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A First Experimentally Derived Classification of Submarine Sediment Gravity Flows*

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Search and Discovery Article #40554 (2010)
Posted June 30, 2010

*Adapted from oral presentation, with Richard Eduard Dücker as speaker, at AAPG Annual Convention and Exhibition, New Orleans, Louisiana, April 11-14, 2010

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Abstract

Our ability to interpret the deposits of marine sediment gravity flows (SGF) has been greatly restricted by a lack of understanding of their flow processes. This limitation is reflected in the numerous classification schemes and the difficulty in using terms such as low (LDTC) and high-density turbidity currents (HDTC).

Here we report a novel experimentally derived classification scheme that for the first time identifies flow types and quantifies their transition points. A series of 25 runs of three types of turbidity currents ranging from 2.5% to 35% concentration by volume with non-cohesive (silt-sized glass beads) and cohesive (kaolin) sediment was performed at different clay-silt ratios. Digital camcorders, Ultra-High Concentration Meters, Ultrasonic Velocity Profiler and a Rheometer were used to acquire flow and rheological data.

The hydrodynamic properties of the flows were determined using changing flow geometry, and high-frequency time-series, depth-average values and vertical profiles of velocity and sediment concentration. Moreover, the deposits were studied using Scanning Electron Microscopy.

Six types of flows were distinguished based on a comparison of hydrodynamic, depositional and rheological properties. A 3D phase diagram was created, showing the boundaries between these flow types in terms of rheological behaviour, bulk volumetric and clay concentration. The main characteristics of the flow types are:

- Type I: Newtonian; grains supported by turbulence; segregation of grains and normally graded beds.
- Types II and III: Newtonian; grains supported by turbulence, hindered settling; undulating high-concentration near-bed layer (stronger in type III); partial size segregation forming partially graded beds.
- Type IV: non-Newtonian; viscous flow; formation of plug (flow freezing) and shear flow generating graded beds of muddy sand.
- Types V and VI: non-Newtonian; viscous flow with thick mud layer; grain support by matrix strength; cohesive freezing forms ungraded muddy sand with coarse-tail grading near to the top.

A new process-related classification of sediment gravity flows is proposed. Type I resembles classic LDTC behavior, and Types V and VI are similar to the debris flow behavior. Types II and III are classified as inertial HDTC, due to flow turbulence, and Type IV represents a viscous HDTC, due to cohesive clay influence on flow and deposit.

The implications of the new classification scheme for natural deposits of SGF will be discussed.

Selected References

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Speaker: **Richard Eduard Dücker**

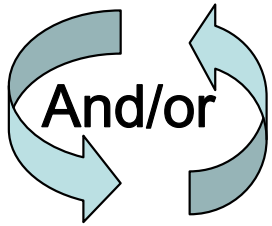
AAPG Annual Meeting – New Orleans - USA
April 11th to 14th 2010

SEDIMENT GRAVITY FLOWS

Classification of Sediment gravity flow based principally

FLOW PROPERTIES

- Concentration
- Mechanism support -Turbulence
- Rheology
- Grain size and type



DEPOSIT PROPERTIES

- Gradation
- stratigraphy
- facies

Two approaches

⇩

Lots of classifications in literature – some examples

PROPERTY USED TO CLASSIFY	AUTHORS										
	KUENEN	DOTT	SANDERS	MIDDLETON HAMPTON	LOWE	POSTMA	KNELLER	SHANMUGAN	MUTTI	MULDER ALEXANDER	GANI
YEAR	1950	1963	1965	1976	1982	1988	1995	1996	1999	2001	2004
DENSITY	■			■							
CVOL						■	■	■		■	
RHEOLOGY		■			■			■	■	■	■
MEC. SUPPORT			■	■	■	■		■	■	■	
GRAIN SIZE					■			■			
FLOW DURATION										■	
CLAY PRESENCE										■	

NOT COMPLETE UNDERSTOOD AT ALL

MAIN GOAL

Generate experimentally different flows

RHEOLOGY OF THE MIXTURES

HYDRAULIC PROPERTIES

DEPOSITIONAL PROPERTIES

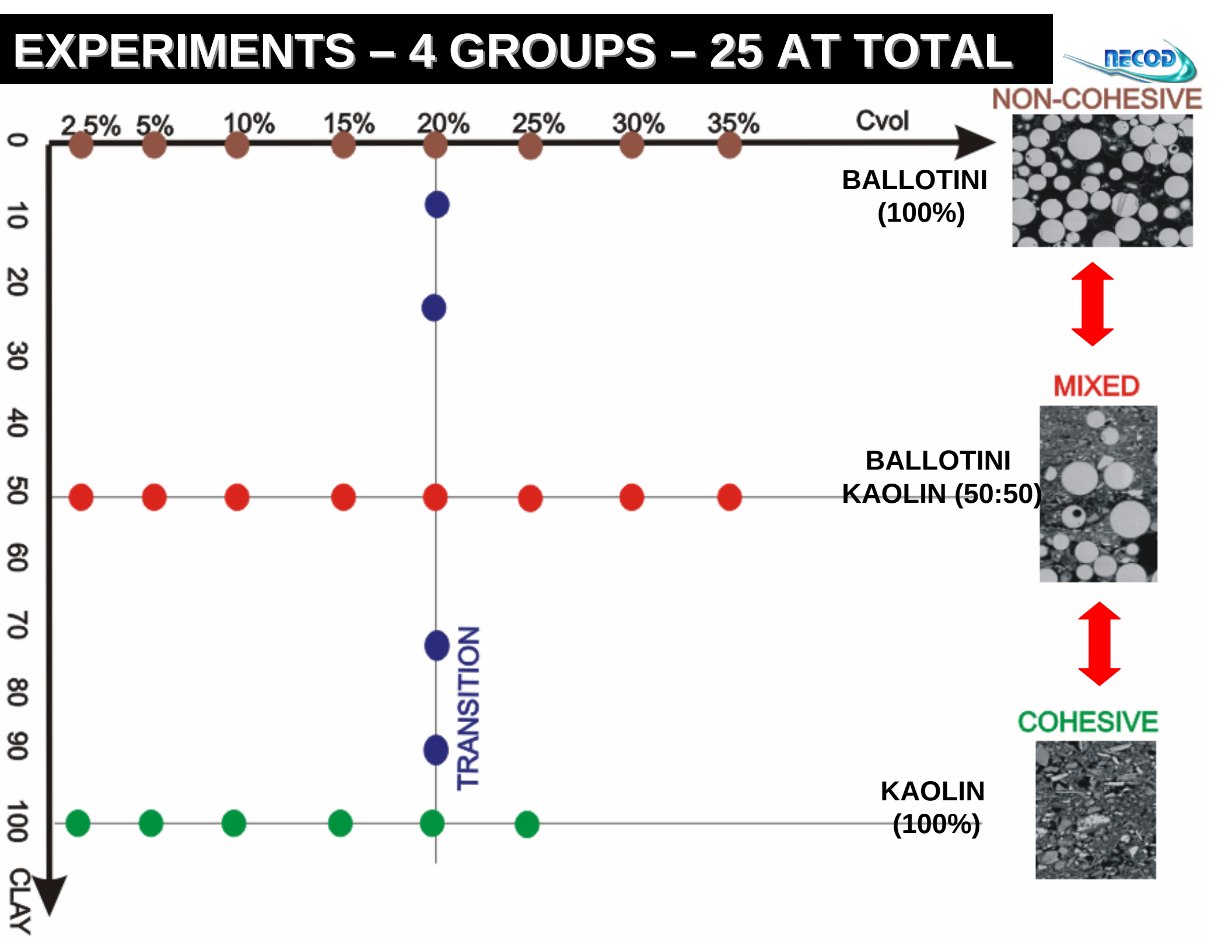
Link hydrodynamics and depositional process

Model of sedimentation process (natural analogue)

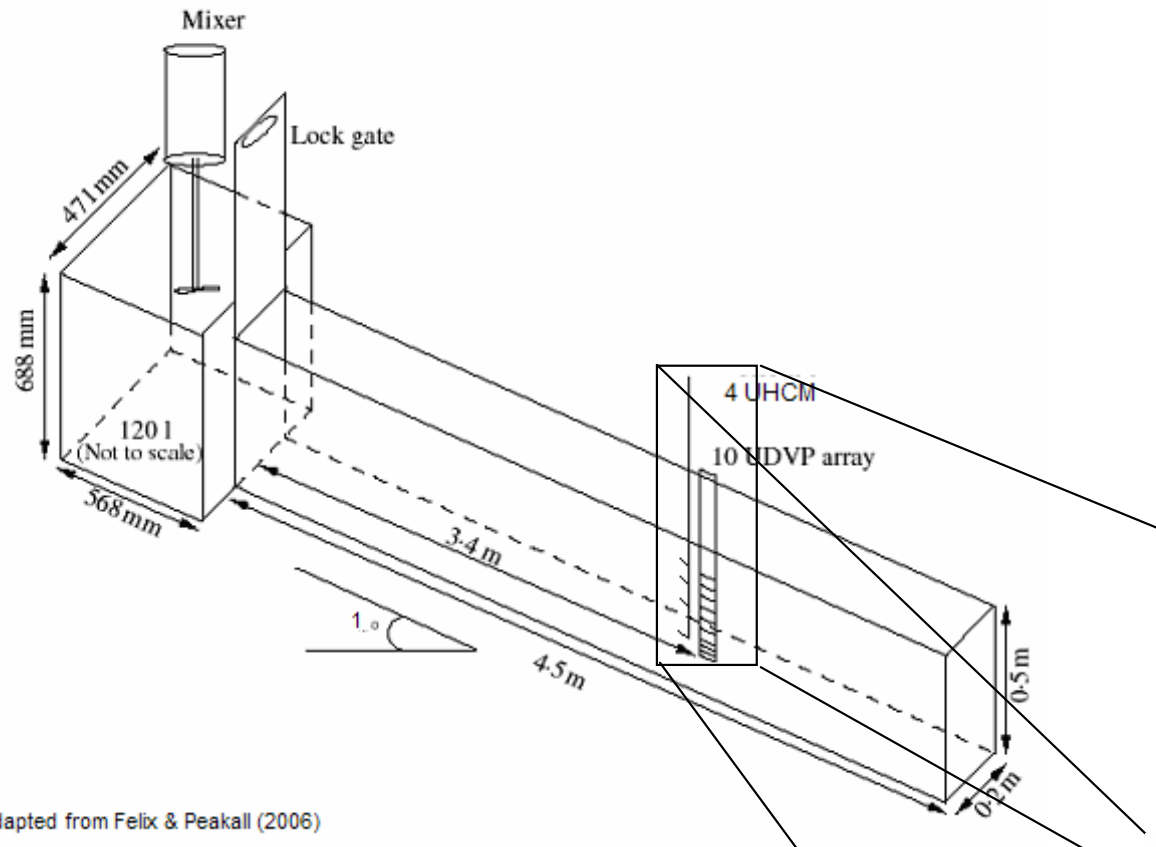
Distinguish those flows from other sediment gravity flows (LITERATURE REVIEW- COMPARE)

Experimentally-derived classification

EXPERIMENTS – 4 GROUPS – 25 AT TOTAL

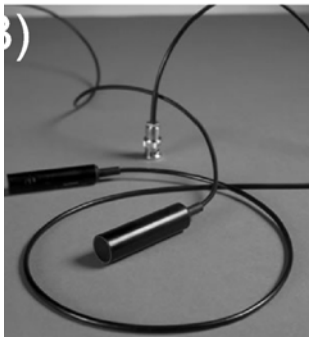


Apparatus

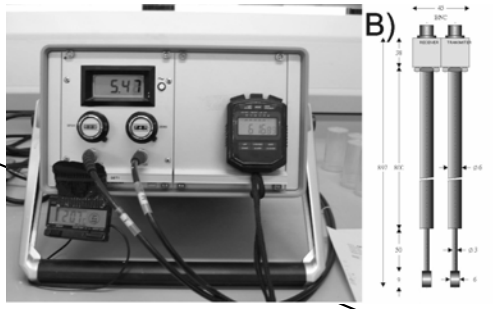


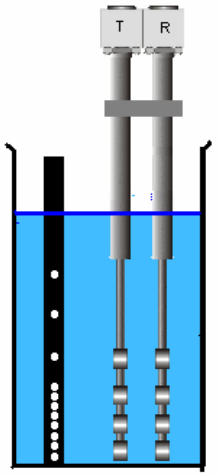
Adapted from Felix & Peakall (2006)

