Drone Surveys and Geology
Is there any value beyond fun?

by Riccardo Rocca

Webinars

About myself

Webinars

Riccardo Rocca
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https://sites.google.com/site/riccardorocca62/

- Italian, 56 years old, living in Madrid-Spain.
- Geologist in petroleum exploration, focusing on regional geology, data integration and prospects evaluation.
- Worked with ENI (Italy), Halliburton-Landmark (Nigeria-Angola), Repsol (Spain-Venezuela).
- Enthusiast in electronics and remote controlled models.
- Practicing drone flights, images acquisition and photogrammetry since 2015.
- Interested in using the information from drones to help understand landscape features related to geological processes.

Background: RC model airplanes (video 1)

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Background: Roboat

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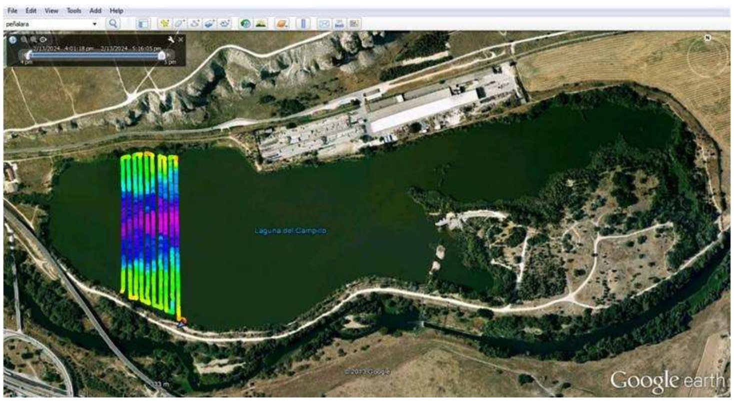

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Drone mapping (video 2)

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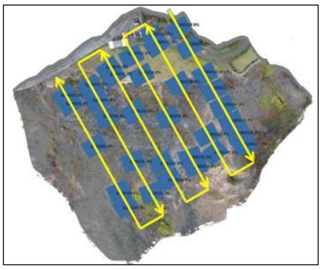
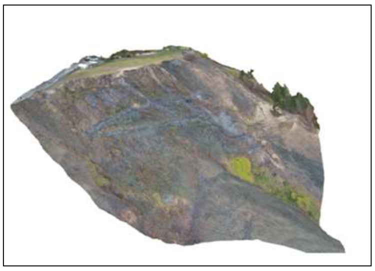
Drone DJI Phantom 2 Vision Plus

Images acquisition and merge

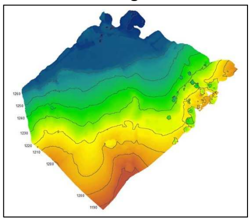


3D model



Georeferenced orthoimage

2D grid



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Drone Surveys and Geology
Is there any value beyond fun?

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Technical details: Drone, Software, Regulations

Current drone applications in geology

Test in the Venezuelan Andes: Boconó fault - Los Zerpa Moraine
- **Regional framework**
- **Drone acquisition and 3D model**
- **3 exercises**

A few more examples…

Conclusions

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UAV: Unmanned Aerial Vehicle

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Drone: DJI Mavic Pro

folded drone:
20 x 8 x 8 cm

Drone: ~1000 €
Extra battery: 99 €
Own display: Smartphone or Mini Tablet

unfolded drone:
24 x 24 x 8 cm

Weight: 740 g
Camera: 12 Megapixels (5 cm @ 100 m altitude)
Flight authonomy: 27 minutes (15 minutes practical mission)
Radio link: 7 km / 4 km in Europe (500 m visual line of sight)
Speed during survey: 10 m/s (36 km/h)
Survey area covered per flight: ~500 x 500 m (100 m altitude)

remote control
+ personal smartphone

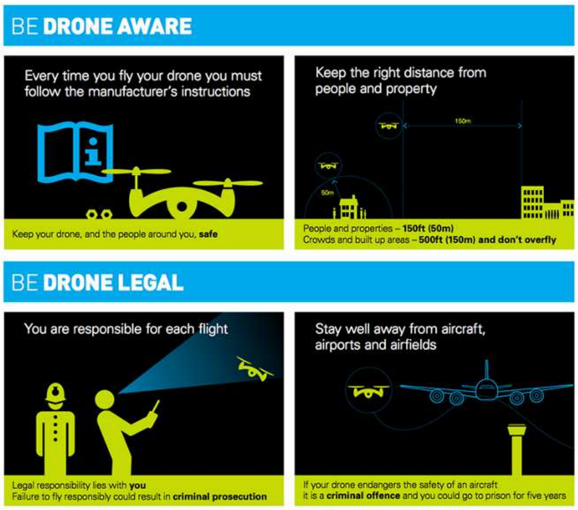
Equipped with GPS, digital compass and barometer, can hold position, direction and altitude.
Can fly autonomously along a route saved in memory. Can detect obstacles and halt.

Safety and Legal issues

Commercial use:
- License required
- Insurance required

Non Commerical use:
- No license required
- Insurance recommended

License (course + exam + medical): ~1000 €
Insurance: variable (including cheap one day insurance)



The UK Dronecode is published by the Civil Aviation Authority to assist drone users in flying safely.

Photogrammetry principles

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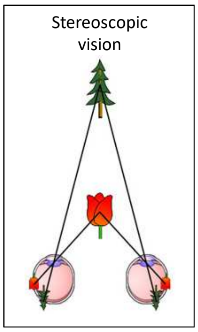

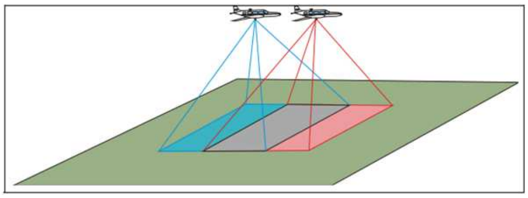

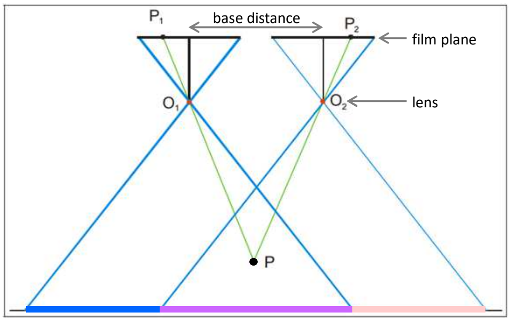

The location in space (x,y,z) of a point P can be calculated by comparing the positions (P_1 P_2) where the point appears on two adjacent pictures.

