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

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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 para- 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

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

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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. **<u>Models require an accurate knowledge of the palaeocurrent directions within the turbiditic systems</u>**<u>.</u>
- 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)

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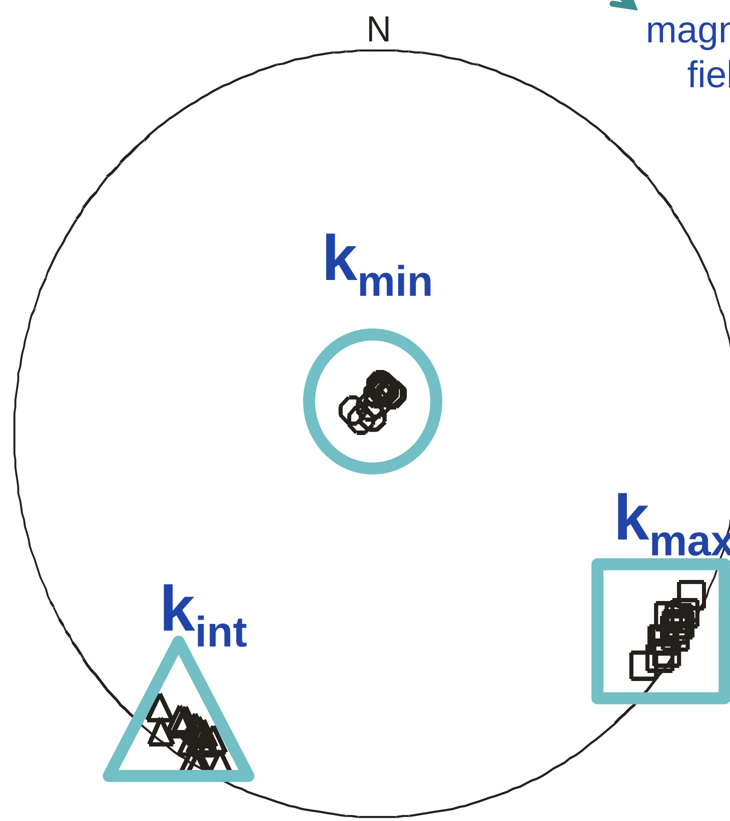
magnetic susceptibility

magnetic moment

$$K = M / H$$

magnetic field



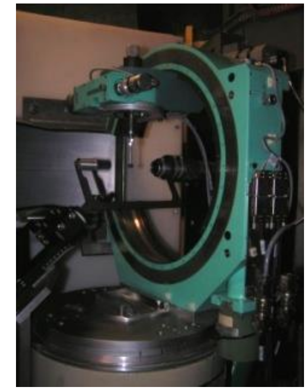
Paleomagnetic analyses
AMS, IRM, ThIRM, NRM, AIRM

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).

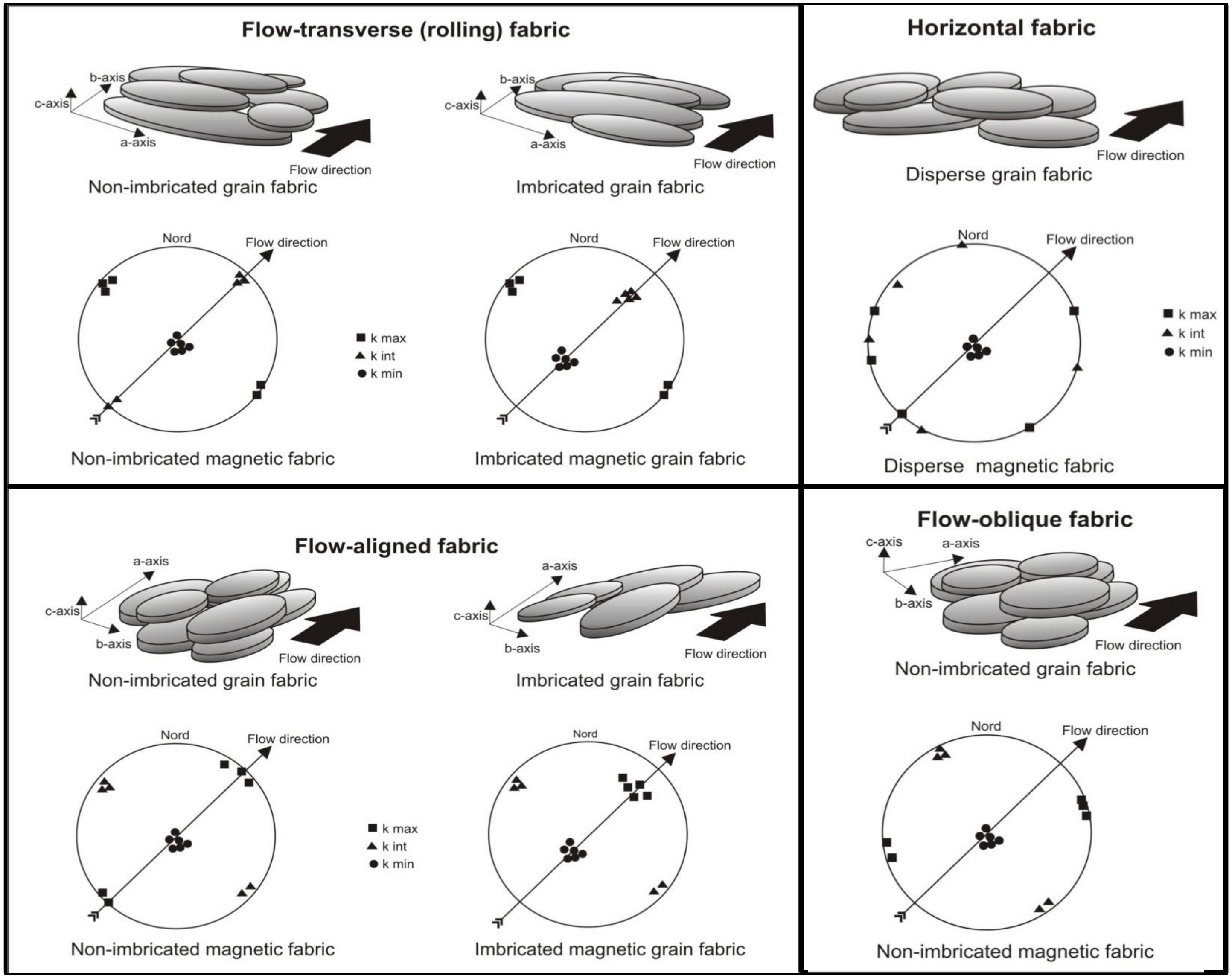
Susceptibility tensors were subsequently rotated into tilt-corrected coordinates using site-mean bedding attitudes, and then plotted on stereographic projections.

- This method is based on the fact that a current is able to orient **paramagnetic** grains (e.g., phyllosilicates, olivines, pyroxenes, anphiboles), **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

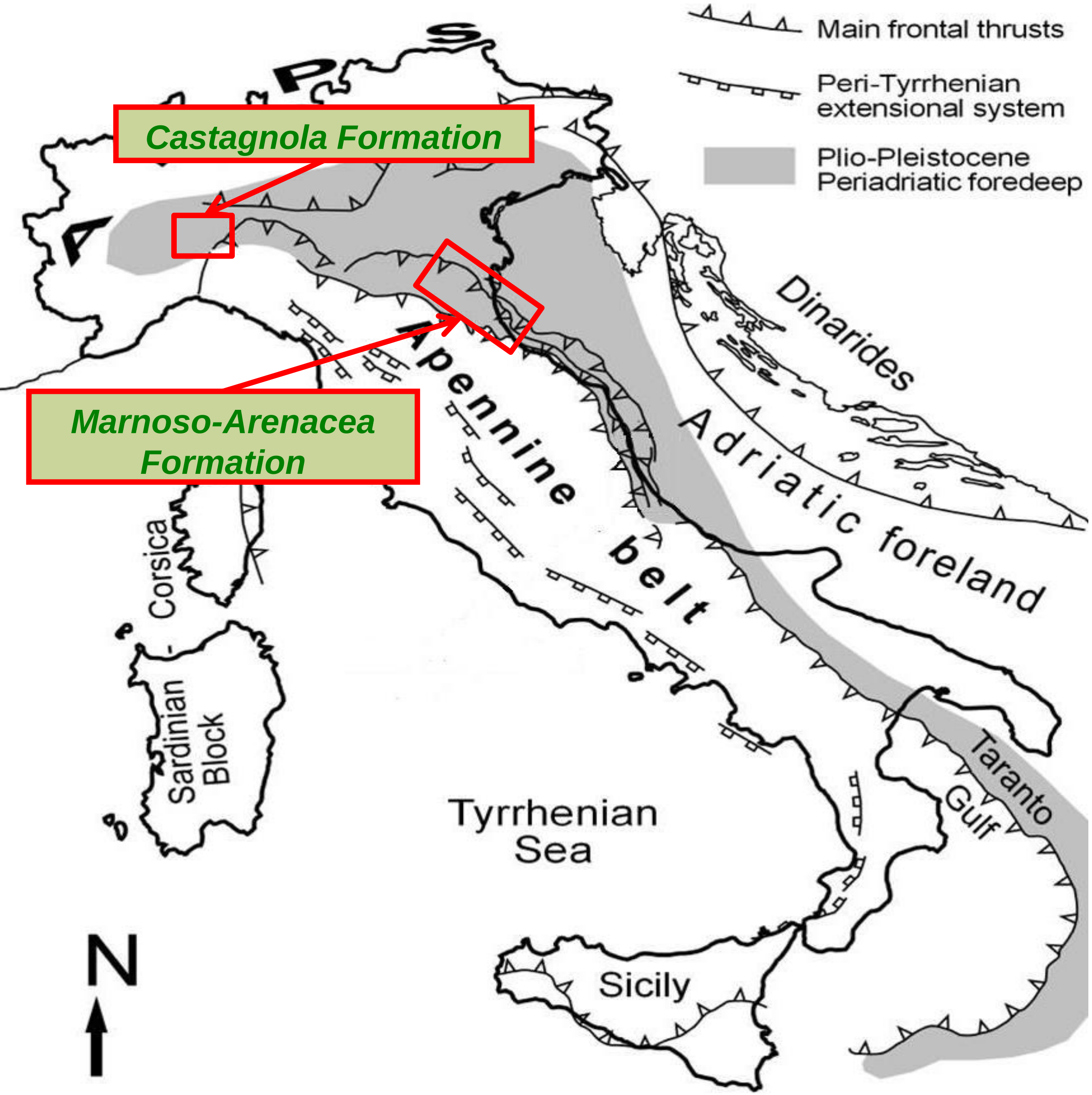
Main types of anisotropic grain shape fabrics



