene lava of Generation 2 is found on the western flank of Porak volcano, does not have soil cover, and flowed into Lake Alaghel (Figs. 8 and 9).

At Site 2 (Fig. 8), we uncovered the ruins of a previously unknown ancient town (Philip and Karakhanian, 1999). The lower part of the town, containing housing remnants, rests on the surface of the Late Pleistocene lava and is near the foot of a Generation 1 Holocene lava flow. Above the city, on the surface of the Generation 1 lava flow, there is a strong fortification structure – a citadel. The age of the town is difficult to estimate precisely. A pit made in the center of one of the houses exposed a cultural layer at a depth of 1.2 m. It contained an intra-layer of charcoal, obsidian tools, and primitive ceramics. ^{14}C dating of the 1–2-cm-thick charcoal layer established an age of 3080 ± 40 BP (GIN-9913), and for organics from the loam layer under the charcoal the age was 3200 ± 40 BP (GIN-9914). Archeological dating based on the analysis of the surface and pit (1.5–2 m) ceramic samples, and design features of the walls and the masonry, dates the town to the pre-Urartian period of 1000–700 BC (Middle Iron

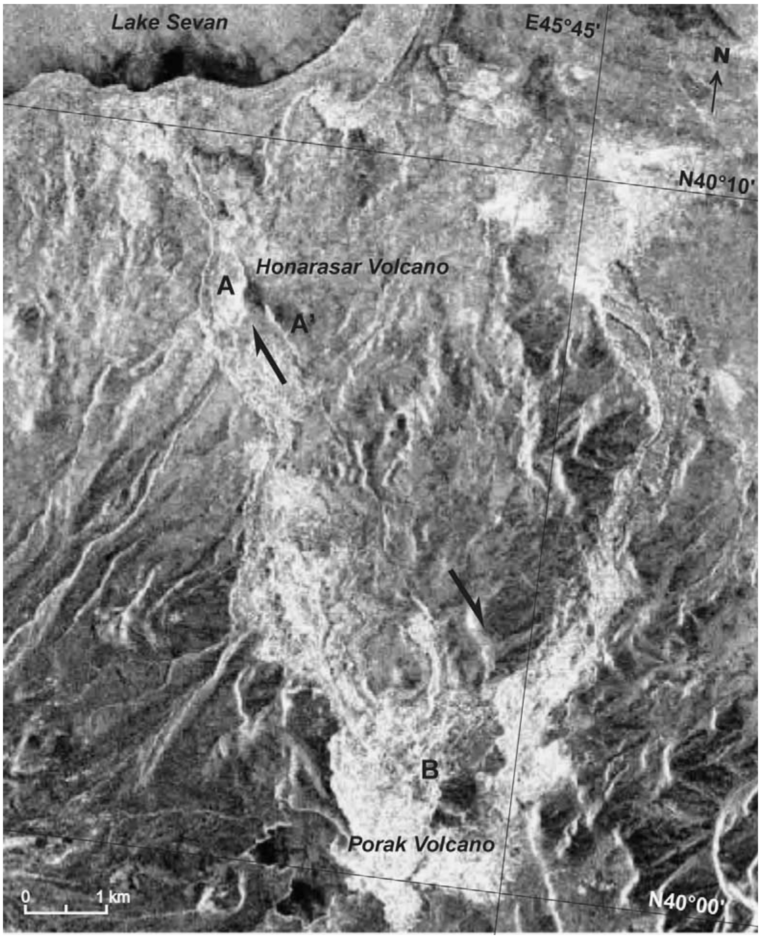

Fig. 7. ERS satellite image of the Porak group volcanoes (the northern part). Arrows point to the active Pambak–Sevan right-slip fault. A–A_1, Khonarassar volcano cone offset by the fault; B, Porak volcano.

Age). However, the town may appear to be even older, considering that the pit did not cut through the whole depth of the culture layer.

We found many settlements and fortification structures of the same age in the vicinity of today's village of Akhpiuradzor, at the northern and western foot of Porak volcano, and at the eastern coast of Lake Alaghel (Fig. 8). All old structures and settlements are on the lava of Generations 1 and 2, and there are none on Generation 3 lava. Lengthy and multi-tier defense walls were found on the lava of Generation 1 and particularly Generation 2 at the eastern coast of Lake Alaghel. The walls terminate abruptly immediately at the edge of Generation 3 lava flow (IV in Fig. 8). Could that be a result of historical volcanic activity? We assume such a possibility.

The famous Khorkhor cuneiform inscription, belonging to King Argishti I, was found in the Lake Van region (Eastern Anatolia) (Shultz, 1840). The inscription recounts the victorious military campaign to the north, into the area of present-day Armenia. One of the inscription columns reads as follows:

"...when I again (for the second time) laid the siege of the town of Behoura, Mount Bamni in the area of Behoura Town was destroyed ...; smoke and soot now rise from it to the sun. When Mount Bamni was destroyed, I took the town of Behoura."

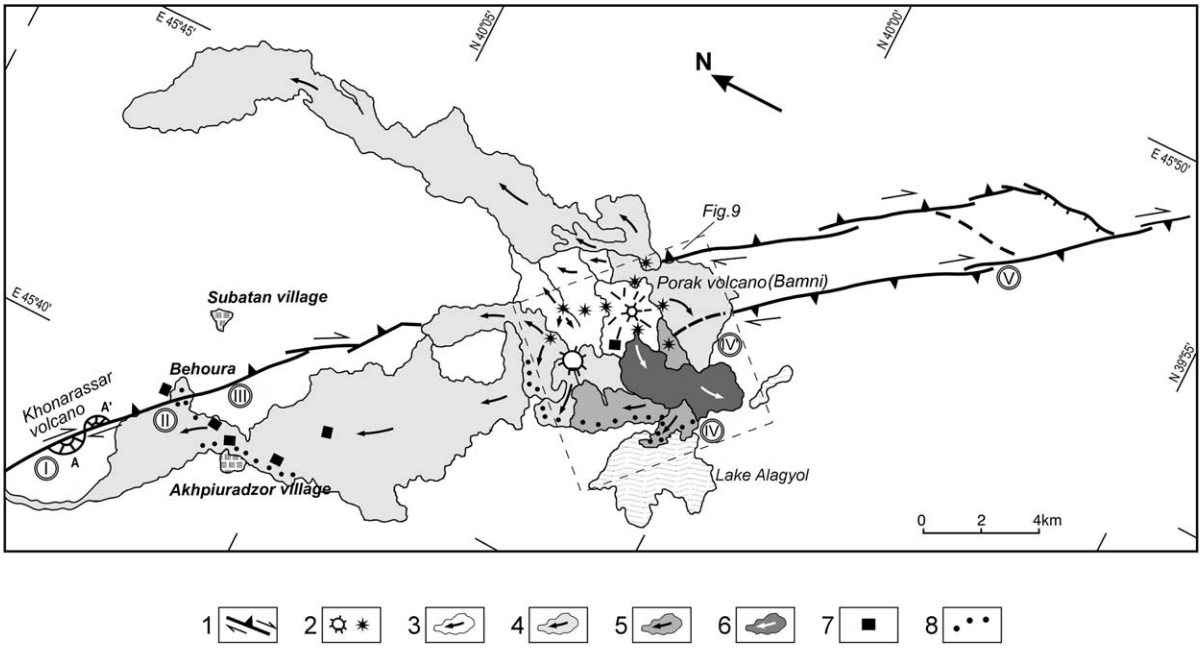

Fig. 8. Pull-apart basin with the Porak group volcanoes. 1, Active faults; 2, volcanoes; 3, pre-Holocene lava flows; 4, Generation 1 Holocene lavas; 5, Generation 2 Holocene lavas; 6, Generation 3 Holocene lavas; 7, large ancient settlements; 8, old fortification walls.

Translation according to Ohanessian and Abramian (1981), p. 66

Sardour II, son of Arghishti I, left another cuneiform inscription:

"...the people who ran away frightened of the arms and climbed Mount Ushkiani and Bamni; I encircled them and killed, others who escaped were burned by Teishebah the God"

translation according to Melikashvili (1960), p. 254

Historians believe that the northern campaign of Arghishti I was between 782 and 773 BC and assume that Behoura Town and Mount Bamni were in the Lake Sevan basin, within the region of the Vardenis volcanic ridge. Teishebah was the god of the underground kingdom. We interpret the content of these cuneiform inscriptions as the description of a volcanic eruption on Mount Bamni during the campaign of Arghishti I, the Urartians' king. The eruption was accompanied by the destruction of Behoura and the death of the people who tried to escape on Mount Bamni. Taking into account the evidence from paleoseismicity, volcanism, archeology and history, we can suggest that the ancient town, other settlements and fortification structures found are the remains of Behoura, while Porak volcanoes correspond to Mount Bamni (Fig. 9).

