Mapping arid alluvial surfaces using reflective hyperspectral remote sensing

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I Introduction

The conventional mapping method of alluvial surfaces in arid areas is based on estimation of relative time characteristics of the surfaces and their underlying soils. Most of the mapping is made manually using air-photos, which manifest the surface brightness differences. Yet, this method is subjective and qualitative, and usually enables only rough discrimination between mapping units. In this study we examined the feasibility of mapping arid alluvial surfaces using reflective hyperspectral remote sensing. This method identifies the surficial mineralogy based on specific spectral absorption features.

The study area – Wadi Raham alluvial fan

- The fan is located along the Dead Sea rift, in the southern Negev desert, Israel (Fig. 1), and spreads over ~20km². The climate in the area is extremely arid, with average annual precipitation of 30mm.
- Most of the surficial clasts on the alluvial fan surfaces are carbonates (Fig. 2).

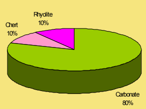


Fig. 2. Surficial clasts lithology distribution on the alluvial fan surfaces.

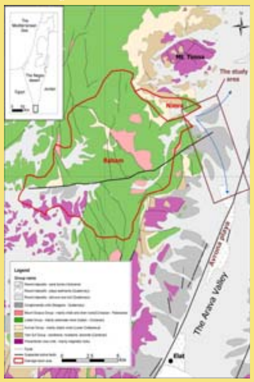


Fig. 1. Wadi Raham drainage basin and alluvial fan on the background of the geological map of Israel (modified after Sneh et al., 1998).

II The reflectance of the alluvial surface components

- The spectra of the freshly-broken surficial clasts and of the fine-particles between the clasts show distinctive absorption features, which relate to their mineralogy (Fig. 3).
- On the old surfaces, the rock coating on the carbonate clasts does not alter significantly the underlying spectrum. On the other hand, the spectra of the frehsly-broken chert and rhyolite clasts are attenuated by the rock coating.

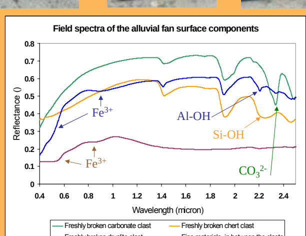
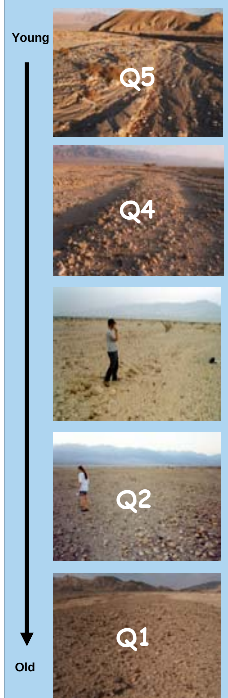


Fig. 3. The surficial clasts from the oldest alluvial fan surface (Q1 – Late Pleistocene): photos and field spectra. The fine particles spectrum is from the active channel surface (Q5).

III The reflectance of the overall alluvial surfaces

- We divided the fan into five alluvial surfaces, based on a field survey. The surfaces differ mainly by the degree of the desert pavement development and the degree of rock coating accretion (Table 1).
- Our results show that the absorption features depth of the alluvial surfaces are controlled mainly by the degree of desert pavement development (Fig. 4): as the clast coverage percentage increases, the absorption depth of the carbonate feature (contributed by the carbonate clasts) increases; whereas the absorption depths of the hydroxyl and ferric features (contributed by the fine particles between the clasts), decreases (Fig. 5).
- The carbonate rock coating main affect on the surface reflectance is albedo lowering.



Alluvial surface	Surface appearance (dissection degree)	Degree of desert pavement development	% Clasts coverage	Common coating color on carbonate clasts [No. of clasts]	Estimated age
Q5	Bouldery bars and channels of active streams with fine particle	None	20-30	None (2.5Y 8/2) [21]	Present
Q4	Clear abandoned bouldery bars and stream channels with small clasts	Poor	40-50	10YR 6.5/3.5 on bar 10YR 7.5/4 on stream [12,11]	Late Holocene
Q3	Clear remains of abandoned cobble bars and stream channels with small clasts	Medium	~60	10YR 6.5/3 [11]	Early Holocene
Q2	Nearly smooth surface, with remains of bar-and-swale pattern	Good	~90	10YR 7/3 to 3/7 Y2.5 [19]	Late Pleistocene – Early Holocene
Q1	Smooth surface, in places new incision appear	Excellent	~95	2.5Y 6/2.5 [11]	Late Pleistocene

Table 1. The alluvial fan surfaces characteristics. Age estimations are according to Amit et al. (1993).

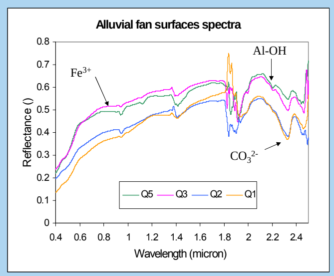


Fig. 4. The field spectra of the overall alluvial fan surfaces. All surfaces show a distinct carbonate absorption feature at 2.33µm due to the dominance of carbonate clasts. The fine particles in-between the clasts contribute hydroxyl and ferric absorption features (2.2µm, and 0.87µm, respectively). See also Fig. 3. The absorption features at 1.4 and 1.9 are due to the presence of water vapor in the atmosphere.

