Palaeogeography, Palaeoclimatology, Palaeoecology 300 (2011) 67–83

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

journal homepage: www.elsevier.com/locate/palaeo

# Ichnological characterization of Eocene/Oligocene turbidites from the Grès d'Annot Basin, French Alps, SE France

Christopher Phillips [a,*], Duncan McIlroy [a], Trevor Elliott [b]

[a] Department of Earth Sciences, Memorial University of Newfoundland, St. John's, NL Canada A1B 3X5
[b] Department of Earth and Ocean Sciences, University of Liverpool, Liverpool L69 3BX, UK

ARTICLE INFO

*Article history:*
Received 17 December 2008
Received in revised form 20 November 2010
Accepted 16 December 2010
Available online 22 December 2010

*Keywords:*
Trace fossil
Turbidite
Ichnofabric
*Ophiomorpha*

ABSTRACT

The ichnology of the Grès d'Annot Basin, SE France, is described in detail for the first time. Deep marine palaeoenvironments from basin slope to basin floor settings are preserved. The Grès d'Annot Formation is a sand-rich, thick-bedded, and coarse-grained turbidite succession. The Marnes Brunes Inférieures Formation is a succession of thin-bedded, fine-grained turbidites interpreted as lateral and distal equivalents of the Grès d'Annot Formation. The siliciclastic basin fill is highly bioturbated and characterized by low diversity, high abundance ichnological assemblages which are described herein. Trace fossil and ichnofabric analysis of the Grès d'Annot Basin is used as a tool for interpreting palaeoenvironmental and depositional changes.

Heterolithic successions of thin-bedded turbidite sandstone and inter-turbidite mudstone contain the most diverse trace fossil assemblages found in the Grès d'Annot Basin. Sedimentological and ichnological data suggests that heterolithic facies are found on either relatively quiescent confining slopes as lateral and distal equivalents of larger turbidites or as channel-fill deposits. In these settings trace fossil assemblages are dominated by the deposit feeding activity of vagile, endobenthic organisms (e.g., *Ophiomorpha*, *Phycosiphon*, *Planolites*, and *Scolicia*).

Thick-bedded and channel sandstones contain low diversity trace fossil assemblages dominated by *Ophiomorpha*. *Ophiomorpha* in the Grès d'Annot Basin is inferred to have been produced by organisms mostly deposit feeding on buried organic-rich material during inter-turbidite intervals. *Ophiomorpha rudis* is the most prominent trace fossil found in the Grès d'Annot Basin and dominates the ichnofabrics in all locations within the basin. The deep-burrowing ability of the *Ophiomorpha* animal is considered to be an adaptation for exploiting buried organic nutrients found in inter-turbidite mudstones.



## 1. Introduction

The deep marine, currently comprising approximately 40% of the Earth's surface, is perhaps the single most widespread depositional environment. This vast ecosystem has been greatly understudied with respect to palaeo- and neoichnology in comparison with shallow-marine settings. This disparity is partly due to the technological challenges of studying modern deep marine settings. This work details trace fossil assemblages of the Grès d'Annot Basin, one of the best preserved, and well exposed, ancient deep-water systems (Apps et al., 2004; Kneller and McCaffrey, 1999, 2003; Sinclair, 1997). Large-scale facies architecture and its relationship to process sedimentology and basin structure have been well constrained, but no study has focused specifically on the ichnology of the Grès d'Annot Basin. The pre-existing sedimentological and stratigraphic framework makes this an ideal site for an integrated ichnological and sedimentological analysis of an ancient, deep-water depositional system.