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Software: Pix4D

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Acquisition: App Pix4Dcapture

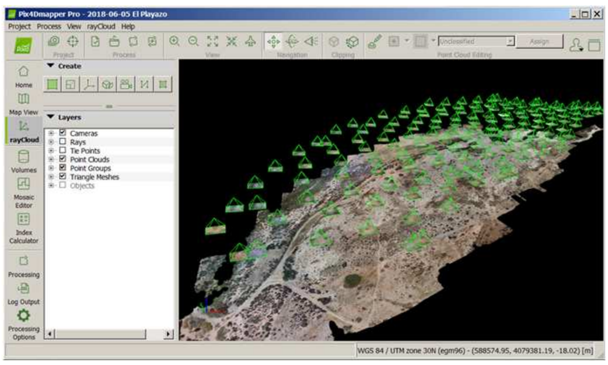
Processing (desktop / cloud):
- Load images and control points
- Generate Point Cloud
- Generate Triangle Mesh

Outputs:
- 3D model (geometry + texture)
- 2D grid (DEM, topography)
- Orthomosaic (ArcGis, GoogleEarth)

Processing time: “one night”

Yearly subscription: 2600 € / year

Permanent non commercial license: 3900 €
Upgrades and Support: 650 € /year



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Applications in Geology

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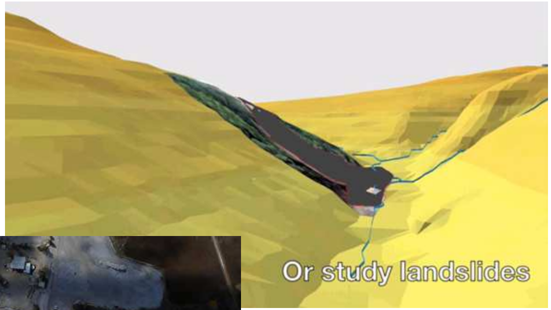
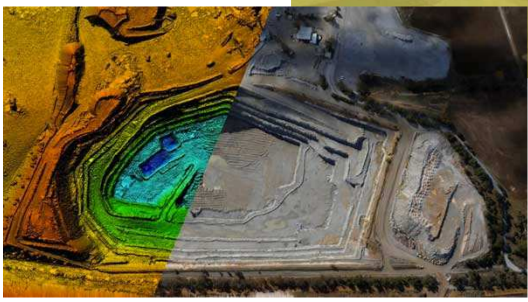
Mapping
3D rendering
Area/Volume calculation





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Safari: repository of geological outcrop data from clastic sedimentary systems

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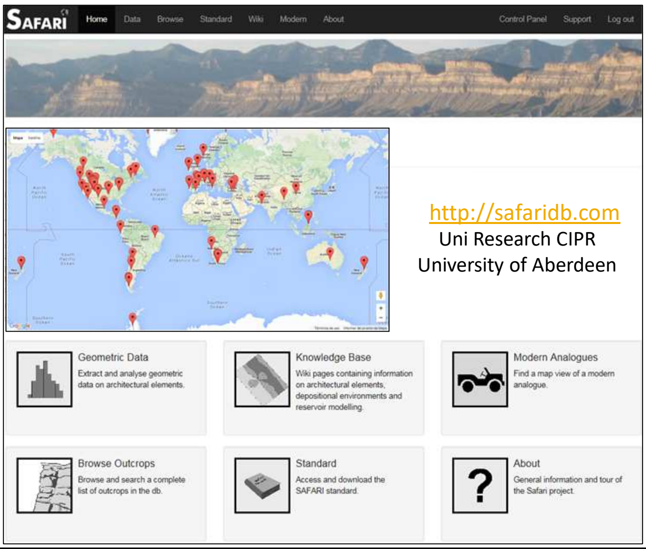

http://safaridb.com
Uni Research CIPR
University of Aberdeen

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Virtual outcrops: Spain - Ebro basin

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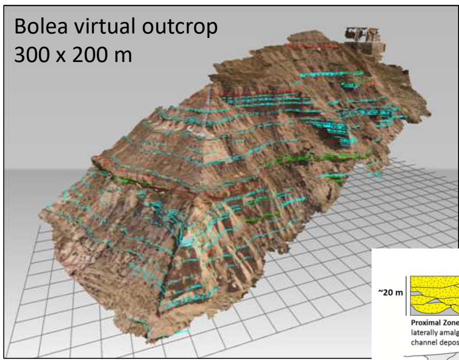
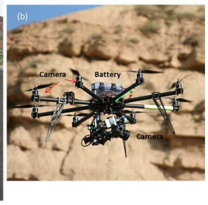
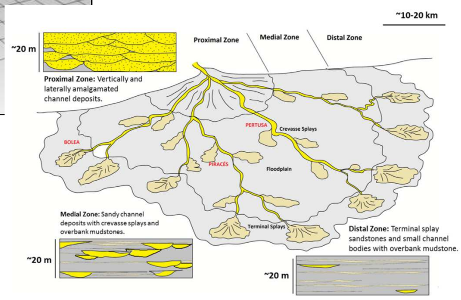
Bolea virtual outcrop
300 x 200 m



LiDAR scanner

UAV camera





LiDAR and UAV data were collected to build three virtual outcrop models for the quantitative analysis of variations across the system:

- Pertusa: Upper medial zone
- Piracés: Lower medial zone
- Bolea: distal zone

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Practical uses of a virtual outcrop

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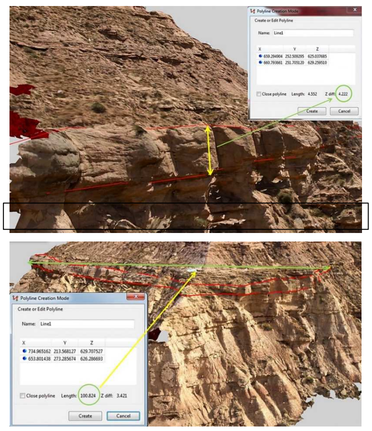
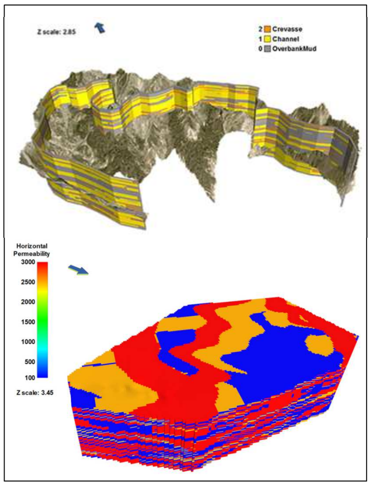


Sandstone bodies can be interpreted and their geometry be measured on the virtual model to populate the Safari statistic database



Input to facies and geocellular models to test flow simulations

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Applications in Geology: Training

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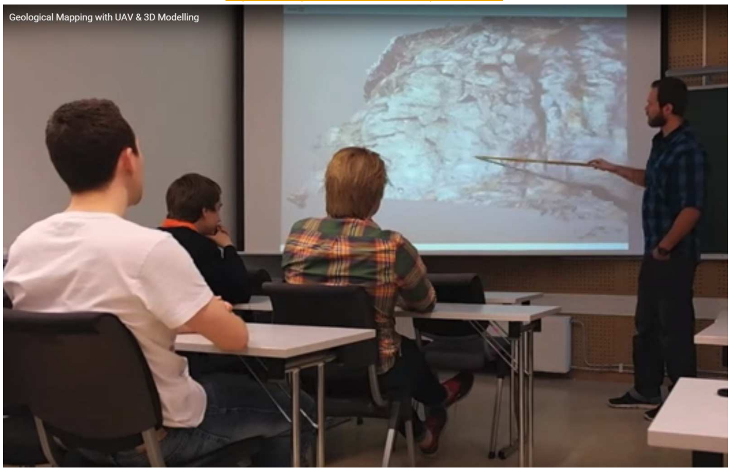
Virtual field-trip on a virtual outcrop
Project sponsored by Statoil – Trondheim
https://www.youtube.com/watch?v=pKtNZS43aDc



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Drone test
Geological background

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Caribbean and Central America tectonic framework

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Seismicity from the USGS/NEIC database (1974 to present)

