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THE USE OF LASER SCANNING TECHNOLOGY IN LAND MONITORING OF MINING AREAS

Tudor SĂLĂGEAN[1], Teodor RUSU[2], Dumitru ONOSE[3], Raluca FARCAŞ[4], Bogdan DUDA[2] & Paul SESTRAŞ[5]

[1]*University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Faculty of Horticulture, Department of Land Measurements and Exact Sciences, Calea Mănăştur 3-5, 400372, Cluj-Napoca, Romania, tudor.salagean@usamvcluj.ro*

[2]*University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Faculty of Agriculture, Department of Technical and Soil Sciences, Calea Mănăştur 3-5, 400372, Cluj-Napoca, Romania, rusuteodor23@yahoo.com, bogdan.duda@usamvcluj.ro*

[3]*Technical University of Civil Engineering Bucharest, Faculty of Geodesy, Department of Topography, Lacul Tei 122-124, District 2, 020396, Bucharest, Romania, balanta7@hotmail.com*

[4]*Technical University Cluj-Napoca, Faculty of Civil Engineering, Department of Land Measurements and Cadastre, Memorandumului 28, 400114, Cluj-Napoca, farcasraluca19@yahoo.com*

[5]*University of Agronomic Sciences and Veterinary Medicine of Bucharest, Faculty of Land Reclamation and Environmental Engineering, Department of Environment and Land Reclamation, Mărăşti 59, District 1, 011464, Bucharest, Romania, psestras@yahoo.com*

Abstract: The use of laser scanning for topographic monitoring in areas of closed mines is useful for preventing and detecting problems which can negatively influence the environment and the population. In Romania, almost all perimeters with salt deposits present the phenomena of instability, both underground as well as at ground surface. Terrestrial laser scanning was performed with a 3D laser scanner on the corresponding surface of mine Victoria, Slănic Prahova salt deposit, Prahova County with a network support made using GNSS technology. The density of the approximately 23 million points was of 600 points/m^2 with an accuracy of less than 1 cm on a surface of 38515.84 m^2 (3D surface), respectively 36717.30 m^2 (2D surface - in horizontal projection). For comparison and control of the registration, two methods have been applied, namely using a scanning interface control for the first and making of the registration using the *traverse method* for the second. Based on data obtained from laser scanning we realized the DEM (Digital Elevation Model) and the level curves, both obtained using the model TIN (Triangulated Irregular Networks), which is a network of spatial triangles. The volume of the resulting material by overlapping areas (that generated by 3D scanning and the one generated by vectorizing contour lines) was -250 490.01 m^3. The most important deformation of the studied area is outlined on the right side of the stream Baia Verde, in the area of Slănic relay, having a value of -14.7 m. Tulburea stream slopes are affected to an extent of 60-70% by landslides of areal nature. In terms of displacements and deformations active geomorphologic processes shaping the landscape on large surfaces are present in the studied area. The most intense and widespread are sliding processes, erosion and dissolution of salt. In the mining area more and more frequently are recorded landslides, which make the formation of water sources infiltrations through unveiling at certain points the massif of salt. The use of laser scanning reduces the time to perform measurements, which helps the correct interpretation of scanned targets.

Keywords: level curves, land shifting, digital design, salt mine, 3D scanning

1. INTRODUCTION

Topographic monitoring of lands and buildings in the area of closed mines is made in order to prevent and detect possible problems that may occur after completion of closure and rehabilitation carried out in the area and can impact of the gravest the environment and the population (Prokop & Panholzer, 2009).

As a result of extracting a volume of useful minerals from a deposit, the state of stress and strain from the massif changes. This has the effect of destroying the stability of surrounding rocks, so fractured rocks from the excavation contour are set in motion. The displacement is transmitted to the massif on a distance that can reach the ground surface up to day, causing its degradation and thus destroying buildings situated on the surface or in the underground (Vereș et al., 2013).

Displacement of the surface is the result of the massif tension redistribution of rocks under the influence of underground excavations created by mining activities or the effect of changes that may occur over the aquifer formations (i.e. dewatering, flow variations, etc.). Displacement of land surface causes a cavity in the earth's crust called a dipping bed (Dragićević et al., 2012; Goel & Adam, 2014; Vereș et al., 2014).

Instability phenomena generally highlighted both in underground salt mining (flaking, fissures, cracks, holes in the walls of separation plates, pillars and floors with drastic deformation) and at ground surface (cracks, slides, diving, collapses with or without formation of lakes) require a complex and continuous monitoring.

To almost all operating perimeters of salt in Romania the phenomena of instability stands out, both underground (flaking, cracking, splitting, sharp deformation of pillars and floors) as well as at ground surface (slides, cracks, displacements and deformations of land subsidence with or without formation of lakes). For all of these phenomena is required continuous, complex and detailed monitoring (Teza et al., 2008).

In order to identify the instability of these phenomena in the early stages is necessary a permanent monitoring by various techniques and technologies that are designed to detect, prevent and solve problems in the areas of influence of mines, in order to protect the environment and population (Perski et al., 2009; Arad et al., 2012; Corsini et al., 2013; Vereș et al., 2013).

