Development and Testing of New Automated Methods for the Capture of Quantitative Fracture Data from Outcrop Analogues*

David W. Hunt[1], Paul Gillsepie[4], John Thurmond[2], Giulio Casini[2], and Erik Monsen[3]

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[2]Technology & New Energy, Statoil, Bergen, Norway
[3]Schlumberger Stavanger Research, Schlumberger, Stavanger, Norway
[4]Global Exploration Technology, Statoil, Stavanger, Norway

Abstract

Natural fracture systems commonly act as an important control on the production of hydrocarbons from carbonate reservoirs. In the subsurface, significant enhancement of fracture models can be gained through the study of appropriate outcrop analogues (i.e. fracture orientation, spacing, height, connectivity etc.). However, a major bottleneck in the utilization of outcrop data is the time required for the collection of statistically meaningful fracture data from geological field work and/or remote sensing data. In order to eliminate this bottleneck we have successfully adapted 3D seismic technologies, originally developed for automated fault extraction, for the automated extraction of bedding and fracture data from a range of different digital remote sensing data types. The results derived from automatic analysis of the remote sensing data have been independently quality-controlled using traditional outcrop-based field studies on world-class carbonate exposures (USA, Europe, Middle East). The analyzed data include ground-based and airborne LIDAR-derived photorealistic models and orthorectified Quickbird satellite imagery combined with satellite-derived digital elevation models. Data are derived from surface surveys and also subsurface tunnel surveys. The examples have been chosen in order to 1) capture variability in terms of fractured carbonate reservoir types and structural setting and 2) to develop and prove the technology using a range of remote sensing data types and different data qualities. We contend that the research has led to development of a rapid and robust method that allows for the extraction of statistically representative fracture populations. The new technology frees the structural geologist from laborious digitizing work, and provides access to a plethora of relevant fracture data. The technology therefore allows the geologist to better focus on the interpretation and analysis of relevant outcrop analogue data in order to better parameterize the building of subsurface fracture models.

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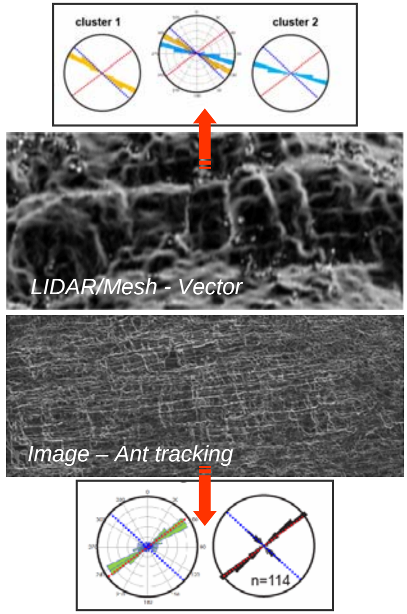
David Hunt, Paul Gillespie, John Thurmond, Giulio Casini (Statoil)

Erik Monsen (Schlumberger)

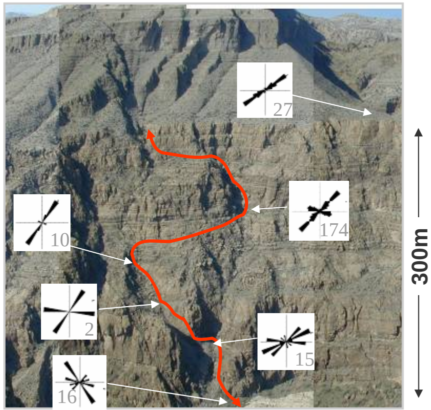
Objectives

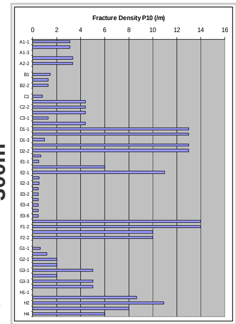
- Rationale
- Photorealistic models, purpose specific
- Method Overview
- Independent QC, results evaluation
- Conclusions, directions



Business Driver - Rationale

- **Middle East:- Fractured carbonate reservoirs intervals exposed only a few km from producing field/discoveries.**
- **But:- Exceptional exposures, but are very steep, difficult to work on and therefore extract meaningful quantitative data (i.e. fracture stratigraphy).**





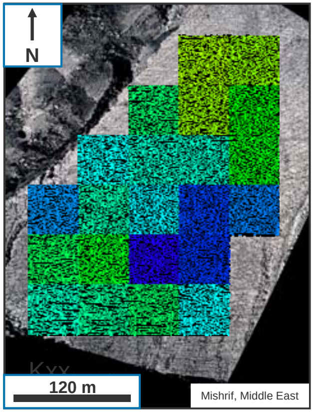
Statoil

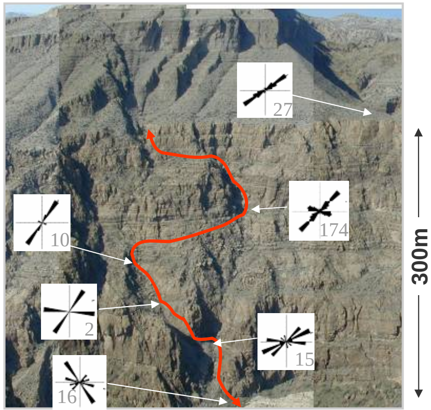
Presenter's Notes:

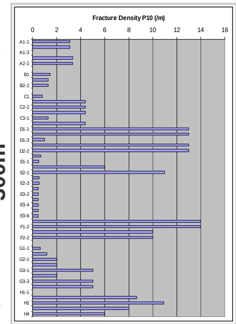
1. StatoilHydro geoscientists have had the opportunity to characterize fractured and diagemetically-modified carbonate reservoirs at on exceptional exposures that are located only a few kilometres from major discoveries and producing fields in the Middle east.
2. A major challenge related to this work was the scale and steepness of the exposures, making it difficult to collect large quantoties of quantitative data. The images show fracture heterogeneity exposed on large bedding planes and also in steep section. The fractures clealy vary in orientation between different reseervoir layers.
3. The fracture density also changes between reservoir layers. However, the density differences are based on 2D interpretation from photographs, and contain to diectional information.
4. Fracture map (50 m squares) or Fracture map illustrates a grid of 50 m squares.
5. The primary aim of the project, initiated in 2004, was to develop new techniques for the automated extraction of quantitative fracture data from outcrop analogues. The company is studying outcrops where the reservoir section is exposed only a few kilometres away form the prodicing fields, and show comparable fracturing in terms of both orientation and relationships to bedding/bed sets. Unfortunately despite superb exposures, access is limited and so the actuay capacity of the geologist to measure large numbers of stastically- represensentative quantitative fracture data is limited.

