Using 3-D Outcrop Laserscans for Fracture Analysis*

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General Statement

Understanding natural fracture systems may be difficult using limited borehole, production, or seismic data. When available, fracture data from analog outcrops provide additional insight necessary for effective exploration and production in fractured reservoirs. Surficial fracture data are often collected using hands-on, time-tested techniques such as:

- Scanline analysis, which includes recording the attitude and location of each fracture intersecting a measuring tape at the base of an analog outcrop.
- Cell mapping, which is performed by spatially dividing the survey area into cells and measuring gross orientations of primary fracture sets within each cell.

Although widely utilized, these inherently two-dimensional techniques may be biased or provide an incomplete assessment of fracture systems -- so we address these challenges by using a new fracture analysis methodology based on high-resolution laserscan technology. This technology is successfully being used for a wide variety of technical and mapping applications, and also has been successfully applied in the petroleum industry (see example of similar airborne technology in the February, 2002, EXPLORER, p. 6-9), but on a much larger scale.

Method and Example

The fine-scale laser scanner is tripod mounted, laptop-controlled and reasonably portable (Figure 1). The system collects three-dimensional data by measuring the elapsed time between emitting and detecting laser pulses to determine the distance between the scanner and the scanned surface, much like radar or sonar. The unit measures approximately 1,000 points per second, with maximum expected error of about five millimeters measured along the scanner axis. A single collection of points produced by the scanner typically comprises 750,000 to 1.25 million points and is termed a point cloud. Each point is composed of a three-dimensional location and a measured intensity value, which is dependent on surface roughness, moisture, etc.

Figure 1. The laser scanner is laptop-controlled and reasonably portable. Here, it is set up for mapping fractures in the San Xavier Mine, south of Tucson, Arizona.

For large areas or regional analysis, multiple point clouds may be collected and merged into a single scene during post-processing. Prior to utilizing the scan for geological analysis, the unconnected points must be triangulated to produce a three-dimensional convex hull, which is then visualized and analyzed as desired (Figure 2). Processing also includes registering the data within a UTM coordinate system, smoothing to reduce noise and decimating to reduce point density. Decimating is especially important when processing larger datasets, as it helps to reduce processing time.

Fracture detection is best performed on relatively high-quality laserscan data free from noise and obstructions, such as rockfall, trees, and shrubs. Fractures are extracted from the laserscan data using an automatic feature detection algorithm, which is controlled by user-supplied parameters, such as minimum patch size and desired patch quality. After collection, patches are exported with orientation and location for analysis and visualization on stereonets, rose diagrams, and within three-dimensional structural models (Figure 3).

