Tectono-Stratigraphic Analysis of a Deep-Water Growth Basin, Ainsa Basin, Northern Spain*

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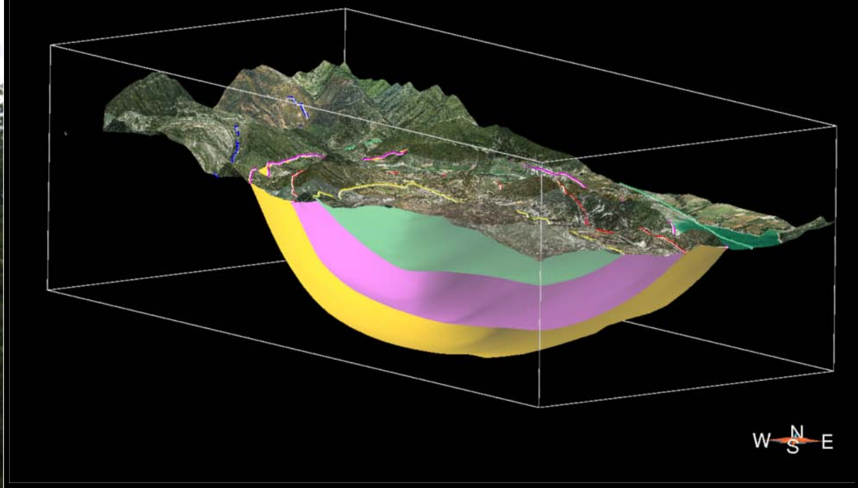
Abstract

Growth structures influence coeval deep-water deposition in many of the world's largest hydrocarbon producing regions (i.e. Gulf of Mexico, Indonesia, Nigeria, and Angola). Outcrop studies of analog basins provide important insight into both the reservoir- and basin-scale stratigraphic architecture. The Ainsa Basin in the Spanish Pyrenees is unique in that it is one of the few locations in the world where the interaction of deep-water deposits and compressional growth structures can be studied in detail and in three-dimensions. The Middle to Upper Eocene Ainsa Basin fill consist of multiple turbidite systems, including the well-known Ainsa system, that exhibit geometries indicative of syn-growth deposition related to large basin-bounding structures (Mediano, Boltaña, and Añislco anticlines).

This study focuses on the reconstruction of four syn-growth horizons and one pre-growth horizon using Gocad modeling software in a three-dimensional structural model of the basin. The base of each syn-growth turbidite system (condensed section) is mapped across the basin and used in the reconstruction to define successive basin paleo-bathymetry during stages of basin-fill. Syn- and pre-growth horizon reconstruction is constrained by (1) new surface orientation measurements, (2) balanced cross-sections, and (3) published sub-surface data. Deep pre-growth and detachment geometries are interpreted from surface data and two depth-converted seismic lines that trend roughly perpendicular and parallel to the basin axis.

Combined with a detailed stratigraphic analysis of the Morillo depositional system, the structural model provides 3-D geometric constraints on a feeder canyon identified on the western limb of the Mediano anticline. The structural model also enhances the understanding of the relationship between the basin-fill and growth of the Boltaña Anticline, which initiated during Morillo deposition, with increased shortening to the north leading to sediment shedding off a paleo-high. This structural growth constrained and focused the Morillo deep-water channels from a lateral offset-stacked geometry at the basin axis to vertical-stacking at the basin exit point. This study can be used as an analog for complex tectono-stratigraphic settings where syn-depositional structures play a major role in the distribution and evolution of deep-water reservoirs.

Tectono-Stratigraphic Analysis of a Deep-Water Growth Basin, Ainsa Basin, Northern Spain



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- Prianto Setiawan (CSM)
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- Henri Silalahi (CSM)
- Amy Moss-Russell (CSM)

Acknowledgements

- Chevron and CoRE
- AAPG Grants-in-Aid: Kenneth H. Crandall Memorial Grant
- Charlie Rourke
- Dr. Bruce Trudgill

Presentation Outline

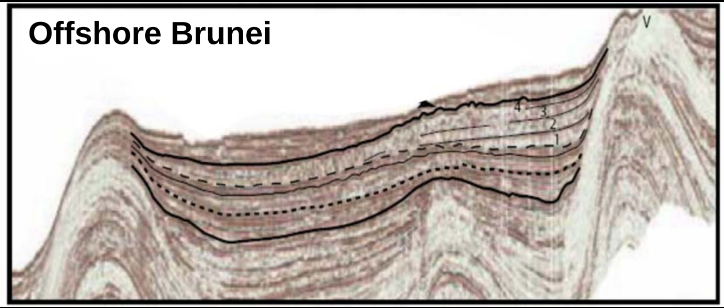
- Research goals
- Geologic setting
- Overview of Ainsa Basin structures and deepwater basin-fill
- 3-D structural model construction methodology
- 3-D structural model results
- Timing of growth structures
- Application and future work

Goals

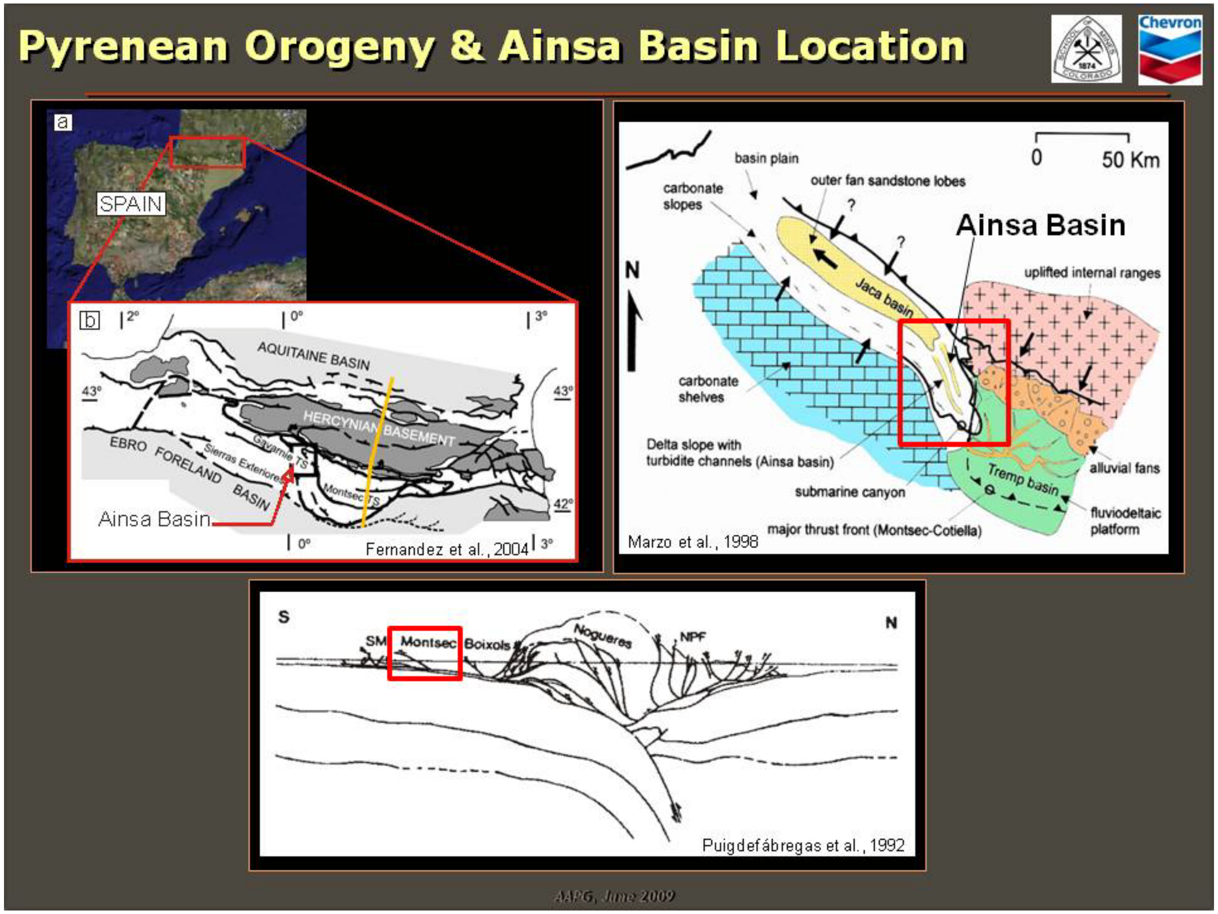
1. Understand the complex relationship between basin-fill and basin bounding growth structures
2. Constrain 3-D geometries of syn-growth deepwater systems
3. Test new techniques in 3-D structural model construction
4. Understand the relationship between depocenters and deepwater sand body distribution
5. Define timing and style of deformation

•Why Ainsa Basin?:

- World-class exposure of deep-water growth stratigraphy
- Stratal relationships between syn-growth and pre-growth observed
- Study associated with detailed stratigraphic studies carried out at CoRE



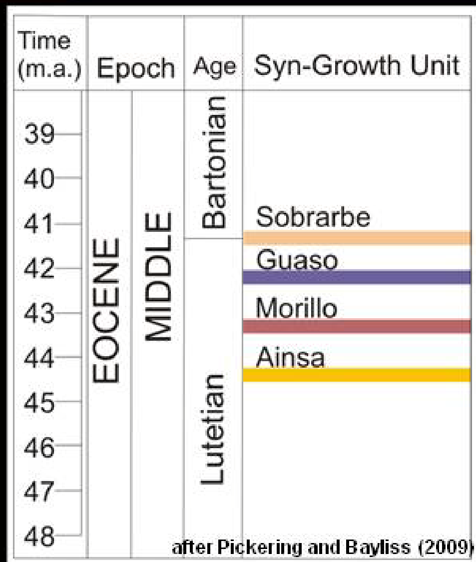
Morley and Leong, 2008



Notes by Presenter:

- As seen in xsection marked by tan line, the Pyrenees divided into 3 zones (NPFB, Axial Zone, SPFB).
- Ainsa Basin, located in the SPFB, began in late Paleocene, early Eocene as a foredeep and evolved in the mid Eocene into a piggy-back basin, as it was incorporated into the hanging wall of the southward propagating imbricate thrust system
- At this time, Ainsa served as a deepwater slope transfer basin between fluvio-deltaic systems in the Tremp basin to the E and deepwater Jaca basin to the W.
- Ainsa basin located in the Southern Pyrenees of NE Spain
- Doubly verging, 400 km long orogen caused by the N-S collision of Iberia and Eurasia.
- Iberian plate movement coupled with the northward movement of Afirica from Cretaceous through Eocene.
- Initiated with thick-skinned Jurassic rift inversion in Late Cretaceous;
- pre-rift thickness regained by Paleocene.
- Eocene/Lutetian: phase of maximum shortening southward directed imbricate thrust system.
- Floor thrust of Southern Pyrenees is the sole thrust of the Pyrenean chain, implying subduction of Iberia below Eurasia (ECORS).

