PS Applications of Three-Dimensional Digital Mapping and Hyperspectral Imaging for Outcrop Characterization*

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Abstract

The study of outcrops is a viable tool in facies architecture and reservoir characterization studies. High-resolution geometric surveys, including terrestrial laser scanning (TLS), allow 3-D photorealistic outcrop models to be captured and interpreted using robust analysis and visualization environment. A Riegl VZ-400 TLS was used to scan vertical cliffs of incised valleys within the Turonian Ferron Notom Delta in South-Central Utah. Twenty-two scans from different positions were merged with high accuracy (average RMS 0.003 m) by using numerous retro-reflective targets. High precision differential GPS solutions have been used to rotate and translate the survey frame coordinates to global coordinates, allowing the digitized geologic surfaces to be used in a GIS environment. Nearly five thousand digital images have been captured with the use of a tilting and rotating stage (GigaPan™). A super-telephoto lens with focal length up to 500 mm allowed identification of small features, such as mud drapes, that are as small as a few millimeters in thickness. These high-resolution digital images and the TLS data have been fused to create a 3-D virtual outcrop model. An approximately 600 m strip of river cut cliff faces have been modeled. The outcrop is composed of a series of laterally and vertically accreting tidally influenced channels that are exposed in a series of strike and dip aligned sections. Geologically important surfaces, such as sequence boundaries, maximum flooding surfaces and structural elements were mapped accurately in 3-D space on the model. Ongoing investigation is focused on a data fusion of the geometrically accurate 3-D photorealistic outcrop model with the hyperspectral imaging technology and ground penetrating

radar (GPR) data. This type of data fusion will output a “true” 3-D reservoir model, and help address two issues of concern: (1) accurate 3-D geometry and heterogeneity of the facies architectural elements, and (2) porosity and permeability of reservoir facies. Resolving these types of unknowns is paramount to the oil and gas industry in developing accurate fluid flow simulations, which, in turn, yield to enhanced recoveries from similarly deposited incised valley type reservoirs such as the one that occur within heavy oil deposits of the Cretaceous McMurray Formation in Northeastern Alberta.

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(1) Summary

The study of outcrops is a viable tool in facies architecture and reservoir characterization studies. This research aims to provide solutions to integrate two methods of observations made on outcrops: a geometrically accurate terrestrial LiDAR scanning, and spectrally rich hyperspectral imaging. By combining these two sets of observations, the geologist will be able to improve his sedimentological and sequence stratigraphic interpretations by using laterally continuous observations, unlike the traditional observation methods such as measured sections or e-logs.

Terrestrial laser scanning and high-resolution panoramic imagery was used to create a photorealistic outcrop model. Combination of different sets of observational data resulted in a single suite for visualization, integration and interpretation. Geological surfaces accurately mapped onto the 3-D outcrop model and later will be used in developing a geocellular reservoir model.

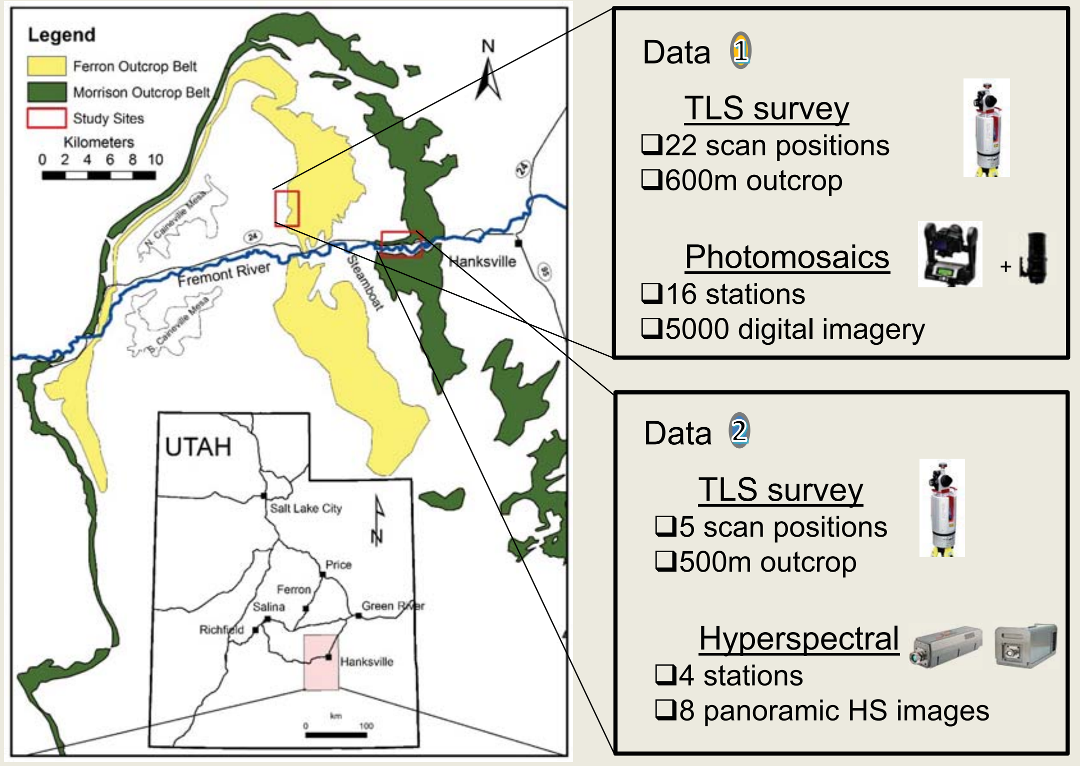
Two ground-based hyperspectral sensors were used to image the Morrison Formation outcropping near Hanksville, UT. Preliminary results show fluvial sand-bodies and associated flood plain deposits can be distinguished from their reflectance signatures.

