Istituto Nazionale di Oceanografia e di Geofisica Sperimentale

Università degli studi di Trieste

LAUREA MAGISTRALE IN GEOSCIENZE

Classe Scienze e Tecnologie Geologiche

Curriculum: Esplorazione Geologica

Anno accademico 2021 - 2022

Analisi di Bacino e Stratigrafia Sequenziale (426SM)

Docente: **Michele Rebesco**

Modulo 3.10
Faults, volcanoes, submarine fans, synthesis

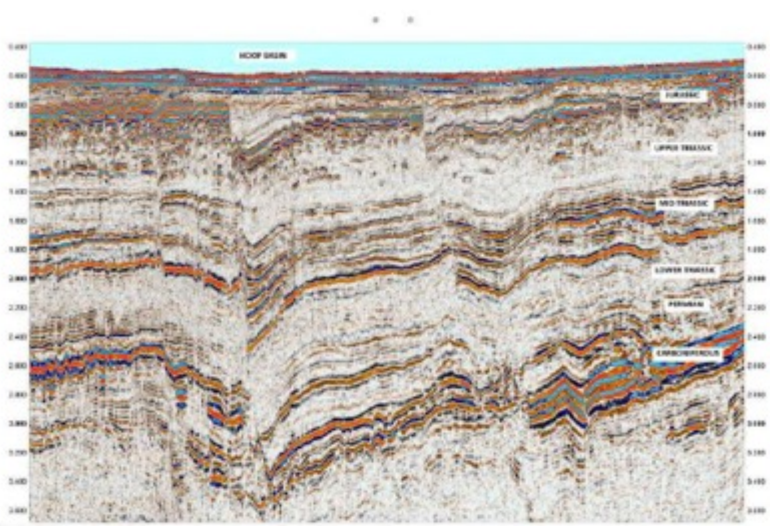
Outline:

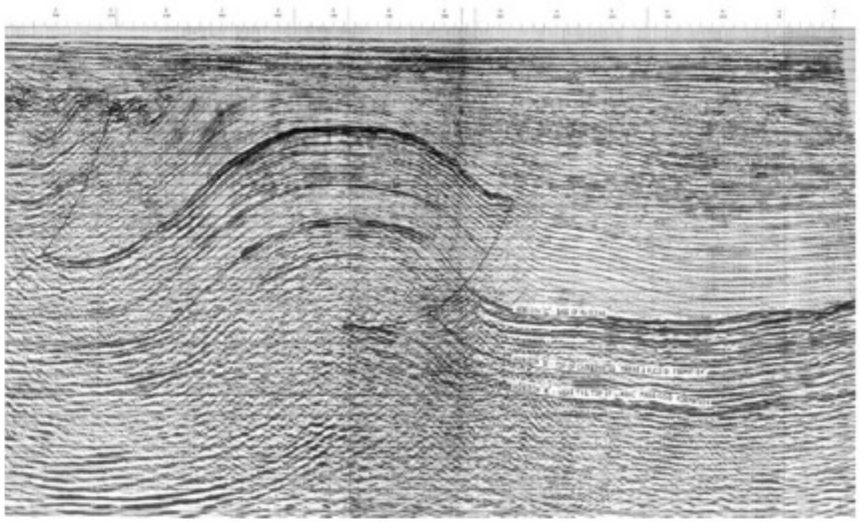
- Faults (after Anna Del Ben)
- Volcanoclastic deposits
- Volcanoes in the seismic records
- Submarine fans (addendum)
- Synthesis

Anna Del Ben: Corso di Interpretazione sismica

Evidenze sismiche di (sistemi di) faglie

Un regime tettonico è caratterizzato dalla presenza di un sistema più o meno complesso di fratture associate alla deformazione fragile degli strati sedimentari, a cui si associa spesso una deformazione duttile.

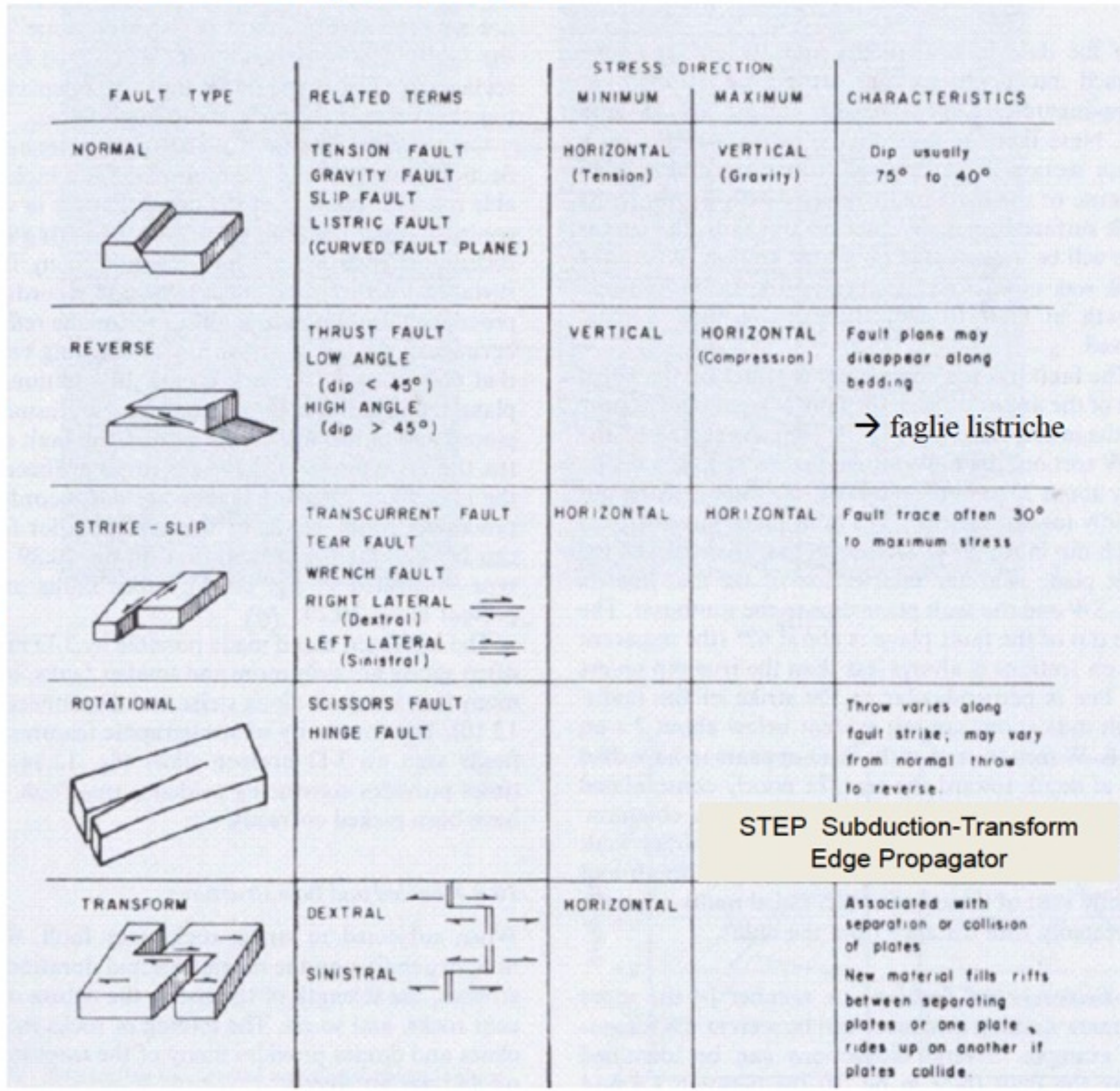




Diversi tipi di faglie

Lungo i profili sismici le faglie possono avere aspetto molto variabile: superfici di riflessione vera e propria o sistemi diffusi di fratture che interrompono la continuità dei riflettori.

La pendenza è apparente, in funzione delle velocità delle onde P, del fattore di scala adottato (esagerazione verticale), della direzione del profilo sismico rispetto alla direzione della faglia.

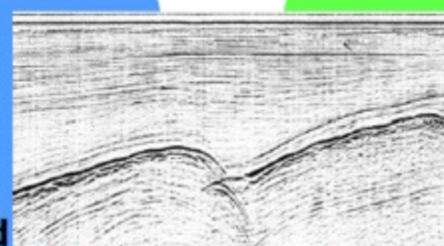


FAULT TYPE	RELATED TERMS	STRESS DIRECTION MINIMUM	STRESS DIRECTION MAXIMUM	CHARACTERISTICS
NORMAL	TENSION FAULT GRAVITY FAULT SLIP FAULT LISTRIC FAULT (CURVED FAULT PLANE)	HORIZONTAL (Tension)	VERTICAL (Gravity)	Dip usually 75° to 40°
REVERSE	THRUST FAULT LOW ANGLE (dip < 45°) HIGH ANGLE (dip > 45°)	VERTICAL	HORIZONTAL (Compression)	Fault plane may disappear along bedding → faglie listriche
STRIKE - SLIP	TRANSCURRENT FAULT TEAR FAULT WRENCH FAULT RIGHT LATERAL (Dextral) LEFT LATERAL (Sinistral)	HORIZONTAL	HORIZONTAL	Fault trace often 30° to maximum stress
ROTATIONAL	SCISSORS FAULT HINGE FAULT			Throw varies along fault strike; may vary from normal throw to reverse STEP Subduction-Transform Edge Propagator
TRANSFORM	DEXTRAL SINISTRAL	HORIZONTAL		Associated with separation or collision of plates New material fills rifts between separating plates or one plate rides up on another if plates collide.

Interpreting Faults

Structural Observations

- Fault segments on seismic lines
- Fault plane orientation
- Sense of motion
- Magnitude of offset
- Range of depths
- Relative timing
  - when faults moved
  - when structures grew



Structural Concepts

- Tectonic Setting
  - Divergent zones
  - Convergent zones
  - Strike-slip zones
  - Mobile substrate
- How Structures Evolve
  - Fault-bend folds
  - Fault-propagation folds
  - Salt movement
  - etc.

Courtesy of ExxonMobil

Riconoscimento di faglie

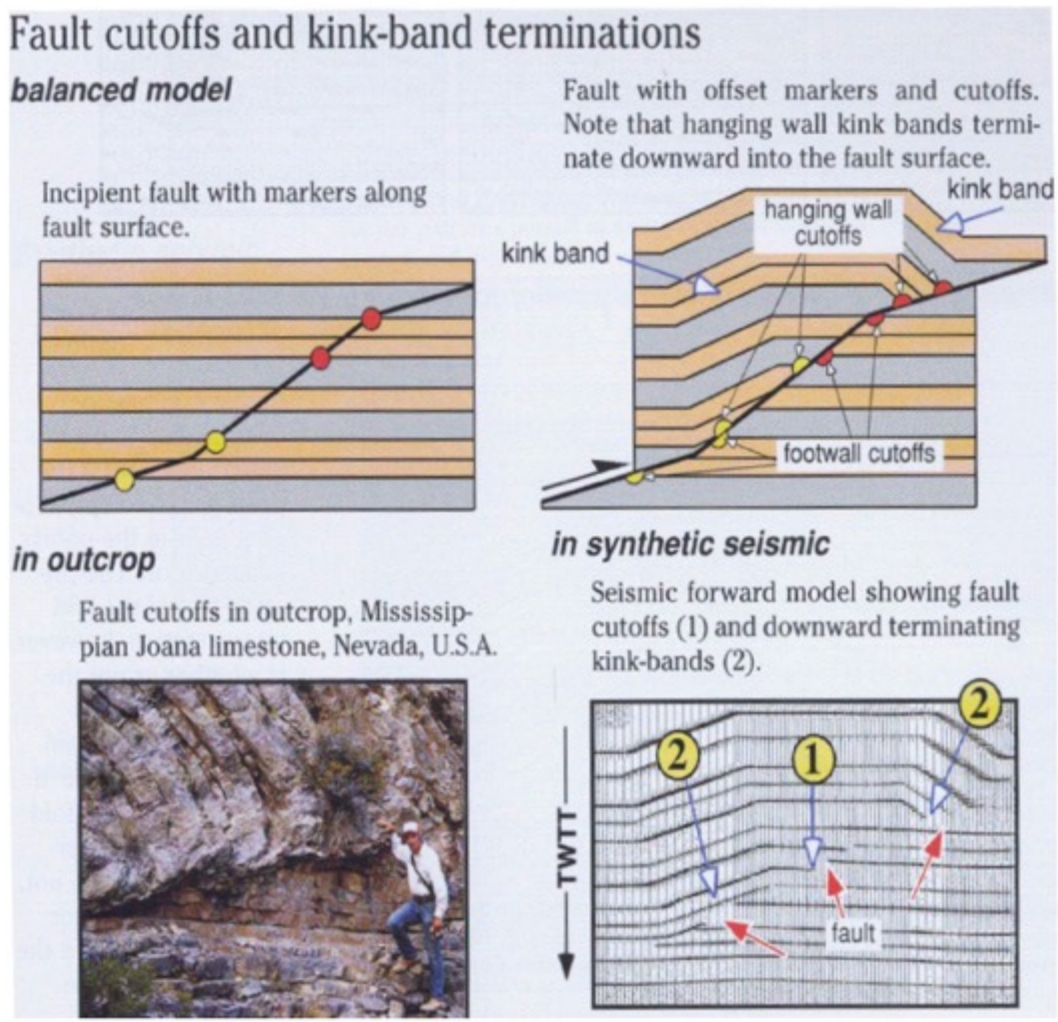
Le faglie vengono identificate nei profili sismici in base a:

1 - *Fault cutoffs*: terminazione delle riflessioni o brusca variazione degli attributi

2 – *Kink bands*: "piega a gomito" degli strati

3 – Riflessione direttamente dal piano di faglia.

I criteri 1 e 3 forniscono direttamente la posizione della faglia; tutti i tre criteri, se applicabili, sono utili per identificare e interpretare correttamente una faglia.



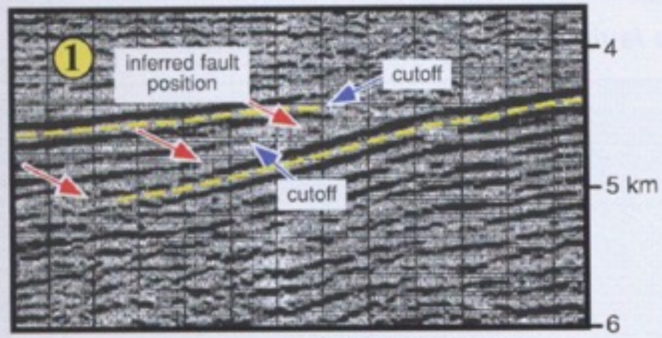
Esempio di profili sismici in cui si possono riconoscere:

1 - ***Fault cutoffs***: terminazione delle riflessioni o brusca variazione degli attributi

2 – ***Kink bands***: "piega a gomito" degli strati

3 – Riflessione direttamente dal piano di faglia

Recognizing and interpreting faults in seismic section



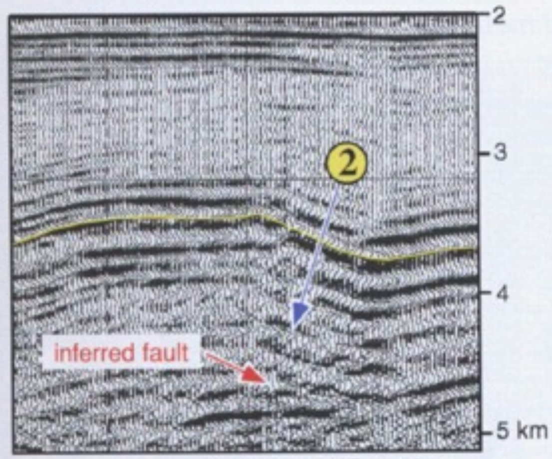
Data courtesy of Texaco, Inc.

fault cutoffs

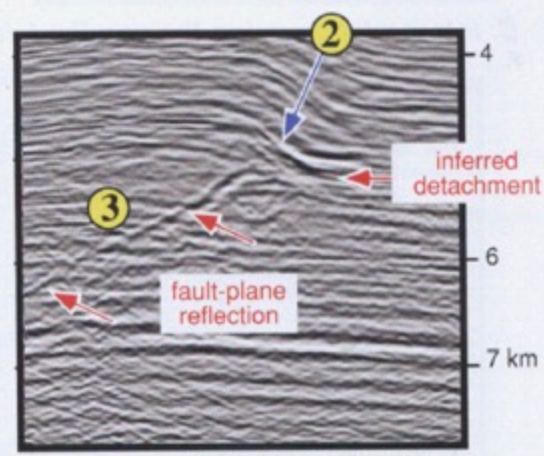
Abrupt terminations (cutoffs) and duplications of prominent reflections constrain the position of a gently dipping thrust fault. (2-D seismic data, Permian basin, Texas, U.S.A.)

kink-band terminations

Thrust faults and bed-parallel detachments can be identified by the abrupt, downward terminations of kink bands. Terminations are generally marked by regions of dipping reflections above horizontal or more gently dipping reflections, and may contain fault cutoffs. Dipping reflections in kink bands represent strata folded in the hanging wall of a thrust/reverse fault or detachment; whereas, horizontal or more gently dipping reflections represent footwall strata below the fault or detachment. Thus faults and/or detachments should be interpreted at the transition between these two dip domains.



Data courtesy of Texaco, Inc.



Data courtesy of Mabone, Ltd.

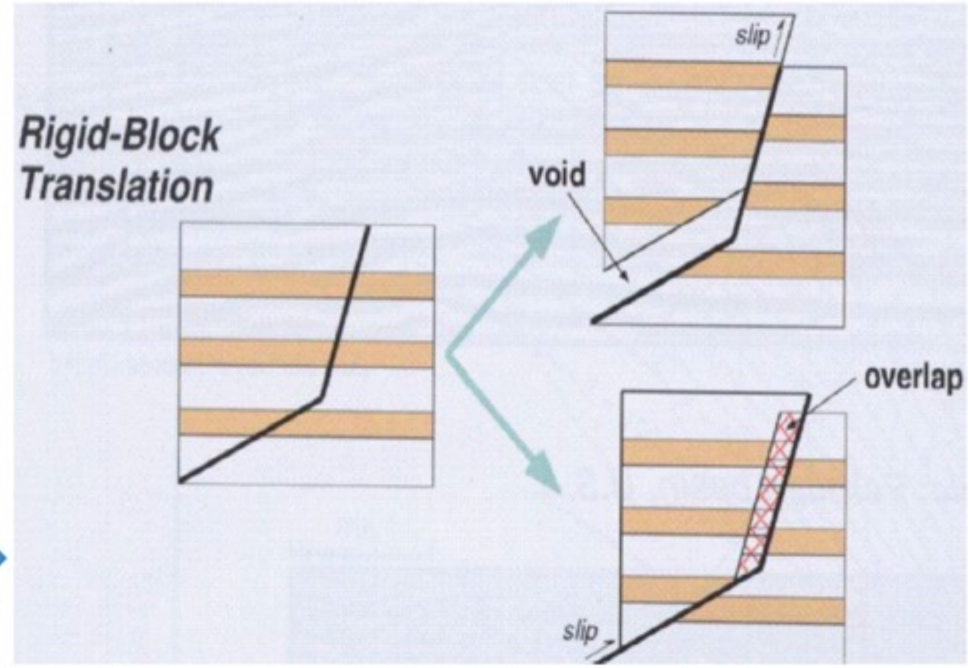
Fault-bend folds

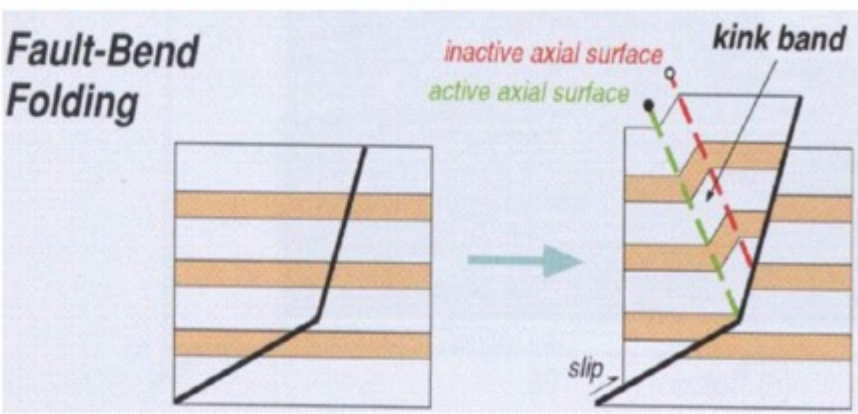
(bending of fault blocks as they ride over non planar fault surfaces)

Si formano quando l'*hanging wall* si muove sopra il "gomito" di una faglia.

Nello scorrimento lungo segmenti diversi della faglia, la traslazione di un blocco rigido produrrebbe un vuoto o una sovrapposizione → tra i due blocchi delimitati dalla faglia.

Entrambe queste situazioni sono irrealizzabili nella realtà.





L'accomodamento si ottiene attraverso la formazione di una piega nel blocco di *hanging wall*, localizzata lungo una superficie assiale attiva, mentre la superficie assiale inattiva localizza la superficie attiva nella fase iniziale.

