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SPECIALISTS MANAGING THE EARTH

ENGINEERING GEOLOGY & GEOTECHNICAL MODELS

ENGINEERING GEOLOGY

Carbonates - Evaporites

Limestone

1. **INTRODUCTION**

Chemical and or biochemical sedimentary rocks originate by precipitation of minerals from water through various chemical or biochemical processes.

Distinguished from clastic sedimentary rocks by their chemistry, mineralogy and texture. May be divided into five basic groups:

1. Carbonates,
2. Evaporites,
3. Siliceous sedimentary rocks, eg Cherts,
4. Iron rich sedimentary rocks and
5. Phosphorites.

Carbonates are the most abundant rocks by far and the focus for this lecture. They comprise about 20% of all sedimentary rocks; although some sources quote 10%.

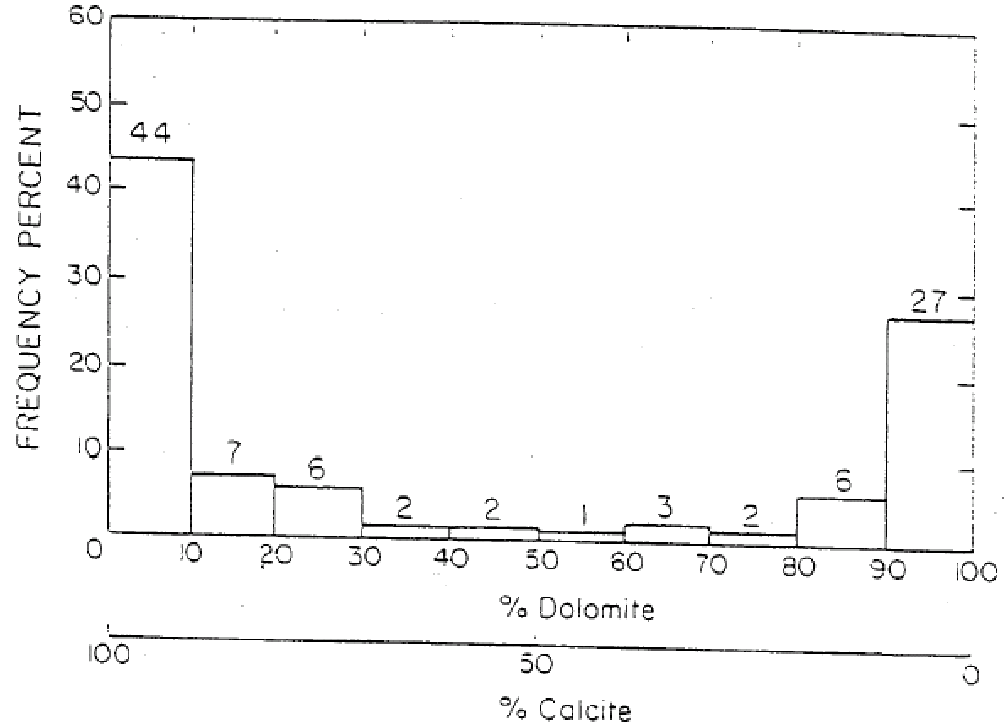
Evaporites are also covered because of their engineering significance.

Carbonate Rocks

Carbonates may be divided into limestones and Dolomites on the basis of mineralogy, with limestones mainly formed from calcite (CaCO3) and Dolomites mainly formed from Dolomite (CaMg(CO3) 2). Dolomites are more common in very old rocks. Paleozoic and Precambrian, while calcite dominates in younger Cenozoic and Mesozoic rocks.

