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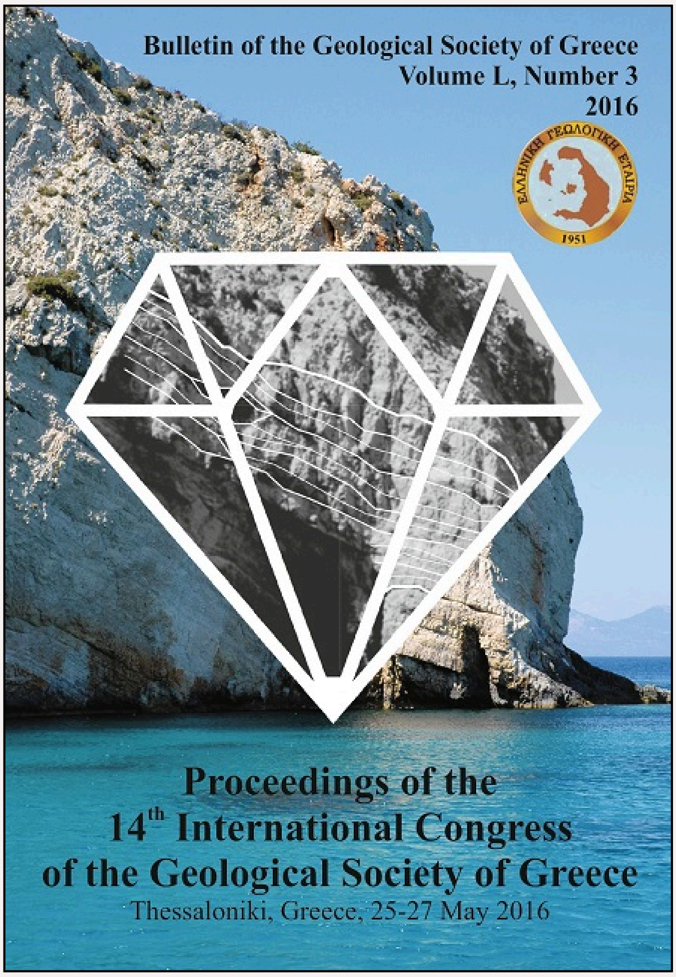

UNMANNED AERIAL VEHICLES FOR GEOLOGICAL APPLICATIONS

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UNMANNED AERIAL VEHICLES FOR GEOLOGICAL APPLICATIONS

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Abstract

Remote Sensing and photogrammetric techniques have always been used in geological applications. Current advancements in the technology behind Unmanned Aerial Vehicles (UAVs), in accordance with the consecutive increase in affordability of such devices and the availability of photogrammetric software, makes their use for large or small scale land mapping more and more popular. With the UAVs being used for mapping, the problems of increased costs, time consumption and the possible accessibility problems -due to steep terrain-, are all solved at once.

In this study, a custom-made UAV with 2 cameras onboard, is used to monitor two complex –regarding their topography- regions in Western Greece. One open pit limestone mine and a landslide occurring on sandy-clayous sediments. Both regions were mapped using surveying instruments like tachymeters and geodetic GPS, as well as using the aforementioned UAV system. 3D models of both regions were created using off-the-shelf photogrammetric software. For the creation of the 3D models, multiple targets were placed on the ground, to indicate GCPs with precisely known coordinates that could be identified in the high-resolution air photos, in order to maintain low Root Mean Square Error, while creating the DSMs and Orthophotos. In addition, the fish-eye effect caused by the cameras' wide-angle lens was taken into consideration, regarding whether or not it affects the models' overall geometric accuracy. Finally, the 3D models were compared to the survey measurements and the results are presented in this paper.

Keywords: *Landslide, open-pit mine, monitoring, airphoto UAV.*

Περίληψη

Οι τεχνικές της Τηλεπισκόπησης και της Φωτογραμμετρίας ανέκαθεν χρησιμοποιούνταν σε γεωλογικές εφαρμογές. Η πρόοδος της τεχνολογίας των μη Επανδρωμένων Αέριων Οχημάτων (UAV), σε συνδυασμό με τη συνεχόμενη μείωση του κόστους απόκτησης των και την αυξημένη διαθεσιμότητα φωτογραμμετρικού λογισμικού, καθιστούν ολοένα και πιο δημοφιλή την επιλογή τους για μικρής έκτασης και μεγάλης κλίμακας χαρτογραφήσεις. Με τη χρήση των UAVs σε χαρτογραφήσεις, ξεπερνιούνται τα προβλήματα του αυξημένου κόστους, της κατανάλωσης χρόνου και των πιθανών δυσκολιών στην προσβασιμότητα –λόγω απότομου αναγλύφου.