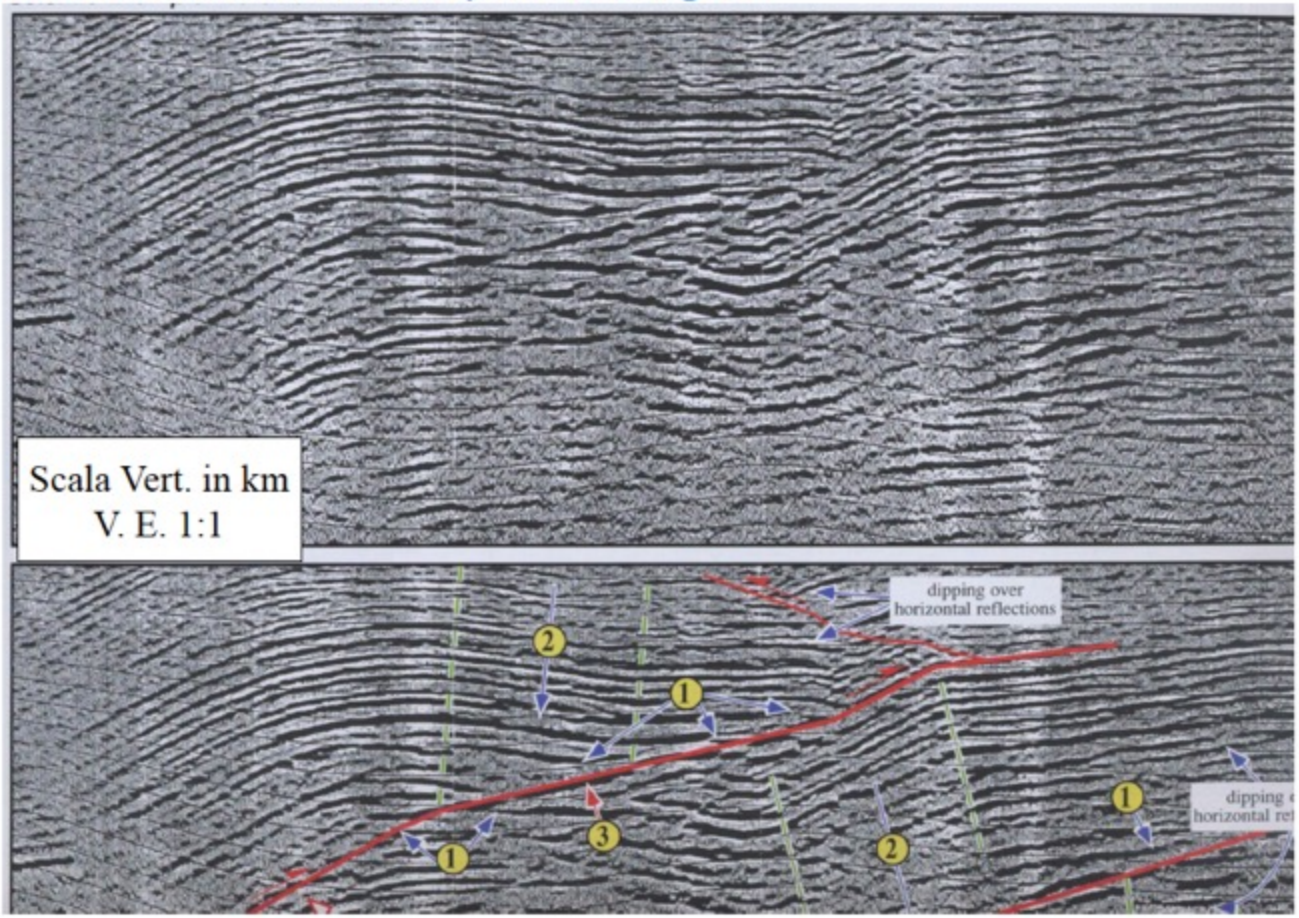
https://www.researchgate.net/profile/John_Suppe/publication/237044249_Geometry_and_Kinematics_of_Fault-bend_Folding/links/0c960522d463fbbfe6000000/Geometry-and-Kinematics-of-Fault-bend-Folding.pdf

Esempio di interpretazione di una faglia inversa basata sul riconoscimento di:

1 - *Fault cutoffs*: terminazione delle riflessioni o brusca variazione degli attributi

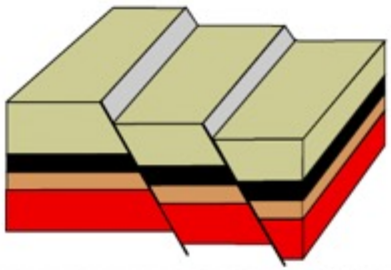
2 – *Kink bands*: "piega a gomito" degli strati

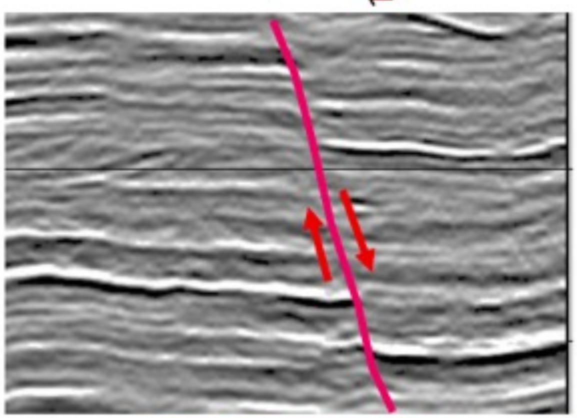
3 – Riflessione direttamente dal piano di faglia

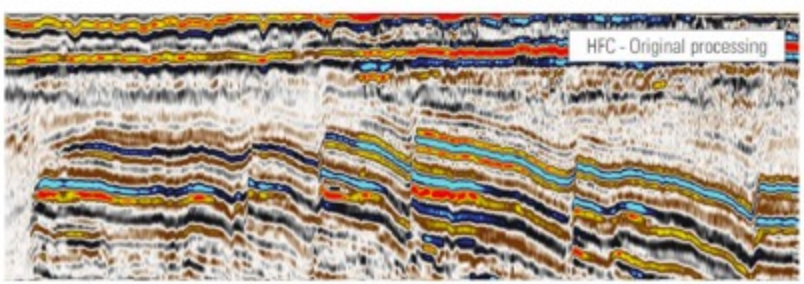


Faglie normali

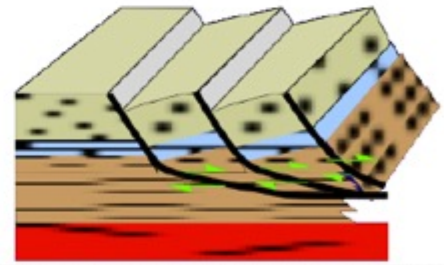
Planari

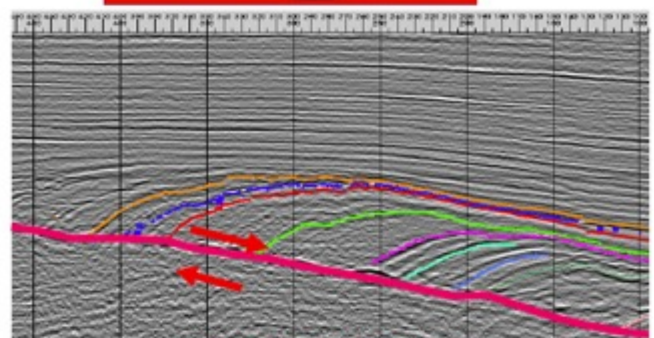


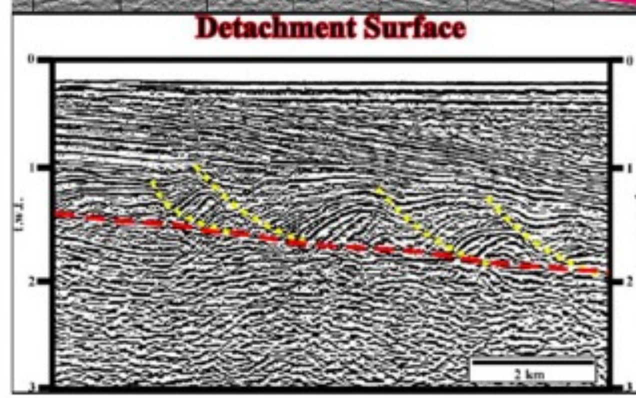




Listriche



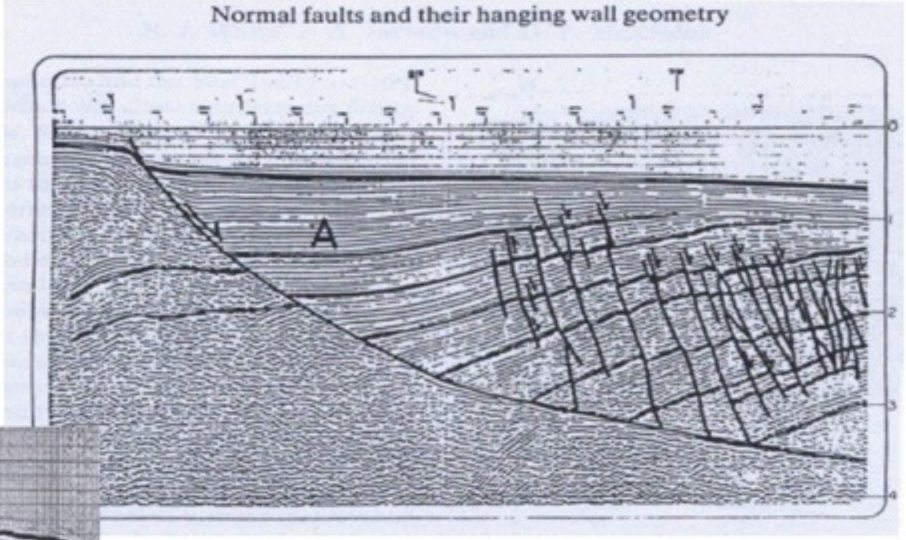


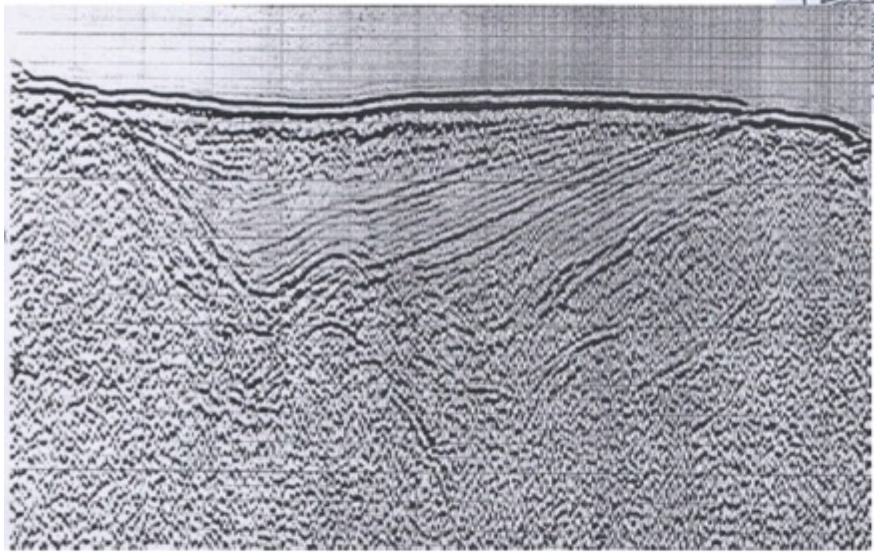


GROWTH (o SYNTECTONIC) STRATA

Sono intervalli stratigrafici **depostisi durante la deformazione**.
La loro età definisce, quindi, l'età della deformazione.

In regime distensivo danno luogo ad un caratteristico cuneo sedimentario (*sedimentary wedge*): in tale contesto possono assumere notevole importanza i fenomeni di *tuning.*



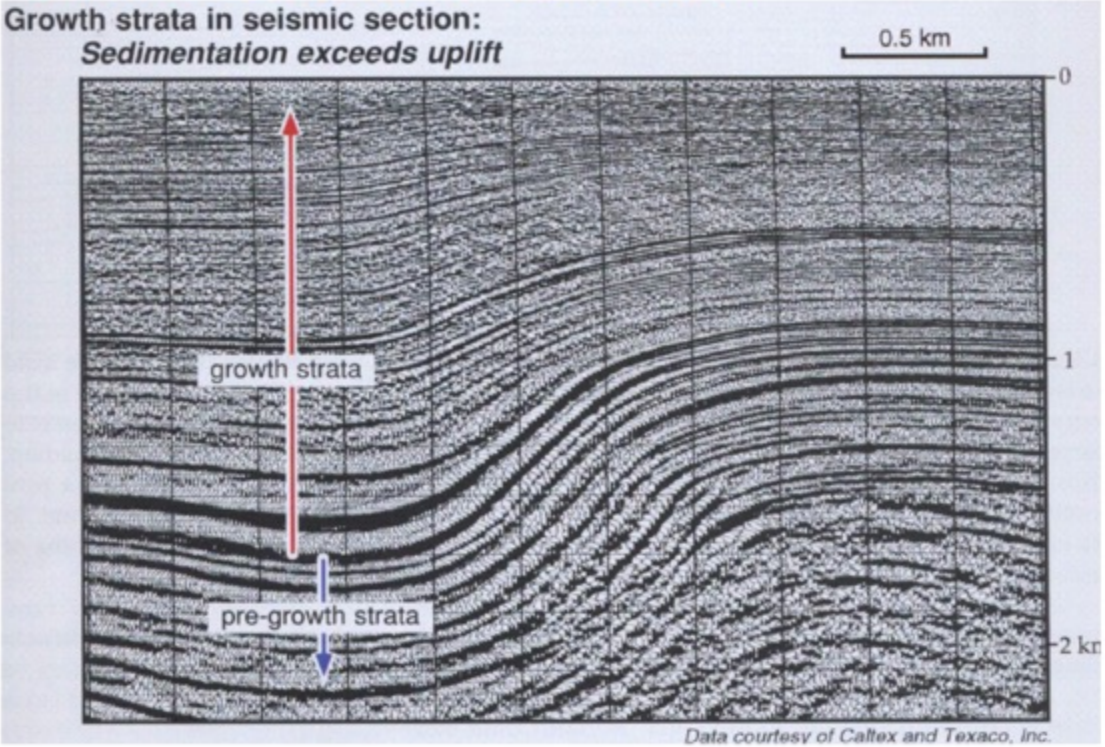


A sn:cuneo sedimentario sintettonico nello Ionio occidentale, testimone di una deformazione a carattere distensivo

GROWTH o SYNTECTONIC STRATA

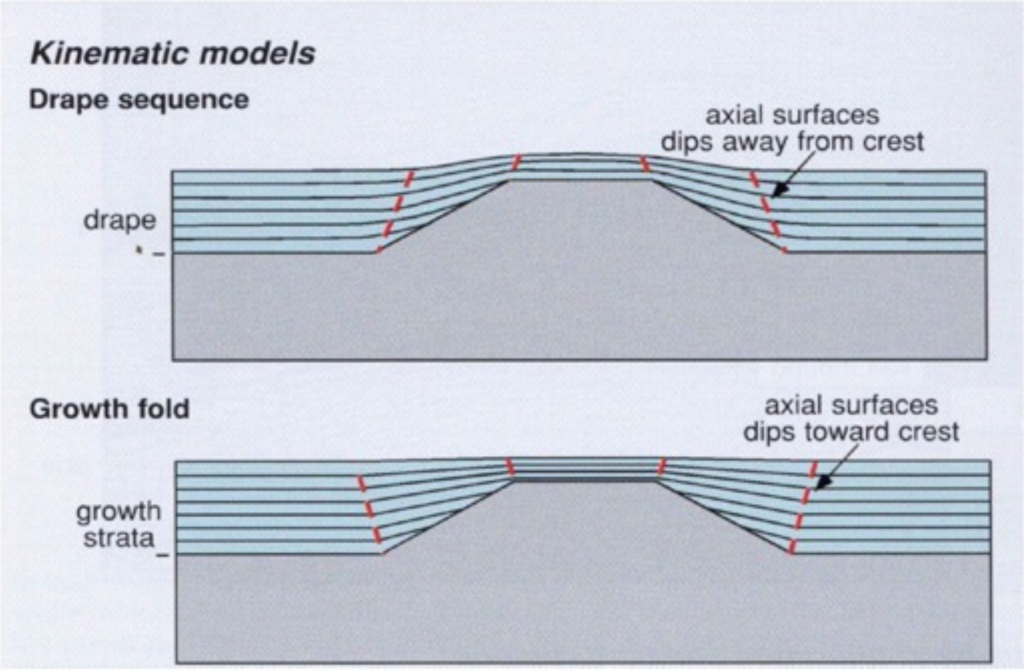
In regime compressivo i *growth strata* si assottigliano verso l'alto strutturale.

La variazione laterale di spessore denota la sedimentazione sintettonica.



Analogia tra "*growth folding*" e "*drape folding*"

Una "*sedimentary drape sequence*" è un intervallo stratigrafico depostosi sopra una struttura dopo che la deformazione sia cessata. I sedimenti possono essere leggermente inclinati sia per deposizione primaria che per compattazione differenziata.



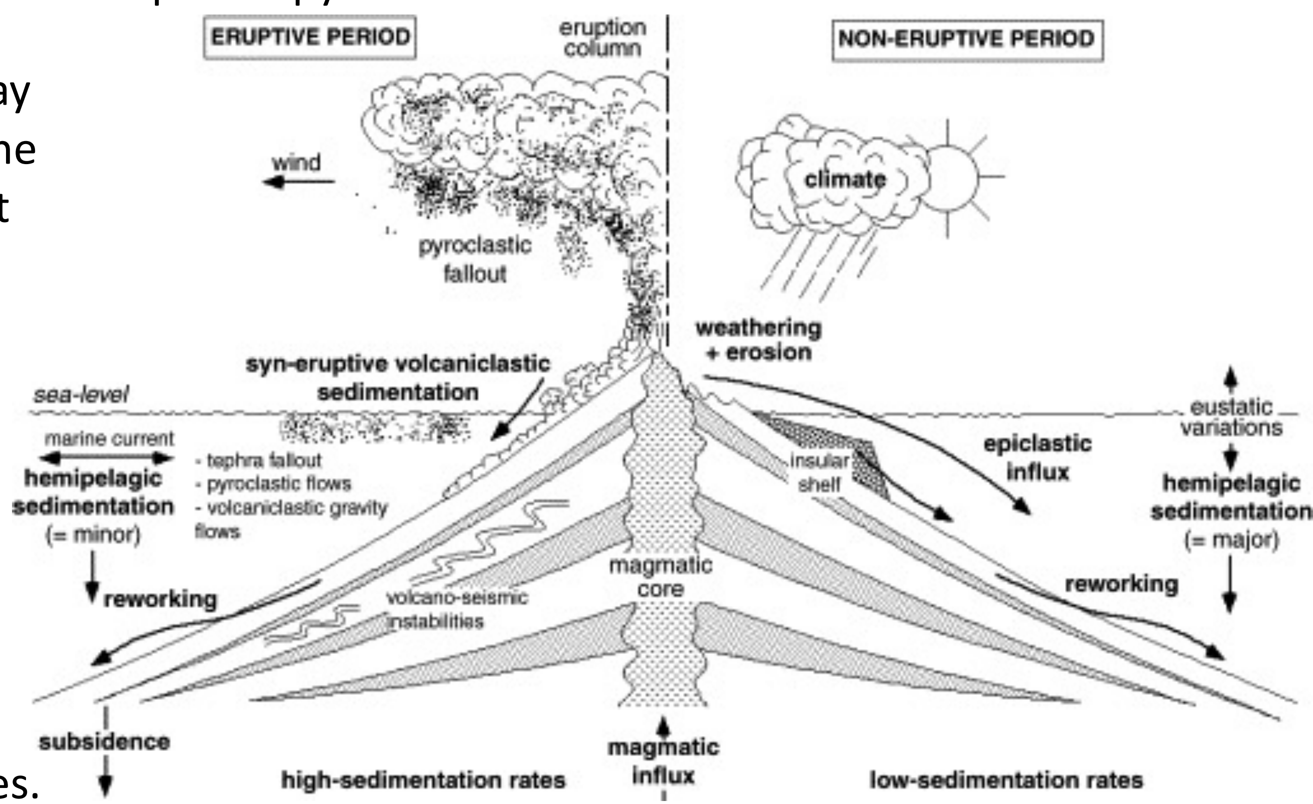
Talvolta tali sequenze possono assomigliare a dei *growth strata*, inducendo ad errori nella valutazione della data-zione della deformazione. Anche se non sempre facili da distinguere tra loro, spesso gli assetti stratigrafici specifici permettono una corretta interpretazione: si notino le diverse vergenze delle superfici assiali.

volcaniclastic deposits

volcaniclastic deposits

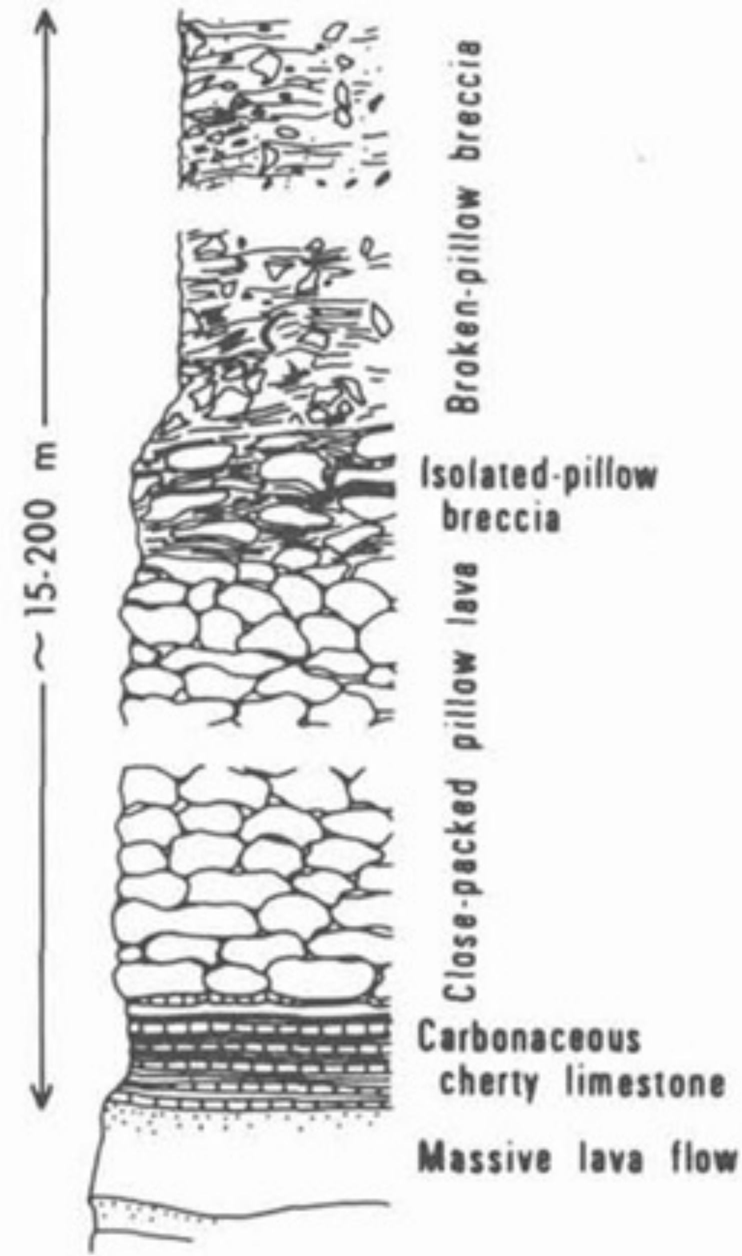
Facies Model, Walker and James, 1992

Oceanic volcanism at midocean ridges, seamounts, and oceanic islands is dominantly basaltic. Due to the lower volatile content of basaltic magmas, volcaniclastic rocks in these regions tend to be formed by fragmentation of lava flows rather than by explosive eruptions. Pillow breccias and hyalo- clastites are commonly formed. By contrast, island arc environments are dominantly basaltic to andesitic in composition. Explosive volcanoes com- monly produce subaerial and sub- aqueous pyroclastic fallout and flows. Remobilized volcaniclastic mass flows and turbidites may be deposited in the submarine environment. Continental rift environments are commonly associated with caldera structures where pyroclastic deposits are found. Basaltic cinder cones and tuff rings also occur here, and are commonly associated with lava flows. Thus, different tectonic environments have distinctive volcaniclastic facies.



Typical pillow breccia-hyalo- clastite sequence.

Triassic of Quadra Island, British Columbia. From Carlisle (1 963).

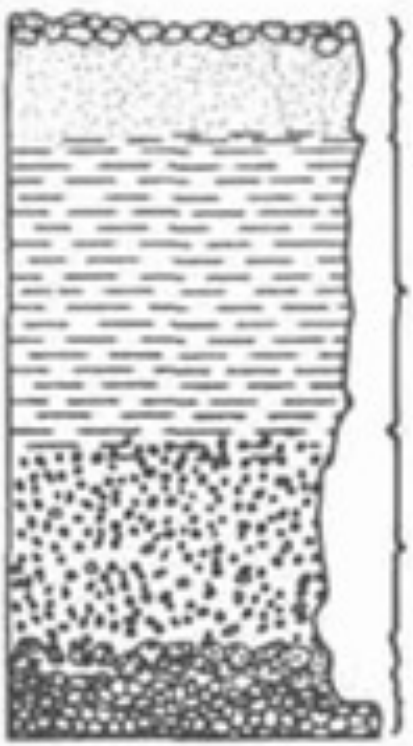


The pillowed (basaltic) lava grades upward into an isolated-pillow breccia that is overlain and transitional with a broken-pillow breccia. In this succession, clast size decreases from base to top. This grain size variation cannot properly be called graded bedding because there is no bedding to begin with. The clasts are formed in situ rather than being transported and deposited. The distinctive characteristics of this type of breccia are the monogenetic composition of the clasts and the transitional contact with the underlying lava.

Schematic cross section of rhyolitic obsidian flow. After Fink (1980), based also on studies from Lipari in the Eolian Islands

Subaerial lava flows of acid composition commonly have flow breccias which underlie and/or overlie the lavas.

The approximately 30 m-thick lava flow has a two m-thick breccia at the base and a one m-thick flow-top breccia. The texture and composition of the fragments are similar to those of the associated parent lava flow. Compared to flow breccias of basaltic composition, however, the breccias of acid flows are thinner; the transition with the parent lava is more abrupt, and may even be sharp; and the fragments are large and chaotically organized.



