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STUDY OF TECTONIC SURFACE AND SUBSURFACE STRUCTURES BY GPR SURVEY IN ACTIVE FAULTS AREA

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The Republic of Armenia (RA) is located in the Arabian and Eurasian plates collision zone. The Pambak-Sevan-Syunik (PSSF) active fault extends almost throughout the whole territory of Armenia. The issue of geometry of the surface and near-surface structures in the most segments of the PSSF remains open. In the Syunik segment of this fault there is a site called Karkar with a high hydrothermal potential. Surface and near-surface structures in the Karkar site were first identified and studied in Armenia with using of GPR survey. Ruptured and depletedzones representing secondary surface deformations of the active fault were revealed.

In the initial stage, a GPR 2D survey was done in separated sites; afterwards, a GPR 3D survey was done in revealed anomalous sites. As a result, the 3D models of surface and near-surface structures (flower structure, pull-apart basin, and other structures) allowed to more accurately estimate the width of the active fault zone, to develop an adequate seismotectonic model of the territory. The carried out researches will have a great importance for the seismic hazard and risk assessment for the studied territory.

Keywords: active fault, surface and near-surface structures, GPR survey, anomaly.

Introduction

The Republic of Armenia (RA) is located in the Arabian and Eurasian plates collision zone. The Pambak-Sevan-Syunik (PSSF) active fault extends almost throughout the whole territory of Armenia. In the Syunik segment of this fault there is a site called Karkar with a high hydrothermal potential, where the main segments of the active fault are known. However, the issue of geometry of the surface and near-surface structures existing in the surroundings of the main fault remains open. This issue is important for seismic hazard and risk assessment.

With the purpose of revealing and comprehensively studying the surface and near-surface structures, 2D and 3D ground penetrating radar (GPR) surveys were used in the Karkar site. During the survey, anomalous areas were identified, which need to be studied in detail. To determine the three-dimensional structure of the mentioned structures in the anomalous areas, 3D GPR survey was used. As a result of the surveydisrupted, ruptured, deformed surfaceand near-surface zones were revealed and mapped. Based on these results, it becomes possible to more thoroughly examine and estimate the width of the active faults.

Characteristics of the Karkar site

The Karkar site (Figure 1) is located in the south of the Republic of Armenia, in Syunik region. The site is a part of the Pambak-Sevan-Syunik active fault, which is the longest (490 km) active fault in Armenia [Trifonov et al., 1990; Philip et al., 1988; Karakhanyan et al., 1997; Rebai et al., 1993]. Numerous geological and geophysical investigations have been carried out in the Karkar site, among them being as follows: the Karkar site is situated in the area, where the western branch of the pull-apart basin structure splits into seven subsegments. The total rightlateralstrike-slip fault displacement along all segments equals 600 m, and the vertical displacement is 47 m. [Karakhanyan et al., 2015]. We surveyed the western branch of Karkar site (Figure 1).

The seismic translucence implemented in Jermaghbyur area in 1988-1989 resulted in detection of two areas of low-velocity inhomegeneities: the first one waslocated in the area of the Jermaghbyurthermal spring and the other one was located in the area of the Karkar volcanic group.

