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	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

Modulo 3.9
Lacustrine, aeolian and carbonate deposits

Outline:

- Lacuatrine sediments
  - Seismic example
- Aeolian sediments
  - Seismic example
- Carbonate sediments
  - Seismic example

Lacustrine sediments

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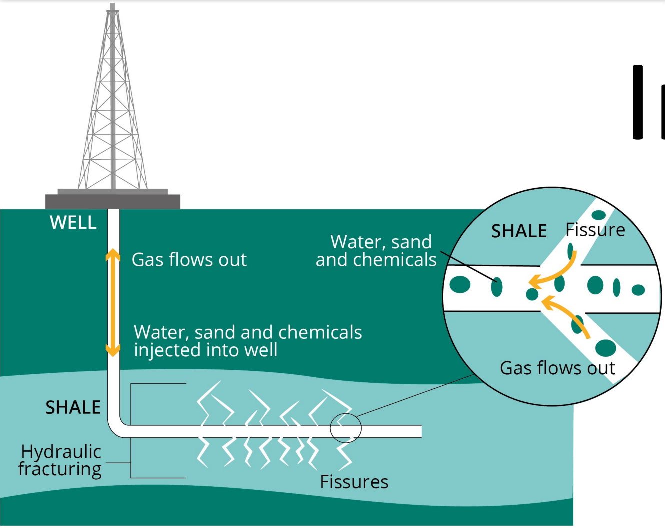
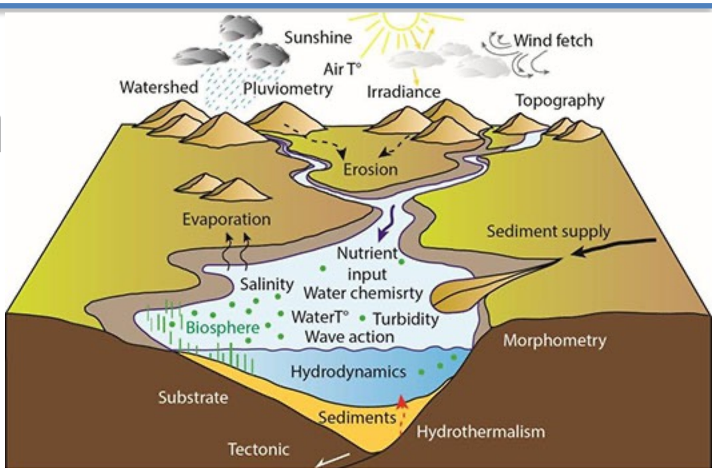
West Virginia University

Introduction





Lacustrine deposits are important, but relatively understudied terrestrial depositional environments. The discovery of large shale gas reservoirs in lacustrine systems and the development of hydraulic fracturing (fracking) has led to a renewed interest in exploring the lacustrine systems. Oxygen depleted waters near the base of lakes can preserve and breakdown organic material, creating oil shale's that serve as common source rocks in reservoirs.

Lacustrine deposits are often confused with marine deposits due to similar lithologies. The main distinguishing feature between lacustrine and marine systems is differences in sedimentary structures. Lakes have little wave/storm action, so lacustrine deposits are typically laminated shale/ mudstones deposited with limited sedimentary structures.
Because lakes are typically not influenced by eustatic sea level rise, lakes tend to shallow and coarsen upward with time. Lake systems also experience seasonal alterations in sediment infill. Lacustrine and marine systems can also be separated based on fossil assemblages.

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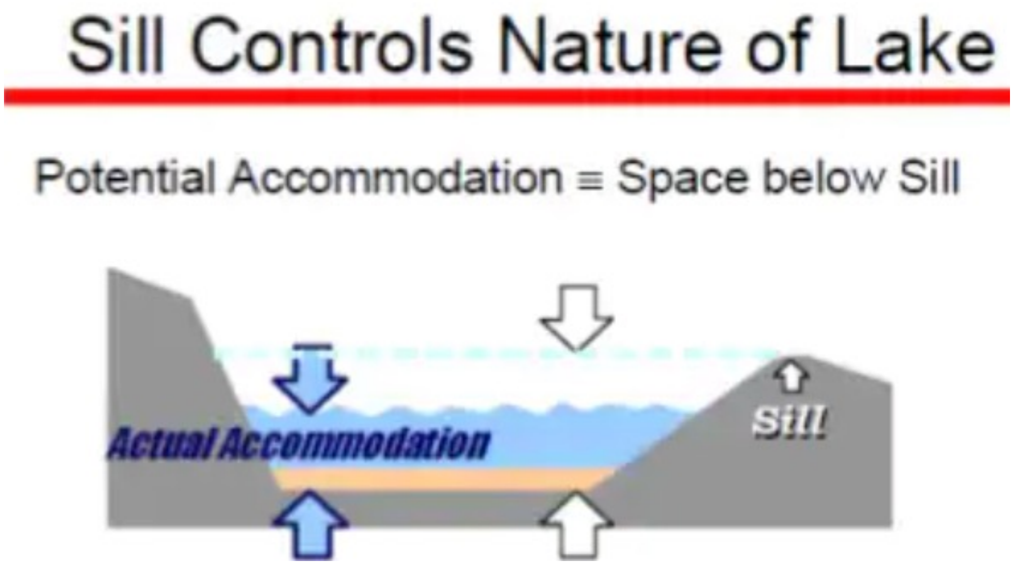
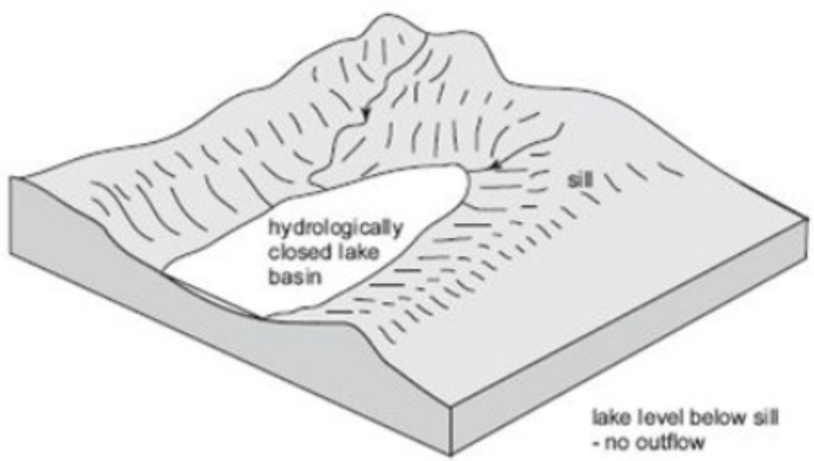
Geomorphology and Modern Analog

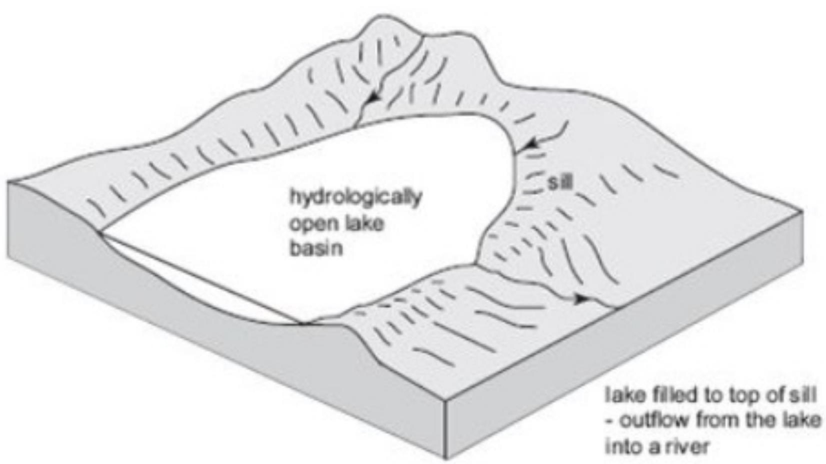
Lacustrine systems can form in a variety of settings. Large lakes may form in areas with sufficient accommodation space and inflow of water. Accommodation space is required in a closed system to trap water and sediment. Accommodation spaces typically include tectonic depressions, glacial depression, calderas, and karst sinkholes.

The barrier are called sills. If the lake level is above the sill, the lake is called open and overflow will be common. If the lake level is below the sill, water and sediment will be trapped behind the sill, and evaporation/dessication will occur if more water is not introduced into the system. Common features of a lake system include a fluvial system bringing water into the lake, a delta where sediment is deposited, and a deep lacustrine system where fine muds are deposited.



Lake Classification





Lacustrine systems can be classified as open or closed lakes.

Open lake systems input and output water and sediment from rivers, ground water, or other lakes. Open lake systems are freshwater and typically form stratified, organic rich shales. Clast dominated lakes often form in open systems due to influx of sediment and water from rivers. Clast dominated lakes are mud dominated in the center, and sand/cobble dominated near the beach.

Closed lake systems do not recieve, or output sediment and water. Water can be either fresh or saline with lithologies including organic-rich shales, carbonates, and evaporites. Closed lake systems can often form saline lake systems. Closed lake systems tend to be evaporate and carbonate rich due to precipitation and little influx of water sedimentation.

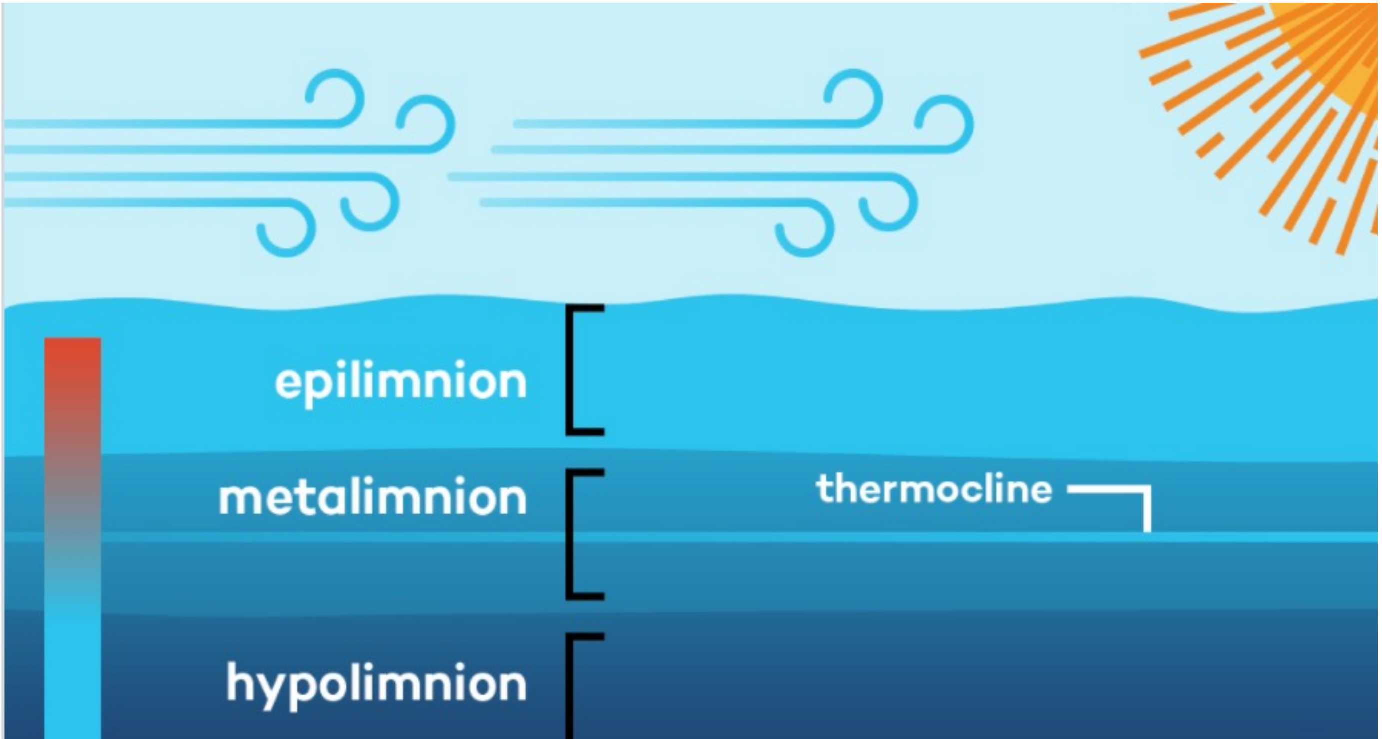
Modern Example: Crater Lake

Crater Lake, Oregon, formed in the collapsed cadera after the Mazama eruption 7,700 years ago. Following the eruption, the magma chamber was drained and the mountain collapsed. The caldera is over 5 miles in diameter, and the caldera is 600 m deep, making it one of the deepest lakes in North America. The Caldera infilled with rain water and snow melt. The Lake is a closed system, with no inflow from other rivers. Water enters the lake through precipitation and flow through rocks, and leaves through evaporation.

Due to the lack of river channels entering the basin, sedimentation is limited. Sedimentation is mainly derived from mass wasting deposits of volcanic rocks on the side. Pelagic sediments can also ooze out. Fine grained deposits of mud and sand can be transported by wind, or eroded by the edges. The bottom of the basin is composed of small volcanoes, while the sides are composed of colluvial deposits near the edge of the crater.

Stratification

Temperature stratification forms due to the higher density of hot fluids. The Epilimnion is the top of the lake, which is oxygenated. The middle layer is the Metalimnion, which contains the thermocline. The bottom is the Hypolimnion, which is anoxoic, cold water. The colder water will typically be trapped on the bottom, while hotter water will be trapped above the thermocline. Very fine sediment can be trapped above the thermocline boundary. Stratification can also occur due to salinity, with more saline water trapped under less saline water (hylocine).



Oxygen-rich water will be trapped on the upper surfaces of water, while oxygen-depleted water will be closer to the bottom. The anoxic conditions at the bottom of lakes will preserve organic matter and create kerogen rich shales that are common source rocks.

Streamflow and Waves/shore processes

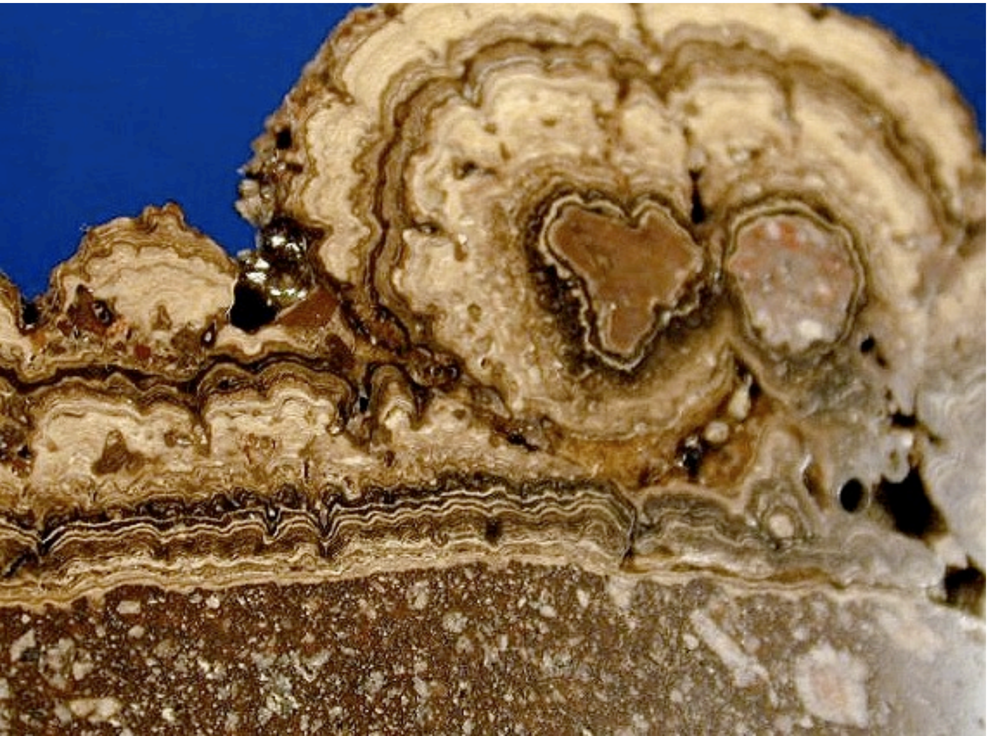
Inflowing streams will disrupt pre-exisiting stratification. In overflow, water will float above the thermocline. If the water is cold and dense enough, it can sink to the bottom in underflows. Cold water will also drag sediment down with it, creating small scale turbitide deposits. Stream flow varies seasonably. Melting of snow melt will introduce high discharge of cold water into lacustrine systems. Stream flow will often deposit the coarsest sediment near the margin in deltatic deposits, with finer material deposited offshore.

