LANDSLIDES IN ARMENIA[1]

*VLADIMIR BOYNAGRYAN**

Key words: Armenia, landslides, Ahardzin.

Erdrutschungen in Armenien. Die Folgenden wurden untersucht: Ausbreitung der Rutschungen in Armenien, ihre Formungsbedingungen und -ursachen, Vielfalt der Rutschungen, ihre Verschiebungsintensität, natürliche und anthropogene Auslöser der Rutschungen u.s.w. Der Höchstvorfall von Rutschungen kommt in einer Höhe von 2000–1500 m und tiefer vor. Die an die aktiven Bruchzonen angrenzenden, von Erdbeben verursachten Rutschungen sind in Armenien vorherrschend.

INTRODUCTION

Armenia is a typically mountainous country with wide spreading steep and not often convex slopes on which varied processes develop strongly, mainly landslides. According to our data, there are more than 3,500 landslide sites in Armenia. This is confirmed by our detailed field investigations with mapping of landslide displays on a scale of 1:25,000, as well as their interpretation by aerial photographs on the same scale.

Landslides in Armenia have been studied since 1926, but their systematic instrumental and reliable observations were organized at the Institute of Geological Sciences of the National Academy of Sciences of the Republic of Armenia in the 1970s. A.T. Aslanyan, G.I. Ter-Stepanyan and R.B. Yadoyan headed the researches. Since 1965, specialists of the Geological Administration have started studying this problem. The cadastre of landslides was created by the effort of these specialists. G.D. Sahakyan made a significant contribution to compiling it.

Separate problems of the formation and spreading of landslides in Armenia are interpreted in the works of A.A. Avagyan (2000, 2002), A.T. Aslanyan (1979), V.R. Boynagryan (1988, 1990), A.S. Kharakhanyan (1981), A.G. Sahakyan (1989), V.E. Stepanyan (2007), R.B. Yadoyan (1987), etc. The detailed description of landslides (their formation, spreading, varieties, etc.) is given only in V.R. Boynagryan's monograph (2007, pp. 172–203), as well as in his magazine articles (2000, 2001, 2005).

GEOGRAPHICAL SPREADING OF LANDSLIDES

Landslides in Armenia occur almost everywhere, but mainly in the north and south regions, where folded block-mountains exist (Fig. 1).

The entire territory of Armenia is subdivided in four engineering-geological regions in terms of geological structure, lithology, seismic activity, etc. Every region shows different susceptibility to landsliding and types of display (Fig. 2).

* Professor, Yerevan State University, Geomorphology and Cartography Department, A. Manoogian 1, Yerevan 0025, Armenia.

[1] Paper presented at the IAG Regional Conference on Geomorphology *Landslides, Floods and Global Environmental Change in Mountain Regions*, Braşov, September 15-26, 2008.