Σε αυτή τη μελέτη, ένα εξακόπτερο UAV το οποίο φέρει δύο κάμερες, χρησιμοποιείται γα την παρακολούθηση δύο πολύπλοκων –από πλευράς τοπογραφίας- περιοχών στη Δυτική Ελλάδα. Ένα λατομείο ασβεστολίθου και μία κατολίσθηση επί αμμοαργιλωδών ιζηματογενών πετρωμάτων. Και οι δύο περιοχές χαρτογραφήθηκαν με τη βοήθεια τοπογραφικών οργάνων, όπως ταχύμετρα και γεωδαιτικά GPS, όπως επίσης και με το προαναφερθέν UAV. Τρισδιάστατα μοντέλα δημιουργήθηκαν και για τις δύο περιοχές *με τη χρήση ειδικού φωτογραμμετρικού λογισμικού. Για τη δημιουργία των τρισδιάστατων μοντέλων, πολλαπλοί στόχοι τοποθετήθηκαν στο έδαφος και μετρήθηκαν με τη βοήθεια διαφορικού GPS για να χρησιμοποιηθούν ως σημεία εδαφικού ελέγχου. Οι στόχοι αυτοί με γνωστές συντεταγμένες μπορούσαν εύκολα να εντοπιστούν στις υψηλής ανάλυσης αεροφωτογραφίες, και να χρησιμοποιηθούν στην φωτογραμμετρική διαδικασία για να διατηρηθεί χαμηλό το σφάλμα RMS, κατά τη διάρκεια της δημιουργίας Ψηφιακού Μοντέλου Επιφανείας και ορθοεικόνων. Επιπρόσθετα, εξετάστηκε το κατά πόσο οι όποιες παραμορφώσεις προκαλούνται από τον ευρυγώνιο φακό των καμερών επηρεάζουν τη συνολική γεωμετρική ακρίβεια των μοντέλων. Τέλος, τα τρισδιάστατα μοντέλα συγκρίθηκαν με τις τοπογραφικές μετρήσεις και τα αποτελέσματα παρουσιάζονται σε αυτή τη μελέτη.*

Λέξεις κλειδιά: *Λατομείο, κατολίσθηση, παρακολούθηση, αεροφωτογραφίες.*

1. Introduction

Landslides have always been an important natural hazard in Western Greece as a result of a variety of factors with the most important being, the lithology of the prone to slide, their tectonic structure, the seismicity and the heavy rainfalls (Sabatakakis *et al.*, 2013; Koukouvelas *et al.*, 2015). Landslide events can occur without a warning and thus can harm civilian lives or properties. Because of harmless landslides monitoring techniques, should be able to come up with results very fast. Thus the traditional landslides monitoring techniques using field instrumentation, like topographic surveys (tacheometry, geodetic GPS networks), inclinometers and open standpipe piezometers are progressively benefited by the remote-sensing technology improvements. The last decades, more and more researchers have turned towards remote-sensing and photogrammetry in order to monitor landslides. For example satellite or aerial panchromatic imagery (Kääb, 2007) provide medium to high spatial resolution and in the case of satellite imagery a re-capture of an area can be performed within a few days, depending on the satellite. Radar imagery (DInSAR) is also used to monitor terrain deformations as well as to estimate the rheology, volume and kinematics of a landslide with very high accuracy (Belardinelli, 2003; Delacourt, 2007; Booth, 2013). Combined use of optical and radar data has been assessed for a small landslide mapping in western Greece (Nikolakopoulos *et al.*, 2013). Another high accuracy method is the LiDAR, which creates very detailed terrain representations since it has the ability to penetrate the canopy, but LiDAR expeditions can be extremely costly. Relative to the latter is the terrestrial laser scanning method (Cheok, 2002; Lichti, 2005) which provides highly dense and accurate point clouds, but the deployment of such surveys can be time consuming and –sometimes- very difficult when having to deal with very steep terrain. Using the techniques mentioned above, fast response to landslide events might not be possible.