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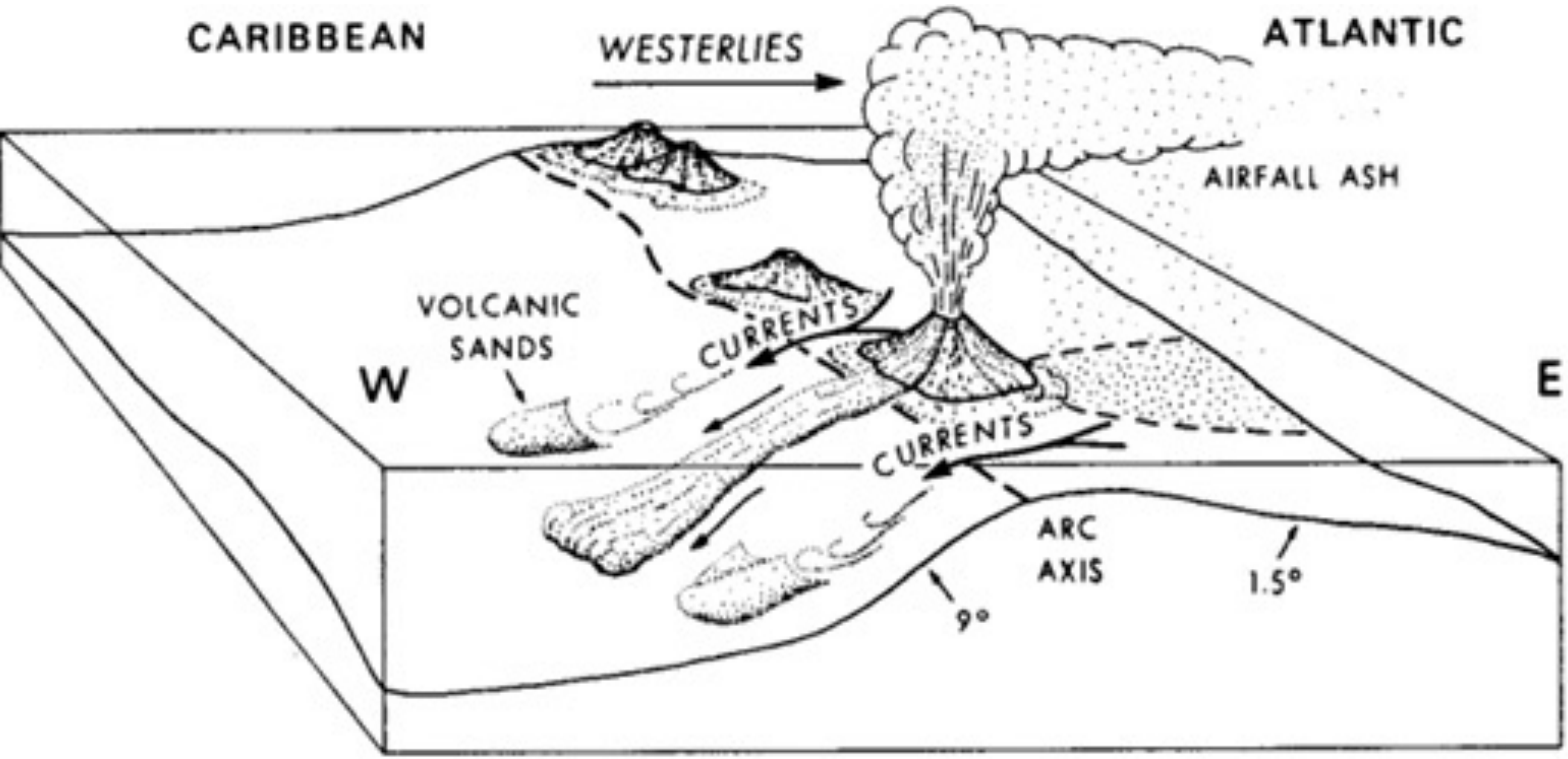
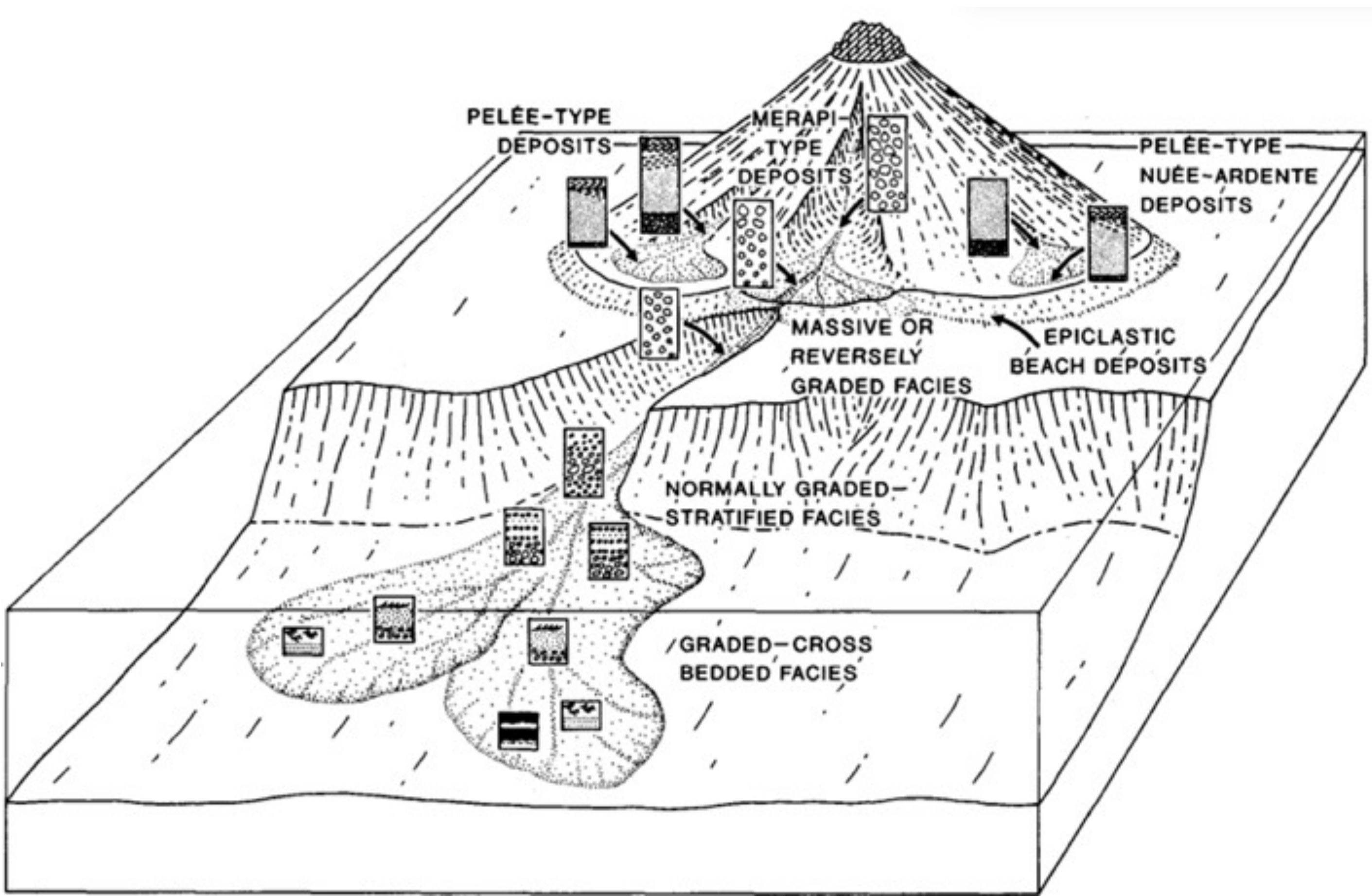
influence of the environment

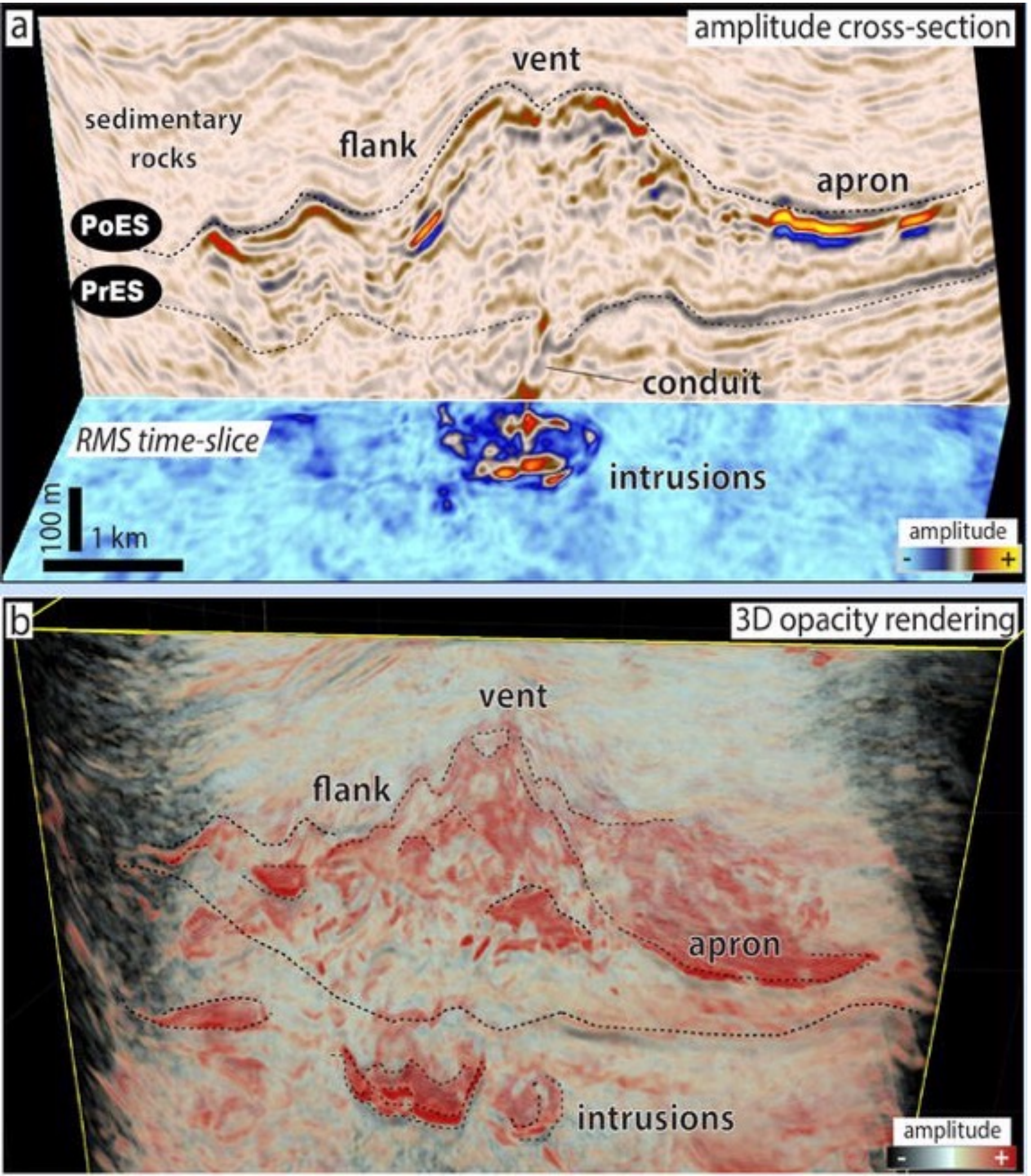
On the west side of the Lesser Antilles arc, nubes ardentes entering the Caribbean Sea descend on steep slopes and are transported into deep water where their characteristics are preserved, and they form various types of density-current deposits. Conversely, due to the prevailing winds, most of the fallout deposits are found on the Atlantic side of the arc.



Idealized vertical and lateral facies variations in subaerial and subaqueous environments for an explosive island volcano

In subaqueous deposits the grading of all fragments is generally normal, but in many subaerial deposits pumices and scoriae are re- versely graded. The primary structure sequences vary systematically down- flow in most of the deposits and depict changing flow conditions and grain sizes that are beingtransported.

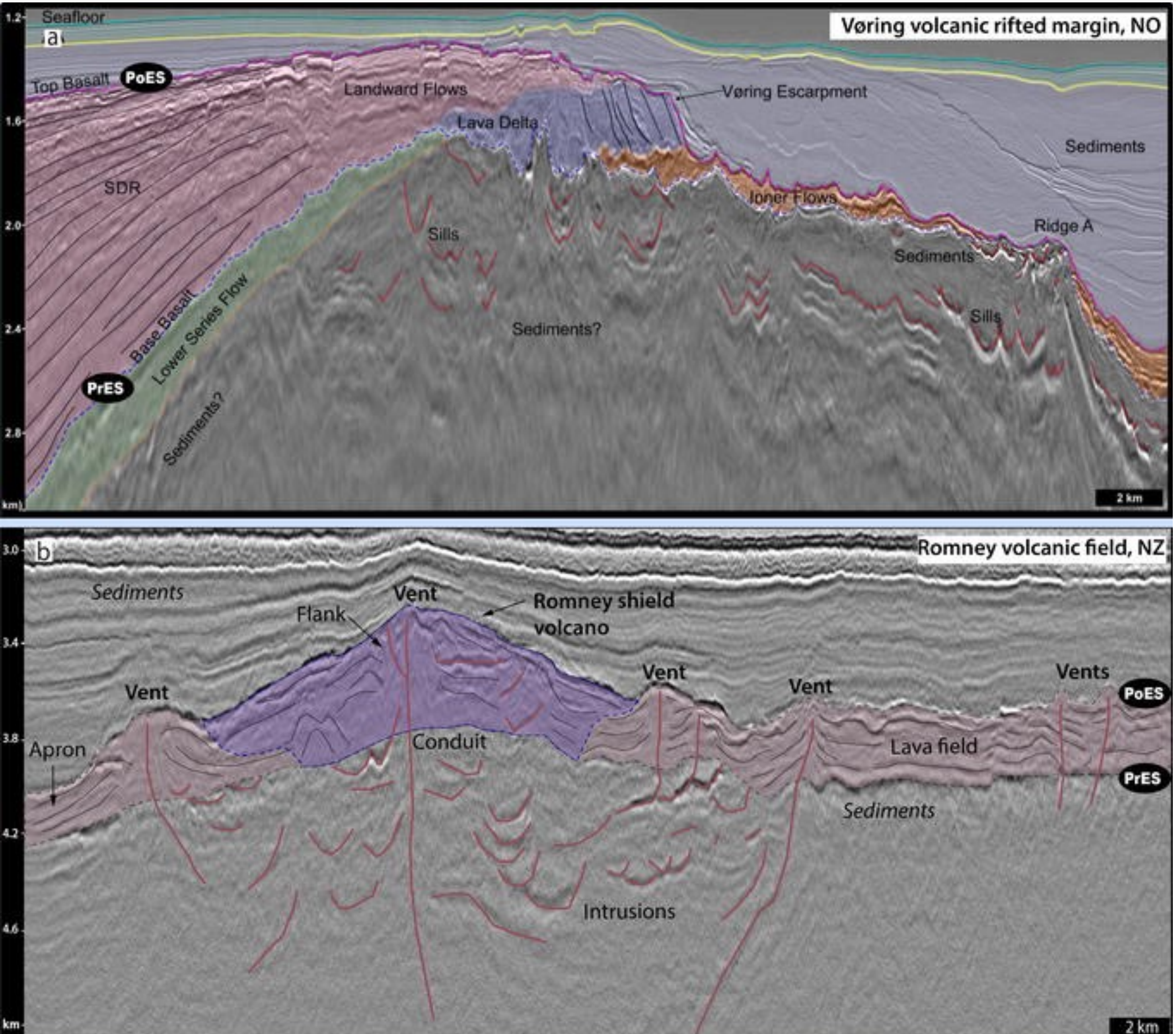




Seismic Geomorphology, Architecture and Stratigraphy of Volcanoes Buried in Sedimentary Basins

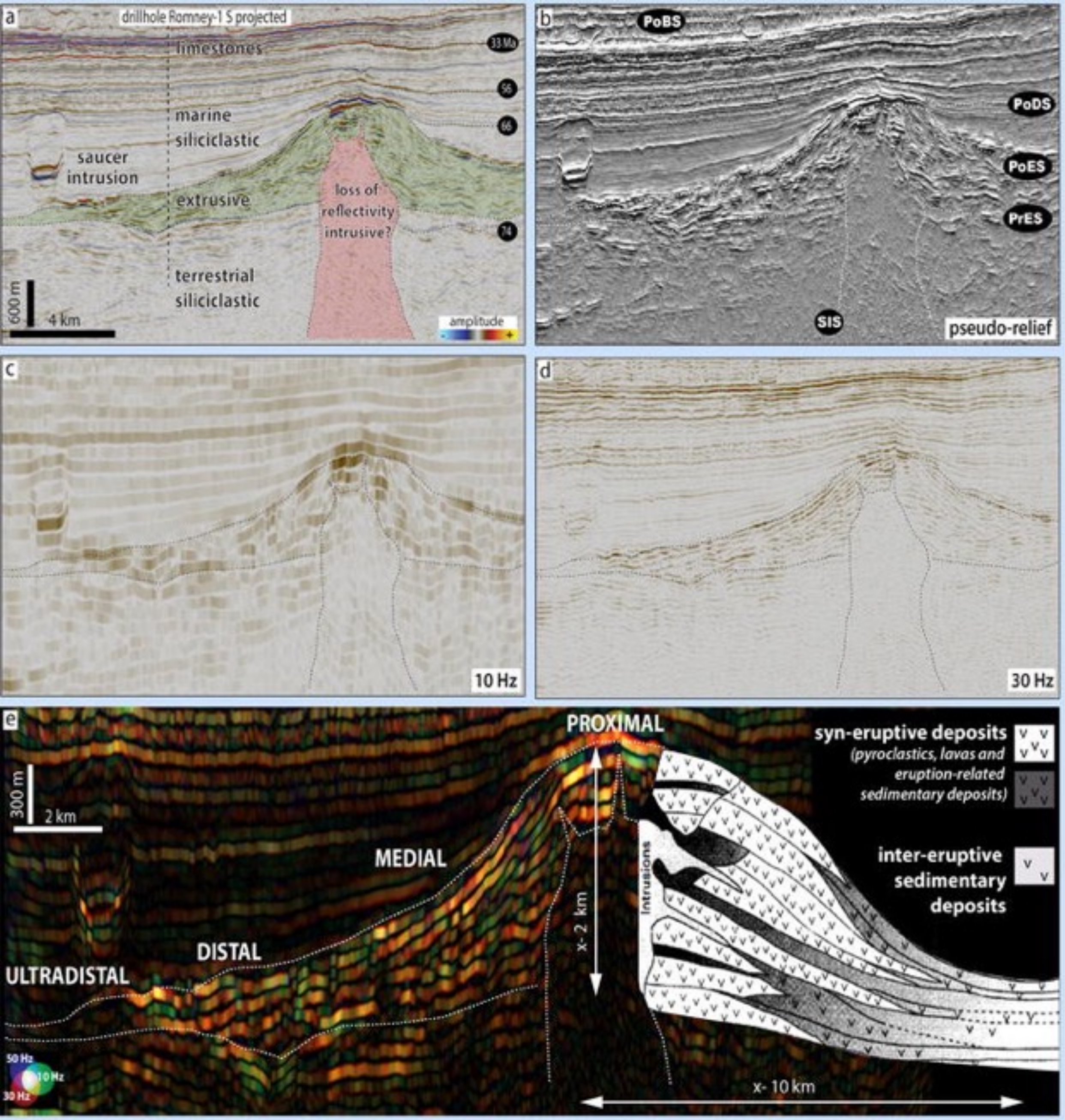
Bischoff et al., 2021. DOI: 10.5772/intechopen.95282

Seismic reflection visualisation of a small cone-shaped volcano buried in the Taranaki Basin, New Zealand. (a) amplitude display of a seismic profile coupled with time-slice RMS amplitude display of its plumbing system. (b) 3D opacity-rendered perspective view and its shallow (<200 m) plumbing system, in which the low-amplitudes are set as transparent. Note the spatial relationship between the saucer-shaped intrusion and the central vent of the volcano. PrES = pre-eruptive surface and PoES = post-eruptive surface.



Amplitude display of seismic reflection profiles across the Vøring volcanic rifted margin, offshore Norway (a) and the Romney volcanic field, offshore New Zealand (b).

Note that the internal and external configuration of seismic reflections determines the spatial relationship of distinctive seismic units, providing information about the succession of events that have formed these units.

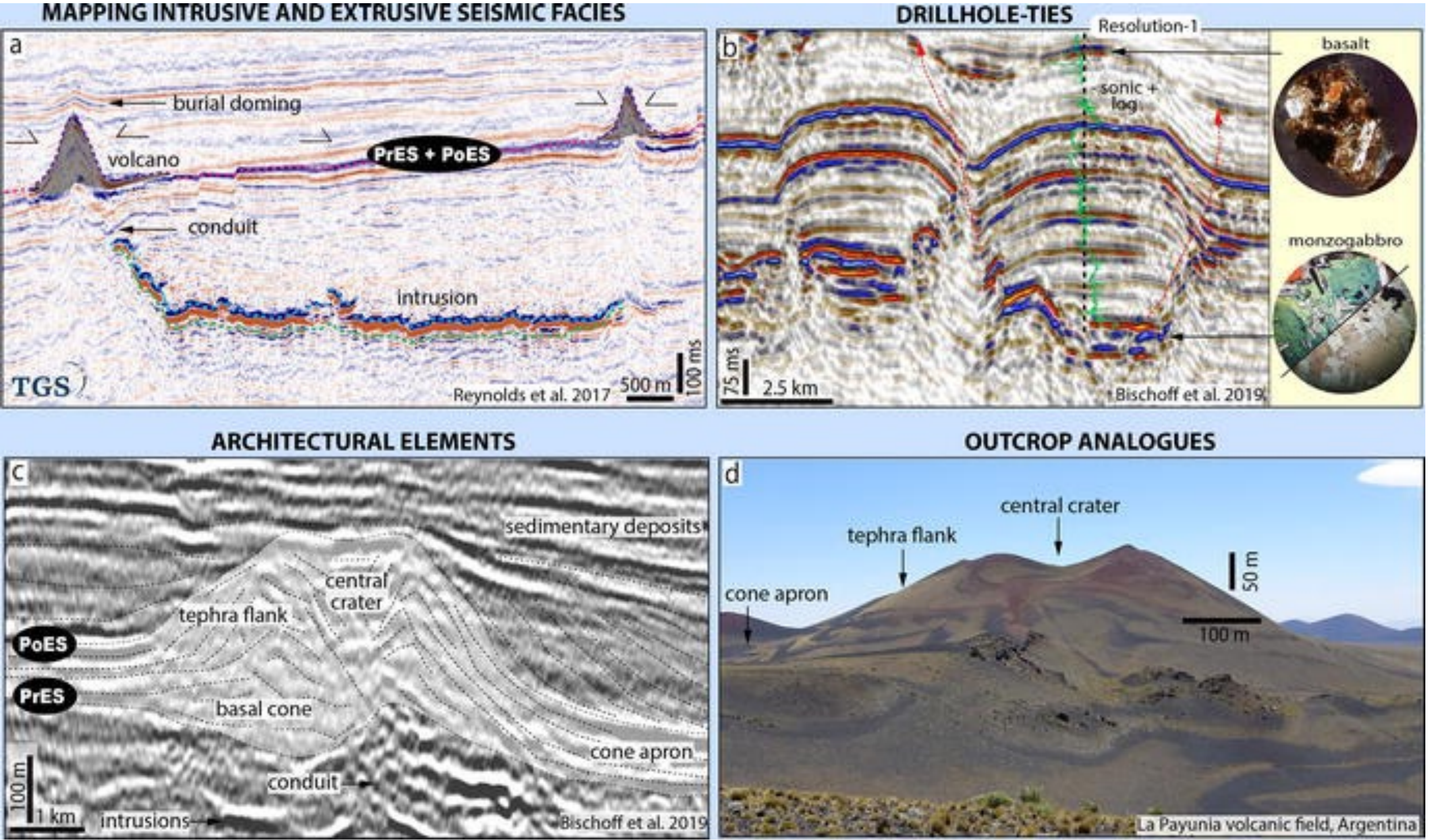


Vulcan composite volcano, offshore Deepwater Taranaki Basin, New Zealand

(a) Amplitude display of a seismic reflection profile, illustrating a variety of intrusive, extrusive and sedimentary seismic facies.
(b) Pseudo-relief and amplitude displays (c and d) seismic profiles that highligh the differences between igneous and sedimentary rocks.
(e) Spectral-decomposition display of a seismic reflection profile illustrating the idealised facies architecture of large polygenetic volcanoes.