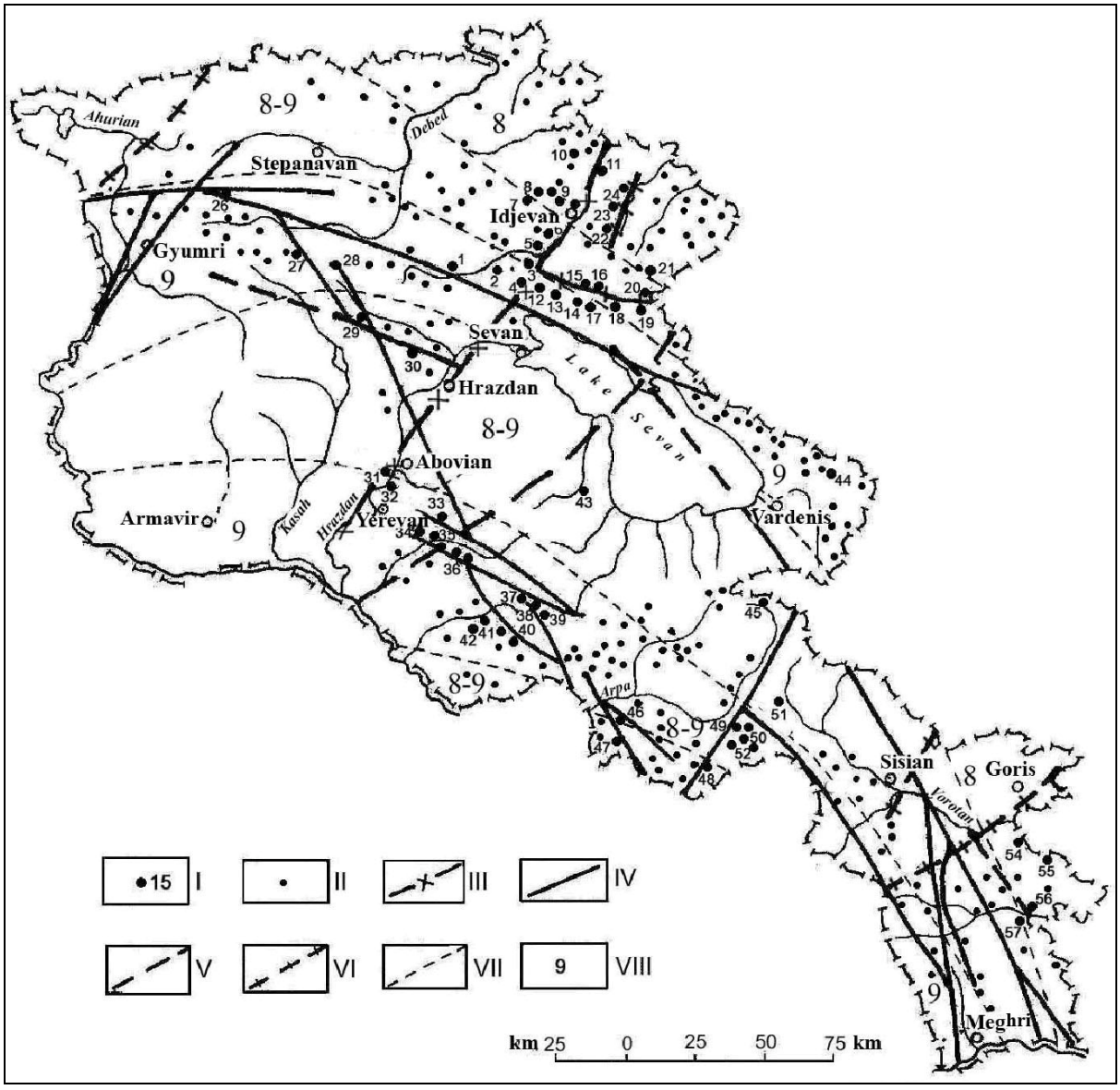


Fig. 1 – Map of large landslide spreading in Armenia: *I* – tectonic-seismogravitational landslide–blocks and floodslidings and their numbers; *II* – large landslides of nonseismogenic genesis; *III* – trans-Orogene Aghstev-Hrazdan fault; *IV* – authentic active faults; *V* – supposed active faults; *VI* – supposed active faults, revealed by the author; *VII* – borders of seismic regions; *VIII* – degree of the expected earthquakes.