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

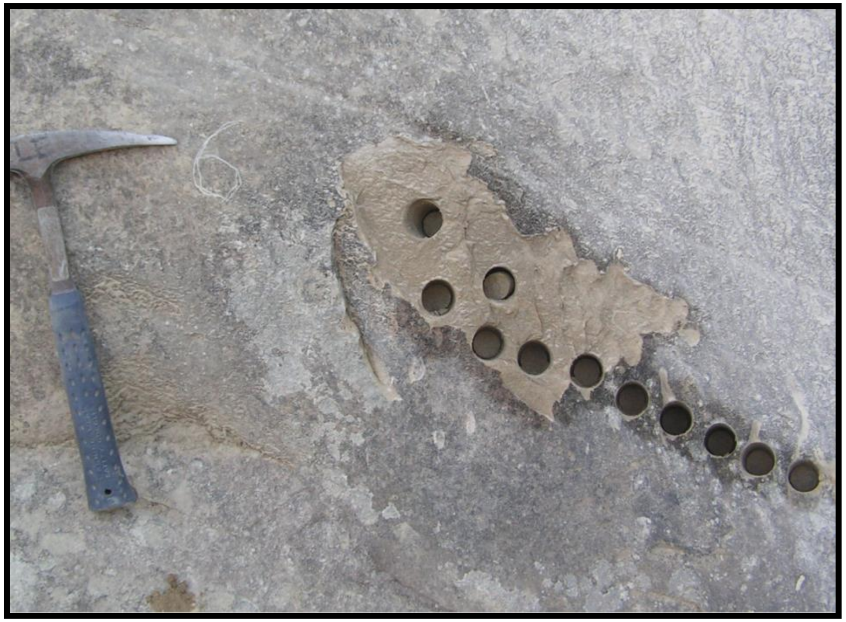
Flute marks or linear grooves

Marnoso-Arenacea Formation

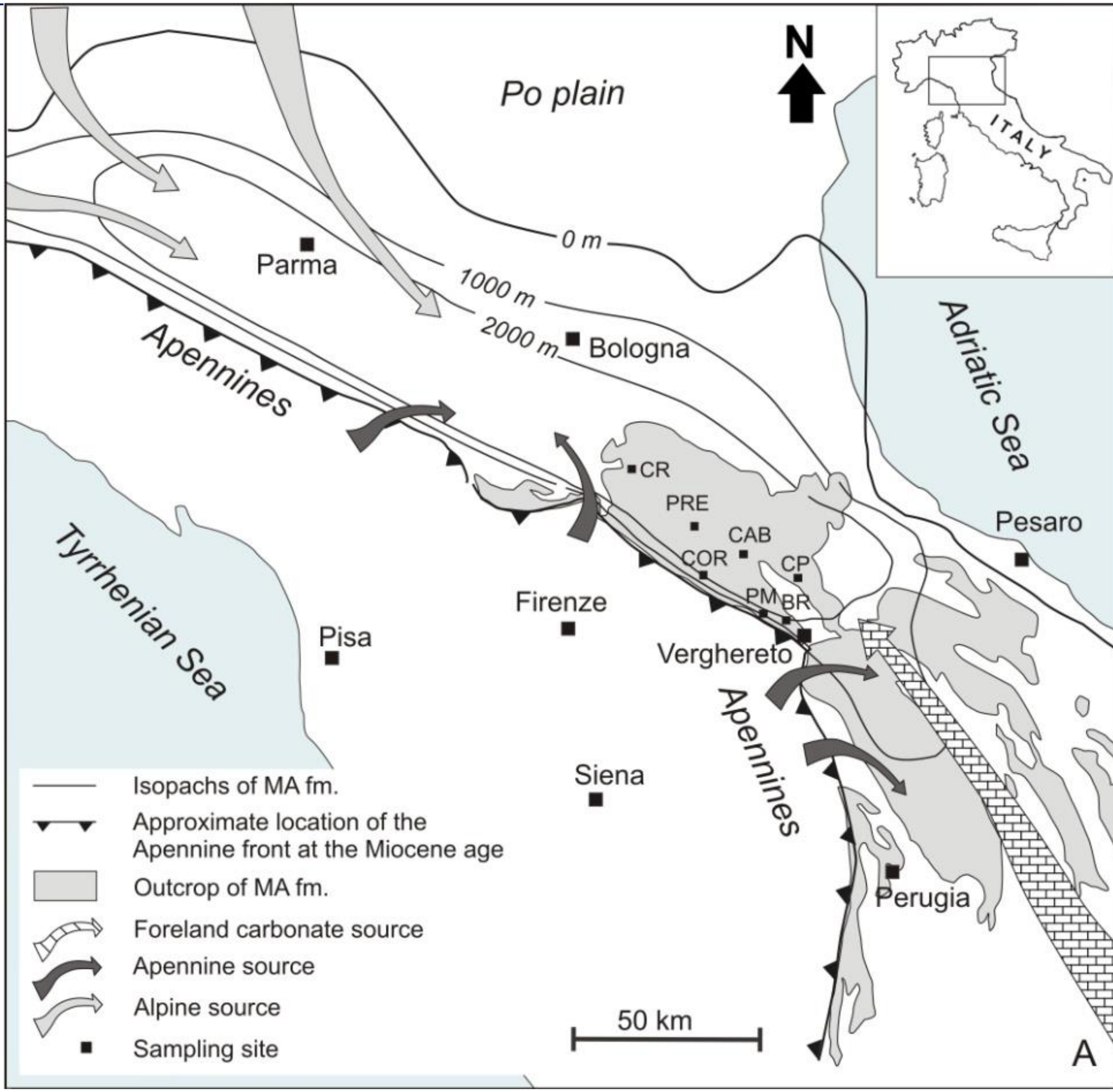
FLUTE MARKS AND LINEAR GROOVES

Castagnola Formation

SAMPLING (853 samples)



MARNOSO ARENACEA FM (Langhian – Tortonian)



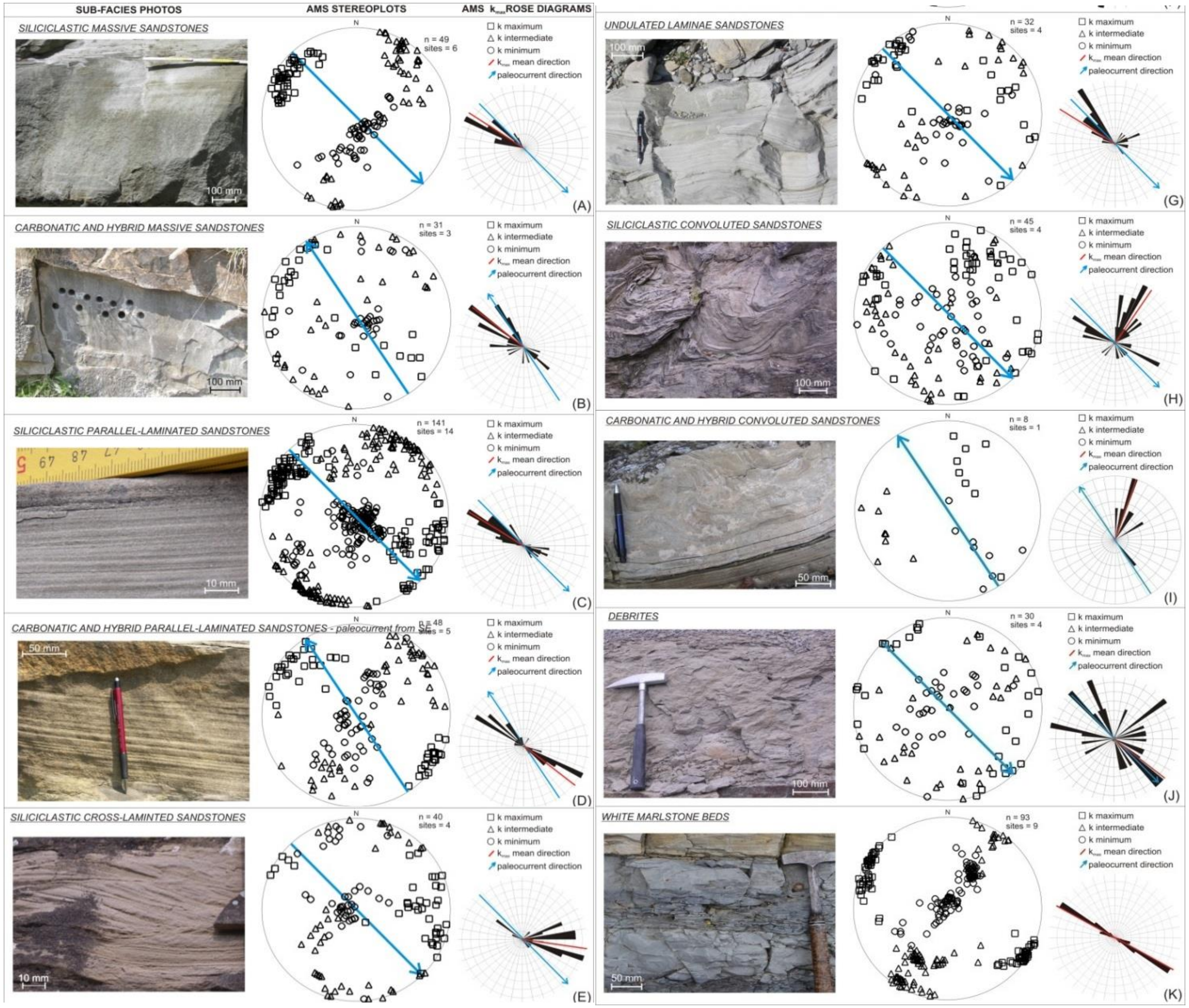
- Elongated **foredeep basin**
- Paleoflow direction from NW and SE
- Basin: 180 km long x 40 km wide
- Basin thickness: ~ 3000 m thick
- Mineralogic composition: monomineralic grains, heavy minerals, lithic fragments, bioclasts (foraminifera)

