# TLS USE FOR THE GEOLOGICAL STRUCTURES DOCUMENTATION

# VYUŽITIE TLS PRI DOKUMENTÁCII GEOLOGICKÝCH ŠTRUKTÚR

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**Abstract**

In recent years, the terrestrial laser scanners (TLS) started being tested and used in addition to their primary determination in surveying and construction of geological structures and phenomena documentation such as landslides, rock collapses and observation of their morphological changes. The aim of this paper is to demonstrate the applicability of terrestrial laser scanning systems for determining geological structural parameters - trend and dip of significant surface areas of rock massif or quarry wall. Compared to the classic method of surveying fieldwork, using the geological compass methodology presented in the article allows to determine the necessary parameters and to measure inaccessible areas, which represents a significant contribution to the structural-geological practice. Methodology verification was done by comparing the values of structural parameters directly measured using geological compass with the values determined from the spatial model measured by TLS.

**Abstrakt**

V posledných rokoch sa začali terestrické laserové skenery (TLS) testovať a využívať okrem ich primárneho určenia v geodézii a stavebníctve aj na dokumentáciu geologických štruktúr a javov ako sú napr. zosuvy, skalné zrútenia a pozorovanie ich morfologických zmien. Cieľom tohto príspevku je preukázať použiteľnosť TLS pri určovaní geologických štruktúrnych parametrov smeru a sklonu významných plôch skalného masívu či steny povrchového lomu. Oproti klasickému postupu meračských prác v teréne s použitím geologického kompasu metodika predkladaná v článku umožňuje určovať potrebné parametre aj meračovi neprístupných plôch, čo predstavuje významný prínos pre štruktúrno-geologickú prax. Overenie metodiky bolo vykonané porovnaním hodnôt štruktúrnych parametrov priamo meraných geologickým kompasom s hodnotami určenými z priestorového modelu meraného pomocou TLS.

**Keywords**

*Geological structural parameters, terrestrial laser scanning, 3D model*

**Kľúčové slová**

*Geologické štruktúrne parametre, terestrické laserové skenovanie, 3D model*

## 1 Introduction

Structural geology deals with the distribution of rock solids through the study of geological structures in the area, particularly studying their formation and evolution. It is an interdisciplinary science, incorporating knowledge of geomorphology, tectonics and metamorphic processes. When studying the rock deformation methods of structural analysis are used, which are applied in the analysis of changes in shapes of rock solids. It is necessary to analyze the data from the earth's surface, geological borehole and seismic measurements. Currently, structural geology increasingly begins to use 2D/3D modelling. Structural - geological geometric analysis as its basic method of analysis of spatial and orientation data, collects and evaluates information obtained by field research, from maps or GIS. Measurement data obtained in the field are captured in the geological maps using map symbols and dip and trench numerical values of significant surface areas or lines (Fig.1). The most common form of acquiring data is measurement by geological compass. In this case the measured areas must be directly accessed by the surveyor, which in practical terms is often difficult, or even impossible.