Open-pit or quarry monitoring is carried out with multitemporal topographical surveys using field instrumentation (tachymeters, geodetic GPS etc.). Thus, one can come up with excavation volumes with high accuracy. However, such methodology is very time consuming -given the area that has to be mapped, which leads to high costs. In similarity as analyzed above quarry or open-pit mines monitoring surveys, are also benefited from remote-sensing techniques. Almost all the types of remote sensing data are used for quarry monitoring with quite good results. In previous studies multispectral data with medium spatial resolution (from satellites like ASTER, Landsat 5 and Landsat 7) were used to examine the expansion of quarries and their affect on the vegetation cover (Schmidt and Glaesser, 1998; Koruyan *et al.*, 2012). High resolution remote sensing data like Formosat, Ikonos, Quickbird etc., have been also used during over the last decade (Bonifazi *et al.*, 2003; Cheng *et al.*, 2005; Nikolakopoulos *et al.*, 2010). Stereo-pairs of ALOS and Cartosat with a spatial resolution of 2,5m and digital photogrammetry have been proved an effective tool for open pit mine monitoring in Greece (Argyropoulos *et al.*, 2014). The differential interferometric synthetic aperture radar (DInSAR) technique is used to derive the temporal land subsidence information in coal mine areas (Yue *et al.*, 2011; Liu *et al.*, 2013). The combination of InSAR and GPS technology is also used to monitor subsidence in coal mining areas (Tang *et al.*, 2012; Wu *et al.*, 2012).

A newer and more comfortable solution for both landslide and mine monitoring could be the use of Unmanned Aerial Vehicles (UAVs) as they provide ultra-high, centimeter grade spatial resolution imagery from onboard cameras. In addition to that and regarding the case of landslides, they can be deployed when fast response is needed. Also, the use of such systems is time effective, since large areas can be mapped in a fairly small time. When their use is combined with Ground Control Points, highly accurate 3D models can be created that can be used to carry out qualitative and quantitative measurements.

In the current study two characteristic examples of using UAVs for monitoring a landslide and an open-pit mine are presented. The photogrammetric results obtained from the aerial campaigns are compared to classical topographic surveys and their accuracy is estimated.

2. Study Areas

2.1. Geographical Setting

Both areas are located in Western Greece. The open-pit limestone mine is located at the Araxos Peninsula near Patras and the landslide is located at the Analipsis village near Amalias (Figure 1).

2.2. Geological Setting

The Analipsis village landslide encountered sands of the Vounargo formation (Pl_8-Pt.l,s). The marine-lacustrine Vounargo formation consists of sands with alternations of clays, silts, sandstones and marls deposits. The encountered sands are fine- to medium-grained and are characterized by well developed sedimentary structures (banded stratification, flute casts, mainly in the sand members of the formation etc.). They include macro- and micro-fossils or their casts (calcitic or arenaceous), which often form lenses and layers of “lumachelle” of small thickness (0.1 m to 1.2 m).These layers are usually succeeded by thin-bedded calc loams and arenaceous limestones 0.5-1m thick, as well as lenticular lignite bodies with rich fauna or lacustrine and marine mollusks. Locally, their thickness becomes up to 10 m. The Vounargo formation has Upper Pliocene-Pleistocene age and stratigraphically lies over the Peristeri formation and is overlaid by the Keramidia formation (Geological map of I.G.M.E.-Amalias 1993).

The Araxos open-pit mine is located in Upper Cretaceous white to light brown limestones. These limestones belong to the “Vigla” formation of the Ionian zone. These limestones are pelagic in origin; oolithic with fragments of echinoderms and small foraminifera. Overlying them, are pelagic limestones with radiolarian. These limestones are thin bedded microbrecciated, lumpy, bioclastic limestones with rudist fragments (Geological map of I.G.M.E. - Nea Manolas 1977).

3. Methodology-Equipment

Both areas were mapped with high precision using a tachymeter and a geodetic GPS (Figure 2). Especially in the case of the Analipsis landslide, a geodesic network consisting of about 20 control points –in and out of the landslide zone- was created in order to monitor the landslide kinematics and several other thousand points were acquired to create accurate DSMs. After statistical analysis of the GPS measurements, we came with an average 2DRMS value of about 2.1cm that represents a 95%-98% confidence level.