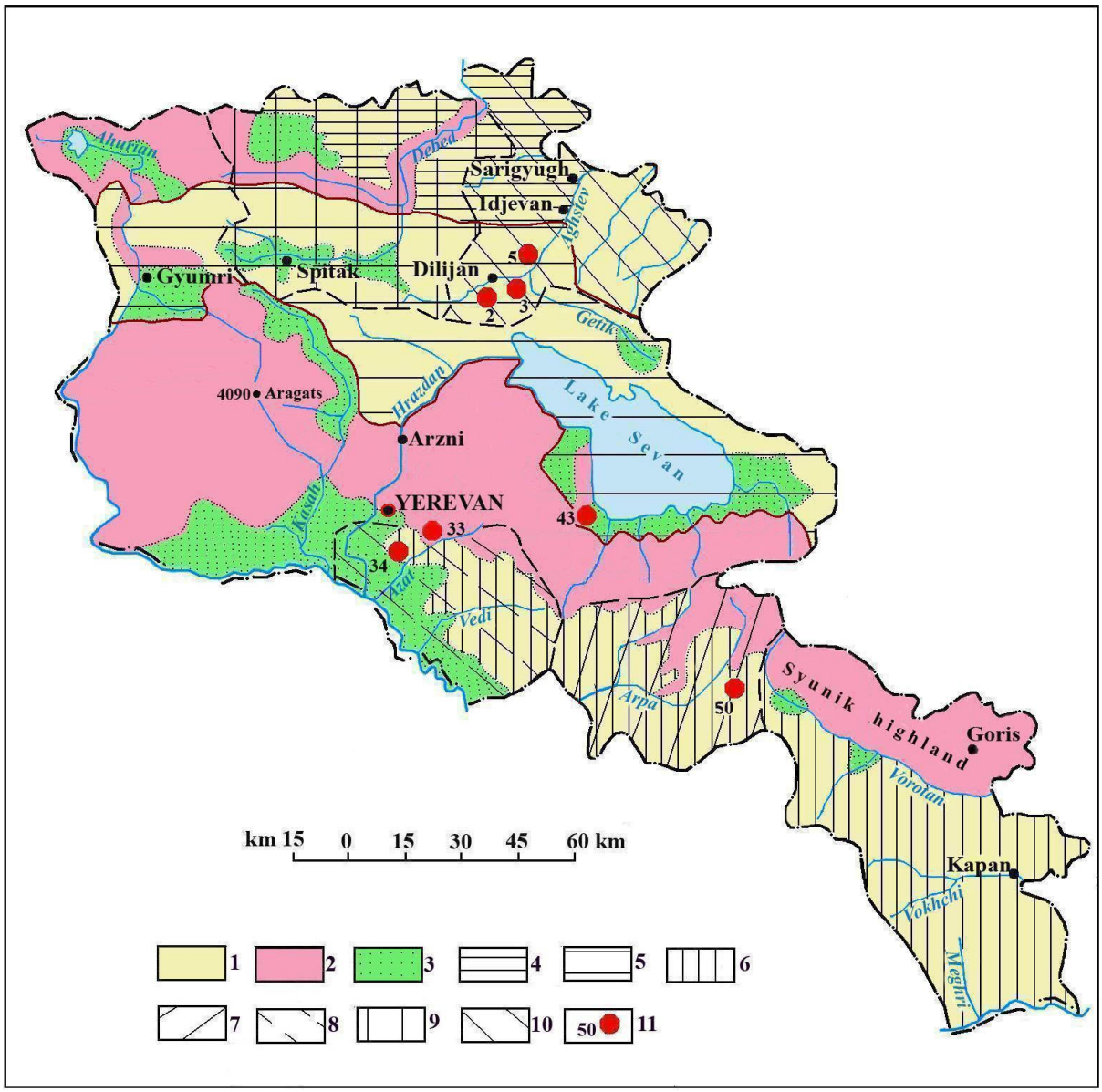


Fig. 2 – Map of engineering-geological regions of Armenia and position of some large landslide districts: 1 – folded block-mountains; 2 – volcanic massifs and plateau of the volcanic Highland regions; 3 – aggraded plains; 4 – Virahayots (Somhet) region; 5 – Sevan-Shirak region; 6 – Urts-Zangezur region; 7–10 – administrative districts: 7 – Vayots Dzor, 8 – Ararat, 9 – Lori, 10 – Tavush; 11 – large landslide districts: 2 – Dilijan, 3 – Ahardzin, 5 – Hovk, 33 – Vokhchaberd, 34 – Nubarashen, 43 – Eranos, 50 – Ugedzor (Kochbek).

– **Landslides in Virahayots (Somhet) region** are in the middle-mountain belt with the exception of the low-mountain belt of Sarigyuh, where very thick bentonite clays are bedded. These clays are easily drawn into landsliding.

– **Landslides in Sevan-Shirak region** are characterized by large and huge landslide-blocks and floodslidings in the basin of the River Getik, Dilijan-Hovk zone of the middle- and high-mountain belt, where volcanogenic-sedimentary rocks and tectonic faulting zones are found (Fig. 3).

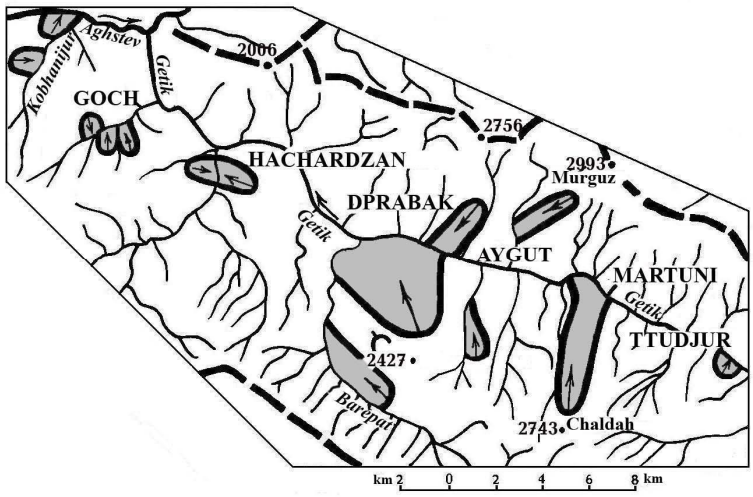
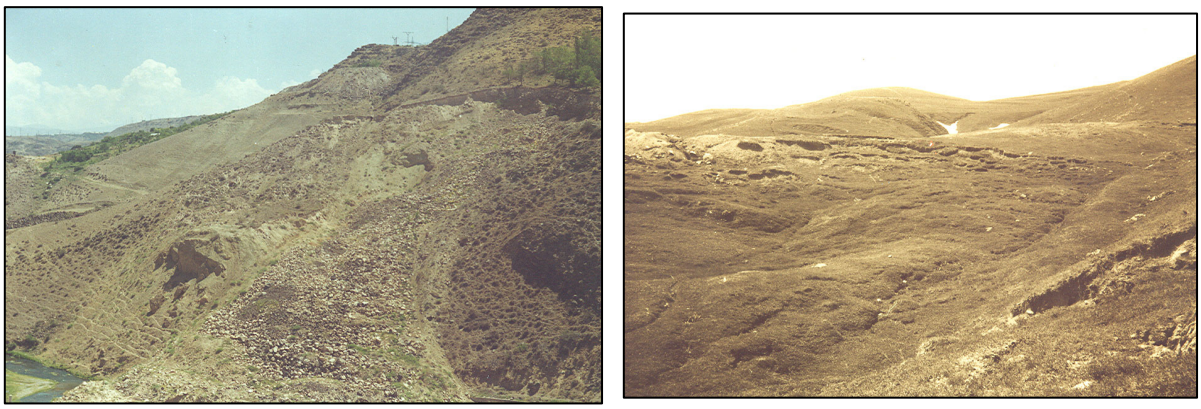


Fig. 3 – Landslides in the River Getic basin.

Landslides in the north-east coast of Lake Sevan have a beaded position along the overthrust displacements and are of medium and small size (rockfalls and floodslidings).