As in the case of Tskhouk–Karckar, the origin of the Porak group of volcanoes is associated with local extension conditions in the pull-apart basin formed by the segments of the Pambak–Sevan active strike-slip fault. Scarps of seismogenic surface ruptures are identified on the borders of the Porak pull-apart. The faults have displaced cemeteries and walls in the ancient town citadel. Paleoseismological trenches made to the south of the old town provide indications of two earthquakes and expose ceramics buried in the paleosoil and similar to the ones found in the town (Philip and Karakhanian, 1999; Philip et al., 2001). The lower limit age for one of the earthquakes with $M \geq 7.3$, estimated by radiocarbon analysis of the paleosoil in the Paris Sud University, is 6640 ± 90 BP (UPS, V/3A) (Philip et al., submitted). By the same analysis for the second earth-

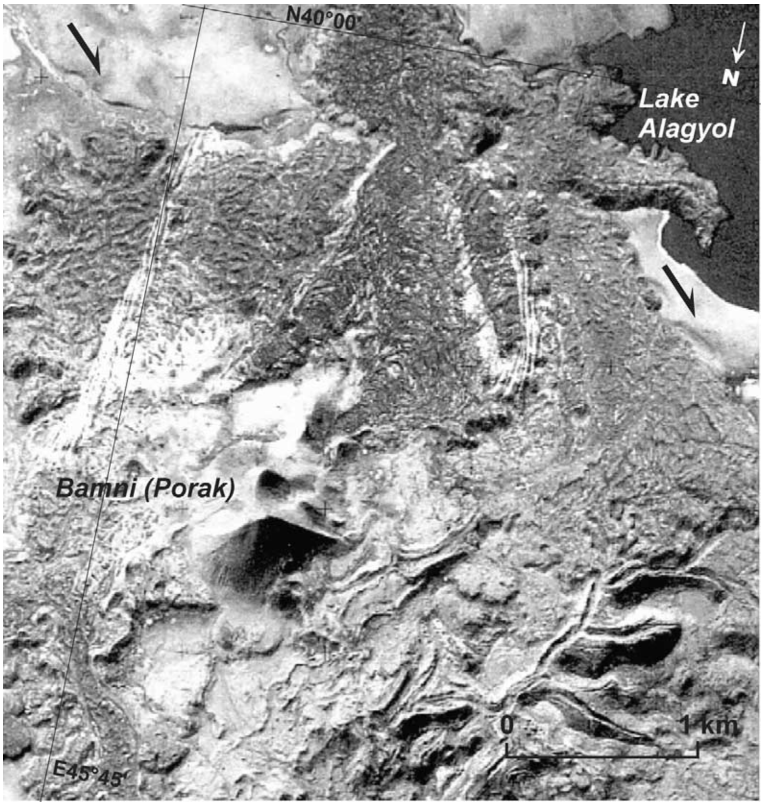

Fig. 9. Air photo of Holocene lava flows of the Porak group volcanoes (see Fig. 8).

quake of $M \geq 7.3$, it was between 782 and 773 BC (Philip et al., submitted).

The Porak (Bamni) volcano eruption and strong earthquake between 782 and 773 BC facilitated the conquest of Behoura by Urartian troops, which, as a result, led to the change of archeo-cultures in the region. That was not the only historical volcanic eruption of Porak volcano. In the summer of 1999, we found six petroglyphic pictures 9 km S-SE from the Porak volcano within the limits of the pull-apart (V in Fig. 8). Judging from the carving technique and preliminary archeological dating of obsidian tools found nearby, the age of the petroglyphs is 5th millennium BC (Fig. 10).

Palynology analysis of lacustrine deposit sections in the SW part of the Sevan basin points to the abrupt and short-term disappearance of vast forests (Sayadian et al., 1977; Sayadian, 1983). The ^{14}C analysis of clam shells made in the Moscow State University (MSU) establishes the upper time boundary of forest disappearance at 6270 ± 110 BP (MSU-215, Sayadian et al., 1977). Archeological dating agrees with this age (Sayadian et al., 1977). The total disappearance of the forests is related to fires caused by volcanic eruptions in the Sevan basin in the 5th millennium BC (Sayadian, 1983). The coincidence of the following quite relatable phenomena in time and in the narrow space of the S and SW parts of the Lake Sevan basin is of interest:

– extermination of forests by fires in volcanic eruptions before 6270 ± 110 BP;

– creation of petroglyphic volcano pictures in the 5th millennium BC; and

– a strong earthquake after 6640 ± 90 BP.

These dates suggest a volcanic eruption and strong earthquake within the interval 6640 ± 90 to 6270 ± 110 BP, i.e., in the 5th millennium BC, in the region of Porak volcano.

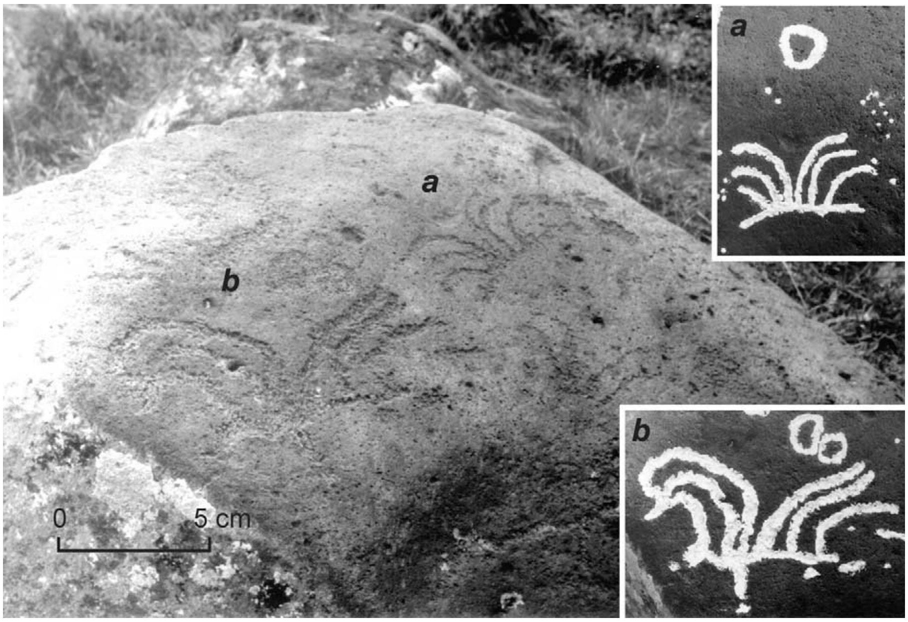

Fig. 10. A group of six petroglyphs dated 5th millennium BC, which may be interpreted as a depiction of a volcanic eruption.

These petroglyphs are the only ancient pictures of volcanic eruptions found in Armenia, Eastern Turkey, the Caucasus and Iran. Pictures of the active Hasan-dag volcano on the frescos of Catal Huyuk (Konya Plateau, Southern Turkey) have a much greater age of 6500 BC (Mellaart, 1967).

4. Vaiyots-Sar and Smbatassar volcanoes

These volcanoes are 17 km apart on the southern slope of the Vardeniss ridge. Vaiyots-Sar Volcano (III in Fig. 1) is at an altitude of 2500 m (lat. 39°48′N; long. 45°30′E), whereas Smbatassar Volcano (IV in Fig. 1) is at an altitude of 2700 m (lat. 39°57′N; long. 45°20′E).

In front of the village of Arin (SE slope of Vaiyots-Sar Volcano), we found evidence of a fissure eruption of the most recent generation in the area. Moving down-slope, a lava flow from that eruption dammed the Arpah river valley near the town of Vyke and flowed westward along the valley for 6 km. The lava flows are almost entirely without a soil layer and overlie an Upper Pleistocene terrace of the Arpah River. This suggests a Holocene age for the lava.

Smbatassar volcano is a cinder cone. The cinder cone is cut through by a fault and has two lava flows in the N and S directions, 11 and 17 km long, respectively. In the Yeheghis river valley, the western lava flow overlies an Upper Pleistocene terrace. The latter, combined with the perfectly intact morphology of the volcano cone and its flows, dates the eruption to the Holocene.

Of interest are legends and unclear indications in later chronicle sources about a possible link between the destruction of the towns of Moz and Yegheghis in 735 AD in the valleys of the Arpah and Yegheghis rivers, respectively, and eruptions of Vaiyots-Sar and Smbatassar volcanoes and a strong earthquake. Although the possibility of strong historical eruptions of the Vaiyots-Sar and Smbatassar volcanoes is still unclear, nevertheless this is quite probable and requires further detailed study.

5. Ararat volcano

This is the largest volcano in the region known from biblical times and is considered a traditional symbol of ancient and modern Armenia (V in Fig.

