Facies Characteristics in a Semi-Confined Basin: From High Net:Gross Channelized Sheets to Lower Net:Gross Onlap Margins, Grand Coyer Basin, Southeast France

Stanbrook, David A.
Present address:
Maersk Olie og Gas A/S
Esplanaden 50
1098 København K
Denmark
e-mail: dast@maerskoil.com

Pringle, Jamie K.
Present address:
School of Physical Sciences & Geography
Keele University
Keele, Staffs. ST5 5BG, UK

Abstract

Common stratigraphic-trap reservoirs in the Gulf of Mexico and along the margins of the Atlantic are found within channelized (*e.g.*, Tahoe) or basin margin settings (*e.g.*, Auger, Mars). These are frequently within small, structurally controlled and topographically complex "fill and spill" minibasins; most often in salt-provinces. High net/gross channel and lower net/gross basin-margin environments occur concurrently in most basins and deciphering the lateral and distal relationships between these environments may be key to understanding reservoir connectivity.

The Grand Coyer remnant (Grès d'Annot, southeast France) demonstrates lateral and distal facies changes in a confined basin with complex paleotopography. Within the basin a relatively thin-bedded unit, the Marnes Brunes Inférieures, is interpreted as a distal and lateral equivalent of the thick-bedded and channelized Grès d'Annot (Stanbrook and Clark, 2004). The Marnes Brunes Inférieures represents deposition away from the main axis of flow which is represented by the Grès d'Annot.

The finer grained facies of the Marnes Brunes Inférieures is shown to pre-date as well as to intercalate with the higher net/gross sections the Grès d'Annot in both a lateral and distal sense. Also the bedding of the Marnes Brunes Inférieures is shown to onlap the underlying paleotopography, with higher net/gross Grès d'Annot, in turn, onlapping the Marnes Brunes

Inférieures; these bedding discordances are often associated with slumping. The intercalation and bedding-discordance has implications for hydrocarbon charge, seal and distal connectivity in a lateral sense. Multiple examples of, and the relationships between, these facies are shown.

Introduction

Topographically confined turbidite systems are important sources of petroleum production, especially in the Gulf of Mexico (Prather *et al.*, 1998; Weimer *et al.*, 1998) and the West African margin (Armentrout *et al.*, 2000). The distribution of producible turbidite reservoir facies is strongly dependant on the flow interaction of turbidity currents with the underlying basin-floor and slope topography and leads to complex sand distribution patterns (*e.g.*, Kneller, 1995; Amy *et al.,* 2004). Even high quality, 3D seismic data may not have sufficient resolution to identify stratigraphic traps in these environments, especially if associated with salt diapirism which can obscure seismic signals (*e.g.*, Prather *et al.,* 1998). Resolving the relationships of sand-body onlaps on submarine paleo-slopes forming these stratigraphic traps can be crucial for hydrocarbon recovery (Gardiner, 2004).

Geological setting

The Grand Coyer subbasin is one of a series of outliers in the Grès d'Annot turbidite system (Fig. 1) exposed as numerous remnants as a result of the Tertiary Alpine foreland basin that developed in response to loading in front of the southwest-directed Alpine fold-belt (Apps, 1987). During the Eocene-Oligocene, the Alpine foreland basin was ~160 km long, ~80 km wide and orientated approximately northwest-southeast. The early Eocene basin-fill consists of a deepening succession of carbonates; firstly the shallow water Calcaires Nummulitiques Formation, a macro-scale foraminiferal death-assemblage forming a system-wide marker horizon, followed by deeper-water paleo-slope and basinal marls known as the Marnes Bleues Formation. Later the Marnes Brunes Inférieures Member and succeeding Grès d'Annot Formation both represent the onset of clastic input that was primarily fed with sediments from the uplifted Corsican-Sardinian Massif to the south; primary paleocurrents were directed to the north (Stanley, 1975; Elliott *et al.,* 1985; Ravenne *et al.,* 1987).

The Grand Coyer outlier is generally considered to be a subbasin (Apps *et al.,* 2004), positioned midway along the axis of the Grès d'Annot turbidite system, with the proximal area, Annot (see Joseph and Ravenne, 2001) to the south and the more distal area,

TOC
Start
Author
Search
Help

Trois Evêchés (see Clark and Stanbrook, 2001; Lomas *et al.,* 2008) to the north (Fig. 1). Grand Coyer is considered to represent an incised, inter-basinal "trough" between the Annot and Trois Evêchés basins, in which initial fill before considerable sediment by-pass of material is deposited to the north in the Trios Evêchés area (Joseph and Ravenne, 2001; Sinclair and Tomasso, 2002; Du Fornel *et al.,* 2004).

Eocene sedimentary deposits, preserved in a northwest-southeast trending syncline in Grand Coyer, record a succession of basin-floor and lower- to mid-slope facies. Onset of deposition is predominantly pelagic deep-water marls (the Marnes Bleues Formation), followed by the Marnes Brunes Inférieures (or Lower Brown "Marls") which represented a mixture of continued pelagic deposition and early phase turbidite clastics. The Marnes Brunes Inférieures are thus typically composed of 40% sandstone as well as clastic and nonclastic muds (detailed in Stanbrook and Clark, 2004). The Marnes Brunes Inférieures is succeeded by the Grès d'Annot Formation which represents a fully clastic depositional environment of turbidity current deposits and associated gravity driven sediments. Predominantly sand-rich and typically coarse-grained, the Grès d'Annot Formation clastics have at least a 500 m thick succession in Grand Coyer (Fig. 2). Sediment dating is relatively poorly constrained, as there is little volcanic input and a poor fossil preservation record, although Du Fornel *et al.* (2004) have detailed a seven-stage, 1-3 Ma chronostratigraphic Grès d'Annot succession using microfossil assemblages (planktonic foraminiferal and calcareous nannofossils) in fine-grained sedimentary intervals. This paleontological evidence shows a two-stage sedimentation process, both to the south (Annot) and north (Trios Evêchés) before onset of Grand Coyer sedimentary deposits.