Trace fossils, and the ichnofabrics they produce in sediments have many applications particularly for palaeoenvironmental and stratigraphic studies (McIlroy, 2004a, 2008; Taylor et al., 2003). Trace fossils preserve the response of benthic organisms to prevailing environmental and depositional conditions. To this end, they are constructive to workers in many different disciplines as they provide data that can aid in: (1) the identification of key stratal surfaces, usually omission surfaces (Ghibaudo et al., 1996; MacEachern et al., 1991, 2007a); (2) the identification of stressed conditions on the seafloor (MacEachern et al., 2007b; Uchman, 2004); and (3) interpreting palaeoenvironments both in outcrop and in core (MacEachern et al., 2007c; McIlroy, 2004a, 2004b, 2007, 2008; Pemberton et al., 2001). The application of these approaches to the study of deep marine and turbidite depositional systems are being developed.

This paper uses the Grès d'Annot turbidite system to develop trace fossils and ichnofabrics as depositional and environmental indicators in deep-sea siliciclastic turbidite systems. It is the first detailed

* Corresponding author.
*E-mail address:* cphillip@mun.ca (C. Phillips).

0031-0182/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.palaeo.2010.12.011

account of the ichnological assemblages of the Grès d'Annot Formation and Basin. The paper uses trace fossil assemblages as tools for highlighting changes in the palaeoenvironmental and depositional conditions during the deposition of the siliciclastic basin fill.

## 2. Methodology

Excellent exposure within the Grès d'Annot Basin allows detailed logging of extensive areas and sections of cliff-face. The main focus of this work was to document the trace fossils in the sand-rich Grès d'Annot Formation which had hitherto had not been documented in detail. In areas of onlap with the Grès d'Annot Formation the trace fossils of the underlying Marnes Brunes Inférieures Formation and Marnes Bleues Formation were also studied. This paper centres on the work carried out in four areas (Fig. 1). Facies architectural elements logged include channel sands and channel-fill at the Col de la Cayolle area, a proximal fan environment at Baisse de l'Aiguille, and basin slope settings (onlap surfaces) at the Braux and Montage de Chalufy outcrops (Fig. 1).

## 3. Geological setting

The Grès d'Annot Basin is not a foreland basin *sensu stricto*, but a thrust sheet-top (piggyback) basin formed behind the thrust front on top of already compressed and shortened crust (Apps et al., 2004). As a result, the Grès d'Annot Basin and other thrust sheet-top basins are found localized in the synclinal sectors of compressional structures and are topographically complex (Apps et al., 2004; Ford and Lickorish, 2004).

The fill of the Grès d'Annot Basin shows a sharp deepening following basin formation, to its eventual filling. The Calcaires Nummulitiques Formation is a regionally extensive shallow marine bioclastic limestone unit consisting of patch reefs made by accumulations of giant nummulite foraminiferans (Apps et al., 2004). Its deposition represents transgression of the basin margin during a period of relative sealevel rise induced by flexural loading of the crust by the Alpine Orogeny (Callec, 2004). The overlying Marnes Bleues Formation is a deep-water, mudstone-dominated succession deposited during a phase of rapid subsidence and low sediment supply. Basin deepening is evident from a gradual loss of shallow-water benthic foraminifera to the dominance of planktonic species at higher stratigraphic levels. Water depths of approximately 900 m are estimated from the uppermost marls in this formation (Apps et al., 2004). The last phase of basin fill is dominated by deep-water sands and mass wastage deposits of the advancing Alpine Orogeny (Sinclair, 1997). These siliciclastic deposits consist of thin-bedded turbidites of the Eocene Marnes Brunes Inférieures Formation which are interpreted as the lateral and distal equivalents of the thick-bedded turbidites of the 500–1500 m thick Eocene/Oligocene Grès d'Annot Formation (Stanbrook and Clark, 2004).

At the time of turbidite deposition regional tectonics had folded and continued to fold the underlying formations producing a province of thrust sheet-top basins in which structural highs bound confined sub-basins (Apps et al., 2004). Turbidite deposition suppressed the basin floor topography onlapping it and eventually filling the basin (Sinclair, 2000). The provenance of these turbidites could have been a southerly granitic source, the Corsica–Sardinia and Maurès–Esterel Massifs (Apps et al., 2004) or a source to the east, possibly early Alpine, or a NE extension of the Corsica–Sardinia Massif (now removed by erosion; Apps, 1987).