551 samples in 58 beds

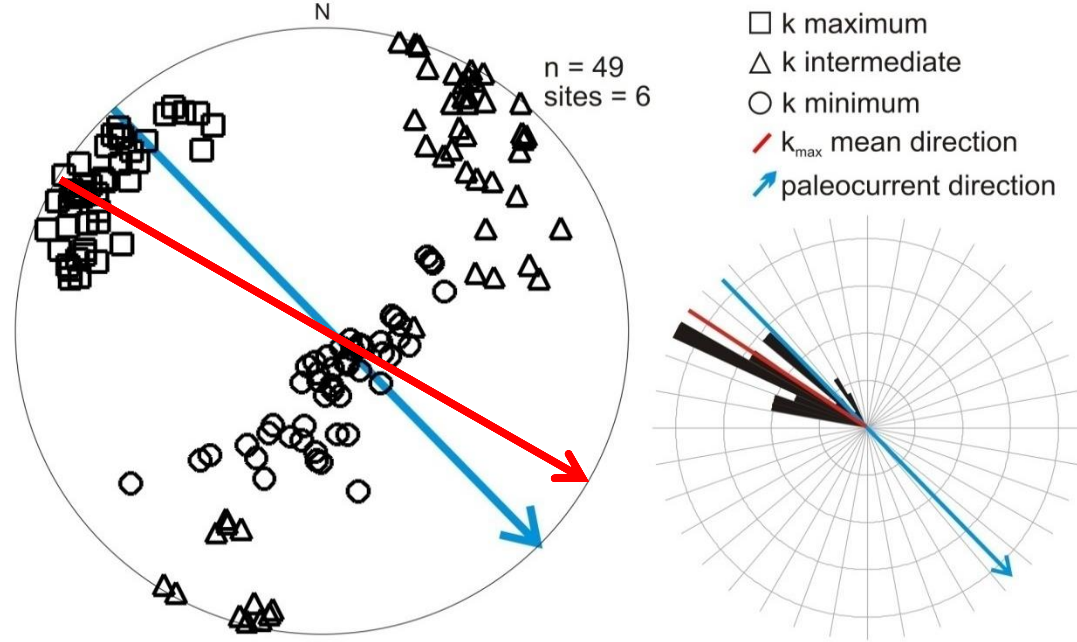
7 stratigraphic sections

AMS STEREOPLOTS

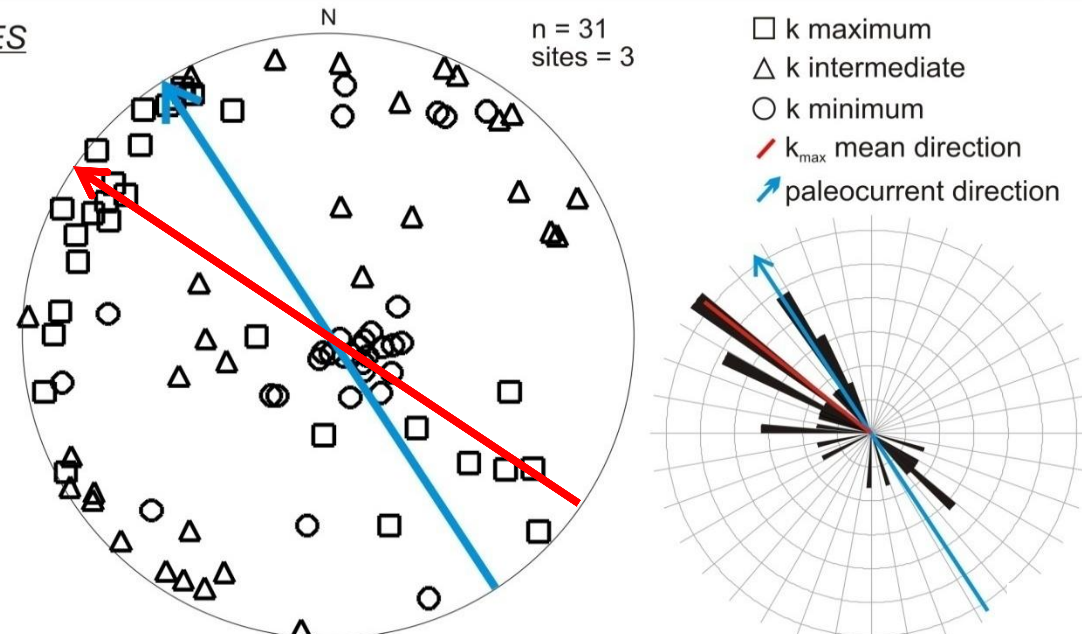
Marnoso-Arenacea Fm.



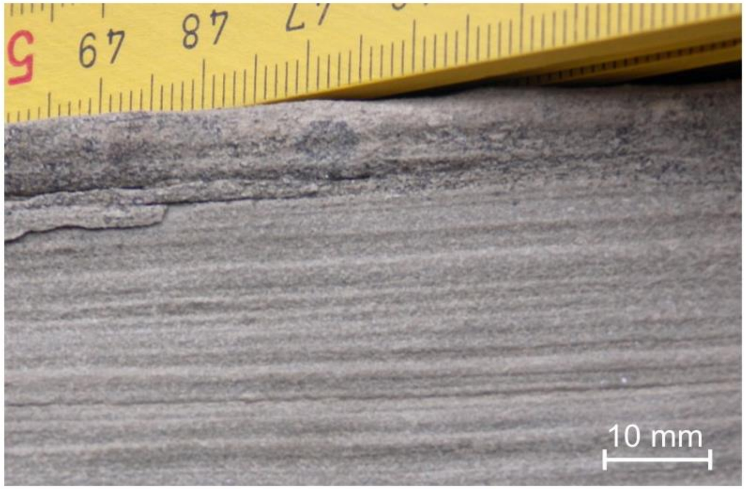
SILICICLASTIC MASSIVE SANDSTONES

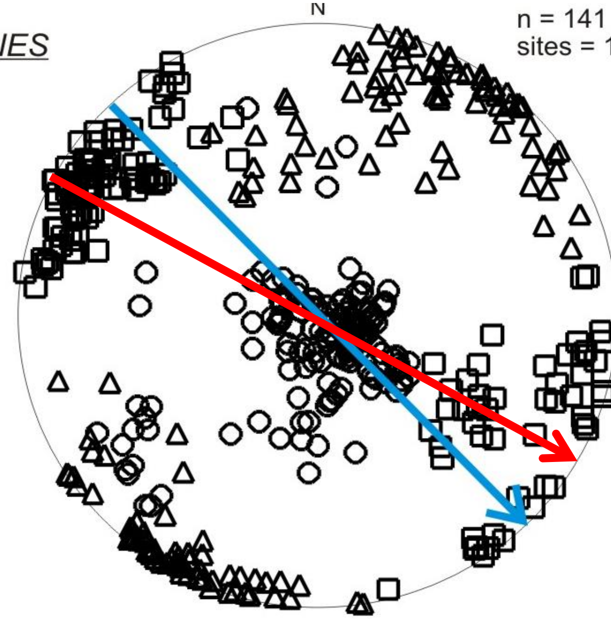


CARBONATIC AND HYBRID MASSIVE SANDSTONES

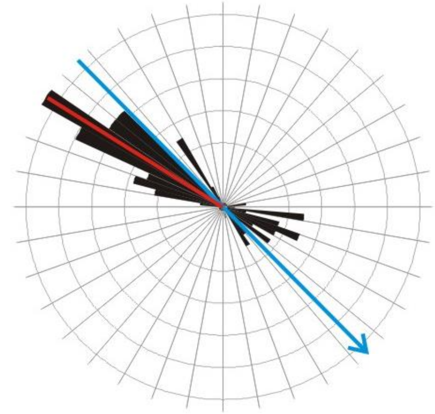


SILICICLASTIC PARALLEL-LAMINATED SANDSTONES

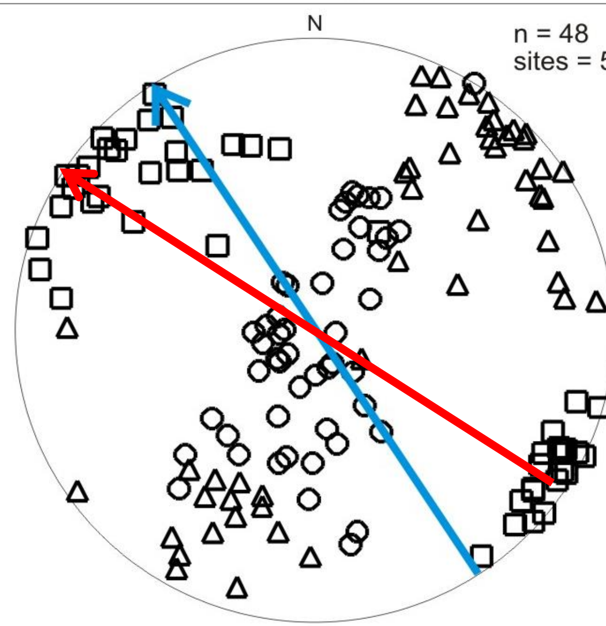




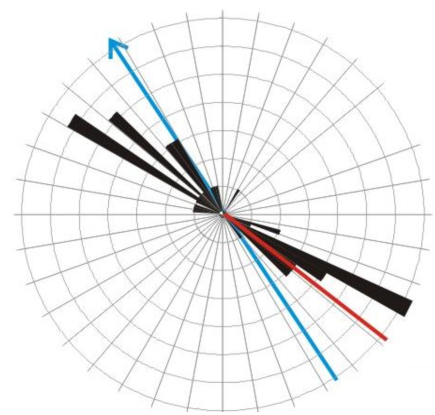
□ k maximum
△ k intermediate
○ k minimum
k$_{max}$ mean direction
paleocurrent direction