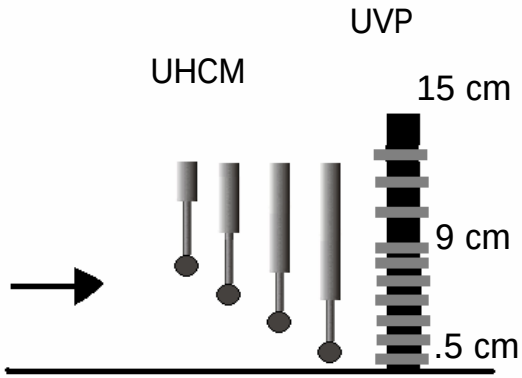
Velocity data –
UVP – 10 probes



Concentration data
4 UHCM´s







Perspex Long Tank: 4,5 m long x 0,2 m wide x 0,5 m high

Slope: 0,8°

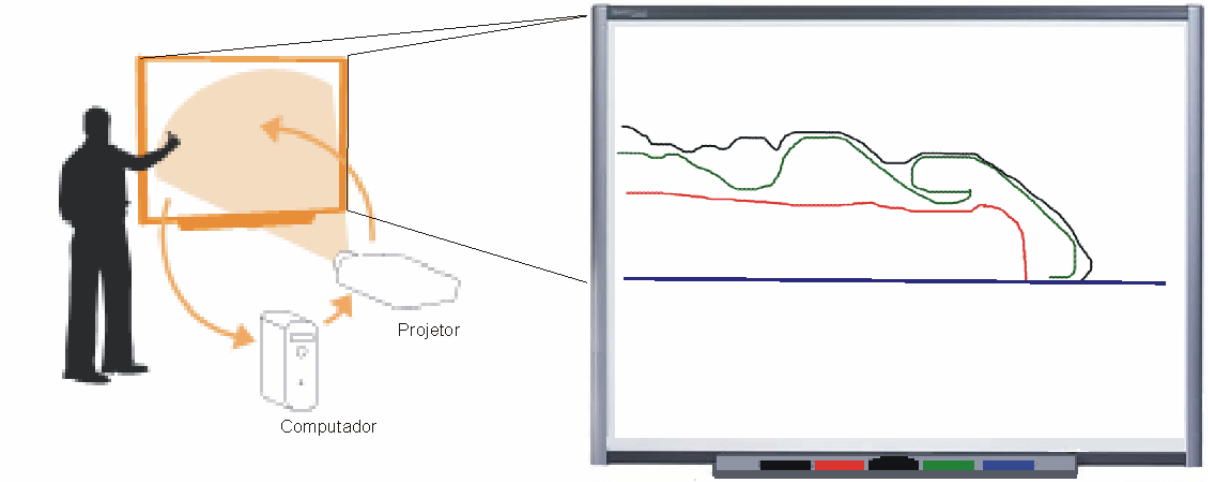
Mixture volume: 120 litres

Lock-exchange experiments

EQUIPAMENTS

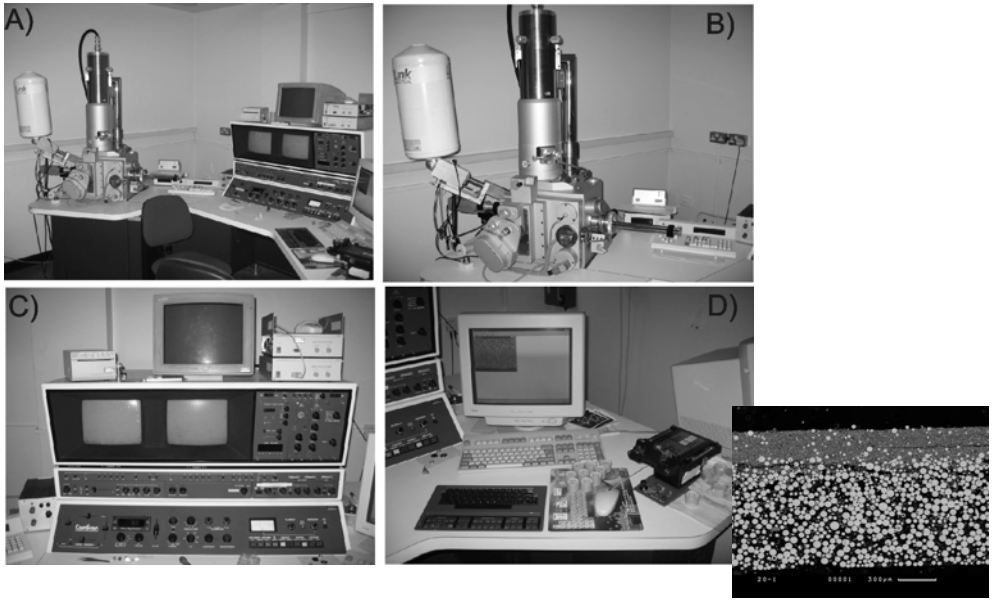
Flow geometry

2 Video-cameras and interactive white board



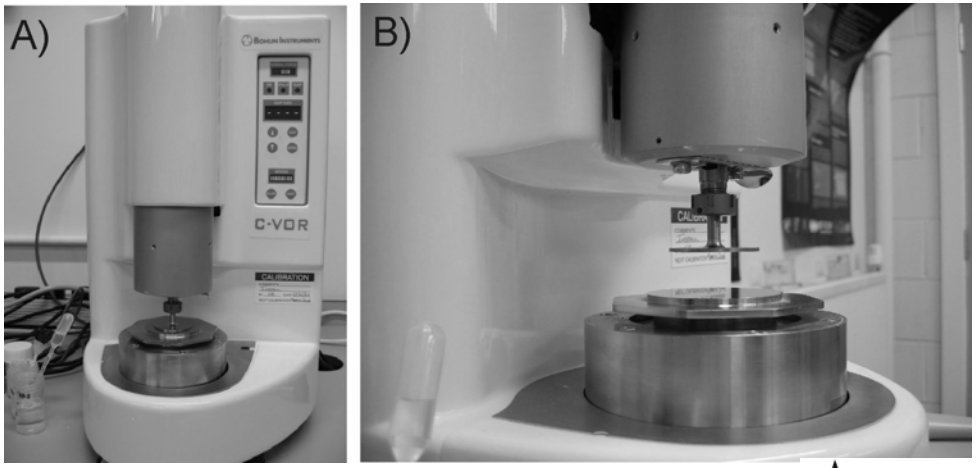
Deposit samples

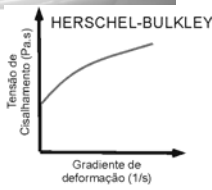
Scanner Electron Microscopy



Mixture rheology

Bohlin rheometer





VIDEO OF THE EXPERIMENT

Experimental Results

RHEOLOGY OF THE MIXTURES

RHEOLOGICAL BEHAVIOUR

VISCOSITY OF THE MIXTURES

RELATION WITH Cvol AND %CLAY and others ....

HYDRAULIC PROPERTIES

TIME SERIES

GEOMETRY

VERTICAL PROFILES

VELOCITY

MEAN VALUES

CONCENTRATION and others ....

DEPOSITIONAL PROPERTIES

GRADATION

DISTRIBUTION OF SEDIMENTS

CAPACITY TRANSPORT

GRAIN TYPE AND SIZE

DEPOSITIONAL RATE and others...

MORE THAN 20 PARAMETERS EVALUATED
IMPOSSIBLE TO SHOW ALL – SORRY !

SHOW SOME RESULTS FOR EACH PROPERTIES

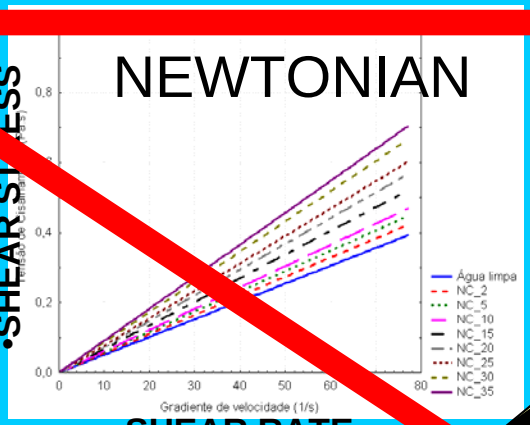
•RHEOLOGY MEASUREMENTS FOR ALL 25 MIXTURES

2.5% 5% 10% 15% 20% 25% 30% 35% Cvol

•Non-cohesive

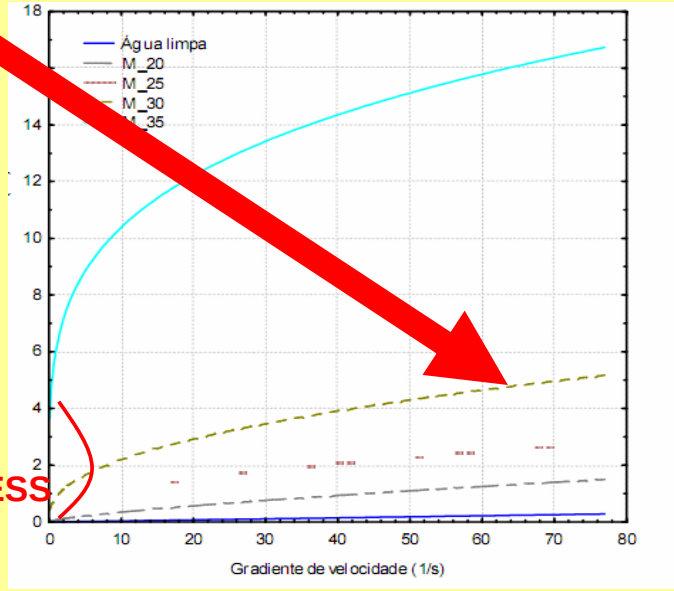
0 10 20 30 40 50 60 70 80 90 100 CLAY

NEWTONIAN



•SHEAR RATE

HERSCHEL BULKLEY



YIELD STRESS

•Mixed

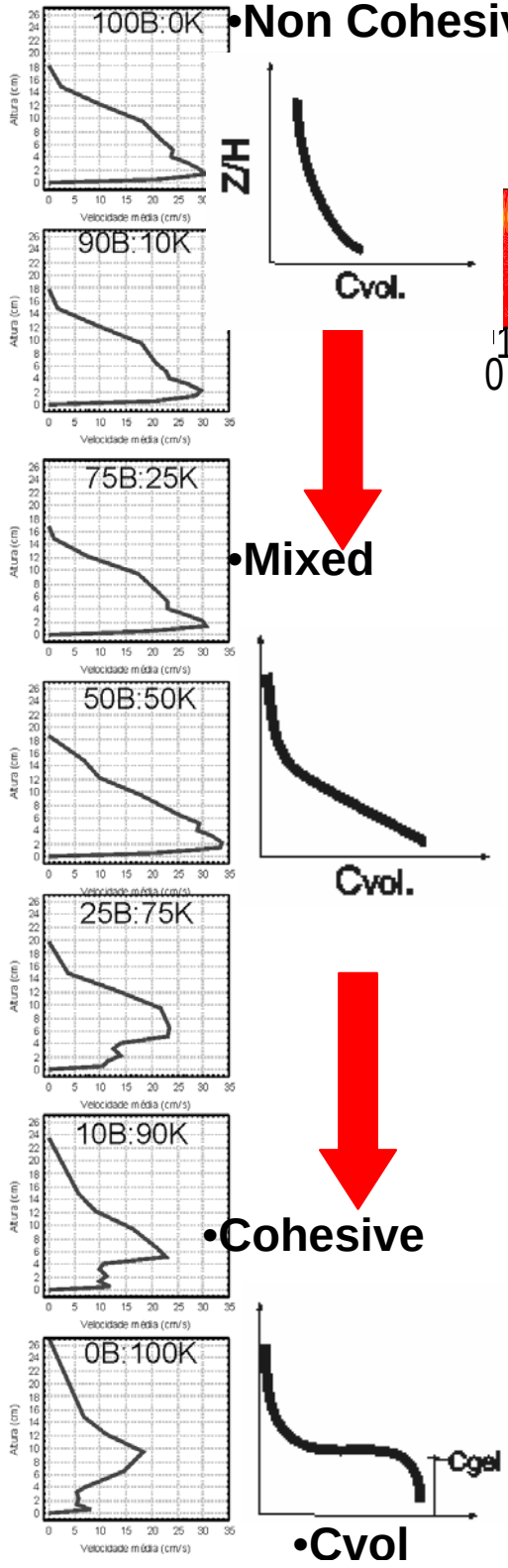
Changing behaviour as Cvol and % clay increases