A 3D laser scanner is a device that analyzes a real object or scene to collect data on its form and possibly color. The collected data can be used to build three-dimensional digital models useful for a wide variety of applications, such as: reverse engineering and of prototypes, quality control / inspection and documentation of archaeological sites and historical monuments (Herban, 2012; Didulescu et al., 2013; Abellan et al., 2014; Blasone et al., 2014; Szostak et al., 2014).

Terrestrial laser scanning is a modern technique of measuring with a number of advantages: high precision and accuracy, reduced cost and time, speed recording, remote data logging, recorded data consist of a set of points with coordinates X, Y, Z, the possibility of performing spatial analysis etc., used in almost all areas of activity (Coșarcă et al., 2013; Ghuffar et al., 2013; Lowry et al., 2013; Pierzchala et al., 2014).

This method is feasible and convenient to determine the vertical displacements by comparing a number of scanning cycles providing a high precision (Negrilă, 2013; Singleton et al., 2014; Tarolli, 2014).

Laser scanning is the most modern method of acquiring precise information about complex spatial objects such as building facades with historical valences, industrial or construction areas and underground areas (Starek et al., 2011; Bozzano et al., 2014; Negrilă, 2014; El-Ashmawy, 2015; Lato et al., 2015).

Based on the many fields in which terrestrial laser scanning proves its usefulness and if we speak of topographical measurements and geodetic applications, the accuracy of determining the spatial position of the point cloud is an important parameter that should be considered and analyzed (Zhou et al., 2010; Sijercic et al., 2011; Rodriguez-Galiano & Chica-Rivas, 2014).

The purpose of this paper is to determine displacements and deformations that occur in the mining area of Slănic Prahova salt mine, using techniques and technologies for optimizing topographic works.

2. MATERIAL AND METHOD

The city of Slănic Prahova is located in the center of Romania, Prahova County, 45 km north of Ploiești, situated at an altitude of 413 m (Fig. 1). This settlement became known primarily due to salt deposit exploited for over three centuries.

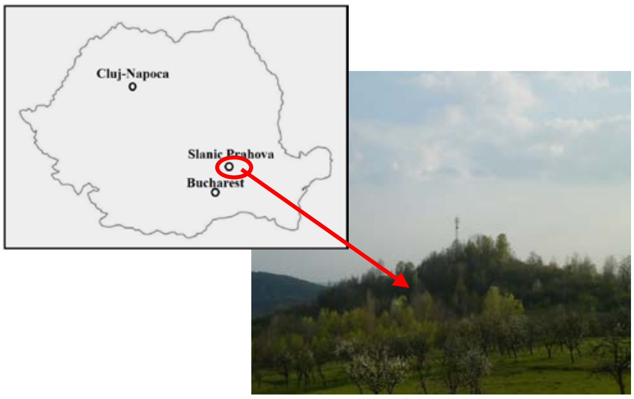

Figure 1. Geographical location of the study site.

The primary aims of this paper are:

- Performing surveying, plan-metric and leveling using the laser scanning technology.
- Processing measurements resulting from the scanning using software that enables the user to choose the appropriate method of processing

according to the characteristics of the object monitored in a more clear and detailed way.

- Creating the DEM (Digital Elevation Model) and the level curves, based on the model TIN (Triangulated Irregular Networks);
- Analysis of the current state of displacements and deformations.

Terrestrial laser scanning was performed with a 3D laser scanner Leica C10, on the corresponding surface of mine Victoria, Slănic Prahova salt deposit, Prahova County. Network support was performed using GNSS technology. Used receptors belong to the 1200 Series.

Terrestrial laser scanning was performed with a resolution of 5 cm, to a radius of 80-130 m. All scans had a common local coordinate system (created using the polygonal route supported on the retro-intersection points).

After completing these stages, the scan was conducted entirely by the specialized software of the instrument, the operator intervention not being needed. Scanning progress was monitored on the laptop screen.

The scans were performed independently from each station, at a resolution of 10 cm to 50 m, using *fine scanning* at the end of the targets attached on tripods or cane tripod at a resolution of 2 mm to 50 m. For a better identification of targets for sighting (prisms) in the cloud points, were made pictures in stations. We chose scan mode "*target all*" which involves 360^o scanning both vertically and horizontally.

Post processing was performed using Cyclone software v 5.0. Whether after registration the results correspond in terms of geometric and we consider them acceptable (deviations results fall within the required accuracy), the unwrought point cloud results in a single coordinate system, in this case being in the system of the national coordinates.

3. RESULTS AND DISCUSSIONS

During the actual scan were measured approximately 23 million points at a density of 600 points / sqm with an accuracy of less than 1 cm.

The resulting surface by laser scanning is 38515.84 m^2 (3D surface), respectively 36717.30 m^2 (2D surface - in horizontal projection) and represents the model of bare terrain (DTM).

In the case of the slope of Slănic Prahova salt mine, given the accuracies required for determining the 3D position of points, we chose a registering based on targets sight, which is the most accurate method of registration (georeference). Thus were placed 9 targets for sighting on which georeferencing was performed (Figure 2).