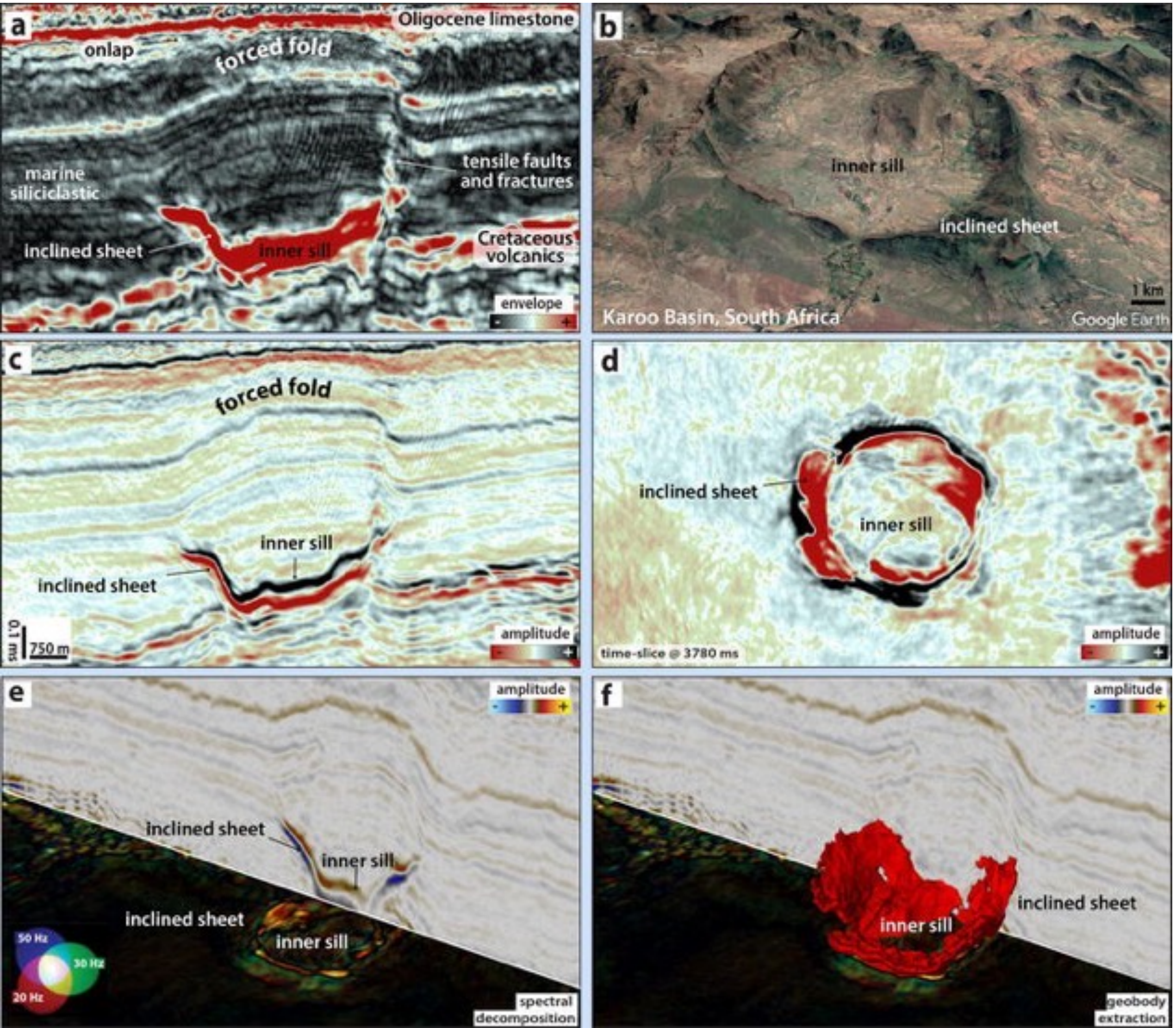
similar morphology of volcanoes in seismic imagery and modern outcropping analogues

(a) Amplitude display of typical saucer-shape sill and related vents above, Bight Basin, S. Australia. (b) 2D seismic section showing a monzogabbro intrusion and associated volcanogenic deposits, Canterbury Basin, New Zealand.

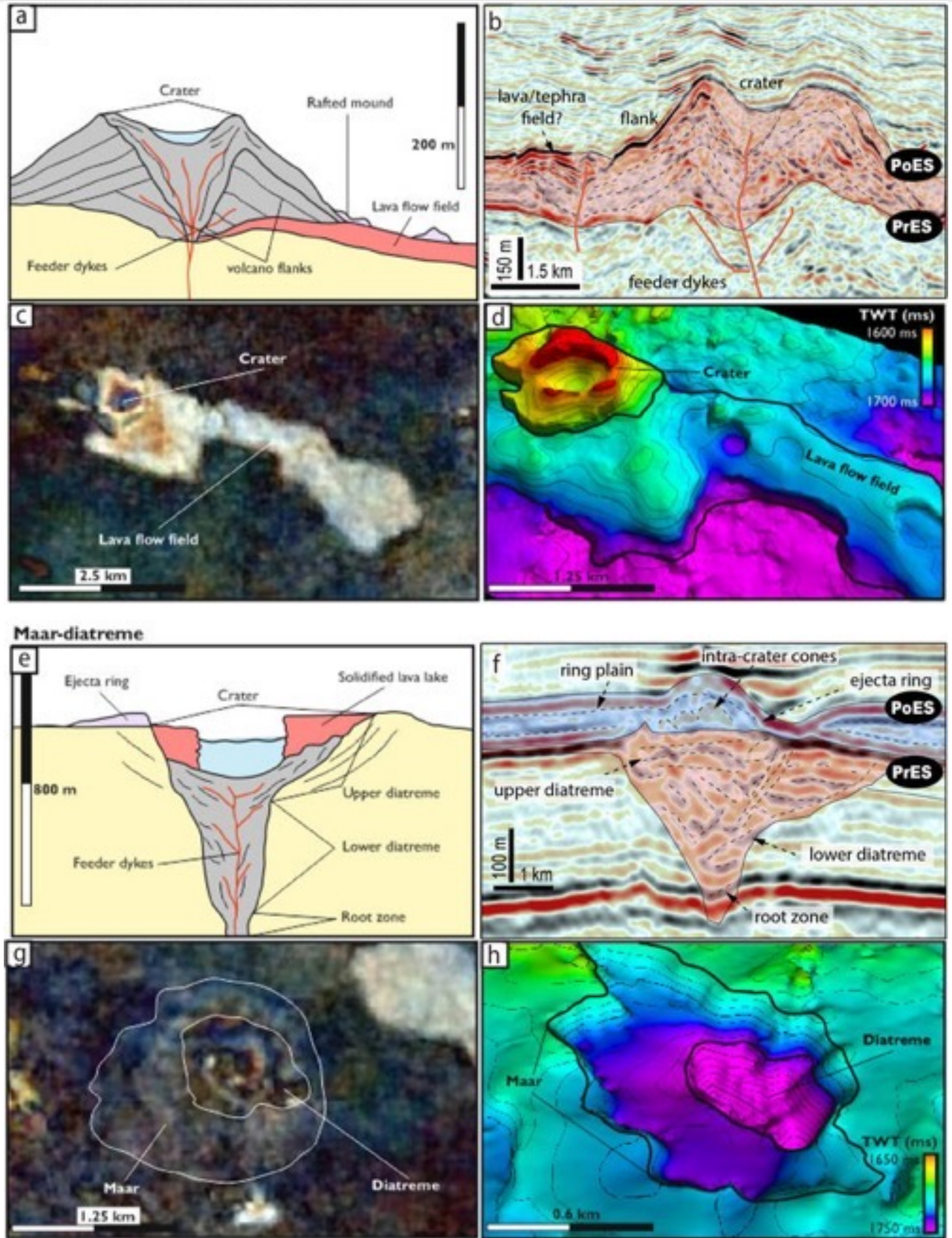


(c) 2D amplitude seismic section illustrating the architectural elements of a small mound-shaped volcano buried in the Canterbury Basin, New Zealand. (d) Photograph illustrating the main architectural elements of a Holocene cinder cone in the La Payunia volcanic field, Argentina.

Seismic and outcrop examples showing the typical geometry of saucer-shaped intrusions

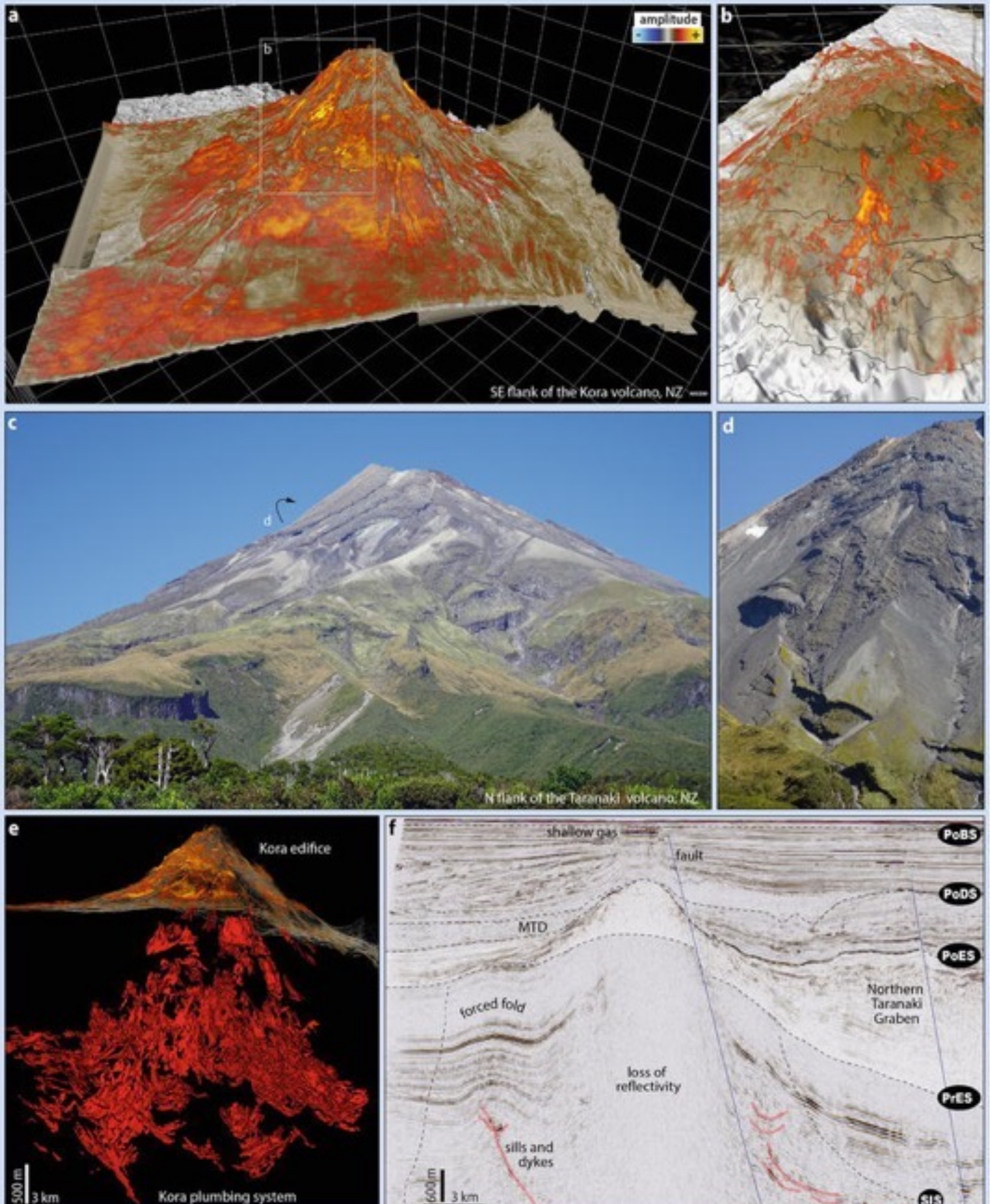


Displays of saucer hybrid intrusion comprising an inner sill parallel to the sedimentary strata, and peripheral inclined sheets cross-cutting the host strata, Deepwater Taranaki Basin, New Zealand: Envelope (a), amplitude (c), plain view (d), composite 3D perspective of an amplitude section and a time-slice of a spectrally decomposed seismic cube (e), extracted seismic geobody (f). (b) Saucer-intrusion emplaced in sedimentary strata of the Karoo Basin, South Africa.



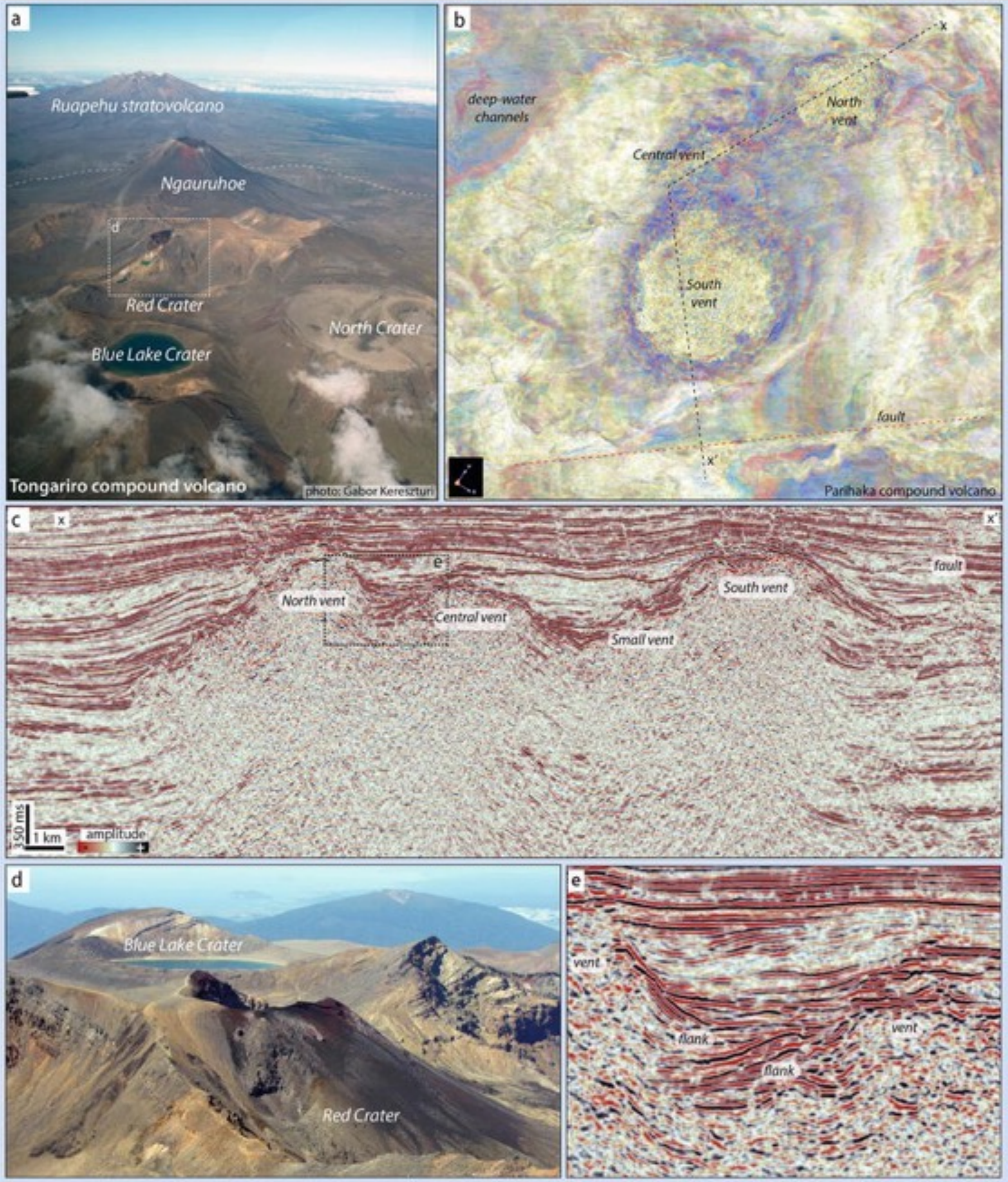
small-volume cones and craters with associated lava flow

(a) Schematic cross-section. (b) Seismic section offshore Taranaki Basin, New Zealand. (c) Plan view spectral decomposition and (d) Horizon mapping of the top surface of the cinder cone taken from the Winnie 3D survey, Eromanga Basin, Australia. (d) Schematic cross-section through a maar-diatreme. (f) A seismic line across a maar-diatreme volcano buried in the offshore Banks Peninsula, New Zealand. (g) Plan view and spectral decomposition and (h) oblique, TWT view of a maar-diatreme buried in the Eromanga Basin, Australia.



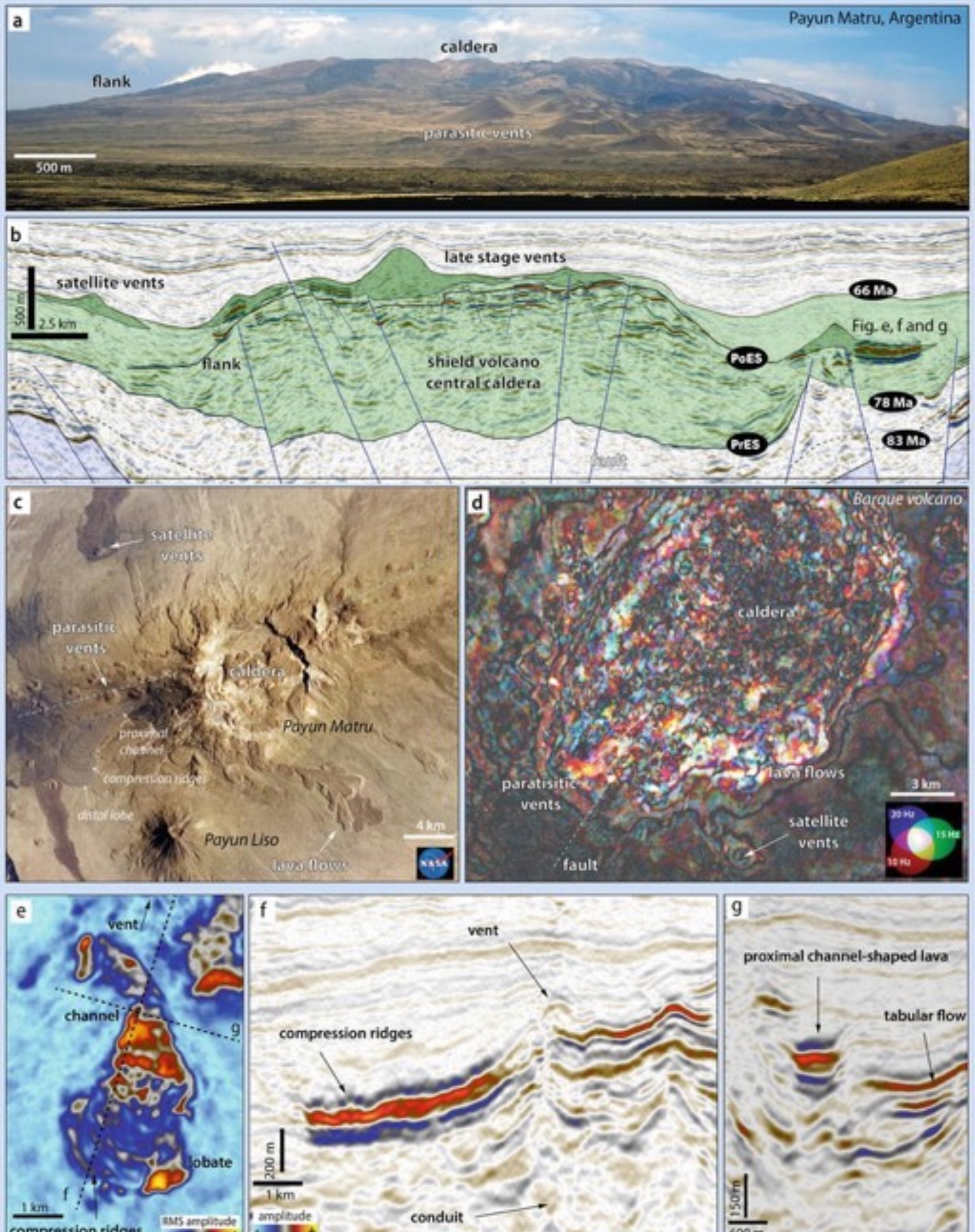
Seismic and outcrop examples of large (>5km^3) **composite volcanos** (single cone-shaped body with a central vent)

Kora volcano, New Zealand: (a and b) 3D perspective of a rendered amplitude seismic cube, (e) oblique 3D view with the edifice highlighted by an opacity rendered amplitude cube, and the plumbing system mapped as numerous interconnected geobodies, (f) amplitude display of a seismic section. (c and d) View of the north flank of the Taranaki volcano, New Zealand. Note in (b) the discontinuous and disrupted high-amplitude reflections (red), which likely reflect multiple depositional and erosional events, such as observed to form at the flanks of Taranaki volcano in (d).



