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GEOLOGICAL ANALYSIS USING UAV IMAGERY AND POINT CLOUDS

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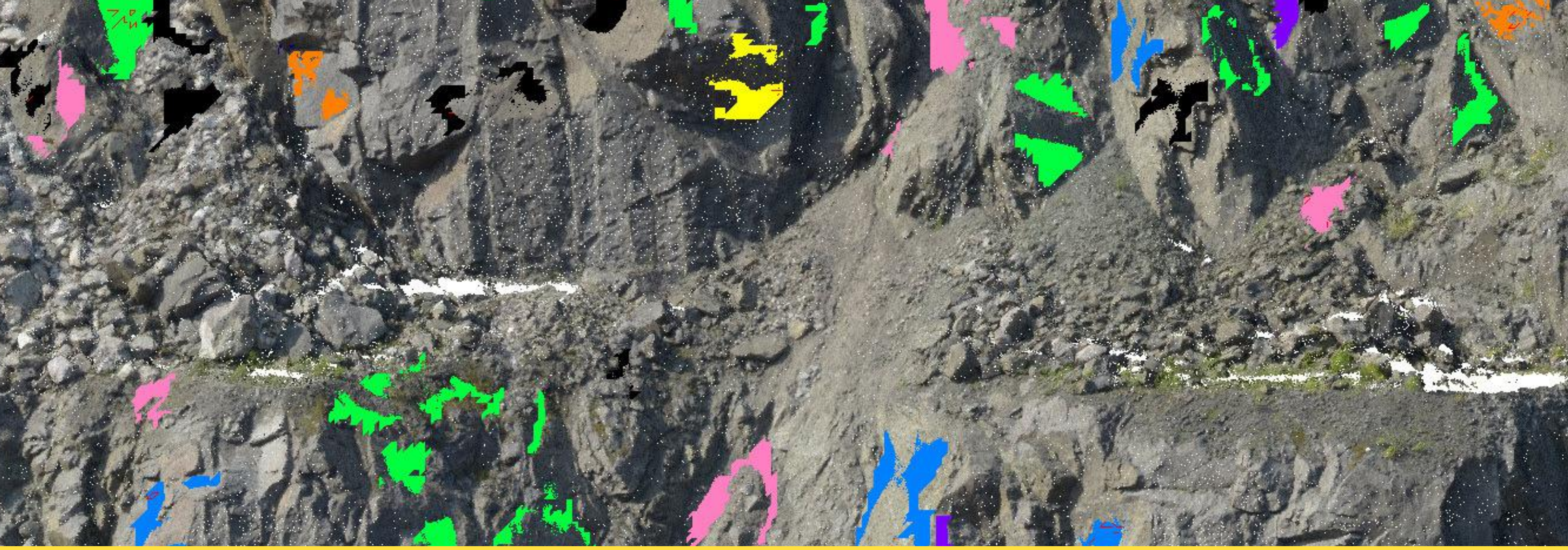

Geological Analysis Using UAV Imagery and Point Clouds

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Unmanned Aerial Vehicles, typically called UAVs, are quickly becoming prominent in the earth sciences and engineering fields. Their ability to quickly and simply collect high resolution, multi-perspective, multi-sensor imagery for site characterization is unparalleled. When you add the 3D deliverables that photogrammetric processing produces from the imagery, you have a powerful tool at your disposal to analyze a site's geology. This analysis can be done through visual inspection, through image and remote sensing analysis, and through geometric point cloud and digital elevation model (DEM) analysis. Depending on the sensor used, the analysis can extract and map digital features for lithology, mineralogy, large- and small-scale structure, geomorphology, water, temporal changes, and more. In this article, I will relate UAV methods with existing image and remote sensing analysis methods, discuss a method of geological site characterization using UAVs, and mention some of the challenges using UAVs for this work.

Although the use of laser scanners (LiDAR) on UAVs is possible, I do not consider them in this article. For one, they are not prevalent yet. Two, they are not as precise as terrestrial LiDAR yet. And three, if you only have a LiDAR on a UAV and not a good high-resolution camera, you will miss the critical image-based geologic features that are obvious to both your eye and to the image-processing software.