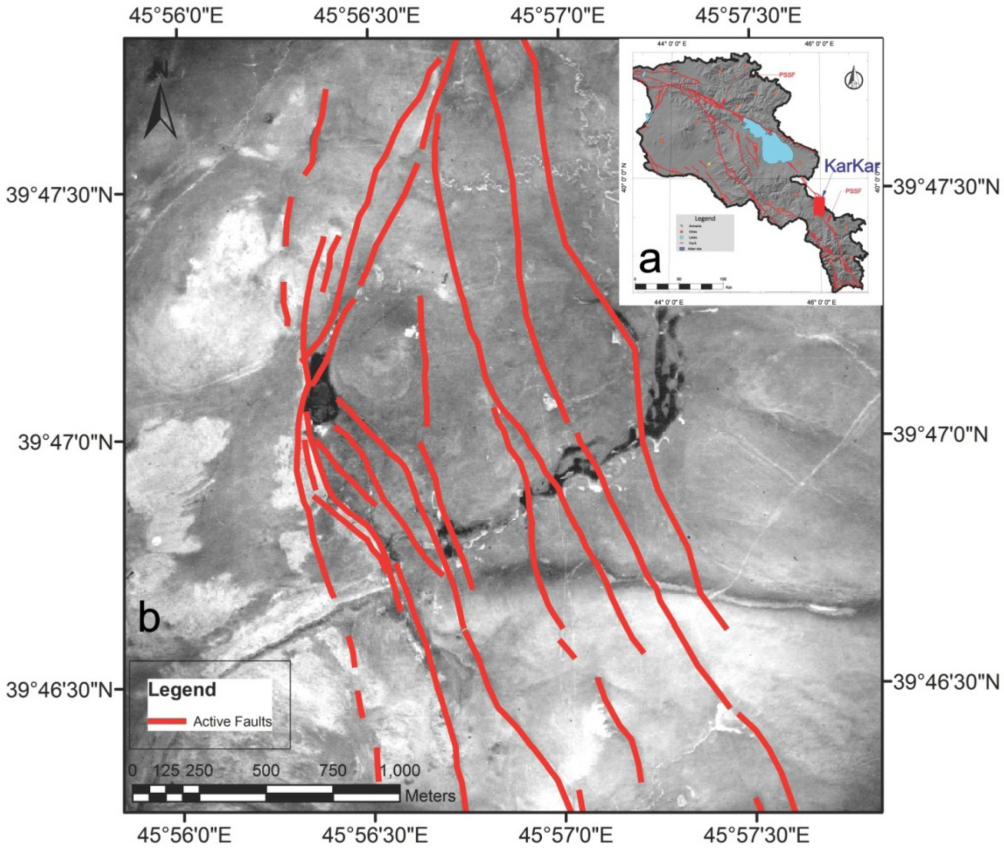

Fig. 1. a) Map of Armenia, b) The area under study

The identified seismic inhomogeneities are located above the refraction boundary, which is at a depth of 2,0-2,5 km., and represent bodies, in which velocities of propagation of electromagnetic waves are much lower as compared to covering medium and their filling substance is characterized by a higher attenuation factor.According to the seismic characteristics these bodies might represent near-surface magma chambers filled with still substance [Independent…, 2012].

The main out come of the structural-geological and volcanological investigations conducted in the Karkar site was the identification of a major structure of pull-apart basinon the southern flank of the Pambak-Sevan-Syunik active fault [Karakhanyan et al., 2002].

Based on the structural-geological investigations conducted in 2004 the map of faults in the Karkar site was compiled at a scale of 1:25.000, which served a basis for the development of the «conceptual model of the geothermal site [Independent…, 2012]. In the same year, a magnetotelluric (MT) sounding was conducted in the site by «Nord-West» Company (Moscow) in cooperation with the Institute of Geophysics and Engineering Seismology of the National Academy of Sciences of Armenia [Independent…, 2012].

The critical analysis of the MT survey results of 2004, 2009 and 2011 indicates that they are fully compatible and can be used for interpretation, in particular for assessment of the geothermal potential of the Karkar site [Independent…, 2012].

The results of 3-dimensional inversion of gravity data provide key inputs into a hydrothermal circulation model of the system and associated hot springs, which is used to evaluate possible geothermal system configurations. Hydraulic and thermal properties are specified using maximum a priori estimates. Limited constraints provided by temperature data collected from an existing down-gradient borehole indicate that the geothermal system can most likely be classified as low-enthalpy and liquid dominated [White et al., 2015].

The results of the conducted ground penetrating radar survey

The most important task was to detect, study and map the surface and surface structures. Then made for them the three-dimensional models. For this purpose, a 2D and 3D GPR survey was implemented for the first time, using GSSI SIR 3000 GPRequipment, and the data were processed using «Radan 6,5» software [Lehmann, Green, 2000].

For the 2D survey a 100 MHz antenna was used, which enabled to study the Earth's crust to a depth of 30 m, and for the 3D GPR survey a 200 MHz antenna was used to study the Earth's crust to a depth of 10 m. The anomalous areas and zones revealed as a result of the 2D survey were subject to quantitative and qualitative processing, during which the nature of the anomalies was identified and the tectonic elements were separated.

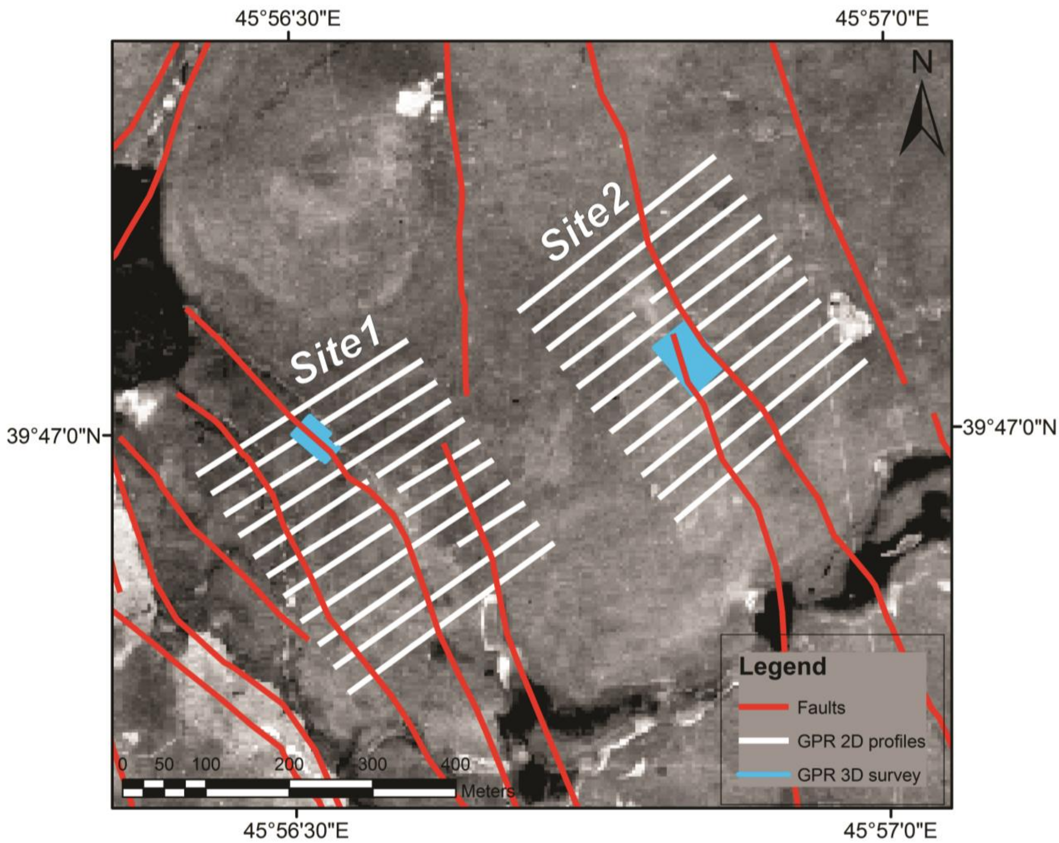

Fig. 2. Factual evidence sketch: first and second sites

To obtain the image of tectonic structures in the anomalous areas 3D GPR survey was conducted and the model of tectonic elements was compiled as a result.

Based on the characteristics of the relief, the site was divided into two parts during the studies (Figure 2).

In the first site, rectangular grid 2D GPR survey was conducted, which included 11 profiles. Conditioned with the roughness of relief, 4 profiles of the survey have interruptions of up to 10 m length. This area coincides with the main disruption of the active fault, which is well manifested on the terrain.

Figure 3 represents the radargram of Profile 10 and its processing results.The first 0,3 m layer of the profile is the top soil layer, followed by tectonic structures.In the 15 to 100 m segment of the Profile, there is a ruptured and disrupted zone, which is 85 m long and 20 m deep. Such deformations represent by-products of the active fault.