Business Driver - Rationale

- **Objective:- To develop rigorous automated techniques to rapidly and accurately extract quantitative fracture data from outcrop analogue data.**
- **Initiative:- 2004 sought collaboration with Schlumberger to adapt 'ant tracking' seismic technologies to work on digital outcrop datasets.**







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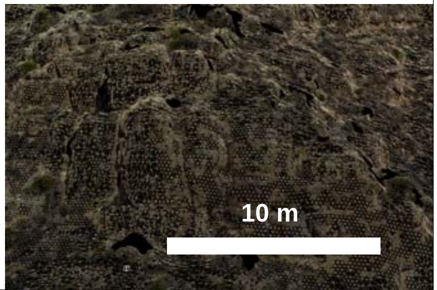
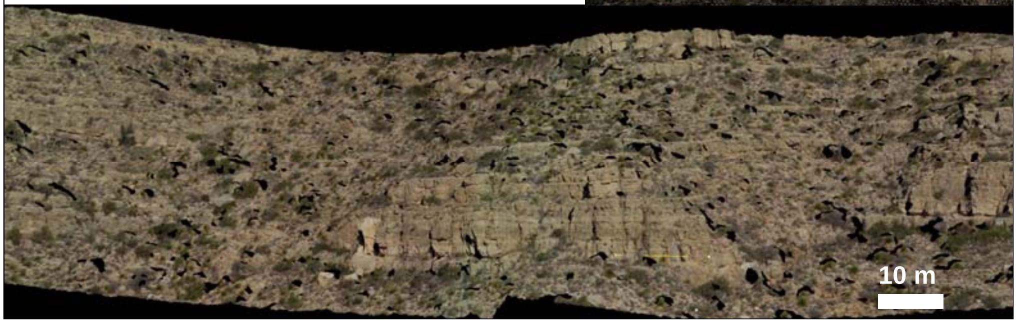
LIDAR-Derived Photorealsitic Models

- Laser scans outcrop at 10’s of millions of points
- Adaptive intelligent mesh made from scan – reduces data size by c. 90%
- Photo’s mapped onto this with cm-scale accuracy

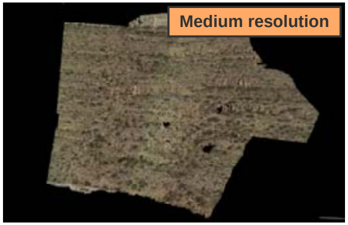




Data: Photorealistic Models

- Same data, 3 models with different resolution

Main stratigraphic surfaces

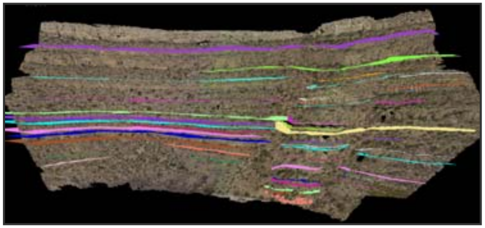


Stratigraphic detail, Karst mapping, facies

Fracture mapping

Data: Photorealistic Models

- Same data, 3 models with different resolution



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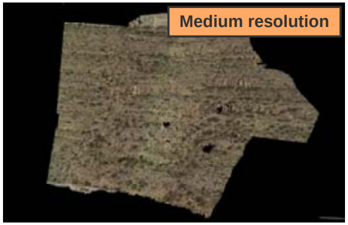

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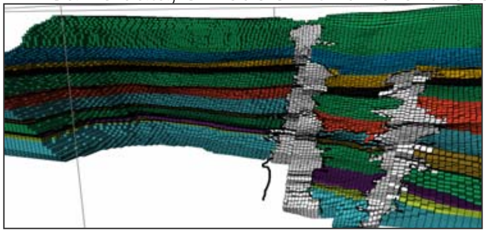

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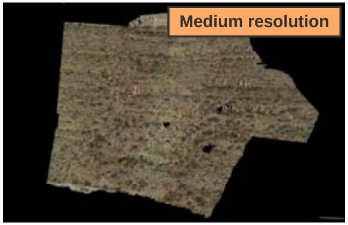

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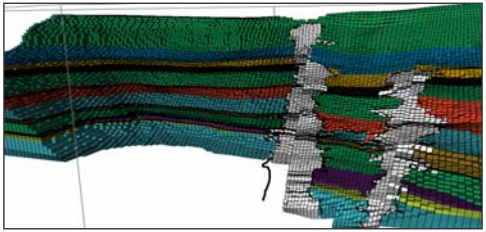
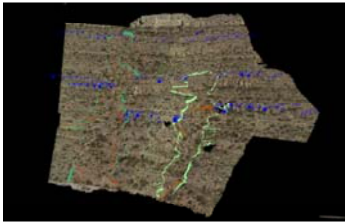


Main stratigraphic surfaces



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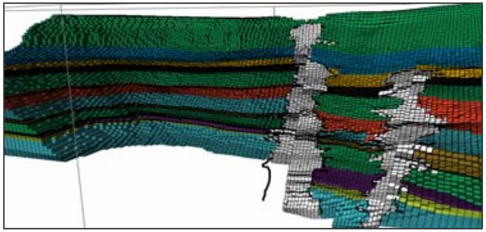

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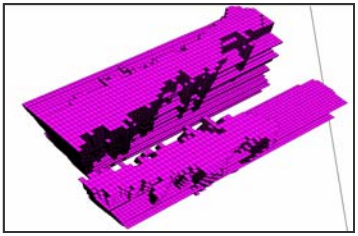

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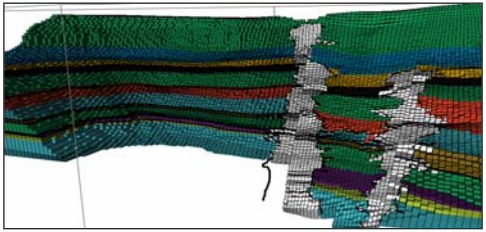
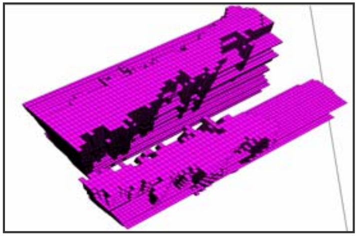


Main stratigraphic surfaces



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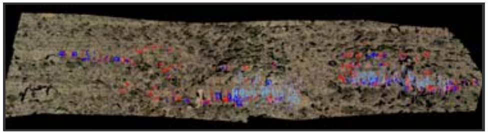

Fracture mapping

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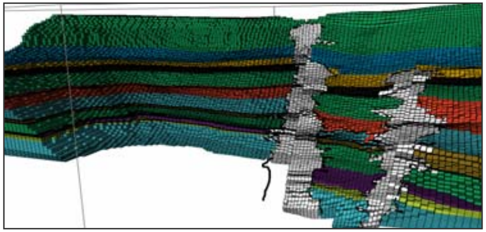

