Determining Flow Directions in Turbidites: An Integrated Sedimentological and Magnetic Fabric Study of Two Miocene Turbiditic Systems (Northern Apennines, Italy)*

Fabrizio Felletti¹, Eleonora Dall'Olio¹, and Giovanni Muttoni¹

Search and Discovery Article #30417 (2015)**
Posted October 13, 2015

*Adapted from oral presentation given at AAPG 2015 Annual Convention and Exhibition, Denver, Colorado, May 31 – June 3, 2015
**Datapages © 2015 Serial rights given by author. For all other rights contact author directly.

¹Earth Science Department, Università degli Studi di Milano, Milano, Italy (fabrizio.felletti@unimi.it)

Abstract

Turbiditic systems are characterized by a great variability in size, geometry, facies, and stacking patterns. The development of depositional models at the basin scale is essential to understand this variability. Models require an accurate knowledge of the paleocurrent directions within the turbiditic systems. Traditionally, sedimentological current indicators (flute marks, ripple marks, etc.) are used to obtain paleocurrent directions, but these are not always present in outcrop sections and are virtually absent from drill cores. This limitation raises the need to identify an alternative, objective method to define paleocurrent directions in turbiditic successions. The anisotropy of magnetic susceptibility (AMS) is a useful tool to estimate paleocurrents in sedimentary rocks (e.g. turbiditic, fluvial, tide-dominated deltaic and estuarine environments). This method is based on the fact that a current is able to orient paramagnetic and ferromagnetic grains and minerals. The AMS ellipsoid often reflects the orientation imparted by the current to such grains. We experiment this method, in concert with classic sedimentological analyses, in two well-exposed Miocene turbiditic systems cropping out in the Northern Apennines (Italy): the Castagnola turbidite system (Tertiary Piedmont Basin) and the Marnoso Arenacea Formation (Northern Apennines foredeep). They are both characterized by well-exposed stratigraphic sections and by the presence of evident sedimentological indicators of paleocurrent at the base of the beds that have been used to validate the AMS measurements. As we were interested to calibrate this method and to determine which sediment composition and texture (grain size and sedimentary structures) work best for the application of the AMS methodology, numerous turbiditic sandstone beds have been sampled (nearly 900 samples collected) into different depositional intervals (e.g., fine- to medium-grained massive sands, fine- to medium-grained parallel-laminated sands and fine-grained cross-laminated sands). AMS fabrics have been compared to sedimentological indicators of paleocurrent direction at the base of turbidite beds; a good agreement between paleocurrents from flute casts and AMS measurements has been observed, even if a relatively small but consistent offset of ~15–20° seems to be present. Nonetheless, these data confirm the substantial validity of the AMS method as a tool to estimate flow directions in absence of sedimentological indicator.
Selected References


DETERMINING FLOW DIRECTIONS IN TURBIDITES: AN INTEGRATED SEDIMENTOLOGICAL AND MAGNETIC FABRIC STUDY OF TWO MIOCENE TURBIDITIC SYSTEMS (NORTHERN APENNINES, ITALY).

F. Felletti, E. Dall’Olio, G. Muttoni

Università degli Studi di Milano
Earth Science Department
Milano, Italy
INTRODUCTION

- Turbiditic systems are characterized by a great variability in size, geometry, facies, and stacking patterns.
- The development of depositional models at the basin scale is essential to understand this variability. **Models require an accurate knowledge of the palaeocurrent directions within the turbiditic systems.**
- Traditionally, sedimentological current indicators (flute marks, ripple marks, etc.) are used to obtain paleocurrent directions, but these are not always present in outcrop sections and are virtually absent from drill cores.
AIM

The aim is to validate an objective tool to define palaeocurrent directions in turbiditic systems …in order to be able to apply it on cases where sedimentological paleocurrent indicators are absent.

THE ANISOTROPY OF MAGNETIC SUSCEPTIBILITY (AMS)
THE ANISOTROPY OF MAGNETIC SUSCEPTIBILITY (AMS)

\[ K = \frac{M}{H} \]

- Magnetic moment
- Magnetic field
- Magnetic susceptibility
- \( k_{\text{min}} \)
- \( k_{\text{max}} \)
- \( k_{\text{int}} \)
Paleomagnetic analyses
AMS, IRM, ThIRM, NRM, AIRM

Textural analyses
Image analysis, neutron diffraction, tomography
Paleomagnetic analyses
AMS, IRM, ThIRM, NRM, AIRM

Textural analyses
Image analysis, neutron diffraction, tomography

AMS analyses have been carried out on 853 samples with a KLY-3 Kappabridge adopting the standard measurement scheme illustrated in Agico KLY-3 User’s Guide (1998).

Susceptibility tensors were subsequently rotated into tilt-corrected coordinates using site-mean bedding attitudes, and then plotted on stereographic projections.
This method is based on the fact that a current is able to orient paramagnetic grains (e.g., phyllosilicates, olivines, pyroxenes, amphiboles), diamagnetic grains (e.g., quartz, calcite, feldspars), and ferromagnetic grains (e.g., magnetite, goethite, hematite), and that the resulting AMS ellipsoid reflects the orientation imparted by the current to such grains in the final stages of sediment transport (e.g., Ellwood, 1980; Lowrie and Hirt, 1987; Taira, 1989; Sagnotti and Meloni, 1993; Parés et al., 2007).