Cohesive

RHEOLOGICAL THRESHOLD

RHEOLOGY OF THE MIXTURES

Velocity Time Series
TRANSITION GROUP



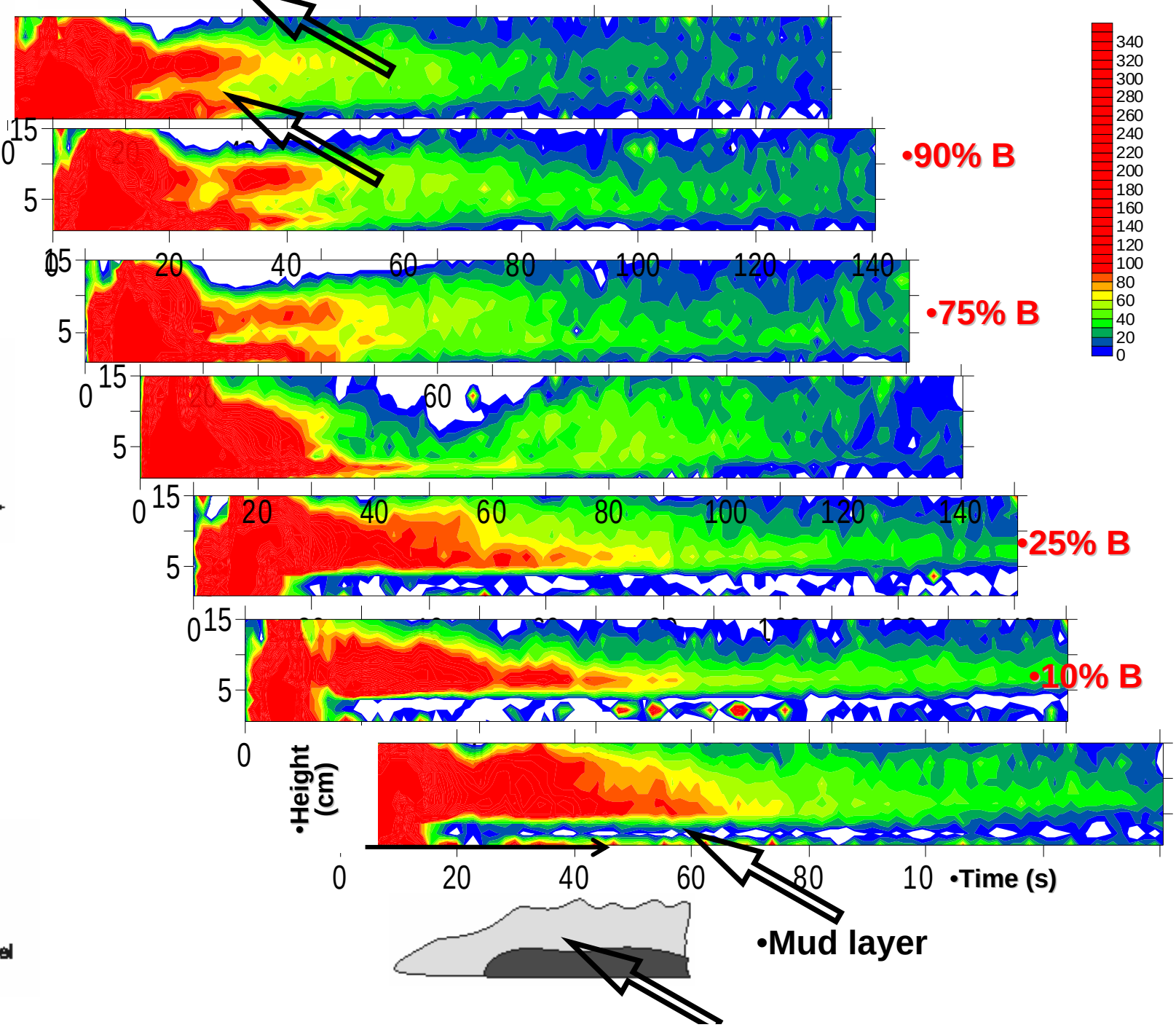
•Non Cohesive

•Mixed

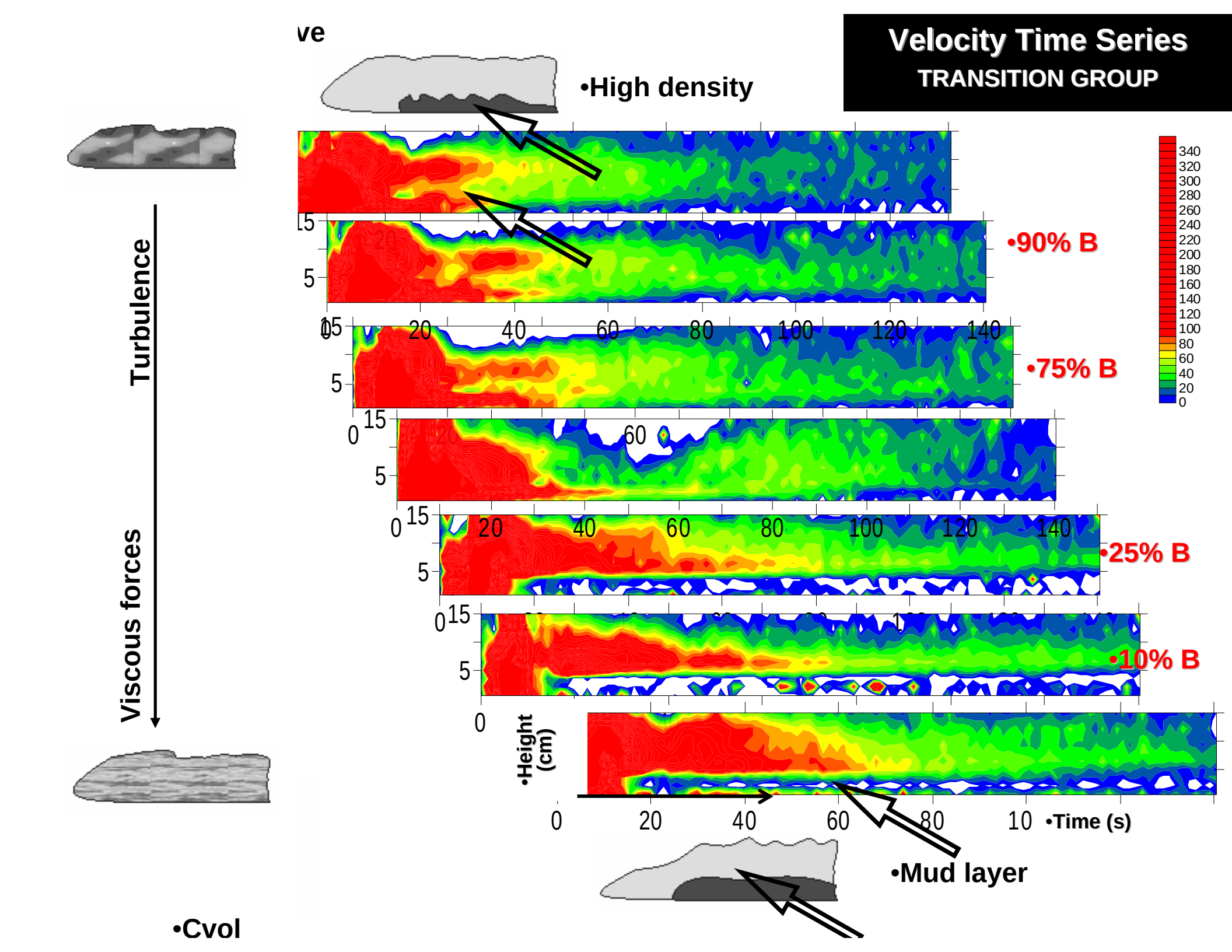
•Cohesive

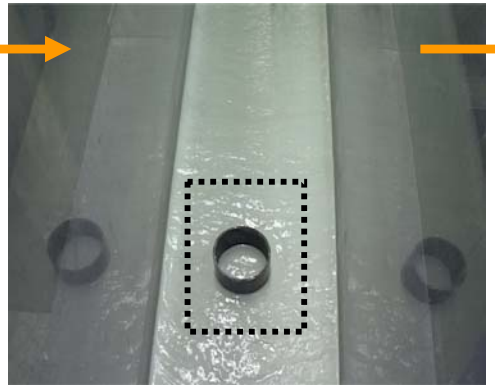
•Cvol

•High density



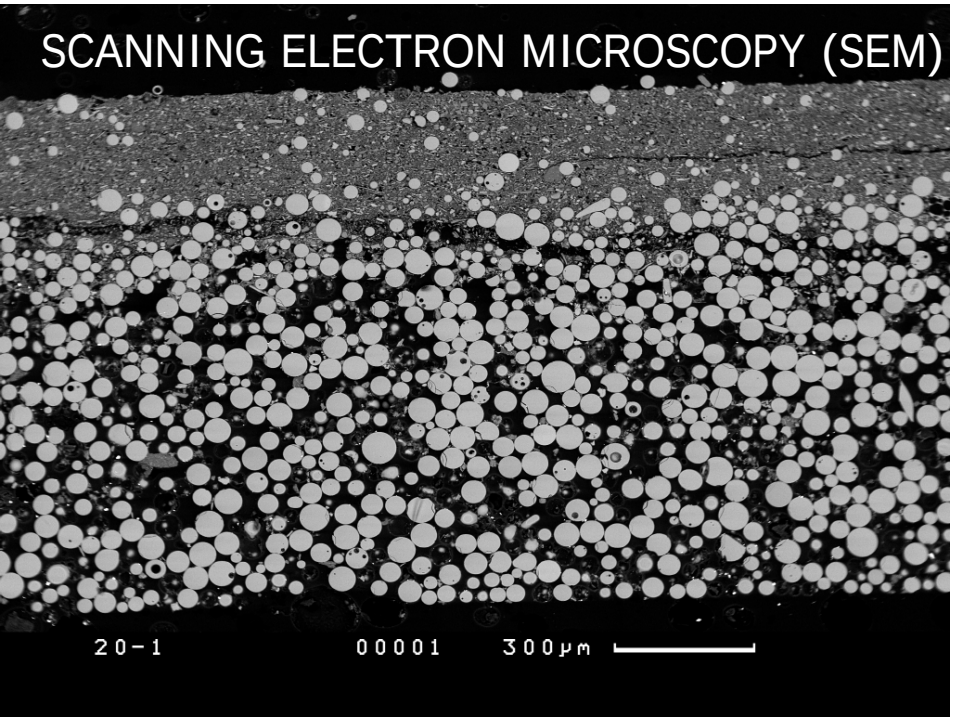
•Mud layer

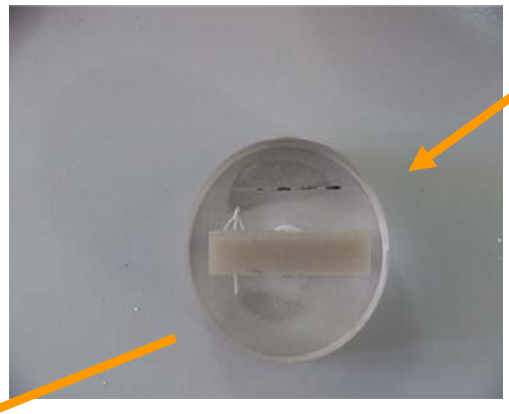

ve
Velocity Time Series
TRANSITION GROUP
•High density
Turbulence
Viscous forces
•90% B
•75% B
•25% B
•10% B
•Height (cm)
•Time (s)
•Mud layer
•Cvol



