N056: Turbidite Systems and Their Response to Thrust and Fold Structures *(Pyrenees, Spain)*

Instructor(s): Josep Anton Muñoz and Pau Arbues

Format and Duration

Field - 6 Days
Moderate Physical Demand

Summary

The course traces the evolution of the Pyrenean orogen from extensional margin through inversion to fold and thrust belt with its associated foreland basin. Deepwater clastic deposition occurred in the developing foreland basin where growth strata and synsedimentary deformation are recorded. Participants will be trained in the analysis of tectonics and sedimentation, and the recognition of turbidite reservoir systems and structural traps, using field and outcrop examples.

Learning Outcomes

Participants will learn to:

1. Appraise the underlying extensional, strike-slip and inversion structures that influence the foreland Ainsa and Jaca basins.
2. Reconstruct the evolution of a basin from foreland basin to detached piggy-back/thrust-top basin.
3. Assess the deposits and processes of gravity driven deepwater systems and the tectonic controls on major mass-wasting events.
4. Characterise facies, architecture, geometry and structure in the Ainsa turbidite slope complex and interpret key surfaces in ponded deepwater basins and relate these to significant tectonic events.
5. Appraise the variations in the main facies and sedimentary architecture of sand bodies in confined basins with less confined systems.
6. Characterise and assemble significant parameters for input into reservoir models for deepwater reservoirs deposited in tectonically active basins.
7. Evaluate analogous deepwater depositional models and predict possible sediment fairways and likely reservoirs from structural and sedimentary observations made in the field.

Training Method

A six-day field course comprising of observations, discussions and exercises in the field, accompanied by some classroom lectures.

Physical Demand

The course is graded MODERATE on the Nautilus Training Alliance field grading system. The field area is at relatively high altitude in the Pyrenees and some participants may experience unexpected fatigue or shortness of breath. The longest walk is approximately 5 km (3 miles) on steep trails at altitudes up to 2000 m (6000 ft). There are walks up to 1 km (0.6 mile) most days and participants can expect both hot and cold conditions and should be prepared for wet weather. Field days start around 8.30 am and finish at 7 or 8 pm (please note that meals are taken rather late by North American and Northern European standards, generally after 9pm).

Who Should Attend

Geophysicists and geologists working in deepwater clastic reservoirs, particularly those with an interest in the tectonic controls on the deposition of reservoir units.

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Prerequisites and Linking Courses

There are no formal prerequisites for this course, although familiarity with the basics of seismic interpretation, structural geology and the principles of sedimentology are assumed. Upon completion of this course, there are a number of other courses on the Structure and Tectonics and Clastics course portfolios that would be suitable to be taken as part of a training and competency progression programme.

In Clastics, these include N028 (Sand-rich Turbidite Systems and Megaturbidites: From Slope to Basin Plain. Facies, Stacking Patterns and Controlling Factors, Pyrenees Spain), M315 (Submarine Canyon, Channel and Slope Systems, California, USA), M102 (Deepwater Slope Channel Complexes: Architecture and Evolution to Distal Facies, South and East Turkey) and N033 (Characterisation, Modelling, Simulation and Development Planning in Deepwater Clastic Reservoirs, Tabernas, Spain).

In Structure and Tectonics, these include N053 (Compressional Structural Styles: Models for Exploration and Production, Alberta, Canada) N218 (Structural Controls on Deepwater Systems: Growth Structures and Minibasin Fill (Austrian Alps) and N074 (Geological Seismic Interpretation Field Seminar: Compressional Systems, Montana, USA). N072 (Workshop in Geological Seismic Interpretation: Deep Marine Systems), on the Nautilus Geophysics and Seismic Interpretation portfolio would also be suitable for individuals wishing to gain greater experience in seismic interpretation of deepwater depositional systems.

Course Content

The Spanish Pyrenees is one of the best-exposed fold and thrust belts in the world. It is unique in that exceptional preservation of the syntectonic sedimentation and the level of erosion have preserved not only the structures but also the foreland basin and thrust-top basin sediments. For decades it has been one of the classic areas for the study of turbidite sedimentation and has been used as a training ground for many European oil companies.

The Spanish Pyrenees evolved from the inversion of a Jurassic – Lower Cretaceous rift system into a thin-skinned fold-thrust belt. Syn-tectonic turbiditic growth strata record the development of both the inversion structures as well as the thin-skinned thrust structures. Turbidite channels, turbidite deposition and deep marine sequence stratigraphy are controlled by the thrust systems and associated detachment folds. The timing, uplift and exhumation of the Pyrenees is constrained by analysis of growth strata, palaeomagnetic results and fission track studies.

