QUANTITATIVE STRUCTURAL ANALYSIS OF FRACTURES USING DIGITAL OUTCROP MODELS

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VIRTUS IMPAVIDA

INTRODUCTION

Digital Outcrop Model - **DOM**

~2000 Technological Advances Present

- Image-quality
- Data collection
- Processing
- Positional data
- Visualization

- Practicality
- Agility
- High positional accuracy
- High spatial resolution
- Improved image-quality

- Visualization and interpretation in the office
- Field data analysis complementation
- Improvement of dataset representativity

Challenge

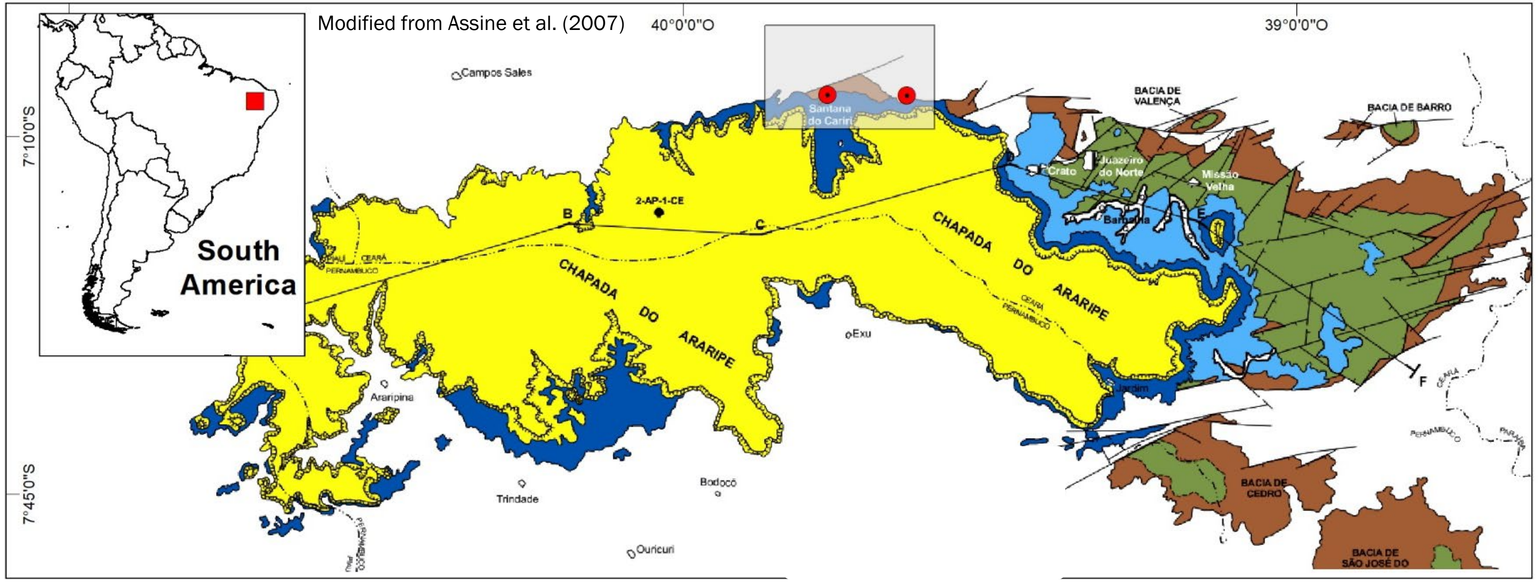
- Tools and methodologies for interpretation of linear and planar features from DOMs
- Handle large data set