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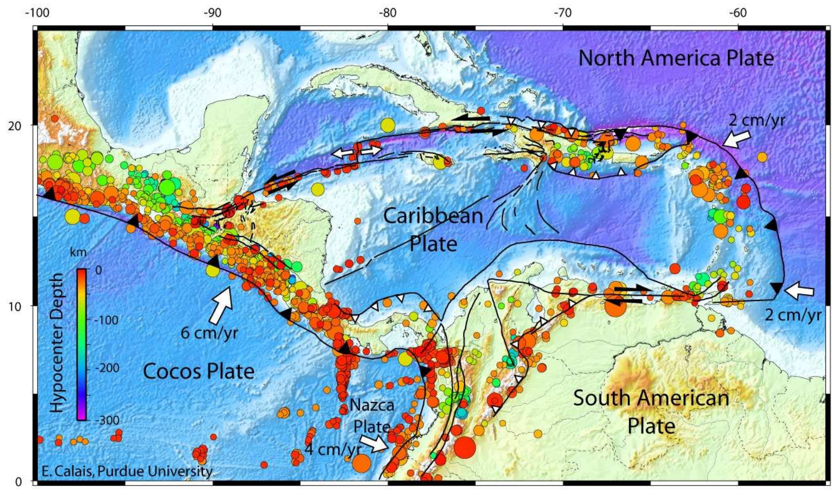

http://web.ics.purdue.edu/~ecalais/haiti/figures/

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Maracaibo block and Venezuelan Andes: Physiography and Structural elements

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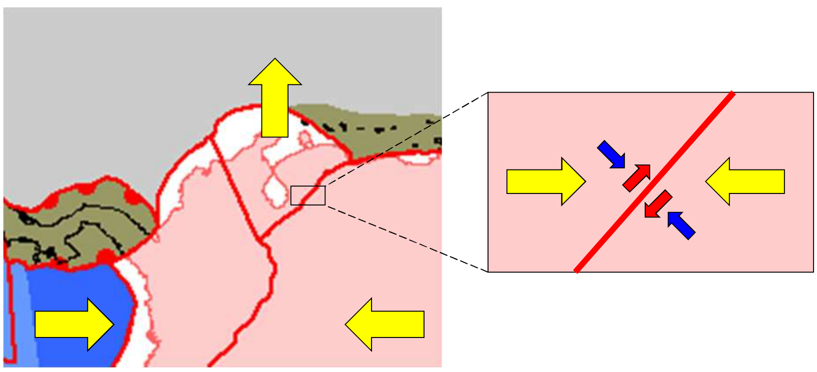


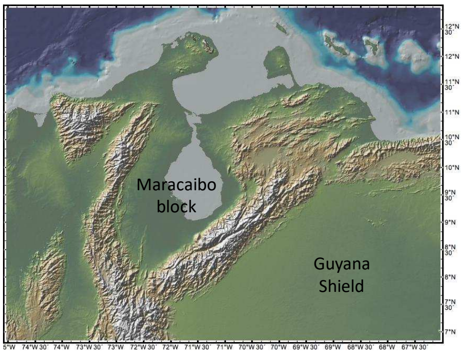
The convergence of the Nazca plate against the Guyana shield has led to the northward extrusion of the Maracaibo block.

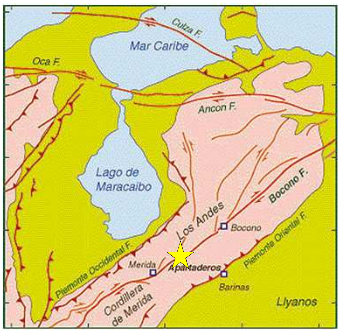
The convergence between the Maracaibo block and the Guyana Shield is oblique along the Boconó fault and can be subdivided into:

- Compressional component (orthogonal to the fault)
- Lateral component (parallel to the fault)

Maracaibo block and Venezuelan Andes: Physiography and Structural elements

Webinars





The oblique convergence between the Maracaibo block and the Guyana Shield has led to:

- rise of the Venezuelan Andes belt (Mio-Pliocene)
- right-lateral strike-slip movement along the Boconó fault

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★ Apartaderos: drone test location

Apartaderos: Boconó fault vs. topography

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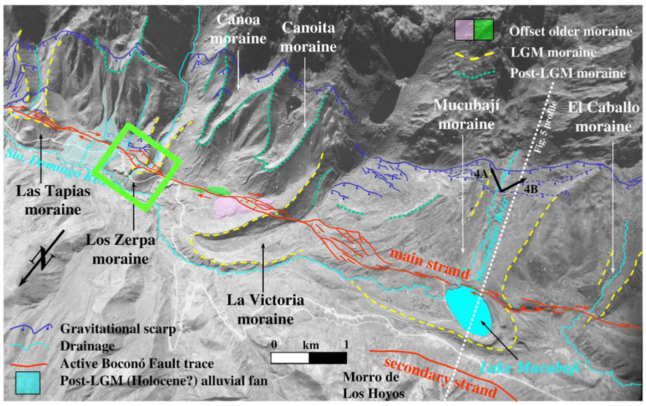
Several topographic features (3000-3500 m) appear displaced along the fault trace:

- rivers drainage
- glacial moraines (Pleistocene-Holocene)

"Los Zerpa" moraine selected for the test



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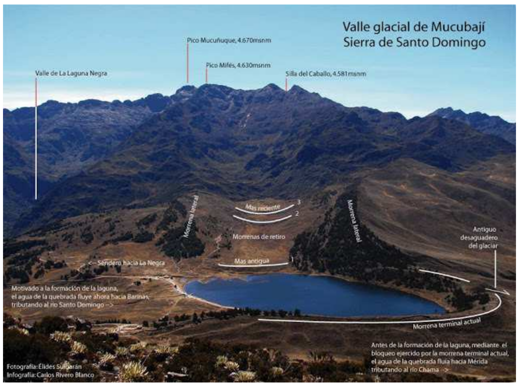
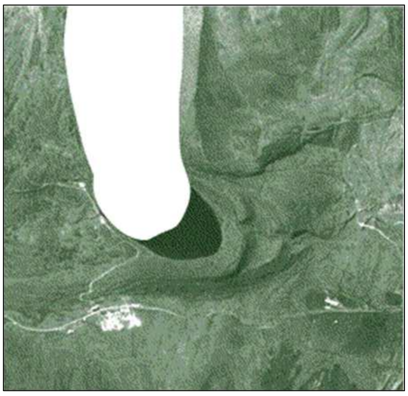
"Deep-seated gravitational slope deformations along the active Boconó Fault in the central portion of the Mérida Andes, western Venezuela"
Franck A. Audemard, Christian Beck, Eduardo Carrillo - Geomorphology - 2010

Mucubají lagoon: Glacial morphology (video 3)





Excursión Geomorfológica a la Laguna de Mucubají
http://geologiavenezolana.blogspot.com/2011/09/excursion-geomorfologica-la-laguna-de.html

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Mucubají lagoon (video 4)

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Drone test in the Venezuelan Andes

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Boconó fault - Los Zerpa Moraine

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Drone acquisition

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The acquisition was performed in August 2015, covering an area of 400 by 600 m over the moraine system.
The images were acquired at an initial altitude of 80 meters at take-off and with a 70% overlap.
A total of about 300 images were acquired in two flights 20 minutes long.
The picture shows the location of these images and the topography generated by processing them with Pix4D