Figure 2. Targets for sighting

For comparison and control of the registration, two methods have been applied on the registration of targets.

The first method involved the introduction, using a scanning interface control, for each scanning station of the following items:

- coordinates of the station;
- instrument height;
- coordinates of the points on which were placed targets for sighting;
- target height.

As a result of registration performed with this method resulted: 6 mm absolute error, total errors for measured vectors with values between 2 mm and 9 mm, measured error for vector with the component values e_x between 0 mm and 6 mm, e_y between 0 mm and 9 mm and e_h between 0 mm and 6 mm.

The second method involved the making of the registration using the *traverse method.*

For this has been introduced the elements for both starting and closing points:

- coordinates of points;
- instrument height;
- target height.

As a result of the second registration resulted the following: absolute error of 5 mm, total errors for measured vectors with values between 2 mm and 10 mm, measured error for vector with the component values e_x between 0 mm and 4 mm, e_y between 0 mm and 7 mm and e_h between 0 and 10 mm.

The software component according to these data carried out automatically the registration of the cloud points. On the diagnostic interface of the registration one can follow: absolute recorded error, total errors for measured vectors, errors for measured vectors (by the components e_x, e_y and e_z) and transformation parameters (translations and rotations).

If the resulting error values exceed the required geometric precision of the final products it can be interfered with the control interface for registration by removing certain vectors in order to obtain results that are integrated in the proposed geometrical precision.

Based on data obtained from laser scanning we created the digital terrain model (Fig. 3) and the leveling contours (Fig. 5). These were obtained using the model TIN (Triangulated Irregular Networks), which is a network of spatial triangles (Fig. 4).

Based on TIN model and a chosen reference projection plan, we can calculate cut and fill volumes in order to choose the most convenient situation in terms of volume of excavation, filling volume and the surface on which engravings and the area will be filled. The position of the reference plane was set based on the square network on which the side length had been set, a table grid square corner position, its share and the difference between the reference and ground elevation. The differences are positive or negative depending on the position of the reference projection plan. In each position of the reference plane is obtained the cut and fill volumes and surfaces that must be cut and fill. Through successive attempts was obtained the best solution in terms of technical and economic factors, for the cut and fill area.

The volume of the resulting material by overlapping areas (that generated by 3D scanning and the one generated by vectorizing contour lines) was -250 490.01 m^3.