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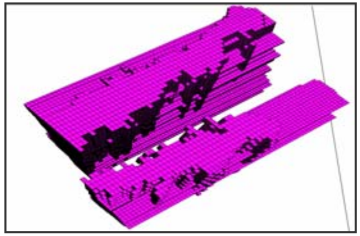

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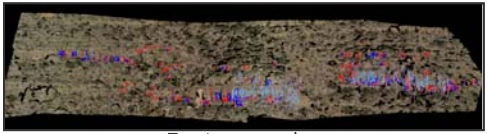


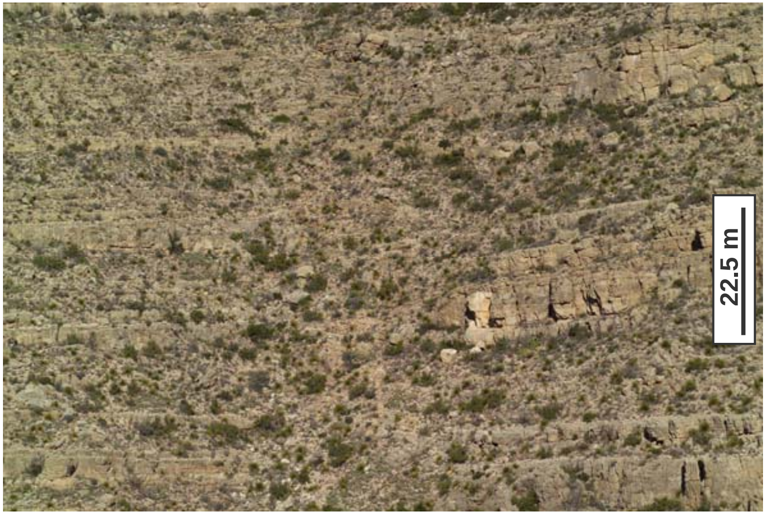
Fracture mapping

LIDAR – c 10 million points

Each image (4500 x 3000 = 13 500 000)

7 images used

Image Resolution at 0.7-1.1 km (13.5 mpixels)



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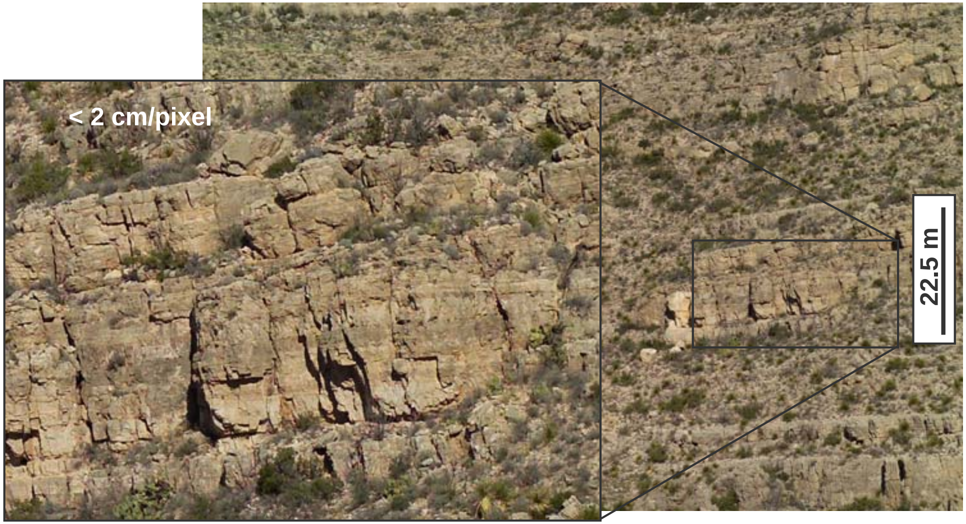

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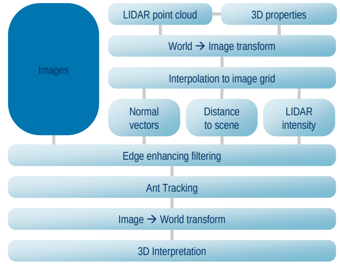
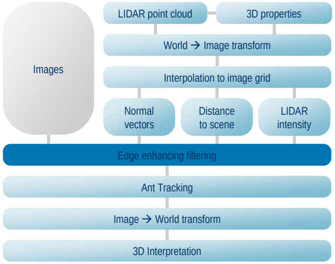
Results: Fracture mapping
Original 2D high resolution image