Remote Sensing Analysis

Image analysis technology has been used extensively for many decades now, with satellite and airborne sensors providing multiple data products to analyze. Satellites and airplanes deliver data products using multiple sensors, both passive and active. Satellite interferometric synthetic aperture radar (InSAR), multi and hyperspectral imagery, and airborne imagery and LiDAR have been processed for GIS for many decades now, with continuous improvements. These data provide DEMs, orthomosaic imagery, deformation monitoring, and many other deliverables. With these products, geological features can be identified and mapped, creating advanced geologic maps for vast areas and at high-resolution. With the advent of UAVs, these principles are being applied to lower level air-based image data, but with the addition of more 3D needs for modeling and analysis.

Using LiDAR for geological analysis of discontinuity properties has been around for over a decade now. The true 3D nature of the LiDAR point clouds has permitted excellent analysis and mapping of geomorphological and structural geology data. A few commercial software and freeware exist to conduct this analysis. The accuracy and validity of this digital methodology has been proven. The use of this method for production and consulting rock mass characterization has only slowly grown over this period due to the large nature of the data, often resulting in both slow processing times and cumbersome data management. However, the processing software has recently been relieving this pain with level-of-detail data rendering, taking advantage of computer graphics cards and limiting the amount of detail displayed and processed based on distance to the scene and the area visible.

A UAV Method for Site Characterization

Here, I will describe a UAV workflow for analyzing and extracting geological data using UAV captured data in a GIS/CAD environment. This workflow describes from field to office, from image data to digital geologic features, interpretation, and models.

1) Flight planning

- a) Use existing geologic maps, imagery and site data to design automated flight plans.
- b) Optimize your flight plan to give you the resolution and details you really need for the project.
  - i) Pick the right camera for your job.
    - • Consider camera specifications, image overlap, distance from the ground, lighting, time of day.
  - ii) If you maximize, not optimize, your resolution, your field, processing and analysis time will increase accordingly.
- c) Plan enough ground control points (GCP) and consider availability of real-time kinematic (RTK) and Differential-corrected Global Navigation Satellite System (GNSS) for positioning to ensure your latitude, longitude and elevation accuracy meets your project requirements.
- d) Complete flight planning FAA (Federal Aviation Administration) safety requirements & notifications.

2) Field data capture

- a) Always perform preflight safety checks and local notifications and communications.
- b) Check the site conditions that day.
  - i) Consider time-of-day lighting, angles, reflections, clouds, weather, and operations.
- c) If it is not safe or the data capture conditions are poor, you may need to reschedule.
- d) Fly your routes and capture your intended images.
- e) Manually fly hard-to-reach perspectives for truly 3D data capture.
- f) Onboard the UAV, a GNSS and IMU (inertial measurement unit: accelerometer, gyroscope, magnetometer) record positions and camera orientations for each image capture.
- g) Check image quality right away in the field so that you can fix mistakes in the field before wasting your field time and bringing large amounts of bad data to the processing stage.
- h) Download geo-tagged and orientation-tagged images from the UAV or upload directly to the cloud or a server if your system has the capability.
  - i) Run another image quality check, this time to remove bad images before processing begins.

3) Photogrammetric data processing

- a) A method of stereographic triangulation calculations is performed on two or more overlapping images covering some common objects and unique points.
- b) Images with georeferencing data will be processed to create 3D point clouds, orthorectified mosaic images and DEMS.
- c) Georeferencing accuracy improvements are made using the ground control points (GCP) surveyed in the field and clearly visible in the images.
  - i) Some software now can automatically locate and adjust the data from uniquely coded GCP in the images and the list of corresponding survey coordinates.

4) Point cloud cleaning, editing and registration

- a) With the full point clouds, it is best to quickly optimize the data to the minimum required level of detail.
  - i) Doing this at the beginning of the workflow speeds up every downstream.
  - ii) Too often, this part is neglected or not done sufficiently, resulting in noisy, inaccurate and data-heavy surfaces.
    - • This makes downstream data usage slow, cumbersome and often deters users from taking advantage of the full information being presented to them.
- b) Cleaning and editing:
  - i) Photogrammetric point clouds typically have denser points than the accuracy and precision of the data permit and it makes the files larger and slower than they should be.
  - ii) Different cleaning algorithms exist to:
    - • Remove noisy points, outlier points that fall too far away from a certain range of the local statistical range of the data.
    - • Remove points based on spacing.
      - (a) Point density, where points are removed where the density is greater than specified.
        - • For example, if you know your accuracy is 10 centimeters (cm), then you may choose to set your point cloud density to 5 or 2.5 cm.
        - • Or if you need one-foot contours, you may choose to reduce your point cloud density to 0.5 or 0.25 feet.
    - • Other options exist depending on the software.
  - iii) Editing:
    - • Separating and merging point clouds.
      - (a) Specific jobs with the data downstream have different requirements.
      - (b) Optimize your file sizes by cropping and merging data where needed and set

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the noise reduction and densities according to the requirements.