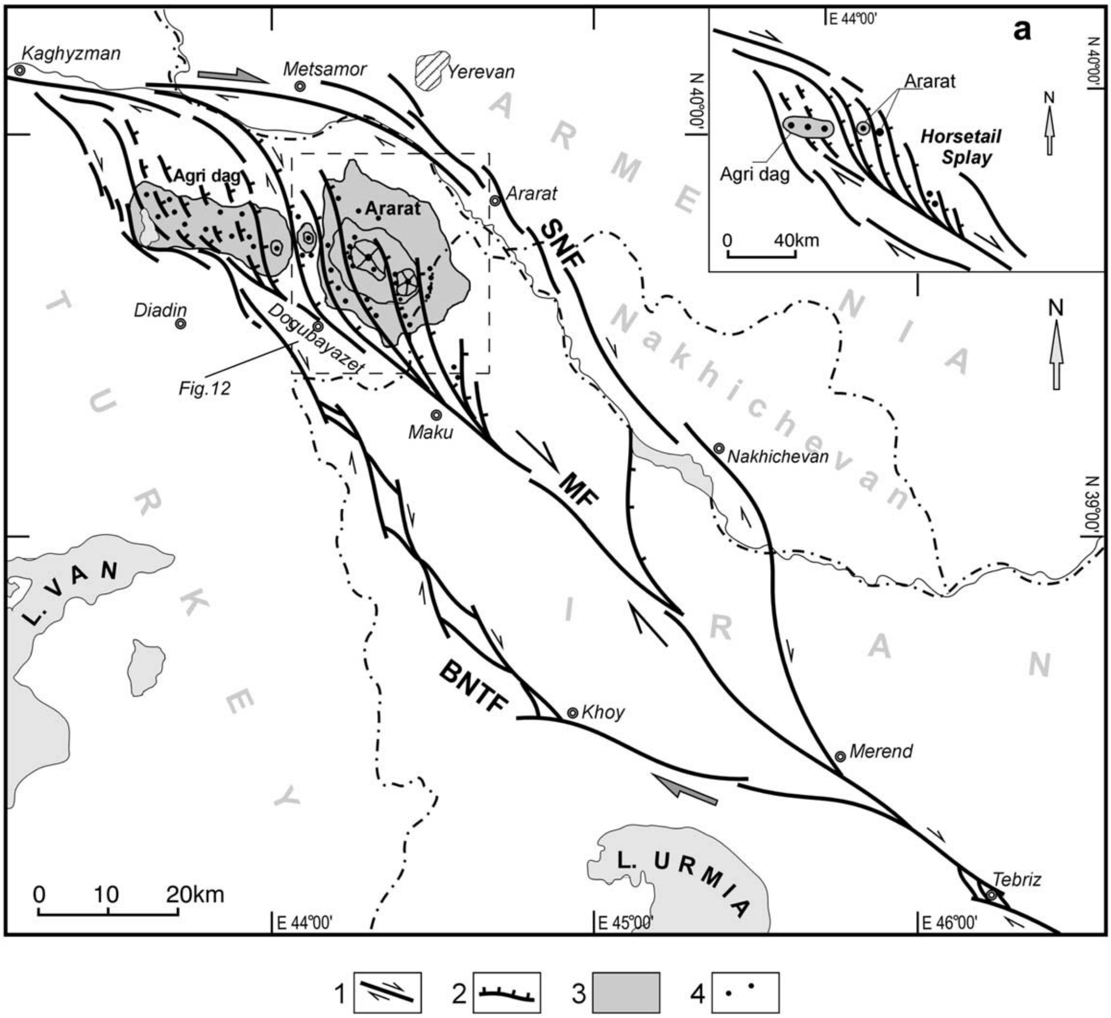

Fig. 11. Ararat pull-apart basin. 1, Strike-slip faults; 2, normal faults; 3, Ararat and Agri-Dag volcanoes; 4, parasitic volcanoes. Active faults: SNF, Sardarapat–Nakhichevan fault; MF, Maku fault; BNTF, Balikghel–North-Tabriz fault. (a) Conceptual geodynamic model.

1). Ararat is in the territory of Turkey, at the junction of the state borders of Armenia, Turkey, and Iran (lat. 39°42′N; long. 44°18′E) and rises more than 4 km above the Ararat valley. The altitude of its top is 5165 m. The volcano forms two conical summits: the Greater Ararat (5165 m) and the Lesser Ararat (3925 m). Westward from the Ararat volcanoes, there is the W–E elongated linear volcanic area of the Agri-Dag ridge.

Ararat is a calc-alkaline, polygenic, compound stratovolcano (Yilmaz et al., 1998). There is still much unclear about the structural position of Ararat volcano. Dewey et al. (1986) mention that Ararat lies in a complex pull-apart graben on a wide zone of dextral transcurrent motion. Parasitic cones on its slope form a NW-trending alignment. In contrast, Yilmaz et al. (1998) consider that Ararat is within a sinistral pull-apart basin. Their opinion is that Ararat volcano was developing along an extension zone formed between two en echelon segments of a sinistral strike-slip fault system. To analyze the structural position of Ararat and Agri-Dag, as well as their recent eruptive activity, we have studied remote

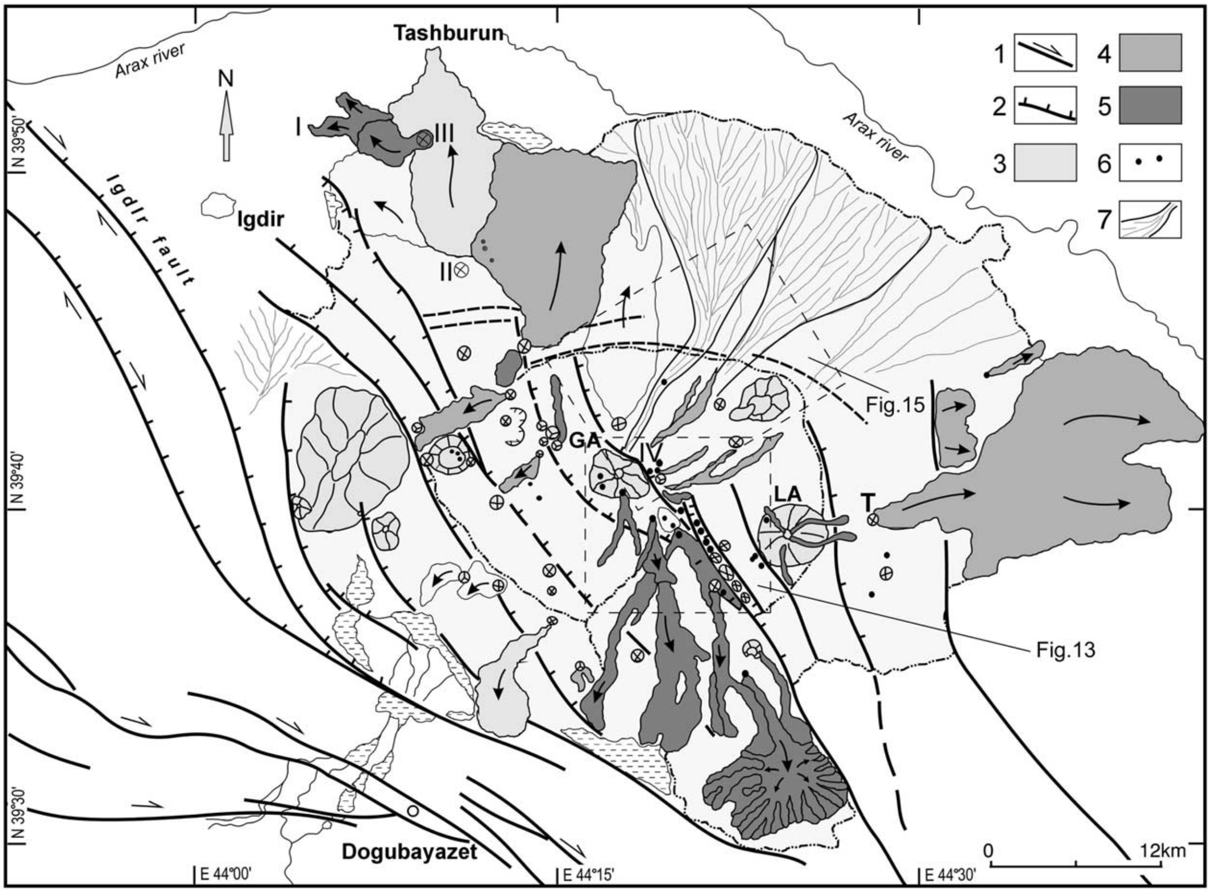

Fig. 12. The Greater and Lesser Ararat volcanoes. 1, Active strike-slip faults; 2, active normal faults; 3, young lava of Generation 1; 4, young lavas of Generation 2; 5, supposed Holocene lavas; 6, parasitic cones; 7, mud layer deposits. GA, the Greater Ararat; LA, the Lesser Ararat; T, Mount Touzhik.

sensing data, historical and archeological sources, and conducted field work. The field work sessions were carried out in Turkey (1993), Iran (1996) and Armenia (1997–1999); the field work sessions in Turkey and Iran were conducted with the participation of S. Bayraktutan (Ataturk University, Erzurum), and H. Hessami and F. Jamali (International Institute of Earthquake Engineering and Seismology).