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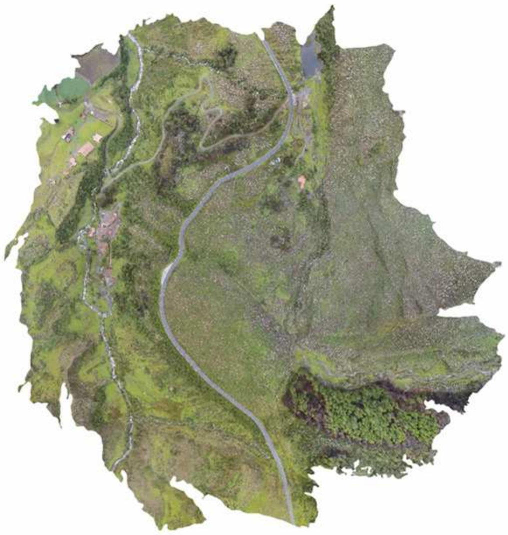
3D Model (video 5)



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Resolution

Satellite image:
Grid size: 30 x 30 cm

Drone image:
Grid size: 5 x 5 cm

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Exercise 1:

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Highlighting the landscape

3D model

(color-coded by relative elevation)

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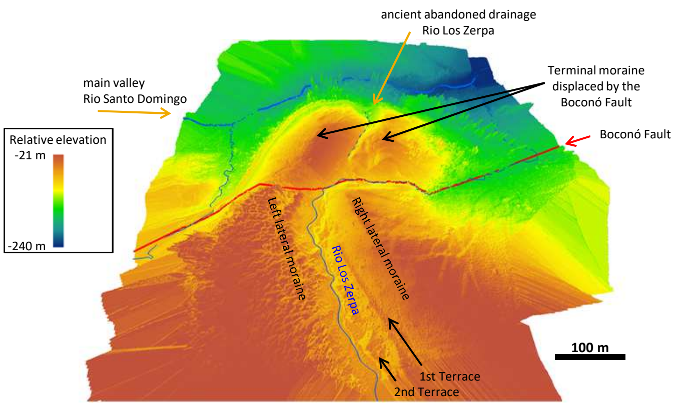
Several geomorphic features related to the interaction between the Boconó fault and the moraine deposits:

- the trace of the Boconó fault, marked by a series of aligned tectonic scarps
- the sharp bend of the Rio Los Zerpa, that deviates 90º when it intersects the fault trace
- the dextral displacement of the lateral moraines as they cross the fault
- the ancient fluvial valley incised in the terminal moraine and now abandoned
- two terraces witnessing past periods of fluvial infill and later erosion



Exercise 2:

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Modeling the fault displacement

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Fault model

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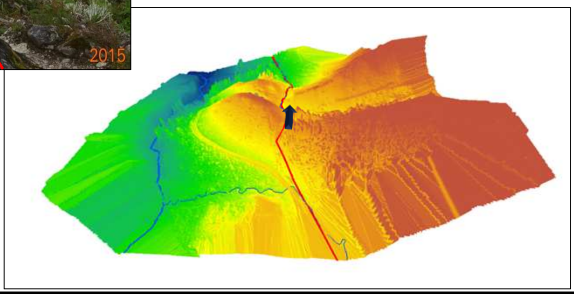

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Fault model

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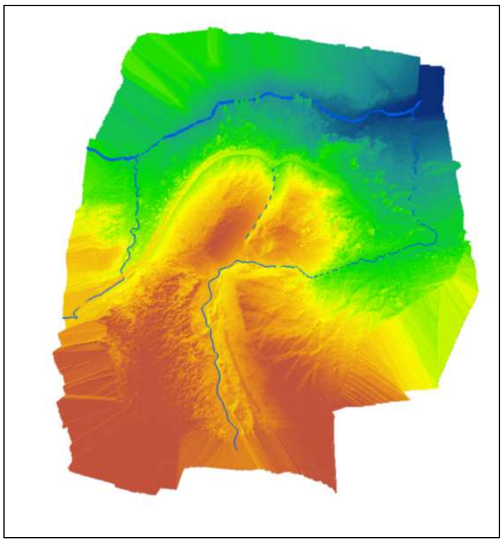
The fault trace is highlighted by:

- scarps in the topography
- present day drainage



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Fault model

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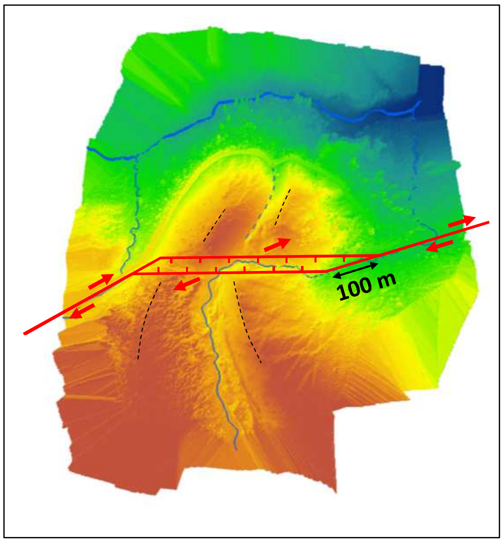
The deviation in the fault trace is interpreted as a releasing bend associated with a small transtensional graben

The fault displacement is highlighted by:

- displaced drainage
- displaced topographic crests



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Fault model

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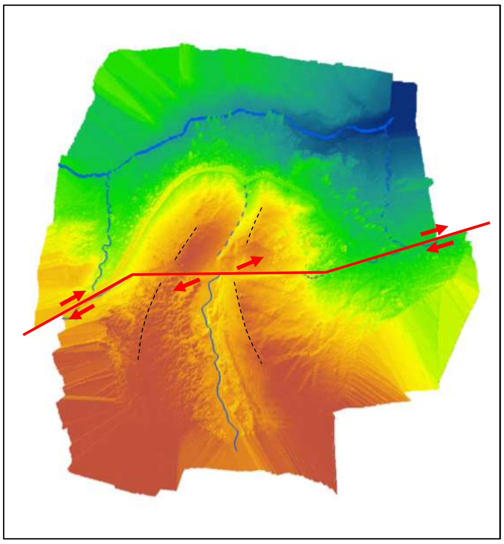
Reconstructing the original fault setting brings to align:

- the displaced portions of the moraine crests
- the present day fluvial valley with the ancient abandoned drainage



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Boconó fault: displacement velocity

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Age of glacier retreat: 16000 years

Current displacement along the Boconó Fault: 100 m

Velocity of displacement: 100 m / 16000 years = 6.3 mm / year

Regional velocity measured with GPS: 12 mm /year

=> The Boconó fault contributes to half of the total regional displacement

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Boconó fault: displacement velocity

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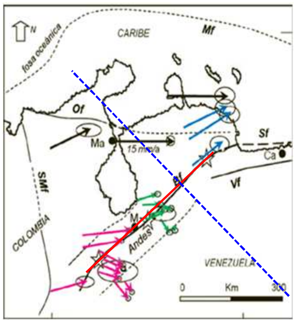
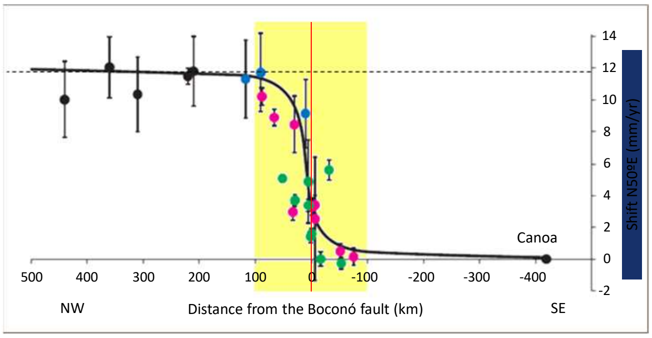
Velocity field component parallel to the Boconó fault (N50ºE).
South-American craton (Canoa) as reference.