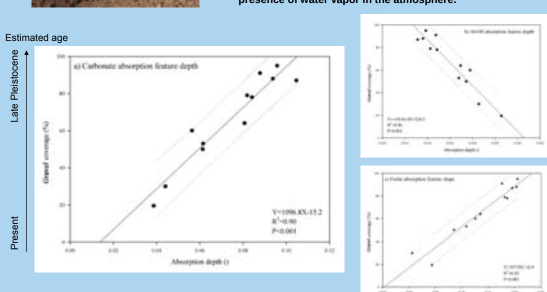


Fig. 5. The relationship between the absorption features of the alluvial fan surfaces and the degree of desert pavement development. The ferric absorption feature is quantified by its slope. Predicted 95% confidence intervals are plotted in gray. We can predict the gravel coverage with accuracy of ±15% gravel coverage

IV Mapping the alluvial surfaces using hyperspectral remote sensing

We used the hyperspectral sensor DAIS-7915 (72 bands in the 0.4-2.5µm region) to map the alluvial fan surfaces. Based on the findings of the field measurements we quantified the three absorption features that represent the degree of desert pavement development throughout the fan area, and converted them into clast coverage percentage values, accordingly to the regression equations in Fig. 5.

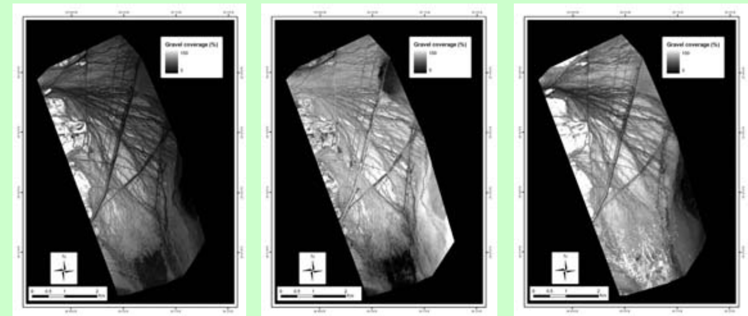


Fig. 6. Continuous grayscale images of the WRAF, representing the gravel coverage (%) after applying the linear regressions from Fig. 9: a) carbonate absorption depth; b) Al-OH absorption feature; and, c) ferric absorption slope. For each grayscale image, high values appear in light tones, while low values appear in dark tones. The images were stretched to 0-100% values. Values below or above this range appear mostly outside of the alluvial fan. Note that the active channels are in dark hues (i.e., low gravel coverage), while the old alluvial fan surfaces exhibit light hues (i.e., high gravel coverage).

Accuracy assessment results

We tested the accuracy of the continuous maps using 77 test sites that were sampled throughout the fan. By plotting the field-based against the image-based gravel coverage of the 77 test sites (Figs. 7, 8), the accuracy of the images (in terms of R^2) are 0.83, 0.67, and 0.57 for the ferric, Al-OH and carbonate absorption feature images, respectively.

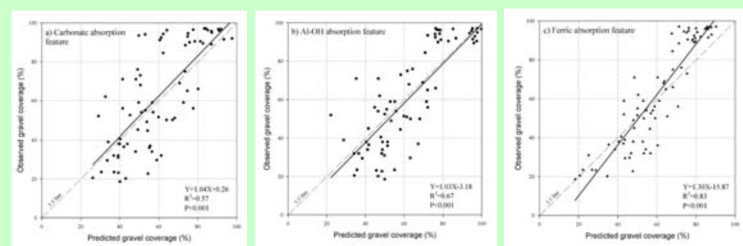


Figure 7. The relationship between observed gravel coverage (estimated in the field) and predicted gravel coverage, derived from the image analysis: a) for the carbonate feature; b) for the Al-OH feature; and c) for the ferric feature.

Conclusions

- The variations in the spectral signature of alluvial surface was found to be controlled by two main processes: the desert pavement development controls mainly the location and depth of the different absorption features, while the rock coating accretion controls mainly the reflectance of the surface.
- We were able to continuously map the gravel coverage percentage of the alluvial fan surfaces using hyperspectral data with predicted accuracy of ±15% gravel coverage.
- In order to create quantitative and accurate geomorphic maps of alluvial surfaces, instead of the conventional manual interpretation of air photos, we suggest using this method, combined with other remote sensing techniques.

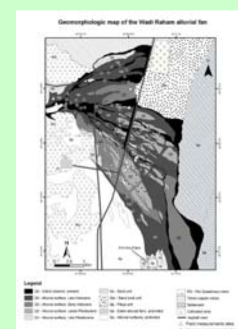


Fig. 8. Geomorphic map of WRA from visual interpretation of air photos. Field measurements and accuracy assessment sites are marked. Original scale 1:12,000.

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