STUDY AIMS

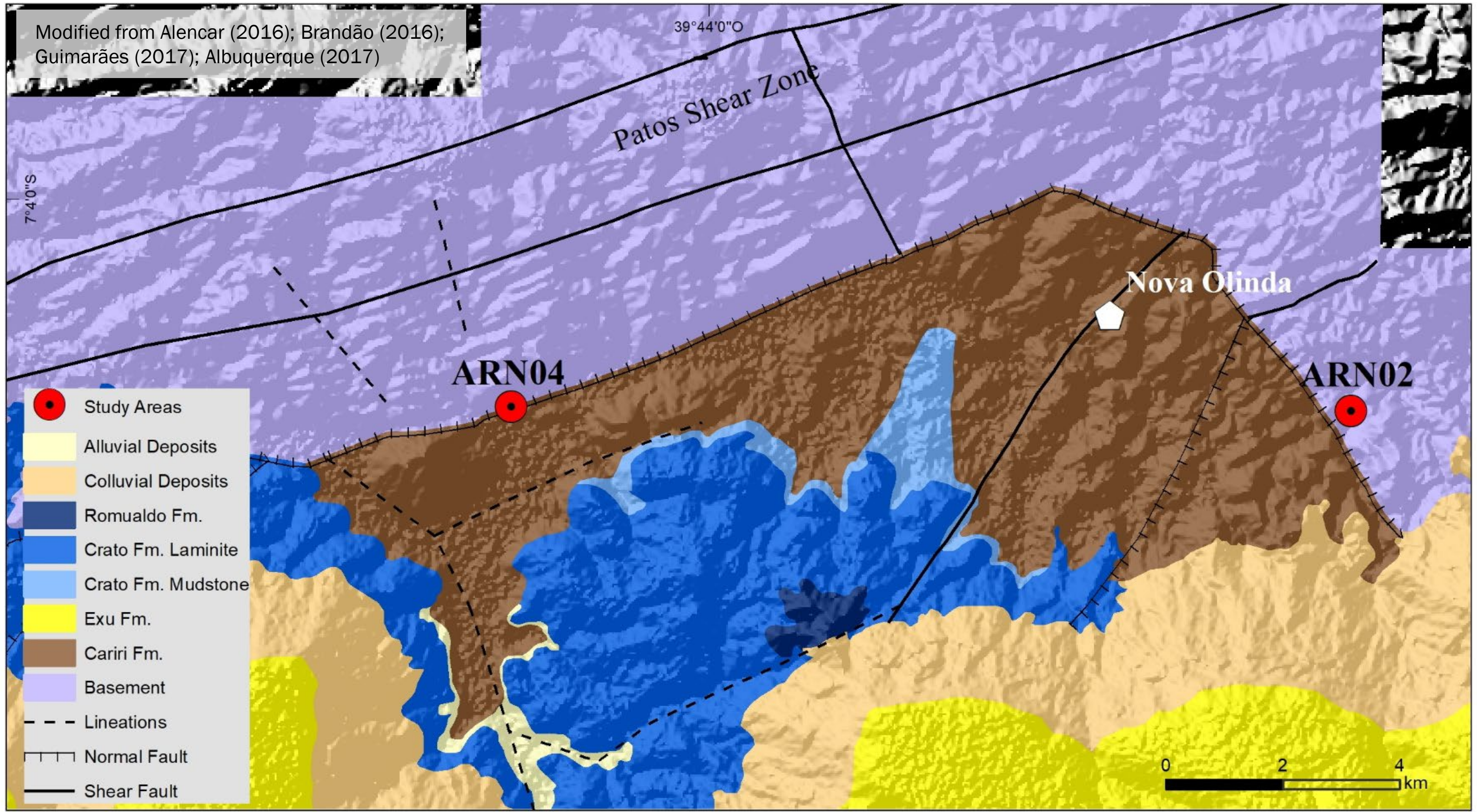
➢ **Systematize** the manual and semi-automatic **methods of plane extraction** using tools available in the open-source **CloudCompare** (e.g., Compass and Facets).

INTRODUCTION

Study area



- Location of the Araripe Basin in Northeastern Brazil
- Intracontinental rift basin positioned between the Patos and Pernambuco shear zones (Brazilian/Pan-African orogeny)



- Two different DOMs in this work (ARN02 & ARN04)
- They are on the fault zone context and represent the Araripe's Basin basement

INTRODUCTION

ARN02

- Natural outcrop along a creek
- Approximately 35m long and 5m height
- Tilted metamorphic rocks
- Intensely fractured with breccia zones (see dashed lines)

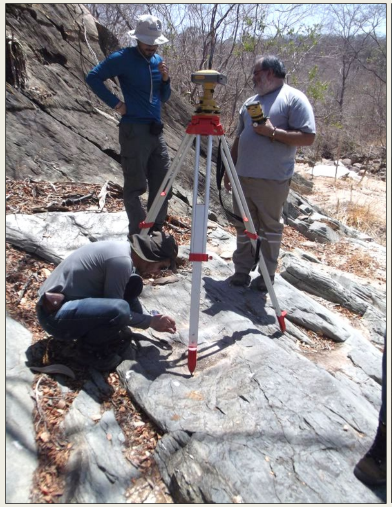
ARN04

- Road pavement pit
- Approximately 45m long and 4m height
- Orthogneisses and amphibolites
- Intensely fractured (joints and faults), mostly perpendicular to the outcrop wall.