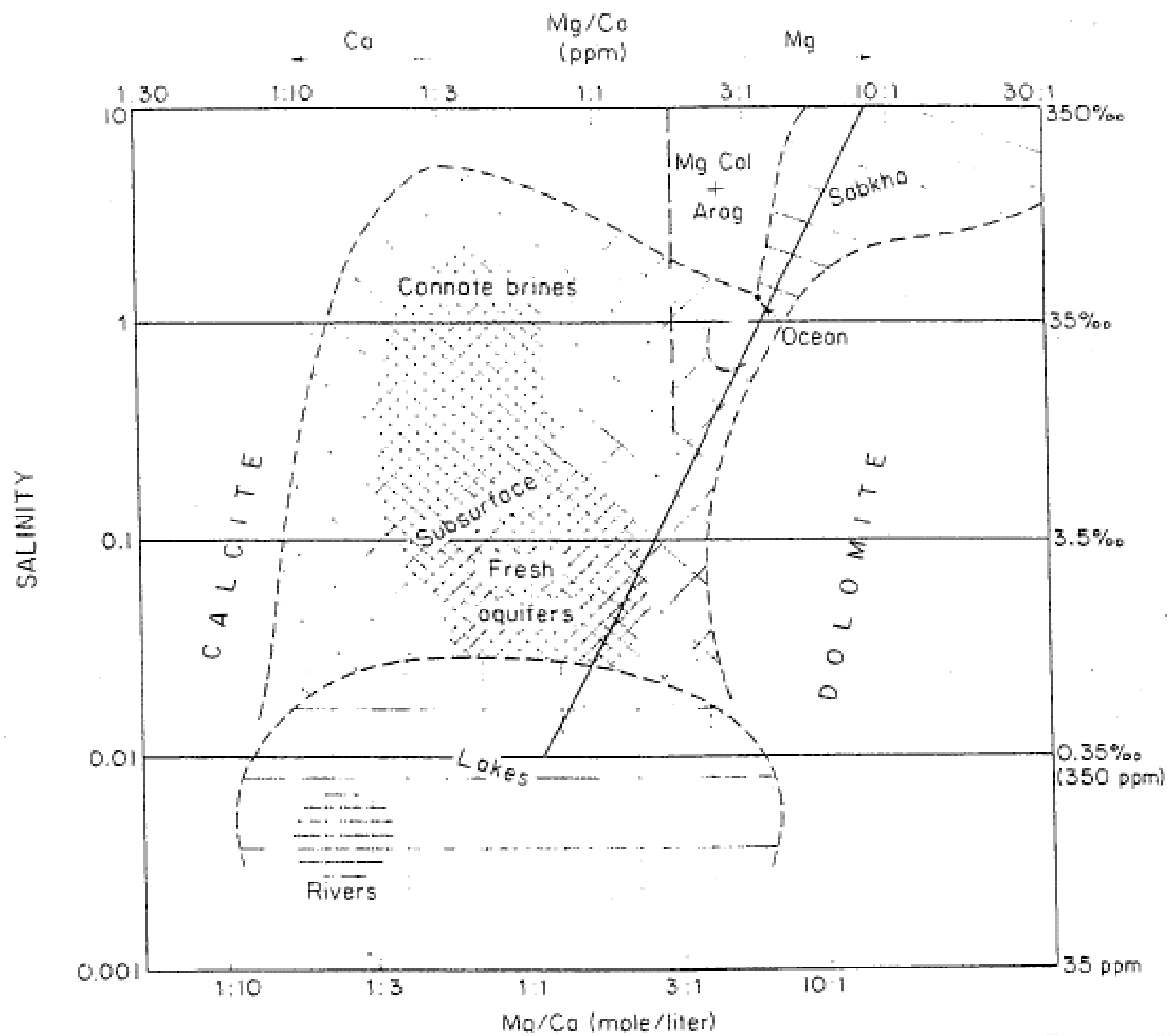
Table 1 gives a classification system for carbonate rocks and Figure 1 shows the continuum between the two end members, although most samples are either limestone or dolomite Figure 2.

Carbonate Rocks



Computed percentages of calcite and dolomite for 1148 analyses of North American carbonate rocks. (Steidtmann, 1917)

