Deposition of a Structurally Confined Submarine Fan in an Evolving Basin: The Guaso I Turbidite System, Ainsa Basin, Spain

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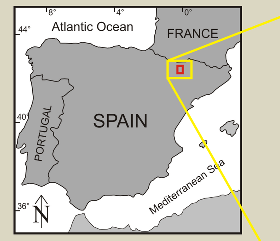
Introduction

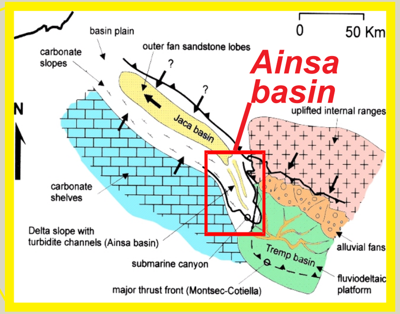
- Structurally confined turbidite systems are common on continental margins around the world, in regions such as the Gulf of Mexico, southern California, offshore West Africa, and the North Sea.
- These depositional systems, which are often prolific hydrocarbon reservoirs in the subsurface, are most commonly characterized with seismic, well log, and/or conventional core data. Each of these datasets, however, has limitations in either detail or spatial extent.
- Detailed field studies in analogous (ancient) basins, such as the Ainsa basin, will yield critical quantitative data regarding styles of longitudinal, lateral, and temporal variations in stratigraphic architecture.

Geologic Setting

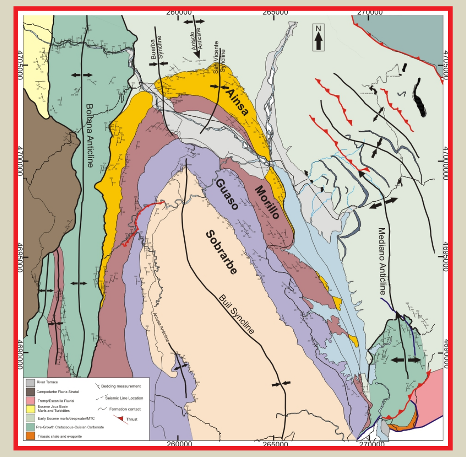
- In the early Eocene, the Ainsa basin developed as a foredeep in the South Pyrenean foreland basin system (Fernandez et al., 2004).
- As thrusting propagated toward the foreland in the middle Eocene, the Ainsa basin evolved into a piggyback basin (Fernandez et al., 2004; Hoffman, 2009).



Ainsa basin (see red box), southern Spanish Pyrenees.



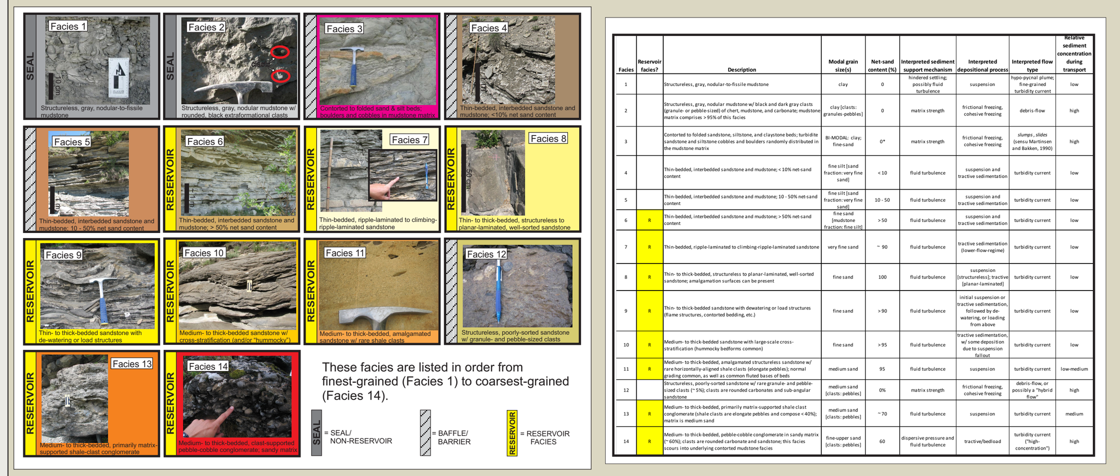
Above figure: Munoz et al. (1998)


Above: Geologic map of Ainsa basin (Hoffman, 2009).