Ainsa Basin

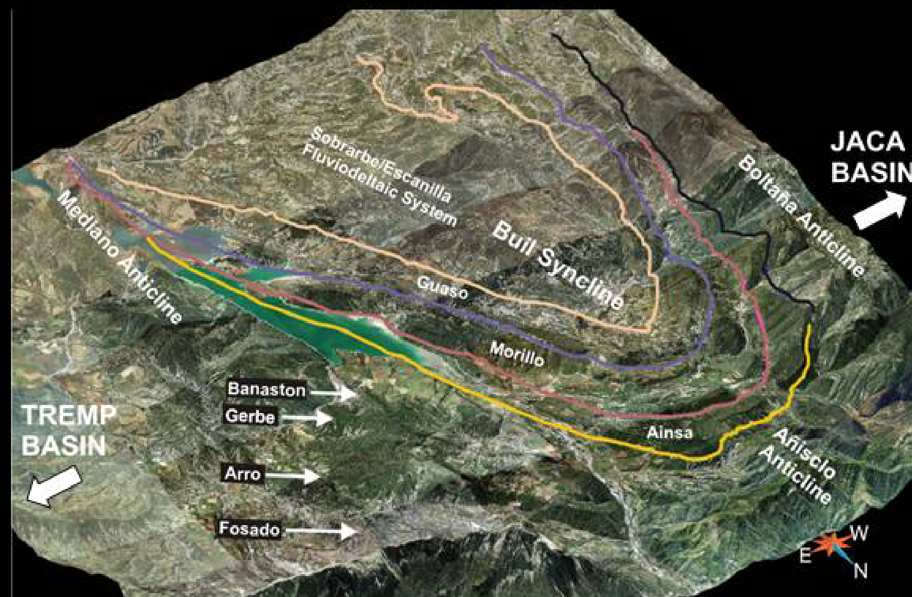


Pre-Growth Units:

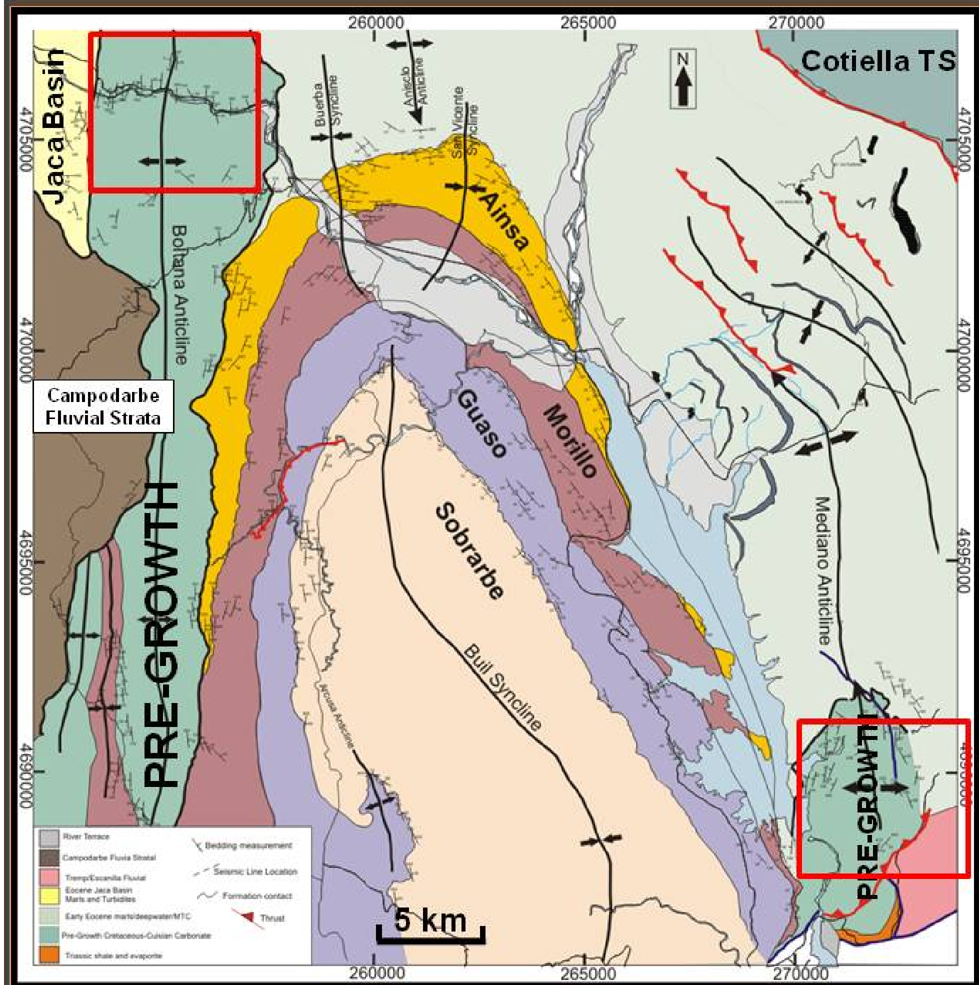
- Triassic shale and evaporites
- Upper Cretaceous-Paleocene limestone/dolomite
- Lower Eocene marls and platform carbonates

Syn-growth:

- >4000 m of total basin-fill
- Consists of 8 stratigraphic units; defined by sand bodies, unconformities, & condensed sections
- Bounded by anticlines to N, E, and W; all active at various stages of basin-fill



Notes by Presenter:
•Focus of this study is the Eocene deepwater basin-fill
•Ainsa basin is bounded by anticlines that were all active during basin-fill. These include the Mediano Anticline to the E, the Anisclo Anticline to the N, and the Boltana Anticline to the W.
•The four units that make up the 3-D model construction and that exhibit relationships that constrain timing on the growth on the bounding structures include the Ainsa, Morillo, Guaso, and Sobrarbe systems.
•As seen in this graph, these systems were deposited in a 4-million year period in the Middle Eocene.



FIELD METHODS

- Mapped four syn-growth horizons that are regional ***condensed sections***
- Mapped bounding growth structures
- Seismic interpretation (lines from IGME)

DATA

- Collected >600 structural orientation measurements (bedding, faults, minor folds)
- Aerial photo analysis: 70 three-point problems
- Photo panel interpretation
- Aided by 2700 m of measured section (Prianto Setiawan)

Notes by Presenter:

•This is unique in that this is the first time the basin has been mapped on time-correlative surfaces. Prior work has focused on mapping systems at top and base of sands or on facies.

•Additionally, bounding growth structures were mapped and characterized to understand their relationship to the syn-tectonic fill.

•Interpretation of these structures aided by 2 seismic lines discussed later.

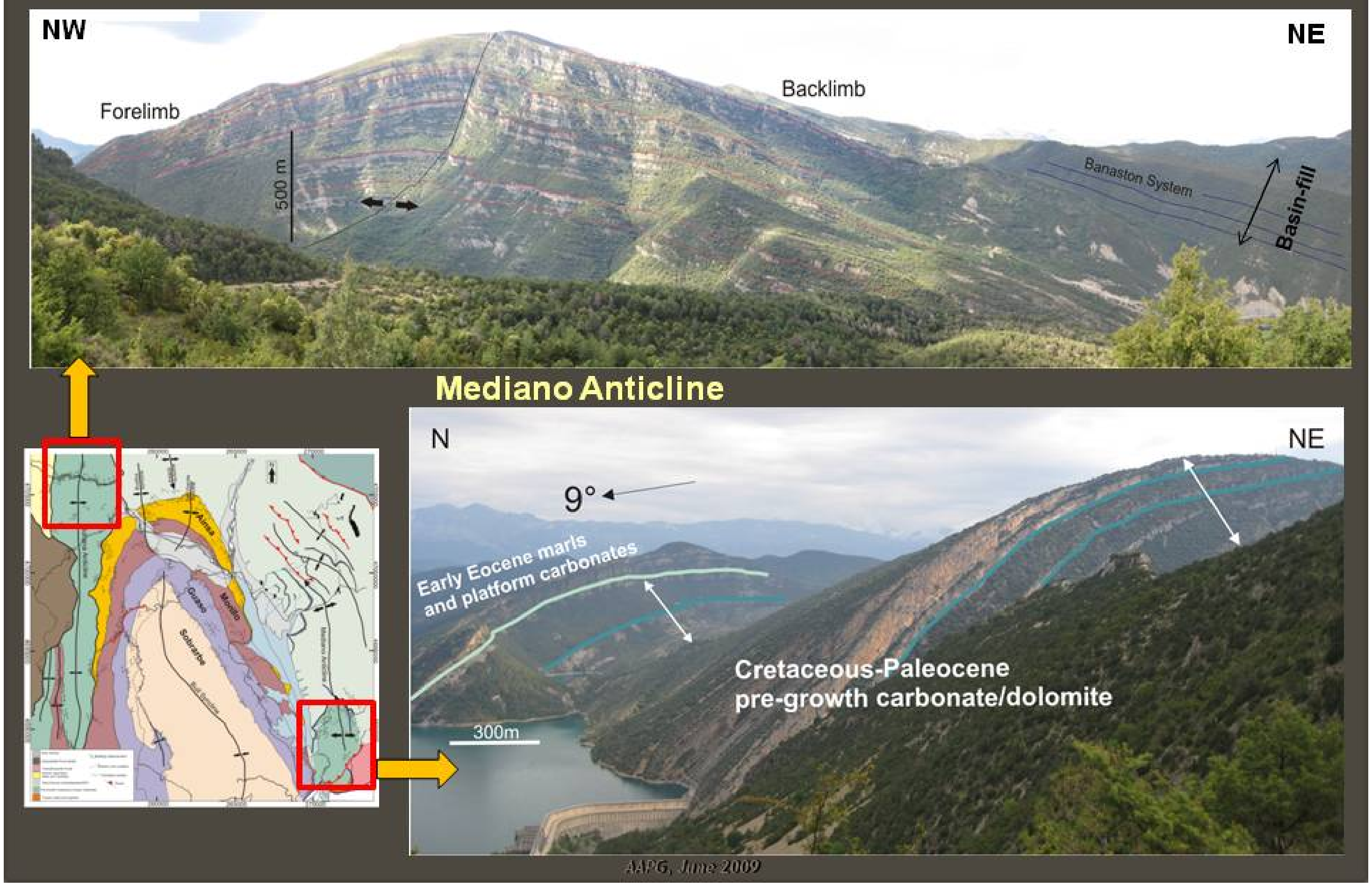
•Aerial photo analysis draped on a digital elevation model aided in constraining contact location and obtaining orientation measurements through three point problems.