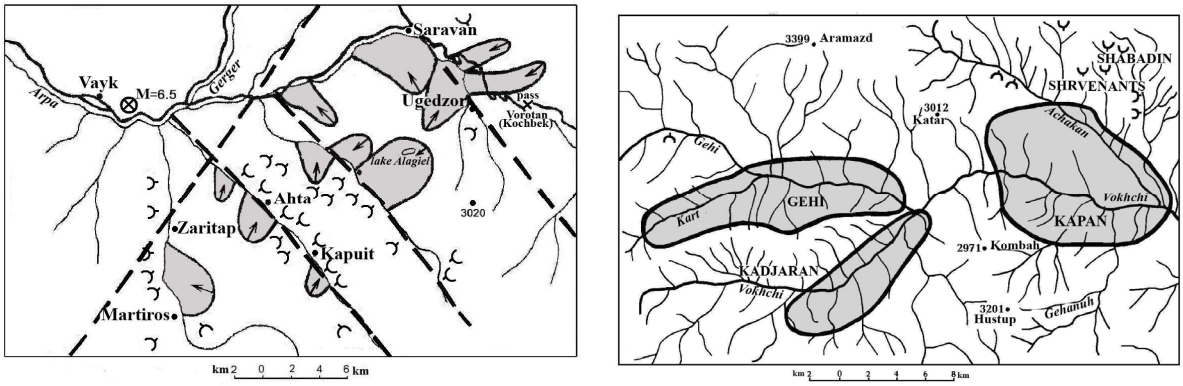
– **Landslides in the Volcanic Highland.** Landslides in the Lori district are developed in the middle-mountain belt and are small in size; landslides in the Hrazdan Gorge near Arzni were formed in a fault area; landslides in the Gegham Massif occur in the basin of the rivers Azat and Vedi in the form of floodslidings and partially landslide-rockfalls; in the upper part of the River Jermuk landslides are in a zone of tectonic faulting in the effusive-terrigenous rocks; in Syunik Highland small and very small landslides are found in the upper part of the River Goris only in effusive-terrigenous rocks (Fig. 4).



a **b**

Fig. 4 – Landslides in the Volcanic Highland: *a* – in the Hrazdan Gorge near Arzni;
b – "Eranos" landslide on the west coast of Lake Sevan.

– **Landslides in Urts-Zangezur region** are of medium and small size, but there are also huge ones (for example, the Jermanis structure in the upper part of the River Vedi); landslides here are developed in volcanogenic-sedimentary rocks, e.g. landslide-blocks, floodslidings and landslide-rockfalls; the basins of the Vorotan, Vokhchi and Meghri are severely affected by landslides (Fig. 5).



a **b**

Fig. 5 – Landslides in Urts-Zangezur region: *a* – landslides in Ugedzor (Kochbek); *b* – landslide districts in the River Vokhchi basin.

Our research has shown that more than 3,500 landslides of various sizes occur in Armenia. 90% of them are situated at altitudes of 2,000–1,500 m and below, others are recorded at altitudes of 2,200–2,400 m and rather rarely at 2,500–2,600 m and higher. The largest landslides coincide with fault zones (tectonic active districts of high seismicity), where rocks are often altered to clay.

CONDITIONS FOR AND CAUSES OF LANDSLIDE FORMATION

The formation of landslides in Armenia is caused by the region's geological-geomorphological conditions, as well as by the development of this territory in the Pliocene-Quaternary period:

– the presence of steep and convex slopes;

– the deep relief fragmentation;

– the variety of rocks with a different degree of weathering and claying;

– the presence of numerous ancient hollows filled in with friable deposits 3–5 m to some tens of meters thick on slopes;

– the presence of large amounts of underground water;

– the presence of numerous faults of different activity level where dislocation of separate blocks and outflow of hydrothermal solutions to the surface occurs; these solutions severely alter the rocks (claying and moistening them);

– strong earthquakes with magnitude of 7–8 occur quite often here; they can be the cause of collapse of rocks from slopes and create conditions for the formation as they break rock massive and influence their solidity and shearing strength, generate forces of inertia;

– differential vertical displacements of separate blocks violate the condition of slope stability by changing base level of denudation, slope declivity and height;

– the mechanical and chemical composition of friable formations favor the development of piping processes which promote formation of landslide;

– anthropogenic factors: cutting and overloading of slopes, their remoistening during water leakages from irrigation canals, water-supplies and excessive watering of agricultural areas, slope vibrations during vehicle passage, etc.

The above-mentioned factors create "favorable" conditions for the formation of landslides. But the landslide process (dislocation of rocks) starts when one of the factors outweighs and violates a limit of rock stability. Therefore, each concrete landslide is triggered by definite causes.

VARIETIES OF LANDSLIDES

Landslides display various sizes – from small surface dislocations (ruptures of turf with slidings, overflows, and slumps) and small landslides on terraces or valleys to large landslide-rockfalls, landslide-blocks and floodslides of huge size – were revealed by us during field works and the interpretation of aerial photographs. The exogenous and anthropogenic factors led to the formation of the former ones, and the endogenous factors to the latter.

We subdivided the Armenian landslides according to the time of their formation into:

– Lower Pliocene – Upper Quaternary,

– Upper Holocene and new ones.

Old landslides are large and huge landslide-blocks and floodslidings long of 5–8 km, wide of 1–2 km, and thick of 100–170 m and more. We named these landslides "complex tectonic-seismo-gravitational displaced bodies". Their formation is connected with strong earthquakes of the past, as well as slow (creep) dislocations of active fault sides.

These huge seismic landslides have relatively small size of vertical displacement (100–200 m), but the amplitude of horizontal displacement reaches 0.5–1 km. Therefore riverbeds in their tongue area are heavily deviated to the opposite side (Fig. 6).

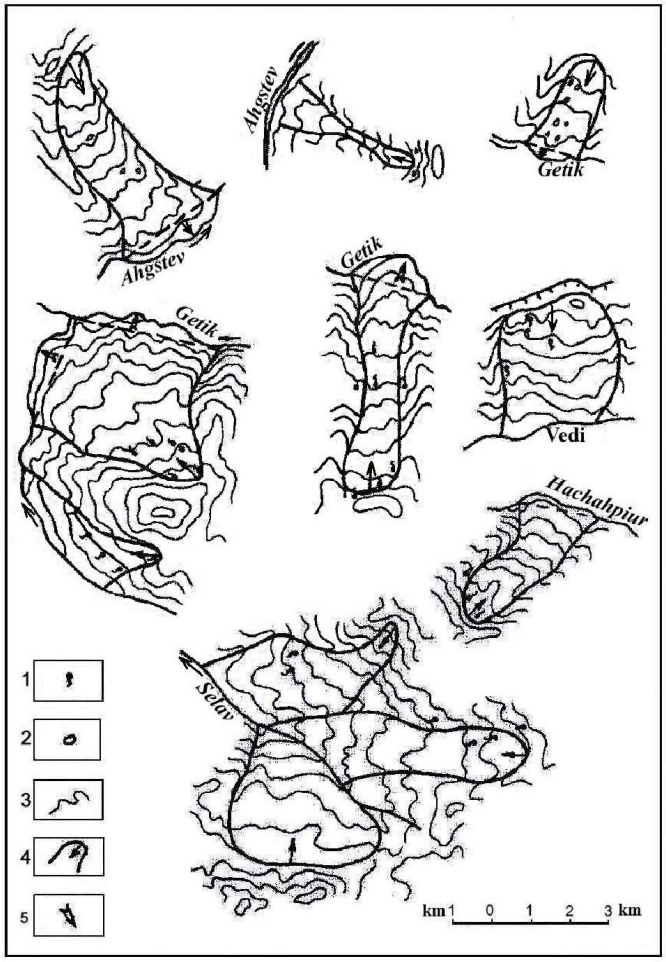


Fig. 6 – Examples of large landslide forms in plan: *1*, springs, *2*, lakes, *3,* contours of map, *4*, landslides, *5*, direction and size of displacement of landslide "tongue".

The large amplitude of horizontal displacement is accounted for by the surplus of horizontal acceleration received by landslides during the earthquake.

At present the majority of old seismic landslides are stable, with some activity observed in certain "tongue" areas. This is a result of anthropogenic influence.

Dilijan, Ahardzin and other landslide blocks are outstanding in this respect. Their surface areas are activated and cause considerable damage to the economy of Armenia.

The Ahardzin landslide is situated in the middle current of the River Ahgstev, on its right bank. The first landslide phenomena were marked here in the 1980s, when the slope began being cut for the construction of a highway and a railway, without proper evaluation of slope stability and essential engineering protection.

Considerable displacement first occurred in 1985 on the slope between a permanent road and a motorway. At that time landslide processes started on the slope above the permanent road. It led to the complete destruction of that portion of the railway in the 1990s, and in 1997 the landslide body covered the motorway (Fig. 7).

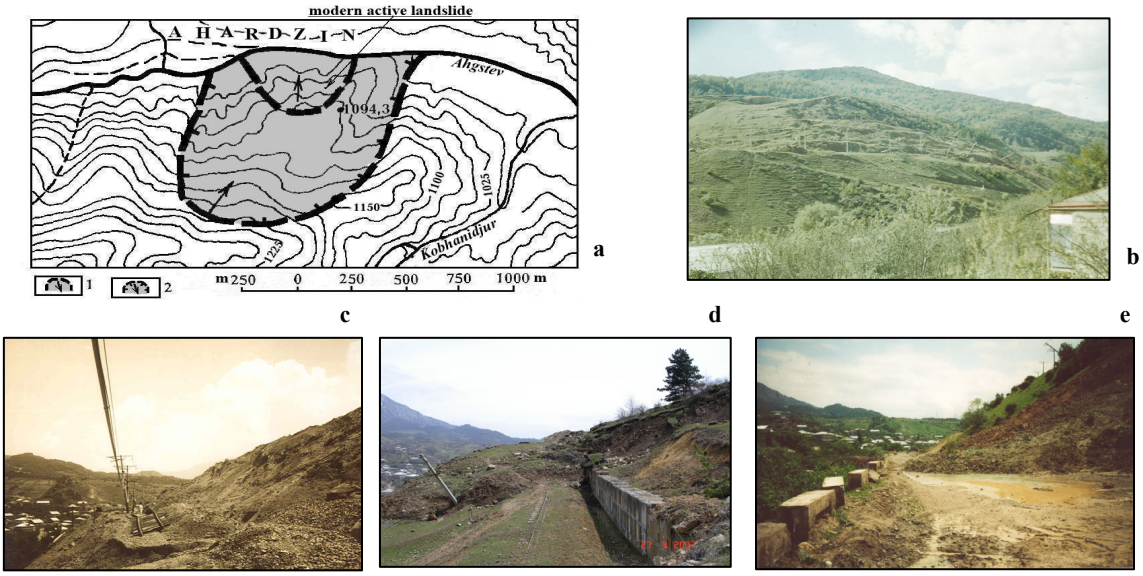


Fig. 7 – Ahardzin landslide: a – topographical map of landslide area: 1, modern active landslide, 2, old seismic landslide; b, general view of landslide area; c, railway destroyed by landslide; d, permanent road blocked by the mass slided from the slope; e, blocked motorway

The Ahardzin landslide belongs mainly to the block landslide type of displacement in terms of its mechanism of display, but the east part (east block) – to viscous-plastic type entailing piping processes.

The landslide body covers an area of 82,000 sq.m, long of 270 m, wide of 30 m, volume of landslide masses – 2,184,000 cu.m. (Table 1, Fig. 8).

Table 1

Correlation of parameters of "Ahardzin" district landslide blocks.