We believe that the methods that are being developed in this research will complement the traditional geologic data collection techniques by providing laterally continuous remote mapping of reservoir facies while preserving the 3-D nature of outcrops.

(2) Project Goals

1) Create a suite for visualization, integration and interpretation and develop a reservoir analog model from high accurate spatial and spectral datasets
2) Perform remote mapping of chemical-mineralogical distribution on geologic outcrops by using ground-based hyperspectral spectroscopy
3) Develop methods of integration of TLS and hyperspectral data, and test applicability of fusion products in terms of their ability to quantitatively map sandstone-body and shale-body volumes

(3) Data



Data ①

TLS survey
❑22 scan positions
❑600m outcrop

Photomosaics
❑16 stations
❑5000 digital imagery

Data ②

TLS survey
❑5 scan positions
❑500m outcrop

Hyperspectral
❑4 stations
❑8 panoramic HS images

Fig.1. Map showing the location and extent of the two studied outcrops, the Ferron Sandstone and the Morrison Fm. (Geological data source: Utah Geological Survey, 2000)

(4) Photorealistic 3-D Digital Outcrop Modeling

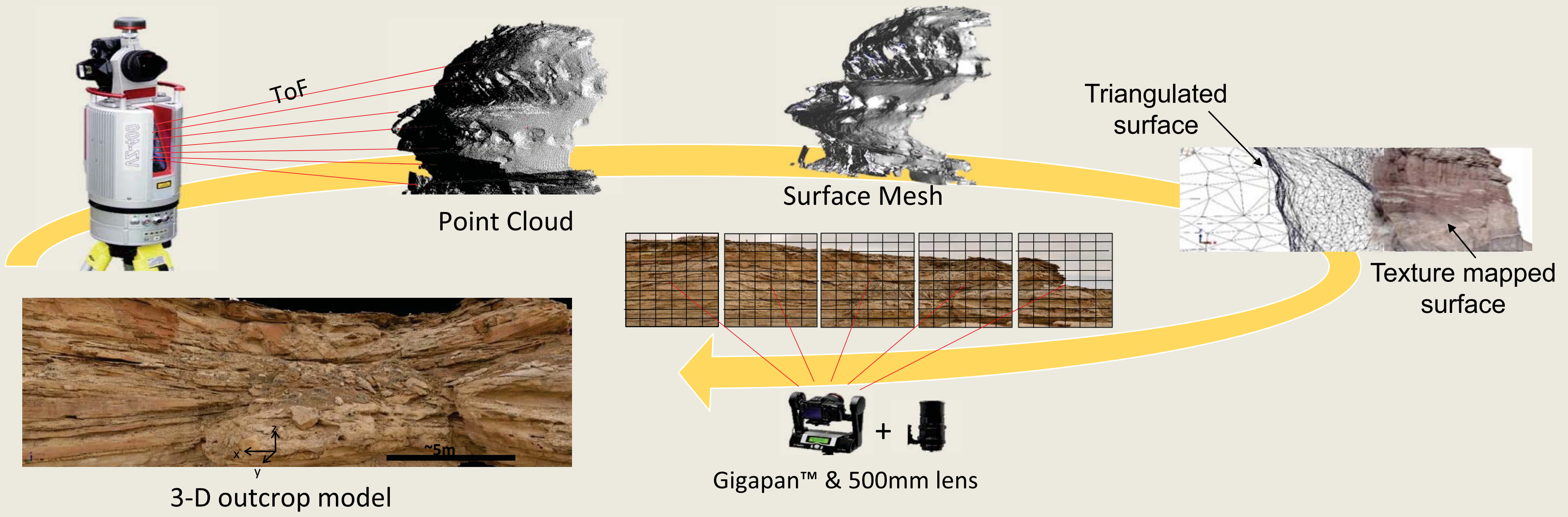
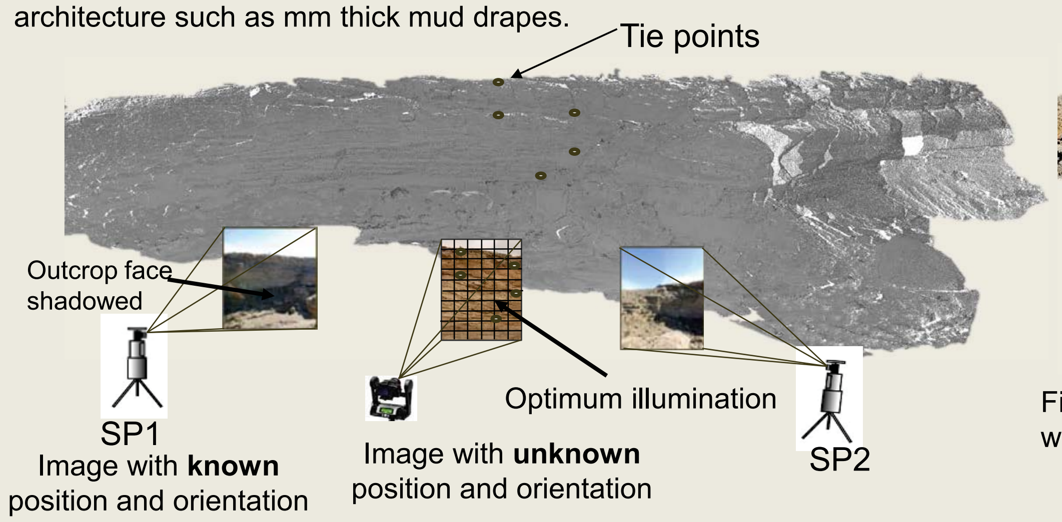


Fig. 2. Steps in creating a 3-D photorealistic digital outcrop model from a laser digitized point cloud data. High resolution panoramic imagery from a GigaPan rotating stage have been modeled onto the laser-derived surfaces. Average pixel density was around 1 mm. This allowed subtle changes in the reservoir architecture such as mm thick mud drapes.



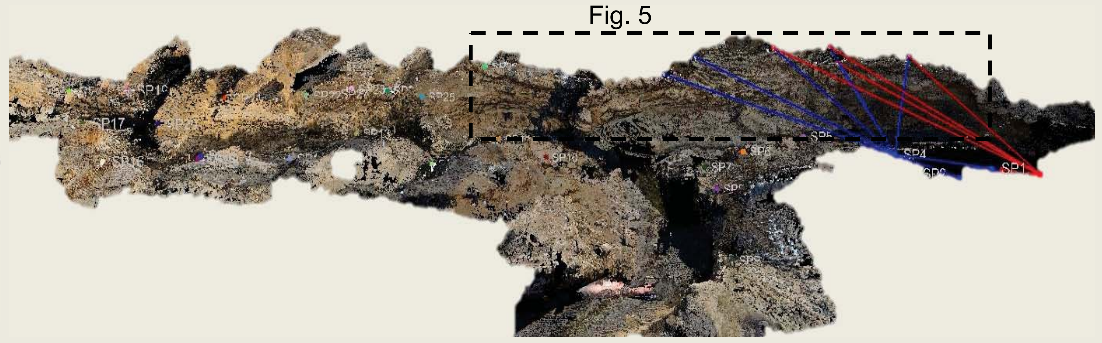


Fig. 4. Textured point cloud from 22 scan positions, covering a 600-m long cliff face with great vegetation-free 3-D exposures.