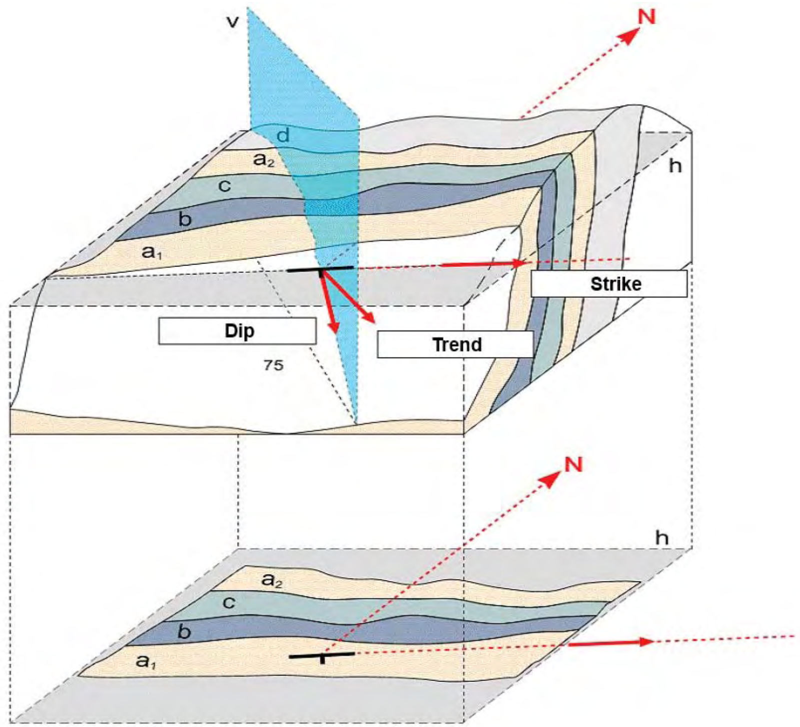


***Fig.1 Structural parameters expression (www.1).***

This problem can be solved by using contactless geodetic methods in order to create a spatial model of the measured object. Such methods are particularly the spatial polar method using total stations (TS), photogrammetric methods and terrestrial laser scanning (TLS) (BLIŠŤAN and KOVANIČ, 2012). Their use is now common and has also been published in works about the documentation of surface and line structures, historic sites (BARTOŠ et al. 2011; PUKANSKÁ, 2013), geological objects, underground and surface mining areas (FRAŠTIA, 2012; GIGLI and CASAGLIA, 2013; GARCÍA-SELLES et al., 2011; GAŠINEC et al., 2012; KYŠEĽA et al., 2013), volume determination (BLIŠŤAN, 2012; CANCER, 2013; LABANT et al., 2013) and others. Measurement result and input for processing are point clouds in the selected coordinate and height system. Point quantity in the clouds depends on the speed of the different methods of measurement and ranges from hundreds when the TS is used to millions points using photogrammetry and TLS. Processing files with a large amount of points and creation of spatial models requires a specific software package (BARTOŠ et al., 2014; KUZEVIČOVÁ et al., 2014). The intention of this paper is the verification of the possibility for modern contactless geodetic method TLS to obtain geological structural parameters that are derived from the 3D model indirectly in office evaluation.

## 2 Terrestrial laser scanners

TLS is a modern and fast method for spatial data collection about objects with the goal to create their 3D models. Similarly like the geodetic total stations, the fundamental principle for determining the spatial coordinates of the measured points is spatial polar method (BLIŠŤAN and KOVANIČ, 2012). Measurement with TLS is highly automated; the main surveyor´s task is the definition of the measuring range (area of interest) and setting the density of measured points through the planar distance of neighbouring points. Its value can theoretically be from 1 mm; in practical measurements it depends on the size and complexity of the subject and also the required degree of detail and it ranges from centimetres to decimetres. The next measurement process is then fully automated and extremely fast. In consideration with the speed of measurement by TLS device, resulting point cloud can contain millions of points in a short time needed for field surveying. High density of measurement points ensures the required level of detail of the resulting 3D model and the highest degree of similarity with the real object. TLS Leica ScanStation C10 device was used (Fig.2) in our work. Before data collection it is important to evaluate the accuracy of the method. Positional accuracy of TLS can be expressed as polar method accuracy, namely the mean positional error of point coordinates $m_p$ according to the equation (BLIŠŤAN and KOVANIČ, 2014):

$$m_P^2 = m^2{}_{pA} + \sin^2 z \times m_S^2 + s^2.\cos^2 z \times \left(\frac{m_z}{\rho}\right)^2 + s^2 \times \sin^2 z \times \left(\frac{m_\omega}{\rho}\right)^2 , \qquad (1)$$

where: $m_{pA}$ = *instrument station positional error,*
$s$ = *slope distance,*
$z$ = *zenith angle,*
$m_\omega$ = *mean error of measured bearings,*
$m_z$ = *mean error of measured zenith angles,*
$m_s$ = *mean error of measured distance,*
$\rho$ = *conversion coefficient from arc unit.*

Height accuracy is determined by the mean error derived for trigonometric measurement heights according to the relation (BLIŠŤAN and KOVANIČ, 2014):

$$m_h^2 = m^2{}_{hA} + \cos^2 z \times m_S^2 + s^2 \times \sin^2 z \times \left(\frac{m_z}{\rho}\right)^2 , \qquad (2)$$

where: $m_{hA}$ = *instrument station height error.*

Selected technical parameters of the used instrument are show in www.2.

