



Landslide behaviour and Risk Reduction using SfM and 3D modelling techniques with Unmanned Aircraft Systems (UAS). Chios island (Greece).

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ABSTRACT

Chios is a semi-mountainous island located in North Aegean Sea (Greece), a few nautical miles from west coast of Turkey and it has a coastline of 215 Km. The study area is located on Chios island along the Chios-Kardamyla Road in the region from Mersinidi to Myliga, in the northeastern part of the island (Fig. 1), where there is a significant thrust between Paleozoic clastic and Triassic carbonaceous formations. In this region, a great number of natural disasters, including landslides are generated by the earthquakes caused by the particular geodynamic and seismotectonic regime. Many slopes and rotational slides have occurred in the area and in combination with the regime and the human activities, they can lead to expansive damage. The research team identified the hazardous areas and examined the places affected by earthquakes or considered as dangerous to landslides.

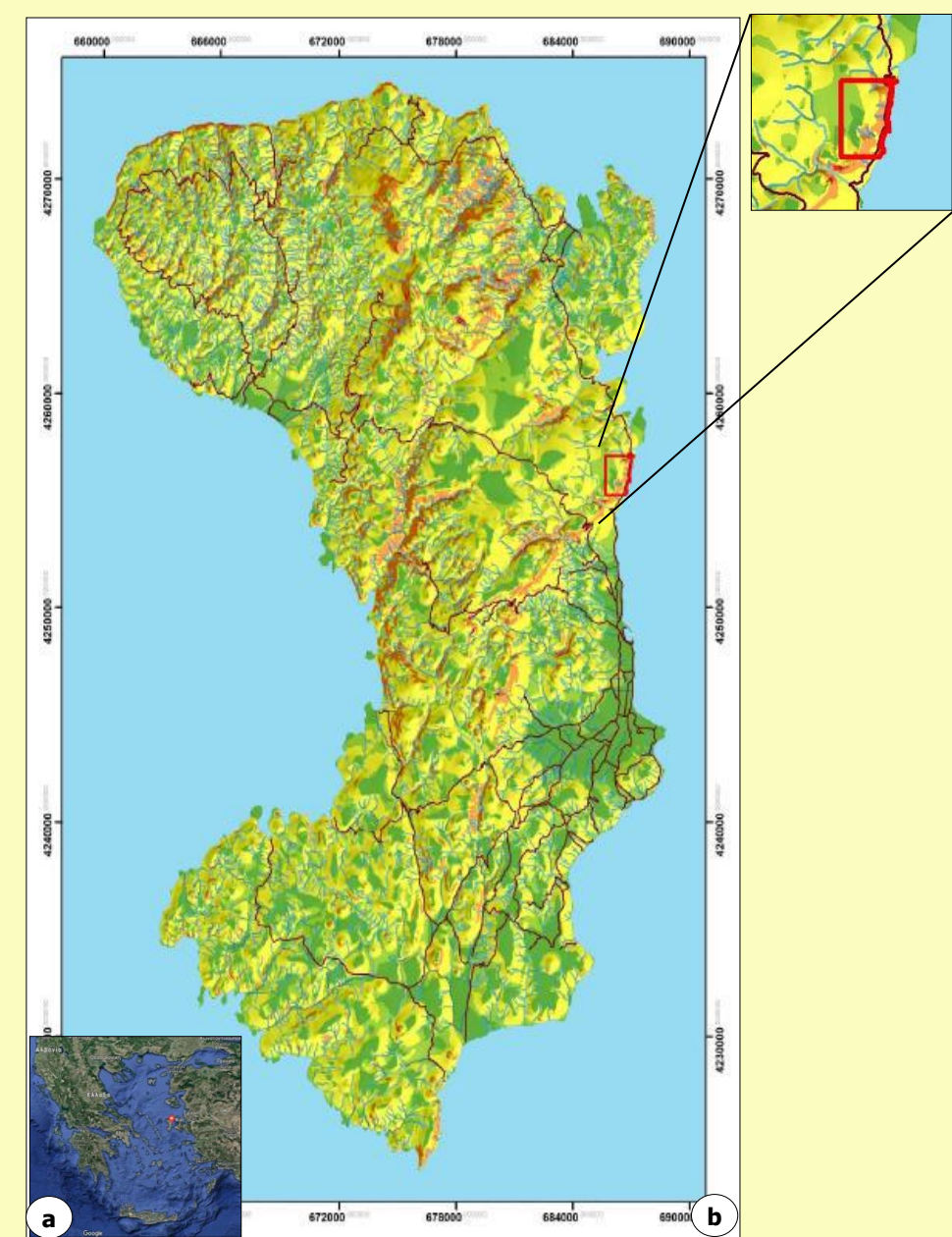


Figure 1: (a) The geographical location (red mark) of Chios island (Google Earth), (b) the study area (red framework) on morphological map of Chios island.

The issue of the inaccessibility of the largest part of the study area was overcome using Unmanned Aircraft Systems (UAS) that are increasingly being applied to research in Natural Hazards and Risk Management, specifically when it comes to such areas where the thorough examination of the existing geological-tectonic structures cannot be complete and accurate only by field work. The research team used SfM (Structure from Motion) techniques to obtain data from the UAV (Unmanned Aerial Vehicle) flights above the study area. Thus, not only were there detailed Digital Surface Models (DSM) and Digital Terrain Models (DTM) produced, but phototopographic, photomorphological, photogeological - tectonic, photohydrological and photogeotechnical mapping, detailed boundary and surface tectonic mapping and high-accuracy structural analysis in 3D environments were also carried out.

The combination of field work and UAS-based photogrammetry, consisting of rapid and low-cost procedures, led to complete and valid results by using geological compasses, UAV (DJI Mavic Pro) and Pix4D, ArcGIS, Rockware Rockworks 17, Rocscience Rocfall, Rocscience Slide and CAD software.