Waves are low intensity compared to oceans. There are no tides in lakes, although lake level can transgressive/regressive as water level changes. Wave action will rework sediment, creating small climbing ripplies. Hummocky cross stratification is common in storm influenced settings.

An example of stratified mud deposits that are the most common features in lacustrine systems

Groundwater and Chemistry

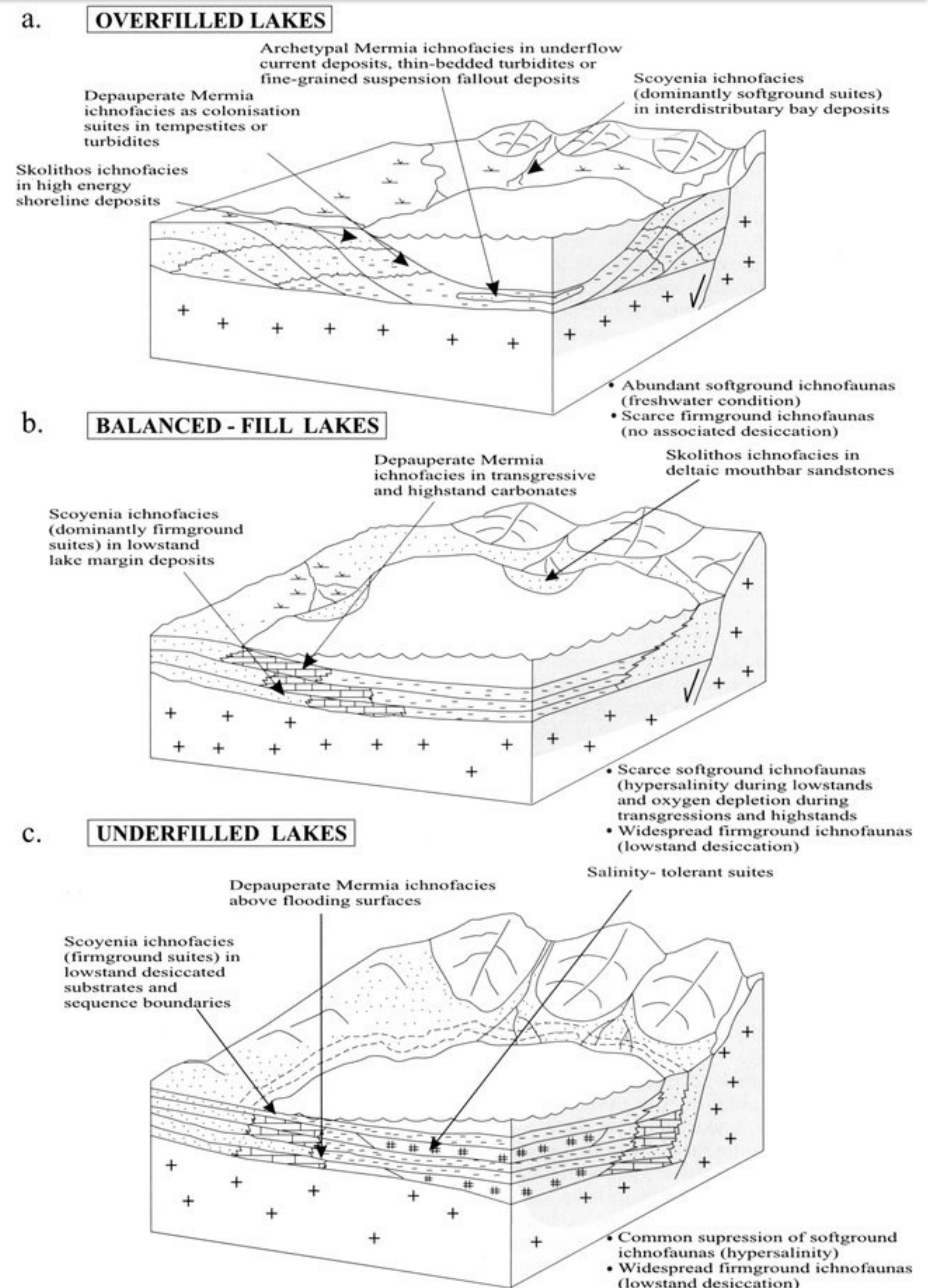
Groundwater is discharged into lacustrine systems through springs. In arid regions, influx of water may be entirely through ground water. Ground water influx into lakes occurs mainly on the sandier margins. Ground water cannot penetrate through the deeper, muddier shale on the bottom due to its low permeability. Evaporate and carbonate minerals will precipitate on the margin where ground water inflows/outflows from lakes, and these are often distinguishing features of arid lakes in the rock record.



Chemical sediment can predominate in lacustrine systems, producing carbonate and evaporate deposits with salinities higher then oceans (see acid-saline lakes). Precipitation of lacustrine carbonates can also occur due to fluctuations in pH. Carbonate ions are derived from surrounding limestones. Typical carbonate lacustrine sediments are called oncolites.

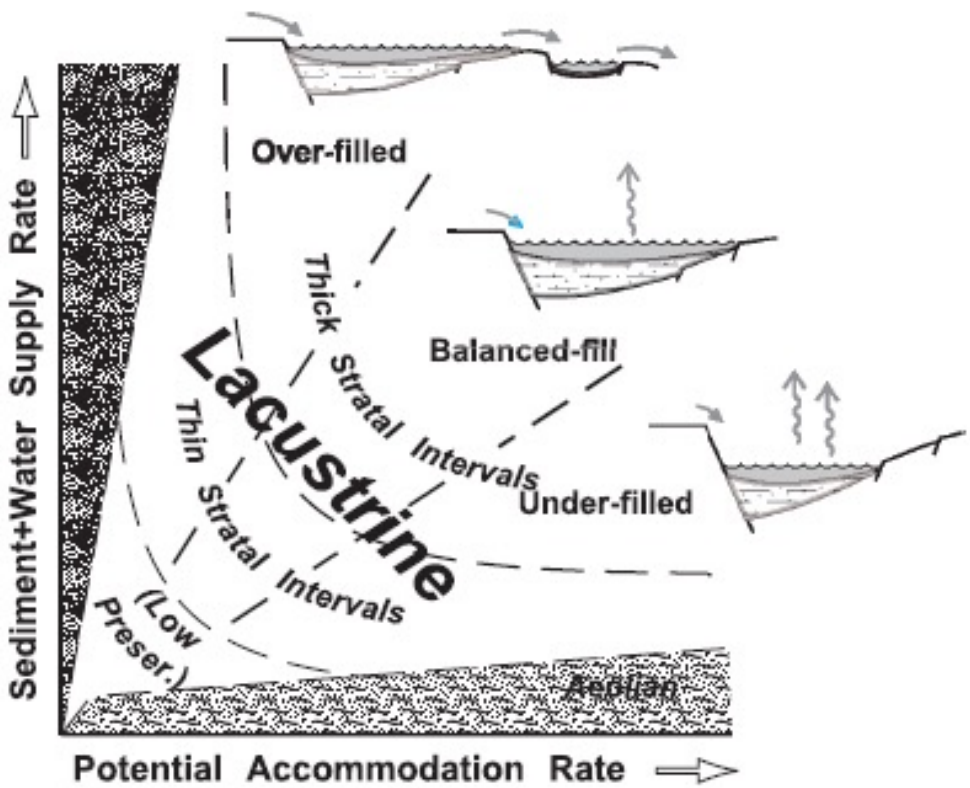
Accomodation space

If accommodation space increases faster then water-sediment infill rate, the basin will be **underfilled** and will typically contain evaporate and lacustrine carbonate precipitated minerals. In **balanced** basins, sediment water inflow into and out of the the basin matches the accommodation space. With high sediment-water influx into the basin vs little accommodation space, the basin will **overflow**.



Controls on Depositional System Evolution

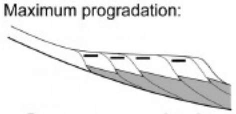
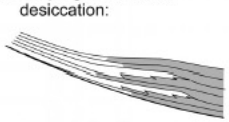
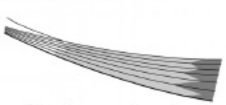
Accommodation space is typically created through **tectonic** processes. Rift basins commonly result in graben or half graben structures. Collision can also create create accommodation space by flexure. The foreland basin can often fill with sediment and the forebuldge will serve as the sill. Cratonic sag can occur in old dense, crust forming intracratonic basins.



Changes in **climate** will influence the amount of material that enters or leaves a lake basin. If climate is arid, the influx of water into the basin will decrease, causing lake level to drop and mineral formation will dominate. If the climate is wet, increased volumes of sediment and water may enter the basin, overfilling it. High discharge sedimentary structures can also form, such as ripple marks. Storms may create hummocky cross stratification in the beach deposits.

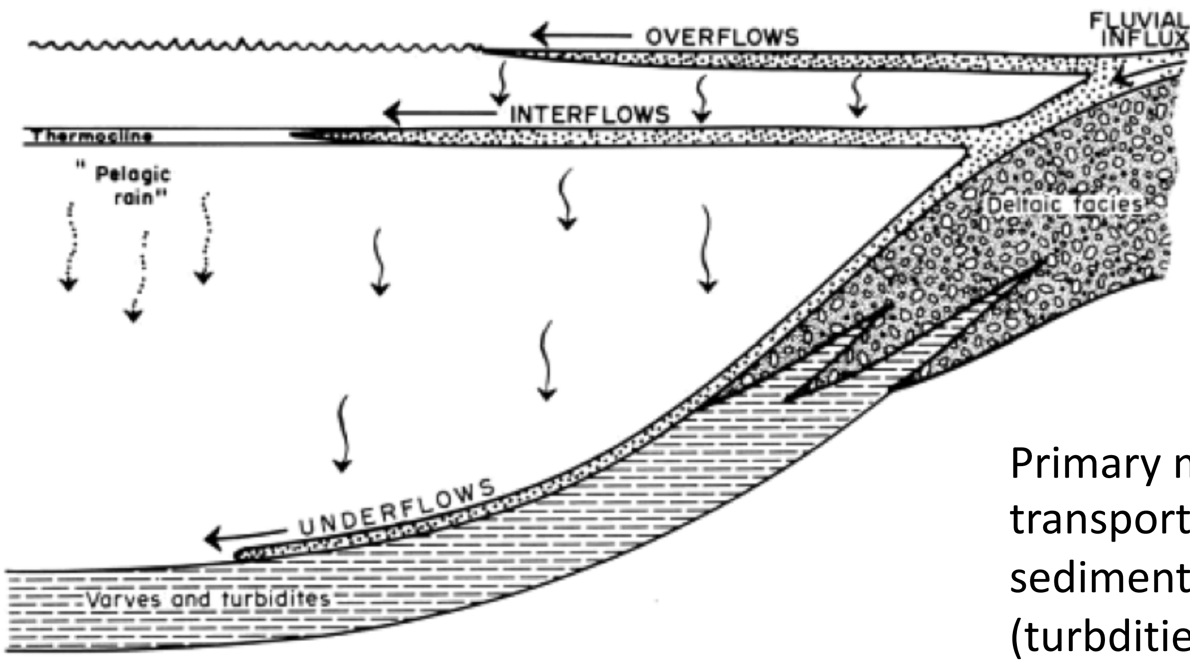
Facies related to inflow and outflow of water

In a **overfilled lake**, there is progradation away from river to the lake margins. Parasequences develop related to alterations in fluvial input and water level. Sedimentary structures include ripples, dunes, and flat beds. Lithology can include sandstone, mudstone, coal, and limestone. In a system **where fluvial input is variable**, there are mixed episodes of progradation and dessiciation. These are expressed as distinct parasequences. Sedimentary structures are similar to the over filled lake basin, but include mudcracks, stromatolites, pisolites, and oncolites. Carbonates are more common.

Lacustrine facies association; lake basin type	Stratigraphy	Stratal stacking patterns	Sedimentary structures	Lithologies	Organic matter
Fluvial-lacustrine; overfilled lake basin	Maximum progradation:  ▪ Parasequences related to lateral progradation ▪ Maximum fluvial input	Dominantly progradation Indistinctly expressed parasequences	Physical transport: ripples, dunes, flat bed Root casts Burrows (in- and epi-faunal)	Mudstone, marl Sandstone Coquina Coal, coaly shale	Freshwater biota Land-plant, charo-phytic and aquatic algal OM Low to moderate TOC Terrigenous and algal biomarkers
Fluctuating profundal; balanced-fill lake basin	Mixed progradation and desiccation:  ▪ Distinct shoaling cycles common ▪ Fluvial input variable	Mixed progradation and aggradation Distinctly expressed parasequences	Physical and biogenic: flat bed, current, wave, and wind ripples; stromatolites, pisolites, oncolites Mudcracks Burrows (epifaunal)	Marl, mudstone Siltstone, sandstone Carbonate grain-stone, wackestone, micrite Kerogenite	Salinity tolerant biota Aquatic algal OM Minimal land plant Moderate to high TOC Algal biomarkers
Evaporative; underfilled lake basin	Maximum desiccation:  ▪ Closely spaced packages of wet-dry lithologies ▪ Minimum fluvial input	Dominantly aggradation Distinctly to indistinctly expressed parasequences	Physical, biogenic, and chemical: climbing current ripples, flat bed, stromatolites, displacive fabrics, cumulate textures	Mudstone, kerogenite Evaporite Siltstone, sandstone Grainstone, bound-stone, flat-pebble conglomerate	Low-diversity, halophytic biota Algal-bacterial OM Low to high TOC Hypersaline biomarkers

The third facies associated in the **evaporative underfilled lake** basin, which is a closed lake basin dominated by evaporation. Sedimentary structures include climbing current ripples, and dessiciation cracks. Lithology can include mudstone, evaporate, siltstone, sandstone, and carbonate minerals.

Depositional Processes and Depositional Facies



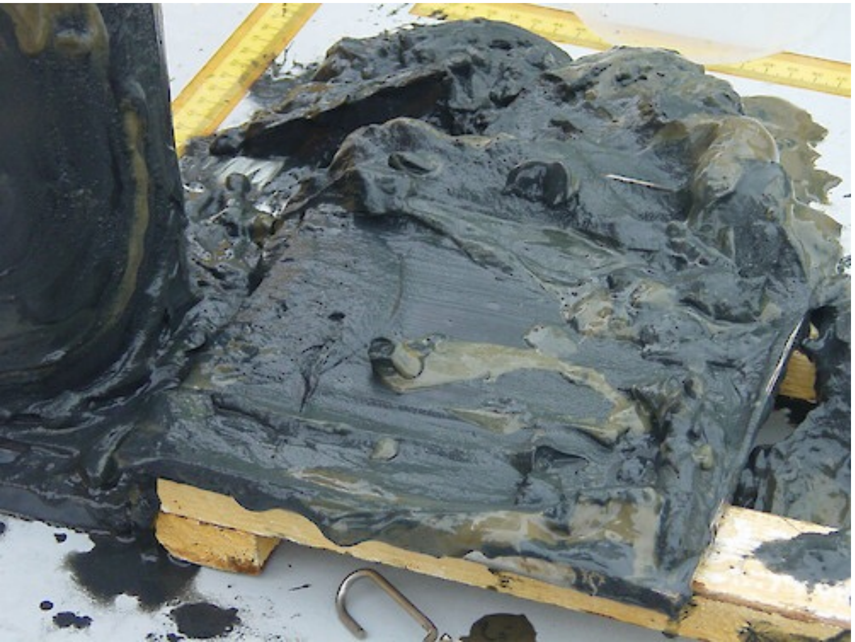
Model showing the main settings and sediment deposition patterns in a lacustrine system (Galloway and Hobday, 1993). Sediment originates from the fluvial channel, and is deposited in the fluvial delta, or in overflows/underflows. Overflows occur over the thermocline, while underflows occur under it.

Water infills lacustrine systems through rivers, rain, and groundwater, and will leave through similar methods or evaporation.

Primary mechanisms of sediment transport include wind blown sediment, gravity processes (turbdities), and river infow. The supply, ratio of water to sediment, influences lake fill. The facies of a lake changes with time, with evaporites in under filled lakes, fluctuating profundal in balanced fill lakes, and fluvial-lacustrine in over filled lakes.