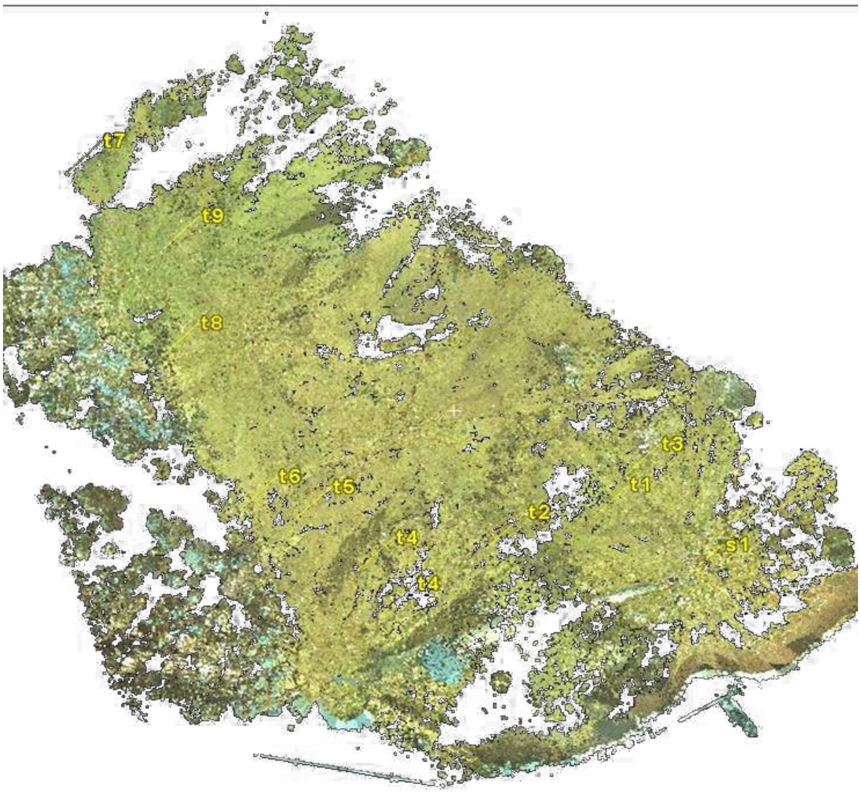

Figure 3. Georeferencing scanned area

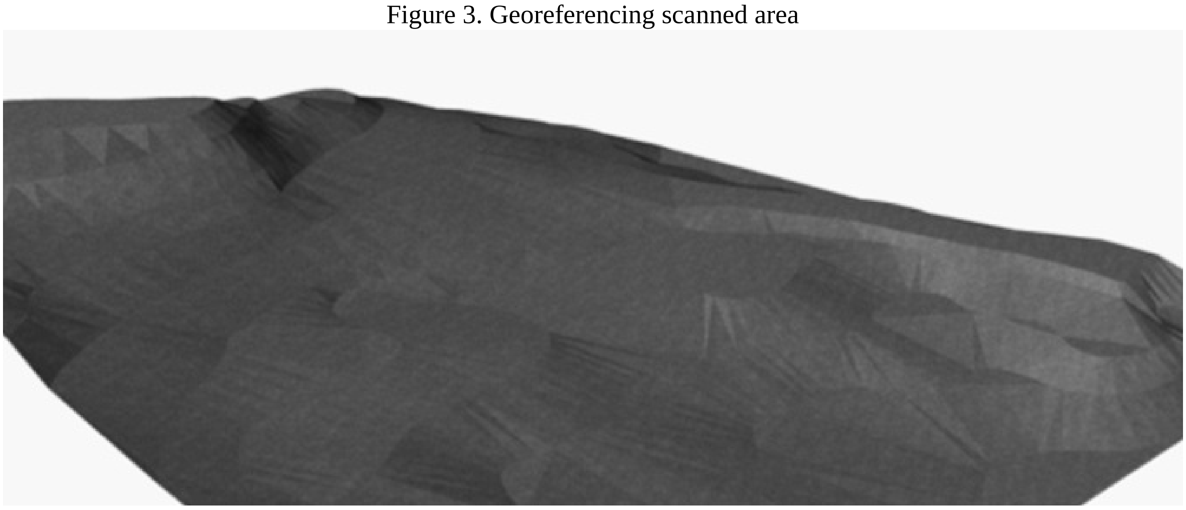

Figure 4. TIN model (Triangulated Irregular Networks)

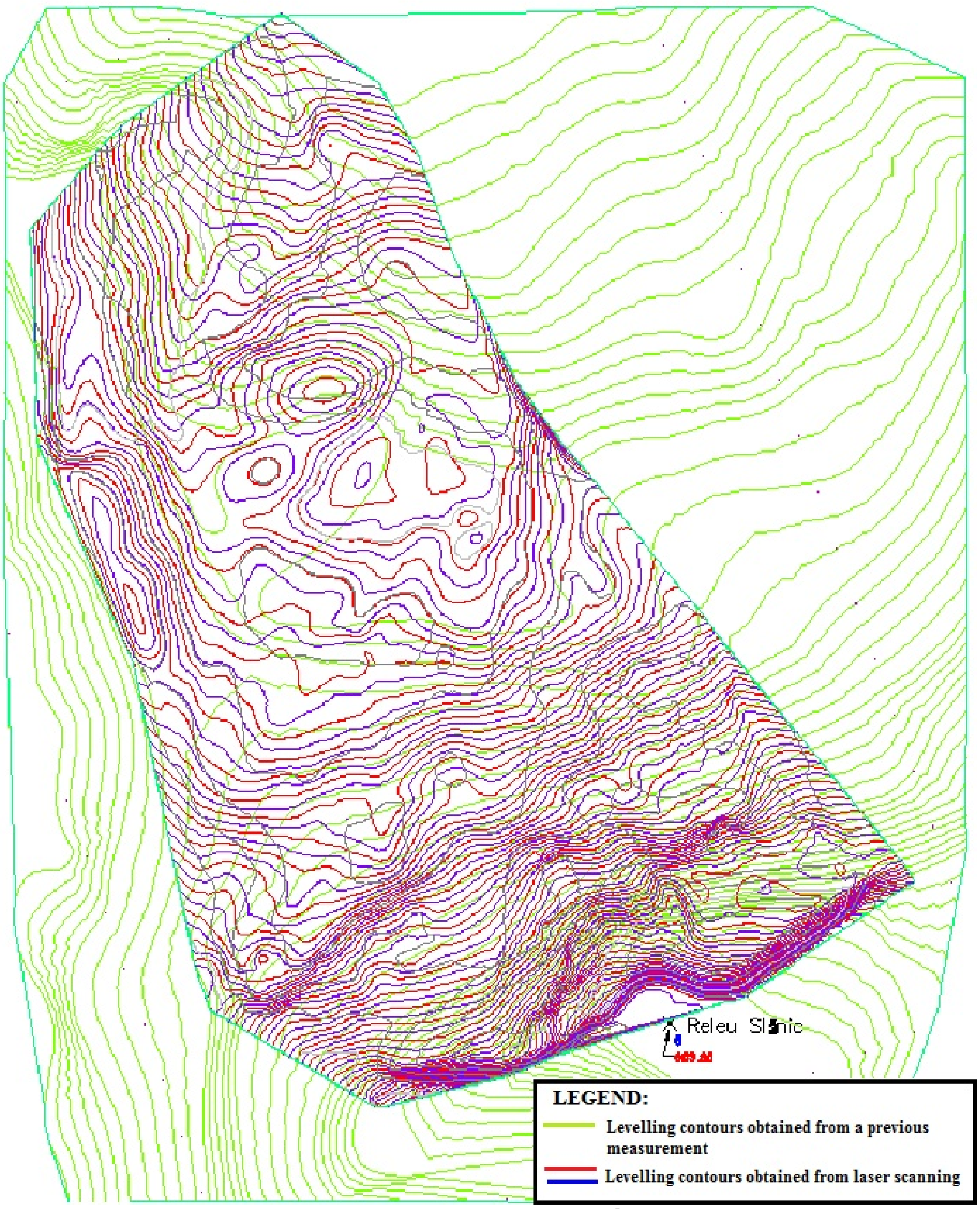

Figure 5. Contours generated

In the graphics program we have overlapped the two digital models of land, the reference level curves obtained by vectorization contained in the latest plane and the digital model obtained from scan processing. From the created model (Fig. 6) were extracted transverse and longitudinal sections to highlight the vertical movements of the land.