The two blocks separated by the Boconó fault move side by side at 12 mm / year.
The strike-slip movement deforms a swath extending 100 km on either side of the fault.
The maximum deformation occurs along the fault at 6 mm / year.





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“Campo de velocidades GPS en el occidente de Venezuela: componente lateral derecha asociada a la falla de Boconó y componente convergente perpendicular a los Andes”
O.J. Pérez, R. Bilham, M. Sequera, L. Molina, P. Gavotti, H. Codallo, C. Moncayo, C. Rodríguez, R. Velandia, M. Guzmán, P. Molnar – Interciencia 2011

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Exercise 3:

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Modeling the drainage evolution

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Geological evolution: Glacier advance

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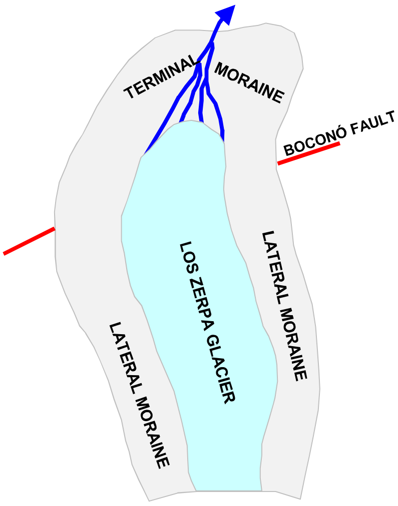

"Tectonics and Sedimentation: an example from the Mérida Andes (Venezuela)"
C. Schubert - Acta Geologica Hispanica - 1983

- 18,000 - 13,000 years B.P., the valley of the Los Zerpa river was occupied by a glacier, which deposited the moraines that bound the valley today.
- The glacier melt-water drained over and through the end moraine.

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Glacier retreat

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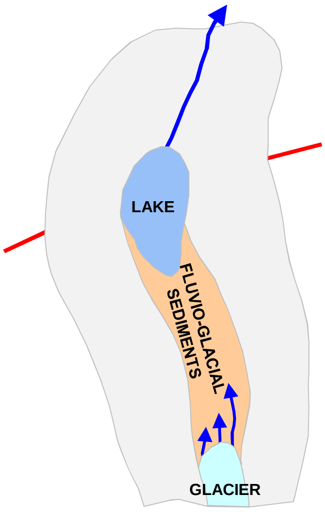

- When the glacier retreat began, a lake probably was dammed in the lower part of the valley.
- Fluvio-glacial sediments were deposited in the rest of the valley.
- Outward drainage continued through the terminal moraine.

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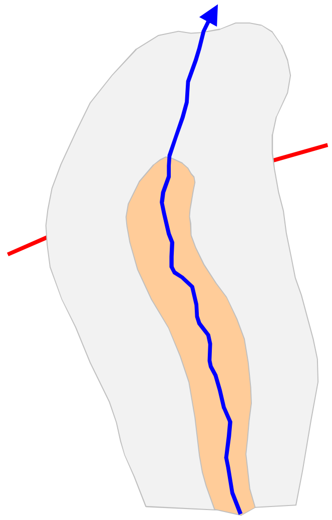
Fluvioglacial sedimentation



- Fluvioglacial sedimentation continued until the valley was filled to an elevation of 20-25 m above the present-day river level.
- An alluvial plain of the Los Zerpa river formed at this elevation draining through the terminal moraine.

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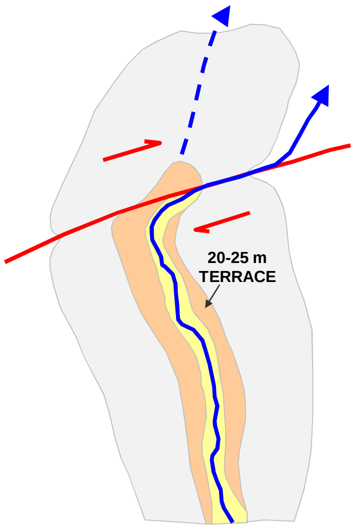
Boconó fault offset



- Right-lateral offset along the Boconó fault opened a breach through the right lateral moraine.
- The Los Zerpa river started to drain through it.
- The old drainage over and through the terminal moraine was abandoned.
- The Los Zerpa river gradient increased, as well as its erosive power.
- The river incised the fluvio-glacial fill of the previous stage and originated a 20-25 m terrace.

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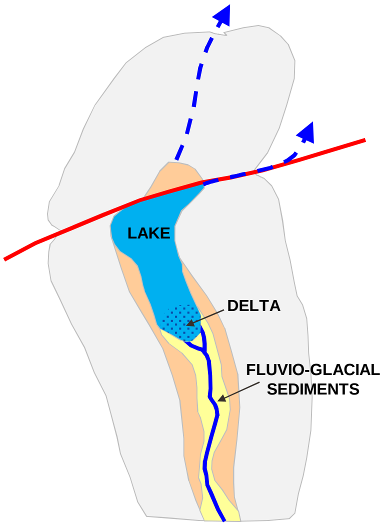
New sedimentary cycle



- The breach along the fault trace eventually was closed giving rise to a new sedimentary cycle within the morainic valley.
- A lake was formed in the lower part of the valley.
- It probably drained through the same locality of the previous breach, but at a higher level.
- Fluvioglacial sediments were deposited on an alluvial plain in the higher part of the valley.

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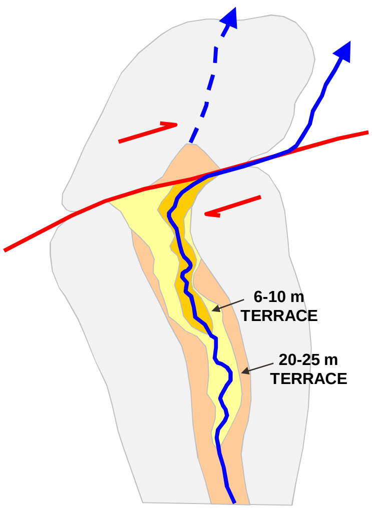
Present day



- Thus, we arrive at the present geological conditions.
- Renewed right-lateral offset along the Boconó fault re-opened the breach through the right lateral moraine.
- The lake was drained
- The Los Zerpa river incised the sediments, and formed a second terrace 6-10 m above the present day river level.