Fig. 3. a) Calibrated TLS-mounted camera takes images with known position and orientation. Laser mapping does not require optimum illumination, but TLS mounted camera can be affected by the Sun's position resulting in shadows in some imagery. b) High resolution panoramic imagery with optimum illumination. Each panoramic image is composed of hundreds of very high resolution imagery. Position and orientation are solved by using tie-points both visible in 3D laser data and digital imagery.

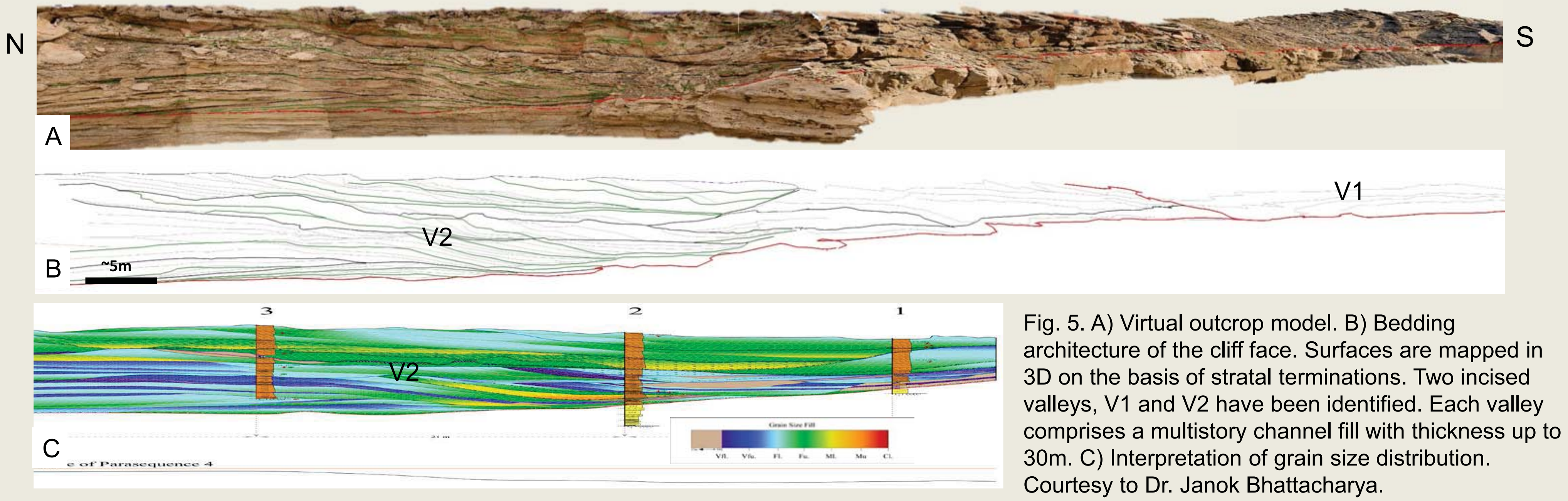


Fig. 5. A) Virtual outcrop model. B) Bedding architecture of the cliff face. Surfaces are mapped in 3D on the basis of stratal terminations. Two incised valleys, V1 and V2 have been identified. Each valley comprises a multistory channel fill with thickness up to 30m. C) Interpretation of grain size distribution. Courtesy to Dr. Janok Bhattacharya.

(5) Hyperspectral Imaging

	VNIR	SWIR
Spatial pixels	1600	320
Spectral bands	840	256
Avg. band width	0.7 nm	6.3 nm
Spectral range	VNIR 0.4-1.0 µm	SWIR 0.9-2.5 µm
Spatial res. @100m	~3 cm	~13 cm

Fig. 6. Two hyperspectral imagers and their specifications used in the study. Complete spectral coverage from 0.4µ to 2.5µ can be achieved by combining data from both sensors.