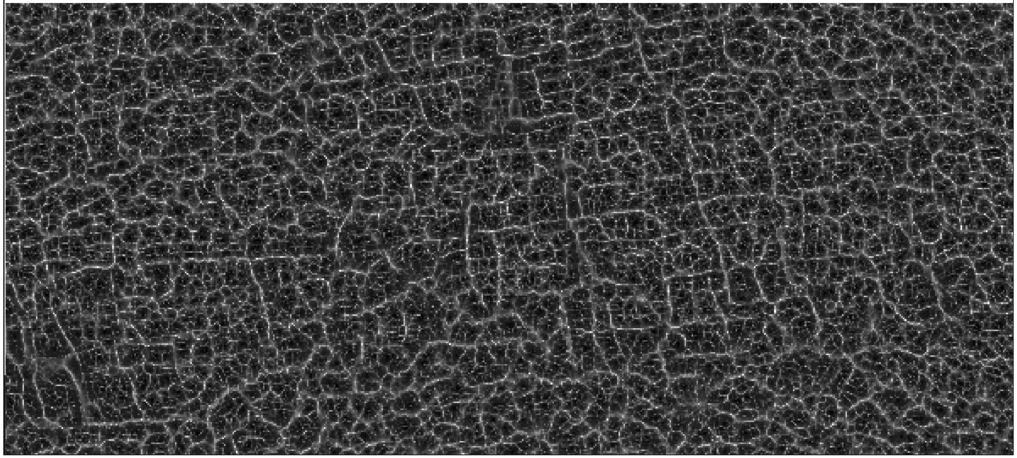
High resolution

Results: Fracture mapping

2D image curvature

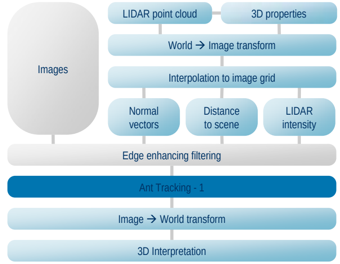


High resolution

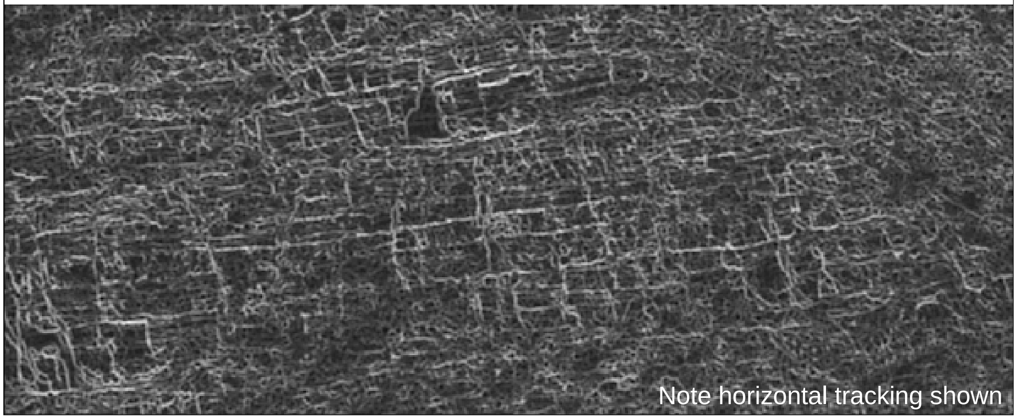


Results: Fracture Mapping

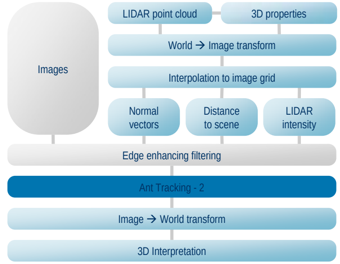
2D iterative Ant Tracking



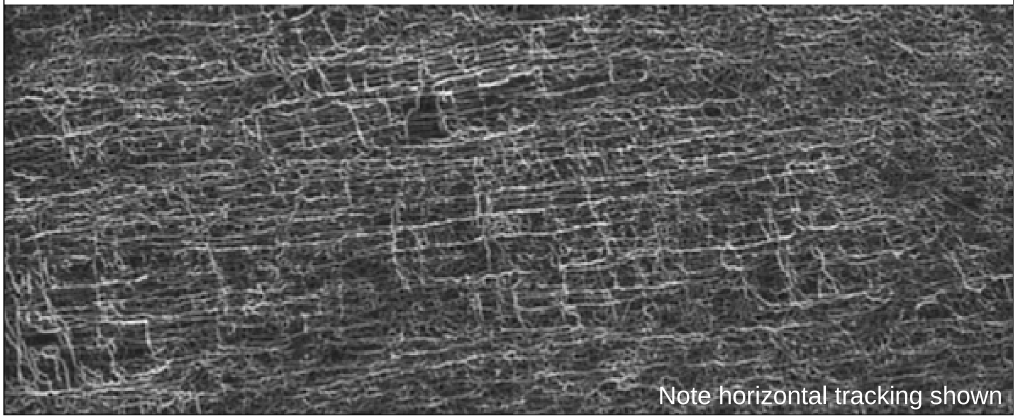
High resolution



Results: Fracture Mapping
2D iterative Ant Tracking

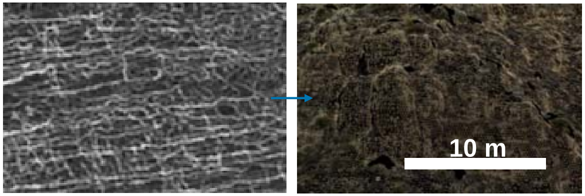


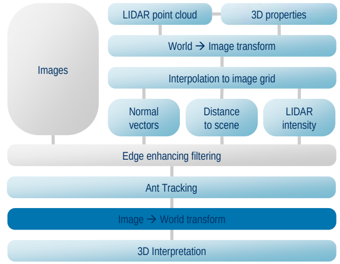
High resolution

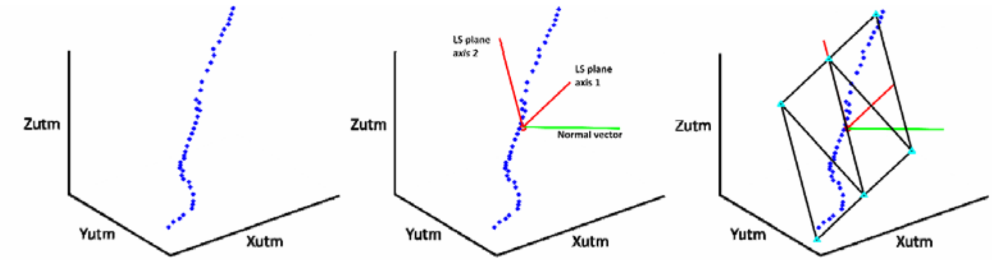


Results: Fracture Mapping

2D*Image* → *World Transform*





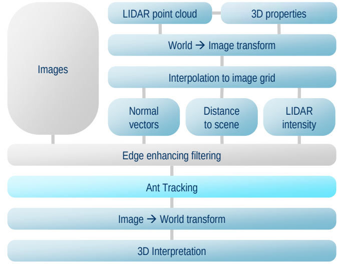


- **Note:- intersection of fracture/bedding with surface topography retained as a confidence factor of the planes strike and dip**