In standing water deposition, the minimum susceptibility axes are clustered around the pole to the depositional plane within which maximum and intermediate susceptibility axes are uniformly dispersed, defining a planar, near-horizontal, gravity-induced settling fabric,

the magnetic fabric of sediments deposited from flowing water is typified by a current-oriented magnetic foliation plane.
Main types of anisotropic grain shape fabrics

Flow-transverse (rolling) fabric
- Non-imbricated grain fabric
- Imbricated grain fabric
- Flow direction

Horizontal fabric
- Disperse grain fabric
- Flow direction

Flow-aligned fabric
- Non-imbricated grain fabric
- Imbricated grain fabric
- Flow direction

Flow-oblique fabric
- Non-imbricated grain fabric
- Flow direction

Non-imbricated magnetic fabric
- Imbricated magnetic grain fabric
- Flow direction
CASE STUDIES

• well-exposed stratigraphic sections

• presence of evident sedimentological indicators of palaeocurrent direction (i.e., flute casts and ripple marks) at the base of the beds, which have been used to validate the AMS measurements.

• different sedimentary structure (e.g. massive, laminated, and convoluted sandstones, debrites, etc.), composition and texture (grain size, selection, etc).
CASE STUDIES

**Marnoso Arenacea Turbidite System**
- Max length 400 km NW-SE
- Max width 90-140 km SW-NE
- Max thickness 3500 m

**Castagnola Turbidite System**
- Max length 6 km SW-NE
- Max width 4 km NW-SE
- Max thickness 900 m
CONTESSA BED, Marnoso-Arenacea Formation

Flute marks or linear grooves
FLUTE MARKS AND LINEAR GROOVES

Marnoso-Arenacea Formation

Castagnola Formation
SAMPLING (853 samples)
Elongated **foredeep basin**

- Paleoflow direction from NW and SE
- Basin: 180 km long x 40 km wide
- Basin thickness: ~3000 m thick
- Mineralogic composition: monomineralic grains, heavy minerals, lithic fragments, bioclasts (foraminifera)

551 samples in 58 beds
7 stratigraphic sections
AMS STEREOPLOTS
Marnoso-Arenacea Fm.
SILICICLASTIC MASSIVE SANDSTONES

n = 49
sites = 6

k maximum
△ k intermediate
○ k minimum
\( k_{\text{max}} \) mean direction

paleocurrent direction

CARBONATIC AND HYBRID MASSIVE SANDSTONES

n = 31
sites = 3

k maximum
△ k intermediate
○ k minimum
\( k_{\text{max}} \) mean direction

paleocurrent direction
SILICICLASTIC CROSS-LAMINTED SANDSTONES

CARBONATIC AND HYBRID CROSS-LAMINTED SANDSTONES
White Marlstone Beds
(HEMIPELAGITES)
White Marlstone Beds
(HEMIPELAGITES)
White Marlstone Beds  
(HEMIPELAGITES)

These results suggest that the WM beds **deposited** under weak velocity flows that oriented the $k_{\text{max}}$ axes of paramagnetic grains (slightly elongated phyllosilicates), parallel to the mean current direction in the final stages of transport.
Excluding purely hemipelagic settling, the WM beds could arise from two alternative depositional mechanisms: (A) turbidity currents or (B) bottom currents.

These results suggest that the WM beds deposited under weak velocity flows that oriented the $k_{\text{max}}$ axes of paramagnetic grains (slightly elongated phyllosilicates), parallel to the mean current direction in the final stages of transport.
CASTAGNOLA TURBIDITE SYSTEM
(TERTIARY PIEDMONT BASIN - NW ITALY)

CASTAGNOLA FM
(Oligo-Miocene)

- Episutural basin
- Paleoflow direction from SW
- Basin size and thickness: 6 km long x 4 km wide; ~ 900 m thick
- Mineralogic composition: quartz, feldspars, micas, magmatic lithic fragments

302 samples in 11 beds
3 stratigraphic sections
CASTAGNOLA TURBIDITE SYSTEM
(TERTIARY PIEDMONT BASIN - NW ITALY)

Southern et al., 2015
Stocchi et al., 1992

KEY BED 2

AAPG Annual Convention & Exhibition 2015

UNIVERSITÀ DEGLI STUDI DI MILANO
AMS STEREOPLOTS

302 samples
Impact of basin topography on flow behaviour:

(1) density stratification of the turbidity current; (2) the dense basal part of the flow is partially blocked and deflected; (3) the less dense muddy and silty fraction surmounts the palaeoslope and surges backwards as a series of reflections; (4) complex interaction between the dense basal part of the flow and the passage of internal waves present in the less dense part of the flow (Felletti, 2002).

Southern et al., 2015
KEY BED 2

depocentral area

marginal area
AMS is a useful fabric analysis technique

- to quantify flow directions in turbiditic sandstones
- to discriminate different mechanisms of deep-water mudstone deposition
- to investigate the effects of basin confinement on turbidity flow dynamics

The advantages of this tool are:

- the significantly faster measurement time compared to standard petrographic fabric analysis
- the capability to characterize the orientation of the entire population of (magnetic) grains in three dimensions
- objective method to define palaeocurrent direction in turbiditic successions when sedimentological current indicators (*ripple marks, flute marks, etc.*) are virtually absent (*eg. drill cores*)