Ararat and Agri-Dag volcanoes are at the NW flank of a large pull-apart, which is 320 km long, 80 km wide, and elongated N-W (Figs. 1 and 11). The Balikghel–North-Tabriz fault (total length 465 km) forms the SW flank of the pull-apart (Berberian, 1976, 1981, 1997; Ambraseys and Melville, 1982; Karakhanian et al., 1997b, 1998). This fault is a right-lateral strike-slip with reverse vertical component. The horizontal slip rates are 5–7 mm/yr. In the region of Zurabad city, recent creep motion has a vertical slip rate of up to 3 mm/yr (Karakhanian et al., 1998). The fault zone is characterized by high seismic activity and earthquakes of $M = 7.0–7.7$. The Sardarapat–Nakhichevan active fault zone forms the NE flank of the Ararat pull-apart. The active Maku fault passes along the axial part of the Ararat pull-apart (Figs. 1 and 11). Individual segments of the Maku fault were described by Berberian (1976, 1981, 1997).

In the light of this work, the system of N-NW faults branching from the NW flank of Maku fault is most important (Fig. 11). This fault sys-

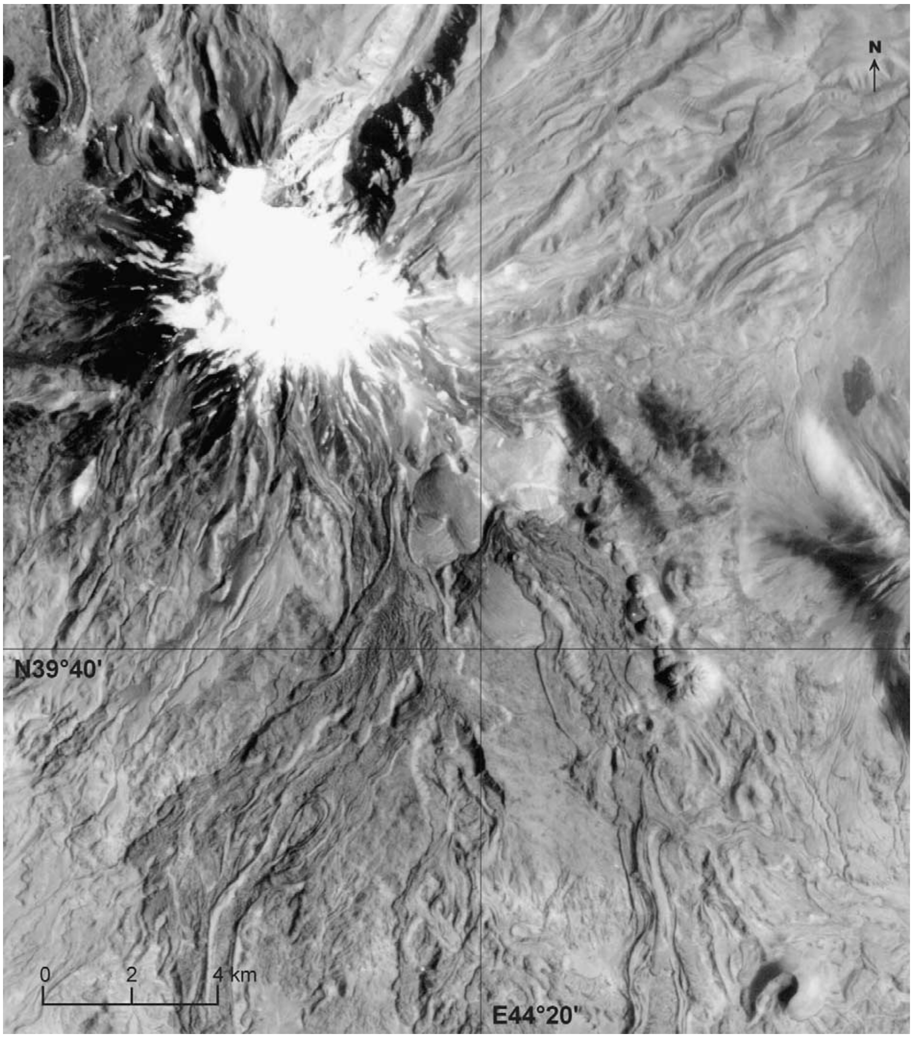

Fig. 13. Satellite image (Russian system) of the southern slope of the Greater Ararat (see Fig. 12).

tem is a *horsetail splay* structure at the flank of the Maku fault. In addition to the right-slip, these faults have a normal component. The largest and most typical of them is the one bordering the Igdir Depression from the west (Figs. 11 and 12). The *horsetail splay* fault system cuts through the Greater and Lesser Ararat volcanoes and Agri-Dag volcanic ridge, and controls the position of the main eruption centers of Ararat and Agri-Dag, as well as the alignment of parasitic cones (Figs. 1, 11 and 12).

The youngest eruptions from the Ararat volcano have an age of more than 10 000 years, and isotopic dating of the youngest lavas gives an age of 20 000 years (Yilmaz et al., 1998).

Analysis of high-resolution satellite images allows identification of three generations of the youngest lava flows on Ararat (Fig. 12). Figs. 1, 12 and 13 show the spreading areas and eruption centers of these lava flows. On Ararat volcano, they have a clear N-NW trend (Fig. 13) and are mainly within the N-NW and S-SE flanks of the volcano. This trend is most distinct for Generation 3 lava (supposedly, of Holocene age). An extensive lava flow from the parasitic cone of Mount Touzhik (1815 m) at the east flank of

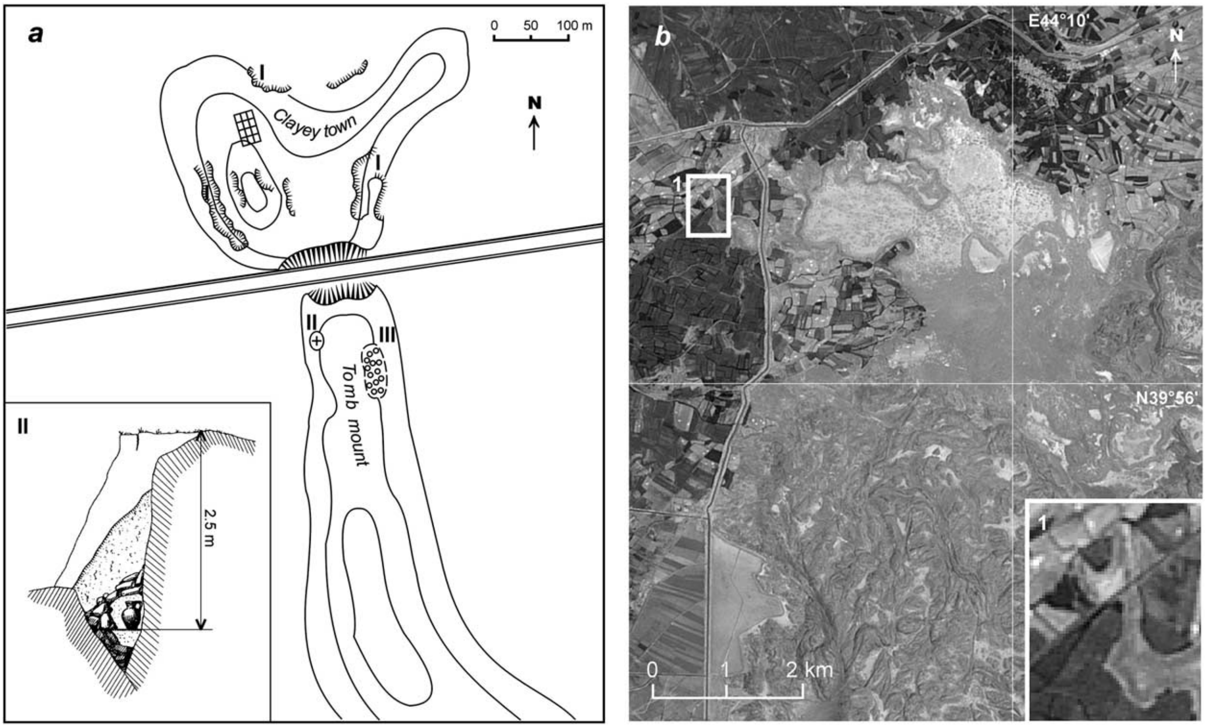

Fig. 14. Scheme of the ancient settlement excavations near the village of Markara carried out by P. Petrov. (a) I, Places where the traces of the Koura–Arax culture were found buried under volcanic tuff; II, III, Urartian age burial places (orientation to the north). (b) Excavation sites in the SPOT satellite image.

the Lesser Ararat is also noteworthy (VI in Fig. 1). This flow, and fissure flows to the north of it, formed vast E-stretching lava fields toward Lake Akgyol (Iran). These may also be very young (Fig. 12). Lava flows in the Makuchai river valley (NW Iran), sometimes referred to as the Arablar valley, also may be of young (possibly Holocene) age. The Holocene age is not only judged from the appearance of these lava flows, but also supported by the fact that the lava overlies Late Pleistocene and Lower Holocene deposits and terraces of the Arax River. The Makuchai lava flow dammed the Arax River to the E-SE of Lake Akgyol, and the dam also looks quite young.