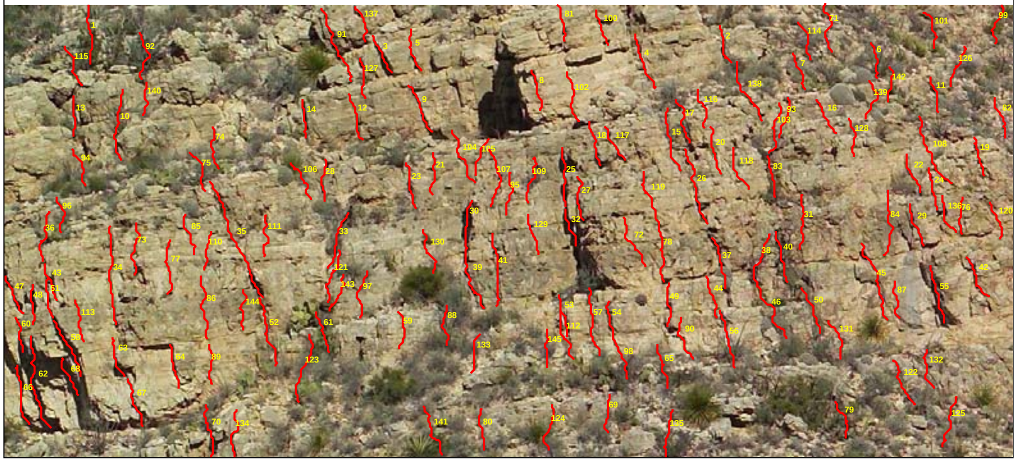
Results: Fracture mapping

Ant-tracks –image analysis

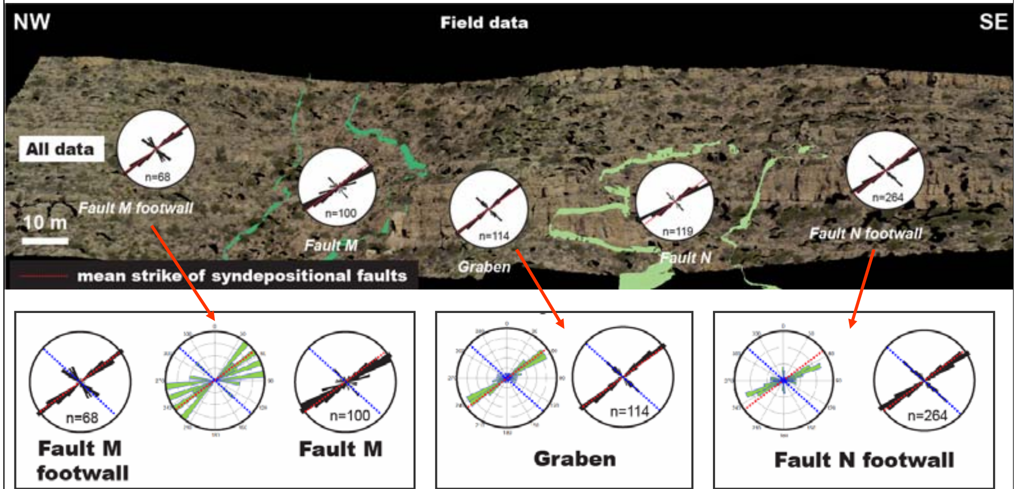
Fracture no	Dip	Dip direction
:	:	:
137	64	192
:	:	:



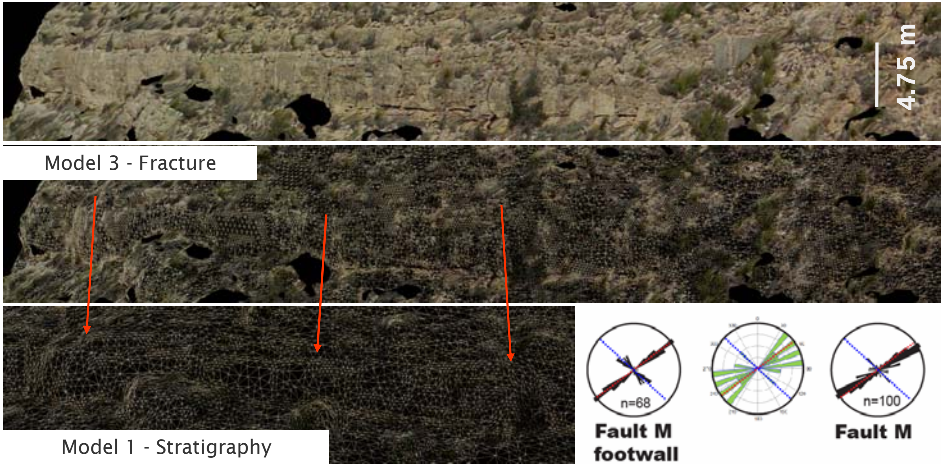
High resolution



Field Data vs Ant Track Data

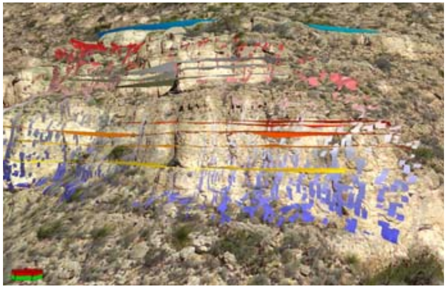


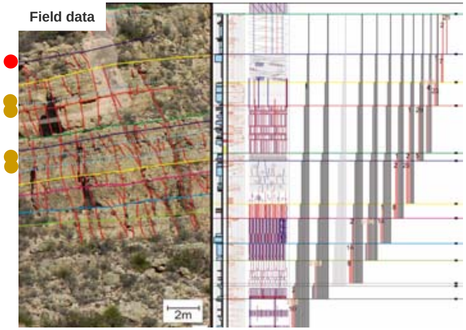
Ant Tracking: Quality Control - Mesh

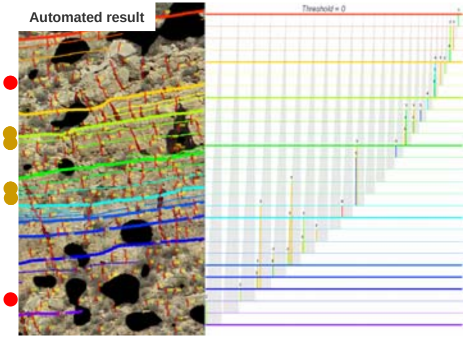


Mechanical Stratigraphy

- Final LIDAR study phase:- develop and qc fracture-bedding relationships 'mechanical stratigraphy'
- 2007 field study (blind from Schlumberger) vs fully automated result – minor discrepencies