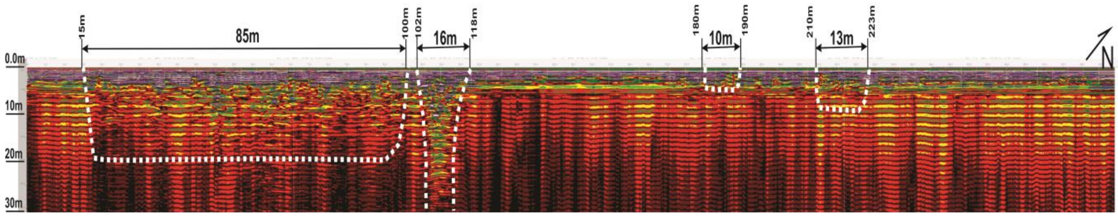

Fig. 3. Quantitative and qualitative interpretation of Profile 10 of GPR 2D survey

In the 102-118 m segment of the Profile an anomaly is distinguished, which is more than 30 m deep. The structure swidth is decreasing with the depth and becomes 8 m at 30 m (Figure 4). The anomaly revealed in the 180-190 m segment of the Profile is 5 m deep, however it is not linked to the active tectonicsin any way. Presumably, it is connected with a cultural and historical heritage site, since this area was a settlement in the late Bronze Age; there are many historical and cultural heritage sites here. A similar structure is also present in the 210-223 segment of the Profile.

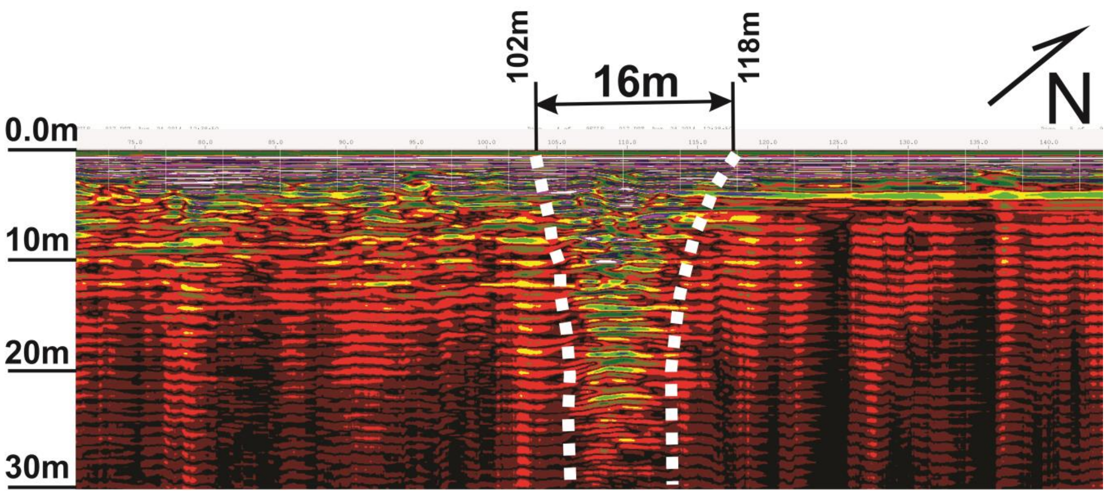

Fig. 4. A flower-type structure

Taking into consideration the fact of the tectonic origin of the structure, it can be argued that the revealed structure has a flower-type shape. As a result of the GPR 2D survey conducted with antennas of up to 30 m penetration depth, numerous flower-type structures were revealed.