METHODOLOGY

At first, the research team made the UAV flight planning project (Fig. 2) via Pix4Dcapture. This project was based on the technical capabilities, the equipment, the needs of visual analysis, the extent of the area, the physio-geographic peculiarities and weather conditions during the days of the field work. As far as the factors adjusted are concerned, the angle of the camera was arranged at the pitch of 60° – 70°, the flight above the take off position altitude was adjusted according to the required analysis and the morphology and the altitude of the area (i.e. heights of 100m and 150m were selected with GSD 3.94 cm/pixel and 4.64cm/pixel in the southern and the northern part respectively), the orbital of the UAS was adopted so that the study area would be scanned in two directions perpendicular to each other in order for 3D maps to be created, and the overlap rate was above 80% so as to maximize the number of confirmed tie points and increase the accuracy of the results.

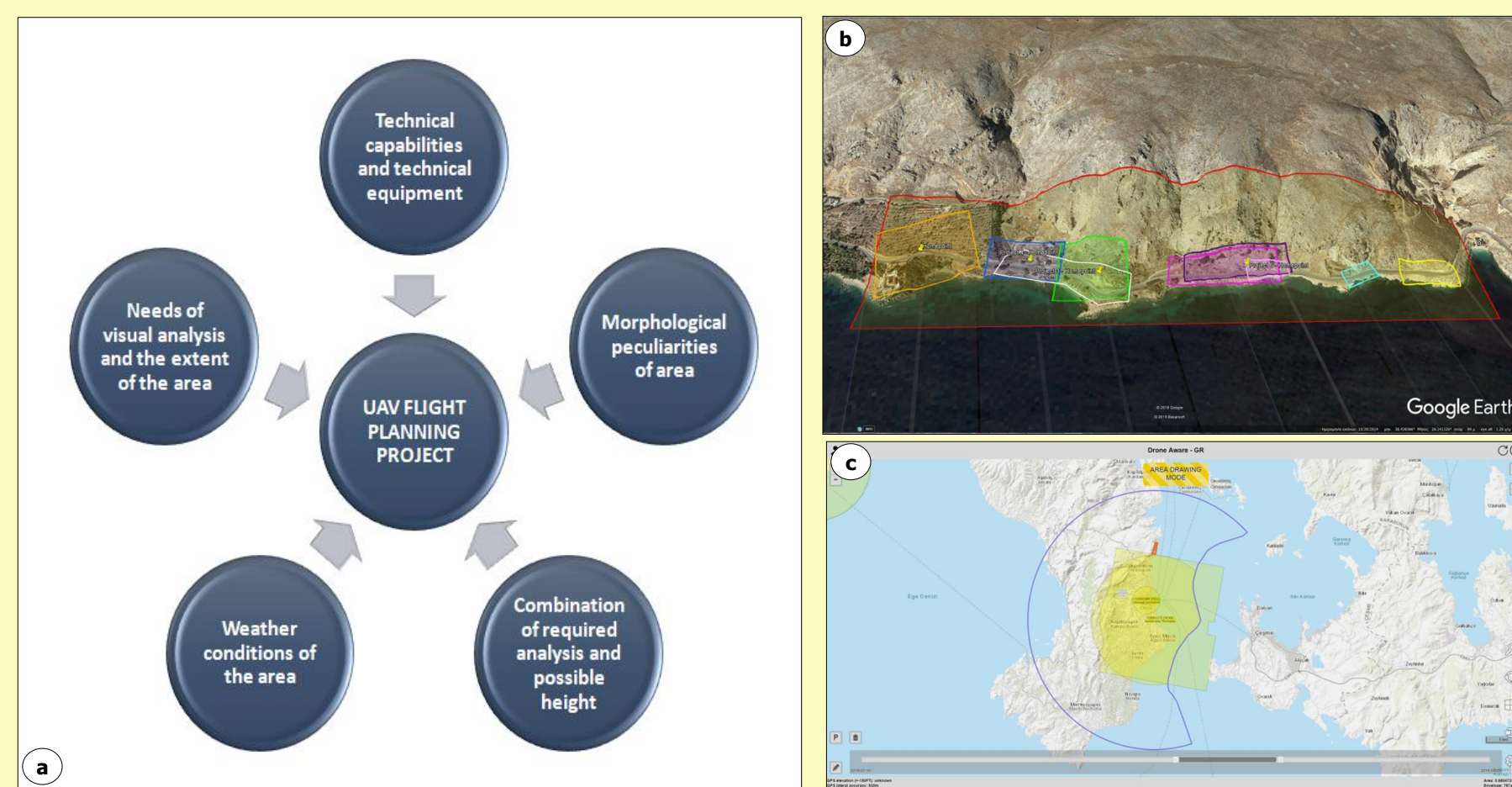


Figure 2: The parameters taken into consideration for UAV flight planning project (a), 3D visualization of the study area that was covered by the UAV flights (b), and the survey area (orange frame) is located north of the General Restriction zones of Airport Perimeter (Hellenic CAA, n.d.) (c).

Field mapping and 3D-mapping on the models produced via Pix4D software, in combination with the examination of simultaneous second-time videos in order for interpretation problems to be resolved and the study of the existing references, led to detailed examination of the geological structures and the geomorphology of the study area. Visual data and metadata from UAV photogrammetry flights, as well as static RGB images and high-resolution videos were obtained, by using the DJI Mavic Pro drone. According to the procedure followed during the survey (Fig. 3), the derivatives from the photogrammetry data process via Pix4Dmapper, were exported for further analysis in all software environments used in geographic, geological and design applications (GIS, Modeling, CAD) in applicable format (shp, dxf, asc, pdf, etc.). Initial data processing via Pix4Dmapper led to orthomosaics, DSM (Fig. 4c & 4f), DTM and 3D models (Fig. 4b & 4e).