***Fig.2 TLS Leica ScanStation C10 (www.2)***

## 3 Object of measurement description, data collection and data processing

Research on the use of TLS for documentation of geological structures was carried out on two quarry walls. First chosen quarry wall (Fig.3) is a relatively regular solid with dimensions 80 m (length) x 20 m (height). Second chosen quarry wall has mostly irregular surface (Fig.4). It has dimensions 50 m (length) x 10 m (height). Geological compass measurement was made at geologically significant areas. For their easy identification in the future point cloud these areas were continuously measured by single point with spatial polar method using TS in the same coordinate and height system in which the terrestrial laser scanning was realized (KOVANIČ and NÉMETH, 2013).

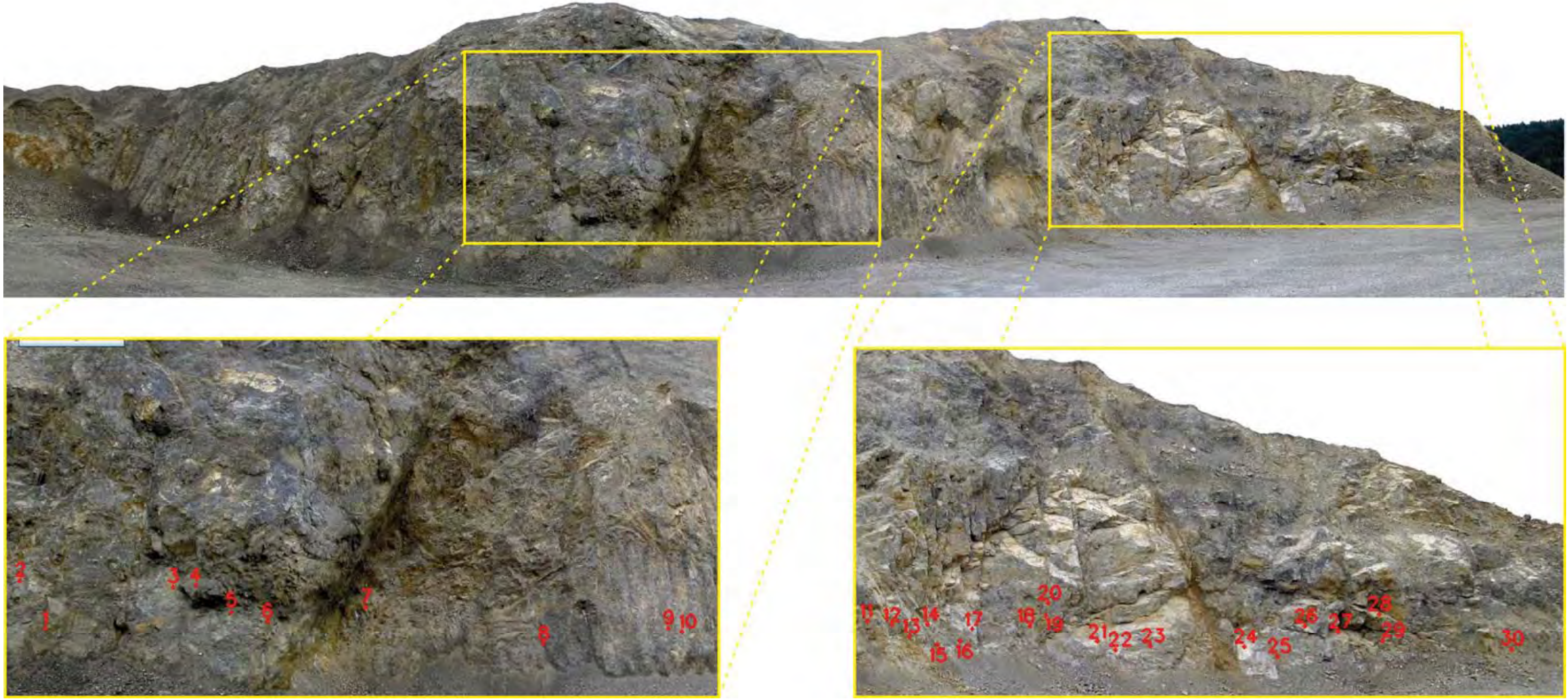


***Fig.3 First object of measurement – quarry wall. Localization of measured points.***

Auxiliary measuring points, serving as station and orientation of the device, have been given due the operation in the quarry stabilized temporarily by surveying nail. Coordinates and heights of these points were determined by RTK GNSS Leica GPS900CS networked with reference stations SKPOS. The observation period at one point was set to 10 minutes. The horizontal accuracy of the coordinates of points determined as follows (guaranteed service SKPOS) is usually ± 20 mm and ± 40 mm vertically with respect to the measurement conditions.

Measurement of detailed points on the surface of the mining wall was performed from a distance of approximately 50 m by terrestrial laser scanning method. The mean errors of coordinates and a height of detailed points determined by the method according to the device parameters provided by the manufacturers are about the same: $m_P \doteq m_h \doteq \pm 6mm$ . The measurement result was a point cloud in a coordinate system S-JTSK and height system Bpv consisting of about 1.2 