Relatively steep and structurally complex Marnes Bleues Formation paleoslopes (typically 8º–15º dips; Hilton and Pickering, 1995) have been found within Grand Coyer as supported by field evidence of onlapping of Marnes Brunes Inférieures and Grès d'Annot sandstone intervals (Stanbrook and Clark, 2004). One potential reason that these steep slope angles were possible is by virtue of a high carbonate content, (estimated at 65% by Ravenne *et al.,* 1987) and partial lithification of sediments prior to remobilisation and slumping. Field evidence has also shown that paleo-flows were confined by a paleoslope in the southwest (Hilton and Pickering, 1995; Sinclair and Tomasso, 2002; Stanbrook, 2003; Stanbrook and Clark, 2004). The mean paleocurrent direction for the Grand Coyer subbasin has been established to be towards the northwest (336º) though there is variation in different parts of the basin and stratigraphy (Stanbrook, 2003).

Regional-scale structural data from the Grès d'Annot Basin (Apps, 1987; Lickorish and Ford, 1998; Evans and Elliott, 1999) also recognised significant paleotopography, in the form of the Dôme de Barrot high, to the east of Grand Coyer (Apps *et al.,* 2004). Based on this structural evidence, Sinclair and

Tomasso, 2002 and Du Fornel *et al.,* 2004 prescribe a simple trough-like topography for Grand Coyer that implied a northeast margin but did not show any field data from Grand Coyer to support this. Despite the regional structural evidence, little field data have been described locally to substantiate a northeast margin confining paleoflow to the Grand Coyer subbasin. A "fill and spill" subbasin model has also been proposed (Sinclair, 2000; Sinclair and Tomasso, 2002; Joseph and Ravenne, 2001) with a significant structural high to be overcome before subsequent northeast sedimentary deposition into the Trois Evêchés subbasin. Joseph and Ravenne (2001) and Stanbrook, (2003) indicate that this high was likely to be approximately 300 m in height.

Early reconnaissance photomontage interpretations on some of these outcrops were described in Hilton (1994) and later Pickering and Hilton (1997). Clark and Gardiner (2000) interpreted the Grand Coyer outcrop itself; Clark *et al.* (2008) quantified the architectural geometries. Stanbrook and Clark (2004) described the Marnes Brunes Inférieures and its relationship to the Grès d'Annot Formation as the precursor of the main sedimentation episodes as well as lateral equivalents to the axial deposits within the subbasin. A map of the structurally restored, Marnes Bleues Formation palaeoslope topography and onlap directions in the Grand Coyer subbasin is shown in Figure 3 (Stanbrook and Clark, 2004).

Facies characteristics and distribution

Generalized Grand Coyer subbasin facies descriptions are detailed in Figure 4 with typical facies photographs appended. The Grès d'Annot Formation sediments predominantly consist of laterally continuous packets of thin- to thick-bedded sandstones interbedded with thin heterolithics and shale intervals. Sandstones subdivisions could be observed between thin- (0.05 m - 0.1 m thick), medium- (0.1- 0.5 m thick) and thick-bedded (0.5 m – 10 m thick) sandstones. Typically 1 m – 30 m thick, erosionally based, sandstone-filled channels occur with channel-fill consisting of amalgamated medium to granule-grade, thick-bedded sandstones with outsized extra-clasts (Fig. 4). Channel surfaces could be sometimes be laterally traced into thinly interbedded, coarse-grained, cross- and planar-laminated sandstones and shale intervals that probably represented overbank and levee deposits (Fig. 4; Clark and Gardiner, 2000; Clark *et al.,* 2008). Through correlation of these channels in over 45 logs throughout Grand Coyer (Stanbrook, 2003) the channels within this interval are sinuous in nature, given their nested and laterally-offset nature in the Grand Coyer face (Clark *et al.,* 2008), facies asymmetry, diverging measured secondary paleocurrent indicators, and the occurrence of cross-sectional to oblique channel features in the Rocher du Carton section (no. 22 in Fig. 1; Pickering and Hilton, 1997). Chaotically deposited, typically 0.5 m – 5 m thick debrites, slumps, slides and rotational failures are sometimes present adjacent or within channel bodies and may represent channel wall collapses. The turbidite channels themselves show evidence of sinuosity preserved as lateral accretion surfaces (Fig. 5). The Marnes Brunes Inférieures Member varies in character across the basin but is typically sharp-based and sharp-topped, nongraded with very fine-grained sandstones that are predominantly less than 5 cm thick, and is considered to be the lateral and distal relation to the Grès d'Annot Formation (Fig. 2; Stanbrook and Clark, 2004).

The mean primary paleocurrent indicator direction for the Grand Coyer subbasin is 345º, based on 309 measurements, although at specific localities, quite different mean basal directions have been measured; see example in Figure 6. These diverging directions have been interpreted to be due to both complex basin topography and paleotopography. Secondary paleocurrent indicators also have differing mean directions and are inferred to be secondary currents or reflected currents (see discussion).

Discussion

The initial, sand-poor, Marnes Brunes Inférieures is seen in some areas to partially infill the pre-existing, relatively steep Marnes Bleues paleoslopes and basin-floor before onset of the main sand-rich Grés d'Annot Formation clastics. The thickest sequences of the Marnes Brunes Inférieures are found in the axial and proximal regions of the Grand Coyer subbasin with thinner sequences found laterally towards the basin margins and towards the distal end of the subbasin (Fig. 7). This pattern is through a combination of 1) greater original depositional thickness in the proximal/axial areas and 2) a combination of thinner original depositional thickness on the slopes/distal areas combined with erosion in these areas by the later Grès d'Annot (Stanbrook, 2003; Stanbrook and Clark, 2004).

Detailed analysis of measured paleocurrents initially appear to have a widely differing primary paleoflow direction across the subbasin, indicating significant flow divergence, most probably caused by the topographically complex, paleoslope and basin floor topography (Figs. 3 and 7). However, with further analysis this apparently confused paleoflow pattern becomes clear; in the lower parts of the stratigraphy paleocurrents flowed generally eastwards (with obvious measured divergences by reflection and deflection), but as the sedimentation continued, paleocurrent became more directed to the north. The early basin fill was not restricted from flowing to the east but as time passed, topography must have been present in the east that confined flows towards the northwest. In connection with this pattern, from the frequency of exposed channels

TOC
Start
Author
Search
Help

and their associate overbank facies, sinuosity generally increased as the succession continued, with lower sinuosity earlier in the depositional sequence of the Grès d'Annot Formation in Grand Coyer. This pattern of change in sinuosity is similar to patterns observed in other areas of complex topography such as the Gulf of Mexico (*e.g.*, Mayall and Stewart, 2000).