In the transversal (Fig. 8) and longitudinal (Fig. 7) sections vertical displacements resulting from the superposition of the two digital terrain models can be highlighted.

In the perimeter of Slănic Prahova, landslides are very common especially on slopes of the streams Tulburea, Baia Verde and Malul Roșu.

The most important landslide of the perimeter emerges on the right side of the stream Baia Verde, in the area of Slănic relay, the waters from the sliding surface having a salt-emergence at a rate of up to 4 l/s. The nature of the distortions and their size can be inspected visually and quickly identified through a comparative analysis presented in the next image.

In figure 9 is presented the scanned area and the most pronounced deformations. The most important deformation of the studied area is outlined on the right side of the stream Baia Verde, in the area of Slănic relay, having a value of -14.7 m.

For a clearer record of the areas where there was vertical displacement we achieved through color zoning the movements depending on the range displacements.

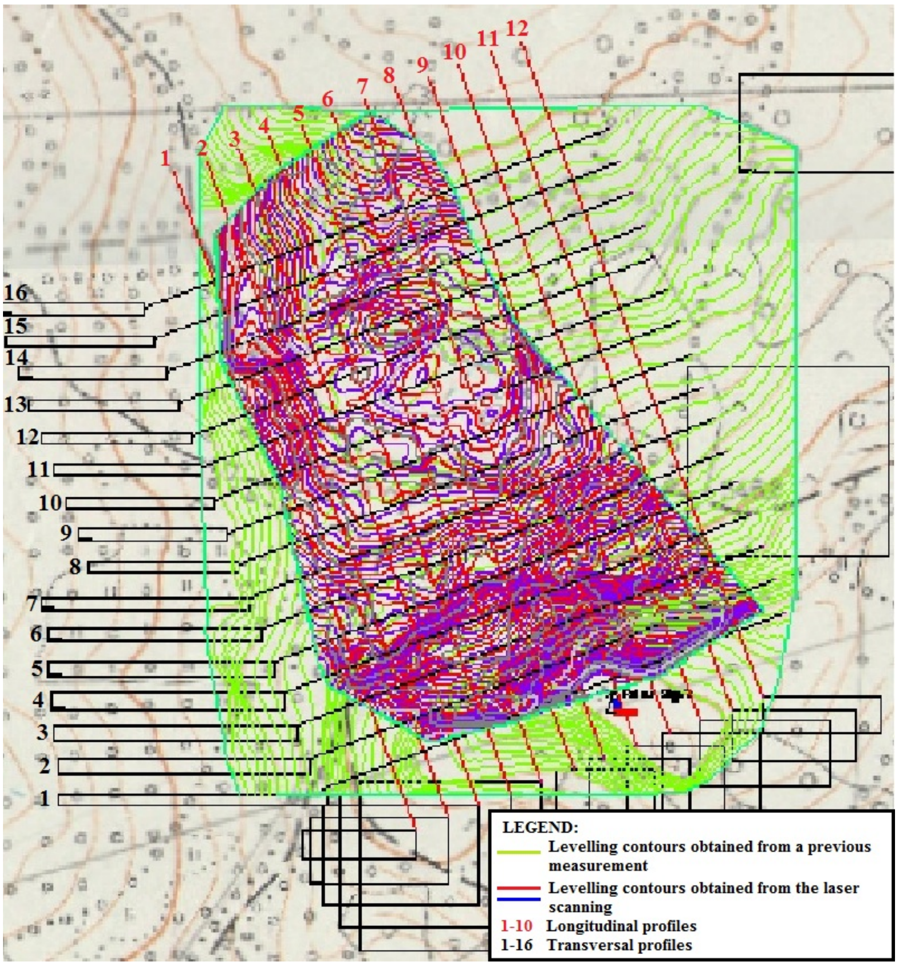

Figure 6. Situation plan with the two models presented digital of transverse and longitudinal sections

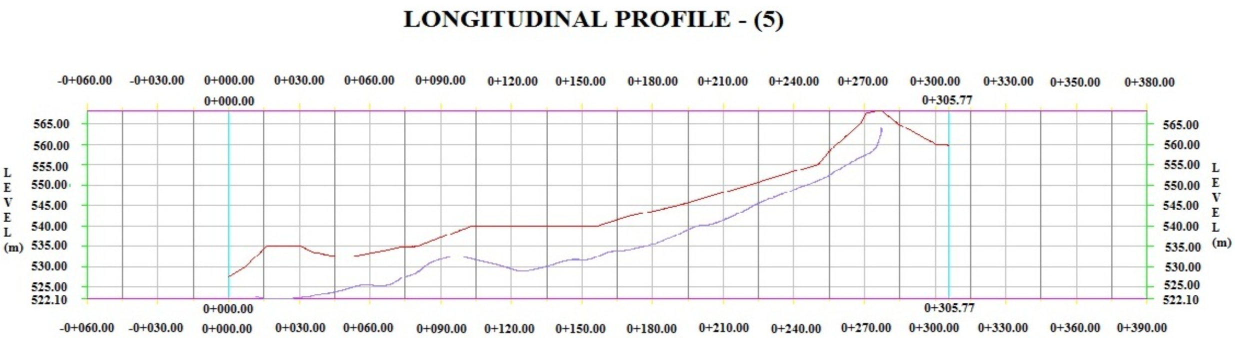

Figure 7. Longitudinal profile (longitudinal profile no. 5 from fig. 6)

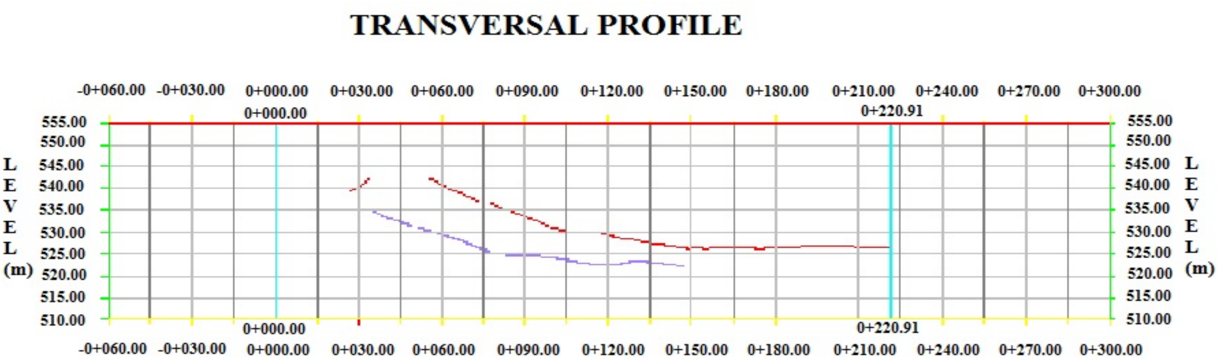

Figure 8. - Transversal profile (transversal profile no.10 from fig. 6)