Analysis of archive, chronicle and archeological sources has allowed us to uncover certain evidence on the historical volcanic activity of Ararat. In the work of Kouftin (1944), we found the most accurate and best supported information related to the historical volcanism on Ararat. That was the first publication describing archeological artifacts belonging to the Koura–Arax culture of the early Bronze Age. Later, numerous archeological data proved that the culture spread across the entire Caucasus, Eastern Anatolia and Northern Iran. Recognized as a fundamental classic for the Koura–Arax culture archeology, Kouftin's work (1944) is extremely important to support the fact of a historical eruption from the Ararat volcano.

Kouftin mentions the results of digs performed in 1914 by P.F. Petrov, a Russian mining engineer, at the Igdir site of the Sourmalin province, which was by the foot of Ararat. The location of digs was 8 verst (the Russian verst of the 20th century equals 1.0668 km) away from the town of Igdir (near the village of Malakliu) on the road to the village of Markara, more precisely, at the tenth verst pillar to the south from the latter village (1 in Fig. 12). The site is at the termination of a 2.5-m-high narrow rocky ridge elongated northwards. The ridge is formed by the pyroclastic tuff deposits of Ararat, which cov-

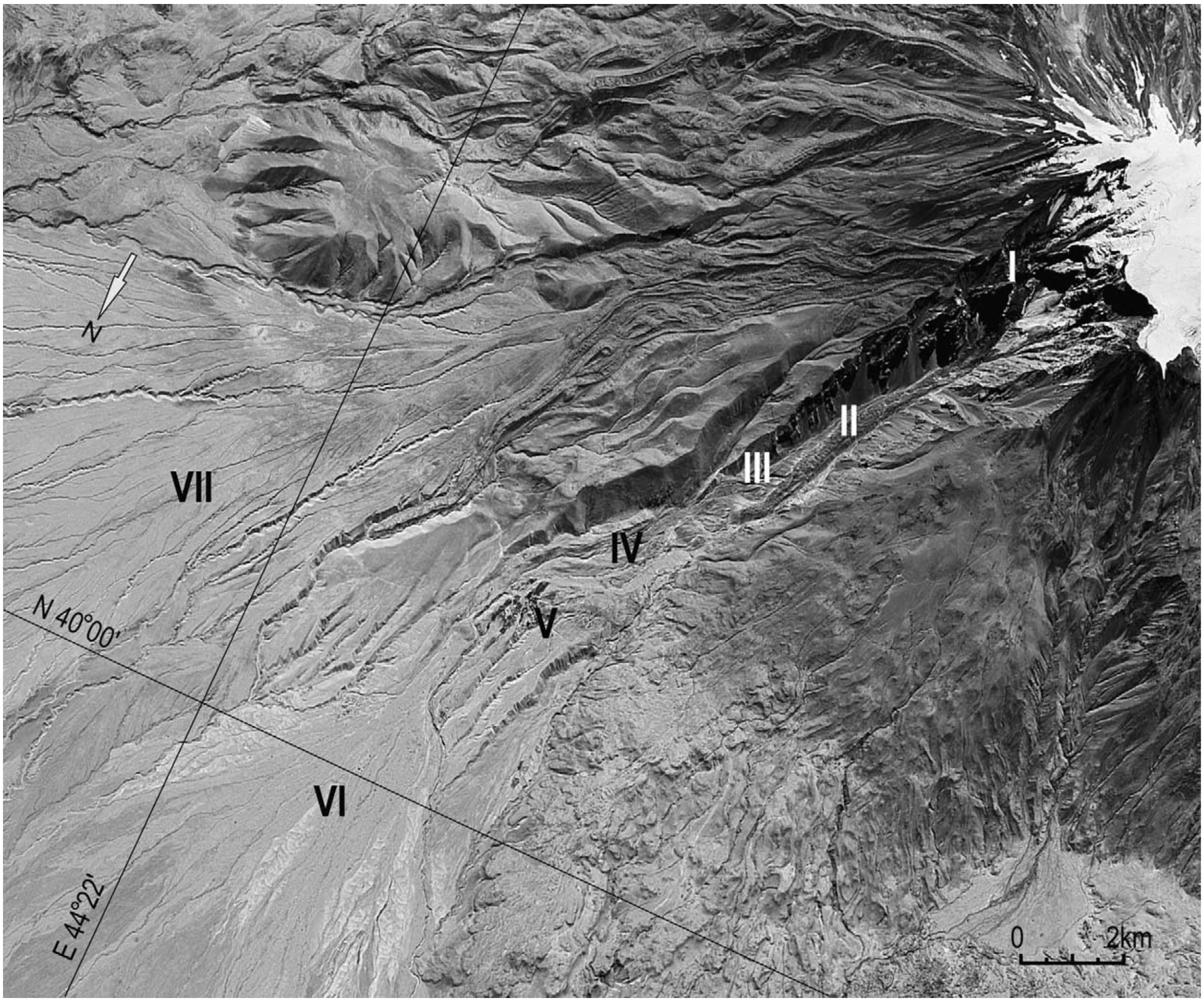

Fig. 15. Corona satellite image of the northern slope of Ararat and the Akory Canyon: 1, supposed center of the July 2, 1840, phreatic explosive eruption; 2, deposits of the first flow-landslide of July 2, 1840; 3, St. Jakob's Monastery; 4, old village of Akory; 5, today's village; 6, deposits of the July 6, 1840, flow-landslide; 7, deposits of the earlier flow-landslides.

er alluvial and lacustrine deposits of the Ararat valley. The road bisects the ridge into two parts: the northern part is an isolated hill Petrov named *Clayey Town*, and the southern one he called *Tomb Mount* (Fig. 14a). On the SPOT satellite image, we identified the location of those digs as indicated by Petrov (Fig. 14b).

One fact Petrov came across in the excavations is extremely important for us. In the northern part isolated by the road (*Clayey Town*), there was a thick stratum of organic cinder and ashes that occurred under the pyroclastic rock layer. The stratum contained the remains of dwellings, broken bricks, carbonized timber, human and animal bones, and numerous household articles – ceramics, obsidian tools, grain grinders, mortars, etc. (I in Fig. 14a). According to Petrov, the cinder stratum was so thick that the local population was using it to fertilize agricultural fields and, as a result, destroying it quite rapidly.

Southward from the road (the area of *Tomb Mount*), Petrov found numerous graves in the pyroclastic tuff deposits. The graves were placed in the flow fractures, closed with blocks taken from