At the meso-scale, the Grès d'Annot Formation succession shows alternations of sand-rich and -poor packages in an apparently nonpredictive manner that seems to depend on location within the subbasin. This is interpreted to be potentially caused by switching of material within a sand-sheet environment. However, more predictive intervals with isolated, sinuous turbidite channels with their associated overbank/levee deposits have been documented within the upper stratigraphic intervals in Grand Coyer (Clark and Gardiner, 2000). At the subbasin scale it can be observed that packages of sedimentary material tend to narrow, both in thickness and lateral extent, towards the northern end of the basin at a relatively gentle dip (Fig. 7). In the lower parts of the stratigraphy, there is a noticeable difference in the nature of sedimentary deposits up- and down-dip of the topographic high-point at Sommet de la Mole (no. 13 in Figs. 1 and 7). Interestingly, there does not seem to be a coarsening up succession; Clark and Gardiner (2000) identified the opposite trend of a fining-up sequence in the main Grand Coyer section (no. 5 in Figs. 1 and 7). The other main exception from this depositional pattern is that the main channelized sequence is found in the upper part of the Grand Coyer stratigraphy as described above. If the overall fining-up sequence is taken to indicate either retrogressive system behaviour or autocyclic control within the system, the sand-poor nature of the channelized sequence can be taken to represent a temporary slow-down (Clark and Gardiner, 2000).

Conclusion—Applicability to industry

Implications for subsurface reservoir characterisation from this study of a confined, topographically complex subbasin are: 1) From field-evidence shown, generally high percentage sandstone bodies on paleoslopes rapidly terminate with little draping. Lower percentage sandstone bodies on paleoslopes appear to drape, albeit for small intervals. 2) There appears to be cyclical, ~50 m thick, sedimentary packages of sand-rich and mud-rich sedimentary intervals that appear to be unpredictable in both their repetition and in their distribution across the subbasin. 3) Channel sinuosities tend to increase as the basin is progressively filled and lateral accommodation space increases. 4) Marne Bleues paleoslopes are characterised by steep (15º+ dip) paleoslopes, partial remobilized and chaotically deposited material and deformation creating complex paleoslopes and paleofloors, which are then in-filled with terrigenous-derived sediment.

Acknowledgments

Schlumberger is acknowledged for Petrel software donation and technical support. Fieldwork was undertaken as part of the Deep Water Clastics module of the Genetic Units Project (GUP) at Heriot-Watt University. S. Stanbrook would like to thank industrial sponsors; BG, BP, Chevron, Conoco, Enterprise, ExxonMobil, Petrobras, Statoil, Unocal as well as funding and support from the American Association of Petroleum Geologists (AAPG) grants-in-aid program, the International Association of Sedimentologists (IAS), the British Sedimentologists Research Group (BSRG) and Nautilus UK for drafting. The authors would also like to express their appreciation to field assistants, M. Porter, D. Tatum and J. Guest. Lawrence Amy, Gilbert Kelling, and Mark Leander are acknowledged for constructive comments of an earlier version of this paper.

References

Amy, L.A., W.D. McCaffrey, and B.K. Kneller, 2004, The influence of a lateral basin slope on the depositional patterns of natural and experimental turbidity currents, *in* P. Joseph, S.A. Lomas, ed., Deep-water sedimentation in the Alpine Basin of SE France: New perspectives on the Grès d'Annot and related systems: Geological Society of London Special Publication 221, p. 311-330.

Armentrout, J.M., K.A. Kanschat, K.E. Meisling, J.J. Tsakma, L. Antrim, and D.R. McConnell, 2000, Neogene turbidite systems of the Gulf of Guinea continental margin slope, offshore Nigeria, *in* A.H. Bouma, C.G. Stone, ed., Fine-grained turbidite systems: AAPG Memoir 72, p. 93-108.

Apps, G., 1987, Evolution of the Grès d'Annot basin, SW Alps: University of Liverpool PhD dissertation, 451 p.

Apps, G., F. Peel, and T. Elliott, 2004, The structural setting and palaeogeographic evolution of the Grès d'Annot basin, *in* P. Joseph and S. Lomas ed., Deep-Water Sedimentation in the Alpine Foreland Basin of SE France: New Perspectives on the Grès d'Annot and Related Systems: Geological Society of London Special Publication 221, p. 65-96.

Bouma, A.H., and J.M. Coleman, 1985, Pïera-Cava turbidite system, France, *in* A.H. Bouma, W.R. Normark, and N.E. Barnes, eds., Submarine fans and related turbidite systems: Springer-Verlag, New York, p. 217-222.

Clark, J.D., and A.R. Gardiner, 2000, Outcrop analogues for deep-water channel and levee genetic units from the Grès d'Annot turbidite system, SE France: GCSSEPM Foundation Bob F. Perkins 20th Annual GCSSEPM Research Conference, p. 175-190.

Clark, J.D., and D.A. Stanbrook, 2001, Formation of large-scale shear structures during the deposition of high-density turbidity currents, Grès d'Annot Formation, SE France, *in* W.D. McCaffrey, B.C. Kneller, J. Peakall, T. Druitt, ed., Particulate Gravity Currents: International Association of Sedimentologists Special Publication 31, Blackwell Science London, p. 219-232.

Clark, J.D., D.A. Stanbrook, and A.R. Gardiner, 2008, Architecture and Facies of Confined Deepwater Clastics in the Grand Coyer Remnant, Grès d'Annot, France, *in* T. Nilsen, J. Studlick, R. Shew, G. Steffens, ed., Atlas of Deep-Water Outcrops: AAPG Studies in Geology 56.