DEPOSIT PROPERTIES

DEPOSIT SAMPLES METHODOLOGY





Mixed – 2.5% Cvol

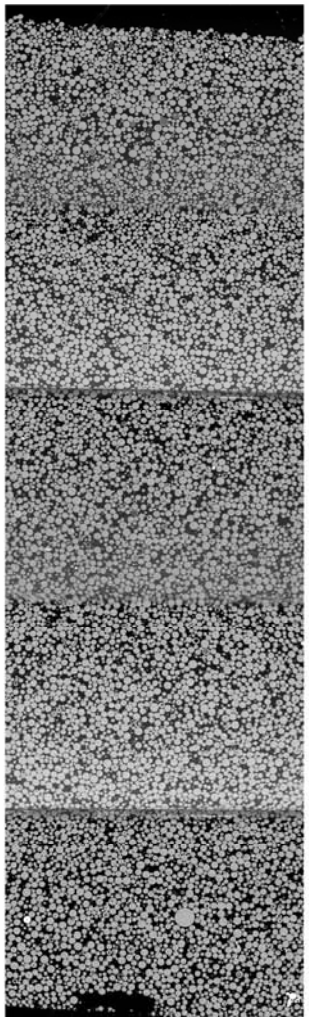
NON-COHESIVE 90 % B

75 % B

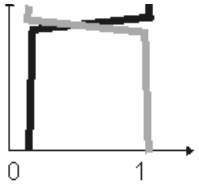
MIXED 50:50

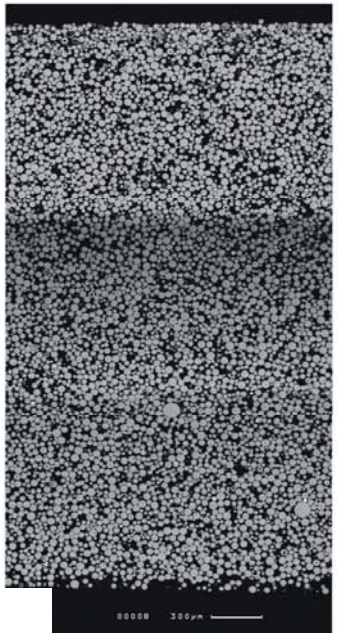
25%B

TYPE OF SEDIMENTS

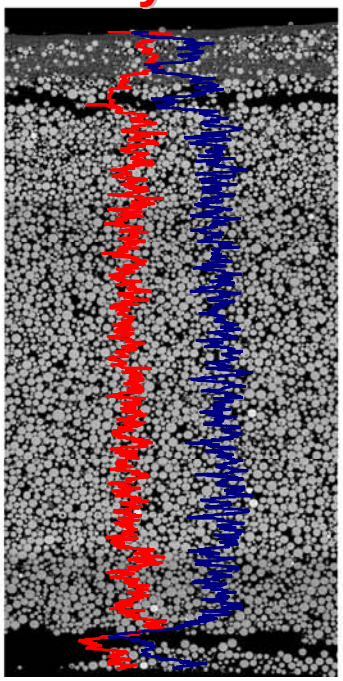


%Ballo. % Clay

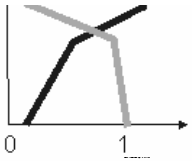


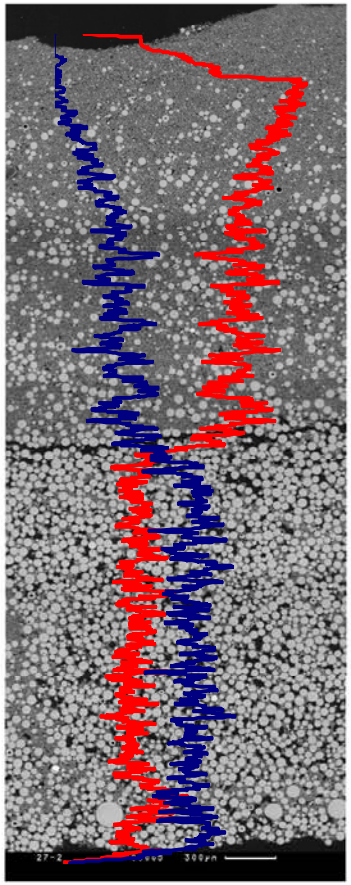


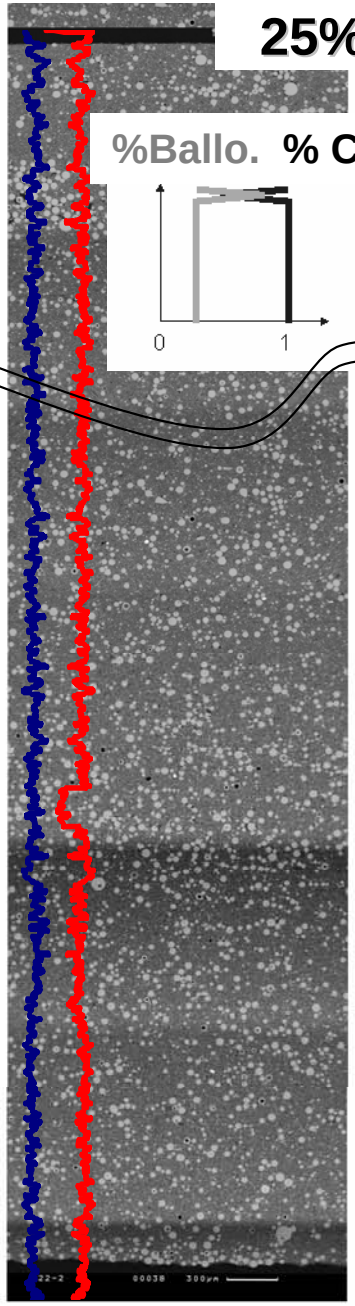
Clay Ballotini



%Ballo. % Clay

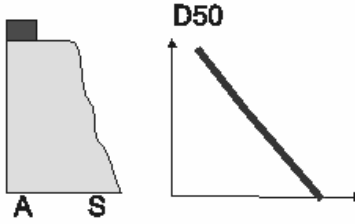


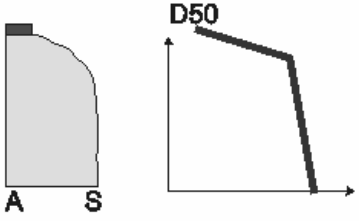


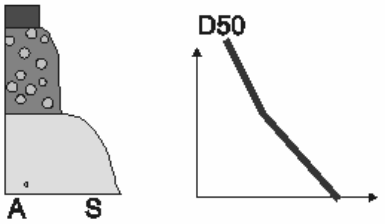


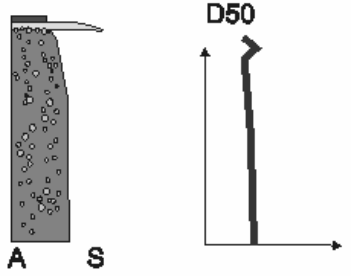
%Ballo. % Clay

GRADATION









Evaluating the results altogether

RHEOLOGY OF THE MIXTURES

RHEOLOGICAL BEHAVIOUR
VISCOSITY OF THE MIXTURES
RELATION WITH Cvol AND %CLAY

HYDRAULIC PROPERTIES

TIME SERIES
GEOMETRY
VERTICAL PROFILES
VELOCITY
MEAN VALUES
CONCENTRATION

DEPOSIT PROPERTIES

GRADATION
DISTRIBUTION OF SEDIMENTS
CAPACITY TRANSPORT
GRAIN TYPE AND SIZE
DEPOSITIONAL RATE

MORE THAN 20 PARAMETERS

GEOMETRY
RHEOLOGY
MEAN VERTICAL PROFILES
MEAN GLOBAL VALUES
TIME SERIES
INTERNAL DYNAMICS
DEPOSITIONAL PROPERTIES
NON-DIMENSIONAL RELATIONS

GROUPING FLOWS WITH SAME PROPERTIES

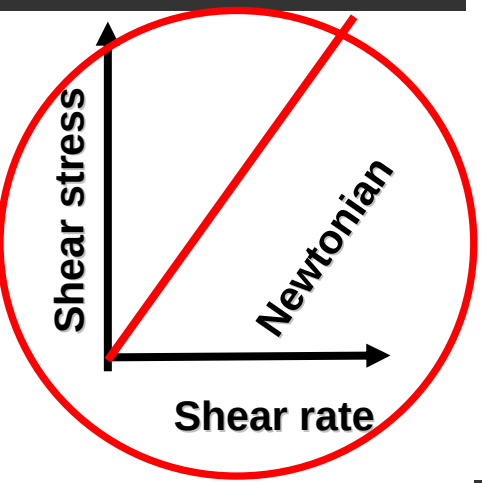
Defining thresholds and transition points

6 regions

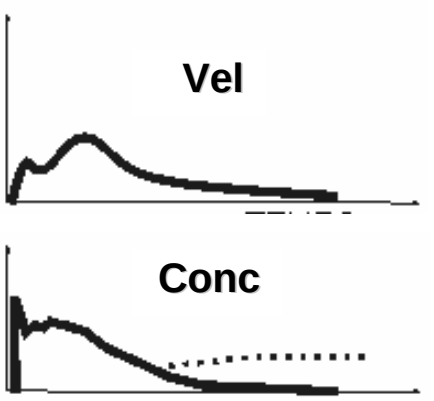
•REGION I

SOME OF THE 22 PARAMETERS
•Highlighting the main ones

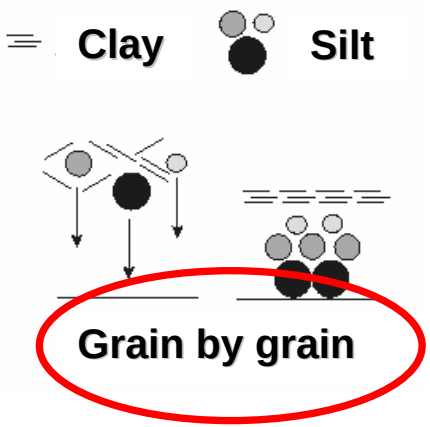
Rheology



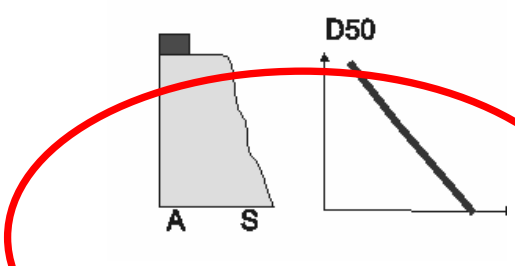
Time Series



Deposition Process

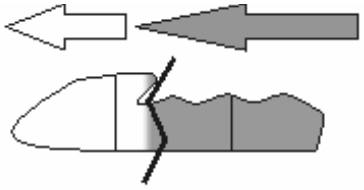


Gradation

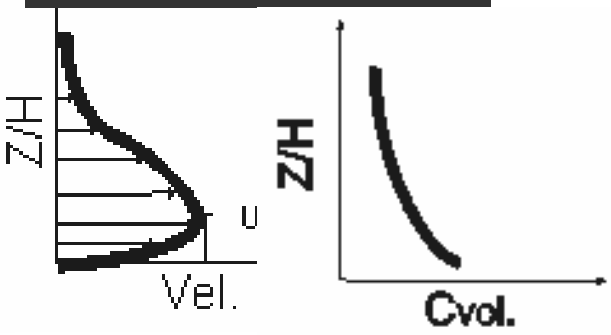


VELOCITY BODY/HEAD

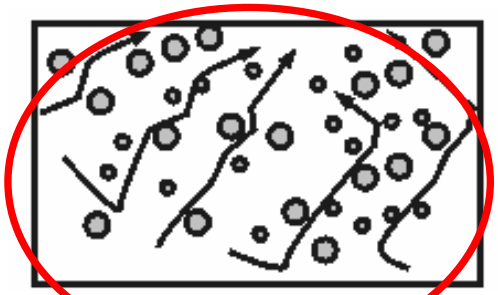
$V_{Head} < V_{Body}$



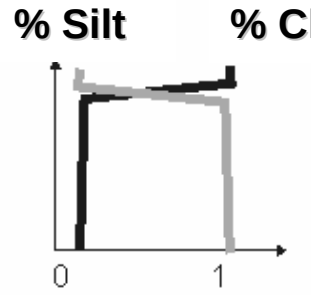
VEL AND Cvol PROFILE



MECHANISM SUPPORT

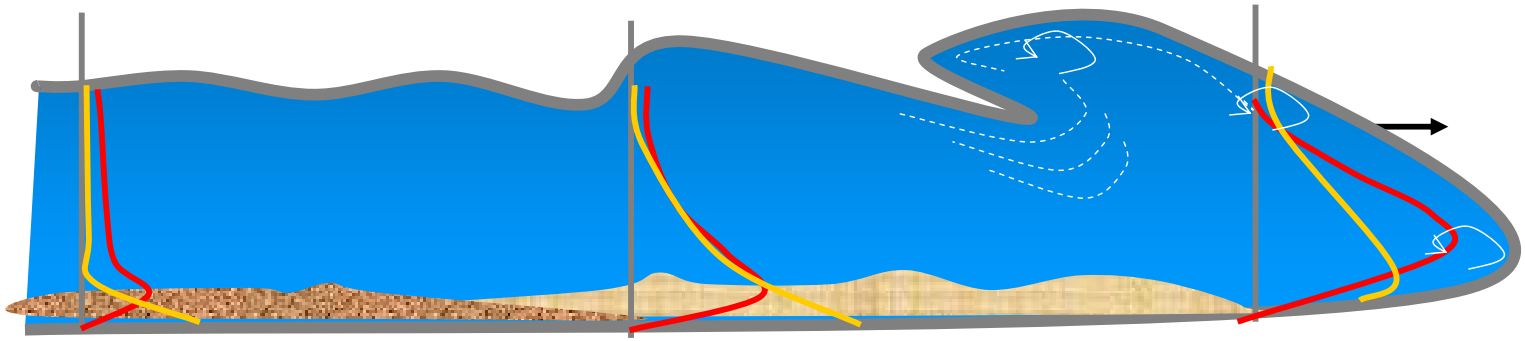


% SEDIMENTS



GEOMETRY BODY/HEAD

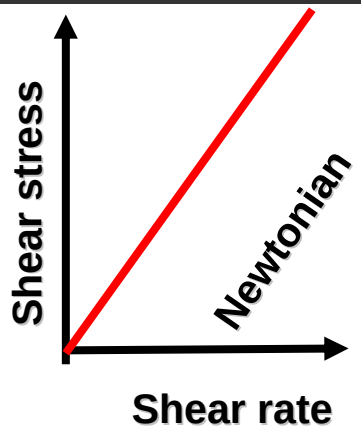
$H_{Head} > H_{Body}$



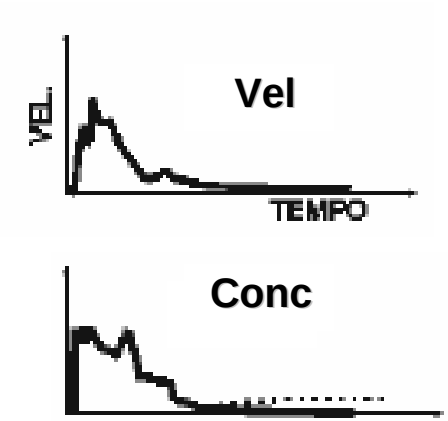
•REGION II AND III

SOME OF THE 22 PARAMETERS
•Highlighting the main ones

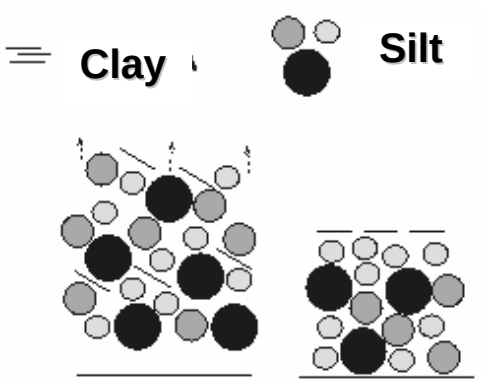
Rheology



Time Series

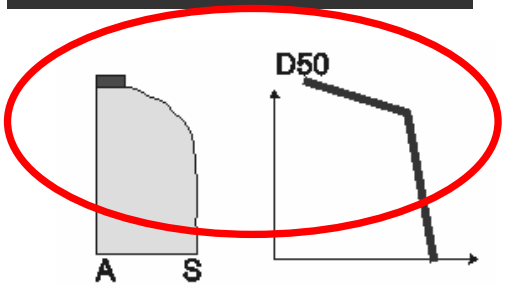


Deposition Process



Frictional freezing

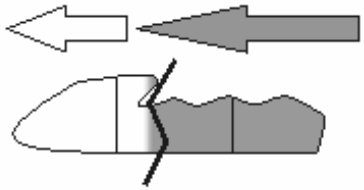
Gradation



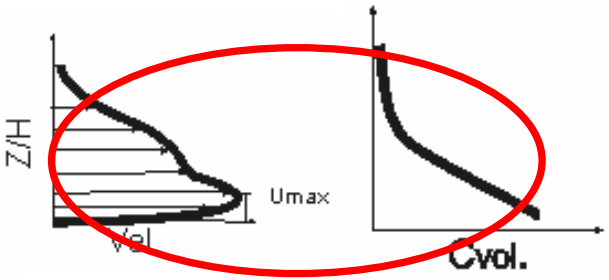
Massive gradation

VELOCITY BODY/HEAD

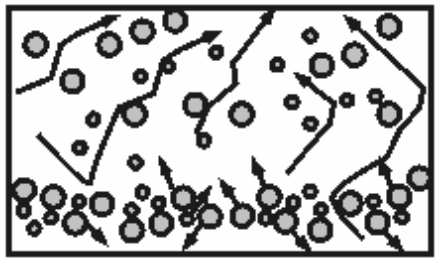
$V_{Head} < V_{Body}$



VEL AND Cvol PROFILE

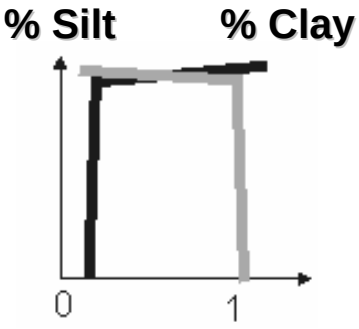


MECHANISM SUPPORT



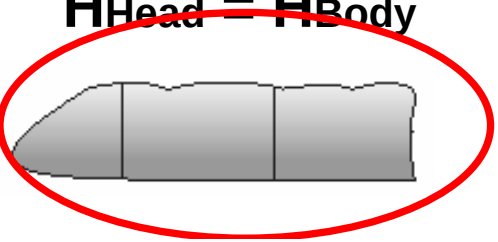
Turbulence and hindered settling

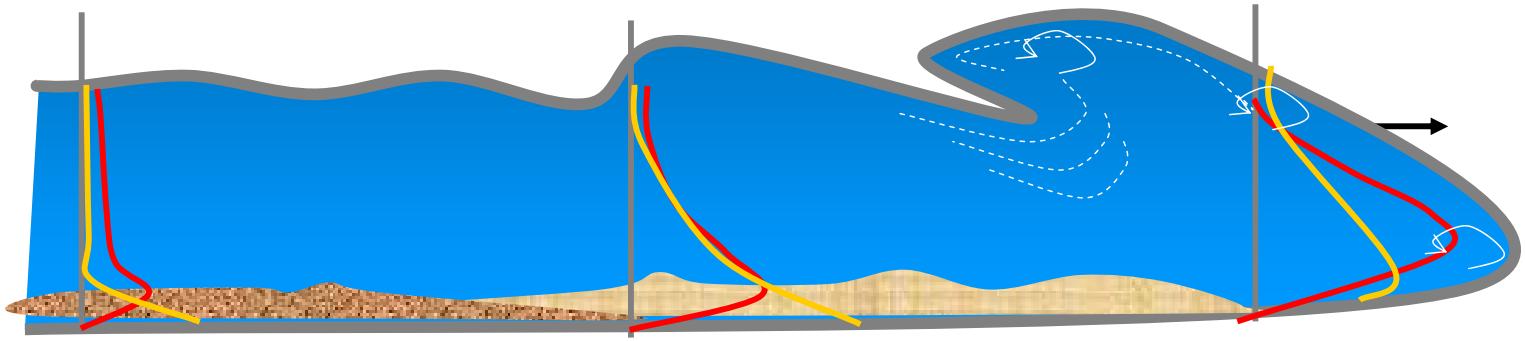
% SEDIMENTS



GEOMETRY BODY/HEAD

$H_{Head} = H_{Body}$



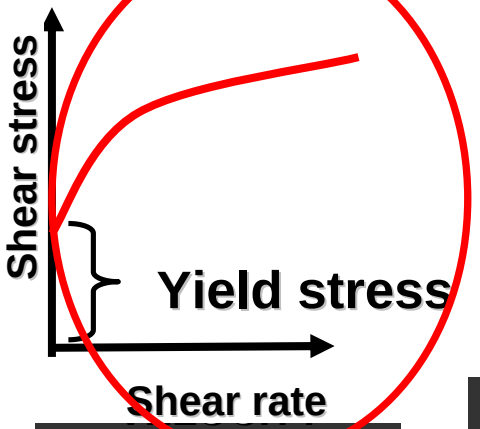


•REGION IV
HYDRID

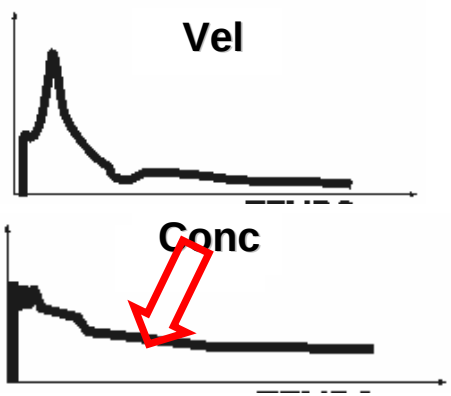
SOME OF THE 22 PARAMETERS
•Highlighting the main ones

Rheology

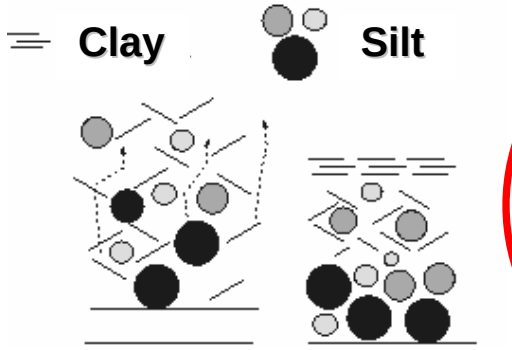
Non -Newtonian



Time Series

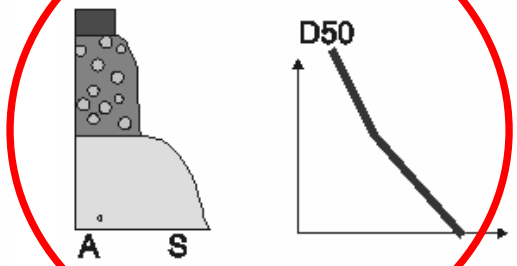


Deposition Process



Transition to Cohesive freezing

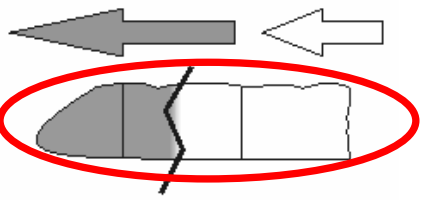
Gradation



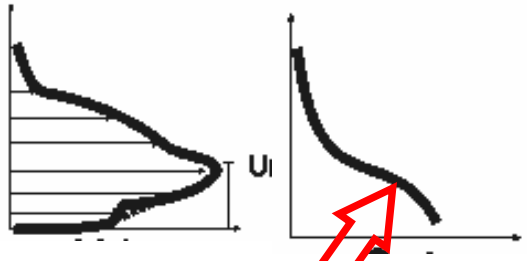
Hydride deposit

BODY/HEAD

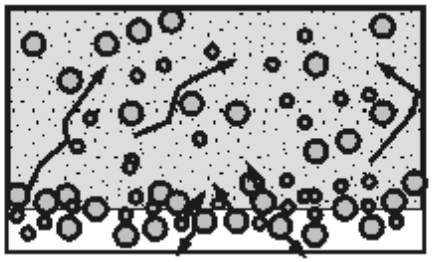
$V_{Head} > V_{Body}$



VEL AND Cvol PROFILE

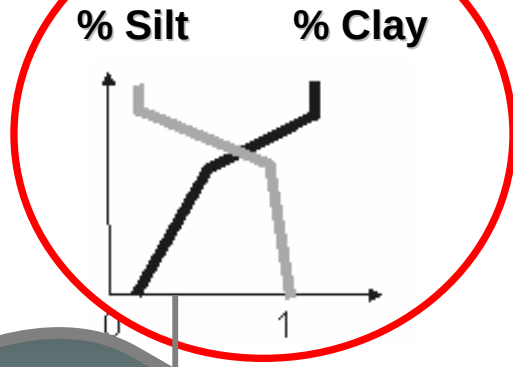


MECHANISM SUPPORT



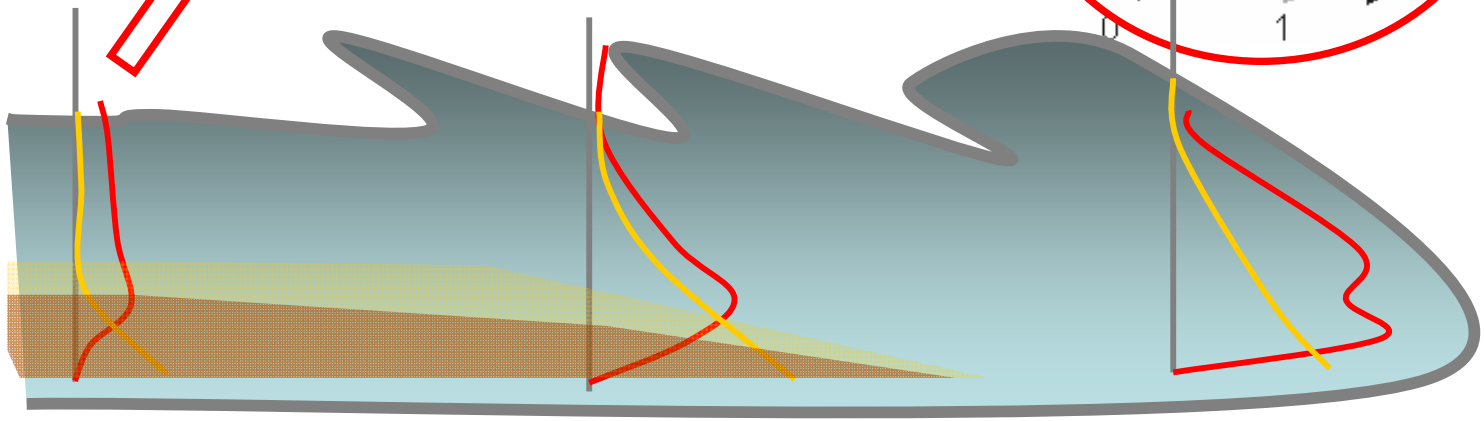
Viscous forces starting act

% SEDIMENTS



GEOMETRY BODY/HEAD

$H_{Head} = H_{Body}$

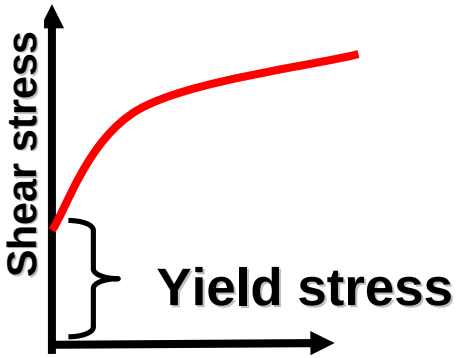


•REGION V and VI

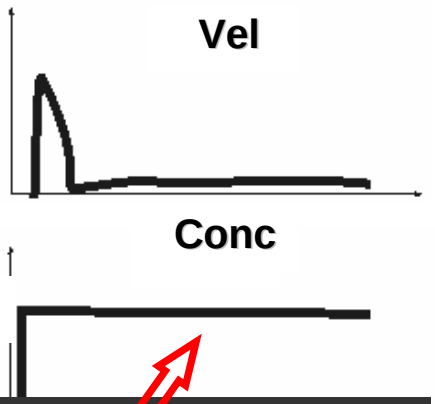
SOME OF THE 22 PARAMETERS
•Highlighting the main ones