METHODOLOGY

Field Data Collection
→ ARN02 & ARN04

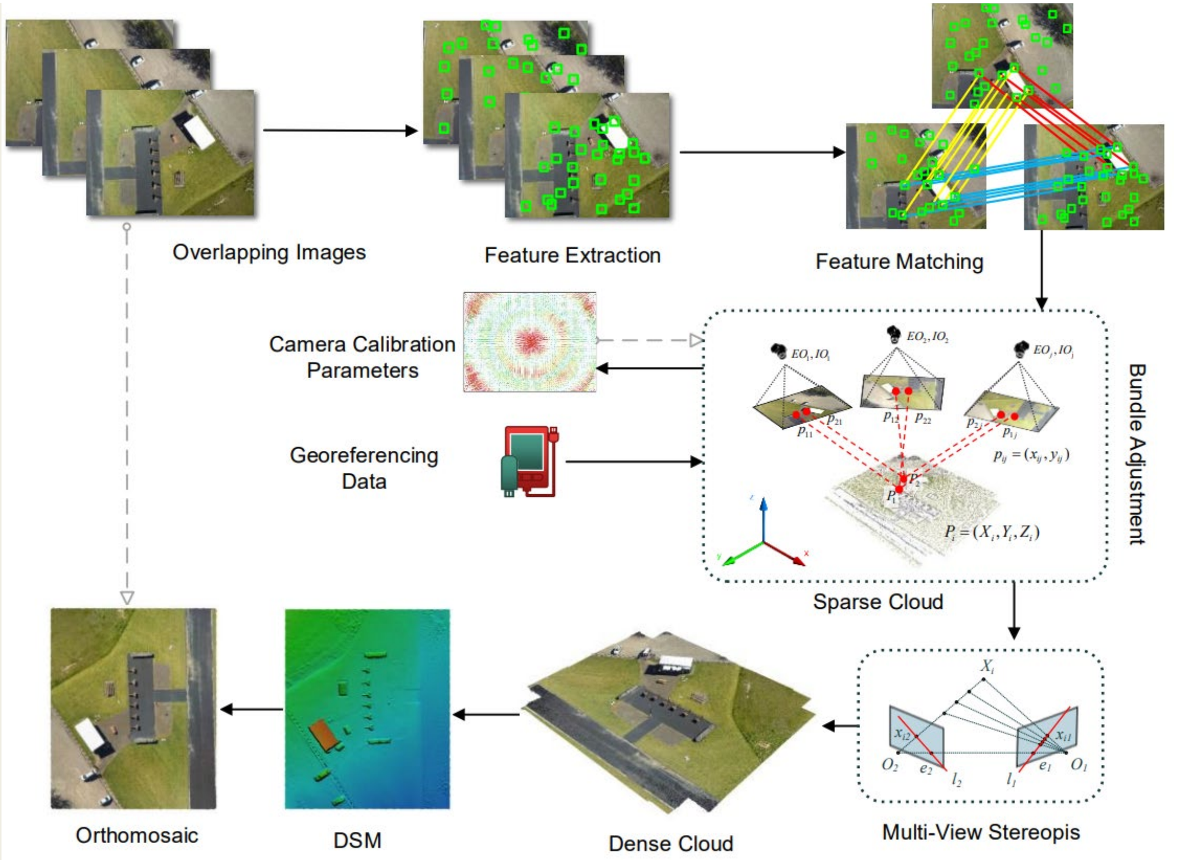
Photographs captured directly from the ground



- GNSS RTK positioning system + ground control points
- Positional errors smaller than 2 cm

3D Model reconstruction
- Photogrammetric models
- Structure from Motion (SfM) technique
- Spatial resolution 0.3 mm/pixel

Example of SfM Photogrammetry workflow Javadnejad (2018)



DOMs analysis
- Extract fracture patterns with CloudCompare
- Plugins:
  - Compass
  - Facets

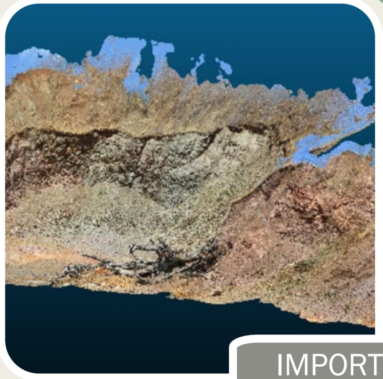
Results & Interpretation

METHODOLOGY

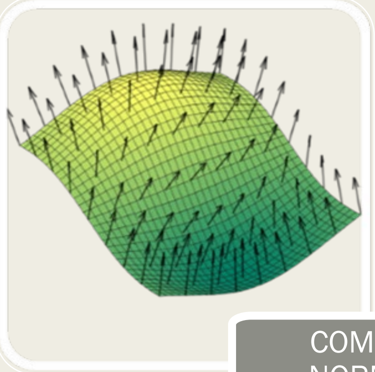
FACETS PLUGIN → PLANES EXTRACTION METHODOLOGY

- **FACETS** → plugin within CloudCompare (Dewez et al. 2016)
- Perform automatic planar facet extraction
- Segmenting massive 3D point clouds into individual planar facets
- Calculate their dip and dip direction
- Report the extracted data in interactive stereograms

Geological planar facets extracted are easily separated in families, and subfamilies sets → spatial orientation similarity (azimuth).