•Photo pans were interpreted to document key relationships.

•Condensed section system boundaries were constrained by nearly 2700 m of measured section obtained by fellow CoRE student Prianto Setiawan
Two photopans from the Mediano and Boltana anticlines give a sense of the scale and geometry of these structures.

Bounding Structures

Boltaña Anticline

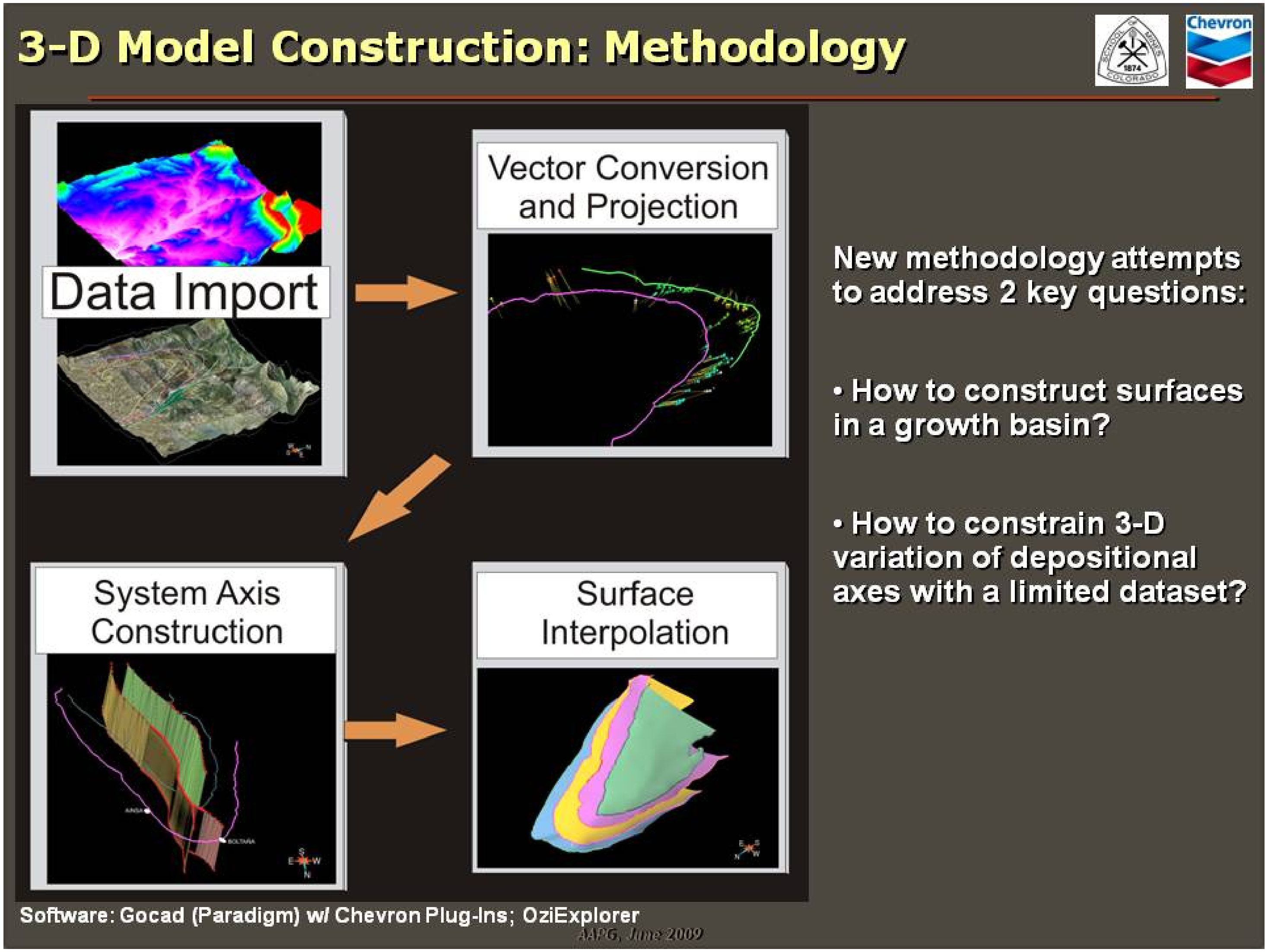


Notes by Presenter:

Boltana Anticline is interpreted as a fault propagation fold; consistent with prior studies done in the basin, such Fernandez et al. (2004). Characterized by a steeply dipping forelimb with dips that go from vertical to overturned, and a gently dipping backlimb with dips at ~ 30 degrees. To the right we see strata of the Banaston system, a portion of of Ainsa Basin's deepwater fill.

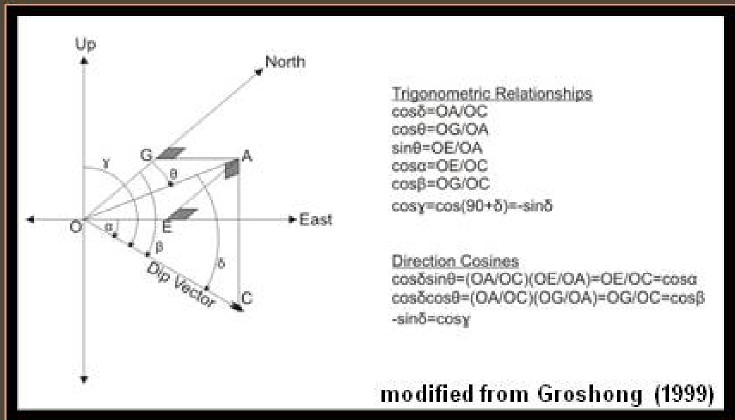
At the bottom we see the Mediano Anticline, the site of a detailed study on detachment fold kinematics by Poblet et al. (1998).

The Cretaceous-Paleocene pre-growth carbonates are on out. Mediano plunges approximately 9 degrees to the N and displays an along-strike displacement gradient. To N are gently dipping fold limbs and a symmetrical, cylindrical geometry. This changes to S where the fold becomes tighter with vertical to overturned fold limbs.



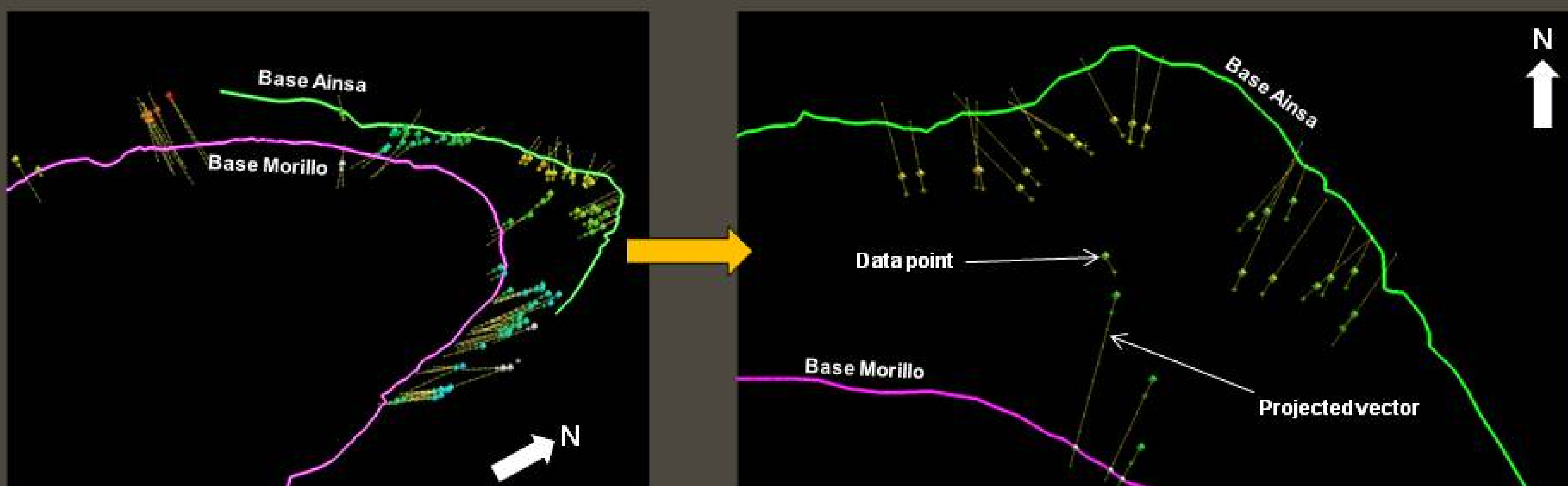
Notes by Presenter:
Use data and observations from the field that were described, and construct a 3-D structural model of four syn-growth basin-fill units.
To do this, a 3-D construction methodology was developed around 2 key questions:
How to construct surfaces in a growth basin (where there is variation in unit thickness) ?
How to constrain 3-D variation of depositional axes with a limited dataset (from surface data and limited seismic) ?
The model was constructed in Gocad modeling software with the aid of Chevron plug-ins and the first step was to import a digital elevation model for the basin, digitize all contacts and important all structural orientation measurements.
The second step was to convert structural orientation measurements unit vectors and project to the contacts (NEXT SLIDE).