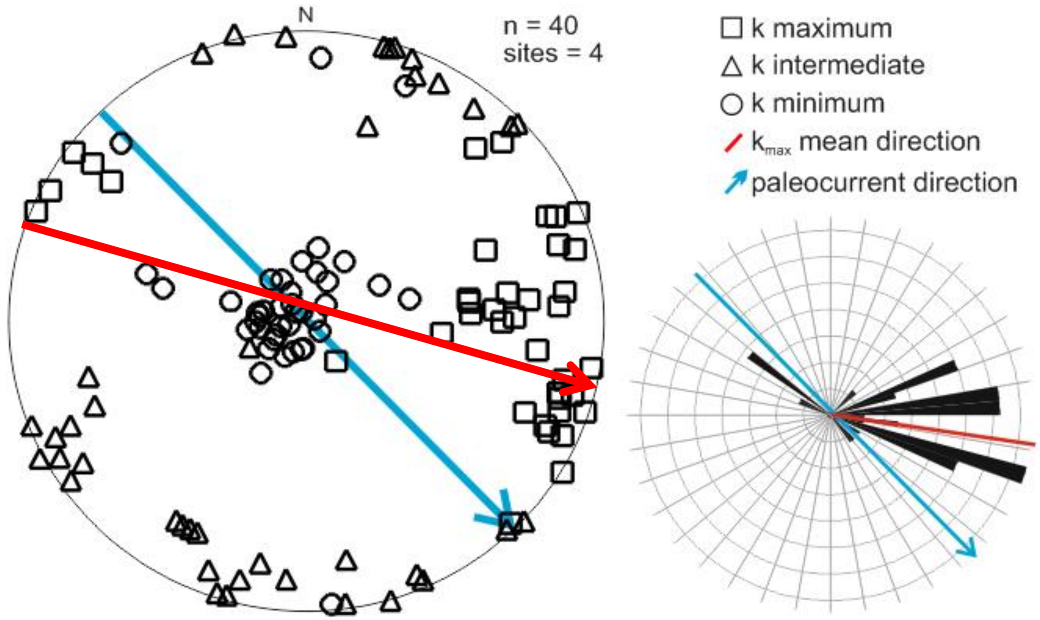
CARBONATIC AND HYBRID PARALLEL-LAMINATED SANDSTONES - paleocurrent from SE



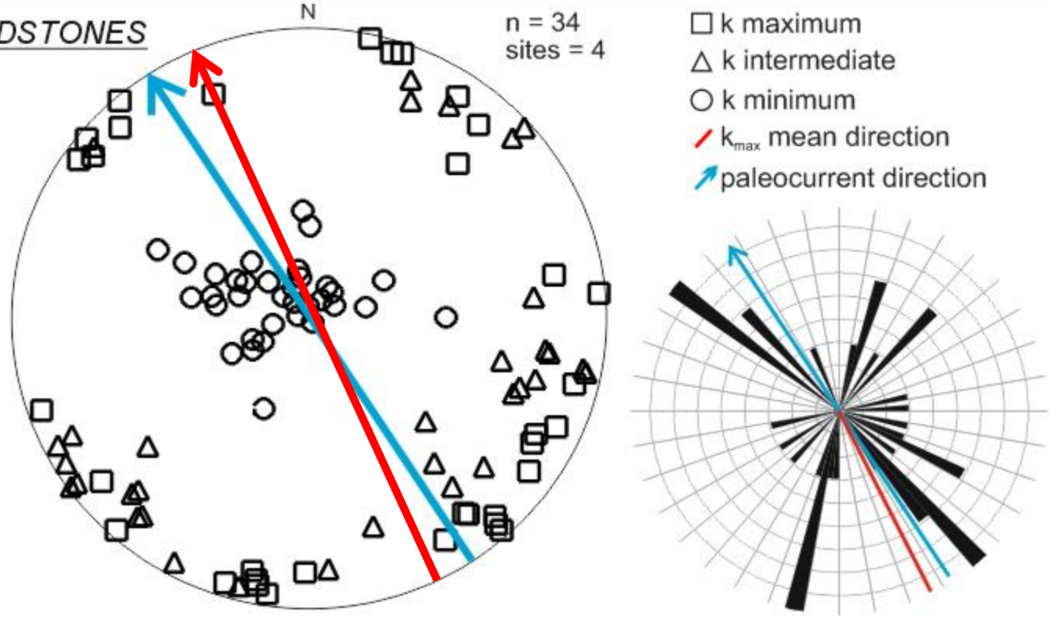
□ k maximum
△ k intermediate
○ k minimum
k$_{max}$ mean direction
paleocurrent direction



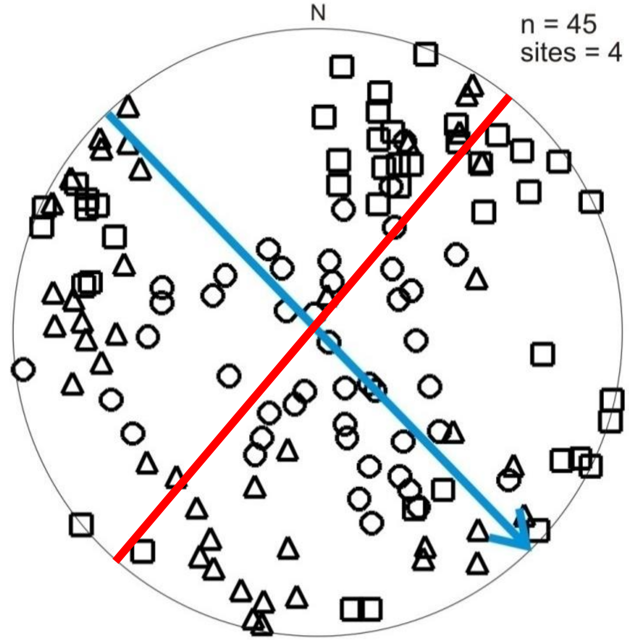
SILICICLASTIC CROSS-LAMINTED SANDSTONES



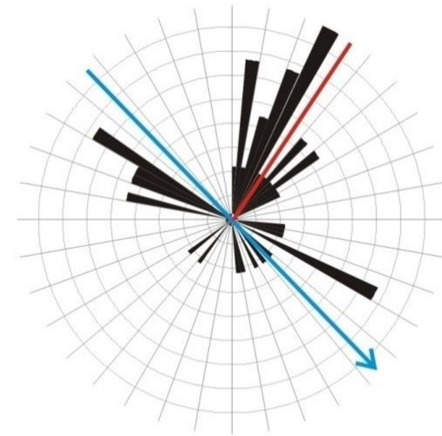
CARBONATIC AND HYBRID CROSS-LAMINTED SANDSTONES



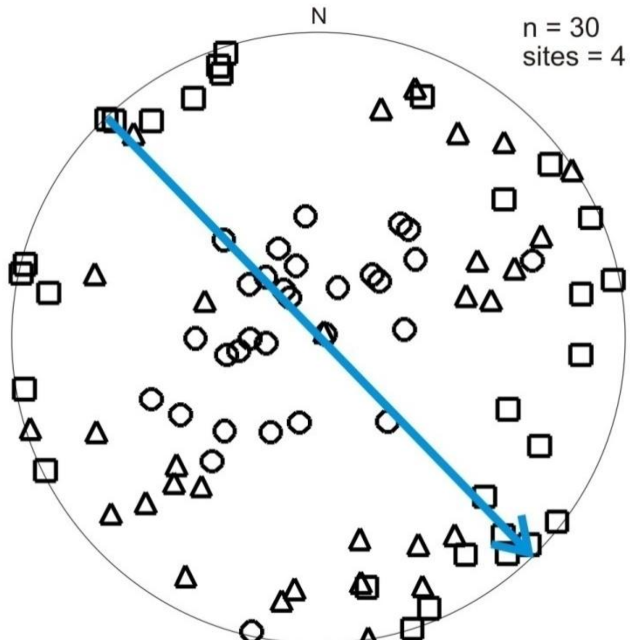
SILICICLASTIC CONVOLUTED SANDSTONES



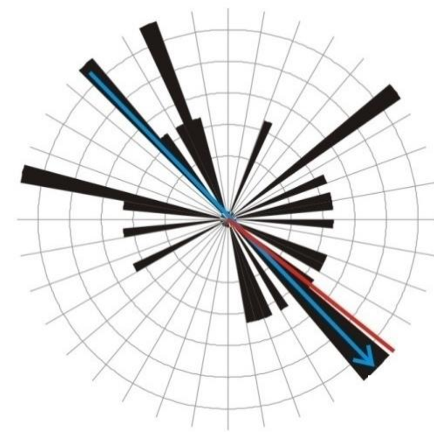
□ k maximum
△ k intermediate
○ k minimum
k_{max} mean direction
paleocurrent direction



DEBRITES

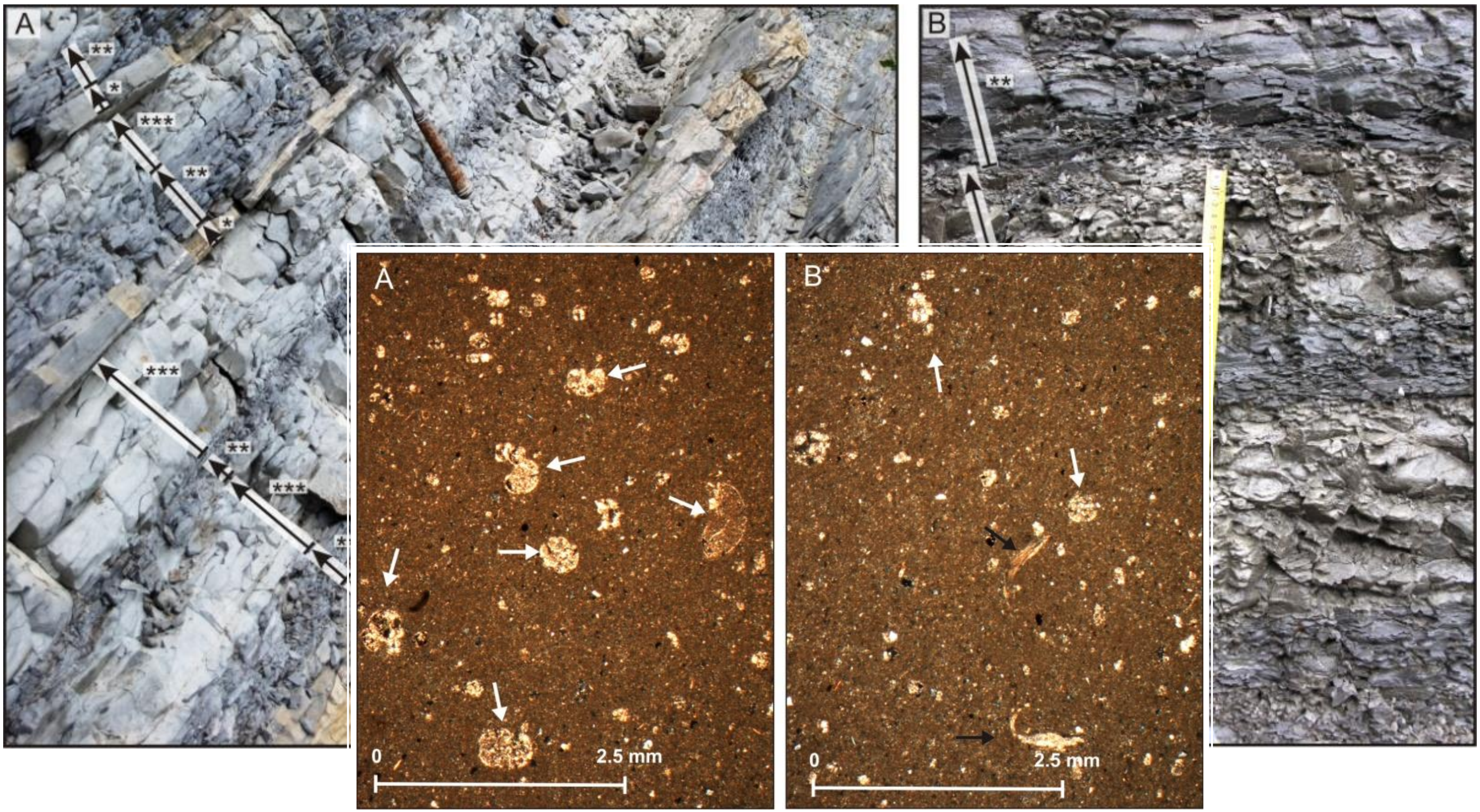


□ k maximum
△ k intermediate
○ k minimum
k_{max} mean direction
paleocurrent direction