Carbonate Rocks



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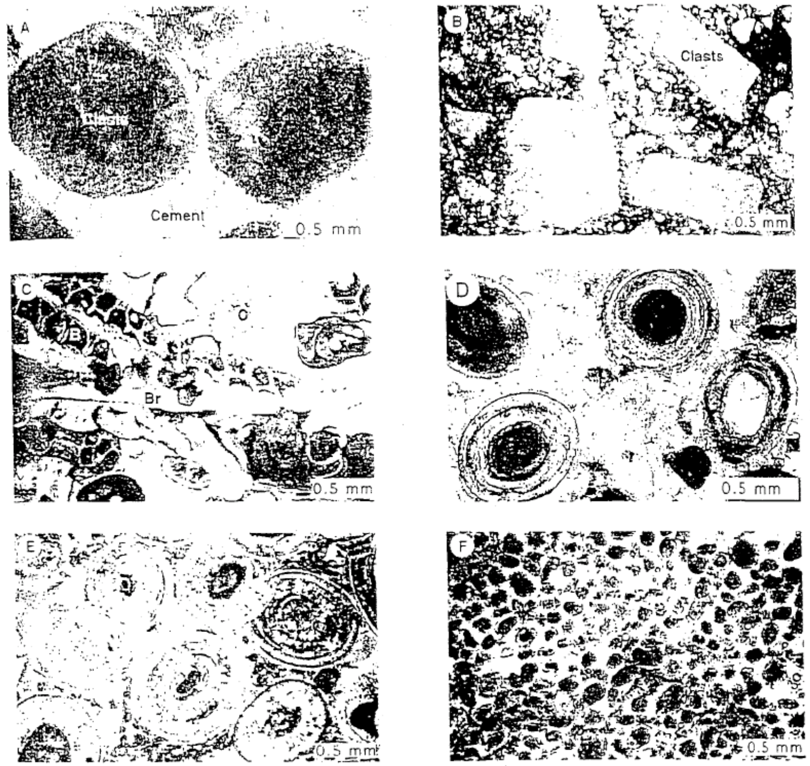
Carbonate Rocks



Fundamental kinds of carbonate grains (allochems) in limestones: (A) rounded clasts cemented with sparry calcite cement, Devonian limestone, Canada, (B) angular to subangular clasts in a micrite (dark) matrix, Calville Limestone (Permian), Nevada, (C) mixed skeletal grains (B = bryozoan, Br = brachiopod, C = crinoid, F = foraminifer) cemented with sparry calcite, Salem Formation (Mississippian), Missouri, (D) normal ooids cemented with sparry calcite (white), Miama Oolite (Pleistocene), Florida, (E) radial ooids cemented with sparry calcite (white) and micrite (dark); note relict concentric layering, Devonian limestone, Canada, (F) pellets cemented with sparry calcite, Quaternary-Pleistocene limestone, Grand Bahama Banks. Crossed nicols.

