Turbidites*

Emiliano Mutti[1]

Search and Discovery Article #30214 (2011)
Posted December 12, 2011

*Adapted from special lecture at AAPG International Conference and Exhibition, Milan, Italy, October 23-26, 2011

[1]University of Parma (mutti@unipr.it)

Abstract

Prior to the advent of new seismic and marine geology techniques, most of our understanding was based on the classical approach of detailed studies of facies and facies associations. The new data that have emerged from increasingly detailed seismic and marine geology studies of continental margins have cast serious doubts on our initial, relatively simple, perception of deep-water sedimentation, which now appears to be much more complex than originally thought and difficult to predict only on the basis of what we had learned from exposed thrust-fold belts.

Differences in data sets and a plethora of new terms are increasingly hampering significant comparisons of two inherently different geodynamic settings and highlighting an already obvious dichotomy between the classic world of turbidite/flysch basins in orogenic belts and that which we are discovering day after day in divergent margin settings through increasingly more sophisticated techniques. A growing body of evidence also suggests that, in these basins, oceanic bottom currents may have played a major role in reworking and redistributing sand originally transported by turbidity currents.

Selected References

Amy, L.A., and P.J. Talling, 2006, Anatomy of turbidites and linked debrites based on long distance (120x30km) bed correlation, Marnoso Arenacea Formation, Northern Apennines, Italy: Sedimentology, v. 53/1, p. 161-212.

Kuenen, P.H., 1957, Review of marine sand-transporting mechanisms: Journal of the Alberta Society of Petroleum Geologists, v. 5/4, p. 59.62.

Kuenen, P.H., and C.I. Migliorini, 1950, Turbidity currents as a cause of graded bedding: Journal of Geology, v. 58/2, p. 91-127.

Lowe, D.R., 1982, Sediment gravity flows; II, Depositional models with special reference to the deposits of high-density turbidity currents: Journal of Sedimentary Petrology, v. 52/1, p. 279-297.

Middleton, G.V., and M.A. Hampton, 1973, Sediment gravity flows; mechanics of flow and deposition: Soc. Econ. Paleontol. Mineral., Pacific Section, Los Angeles, California, USA, p. 1-38.

Mutti, E., D. Bernoulli, F. Ricci Lucchi, and R. Tinterri, 2009, Turbidites and turbidity currents from Alpine "Flysch" to the exploration of continental margins *in* J.A. McKenzie, D. Bernoulli, and M.B. Cita, (eds.), Symposium on Major discoveries in sedimentary geology in the Mediterranean realm from a historical perspective to new development: Sedimentology, v. 56/1, p. 267-318.

Mutti, E., R. Tinterri, G. Benevelli, D. DiBiase, and G. Cavanna, 2003, Deltaic, mixed and turbidite sedimentation of ancient foreland basins *in* E. Mutti, G.S. Steffens, C. Pirmez, M. Orlando, and D. Roberts, (eds.), Turbidites; models and problems: Marine and Petroleum Geology, v. 20/6-8, p. 733-755.

Mutti, E., G.S. Steffens, C. Pirmez, M. Orlando, and D. Roberts, 2003a, Turbidites: Models and Problems: Marine and Petroleum Geology, v. 20, p. 523-933.

Mutti, E., E. Remacha, T. Rinterri, N. Mavilla, S. Angella, and L. Fava, 1999, Facies tracts of highly-efficient turbidity currents in large and elongate foreland basins, and their implications for basin analysis and exploration: Annual Meeting of Italian Sedimentology Group, CNR, v. 61, Serie 3C, p. 187-190.

Mutti, E., G. Davoli, S. Mora, and L. Papani, 1994, Internal stacking patterns of ancient turbidite systems from collisional basins *in* P. Weimer, A.H. Bouma, and B.F. Perkins, (eds.), Submarine fans and turbidite systems; sequence stratigraphy, reservoir architecture and production characteristics, Gulf of Mexico and international: Papers presented at the Gulf Coast Section SEPM Foundation Annual Bob F. Perkins Research Conference, v. 15, p. 257-268.

Mutti, E., 1992, AGIP Italy *in* E. Mutti, (ed.), Turbidite sandstones: 275 p.

Mutti, E., 1990, Relationships between sequential stratigraphy and tectonics: Memorie della Societa Geologica Italiana, v. 45, p. 627-655.

Mutti, E., 1989, Alcuni problemi relativi all'applicazione dei concetti della stratigrafia sequenziale all'Eocene e al Cretacico superiore Sud-Pirenaico: Supplemento al Giornale di Geologia, Bologna, v. 51, p. 37-53.

Mutti, E., 1979, Turbidites et cones sous-marins profonds: 3me Cycle Romand Sciences de la Terre, Friourg, Sedimentation detritique: p. 355-419.

Mutti, E., and F. Ricci Lucchi, 1975, The significance of certain sequential units in turbidite series: Bulletin de la Societe Geologique de France, v. 16/6, p. 577-582.

Mutti, E., and F. Ricci Lucchi, 1974, La signification de certaines unites sequentielles dans les series turbiditiques: Bulletin Soc. G., ol. France, 16/7, p. 577-582.

Mutti, E., and F. Ricci Lucchi, 1972, Turbidites of the northern Apennines: Introduction to facies analysis (English translation by T.H. Nilson, 1978): International Geology Review, v. 20, p. 125-166.

Muzzi Magalhaes, P., and R. Tinterri, 2010, Stratigraphy and depositional setting of slurry and contained (reflected) beds in the Marnoso-arenacea Formation (Langhian-Serravallian) Northern Apennines, Italy: Sedimentology, v. 57/7, p. 1685-1720.

Normark, W.R., 1970, Growth patterns of deep-sea fans: AAPG Bulletin, v. 54/11, p. 2170-2195.

Parea, G.C., 1965, Sedimentologic types of the Pre-Oligocene Turbidites of the North-Central Apennines: Geological Society of Italy Bulletin, v. 84/1, p. 223-256.

Pickering, KT., R.N. Hiscott, and F.J. Hein, 1989, Deep Marine Environments: Clastic Sedimentation and Tectonics: Unwin Hyman, London, 416 p.

Posamentier, H.W., and P.R. Vail, 1988, Sequence Stratigraphy: Sequences and Systems Tract Development: AAPG Memoir 15, p. 571-572.

Schumm, S.A., 1981, Geomorphology: Geotimes, v. 26/2, p. 32-33.

Schumm, S.A., 1981, Evolution and response of the fluvial system, sedimentologic implications *in* F.G. Ethridge, and R.M. Flores, (eds.), Recent and ancient Nonmarine depositional environments; models for exploration: SEPM Special Publication, v. 31, p. 19-29.

Schumm, S.A., 1977, Applied fluvial geomorphology *in* J.R. Hails, (ed.), Applied geomorphology; a perspective of the contribution of geomorphology to interdisciplinary studies and environmental management: Elsevier Scientific Publishing Co., Amsterdam, Netherlands, p. 119-156.

Tinterri, R., and P. Muzzi Magalhaes, 2011, Synsedimentary structural control on foredeep turbidites; an example from Miocene Marnoso-Arenacea formation, Northern Apennines, Italy *in* S.M. Hubbard, B.W. Romans, and A. Fidani, (eds.) The stratigraphic evolution of deep-water architecture: Marine and Petroleum Geology, v. 28/3, p. 629-657.

Tinerri, R., M. Drago, A. Consonni, G. Vaoli, and E. Mutti, 2003, Modeling subaqueous bipartite sediment gravity flows on the basis of outcrop constrains: first results: Marine Petroleum Geology, v. 20, p. 911-933.

Walker, R.G., 1975, Upper Cretaceous resedimented conglomerates at Wheeler Gorge, California; description and field guide: JSR, v. 45/1, p. 105-112.

Walker, R.G., 1967, Turbidite sedimentary structures and their relationship to proximal and distal depositional environments: JSR, v. 37/1, p. 25-43.

Walker, R.G., and E. Mutti, 1973, Turbidite facies and facies associations: Turbidites and Deep-Water Sedimentation, SEPM, Pacific Section, Los Angeles, p. 119-157.

TURBIDITES

Emiliano Mutti
University of Parma

OBJECTIVES

From a personal perspective, I will discuss some problems of turbidite sedimentation 60 years after these sediments were discovered by Kuenen and Migliorini (1950)

- **Brief historical introduction and early models**
- **The foredeep basin turbidites of thrust-and-fold belts**
- **Turbidite Facies, i.e. rocks**
- **Marginal flood-dominated fluvio-deltaic deposits**
- **Cyclic stacking patterns and sequence stratigraphy**
- **Comparison of turbidites of thrust-and-fold belts and deep-water sedimentation of divergent continental margin sedimentation**

Historical introduction and early models

FLYSCH

The term, introduced by Studer (1827), was used by Alpine geologists to define regular and monotonous alternations of sandstone, shale and calcareous beds forming very characteristic stratigraphic units of thrust-and-fold belt basins, i.e. an *ante-litteram* recognition of turbidites. Both sandy and calcareous flysches were recognized.

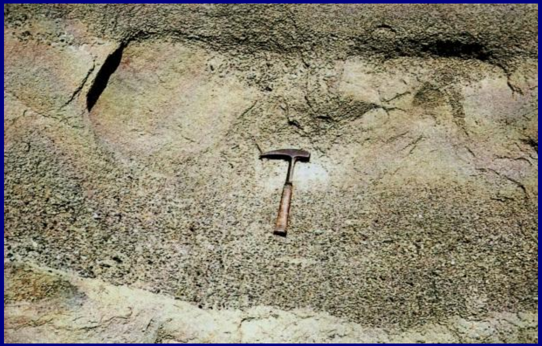
In its original definition, the term had only a lithologic significance. With time, the term has become synonimous with a tectofacies. “Flysch” is a synorogenic deposit in contrast with “molasse” which is a late-orogenic or post-orogenic deposit. This terminology is still in use among many Alpine geologists.

At present, the term has virtually lost any sedimentological meaning

- **Historical introduction and early models**

KUENEN AND MIGLIORINI (1950)
(but see also Migliorini, 1943)

"Turbidity currents as a cause of graded bedding"



Shallow-marine sand is re-deposited in deep-marine environments by sediment-laden flows that move downslope because of their excess density

These flows were called "**turbidity currents**"

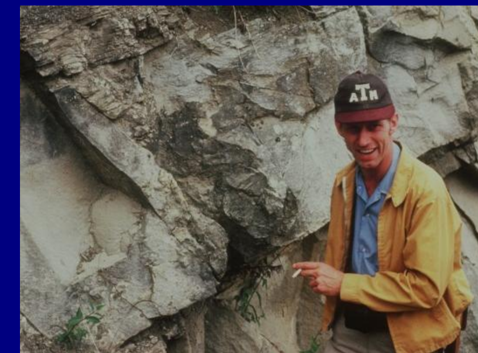
The term "**turbidites**" was introduced later Kuenen, 1957) to denote the deposits of turbidity currents.
The term was essentially synonimous with re-sedimented graded sandstone beds

Ph.H. Kuenen

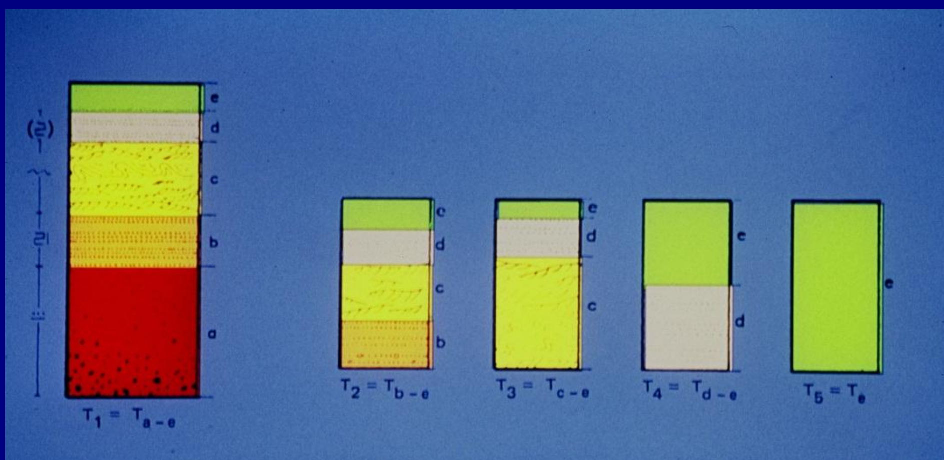
C.I. Migliorini

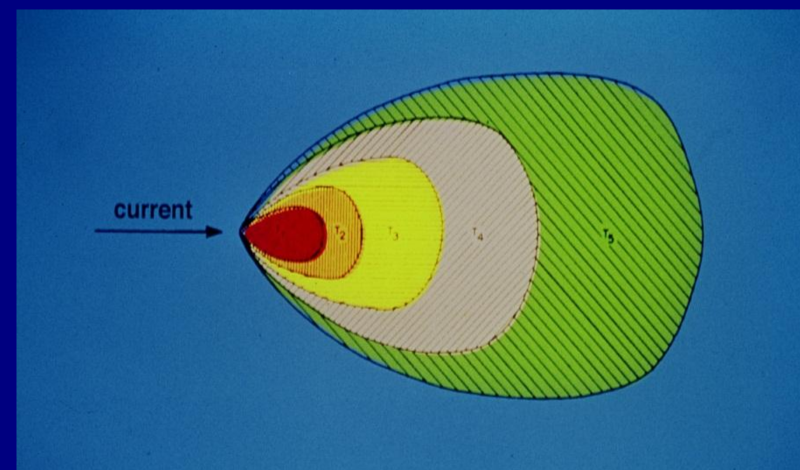
- **Historical introduction and early models**

The BOUMA SEQUENCE (1962)



The model is based on outcrop observations in the Tertiary Annot Sandstone (Maritime Alps)





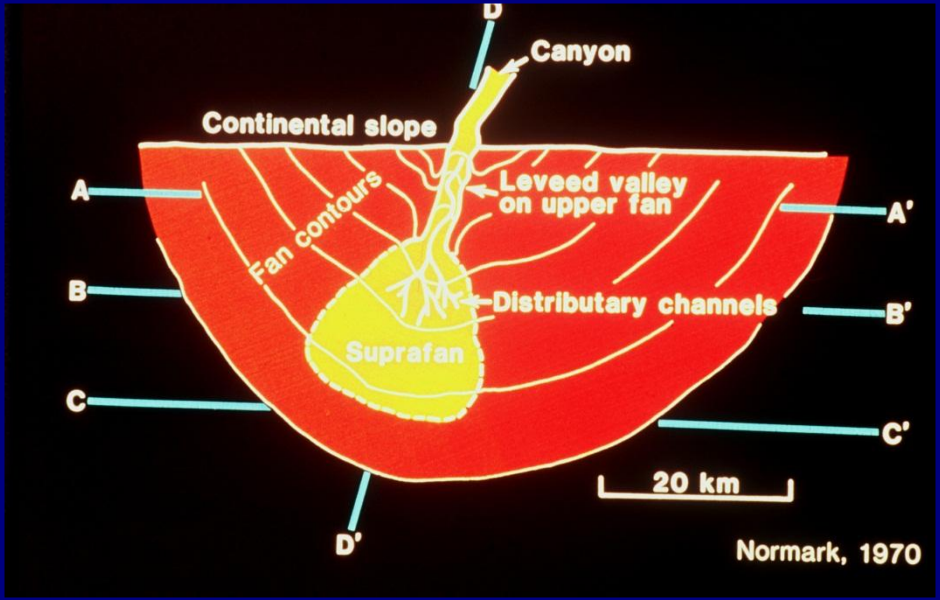
The model describes a typical turbidite bed consisting of 5 depositional divisions (Ta-e). Base-missing sequences develop in a downcurrent direction.