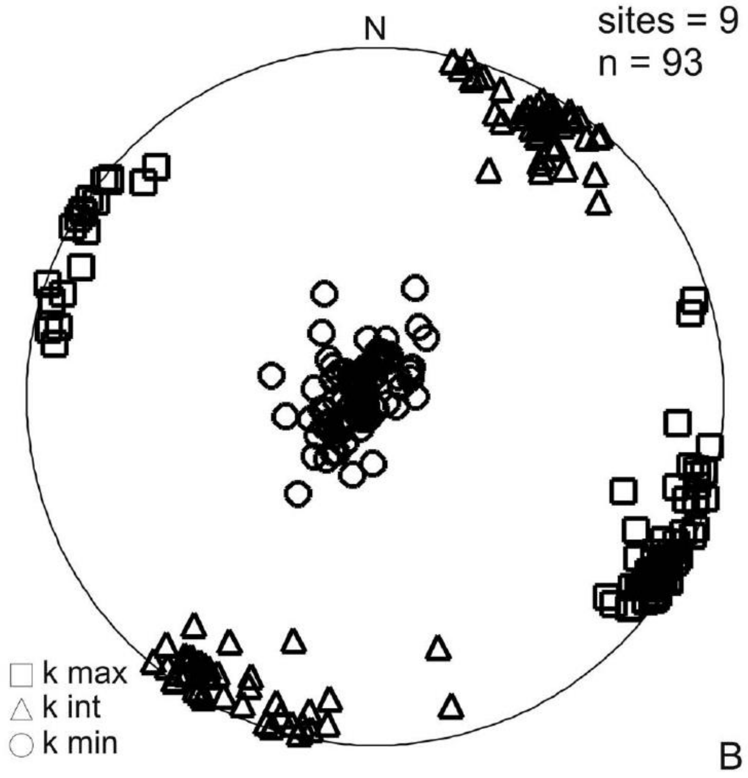


White Marlstone Beds
(HEMIPELAGITES)

White Marlstone Beds
(HEMIPELAGITES)

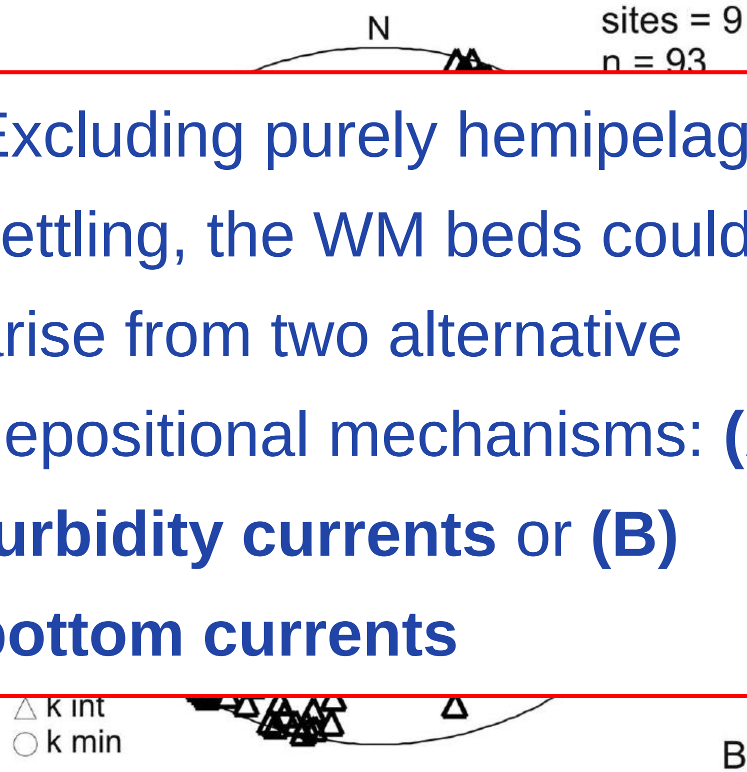


White Marlstone Beds
(HEMIPELAGITES)



These results suggest that the WM beds **deposited under weak velocity flows** that oriented the k_{max} axes of paramagnetic grains (slightly elongated phyllosilicates), parallel to the mean current direction in the final stages of transport.

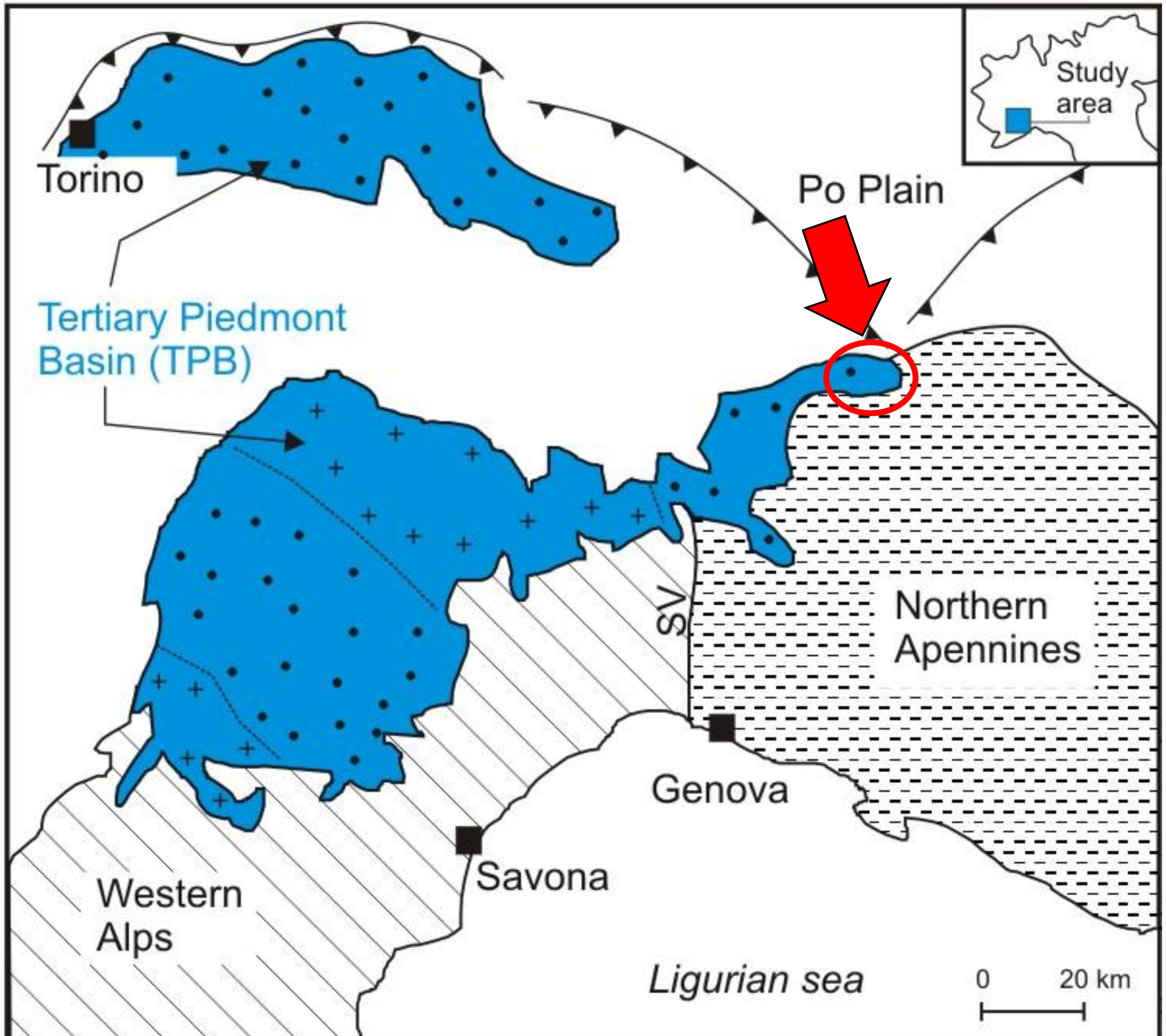
White Marlstone Beds (HEMIPELAGITES)



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_{max} axes of paramagnetic grains (slightly elongated phyllosilicates), parallel to the mean current direction in the final stages of transport.