The Spanish Pyrenees is an exceptional natural laboratory for the study and interpretation of thrust tectonics, inversion tectonics and the associated deep marine sedimentation. At the end of the course participants will be trained in the analysis of tectonics and sedimentation and in the applications to structural trapping and development of turbidite reservoir systems using field and outcrop examples.

The field course will integrate the regional tectonics and geodynamic evolution of the Pyrenean orogeny

together with detailed appraisals of the syntectonic sedimentation in the context of the development of the fold/thrust belt.

The course will involve:
- A regional transect across the central Spanish Pyrenean Axial Zone.
- Detailed examination of thrust fault geometries and fold geometries.
- Analysis of the Ainsa turbidite basin – tectonic evolution and relationships to thrusting and detachment fold evolution.
- Analysis of inversion tectonics and syn-inversion growth strata.
- Observation of passive margin raft tectonics preserved along the palaeo-rift margin.
- Study of turbidite sequence stratigraphy and its relationship to tectonics – extensional growth faults and later thrust faults.
- Analysis of thrust front structures and related syn-tectonic sedimentation.
- Discussion of fl uvial and deltaic sedimentation in terms of the evolution of the foreland basin systems in the Spanish Pyrenees.

The following topics form the basis of the course delivery:

Regional structure of the Axial Zone and mesozoic upper thrust sheets

Excursion to overview locations in the Axial Zone and in the adjacent south central exterior zone of the mountain chain with the aim of identifying the principal sedimentary and tectonic units of the Pyrenean orogen.

The Cotiella Thrust Sheet and the Turbon Fold System

Triassic - L. Eocene history of the Pyrenees. Cretaceous rifting and extensional structures are detached on salt and demonstrate listric fault geometries, growth strata and gravity-driven extensional collapse of the rift shoulder. Subsequent late Cretaceous inversion of extensional structures produced hangingwall anticlines, unconformities and syn-inversion breccias and turbidites. Also, pre-existing extensional structures (faults and relay ramps) strongly influenced the location of, respectively, thrusts and anticlines (Serrado and Turbon anticlines). Syn-tectonic sedimentation on the flanks of these folds shows growth, fanning and onlapping strata and masswasting deposits.

General tectono-sedimentary evolution of the Ainsa Basin

The broad-scale tectonic-sedimentary relationships of the Eocene Ainsa Basin slope complex to the surrounding coeval thrust systems are examined. The Ainsa Basin originated as a foreland basin before being thrust-detached from the basement to evolve into a piggy-back basin. Truncation surfaces observed within the turbidite fill are the result of mass-wasting on a slope
generated by episodes of thrusting and represent submarine unconformities. During thrusting, salt-cored detachment folds developed within the basin and these profoundly affected the location of channels and fl ow directions. Examination of growth strata and their onlap onto the flanks of the Mediano Anticline shows the effects of fold growth mechanisms on uplift rates.

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Processes and sedimentary evolution of a turbidite system in the Ainsa slope complex

The Ainsa turbidite system shows the variability of turbidite systems in the Ainsa slope complex. Its detailed facies, architecture, geometry and structure illustrate: 1) Transport and sedimentation processes, which relate to a variety of turbidity currents, debris flows and slumps; 2) Hierachical architectural subdivision scheme including, among the basic elements, two types of channelforms, thinbed and sheet elements, and slump-deformed units; 3) Depositional model with predictive implications; 4) General evolution of the system, with special focus on the effects of thrusting and folding on turbidite system architecture. An evaluation of reservoir modeling techniques by comparison to outcrop data and flow simulation results is presented.

From slope to basin across the Boltana Anticline: An overview of the depositional turbidite elements in the Eocene Jaca Basin

Aims are to examine and discuss the geometry and effect on sedimentation of the Boltana Anticline (an asymmetric fault propagation fold) and to compare the main facies and architectural characteristics of progressively deeper-water and unconfi ned turbidite elements from the Ainsa and Jaca Basins. Towards more distal localities in the Jaca Basin, different facies associations are found which are characteristic of an unconfi ned, deepwater system. The depositional interpretation and economic signifi cance of a gas producing facies (resedimented carbonate megabeds) is discussed.

3D structure and stratigraphy of the Ainsa Basin

Results of 3D modelling of the Ainsa Basin by the Geodynamics and Basin Modelling Group at Barcelona (GGAC). Examination of syn-tectonic deformation of developing fluvial systems.

Information and data from the field course may be applied to exploration and production problems in:
- Growth stratal analysis – cf. Gulf of Mexico; West Africa, Brazil.
- Thrust and Inversion Terranes – cf. Southern North Sea, North Africa;
- Turbidite Sequence Stratigraphy – cf. deepwater deltas, NW Atlantic margin;
- Fluvial, Deltaic and Turbidite Reservoirs; - deepwater deltas, NW Atlantic margin, Gulf of Mexico.