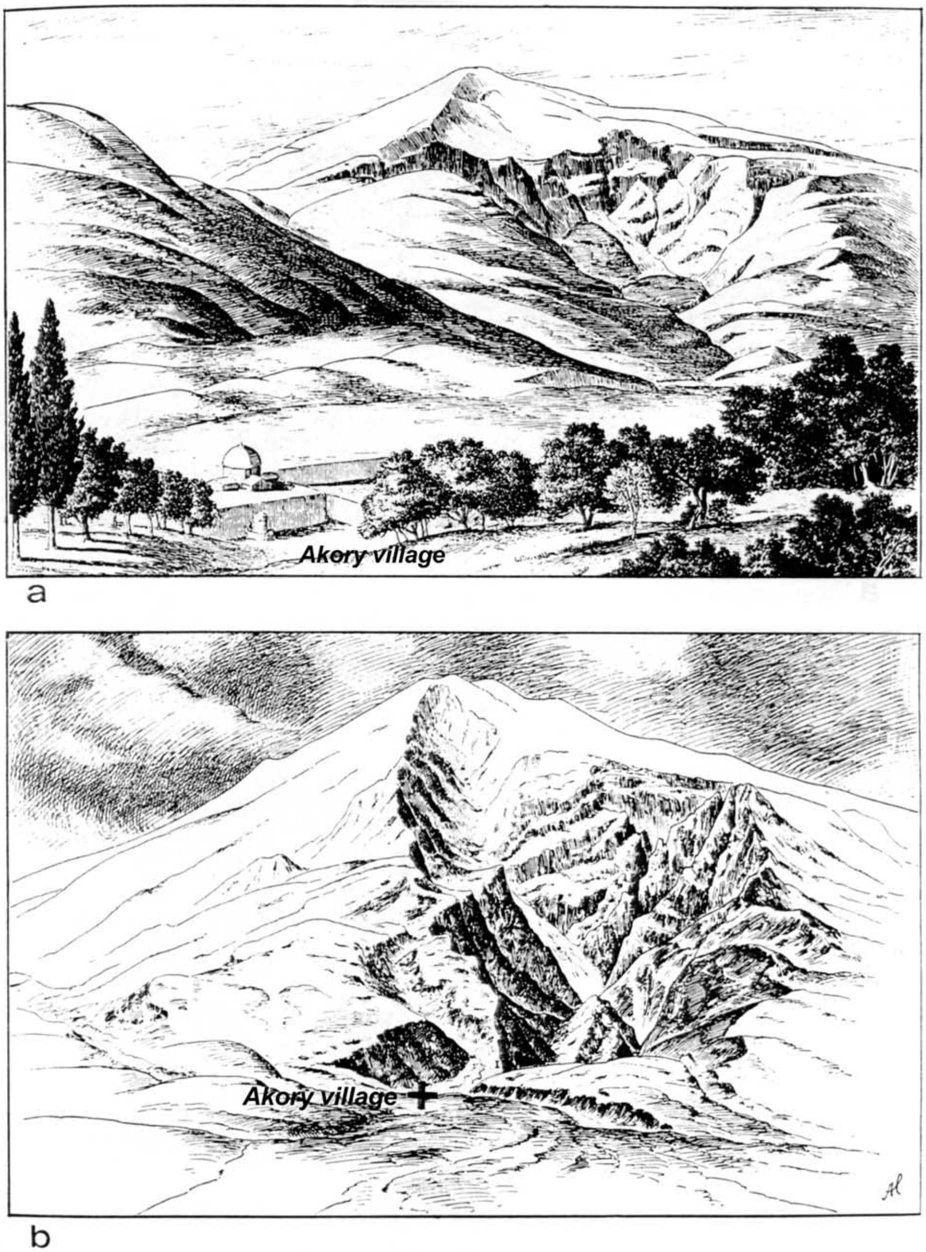

Fig. 16. Drawings of the north slope of Ararat summit and upper parts of the Akory Canyon: (a) before the eruption, flow-landslide and earthquake of July 2, 1840, made by Parrot (1834) in 1829; (b) after the July 2, 1840, eruption made by Abich in 1845 (according to Ebeling, 1899; Eisbacher and Clague, 1984).

the flow, and contained iron weapons, bronze kitchen utensils and glass beads (II and III in Fig. 14a).

Archeologically, the age of the ceramics and other articles from *Clayey Town* is dated back to 2500–2400 BC with confidence, while the age of *Tomb Mount* artefacts is estimated at 700–500 BC. Therefore, one indisputable archeological fact is that the pyroclastic flow, containing graves of the Urartian epoch, overlies the Koura–Arax culture settlement. This constrains the eruption of the pyroclastic tuff from the Ararat volcano between 2500–2400 BC (the lower date) and 700–500 BC (the upper date). The large numbers of household utensils, remains of carbonized timber, and human and animal bones attest that the volcanic eruption fell within the period of populated Koura–Arax settlement and ended with a catastrophe for the latter. Thus, the volcanic catastrophe may date back to 2500–2400 BC.

The most probable sources of the pyroclastic tuff covering the Koura–Arax settlement include eruptive centers on the northern slope of the Greater Ararat, or those between the summits of Kariyarikh (1475 m) and Shouper (1222 m), or the ones 4 km to the south of the village of Tashbouroun (II and III in Fig. 12).

Petrov was not alone in providing information about volcanic activity on Ararat. There are some obscure indications of possible volcanic activity on Ararat in the first half of the 2nd century AD and late 3rd–early 4th century AD by Armenian chroniclers and historians (Movses Khorenatsi, 1990; Aghatanghehos, 1983; Alishan, 1890). Tiedeman (1991) provides data on the historical eruption SE from the Lesser Ararat in 1450 (possibly, in the Makuchai–Arablar river valley, NW Iran). The German traveler Rainex left hazy recollections of himself and fellow travelers observing bright luminescence and red light on the eastern slope of the Greater Ararat (Wagner, 1848).

The latest significant volcanic activity on Ararat is most probably related to 1840. The disastrous $M = 7.4$ Ararat earthquake occurred on July 2, 1840 (Ambraseys and Melville, 1982). Many villages in the area around Ararat volcano and the towns of Dogubayazet, Maku, and Ordoubad were completely destroyed. Up to 10 000 people were killed. The earthquake was accompanied by the formation of a 72-km-long seismogenic surface rupture and the failure of a landslide from the Ararat summit (Stepanian, 1964; Ambraseys and Melville, 1982).

After the 1840 earthquake, a fierce polemic started between the researchers who surveyed the earthquake effects in 1840–1845. Voskoboinikov (1840), Chief Engineer of the Russian Army, and Abich (1846, 1862), a German geologist, considered that the 1840 earthquake was exclusively tectonic, while the Ararat landslide was one of its consequences. The German geologist Wagner (1848) considered both events to be consequent to a volcanic eruption from Ararat.

Information in the works of Parrot (1834), Voskoboinikov (1840), Abich (1846, 1847, 1862), Wagner (1848), Shahatouniants (1842), Alishan (1890), Leclercq (1982), Markov (1983), Ebeling (1899), Kovalewsky and Markov (1903), Lynch (1910) and Ambraseys and Melville (1982), and, especially, in the clerical archives of the Ararat Diocese allowed us to find eyewitness accounts about the earthquake and landslide from the Ararat summit in 1840. Many of the eyewitnesses mentioned the following:

(1) Immediately after the main shock of the earthquake, a huge cloud resembling a smoke column rose over the canyon at the northern Ararat slope, where Akory Village and St. Jakob's monastery were situated.

(2) From the inside, the cloud was illuminated with bright-red and blue light, while a strong acrid smell of sulfur spread around. Large stones weighing 3–5 centner were thrown up and forward out of the fissure upslope from the monastery and the village, and fell down at a distance of 3–4 km. This was accompanied by acute sounds in the canyon that resembled cannon gunnery.

(3) The cloud rose up to the Ararat summit, and another cloud of red-lucent dark dust rolled down at a great speed from beneath it.

(4) In a moment, a dark fiery whirlwind of cloud attacked the village of Akory, destroyed it and killed 1900 of the villagers, burned trees in the village gardens, and pulled them out with their roots. After that, the landslide came down to the village and the monastery.

(5) The landslide of blue liquid mud mixed with large stone blocks was moving at a great speed and had an acute smell. An airwave of huge speed and destructive force was moving ahead of the flow front. The landslide flow passed a distance of 7 km and stopped at an elevation of 900 m above the Ararat valley level, forming a dam at

the exit from the Akory canyon. Large masses of semi-melted ice, mud, stones and water accumulated behind the dam.

(6) The cloud, which rose to the Ararat summit, covered the sky and poured down with rain although the weather was clear.

(7) Soil and fields in the area touched by that pouring rain were covered with a thick layer of liquid mud dirt, blue in color and smelling harshly. Rainwater in pools was bright blue, resembling the color of vitriol.

(8) Deep fractures formed in the Akory canyon after the earthquake: they were releasing turbid (vitriol) water of harsh sulfuric smell.

(9) Monks of the Echmiatsin monastery 55 km from Ararat also noticed a harsh smell of sulfur.

(10) On July 6, 1840, at 7 a.m., a strong aftershock broke the landslide dam at the exit from Akory Canyon, and flows of melted ice, mud and stones swooped down again. Having passed 21 km at a great speed and reached the Arax river valley, they spread with a 12-km-wide front and solidified shortly after that. The solidified deposits contained stone blocks and a thick layer of blue clay with pools of water of intense blue color. The flow-landslide destroyed the town of Aralik, several villages, and a Russian military barracks, and dammed the Sevjour River.

(11) Digging at the location of Akory Village in 1840, Voskoboinikov found a thick layer of blue clay and stones covering the ruins of the village. The digs showed that the lower thirds of the walls had been preserved in all the houses, while timber roof slabs had been pressed into the floor by falling stones. According to Voskoboinikov, this proves that the village was ruined not by the rolling stones of the landslide, but rather by blocks falling vertically from above.

(12) Describing the 1840 flow-landslide, Voskoboinikov (1840) in 1840, Abich (1846) in 1845 and Lynch (1910) in 1874 each provided drawings and photos of the flow deposits. According to their descriptions, the flow-landslide consisted of poorly cemented conglomerate with fragments of red–orange weathered volcanic rock, blue clay, mud and ice fragments.

(13) In 1845 Abich (1846) identified a lengthy NW-striking fissure at the Greater Ararat summit, from which a smell of volcanic gases was felt strongly. Since preceding investigations of the Ararat summit by Parrot (1834) in 1829 and Spassky-Antonov (1835) contained no mention of that fissure, Abich considered it was an 1840 earthquake effect.

The analysis of the above accounts suggests that the 1840 ($M = 7.4$) earthquake was accompanied by an explosive Bandai-type phreatic eruption from the northern slope close to the Ararat summit (IV in Fig. 12). The eruption produced ejection of ballistic projectiles (reports 2 and 11), an eruptive cloud rising to the Ararat summit (reports 1, 2, 3, 6, 7 and 9) and pyroclastic flow swept down on the Akory village (reports 3, 4, 8, 11, 12 and 13). Rittman (1964) also mentions an explosive gas eruption on Ararat in 1840 and the close similarity of that eruption to the Bandai Volcano eruption in 1888.