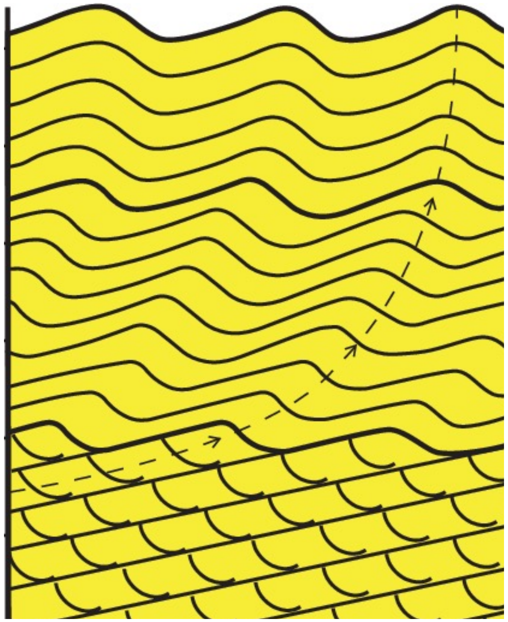
Depositional Facies

Facies associations with lacustrine systems are related to the main depositional processes.
Lacustrine Delta facies consist of delta deposits immediately adjacent to river inflow into the river. They typically contain a coarsening upward sequence, gilbertian foresets, and climbing ripples. Gilbert deltas consist of coarse grained, well bedded deposits. Turbitide sequences can be present down fan.
Wind tidal flat facies: Although lacustrine systems do not have tides, shoreline deposits do bear similarities to tidal shoreline deposits. Lake shorelines contain small diverse, small scale structures, including lenticular, wavy bedding, flasar bedding, mud drapes, and dessiciation cracks. There can also be bioturbation, including root and burrowing structures.



Deepwater facies: Typically flat, laminated shale and mudstone. High organic content due to anoxoic conditions.

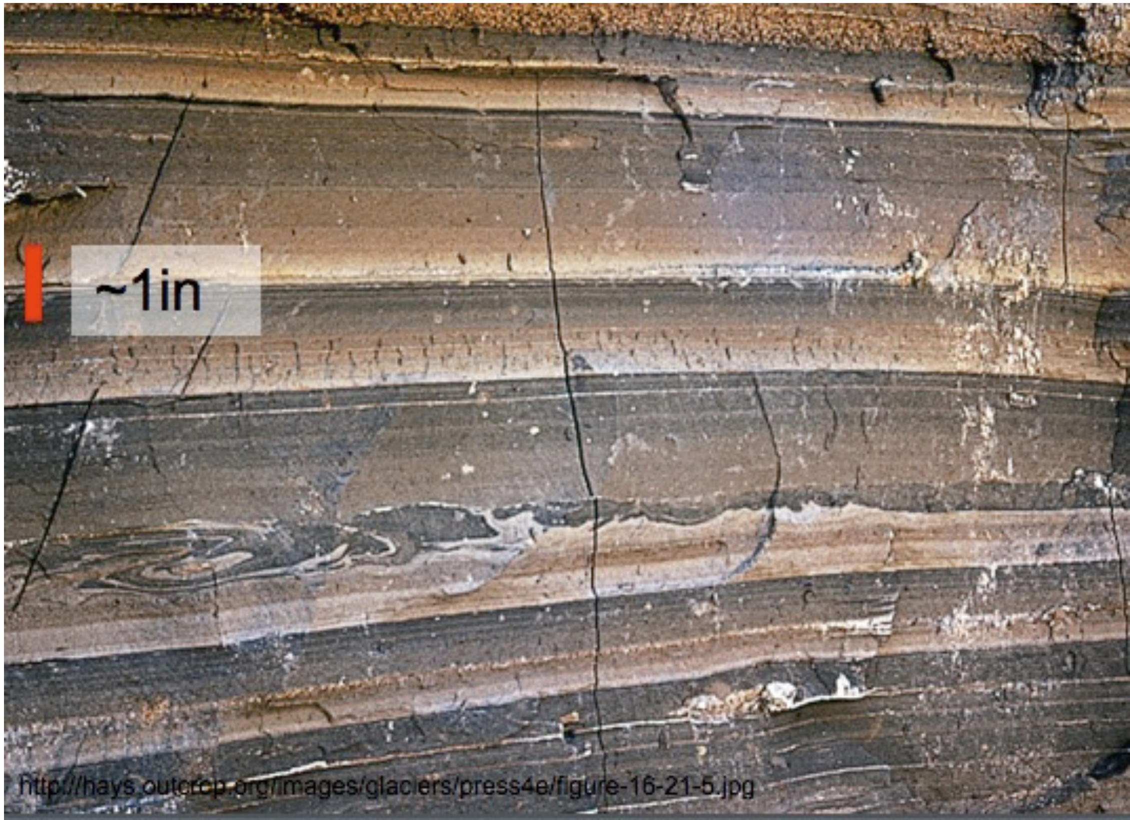
climbing ripples



What they generally have that oceans lack:

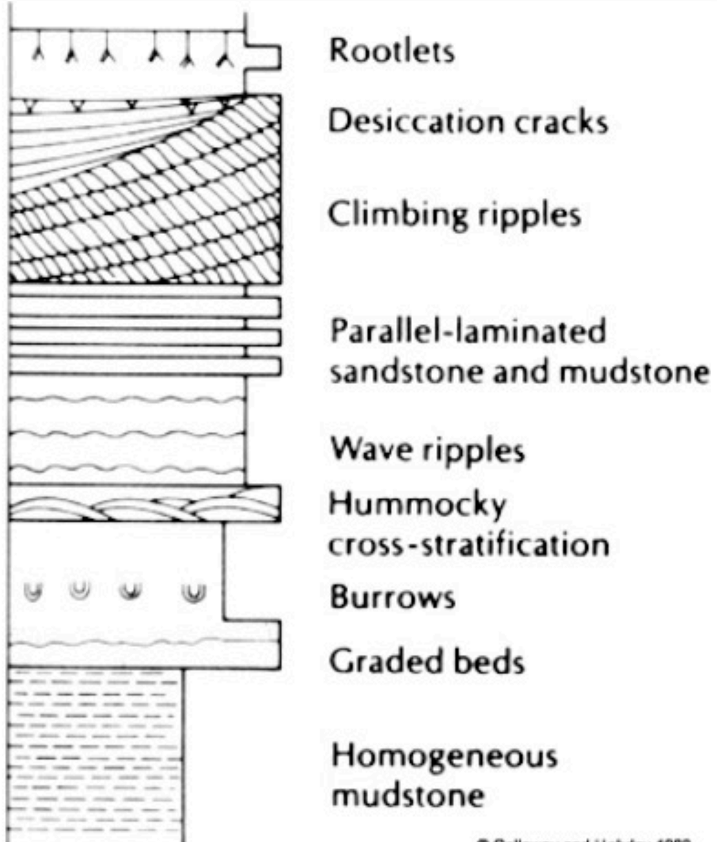
Seasonal alternation of turnover and stagnation.
Because lakes tend, geologically speaking, to be ephemeral, their deposits are often sandwiched between adjacent continental deposits.
Because they are comparatively deficient in critters with $CaCO_3$ skeletons, carbonate deposits are likely to occur as direct precipitates.

As such, laminated fine-grained deposits dominate all but the margins of ancient lake deposits. If the laminations show alternating seasonal variation, they are called varves. They are commonly characterized by a low abundance, low diversity fauna.



Facies Models

coarsening up lacustrine sequence, Karoo Basin, South Africa (Galloway and Hobday, 1983)



The deepest part of the lacustrine system contains homogeneous, horizontally laminated mudstone. The deepwater deposits contain anoxoic conditions with potential for black shale deposits. Above the mudstone are graded bed deposits. Graded bed deposits are found on the slope of lacustrine systems, and are coarsening up .

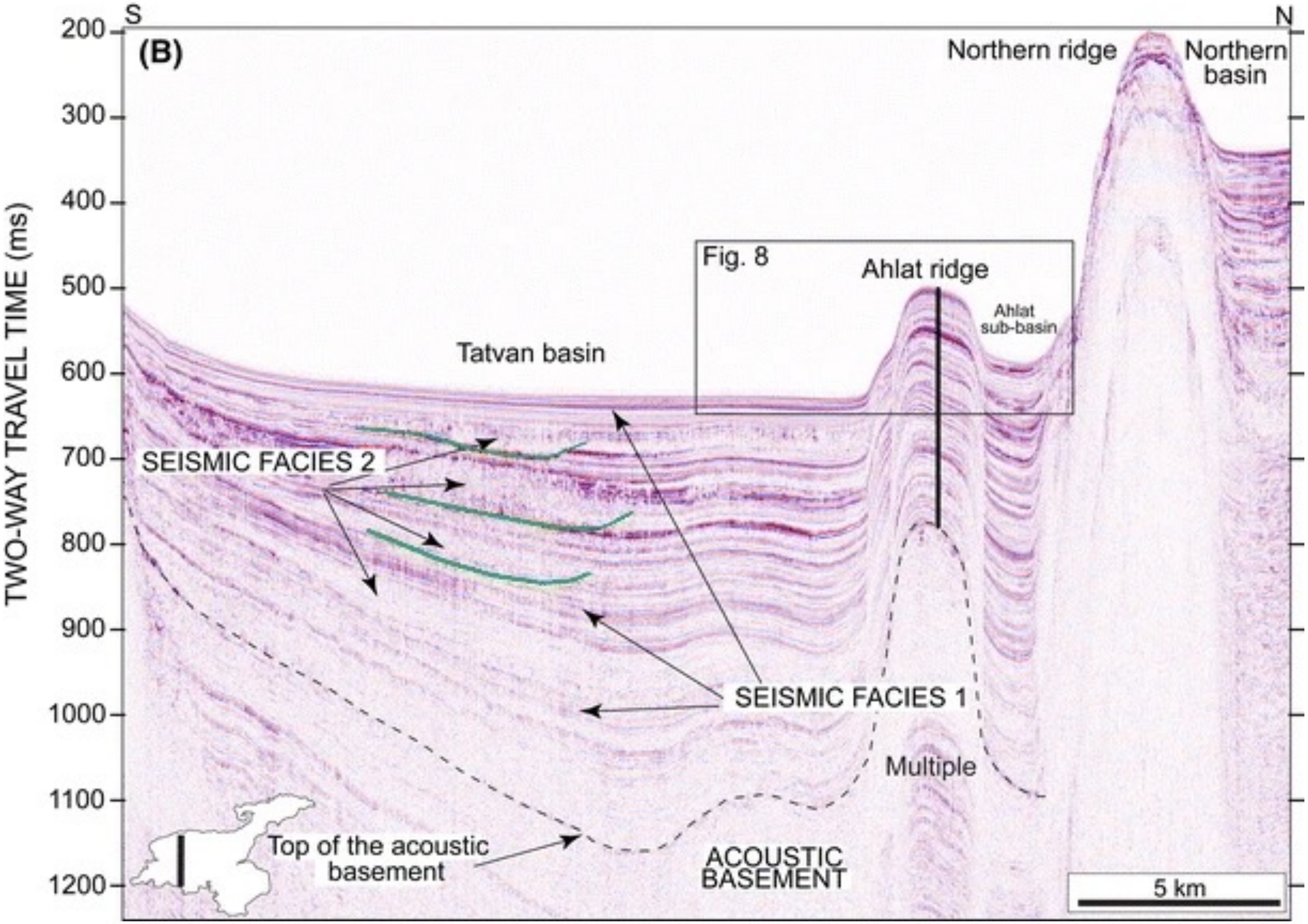
Burrows are also found close to the shelf and lacustrine shore. Hummocky cross-stratification forms in shallow waters due to storm events. Wave ripplies occur in a shallow water beach setting due to the gentle wave action of water. Parallel laminated sandstone and mudstone are deposited during periods of fine and coarse deposition from river influx. Climbing ripples represent the vertical and horizontal aggradation of sediment from unidirectional flow, often from rivers. Desiccation cracks are found in settings with occasional influx of water, probably along the side of a river or up on a beach.

Lake Van

Sedimentary evolution of Lake Van (Eastern Turkey) reconstructed from high-resolution seismic investigations.

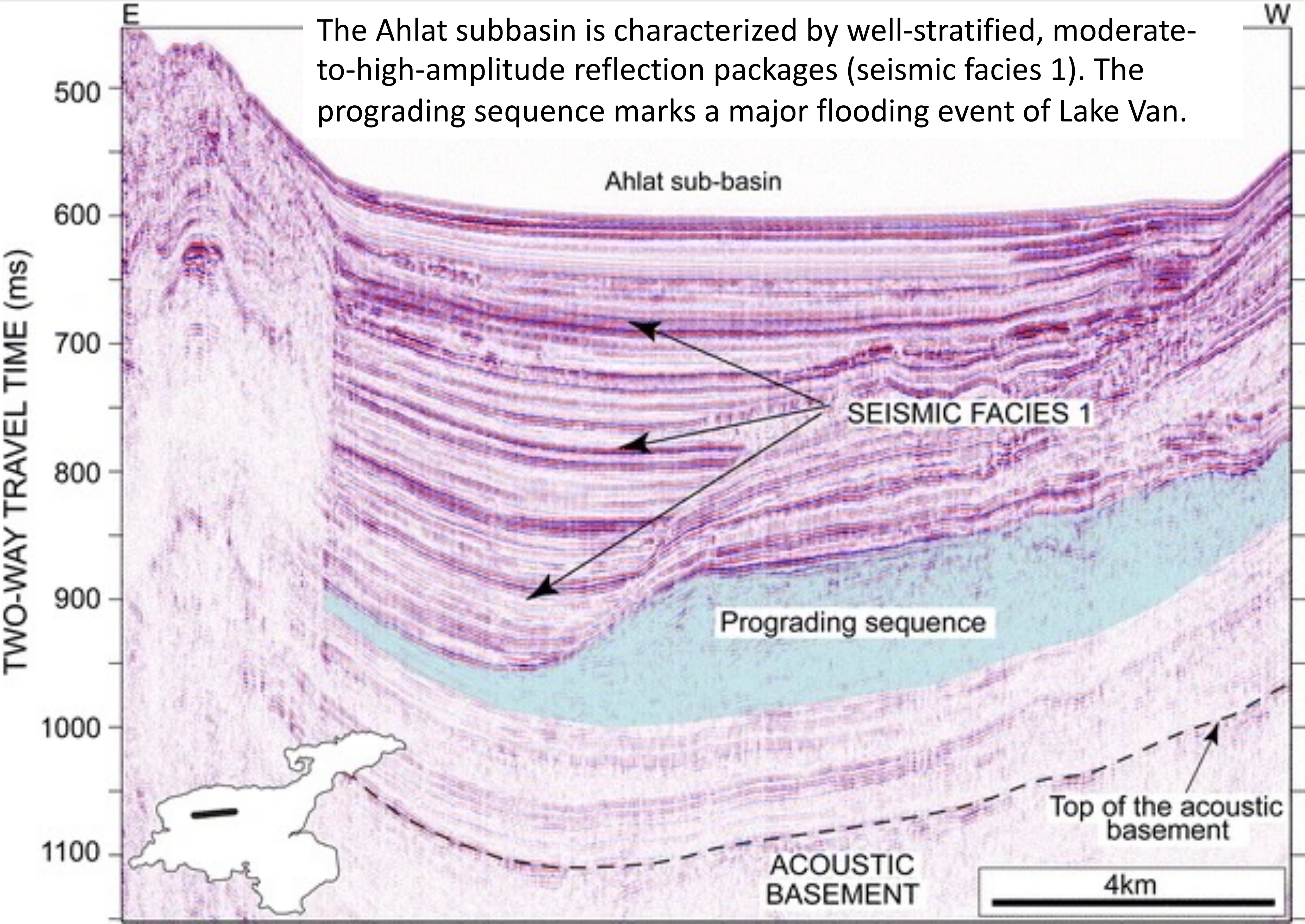
Cukur et al. (2013) Int J Earth Sci 102, 571–585

seismic reflection profile crossing the Tatvan basin.



The sub-surface section in the Tatvan basin is largely characterized by well-stratified, moderate-to-high-amplitude, continuous reflections (seismic facies 1) that are interpreted as lacustrine sediments and tephra layers. Transparent-to-chaotic seismic facies (seismic facies = 2) are seen locally and are interpreted as mass-flow deposits.