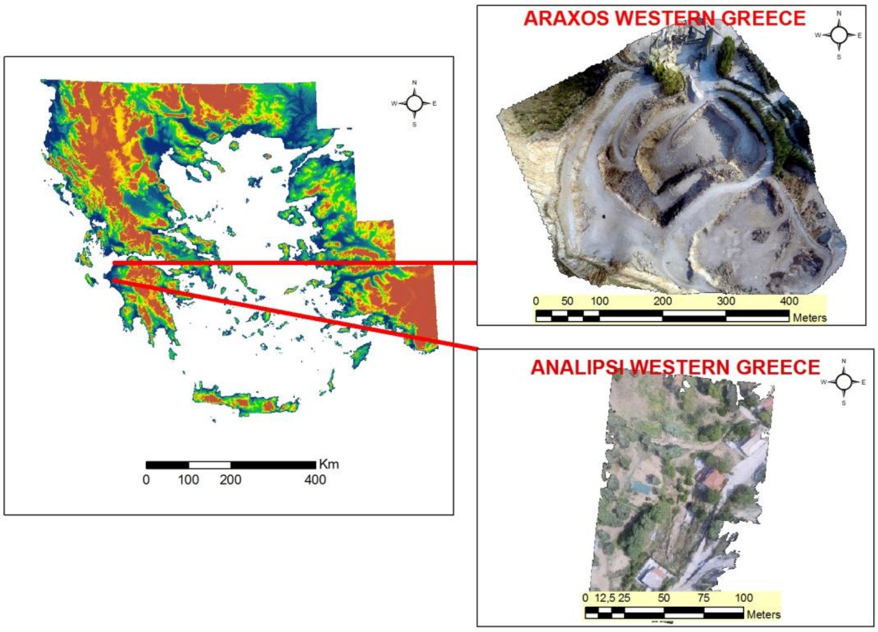

Figure 1 – Top: The two study areas relatively to the Northwestern part of Peloponnese, Bottom right: the Analipsis village, Top Right: the open-pit limestone mine at the Araxos Peninsula.

Figure 2 – On the left appears the Leica TCR1102 tachymeter used for the surveying. On the right appears the Trimble R8 GNSS 5800 Geodetic GPS used for the surveying and the control point monitoring.

After the surveys were carried out, targets were distributed across the areas of interest. Those targets' 3D coordinates were obtained using the geodetic GPS for optimal accuracy. In continuation, the UAV flights were performed.

The UAV is a custom made hexacopter, equipped with two GoPro Hero 3+ Black Edition Cameras (Figure 3). The two cameras that are fixed on gimbals -in order to prevent distortion caused from the motors' vibrations-, allow for image capturing in different angles.

The mapping of the quarry was performed during a half-day campaign on July 14th 2015. During a flight time of approximately 15 minutes a total of 682 UAV images were collected over the study areas. Table 1 shows the particular information of the data acquisition. The spatial resolution of these UAV images is approximately 1 cm, with more than 90% forward lap and side lap.

Table 1 - Quarry UAV campaign characteristics.

Number of images:	682
Flying altitude:	40.7089 m
Ground resolution:	0.0182745 m/pix
Coverage area:	0.168697 sq. km

The same overlap was programmed for the acquired images for the landslide monitoring in Analipsi. A total of 314 UAV images were collected over the study areas. Table 2 shows the particular information of the data acquisition.

Table 2 - Landslide UAV campaign characteristics.

Number of images:	314
Flying altitude:	34.2081 m
Ground resolution:	0.0148816 m/pix
Coverage area:	0.0226511 sq. km

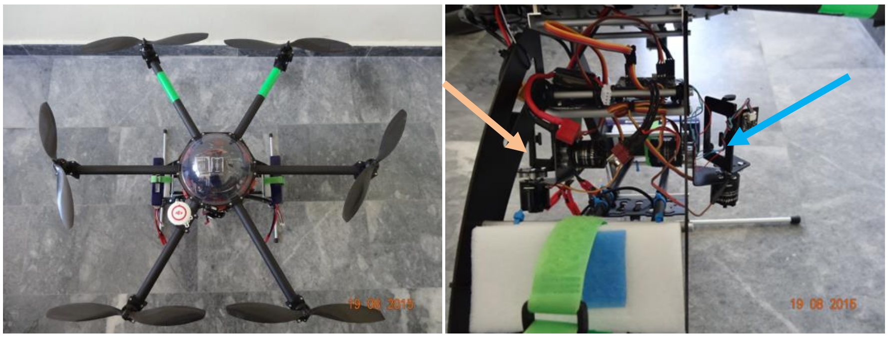

Figure 3 – The left picture depictsthe Unmanned Aerial Vehicle. At the right picture, the two arrows point to the two Gimbals onboard the UAV that absorb the vibrations caused by the motors during the flight.

4. Data Processing-Results

The aerial images collected during the UAV campaigns were imported in Agisoft's Photoscan software. As described in details in previous study (Skarlatos *et al.*, 2013), the software employs computer vision techniques along with photogrammetric analysis to perform direct georeferencing or bundle adjustment with ground control points or simple similarity transformation over the whole block without ground control points. As more images are added to the block more points are taken into consideration and ensure the internal block geometry. The final accuracy of the project depends mainly on the ground control point's accuracy. The whole block as a 3D texture model obtain from Photoscan is projected to the Greek Geodetic Reference System (EGSA87). The 3D texture model is one of the most important photogrammetric products, and it provides useful information for the monitoring, assessment and planning of mine areas.

Orthomosaics and DSMs with a spatial resolution of 10 cm were created. The orthomosaics from the two case studies are presented in Figure 4 while the respective DSMs for the same areas are displayed in Figure 5. The extreme high spatial resolution of both the orthomosaics and the DSMs guarantee that it will be possible to monitor terrain deformations at the Analipsis landslide area or even minor excavations at the Araxos open-pit mine in the near future.

After the creation of the 3D model and the export of the respective DSM and orthomosaic, both the DSMs and orthomosaics were validated regarding their geometric accuracy. As it proved, the fisheye-like lens distortion that the GoPro cameras have, affects the models a lot, both regarding their georeference and their height accuracy.

In order to control the vertical DSM accuracy of the Araxos area, 120 check points that were measured during the surveys were used (Figure 4). For each check point the respective elevation value was extracted from the DSMs. Then, the elevation difference between the GPS measurements and the DSM values was calculated.

The elevation difference ranges between some cm and almost 5 meters depending on the allocation distance between the ground control points and the check points. More especially, in the open pit mine only four ground control points were used and they were spread on the top two excavation planes. As a result the check points that were measured at the top planes gave very accurate results (a few cm elevation difference) while the check points that were measured at the lower planes gave unacceptable results (elevation difference up to 5m). Such errors are really large in comparison to the ultra-high spatial resolution the imagery offers and they are due to the lack of ground control points at the lower excavation planes.

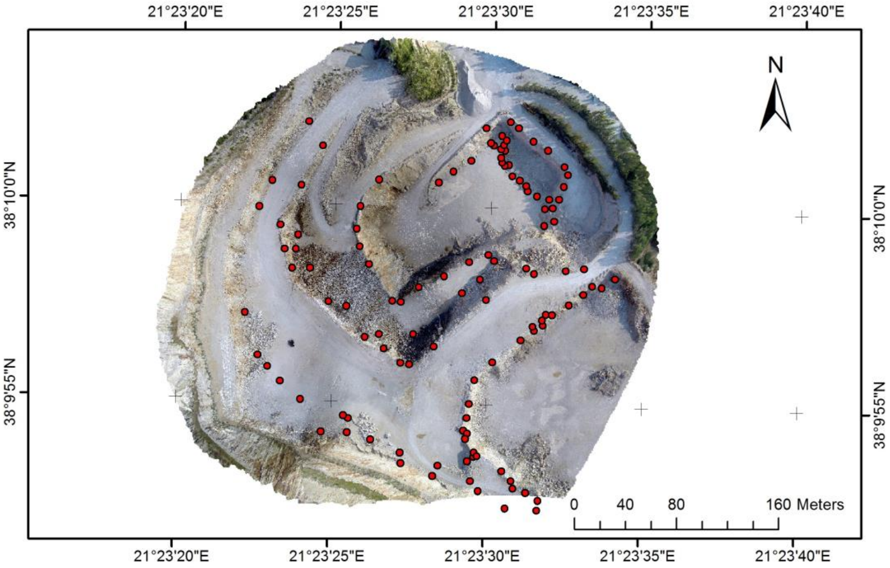

Figure 4 – The 120 red points shown above were derived from the GPS survey and were used to validate the orthomosaics and DSMs for the Araxos open-pit mine case study.