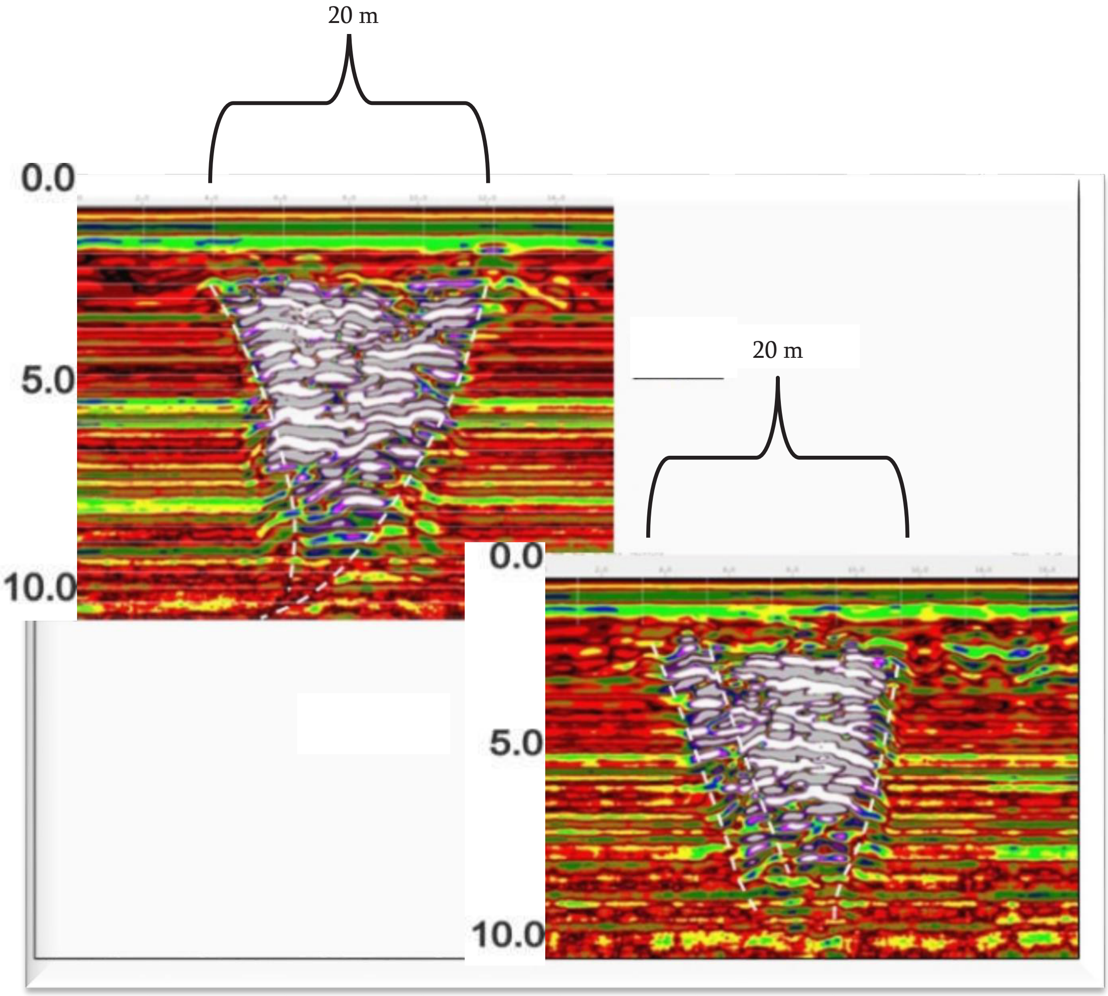

Fig. 5. An identified flower-type structure

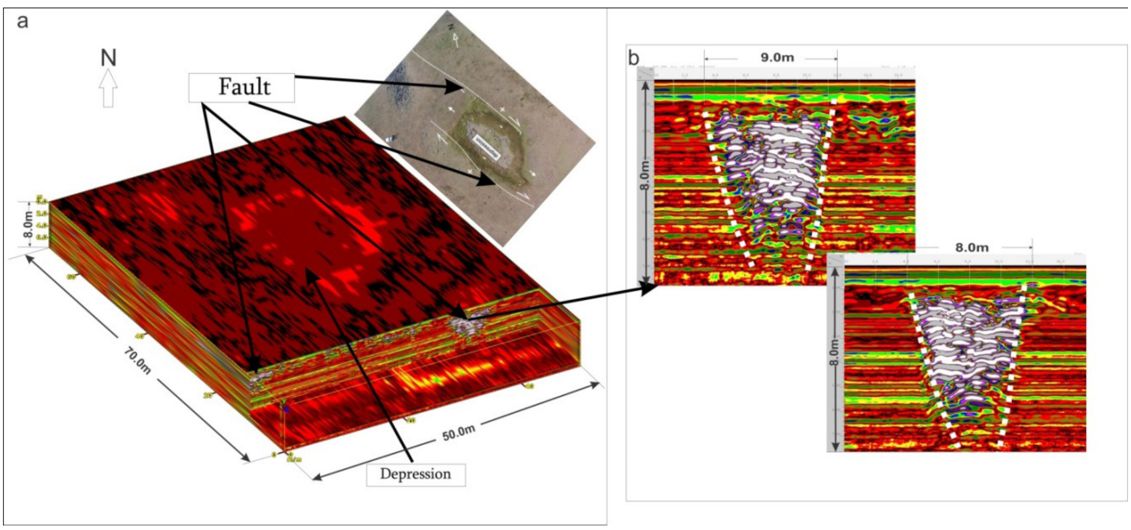

Fig. 6. Analysis of GPR 3D survey and compilation of 3D model

All profiles in the site were subject to similar processing and the anomalieswere plotted on the factual evidence sketch (Figure 8).