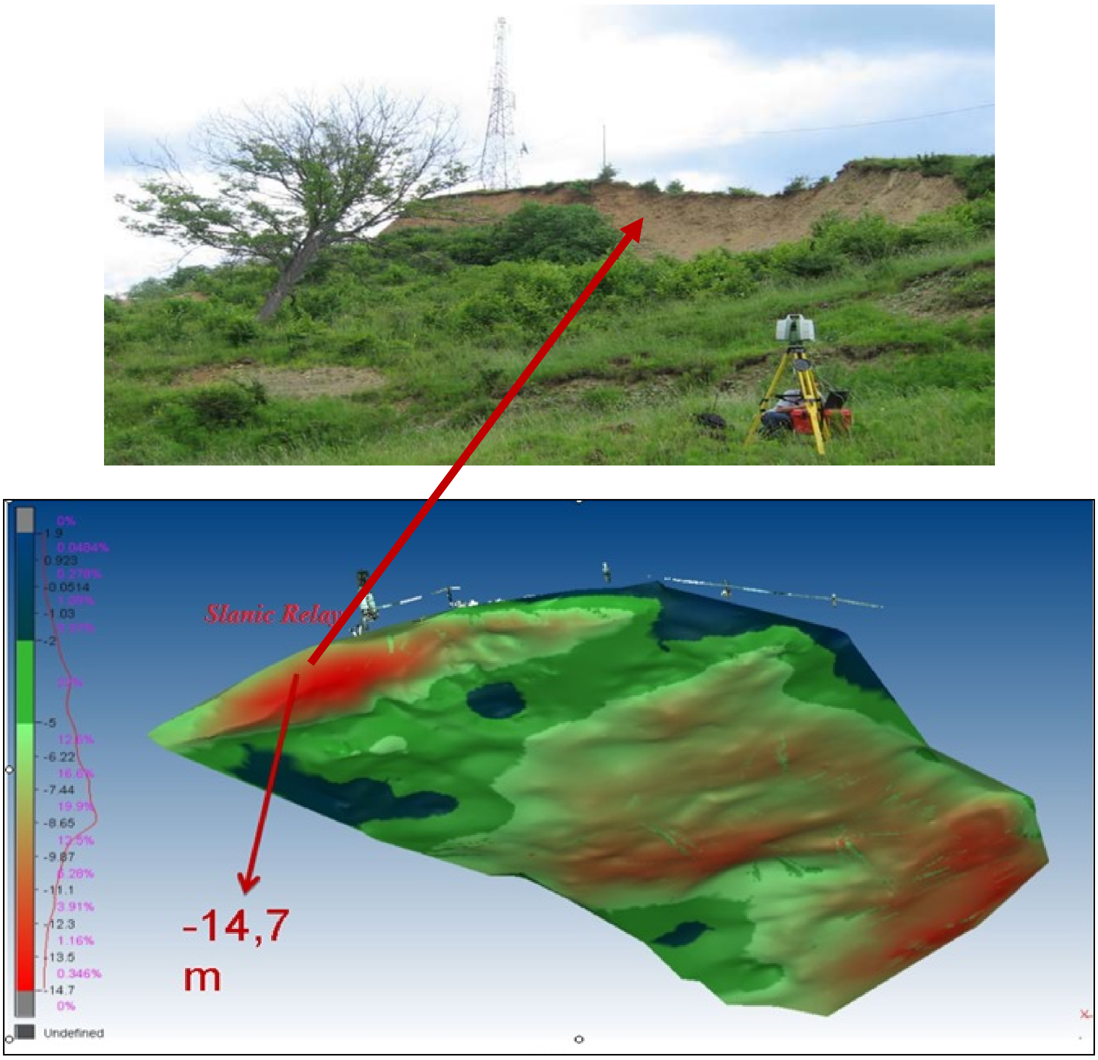

Figure 9. Deformations occurring between the reference surface and that from 3D scanning

Tulburea stream slopes are affected to an extent of 60-70% by landslides of areal nature. The ones from the right side are active and the ones from the left side are generally stabilized.

4. CONCLUSIONS

In terms of displacements and deformations one can conclude that there is, in the perimeter of Slănic, active geomorphologic processes shaping the landscape on large surfaces. The most intense and widespread are sliding processes, erosion and dissolution of salt. Perimeter surface modeling processes which are affecting large areas are due to a number of factors such as: topography, lithology, geological structure, precipitation patterns, lack of measures to combat erosion and landslides, etc.

In the mining area more and more frequently are recorded landslides, which make the formation of water sources infiltrations through unveiling at certain points the massif of salt and creating favorable conditions for the movement of water over the back of the salt where its drainage is secured.

Use of laser scanning considerably reduces the time to perform measurements and also the number of points acquired in a short time is very high, which helps the correct interpretation of scanned targets.

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REFERENCES

Abellan, A., Oppikofer, T., Jaboyedoff, M., Rosser, N.J., Lim, M. & Lato, M.J., 2014. *Terrestrial laser scanning of rock slope instabilities.* Earth Surface