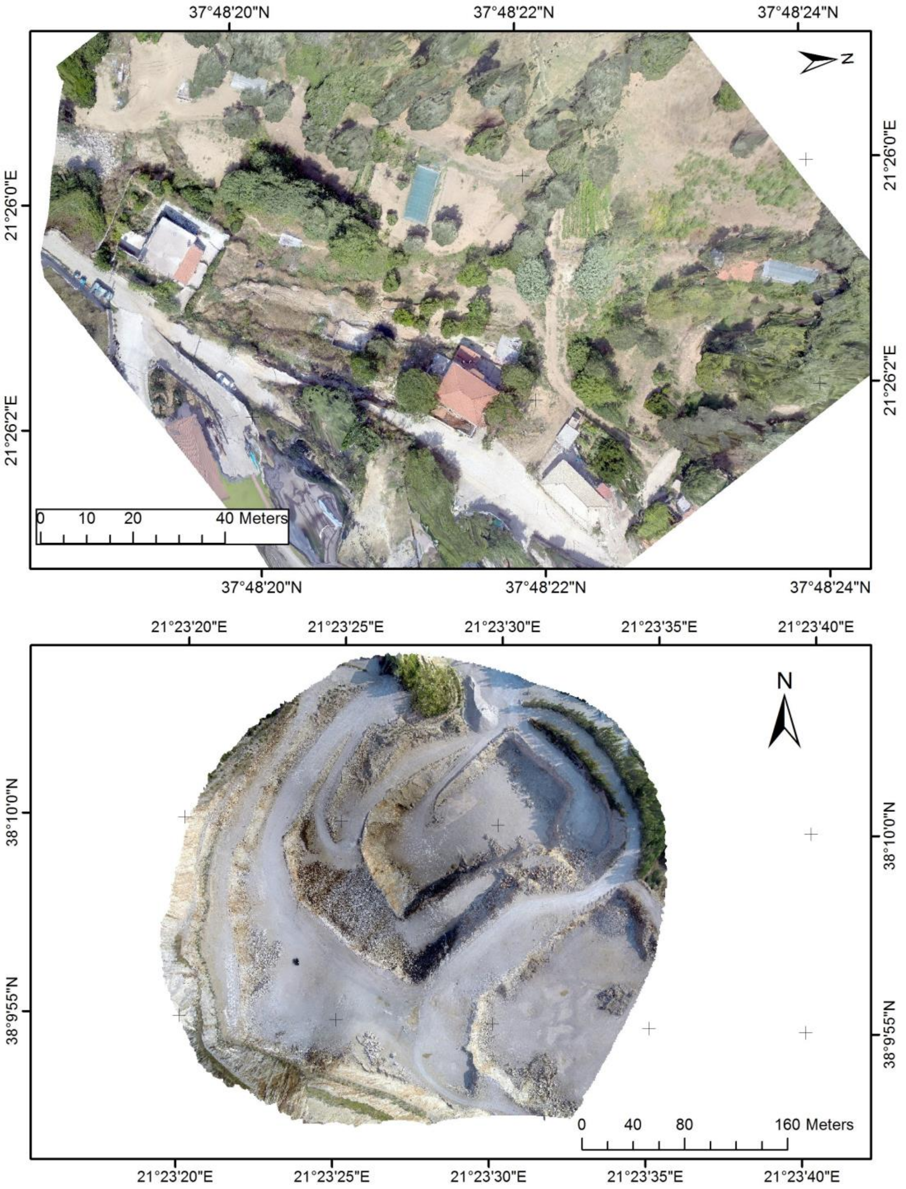

Figure 5 – The orthomosaics created by the UAV campaigns. The top picture depicts the Analipsis landslide orthomosaic and the bottom picture depicts the Araxos open-pit mine orthomosaic.

