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The geological extension of the Alburz sulphur deposit depicted by hyperspectral remote sensing and GIS: Development of new methods for interactive mineral exploration with UAV in inaccessible areas of Afghanistan

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Abstract

Our study has shown that even a relatively inexpensive UAV has great potential for detailed geological investigations in partly inaccessible terrain. Obtained still imagery, preferably in raw format, can be post-processed to achieve high resolution mosaics, and through overlapping imagery a digital photogrammetric analysis is possible. Due to the present poor security situation at the Alburz site, we decided to do field work in another area, which exposes similar rocks from the same stratigraphic level. Parallel to our own field documentation we examined and analysed freely available space borne imagery from different sensors covering larger, adjacent areas. We examined also pre-processed HyMap data registered on-board an air borne platform over vast areas of Afghanistan. In these data it was possible to independently identify our small gypsum deposit but not the Alburz sulphur deposit itself. None of the methods enabled us to detect further outcrops of sulphur or gypsum layers in the vicinity of along strike.

Keywords: remote sensing, UAV, hyperspectral data, HDR, DTM, Afghanistan

1. Introduction

The Alburz sulphur deposit is situated in Late Cretaceous alum-gypsum beds and strongly altered siliceous-carbonate rocks that are exposed in the core of an anticline situated 50 km WSW of Mazar e Sharif in northern Afghanistan. Some of its characteristics are described in http://www.mindat.org/loc-30575. html, but to our knowledge no detailed study has been carried out. Like for many other known or suspected mineral occurrences in Afghanistan, the access to the site is limited due to lack of road infrastructure and poor security in these often remote areas. During our project security did not allow us to perform field work in the Alburz area, and we decided to test our remote sensing technology about 100 km eastwards along geological strike in the same stratigraphic horizon, where instead of sulphur gypsum is exposed. The results of these studies were published in Bax *et al.* (2016).

The geology of Afghanistan has in very few places been mapped in detail during the last decades, as many parts of the country have been inaccessible for traditional mapping techniques due to on-going armed conflicts. Even with improved security, vast areas remain inaccessible because of rugged terrain and a still very coarse road network.

Recent map compilations [1] and the investigation of other geological data have however shown a great wealth of mineral resources in Afghanistan. The whole country is covered with geological maps at the scale of 1: 250 000 available from (http://pubs.usgs.gov/of/afghan/), where the distribution of depicted rocks units is entirely based on Russian (northern part) and German (southern part) field work. See [2] and [3] for an overview.

Entirely new contributions are the US remote sensing missions registering hyperspectral data over almost the entire country (Fig 4 http://pubs.usgs.gov/of/2008/1235/).

The surface conditions in Afghanistan are ideal for geological remote sensing and already multispectral data from the visible (VIS) and near infrared (NIR) part of the spectrum show the distribution of rock units in general very well. Therefore it is possible to perform photogeological investigations with great success. The aim of our study was to develop and test a robust method that allows volumetric calculations of mineral occurrences already depicted by other techniques. We also wanted to obtain imagery of even higher spatial resolution than what is shown for example in Google Earth (GE) or other online data (World Imagery). To achieve this, an obvious choice was to use a miniaturized UAV equipped with a high resolution camera.

The purpose of the study was to develop a prospecting method that can be used in areas that can presently, due to security reasons, not be visited by geologists performing traditional field methods. The high resolution imagery acquired by the UAV can be processed to obtain very detailed 3D-modells later used to calculate the volume of the deposit. By developing the method we enable the detailed study of many other poorly known mineral deposits in Afghanistan.

CMOS and CCD sensors are far more sensitive to infrared radiation than those from the visible part of the spectrum. To avoid noise in the image, the infrared part of the spectrum is optically filtered away by a physical filter that is placed in front of the sensor. By mechanically removing this filter and replacing it with one omitting the visible light, one create a low cost but very effective IR-sensor. The transmitted wavelength is defined by the filter used. This approach should be tested in a future study.

2. Geological and Geomorphological context

Our study area and test site close to the village of Chetgari is situated 50 km E of Mazar e Sharif, the capital of Balkh province in norther Afghanistan (se Figure 1). As shown in Figure 1 Chetgari is situated at the SE rim of a Late Mesozoic sedimentary basin indicated on the map by the faces distribution of the Jurassic evaporates.