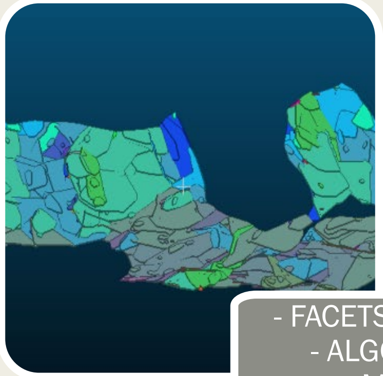


IMPORT POINT CLOUDS

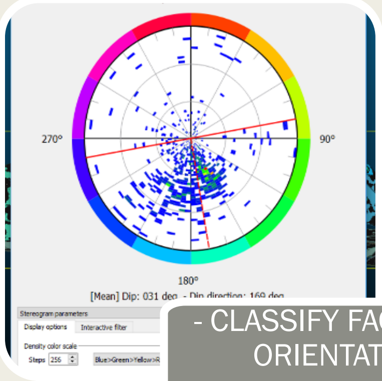


COMPUTE NORMALS

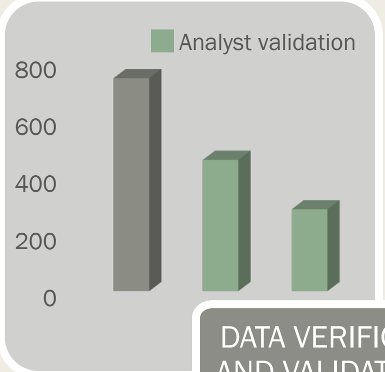
POINT CLOUD MANUAL CLEAN-UP



- FACETS SEGMENATION
- ALGORITHM FAST MARCHING



- CLASSIFY FACETS BY ORIENTATION
- SHOW STEREOGRAM



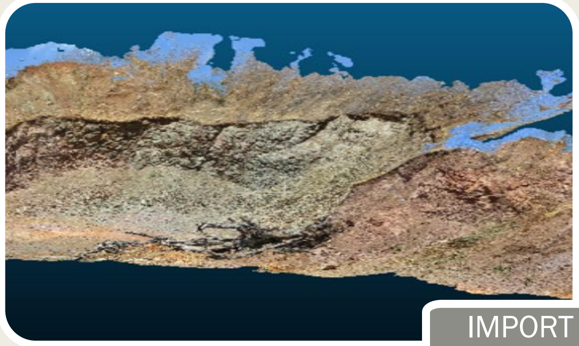
DATA VERIFICATION AND VALIDATION BY AN EXPERT

For further details: https://www.cloudcompare.org/doc/wiki/index.php?title=Facets_(plugin)

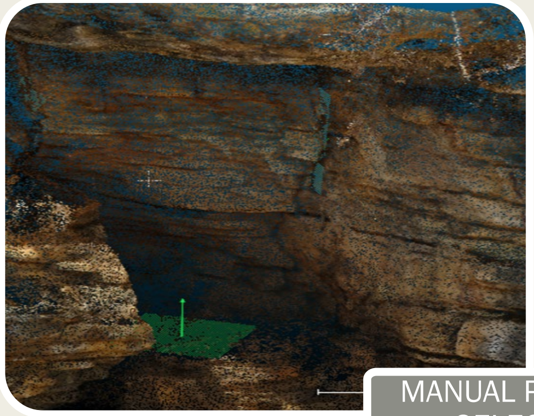
METHODOLOGY

COMPASS PLUGIN → PLANES EXTRACTION METHODOLOGY

- **COMPASS** → plugin within CloudCompare (Thiele et al. 2017)
- Rapidly interpolate structural features between manually defined control points → point cloud and raster datasets
- Tools for measuring surface orientations, lineations and true thicknesses
- Map Mode → delineating geological units
- **Compass Mode** → measuring orientations and thicknesses
  - **Plane tool → Measure surfaces orientation**
  - Trace tool → Digitize and measure traces and contacts