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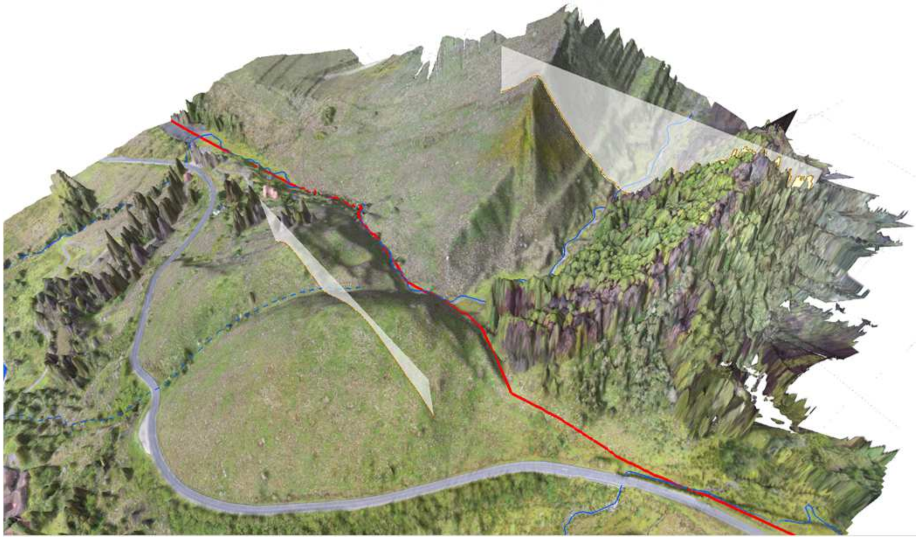
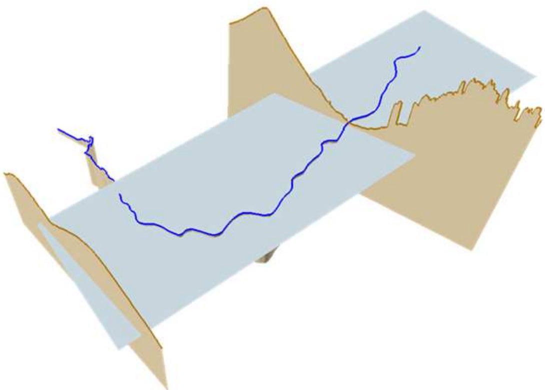
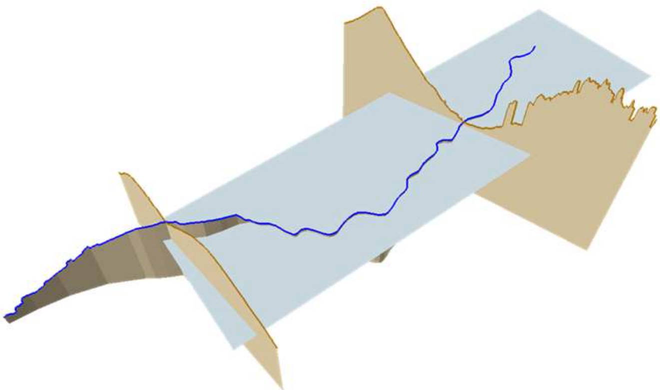
Defining 2 cross sections



Modeling the slope of the present day river valley



The present day river should flow updip in order to reach the abandoned valley



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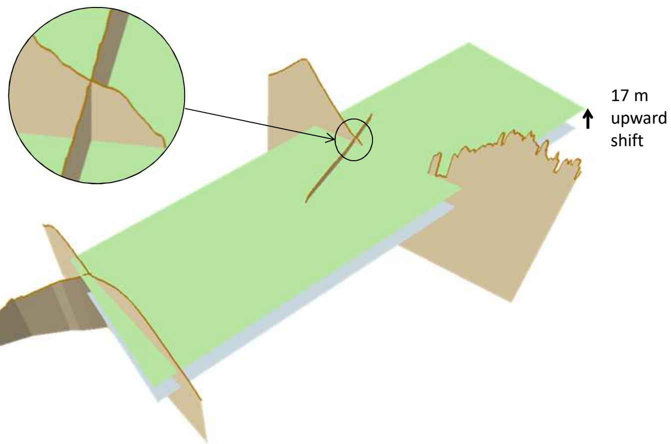
In order to reach the abandoned river valley a higher alluvial plain should be considered aligned with the terrace on the flank of the moraine



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Fluvial drainage modeled at the time when the alluvial plain was filling the glacial valley

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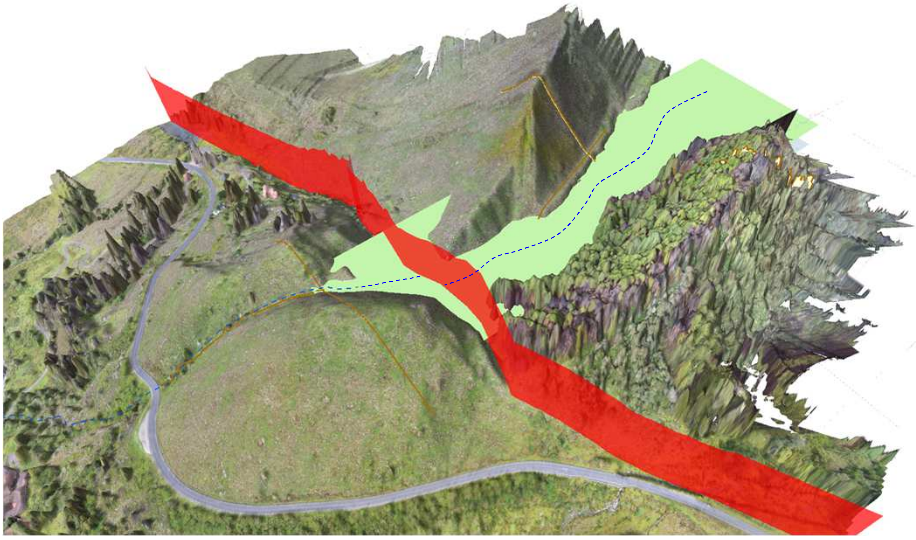

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3D printed model

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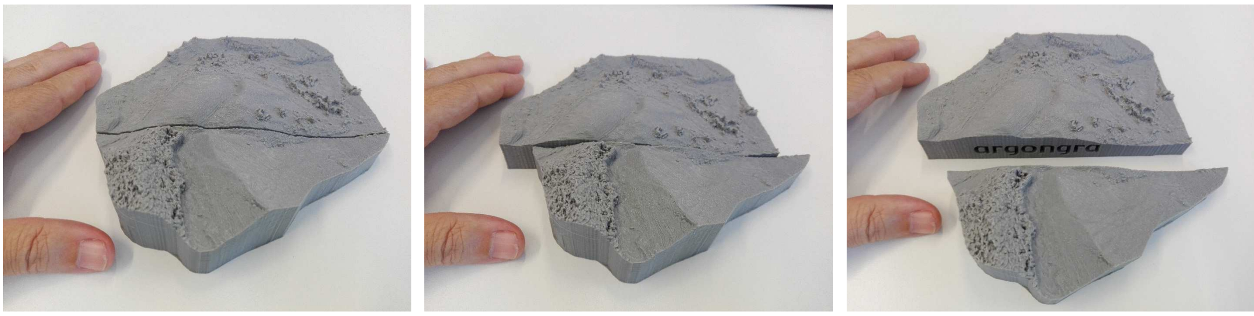


Model made by Argongra: www.argongra.es

The 3D model built as a physical object helps testing and sharing ideas.