According to the 1: 250 000 scale geological map [4] shown partly in Figure 2, the study areas comprises sandstones and limestones of upper Cretaceous age. The complex geological structure is closely related to Alburz–Mormul EW-trending high angle fault zone [5], situated just S of our site. Tilt angles of Quaternary sediments north of the area indicate recent uplift rates of the southern blocks in the order of 3 cm/year [6].

The main displacement is, however, according to Nikolaev [5], sinistral strike slip. The overall tectonic structure of the area around Chetgari is a complex anticline with vertical limps in Cretaceous limestones along the narrow gorge along the northbound road to the minor city of Kholm, 5 km to the north of Chetgari. The Alburz area is situated in an identical stratigraphic and tectonic position. Geomorphologically both areas are in eroded cores of major anticlines, representing inverted relief.

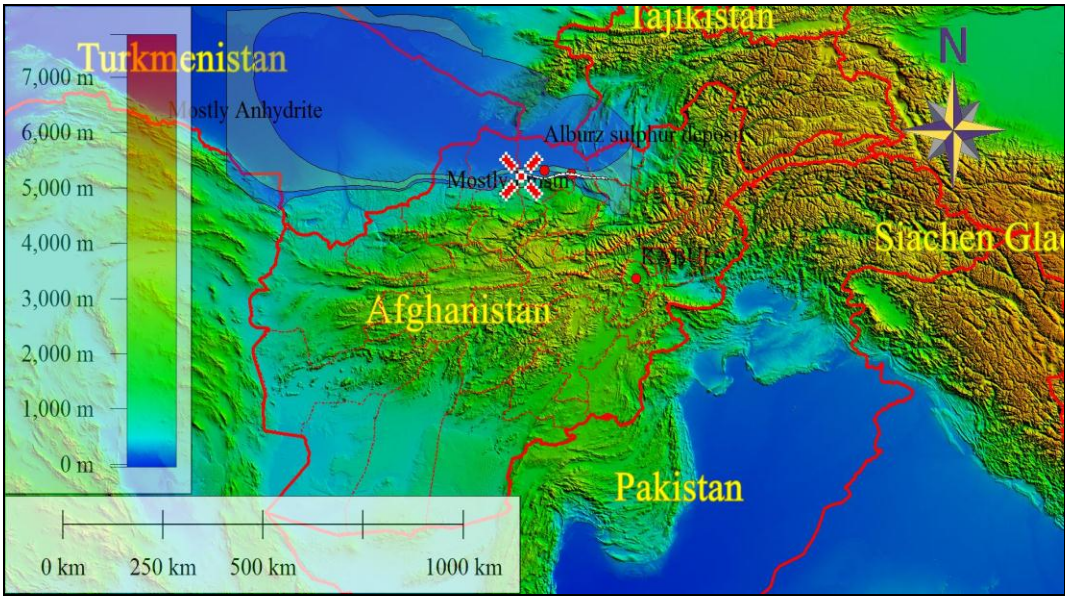

Fig 1: Location of the Alburz area SE of Mazar I Sharif in northern Afghanistan marked with X. Chetgari, the test site with gypsum, is located 50 km E of Mazar e Sharif and 300 km NNE of Kabul, all marked with minoir red dots. Alburz-Mormul Zone is dotted and the approximate extension of the Afghan-Tadjik depression is indicated by an overlay showing the Jurassic evaporite facies distribution http://pubs.usgs.gov/of/2006/1179. Hillshaded, SRTM derived elevation and political boundaries (in Afghanistan on provincial level) for orientation.