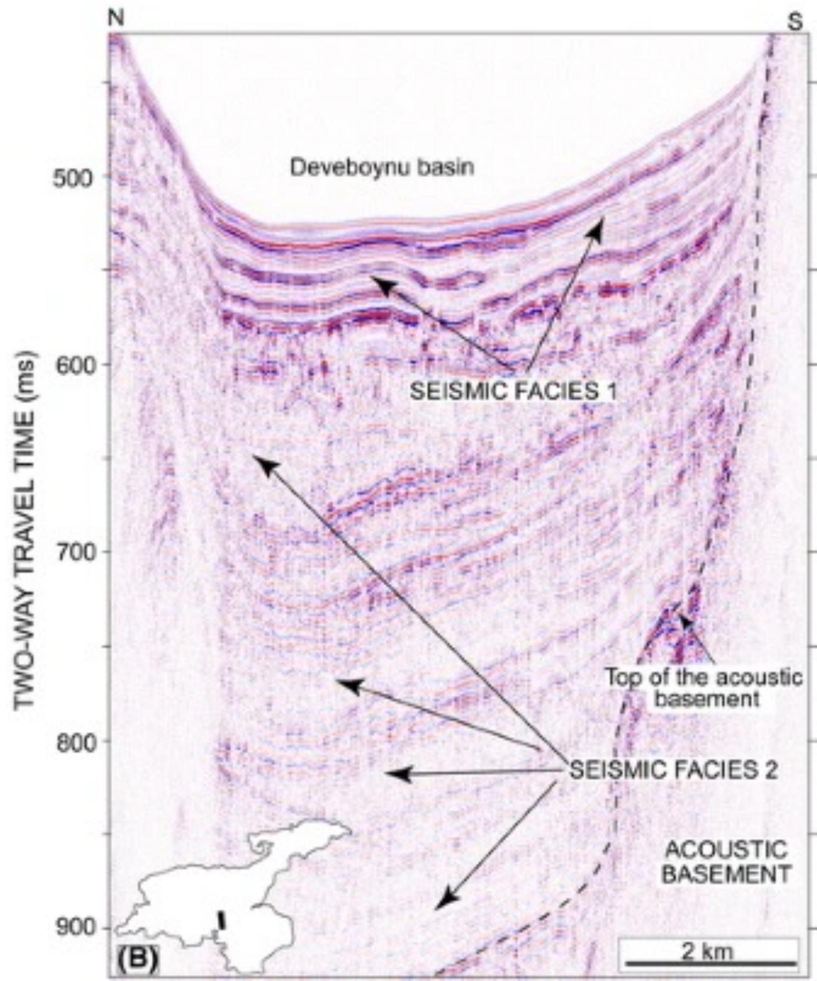
The Ahlat subbasin is characterized by well-stratified, moderate-to-high-amplitude reflection packages (seismic facies 1). The prograding sequence marks a major flooding event of Lake Van.



Seismic reflection profiles from the Northern basin (a) and the Deveboynu basin (b).

The sedimentary section in the Deveboynu basin is dominantly characterized by low-to-variable-amplitude, discontinuous or chaotic reflections (seismic facies 2). Seismic facies 1 (lacustrine and tephra layers) is seen in the upper part of the basin

The Northern basin is dominated by seismic facies 1. Seismic facies 2 (mass-flow deposits) are also seen locally.



Aeolian sediments

The work on both modern and ancient desert sediments has been stimulated by economic pressures.

Aeolian dune sandstones, which commonly have high initial porosities, may be important aquifers and hydrocarbon reservoirs, as, for example, the gas fields of the North Sea. Ancient playa lake deposits are a rich source of evaporite minerals and desert alluvium may provide hosts for mineralization.

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Aeolian deposits

Aeolian deposits are sediments transported by the wind.

The most important environments of aeolian transport and deposition are deserts, beaches and glacial outwash plains.

Mechanical weathering supplies large quantities of sand for transport.

Desert regions are subject to strong winds capable of moving large quantities of material.

Deserts cover 30% of present day land surface.

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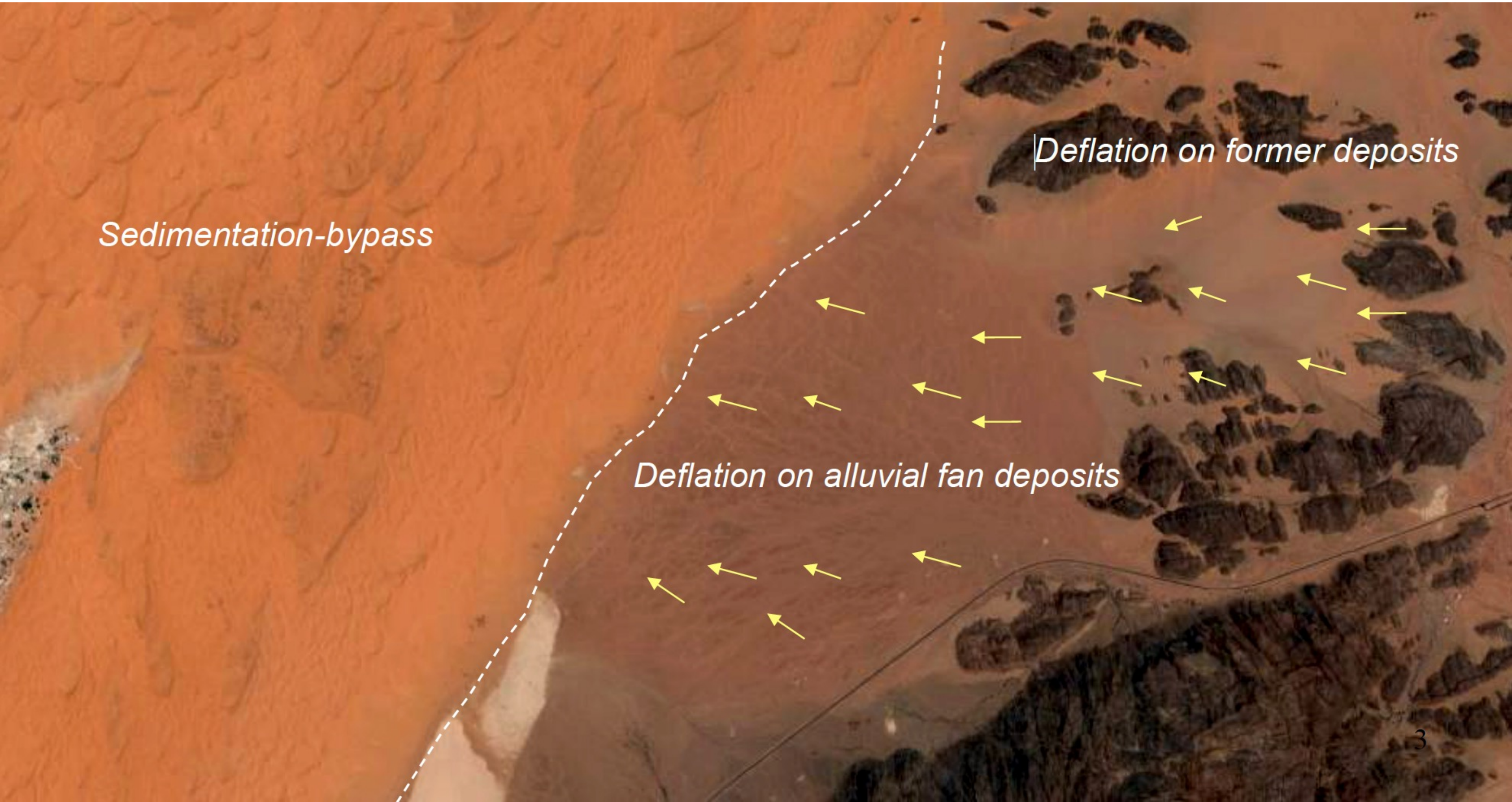
Deflation/accumulation areas

A deflation area (i.e. where sediment is picked up by winds) and a by-pass/accumulation area (where sediment is incorporated in the geological record) can be generally distinguished

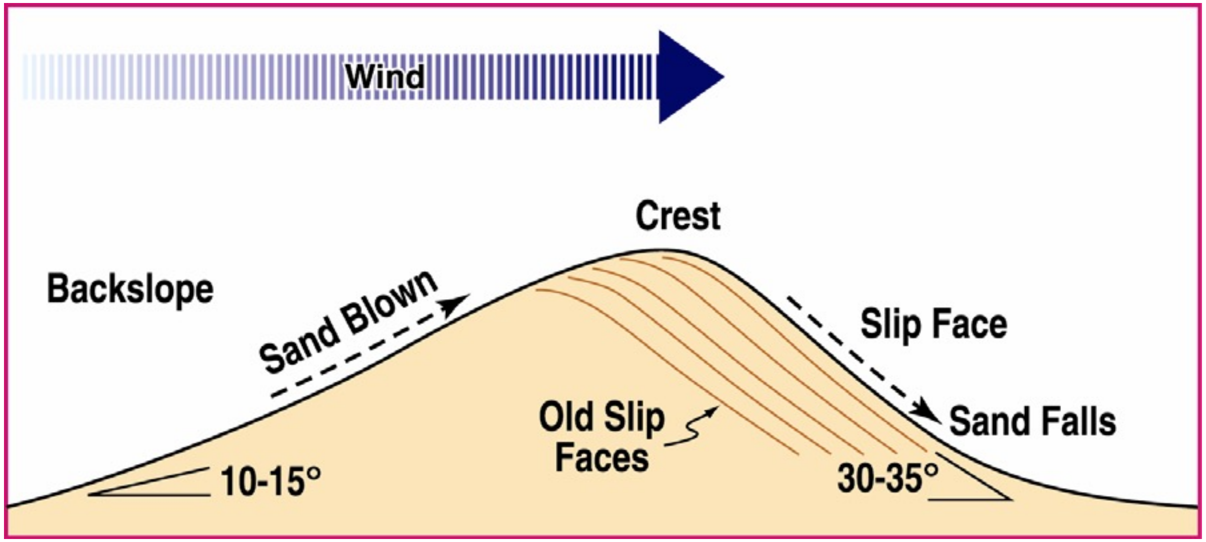


deposition

sand which can be accumulated in the shadow zones close to obstacles (gravels or bushes)

sedimentary structures

The main eolian sedimentary structures are dunes and ripples.



Bedforms

Ripples – 6 cm to 1+ m wavelength - rapid migration (>1 km/yr). Ripples occur on dune stoss slopes and (<20°).

Dunes - 10 to 100 m wavelength - moderate to slow migration (10-100 m/yr).

Draa - a very large eolian landform, with a length of several kilometers and a height of tens to hundreds of meters, and which may have superimposed dunes. - very slow migration(<10 m/yr).

In addition, aeolian processes may deposit plane beds, adhesion ripples, wavy lamination, crinkly lamination and brecciated lamination

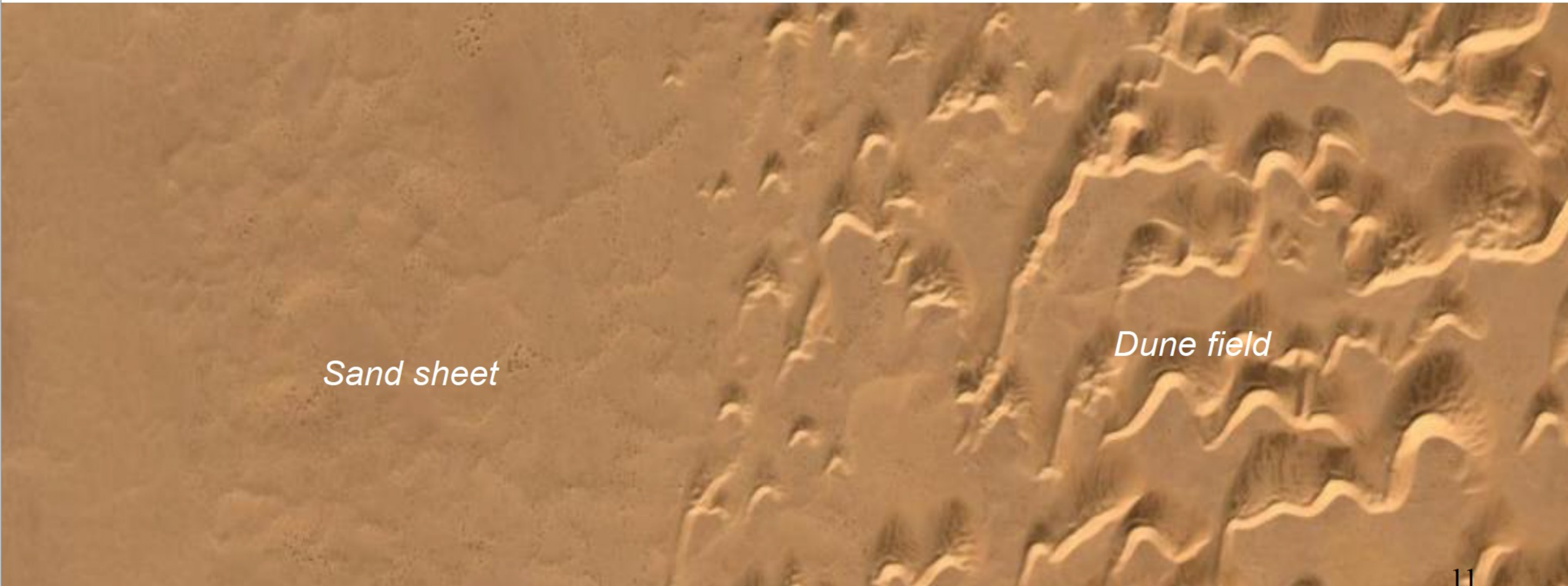
A draa in Sossusvlei, Namibia.

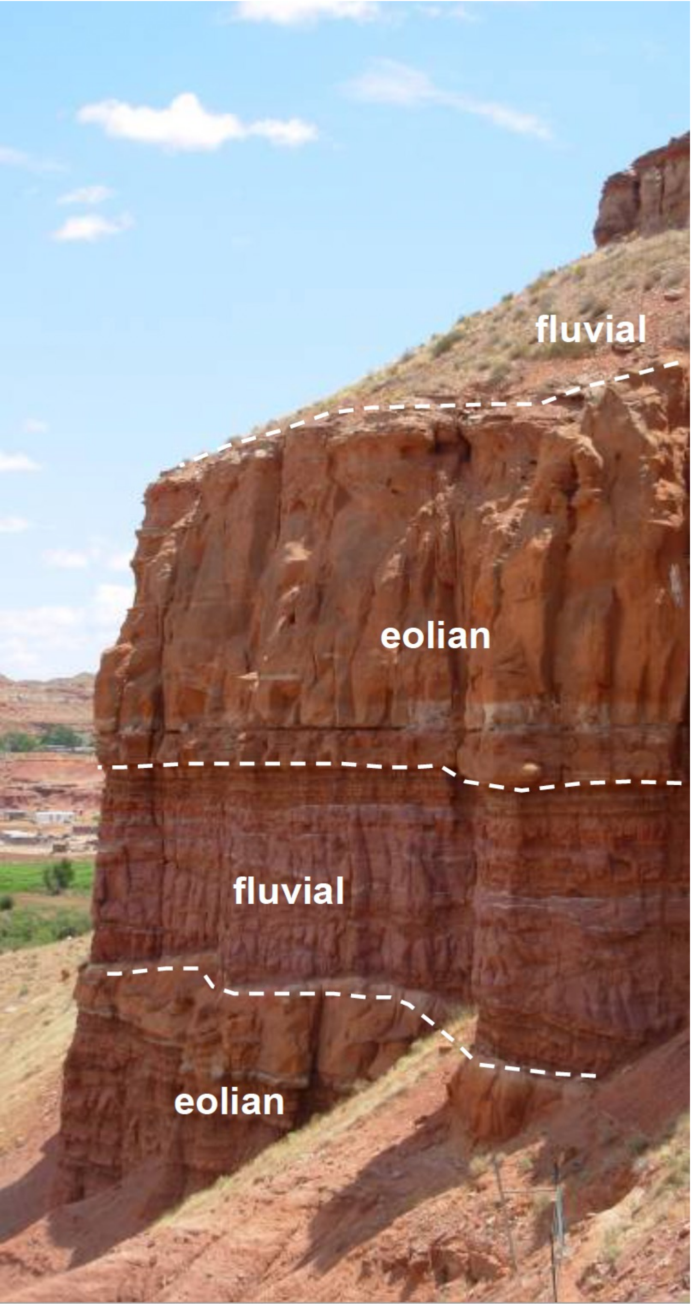
Distribution of sedimentary structures

The main eolian sedimentary structures are dunes and ripples. The distribution of sedimentary structures within eolian systems is not uniform, since it reflects the amount of available sediment and the interplay between eolian and other depositional systems.