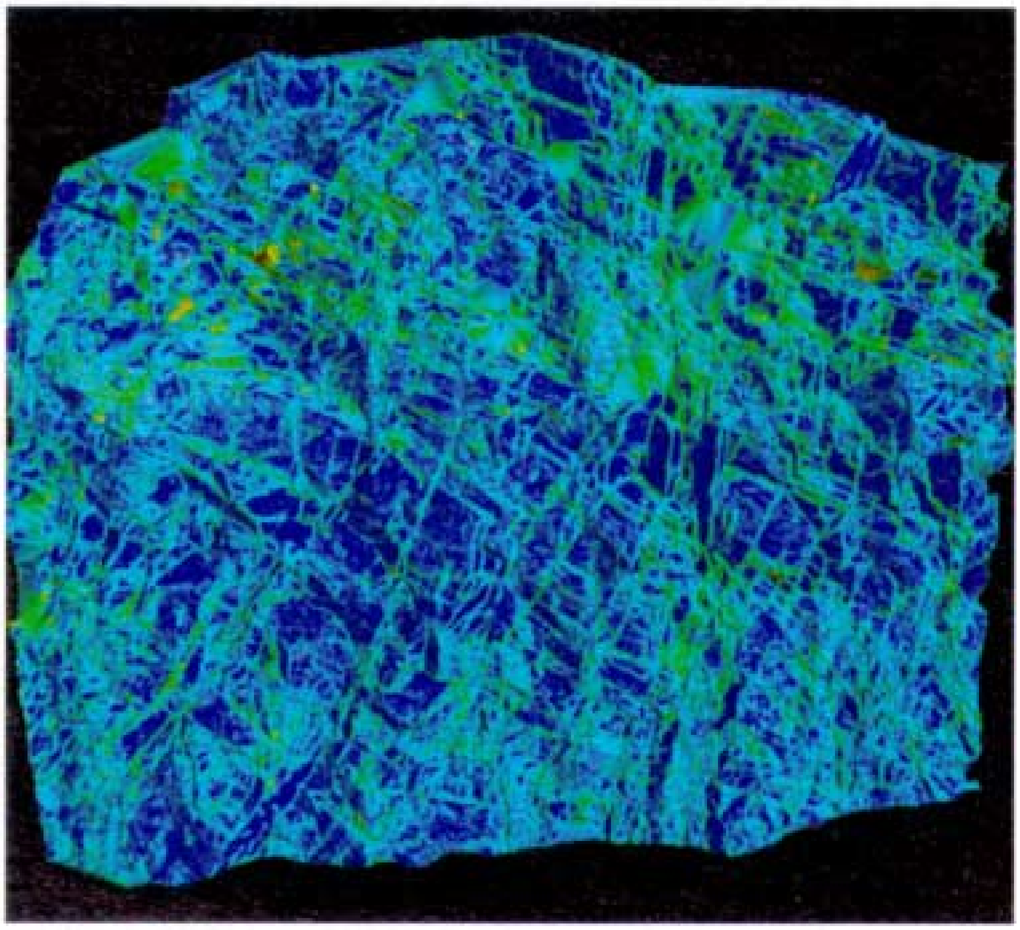

Figure 2. After triangulating the point cloud, the laserscan data are most easily visualized as a three-dimensional mesh, color-mapped by curvature to highlight fractures. This example is from a fractured road cut on Mt. Lemmon, Arizona, which measures approximately 28m x 18m.

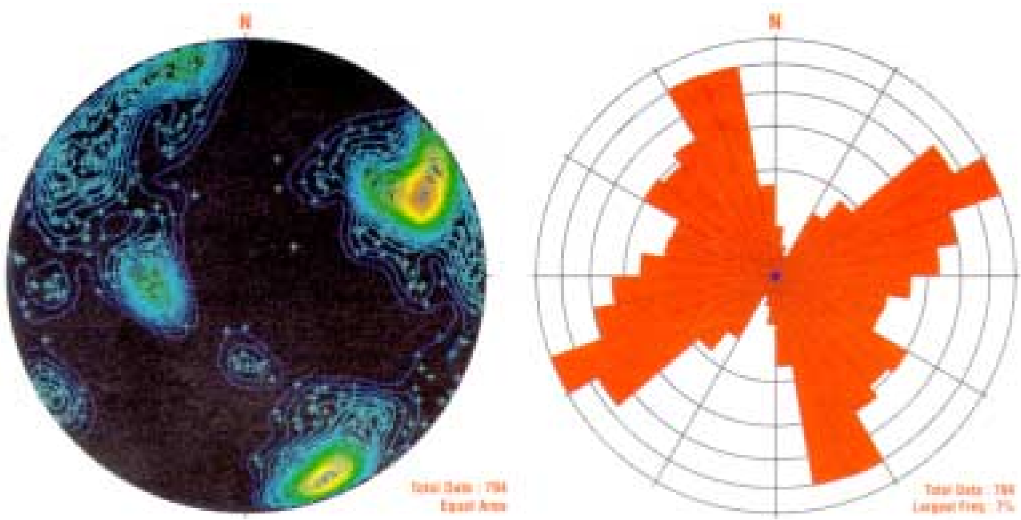

Figure 3. Auto-detected fractures from the Mt. Lemmon dataset (N = 794) plotted as poles on a lower-hemisphere stereonet (left) and rose diagram (right). The results compare favorably with scanline data from the same outcrop. Note that only relatively large-area fractures are plotted here.

In addition to simple orientation and location information, the fracture data are also automatically divided into related populations, and descriptive statistics are collected for each of these populations. These data are then used to synthesize three-dimensional fracture models with the same statistical footprint as fractures measured in the field (Figure 4). The fracture models may be used in myriad ways, for example, populating a structural model of the fractured reservoir with a realistic, three-dimensional fracture network.