million detailed points of the object with their mutual spatial distance approximately 1 cm. Dip and trend values of significant areas from the measurements obtained by the TLS method were determined in a graphical software environment Trimble RealWorks 6.5 by inserting surfaces through corresponding points in the contoured shape, and were corrected by the meridian convergence value - the angle between parallels to the + X axis of coordinate system and the direction of the geographic meridian in point of measurement (BUCHAR, 1981; GAŠINEC and GAŠINCOVÁ, 2013) and the value of magnetic declination - the angle between the direction of the magnetic and geographic meridian at the point of measurement (www.3). Such modified results are mutually compatible and comparable with values obtained by geological compass.


***Fig.4 Second object of measurement – detail of quarry wall. Localization of measured points.***

## 4 Results and discussion

The results of experiments conducted on the first quarry wall suggest the following conclusions. Trend and dip values determined from the TLS model were compared with values obtained by geological compass on the 29 identical points some of which are shown in Fig.3 The trend values differences are in the range of - 24° to 8°, which corresponds to the percentage of values from - 6.7 % to + 2.2 %. The dip values differences are in the range of - 19° to + 14°, which corresponds to the percentage of values from - 21.1 % to + 15.5 %.

Mean of the trend values differences is - 8.9° which is equivalent to - 2.5 %. Mean of the dip values differences is - 0.1° which is equivalent to - 0.1 %. Table 1 demonstrates the small difference of trend and dip values at comparing areas.

***Tab.1 First quarry wall - structural parameters (trend and dip) comparison measured by geological compass and the same parameters obtained by the methodology of terrestrial laser scanning (TLS) (KOVANIČ and NÉMETH, 2013)***