- However, if you create many data deliverables, you now have more files overall to store and manage, and even though they are smaller optimized files, you should consider your today data storage and management capabilities.

c) Internal data registration:

i) Assuming the data has been adequately georeferenced to the project requirements for spatial accuracy, there is often a need to co-register the 3D data for temporal change analysis

ii) When running change detection, you need to register the two clouds or surfaces to each other to make sure the areas that have not changed are within a desired tolerance of each other, otherwise you will not detect true change in your space.

iii) Best fit algorithms and manual registration if required to marry the 3D clouds or surfaces before comparing.

iv) Either one of the time periods needs to be considered the truth, or you don't care which is true and just marry them as best together to highlight the changed areas.

d) LiDAR can also be used to improve 3D registration for change detection and overall accuracy.

5) Image and point cloud analysis

a) UAV data has the advantage over LiDAR data in that it provides full image coverage of sites, while LiDAR typically has single 3D points attributed with image color or reflectivity.

i) What this means is that with UAVs, you get a true high-resolution 3D point cloud and true high-resolution imagery.

ii) Both can be analyzed separately and together for classifications, filtering and editing, feature extraction and terrain analysis.

b) I will mention a few image analyses that can be useful from UAV data.

i) Classification

- Pixels can be trained and classified to attribute various vegetation, buildings, man-made ground, bare earth and geology types.
- If multispectral, hyperspectral and other specific sensors are used, then possible classifications increase.
  (a) It is possible to map the various observable lithologies and mineralogies, alteration and weathering fronts.
  (b) Both automated and manual mapping of geology.

ii) Feature extraction

- Images can be analyzed for delineating areas of common classifications or analysis results, allowing attributed point, linear or polygonal vector data creation.
- Geologic lineations and polygons of differing surface geology can be automatically mapped this way.

iii) Change detection:

- Image-based changes.
- Polygons of measured change.
- Raster change maps.
- Minerals, vegetation, moisture, weathering, material depositions.

c) Point cloud analysis:

i) Classification

- This classification is based on local topographic changes and lowest points in a local topography.
- Classification scheme defines low and high vegetation, buildings, bare-earth and outliers.
- Topographic analysis can be conducted to extract geologic features.
  (a) Fault and landslide scarps and offsets.
  (b) Lineations.
  (c) Karst features.
  (d) Structural trends.
  (e) Hummocky terrain and levees for landslides and debris flows.