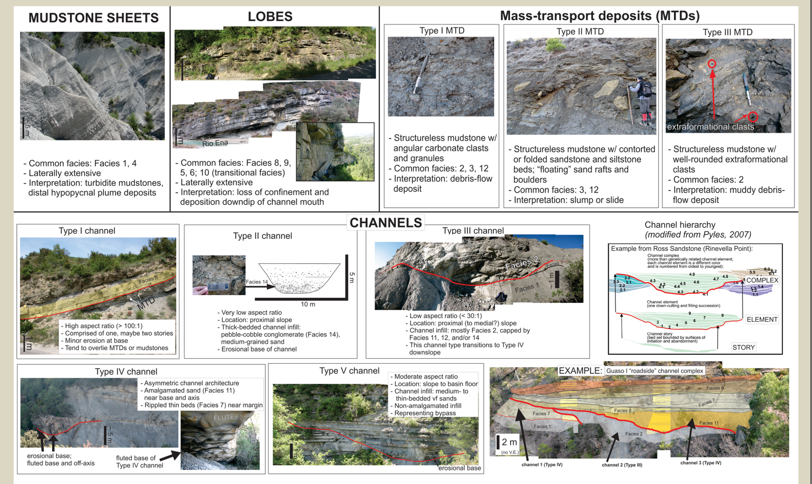
Data and Methods

- Field mapping of cycle-bounding condensed sections, sandstone bodies, and mass-transport deposits (*MTDs*, i.e. slumps, slides, debris-flow deposits) was conducted.
- We define *cycles* based on condensed sections, not speculative sequence boundaries.
- Measured 30 sections (1980 m total); 429 paleocurrent measurements in the Guaso I.
- We observed four principal architectural element types and 14 facies types.
- We correlated measured sections, and interpreted time-significant surfaces within the Guaso I cycle. We used these correlations to construct stratigraphic cross-sections.
- We used the thickness and net-sandstone values to create isopach maps (gross-thickness and net-sandstone).
- Paleogeographic reconstruction using above correlations and paleocurrent data.

Facies and Architectural Elements

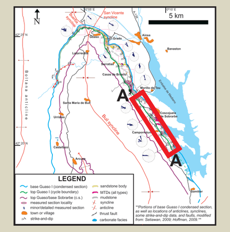

These facies are listed in order from finest-grained (Facies 1) to coarsest-grained (Facies 14).

Above: facies chart for Guaso I strata.