Du Fornel, E., P. Joseph, G. Desaubliaux, R. Eschard, F. Guillocheau, O. Lerat, C. Muller, C. Ravenne, and Sztràkos, 2004, The southern Grès d'Annot outcrops (French Alps): an attempt at regional correlation, *in* P. Joseph and S.A. Lomas, ed., Deep-Water Sedimentation in the Alpine Basin of SE France: New Perspectives on the Grès d'Annot and related systems: Geological Society of London Special Publication 221, p. 137-160.

Elliott, T., G. Apps, H. Davies, M. Evans, G. Ghibaudo, and R.H. Graham, 1985, A structural and sedimentological traverse through the Tertiary foreland basin of the external Alps of southeast France, *in* P.A. Allen, and P. Homewood, ed., Field excursions guidebook: International Association of Sedimentologists meeting on foreland basins, Fribourg, Germany, p. 39-73.

Evans, M.J., and T. Elliott, 1999, Evolution of a thrust-sheet-top basin: The Tertiary Barrême basin, Alpes-de-Haute-Provençe, France: Geological Society of America Bulletin 111, p. 1617-1643.

Gardiner, A.R., 2004, The variability of turbidite sand body pinchout and its impact on hydrocarbon recovery in stratigraphically trapped fields, *in* M.R. Allen, G.P. Goffey, R.K. Morgan, I.M. Walker, ed., The deliberate search for the stratigraphic trap: Geological Society of London Special Publication 254, p. 267-287.

Hilton, V. C., 1994, Architecture of deep-marine confined sandstone bodies, Eocene-Oligocene Grès d'Annot Formation, SE France: Leicester University unpublished PhD dissertation, 314 p.

Hilton, V.C., and K.T. Pickering, 1995, The Montagne de Chalufy turbidite onlap, Eocene-Oligocene turbidite sheet system, Hautes Provençe, SE France, *in* K.T. Pickering, R.N. Hiscott, N. H. Kenyon, and R.D.A. Smith, ed., Atlas of Deep Water Environments: Architectural style in turbidite systems: Chapman & Hall, London, p. 236-241.

Joseph, P., and C. Ravenne, 2001, Overview of the Grès d'Annot basin, *in* P. Joseph and S. Lomas, ed., Turbidite sedimentation in confined settings: Research meeting and field excursion to the Grès d'Annot, Nice, France, 12th – 15th September.

Kneller, B. C., 1995, Beyond the turbidite paradigm: physical models for deposition of turbidites and their implications for reservoir prediction, *in* A. J. Hartley and D.J. Prosser, ed., Characterisation of deep marine clastic systems: London Geological Society Special Publication 94, p. 31-49.

Lickorish, W.H., and M. Ford, 1998, Sequential restoration of the external Alpine Digne thrust system, SE France, constrained by kinematic data and synorogenic sediments, *in* A. Mascle, C. Puigdefàbregas, H.P. Luterbacher, M. Fernàdez, ed., Cenozoic Foreland Basins of Western Europe: Geological Society of London Special Publication 134, p. 189-211.

Lomas, S. A., B.T. Cronin, A.J. Hartley, D. Duranti, A. Hurst, E. Mackay, S.J. Clark, and B. Palumbo, 2000, Detailed characterisation of lateral heterogeneities in an exceptionally exposed turbidite sand-body, Grès d'Annot (Eocene-Oligocene), SE France: 20th Annual Bob F. Perkins GCSSEPM Research Conference, p. 502-514.

TOC
Start
Author
Search
Help

Lomas, S.A., B.T. Cronin, A.J. Hartley, and D. Duranti, 2008, Amalgamated Sheet Sandstone Bodies in the Grès d'Annot, Trois Evêchés area, France, *in* T. Nilsen, J. Studlick, R. Shew, G. Steffens, ed., Atlas of Deep-Water Outcrops: AAPG Studies in Geology 56.

Mayall, M., and I. Stewart, 2000, Architecture of turbidite slope channels: 20th Annual Bob F. Perkins GCSSEPM Research Conference, p. 578-586.

Pickering, K.T., and V.C. Hilton, 1997, Turbidite systems of Northeast France: Vallis Press, London, 229 p.

Prather, R.E., J.R. Booth, G.S. Steffens, and P.A. Craig, 1998, Classification, lithologic calibration and stratigraphic succession of seismic facies of intraslope basins, deep-water Gulf of Mexico: AAPG Bull., v. 82, p. 701-728.

Ravenne, C., R. Vially, P. Riché, and P. Trémolières, 1987, Sédimentation et tectonique dans le basin marin Eocène Supérieur-Oligocène des Alpes du sud: Revue de l'Institut Français du Pétrole 42, p. 529-553.

Sinclair, H.D., 2000, Delta-Fed turbidites infilling topographically complex basins: A new depositional model for the Annot Sandstones, SE France: Journal of Sedimentary Research v. 70, p. 504-519.

Sinclair, H.D., 1994, The influence of lateral basinal slopes on turbidite sedimentation in the Anot Sandstones of SE France: Journal Sedimentary Research, v. A64, no. 1, p.42-54.

Sinclair, H.D., and M. Tomasso, 2002, Depositional evolution of confined turbidite basins: Journal of Sedimentary Research v. 72, p. 451-456.

Stanbrook, D.A., 2003, The geology of Grand Coyer, Southeast France, Relationships between basin floor topography and the deposition of the Grès d'Annot and Marnes Brunes Inférieures: Heriot-Watt University unpublished PhD dissertation, 302 p.

Stanbrook, D.A., and J.D. Clark, 2004, The Marnes Brunes Inférieures in the Grand Coyer remnant: characteristics, structure and relationship to the Grès d'Annot, *in* P. Joseph, and S.A. Lomas, ed., Deep-Water Sedimentation in the Alpine Basin of SE France: New Perspectives on the Grès d'Annot and related systems: Geological Society of London Special Publication 221, p. 285-300.

Stanley, D. J., 1975, Submarine canyon and slope sedimentation (Grès d'Annot) in the French Maritime Alps: 9th International Sediment Conference, Nice, France, p. 131.

Stow, D.A.V., 1994, Deep-sea processes of sediment transport and deposition, *in* K. Pye, ed., Sediment Transport and Depositional Processes: Blackwell Scientific Publications, p. 257-293.