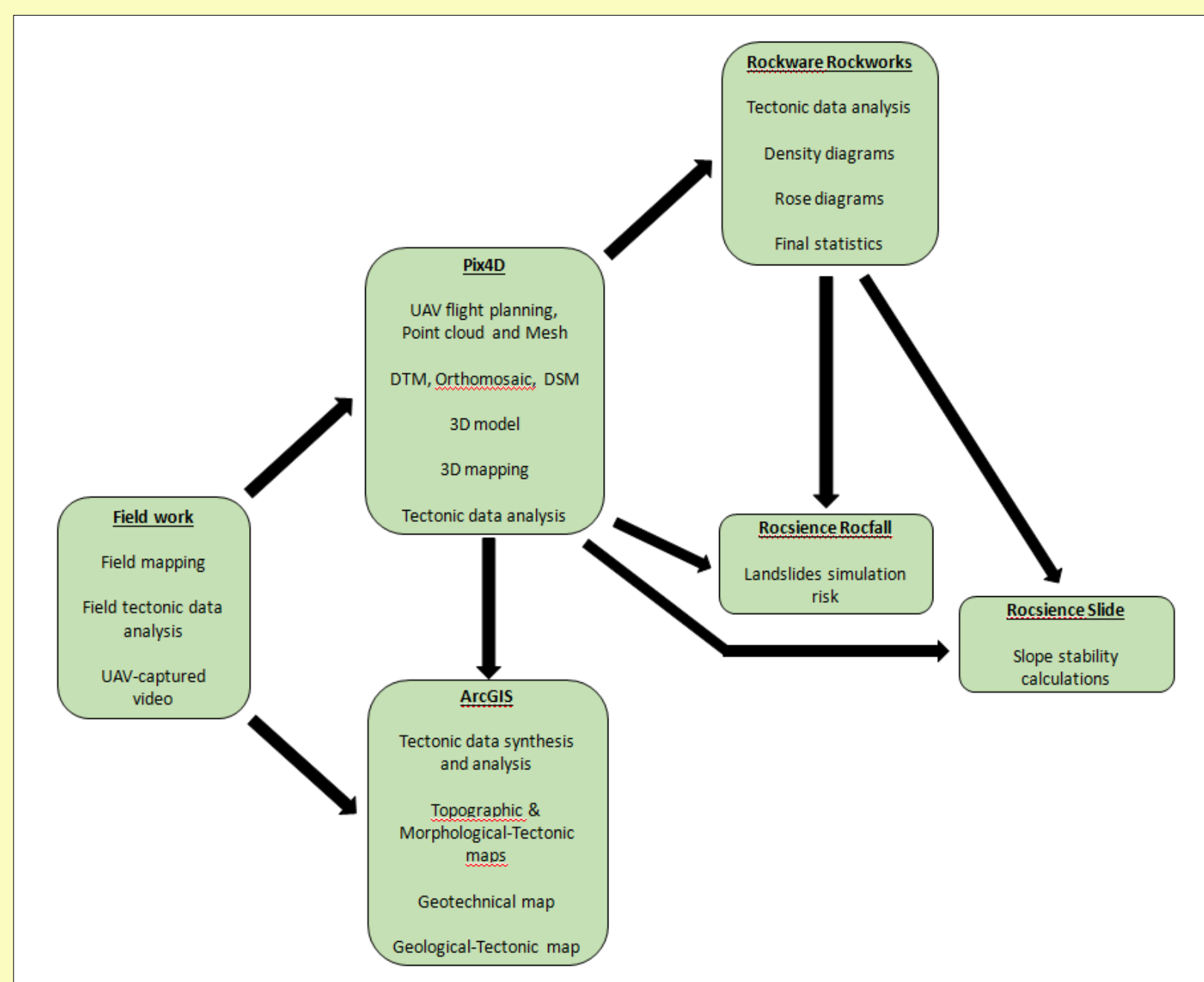


Figure 3: The workflow concerning the software used and the derivatives that were produced during the process in the study.