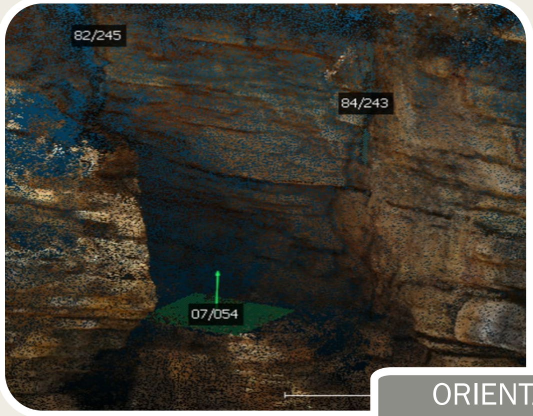


IMPORT POINT CLOUDS

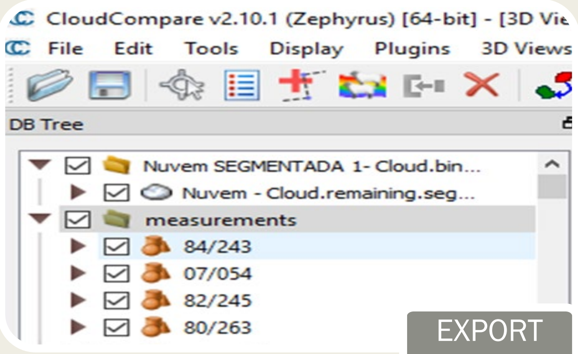


MANUAL PLANE SELECT

TWO PLANES INTERSECTION LINE SELECT



ORIENTATION CALCULATE



EXPORT DATE

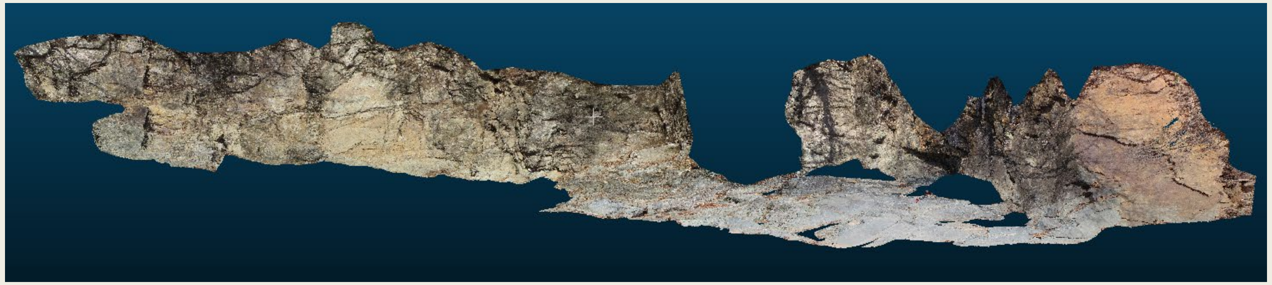
For further details: https://www.cloudcompare.org/doc/wiki/index.php?title=Compass_(plugin)

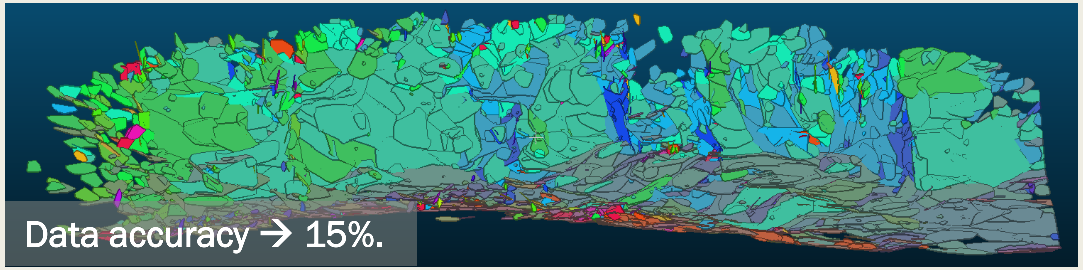
RESULTS ARN04

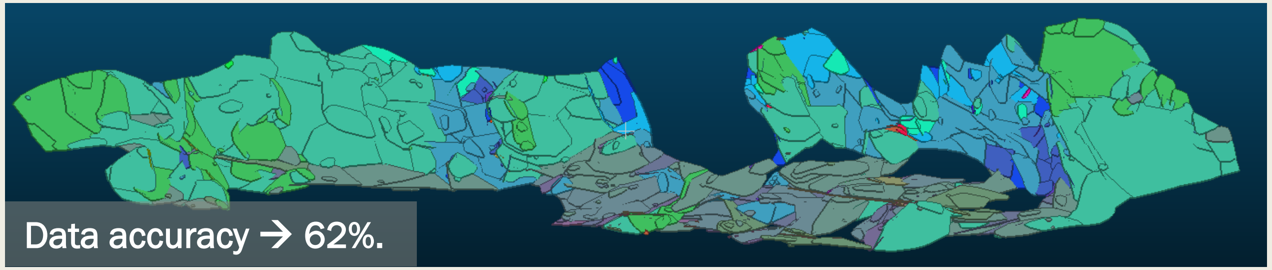
Automatic planar extraction → FACETS SEGMENTATION

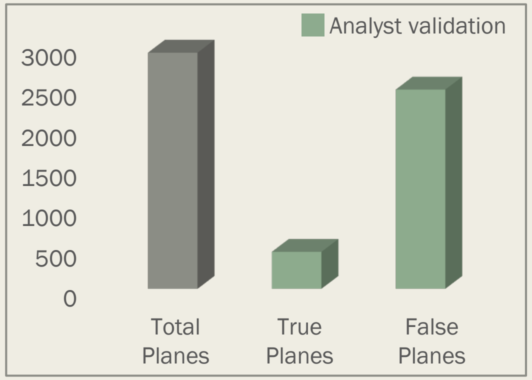
Original Point cloud

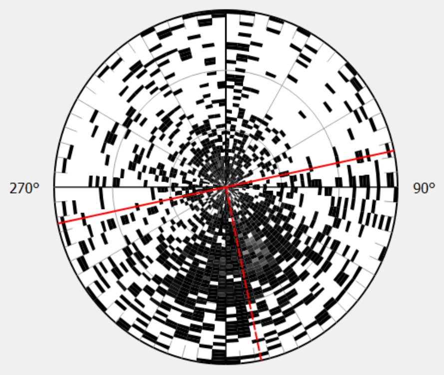
Point cloud manual clean-up → Removed → Vegetation, Soil