low sediment supply areas

sediment-rich areas



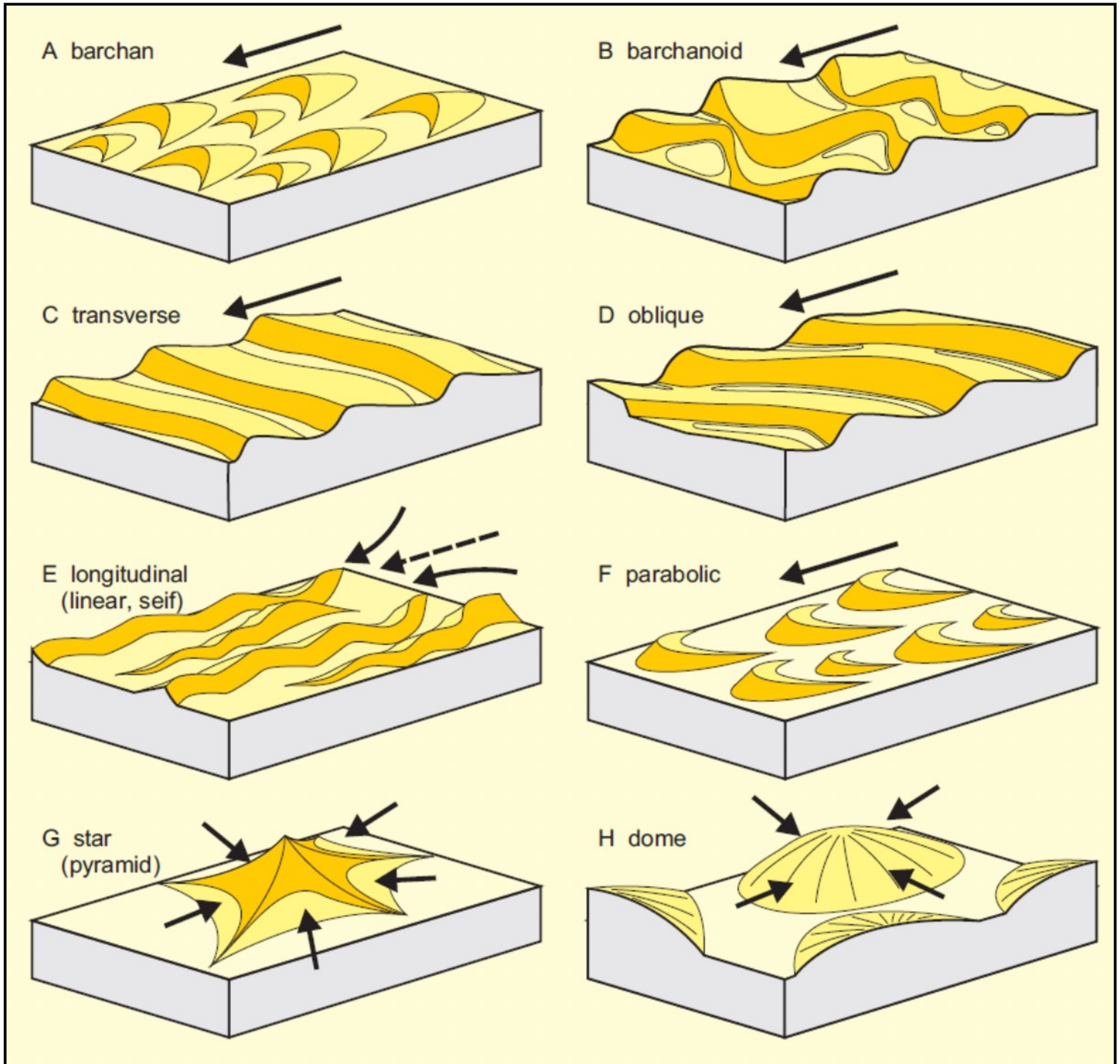


Alternation of depositional systems

Dune fields characterize desertic or coastal areas (i.e. non-deltaic coasts), thus being the depositional sites of thick eolian deposits. Dunes are the most prominent bedforms in terms of sediment volume, although ripples are also common. Eolian deposits often alternate vertically with deposits of nearby depositional systems (e.g. fluvial deposits). Such an alternation may result from alternating different climatic regimes.

Cross stratification

Analogously to subacqueous dunes, eolian dunes originate cross-stratified sets, up to few decameters thick.



Dune shaes

Opposite to subacqueous dunes,eolian dunes shows a variety of shapes, due to the fact that wind can blow from different directions during different time span. Dome and star shapes are indicative of higly variable winds. Dunes with well-defined crests, either transversal orparallel to wind directionare a typical feature ofareas with nearly steady winds.

Characteristics of aeolian deposits

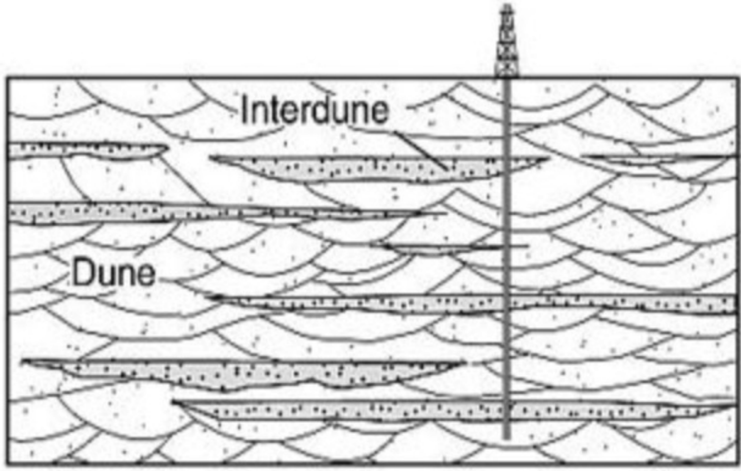
- lithologies –mainly sand and silt
- mineralogy – mainly quartz, with rare examples of carbonate or other grains
- texture – well- to very well-sorted fine to medium sand
- fossils – rare in desert dune deposits, occasional vertebrate bones
- bed geometry – tabular or large scale lenses of sand
- sedimentary structures – large-scale dune crossbedding and parallel stratification in sands (2D /3D cross bedding)
- palaeocurrents – dune orientations reconstructed from cross-bedding indicate wind direction .
- colour – yellow to red due to iron hydroxides and oxides
- facies associations – occur with alluvial fans, ephemeral river and lake facies in deserts, also with beach deposits or glacial outwash facies

Key Criteria for recognizing dune deposits:

- well sorted
- pitted, frosted grains
- thick cross bed sets
- high angle foresets

Implication for petroleum geology

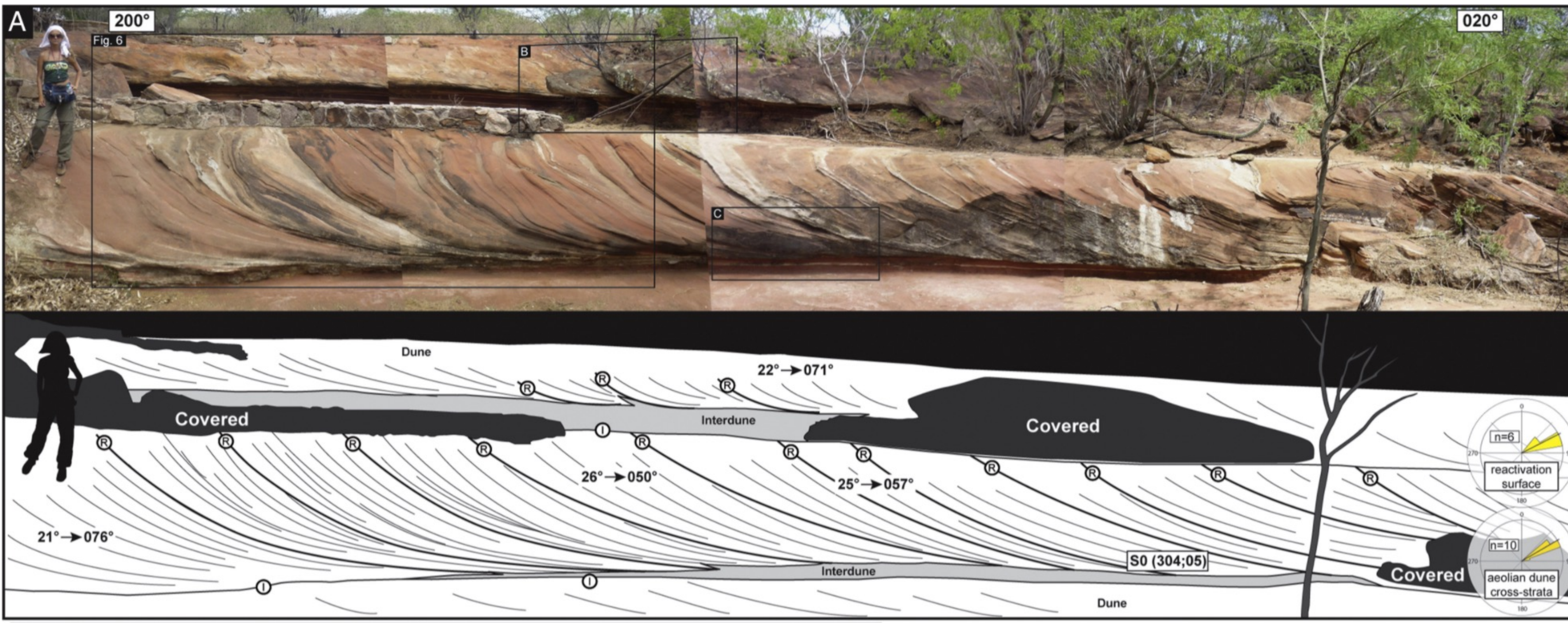
Given the overall lack of fine grained sediments, eolian deposits are commonly prone to be good reservoirs, although characterized by an high complexity.
Complexities of eoilan reservoirs arise from:
i) fine-scale cross-stratification at various angles;
ii) occurrence of related fluvial, playa and marine facies;
iii) existence of differential diagenesis.
All these features contribute to a compartimentalization and an high degree of permeability anisotropy



In eolian successions, reservoir compartimentalization or permeability anisotropy are strictly linked with major bounding surfaces. As a consequence a detailed knowledge of internal architeture and facies distribution is required during exploration of eolian deposits. Further changes in local porosity/ permeability are linked with changes in cementation within laminae, which is commonly controlled by sedimentary and diagenetic processes and interaction between different depositional environments. A exhaustive knowledge of sedimentary processes and their products is therefore required in the frame of a detailed reservoir characterization

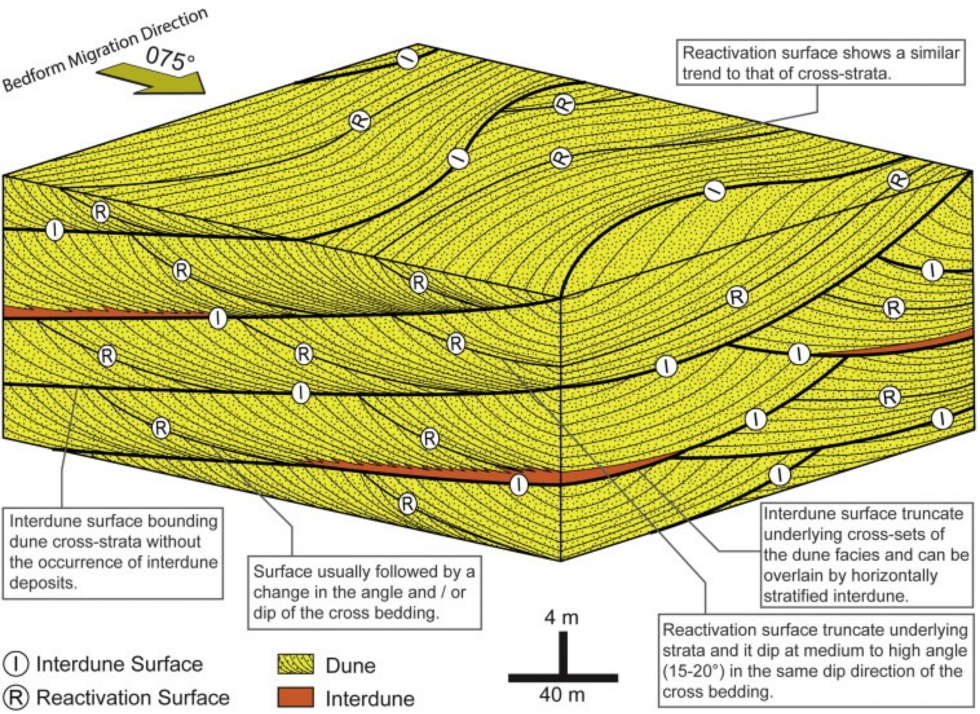
Facies architecture and stratigraphic evolution of aeolian dune and interdune deposits, Permian Caldeirão Member (Santa Brígida Formation), Brazil

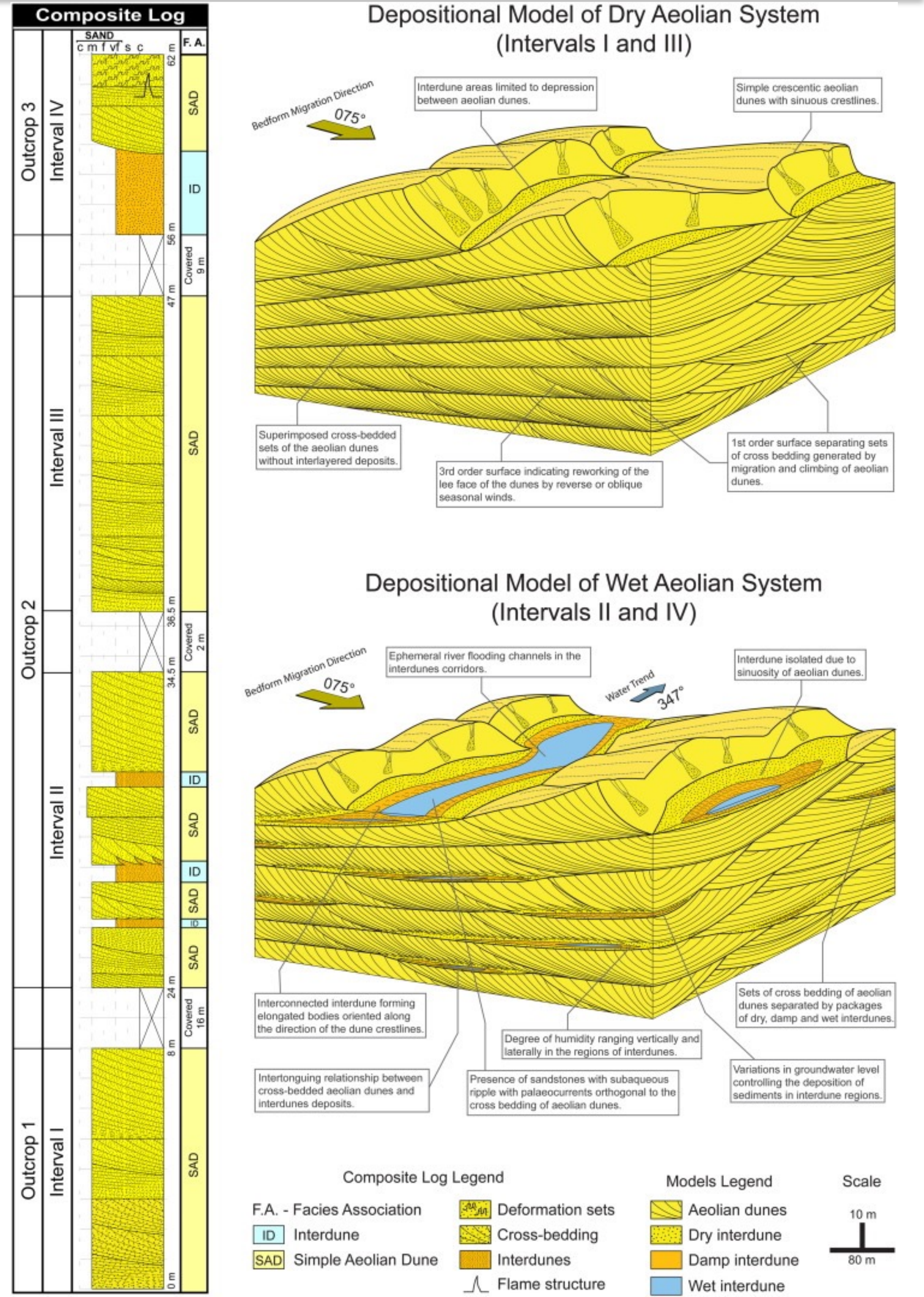
Herbert et al., 2016, Sedimentary Geology 337, 133-150



Photomosaic and interpretative outcrop panel showing the geometry and relationships between dune and interdune sandstones.