Rheology

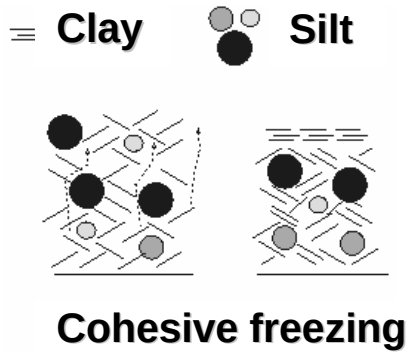
Non -Newtonian



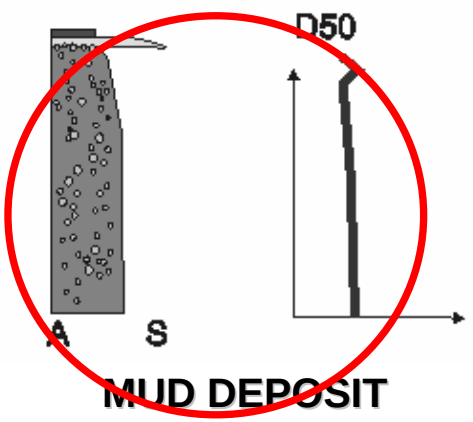
Time Series



Deposition Process

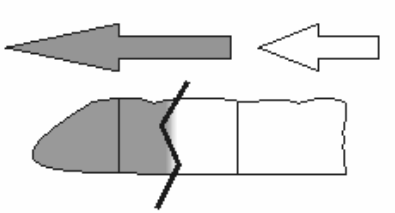


Gradation

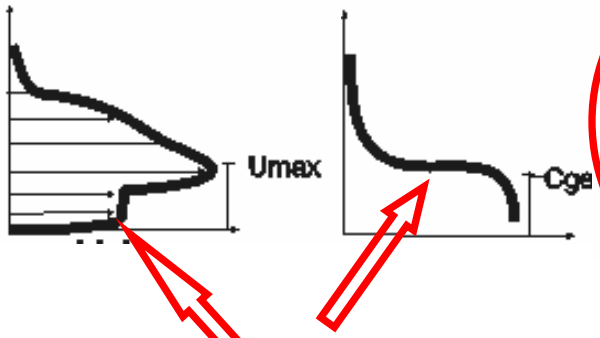


BODY/HEAD

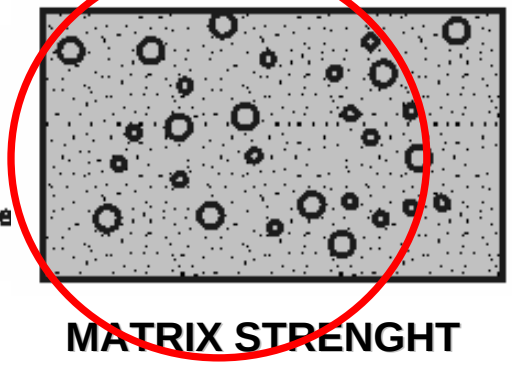
$V_{Head} > V_{Body}$



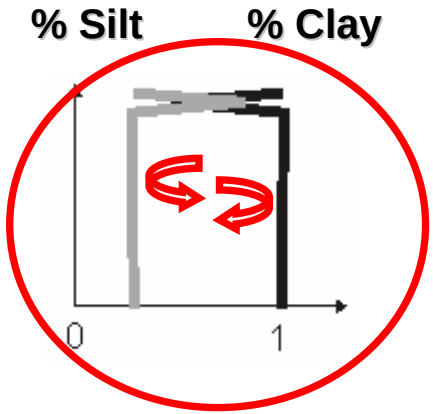
VEL AND Cvol PROFILE



MECHANISM SUPPORT

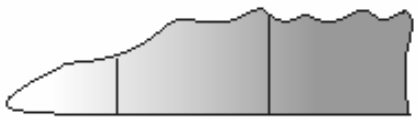


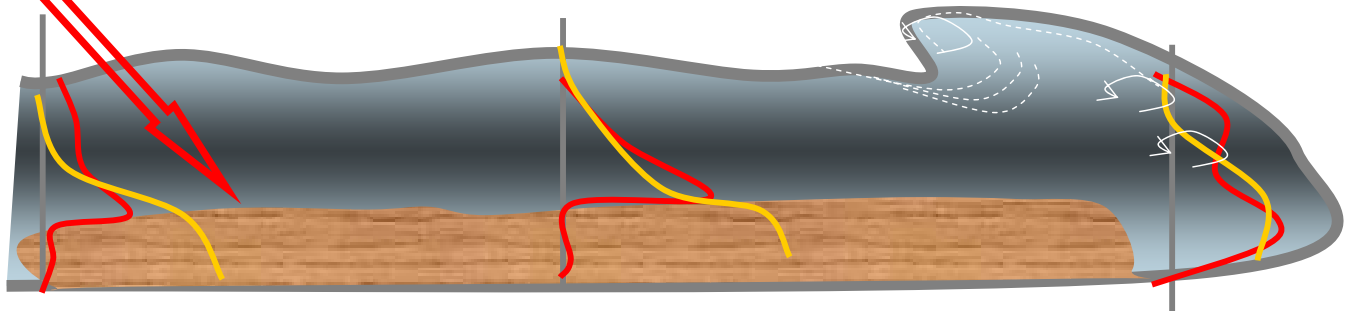
% SEDIMENTS

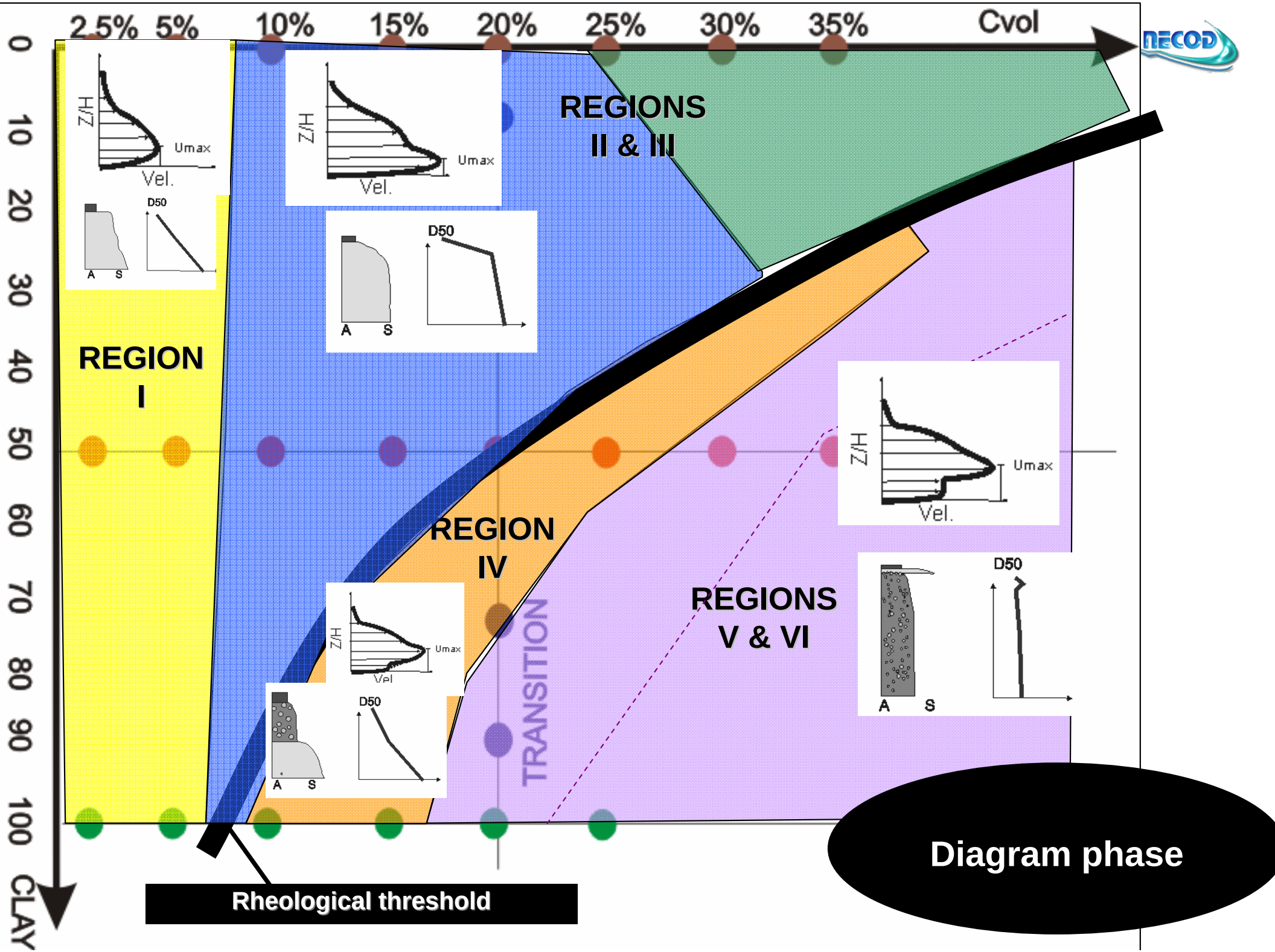


GEOMETRY BODY/HEAD

$H_{Head} < H_{Body}$






2.5%
5%
10%
15%
20%
25%
30%
35%
Cvol
0
10
20
30
40
50
60
70
80
90
100
CLAY
Z/H
Umax
Vel.
D50
A
S
REGION
I
REGIONS
II & III
REGION
IV
TRANSITION
REGIONS
V & VI
Rheological threshold
Diagram phase

• BRIEF SUMMARY

REGION I: Low density flow; **Newtonian**; grains supported by upward component of **turbulence**; no hindered settling; segregation of grains and **normally graded beds**.

REGION II: Newtonian; grains supported by **turbulence**; turbulent flow with gently undulating high-concentration near-bed layer; partial hindered settling and partial size segregation forming **partially graded beds**.

REGION III: Newtonian; **fully turbulent** flow with strongly undulating high-concentration near-bed layer; hindered settling resulting in rapid deposition and generation of **partially graded beds**.

REGION IV: non-Newtonian; **viscous** flow; formation of "plug" and shear flow (mud layer close the bottom); viscous forces cause freezing of the flow and forming **graded beds of muddy sand**.

REGIONS V and VI: **non-Newtonian**; **viscous flow** with thick mud layer; grain support by matrix strength; weakly undulating internal mud layer; cohesive freezing forms an **ungraded muddy** sand with coarse-tail grading on top.

Then…

RHEOLOGY OF THE MIXTURES

RHEOLOGICAL BEHAVIOUR
VISCOSITY OF THE MIXTURES
RELATION WITH Cvol AND %CLAY

HYDRAULIC PROPERTIES

TIME SERIES
GEOMETRY
VERTICAL PROFILES
VELOCITY
MEAN VALUES
CONCENTRATION

DEPOSIT PROPERTIES

GRADATION
DISTRIBUTION OF SEDIMENTS
CAPACITY TRANSPORT
GRAIN TYPE AND SIZE
DEPOSITIONAL RATE

MORE THAN 20 PARAMETERS

GEOMETRY
RHEOLOGY
MEAN VERTICAL PROFILES
MEAN GLOBAL VALUES
TIME SERIES
INTERNAL DYNAMICS
DEPOSITIONAL PROPERTIES
NON-DIMENSIONAL RELATIONS

GROUPING FLOWS WITH SAME PROPERTIES

FINALLY Experimentally-derived classification

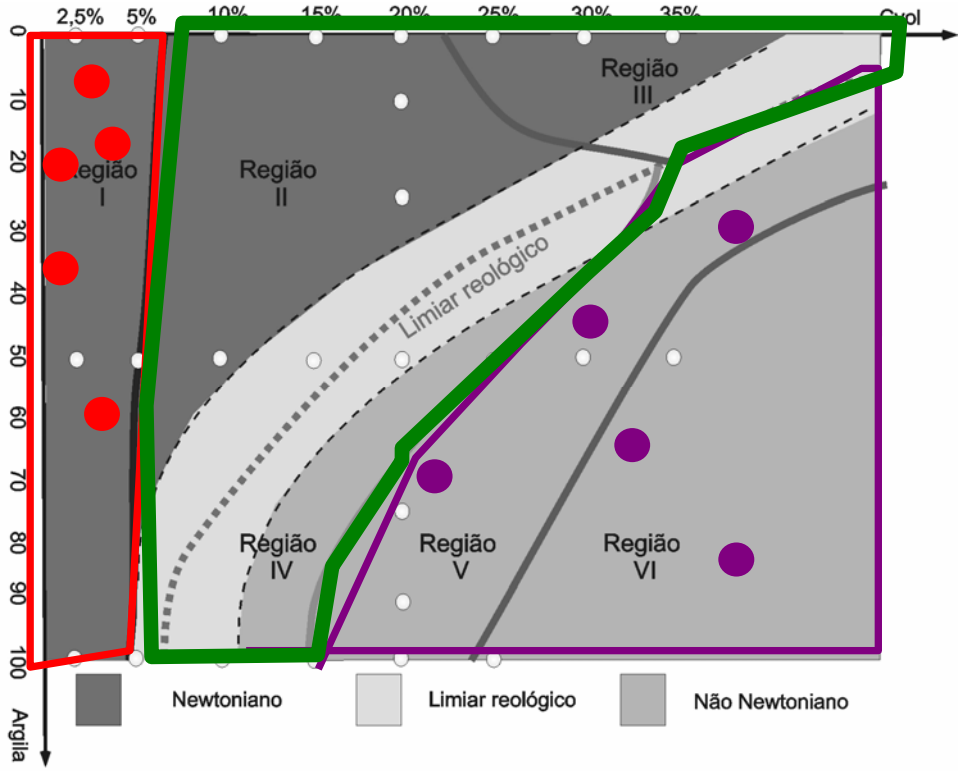
Experimentally-derived classification

IN LITERATURE, THE PROPERTIES OF:

- **LOW-DENSITY TURBIDITY CURRENTS**
- **DEBRIS-FLOW**

} **ARE WELL ACCEPTED!**

COMPARING THESE PROPERTIES WITH THE 6 REGIONS, DIAGRAM PHASE,



REGION I – LOW DENSITY!

REGION V and VI – DEBRIS FLOW

And how about the middle area
HIGH-DENSITY
TURBIDITY CURRENTS ????

Experimentally-derived classification

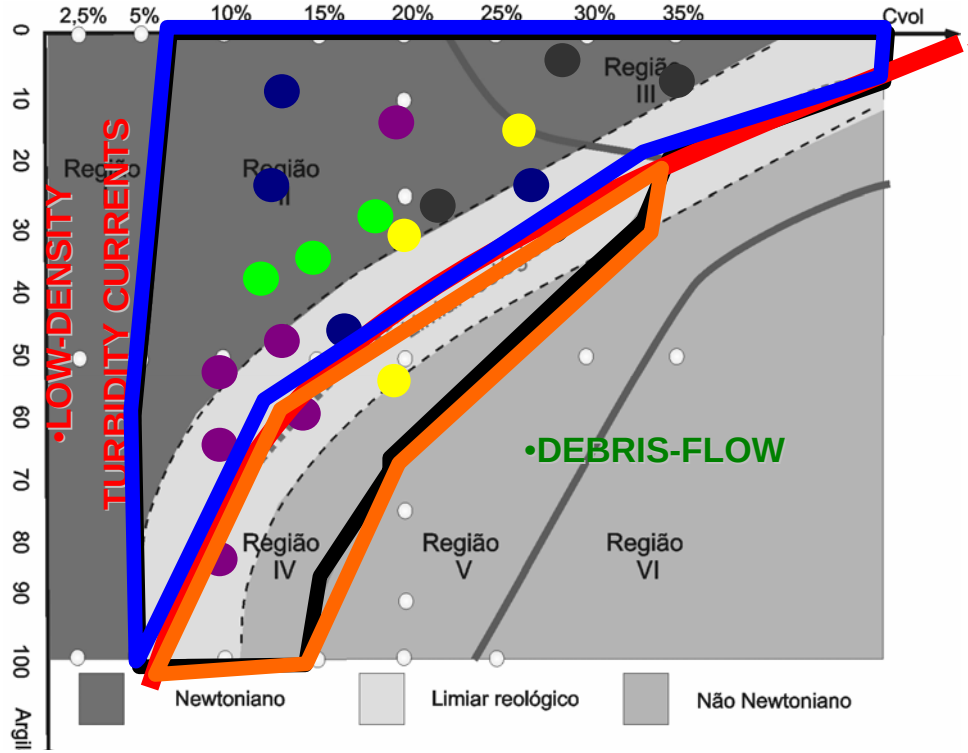
- PREVIOUS CLASSIFICATIONS BASED ON (literature review):

•CONCENTRATION
•RHEOLOGY
•MECHANISM OF SUPPORT
•CLAY PRESENCE

•HIGH-DENSITY TURBIDITY CURRENTS
•DENSE FLOWS
•CONCENTRATED FLOWS
•HYPERCONCENTRATED FLOW

•LINKED DEBRITES and others 30 names...