The 1840 eruption was accompanied by secondary volcanic effects. Eyewitnesses reported rain in the evening of July 2, a layer of blue liquid mud of harsh smell, and vitriol-blue water pools left after the eruptive rain (reports 6 and 7). Apparently, the debris flows (lahars) from the near-summit part of Ararat were another secondary phenomenon accompanying the 1840 eruption (Fig. 15). By our estimates, the volume of the 1840 Ararat debris flow was 3×10^8 m^3, and the speed was about 175 m/s. Reported descriptions of the debris flow (reports 5, 10 and 12) suggest that the synchronous impacts of the explosive eruption and the earthquake destabilized and destroyed the upper slopes of Ararat (Fig. 16). The detached part of the slope swept through the Akory canyon breaking into pieces and gathering speed. Satellite images of the north slope of Ararat show clear traces of the 1840 flow and earlier debris flows (Fig. 15). Deposits of the 1840 debris flow on the Ararat volcano maps (Yilmaz et al., 1998) are mistakenly shown as moraines.

Analysis of satellite images points to the potential of recent thermal activity on Ararat. Anomalies noticed in Landsat-TM and Landsat-7ETM+ images for the period of 1984–2000 in various ranges (RGB 5/4, 7/4/2, 6/9) are apparently related to the outcrop of thermal springs on the E and E-SE slope of the Lesser Ararat. Beginning from 1989 and up to the present, Landsat images have been showing a considerable increase in the area occupied by the thermal anomaly. The considerable increase in fumarole activity noticed on Damavand Volcano in Iran since 1989 is also of interest (Berberian, 1994).

6. Discussion and conclusion

Data from archeology, legends, ancient written sources and Armenian chronicles since the 4th century AD contain reports about many natural phenomena in Armenia, Turkey and Northern Iran. These data form a reliable source allowing assessment of not only the seismic risk in this region (Ambraseys and Melville, 1982; Ambraseys, 1975; Berberian, 1997), but also the volcanic risk.

Many works refer to the Nemrout volcano eruption in 1441 (Oswalt, 1912; Tchalenko, 1977; Yilmaz et al., 1998). To provide an example of precise and realistic chronicle description reflecting many details of volcanic eruptions, below we cite the complete text of an Armenian chronicle evidencing this eruption by witnesses' words (see Appendix 1, text 1).

Berberian (1994) refers to the records of the most ancient pre-Christian epos about Vahagn made by Movses Khorenatsi in 466 AD as a quite convincing example of poetically narrated information about a volcanic eruption in Armenia. Historical volcanic eruptions are reflected in the legends and poems of ancient Iran – *Shahnameh* by Ferdausi-Tusi and *Garshab-nameh* by Asadi Tusi (Berberian, 1994).

Historical volcanic activity is attested by the toponymy of many recent volcanoes in Armenia and Eastern Turkey. In Armenian, for instance, **Tskhouk** (Sissian ridge volcano) means 'smoking', **Karckar** (Sissian ridge volcano) means 'thundering', **Porak** (Vardeniss ridge volcano) is 'belly', **Vaiyots-Sar** (Vardeniss ridge volcano) means 'mountain of trouble cries', **Tondourek** (volcano northwards from Lake Van) means 'underground oven to bake bread', **Touzhik** (east slope of Ararat) means 'punishment, penalty', and **Nemrout** (Lake Van, Turkey) means 'gloomy, angry'.

Within the scope of this work, it is not possible to present all the data on the Holocene-historical volcanism in Armenia. Besides, our studies have been started just recently and are still continuing. Holocene-historical volcanic and tectonic activity could take place elsewhere across the Ararat valley (the Sardarapat swell, Davtiblour Volcano, possible phreatic craters near Echmiatsin and in the mid-course of the Arax River), as well as on Aragats Volcano, in the north of Ghegam and the center of the Siunik ridges, and in other areas.

Appendix 1 presents additional evidence from Armenian chronicle sources on the Holocene-historical volcanism in Armenia, Turkey, NW Iran and Greece, not touched upon in detail by this work. The principal data we have on historical and prehistorical volcanism are provided in the Table of Appendix 2. Information in Appendices 1 and 2 attests to a considerable number of volcanic eruption events and other volcanic activity in the territory of Armenia, Turkey and NW Iran in prehistorical and historical times. Traces of volcanic eruptions of the Holocene-historical age are also found in Eastern Turkey (Hassan-Dagh Volcano), Iran (Damavand, Taftan, Sahand, Sabalan, etc.), Syria (volcanoes of the Drouz Massif in Khirber El-Umbachi and Hebariye, the region of Vadi Ar-Rampliet and Cra) and Northern Caucasus (the volcanic area of Kazbek) (Mellaart, 1967; Berberian, 1994; Dubertret and Dunand, 1954–1955; Trifonov and El-Khair, 1988; Chernishev et al., 1999).

Actually, the sudden increase of fumarole activity of Damavand volcano in 1989 (N Iran) and lava eruptions from Taftan Volcano (S Iran) on April 25, 1993, point to recent volcanic hazard in the region. These events caused considerable social-economic problems and civil unrest in Iran (Berberian, 1994).

The majority of active volcanic centers in the region are controlled by active faults. In many cases, historical volcanic activity coincided with strong earthquakes in time and place. In this work, we do not intend to study possible causative links between the processes of volcanic and seismic activity. There is, however, a series of publications addressing the possibility of such a causal relationship (Doumas, 1990; Hill et al., 1993; Guidoboni et al., 1994; Karakhanian et al., 1997a,b, 1999). This fascinating issue of risk assessment for a summation of various natural hazards calls for targeted research.

Armenia and the bordering countries are within zones prone to diverse natural hazards and as such face a high rate of natural risk. The data presented show that volcanic hazard is among the natural risk factors for these countries. This is particularly true for the Ararat valley, which is the area of the junction between the borders of Armenia, Turkey, Iran and Nakhichevan, having a large population, numerous cities, and crucial agriculture, energy and industrial facilities.

Acknowledgements

This research was supported by the funding of Grants INTAS-0840, NATO EST.CLG.977044 and PICS-417. The authors are grateful to Christine Chataigner (Maison de l'Orient Méditerranéen, Lyon, France), Dr. Charles Connor (Southwest Research Institute, USA), L.D. Soulerzhitsky (Institute of Geology, Russian Academy of Sciences) and Dr. J.L. Michelot (Laboratory of Hydrogeology and Geochemistry, Paris Sud University) for radiocarbon dating of samples, and to Dr. Samira Rebai (Montpellier-II University, France), Dr. M. Ghafory-Ashtiani, Dr. H. Hessami, Dr. M. Abbasi and Dr. F. Jamali (International Institute of Earthquake Engineering and Seismology, Tehran, Iran), Dr. S. Bairaktutan (Erzerum Ataturk University Earthquake Research Center, Erzerum, Turkey), and Dr. Ruben Badalyan and Dr. Pavel Avetissyan from the Institute of Archaeology and Ethnography of the National Academy of Sciences, Yerevan, Armenia, for their inestimable help and support rendered in the course of this work. The authors are grateful to Yelena Abgarian and Vahan Davtian for their contribution to the preparation of this publication.

Appendix 1

(1) "In the year of 1441, Nemrout Mount between the towns of Khlat and Baghesh thundered suddenly as a terrific thunder-storm; the entire country shuddered since they saw how a wide crack split the mountain and misty smoke and fetid flame were coming out of the crack. Children fell sick of that smell, and stones boiled of the burning flame, huge stones five kangoun in weight were thrown into sky; the fire was seen from the two-day travel distance. The town of Khlat was trembling from that thunder. The mountain split and opened a huge abyss, and stones on the summit boiled and melted, and glued each other, and so this continued for years."

1441 AD
Memory Notes of Armenian Chronicles of the 15th century, 1401–1450 AD (1995), pp. 518, 546, and 581
Nemrout Volcano, NE Turkey

Besides, we would like to present new data from Armenian chronicles, which contain direct evidence about other volcanic phenomena, or may be interpreted as such.

(2) "First, Armenian mountains moved away from one another, then approached again with terrible thunder, and fire and smoke were expelled at that, after they returned to their original state."

341 AD
Saint Yeprem from Edessa (1982)
The place being described is unknown

(3) "And a terrific roar was heard in the heaven and mighty flame with stormy wind fell down from above to the towers; dissected from top to bottom, turned down, crumbled, overthrew and scattered ash and earth across the fields."

Late 3rd century AD
Aghatangelos (1983), pp. 323, 455
Town of Echmiatsin, SW Armenia; most probably, Ararat Volcano

(4) "The fires on mountains have died out long time ago, but at the dawn of our history they were still smoking as said in pagan legends that reached us, children of Christ."

Beginning of 4th century AD
Alishan (1890), p. 130a
Most probably, Ararat Volcano

(5) "On August 22, 502 (September 499), Friday in the night, a large fire appeared that blazed in the northern part of the sky all night long and we thought that the fire flow of that night would exterminate the whole land, but remained unharmed. Next morning, mist enveloped everything around, and the ground was covered with ash and sulfur. The same night that we saw the blazing fire, towns of Polomes and Akka were destroyed and nothing remained whole there. The same day, towns of Tyre, Sidon, Nicopolis, Edessa, Nicomedia and Garab were destroyed."