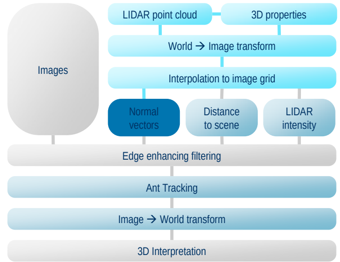




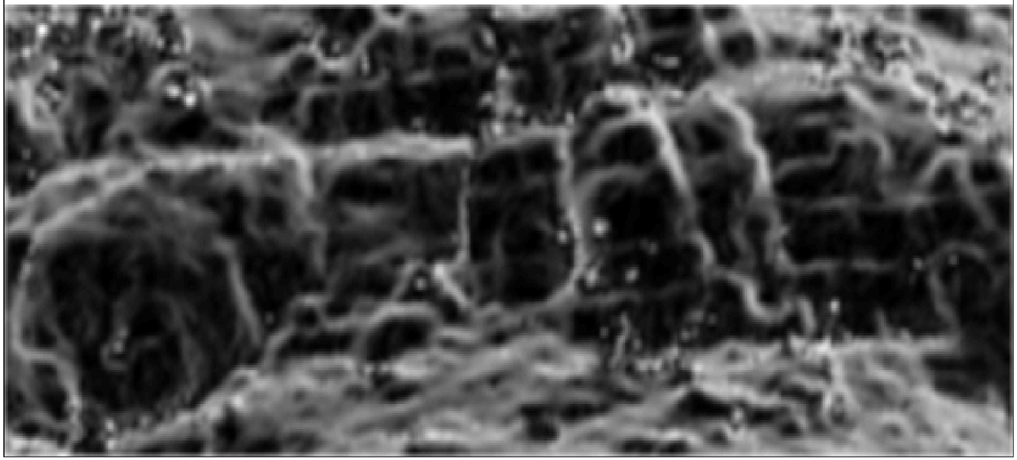


Results: Fracture mapping

Y-component of normal vector field

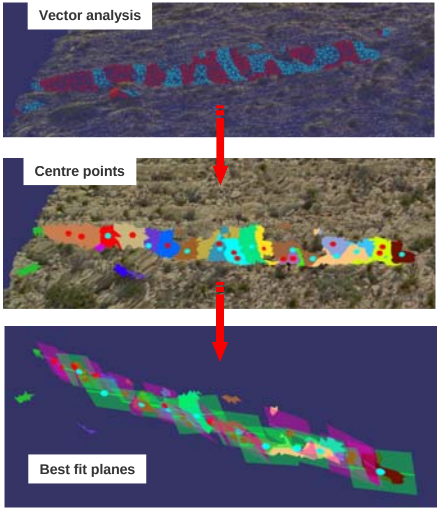


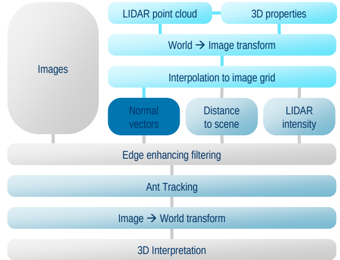
LIDAR - Medium/low resolution



Results: Fracture mapping

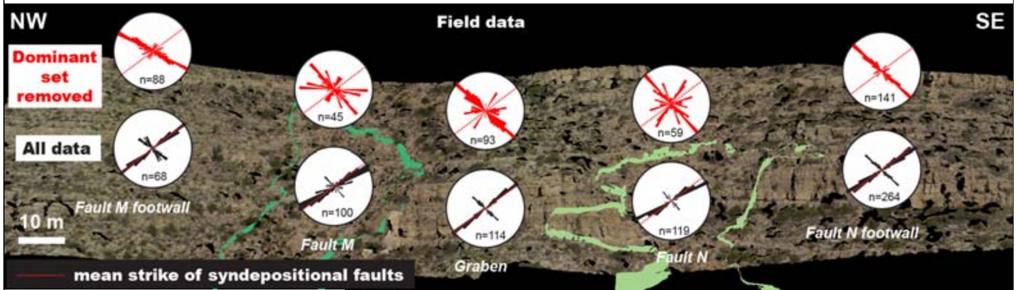
Y-component of normal vector field

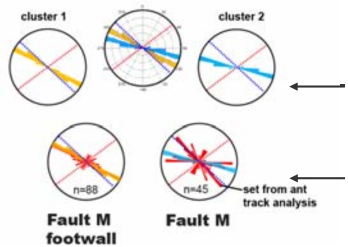




Accuracy from mesh determined by photorealistic model inputs

Field Data vs Mesh Analysis - 1





Mesh analysis
2 clusters

Superimposition
on data

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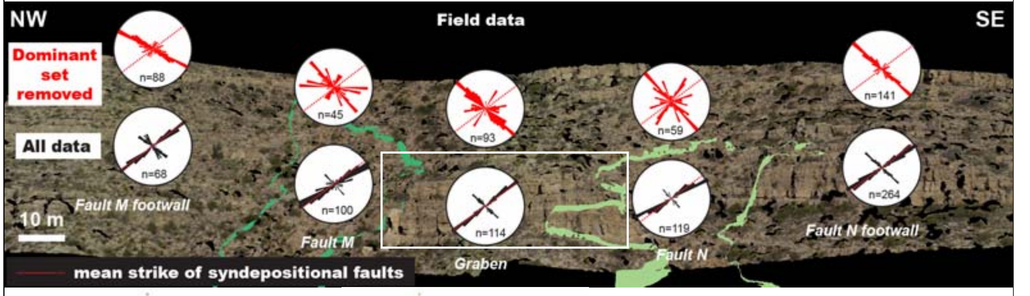
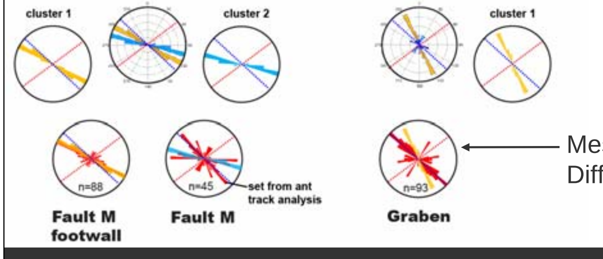
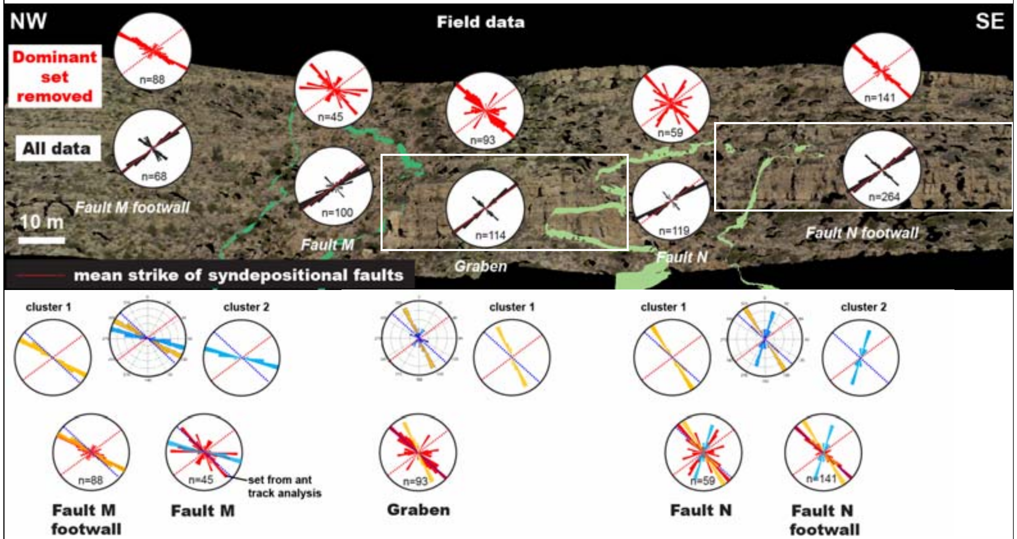
Field Data vs Mesh Analysis - 2





Mesh analysis – main cluster
Difffers from field data

Field Data vs Mesh Analysis - 2



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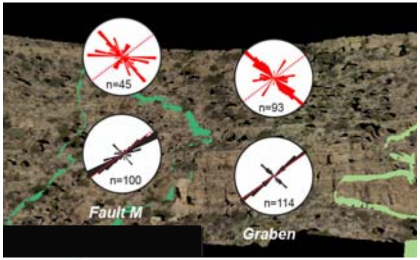
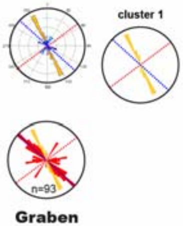
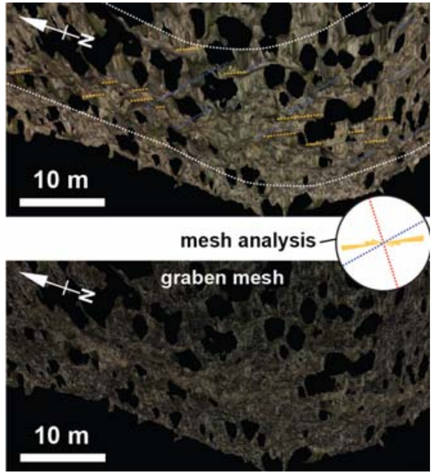
Field Data vs Mesh Analysis - 3





• Why the contrast between field data and vector analysis – are the vector data unreilable?