•HIGH-DENSITY TURBIDITY CURRENTS



REGIONS II and III

NEWTONIAN and INERTIAL FORCES

⇧

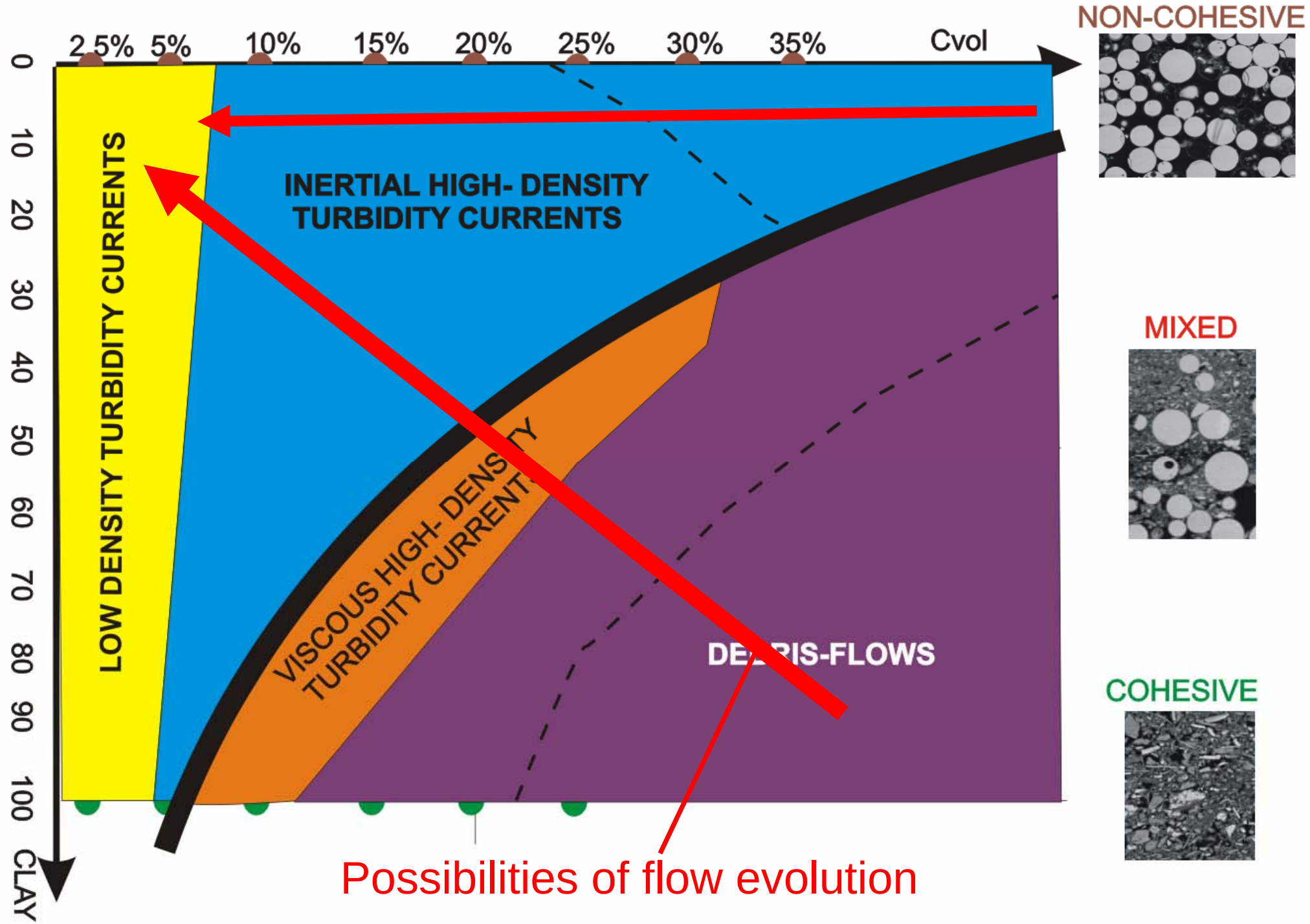
•THRESHOLD RHEOLOGY

⇩

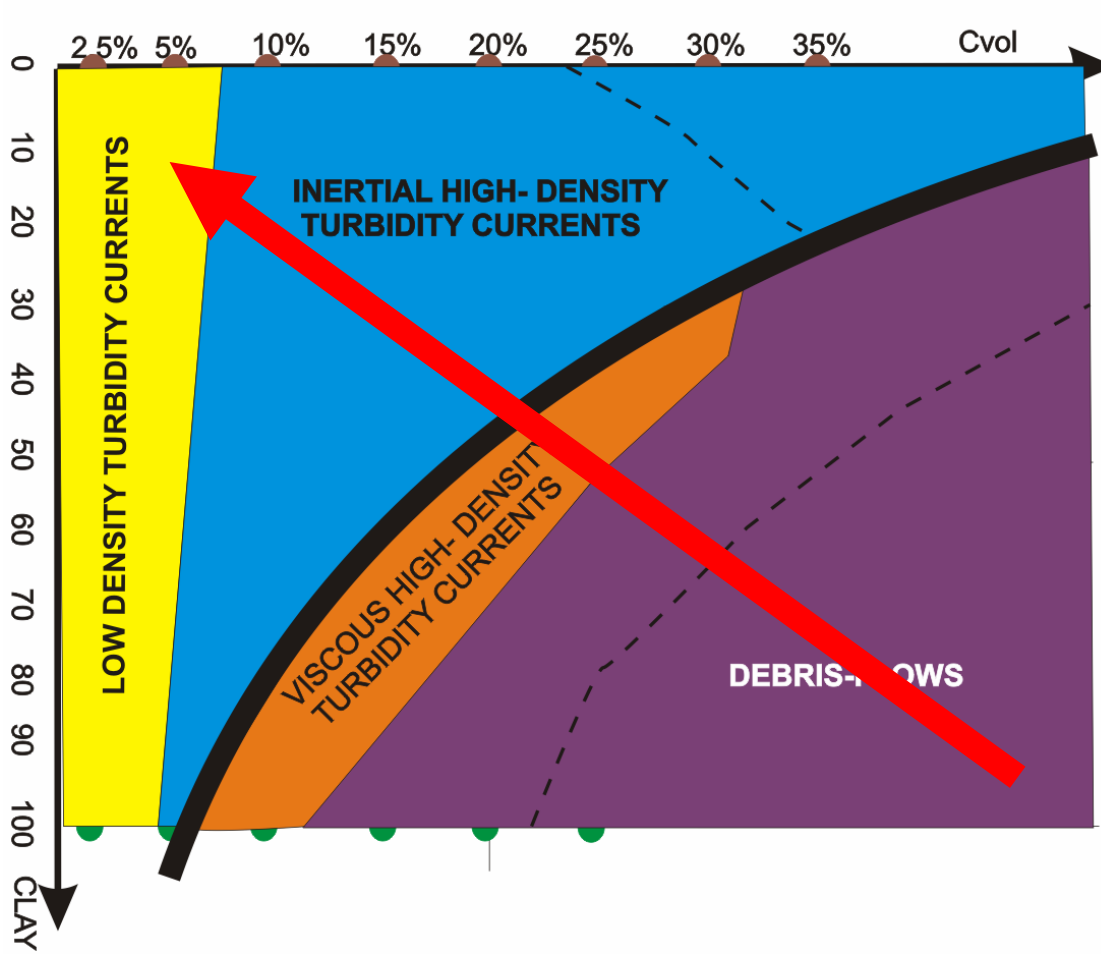
NON - NEWTONIAN and VISCOUS FORCES

REGION IV

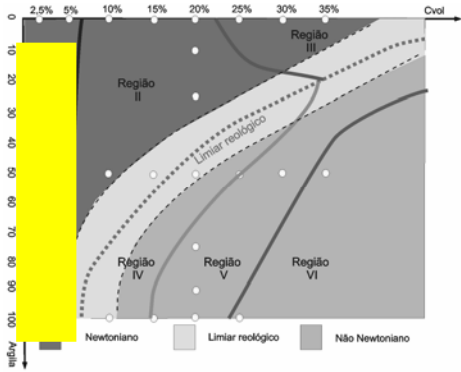
Proposal: Experimentally-derived classification