| Area number | Area dimensions [cm] | Geological compass values | | Values obtained by TLS model | | Differences | | Differences in percentages | |
|---|---|---|---|---|---|---|---|---|---|
| | | Trend [°] | Dip [°] | Trend [°] | Dip [°] | Trend [°] | Dip [°] | Trend [%] | Dip [%] |
| 1 | 10x10 | 150 | 40 | 158 | 47 | -8 | -7 | -2.2 | -7.7 |
| 2 | 8x8 | 162 | 60 | 175 | 64 | -13 | -4 | -3.6 | -4.4 |
| 3 | 20x20 | 137 | 70 | 146 | 70 | -9 | 0 | -2.5 | 0.0 |
| 4 | 30x30 | 176 | 68 | 200 | 66 | -24 | 2 | -6.7 | 2.2 |
| 5 | 10x10 | 182 | 63 | 196 | 60 | -14 | 3 | -3.9 | 3.3 |
| 6 | 5x5 | 118 | 84 | 117 | 77 | 1 | 7 | 0.3 | 7.7 |
| 7 | 5x5 | 140 | 73 | 145 | 67 | -5 | 6 | -1.4 | 6.6 |
| 8 | 5x5 | 172 | 56 | 177 | 56 | -5 | 0 | -1.4 | 0.0 |
| 9 | 5x5 | 192 | 58 | 196 | 77 | -4 | -19 | -1.1 | -21.1 |
| 10 | 10x10 | 202 | 46 | 215 | 49 | -13 | -3 | -3.6 | -3.3 |
| 11 | 15x15 | 28 | 75 | 32 | 89 | -4 | -14 | -1.1 | -15.5 |
| 12 | 10x10 | 18 | 82 | 30 | 89 | -12 | -7 | -3.3 | -7.7 |
| 13 | 5x5 | 200 | 81 | 210 | 82 | -10 | -1 | -2.8 | -1.1 |
| 14 | 7x7 | 194 | 40 | 211 | 37 | -17 | 3 | -4.7 | 3.3 |
| 15 | 5x5 | 204 | 82 | 227 | 75 | -23 | 7 | -6.4 | 7.7 |
| 16 | 10x10 | 206 | 85 | 223 | 77 | -17 | 8 | -4.7 | 8.8 |
| 17 | 15x15 | 186 | 50 | 183 | 48 | 3 | 2 | 0.8 | 2.2 |
| 18 | 5x5 | 181 | 60 | 192 | 58 | -11 | 2 | -3.1 | 2.2 |
| 19 | 10x10 | 212 | 83 | 222 | 79 | -10 | 4 | -2.8 | 4.4 |
| 20 | 10x10 | 28 | 85 | 51 | 87 | -23 | -2 | -6.4 | -2.2 |
| 21 | 15x15 | 205 | 55 | 210 | 53 | -5 | 2 | -1.4 | 2.2 |
| 22 | 10x10 | 201 | 62 | 206 | 60 | -5 | 2 | -1.4 | 2.2 |
| 23 | 10x10 | 218 | 88 | 220 | 85 | -2 | 3 | -0.6 | 3.3 |
| 24 | 15x15 | 210 | 56 | 219 | 56 | -9 | 0 | -2.5 | 0.0 |
| 25 | 10x10 | 217 | 77 | 223 | 81 | -6 | -4 | -1.7 | -4.4 |
| 26 | 15x15 | 175 | 54 | 189 | 56 | -14 | -2 | -3.9 | -0.6 |
| 27 | 20x20 | 188 | 45 | 196 | 48 | -8 | -3 | -2.2 | -2.2 |
| 28 | 20x20 | 199 | 68 | 191 | 54 | 8 | 14 | 2.2 | 15.5 |
| 29 | 20x20 | 261 | 61 | 262 | 64 | -1 | -3 | -0.3 | -3.3 |

Comparison of TLS method against the classic compass method was also conducted by applying standard tectonograms used in structural geology (Fig.5). This expression of structural parameters of selected areas was realized on the eastern side of the quarry wall in the northern end of the second storey. Fig.5 a, b shows the parameters measured by geological compass, Fig.5 c, d parameters derived from the 3D model obtained by laser scanner Leica ScanStation C10. Left tectonograms note with great curves of measured areas (intersections with the lower hemisphere). Right contour tectonograms reflect the position of the poles of these areas.

