Sandy-Mass-Transport Deposits (SMTD) in Deep-Water Environments: Recognition, Geometry, and Reservoir Quality*

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Abstract

Sandy-mass-transport deposits (SMTD), composed of sandy slides, sandy slumps, and sandy debrites, are common in both modern deep-water environments and in ancient rock record. Petroleum-producing SMTDs have been documented from the Bay of Bengal, West African margin, North Sea, offshore Mid-Norway, Gulf of Mexico, California, and Brazil. Criteria for recognizing SMTDs have been developed from description of over 10,000 m of conventional cores and outcrops (1:20 to 1:50 scale), which include cores from 32 deep-water sandstone petroleum reservoirs worldwide (e.g., Shanmugam et al., 1994 and 1995; Shanmugam, 2006).

Incongruous classifications of gravity-driven processes, without a unified concept, have resulted in at least 76 different types of mass-transport processes and related nomenclature with overlapping and confusing meanings. This plethoric lexicon includes four types of slumps, five kinds of landslides, five types of flow slides, and nine kinds of creeps. Dott's (1963) classification, based on mechanical behavior, into (1) elastic (rock fall), (2) elastic and plastic (slide and slump), (3) plastic (debris flow), and (4) viscous fluid (turbidity current) types is the most meaningful and practical scheme for interpreting the ancient mass-transport deposits (MTD). The underpinning principle of this classification is the separation of solid from fluid behavior. In the solid (elastic and plastic) mode of transport, high sediment concentration is the norm (25-100% by volume). In contrast, turbidity currents are characterized by low sediment concentration (1-25% by volume). In this scheme, mass-transport processes do not include turbidity currents. Other classifications, based on sediment-support mechanisms (Middleton and Hampton, 1973) and transport velocity (Varnes, 1958 and 1978), are flawed and impractical. There are no objective criteria for interpreting velocities of mass-transport processes in the ancient rock record. Therefore, the interpretation of fast-moving debris avalanches (Wynn et al., 2000; Lewis and Collot, 2001) from seismic data and bathymetric images is untenable.

Sandy mass-transport deposits, with sand content of over 20% by volume, can be recognized in conventional cores and outcrops. Sandy slides exhibit (1) basal primary glide planes, (2) basal shear zones, (3) sand injections, (4) internal secondary glide planes, (5) internal fabric changes, and (6) sharp upper contacts. Sandy slumps show (1) slump folds, (2) deformed units interbedded with undeformed layers, (3) chaotic sands with deformed clasts, (4) sharp upper contacts, and (5) sand injections. Sandy debrites comprise (1) thick amalgamated massive sands, (2) sharp basal contacts, (3) inverse grading, (4) floating quartz granules, (5) floating mudstone clasts and armored mudstone balls, (6) planar and random clast fabrics, (7) contorted layers, (8) sand injections, and (9) sharp and irregular upper contacts. On RMS seismic amplitude maps, SMTDs exhibit variable planform geometries, but show sharp margins. Sandy debrites exhibit both sinuous and lobate planform geometries. Cross-sectional geometries vary from sheet to lenticular types. On wireline logs, SMTDs exhibit a wide range of log motifs (e.g., blocky, upward-fining, upward-coarsening, etc.). In the absence of conventional cores, however, there are no objective criteria for distinguishing sandy slides, sandy slumps, and sandy debrites on seismic profiles or on wireline logs.

In the offshore Krishna-Godavari (KG) Basin (Bay of Bengal, India), a depositional model has been proposed for deep-water petroleum reservoir sands (Pliocene) based on examination of 313 m of conventional cores from three wells (Shanmugam et al., 2009). These upper-slope sands are composed primarily of SMTDs. Sandy debrites occur as sinuous canyon-fill massive sands, inter-canyon sheet sands, and canyon-mouth lobate sands. Reservoir sands, composed mostly of amalgamated units of sandy debrites, are thick (up to 32 m), low in mud matrix (less than 1% by volume), and high in measured porosity (35-40%) and permeability (850-18,700 mD). In the KG Basin, frequent tropical cyclones, tsunamis, earthquakes, shelf-edge canyons with steep-gradient walls of more than 30°, and seafloor fault scarps are considered to be favorable factors for triggering mass movements.

Earthquakes (e.g., the 1929 Grand Banks earthquake off the U.S. Atlantic coast and Canada), meteorite impacts (e.g., the Chicxulub impact at K-T boundary in the Yucatan, Mexico), volcanic activities (e.g., Hawaiian Islands), tsunamis (e.g., the 2004 Indian Ocean tsunami), tropical cyclones (e.g., the 2005 Category 5 Hurricane Katrina in the Gulf of Mexico), and monsoon flooding events (e.g., Bay of Bengal) initiate SMTDs suddenly in a matter of hours or days. These sediment failures commonly occur during highstands (Shanmugam, 2008). Therefore, the skewed emphasis of sea-level lowstand model, representing thousands of years, is irrelevant for understanding deep-water SMTDs.

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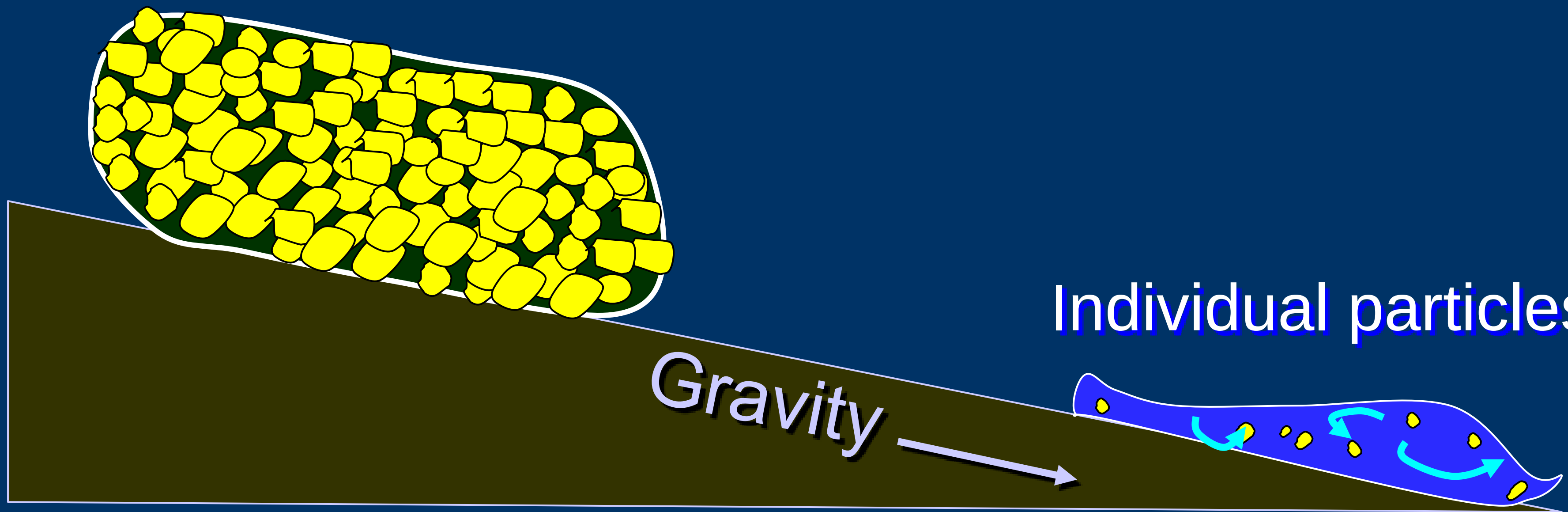
Mechanical Behavior

Elastic	Plastic	Fluid
Slide & Slump	Debris flow	Turbidity current
Mass Transport		🚫

(Dott, 1963; Based on Varnes,1958)

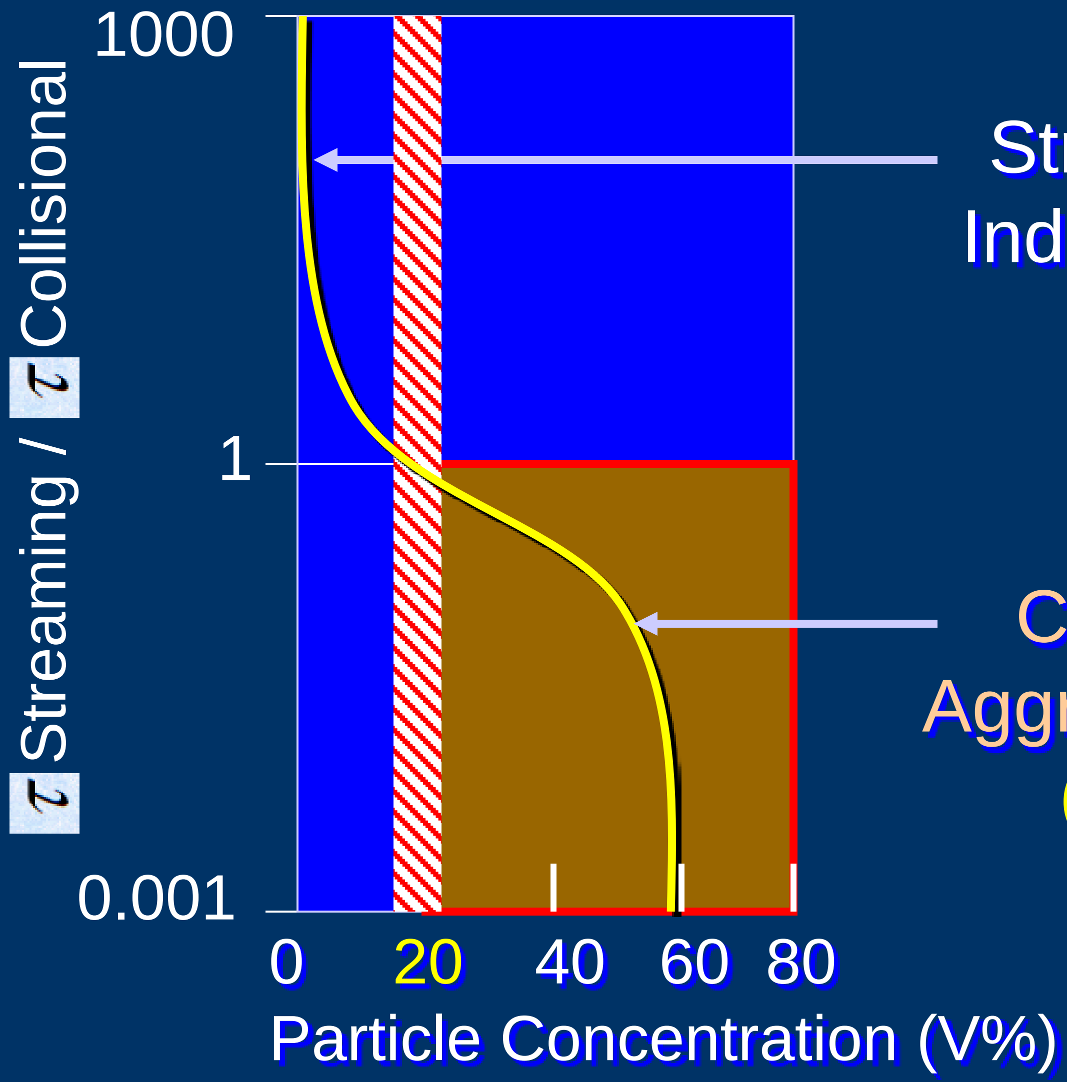


Aggregate of particles (mass)

Individual particles

Gravity

Bulk Stress vs. Particle Concentration In Granular Material

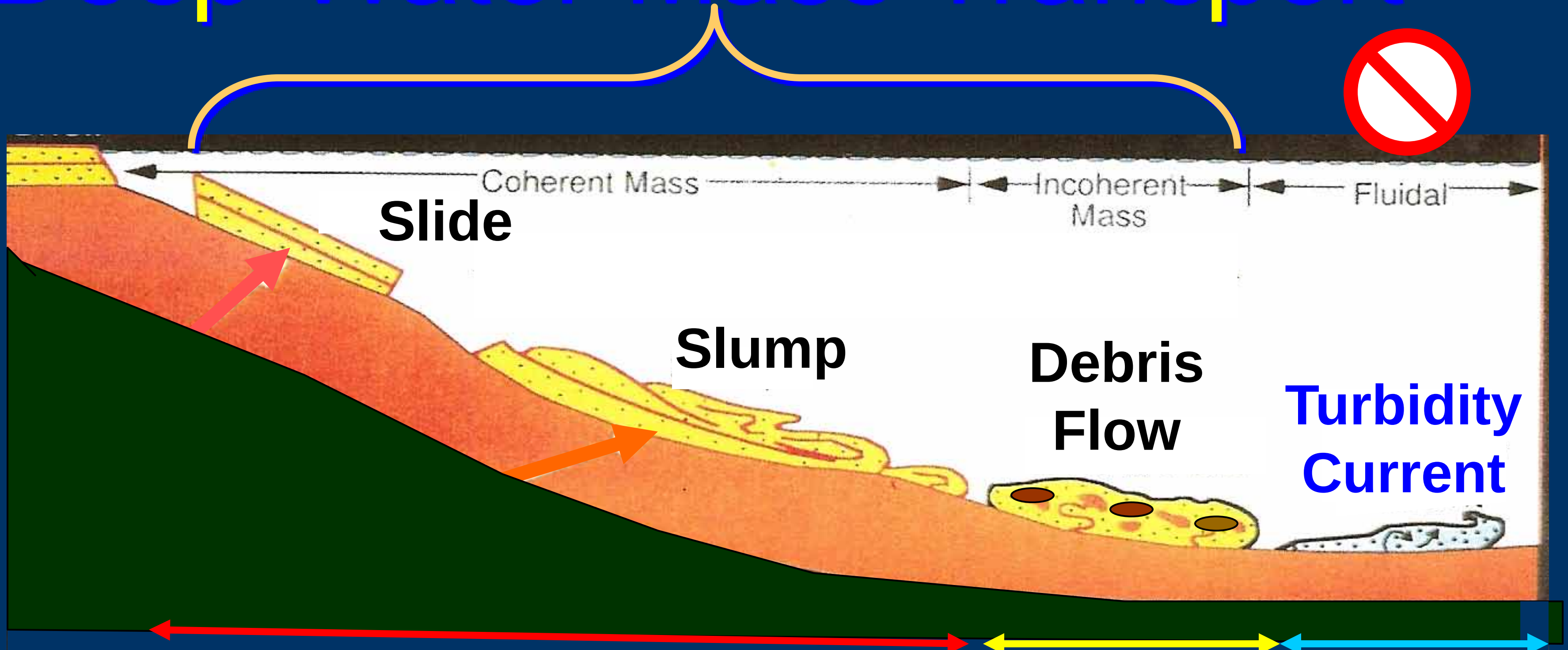


Streaming stress
Individual particles

Collisional stress
Aggregate of particles
(Cohesionless
Debris flow)

(Campbell, 1989; Figure from Nemec, 1990)

Deep-Water Mass Transport



Sed. C. (V%): 95-100 25-95 1-25

SMTD: Sand C. (V%) > 20

Turbidites

(Krynine, 1948; Bagnold, 1956; Varnes, 1958; Dott, 1963; Sanders, 1965; Middleton, 1967; Shanmugam, 2006). Figure from Shanmugam et al., (1994).

High-Volume Transport

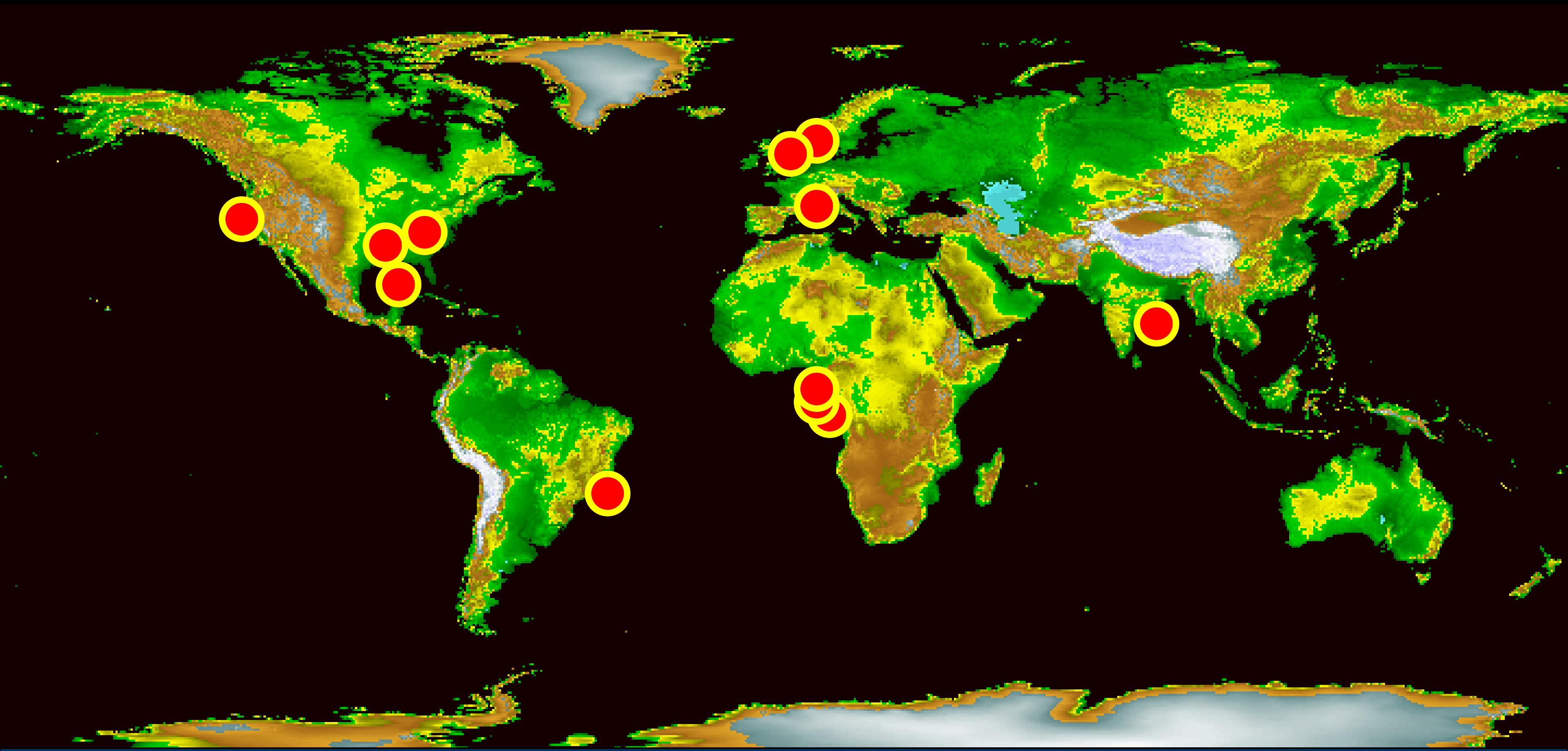
Mass Transport

Highly Efficient

Turbidity Current

Inefficient

Rock Description of Deep-water Facies
1974-2010: >33,000 ft (10,000 m)



32 Sandstone Petroleum Reservoirs

SMTD & BCR: 99%; Turbidites: 1%

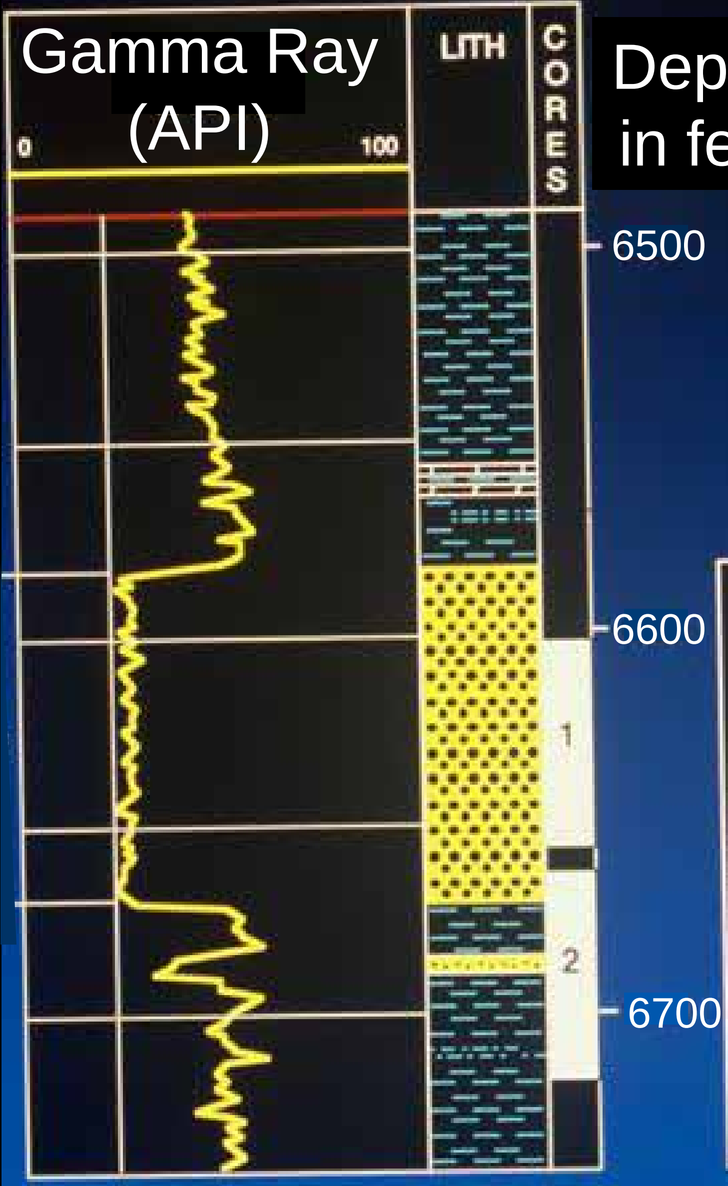
Euphemism for SMTD

(1) High-density turbidite
(2) Fluxoturbidite
(3) Seismoturbidite
(4) Megaturbidite
(5) Atypical turbidite

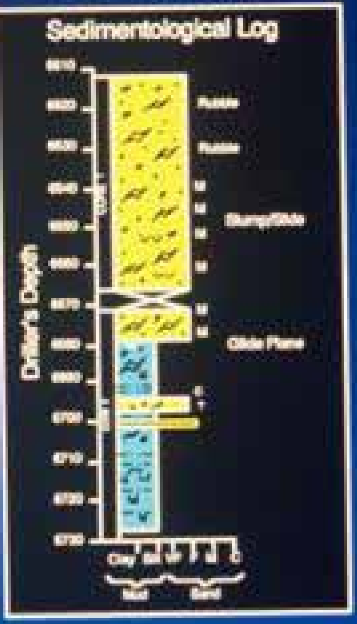
(Shanmugam, 1996, JSR)

Recognition of Sandy Slide

Blocky Log Motif
Eocene
North Sea

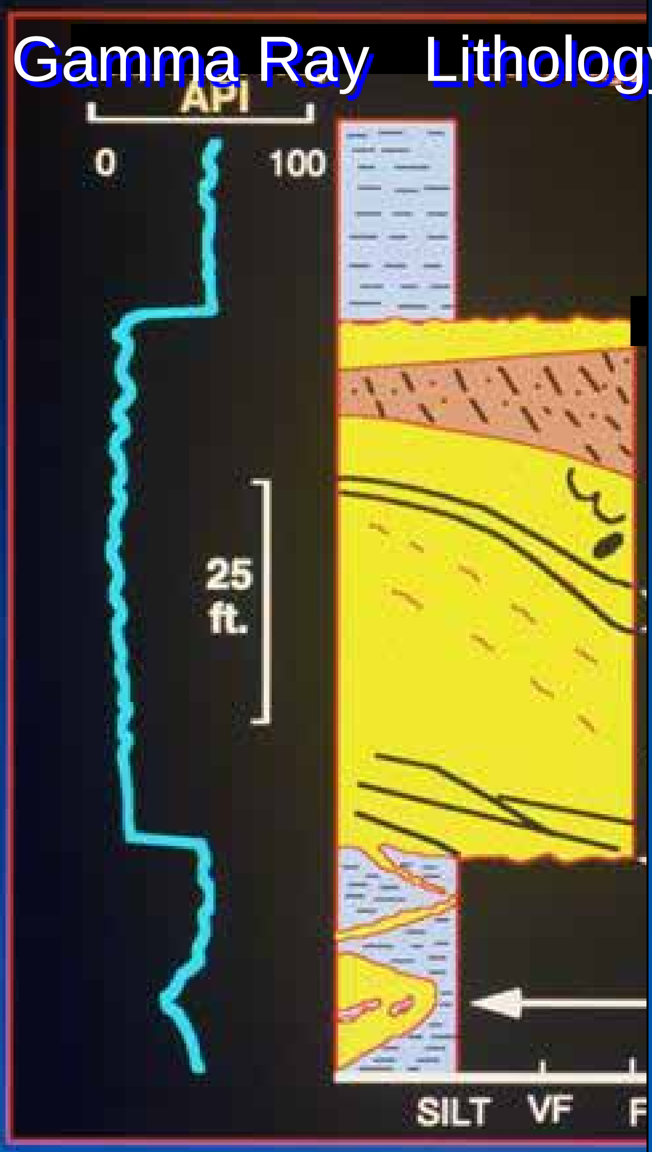


Core



Recognition of Sandy Slide

Gamma Ray Lithology



Features	Photo
Steep fabric	● 4
Mudstone clast	
Secondary glide plane	● 3
Shear surface	● 2
Sand injection	● 1

● 1

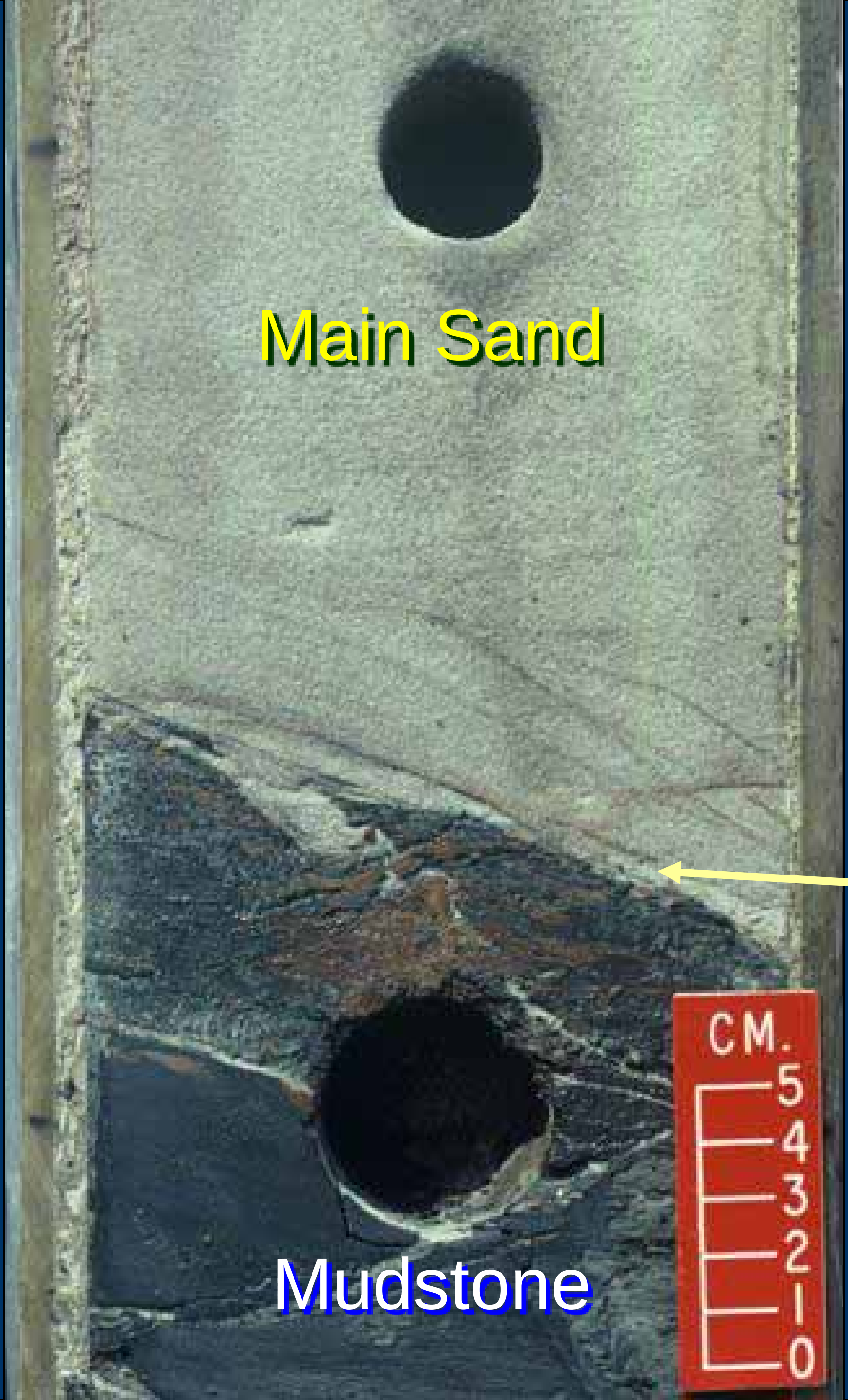
Sand Injection

Indented margin

Mudstone

● 2

Sandy Slide



Shear Surface

● 3

Sandy Slide

Clast

Secondary Glide Plane

● 4

Sandy Slide

Steep Fabric

Recognition of Sandy Slump

Undeformed Mudstone

Deformed Sand

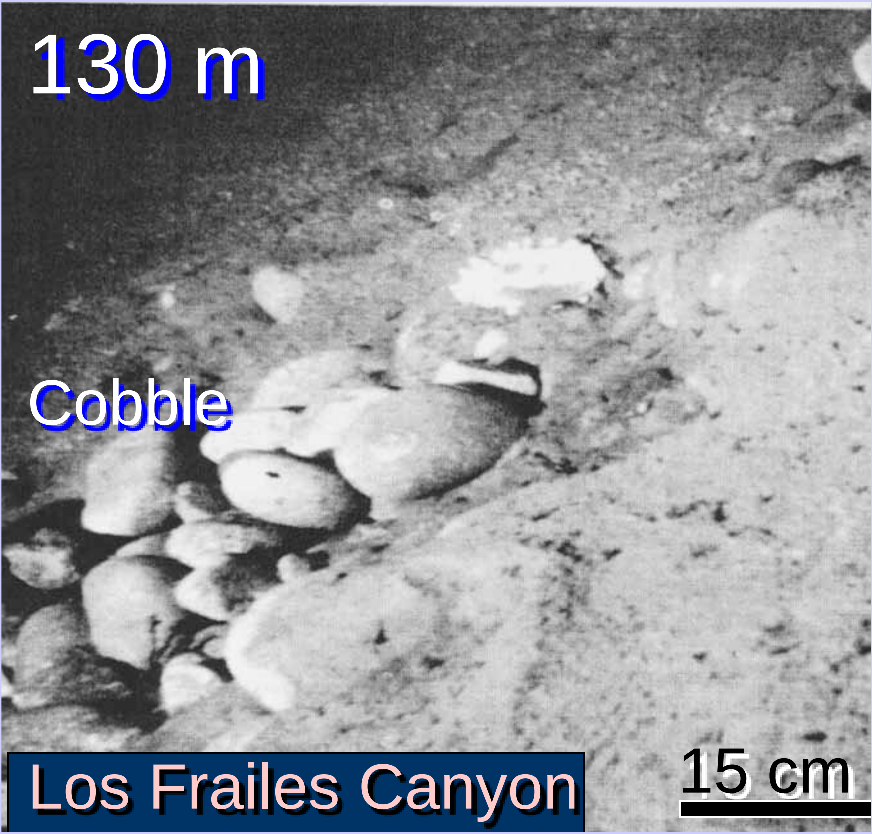
Paleocene North Sea

Sandy Mass Transport in Submarine Canyons

Baja California

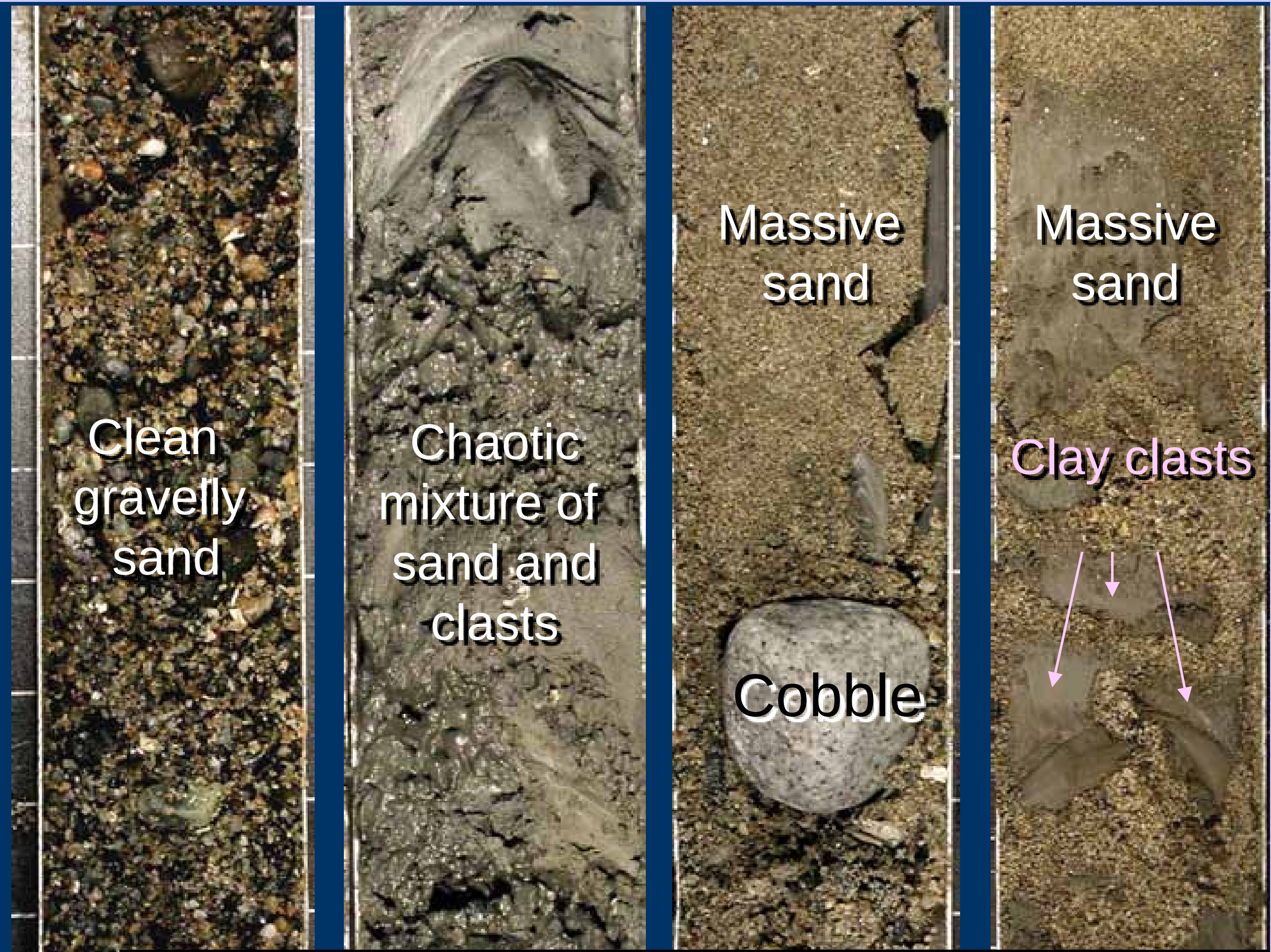
Sand Fall

Sandy Debris Flow



(Shepard and Dill, 1966)

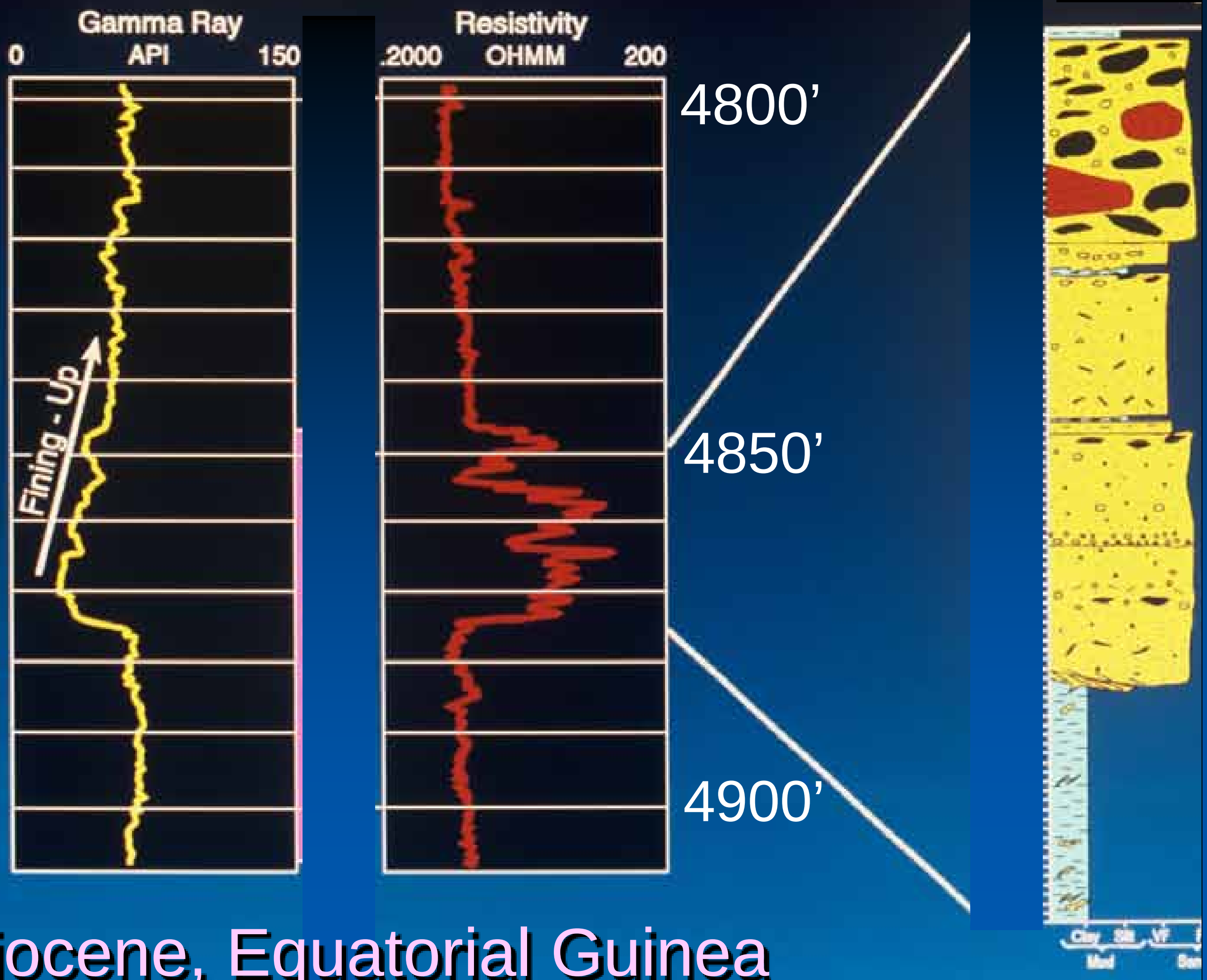
Sandy Debrite in Monterey Canyon, California



(Vibracore Photo Credit: Paull et al., 2005)

Recognition of Sandy Debrite

Gamma Ray Resistivity Core



4800’

4850’

4900’

Photo

● 2

● 1

Pliocene, Equatorial Guinea

Sandy Debrite

● 1

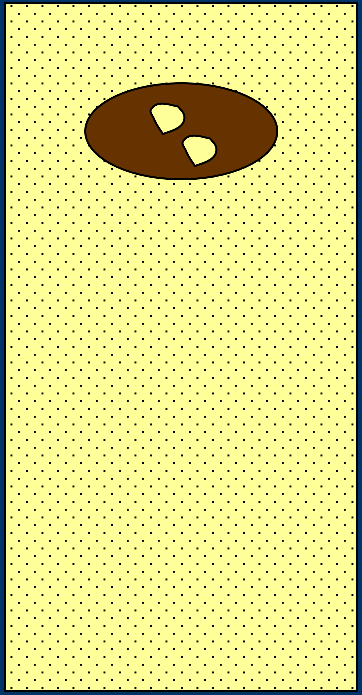
Clast-rich zone

● 2

Floating Clast

Turbidite Myth

Mudstone clasts have lower density than quartz sand (2.65 g/cm ^{3})



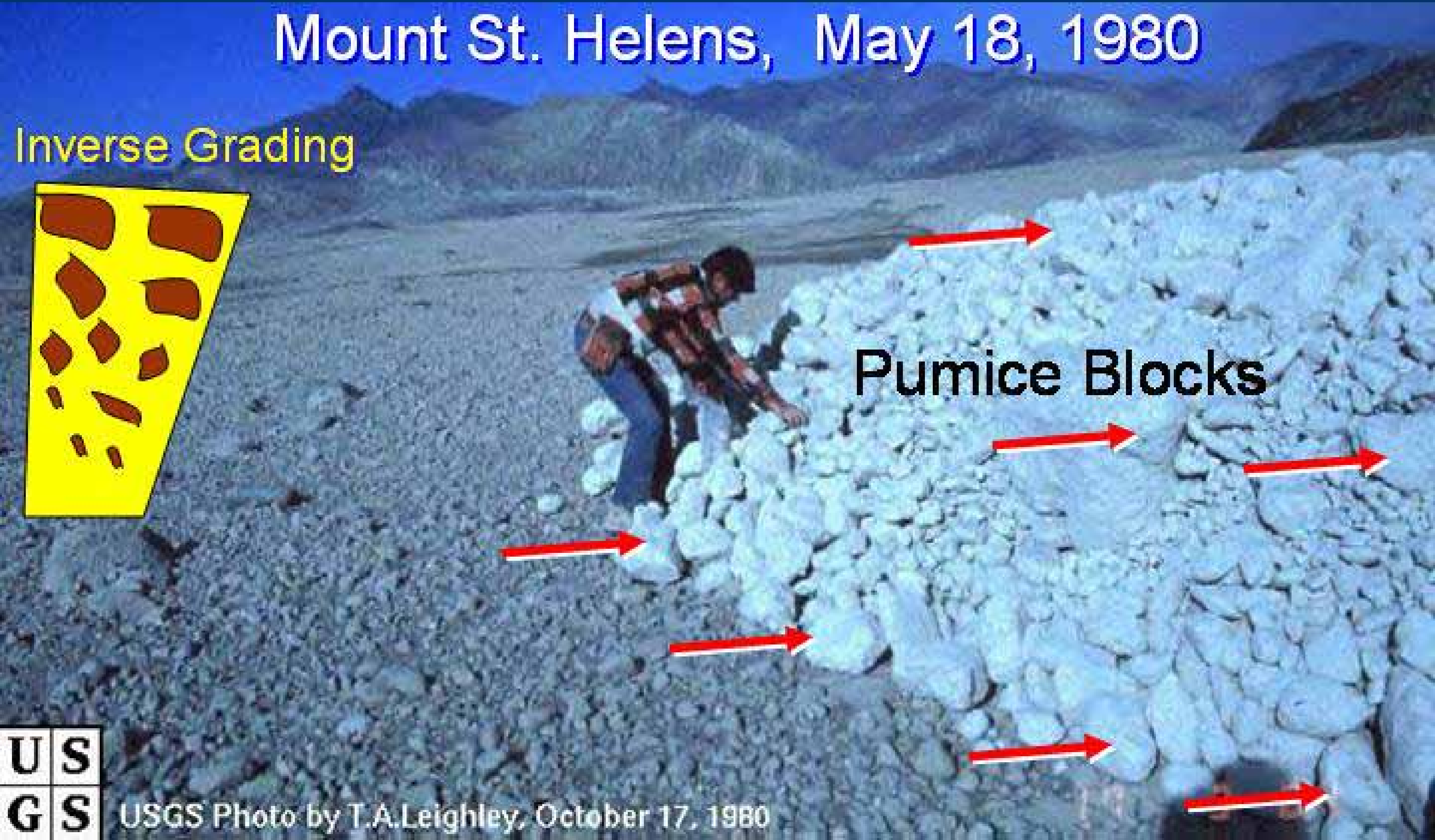
The Reality

1. Density of deep-sea clays:
   2.41 to 2.72 g/cm^3

(Opreanu, 2003-2004)

2. Inclusions

Larger Clasts at the Front of Debris Flow



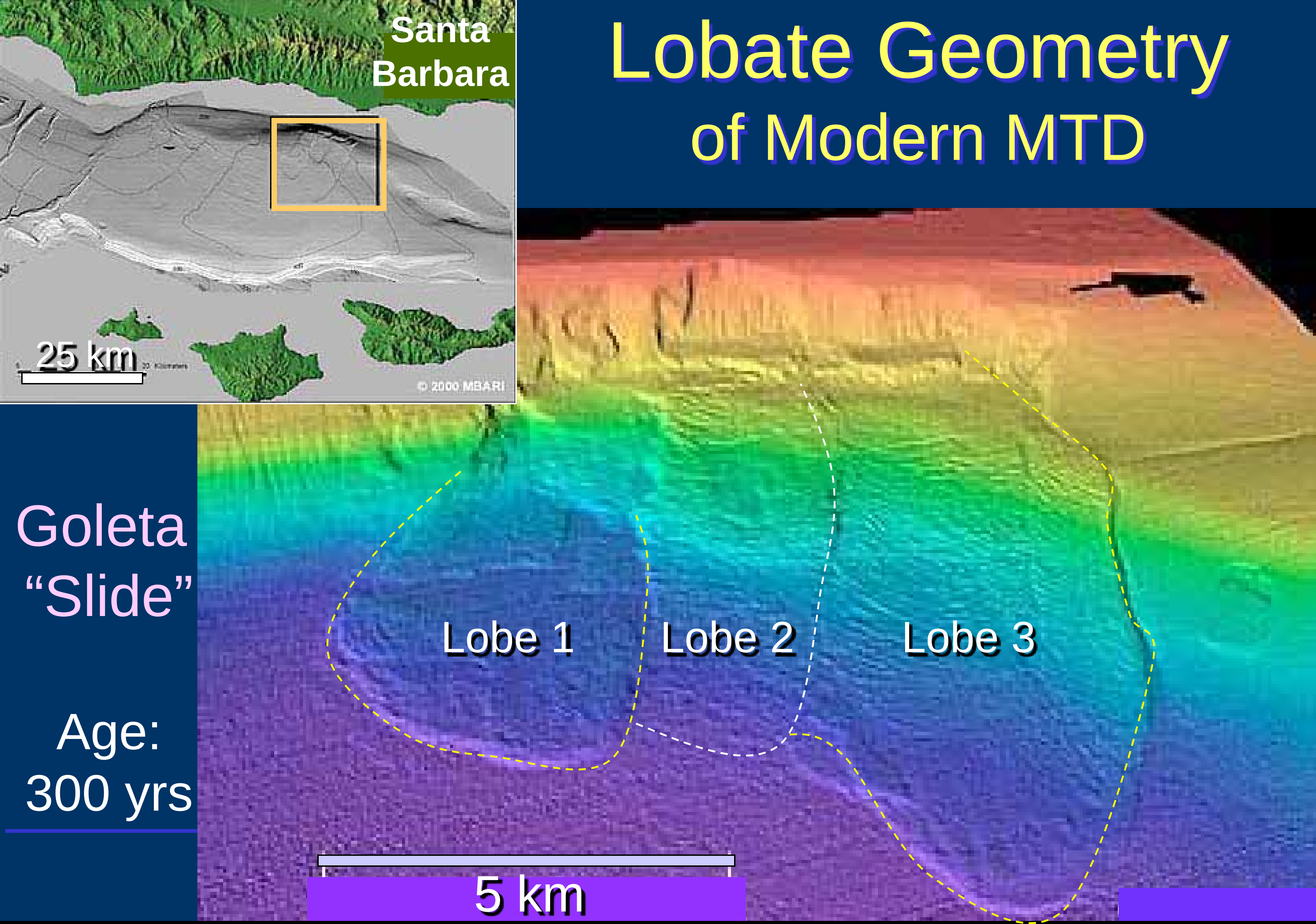
Mount St. Helens, May 18, 1980

USGS Photo by T.A.Leighley, October 17, 1980

Lobate Geometry
of Modern MTD

Goleta
“Slide”

Age:
300 yrs

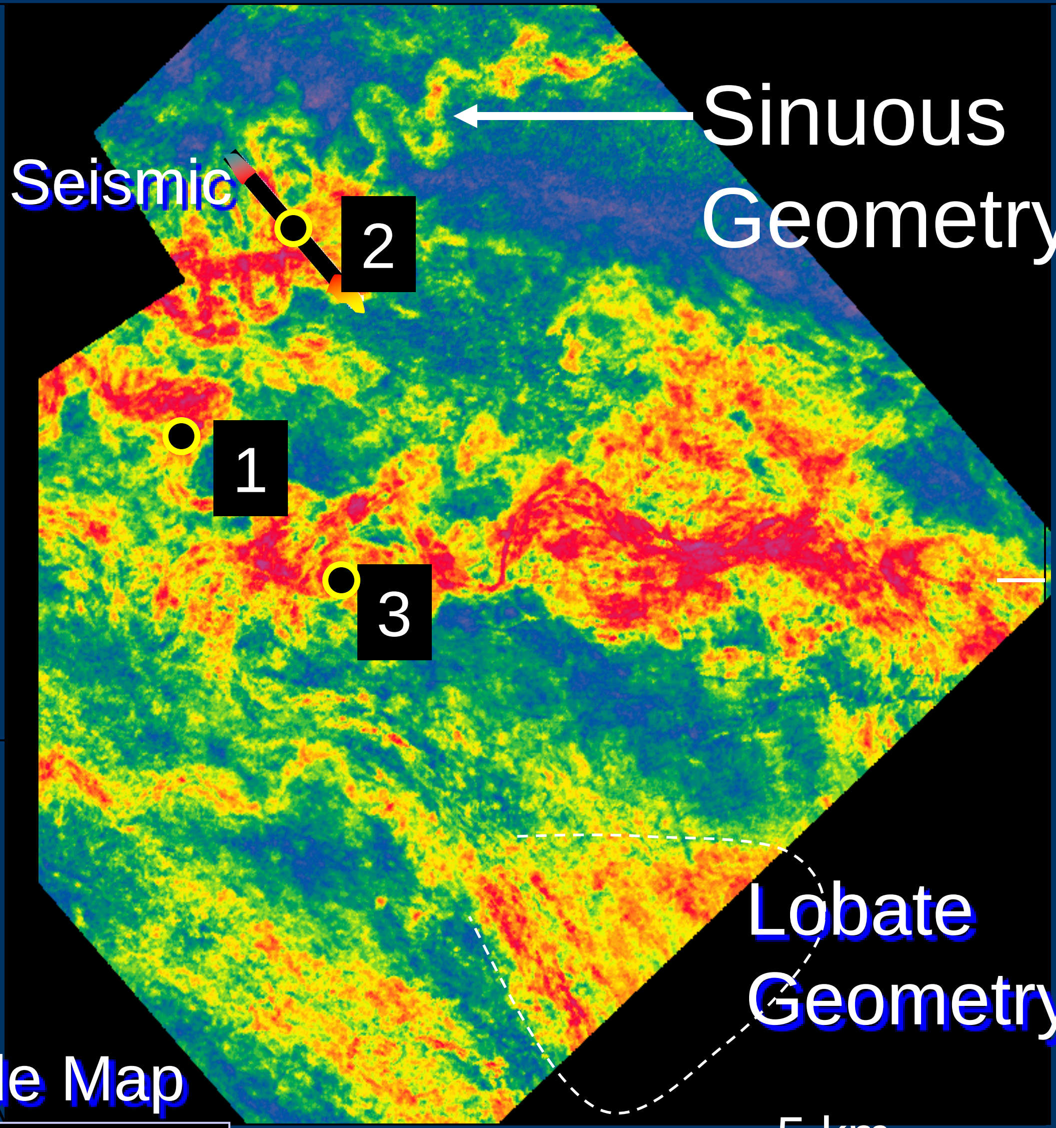


EM300 Multibeam bathymetric image (Greene et al., 2006)

Geometry of Pliocene SMTD

4°

Wells: 3
Core: 313 m



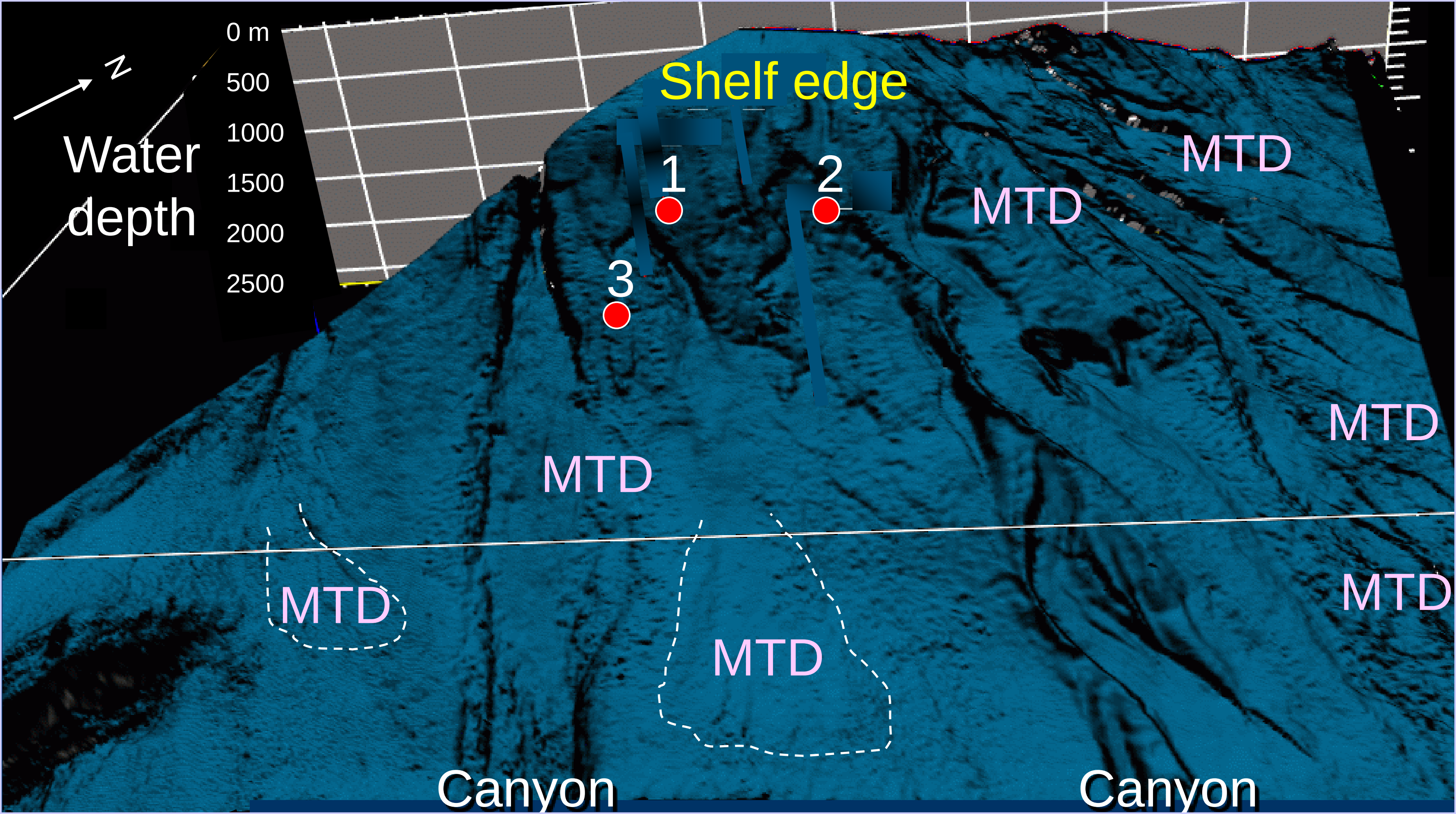
RMS Amplitude Map

🟥	High amplitude (gas sand)
🟦	Low amplitude (mudstone)

nic profile
re 12)

(Shanmugam, Shrivastava & Das, 2009)

KG Basin: Modern Upper Slope



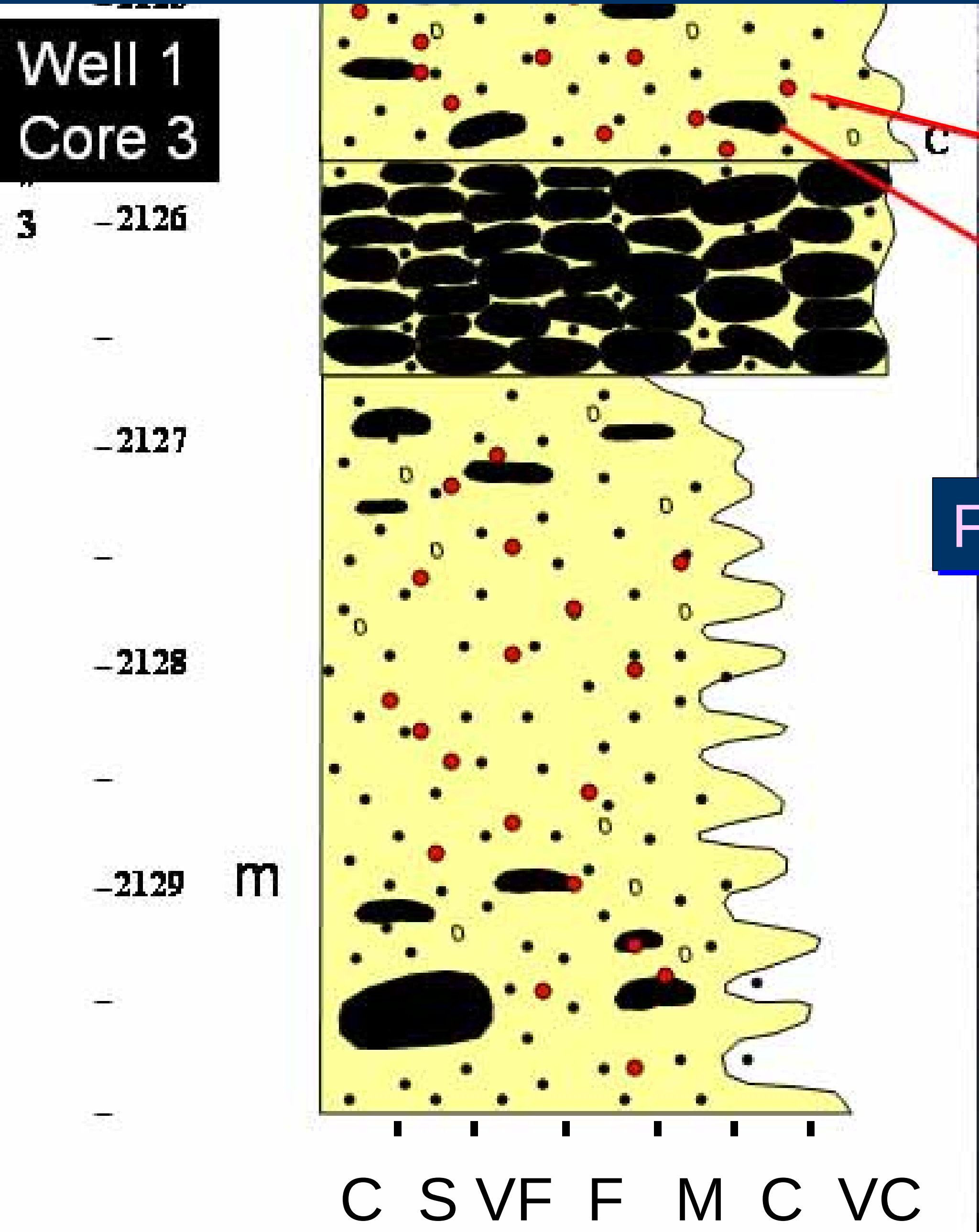
Well 1: 703 m

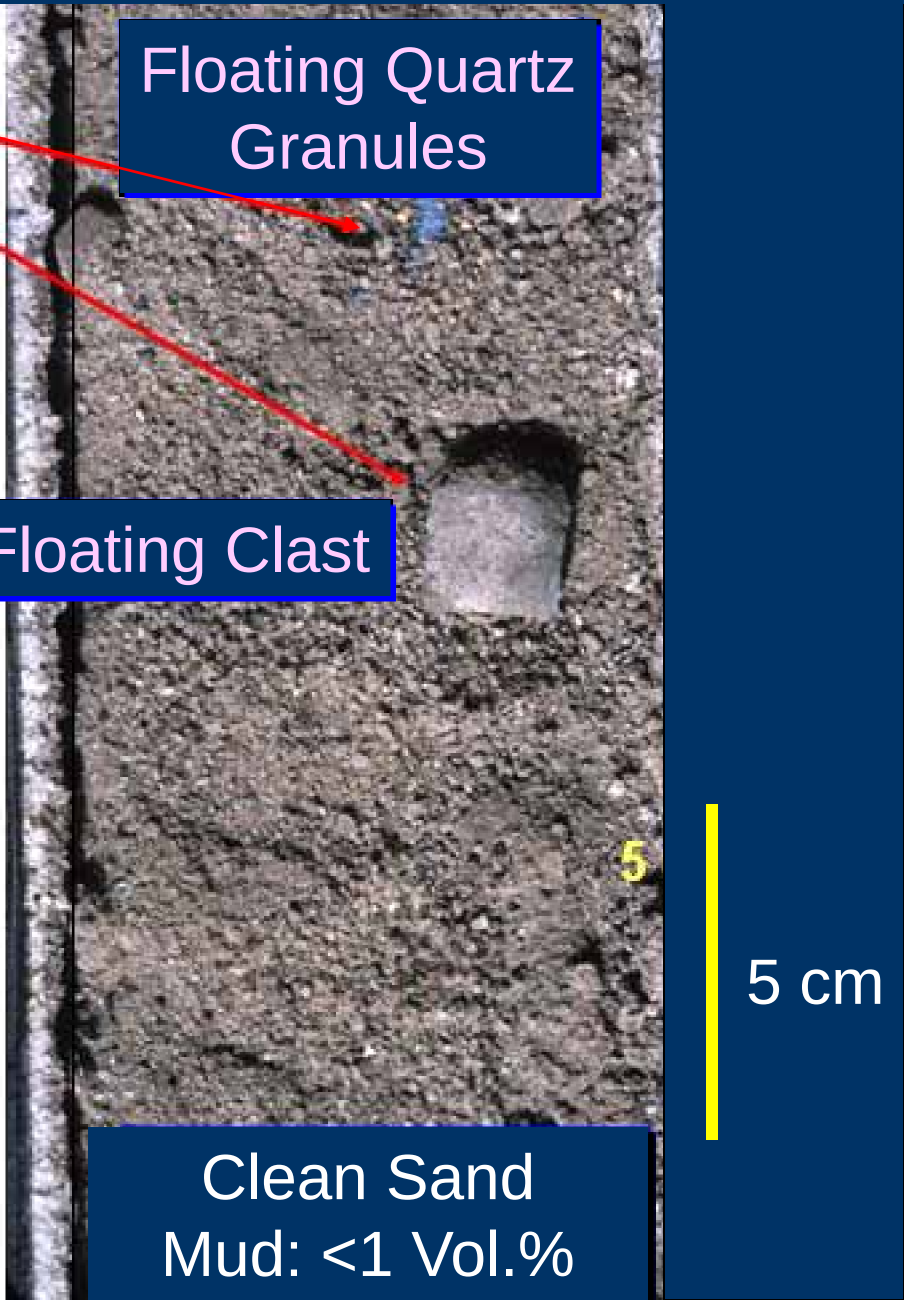
Well 2: 688.5 m

Well 3: 920 m

(Shanmugam, Shrivastava & Das, 2009)

Sandy Debrite

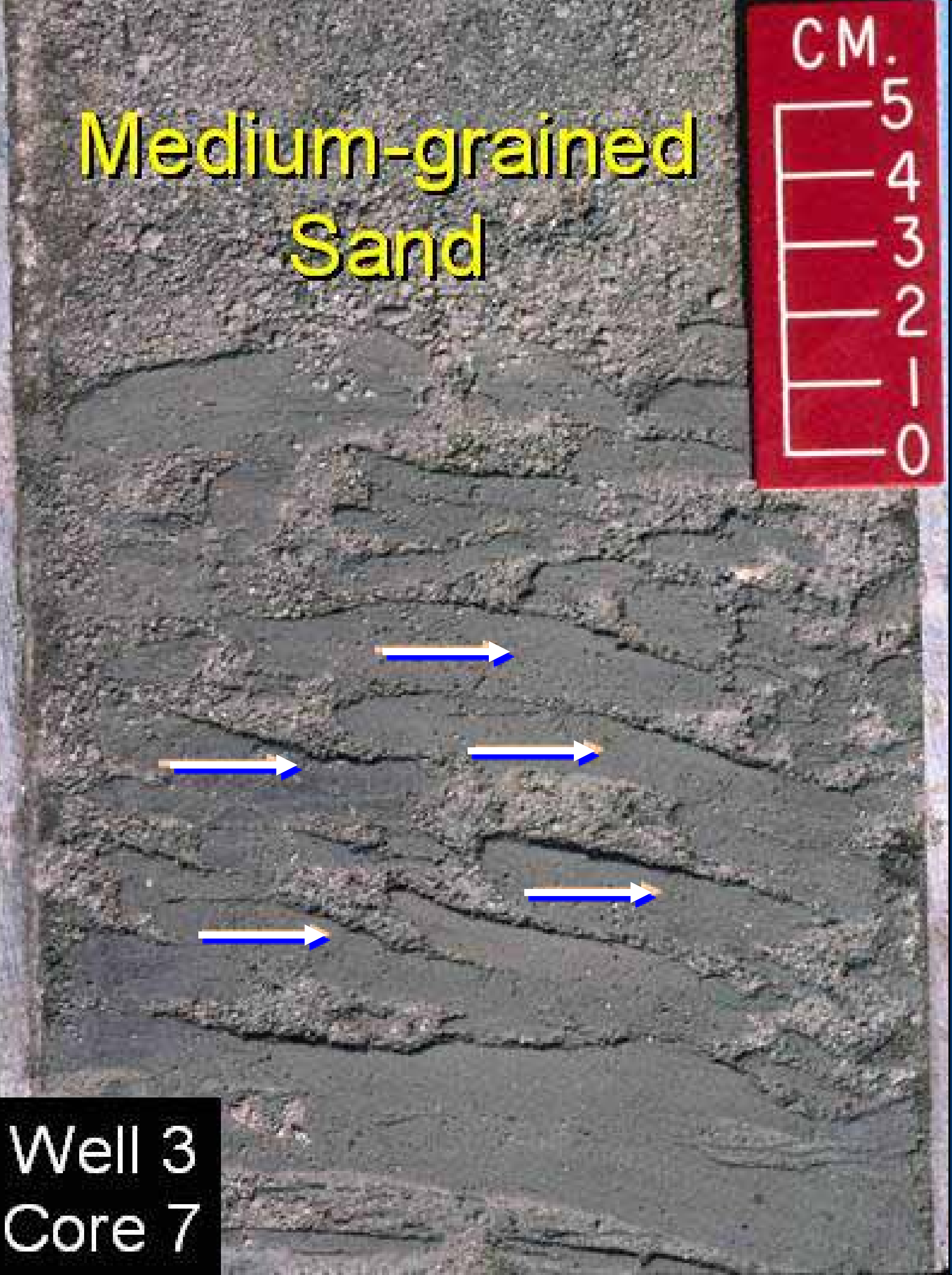

Well 1
Core 3


Floating Quartz Granules

Floating Clast

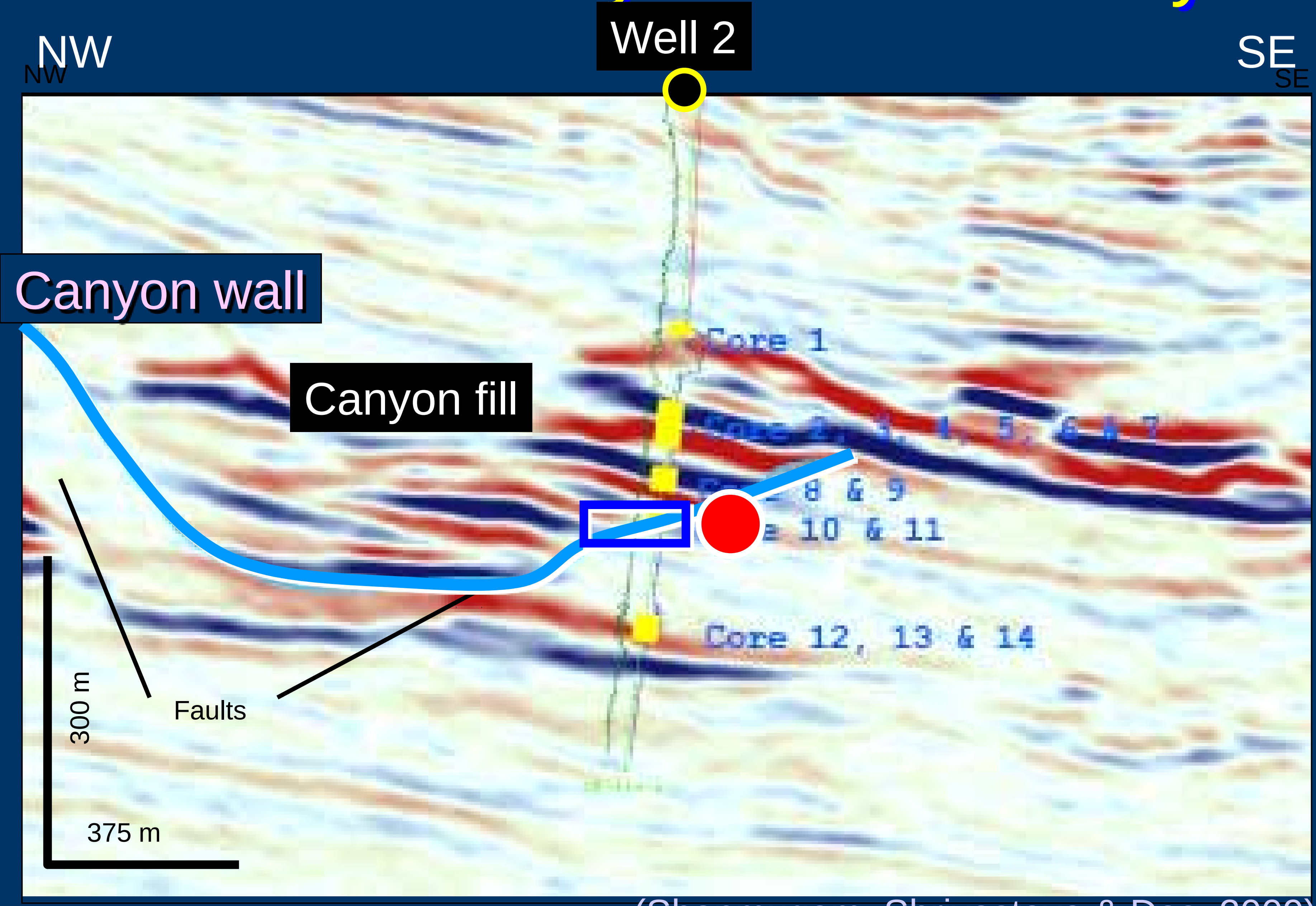
Clean Sand
Mud: <1 Vol.%

Sandy Debrite

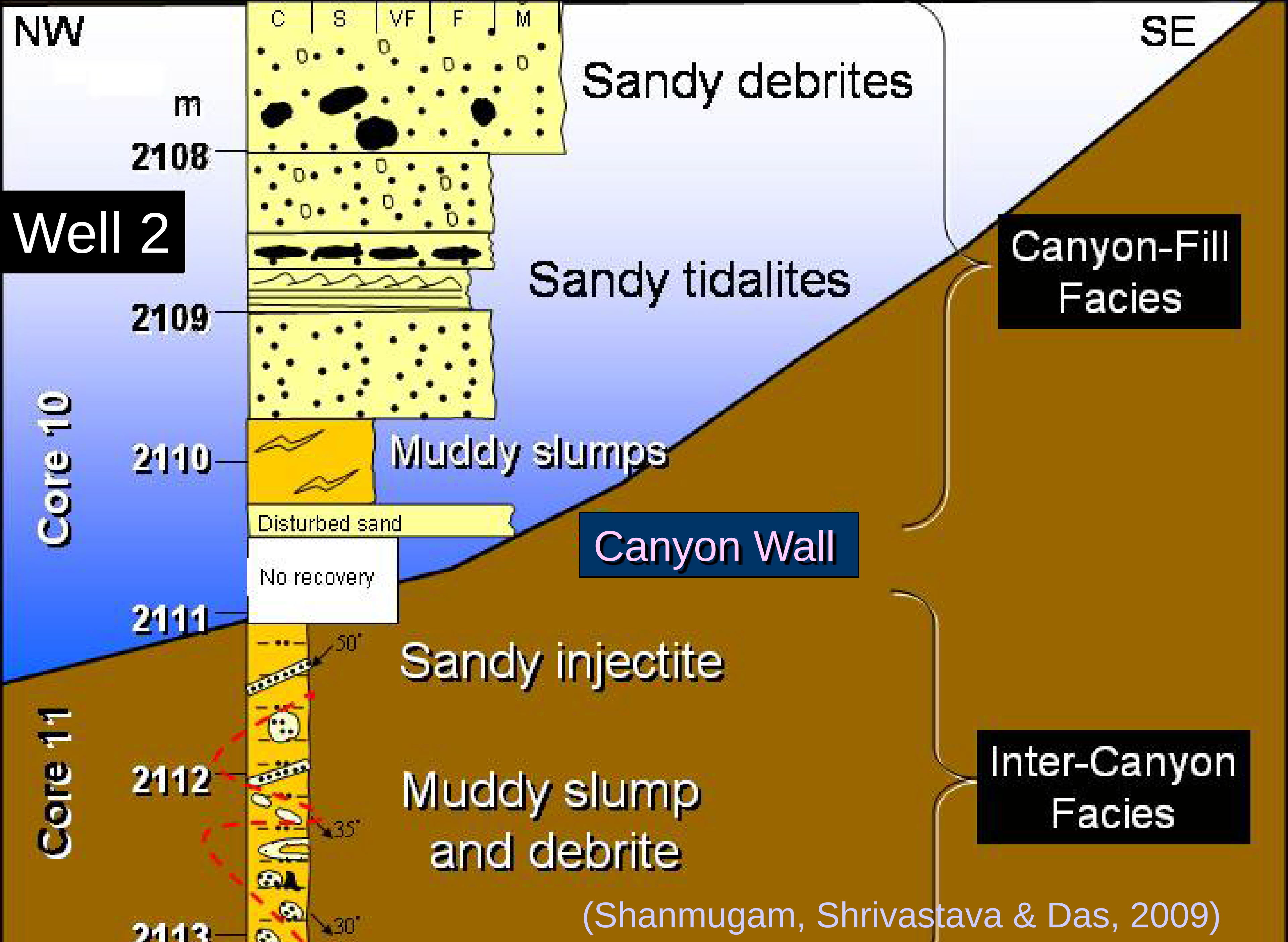


Planar clast fabric (Laminar flow)

Sinuous-Canyon-Fill Geometry



(Shanmugam, Shrivastava & Das, 2009)



Well 2

Sandy debrites

Sandy tidalites

Muddy slumps

Canyon Wall

Sandy injectite

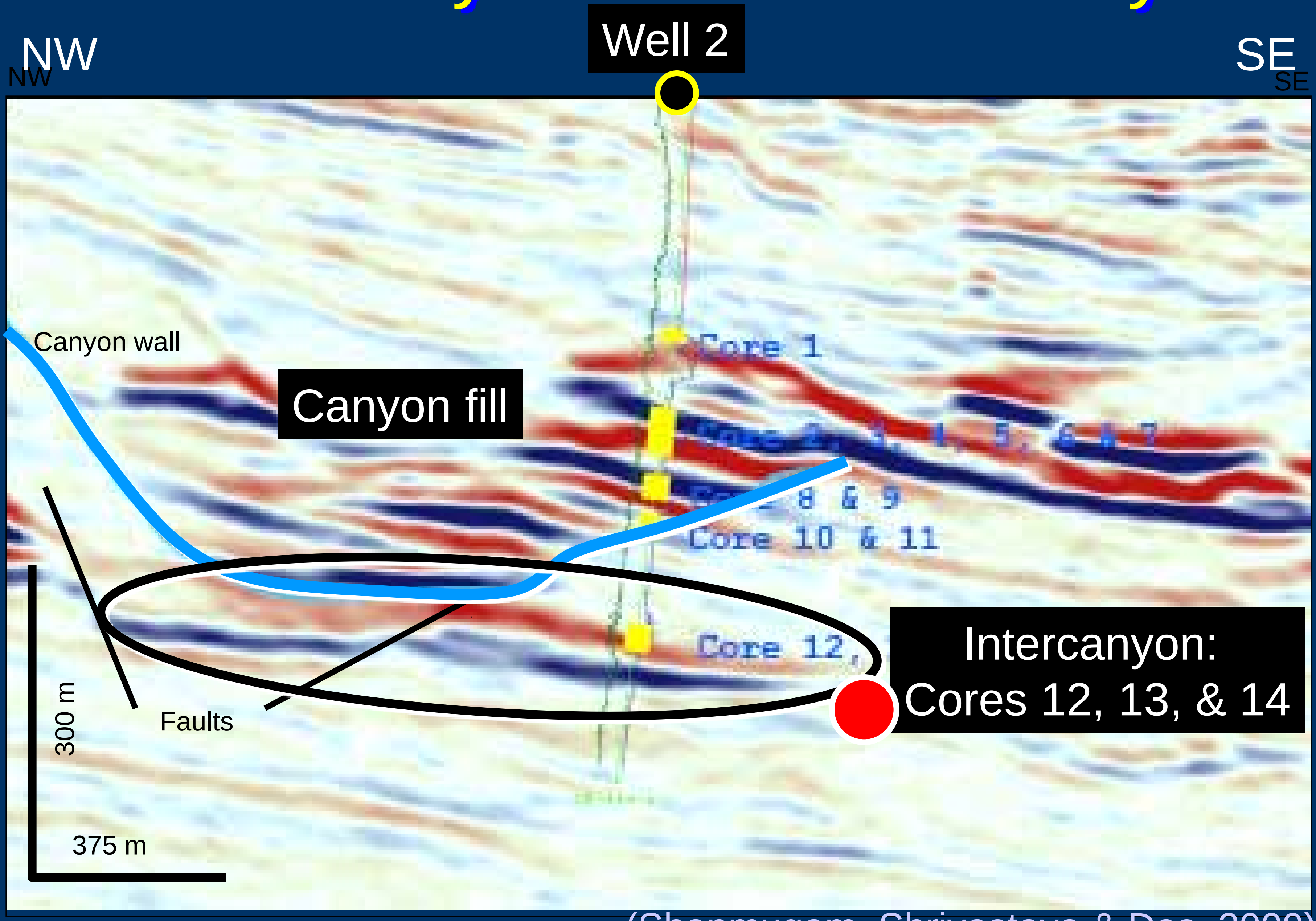
Muddy slump and debrite

Canyon-Fill Facies

Inter-Canyon Facies

(Shanmugam, Shrivastava & Das, 2009)

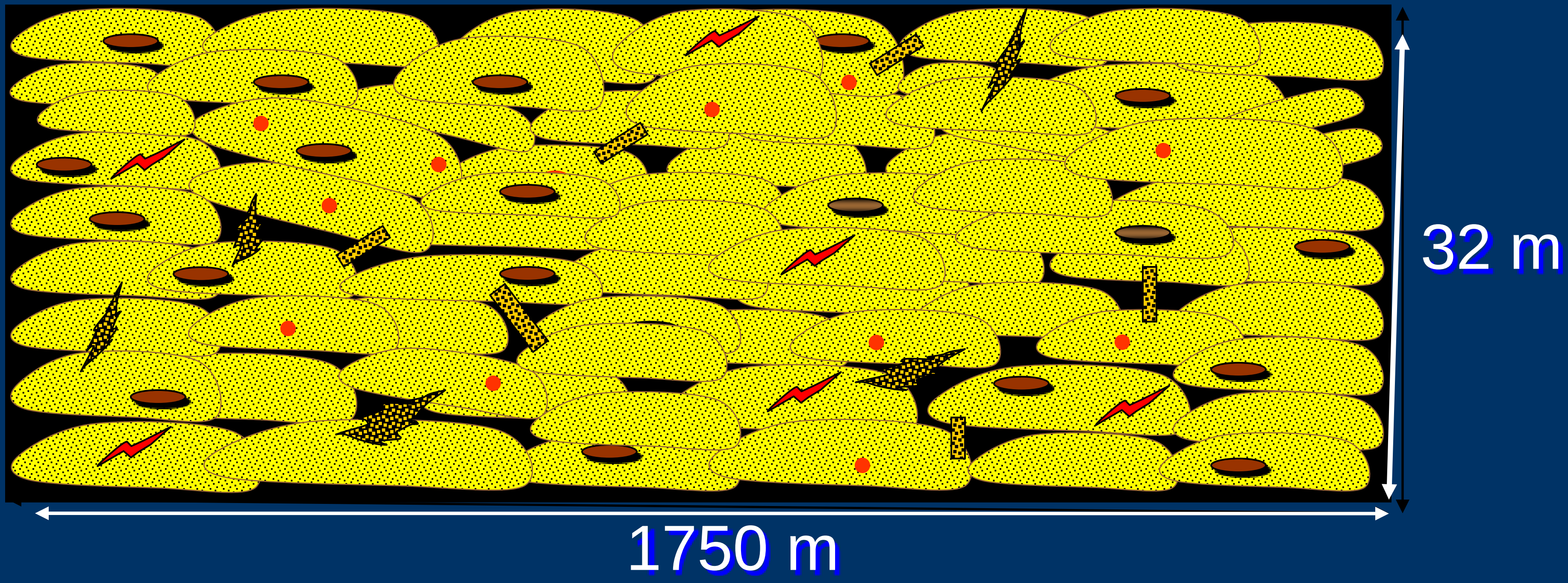
Intercanyon-Sheet Geometry



Intercanyon:
Cores 12, 13, & 14

(Shanmugam, Shrivastava & Das, 2009)

Intercanyon-Sheet Geometry
Sandy Debrite



Planar Clast Fabric

●●● Floating Quartz Granules

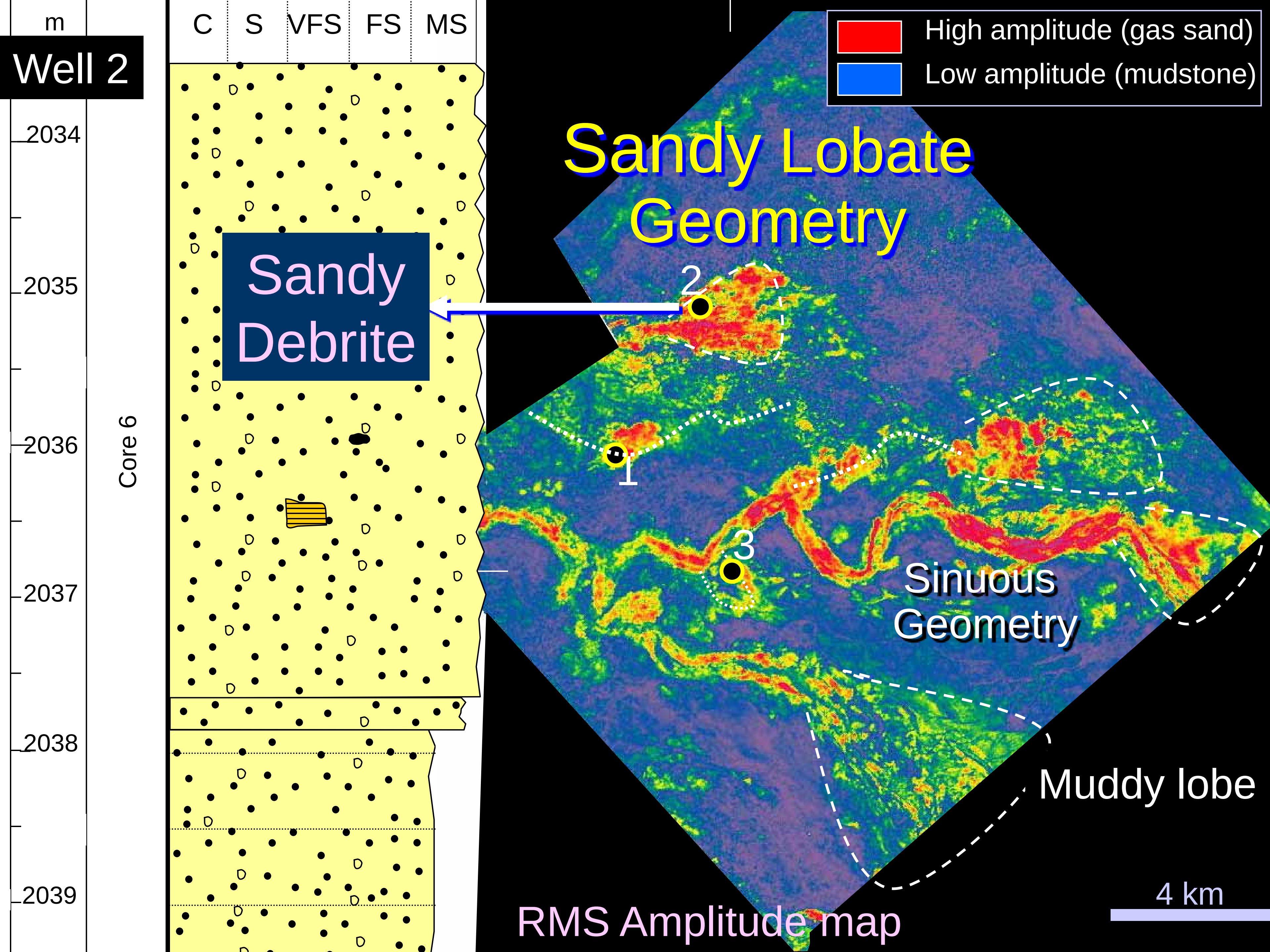
Deformed Layers

Sand Injection

Well 2

Cores 12, 13, 14

KG Basin


Well 2
m
2034
2035
2036
2037
2038
2039
Core 6
C
S
VFS
FS
MS
Sandy Debrite
🟥 High amplitude (gas sand)
🟦 Low amplitude (mudstone)
Sandy Lobate Geometry
2
1
3
Sinuous Geometry
Muddy lobe
4 km
RMS Amplitude map

Reservoir Quality
Pliocene SMTD
KG Basin

- Thick & Clean Sand
- Porosity: 35-40%
- Perm.: 850-18,691 mD

(Shanmugam, Shrivastava & Das, 2009)

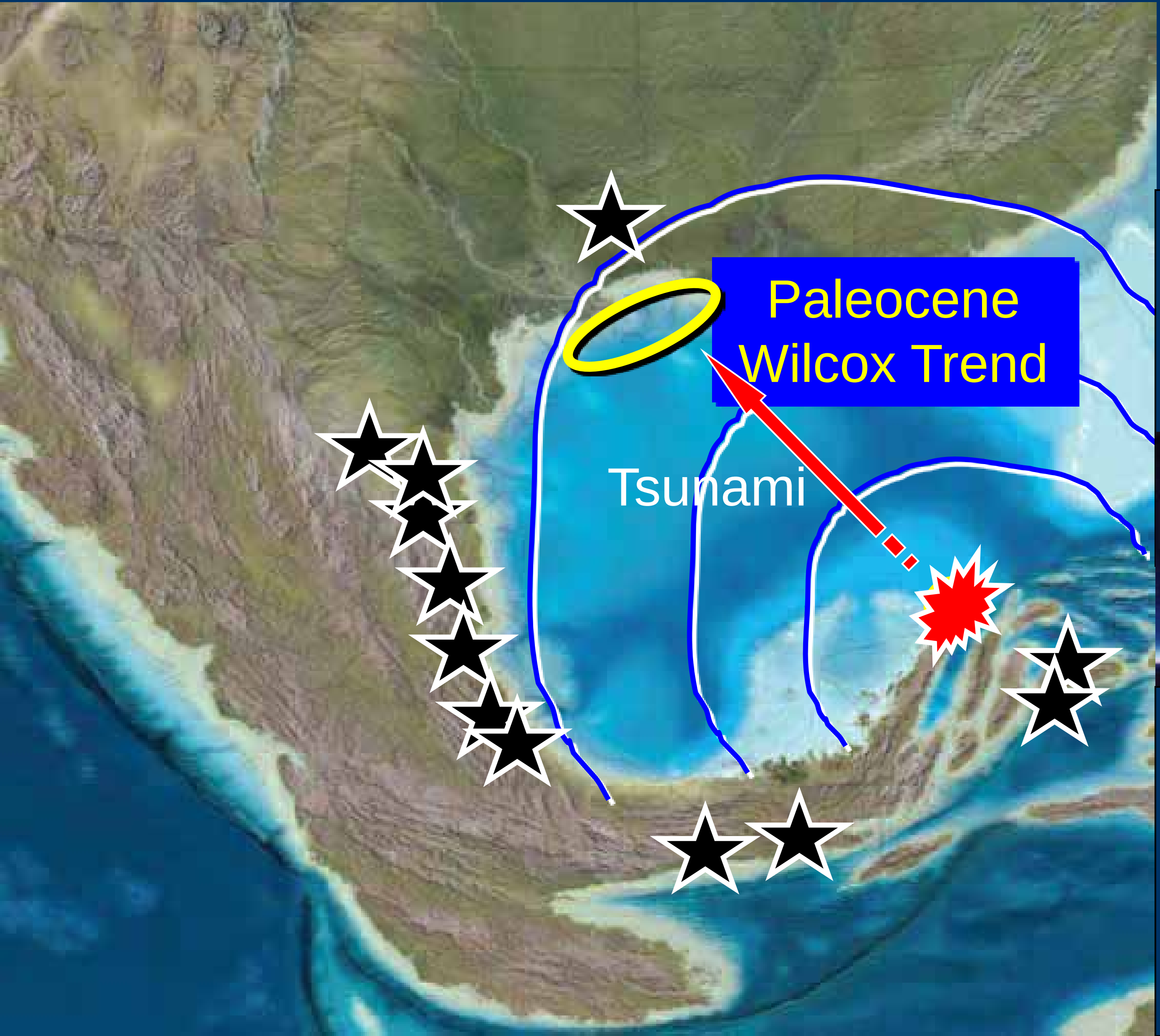
Triggering of MTD

1. Earthquakes
2. Meteorite impact
3. Volcanism
4. Tsunamis
5. Tropical cyclones
6. Monsoon flooding

Hours to Days

7. Tectonic oversteepening
8. Glacial loading
9. Salt movements
10. Sedimentation
11. Biologic erosion
12. Wildfire
13. Gas hydrates
14. Sea-level lowstand } 1000s of yrs

MTD & Chicxulub Asteroid (K-T)



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MTD (K-T)
(Claeys et al. 2002, GSA Sp. Pub. 356)

Chicxulub
65.5 Ma
(Schulte et al., 2010, Science)

(Map from Meyer et al., 2007)

Conclusions

- Recognition: Based on the Rocks
- Geometry: Sheet, sinuous, & lobate
- Reservoir Quality: Good
- Sea-Level Models: Irrelevant

Look at the Rocks Please!!!

THANK YOU