Name of block	Area		Volume		Depth of capture, m	Mechanism of display
	m^2	%	m^3	%		
East	37,000	45.2	1,026,000	46.9	23	Viscous-plastic entailing piping processes
Central	28,000	34.1	638,000	29.3	22	Block displacement
West	17,000	20.7	520,000	23.8	30.5	Technogenic displacement

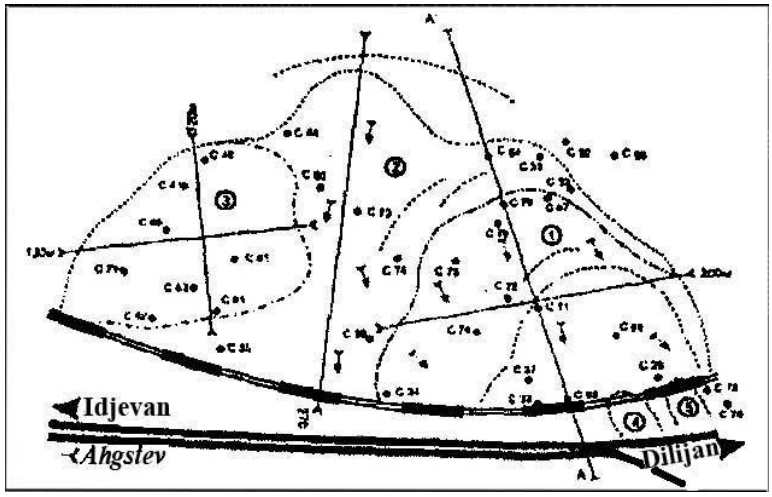


Fig. 8 – Schematic plan of the "Ahardzin"landslide district.

The upper border of the landslide body is marked by the edge of a scarp 70–80 meters long and 12 m high. The west side of the wall of landslide cirques is at the altitude of 17 m, the east side is displayed indistinctly, but it coincides with a fissured zone.

Volcanic-sedimentary rocks of the Middle Eocene, Middle Quaternary landslide and modern formations (clays, loams, shingles, loamy sands and sands) are involved in landslide displacement.

The east block is the most active one.

In the last six years an activation of the entire landslide district occurred as a result of termination of engineering protection works being abandoned for lack of financing. The result was a disastrous displacement of earth masses and the consolidation of all the three landslide blocks into a single massive landslide body.

The permanent road was fully destroyed, the motorway was broken and on April 3, 2001 75% of the River Aghstev bed was barred. Liquidation of such an extraordinary situation (Fig. 9) proved to be very costly.

Fig. 9 – Motorway blocked by landslide (*a*) and landslide masses fallen into the River Ahgstev bed (*b*).

New landslide displacements with blocking of the River Ahgstev bed occurred on May 25, 2005, April 28, 2006, in the spring of 2007 and 2008.

At present the situation of the "Ahardzin" landslide district is extremely critical. Landslide displacements cover all new areas not only in width, but also up the slopes, also affecting deeper portions of the slopes.

In fact, it is already impossible to stop this enormous landslide.

The landslide district of Dilijan health-resort is greatly affected by catastrophic landslide activity. There are more than 160 landslides of various intensity and sizes here (Fig. 10).