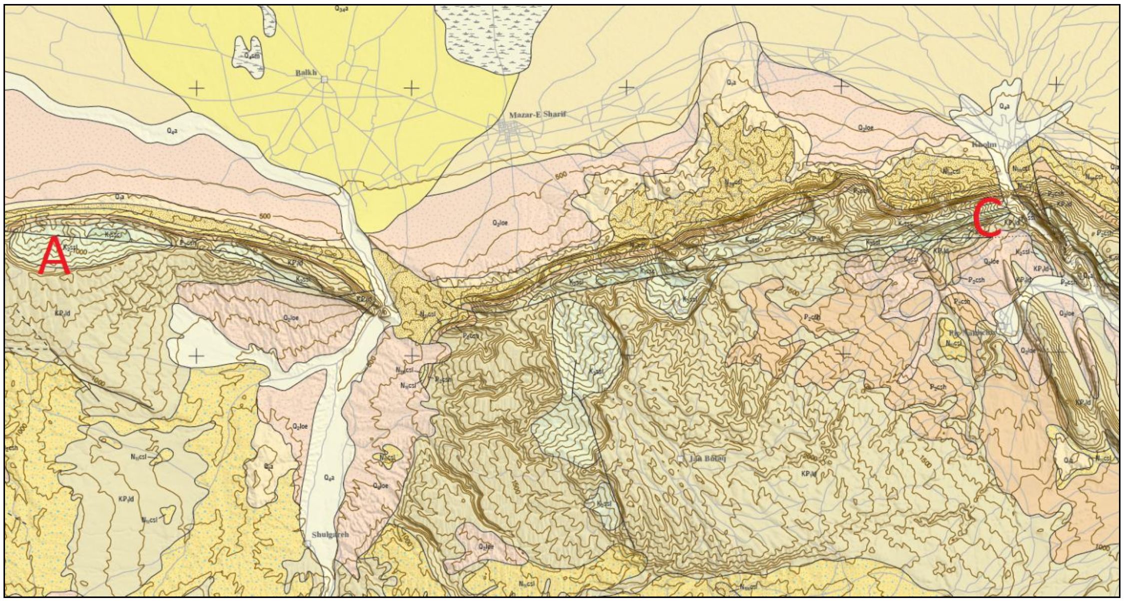

Fig 2: Excerpt from the 1: 250 000 geological map of OF QUADRANGLES 3666 AND 3766, BALKH (219), MAZAR-I-SHARIF (220), QARQIN (213), AND HAZARA TOGHAI (214) QUADRANGLES. Geological symbols according to international conventions. E-W extension of map segment is about 120 km. Red A marks the Alburz site and C the Chetgari test site.

3. Classification from air and space borne imagery

For our study we had access to pre-processed hyperspectral data from the HyMap mission covering also vast parts of Afghanistan [7]. Furthermore we downloaded a time series of Landsat TM and ETM+ data comprising scenes from different vegetation periods, as well as one ASTER scene. In none of the data sets we were able to distinguish the Alburz sulphur from its surroundings, although we tried supervised and unsupervised classification.

Fortunately for our parallel study in the Chetgari area, the datasets of the 1 and 2 micron imagery started at the location of the village Chetgari and all the considered ground to the W (see Figure 5). E of Chetgari there is no HyMap coverage. The surroundings of Alburz area, however, are covered completely by both types of HyMap data.

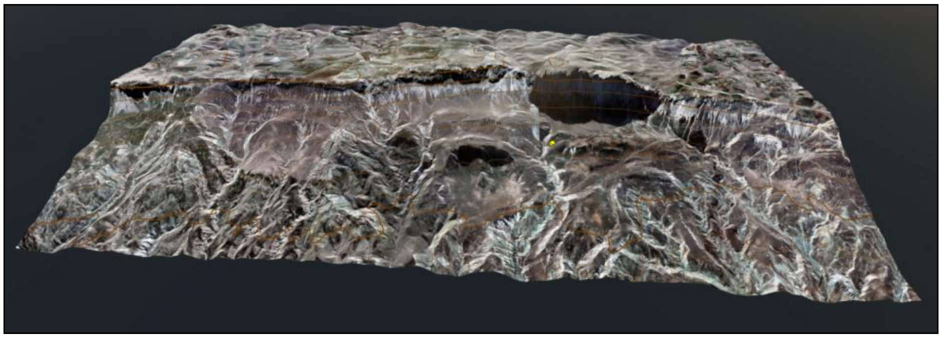

Fig 3: View on the Alburz area from the N (looking S). IKONOS WI data with 1m resolution were draped over 30m resolution SRTM elevation data. The E-W extension of this computer generated 3D view is about 9 km. No vertical exaggeration. 100m contour lines were created from the SRTM data to show the hight of the 200m escarpment behind the sulphur outcrop next to the yellow labelled icon.

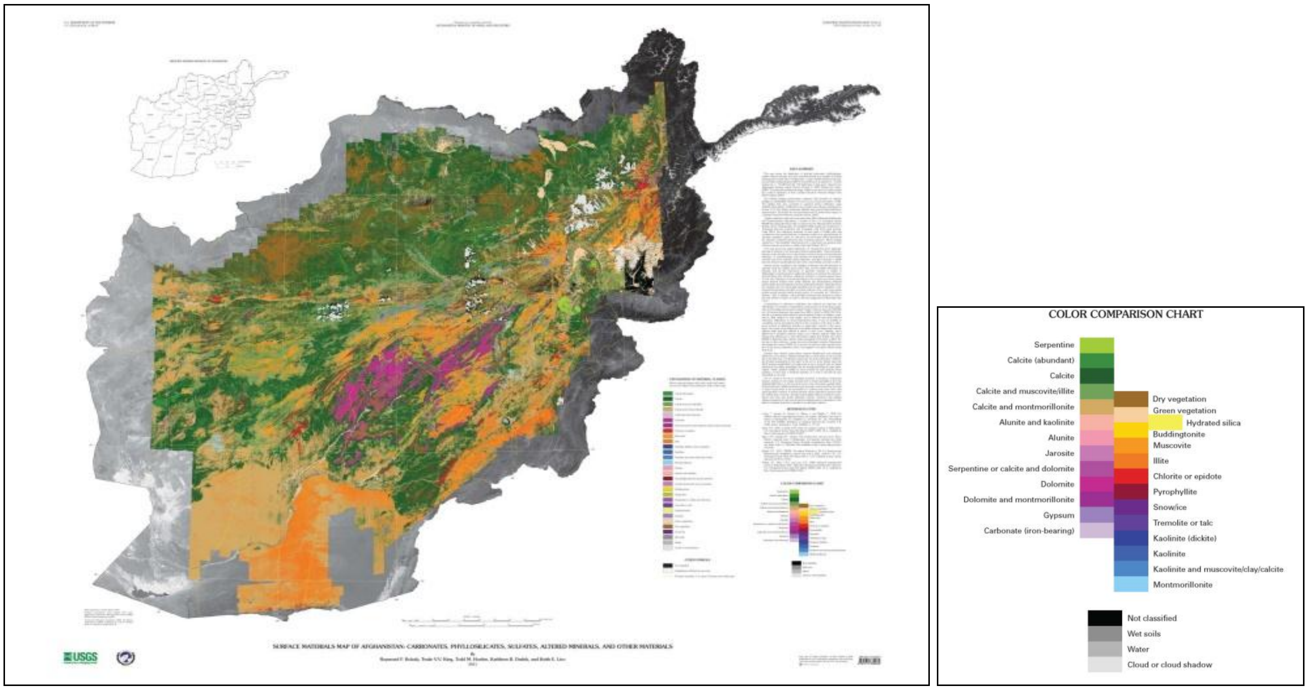

Fig 4: Coverage and interpretation of processed HyMap data over Afghanistan (cf. [7]) to the right a close up from the legend.

As Gypsum, the mineral we were prospecting for in the Chetgari area, was already identified by the algorithm used during the pre-processing by Kokaly *et al.* [7], we reclassified the data and extracted vector files showing the surface locations of gypsum and related minerals [cf. 8]. It turned out that outcrops of gypsum obviously only occur on the east facing slope just west of the village Chetgari. Along strike the same stratigraphic horizon shows only outcrops classified by the algorithm as occurrences of montmorillonite, and – in a few places – serpentinite. Gypsum reappears only in minor occurrences several tens of kilometres to the west in the same stratigraphic level.

Unfortunately, the HyMap data has a shift to the W of about 150 meter in relation to all other used GIS data, and therefore the polygons shown in Figure 4 do not coincide with the locations of the outcrops in the World Imagery (WI).

Despite the lack of metadata for the World Imagery we assume that the imagery with sub-meter resolution is derived from the IKONOS sensor.

Apart from the pre-processed HyMap we had also access to hyperspectral data from the (experimental) Hyperion sensor from the EO-1 satellite, as well as ALI multispectral data registered on-board the same space borne platform. In none of the data sets we were able to identify the relative small outcrop of gypsum, but the surrounding stratigraphic horizon was clearly visible.

Also in Aster and Landsat ETM+ satellite imagery we tried to identify the gypsum outcrop by means of unsupervised classification, but were not able to distinguish it from the surrounding lithologies. Anyhow, the small deposit was already known from previous field work, and the image processing and classification was aiming at the discovery of a possible continuation of the gypsum layers along strike. The satellite imagery was also used for comparison with the imagery derived from the small air-borne sensor described in the following chapter.

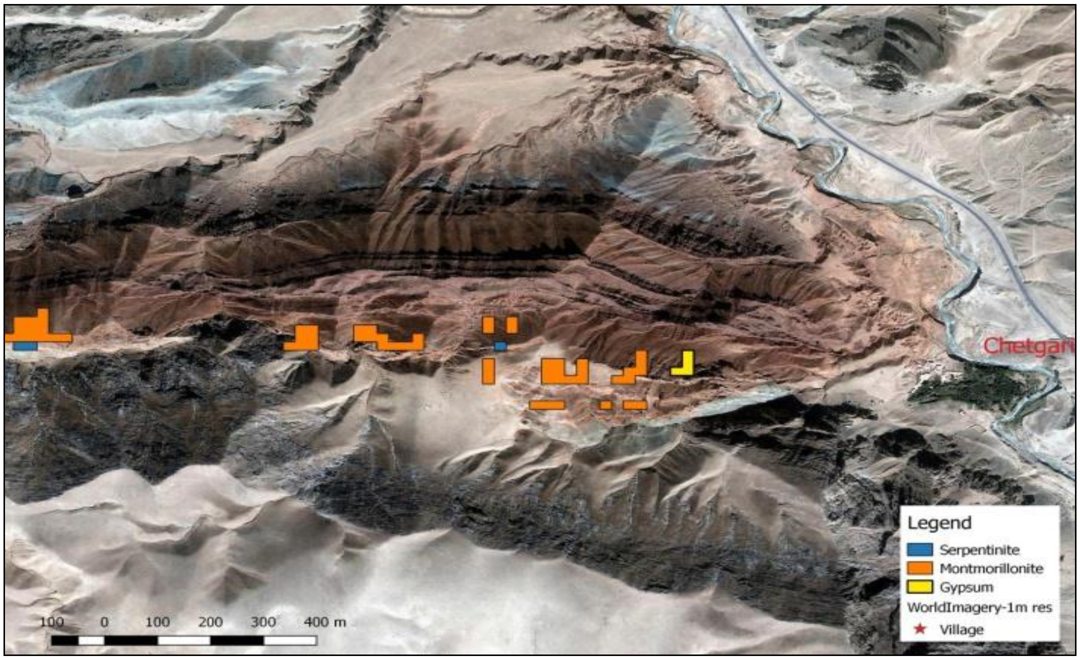

Fig 5: Result of the analysis of preprocessed HyMap data over the study area. Extracted interpretations of Gypsum, Montmorillonite, and Serpentinite from the preprocessed HyMap data draped over World Imagery meter resolution IKONOS image. Observe that the HyMap data has a shift to the W of about 150 meter in relation to all other used GIS data.

4. UAV investigations

The main part of our study was the development of a robust method to obtain very high resolution imagery (cm range) and to be able to create detailed digital terrain models (DTM) by photogrammetric methods using parallax differences from a series of images. The most efficient method seemed to use an unmanned aerial vehicle (UAV) equipped with a high resolution camera that would also allow us to record video sequences for interpretation “on the fly”. This set-up has become very popular in recent years for precision farming and we assumed that it would also be of great value for purposes of photogeology. The semi-professional systems for precision farming include usually sensors registering also in the near infrared part of the electromagnetic spectrum, which would also give valuable information for geological purposes (rock type discrimination). Unfortunately these systems are still relatively expensive, and the image interpretation requires profound knowledge about the reflection properties of rocks and minerals in the infrared part of the spectrum. Therefore we were looking for enhancement methods of imagery from the visible part of the electromagnetic spectrum only.