Weimer, W., P. Varnai, F.M. Budhijanto, Z.M. Acosta, R.E. Martinez, A.F. Navarro, M.G. Rowan, B.C. McBride, T. Villamil, C. Arango, J. Crews, and A.J. Pulman, 1998, Sequence stratigraphy of Pliocene and Pleistocene turbidite systems: Northern Green Canyon and Ewing Bank (offshore Louisiana), Northern Gulf of Mexico: AAPG Bull., v. 82, p. 918-960.

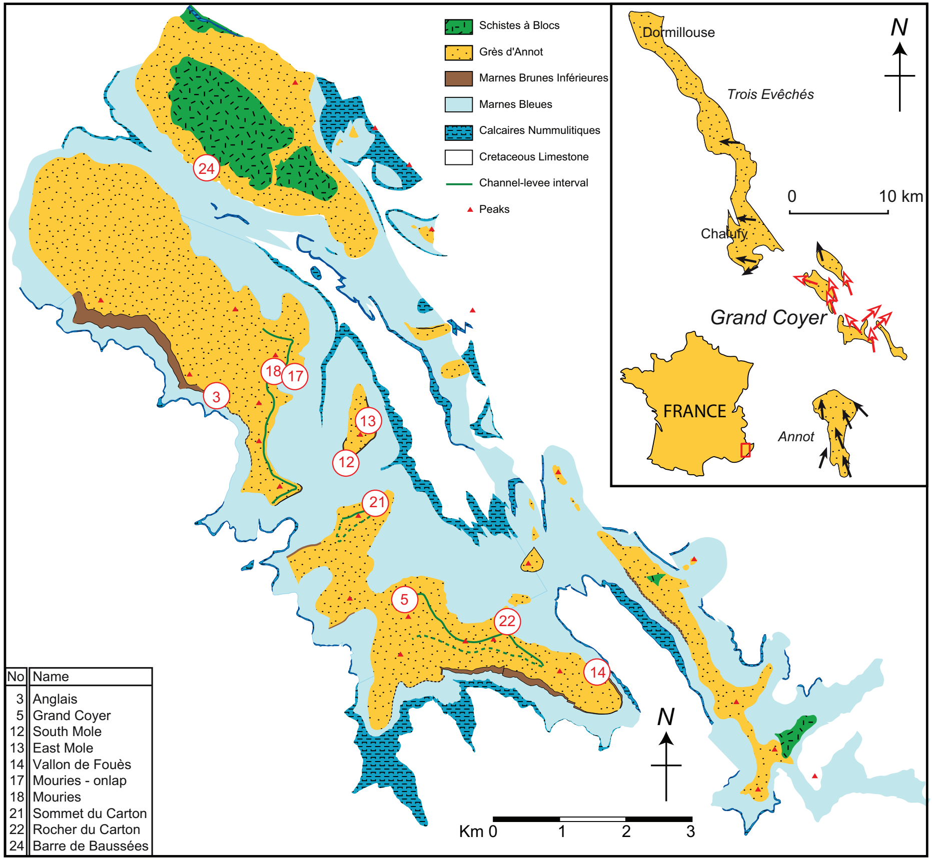


Figure 1. Geological map of the Grand Coyer subbasin, with (inset) location map of the Grès d'Annot Annot turbidite system in the south-east of France, subbasin names are in italics. Paleocurrents with closed arrowheads have been summarised from Sinclair (1994), Bouma and Coleman (1985) and paleocurrents with open arrowheads are summarised from this paper. Localities discussed in the text are numbered.

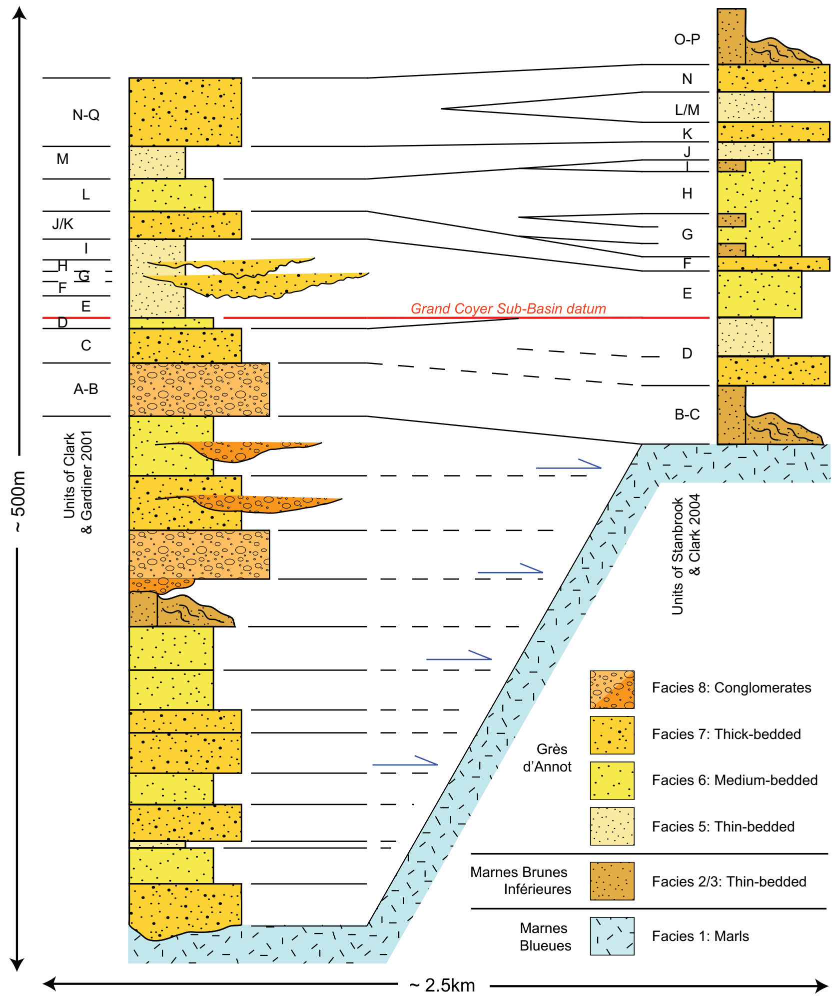


Figure 2. Generalized stratigraphy of the Grès d'Annot and Marnes Brunes Inférieures formations within the Grand Coyer subbasin. The left log represents proximal/axial basin elements and the right log distal/marginal regions. Unit letters from Clark and Gardiner (2000) and Stanbrook and Clark (2004) are shown at their approximately stratigraphic equivalents. Base unit "E" (both logs) represents a datum within the Grand Coyer subbasin previously identified by Clark (per. com.; see Stanbrook, 2003).