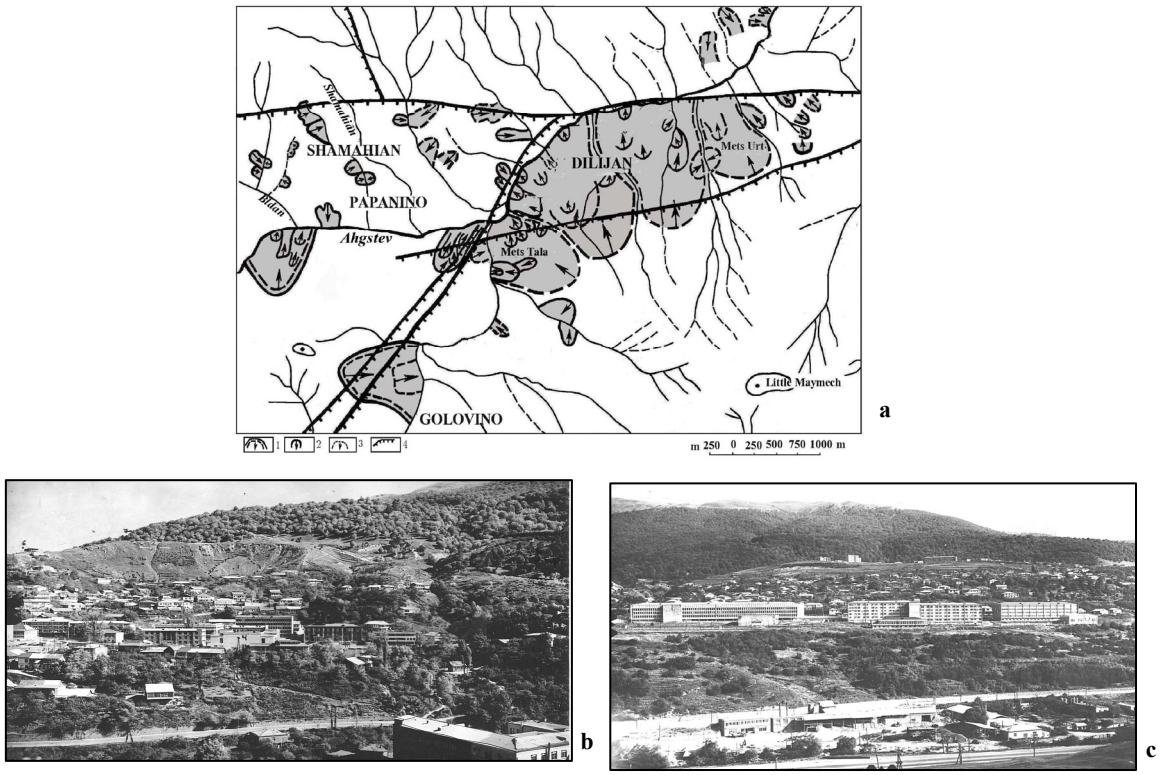


Fig. 10 – Landslides on the territory of Dilijan health-resort: *a*, distribution of the largest landslides: *1*, seismogenic landslides, *2*, active landslides, *3*, dormant landslides, *4*, faults; *b, c*, landslide slopes in Dilijan with landslide circles and landslide terraces.

The formation of the Dilijan landslides is caused by a number of factors:

– the complicated geomorphological and geological structure of the town's territory;

– the diverse lithological composition of rocks, their intensive weathering, bentoniting, intensive fissuring and disintegration;

– the wide-spread of underground water and its outflow to the surface;

– the increase of rock weight on slopes because of moistening by atmospheric precipitation, excessive watering and leakages of water from various flumes;

– the cutting and overloading of the slopes during engineering works, etc.

The displacement of the Dilijan landslides was activated after the 1988 Spitak earthquake and especially after the collapse of the USSR, when financing of antilandslide actions ceased. As a result, the territory of Dilijan is now in a very deplorable condition (Fig. 11).

The Vokhchaberd landslide (size 2.5 x 1.3 km^2, thickness 70–80 m) is also very active. It fell from the steep slope of the Vokhchaberd range and was displaced along an overfault line.

The amplitude of the landslide block vertical displacement is 200–225 m, but horizontal displacement covers 1 km, evidencing its seismic genesis.

The landslide was activated in 1982, but after the 1988 Spitak earthquake its activation became very visible. Listed below are a few factors that cause or facilitate landslide displacements:

– the infiltration of surface and underground water into the landslide body within a fault zone;

– the spreading of unstable clays;

– anthropogenic activities;
– seismic shocks, etc.

The permanent road near Vokhchaberd village was deformed; the village cemetery and many buildings were destroyed (Fig. 12).

Fig. 11 – The consequences of displaced landslide masses in the town of Dilijan: *a, b*, landslide masses fall on streets and buildings; *c*, strained cover of street; *d*, strained stone stairs.

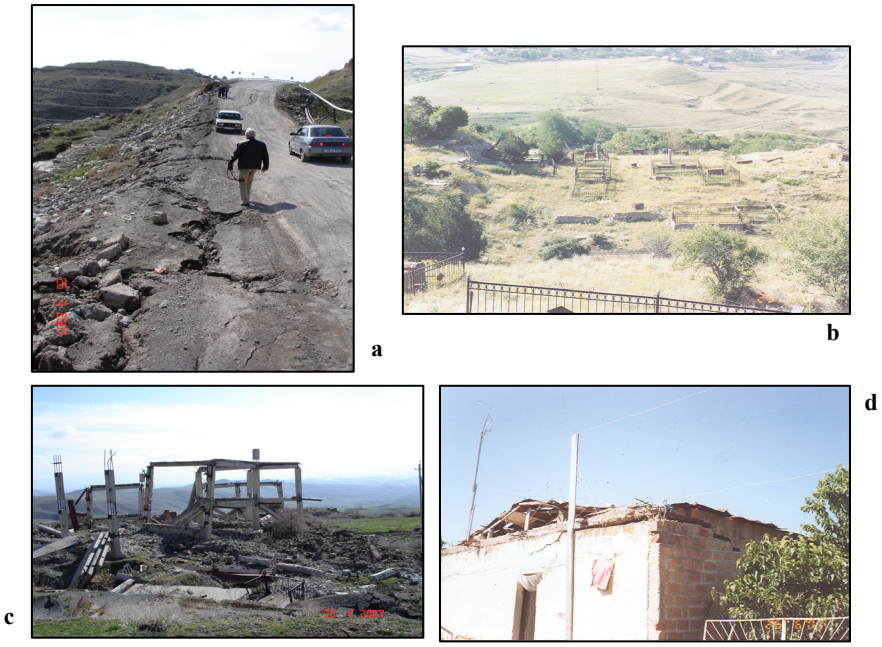


Fig. 12 – The consequences of Vokhchaberd landslide displacement: *a*, deformed motorway; *b*, destroyed of the village cemetery; *c*, destroyed school building; *d*, dramatic condition of buildings.

At present, 44 buildings are completely destroyed, more than 80% of the remaining ones are in a dramatic condition.

There is a very dangerous landslide district in the high-mountain belt of the Zangezur range near the Vorotan (Kochbek) Pass. A few huge landslide-blocks and floodslidings (clearly visible in the relief and on topographical maps) were formed here in volcanogenic-sedimentary rocks along an active fault line (epicentre of destructive Vayots Dzor earthquake in AD 735 is connected with this fault) (Fig. 5a).

These landslides constantly destroy this motorway which is of strategic importance.

YOUNG LANDSLIDES

Upper Holocene and recent landslides quite often complicate the concluding parts of the majority of old landslides, and develop independently in the districts “favorable” to their formation.