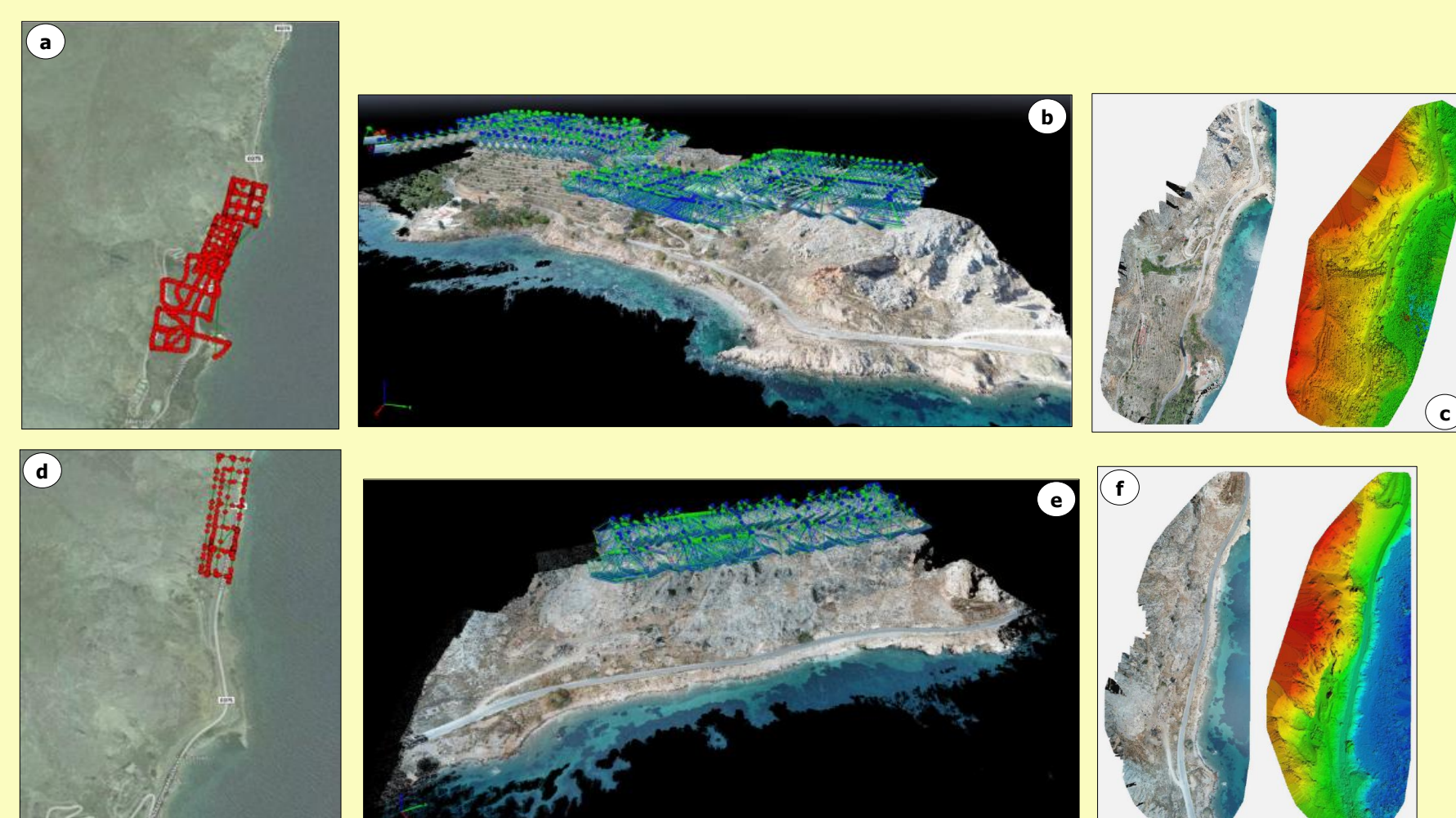


Figure 4: Flight plans of southern (a) and northern study area (d), the 3D models of point cloud and grid of photorealistic surfaces in the (b) southern and the (e) northern region with the positions of the camera, when taking photos, noted, and Orthomosaic (left) and Digital Surface Model (DSM) after the processing was completed for the southern region (c) and Orthomosaic (left) and Digital Surface Model (DSM) after the processing was completed for the northern region (f).

Both SfM photogeological and phototechnical mapping were carried out in Pix4Dmapper and ArcGIS software, where the formation boundaries and the discontinuous tectonic deformation were recognized and analyzed. The tectonic lines and surfaces were digitized directly on 3D relief on the anchor points of the model (Fig. 5) and they were imported individually and in total into AutoCAD and GIS. The geological mapping was highly guided by the overlap of tectonic lines and surfaces on the orthomosaics.

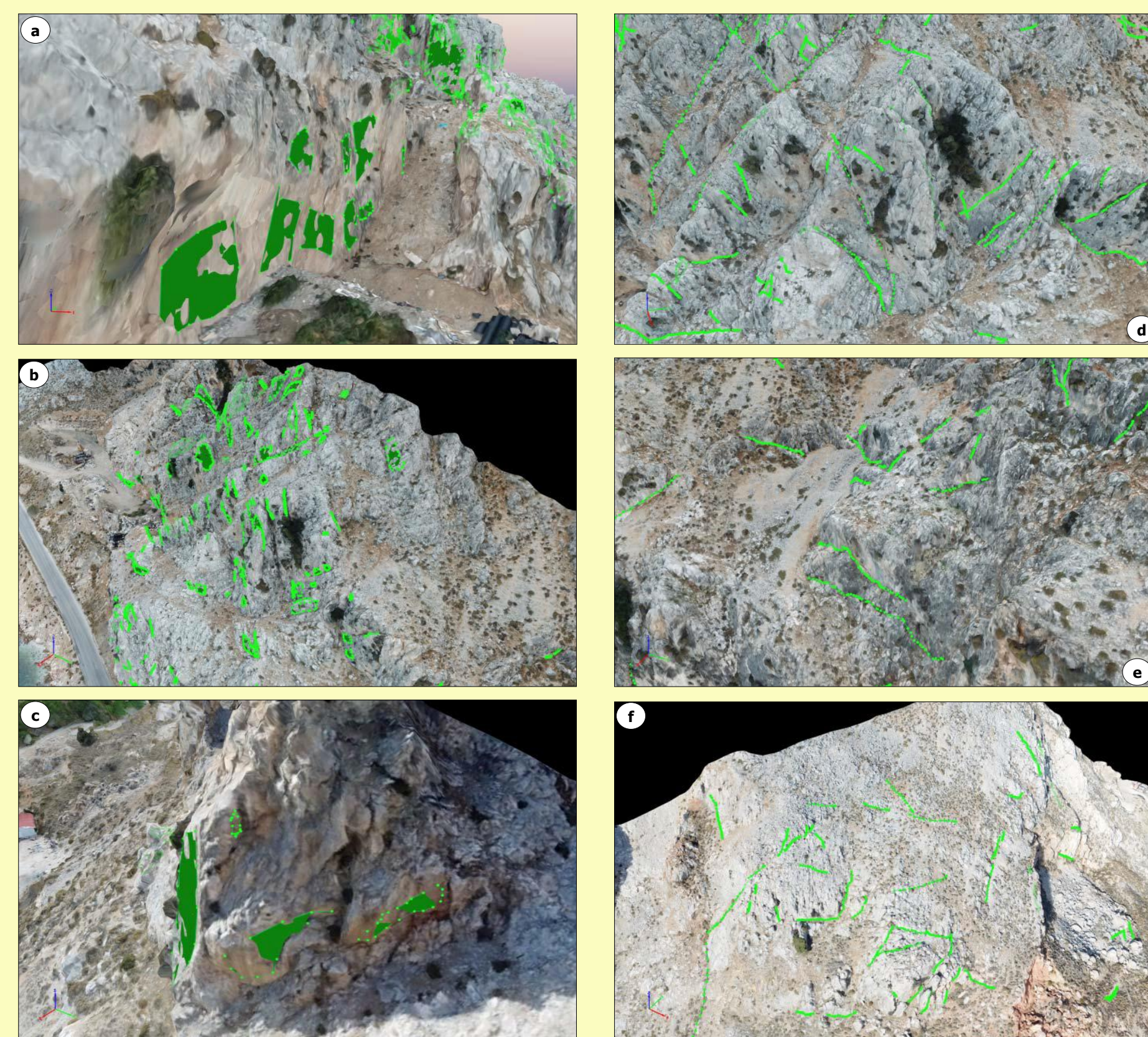


Figure 5: Digitized tectonic surfaces (a, b, c) and digitized tectonic lines (d, e, f).