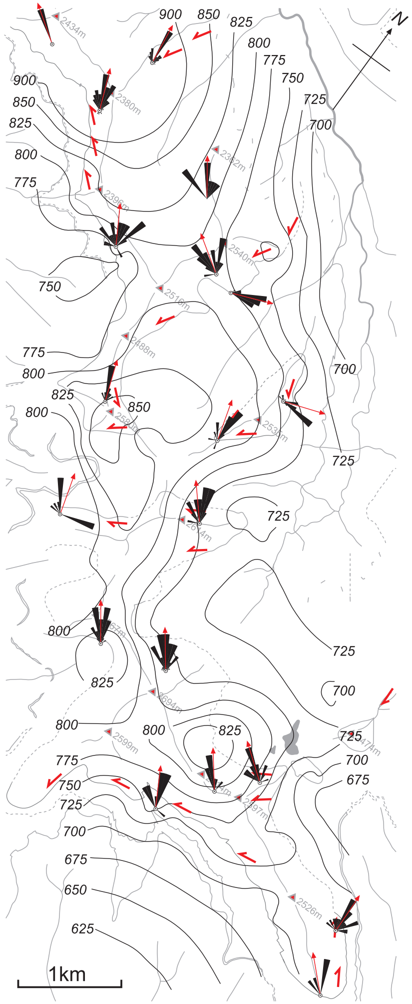


Figure 3. Paleotopographic reconstruction of the Marnes Bleues surface in the west of Grand Coyer at the time of Marnes Brunes Inférieures/ Grès d'Annot deposition. Although the mean dip of the Marnes Bleues is towards the north-east, the topography is highly variable. Paleocurrent and apparent onlap directions are indicated. Bathymetry is in meters above an arbitrary datum. Modified from Stanbrook and Clark (2004).

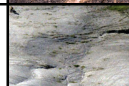
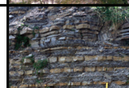
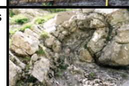
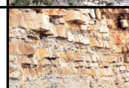
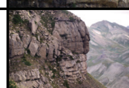
Facies Name & Formation	Example Photograph	Lithology / Facies Code	Description	Internal Character	Out-sized Clasts	Thickness and Outcrop Scale Geometry	Interpretation
Calcaires Nummulitiques		0	Generally massive, due to pervasive bioturbation. Localised bored conglomerate clasts of Cretaceous clasts.	Fine-grained bioclastic silty micritic packstone limestone, with abundant nummulites and bivalves.	N/A	Between 5-30m thick and forms a distinctive erosion resistant horizon - locally thickens into faults.	Shallow marine environment with localised sub-environments associated with fluvial sources
Marnes Bleues		1	Light blue/grey marls with 60-70% carbonate content (Ravenne et al., 1987).	Typically thin, laminated calcarenite beds >10cm thick	N/A	Typically shows local slumping & structural deformation up to 1m thick and 800m laterally	Pelagic marls in deepwater, early lithification forming up to 15º dip palaeoslopes
Reworked Marnes Bleues / Marnes Brunes Inférieures		2	As Marnes Brunes Inférieures (Facies 3) but with remobilisation / reworking of materials by slumps, slides, debris-flows. Also seen as intra-clasts in Massive / Conglomeratic Grès d'Annot (Facies 7 & 8)	As per Marnes Brunes Inférieures (Facies 3) and Marnes Bleues (Facies 2) with some homogenisation through reworking.	N/A	Generally small scale (1-3m thickness). Some sections up to 10m (in Marnes Brunes Inférieures) associated with channels.	Slumps/slides related to slope instability, thicker sequences associated with channel margins
Marnes Brunes Inférieures		3	Dominated by >1cm thick alternations of: A) very fine sharp-based and sharp-topped, non-graded, micaceous sands and, B) shales or carbonate marls. Some 5m thick, discontinuous sand intervals also present (Stanbrook & Clark 2004)	Ripples or planar lamination (usually towards bed tops) with cm-scale slumping, climbing ripples, attenuated flame structures & fluid escape features.	N/A	Sequence 0.5-70m thick but typically 5-10m. Commonly onlapping underlying sequences and occasionally erosional	Distal and lateral form of the Grès d'Annot Formation.
Slumps / Debris Flow Grès d'Annot		4	As Grès d'Annot (Facies 5-7) but with remobilisation / reworking of materials by slumps, slides, debris-flows. Seen as intra-clasts in Massive / Conglomeratic Grès d'Annot (Facies 7 & 8)	As Grès d'Annot (Facies 5-8) with some homogenisation through reworking.	0.5-4.5m diameters observed	5-10m thickness, usually with wedge shaped geometry	Reworking of partially consolidated slope deposited Grès d'Annot
Thin-bedded Grès d'Annot		5	Shale-rich intervals, with coarse-grained, sandstones containing lignite and charred wood fragments	Sandstones commonly cross- and planar-laminated, common bioturbation of *Ophiomorpha*, *Thalassinoides* and *Zoophycos* trace fossils.	N/A	Beds 0.5mm-10cm thick but typically 5cm. Typically discontinuous beds laterally, even over short (>30m) distances	Aggradational levee equivalents to the thick-bedded, channelised deposits
Intermediate-bedded Grès d'Annot		6	Amalgamated, medium-sand to granule grade sandstones	Sandstones commonly cross-bedded with abundant *Ophiomorpha* and *Thalassinoides* trace fossils	Granule grade	Beds 0.1m-0.5m thick but typically 0.25m. Laterally variable, but typically 50-300m wide.	Mixture of high energy channel fill and spill equivalents
Massive Grès d'Annot		7	Typically amalgamated, medium to granule-grained gravelly sandstone beds	Bed-thinning and upwards-fining, common bioturbation of *Ophiomorpha* and *Thalassinoides* trace fossils.	Rare cobble grade sand-stones observed	Beds 0.5m-10m thick and laterally continuous (1000m+), although isolated and stacked channels erode underlying sheet sandstones	High energy conduits of main Grès d'Annot turbidite channels
Conglomeratic Grès d'Annot		8	Rarely exposed, predominantly poorly sorted, re-worked but usually intact entrained beds varying from shale to conglomerates	Chaotically deposited, deformed bedding (where present) with multiple dewatering 'dish' structures	0.5-4.5m diameters observed	Typically rare, and laterally discontinuous (100m max.), up to 5m thick (where exposed)	Reworked material, either small-scale channel edge collapses or channel-lag
Channels (Architectural Element)		9	Variety of morphologies with associated lateral accretion surfaces and megaflute erosion surface	Predominantly Conglomerate and Massive Grès d'Annot (Facies 7 & 8) and subordinate Slumping (Facies 4)	Intra clasts of Facies 1-7 and exotic material. Up to 4m	Channels 1 & 2: in main Grand Coyer face: 900m x 14m, 1600m x 28m (Cleark et al 2008). Other geometries observed..	Two stratigraphic levels of channel, uppermost with greater sinuosity then lower