With the purpose of more detailed studies, GPR 3D survey was used in the anomalous sites revealed during the GPR 2D survey (Figure 2). The survey was conducted with a rectangular grid. It composed of 11 profiles, with 3m distance between them.The findings of the GPR 3D survey fully confirmed the ones of the GPR 2D survey. As a result of quantitative and qualitative interpretation of the survey, the presence of the flower-type structures was identified and confirmed (Figure 5).

Let us consider the findings obtained in the second site (Figure 2). The length of the rectangular grid GPR 2D survey profiles was 300 m and the distance between them was 30 m. As a result of the survey data interpretation, anomalous areas conditioned by tectonic elements were identified that were also conditioned by disrupted and ruptured zones, as well as tectonic elements with flower-type structure.

There is a natural depression in this site. However, targeted studies to verify the conditions of its origin have not been conducted. Taking into account the GPR 2D survey data, as well as the presence of the natural depression in the site, GPR 3D survey was conducted in the site (Figure 2). The survey was conducted with rectangular grid. It consisted of 24 profiles 50 m in length, and the distance between the profiles was 3 m. The data processing revealed that the natural depression was more than 8 m deep and it was bounded by active faults of flower-type structurealong its two flanks (Figure 6).

Taking into consideration the presence of the natural depression and the active faults bounding it along two flanks, as well as the flower-type structure of the faults, it is argued that the natural depression is a pull-apart basin (Figure 6).The obtained data were placed on aerial photograph (Figure 7) and the model of the pull-apart basin was built [McClay, Bonora, 2001], which has 20 m width and 40 m length.