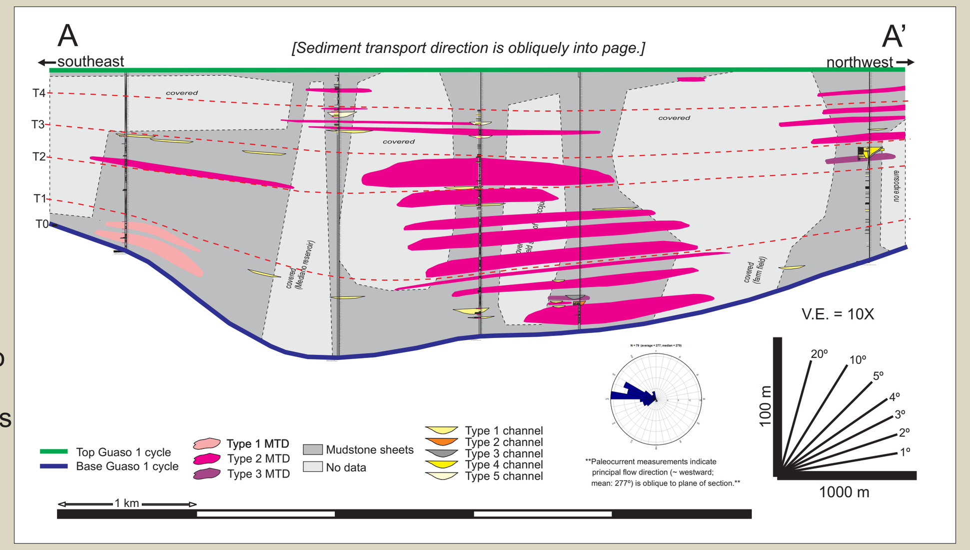


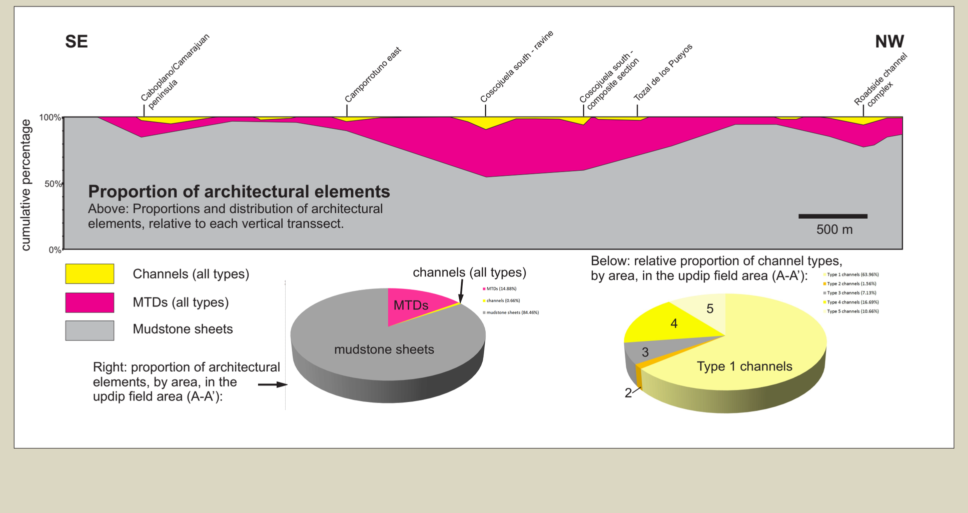
Above: four principal architectural elements encountered in the Guaso I.

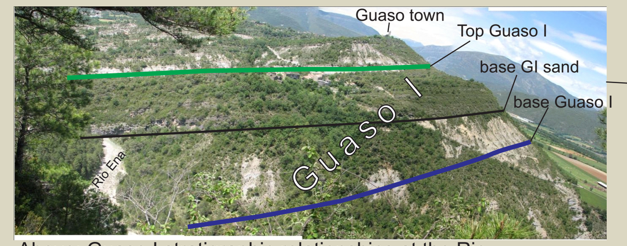
Guaso I Geology


Above: location of cross-section A-A'

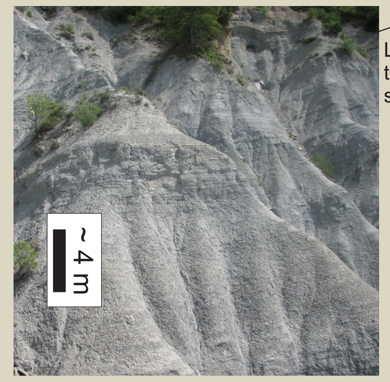
- This area was the entry point for Guaso I sediments into the basin, which were transported from east to west.
- This area contains abundant MTDs and Type 1 channels.
- MTDs are thickest in the axis of this feeder system.