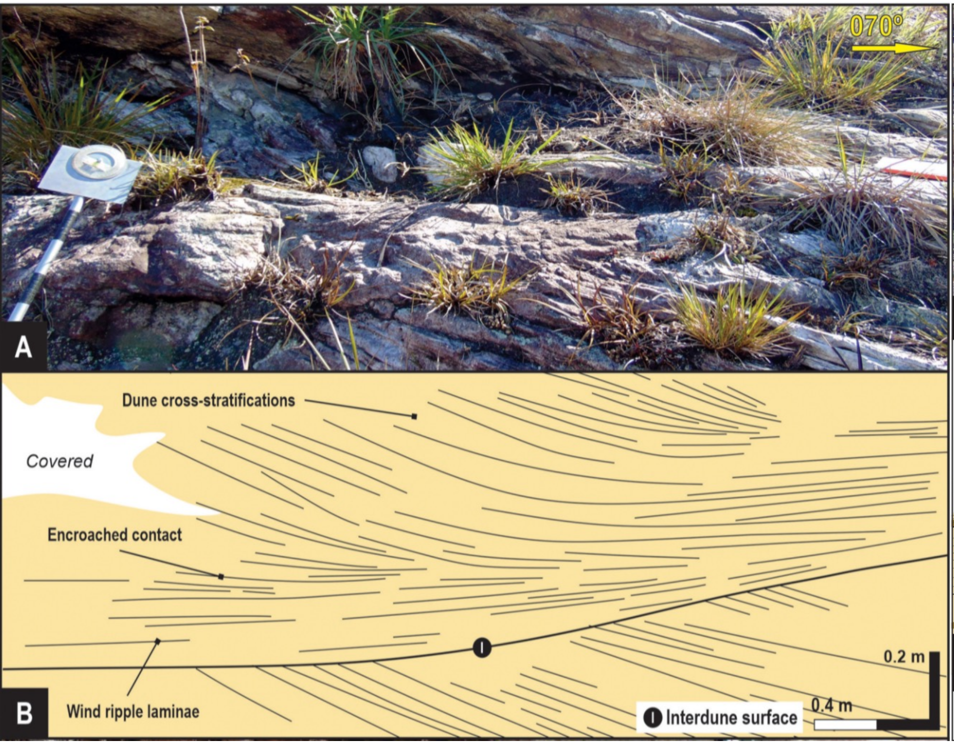
Diagram block showing the bounding surface hierarchy to the aeolian dunes of the Caldeirão Member.



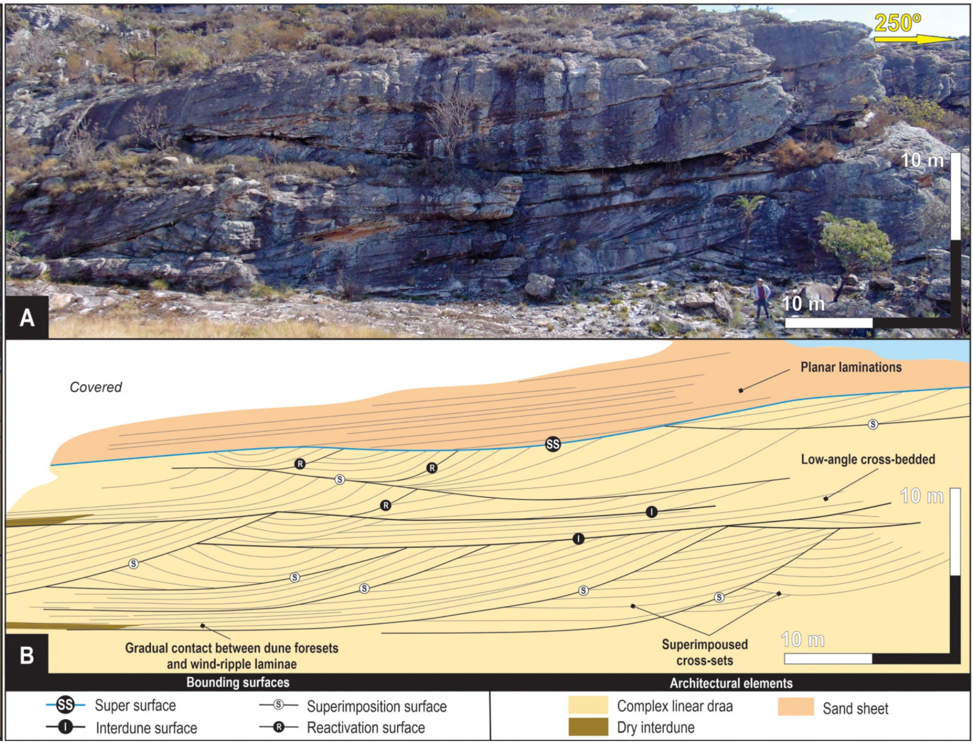


Composite log and summary three-dimensional architectural models for dry aeolian system (Intervals I and III) and the wet aeolian system (Intervals II and IV) to studied outcrop section of the Caldeirão Member.

Morphology, accumulation and preservation of draa systems in a Precambrian erg (Galho do Miguel Formation, SE Brazil). Ferreira Mesquita et al., 2021, Sedimentary Geology 412, 105807



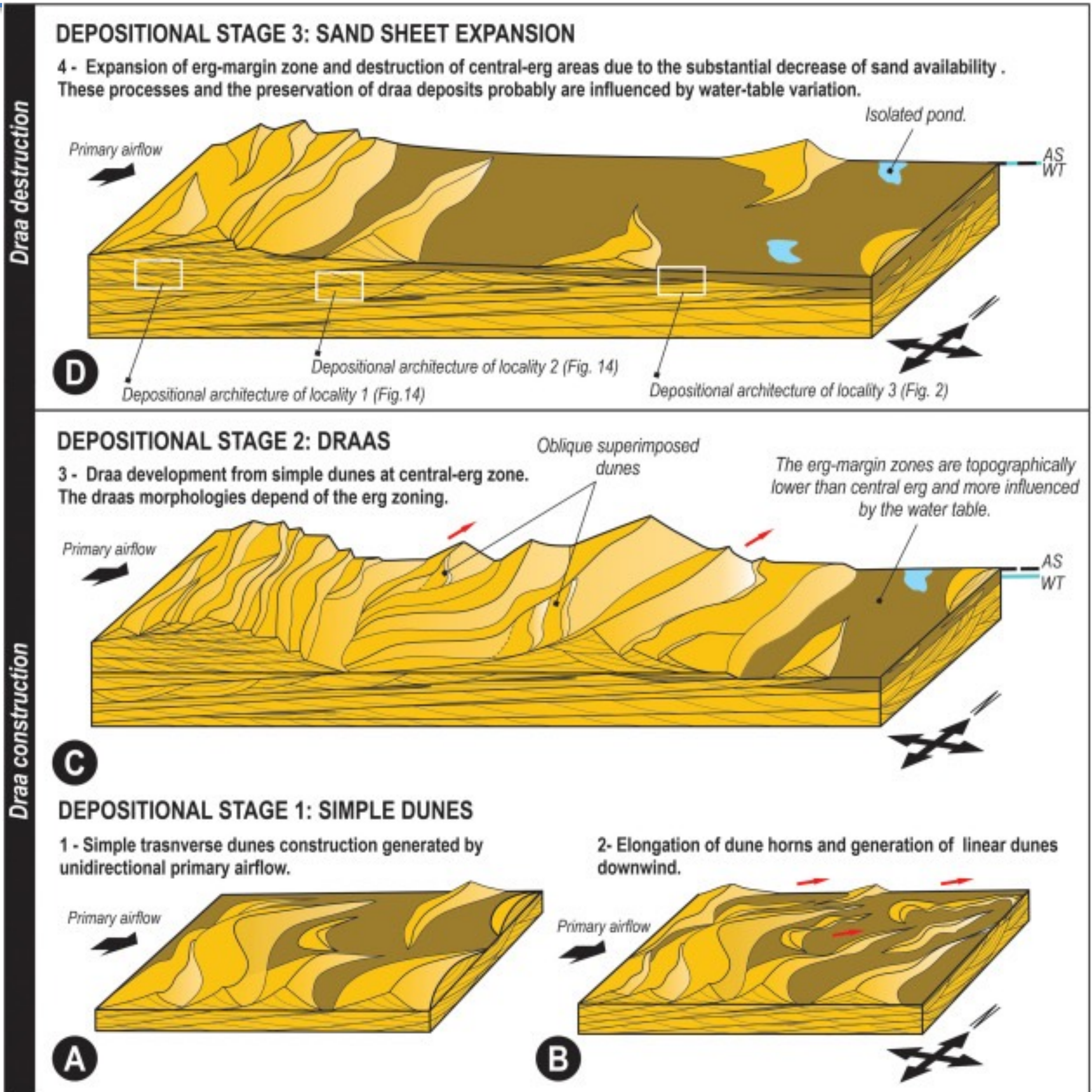
(A) overview and (B) sketch of lens-shaped sets bounded at the bottom by planar and near-horizontal erosive surface (interdune surface) and by aeolian dune deposits.



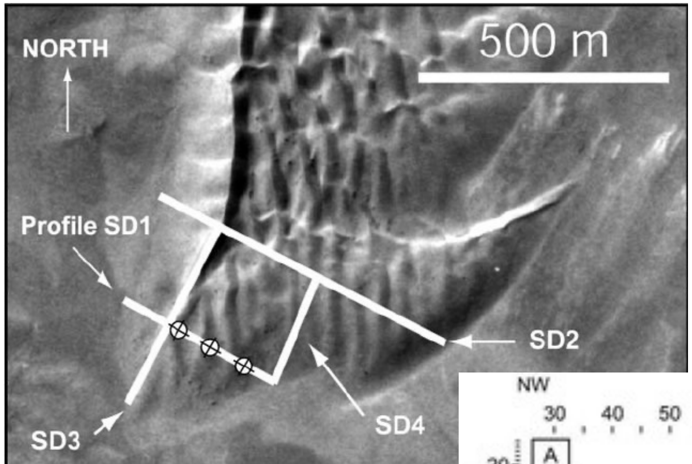
(A) overview and (B) interpretation in palaeowind transverse-section. This succession is interpreted as residual deposits of complex linear draa with important lateral migration.

Depositional model

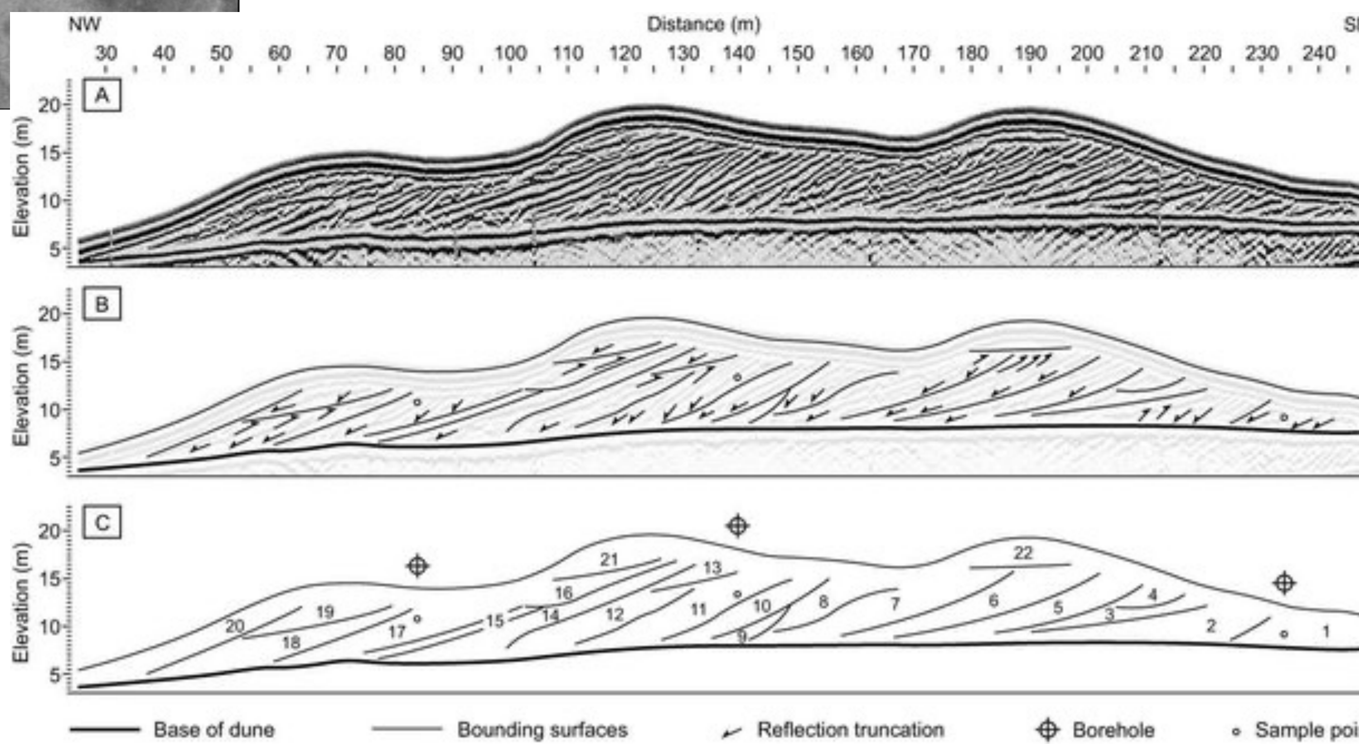
(A) and (B) Depositional stage 1: simple dune construction. (C) Depositional stage 2: draa development. (D) Depositional stage 3: sand sheet expansion. The red arrows represent secondary airflows probably originated by the interference of primary airflow with the draa/dune topography, as identified in current aeolian models. Legend: [AS] accumulation surface; [WT] water table level.



Combining ground penetrating radar surveys and optical dating to determine dune migration in Namibia

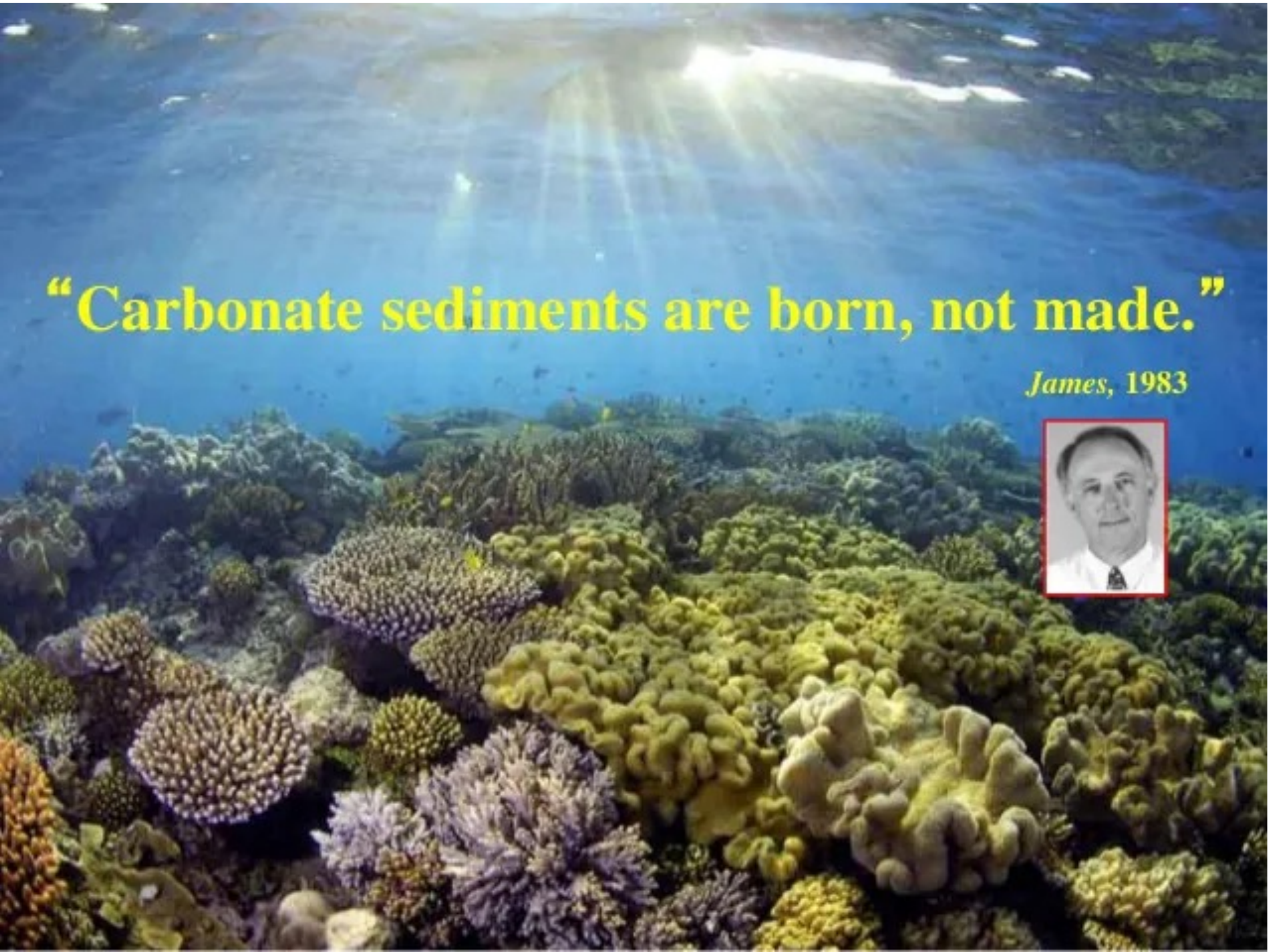


Thick sets of cross-stratification indicate when the dune was most active, whereas thin sets of cross-stratification are interpreted to indicate the increased prevalence of wind reversals and lower rates of dune migration, with bounding surfaces formed during periods of stabilization, non-deposition or erosion.



Bristow et al., 2005. Journal of the Geological Society

Terrigenous clastic sediments are made primarily by the disintegration of parent rocks and are transported to the depositional environment. Once there, patterns of texture and fabric are impressed upon them by the hydraulic regime. The signatures of such facies are in their sedimentary structures and grain-size variations.



Carbonate and evaporite sediments are "born" as precipitates or skeletons within the depositional environment.

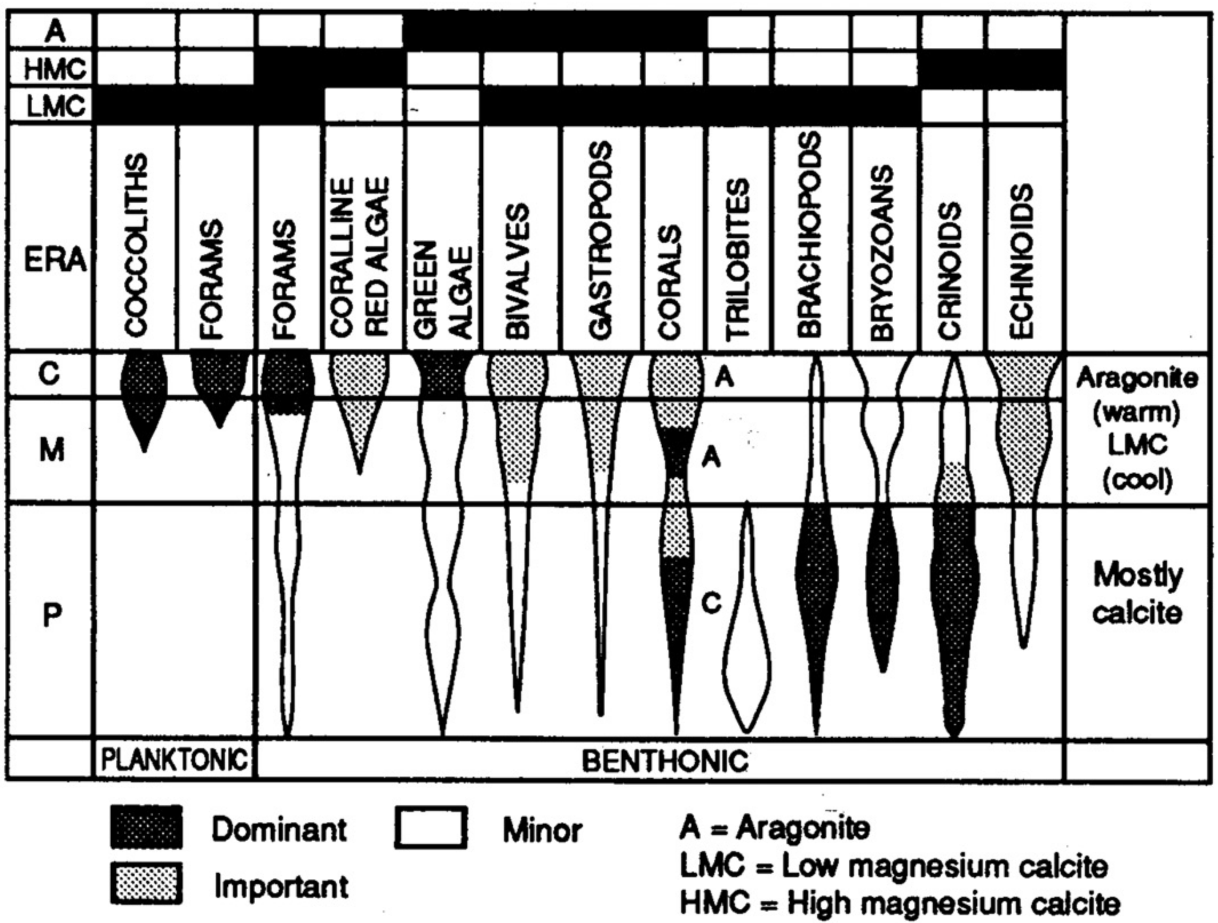
Istituto Nazionale di Oceanografia e di Geofisica Sperimentale

Table 1 *Differences between terrigenous clastic, carbonate and evaporite sediments.*

Terrigenous Clastic	Carbonate	Evaporite
Climate is no constraint, sediments occur worldwide.	Most sediments occur in shallow, warm water environments.	Most sediments occur in shallow-water or mud flat environments.
Sediments are both terrestrial and marine.	Sediments are mostly marine.	Sediments occur only in restricted terrestrial and marine environments.
Grain-size reflects hydraulic energy of the environment.	Grain-size reflects the size of skeletons and precipitated grains.	Crystal size reflects nucleation and growth rate, or diagenetic alteration.
Mud indicates settling from suspension.	Mud commonly indicates prolific growth of organisms that produce tiny crystals.	Fine carbonates/sulphates indicate rapid precipitation.
Currents and waves form shallow-water sand bodies.	Many sand bodies form by localized physicochemical or biological production of carbonate.	Shallow-water sand bodies are rare.
Environmental changes are induced by widespread changes in hydraulic regimen.	Environmental change can be induced by localized buildup of carbonate, without change in hydraulic regimen.	Environmental change is induced by changes in basin dynamics.
Sediments remain unconsolidated in the depositional environment.	Sediments are commonly cemented on the seafloor.	Sediments are commonly cemented or form crystal crusts in the depositional environment.
Periodic exposure does not alter the sediments.	Periodic exposure results in intensive diagenesis.	Periodic exposure results in growth of intrasediment evaporites or wholesale dissolution.
Walther's law applies to most deposits.	Walther's Law applies to many, but not all, deposits.	Walther's law applies to few deposits.

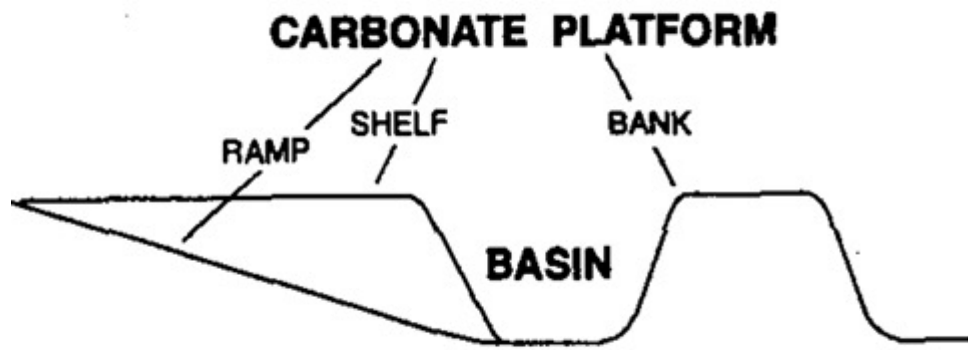
Organisms have changed with time

Dynamic stratigraphy demands that the input distilled from modern and ancient environments should be as fully understood as possible. Problems arise for some carbonates because the ecology of extinct rock-forming organisms may not be fully known. These difficulties are even more prevalent for evaporites because many have no Holocene analogue.



Distribution of main groups of animals and plants through the Paleozoic (P), Mesozoic (M), and Cenozoic (C). The fact that the different groups of animals and plants have skeletons formed of different mineralogies means that there are substantial differences between the Paleozoic and Mesozoic/ Cenozoic sediments and cool versus warm water sediments

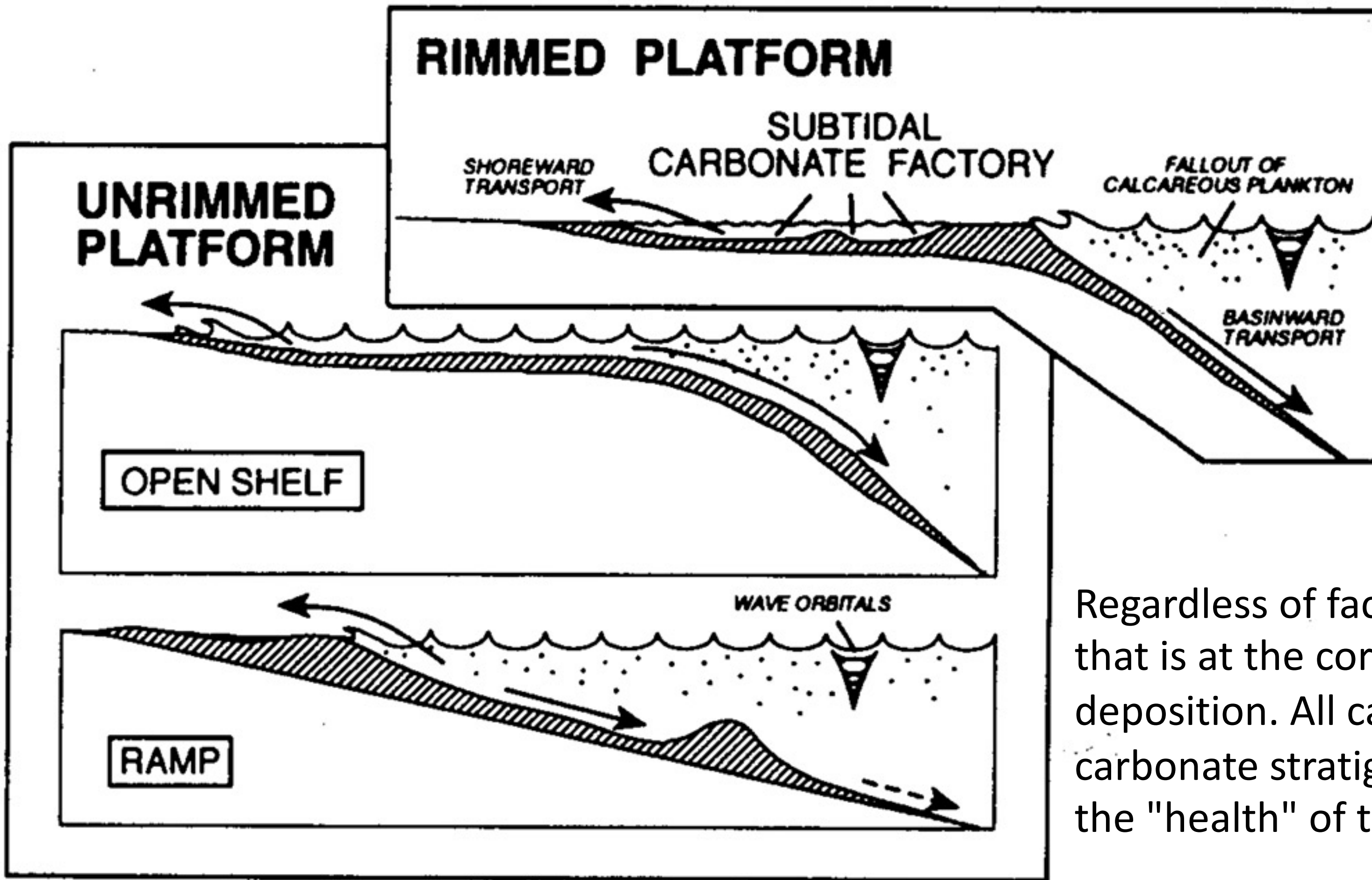
Terminology



- A carbonate platform is a large edifice formed by the accumulation of sediment in an area of subsidence.
- A carbonate bank is an isolated platform surrounded by deep ocean water and cut off from terrigenous clastic sediments.
- A carbonate atoll is a specific type of bank developed on a subsiding volcano.
- Atolls and banks can be so dominated by reefs that their geological expressions are termed reef complexes or carbonate buildups.
- A rimmed platform has a segmented to continuous rampart of reefs and/or lime sand shoals along the margin that absorbs ocean waves.
- An unrimmed or open platform, is one in which there is no barrier.
- A ramp is an unrimmed shelf that slopes gently basinward at angles of less than 1 degree.
- Evaporites are either confined to marginal shelves built on the shallowest parts of older ramps, or they form on the deepest parts, when the adjacent basin desiccates.
- Deep water environments are significant repositories for carbonate sediment and evaporite depositional basins suffered partial or complete desiccation during isolation from the sea.

The carbonate factory

The carbonate factory is the shallow, illuminated seafloor. Particles of all grain sizes are born here, either crystallizing as skeletons or precipitating directly out of seawater. Sediments mostly remain in place forming widespread "subtidal" deposits or reefs and mounds.



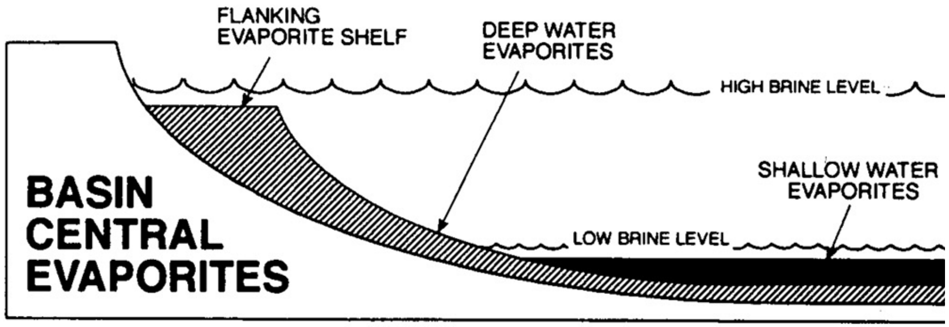
Fine sediment is also swept seaward where, together with sediment gravity flows originating at the margin, it accumulates on the slope and on adjacent basin margin.

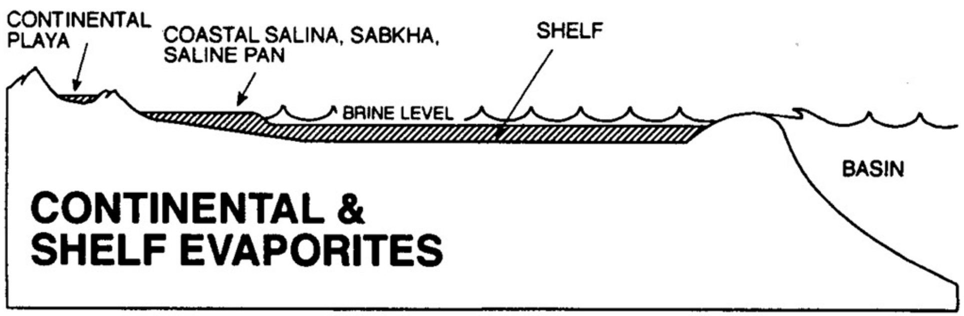
Regardless of facies, it is the factory that is at the core of carbonate deposition. All carbonate facies and carbonate stratigraphy depend on the "health" of this production unit.