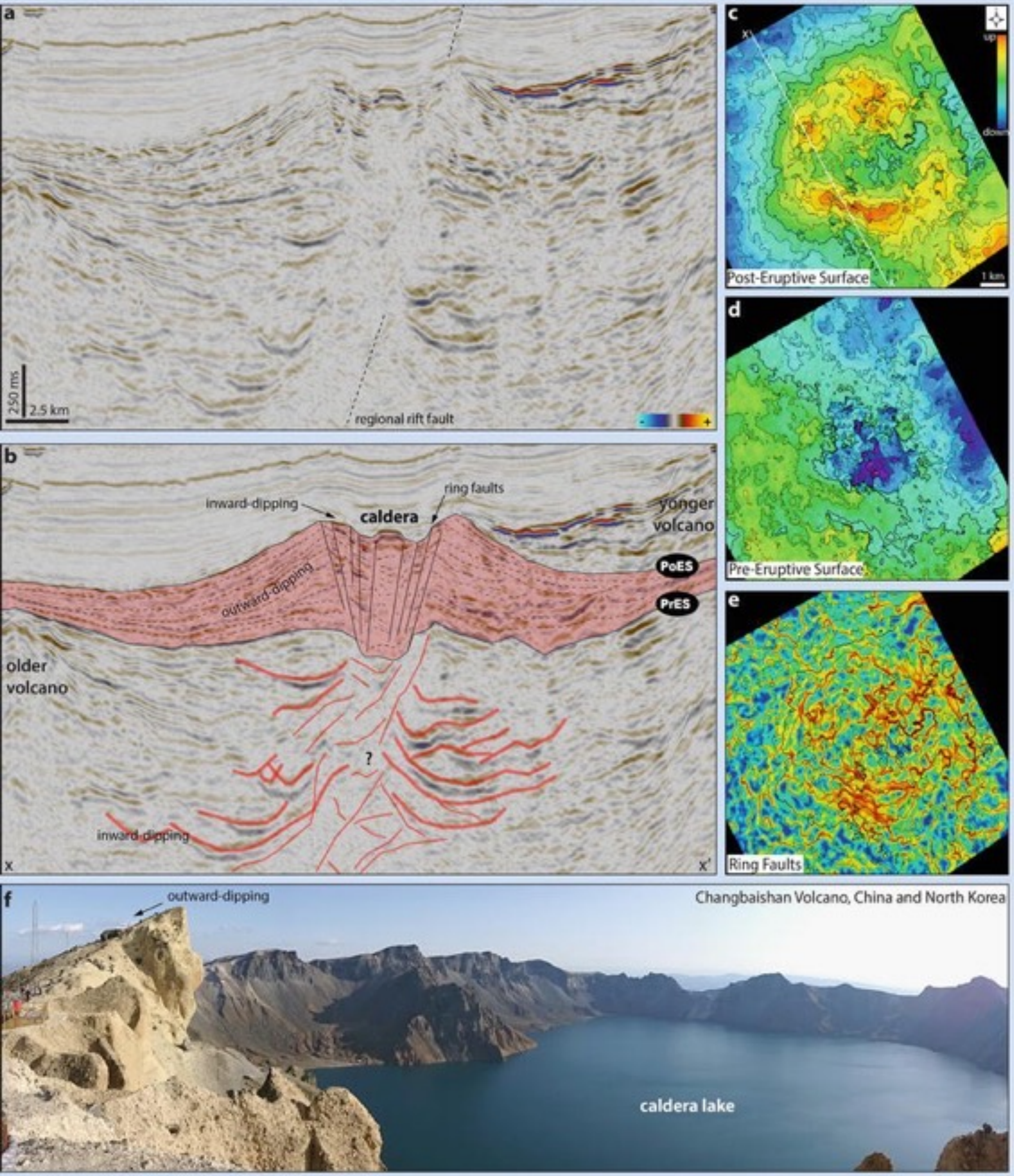
Seismic and outcrop examples of large (>5km^3) compound volcanoes (several overlapping randomly distributed vents)

Tongariro compound volcano: (a) An aerial view with the Ruapehu stratovolcano in the background and (d) Photograph from the summit of the Ngauruhoe volcano showing a detailed view of the Red Crater, Blue Lake Crater and overlapping lavas of the Mangahouhounui Fm. (b) Plain view over a rendered amplitude seismic cube and (c) amplitude display (close-up in e) of a seismic section showing the location of three main vents within the Parihaka compound volcano, New Zealand.



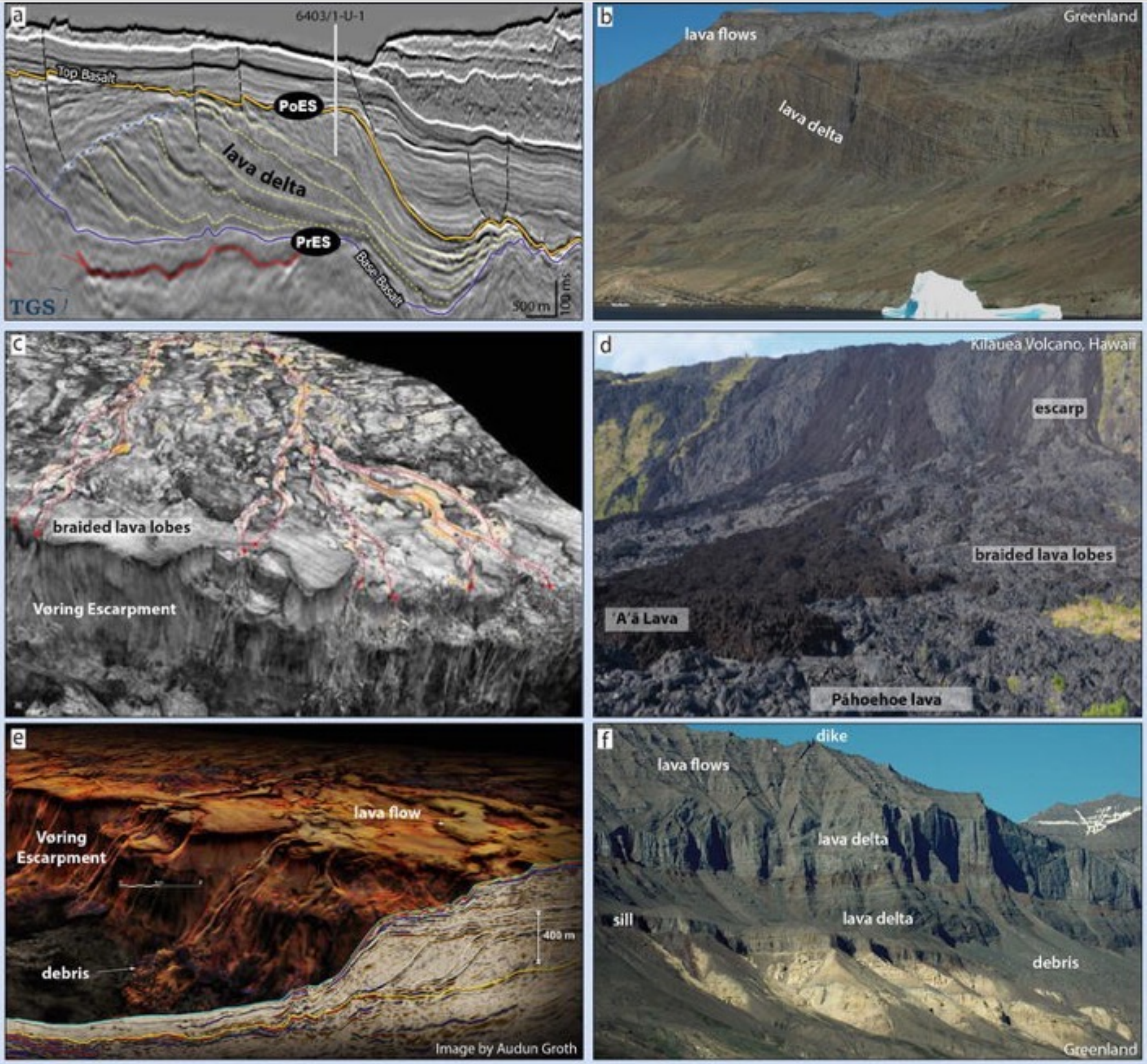
Seismic and outcrop examples of shield volcanoes with a central caldera

Payun Matru Volcano, Argentina: (a) photograph of the northern flank and (c) aerial view. Barque volcano, offshore Canterbury Basin, New Zealand: (b) amplitude display of a seismic section and (d) plain view of a decomposed seismic cube. Lava flow of the Barque volcano: (e) plain view of an RMS seismic cube across and (f and g) amplitude display of a seismic section.



Seismic and outcrop examples of shield volcanoes with a central caldera

(a) Uninterpreted and (b) interpreted amplitude display of a seismic section across the Hades caldera, offshore Deepwater Taranaki Basin, New Zealand. (c) Post-eruptive, (d) pre-eruptive and (e) Pre-eruptive surface isochron horizon maps (the last applying an edge-detection attribute, which is enhancing a series of ring-shaped faults at the location of the caldera depression). (f) Photograph of the crater lake at the summit of the Changbaishan Volcano, Chinese and North Korean border.

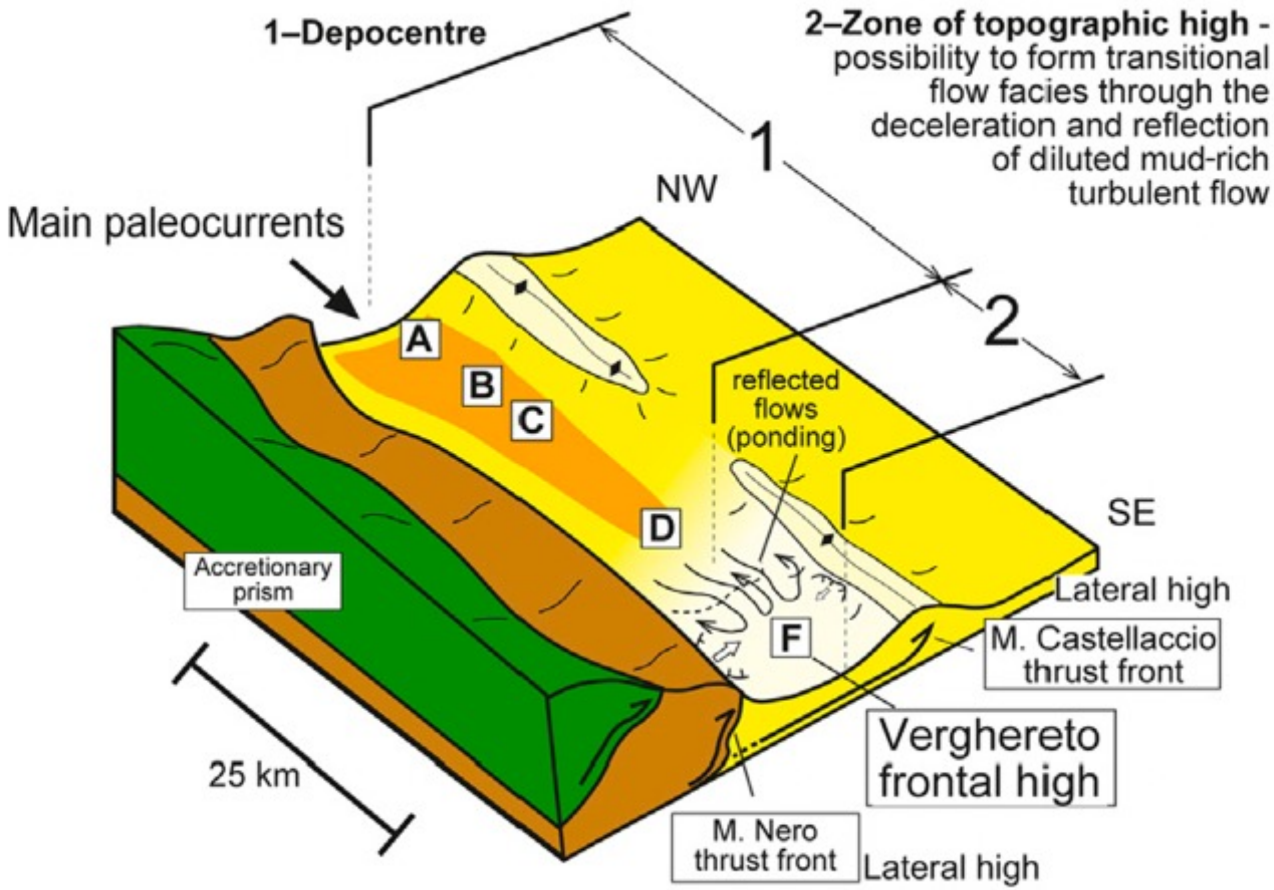


Seismic and outcrop examples of volcanic rift margins and lava-fields

(a) amplitude display across the Kolga Lava Delta, offshore Norway. (b) prograding foresets of a lava delta in w. Greenland. (e) perspective view of the Vøring Escarpment, offshore Norway and (c) of its top-basalt horizon. (d) Lava field and escarpments of the Kilauea Volcano, Hawaii. (f) intrusive and extrusive bodies, lava field in w. Greenland.

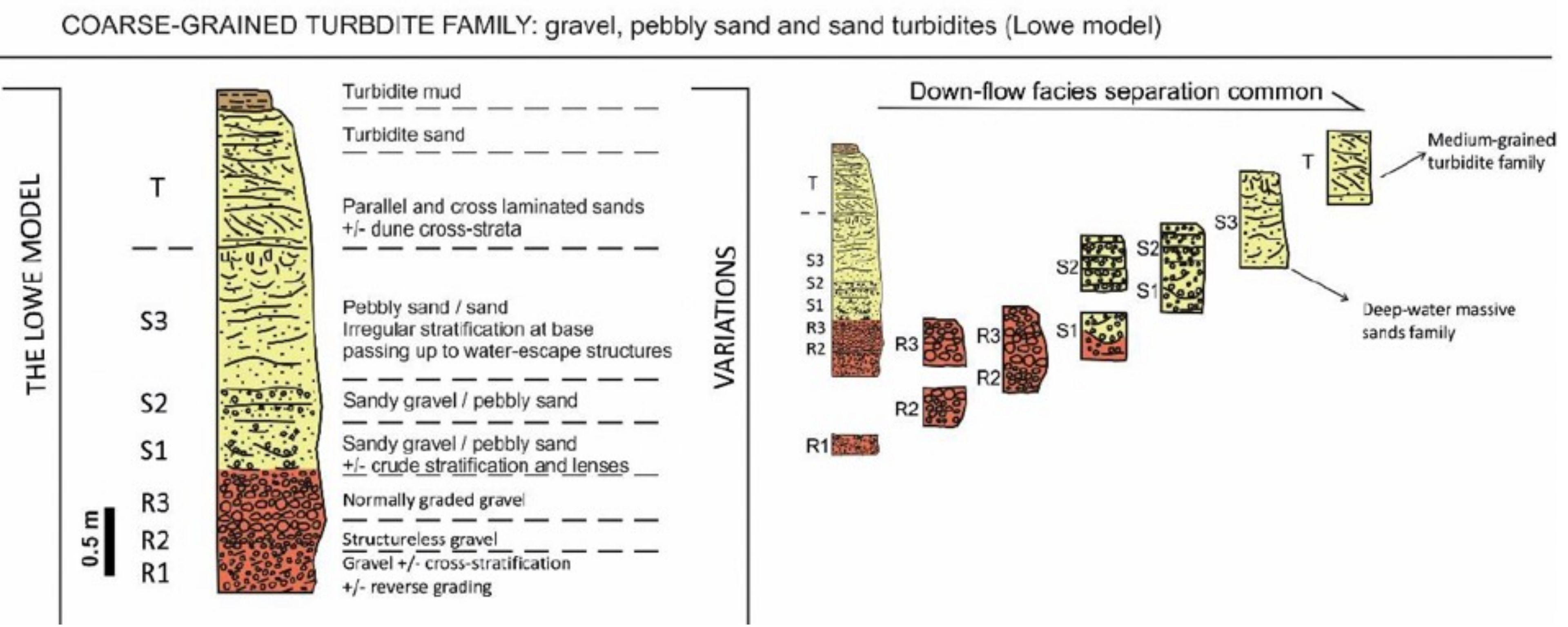
Turbidites & submarine fans (addendum)

Tinterri et al, 2020. Chapter 17 - Turbidites and turbidity currents. In: Scarselli et al (Eds), Regional Geology and Tectonics. Elsevier, 10.1016/B978-0-444-64134-2.00016-X.



Palaeogeography of the basin during the deposition of units able to produce the complete reflection of turbulent flows, where the concomitant downcurrent increase in contained-reflected beds and convolute laminae occur.

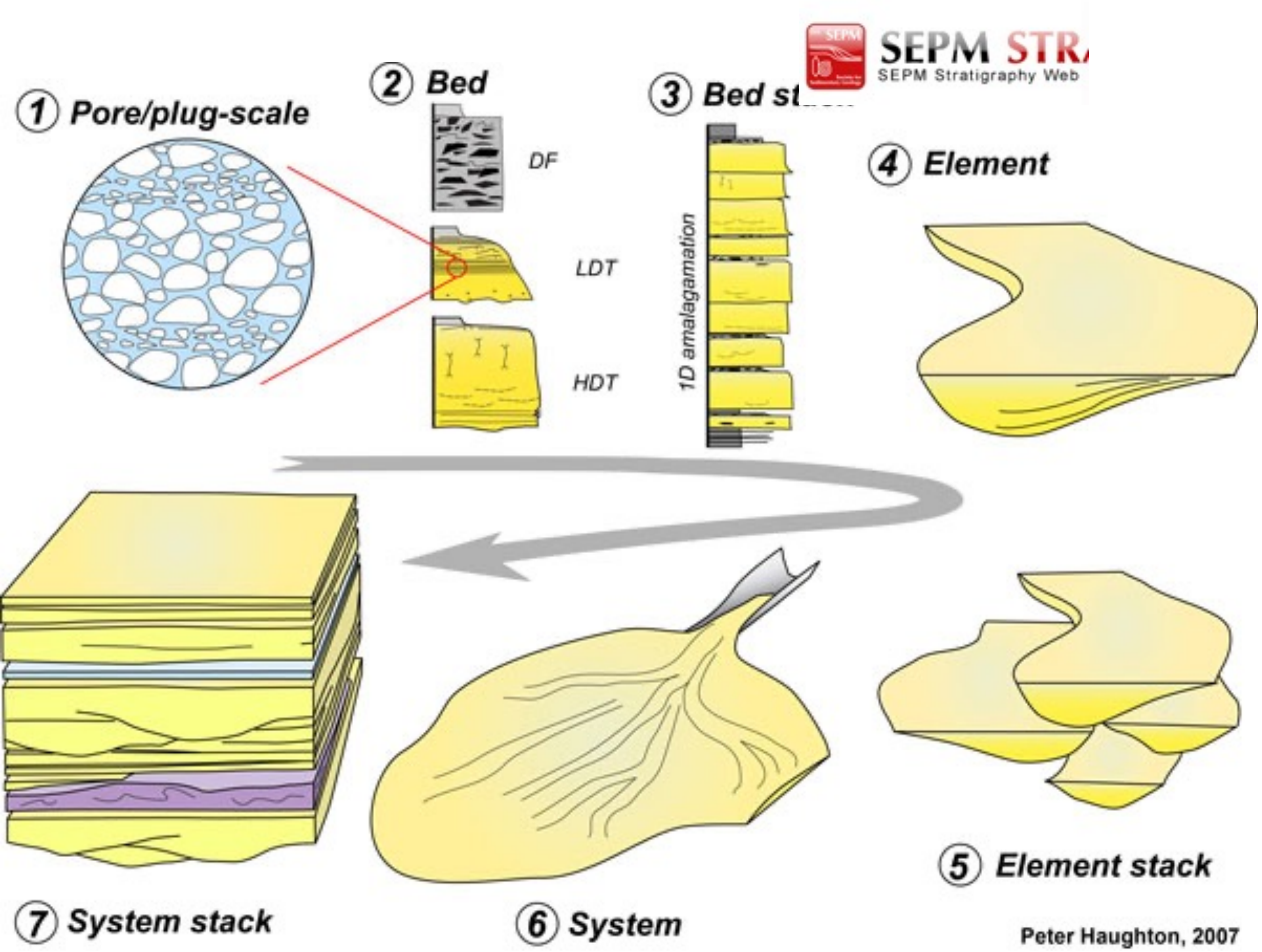
Stow & Smillie Z, 2020. Distinguishing between Deep-Water Sediment Facies: Turbidites, Contourites and Hemipelagites. Geosciences 10, 68, 10.3390/geosciences10020068



The ideal coarse-grained turbidite Lowe facies model showing the complete sequence of gravel, pebbly sand and sandy R2–S3 divisions, and typical partial sequences commonly found.

Deepwater Element & Architecture

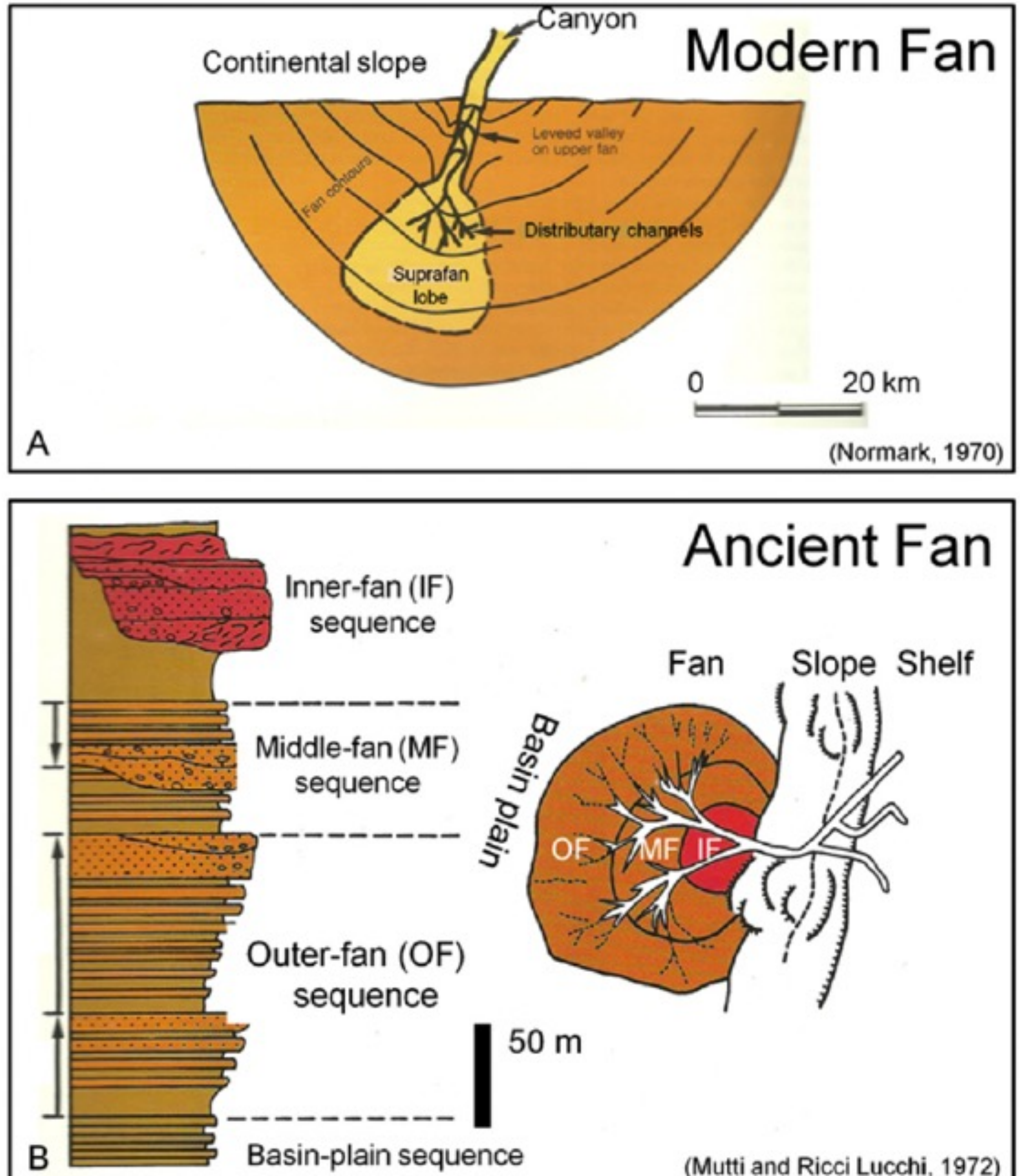
http://www.sepmstrata.org/page.aspx?pageid=39



Collectively the genetically related architectural elements form the sedimentary architecture of the deepwater depositional system. The elements show a progressive increase in scale from the bed to complex system set. This approach enables the classification and eventually interpretation of these sedimentary Rocks and the prediction of their lateral extent as a three-dimensional architecture across the basin.

