Reservoir Scale Modulation of Turbidite Architecture Related to Paleo-gradients Generated by Syn-sedimentary Structural Growth and Segmentation of an Overfilled Foreland Basin System: The Marnoso-Arenacea Formation at the Coniale Anticline, Northern Apennines, Italy*

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Abstract

The link between tectonics and sedimentation is arguably best exemplified in deep-marine foreland basin systems where structural deformation is contemporaneous with turbidite sedimentation. The distribution and modulation of sedimentary attributes defining deepwater sedimentation regions record changes in paleo-gradient framed by five orders of tectonic deformation. Second-order foreland basin systems consist of third-order wedge-top, foredeep, forebulge, and back-bulge structural domains. Fourth-order structural growth of a submarine anticline segments and transforms the third-order foredeep into the wedge-top structural domain. The Coniale Anticline manifests a fourth-order structure containing attendant fifth-order mass-transport-deposits defining four sedimentation regions represented by pre- and syn-kinematic turbidite distributions across the structure.

Tabular lobes and fine-grained carbonate drapes are the dominant sedimentary bodies in an overfilled basin, where lateral expansion of large turbidity currents scale to the basin width. Consequently, sedimentation units are equivalent to sedimentary bodies, simplifying the number of sedimentary attributes required for analysis. Wavy stratification is moderately subordinate to structureless sandstone in pre-kinematic turbidite sedimentation units which contain thinner mudstone caps, but separated by thicker calcareous mud drapes. There is more uniformity in these attributes across the structure (~5 km distance). By contrast, syn-kinematic turbidites show more variation in component facies, sedimentation unit thickness, and cyclic modulation of sedimentary bodies across the structure, including the addition of mass-transport deposits on the east flank of the structure.
Paleo-gradients of fourth- and fifth-order tectonic surfaces are determined from a partial 3D restoration of the structure and correlate structural growth to turbidite distribution and modulation. Fourth-order structural growth segments foreland domains and combined with fifth-order structure-generated surfaces explains changes in the four sedimentation regions. This suggests that lower resolution structural features can be used to assess smaller reservoir-scale architecture relevant to subsalt prediction in the Gulf of Mexico.
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The link between tectonics and sedimentation is arguably best exemplified in deep-marine foreland-basin systems where structural deformation is contemporaneous with turbidite sedimentation. The distribution and modulation of sedimentary attributes defining deep-water sedimentation regimes record changes in paleo-gradient framed by five orders of tectonic deformation. Second-order foreland-basin systems contain third-order submarine rises, forebeachs, foredeep, and back-basin structural domains. Fourth-order structural growth of a submarine anticline segments and transforms the third-order foredeep into the wedge-top structural domain. The Coniale land basin systems consist of third-order foredeep, deformation is contemporaneous with turbidite sedimentation. The distribution and modulation of sedimentary attributes defining mudstone tary bodies across the structure. Paleo-gradients of fourth- and fifth-order tectonic surfaces will be examined from a 3D restoration of the structure and cross- structural growth and transforms the third-order foredeep into the wedge-top structural domain. The Coniale land basin systems consist of third-order wedge-top, deformation is contemporaneous with turbidite sedimentation. The distribution and modulation of sedimentary attributes defining mudstone tary bodies across the structure. Paleo-gradients of fourth- and fifth-order tectonic surfaces will be examined from a 3D restoration of the structure and cross-
Key Concepts:

- Hanging wall of Monte Castellaccio Thrust
- Long correlation lengths of turbidite and debrite sandstones
- Low frequency and magnitude of sedimentation events
- Higher frequency of pelagic mudrocks and wavy stratification
- Low lateral facies evolution in turbidite and debrite event beds
- High frequency vertical cyclicity weakly expressed
- Low spatial-temporal attribute modulation consistent with flat low gradient basin plain interpretation

Detailed facies proportional analysis of the Coniacian Member of the Monte Castellaccio Thrust:

- Footwall of Monte Castellaccio Thrust
- High fidelity correlation of sedimentary attributes with Domain 1
- Lower net/gross down-flow evolution
- Higher proportion of pelagic mudrocks
- Higher frequency of wavy stratification at bed tops, often bioturbated
- Low spatial-temporal attribute modulation across modern structural setting consistent with flat low gradient basin plain interpretation

Domain 1: Contessa Interval at Coniale

- Domain 1
- Domain 2
- Domain 3
- Domain 4

Attributes of Time Space Domains for this Study:

- High fidelity correlation of sedimentary attributes
- Low lateral facies evolution
- Higher frequency of pelagic mudrocks
- Higher frequency of wavy stratification at bed tops, often bioturbated
- Low spatial-temporal attribute modulation consistent with flat low gradient basin plain interpretation

Domain 2: Contessa Interval NW of Modigliana

- Domain 1
- Domain 2
- Domain 3
- Domain 4

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Tobler’s first law of geography: “Near things are more related than distant things.”

- 21 kilometer distance between domains 1 and 2
- Similarity in processes fades
- Wavy stratification - structureless sandstone
- Muddy sandstone
- Correlation of sedimentation events
- 11 events sourced
- Sand thins, muds thicken in down-flow direction

Table of factors of geography:

- Distance between domains 1 and 2
- Similarity in processes
- Spatial correlation
- Spatial autocorrelation
- Spatial randomness
- Spatial variability
- Spatial interaction
- Spatial dependence in adjacent settings
- Spatial distance
- Spatial distribution in adjacent settings

2007

Tailing et al., 2007
Key Concepts

- Hanging wall of Monte Castellaccio Thrust
- Thick bedded, sandstone dominated wedge top basin
- High net/gross
- Structureless and space stratified sandstone dominant, wavy and plane parallel sandstones subordinate
- Amalgamation surfaces frequent; intraclast horizons = amalgamations, not sandwich beds
- No calcareous mudrocks
- Energy increases but modulation of sedimentary attributes is limited

Cranesized distribution of fining up

Weave Top Domain:

High Energy

- Event Magnitude
- Event Frequency
- Calcarenous Drapes
- Wavy stratification
- Sedimentological modulation
- Fully Confined Flows

Domain 3: Firenzuela System at Quarry

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Conclusions

- Stratigraphic metrics defining each domain record multiple orders of tectonic deformation
- Domains 1 and 2 record flat basin plain modified only by 3rd order tectonic evolution:
  - Monte Castellaccio thrust not emergent
  - Remarkable continuity of facies processes, sedimentation units and sedimentary order bodies:
    - depositional topography + climate + fore-field tectonics < local tectonic gradients as forcing function
- Domains 3 and 4: Decoupled relationship of syn-kinematically developing wedge top to foredeep domains:
  - Domain 3 = high frequency and magnitude turbidite events bypassing fine grained sediment
  - Lack of high order stratigraphic modulation
  - Domain 4 = High order modulation of turbidite event frequency and magnitude combined with MTD detachments and facies diversity
    - depositional topography + climate + fore-field tectonics < local tectonic gradients as forcing function

Current Work: Structural Modeling

Use 3D structural restoration of Coniale Anticline to restore to Domain 1 time of a undeformed basin plain
- Test validity of structural motion to accommodate gradient modifications
- Input horizons from lithostratigraphic mapped units, time constrained by biostratigraphic markers.
- Populate deformed model with measured section data and high resolution mapped horizons from photopanels projected onto DEM surface
- Project into cross section network and interpolate horizons
- Retrodeform according to time steps defined by:
  - Low order = Lithostratigraphic chronostratigraphy
  - High order = mapped energy cycles of each domain

Workflow of structural restoration project

3D model of surface geology in the study area

Does Paleo gradient evolution match stratigraphic energy evolution?

Structural Evolution Model: Post Domain 1 and 2 Deposition

GOM Application:

- Deepwater turbidite depositional systems from Paleogene to Miocene
- Allochthonous salt coverage increases uncertainty in subsalt interpretation
- Visible structures that can be mapped
- Use structural hierarchy for prediction
- Sedimentary response documented at Coniale anticline = pattern for subsalt prediction.

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References: