

## Deepwater Sediment Facies and Sole Marks of the Numidian Flysch, Algeria

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**Abstract.** The sedimentology of the Numidian Flysch (Upper Oligocene) of the Ouarsenis Mountains, Northwest Algeria, is presented here for the first time. The outcrops of the Forêt des Cèdres section comprise thick and very-thick bedded sandstones as the dominant facies, interbedded with more minor mudstones. Five distinct facies have been identified including: (1) massive sandstone, (2) normally-graded sandstone, (3) parallel-laminated sandstone, (4) siltstone, and (5) mudstone. The range of bedding and facies characteristics observed can be interpreted as resulting from deepwater gravity flow processes. Many sole marks are present on the bases of the overturned sandstone beds, including groove casts, flute marks, gutter casts, longitudinal ridge and furrow marks, mud ripples, and frondescent marks. A new type of flute-mark structure is documented here for the first time on the base of medium-grained sandstone beds. These features are designated as *curved flute marks*. We suggest that they result from flow interaction with an obstacle or irregular relief on the seafloor in the path of a strong turbidity current. Similar features have been generated in laboratory simulations by [Dzulynski \(1965\)](#).

**Keywords:** Numidian flysch, turbidite, deepwater massive sand, sole structures, curved flute *(Times New Roman 9)*.

### 1 Introduction *(Times New Roman 12)*

The Numidian Flysch in Algeria is characterised by deep sea turbiditic sandstone and mudstone deposits of Upper Oligocene to Lower Burdigalian age ([Durand Delga et Magné, 1958](#); [Mattauer, 1954](#); [Raoult, 1974](#); [Bizon et Hoyer, 1979](#); [Lahondère et al, 1979](#)). This study focuses on the sediment facies and their distinctive suite of sole mark structures as observed in the Numidian Flysch of the Ouarsenis Mountains of NW Algeria. The study area is located 7 km northwest of the town of Theniet El Had, and 50 km northeast of Tissemsilt, in the Nature Reserve of the Forêt des Cèdres.

## **2 Sedimentary succession Results**(Times New Roman 12)

### **2.1 Vertical succession**

The total section measured at the Forêt des Cèdres section is 56 m thick, of which sandstone beds are the dominant facies (50 m thick in total) and intercalated with more minor mudstones (6 m thick in total). Following careful examination of sedimentary structures and other way-up criteria, we found that this series is overturned. On the basis of slight variation in bed thickness and facies associations, the section has been subdivided into two parts: (1) the lower set, dominated by thick to very-thick bedded sandstones, with minor mudstone; and (2) the upper set, with medium to very thick-bedded sandstones and thicker intercalated mudstone units.

### **2.2 Sedimentary facies**

The Forêt des Cèdres section comprises an alternation of sandstone (dominant) and mudstone. Preliminary data on the sandstone composition shows a quartz-dominated mineral assemblage, with minor feldspar, muscovite mica and polycrystalline quartz. There is a restricted heavy mineral assemblage characterized by zircon, tourmaline, glauconite and opaque minerals. Five distinct facies are identified on the basis of bed thickness, sedimentary structures, grain size and texture including five distinct facies have been identified including: (1) massive sandstone, (2) normally-graded sandstone, (3) parallel-laminated sandstone, (4) siltstone, and (5) mudstone.

### **2.3 Process interpretation**

The range of bedding and facies characteristics observed in the Forêt des Cèdres section can be interpreted as resulting from deepwater gravity flow processes (Stow *et al.*, 1996; Pickering and Hiscott, 2016). The massive (structureless) sandstone facies (Facies 1) are very similar to the deepwater massive sands described by Stow and Johansson (2000), deposited from high-concentration turbidity currents and/or sandy debris flows. The graded and laminated sandstone facies (Facies 2 and 3) show typical partial Bouma (1962) sequences, as a result of deposition from medium and low-concentration turbidity currents. The siltstone and mudstone facies (Facies 4 and 5) show typical partial Stow (1977) sequences and/or Bouma Te divisions, and probably result from deposition by low-concentration turbidity currents (Stow and Omoniyi, 2018). Some of the mudstone facies (Facies 5), or marly mudstones, without any clear sedimentary structures and with a high degree of bioturbation, may be the result of hemipelagic deposition (Stow *et al.*, 1996; Stow and Tabrez, 1998). However, further work is needed to distinguish between these and muddy turbidites.

### 3 Sole marks.

The Forêt des Cèdres section is very rich in a range of different sole marks, which are clearly seen on the bases of the overturned beds including The sole structures common at the base of sandstone beds, including groove casts, flute marks, longitudinal ridge and furrow structures, mud ripples, and frondescant marks.

### 4 Curved flute casts

These scour structures appear very similar to normal flute marks but are asymmetrical to curved in shape, in some cases forming almost a spiral pattern or diagonal arrangement. They are preserved on the base of medium-grained sandstone beds, in the lower part of the Forêt des Cèdres section and occurs in 2% of the sandstone beds. The following sections describe the common scour marks and tool marks observed. They are characterized by a longitudinal and parallel furrow ending with a curved nose, as for normal flutes. They range from 3-30 cm in length, 1-5 cm in width and 0.5-2 cm in depth. We believe that this paper is the first documentation of their occurrence in the field.

Similar features have been generated in laboratory simulations by [Dzulynski \(1965\)](#), although they are much smaller in scale and with a more distinct spiral shape. These were the result changing the orientation of the vortex axis towards the horizontal. After his experiments he concludes that the oblique or diagonal arrangement of asymmetrical flutes appeared when the flow of the current was curved ([Allen, 1971](#)). We suggest that the curved flutes recorded in the Forêt des Cèdres section were formed by turbidity currents, in which the development of large-scale and powerful eddies was caused by an upstanding obstacle to the flow path or by a marked irregularity of the bottom morphology. The presence of irregularities on the bottom like bumps or obstacles can cause local acceleration of the flow, which gives rise to flow separation and a local change in flow direction.

### 5 Discussion

This study is the first published account of the Numidian Flysch succession, where it outcrops as a thrust nappe in the Ouarsenis Mountains in the far external part of the Greater Kabylies. The succession of deepwater facies examined are similar to those documented in earlier studies of the Numidian Flysch in Algeria (e.g. [Gelard, 1979](#)), northern Tunisia ([Fildes et al 2009](#), [Riahi et al 2009](#)), and Sicily ([Johansson et al 1998](#); [Stow et al 1999](#)). They also represent a clear example of the globally widespread deepwater massive sandstone facies association, as documented by [Stow and Johansson \(2000\)](#). Very thick-bedded structureless sandstones are common, typically with basal erosion, fluid-escape structures and mud clasts. These characterize rapid deposition and consequent water escape from high-density turbidity currents. The sole structures common at the base of sandstone beds, including groove casts, flute marks, longitudinal ridge and furrow, mud ripples, and frondescant marks, also indicate turbidite sedimentation. A new type of flute-mark structure has been highlighted for the first time in this section, and is designated as a *curved flute*. These structures are similar in some respects to the asym-

metrical flutes of Allen (1971), and to the much smaller-scale spiral flute-like features generated in laboratory simulations by Dzulynski (1965). We suggest that they result from a strong turbidity current with a locally curved flow pathway, caused by interaction with an obstacle or irregular relief on the seafloor, or by flow deflection from the channel margin.

## References

1. ALLEN, J. R. L. Transverse erosional marks of mud and rock: their physical basis and geological significance. *Sediment. Geol.*, 5: 167-385, (1971).
2. BIZON G. et HOYEZ B. Données stratigraphiques sur les formations sous-numidiennes en Algérie. C.R.Acad.Sci., D, t. 289, p. 655-658, Paris (1979).
3. BOUMA, A. H. Sedimentology of some flysch deposits: a graphic approach to facies interpretation. Elsevier, Amsterdam, (1962).
4. DURAND DELGA M. & MAGNE J. Données stratigraphiques et micropaléontologiques nouvelles sur le Numiditique de l'Est de Cordières bétiques. *Revue de micropaléontologie*, 1/3 : 155-175. Espagne (1958).
5. DZULYNSKI, S., WALTON, E. K. Sedimentary features of flysch and greywackes: Developments in sedimentology, v. 7: Elsevier, 274 p, Amsterdam (1965).
6. FILDES, C., STOW, D.A.V., PATEL, U., MILTON, J.A., RIAHI, S., SOUSSI, M., AND MARSH, S. European Provenance of the Numidian Flysch in northern Tunisia. *Terra Nova* (2009).
7. GÉLARD J.P. Géologie du Nord-Est de la Grande Kabylie. *Mém. géol. Univ. Dijon*, n° 5, 335 p., 98 fig., 19 pl., 2 pl h.t, France (1979).
8. JOHANSSON, M., BRAAKENBERG, N.E., STOW, D.A.V. AND FAUGÈRES, J.C. Deep-water massive sands: facies, processes and channel geometry in the Numidian Flysch, N Sicily. *Sedimentary Geology* **115**, 233 -266, Italy (1998).
9. LAHONDÈRE, J.C., FEIBERG, H., HAC. Datation des grès Numidiens d'Algérie orientale : Conséquences structurales, C R. Acad. Sc. 289, N°4, pp 383-386, Paris (1979).
10. MATTAUER M. Etude géologique de l'Ouarsenis oriental (Algérie) *Bull Des Serv Géol. Monographie Régionale* Monographie régionale 17 :534 p, Algérie(1958).
11. PICKERING, K.T., AND HISCOTT, R.N. Deep Marine Systems, Processes, Deposits, Environments, Tectonics and Sedimentation, John Wiley and Sons, 672p, (2016).
12. RAOULT, J. F. Géologie du centre de la chaîne numidique (Nord du Constantinois, Algérie). *Mém. Soc. géol.*, t.111, n° 121, 163 p, France (1974).
13. RIAHI, S., PATEL, U., SOUSSI, M., STOW, D.A.V., CROUDACE, I., FILDES, C., BEN ISMAÏL LATTRACHE, K. AND BOUKHALFA, K. The Onshore Tunisia Numidian Flysch: Petrography, Geochemistry and Reservoir characteristics. EAGE Tunisia, extended abstracts. Tunisia (2009).
14. STOW, D.A.V. Late Quaternary stratigraphy and sedimentation on the Nova Scotian outer continental margin. PhD thesis, Dalhousie University, Canada (1977).
15. STOW, D.A.V., READING, H.G., COLLINSON, J.D. Deep seas. In: Reading, H.G. (Ed.), *Sedimentary Environments*. Blackwell, pp. 395–453, London (1996).
16. STOW, D.A.V. & TABREZ, A. Hemipelagites: facies, processes and models. *Geological Society, Special Publications*, 129, 317-338, London (1998).
17. STOW, D.A.V., JOHANSSON, M., BRAAKENBERG, N.E. AND FAUGÈRES, J.C. Discussion: Deep-water massive sands: facies, processes and channel geometry in the Numidian Flysch, N Sicily - reply. *Sedimentary Geology* **127**, 119-123, Italy (1999).
18. STOW, D.A.V. AND JOHANSSON, M. Deep-water massive sands: nature, origin and hydrocarbon implications. *Marine and Petroleum Geology* **17**, 145-174. (2000).
19. STOW, D.A.V. AND OMONIYI, B. Thin-bedded turbidites: overview and petroleum perspective. *AAPG Memoir* **115**, 45-57. (2018).