Shanmugam (2016) Submarine fans. Journal of Palaeogeography 5, 110-184

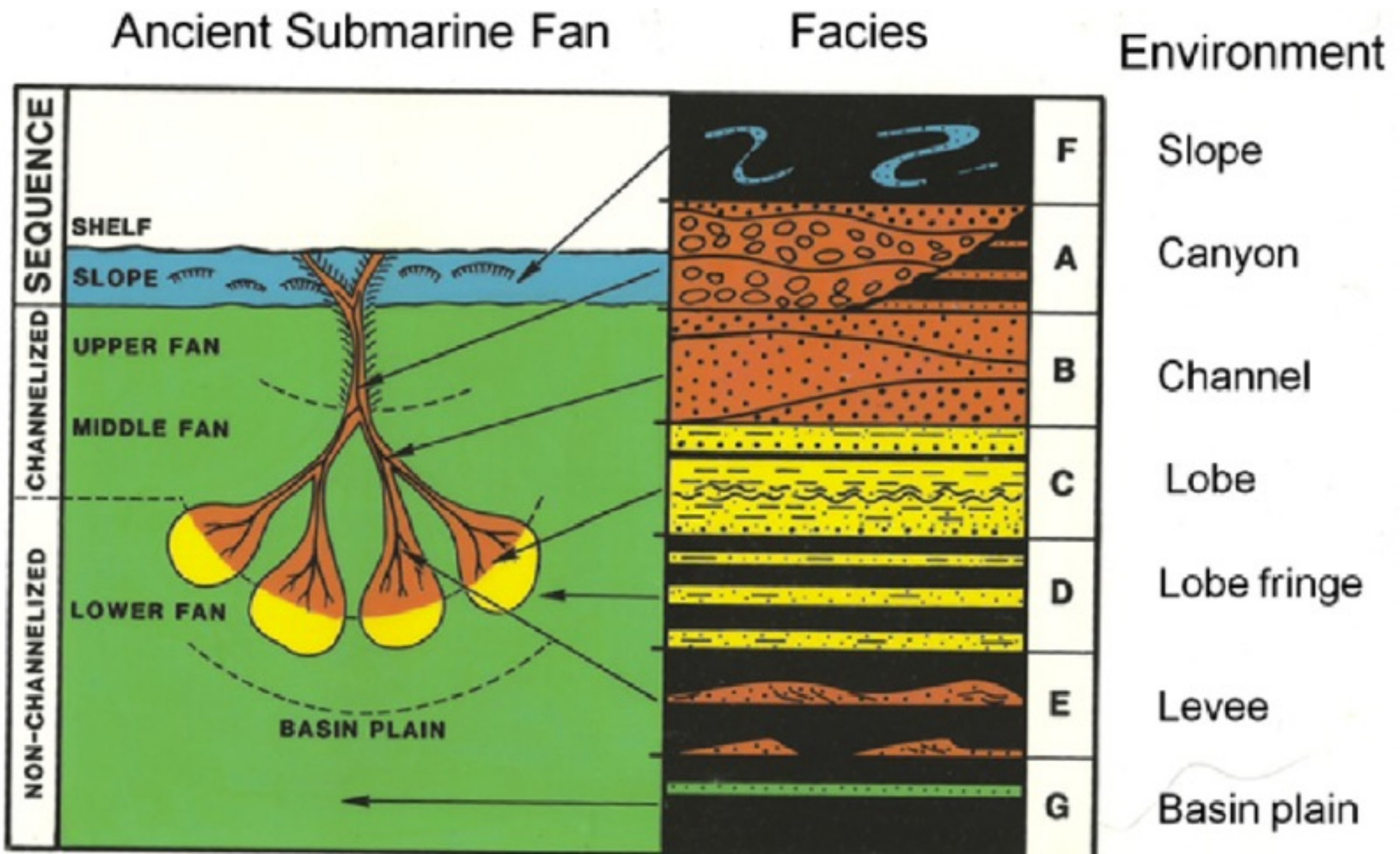
29 Submarine fan-related models primarily based on types of lobes, although other factors are also used. The submarine lobe concept was initiated with the term “suprafan lobe” for modern fans, and the term “depositional lobe” for ancient fans. Since then, the term lobe has been used loosely with divergent meanings. It can be used strictly as a descriptive, geomorphic, term not implying anything about depositional processes or deposits.



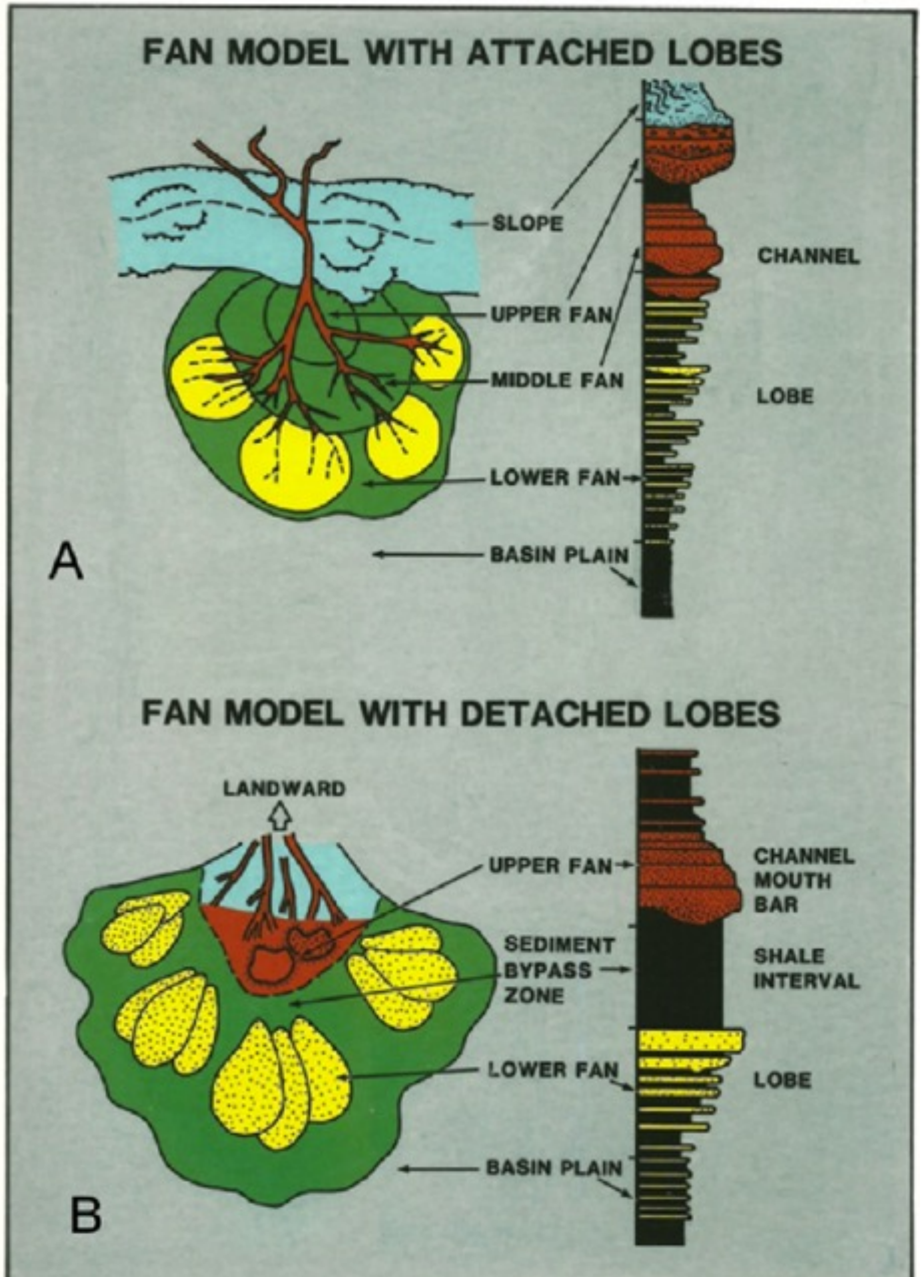
Components of a classic ancient submarine fan with a canyon, distributary channels, and lobes

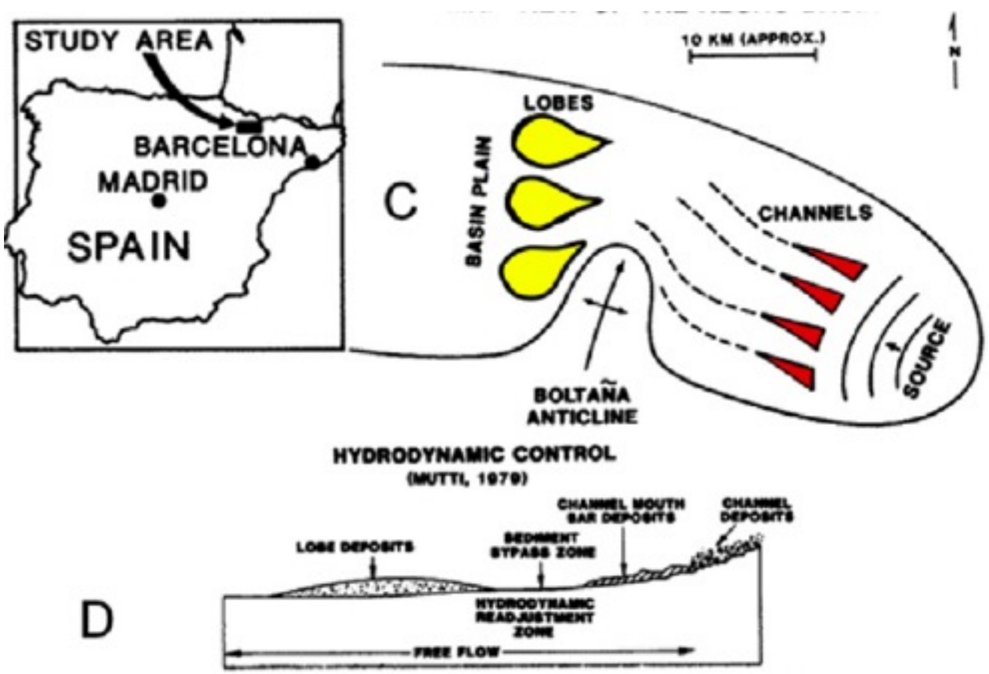
The original turbidite facies scheme (A, B, C, D, E, F, and G), proposed by Mutti and Ricci Lucchi (1972), is applied to a classic submarine fan.

Note each environment is characterized by a turbidite facies (e.g., channel with Facies B and lobe with Facies



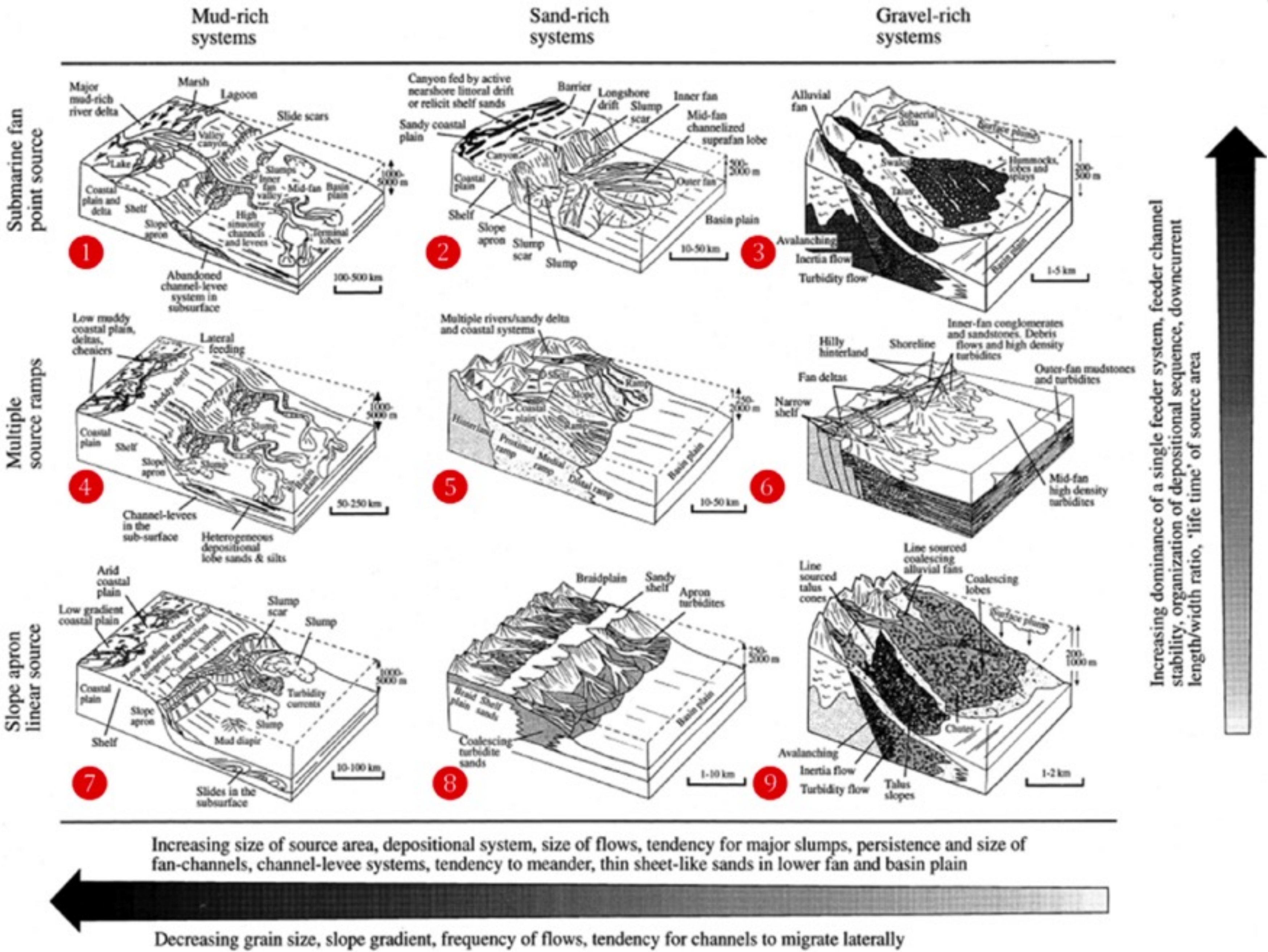
Depositional lobes detached from feeder channels

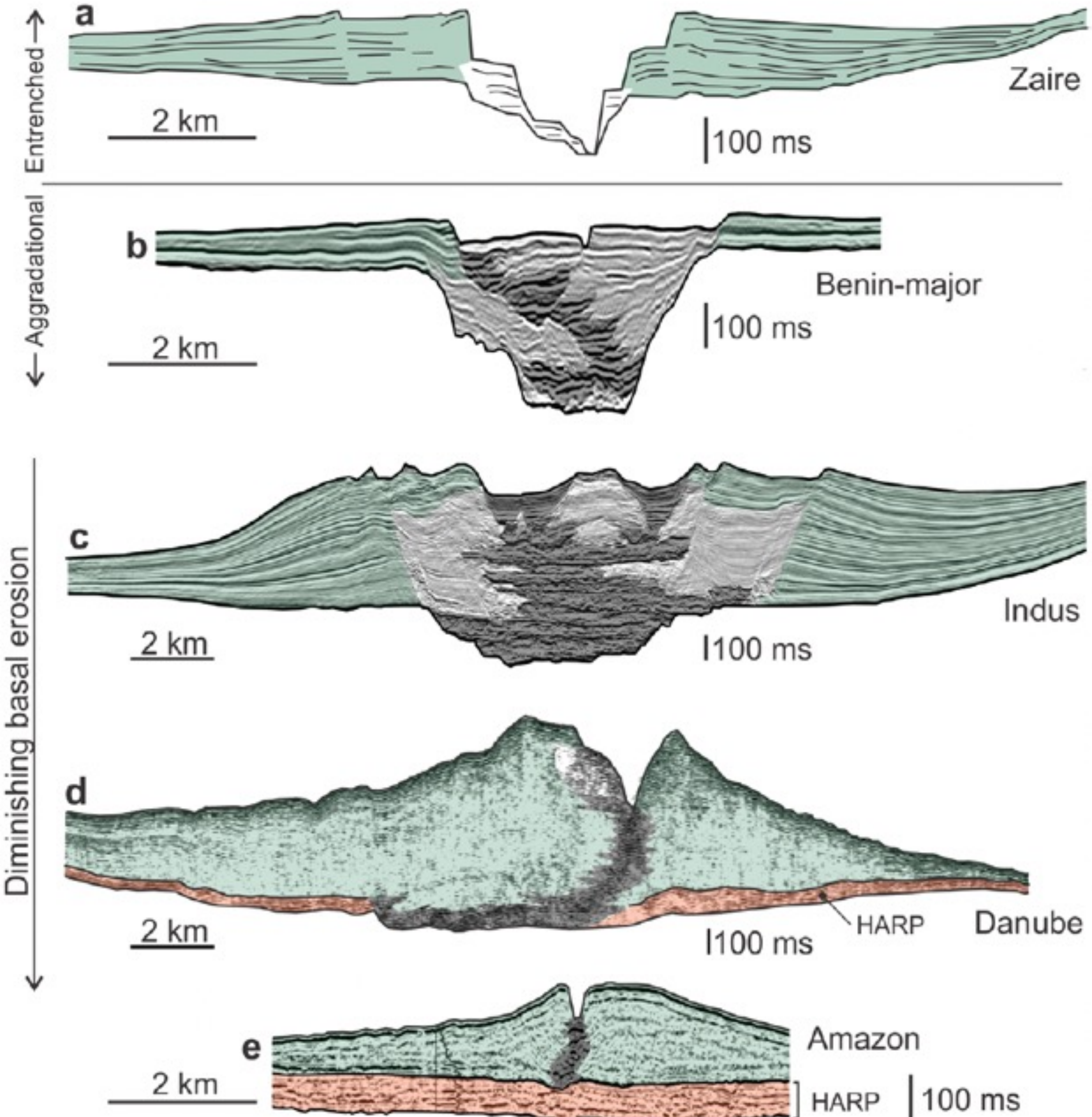




C- Hecho Basin with Boltaña anticline separating lobes from channels; D- Longitudinal section showing hydrodynamic control by sediment bypass zone;

Stow and Mayall (2000).

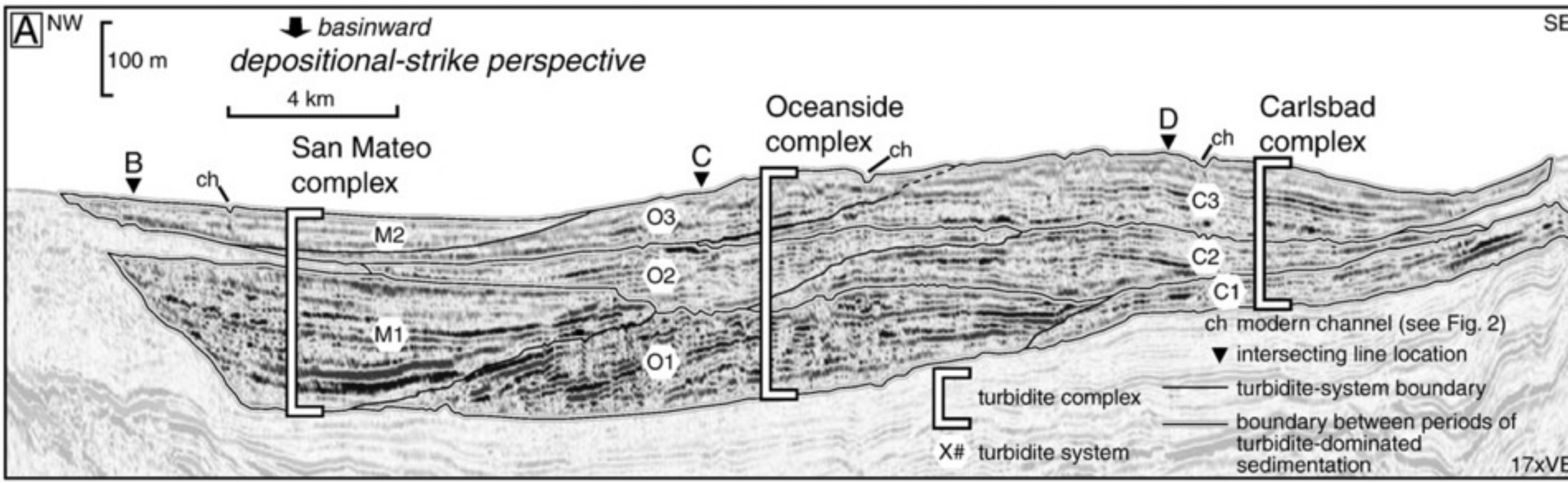




Deptuck & Sylvester, 2018. Submarine Fans and their channels, levees, and lobes. In: Submarine Geomorphology, Springer.

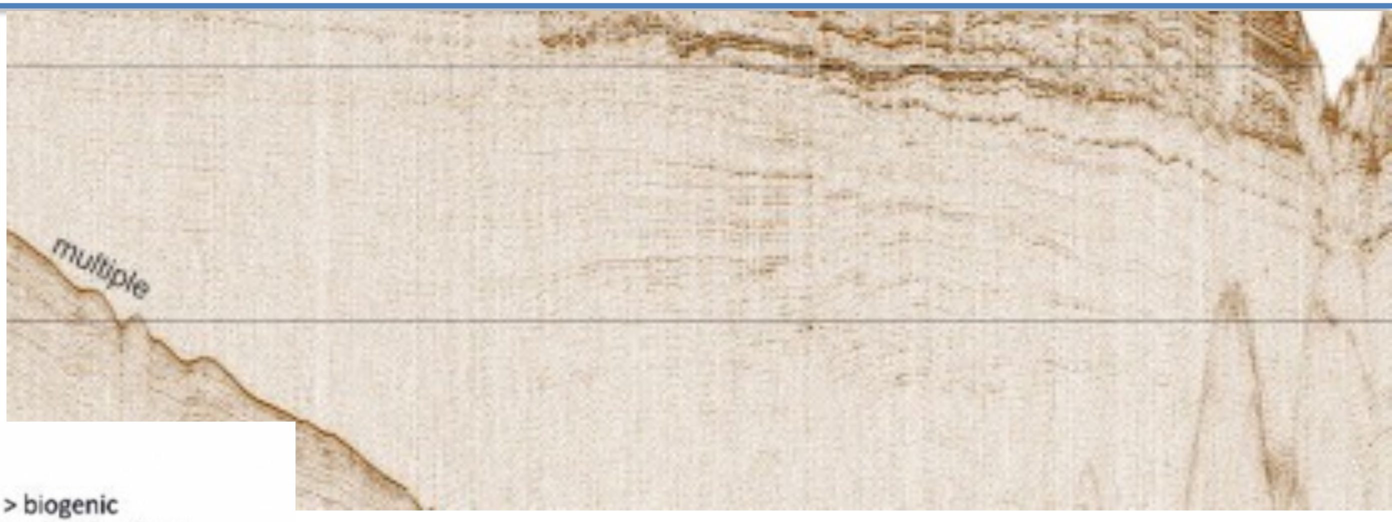
Architectural variations in long-lived channel-levee systems (CLS). Inner levees=light grey; outer levee deposits=green; channel deposits=dark grey; avulsion-related lobe deposits (HARPs - ‘high amplitude reflection packages’)=orange.

