# Tooled up, or fluted and booted? Using sole structures to improve flow and environmental prediction, and geohazard understanding


## Supervisors

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## *Highlights*

- An opportunity to lead and develop the new paradigm of sole structures in deep-water environments and its use in understanding deep-marine environments
- Fieldwork in Eastern Canada, and the Polish Carpathians
- Visits to the University of Urbana-Champaign, Illinois, for experiments and training
- Novel experiments in the national environmental fluid dynamics laboratory, Leeds
- Vibrant research community in the sedimentology / Earth surface processes group
- Internationally leading supervisorial team

Sole structures (flutes, tool marks, and a wide range of currently enigmatic features) are ubiquitous in deep-water clastic sediments, but at present geologists principally utilise them only as palaeocurrent indicators. This limited use is in sharp contrast with almost all other sedimentary structures, from which we interpret flow properties and thus help reconstruct ancient sedimentary environments. Indeed, it is astonishing that geologists have made such poor use of sole structures, given that other sedimentary structures are typically rare in deep-water sedimentary sequences, thus making environmental interpretations difficult, and limiting our ability to predict the character and spatial distribution of these sediments. This lack of progress in understanding sole structures reflects two key factors: a belief that they were all formed by low-concentration turbidity currents, and a near absence of research in this area since the early 1970s. However, since this time, our knowledge of deep-water sediment gravity flows (SGFs) has increased enormously, and we now recognise that there are a wide range of flows in these systems, from low-concentration, turbulent turbidity currents, through to high-concentration subaqueous debris flows, with a range of mud-rich transitional flows (see Baas et al., 2009, 2016) in between these end members. Furthermore, many SGFs change flow type spatially (down and across flow), and temporally, producing more complex, but common, deposits such as hybrid event beds (Haughton et al., 2009).

Recent work by the supervisors has demonstrated that the underlying assumption of the past 65 years that *all* these sole structures are formed by classical low-concentration turbidity currents is fundamentally flawed. Furthermore, we have been able to show that different sole structures can be linked to different SGFs, enabling us to greatly enrich the palaeohydraulic utilisation of sole structures, and to use these features to refine environmental interpretation and improve prediction of deep-water systems. A key implication of this recent work is that the classical Bouma sequence is wrong in its interpretation of many sole structures, and additionally that many of the more advanced models of hybrid event beds require modification. Whilst we have demonstrated the greatly increased utility of sole structures, this has opened up an entirely new field that is ripe for further study, offering huge opportunities to explore the formative processes and utility of sole structures. For example, the spatial distribution of sole structure opens up new research potential in investigations of flow-substrate interactions, the recognition of different flow types and their transport processes in a range of natural flows, their use in resource exploration, and in the assessment of geohazards.

Figure 1. A range of sole structures, flutes, grooves, more enigmatic features, revealing spatial and temporal changes in formative flow behaviour. Imaged from the Cloridorme Formation, Gaspé Peninsula, Quebec, Canada.

## Aims and Objectives

The principal aim of the proposed PhD project is to investigate the formative processes of a range of sole structures, and to determine how to interpret and utilise these within environmental interpretations and predictions. To advance our understanding an integrated field and laboratory approach is needed. The objectives include:

- To understand the diversity of sole structures, their detailed morphology, and their spatial variability, in a range of deep-water settings. This will be achieved through fieldwork (Eastern Canada / Polish Carpathians), recording sole structure type, using photogrammetric and drone-based techniques to collect morphometric and spatial information on sole mark distribution, and sedimentary logging to record bed types, grain size / sorting, and enable environmental interpretations.
- To understand how a range of sole structures initiate and evolve, and the nature of flow dynamics across these bedforms. Laboratory experiments using modern measurement technologies will be utilised to study these processes. A wide range of different types of experiment can be used dependent on the sole structures of interest.
- To use the spatial and temporal relationships between different sole structures, to make big advances in understanding the processes operating in many subaqueous SGFs.
- To combine these approaches to develop new process models for the formation and environmental distribution of different sole structures.

## PhD Schedule, Outputs and Training

This PhD will commence before the end of 2019 and run for 3.5 years. During this period, the student will be eligible for all the postgraduate training typically provided to students attending the University as part of the PANORAMA DTP. The student will receive training in relevant software packages, field based description, experimental techniques and data analysis, technical/scientific writing, and presentation of research to both scientific and public audiences. The student will be based in the Department of Earth and Environment at the University of Leeds, with visits to the University of Illinois, Urbana-Champaign, USA, to both learn new approaches to experimental sedimentology and undertake selected classes to broaden their geological research background. The student will join the sedimentology / Earth surface processes group at Leeds that is one of the largest and most vibrant in the UK, with a very active group of doctoral and postdoctoral researchers.