After the digitization of the boundaries of the geological formations via GIS, polygons and 3D complex lines were imported into the ArcGIS environment. Then, the polygons were transformed into triangular irregular networks (TIN), points were created on the surfaces and tectonic data (slope, aspect, dip, dip-direction values) were calculated and extracted for them. Furthermore, the research team evaluated the geotechnical data and determined the role of groundwater in rock and soil movements according to hydrolithology and tectonic texture in the study area.

As far as the statistical tectonic analysis is concerned, it was carried out in Rockware Rockworks 17 software. Stereographic projections on Schmidt networks as well as circular projections and planar poles density diagrams were made (Fig. 6a & 7a). Furthermore, rose diagrams based on the strike values of the segments were made for the lines and the coordinates of the start and the end of each segment were calculated. Finally, the frequency of measurements' occurrence was calculated and the length of each line was weighed, resulting in the detailed rose diagrams (Fig. 6b & 7b). The field and SfM tectonic data statistics archives were merged and the extracted statistics were weighed.

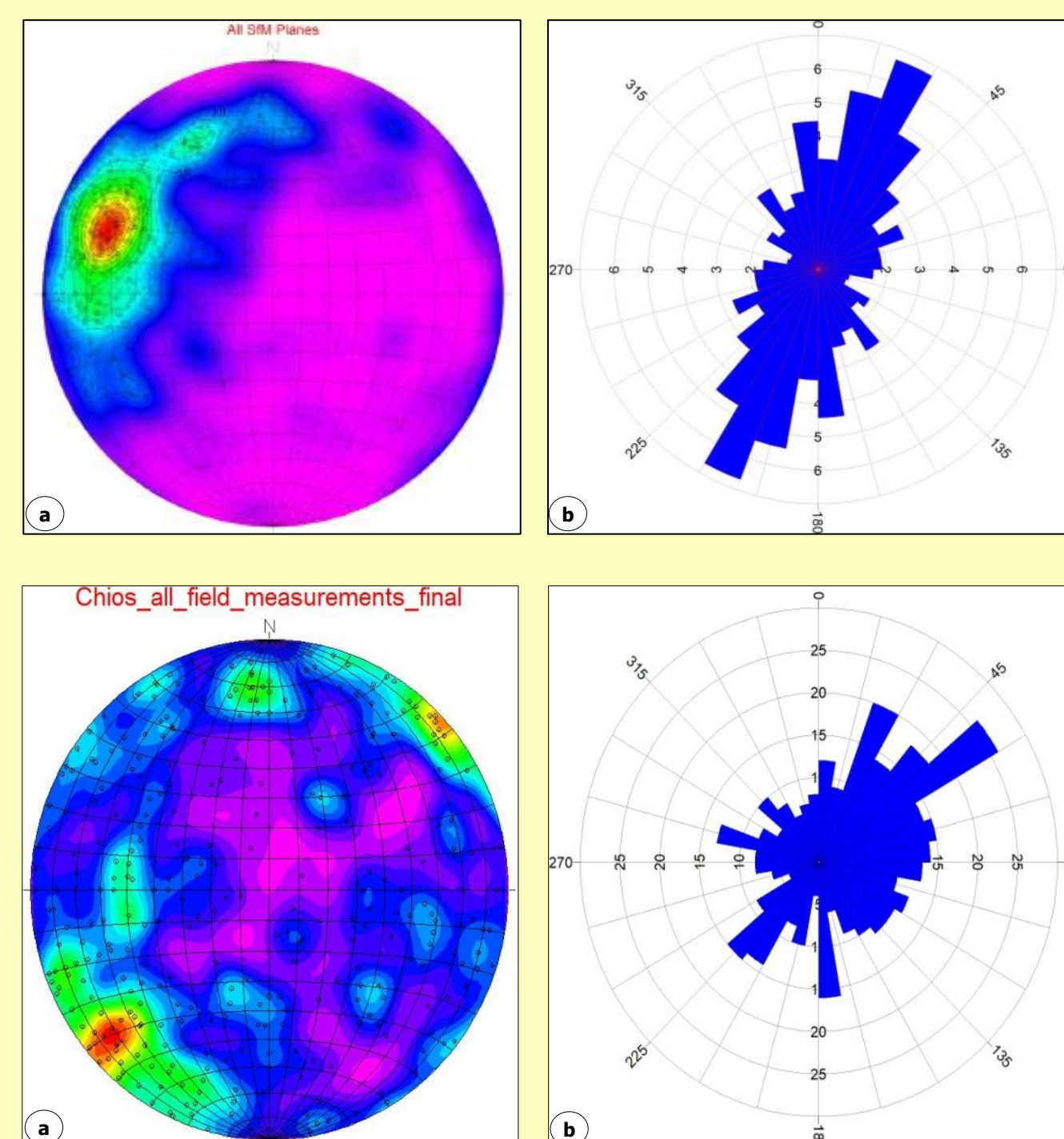


Figure 6: Projection of the poles of the SfM surfaces and density diagram (a), and rose diagram (b) of the surfaces direction for the whole study area.