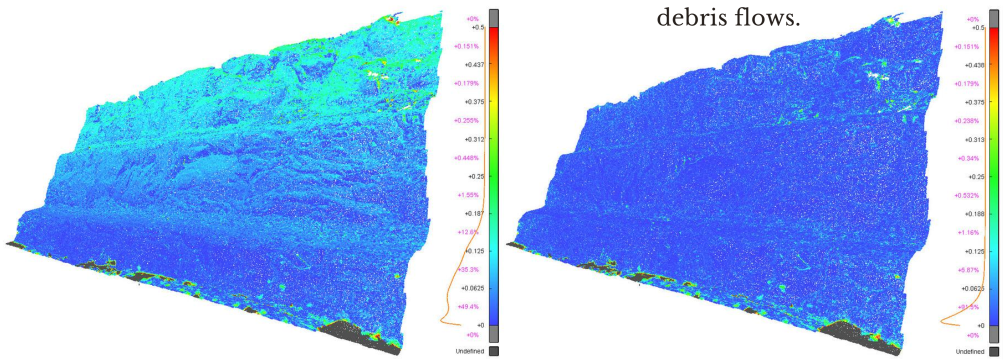

Figure 1. UAV point cloud registration using terrestrial LiDAR

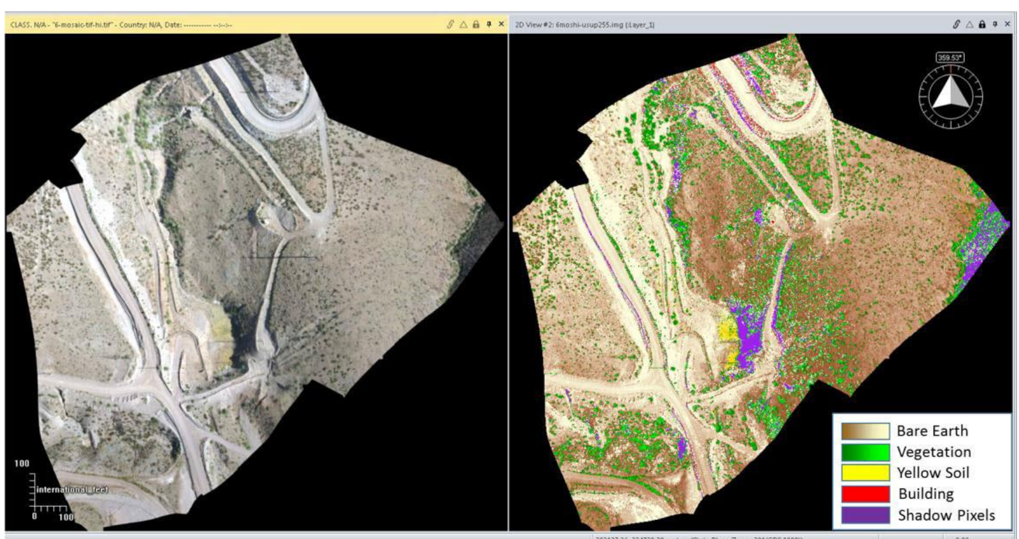

Figure 2. Classification of UAV data using image analysis

• Change detection:
(a) Geometric/terrain change.
(b) Mass-wasting events.
(c) Deformation.
(d) Erosion and hydrologic feature changes.

d) Joint image and point cloud analysis.
i) In some software, the results of both image and point cloud analysis can be attributed to the other data type.
ii) Point clouds can be attributed with the image analysis for the corresponding pixels and vice versa.
iii) The combined data can be combined for an improved classification to enhance vegetation removal from UAV data.

6) 2D and 3D modeling

a) 2D GIS
i) In traditional GIS software, all the above-mentioned products can be imported, visualized and analyzed with geological and other GIS layer maps.
ii) Analysis can include
• Comparing locations of existing and new geologic features and domains.
• Correlating new geologic finds with known data and updating models and maps.
• Further change detection.
(a) Volumetric change measurement.
• Updating of site plans based on the new geology data.
iii) However, for more detailed 3D analysis on a small scale and for the subsurface, the data should be brought into a true 3D environment.

b) 3D GIS/CAD
i) In the true 3D environment on a digital outcrop model, you can conduct more detailed rock mass characterization and outcrop structure mapping.
ii) With high-resolution point clouds, small scale geologic structure is visible as fracture planes and linear traces day lighting in an outcrop.
iii) These features can be automatically and manually delineated and mapped using specialized software.
• Polygons and polylines attributed with orientation data, strike and dip/dip and dip direction.
• Discontinuity spacing.
• Roughness.
• Aperture.
• If multi or hyperspectral imagery is used, then discontinuity fill mineralogy could be determined.
iv) Combine the new features with existing 3D models.
• Add to the 3D geologic structure and domain models.
• Update models and corresponding plans based on those models.