The depositional cone implicitly interprets a turbidity current as a non-uniform flow with decreasing velocity and compence with distance (proximal vs distal) as well as an unsteady flow with decreasing velocity and competence with time (graded beds)

Historical introduction and early models

The DEEP-SEA FAN MODEL (Normark, 1970)

Research started moving to modern deep-water basins

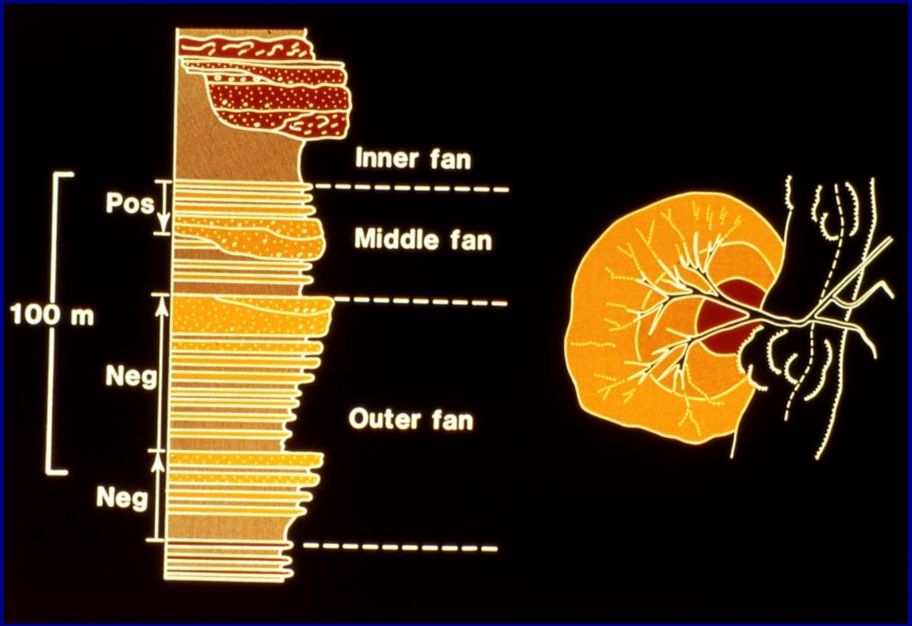


Marine geology thus became increasingly important to understand basin physiography and the primary role of canyons and deep-sea fans in modern turbidite sedimentation.

The first attempt to develop a model from a modern deep-sea fan was that of W.R.(Bill) Normark (1970)

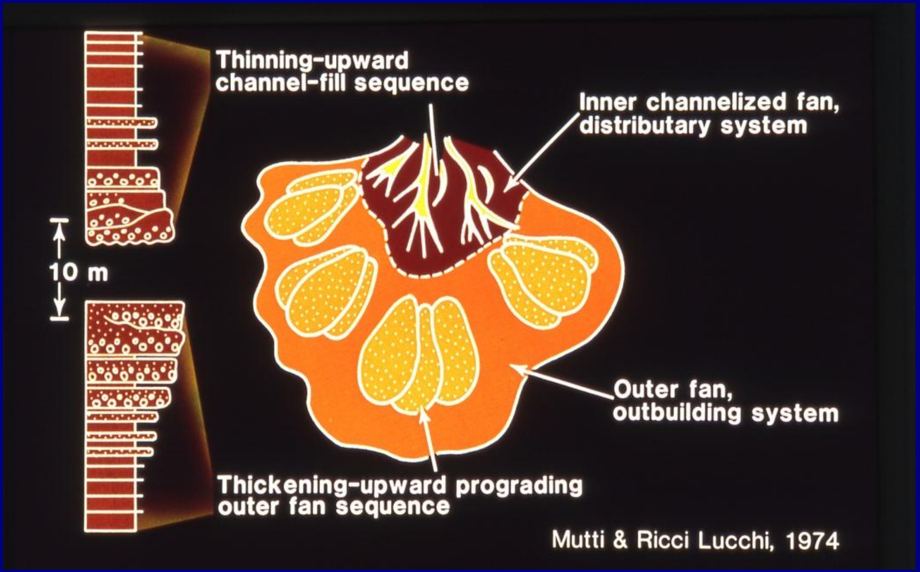
Historical introduction and early models

The DEEP-SEA FAN MODEL (Mutti and Ricci Lucchi, 1972, 1974)

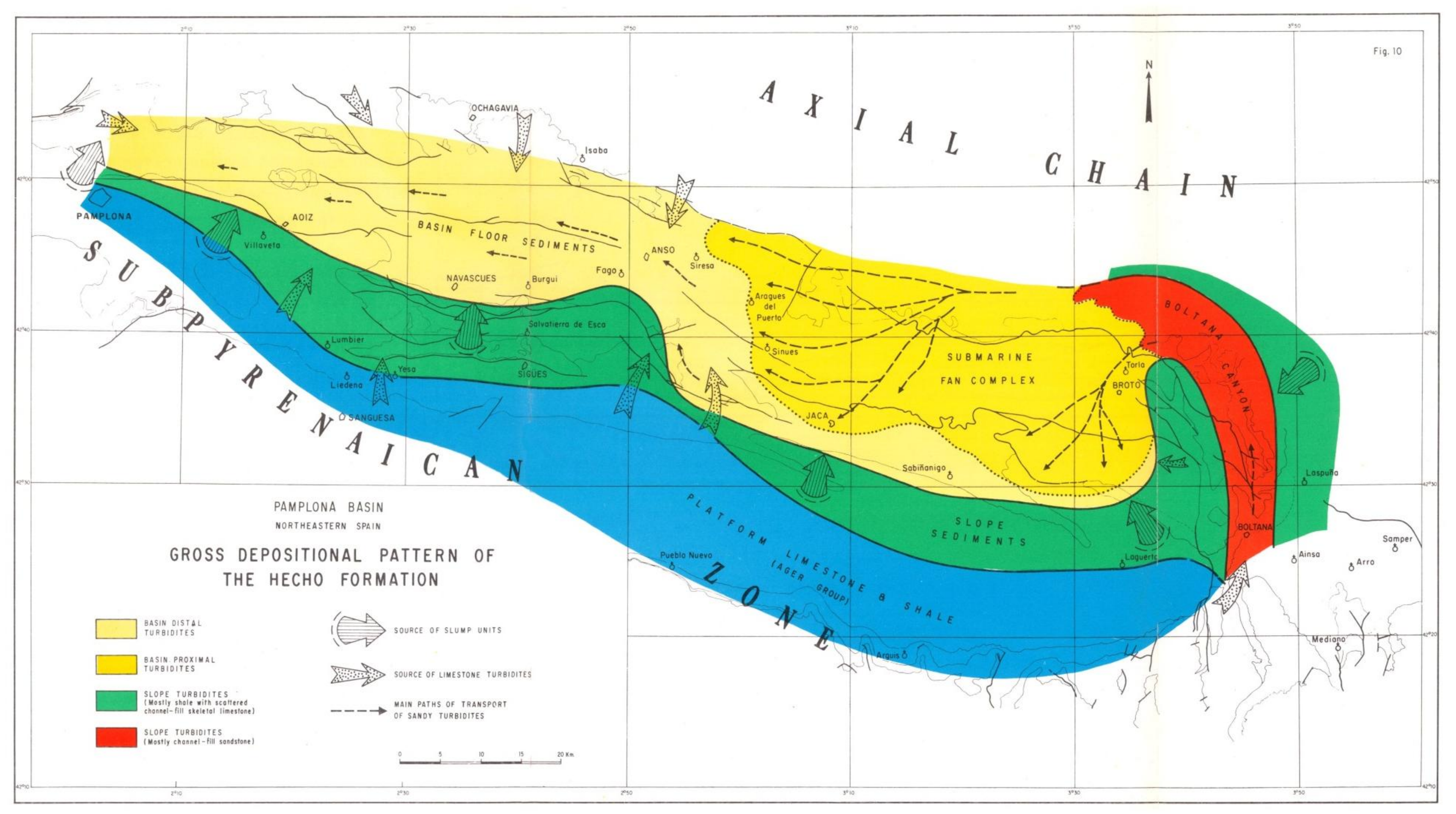


The model was mainly based on outcrop studies of ancient turbidite basin fills exposed in the northern Apennines and south-central Pyrenees (Miocene Marnoso-arenacea, Eocene Hecho Group).

It subdivides a fan system into canyon, inner-, middle- and outer-fan facies associations passing distally into basin-plain strata.



The model strongly emphasizes the similarity with delta systems focusing on distributary channels and prograding outer-fan sandstone lobes.



The first example of a mapped deep-sea fan system in ancient basins: the Eocene Hecho Group turbidites of the south-central Pyrenees (from Emiliano Mutti - An Approach to Turbidite-Facies Analysis. Esso Production Research European Laboratories. March 1971. Published with the permission of ExxonMobil Com., nov. 2010)

- **Historical introduction and early models**

LATER DEVELOPMENTS

- Early turbidite studies were essentially academic contributions mostly based on outcrop analysis and focused in particular on paleocurrent directions, facies and inferred processes

- Beginning in the late 70’s, an understanding of turbidites became more complex and not only strictly a sedimentological problem.The study of turbidites was moving toward basin analysis and exploration of continental margins

LATER DEVELOPMENTS

- The advent of seismic stratigraphy (later sequence stratigraphy), the increased exploration of continental margins by industry through 2D and 3D seismic-reflection surveys and extensive drilling, the great improvements of marine geology techniques, laboratory experiments and numerical modeling led soon to realize that deep-water sedimentation was considerably more difficult than previously thought

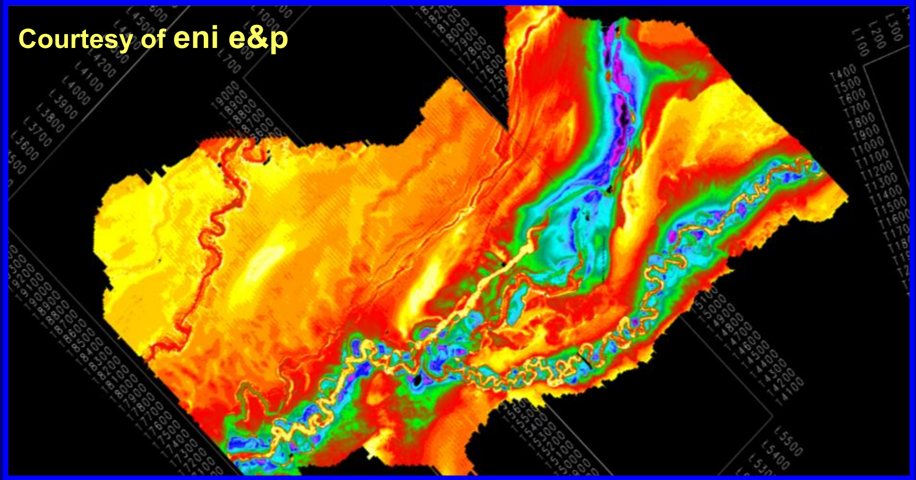
- In addition to the real scientific difficulties encountered, differences in data sets and unnecessary terminology problems started hampering communication among geoscientists. Many of these problems were discussed in several *ad hoc* meetings with increasing participation of industry.

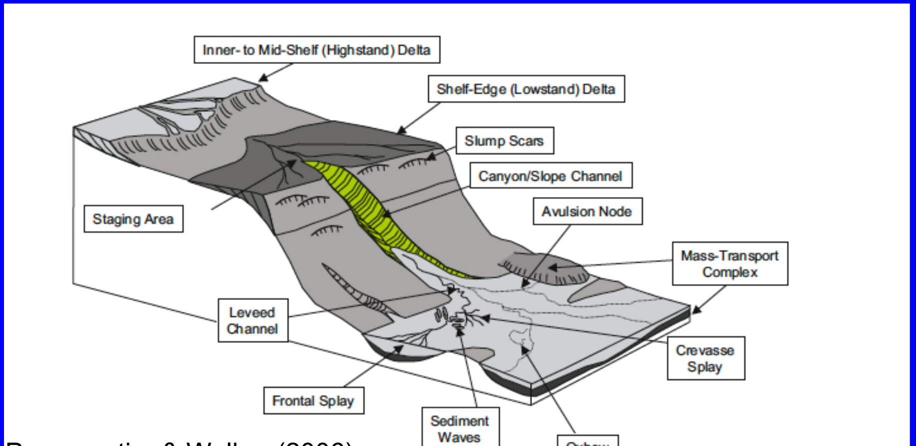
- Historical introduction and early models

LATER DEVELOPMENTS

- One of the main issues remains how to correctly use the wealth of information gathered from outcrop studies over the years to better understand the increasing complexity emerging from deep-water sedimentation of continental margins as depicted by oil exploration and marine geology studies

- Nonetheless, even in most recent literature, deep-water sedimentation is still considered essentially dominated by turbidity currents within the framework of canyon- or channel-fed submarine fan models



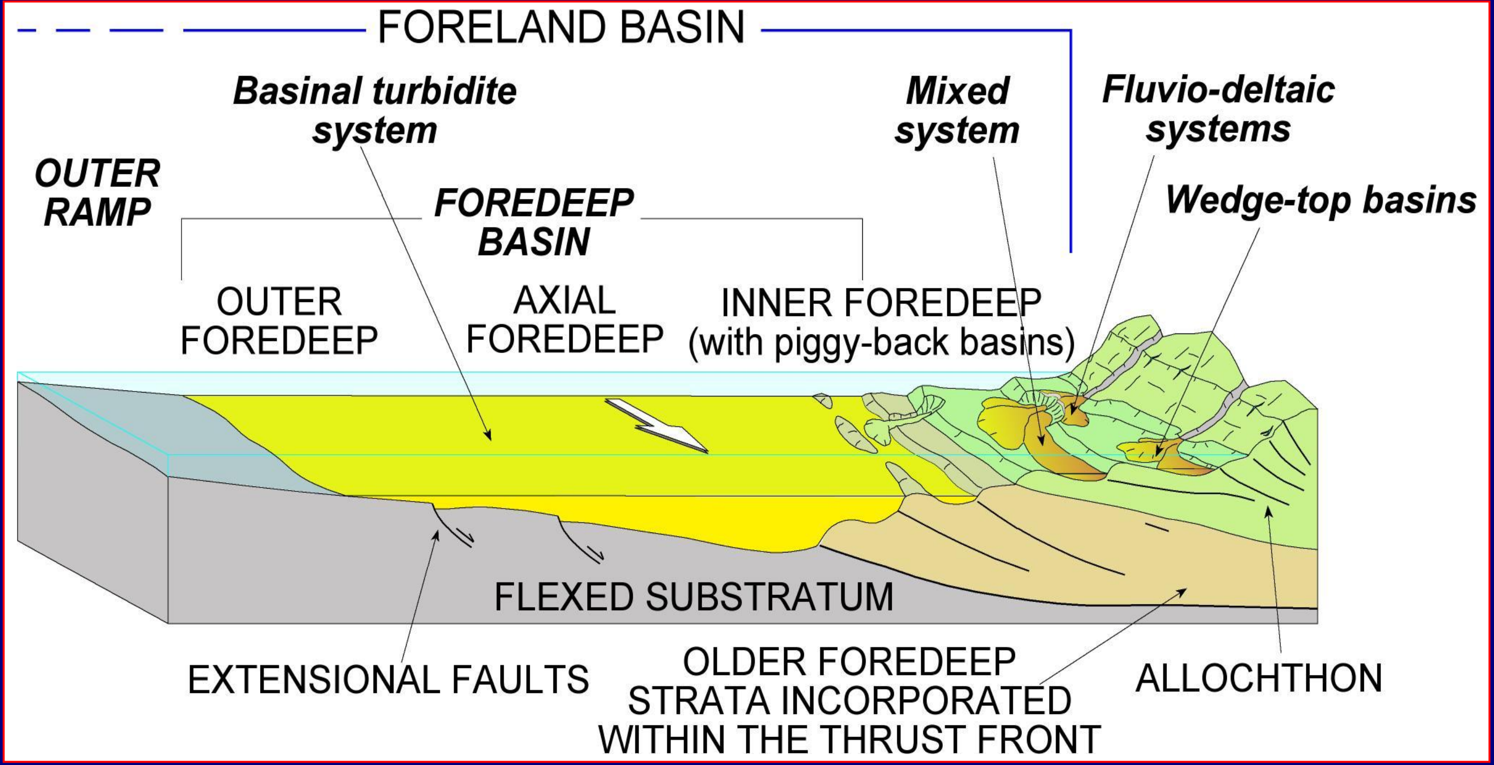


Posamentier & Walker (2006)

- **The foredeep basin turbidites of thrust-and-fold belts**

WHAT DO WE REALLY KNOW ABOUT TURBIDITES OF THRUST-AND-FOLD BELTS FROM WHERE WE STARTED ?

Ancient exposed turbidites are primarily the fill of elongate and highly subsiding troughs, called *foredeeps*, which are part of the *foreland domain* developed in front of an advancing and growing orogenic wedge



- The foredeep basin turbidites of thrust-and-fold belts

FOREDEEP TURBIDITES

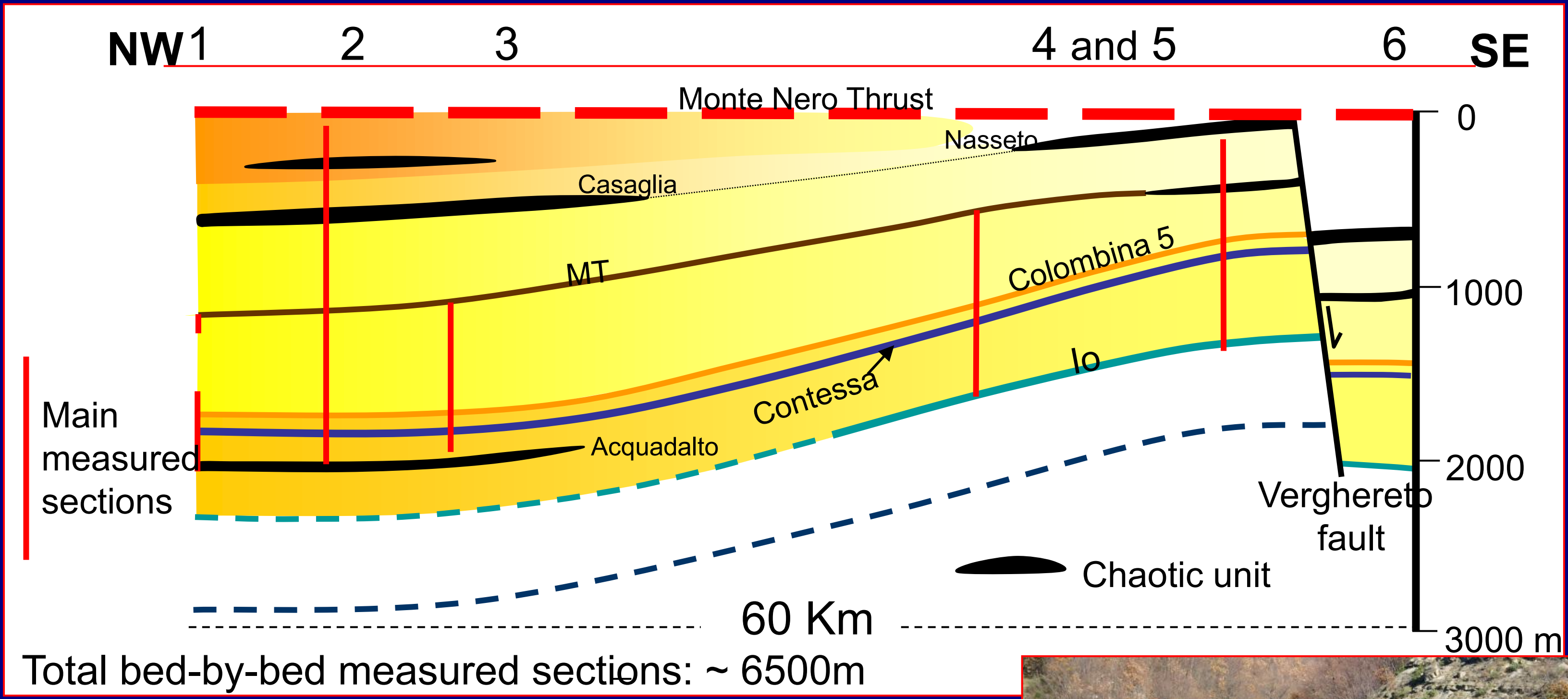
The best known examples of this kind of sedimentation are the Miocene **Marnoso-arenacea** (northern Apennines) and the Eocene **Hecho Group** (south-central Pyrenees) where excellent exposures, detailed mapping, and the occurrence of numerous and distinctive key-beds (calcareous megaturbidites) permit the tracing of individual sandstone beds and packages of beds over considerable distances parallel to basin axis (e.g., Ricci Lucchi and Valmori, 1980 for the MA and Mutti et al., 1988, 1999, for the Hecho Group)

No doubt, foredeep turbidites are essentially sheet-like deposits consisting of outer-fan sandstone lobes passing distally into basin-plain deposits as originally described by Mutti and Ricci Lucchi (1972). Sediments of this kind can only be deposited by highly efficient, large-volume and sustained turbidity currents.

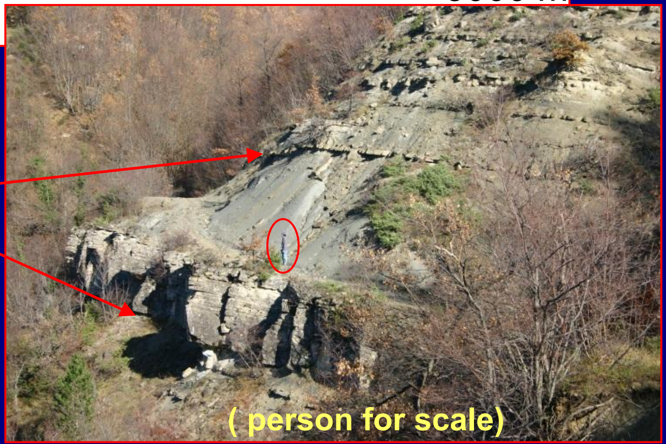
- **The foredeep basin turbidites of thrust-and-fold belts**

Regional cross-section of the Miocene Marnoso-arenacea (MA)

roughly parallel to basin axis (paleocurrents from left to right). Note the main key-beds.
From Mutti et al. (2007). Data from P.Muzzi and R. Tinterri.



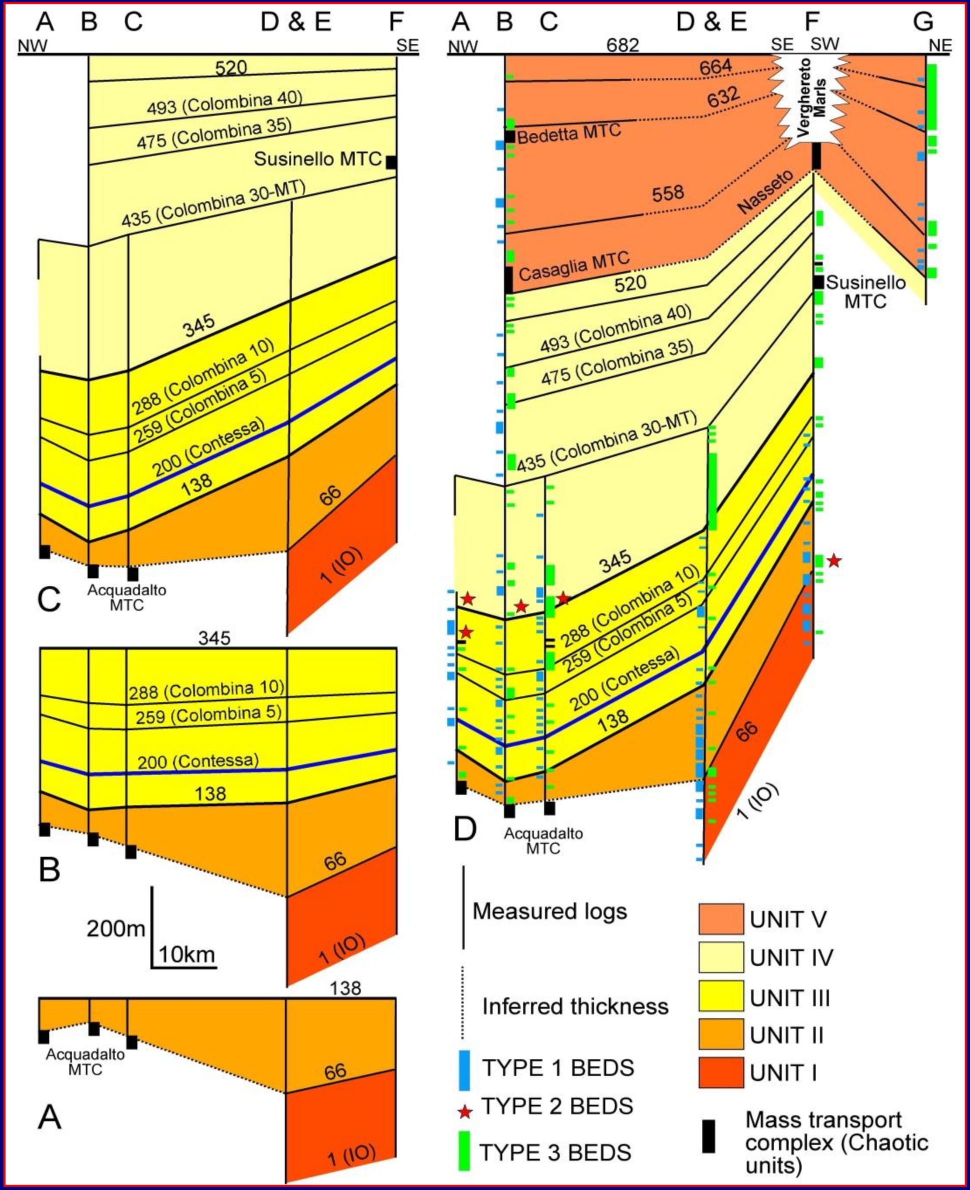
The Contessa key-bed

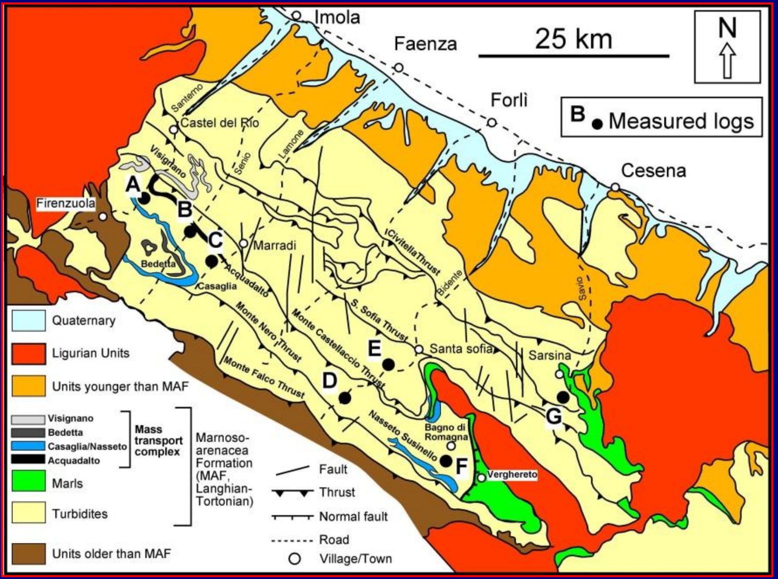


Detailed bed-by-bed regional cross-section of the MA

showing stratal correlations over a distance of some 60 km

(From Muzzi and Tinterri, 2011)





More recently, spectacular bed-by-bed correlations have been provided by Amy and Talling (2006), Tinterri and Muzzi (2010) and Muzzi and Tinterri (2011) for the Marnoso-arenacea and by Remacha and Fernandez (2003) and Remacha et al. (2005) for the Hecho Group. Some of these correlations (Muzzi and Tinterri, 2010) extend over 60 km and are based on more than 6500m of measured sections.

- Turbidite Facies

FACIES, FACIES ASSOCIATIONS AND FACIES TRACTS

- Mainly stemming from the Bouma sequence and from the proximal vs distal concept (Parea, 1965, Walker, 1967), early attempts to develop facies classification schemes were mainly descriptive (Mutti and Ricci Lucchi, 1972, Walker and Mutti, 1973)

- Later, facies classifications started to be process-oriented aiming at developing schemes within which conglomerates, sandstones and mudstones could be viewed as part of the same facies spectrum (Mutti and Ricci Lucchi, 1975, Walker, 1975, Mutti, 1979, Lowe, 1982) (see Pickering et al, 1989 for an extensive review).
  Most concepts were derived from outcrop (rocks) observations.

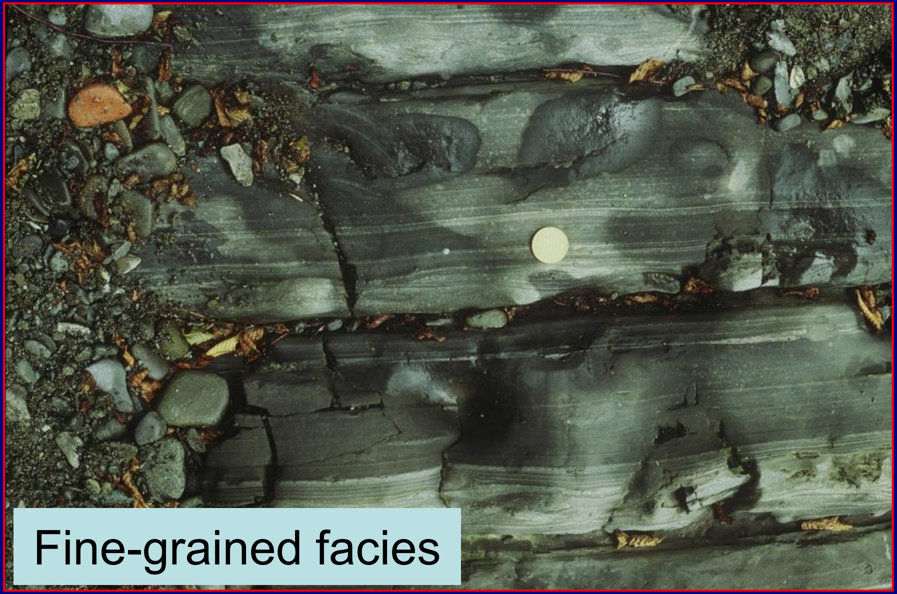
- This phase of research was strongly influenced by the seminal paper of Middleton and Hampton (1973) on sediment gravity flows.

The great variety of turbidite facies of foredeep basin fills

Sand-rich lobe

Mud-dominated basin plain

Coarse-grained facies

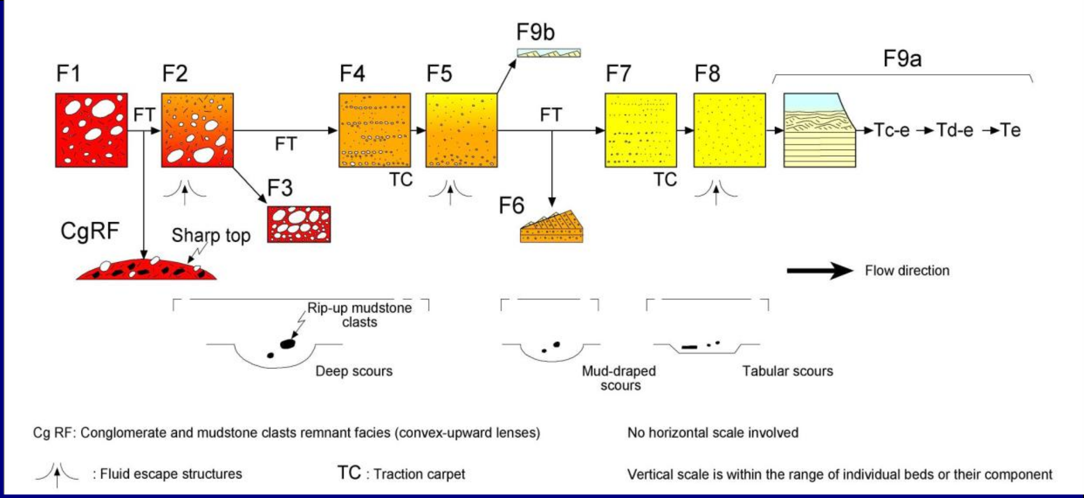


Fine-grained facies

FOREDEEP TURBIDITES ARE AN IDEAL NATURAL LABORATORY
TO STUDY FACIES CHANGES AND FLOW TRANSFORMATIONS OVER CONSIDERABLE DISTANCES

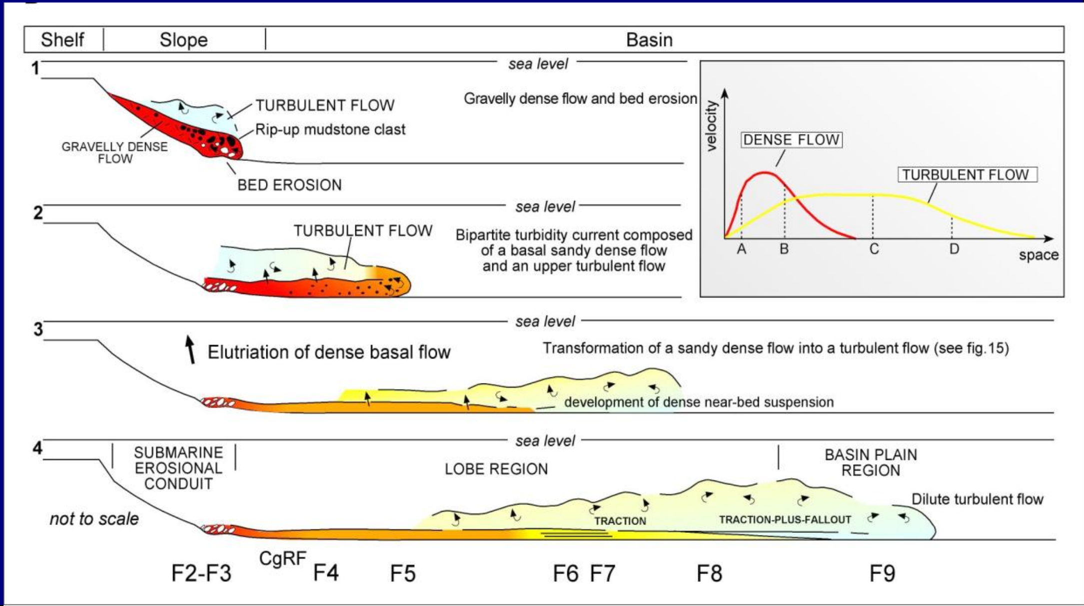
GENERAL TURBIDITE **FACIES TRACT**

Inferred from basinwide detailed correlations in the Hecho Group (Pyrenees) and the MA Fm (Northern Apennines) and observations in many other turbidite basins

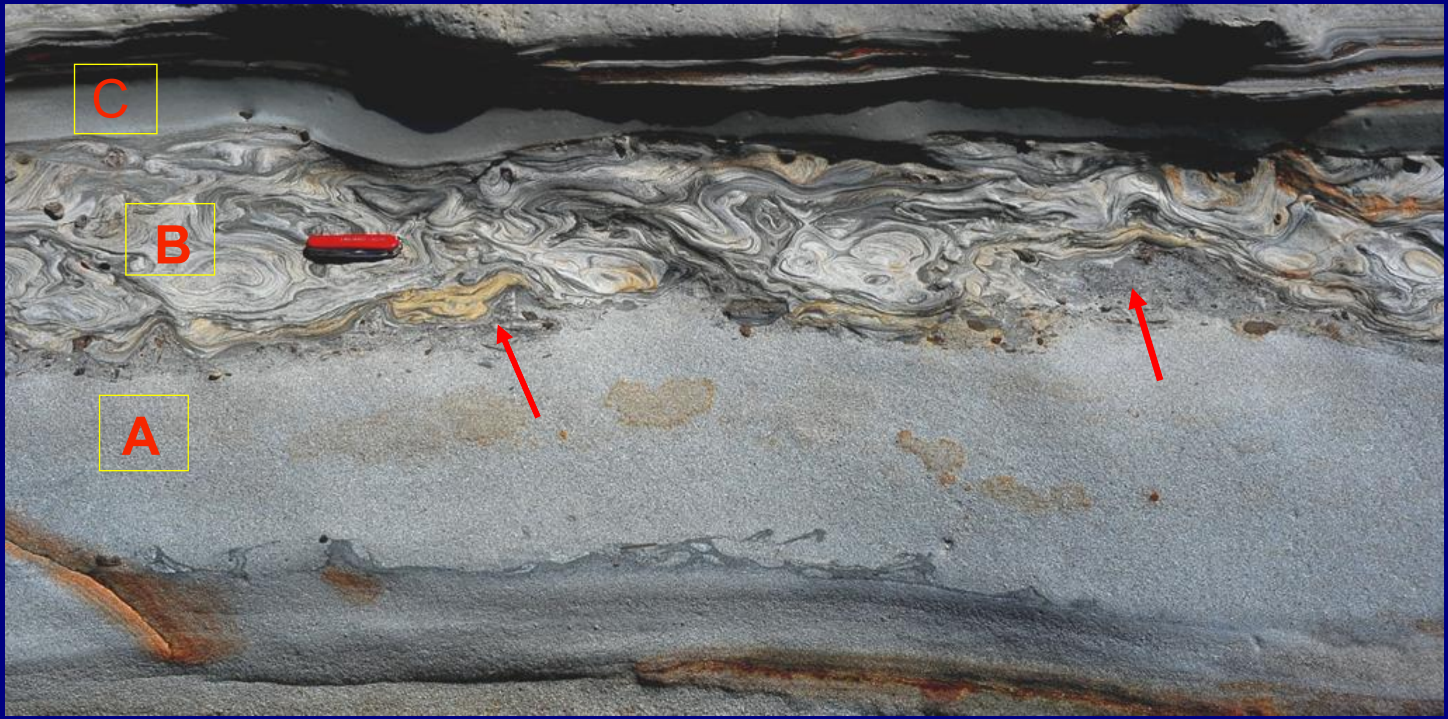


The tract is interpreted as produced by downcurrent transformations of dense frictional flows, impelled by inertia forces under conditions of excess pore pressure, into turbulent flows. For the sake of simplicity and for practical purposes of basin analysis the general terms **turbidity currents** and **turbidites** are here used to define this broad spectrum of processes and resulting deposits respectively (Mutti, 1992; Mutti et al., 2003).

The characteristics of facies tracts depend mainly on the textural composition of parental flows, amount of bed erosion, flow efficiency, and basin configuration.



Example of turbidite bed deposited by a bipartite turbidity current

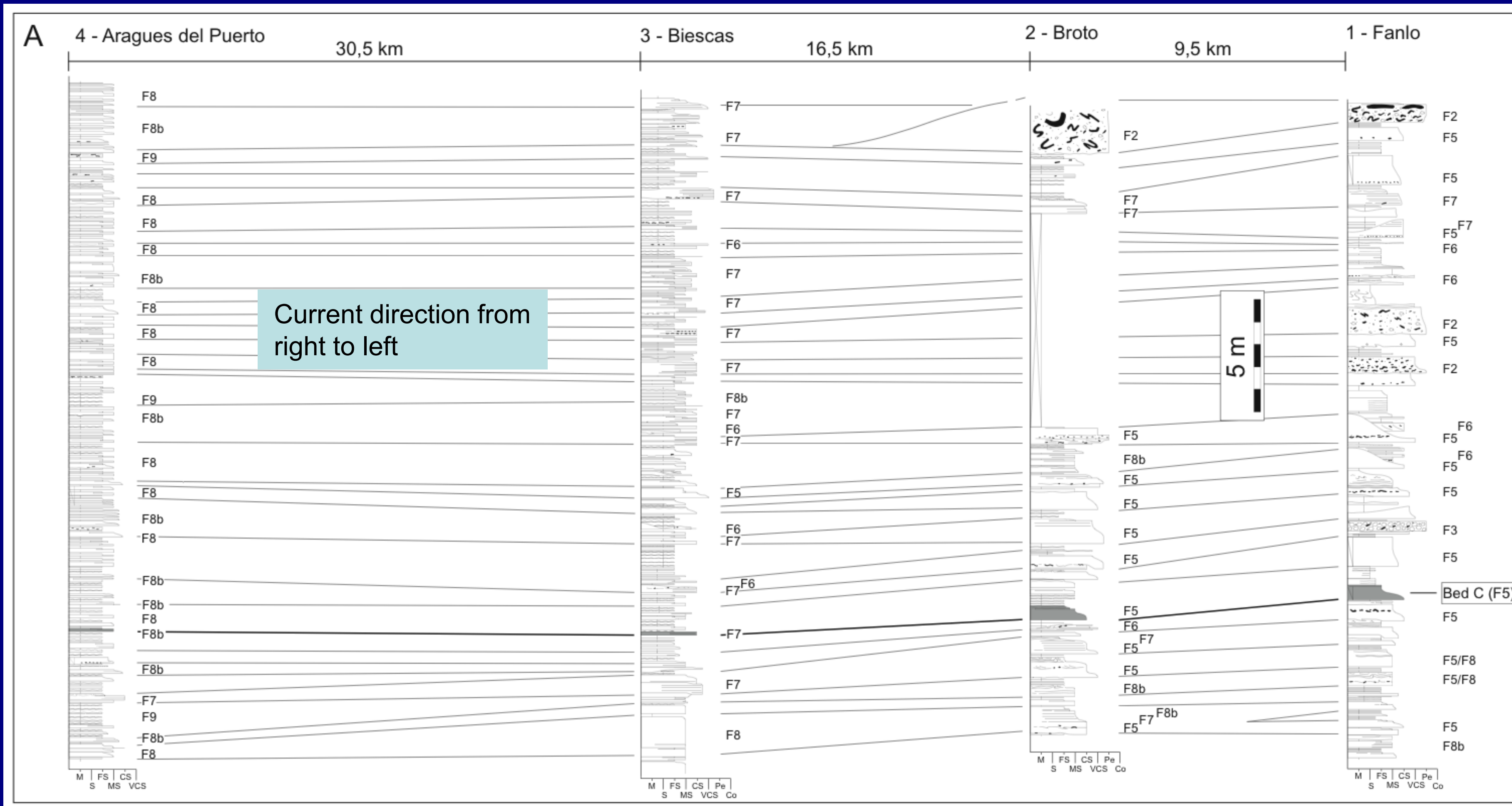


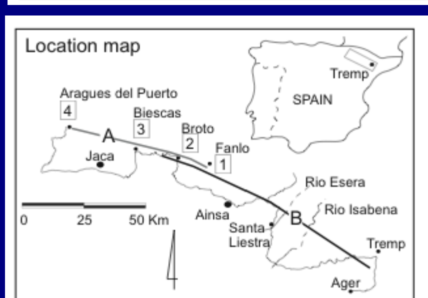
C : Impervious mudstone division

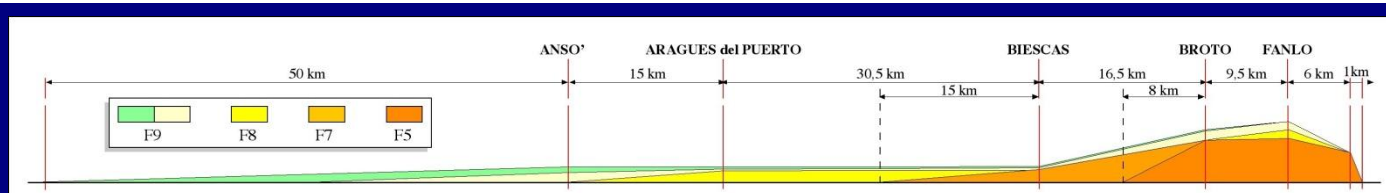
B : Fine-grained current-laminated division (mostly current ripples) deposited by a dilute turbulent flow and plastically deformed by water escape moving upward and laterally

A : Medium-grained structureless division with basal load features deposited by an inertia-driven dense sandy flow under conditions of excess pore pressure. Note the diapir-like features at the top of the division with concentration of mudstone clasts and plant fragments floating at the top of the dense flow (red arrows).

Example of bed-by-bed correlation and facies tracts in lobe sediments of the Eocene Hecho Group (Pyrenees) over a distance of some 55 km (from Tinterri et al., 2003)







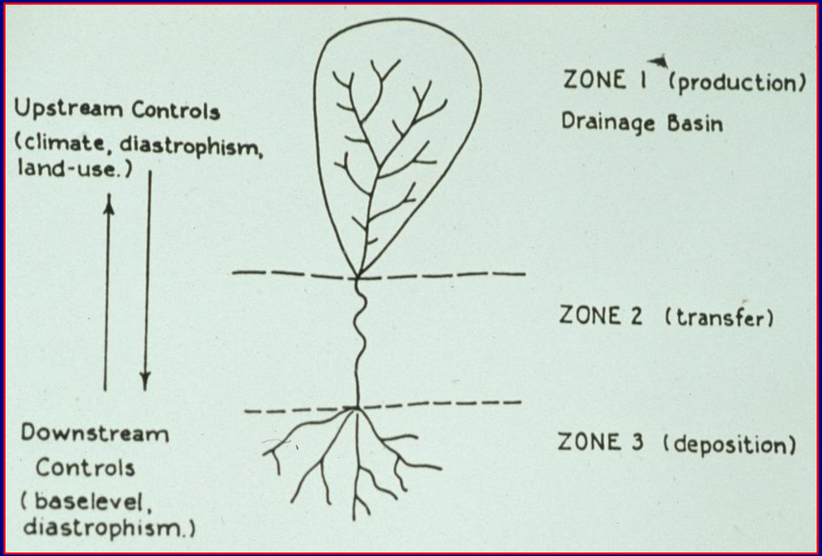
Detailed facies tract of Bed C

AND WHAT ABOUT COEVAL FLUVIO-DELTAIC SYSTEMS?

Terms like "source-to-sink" and "staging areas" have been recently introduced to point out the problem that a full understanding of deep-water turbidite sedimentation can only be achieved through a better knowledge of the coeval fluvial drainage basins (source) and related fluvio-deltaic systems (staging areas).

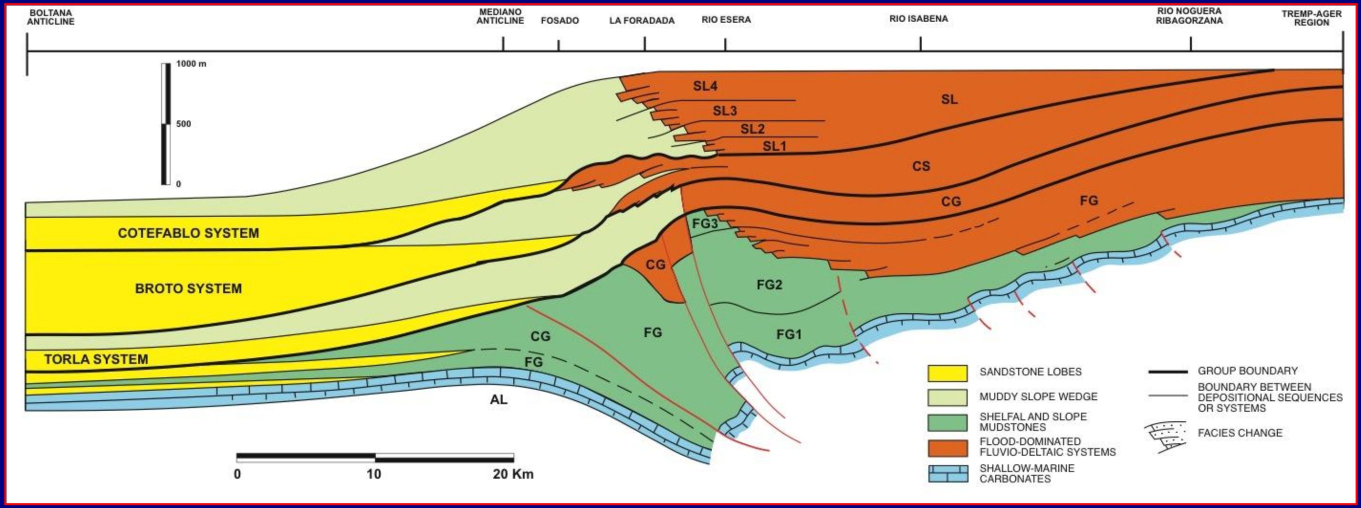
The importance of the problem was emphasized in the workshop entitled "Turbidites: models and problems" which was held on May 21-25, 2002, at the University of Parma, Italy (see Mutti, Steffens, Pirmez and Orlando, Marine and Petroleum Geology,2003).

AND WHAT ABOUT COEVAL FLUVIO-DELTAIC SYSTEMS?



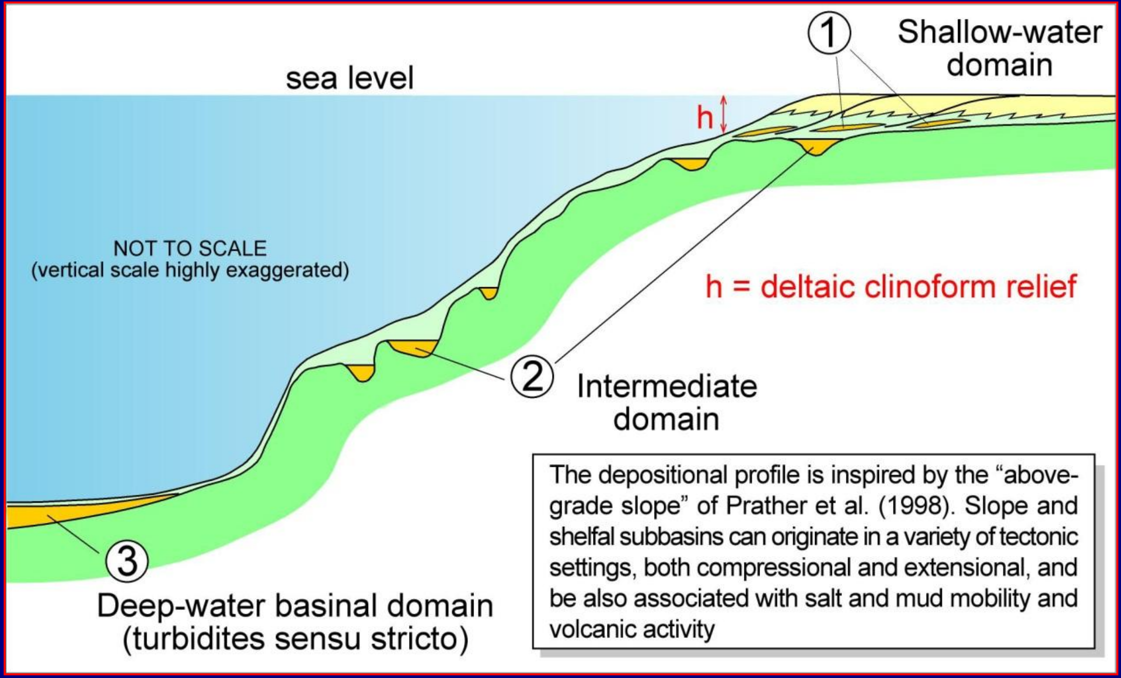
These conclusions are a reappraisal of the model of the fluvial system as envisaged by Schumm (1977,1981). The model defines a fluvial system in a very broad sense including three zones which, together, form a strictly inter-related process-response system. Because of its highest preservation potential, the final depositional zone contains the most complete record of the fluvial regime of the river history though time.

Stratigraphic cross-section of the Eocene foreland basin of the S-central Pyrenees showing the relationship between basinal turbidites and fluvio-deltaic strata



Foredeep turbidites

Fluvio-deltaic systems



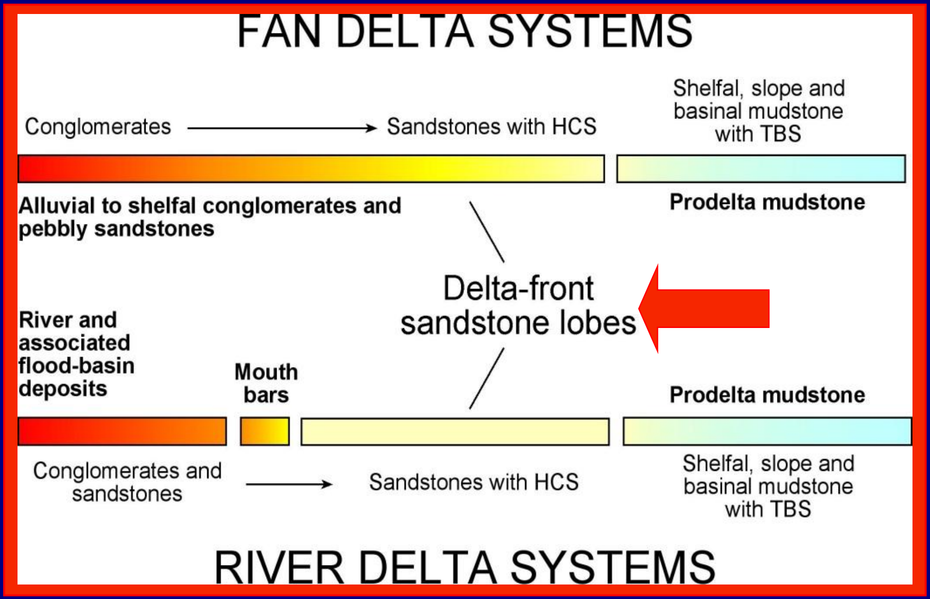
Occurrence of turbidites and their shallower water "cousins":

1 - Delta-front sandstone lobes

2 - Slope channels and thrust-related piggy-back basins or minibasins

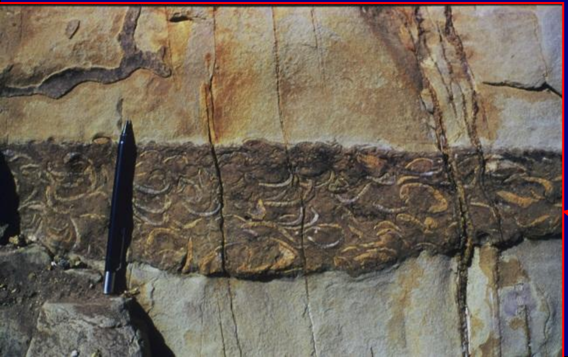
3 - Basinal or foredeep turbidites

In their vast majority, fluvio-deltaic systems of foreland and tectonically active basins are dominated by facies and facies associations related to rivers in flood with the extensive development of delta-front sandstone lobes




Delta-front sandstone lobes of the Eocene Santa Liestra Group (Pyrenees)

Displaced sleletal debris



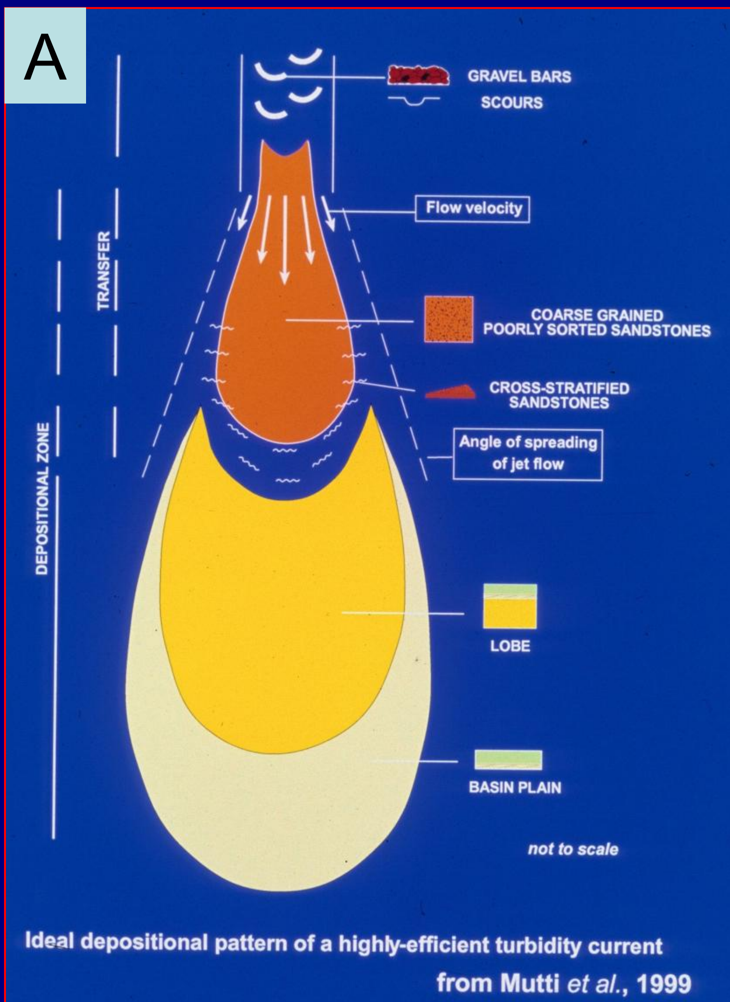
HCS

Tabular geometry of sandstone lobes

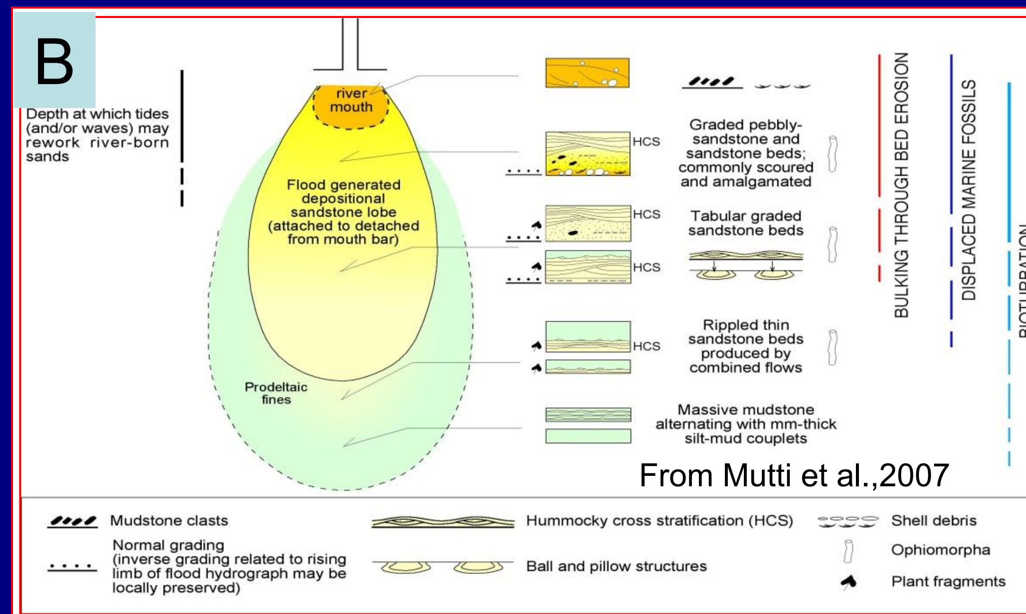

Jurassic Bardas Blanca Neuquen Basin (Argentina)

Facies distribution pattern of a turbidity current exiting a deep-water conduit (A) and a dense sediment-laden flow exiting a river mouth during a severe flood (B).

Except for water depth, fossil assemblages and the occurrence of HCS in (B), the two patterns are essentially similar recording deposition from jet flows. Angle of spreading depends on the local ratio between inertia and frictional forces



Ideal depositional pattern of a highly-efficient turbidity current
from Mutti *et al.*, 1999

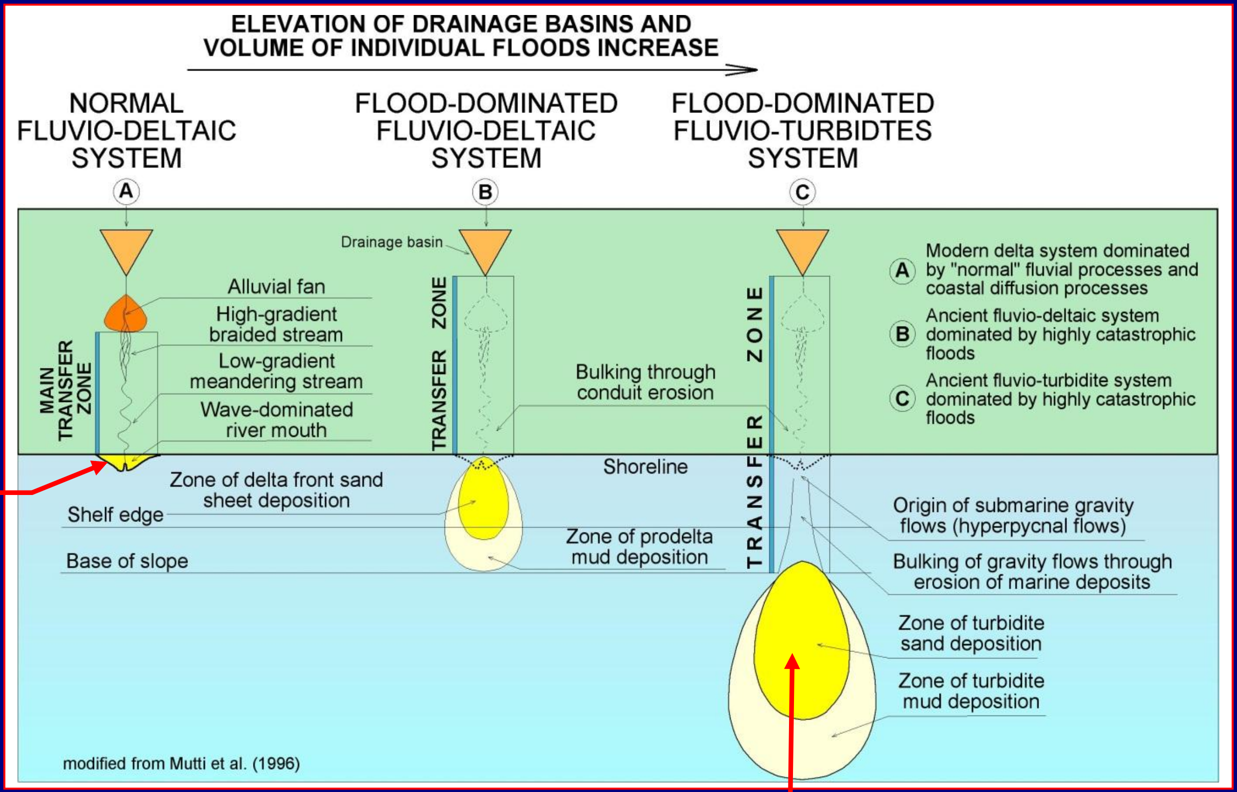


CONCLUSIONS: Both flows are hyperpycnal because of their excess density. Both flows decelerate with distance and time. Both flows are sediment gravity flows. Their deposits, produced by similar processes, should be simply termed deep-water (basinal) and shallow-water (delta front) turbidites.

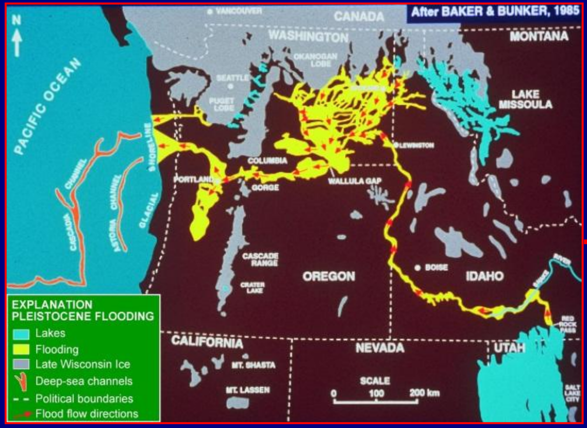
FLUVIO-TURBIDITE SYSTEM

It forms when highly catastrophic floods carry sediment directly from drainage fluvial basins to deep waters eroding former alluvial and nearshore staging areas.

Note how transfer zones and staging areas vary during the evolution from A to C



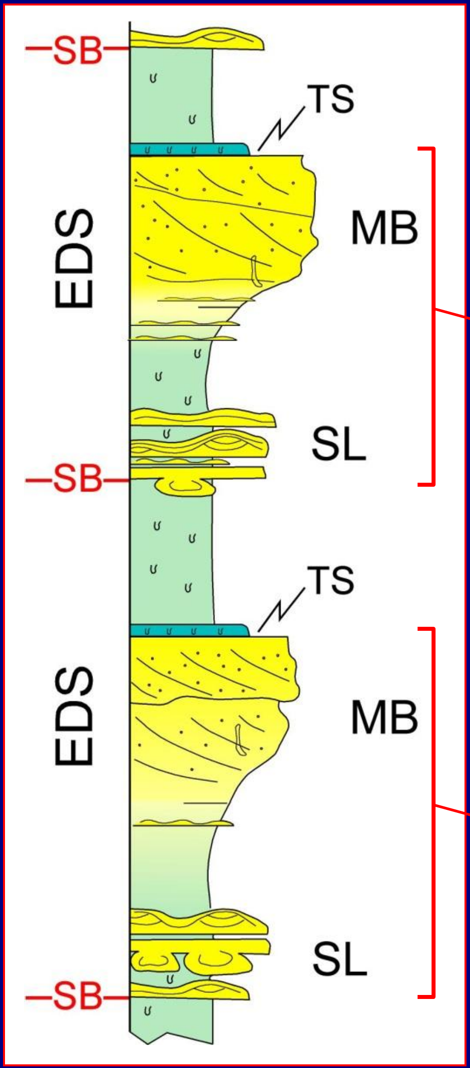
THE MISSOULA FLOOD



CYCLIC STACKING PATTERNS
AND
SEQUENCE STRATIGRAPHY:

The close similarity between shallow- and deep-marine turbidites

ELEMENTARY DEPOSITIONAL SEQUENCES (EDSs): THE BUILDING BLOCK OF SEQUENCE STRATIGRAPHY

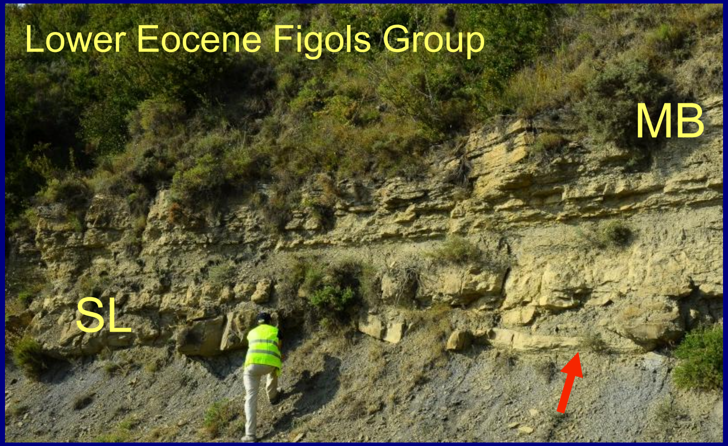


STACKING PATTERN OF DELTA-FRONT FACIES AND FACIES ASSOCIATIONS AS OBSERVED IN OUTCROP

Mouth-bar sandstone

Bar-toe mudstone

Delta-front sst lobe

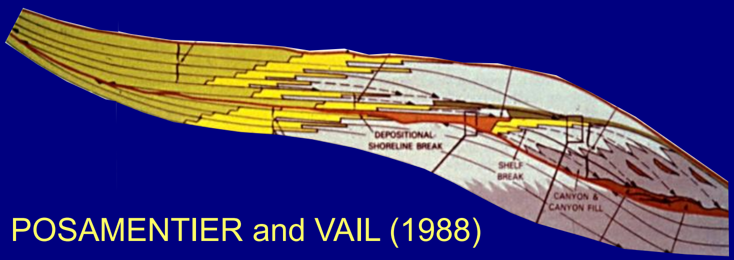


Mouth-bar sandstone

Bar-toe mudstone

Delta-front sst lobe

Sequence boundaries (SB, red arrows) are marked by the sharp basal contact of sst lobes. **Transgressive surfaces** (TS) are marked by thin and bioturbated sst facies, locally replaced by carbonates or sst reworked by tidal action

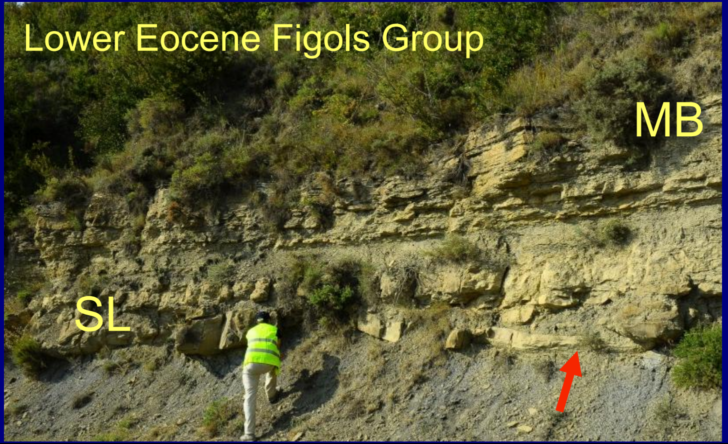


POSAMENTIER and VAIL (1988)

SEISMIC SCALE

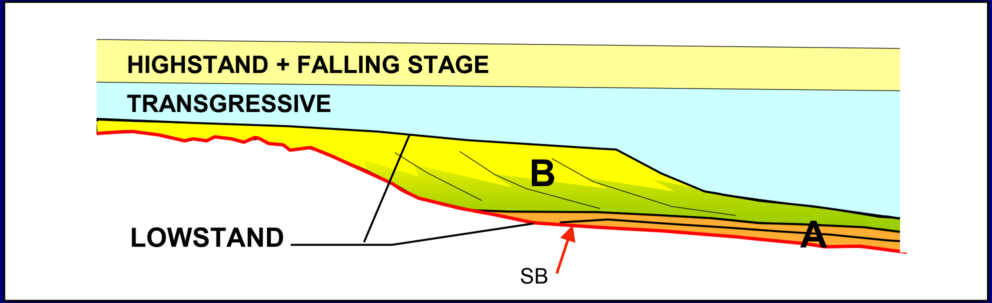
“Third-order” sequences resulting from the interaction of long term sea level variations (eustasy) and tectonics (subsidence and uplift)

OUTCROP SCALE



BASIC SCALE-INVARIANT SEQUENCE PRODUCED BY CYCLIC VARIATIONS OF BASE LEVEL AND SEDIMENT FLUX

THE MODEL IS THE WAY TO LINK SEISMIC STRATAL PATTERNS WITH FACIES AND FACIES ASSOCIATIONS OBSERVED IN OUTCROP AND CORES (RESERVOIR SCALE)



LOWSTAND:

A: Highly-efficient stage dominated by large-volume flood-generated sediment gravity flows (basinal turbidites, delta front sandstone lobes)

B: Poorly-efficient stage dominated by small-volume flood-generated sediment gravity flows (with common tidal reworking at the top of deltaic strata)

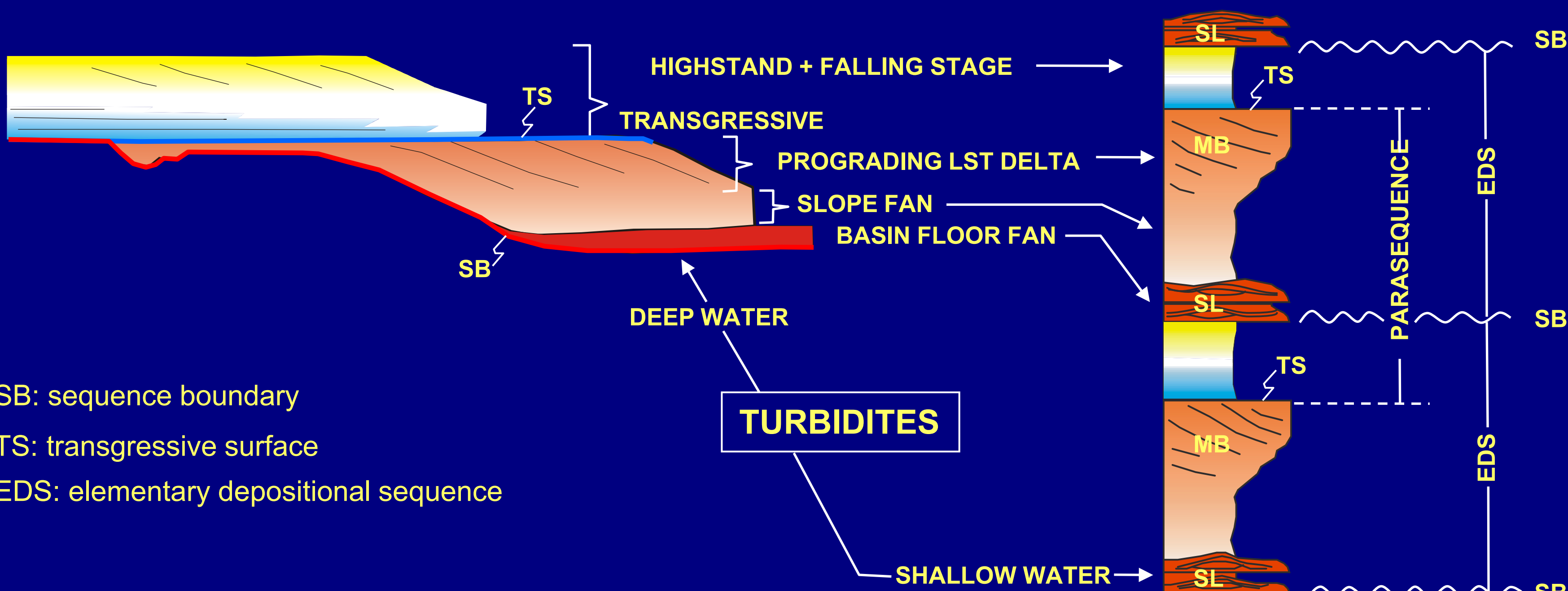
Smallest-scale sequences observed in outcrop result from Milankowitch orbital cyclicity.
(**SL**, delta-front sandstone lobe; **MB**, mouth-bar facies; red arrow: sequence boundary)

THE DIAGRAM COMPARES SEISMIC-SCALE SYSTEMS TRACTS WITH FACIES AND FACIES ASSOCIATIONS OBSERVED AT OUTCROP SCALE

From the smallest to the largest, depositional sequences show a similar stacking pattern related to their fractal nature

SEISMIC STRATAL PATTERN OF A LONG-LIVED (3rd order) DEPOSITIONAL SEQUENCE

OUTCROP EXPRESSION OF SHORT-LIVED DEPOSITIONAL SEQUENCES



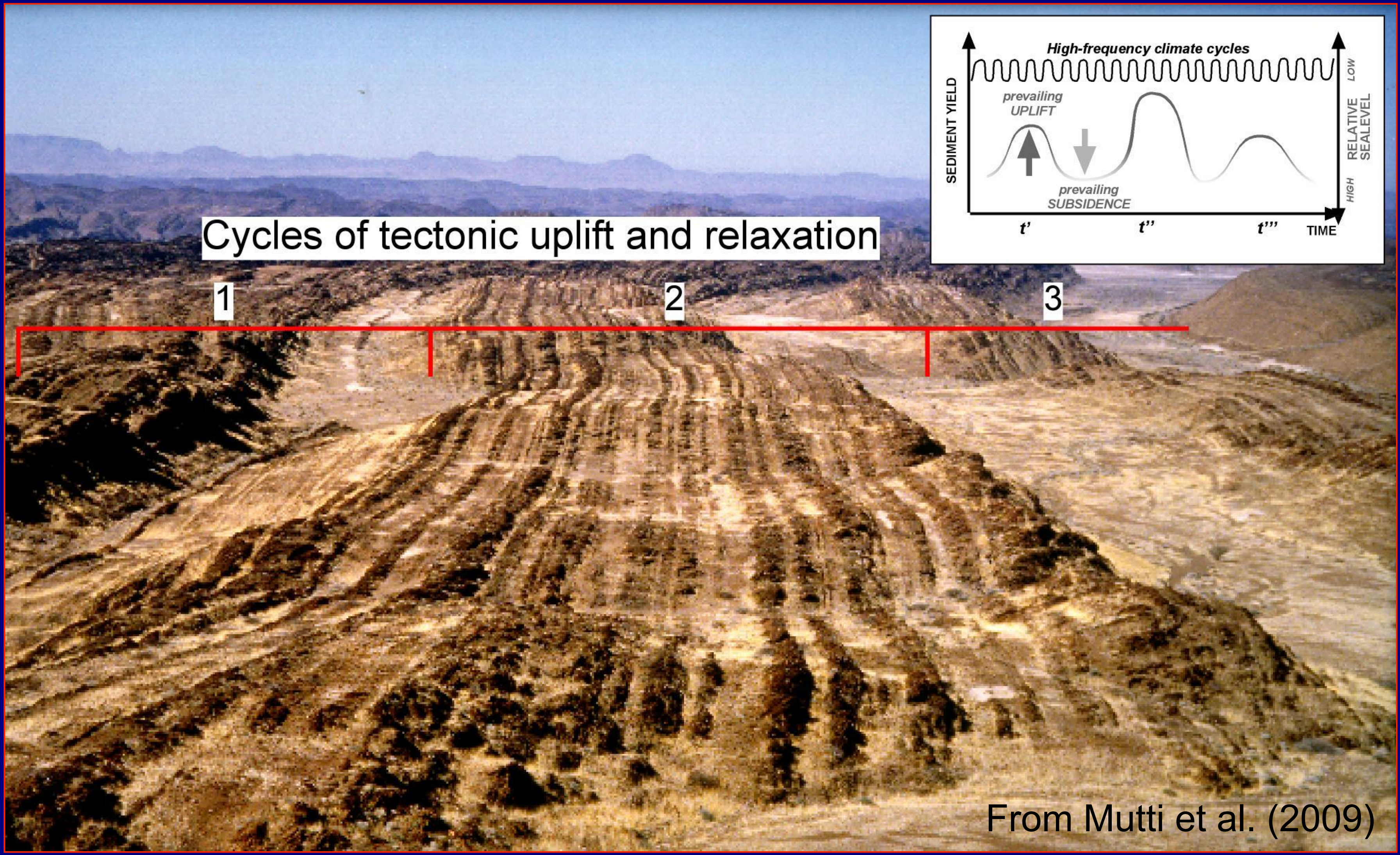
SB: sequence boundary

TS: transgressive surface

EDS: elementary depositional sequence

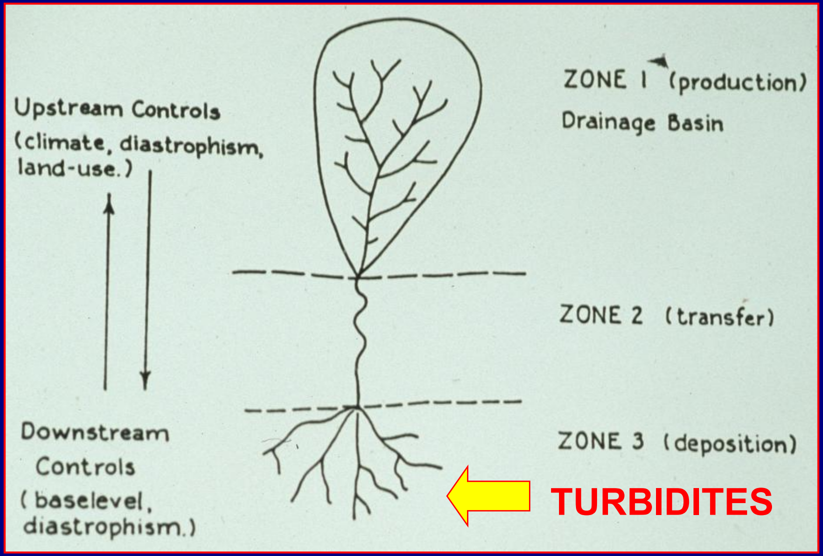
POSAMENTIER and VAIL (1988)

MUTTI (1989, 1990) MUTTI *et al.* (1994, 1999, 2000)



The spectacular exposure of the Proterozoic Zerrisene turbidite sandstone lobes in the Nabib desert showing cyclic stacking patterns at different physical (and temporal) scales. Younging direction from left to right. Note high-frequency cyclicity (EDSs) superimposed on long-period cycles of base level variations.

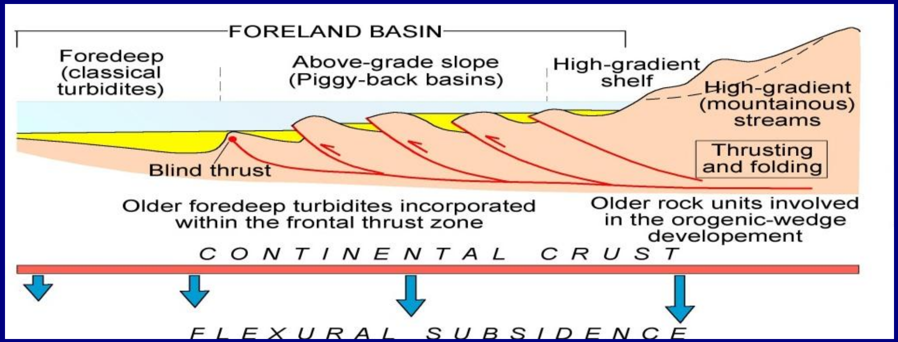
- A conclusion that follows from the previous discussion is that turbidites should not only be viewed in isolation in their deep-water settings, but should also be considered within the broader framework of their stratigraphic and depositional relationships with their equivalent shallow-water fluvio-deltaic deposits.

- 

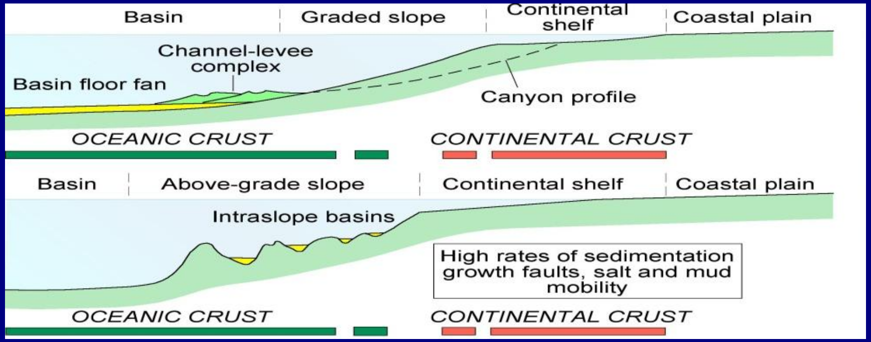
  Essentially, turbidites record the final and deepest depositional zone of fluvial systems during periods of time dominated by high sediment flux to the sea through large-volume turbidity currents triggered by severe fluvial floods.

- Uplift of source areas, lowering of base level, narrow shelves facing deeper-water basins and climate-triggered fluvial floods are apparently the main factors controlling turbidite deposition in tectonically active basins.

Collisional margins



Divergent margins



DATASETS

Geologic maps and regional structural and stratigraphic context

Detailed stratigraphic and sedimentological logs and cross-sections

Detailed facies analysis based on vertical and lateral stratigraphic relationships

Difficulties in reconstructing detailed planview geometries

2D and 3D seismic data

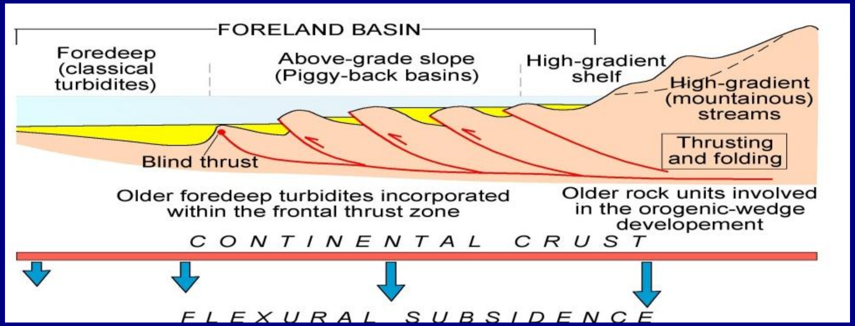
Well logs

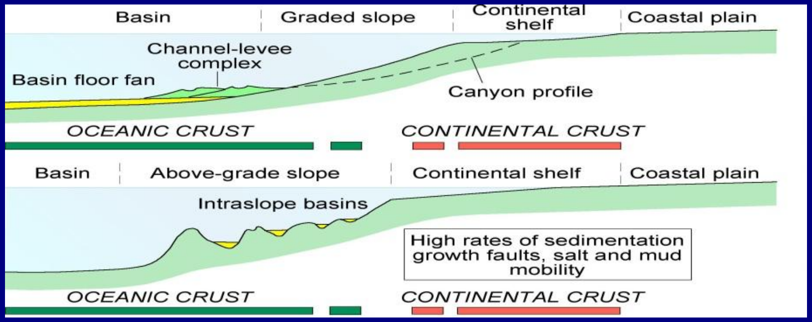
Sparse coring

Facies analysis limited to sparse coring

Planview geometries from 3D seismic maps and spectacular seascape imagery

Collisional margins vs Divergent margins





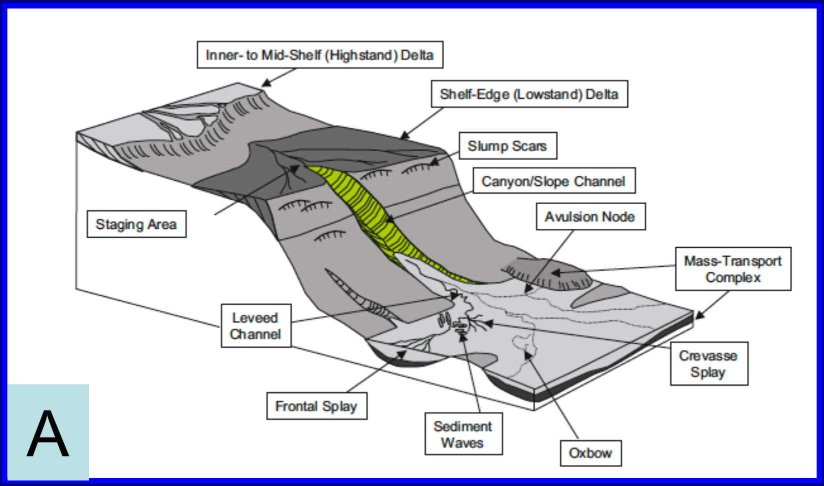
MAIN DIFFERENCES

- River systems (immature vs mature)   Staging-areas (small vs large deltas)
- Sandbody geometry : Mostly sheet-like (foredeeps) vs channelized and /or patchy (above-grade slope minibasins)
- Highly-efficient vs poorly-efficient turbidity currents (mostly thick bedded sdst)
- Lack of large meandering-channel belts in foreland turbidite basins
- Lack of large channel-levee complexes fed by large and mature river systems in foreland turbidite basins
- *Foreland turbidites are conspicuous for the lack of bottom-current deposits. Conversely, growing evidence suggests that these sediments and related mixed turbidite/contourite systems are of primary importance in divergent (and convergent) continental margin basins*.

CONTINENTAL MARGIN DEEP-WATER SEDIMENTATION

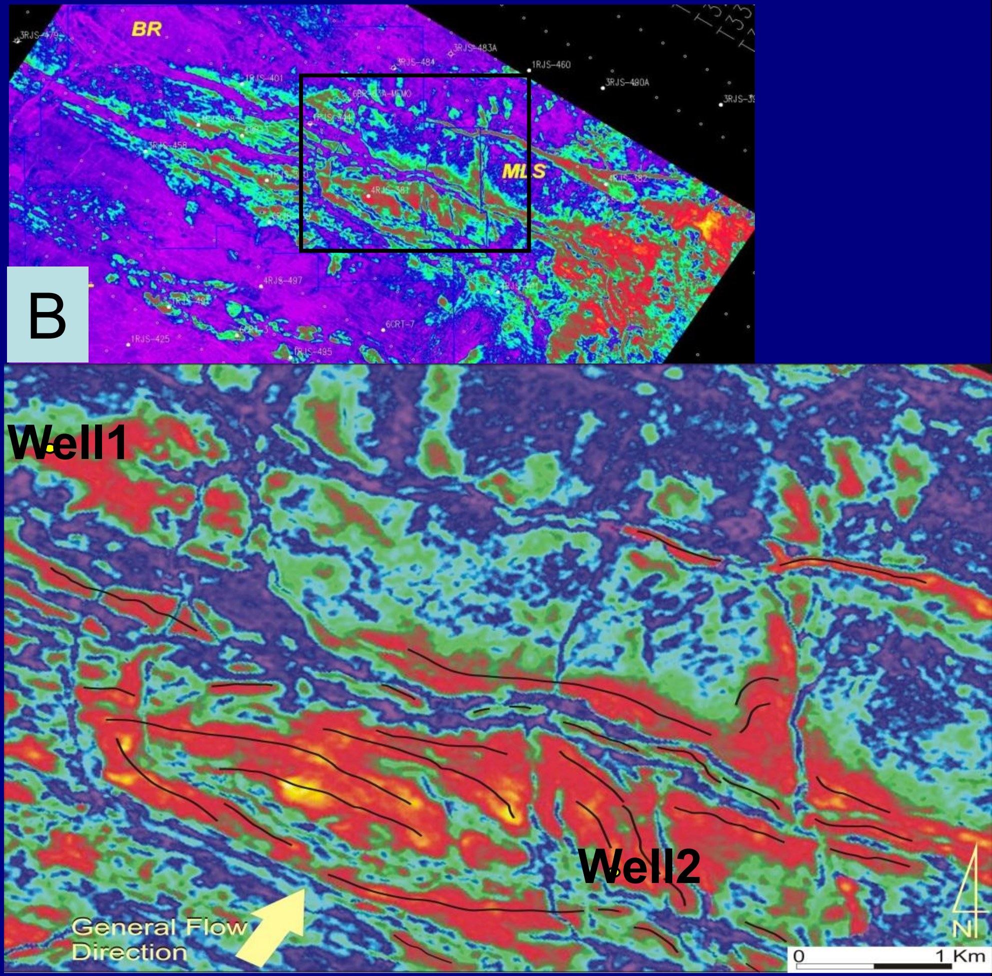
Posamentier and Walker, 2006

Turbidites and deep-sea fans



Mutti and Carminatti, 2011

Contourite sand waves: a new and fundamental depositional element



The two models certainly coexist.
The problem is to understand how, where and to what extent they interact.
There are no analogs for this kind of sedimentation.

MAIN CONCLUSIONS

- Case-by-case studies without preconceived ideas (models and analogs) and based on careful core analyses (facies and facies associations) integrated with 3D seismic data and well-log correlations may open a new and highly promising phase of research for both industry and academia.
- Current models available for continental margin sedimentation, still heavily based only on turbidite-driven depositional patterns, are clearly inadequate to describe the depositional complexity of continental margin basin as depicted by recent advances in oil exploration and marine geology studies

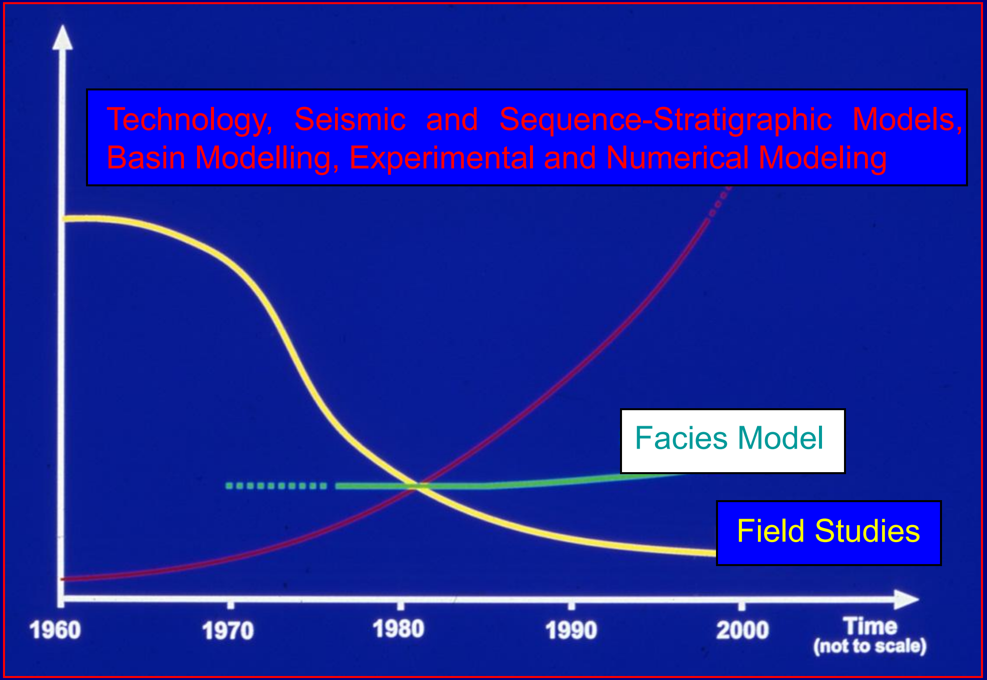
AKNOWLEDGMENTS

Special thanks are extended to Franco Fonnesu (ENI E&P) for help in preparing this presentation and the many useful comments and suggestions.

Roberto Tinterri (University of Parma), Franco Ricci Lucchi (University of Bologna), Mario Carminatti and Pierre Muzzi Magalhaes (Petrobras), Daniel Bernoulli (University of Basel) and many other colleagues and former students for stimulating discussions on turbidite graded sandstone beds over the years

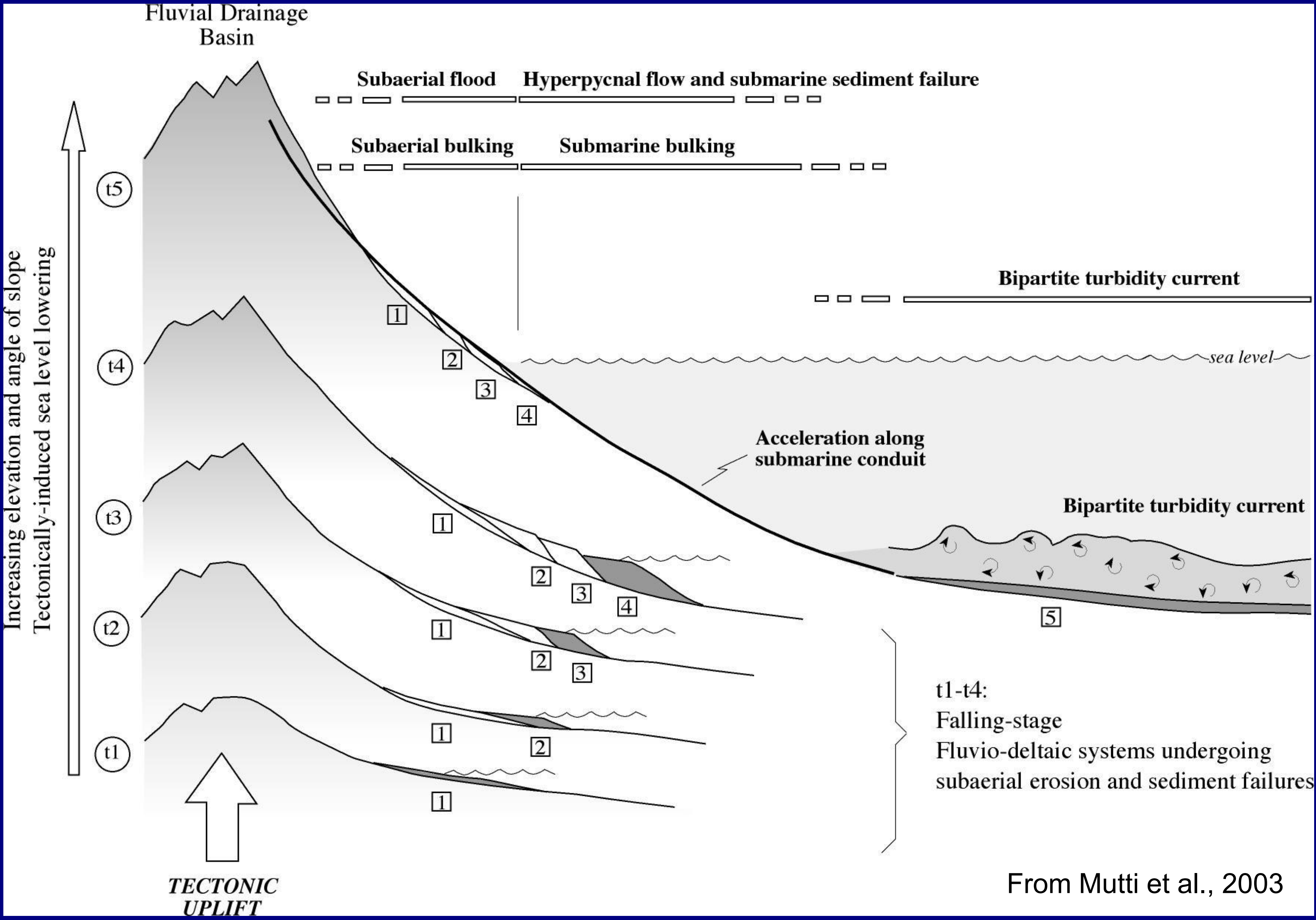
EXXONMOBIL for permission to publish the map of the Hecho Group turbidite depositional system

END



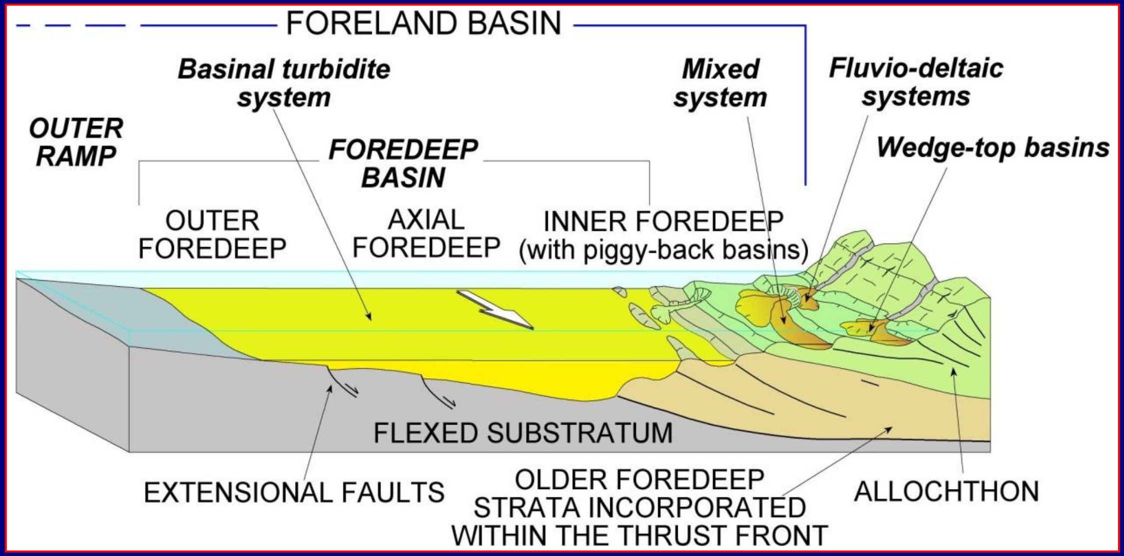
TECHNOLOGY,
FACIES MODELS AND
FIELD STUDIES

(Unpublished diagram, Mutti 2002)



From Mutti et al., 2003

The foredeep basin turbidites of thrust-and-fold belts



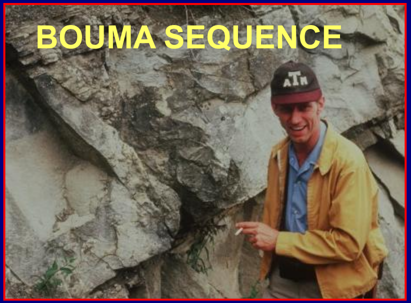
•The foredeeps are parallel to the frontal thrust system and subside because of the loading of the orogenic wedge (**flexural subsidence**)

•They can be subdivided into ***inner***, ***axial*** and ***outer*** foredeep

•In the ***inner*** *foredeep*, thrusting and folding progressively incorporate foredeep turbidites into the advancing thrust front creating structurally-induced topography and related sub-basins (inner foredeep sub-basins or *piggy-back* basins)

•The ***axial*** *foredeep* is relatively undeformed and allows for the deposition of impressively tabular strata over distances up to tens and hundreds of km

•The ***outer*** *foredeep* is where the axial turbidites thin out and onlap onto the outer foreland ramp

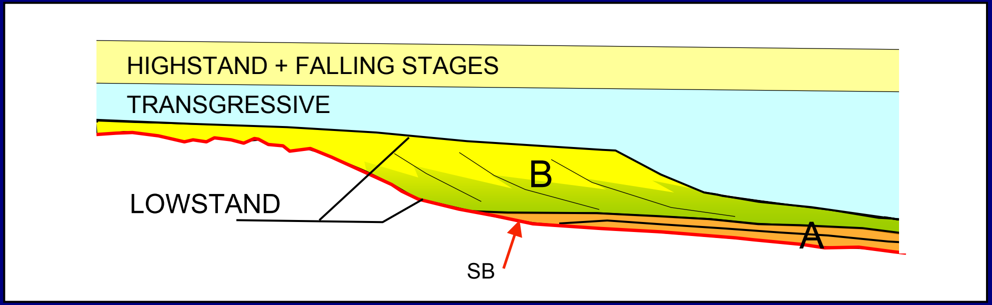


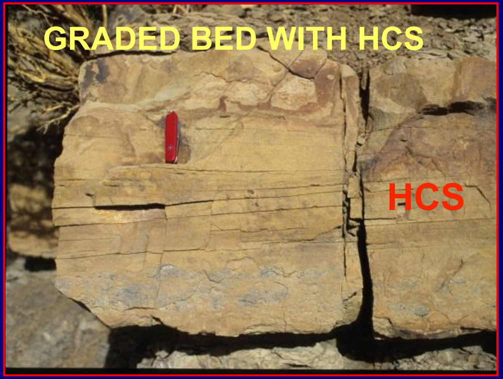
DEEP-WATER SANDSTONE LOBE (fed by fluvio-deltaic systems via submarine channels or canyons)

Sediment gravity flows and particularly dense sandy flows and related turbulent flows are the most effective process to carry sand at considerable distances in both basinal and shelfal regions. In both cases, they can only be triggered by climate-controlled periods of severe fluvial floods enhancing sediment flux to the sea

BASIC SCALE-INVARIANT SEQUENCE PRODUCED BY CYCLIC VARIATIONS OF BASE LEVEL AND SEDIMENT FLUX

THE MODEL IS THE WAY TO LINK SEISMIC STRATAL PATTERNS WITH FACIES AND FACIES ASSOCIATIONS OBSERVED IN OUTCROP AND CORES (RESERVOIR SCALE)





DELTA-FRONT SANDSTONE LOBE (physically connected to a fluvial system)