3-D Model Construction: Vector Projection



modified from Groshong (1999)

- Dip vectors calculated at each data point
- Orthogonally projected to nearby contact
- Extended into subsurface

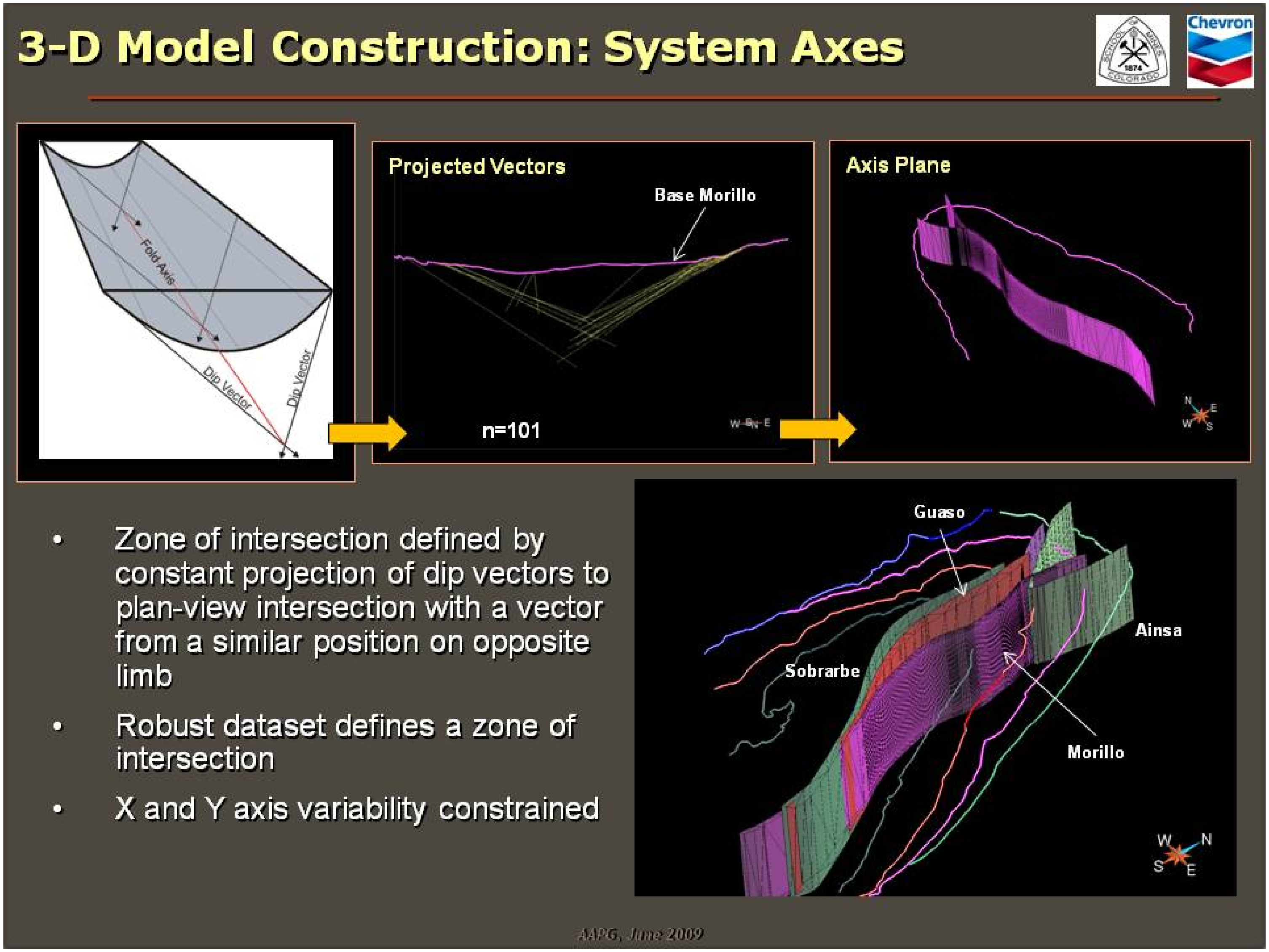


Notes by Presenter:

Dip vectors were calculated at each data point by defining their “direction cosines,” a method described by Groshong (1999).

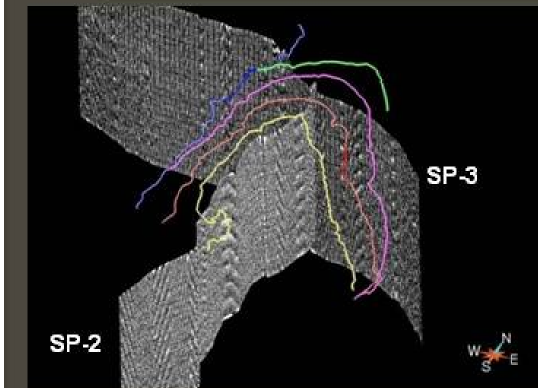
These vectors were projected to the nearby system contact and extended into the subsurface.

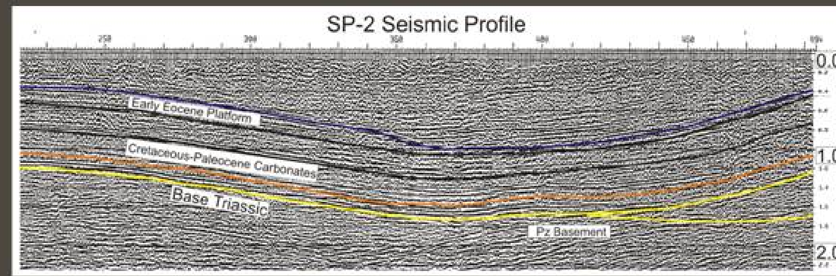
Here dip vectors are projected on to the Base Morillo and Base Ainsa system contacts (NEXT SLIDE).



Notes by Presenter:
This problem was solved by first constraining the axis position in plan view or in the x and y directions.
This was accomplished by extending dip vectors from the surface contact into the subsurface to their plan-view intersection with a vector from a similar position on the opposite limb as shown in this diagram.
Using a robust dataset, this defines a zone of intersection. From this zone of intersection, a vertical surface was constructed that defines the plan view constraint on the system axis position.
In the lower right, vertical surfaces have been constructed for the Sobrarbe, the Guaso, Morillo, and Ainsa systems (NEXT SLIDE).

3-D Model Construction: System Axes

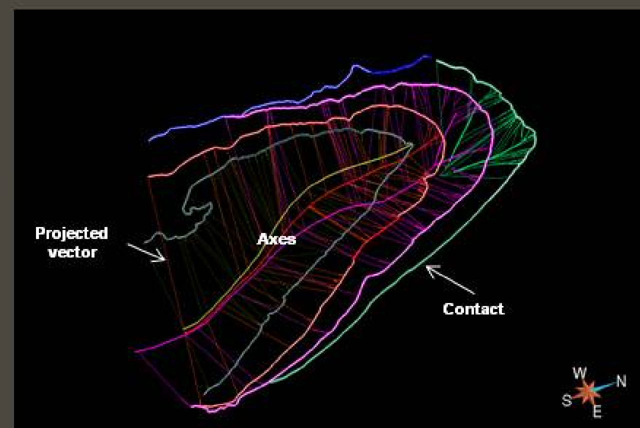




Instituto Geológico y Minero de España - (IGME)

Contraints on Z position of axis

- Dip vectors: represent steepest possible path to axis
- Dip changes and overall shape from SP-2 and SP-3 seismic lines
- Axis anchored at axial trace on contact
- Stereonet modeling from partitioned data



Notes by Presenter:

The next step was then to constrain the vertical postion of the axes. This was accomplished using a number of constraints:

•The dip vectors themselves represent the steepest possible path to the axis

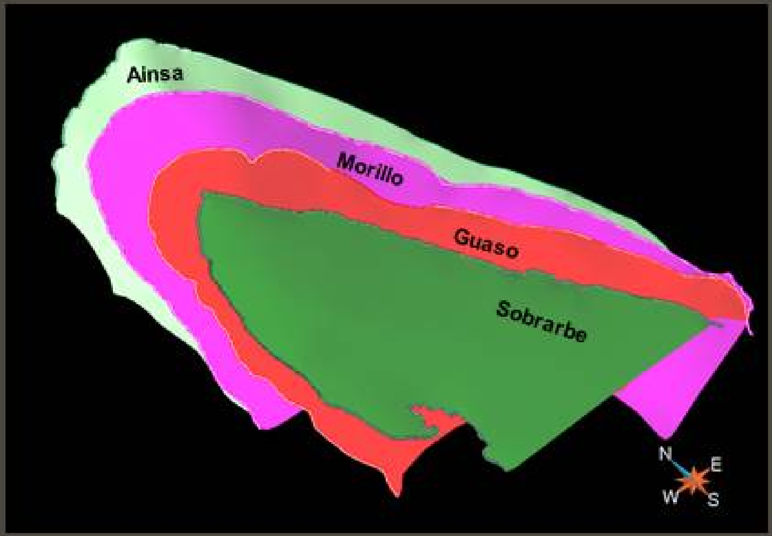
•Dip changes and overall shape were projected from the SP2 seismic line. The axis is anchored at the surface axial trace on contact.

•Top-down succession of construction, or constructing surfaces in order of youngest to oldest allowed me to honor regional thickness trends and avoid unreasonable annomatic thickening and thinning.

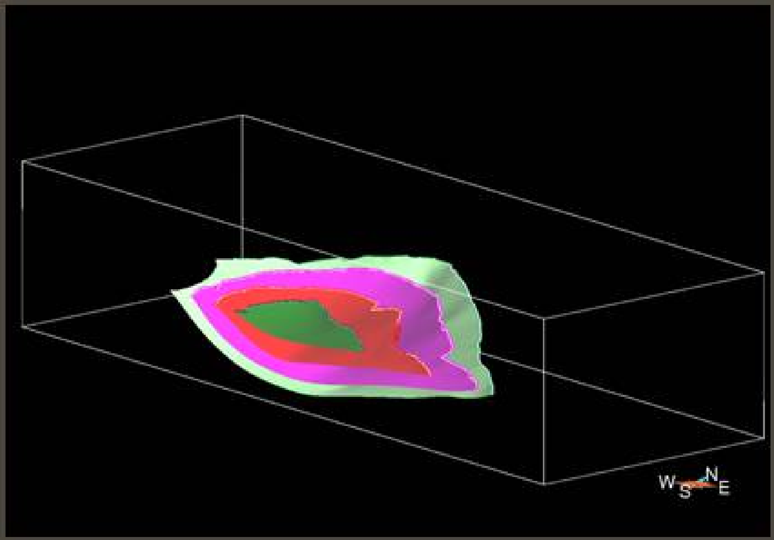
•Partitioning the data from each system and performing stereonet analyses on different regions of the fold served as additional constrain on local axis plunge.

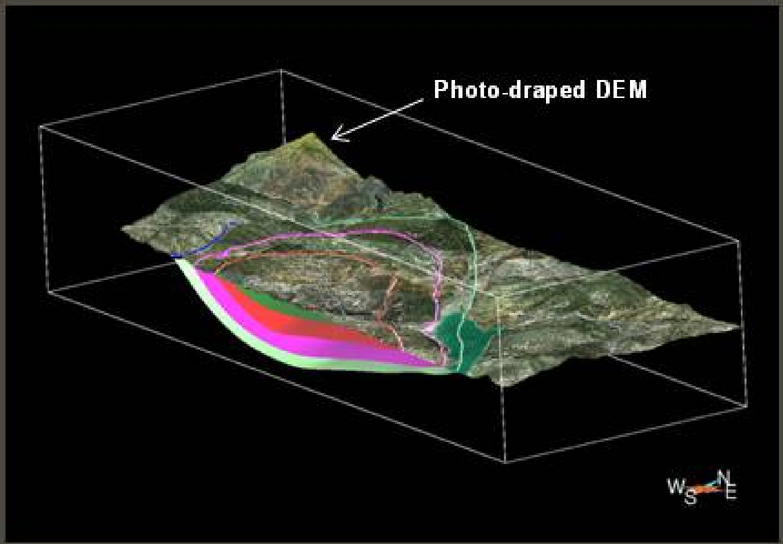
In lower right are the system axes for each system, constrained in x,y,z directions with the projected dip vectors.