These landslides are clearly identified in a slope relief: a scarp wall, cracks of opening, gaps in the soil, landslide body, landslide steps, etc. can be seen very well.

The territory of Greater Yerevan from Vokhchaberd to Nubarashen and then to the west along the north-west slope of the Nubarashen Plateau (shingles and montley clays creep here on the surface of montley clay strata) is severely affected by young landslides.

After the Spitak earthquake the Nubarashen landslide was activated. It caused considerable destruction in the territory of an urban cemetery (Fig. 13).

Fig. 13 – Destruction of graves by the Nubarashen landslide.

DAMAGE FROM LANDSLIDE AND SUGGESTED METHODS OF STRENGTHENING LANDSLIDE-PRONE SLOPES

Landslides in Armenia occupy an area of 34,679 hectares. The highest occurrence rate of this dangerous process is registered in Vayots Dzor (1,181 hectares), Ararat (8,334) and Tavush (5,459).

Damage from landslides in Armenia amounts to 10–30 million dollars a year.

The well-known methods of measures against landsliding do not have the desired effect in Armenia. Besides they are labor-consuming and expensive. Therefore, in our opinion, a method to strengthen the slopes using polyethylene and polypropylene nets and corrugated linen is more applicable. This method is cheaper and more effective, it does not require large amounts of materials and much time to use it in practice.

CONCLUSIONS

The analysis of the present material shows a great variety of landslides in terms of size and origin on the territory of Armenia. Seismogenic landslides (are formed during earthquakes and creep dislocations of boards of active faults) and landslides connected with other causes (overmoistening of slopes during abundant precipitation, etc.) are among the naturally occurring landslides. Seismogenic landslides are characterized by small amplitudes of vertical displacement and great horizontal displacement. Among them are landslides-blocks and floodslidings. The first ones are connected with the most active seismogenic zones where crossing of tectonic faults and the formation of disjunctive knots occur. Floodslidings are related rather to districts of numerous faults and hydrothermal-modified rocks with their breaking up and crushing. Rocks in these districts are very much weakened, their physical-mechanical characteristics changing. They dilute during strong earthquakes and begin to "flow" forming long, up to 5–8 km landslide bodies – floods.

Man's economic activity disturbing the stability of rocks on slopes is a major landslide triggering factor in Armenia.

At present, the elaboration of effective measures to reduce landslide hazard and consolidate the slopes is an essential problem for Armenia.

REFERENCES

Aslanyan, A.T. (1979), *The large olisthostromes of Pliopleistocene age in the valley of the River Aghstev (Armenian SSR)*, Izvestia AN ArmSSR. Nauki o Zemle, N 1, pp. 24–32.

Avagyan, A.A., Boynagryan, V.R., Iadoyan, R.B., Stepanyan, V.E. (2000), *Geoinformation system of landslide processes in the territory of Armenia*, Conversional potential of Armenia and programmes ISTC, Yerevan, pp. 180.

Avagyan, A.A., Movsesyan, V. (2002), *GIS of hazardous exogenious processes in the territory of Armenia,*GIS in Geology, Moscow, p. 18.

Boynagryan, V.R. (1988), *Landslide (block) deformations of the Aghstev river basin (Armenian SSR) slopes and some problems of their study,* Izvestia AN ArmSSR. Nauki o Zemle, N 1, pp. 30–37.

Boynagryan, V.R. (1990), *Altitudinal zonality of slope processes in the Armenian Highland and special features of slope evolution,* Geomorphology, N 4, pp. 49–57.

Boynagryan, V.R., Boynagryan, A.V., Boynagryan, B.V. (2000), *Regularities of spreading and forming of landslides in Armenia, Landslides in research, theory and practice,* Cardiff, UK, Thomas Telford, pp. 163–166.

Boynagryan, V.R. (2001), *Problems of ecological geomorphology and landslide processes of the Armenian Highland,* Problems of geomorphology and geology of Caucasus and Pre-Caucasus. Krasnodar, pp. 129–138.

Boynagryan, V.R. (2005), *Landslides of Armenia (their spreading, conditions and causes of formation, varieties),* Uchenie zapiski YGU, Yestestv.nauki, N1, pp. 3–17.

Boynagryan, V.R. (2007), *Slopes and slope processes of the Armenian Highland,* Yerevan. 279 p.

Kharakhanyan, A.S. (1981), *Selection of large landslides, broken and gravitational sliped down of rock blocks by interpretation of spase photographs,* Izvestia Vuzov. Geologia I razvedka, N3, pp. 130–131.

Saakyan, A.G. (1989), *Development of Vurgun landslide massif by stages (basin of the River Aghstev, Armenian SSR),* Izvestia AN ArmSSR. Nauki o Zemle, N 1, pp. 62–66.

Stepanyan, V.E., Boynagryan, V.R., Gabrielyan, V.V., Sngryan, E.E., Gyurgyan, U.G., Alaverdyan, G.Z. (2007), *On the question of mathematical justification of forecast of stirring of landslide in the clay sediments of Armenia (on the example of Vanadzor of Lori region of Armenia),* Applied problems of geography and geology of mountain regions of Alpine-Himalayas belt, Yerevan, pp. 97–102.

Yadoyan, R.B. (1987), *Protection of geological environment.* Lithomonitoring, Priroda, gorod, chelovek, Yerevan, pp. 15–20.

Received April 29, 2009