Figure 7: Projection of the poles of the surfaces and density diagram (a), and rose diagram (b) of the surfaces direction for the whole study area according to the field measurements.

RESULTS & CONCLUSIONS

During the survey, the research team examined, digitized and measured 23 surfaces and 99 lines for the southern region, and 292 surfaces and 423 lines for the northern one. The lines were divided into 6968 segments of unique orientations.

High slope surfaces were identified mainly on the rocky carbonate basement in the study area and it was found that the examined faults and discontinuities influence the morphology of the terrestrial region and the coastline. According to the extracted statistics, these structures generally have a NNE-SSW direction but there also exist N-S and NW-SE secondary directions. In addition, these structures form the marginal detachment surfaces of segments of the rock mass and they set their sliding or turning over lithological or tectonic boundaries with the overlying formations (i.e. dolomites and clastic formations).

The density and the rose diagrams verify the results of the measurements on the surfaces, except for the N-S directions which show higher frequency and length percentages than the N-E ones.

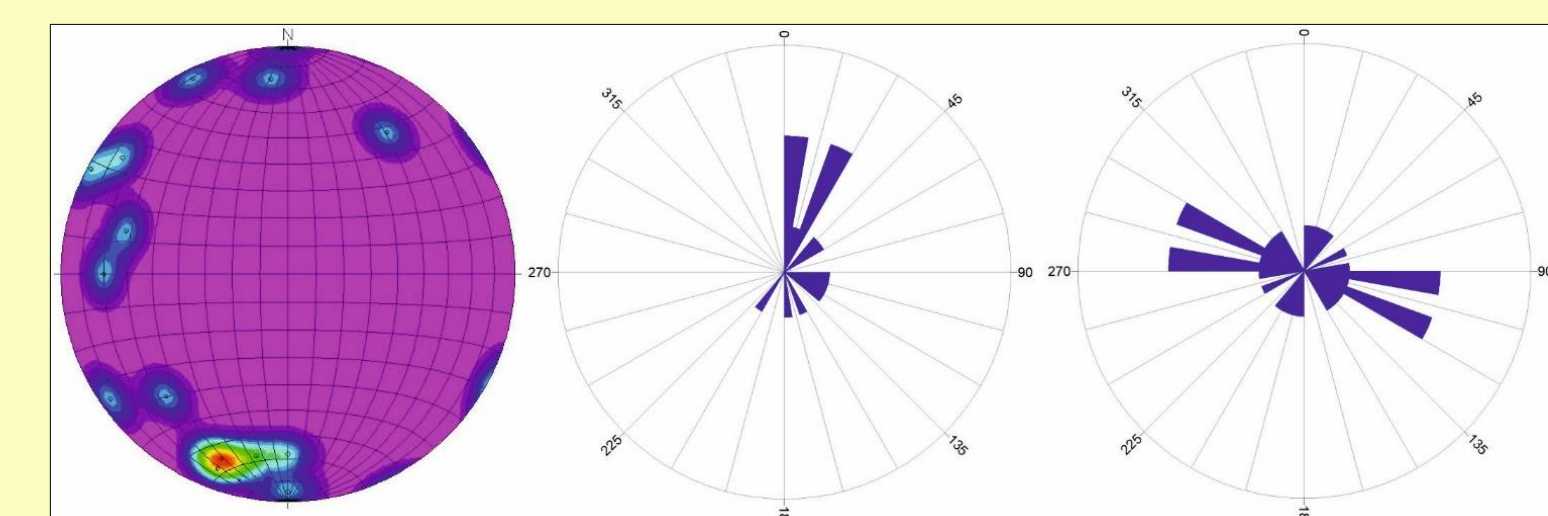


Figure 8: Density diagram (left), rose diagram according to the dip direction values of the surfaces (center), and rose diagram of the surfaces direction (right) for a part of the northern region of the study area. These diagrams indicate that the structures of that region can lead to wedge-shaped or planar slides. As the artificial slope has small height (<3m) in this section, the chances for detaching and sliding are low.

In this study, the slope failures were identified and the rock mass was classified according to the internationally accepted stability calculation methodologies. The study includes specific plans for rockfalls and rock slides, analysis of rockfall estimation and detailed simulation models of rockfalls. The assessment of the geological, geotectonic hydrogeological, seismotectonic and geotechnical data in combination with the estimation of the drilling results along the study area, the causes of landslides, the slope stability calculations and the water activity that were examined, led to the production of detailed geotechnical and geological-tectonic maps (Fig. 9) and the recommendation of countermeasures for landslides.