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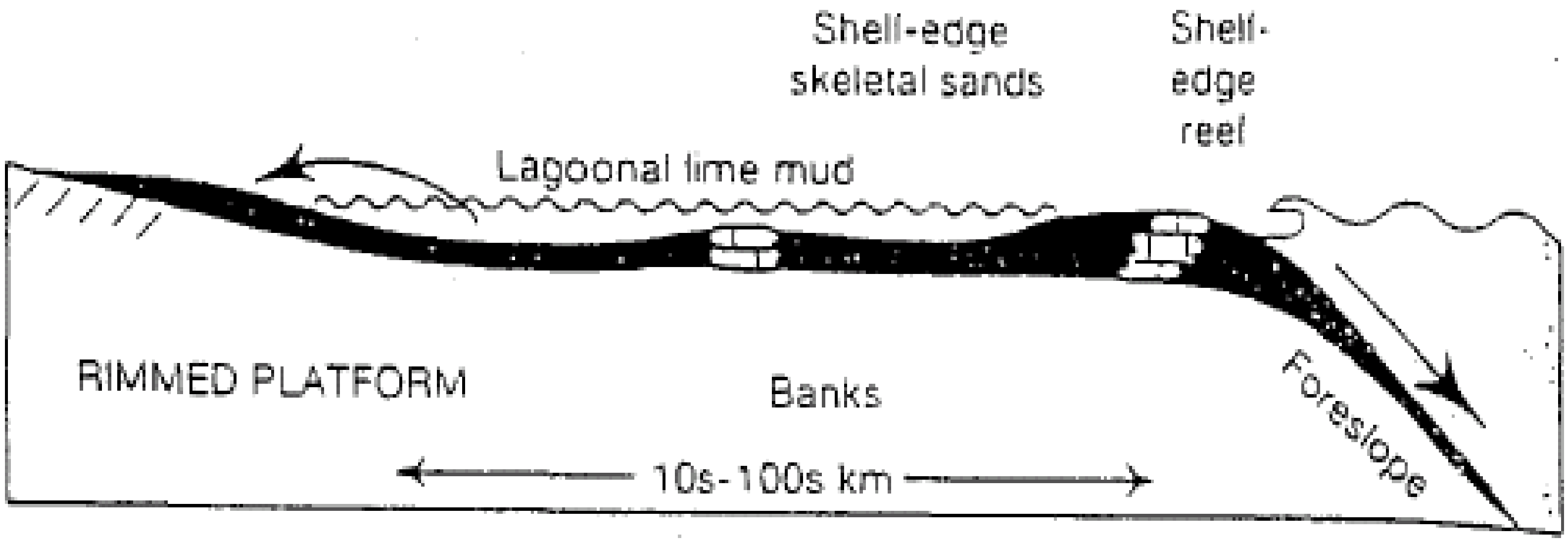
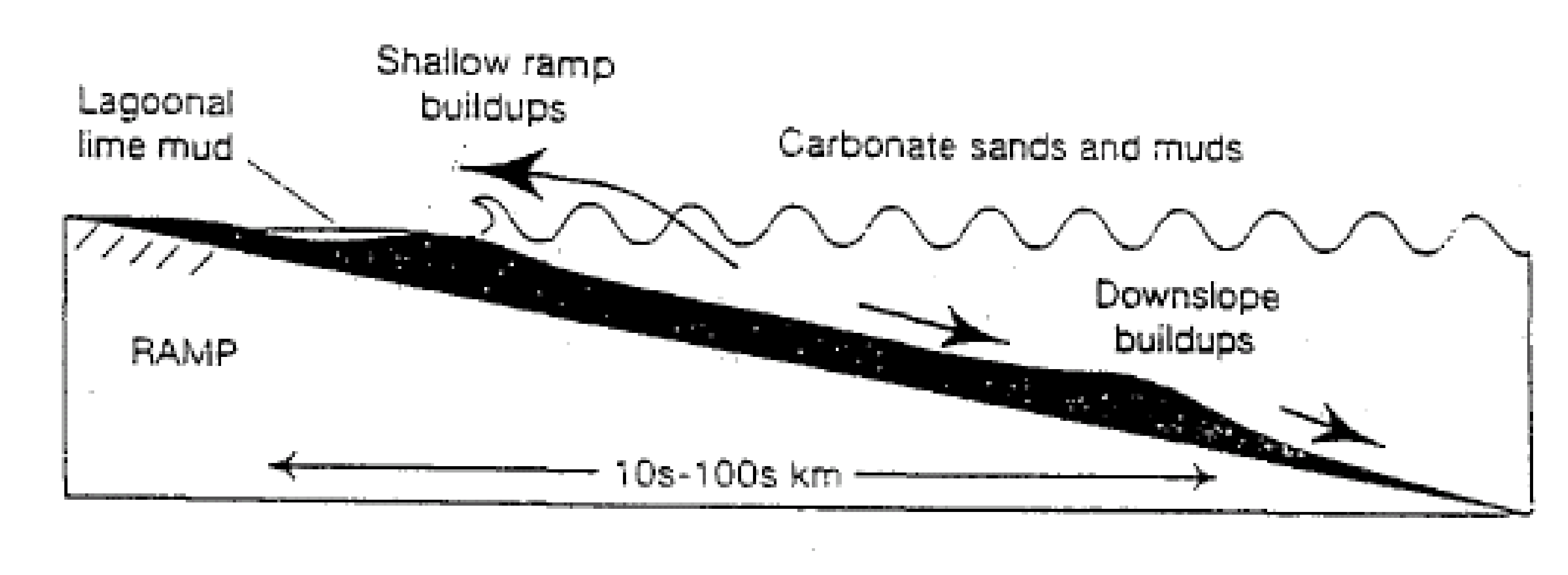
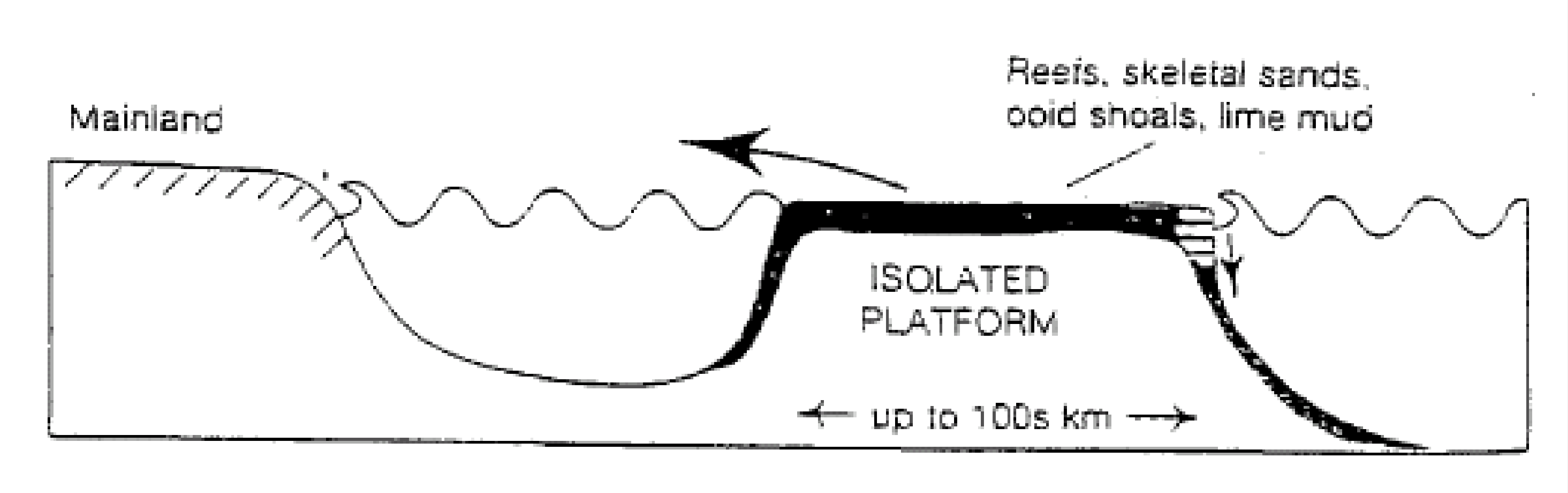
Carbonate Platforms - 1