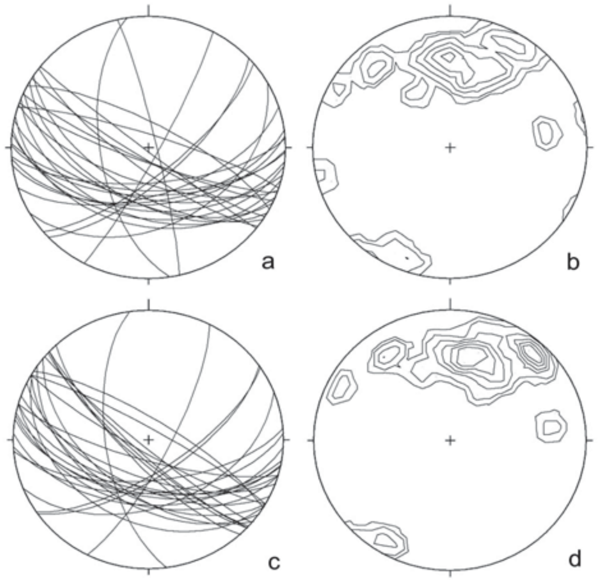


***Fig.5 Tectonograms of compared areas - first quarry wall (KOVANIČ and NÉMETH, 2013)***

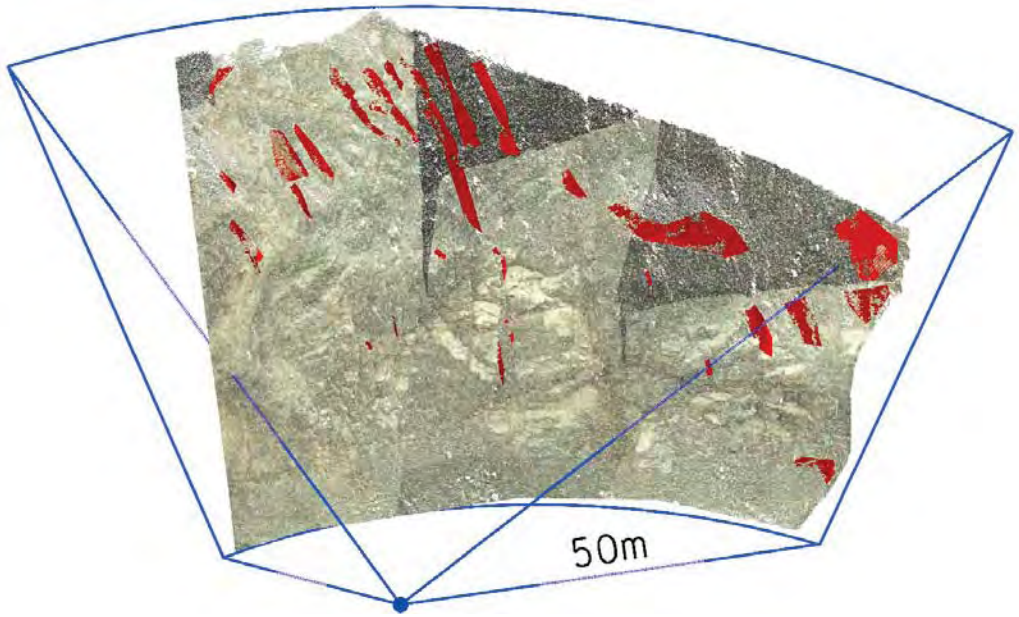


***Fig.6 Not measured area of the first quarry wall - hidden from TLS station (KOVANIČ and NÉMETH, 2013)***

The first quarry wall measurement was realized from only one station of the TLS instrument situated in an upright position about 50 meters from the scanned surface (quarry wall). This allowed scanning only the area immediately reachable by the laser beam, with azimuth in range 90 270$^{o}$ and orientation of the quarry wall to the south (azimuth range up to 180°). Fig.6 shows areas that are hidden from the view of the instrument. For detailed point measurement on this surface, it is necessary to obtain TLS measurements from several stations. The first documented quarry wall is relatively flat, mostly without significant morphological formations on its surface (Fig.3). However not measurable areas on its surface are found mostly in its upper part (Fig.6). Their TLS measurement would require elevated scanner station, but this was not technically possible in the given situation in the quarry.

***Tab.2 Second quarry wall - structural parameters (trend and dip) comparison measured by geological compass and the same parameters obtained by the methodology of terrestrial laser scanning (TLS)***

| Area number | Area dimensions [cm] | Geological compass values | | Values obtained by TLS model | | Differences | | Differences in percentages | |
|---|---|---|---|---|---|---|---|---|---|
| | | Trend [°] | Dip [°] | Trend [°] | Dip [°] | Trend [°] | Dip [°] | Trend [%] | Dip [%] |
| 1 | 100x30 | 185 | 68 | 183 | 66 | -2 | -2 | -0.5 | -2.2 |
| 2 | 7x9 | 113 | 75 | 120 | 70 | 7 | 5 | 1.9 | 5.5 |
| 3 | 40x40 | 110 | 77 | 115 | 70 | 5 | 7 | 1.3 | 7.7 |
| 4 | 35x35 | 209 | 82 | 200 | 85 | -9 | 3 | -2.5 | 3.3 |
| 5 | 150x100 | 200 | 89 | 199 | 87 | -1 | -2 | -0.2 | -2.2 |
| 6 | 30x30 | 68 | 73 | 70 | 70 | -2 | -3 | -0.5 | -3.3 |
| 7 | 50x10 | 208 | 85 | 203 | 80 | -5 | -5 | -1.3 | -5.5 |