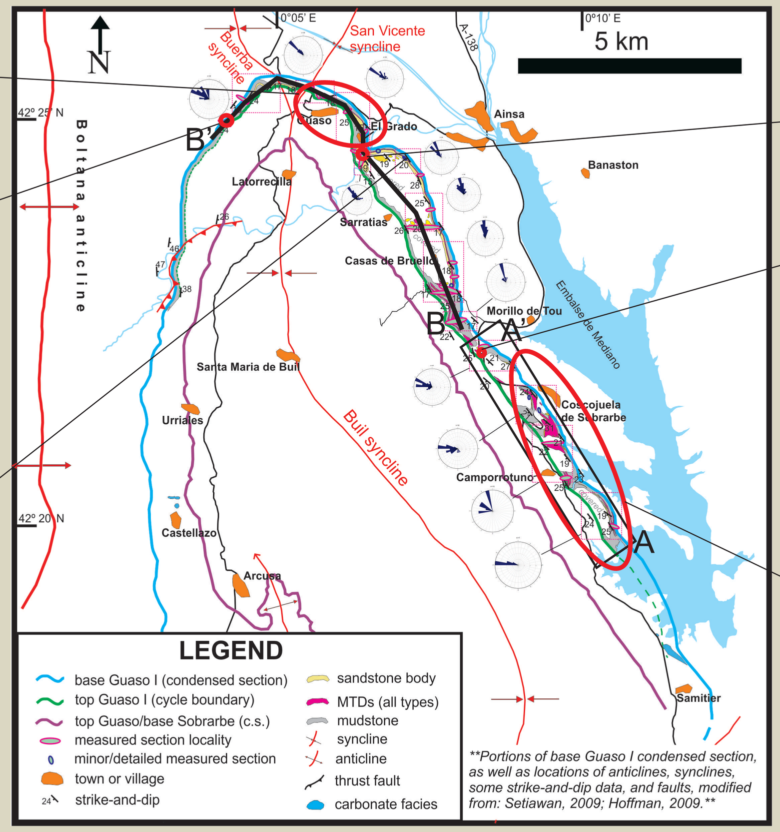


Above: Guaso I stratigraphic relationships at the Rio Ena locality. View looking northwest toward villages of El Grado and Guaso.



Left: mudstone sheets, tens of meters thick, near pinchout of Guaso I sandstone.

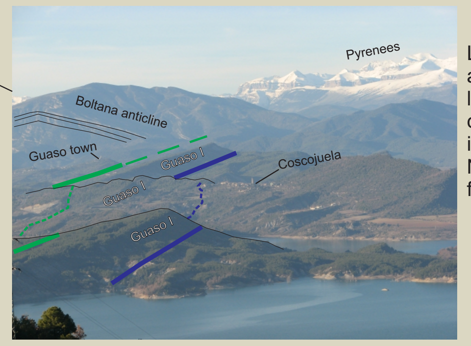
Right: tabular and semi-tabular sandstone beds, near interpreted channel-lobe transition at "Osqueta da Calura" locality.



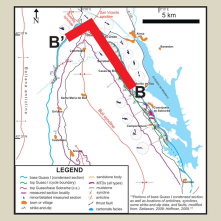
Above: Geologic map of Guaso system

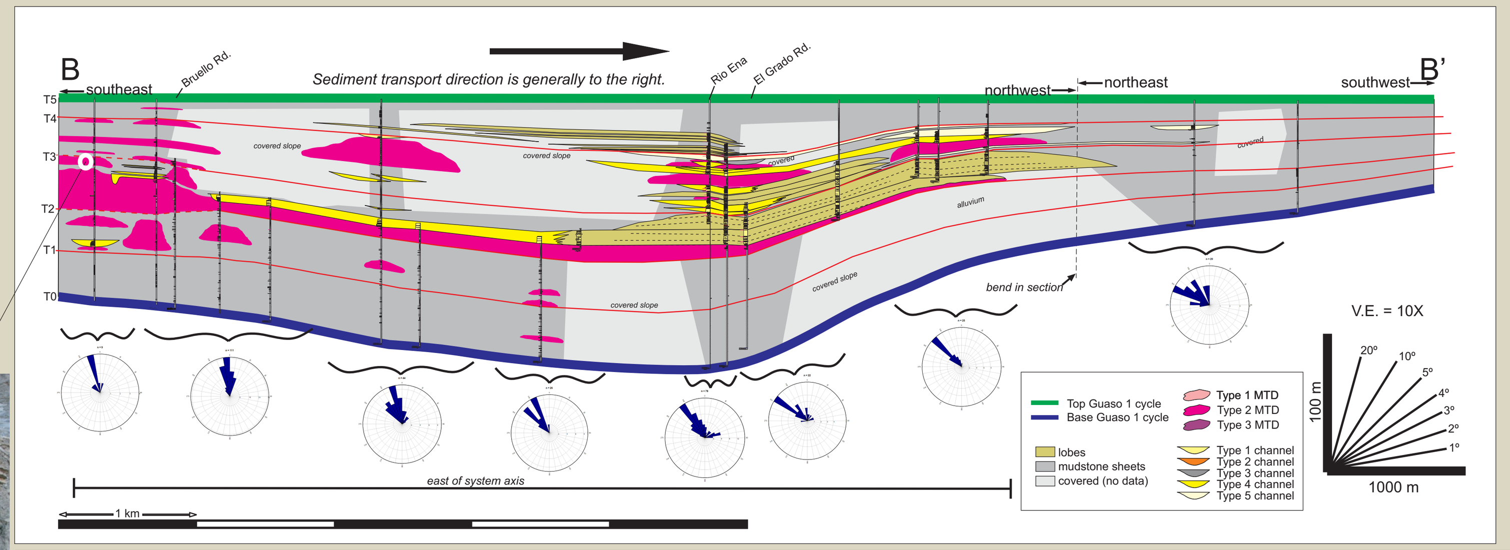
Above photo: proximal lobe elements at base of Rio Ena outcrop locality.