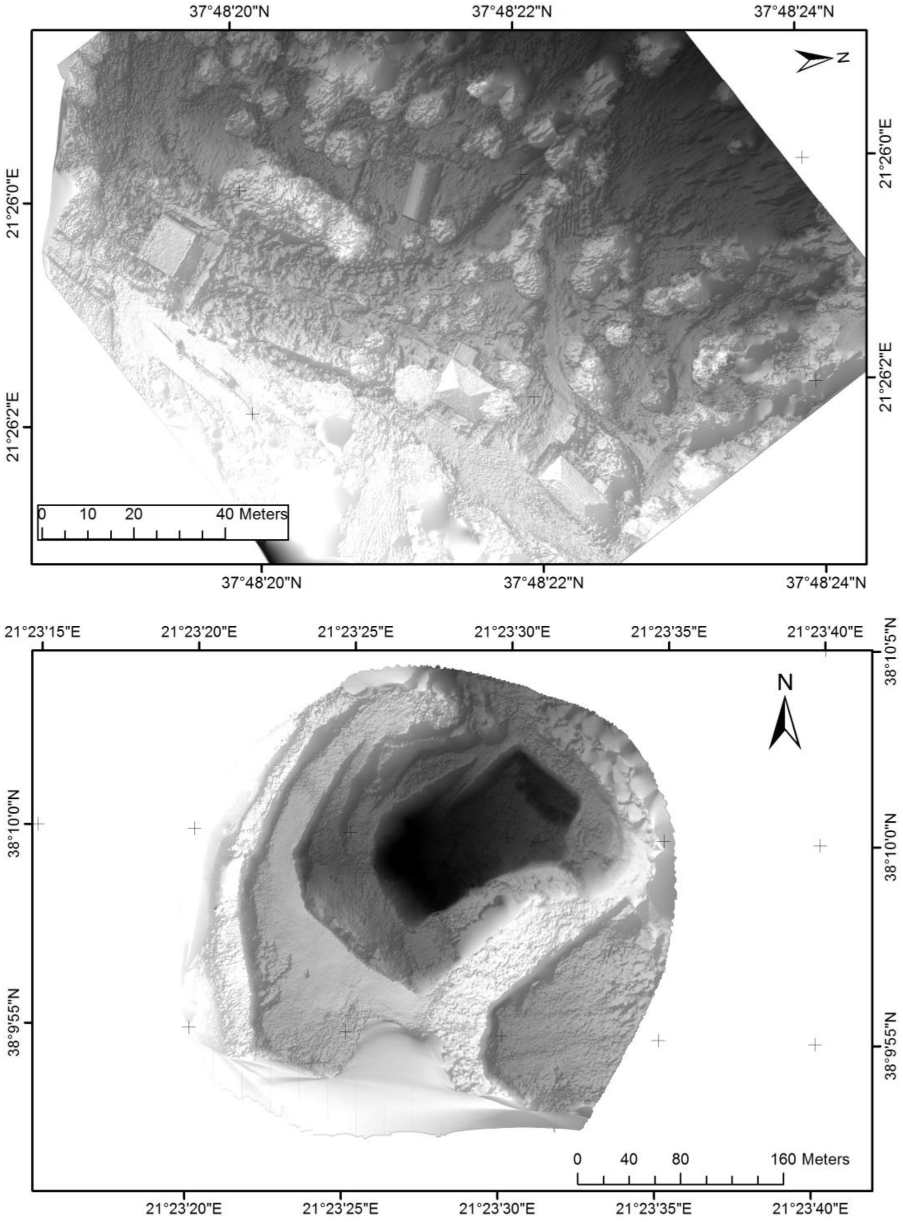

Figure 6 – The DSMs created by the UAV campaigns. The top picture depicts the Analipsis landslide DSM and the bottom picture depicts the Araxos open-pit mine DSM.

5. Conclusions

This paper suggests possible UAVs applications in the field of geology. As it becomes clear, the advancements in UAV-related technology, allow for the acquisition of ultra-high spatial resolution imagery that is used to create extremely accurate 3D models of virtually any terrain when combined with high precision GPS measurements. Such high fidelity models, can be used to monitor terrain deformations like those that occur after a landslide or by those caused due to quarry excavation. In general, UAVs are a great assistance for any geological application since they can be used for large scale mapping resulting in significantly less time and resources' consumption. As it came out of the accuracy assessment the use of many ground control points at different elevation levels is a necessary condition in order to achieve the desired vertical accuracy.

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