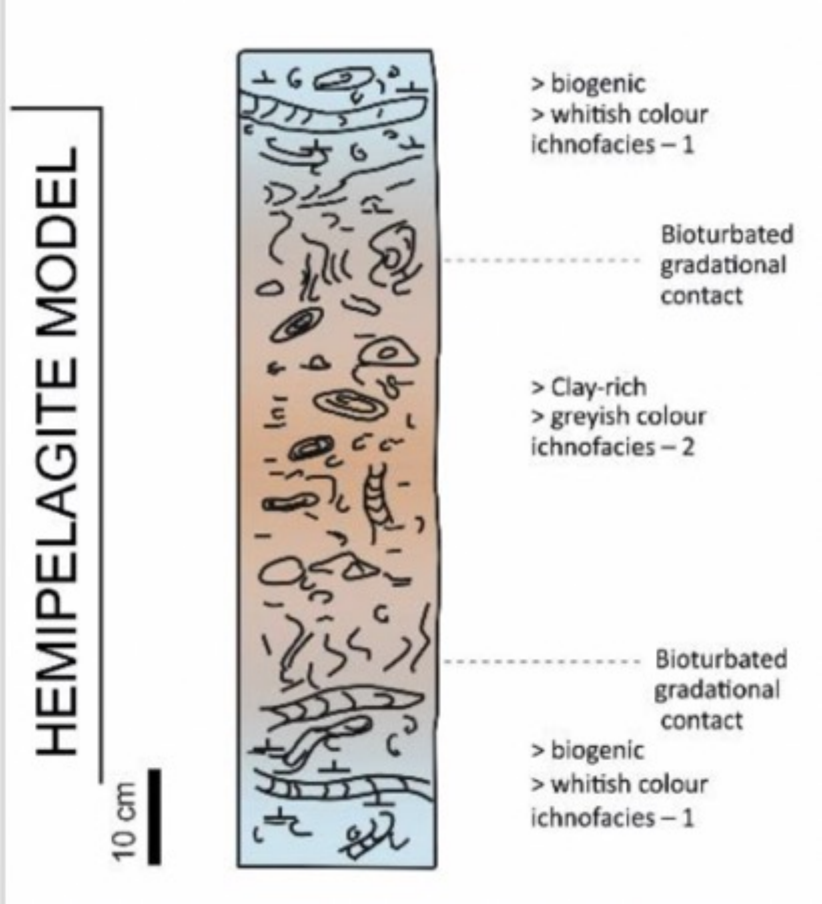
Covault & Romans (2009), Growth patterns of deep-sea fans revisited: Turbidite-system morphology in confined basins, e axamples from the California Borderland. Marine Geology 265, 51–66



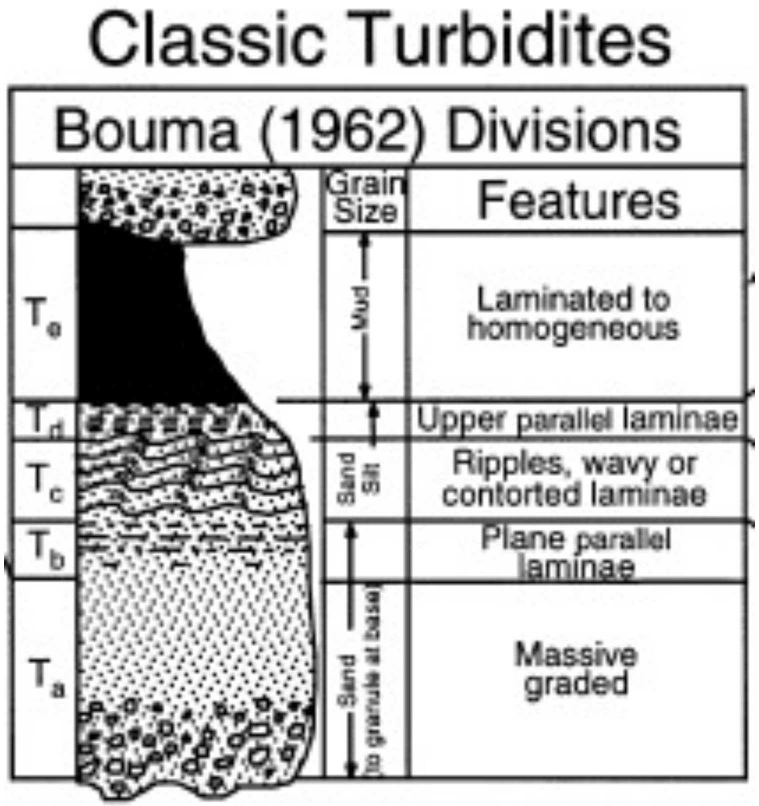
Depositional-strike seismic-reflection profile showing turbidite complexes and component systems in the southeastern Gulf of Santa Catalina.

Depositional environments (synthesis)