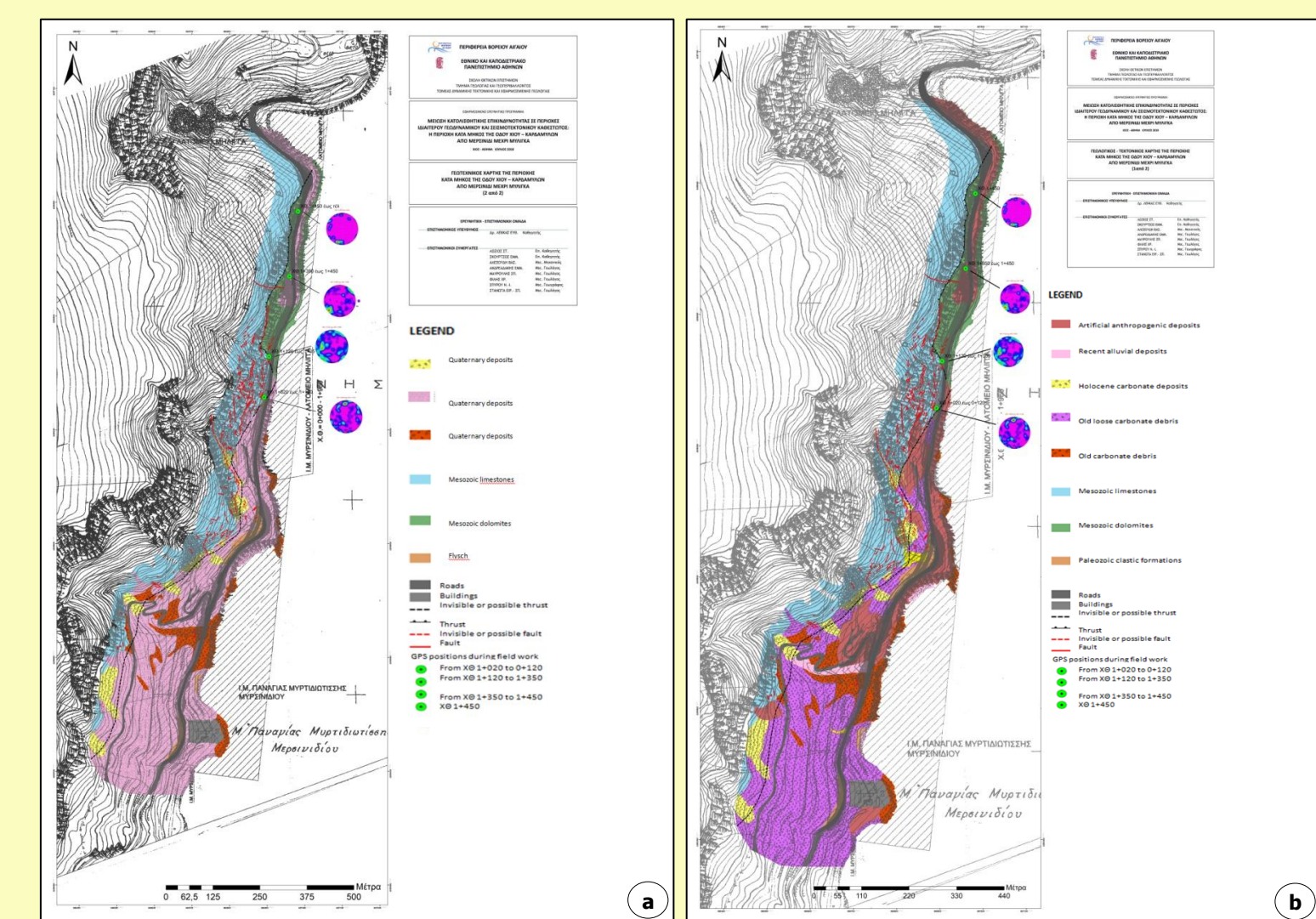


Figure 9: Geotechnical map (a), and geological-tectonic map (b): SfM lines, density diagrams, field and SfM data.

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The carbonate rocks in the area have undergone tectonic strain due to both the activity of the nearly vertical tectonic surfaces crossing their mass and the activity of the significant thrust surface above the Paleozoic clastic formations that has led to their fragmentation into blocks and boulders. The water activity in the region reduces the shear-strength of the discontinuities and the friction in between these rocks and between them and the clastic basement. Thus, these rock blocks are easily detached, and as a result they overturn or slide on the downhill slopes, during intense precipitation or seismic events.

The examination of the high-resolution videos captured from the UAV, transported the research team to the field at any time and in any orientation during processing data, resolving the problem of the inaccessibility of the study area and the issues concerning the quality of the images and the bad illumination during mapping. As a result, the mapping, the analysis and the statistics for the evaluation of the causes and the characteristics of the landslides and the propose of countermeasures for the study area were thorough and reliable.