3-D Model Construction: Surfaces

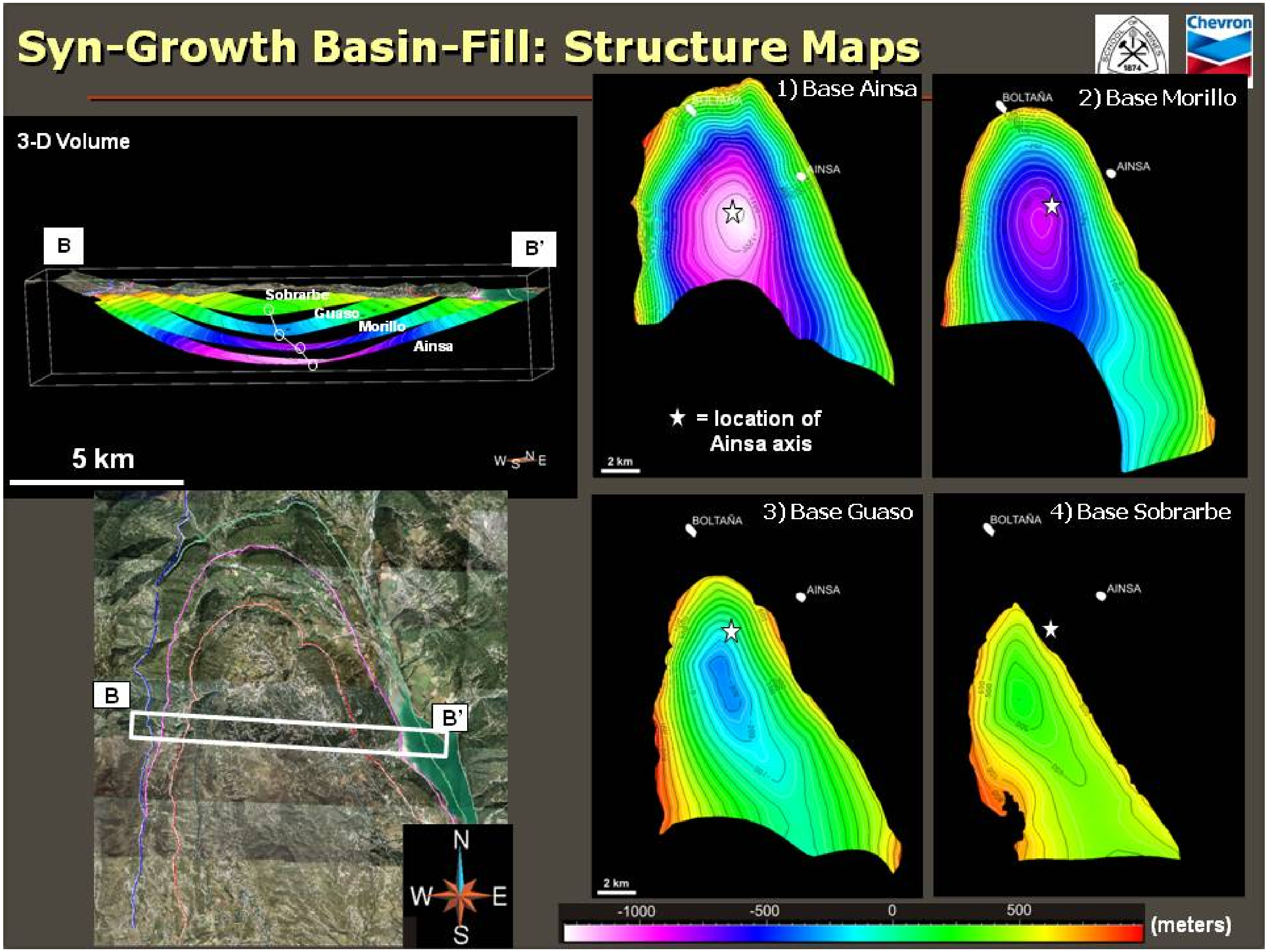


- Surfaces constructed using Gocad's Discrete Smooth Interpolation (DSI) algorithm
- Contacts, dip vectors, and axes defined as interpolation controls

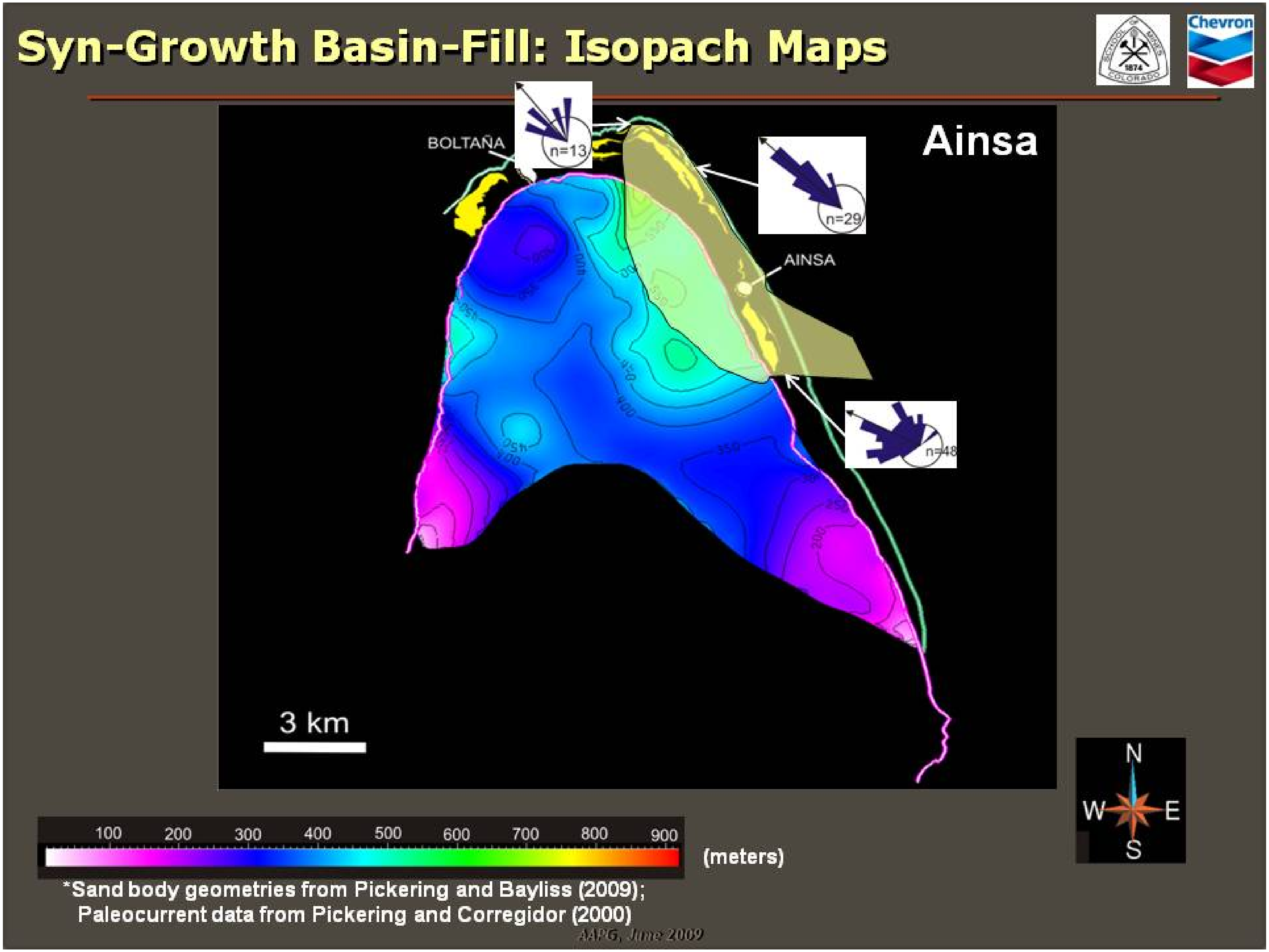




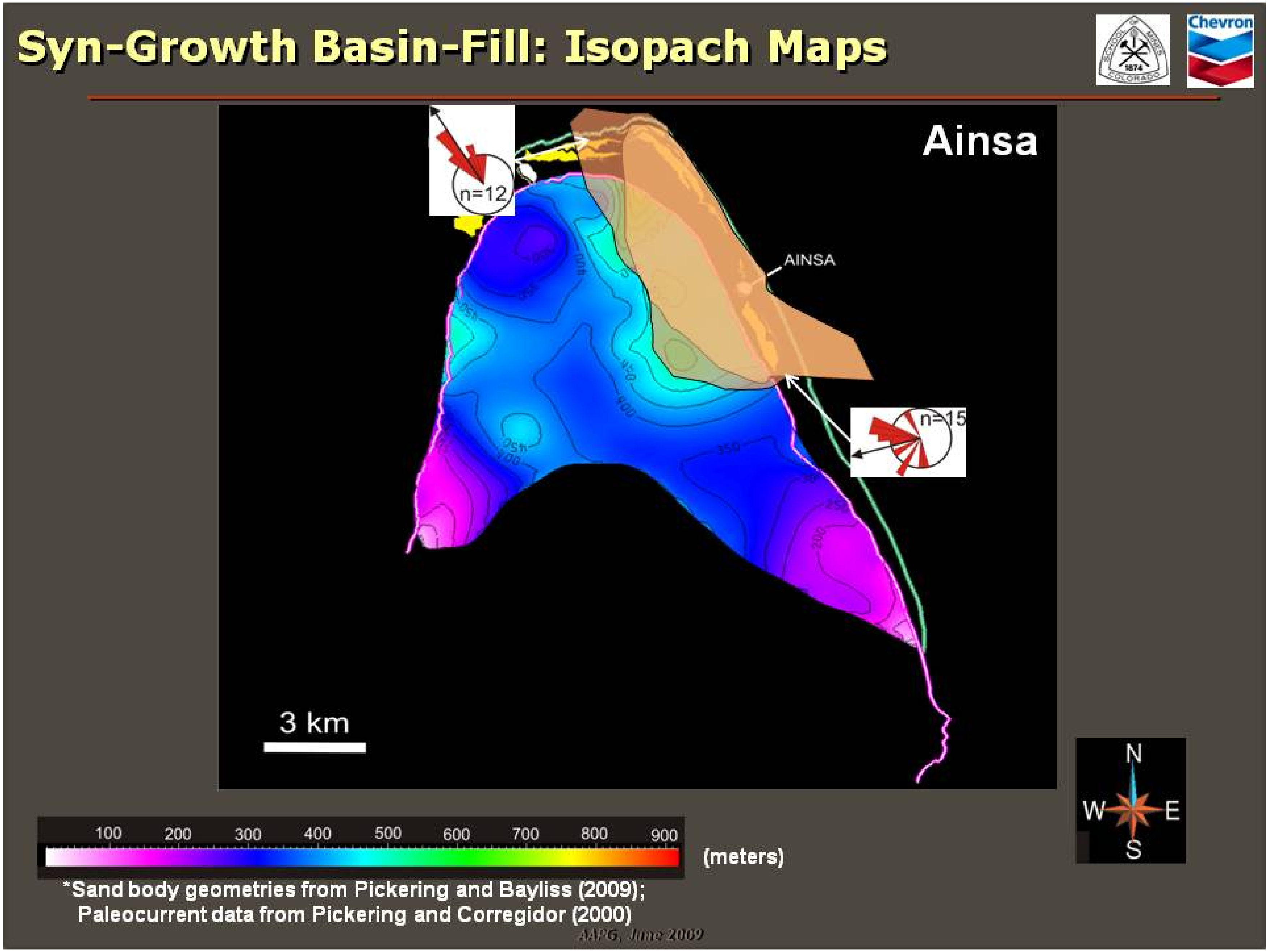
Notes by Presenter:
Dip vector projection methodology combined with fold axis modeling can effectively model syn-growth system axes in 3-D.