September 499–August 502 AD
Anonymous from Edessa (1982), pp. 170–173, 182
Towns: Saida (Sidon), Sur (Tyre), Haifa (Akka) – N Syria; Urfa (Edessa), Hislyakhie (Nicopolis) and others – SE Turkey

(6) "Divine ire came down to Antioch, all towns swayed and collapsed. The earth was burning with fire; water and flame were rising from the abysses. Pernicious smell was coming from there and people died of various diseases. And a large church build by Constantine was trembling for 6 days and a flame came out from fissures in the ground and burned the church and everything around Antioch was ruined. People were dying in mass. Water deserted from Jerusalem and Sidom for 15 days. The fire from heaven burned Balbak."

520–521 AD
Mkhitar Airivanetsi (1860), pp. 41, 48
Antioch (Antakya, S. Turkey)

(7) "In the summer of 715, from March to April, dust and earth were falling in the air and day seemed to be night. Three cloudy columns were seen in the north part of the sky three days long. They were rising up and falling down. The dust falling in the sky for two months settled on the ground with a span-thick layer and there was a strong earthquake. Mynbech, Nicaea, Constantinople and many towns in Boutania (Vifinia) were destroyed."

715 AD
Samuel Anetsi (1893), p. 86
Mkhitar Airivanetsi (1860), p. 52
Old province of Boutania (Vifinia) included town areas of Nicomedia (Izmit) and Nicaea (Iznik), NW Turkey

(8) "In 718, in summer, for several days vapors were rising from the sea depth between the islands of Thera and Theracia. Burned out, they gradually thickened, descended and petrified; the smoke entirely took the form of fire. The earth material had been arriving with such a dense flow that erupted hill-size pumice blocks were scattered across the entire Asia Minor, Lesbos, Abudos, and Coastal Macedonia, and fragments of floating pumice covered the whole surface of that sea. An island that had not existed before formed at the place of the volcano and joined the island of Ghiera."

718–726 AD
Anonymous from Edessa (1982), p. 114
Island of Thera (Thera–Santorini Volcano), Aegean Sea, Greece

(9) "In the summer of 1050 there was a strong earthquake and the whole town of Antiocheans shuddered. Next day, fire came down to the ground, burned St. Peter's Church in Antioch, destroyed the altar conch and pressed the altar into the ground. The flame again descended on the St. Peter's church and burned its stones and timber as did in 40 other churches of Antioch."

1050 AD
Samuel Anetsi (1893), pp. 110–111
March 8, 1053 AD
Matevos Uorkhayetsi (1898), p. 76
Antioch (Antakya, S Turkey)

(10) "In the year of 1111, in Armenia, province of Vaspourakan (Van), in winter, the heavens opened in the night and fire poured down to Lake Van. The waves rushed over the shore with horrible noise. Both the waters, and the land shuddered with terrible thunder. Lake waters colored red. The flame tore the stronghold of abysses. In the morning, people saw that multitude of fish had been killed. The fetid smell filled everything around. Very deep fissures cut through the Earth in many places."

Winter, 111 AD
Matevos Uorkhayetsi (1898), p. 211
Smbat Sparapet (1859), p. 72
Lake Van, NE Turkey

By the data of R. Haroutiunian (Karakhanian et al., 1997b), volcanic activity was observed in the Lake Van region on October 27, 1650 AD, too. However, it would be more correct to attribute the latter event to 1692.

(11) "In the town of Baghesh (Lake Van), on April 13, summer 1692, sunlight dimmed ever since the morning and colored plumbeous; darkness shrouded the earth so that people could not see each other. Till the very evening, red dust had fallen to the ground and there was an earthquake, many settlements were ruined and many people died."

April 13, 1692 AD
Michael Bolnetsi, in Small Chronicles of the 13th–18th centuries (1956), pp. 416 and 418
Nemrout Volcano, NE Turkey

(12) "In summer 1632, ash was falling on Thessaloniki for three days and three nights."

1632 AD
Arakel Davrizhetsi (1973), p. 439
Thessaloniki, Greece

(13) "After the seizure of Bayazet in 1855, Russian troops encamped Tapariz Village by the north foot of Mount Tondrik southward of the Turkish positions. In the night they heard rolls of thunder resembling gunnery. Each of the sides, suspecting another, took the arms. It appeared, however, that the sounds were coming from the interior of Mount Tondrik, which was smoking with sulfur and fire. Flows of ashy liquid were noticed in the vicinity of Tapariz Village and a little way of it."

1855 AD
Alishan (1890), pp. 292b–293a
Tondourek Volcano, village of Tapariz 12.5 km S-SE of the town of Dogubayazet, E Turkey

(14) "On May 18, 1881, there was a strong earthquake in Van; everything was destroyed in Terzour Village. A day before the earthquake, one of the villagers heard terrible underground boom on Mount Nemrout. The village of Terzour is built on a lava flown from the Nemrout crater 400 years ago."

May 18, 1881 AD
Stepanian (1964), p. 183
Nemrout Volcano, NE Turkey

Appendix 2

Historical volcanic eruptions in the territory of Armenia and adjacent regions from data in Armenian historical sources and field research

No.	Date	Location	Lat. °N	Long. °E	Volcanic activity character	Earthquakes[a]	A_C^b
1	5th millennium BC, between 6640 ± 90 and 6270 ± 110 BP	Porak Volcano, NE Armenia, Sunik Ridge	40°01′	45°47′	Eruption of basaltic andesite lava	$M \geq 7.3$ (2)	B a, r
2	Early in the 3rd millennium BC	Tskhouk–Karckar Volcanoes, NE Armenia, Sunik Ridge	35°44′	46°01′	Eruption of basaltic andesite lava	$M > 7.1$ (1)	A a, r
3	2500–2400 BC	N-NE slope of Ararat Volcano, NE Turkey	39°42′	44°18′	Eruption of pyroclastic tuff	–	A a
4	782–773BC	Porak Volcano, NE Armenia, Sunik Ridge	40°01′	45°47′	Eruption of basaltic andesite lava	$M \geq 7.3$ (2)	B a, i, r
5	Late 3rd–early 4th century AD	Ararat Volcano, NE Turkey	39°42′	44°18′	Eruption type is unclear	–	C i
6	Sept. 22, 499–Aug. 22, 502 AD	N Syria–SE Turkey, possibly, Diret-et-Touloul Volcanoes	33°42′	37°00′	Eruption type is unclear	$M \geq 7.4$ (3)	C i
7	520–521 AD	Antioch (Antakya), S Turkey	36°10′	36°15′	Eruption type is unclear	$M = 7.4$ (3)	C i
8	715 AD	Boutania (Vifinia), towns of Izmit and Iznik, NW Turkey	40°24′	29°42′	Eruption type is unclear	$M = 6.8$ (4)	B i
9	735 AD	Vayots-Sar Volcano, S Armenia Smbatassar, S Armenia	39°48′ 39°57	45°30′ 45°20′	Eruption of basaltic andesite lava	$M \geq 7.0$ (3)	C i
10	1050–1053 AD	Antioch (Antakya), S. Turkey	36°10′	36°15′	Eruption type is unclear	$M = 6.2$ (5)	C i
11	Winter, 1111 AD, night	Lake Van, Turkey	38°40′	43°00′	Submarine eruption? Gas eruption?	–	A i
12	1441 AD	Nemrout Volcano, Lake Van, E Turkey	38°37′	42°13′	Lava eruption	–	A i
13	1450 AD	SE slope of the Lesser Ararat Volcano, Maku-chai River valley (Arablar valley), NW Iran	39°15′	44°40′	Eruption type is unclear	–	C i
14	Morning, April 13, 1692 AD	Nemrout Volcano, Lake Van, E Turkey	38°37′	42°13′	Eruption of gas and ash	$M \geq 6.0$ (3)	A i
15	16.00 h, Julu 2, 1840 AD	Greater Ararat Volcano, NE Turkey	39°42′	44°18′	Bandai-type eruption, landslide flow, eruptive cloud	$M = 7.4$ (6)	A i
16	1855 AD	Tondourek Volcano, Tapariz Village, 12.5 km S-SE from the town of Dogubayazet, NE Turkey	39°25′	43°53′	Eruption of gas and ash	–	A i
17	May 18, 1881 AD	Nemrout Volcano, Lake Van, E Turkey	38°37′	42°13′	Weak activity	$M = 6.7$ (3)	A i

[a] Earthquake magnitudes are given by: (1) Karakhanian et al. (1997a,b, 1999), (2) Philip et al. (2001), (3) Shebalin et al. (1997), (4) Soysal et al. (1997), (5) Papazachos and Papazachou (1997) and (6) Ambraseys and Melville (1982).

[b] A_C, accuracy code; A, estimated with great confidence; B, estimated with confidence; C, estimated with little confidence; a, archeological data; r, radiocarbon dating results; i, historical data.

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