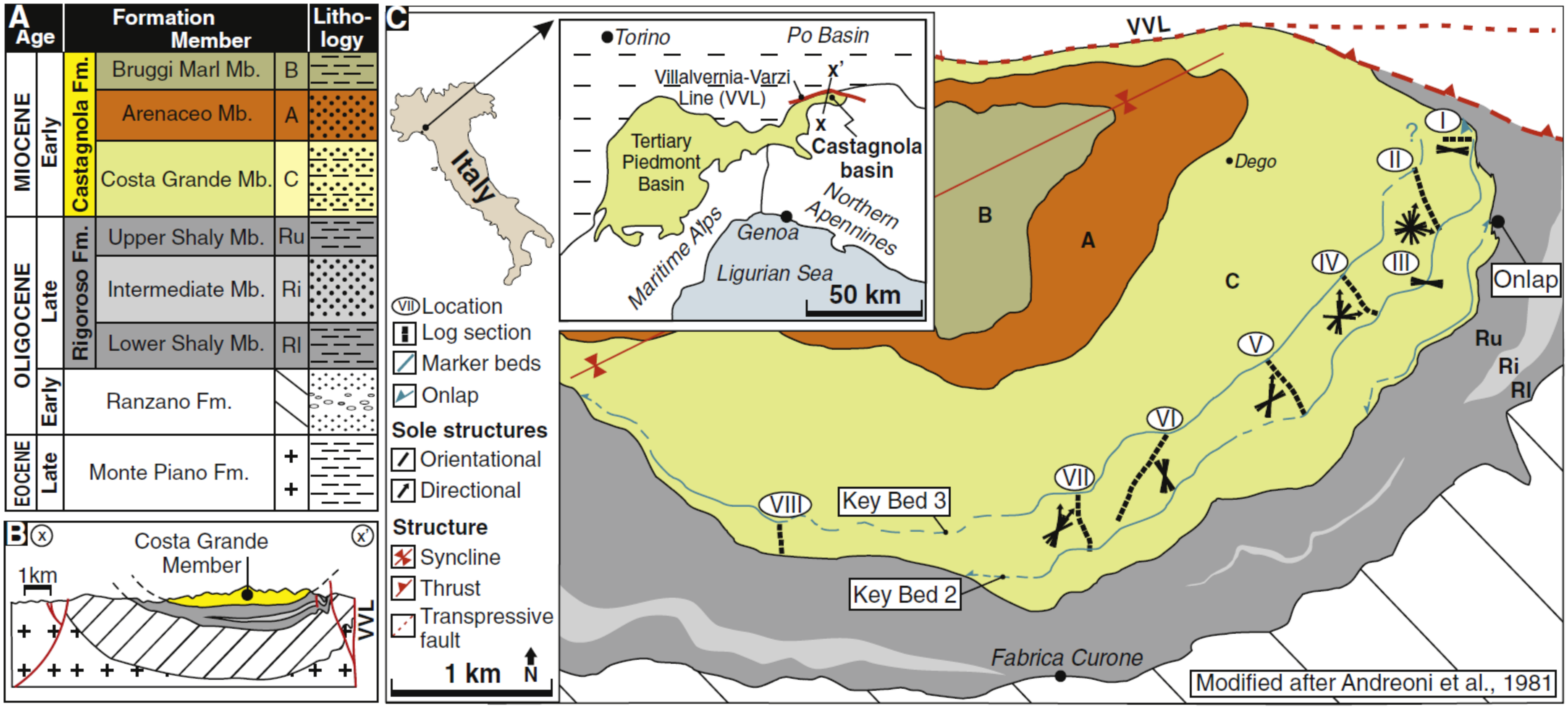
CASTAGNOLA TURBIDITE SYSTEM (TERTIARY PIEDMONT BASIN - NW ITALY)



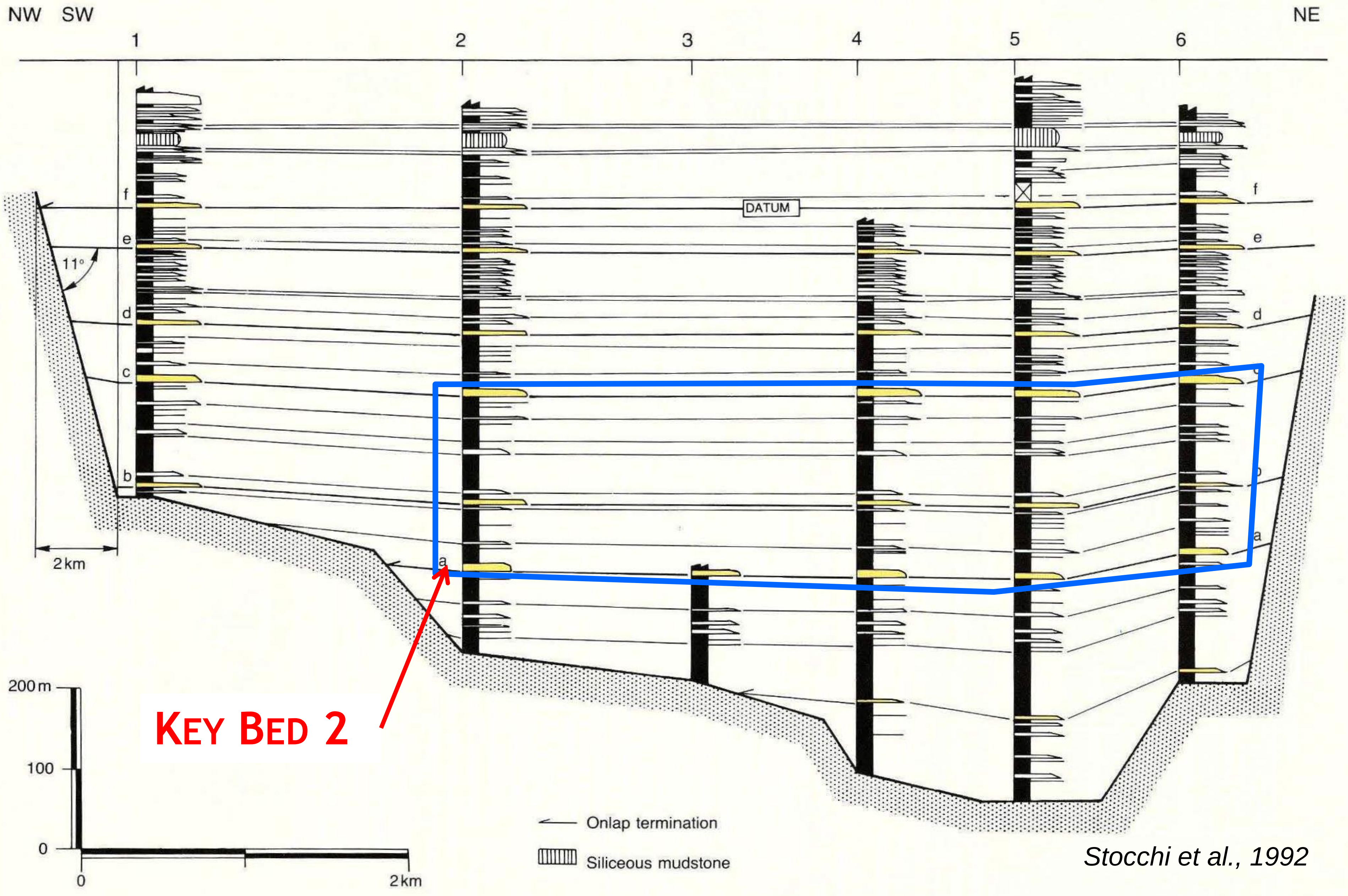
CASTAGNOLA FM (Oligo-Miocene)

- **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)