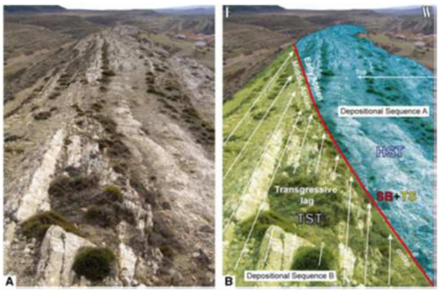
A few more examples…

- Angular unconformity
- Synsedimentary slumps
- Transition continental to marine
- Reverse fault and vertical strata
- Folds and thrusts
- Traces of trilobites
- Pre-Roman archaeological site

All visible in 3D at:
https://sites.google.com/site/riccardorocca62/home/drone-projects

Sedimentary channel fill
Camarillas, Teruel, Spain

This outcrop shows an angular unconformity within a set of vertical strata, but it is difficult to guess the hole picture at ground level.



The orthophoto acquired with the drone allows to clearly distinguish the geometry of a channel erosion and fill.
The channel feature becomes intuitively evident with the help of an image captured from the drone.

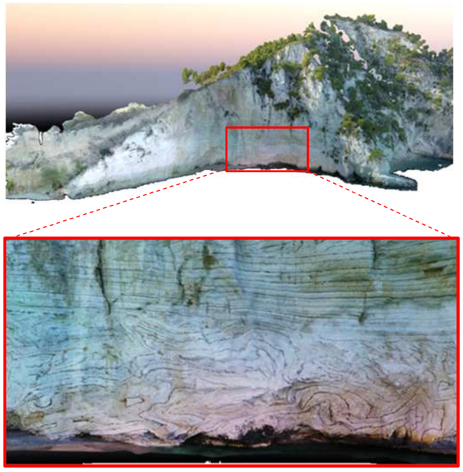
Synsedimentary slumps in the Maiolica formation Gargano, Puglia, Italy

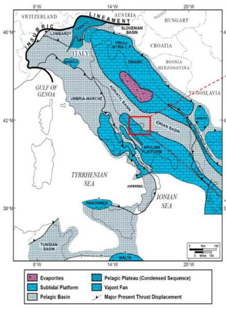
Webinars

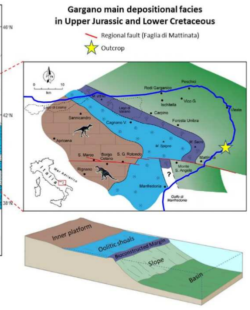
I did this acquisition with the idea of supporting a field trip to see analogs of the carbonate facies that are the reservoir of several recent hydrocarbon discoveries in the western Mediterranean sea.

The sediments in this particular outcrop belong to the Maiolica Formation, which represents the basinal facies of a carbonate platform that developed from the Upper Jurassic to the Eocene and that outcrops today in the Puglia region, in south-eastern Italy.

This outcrop allows to see some typical features of the formation, in particular, the spectacular slumpings that develop as intraformational folds and truncation surfaces.







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Transition from continental to marine sediments Morella Quarry, Teruel, Spain

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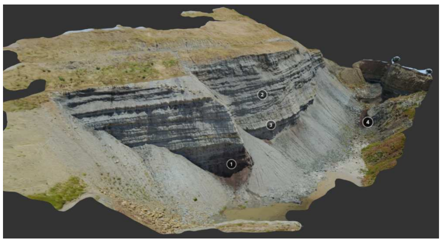
The value of this model is to preserve the display of an outcrop that is going to disappear. It was exposed in order to extract clay for pottery and now, as part of the environmental agreement, is going to be covered again.

The outcrop shows the transition from reddish continental to greenish marine sediments.
The sediments are of Early Cretaceous age and the continental interval is rich in dinosaurs fossils that have been collected and displayed in a local museum.

The understandable requirement of bringing the landscape back to its original condition, is unfortunately going to cover this remarkable outcrop. The drone model is a valuable option to preserve at least its virtual model.

3D model acquired in 2017



Picture taken in 2016

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Reverse fault and vertical strata modeled with Move
Huérmeces del Cerro, Sigüenza, Spain

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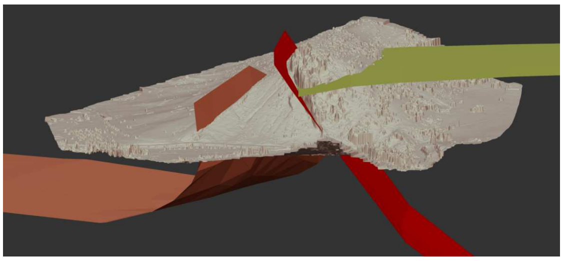
This outcrop is characteristic for the presence of near-vertical strata, interpreted as the result of steepening due to the action of a reversed fault.

I tried to help understanding this structure by adding a few geometrical surfaces representing the reversed fault and the strata in the two faulted blocks. I did the interpretation in Move, a software for structural interpretation distributed by Midland Valley.

The 3D model can be imported in an interpretation software and serve as reference to interpret geological surfaces.



"Move", Midland Valley
https://www.mve.com

Folds and Thrusts in the Pyrenees
Pantano Santa Ana, Llerida, Spain

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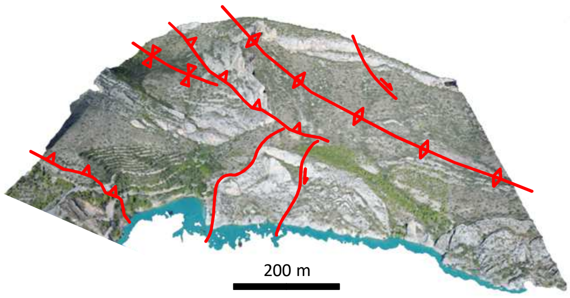
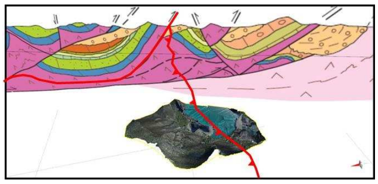
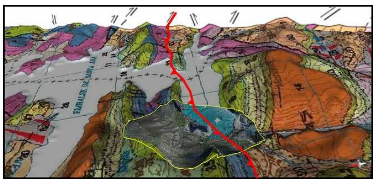
This outcrop is one stop of a field trip in the Pyrenees and it is a good examples of the physical limitation of drone acquisitions.

We wanted to acquire a very large area, in order to represent the main geological structures. In the end we were able to acquire only a part of it (1500 x 1000 m with three flights) and nevertheless this was not enough to properly represent the geology. The acquisition was integrated with geological maps and sections (using Move), but the size of what we desired to represent was much larger than what we could reasonably acquire.

A good lesson for being more realistic in the future and be prepared to adjust the acquisition of geological features to the size of what is actually achievable by means of a drone.





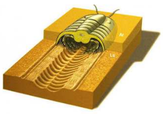


Traces of trilobites (Cruzianas)
By the park of Cabañeros, Ciudad Real, Spain

Webinars

The surface of this outcrop is covered by Cruzianas, the fossil tracks left by Ordovician trilobites during their movements.
The tracks are present on the bottom surface of a steeply inclined layer.
After the model is generated, it is possible to rotate it and display the bottom surface from above, as it was in its natural orientation when the tracks were generated.
The 3D digital model allows to observe the fossil environment from a more natural point of view, that would not be possible with the real outcrop in the field.

Cruzianas:
tracks left by trilobites



The outcrop in its present day orientation.