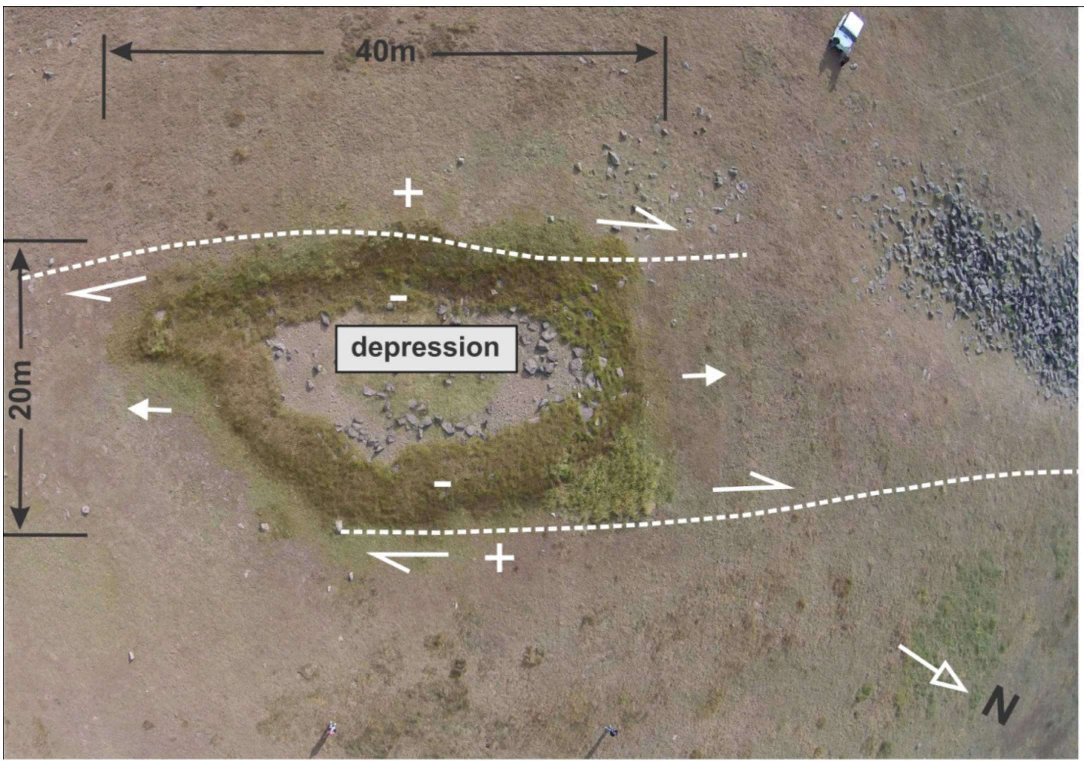

Fig. 7. Pull-apart basin model and active faults

Discussion

Based on the GPR survey in the area under study various surface and near-surface tectonic elements were identified and mapped. The depleted and ruptured structures comprise zones that extend to 20 m depth and are 50 to 230 m wide. They are interrupted by tectonic elements of flower-type structure with different widths varying in a range of 8-9 m to30 m. Regional expansionforces are present in this site, and therefore the tectonic elements are subjected to a stretching process, resulting in the negative flower-type structures. The latter coincide with high accuracy with the flower-structure model proposed by Sylvester in 1988 [Sylvester, Brown, 1988].

A pull-apart basin was identified in the second site, its 2D and 3D tectonic models were developed. The developed model coincides with high accuracy with the Mcklay and Masimomodel [McClay, Bonora, 2001]. All surface and near-surface structures were mapped (Figure 8).

A pull-apart basin was identified in the second site, in the center of which low values of the MT survey were registered.

During the field work were in detail studied surface and sub-surface structures in the active fault zone, which leads to the assessment width of the active fault. These results could evaluate the width of active fault zones. This allows to develop an adequate seismotectonic model of the investigated site, improve accuracy of seismic hazard assessment, thus reducing the seismic risk. Based on the GPR survey data a paleoseismological trench was excavated. The tectonic structures, which were exposed in the trench almost fully confirm the GPR survey results, which confirms the accuracy of the latter [Karakhanyan et al., 2015].

Conclusions

Summing up the results of the conducted studies, the following conclusions can be drawn:

- During study were identified, studied and mapped surface and near-surface structures in the zone of active fault.
- As a result of GPR 2D and 3D surveys surface and near-surface disrupted and ruptured tectonic zones were identified, a part of which have flower-type structures.
- There is evidence that the natural depression in the second site is a pull-apart basin; the 2D and 3D models of the pull-apart basin were built.
- The widths of the Karkar sections of the active Pambak-Sevan-Syunik Fault correspond to about 800 m.

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ИССЛЕДОВАНИЕ ТЕКТОНИЧЕСКИХ ПОВЕРХНОСТНЫХ И ПРИПОВЕРХНОСТНЫХ СТРУКТУР В ЗОНЕ АКТИВНЫХ РАЗЛОМОВ ПРИ ПОМОЩИ ГЕОРАДАРНОЙ СЬЁМКИ

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Территория Республики Армения (РА) расположена в центральной части зоны коллизии Арабской и Евразийской плит. Памбак-Севан-Сюникский активный разлом проходит почти через всю территорию Армении. Вопрос геометрии поверхностных и приповерхностных структур в большинстве сегментов Памбак-Севан-Сюникского разлома остается открытым. В Сюникском сегменте этого разлома находится участок под названием Каркар, с высоким гидротермальным потенциалом. Впервые в Армении при помощи георадарного профиля были выявлены и изучены поверхностные и приповерхностные структуры разлома на участке Каркар. Выявлены разрушенные зоны, представляющие вторичные поверхностные деформации активного разлома.

На начальном этапе для различных участков была проведена двухмерная георадарная съемка (2D). Затем, для выявленных аномальных участков была проведена трёхмерная георадарная съемка. В результате построенные 3D модели поверхностных и приповерхностных структур (структура цветка, бассейна присдвигового растяжения и др.) позволяют более точно определить ширину зоны активного разлома, разработать адекватную сейсмотектоническую модель территории. Проведенные исследования будут иметь важное значение для оценки сейсмической опасности и риска изучаемой территории.

Ключевые слова: активный разлом, поверхностные и приповерхностные структуры, георадарная съемка, аномалия.

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