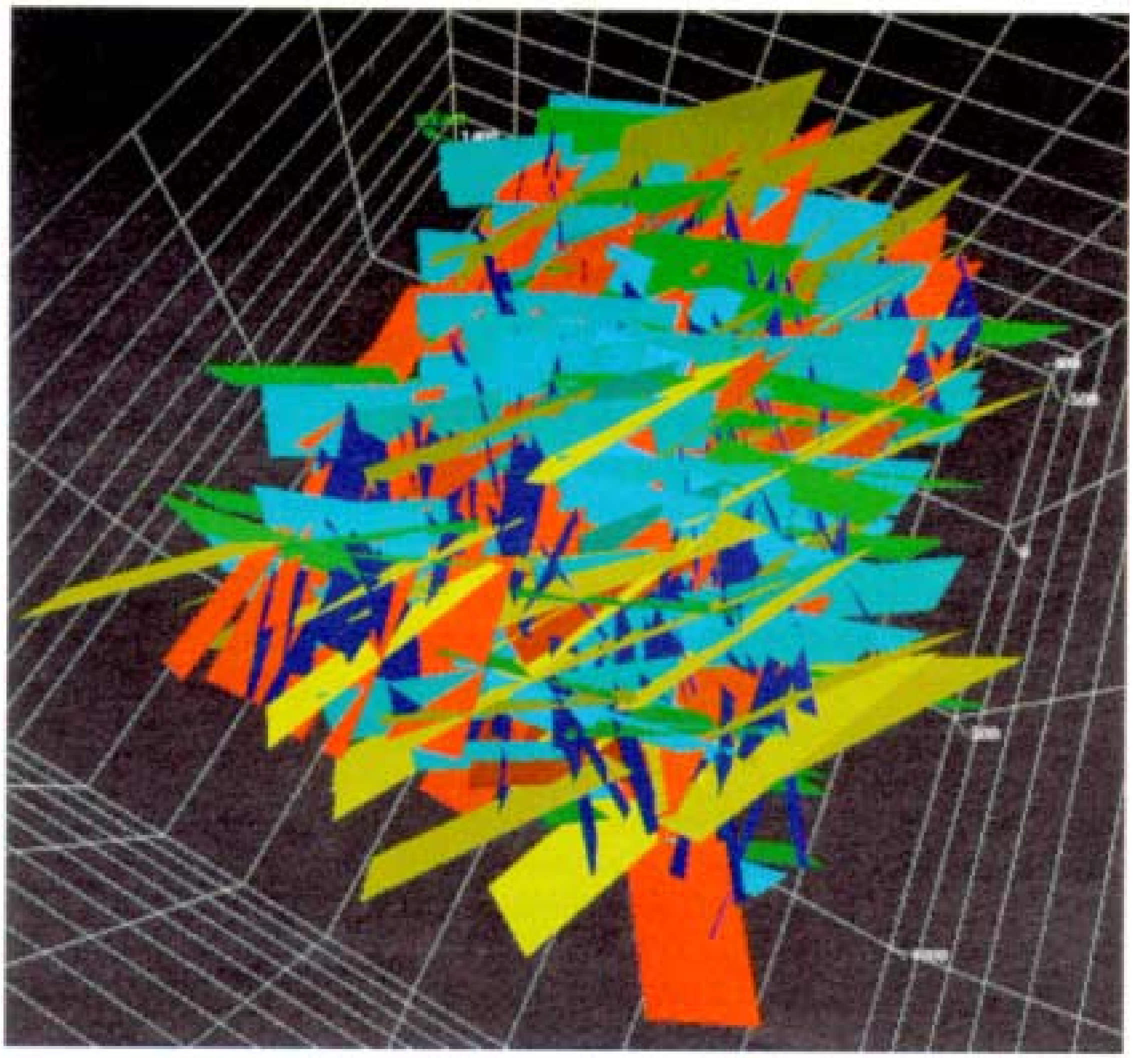

Figure 4. Stochastic fracture model generated in *3DMove* using data from the Mt. Lemmon example. The five fracture sets in the synthetic model are statistically similar to those detected in the fractured outcrop.

Conclusion

- The laserscanning method is the first truly three-dimensional technique for collecting fracture information over broad outcrops.

- The method has numerous advantages over traditional methods including consistent measurement accuracy, processing speed and reduced sampling bias.

- From a safety standpoint, the scanner also is favorable to other techniques because the operator can stand over 100 meters away from the scanned outcrop.

- Models created with the laserscanner not only provide an important conceptual framework for the geoscientist or engineer working to understand a fracture reservoir but also contribute to structural modeling, well planning, and stress analysis.

- Furthermore, the models may be used not only in petroleum geosciences, but also in mining exploration/production, geotechnical assessment and high-precision surveying/mapping.