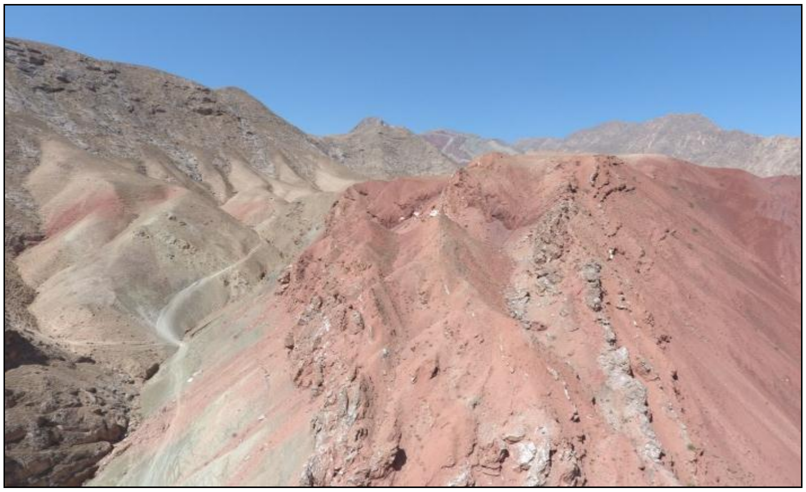

Fig 6: Unprocessed oblique aerial photograph taken from the UAV looking W.Image width in foreground approximately 200 m.

Fig 7: HDR processed image using the above image (Figure 6) "normally" exposed, and combined with an underexposed (-0.66EV) and an overexposed image (+0.66EV) from the same sequence. As the images are taken in a series, it is very critical - for best results - that the camera does not move significantly. Otherwise image alignment algoritms have to be utilized, often degrading the result

After a survey of the present market of "low cost" UAVs, mainly dedicated to recreational use, we decided to purchase a DJI Phantom 4 for our project. Our criteria were: ease of use, price, and image quality. Other brands have similar products, and – due to the extreme popularity amongst hobby users – new models and versions appear on an annual basis. The present price for a ready solution was at the date of purchase (June 2016) just below 2000€ and therefore in the frame of our budget. Phantom 4 is a quadrocopter with a weight of less than 1.5 kg and a size that fits easily in a rucksack for transport by foot. The on-board camera has a resolution of 4000x3000 pixels and can film in 4K. Other criteria to purchase this model were its advanced image stabilization through gimbal and the steadiness of the platform during hovering. This was necessary to obtain stable image sequences for later HDR processing (see above). For the semiautomatic photogrammetry we used Agisoft PhotoScan software. The HDR processing from each triplet of raw images was done in Adobe PhotoShop, but there are also free (nonproprietary) alternatives available like Luminance HDR or Fusion. Above some images of our processed HDR results.

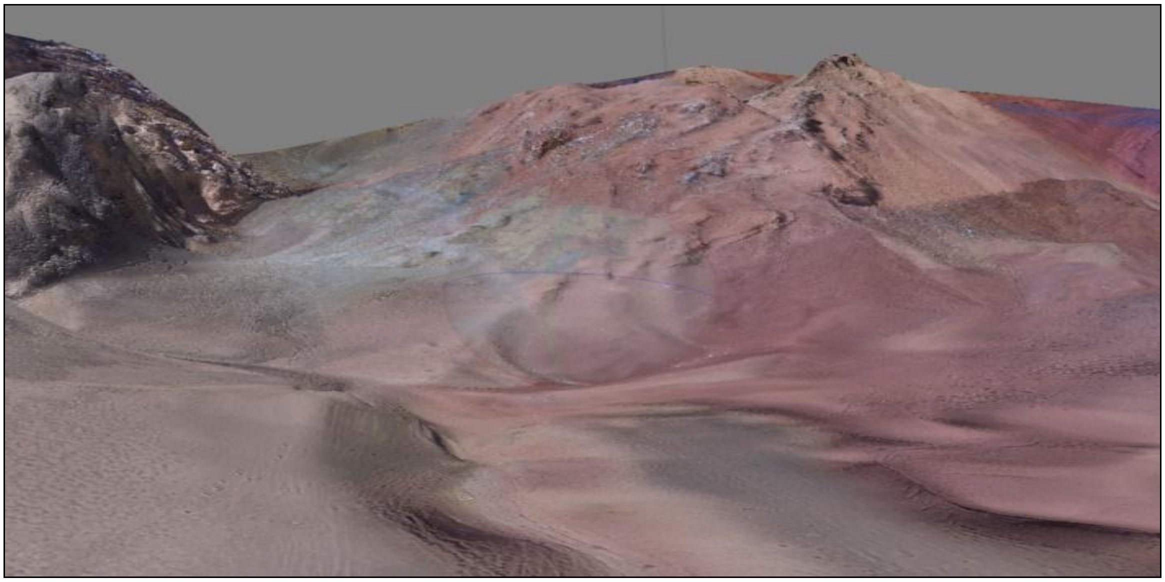

Fig 8: 3D model obtained after processing 114 images taken with the UAV. Note that the software PhotoScan uses EXIF data with GPS and GLONASS positions obtained by the inbuilt receiver in the UAV. For scale compare with Figure 6.