Processes and Landforms 39(1), 80-97.
Arad, V., Vereş, I., Arad, S. & Rotaru R., 2012. *Study On The Surface Instability of the Salt Exploitation in Ocna Mures Area.* Proceedings of the 12th International Multidisciplinary Scientific Geoconference (SGEM), June 17-23, Albena, Bulgaria, 2012, 779-786.
Blasone, G., Cavalli, M., Marchi, L. & Cazorzi, F., 2014. *Monitoring sediment source areas in a debris-flow catchment using terrestrial laser scanning*. Catena 123, 23-36.
Bozzano, F., Cipriani, I., Mazzanti, P. & Prestininzi, A., 2014. *A field experiment for calibrating landslide time-of-failure prediction functions*. International Journal of Rock Mechanics and Mining Sciences 67, 69-77.
Corsini, A., Castagnetti, C., Bertacchini, E., Rivola, R., Ronchetti, F. & Capra, A., 2013. *Integrating airborne and multi-temporal long-range terrestrial laser scanning with total station measurements for mapping and monitoring a compound slow moving rock slide*. Earth Surface Processes and Landforms 38(11), 1330-1338.
Coșarcă, C., Didulescu, C., Savu, A., Sărăcin, A., Badea, Gh., Badea, A.C. & Negrilă, A., 2013. *Mathematical Models Used In Processing Measurements Made By Terrestrial Laser Scanning Technology.* Proceedings of the International Conference on Applied Mathematics and Computational Methods in Engineering (AMCME 2013), July 16-19, Rhodes Island, Greece, 2013, 184-188.
Didulescu, C., Savu, A., Badea, A.C. & Badea, G., 2013. *Using 3D terrestrial laser scanning technology to obtain 3D deliverables*. Advanced Science Letters, 19(1), 70-74.
Dragićević, S., Carevic, I., Kostadinov, S., Novkovic, I., Abolmasov, B., Milojkovic, B. & Simic, D., 2012. *Landslide Susceptibility Zonation in the Kolubara River Basin (Western Serbia) – Analisys of Input Da*ta. Carpathian Journal of Earth and Environmental Sciences, 7(2), 37-42
El-Ashmawy, K.L.A., 2015. *A comparison between analytical aerial photogrammetry, laser scanning, total station and global positioning system surveys for generation of digital terrain model.* Geocarto International, 30(2), 154-162.
Ghuffar, S., Szekely, B., Roncat, A. & Pfeifer, N., 2013. *Landslide Displacement Monitoring Using 3D Range Flow on Airborne and Terrestrial LiDAR Data*. Remote Sensing 5(6), 2720-2745.
Goel, K. & Adam, N., 2014. *A Distributed Scatterer Interferometry Approach for Precision Monitoring of Known Surface Deformation Phenomena*. IEEE Transactions On Geoscience And Remote Sensing 52(9), 5454-5468.
Herban, I.S., 2012. *Terrestrial Laser Scanning Used for3D Modeling.* Proceedings of the 12th International Multidisciplinary Scientific Geoconference (SGEM), June 17-23, Albena, Bulgaria, 2012, 795-804.
Lato, M.J., Hutchinson, D.J., Gauthier, D., Edwards, T. & Ondercin, M., 2015. *Comparison of airborne laser scanning, terrestrial laser scanning, and terrestrial photogrammetry for mapping differential slope change in mountainous terrain*. Canadian Geotechnical Journal 52(2), 129-140.
Lowry, B., Gomez, F., Zhou, W., Mooney, M.A., Held, B. & Grasmick, J., 2013. *High resolution displacement monitoring of a slow velocity landslide using ground based radar interferometry*. Engineering Geology 166(1-2), 160-169.
Negrilă, A., 2013. *Using terrestrial laser scan to monitor the upstream face of a rockfill weight dam.* Proceedings of the 1st European Conference of Geodesy & Geomatics Engineering (GENG '13), 8-10 October, Antalya, Turkey, 2013, 113-120.
Negrilă, A., 2014. *Using Terrestrial Laser Scanning Technology for Acquisition, Processing and Interpretation of Spatial Data from Anthropogenic Hazard and Risk Areas.* International Journal of Systems Applications, Engineering & Development, 8, 139-146
Perski, Z., Hanssen, R., Wojcik, A. & Wojciechowski, T., 2009. *InSAR analyses of terrain deformation near the Wieliczka Salt Mine, Poland*. Engineering Geology 106(1-2), 58-67.
Pierzchala, M., Talbot, B. & Astrup, R., 2014. *Estimating Soil Displacement from Timber Extraction Trails in Steep Terrain: Application of an Unmanned Aircraft for 3D Modelling*. Forests 5(6), 1212-1223.
Prokop, A. & Panholzer, H., 2009. *Assessing the capability of terrestrial laser scanning for monitoring slow moving landslides*. Natural Hazards and Earth System Sciences 9(6), 1921-1928..
Rodriguez-Galiano, V.F. & Chica-Rivas, M., 2014. *Evaluation of different machine learning methods for land cover mapping of a Mediterranean area using multi-seasonal Landsat images and Digital Terrain Models*. International Journal Of Digital Earth 7(6), 492-509.
Sijercic, I., Dervisevic, R., Celikovic, R., Mancini, F. & Stecchi, F., 2011. *Ground surface deformation of the urban area in complex engineering- monitoring slow moving landslides.* Natural Hazards and Earth System Sciences 9(6), 1921-1928.*geological conditions in the sinking town of Tuzla (Bosnia and Herzegovina).* Proceedings of the 11th International Multidisciplinary Scientific Geoconference (SGEM), June 19-25, Albena, Bulgaria, 2011, 481-488.
Singleton, A., Li, Z., Hoey, T. & Muller, J.P., 2014. *Evaluating sub-pixel offset techniques as an alternative to D-InSAR for monitoring episodic landslide movements in vegetated terrain*. Remote Sensing of Environment 147, 133-144.
Starek, M.J., Mitasova, H., Hardin, E., Weaver, K., Overton, M. & Harmon, R.S., 2011. *Modeling and analysis of landscape evolution using airborne, terrestrial, and laboratory laser scanning*. Geosphere 7(6), 1340-1356.
Szostak, M., Wezyk, P. & Tompalski, P., 2014. *Aerial*

Orthophoto and Airborne Laser Scanning as Monitoring Tools for Land Cover Dynamics: A Case Study from the Milicz Forest District (Poland). Pure and Applied Geophysics 171(6), 857-866.

Tarolli, P., 2014. *High-resolution topography for understanding Earth surface processes: Opportunities and challenges.* Geomorphology, 216, 295-312.

Teza, G., Pesci, A., Genevois, R. & Galgaro, A., 2008. *Characterization of landslide ground surface kinematics from terrestrial laser scanning and strain field computation*. Geomorphology 97(3-4), 424-437.

Vereş, I., Farcaş, R. & Ștefan, N., 2013. *Using laser scanning systems in salt mines perimeters in order to determine vertical movements*. Proceedings of the 13th International Multidisciplinary Scientific Geoconference (SGEM), June 16-22, Albena, Bulgaria, 2013, ISSN: 1314-2704, pp. 525-532.

Vereş, I., Farcaş, R. & Poruțiu A., 2014. *The topographic monitoring of the terrain damaged by the exploitation of salt in Ocna Mures, Romania*. Proceedings of the 14th International Multidisciplinary Scientific Geoconference (SGEM), June 19-25, Albena, Bulgaria, 2014, 583-590.

Zhou, Y., Yang, L. & Leng, Y.B., 2010. *Development of Terrain Deformation Monitor System Based on 3-D Laser Scanning Technology*. Applied Mechanics and Materials 36, 192-198.

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