The Surface with Cruzianas seen from above,
in its original orientation

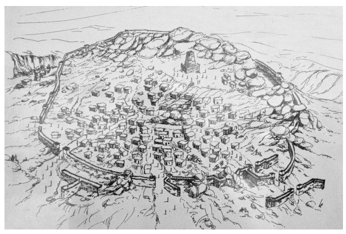
Castro de Ulaca
Pre Roman archaeological site near Ávila, Spain

Webinars

Ulaca is the archaeological site of an ancient pre-Roman village, located 150 km NW of Madrid.

The most impressive ruin is that of an altar, carved in the local granitic rock.

It has stairs, to climb to the the top, and basins, to collect the blood of the victims sacrificed during the rituals.



Ulaca Altar (video 6)

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Lateral stair inclination

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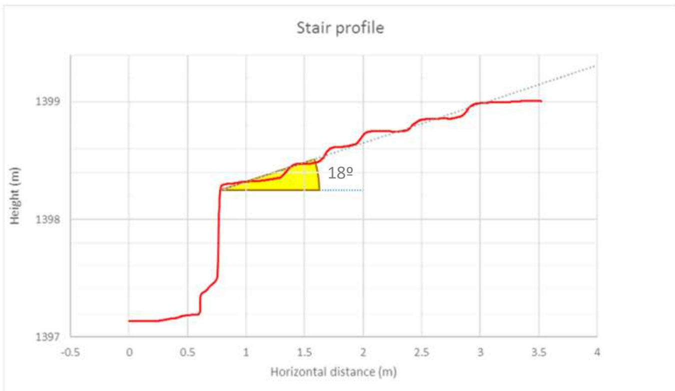

The first step of the lateral stair is anomalously high as it can be seen in the profile.
The stair profile can be extracted from the 3D model generated with the drone, and the stair inclination can be calculated (18º).
Maybe the stair was not meant to climb to the top of the altar and had different use…

Altar orientation in the landscape

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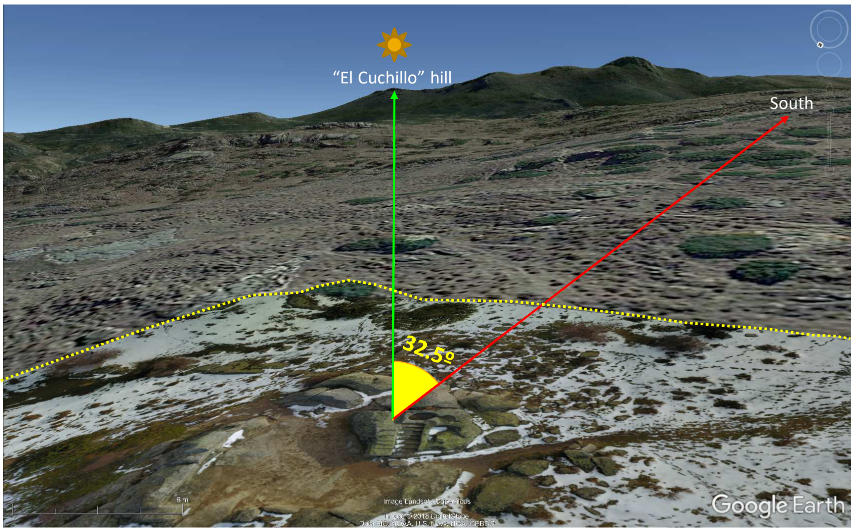
The orthophoto generated with the drone, can be overlain in GoogleEarth and allows to analyse the orientation of the altar with respect to the surrounding landscape.

The altar is pointing towards a hill in the background, named "El Cuchillo".

Its azimuth, with respect to the altar, is 32.5º to the east of the astronomical south.



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Sun altitude at Winter Solstice 200 BC

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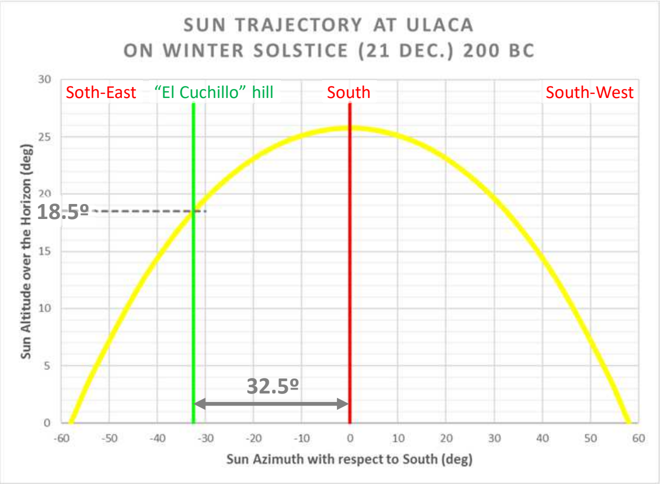
Winter solstice was a special date in the calendar of this ancient people.

The sun trajectory at winter solstice (21st December) at the time of this people (200 BC) was reconstructed by means of the software "Stellarium".

In the direction of "El Cuchillo" hill, the sun altitude over the horizon reached 18.5º.

This is practically identical to the inclination of the lateral stair of the altar (18º).

That day, the stair steps would remain in the shadow until the sun reached its position above the "El Cuchillo" hill.



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Data from "Stellarium"
www.stellarium.org

Ulaca Altar: an astronomical observatory

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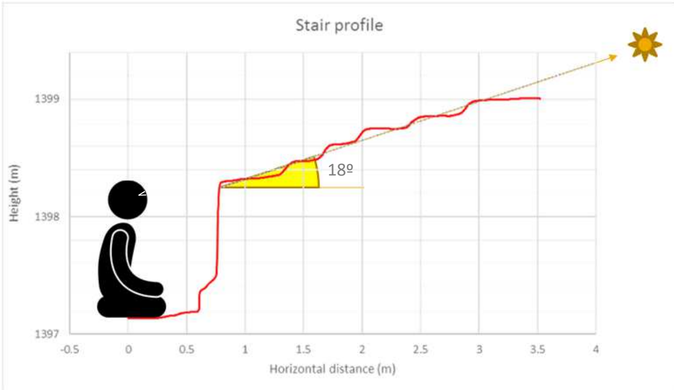

The sun
above “El Cuchillo” hill
at winter solstice,
21st December, 200 BC

Ulaca altar has been interpreted to serve as an astronomical observatory, to mark the occurrence of winter solstice.
The digital model of the altar can be integrated with the digital model of the topography, allowing to test these theories rigorously.

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Reference: “Astronomy and Geometry in Vettonia”, Manuel Pérez Gutierrez, 2009
https://search.proquest.com/openview/b345841c02c81970bed87dd161303ed1/1?pq-origsite=gscholar&cbl=54823

Conclusions
Is there any value beyond fun?

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- Drone technology is a practical tool to capture geological features
- Acquisitions can be made in remote impervious areas with difficult access
- Maps can be acquired at low cost (one man job) and high resolution (a few cm per pixel)
- Geological features can be observed from the most favorable point of view
- The 3D models are suitable for both qualitative and quantitative interpretation
- They are generated at true scale and can be used to measure distances, thicknesses, dips and volumes
- They can be imported in an interpretation software, to draw geological strata and faults

- Areas of application: Environmental, construction, mining
  More typical geological:
  - Virtual outcrops, Virtual field trips
  - Virtual analogs: Facies analysis and sedimentary geometrical patterns
    Fault analysis and statistical parameters
  - what the imagination can inspire …

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Thank you

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