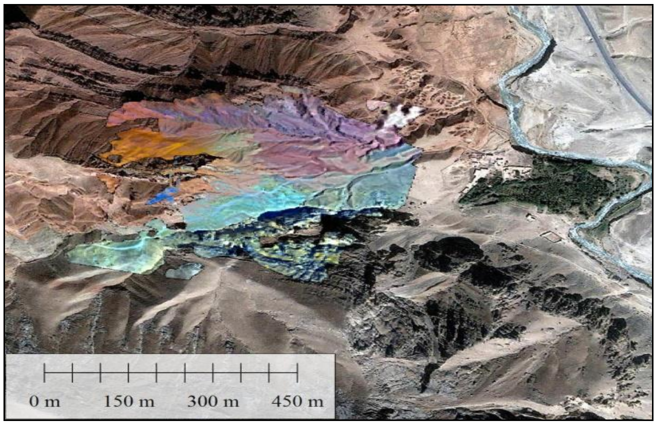

Fig 8: HDR coverage superimposed on IKONOS imagery. Note the very good spatial fit, as the HDR mosaic obtained its position solely based on its EXIF data

For mapping purposes, there are essentially two modes to operate the UAV. In both cases the pilot interacts through a smartphone or tablet app (iOs or Android) connected by cable to a handheld remote controller, which then communicates with the aircraft, that can be operated up to 5km away. One mode is to program the flight route beforehand to ensure optimal spacing and overlapping of the aerial photographs for digital photogrammetry. The apps for this are mainly developed for precision farming in flat terrain and worked not well amongst the rugged mountains of Afghanistan. An alternative would have been to increase the flight altitude, but this would have also decreased the spatial resolution of our images, especially in lower parts of the terrain. Therefore, we operated in manual mode, guided through the real time video from the UAV to our Android device. For later HDR post-processing we obtained 3 images using auto exposure bracketing (AEB) at each of the 114 positions.

5. Discussion and Recommendations

Our study has shown that even a relatively inexpensive UAV has great potential for detailed geological investigations in partly inaccessible terrain, which is the case for vast parts of Afghanistan. Obtained still imagery, preferably in raw format, can be post-processed to achieve high resolution mosaics, and through overlapping imagery, 3D models for detailed volume estimations can be created.

In our case we were not able to estimate the downward continuation of the almost vertical, fragmented gypsum layers, which is a prerequisite for calculating a reliable volume. Anyhow, the lateral extension of the deposit seems to be very limited and indications for gypsum do not reappear in the HyMap image classifications for many kilometres along strike. The visually identified area on our high resolutions imagery dominated by intercalated gypsum layers was about 4000 m², and - as shown in Figure 7 - these make up about 50% of the containing rock units. These outcrop in elongated lenses, up to 100 m long and up to 20 m wide. A very rough estimate would be that the whole deposit contains far less than 100 000 m³ of gypsum layers. Based solely on the HyMap classification, only 2000 m² are covered with gypsum, which would lead to halve of the above volumetric estimation. Therefore the deposit is of low economic value given the deposits inaccessibility up on a mountain ridge 150 m above the village of Chetgari with a mean slope angle of 25°. Apart from roads also a bridge over the river at Chetgari is required to reach the paved main road AH76.

As all recorded images taken by the UAV are automatically geotagged, GIS integration with other data and georeferenced imagery is rather straightforward. For regional photogeological tracing of structures and rock units, the high resolution mosaics can easily exported to KMZ format and draped over the terrain in (for example) Google Earth. As available imagery is taken from nadir position facing downwards, objects exposed on steep slopes are often represented in “smeared out” pixels. The possibility to fly through valleys and to take images perpendicular to the slopes makes it possible to avoid these distortions and gives the same resolution regardless of the tilt of any surface.

One major obstacle for the use of UAV obtaining images and videos for scientific reconnaissance are the misconceptions concerning UAVs (also called drones) in many countries, especially in Afghanistan. Drones are mainly considered to be used for combat purposes or espionage. Small UAVs - like the one used for our study - are however incapable to carry weapons or to be used outside the line of sight.

6. Acknowledgments

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