SPATIAL MODEL OF DEPOSITION

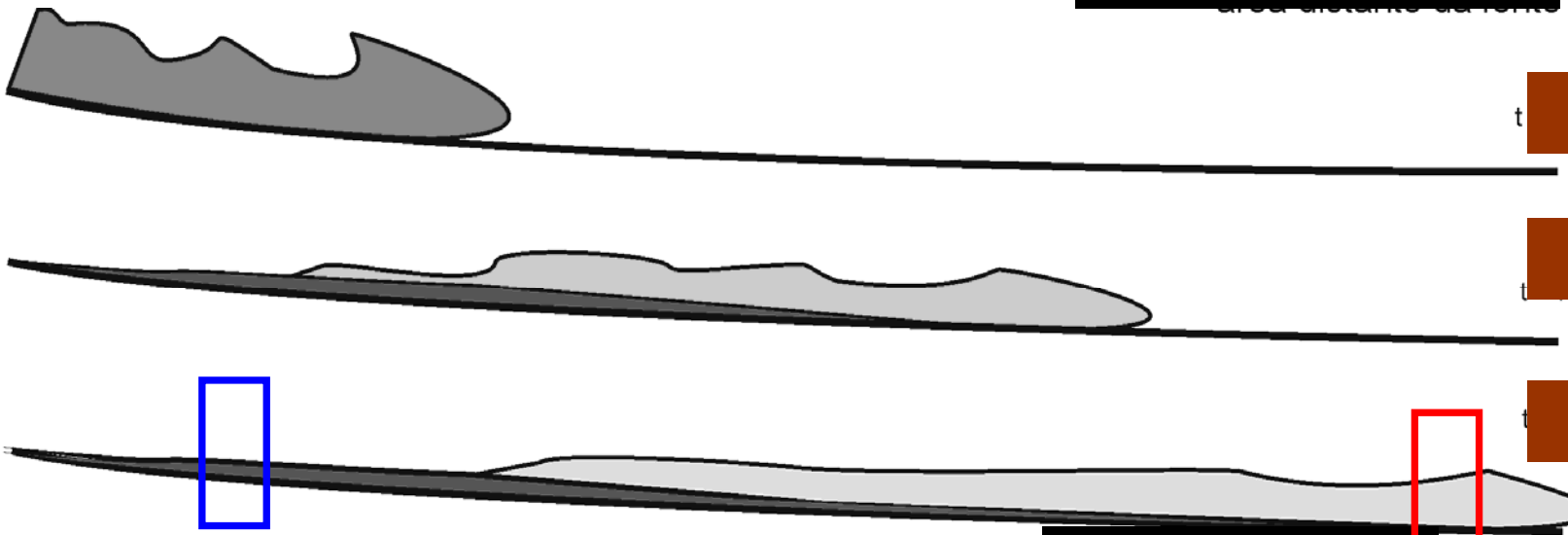


REGION I - LOW DENSITY TC



PROXIMAL

DISTAL

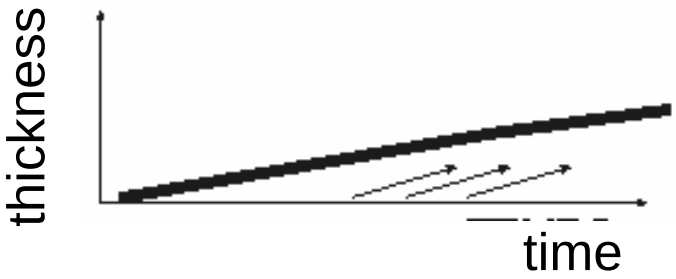


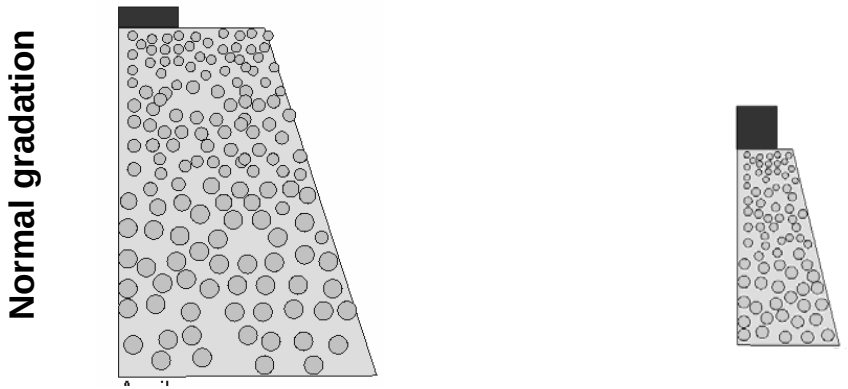
DEPOSIT

PROXIMAL

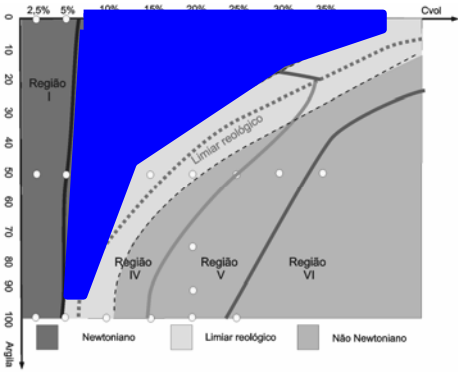
DISTAL

DEPOSITIONAL RATE





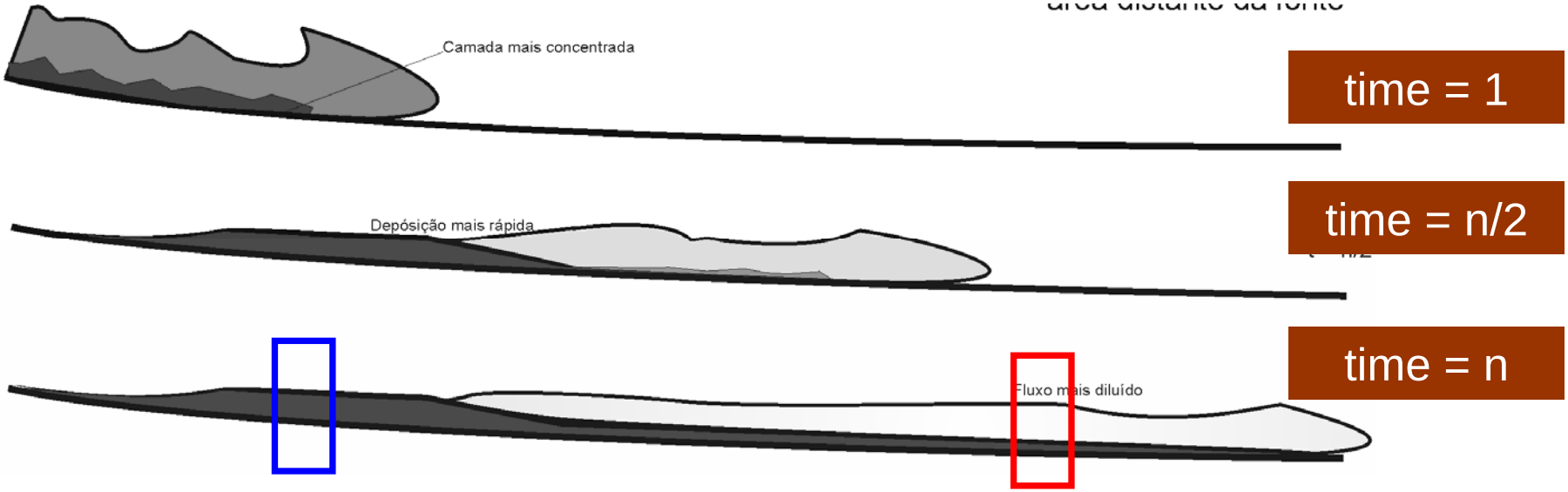
REGIONS II & III – INERTIAL HDTC



CONCENTRATION

PROXIMAL

DISTAL



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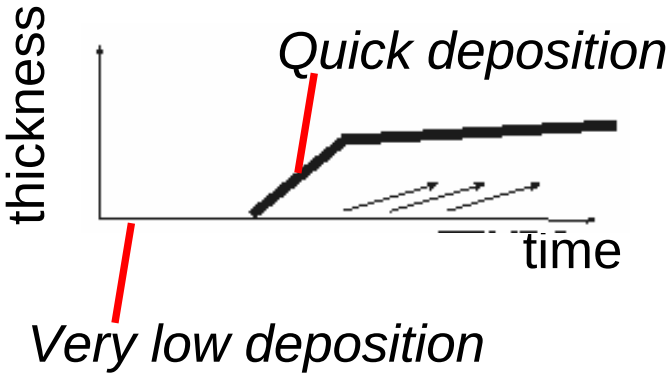
time = n/2

time = n

DEPOSITIONAL RATE

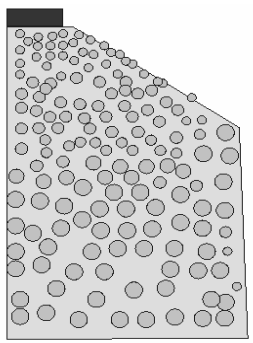


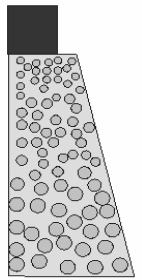
DEPOSIT

PROXIMAL

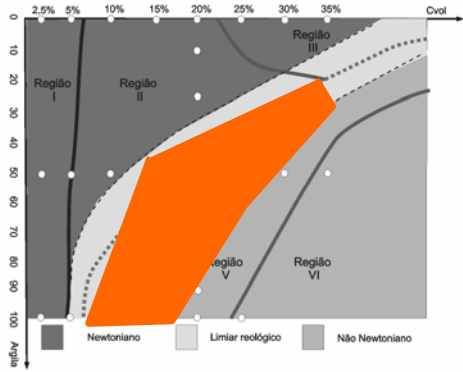
DISTAL

massive





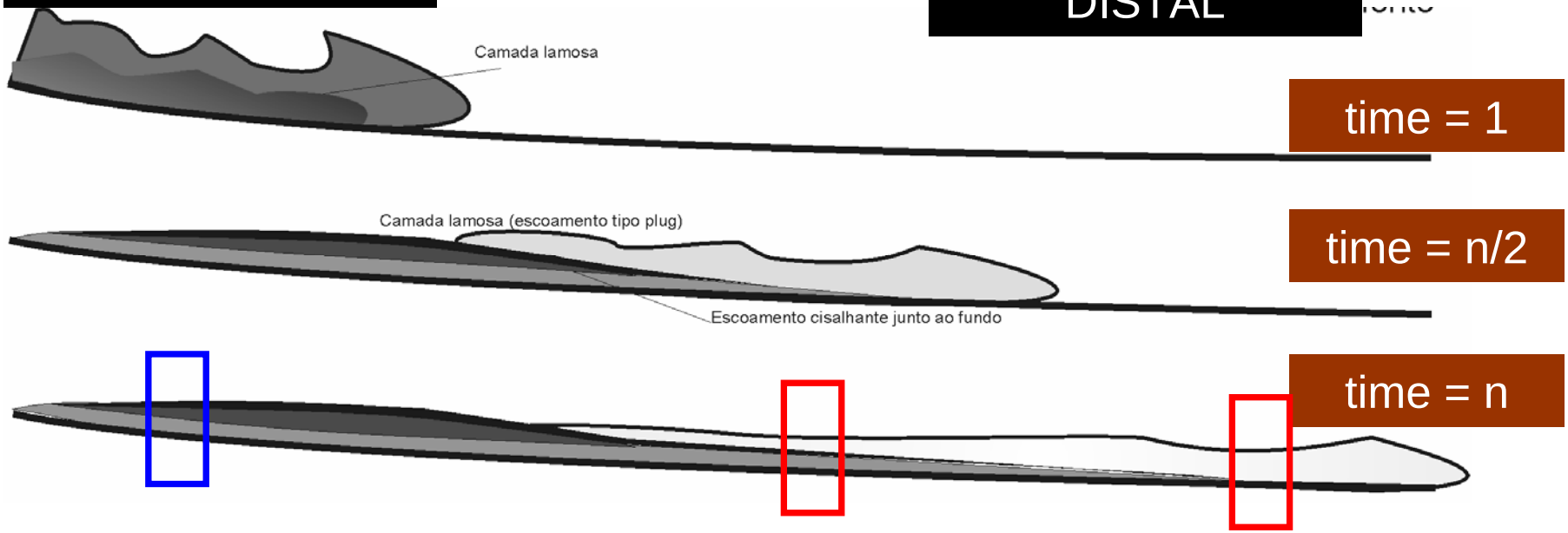
REGION IV –VISCOUS HDTC



CONCENTRATION

PROXIMAL

DISTAL



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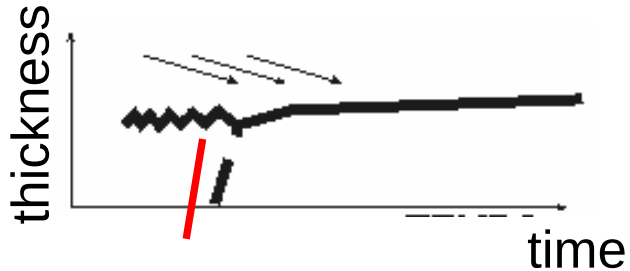
time = n/2

time = n

DEPOSITIONAL RATE



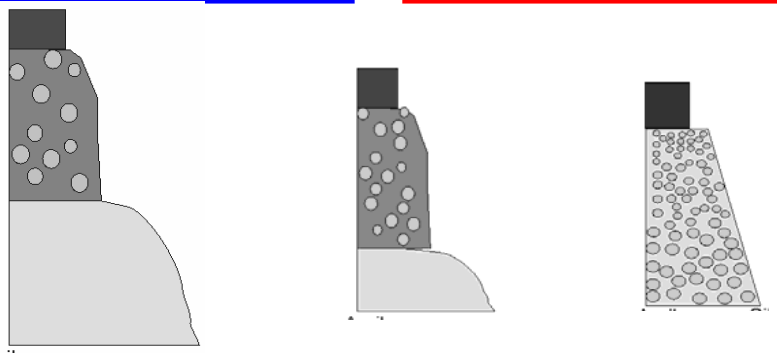
Mud layer freeze

graded beds of muddy sand

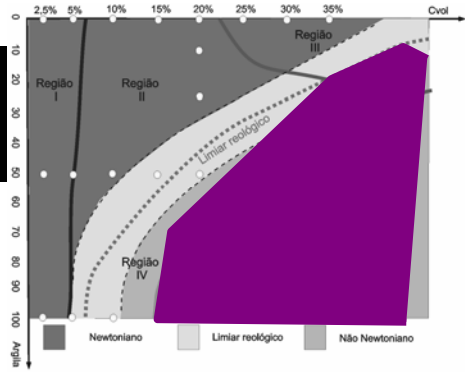
DEPOSIT

PROXIMAL

DISTAL



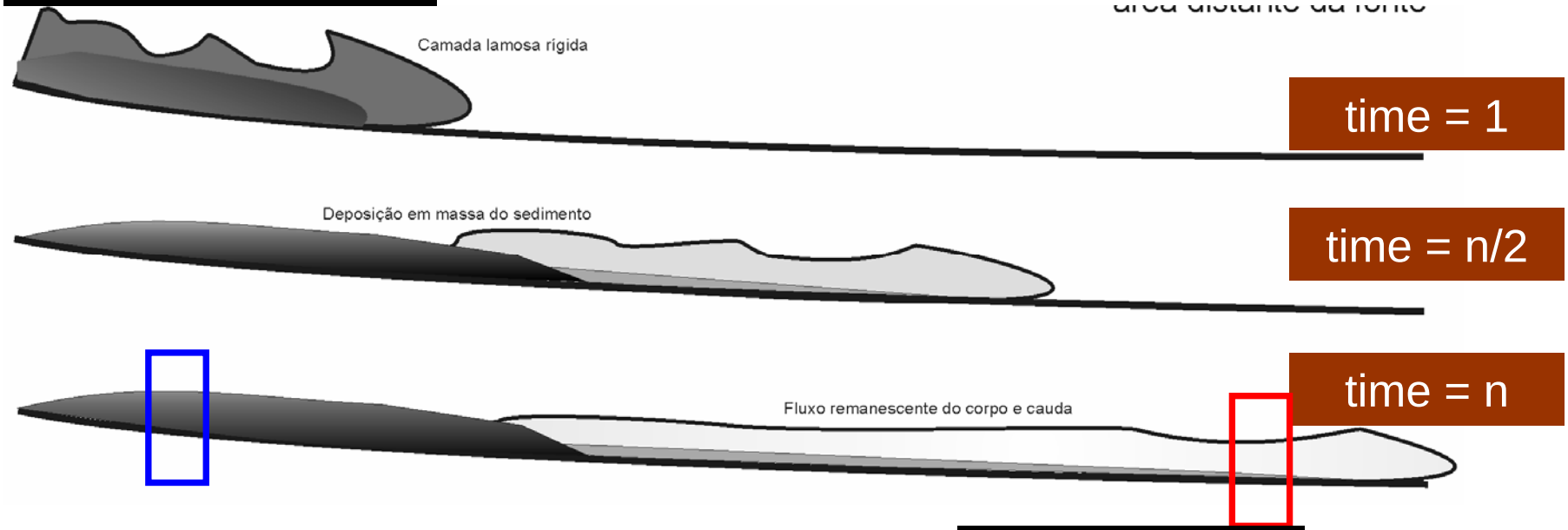
REGIONS V and VI –DEBRIS FLOWS



CONCENTRATION

PROXIMAL

DISTAL



time = 1

time = n/2

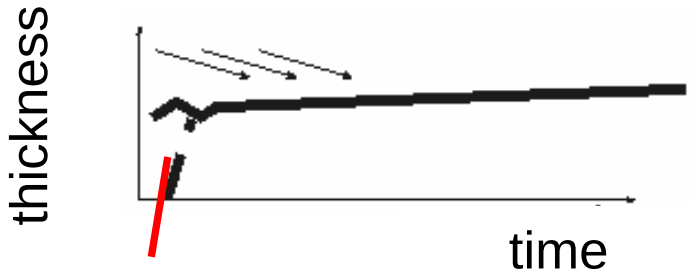
time = n

DEPOSIT

PROXIMAL

DISTAL

DEPOSITIONAL RATE



Mud layer freeze

CONCLUSIONS

First experimentally derived classification coupling flow and deposit process as well as rheological behaviour of the mixtures

do not misunderstand! but clarify some concepts and physics of the flows

Clay presence plays an important role on mixtures (rheology behavior changes) – yield Stress

The 6 regions defined showed a transition between the sediment gravity flows – from debris flows to low density turbidity current

Regions II and III are slightly different as well as regions V and VI

The database of the study can be used as input in numerical models

Acknowledgements

UFRGS
UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL

MY APOLOGIES FOR NOT GIVING A TALK BY MYSELF

But, the co-author Dr. Jaco Baas is in the audience and can answer some doubts or

email me:

rafael.manica@ufrgs.br

Thanks!!!

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