• No – these sets exist in specific parts of the section

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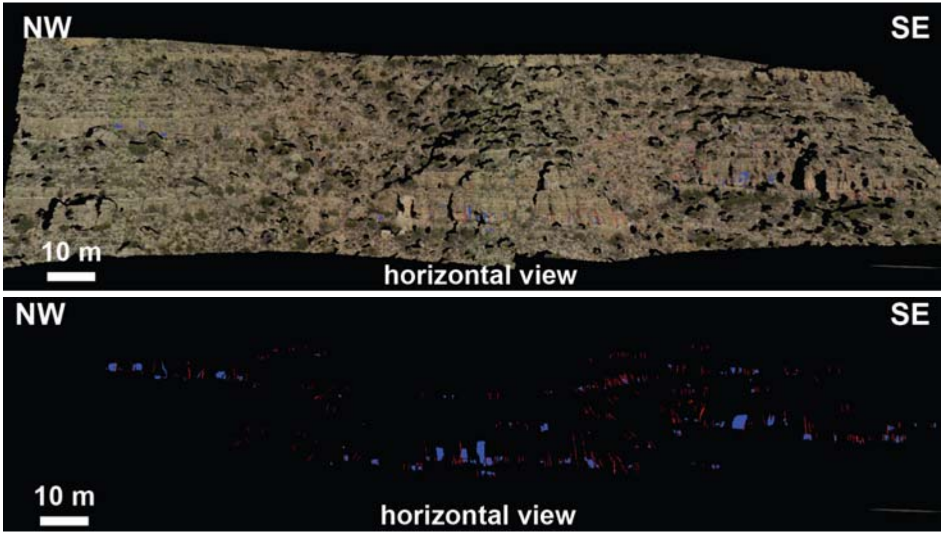
Field vs Automated Data Distribution



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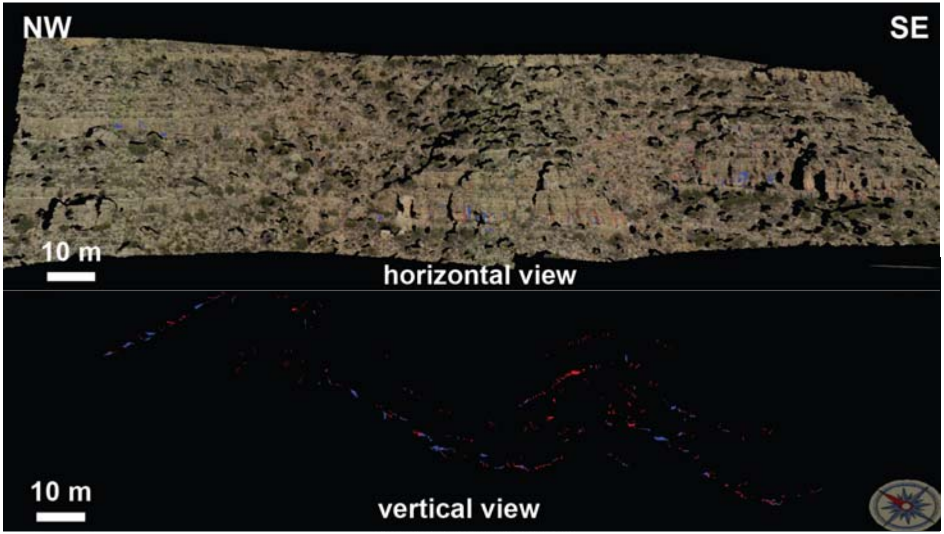
Field vs Automated Data Distribution



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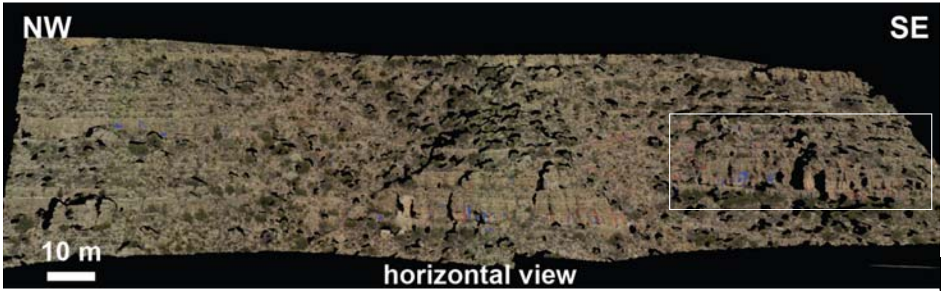
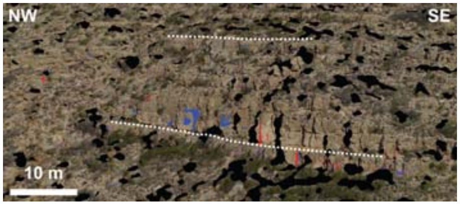
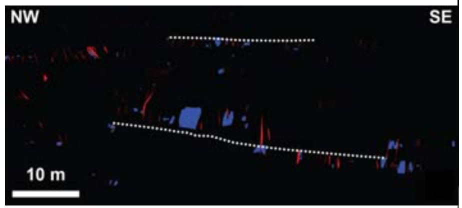
Field vs Automated Data Distribution