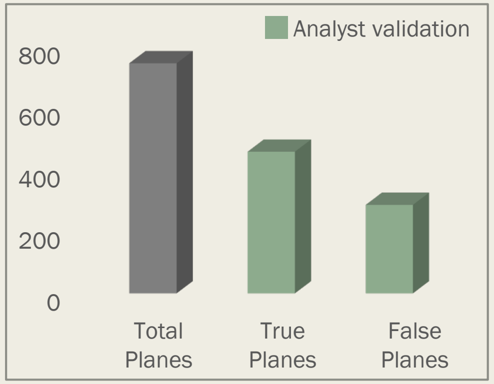


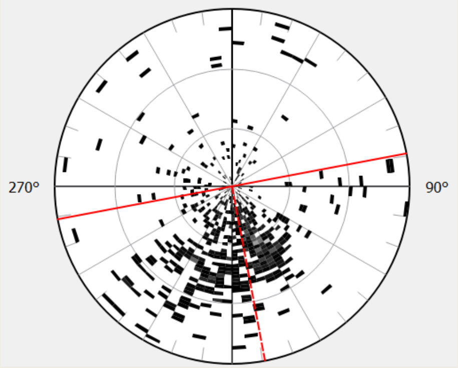








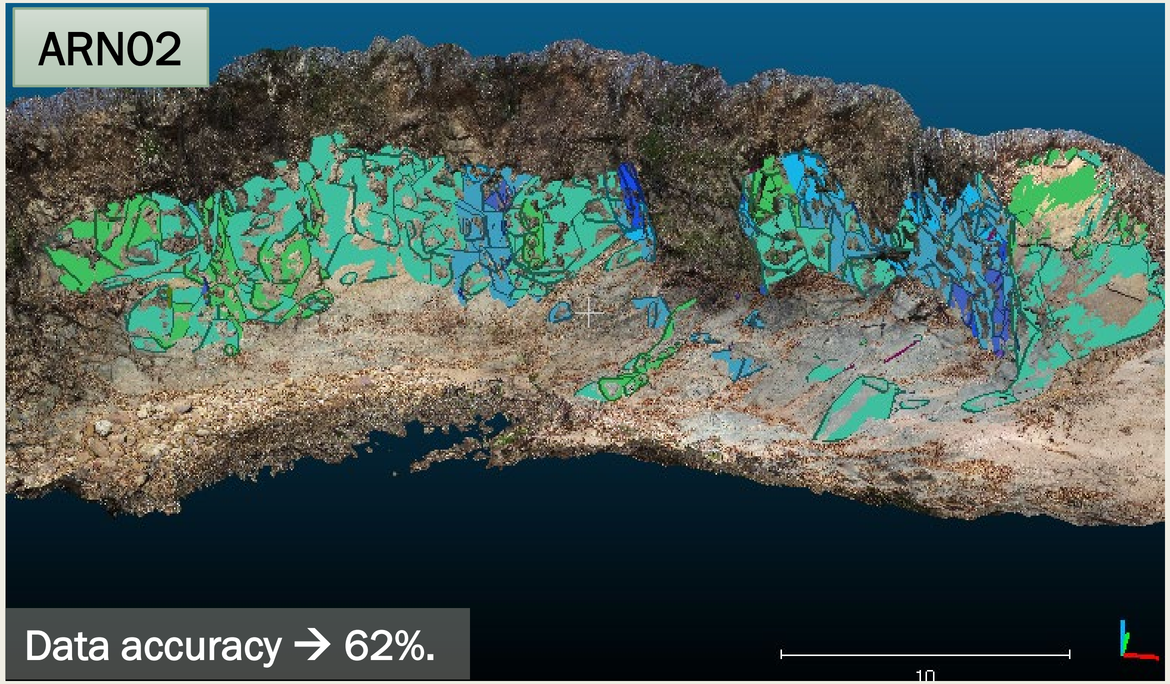


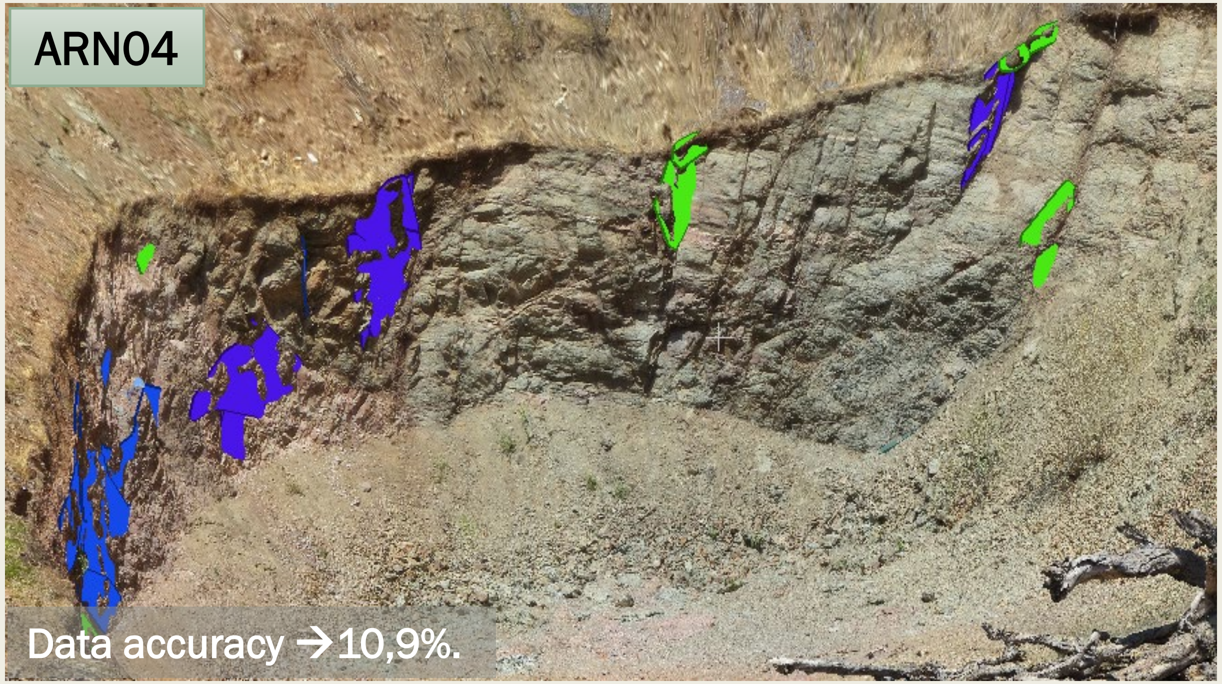


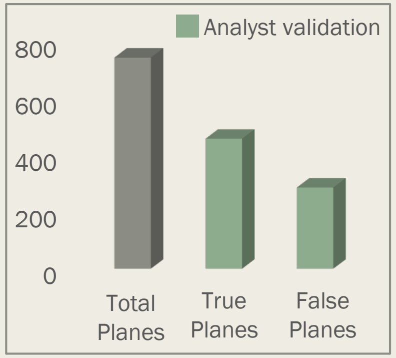
- Why is the point cloud manual clean-up an essential step before extracting the planar structures?
  Reduce noise and point cloud size → optimize processing

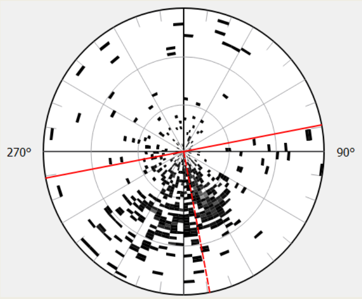
- This step significantly increases the measurement accuracy (True planes x False planes)

RESULTS - ARN02 vs. ARN04







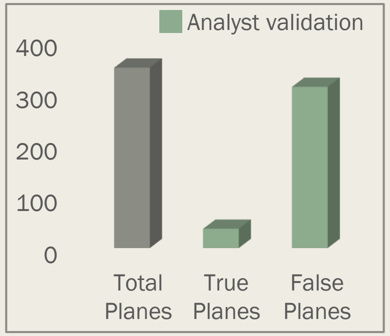


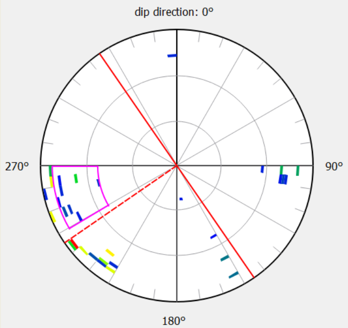
- Facets Tool in the ARN02 area: EFFECTIVE
- Outcrop wall orientation:

  - bedding planes (So) (green): perpendicular → large area

  - breccia zone (blue): fracture dip direction perpendicular and parallel
- **Many true planes extracted (almost all the outcrop) → Why?**

  - True planes are visible





- Facets Tool in the ARN04 area: INEFFECTIVE
- Outcrop wall orientation:

  - fracture dip direction parallel
- **Few true planes extracted → Why?**

  - less visible planes exposed to calculate automatically.