The evaporite factory

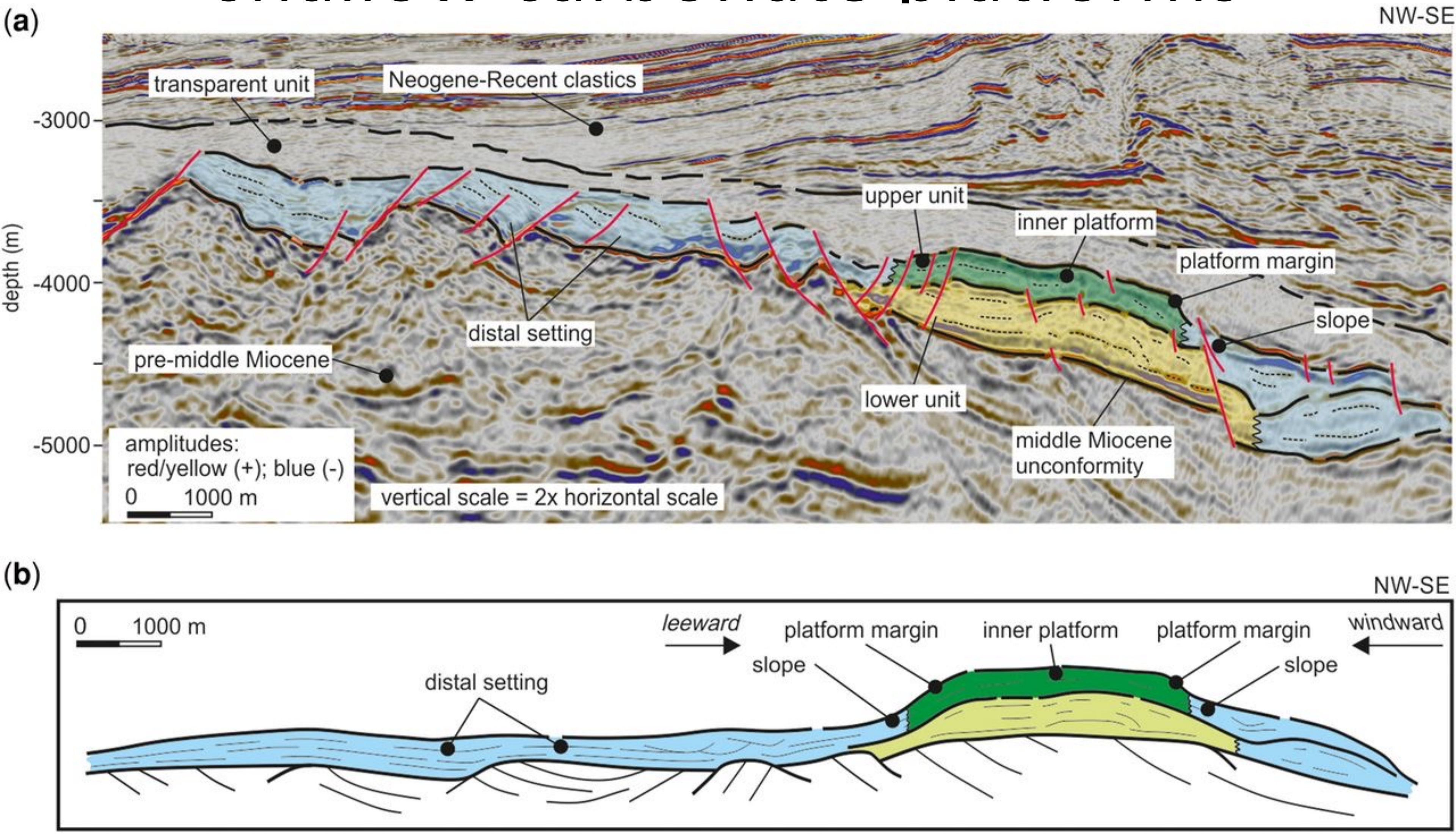
Evaporites can accumulate in both terrigenous clastic and carbonate settings, most rapidly in shallow water conditions. Export of sediment from this evaporite factory does occur, but it is substantially less than in carbonate settings because so much of the sediment is lithified initially, or quickly becomes cemented. Environments range from continental lakes to coastal salinas and sabkhas to shelf-wide complexes. Evaporites can also develop in shallow- and deep-water basin centres.

The original overall composition and mineralogy of an evaporite provide information about the type of water being evaporated, the brine temperature and salinity, and the degree of basin isolation. However: 1) most early models were chemical in nature and/or based upon few examples, 2) evaporites exposed in outcrop (uncommon) are much altered, and subsurface core is limited, 3) no areas of present-day evaporite deposition compare in size with many ancient basins, 4) changes in depositional conditions are rapid, profound and commonly result in superimposed facies, making original environmental recognition difficult, 5) characteristically, new environments destroy and replace older ones, rather than moving laterally, so that associated facies are unreliable when interpreting poorly preserved deposits, and 6) evaporites are susceptible to wholesale, postdepositional change that can remove all primary features.





shallow carbonate platforms

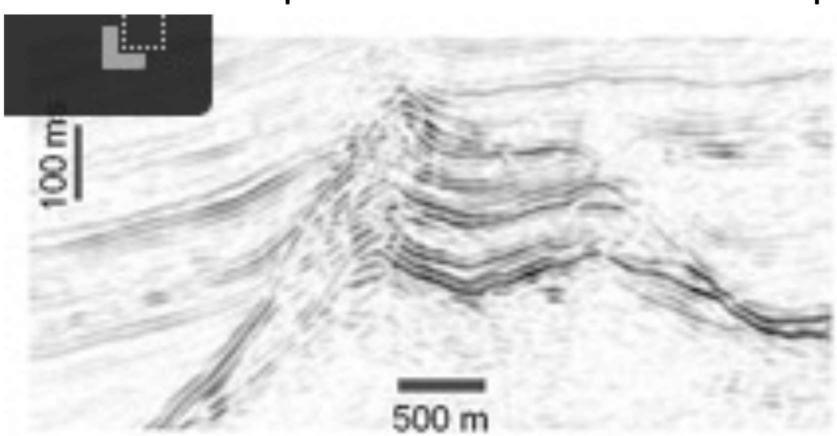


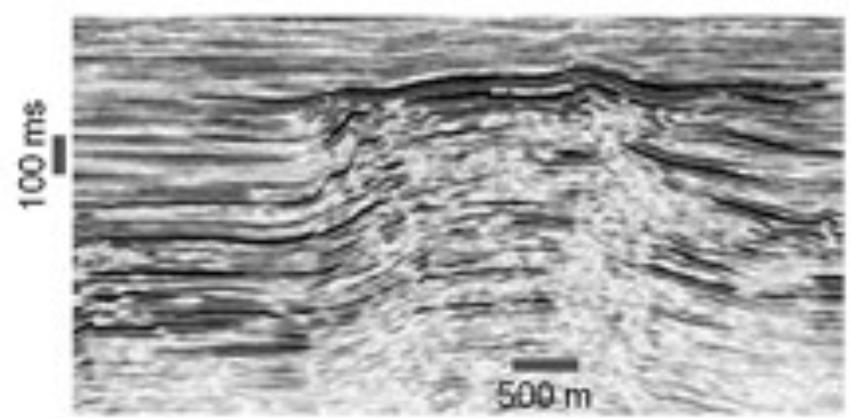
Berrocoso et al., 2021. Challenges of carbonate platform identification and characterization from seismic data in frontier exploration. Geological Society, London, Special Publications 509, 57-88

isolated carbonate buildups

Burgess et al, 2013. identification of isolated carbonate buildups from seismic reflection data AAPG 97

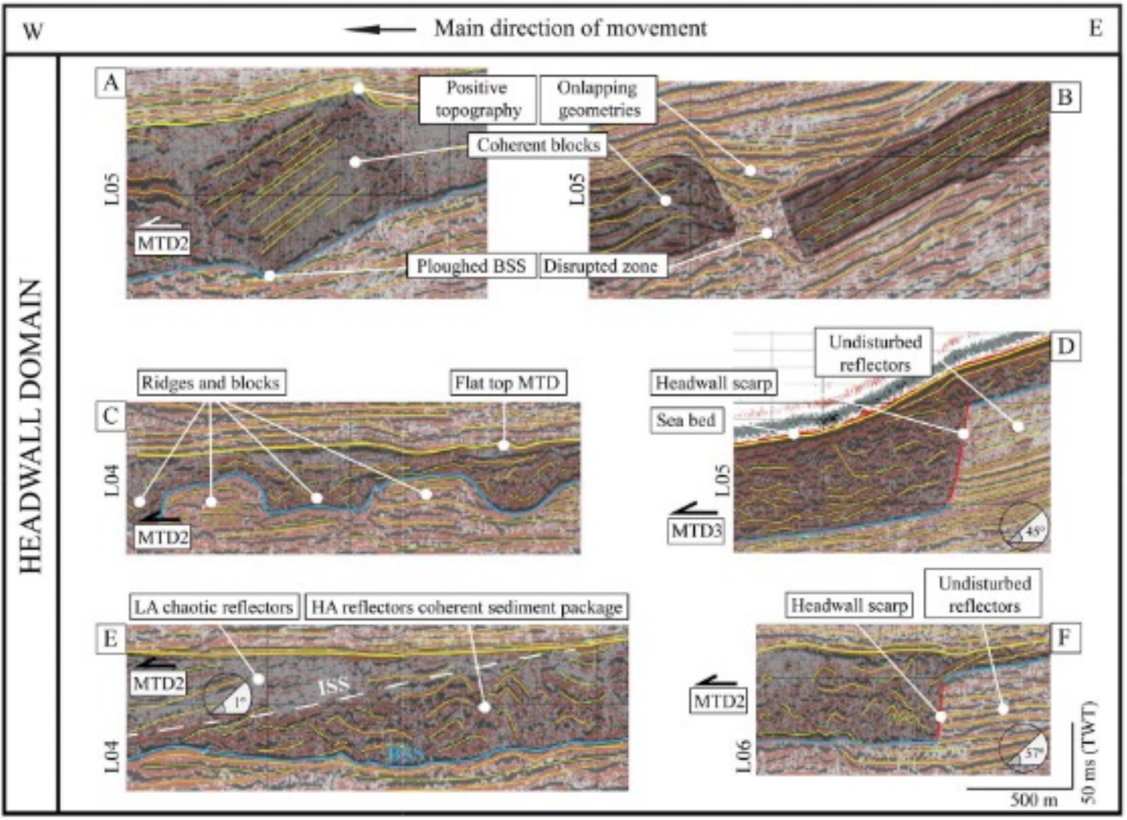
The term “buildup” = positive relief. “carbonate buildup” could include pinnacle reefs, carbonate mud mounds, attached carbonate platforms, and volcanoes.
carbonate platform including several depositional environments. The reference to the several depositional elements highlights the important distinction between an isolated carbonate platform, a pinnacle reef, and a mud mound.
An isolated carbonate platform contains a series of different depositional elements (such as reefs, lagoons, tidal flats, and flanking slopes), may be several kilometers in length, and commonly contains strata with good reservoir properties.
A pinnacle reef is an ICB composed of just one reef and probably has a very small areal extent and, therefore, a small volume and so is of less interest to an explorer.
A mud mound is another type of ICB with quite different depositional elements that probably does not develop in shallow water and has potentially very different reservoir properties.

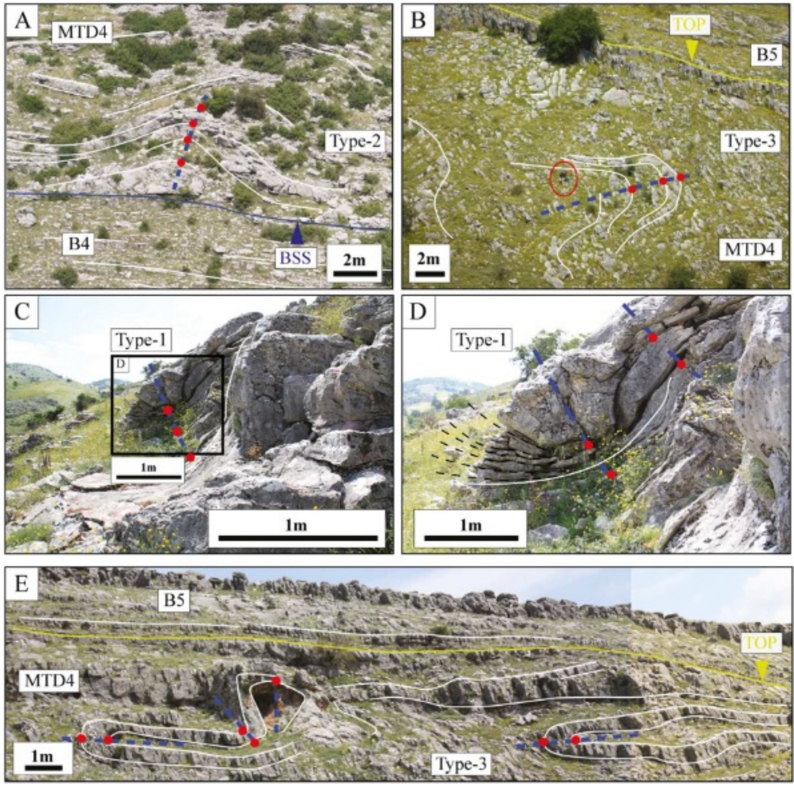




Carbonate slopes

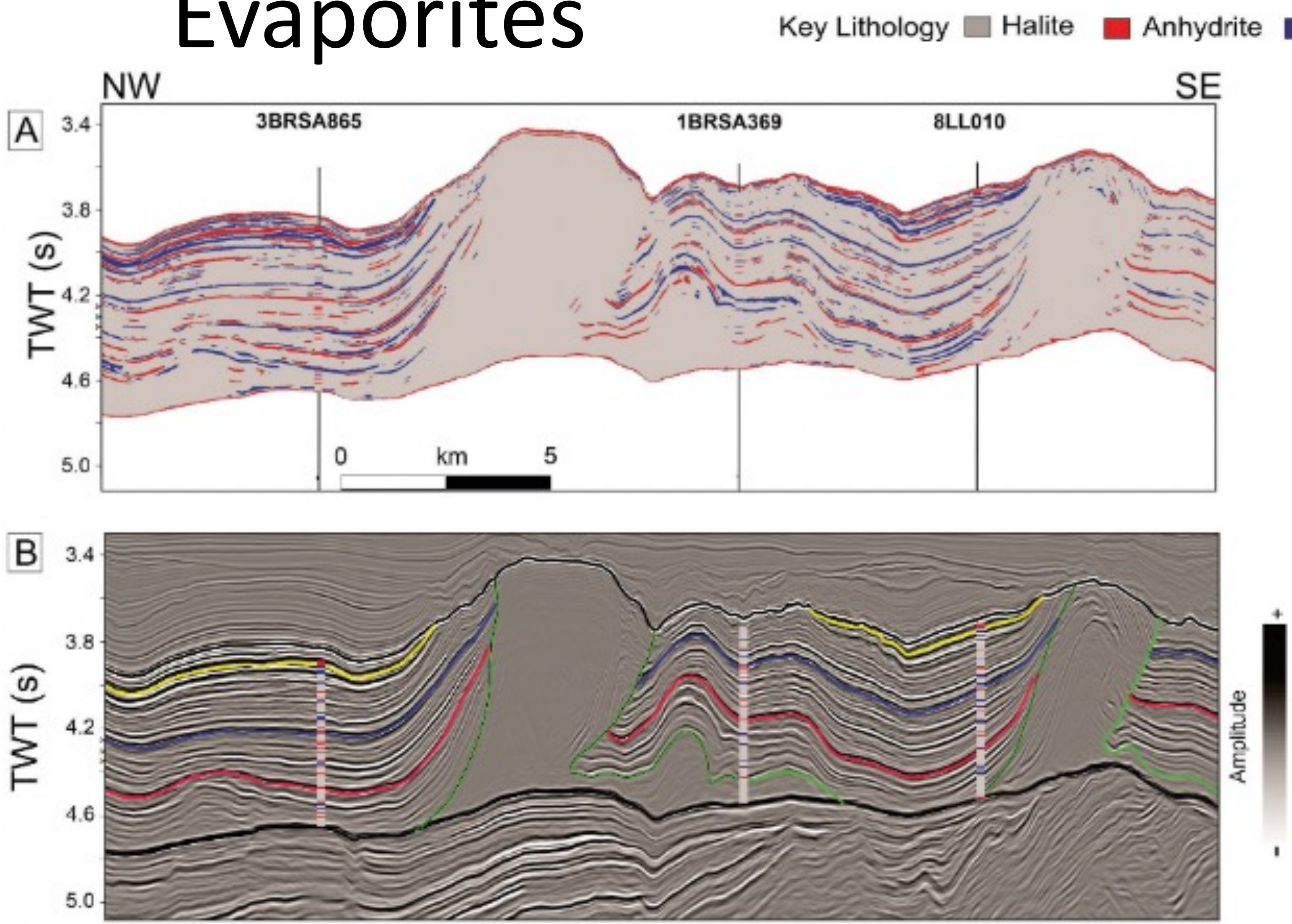
Mass-transport deposits (MTDs) cover a depositional continuum from slides to slumps, creeps and debrites, capturing a broad spectrum of synsedimentary deformation processes. MTDs are a common feature on the slopes surrounding large-scale carbonate platforms and hence constitute a significant part of the slope-to-basin depositional record.





Le Goff et al., 2020. Carbonate slopes of Great Bahama Bank & Apulian Carbonate Platform. Marine Geology 427

Evaporites



Teixeira et al. (2020), Quantitative seismic-stratigraphic interpretation of the evaporite sequence in the Santos Basin. Marine and Petroleum Geology 122