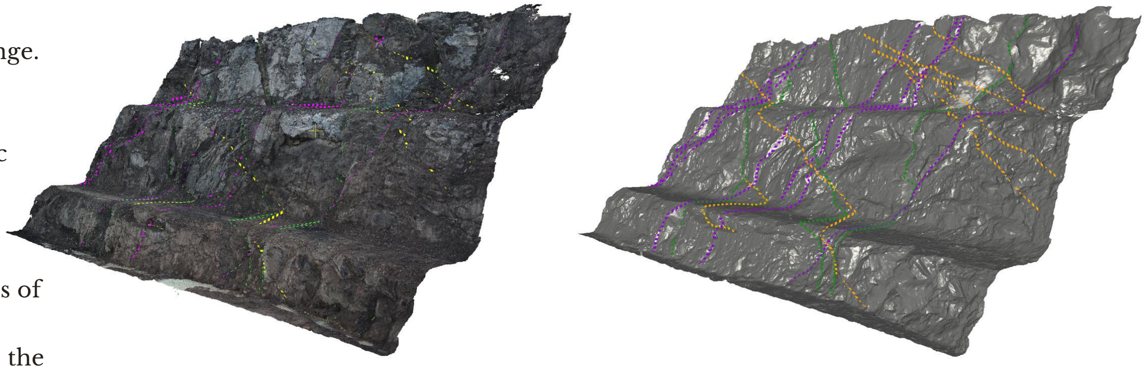

Figure 3. Fault digitization using 3D color UAV point cloud and mesh digital terrain model

Challenges with UAVs

UAVs are a convenient way to collect large amounts of very informative data quickly, but challenges must be noted. These challenges can take a well-intended plan to add UAVs to improve your workflow to a waste of time and money that may not give you a return on your investment and, worse yet, may not be usable.

Flying UAVs is a challenge for a few reasons. Battery life for UAVs is notoriously low, often limiting flight times to 15 minutes or less. This makes it hard to capture large areas in a reasonable time frame. Recently, longer flight times have become more prevalent, with flights an hour or longer being more common.

On the data capture side, flight plans, cameras and pilots are not perfect and imperfect data is common. To start out, you may be fine to use a cheaper UAV and camera, but you may also quickly realize that your data requirements exceed your system's capabilities. For photogrammetric processing to work accurately, the objects in the images must be sufficient resolution to pull out details without distortion from improper camera lenses. Flights must be flown at the proper distance from the object not only for the required overlap, but also to obtain the small enough pixel size to extract the level of detail that your project requires. However, collecting more images and higher resolution than you need, will slow down every step of the processing and analysis because of the unnecessarily huge size of the data.

Site conditions are also a limitation of UAV data collection. Since UAVs are mostly using passive camera sensors, they rely on ambient light conditions to absorb reflected light. This means that they cannot operate in the dark without powerful lights and are highly affected by diurnal light changes from sun angles to clouds. Vegetation is a big challenge for UAVs because imagery does not penetrate vegetation the same way laser scanning does. Because of this limitation, getting bare-earth data is much harder, if not impossible with UAVs. However, flying to capture oblique angle images and utilizing the above-mentioned joint multispectral imagery and 3D point cloud vegetation classification can improve vegetation removal. And surfaces of water and snow can be too mobile, too homogeneous and/ortho reflective, inhibiting the photogrammetric automated detection of matching points, required for generating accurate 3D geometry recreation.

Photogrammetry processing is a slow process. Taking the right number of images with the required overlap and resolution ensures you won't process more than you need to, but it still won't be fast. Algorithms and computing technology are not available yet to make this a real-time process, which is highly desired for instantaneous onboard surveying and mapping. If you don't need the most detailed point cloud or DEM, then make sure you don't choose the densest settings in the software.

As mentioned in the methodology section, the point cloud and imagery data is difficult, if not impossible, to use if not adequately simplified for the downstream uses and project requirements. Although newer, level-of-detail (LOD) file formats are rapidly increasing the size of data that can be viewed in software, it is still best practice to optimize your data to your needs and cut the unnecessary fat. Even with these new formats and computer power, not all software in the workflow or all calculations will run with the heaviest UAV-based point clouds and images. These files are still large by today's standards of large data, with files in the 10s to 100s of gigabytes (GB) becoming common. Along with this large data challenge, comes the challenge of data storage and sharing. The larger the files, the harder it will be to up store, upload and download, always taking up time and clogging up your network bandwidth for other work. In addition to simplifying data, optimizing data can mean taking advantage of the LOD file formats mentioned above as well. These formats are highly compressed, typically taking an ASCII point cloud file to 5% or less of its original size, meaning a 10 GB point cloud goes down to at least 0.5 GB. Hexagon Point Clouds (HPC) and Enhanced Compressed Wavelets (ECW) imagery are two examples of these highly compressed file types. And speaking to the LOD capabilities, this means that users will stream the data to their viewers, only rendering the details they need based on the area they are observing and how zoomed in they are. Your computer power is not wasted on trying to process and visualize details you cannot even see anyway.