Figure 4. Detailed generalised sedimentary facies descriptions, representative outcrop photographs and interpretations from exposures within the Grand Coyer subbasin, southeast France.

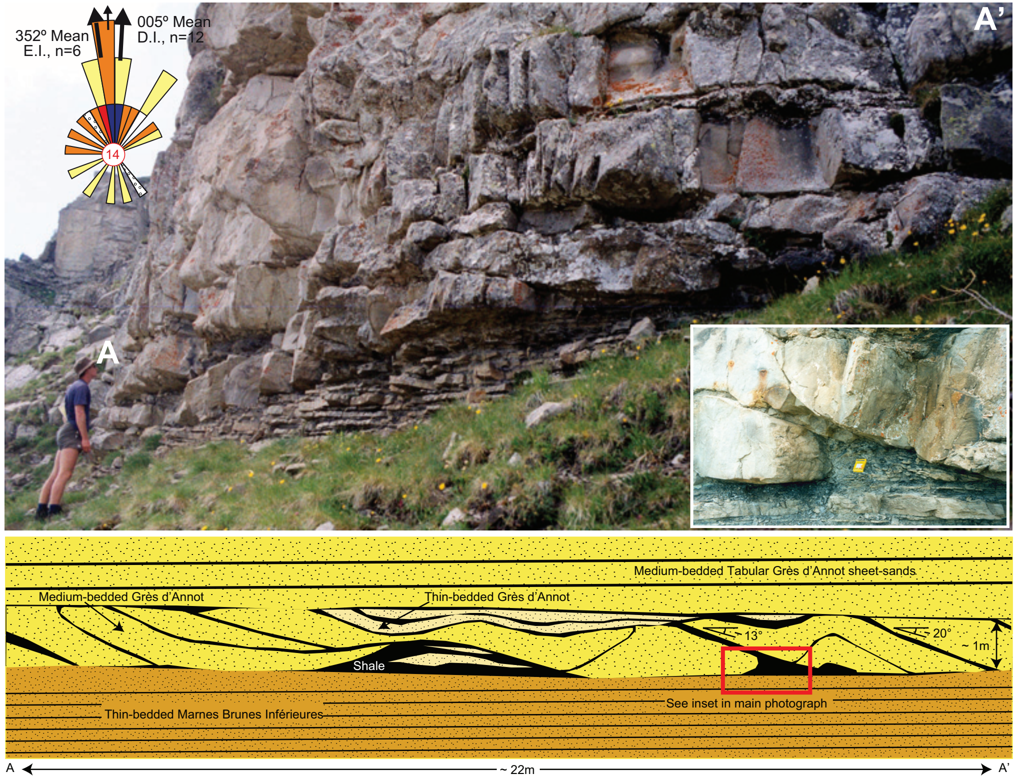


Figure 5. Photograph and interpretation showing lateral accretion surfaces at the Vallon de Fouès outcrop (no. 14 in Figs. 1 and 7). Note the outcrop is seen from an oblique angle in this photograph, while the interpretation is viewed perpendicular to the outcrop face; note A-A' line of section and person for scale. The interpreted accretionary bars immediately overlie the Marnes Brunes Inférieures and exhibit post-depositional soft-sediment deformation in the form of folding of the original bar form. Grouped measured paleocurrents at this locality are shown. Inset: detail of accretionary bar, notebook for scale. This locality represents the first phase of channel formation and bypass through the Grand Coyer subbasin. Approximately 20 m above this section is the main channelized sequence in Grand Coyer.