Notes by Presenter:
From these surfaces, structure maps were generated, shown here in order from oldest to youngest.
On the Ainsa map we see the interaction of the system with the basin's northern bounding structure, the Anisclo Anticline, which created lows to the E and W of its southern termination.
Note that this geometry is healed by Morillo depostional time.
The star on the maps marks the location of the deepest axial position on the Ainsa system, to illustrate the shift in axes through time.



Notes by Presenter:
From the structural surfaces, isopachs were generated for the Ainsa, Morillo, and Guaso systems.



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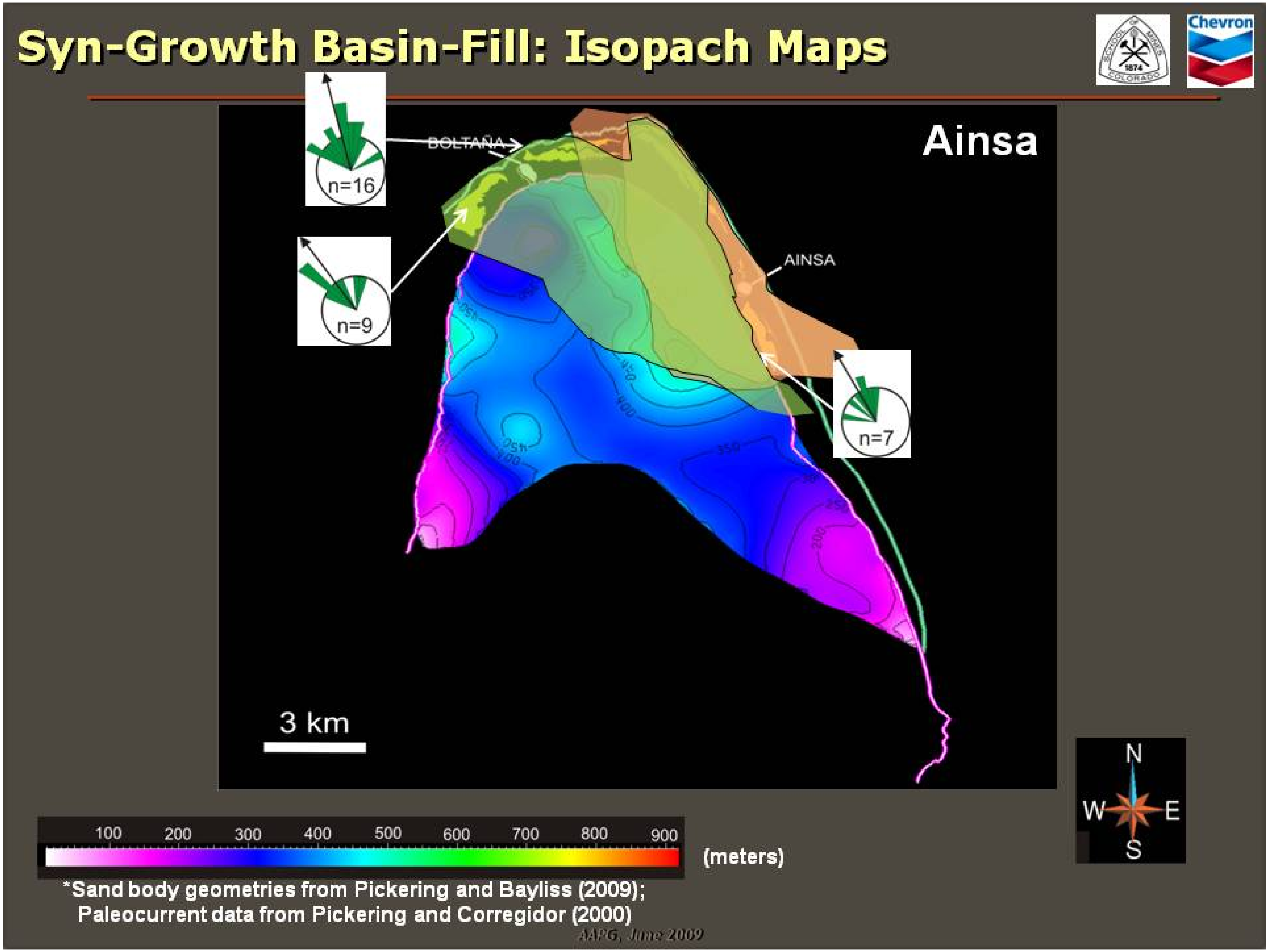

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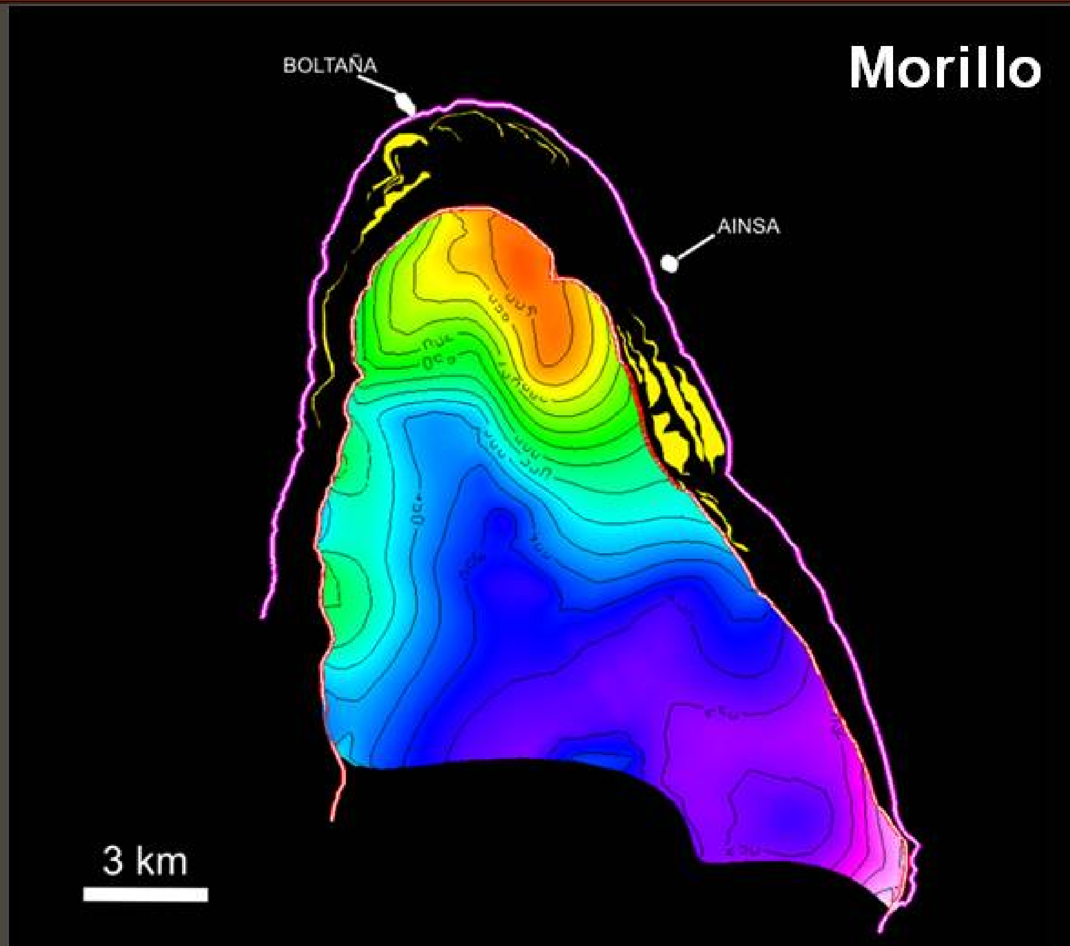
Syn-Growth Basin-Fill: Isopach Maps



(meters)

*Sand body geometries from Pickering and Bayliss (2009)

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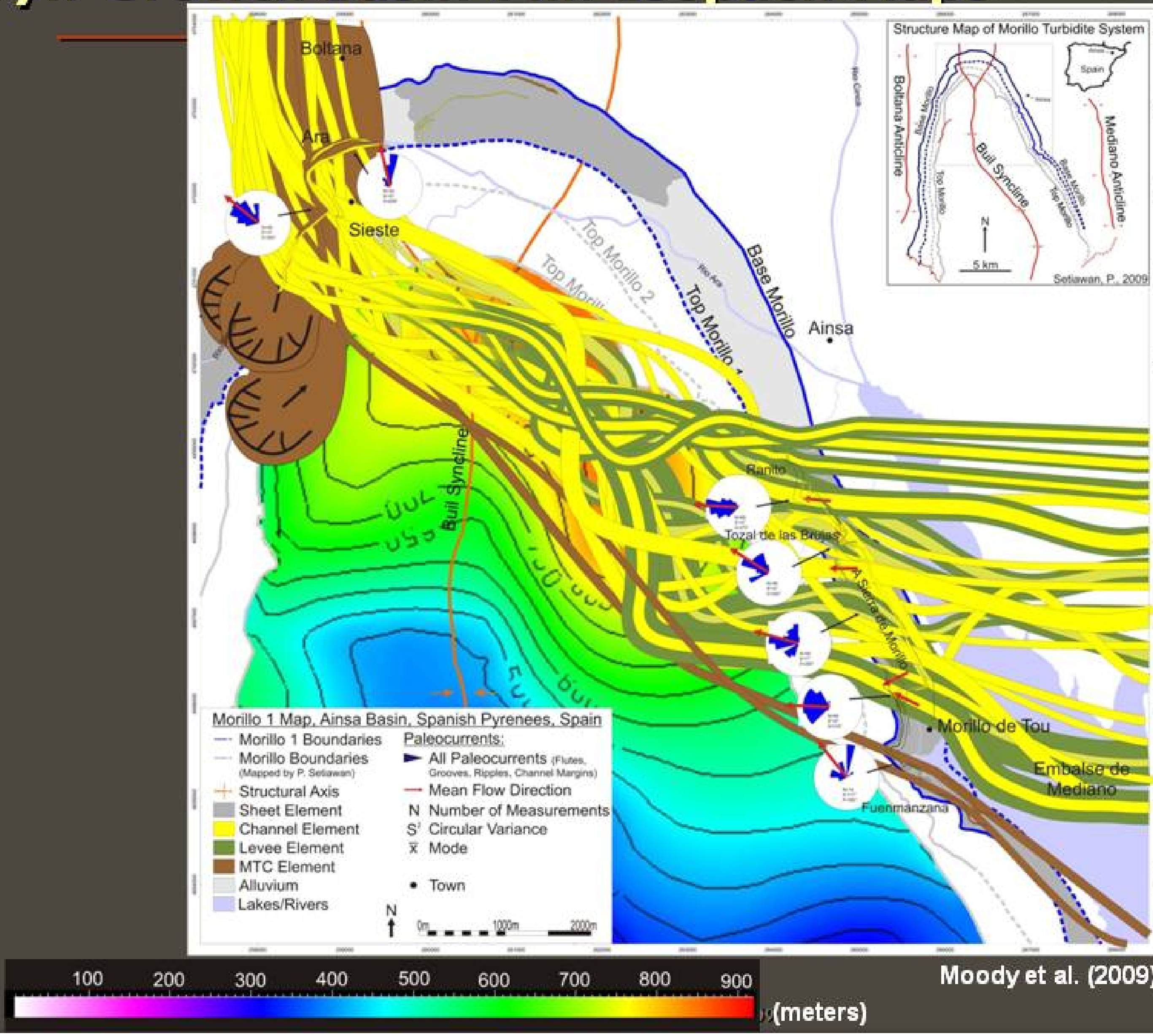
Syn-Growth Basin-Fill: Isopach Maps



Moody et al. (2009)

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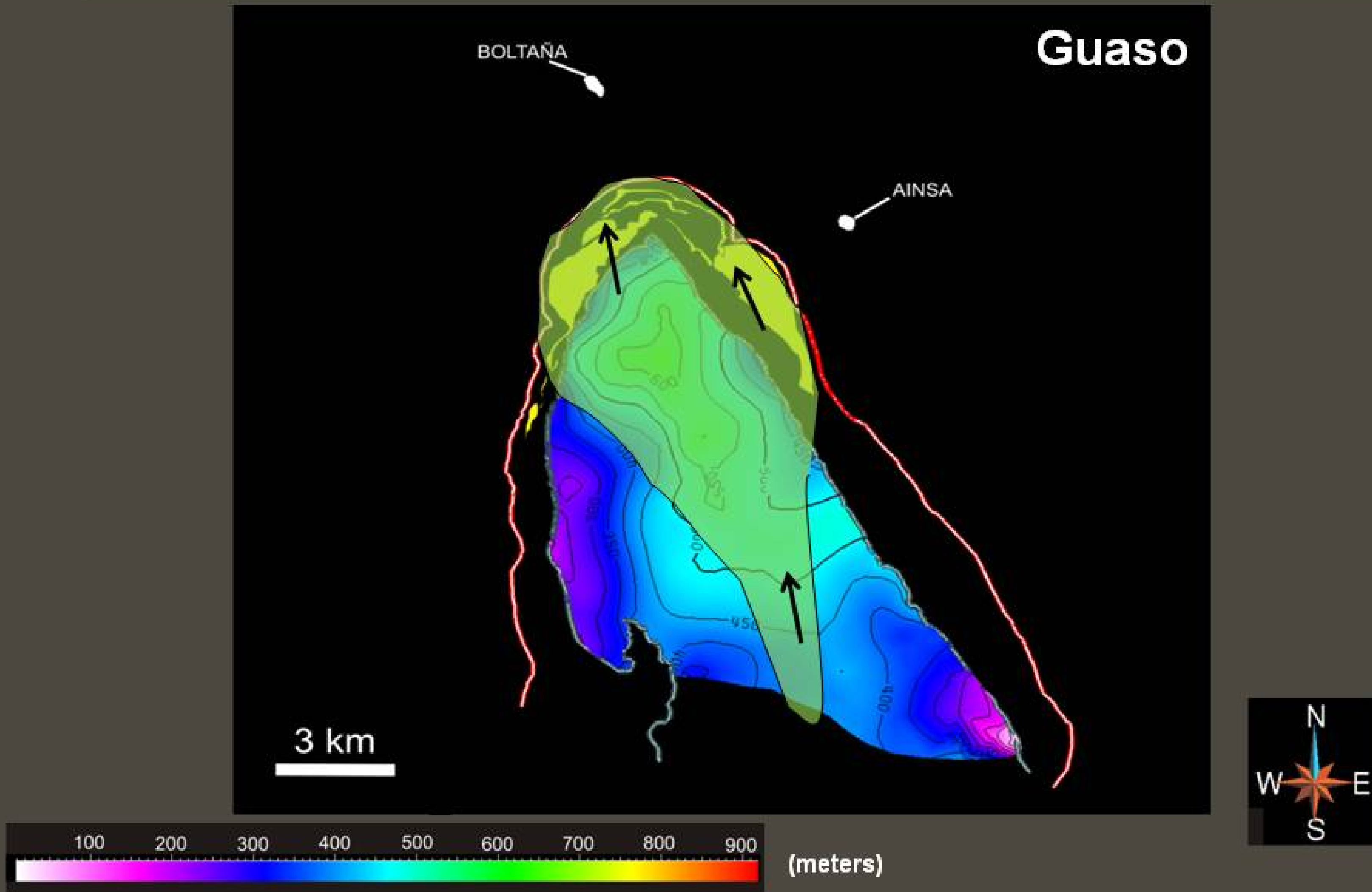

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AAPG, June 2009

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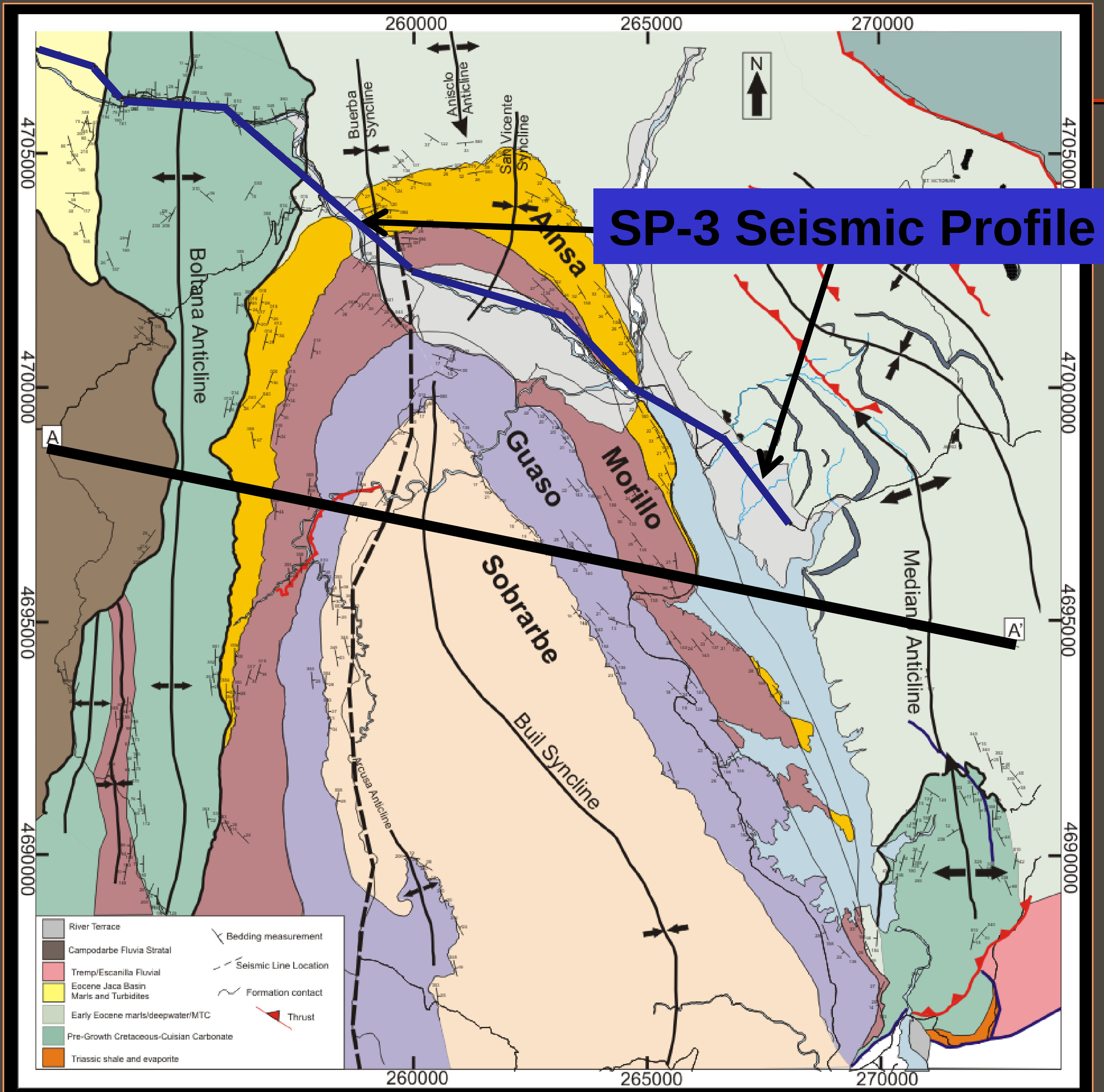
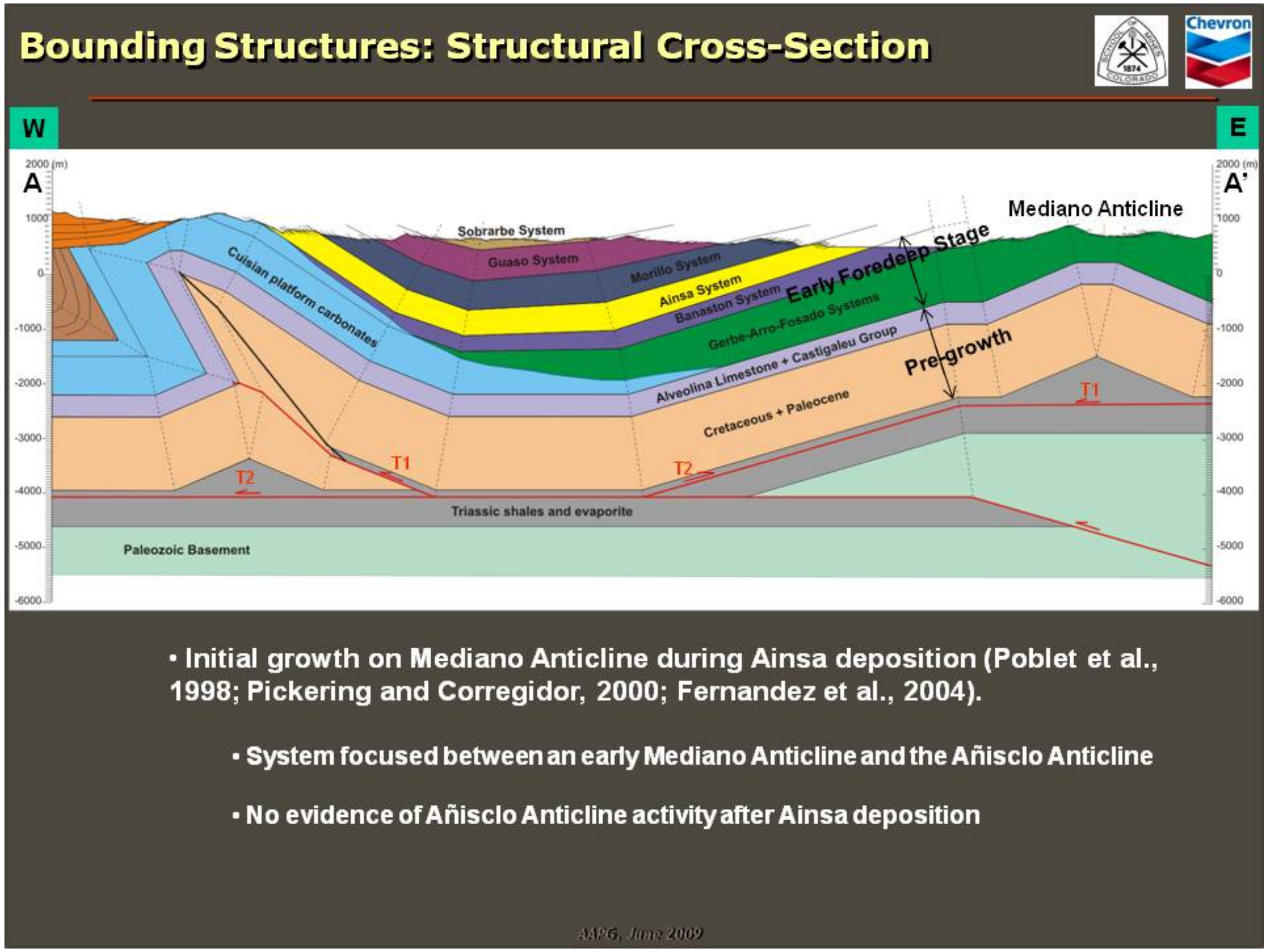
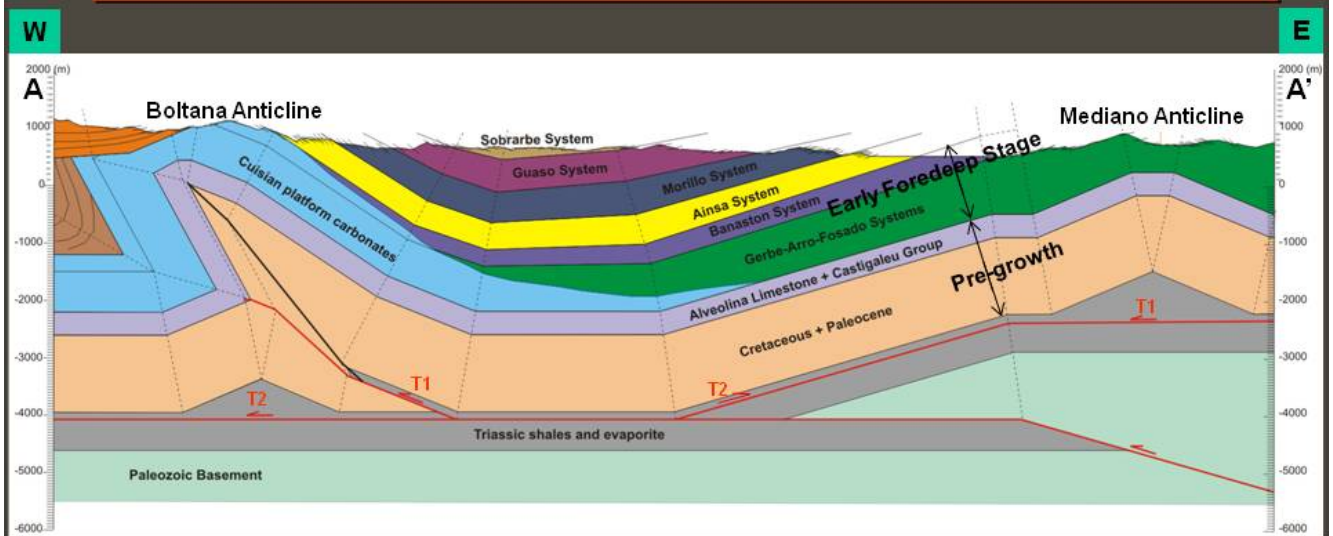

SP-3 Seismic Profile
260000
265000
270000
4705000
4700000
4695000
4690000
N
Buerba Syncline
Anisclo Anticline
San Vicente Syncline
Boltana Anticline
Ainsa
Guaso
Morillo
Sobrarbe
Buil Syncline
Arcusa Anticline
Median Anticline
A
A'
River Terrace
Campodarbe Fluvia Stratal
Tremp/Escanilla Fluvial
Eocene Jaca Basin Marls and Turbidites
Early Eocene marls/deepwater/MTC
Pre-Growth Cretaceous-Cuisian Carbonate
Triassic shale and evaporite
Bedding measurement
Seismic Line Location
Formation contact
Thrust



Notes by Presenter:

- Deposits channeled between an early Mediano Anticline and the Añisclo Anticline.
- Likely late stage Añisclo Anticline with healing of adjacent low by Morillo depostion.
- Boltaña Anticline growth initiated in the latest-Ainsa to earliest-Morillo depositional time.
- Channel stacking and deflection patterns (Prianto Setiawan and Jeremiah Moody).
- Late Eocene regional basement-involved thrusting event.
    - 2nd stage of growth on Boltaña anticline.
    - Steepened ramp of upper structure.
    - Syn-growth stratigraphy of Campodarbe fluvial system.
    - Slip sent eastward by basement wedge, contributing to minor growth on the Mediano Anticline (incorporation of Sobrarbe system into western fold limb).

Bounding Structures: Structural Cross-Section



•Boltaña Anticline growth initiated in the latest-Ainsa to earliest-Morillo depositional time as indicated by channel stacking and deflection patterns (Setiawan et al., 2009; Moody et al., 2009)

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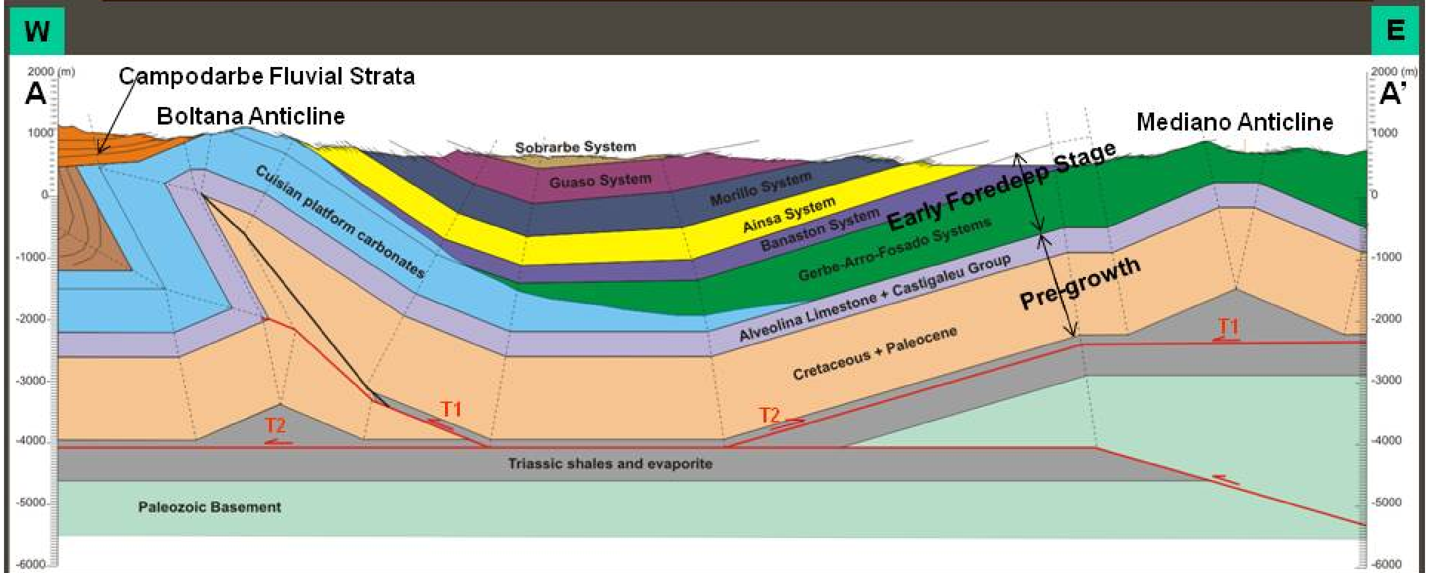

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Application and Future Work

- **3-D structural modeling**
  - Application in future basins: surface construction in data-poor environments
  - Surface construction from projection of dipmeter data
  - Extrapolation into poorly imaged structures
  - Better integration of surface and subsurface data

- **Ainsa Basin as an analog**
  - Boltaña Anticline a good analog for poorly imaged, steeply dipping forelimbs
  - Relationships between isopach maps and sand distribution can be used for predictive modeling

- **Future work**

- Cross-section restoration (ramp v. fault propagation models)
- Input of detailed stratigraphic information into 3-D model
- Decompaction/backstripping to obtain approximate sediment volumes and corrected isopach maps

Thank you.

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