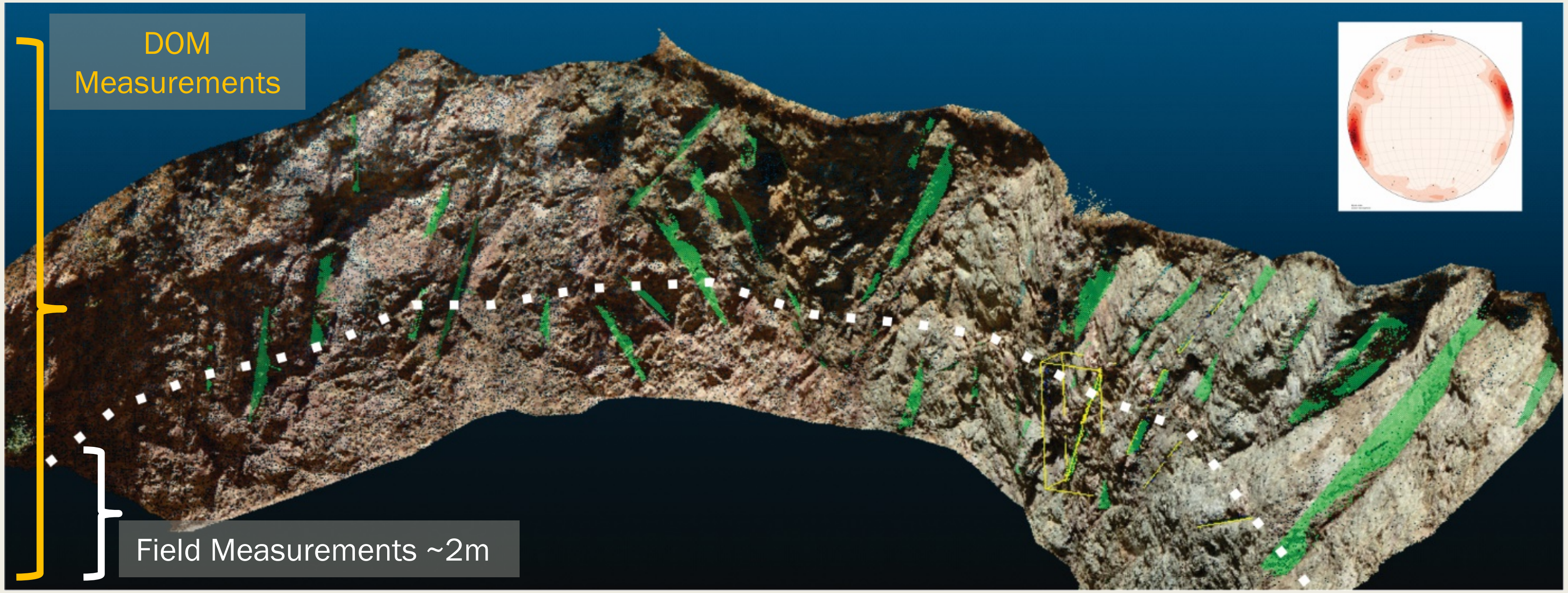
  - most of the fractures are exposed as lines (trace)

In cases like this (only line visible), manual planar extraction using the Compass tool is more effective.

RESULTS

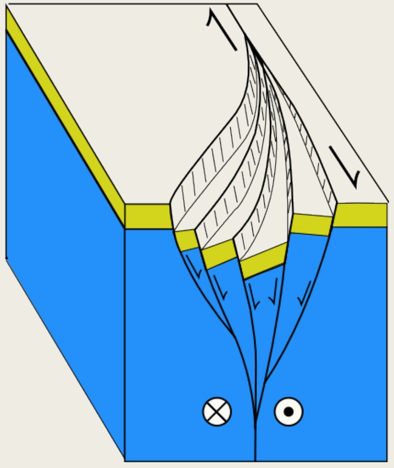
COMPASS vs. Field Measurements - ARN04

- Structural Analysis comparing the DOM measurements (Compass - manual planar extraction tool) and field measurements



- **Field Measurements** (below the dotted line)
  - 80 planes measurements
  - 23 principal fractures
- **DOM Measurements** (overall outcrop)
  - 86 planes measurements
  - 23 principal fractures (same structures that were identified in the field)

- Fractures preferential orientation: N45-50°E
- Dip: variation along the structure
- The fractures measurements in this outcrop are part of a negative flower structure, typical of the shear zone, generated by strike-slip tectonic efforts.



Negative Flower

RESULTS

FACETS vs. COMPASS

FACETS	COMPASS
Good tool for large scale surveys	Good tool for small scale surveys
Semi-automatic	Manual
Exporting data in .csv	Exporting data in .csv
Report the extracted data in interactive stereograms	• Don’t report interactive stereograms. • Necessary export the data collection
• The planar facets extracted are easily separated in families and subfamilies sets (interactive) • Spatial orientation similarity (azimuth).	No interactive data sets
Necessary a good plane exposed to be truly segmented using the tool	Identify planes (with few exposition) and lines using different compass mode tools
Tool advantages: user-friendly (practical, agile and accessible) and free access	Tool advantages: user-friendly (practical, agile and accessible) and free access
Tool disadvantage: Semi-automatic extraction → Slow interpretation process because in this mode a detailed analysis by an expert is necessary to validate the quality and accuracy from the results	Manual extraction → analyst selects the best place to get the measurements.

Comparative table (Facets vs. Compass) according to the results obtained with these two study cases → ARN02 e ARN04

CONCLUSIONS

FACETS ⇨ - ARN04 → EFFECTIVE → 498 true planes → 62% data accuracy
- ARN02 → INEFFECTIVE → 37 true planes → 10.9% data accuracy

⇨ Why exist this accuracy difference? ⇨ Outcrop morphology difference ⇨ Visualization of the true planes in the point cloud

COMPASS ⇨ ARN02 → EFFECTIVE → Comparison between DOM vs. Field measurements ⇨ Good tool to measure no visible planes

- The analyst must observe the outcrop wall orientation, as well as the orientation of the structures → These steps are essential to select the best tool to perform the structural analysis of fractures using digital outcrop model

- Positional accuracy and visual quality are crucial for accurate quantitative interpretation of structural features using digital outcrop models, as well as a well-defined data processing routine and careful inspection of the results by an expert.

- The data obtained from this methodological approach will contribute to quantitative analyzes in structural geology based on robust datasets.

ACKNOWLEDGEMENTS

- We would like to thank PETROBRAS (GEOTEC/CENPES/PDEP) (project n° 2017/00057-3) for the financial support to this project.

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