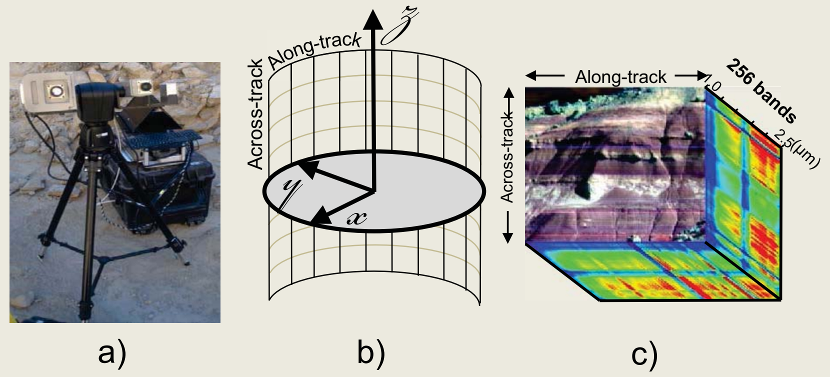


Fig. 7 (a) Specim hyperspectral sensors (left: VNIR, right: SWIR) and pan and tilt rotation stage; (b) cylindrical image coordinate system; (c) SWIR hyperspectral image cube. Third dimension represent the spectral distribution of the edge pixels from 256 bands.

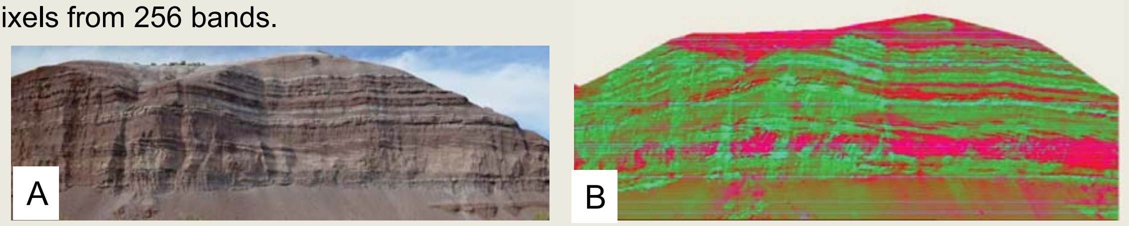


Fig. 8 A) Digital photograph of the Morrison Fm. outcrop near Hanksville, UT. B) A preliminary classification of hyperspectral imagery. Sandy multistory channel facies are distinguishable from the muddy floodplain deposits

(6) Conclusion & Future Work

- A photorealistic virtual outcrop model was used as platform for visualization, integration and interpretation for reservoir characterization.
- Pre-processing results of the hyperspectral sensor showed promising results for the classification of channel sand deposits
- Future work is focused on integration of geometrically accurate virtual outcrop model to the spectrally rich hyperspectral products.

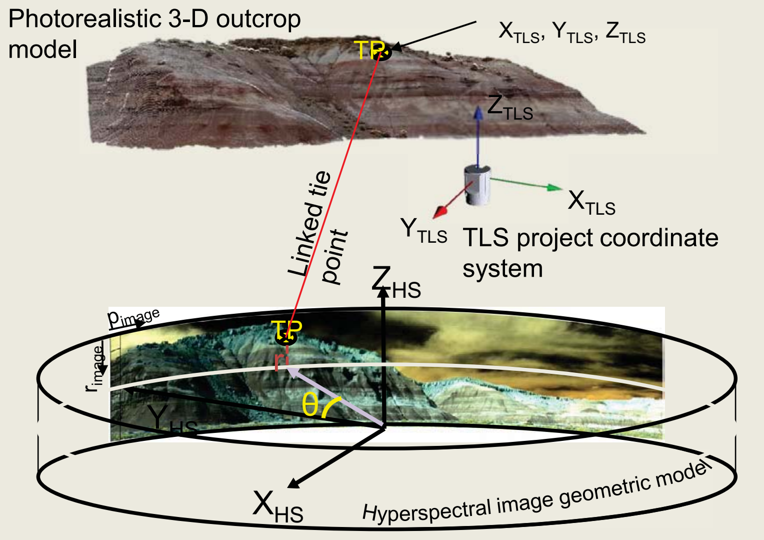


Fig. 9. Geometric model of hyperspectral image acquisition and the use of tie points to model imagery onto TLS generated surface to generate surface models. Hyperspectral imagery is recorded on to a cylindrical projection surface. Every image pixel on this cylindrical surface is transformed to a Cartesian coordinate frame (X_{HS}, Y_{HS}, Z_{HS}) and then linked to TLS coordinates with the use of tie points

Based on a concept by Schneider & Maas, 2006