Eocene–Miocene rifting of eastern Iberia diverted sediment supply away from the Grès d'Annot Basin (Brunet et al., 2000; Séranne, 1999). The remaining accommodation space was filled by the overlying Schists à Blocs Formation which is composed of debris shed from the Embrun–Ubaye Nappes (Apps et al., 2004). These factors, in combination, caused turbidite deposition to cease in the Late Rupelian.

## 4. Systematic ichnology

Although ichnodiversity does not directly correspond to biological diversity, it has conventionally been used as a proxy for the benthic behavioural diversity on the palaeo-seafloor (Herringshaw et al., 2010; McIlroy, 2004a). Low ichnological diversity is thought to

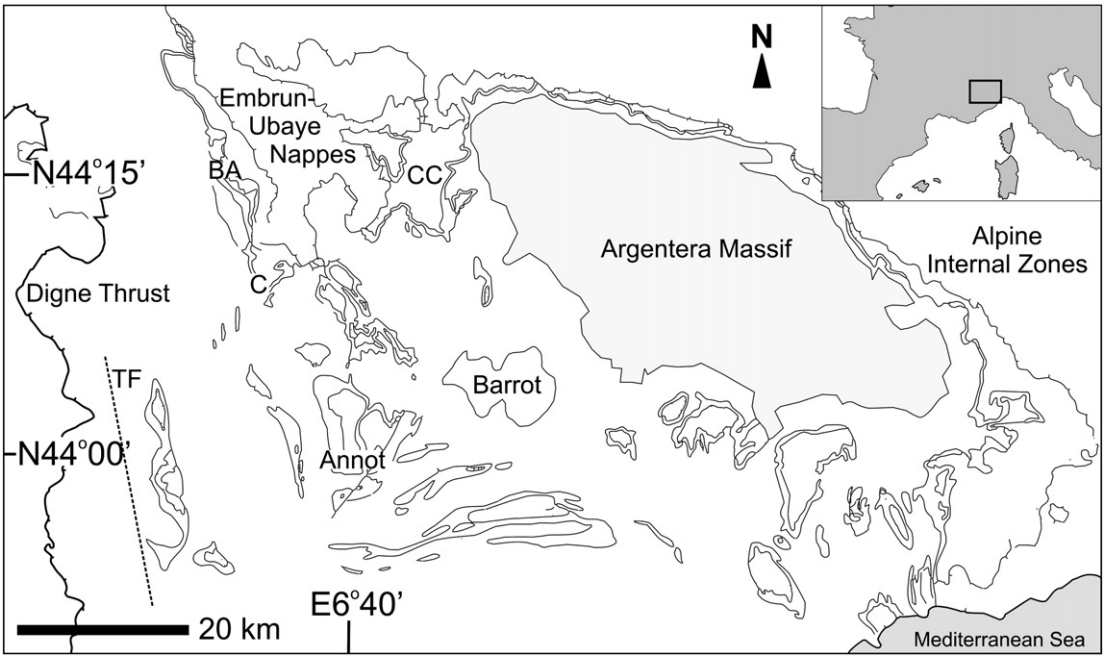


**Fig. 1.** A map of the study area. Tertiary outliers (Marnes Brunes Inférieures and Grès d'Annot Formations; unfilled outlines) and pre-Mesozoic inliers (labelled and filled). The dashed line marked TF indicates the position of the initial (Eocene) thrust front that established the province of thrust sheet-top basins to the east. Locations referred to in the text are labelled: BA, Baisse de l'Aiguille; C, Montagne de Chalufy; CC, Col de la Cayolle. The outcrop studied at Braux is located close to the town of Annot (labelled).
Image modified from Apps et al. (2004).