TOC
Start
Author
Search
Help

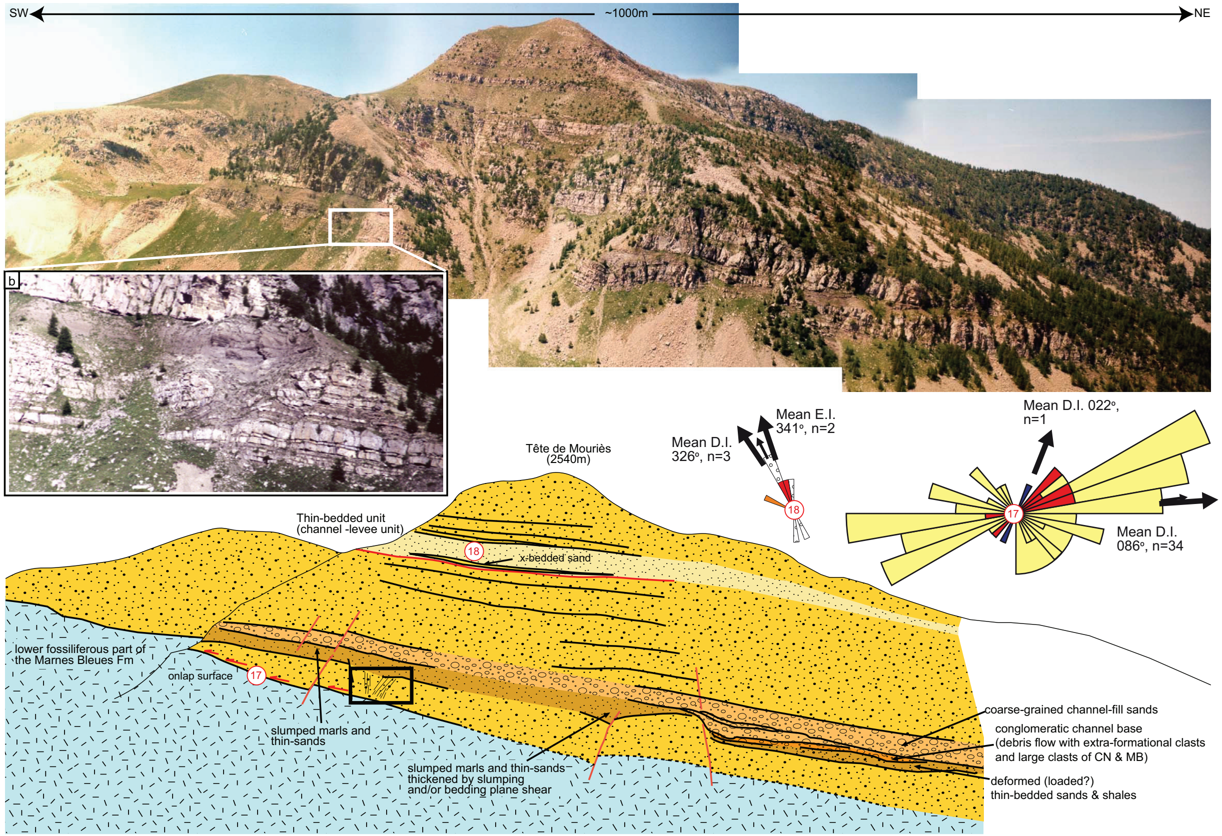


Figure 6. Photomontage and interpretation of the Tête du Mouriès outcrop (no. 18 in Figs. 1 and 7). Paleocurrents here are grouped into two sections; Tête du Mouriès Onlap (17) and Tête du Mouriès Upper (18). The onlap paleoslope here is steep; onlapping units show evidence of slope instability. The boxed inset shows an incipient slide block (*sensu* Stow, 1994) that has detached just above a shale-rich interval within the Grès d'Annot (essentially acting as a decollement surface). Modified from an original interpretation by Julian Clark (pers. com.).

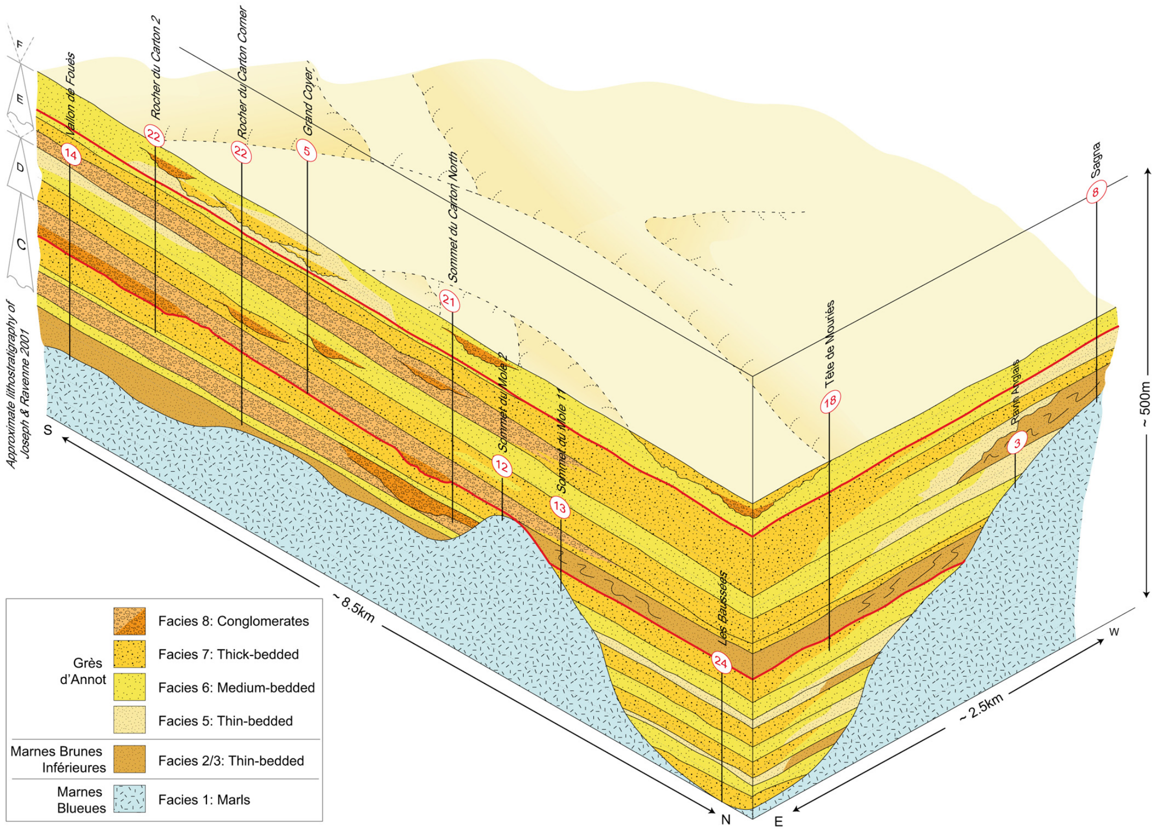


Figure 7. Schematic, deterministic block-diagrams of Grand Coyer showing varying facies architectures and their relationship to the underlying Marnes Bleues palaeotopography; the length (north-south) of the diagram is approximately parallel to axial paleoflow with the east-west section being normal to paleoflow. Approximate sedimentary log positions are shown; see Figure 1 for locations. See Figure 4 for precise facies definitions. This stratigraphy is comparable to that proposed by Joseph and Ravenne (2001).