The second quarry wall was with regard to its pronounced articulation measured from two scanner stations (Fig.4) with the mutual registration of both point clouds. The aim was to cover the whole quarry wall without hidden areas. Scanner stations were chosen so that the incidence angle of the laser beam was approximately perpendicular to the documented surface. By doing this, we wanted to eliminate the effects resulting from the geometry of the laser beam on the error in the determination of a point (SOUDARISSANANE et al., 2011). The measurement results of the second quarry wall are documented by tectonogram (Fig.7) and table 2.

Trend and dip values determined from the TLS model were compared with values obtained by geological compass on the 7 identical points. The trend values differences are in the range of - 9 ° to + 7 °, which corresponds to the percentage of values from - 2.5 % to + 1.9 %. The dip values differences are in the range of - 5 ° to + 7 °, which corresponds to the percentage of values from - 5.5 % to + 7.7 %. Mean of the trend values differences is - 1.0° which is equivalent to - 0.5 %. Mean of the dip values differences is 0.4° which is equivalent to 0.4 %. Tab.1 demonstrates the small difference of trend and dip values at comparing areas.

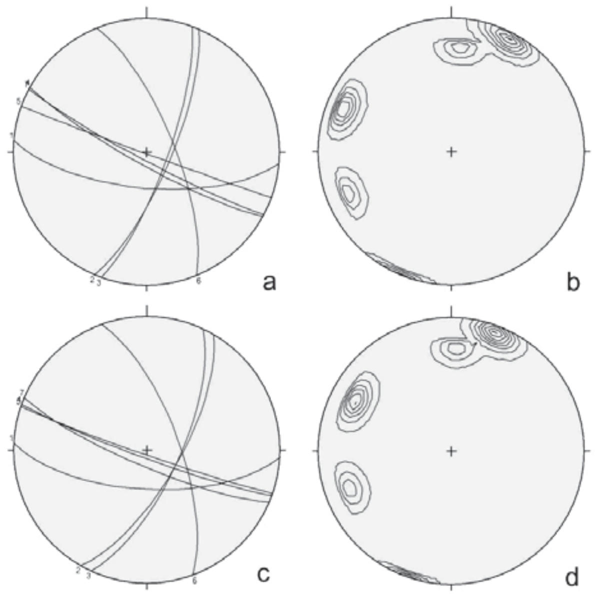


***Fig.7 Tectonograms of compared areas - second quarry wall.***

# 5 Conclusions

Documentation of geological structures plays an important role in modern geology as well. Baseline measurements are performed by geologists still using geological compass – hand measurement directly on the outcrops, fault planes or cracks. For documentation of tall and inaccessible outcrops, the compass measurements can not be implemented. Therefore a methodology for indirect measurement of geological structures has been tested. Methodology is based on a precise geodetic survey of the object using terrestrial laser scanning. Data processing needs special software where the spatial data (point cloud) is used to determine the structural elements (direction of slope and slope), which the geologist would have measured using the geological compass.

The analysis of results of the TLS use for the documentation of geological structures has shown that measurements made on the reference surfaces by the geological compass show considerable conformity compared to the TLS measurements. Certain differences found when comparing the values of measurements obtained by the geological compass and derived from the 3D model obtained by TLS are attributed to the lower precision of compass measurements resulting from its fundamentals. On the basis of the results the presented TLS methodology can be recommended as suitable for obtaining structural parameters of inaccessible areas. The quality of the results obtained from TLS measurement directly affects mainly the density of measured points and the resulting level of detail of the modeled surface. Using the TLS method we are able to obtain files with high point cloud density and also we collect spatial data at the critical (inaccessible) areas of the object without the intervention of the surveyor. To ensure the best results, it is appropriate to survey the object of interest using several stations. It would reduce the quantity of non measured parts of the surface while the point quantity and the accuracy of geological parameters would increase. TLS is a modern and efficient method of data collection and in addition to the traditional use e.g. in construction or engineering it would certainly find utilization in the documentation of geological structures of rock walls.

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