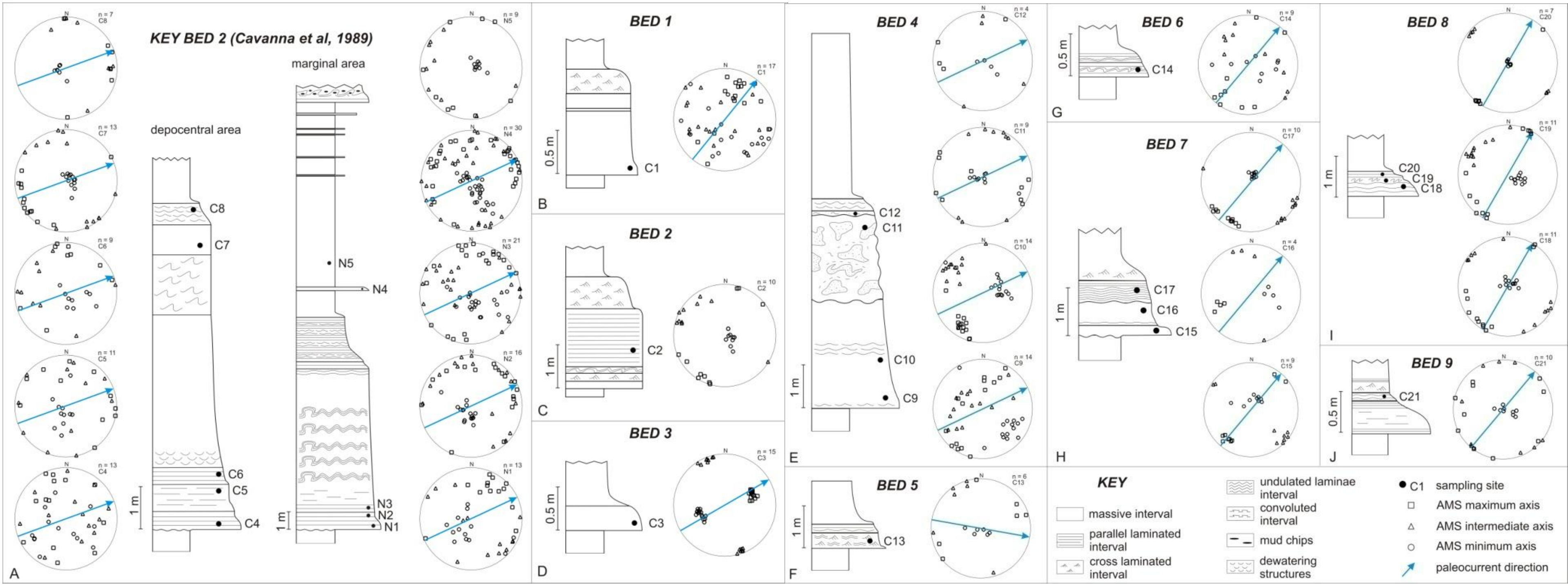
Southern et al., 2015

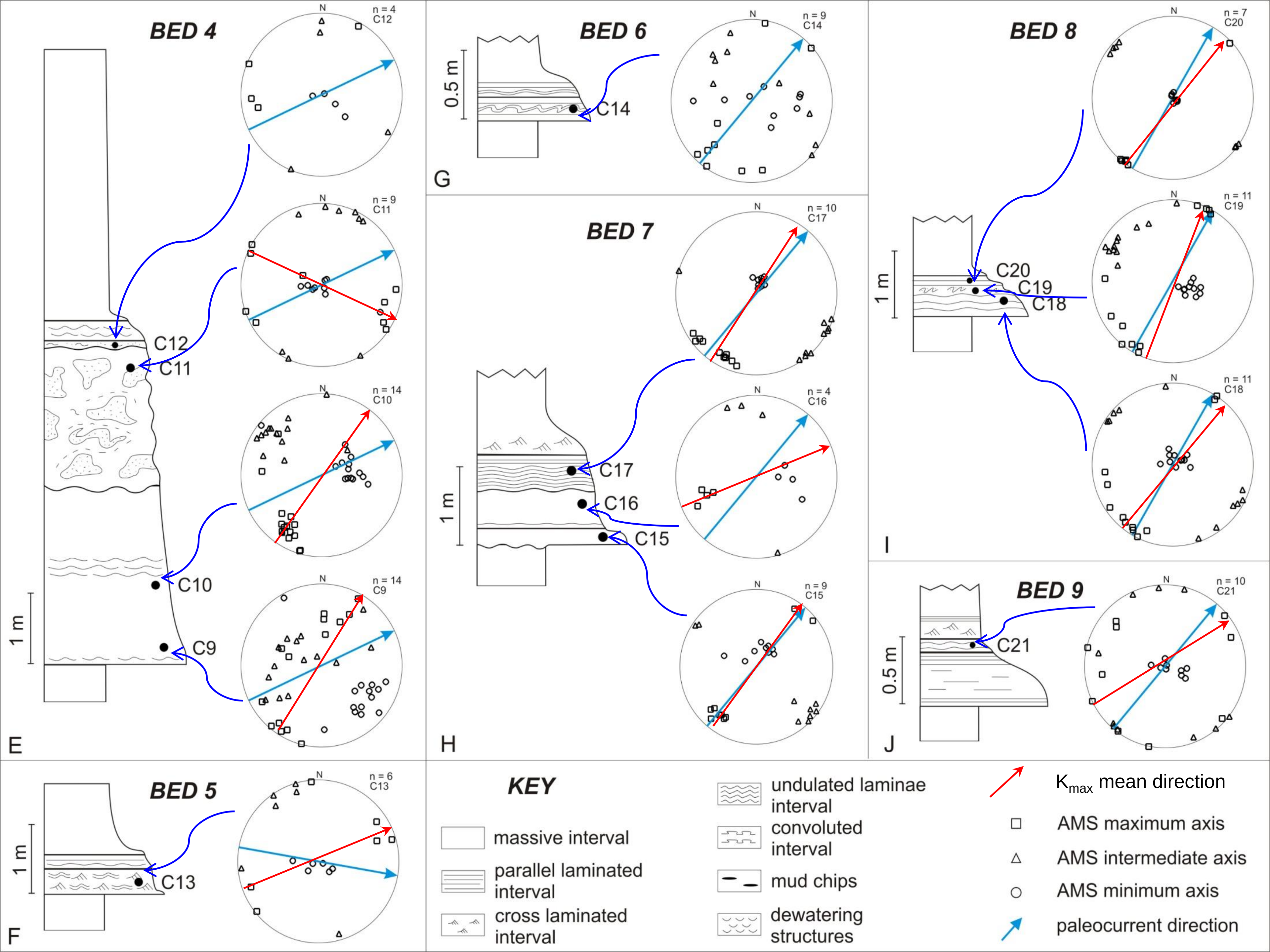


Stocchi et al., 1992

AMS STEREOPLOTS

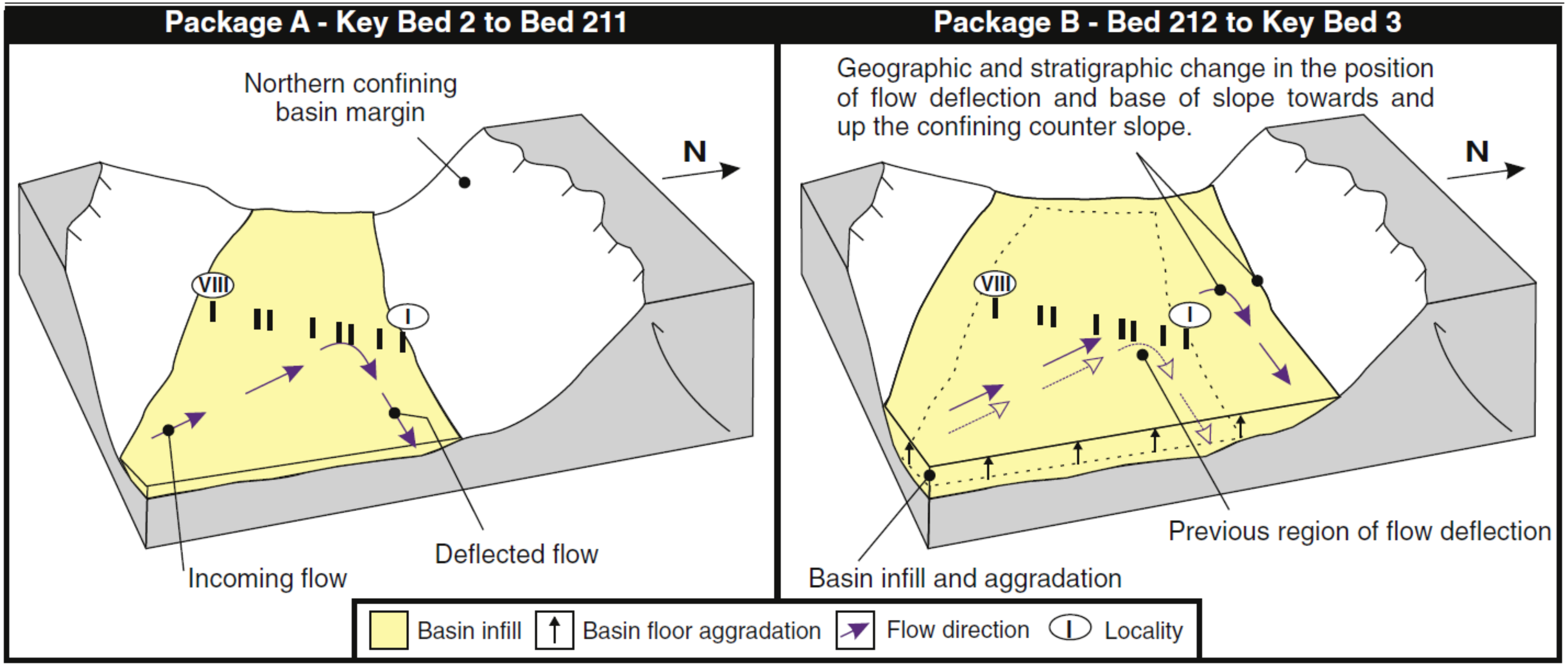
302 samples



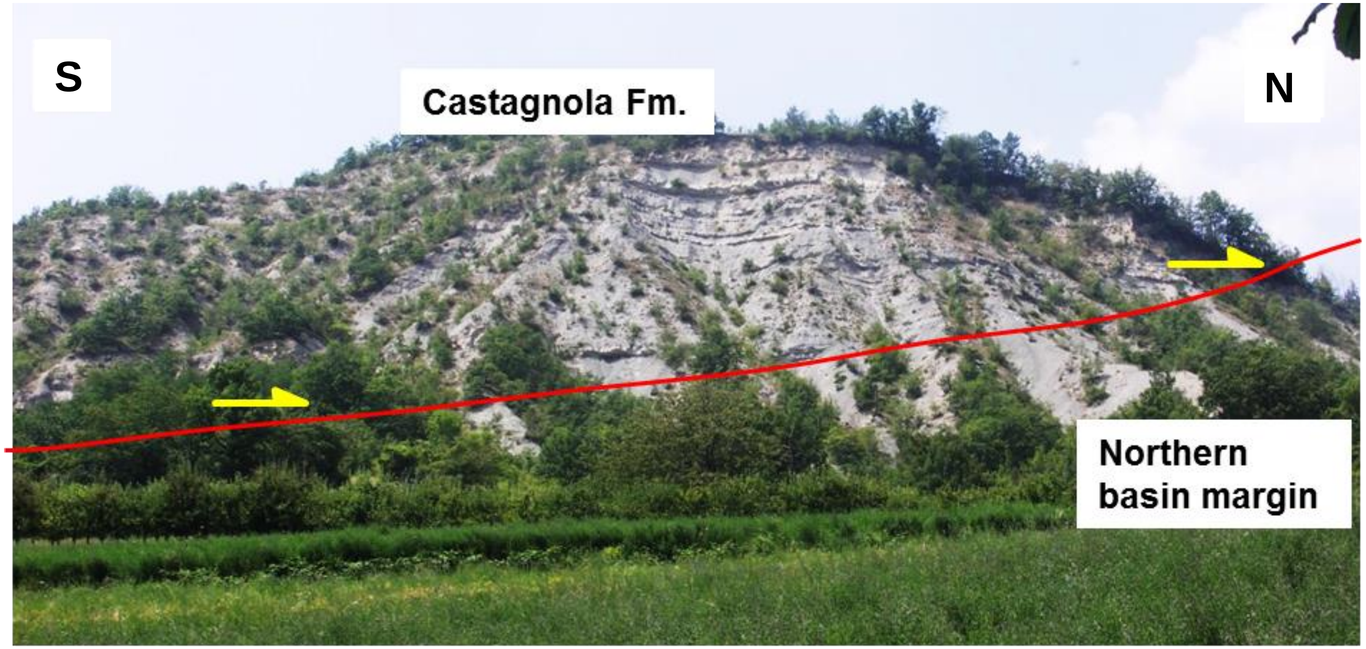

BED 4
BED 5
BED 6
BED 7
BED 8
BED 9
C9
C10
C11
C12
C13
C14
C15
C16
C17
C18
C19
C20
C21
1 m
0.5 m
N
n = 4
n = 9
n = 14
n = 6
n = 10
n = 11
n = 7
E
F
G
H
I
J
KEY
massive interval
parallel laminated interval
cross laminated interval
undulated laminae interval
convoluted interval
mud chips
dewatering structures
K_{max} mean direction
AMS maximum axis
AMS intermediate axis
AMS minimum axis
paleocurrent direction