Above photo: roadside channel complex, northwest of Coscojuela de Sobrarbe. Note erosional bases of channels (red).



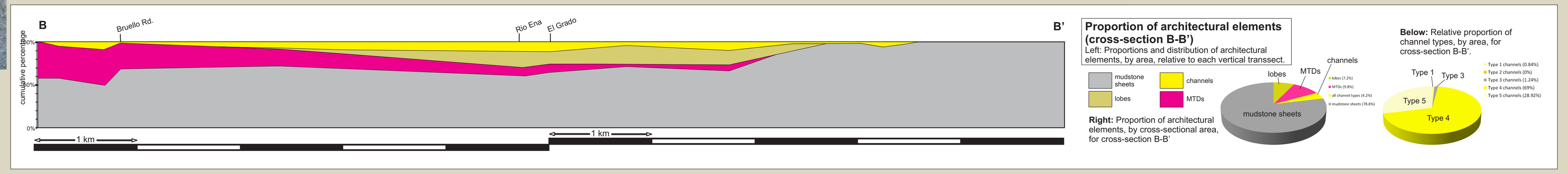
Left: view looking northwest, along strike of Guaso I. Blue line is the base Guaso I condensed section; green line is Top Guaso I mudstone unit. Note the Guaso I package forms a prominent ridge.


Above: location of cross-section B-B'

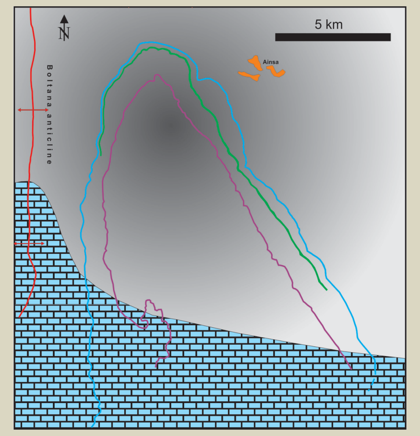


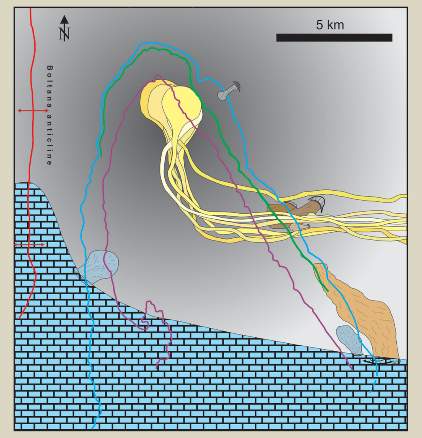
- MTDs are abundant in the southeast part of cross-section B-B'; they decrease in abundance to the northwest (downslope).
- Lobe elements generally increase in abundance to the northwest; they are most abundant near the depocenter. Beyond the depocenter, the abundance of lobes decreases.
- The Type 4 channel overlying the MTD immediately above surface T2 is present in continuous outcrop for ~ 3 km. (Paleocurrents are generally parallel to strike.) This channel feeds the basal lobes at Rio Ena.

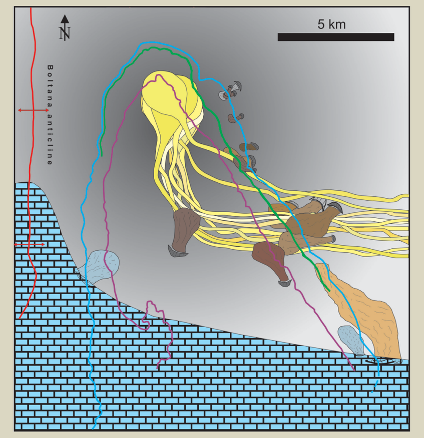

Above: folded sandstone and siltstone beds in an MTD.