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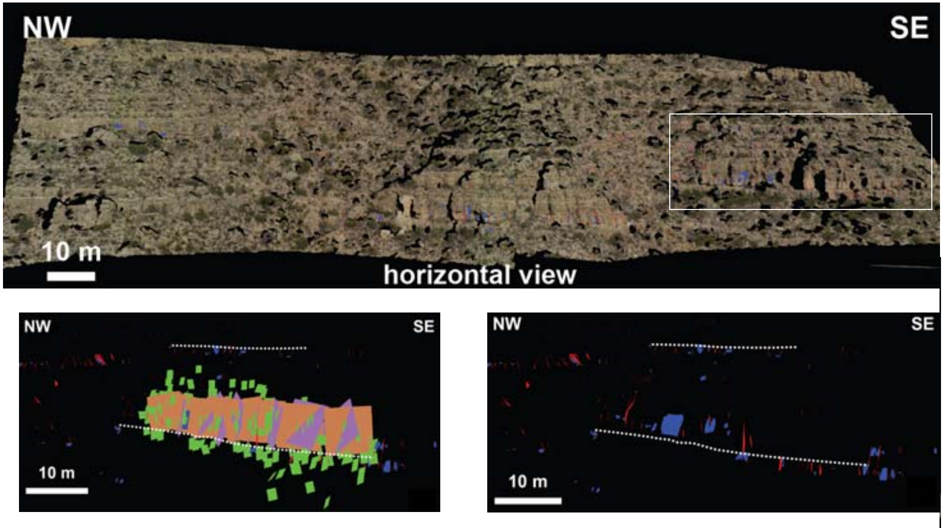
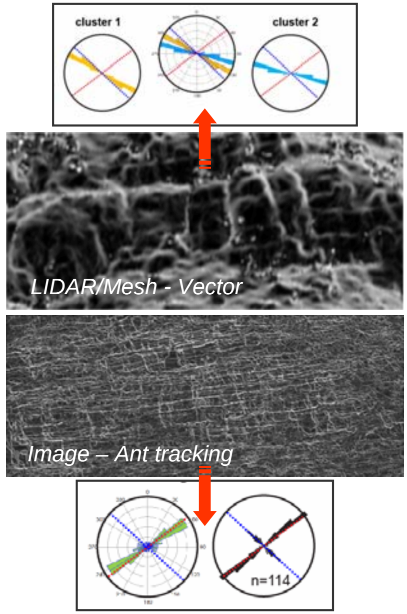


Results, Conclusions

- Different orientation, scales of data obtained from image analysis and vector analysis of LIDAR/mesh data – complimentary



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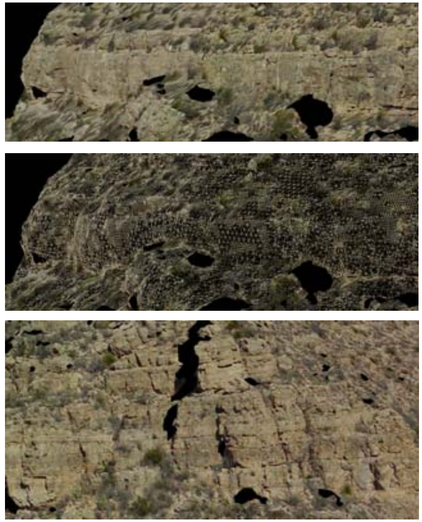
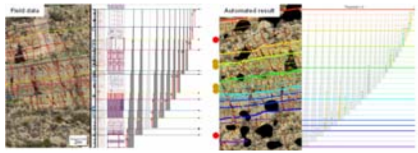
Results, Conclusions

- Different orientation, scales of data obtained from image analysis and vector analysis of LIDAR/mesh data – complimentary
- Limitations and strengths of the technology identified
  - Image quality, illumination, weatherning
  - Mesh quality, cliff topology



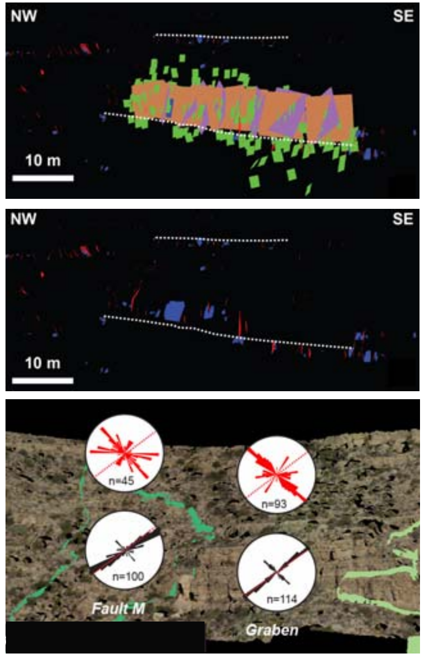
Results, Conclusions

- Different orientation, scales of data obtained from image analysis and vector analysis of LIDAR/mesh data – complimentary
- Limitations and strengths of the technology identified
  - Image quality, illumination, weatherning
  - Mesh quality, cliff topology
- Blind testing & independent QC of study area



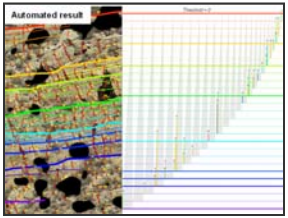
Conclusions

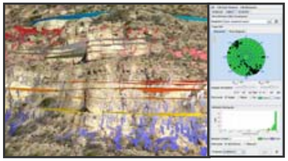
- Technique is complimentary to, not a replacement for field geology
- There is a bias in both field and automated datasets
- The automated results force you to re-evaluate field collected data and to develop better fracture models



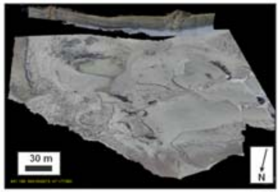
Study Areas, Data Types

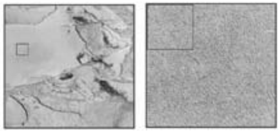
100's m ——— **km** ——— **Multi km** →



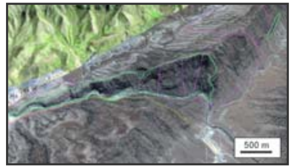


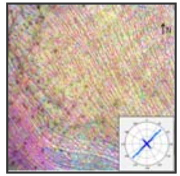
1. **Guadalupe Mountains, USA**
   - Ground Based LIDAR, photorealitsic model





2. Somerset, England, Famous Bench
- **Ground-based LIDAR,**
- **Aerial + ground-based photorealistic models**





3. Mishrif, Middle East
- **Ground basd LIDAR, 8 m tunnels through anticline,**
- **Integrated with orthorectified Quickbird data**

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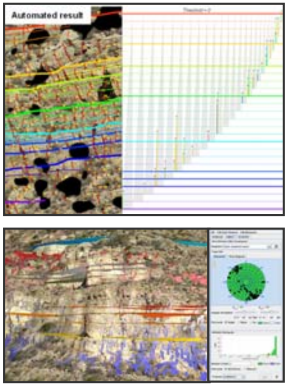
Study Areas, Data Types

High contrast — **High contrast** — **High +low contrast** →



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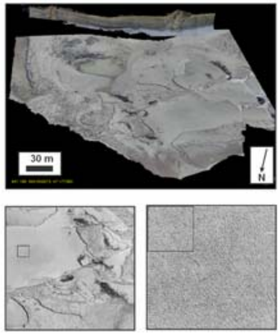

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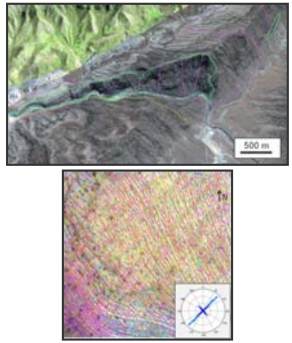

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Thank you

Development and Testing of New Automated Methods for the capture of quantitative fracture data from outcrop analogues

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