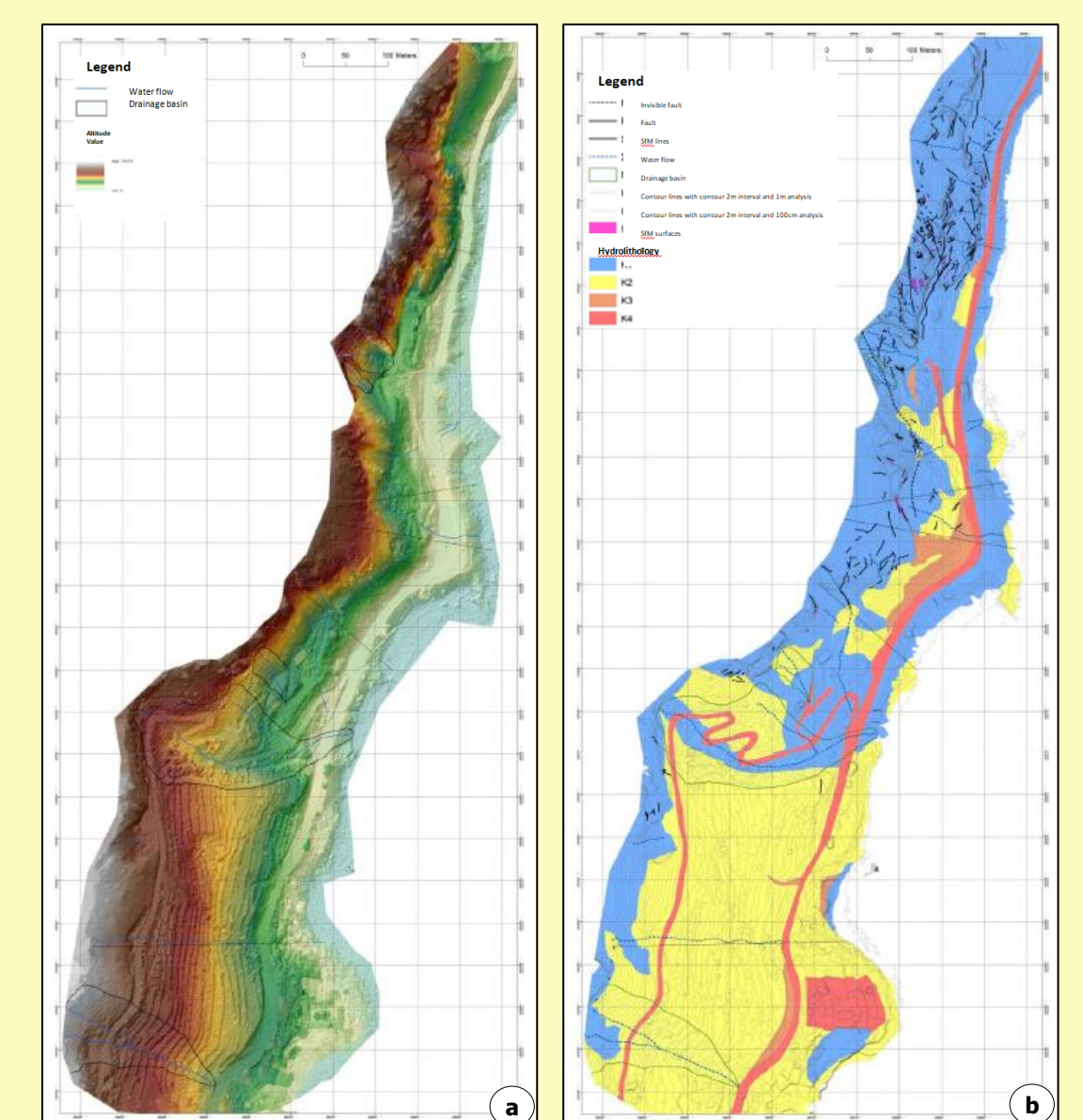


Figure 10: The water drainage and the corresponding basins on the (ortho-)topographic map (a), and hydrological map: middle to high water-permeable carbonate formations (blue), middle to low water-permeable old scree (yellow), very low to low water-permeable clastic formations (orange) and non-permeable artificial constructions (red) (b).

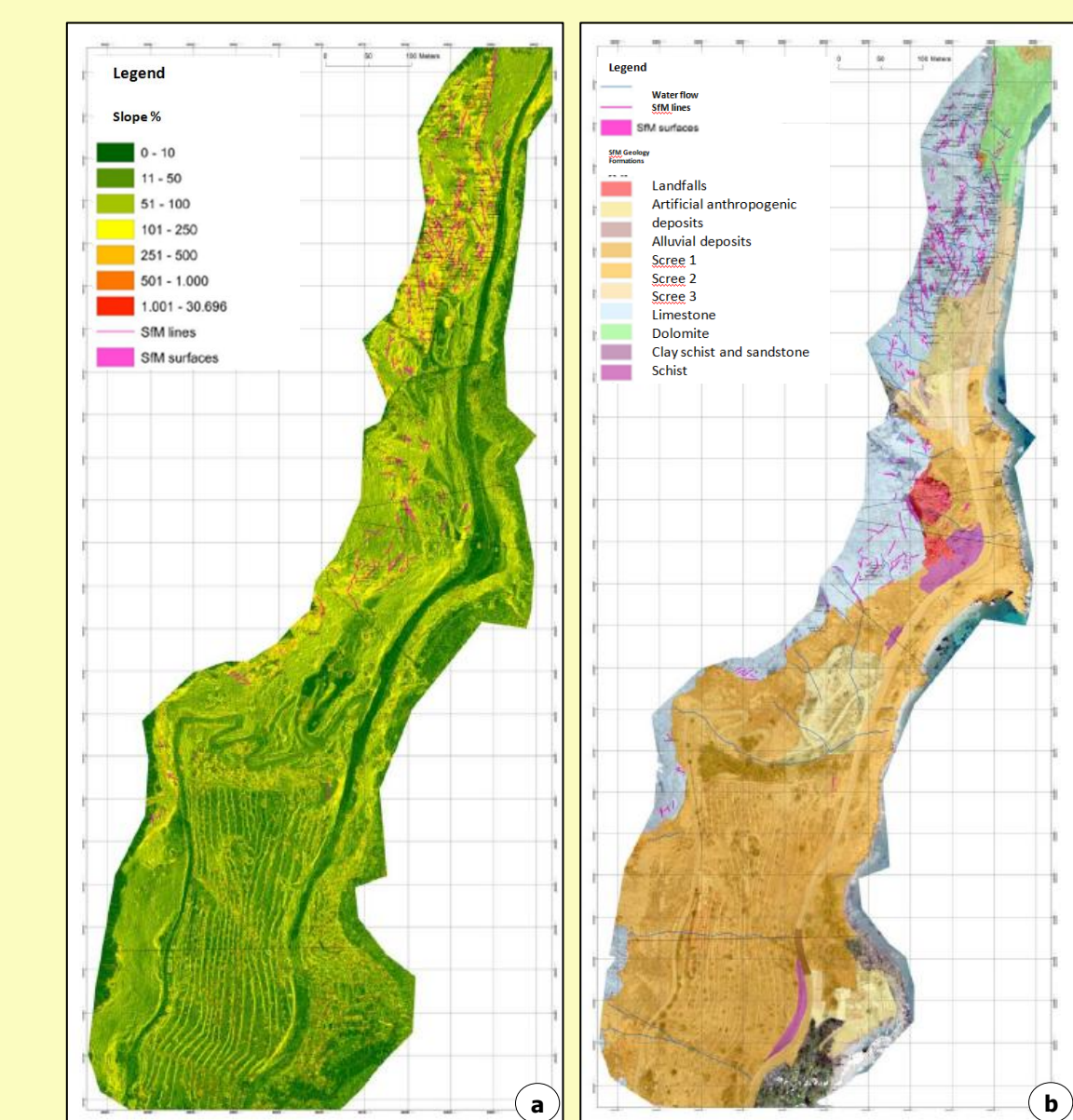


Figure 11: Morphotectonic map, SfM lines and surfaces on the slope map (a), and photogeological - phototectonic map: SfM lines and surfaces on the original geological map that was derived from mapping (b), based on the orthomosaic and the 3D model.