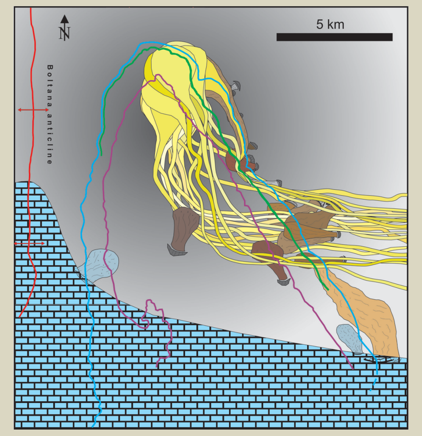


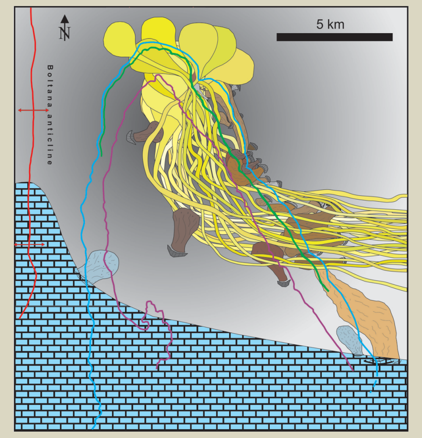
Stratigraphic Evolution and Paleogeography


Guaso I system at ***T0***: At this time, deposition in the basin is primarily hemi-pelagic. This basal Guaso condensed section is the boundary between the Guaso and Morillo systems. (The darker the shading is on the map, the greater the paleo-depth. The blue line represents the base of Guaso I, a condensed section. The green line represents the top of the Guaso I.)

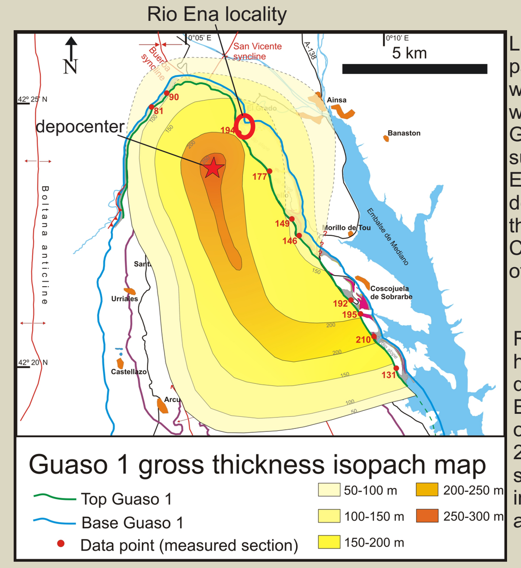

Guaso I system, ***T0-T1***: Initiation of submarine fan, with basal lobe elements deposited in a confined area on the basin floor. Minor slumping and debris-flows from updip and carbonate shelf-edge.


Guaso I system, ***T1-T2***: Slope channels continue to feed basin floor lobe elements. Deposition from one lobe to the next is primarily aggradational. Basin floor is still relatively confined. *Note*: basin floor lobes have not yet intersected the position of the future outcrop belt (at Rio Ena); pervasive MTDs create a "thick" in the updip "feeder" area.


Guaso I system, ***T2-T3***: System begins to fill the confined basin floor; lobes (e.g., base of Rio Ena section) during this time are deposited farther north relative to previously deposited lobes. A:S ratio decreases (due to decrease in effective subsidence?). Note slope channel (*exposed continuously in outcrop along Guaso ridge*) feeding lobes at base of Rio Ena outcrop.