Conclusions & Future Work

UAVs are being used more and more for geologic investigations and site characterization. However, there are challenges that exist that make full implementation challenging and risky. Some of these challenges are simply in the technology and the fact that the initial photogrammetry processing is slow. Some of the challenges are issues you can address by understanding your requirements and optimizing entire workflow to meet those needs, reducing file sizes and downstream processing times. Future work will likely be related to UAVs with combined cameras and LiDAR, longer flight times and real-time data processing and mapping. Currently, Hexagon Mining is working on improving the workflow detailed above, by integrating systems from the UAVs to the processing and analysis to the 2D and 3D modeling. The more automation and integration there is, the faster and less error-prone the data and deliverables will be, resulting in faster and improved decision making from UAV data.

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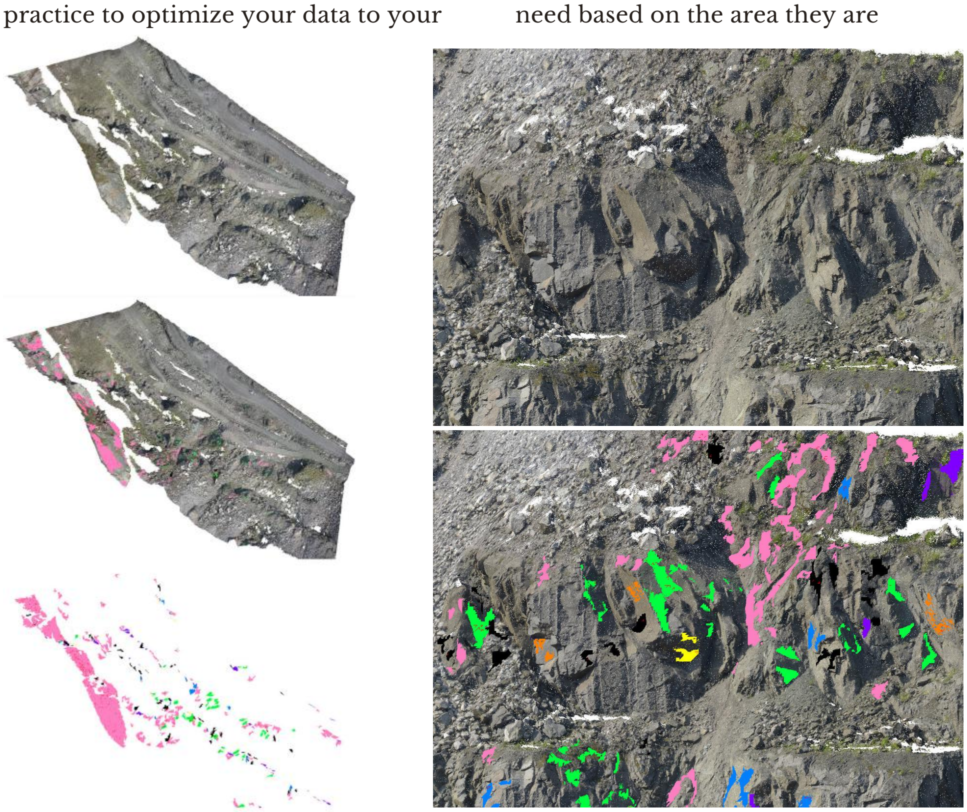

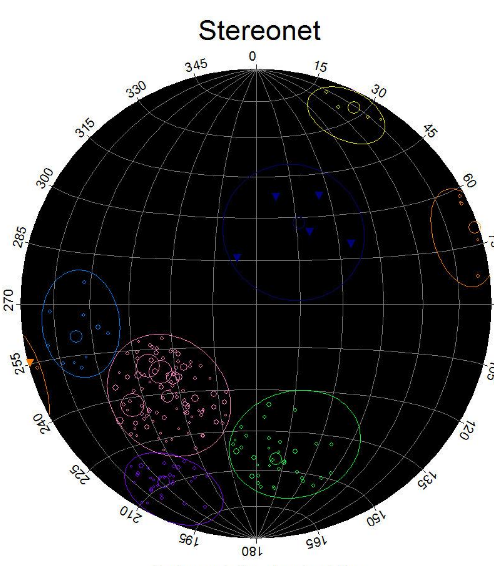

Figure 4. 3D color UAV point cloud model: map view showing automated geologic structure extraction (left), face view showing the same (middle), and resulting stereonet (right).