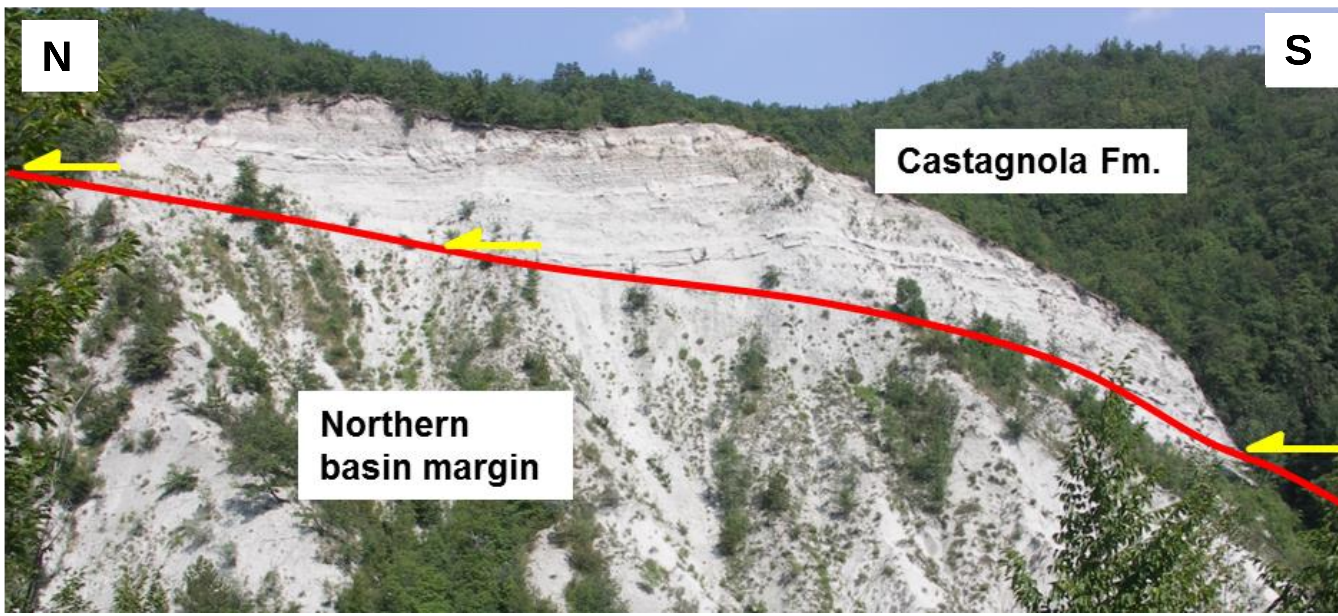
Impact of basin topography on flow behaviour:

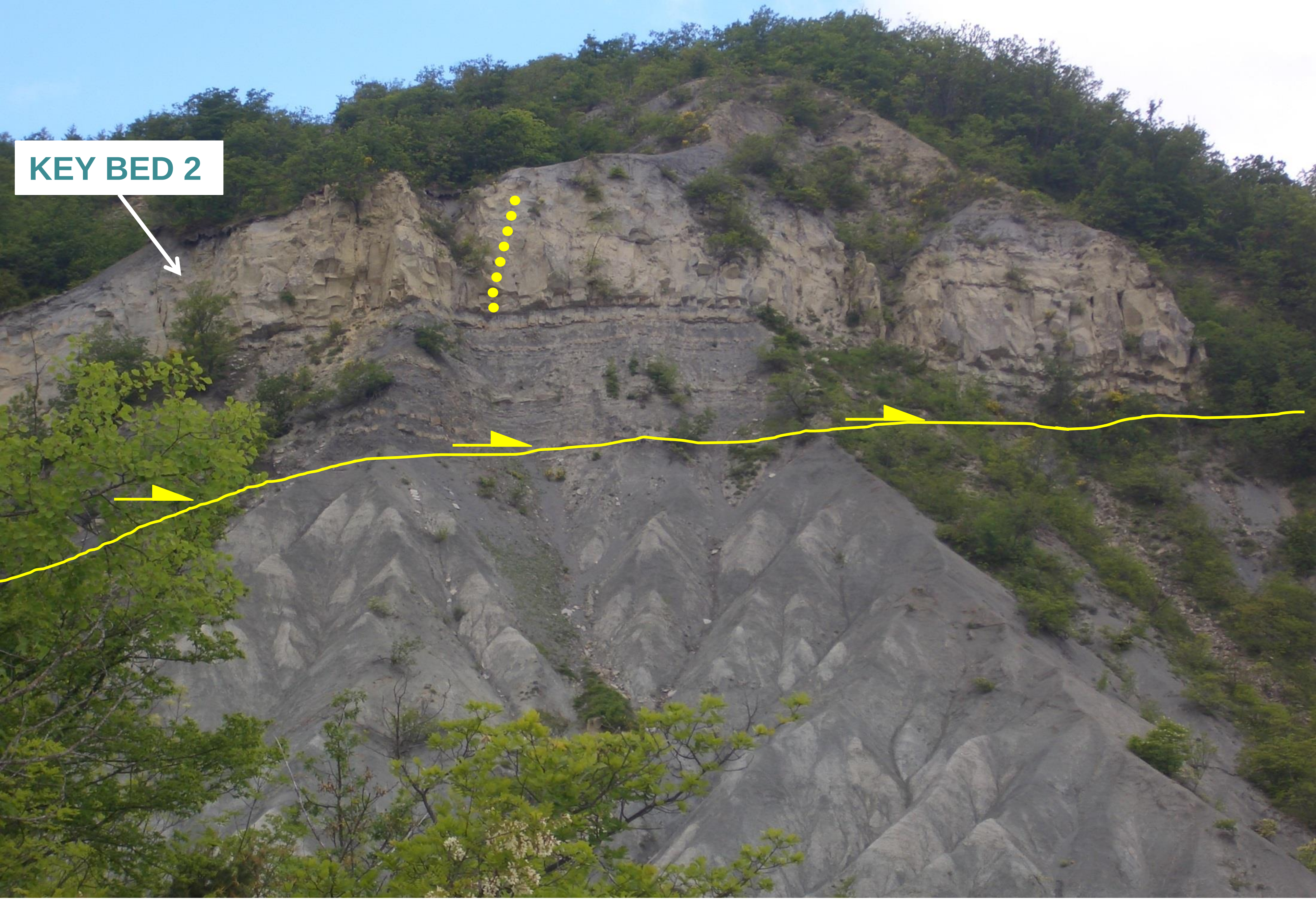
(1) density stratification of the turbidity current; (2) the dense basal part of the flow is partially blocked and deflected; (3) the less dense muddy and silty fraction surmounts the palaeoslope and surges backwards as a series of reflections; (4) complex interaction between the dense basal part of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



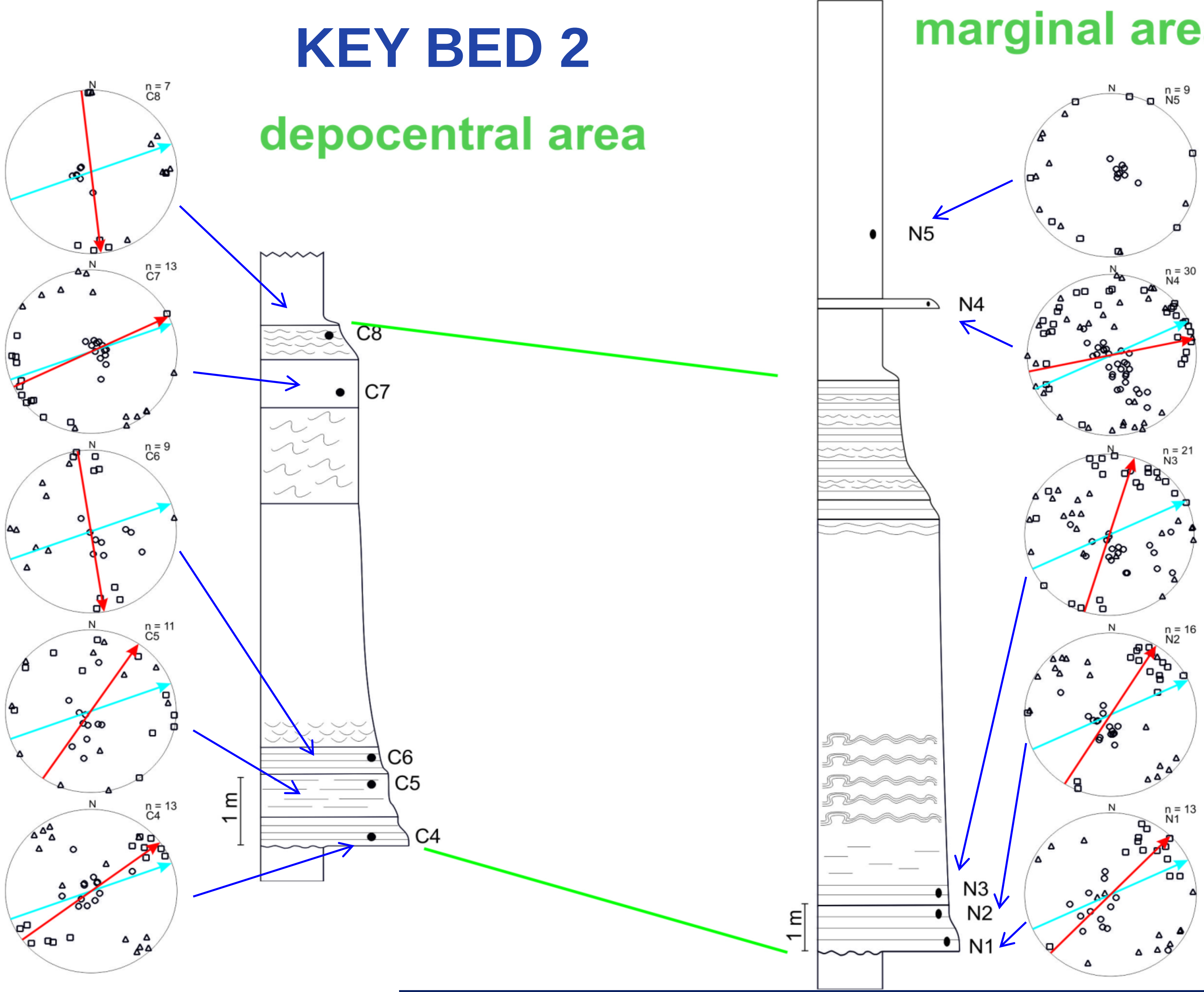
Southern et al., 2015


S
Castagnola Fm.
N
Northern
basin margin


N
S
Castagnola Fm.
Northern
basin margin


KEY BED 2

KEY BED 2



depocentral area
marginal area
n = 7
C8
n = 13
C7
n = 9
C6
n = 11
C5
n = 13
C4
C8
C7
C6
C5
C4
1 m
n = 9
N5
n = 30
N4
n = 21
N3
n = 16
N2
n = 13
N1
N5
N4
N3
N2
N1
1 m

CONCLUSIONS

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)*