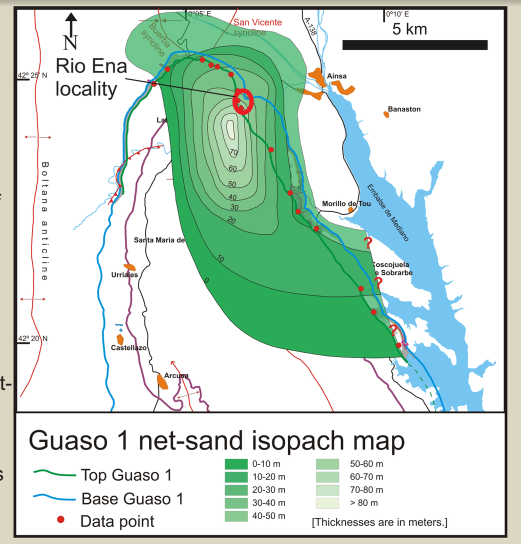

Guaso I system, ***T3-T4***: A:S ratio continues to decrease. Depositional area increases markedly. Compensational stacking increases. The sand-rich turbidite system has "advanced" beyond the original depocenter of ***T0-T2***.

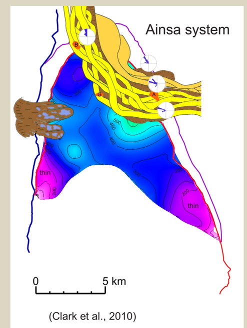
Isopach Maps



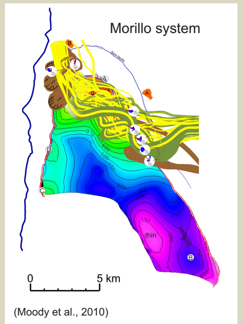
LEFT: Measured sections and correlation panels yielded stratigraphic values which were used to create gross-thickness, as well as net-sand, isopach maps. The Guaso I is interpreted to be thickest in the subsurface, ~ 2 km southwest of the Rio Ena locality. This is defined as the depocenter. Guaso I is also very thick on the slope (at outcrops immediately east of Camporrotuno) in the updip "feeder area" of the system.

RIGHT: The Guaso I system has the highest net-sandstone values near the depocenter, located southwest of the Rio Ena locality. This trend is indicative of out-of-grade systems (*sensu* Pyles et al., 2010), e.g., Ross sandstone and Annot sands. High net-sand content is present in areas dominated by deposition of lobes and distributary channels.

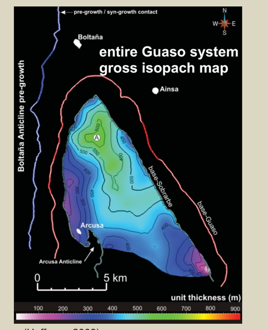




(Clark et al., 2010)



(Moody et al., 2010)



(Hoffman, 2009)

Above: Gross-thickness isopach maps of the Ainsa system, Morillo system, and the Guaso system (originally from Hoffman, 2009).

- In "out-of-grade" systems, it is very likely that any gross isopach thicks will also be the locus of highest sandstone content.
- The Ainsa system and the Morillo system are both dominated by weakly confined channels feeding lobes distally in the Jaca basin, to the west-northwest. Even in these non-ponded, out-of-grade systems, the gross isopach thick is the locus of highest sandstone content.

Conclusions

- The Guaso I turbidite system is a structurally confined 4th-order submarine fan.
- The Guaso I system offers near-continuous exposures from the slope down to near the depocenter and beyond.
- The Guaso I is an out-of-grade system. There are erosional channels and pervasive mass-transport-deposits on the slope, and the depocenter (location of highest gross-thickness value) is on the basin floor. Maximum sandstone content is near the depocenter.
- Maximum sandstone content *exposed at outcrops of the Guaso I* is located at the Rio Ena locality. However, maximum sandstone content for the system is located in the subsurface 2 km southwest of Rio Ena.
- Effective subsidence was highest in the early stages (***T0-T2***) of Guaso I deposition. Later stages exhibit decreased accommodation relative to sediment supply.
- Depositional area and degree of compensational stacking increased through time. The system evolved from primarily aggradational stacking (element- and complex-scale) near the depocenter to a more distributive depositional pattern (at ***T4***) as the area increased.
- This study demonstrates that in out-of-grade, confined deepwater systems, isopach thicks on the slope are largely due to thick complexes of MTDs ("MTCs") and channels, while isopach thicks on the basin floor are attributed to distributary channels and lobes (*not* MTDs).

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