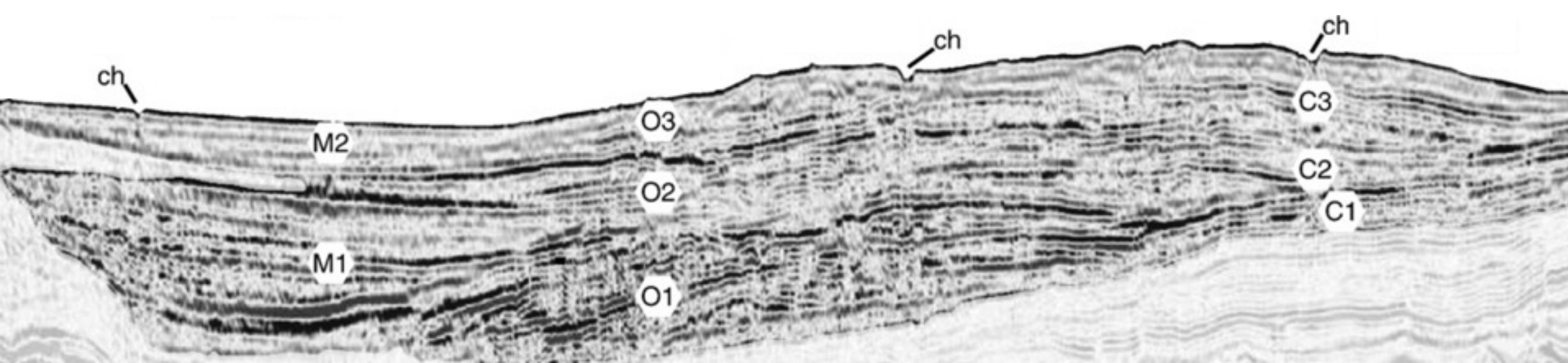




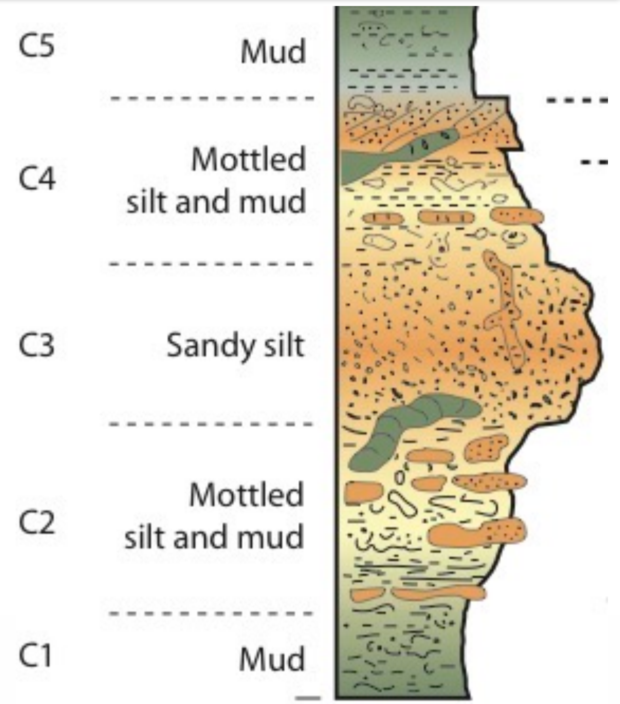
Abyssal plains

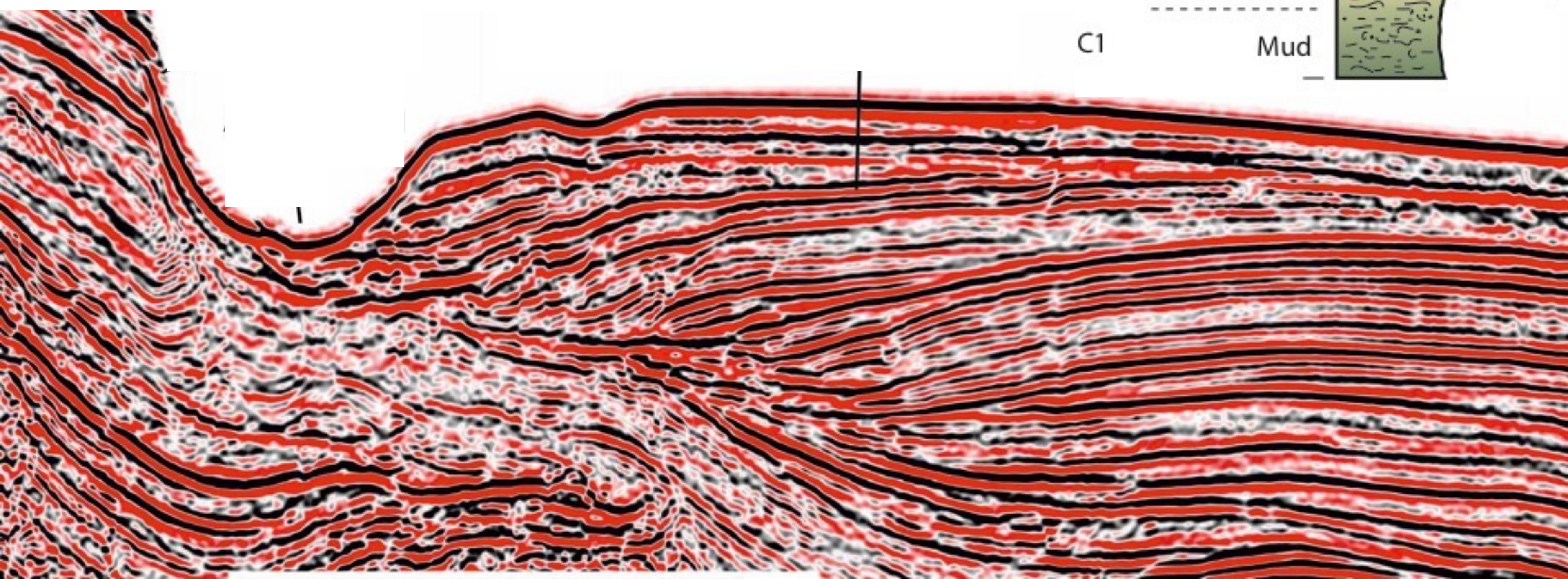


Submarine fans

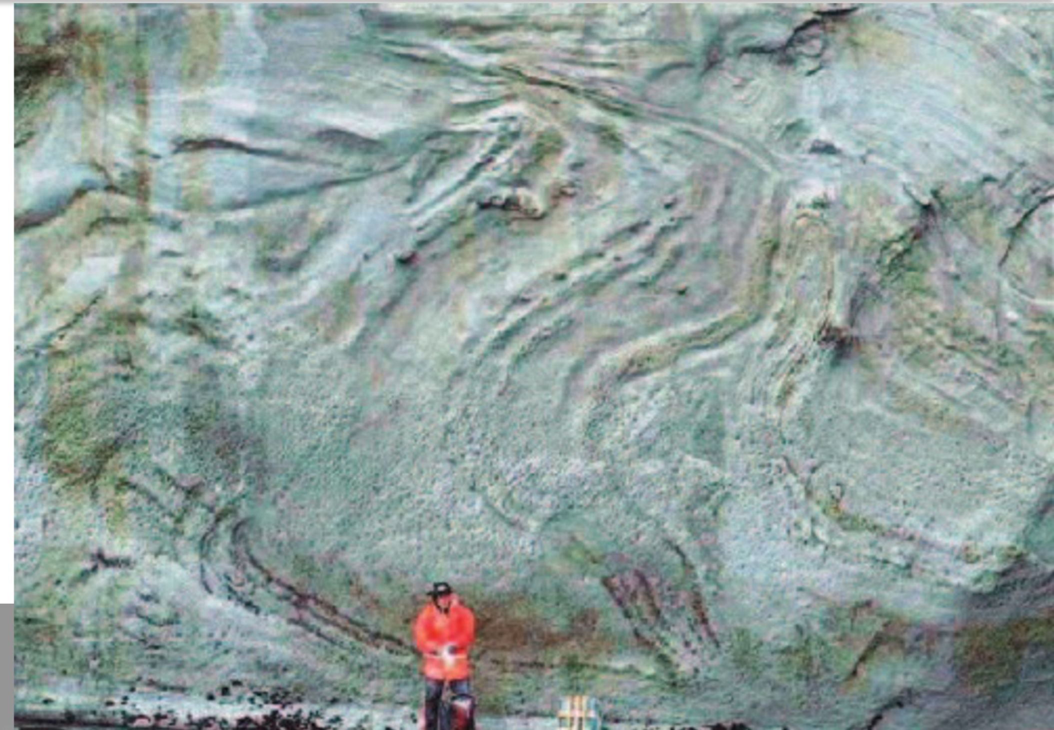


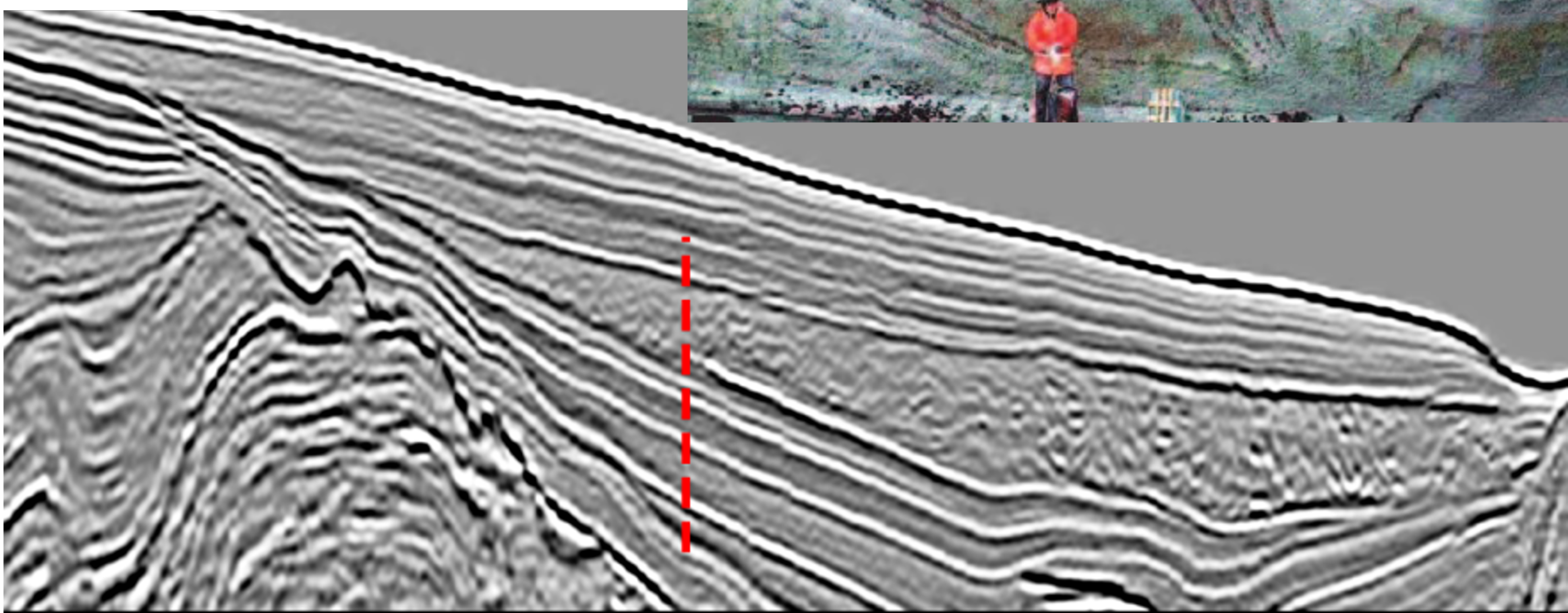
Contourites



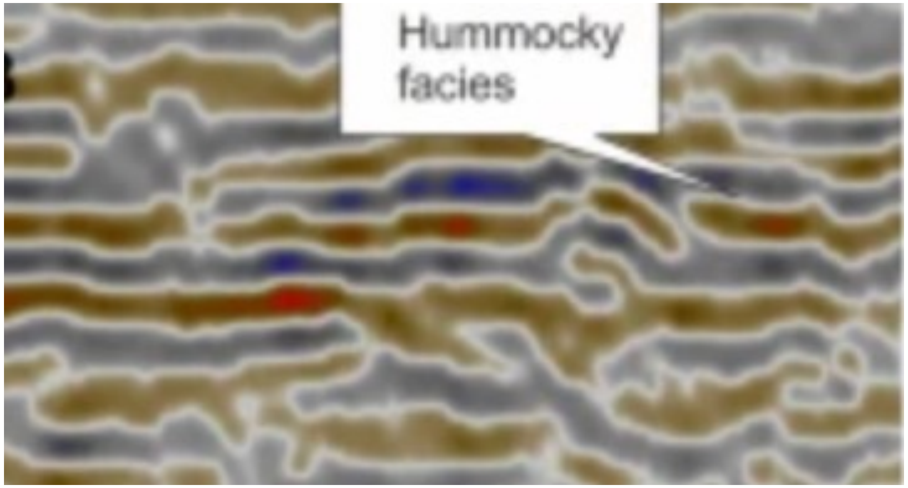


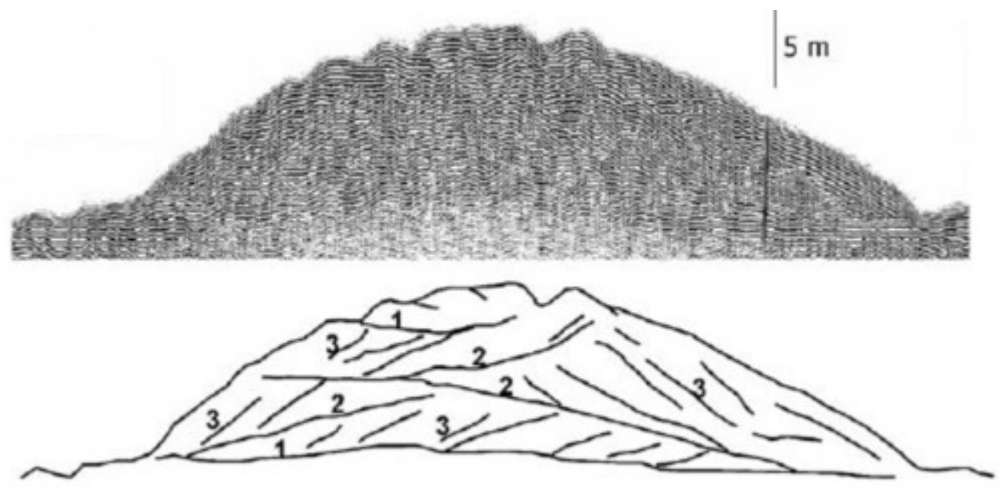
Mass Transport Deposits



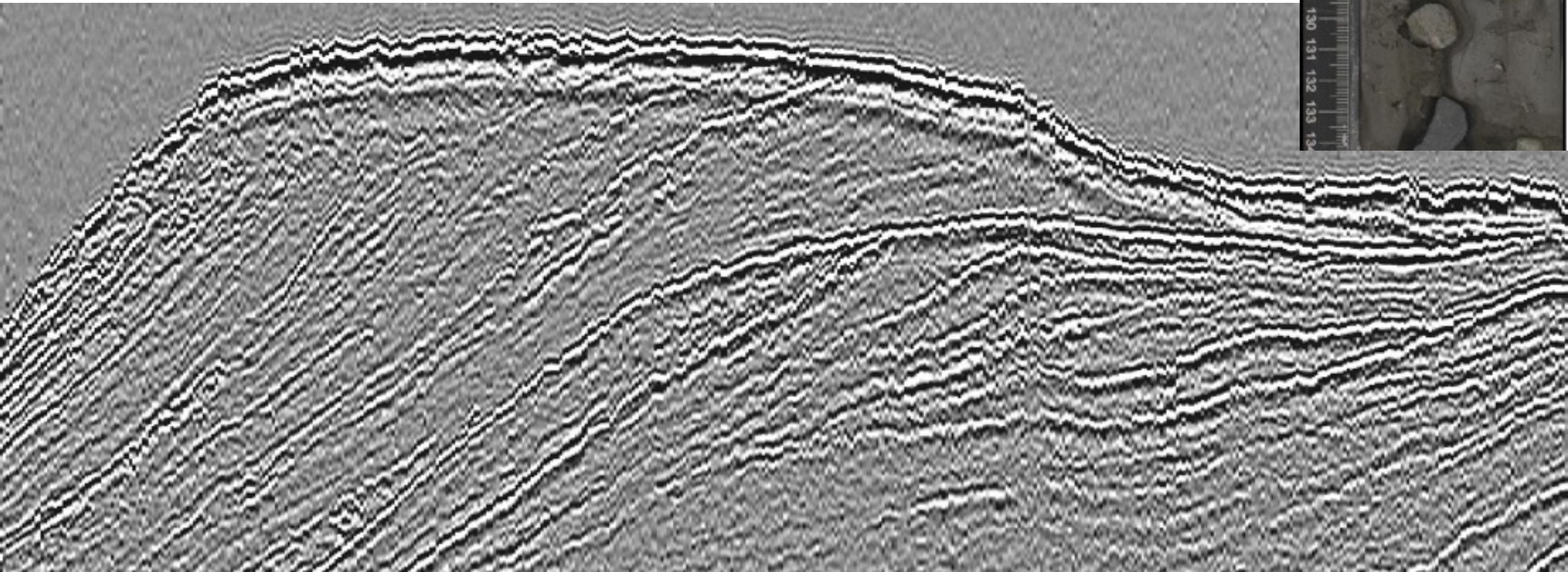


Continental shelves

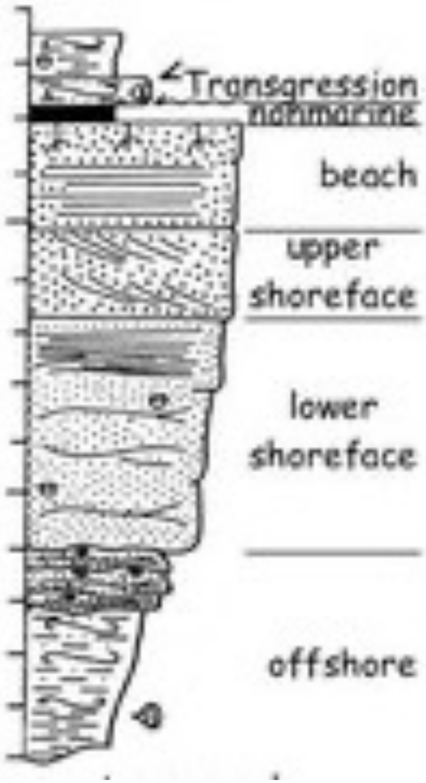


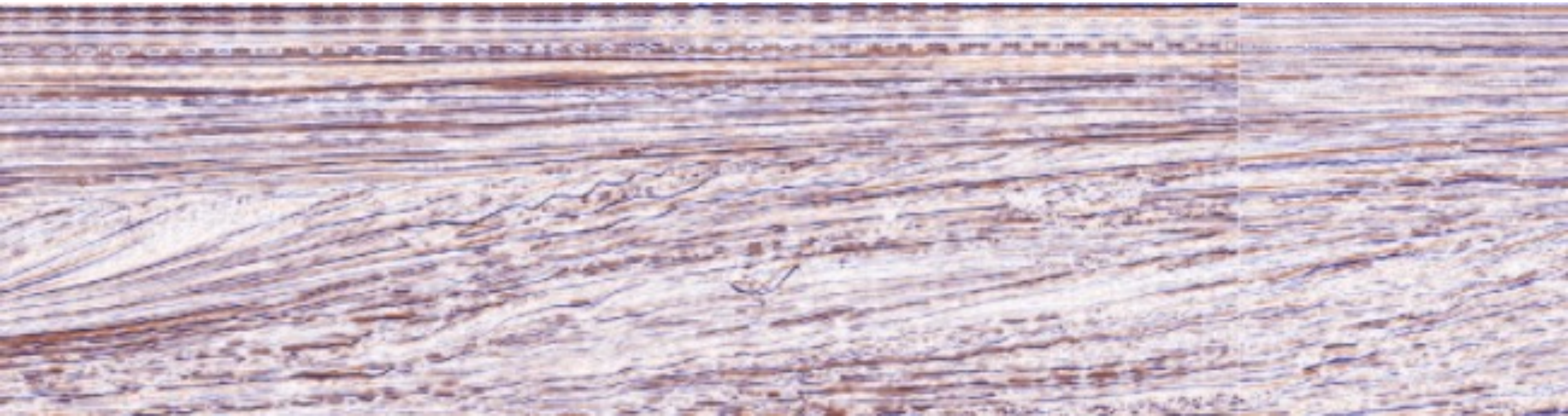


Glacial systems

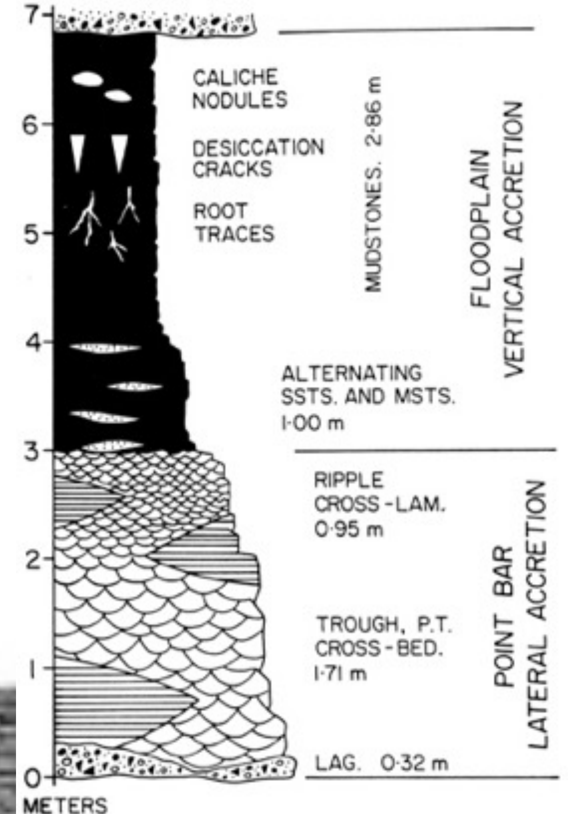


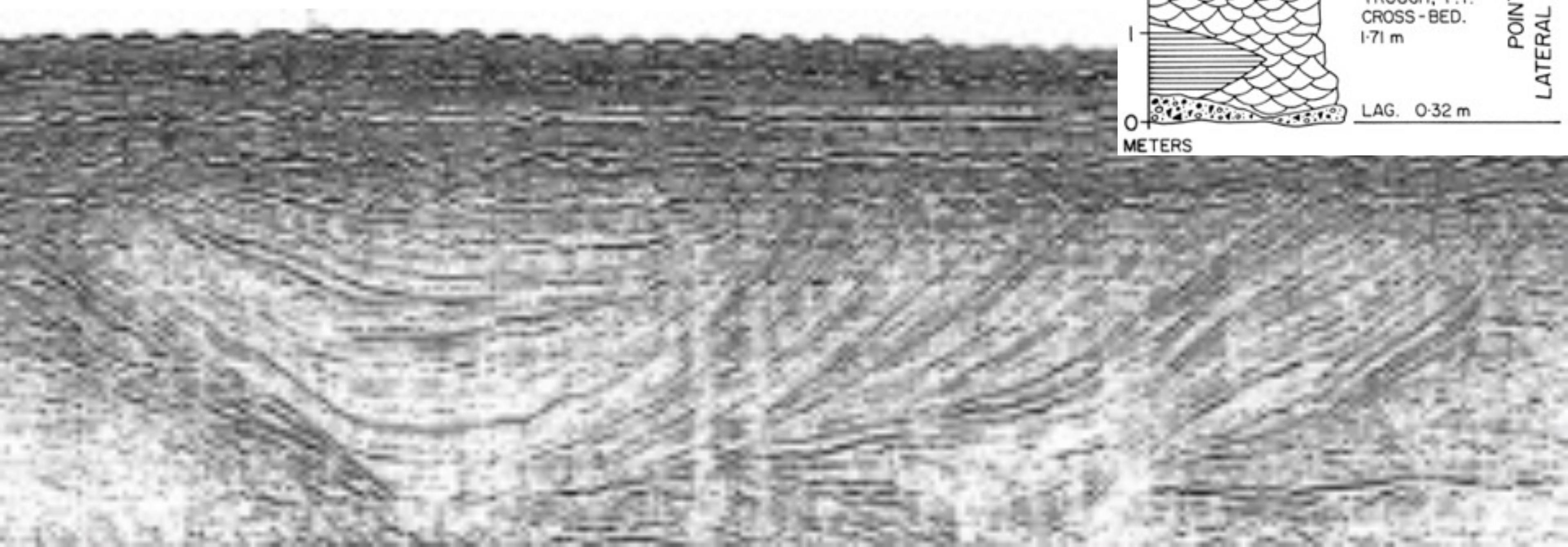
Barrier islands



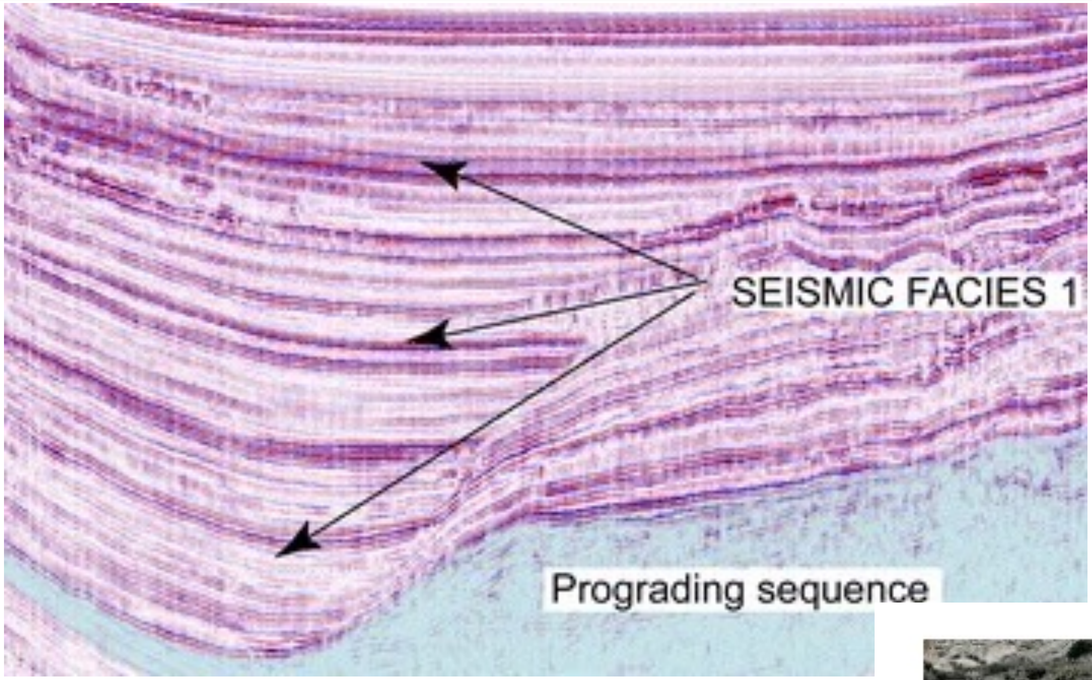


Fluvial deposits

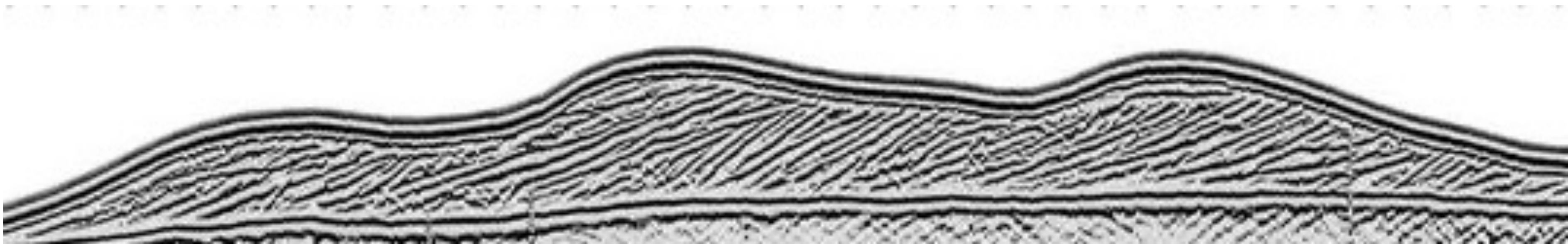




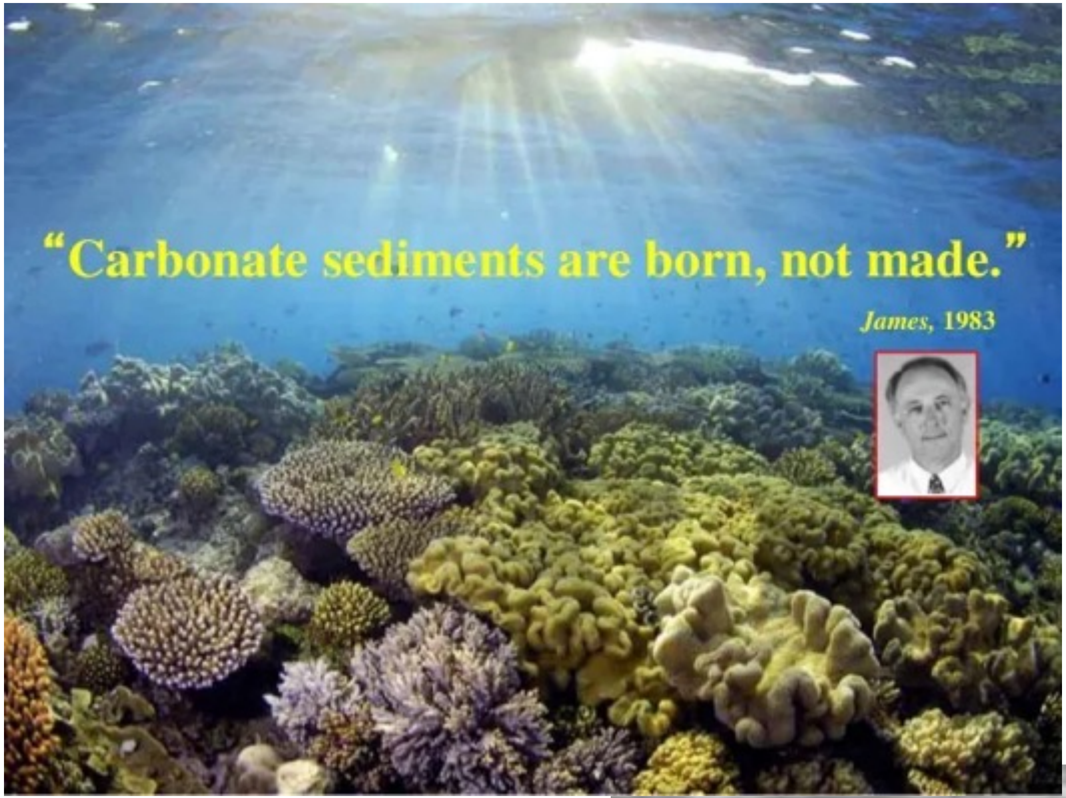
Lakes

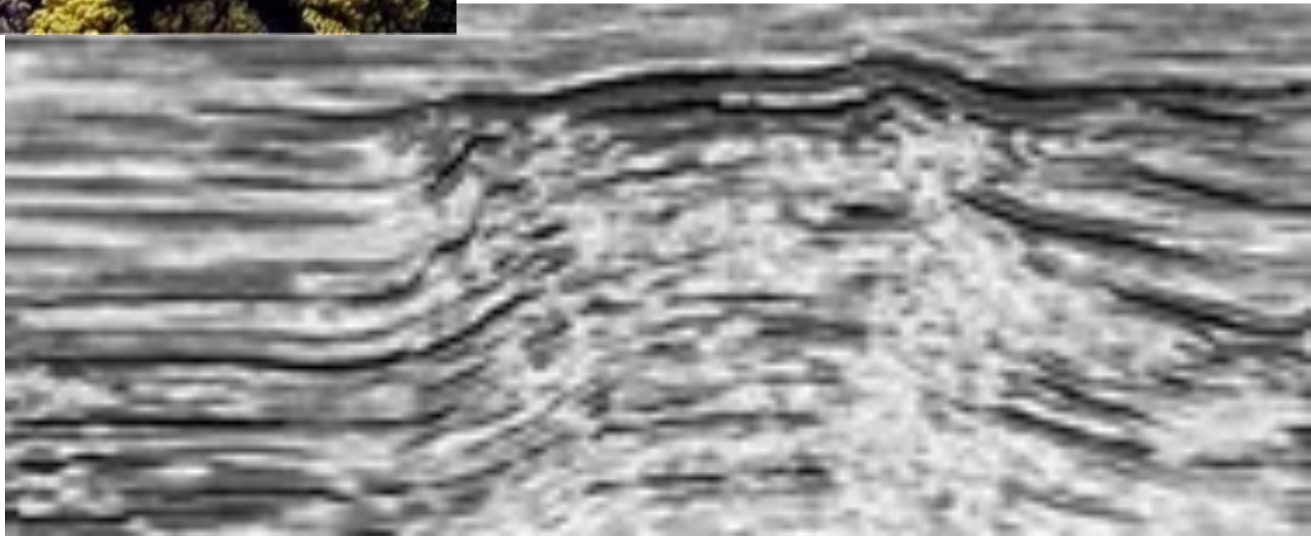


Aeolian dunes

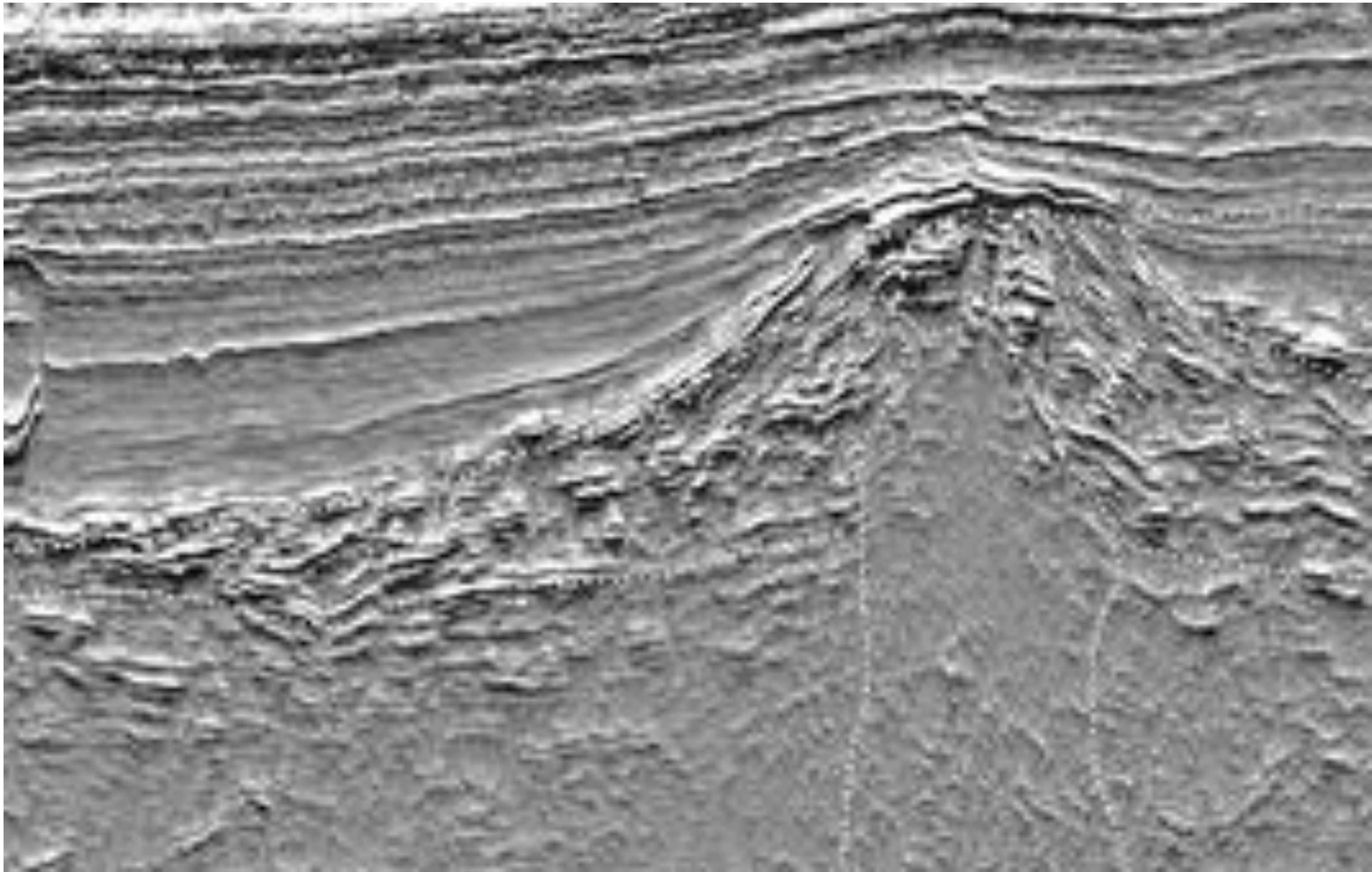


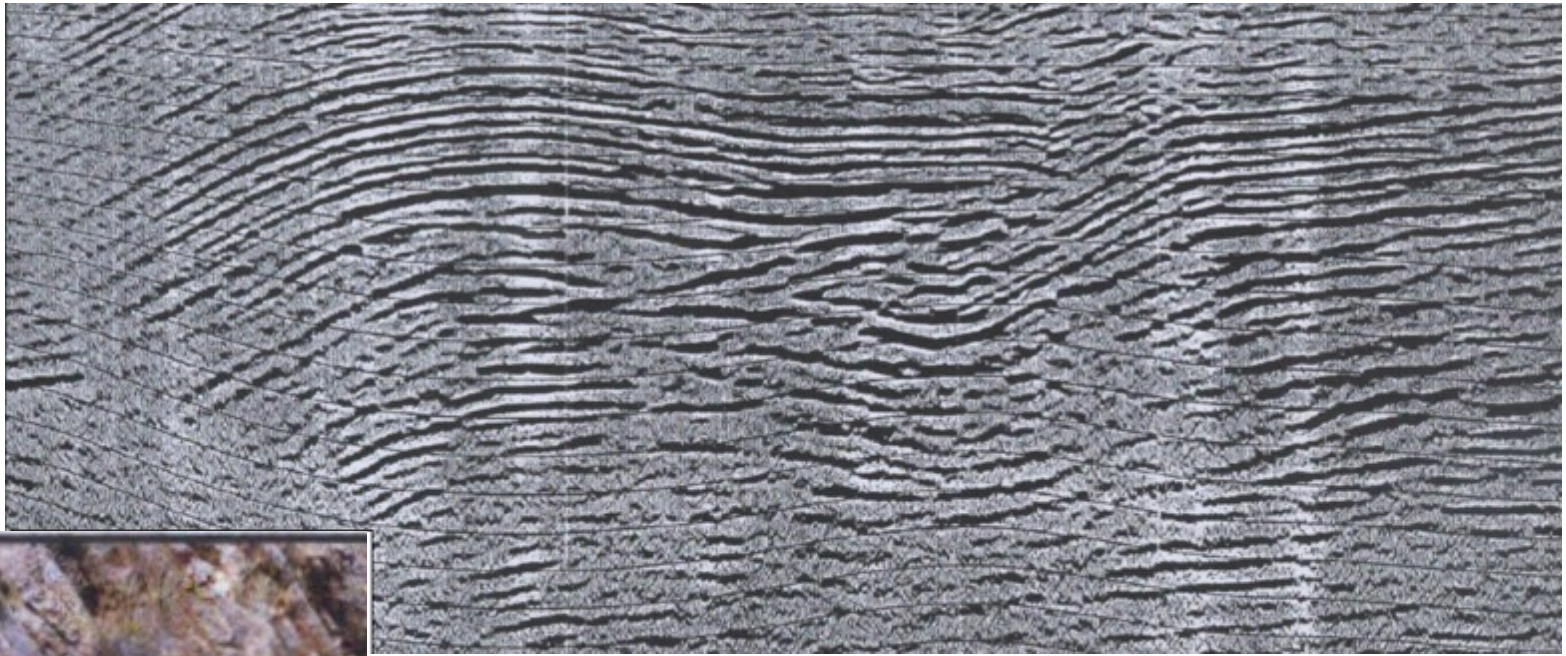
Carbonates





Volcanoes





Faults

Istituto Nazionale di Oceanografia e di Geofisica Sperimentale

Sedimentary environments (Synthesis)
All generalizations are false, this one included

Environment	**Sedim. Struct.**	**Seismics**
pianure abissali	indistinct bedding	low ampl. subparallel comformab.
Conoidi sottomarine	Bouma sequence	onlapping/filling terminations
Contourites	bioturbation	sediment drifts
Mass transport deposits	deformation structures	transparent/chaotic
Piattaforme continentali	hummocky/mud couplets	hummocky/tidal dunes
Sistemi polari	deforming till	trough-Mouth Fans
Sistema di barriera	sand ridges	clinoforms
Depositi alluvionali	trough X-strat	lateral accretion packages
Laghi	varves	well stratified subparallel deposits
deserti	high angle foresets	thick sets of cross-stratification
ambienti carbonartici	cemented deposits	build-up
Faglie	fratture	fault cutoffs
vulcani	pyroclastic deposits	cones and craters

Istituto Nazionale di Oceanografia e di Geofisica Sperimentale

Modulo	Argomento	Docente	Data
1.1	introduzione al corso e argomenti	Rebesco	05/10/21
1.2	metodi (geofisica, affioramenti, geologia marina, ambienti attuali)	Volpi/Rebesco	06/10/21
1.3	meccanismi di formazione dei bacini (geodinamica, tettonica…)	Lodolo	12/10/21
1.4	Interpretazione sismica, facies e strutture primarie	Rebesco	13/10/21
6.1	visita a Rompighiaccio Laura Bassi (assieme a Geologia Marina)	Rebesco	15/10/22
	Martedì 19 Ottobre non c'è lezione		
1.5	Energy storage e CCS	Volpi/Donda	20/10/21
2.1	Processi sedimentari nei fiumi e nei delta	Rebesco	26/10/21
2.2	Azione di maree e onde, del ghiaccio e del vento	Rebesco	27/10/21
	Martedì 2 Novembre non c'è lezione		
	Mercoledì 3 Novembre non c'è lezione		
2.3	Correnti di densità e correnti di fondo, trasporto di massa	Lucchi/Rebesco	09/11/21
3.1	pianure abissali (decantazione emipelagica) e margini continentali	Rebesco	10/11/21
3.2	Conoidi sottomarine (flussi gravitativi dalla scarpata continentale)	Lucchi/Rebesco	16/11/21
3.3	Sediment drifts (correnti di fondo lungo la scarpata continentale)	Rebesco	17/11/21
3.4	Mass transport deposits (accenni a risoluzione/penetrazione)	Ford	23/11/21
3.5	Piattaforme continentali (onde, tempeste, tsunami)	Rebesco	24/11/21
3.6	Sistemi deposizionali in ambiente polare	De Santis	30/11/21
3.7	Sistema di barriera	Rebesco	01/12/21
3.8	Depositi alluvionali	Rebesco	07/12/21
	Mercoledì 8 e martedì 14 Dicembre non c'è lezione		
3.9	Laghi, deserti e ambienti carbonartici	Rebesco	15/12/21
3.10	faglie, vulcani e approfondimento conoidi	Rebesco	21/12/21
4.1	stratigrafia sequenziale: Discontinuità, system tracts, modelli	Rebesco	22/12/21
	Dal 23 Dicembre al 9 Gennaio non c'è lezione		
4.2	livello del mare e spazio di accomodamento	Rebesco	11/01/22
4.3	applicazioni (es. reservoirs di idrocarburi)	Rebesco	12/01/22
5	esercitazione	Rebesco	18/12/21
6.2	visita a CoreLoggingLAB e/o SEISLAB (assieme a Geologia Marina)	Rebesco	19/01/22