Carbonate Platforms - 3



Carbonate Platforms - 4



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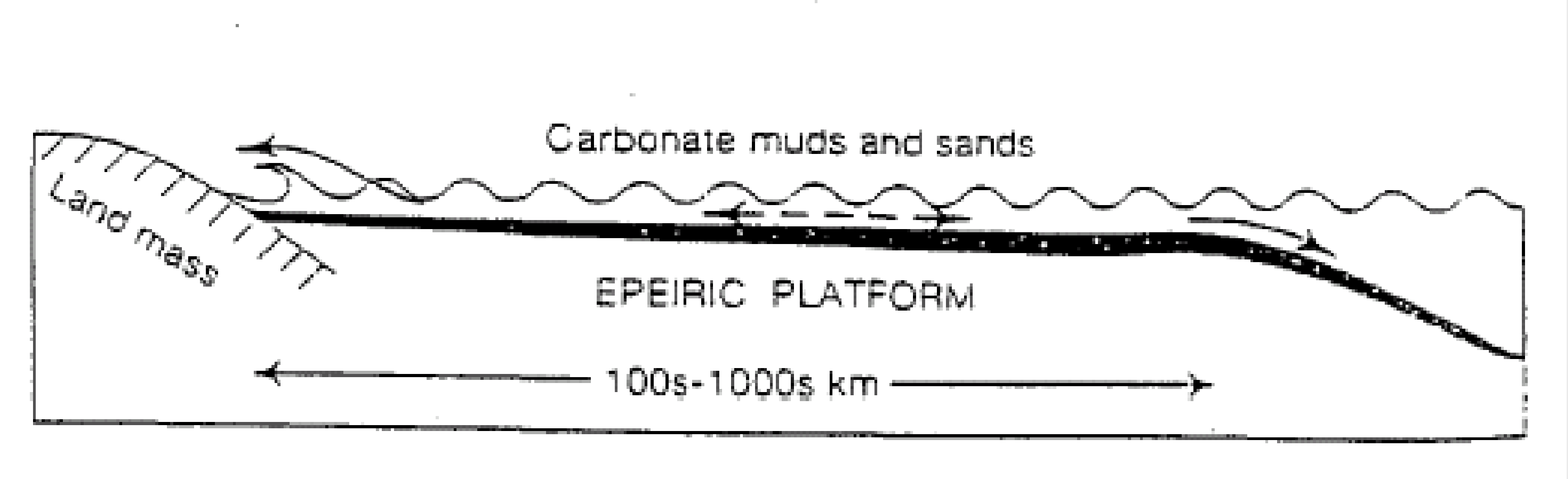
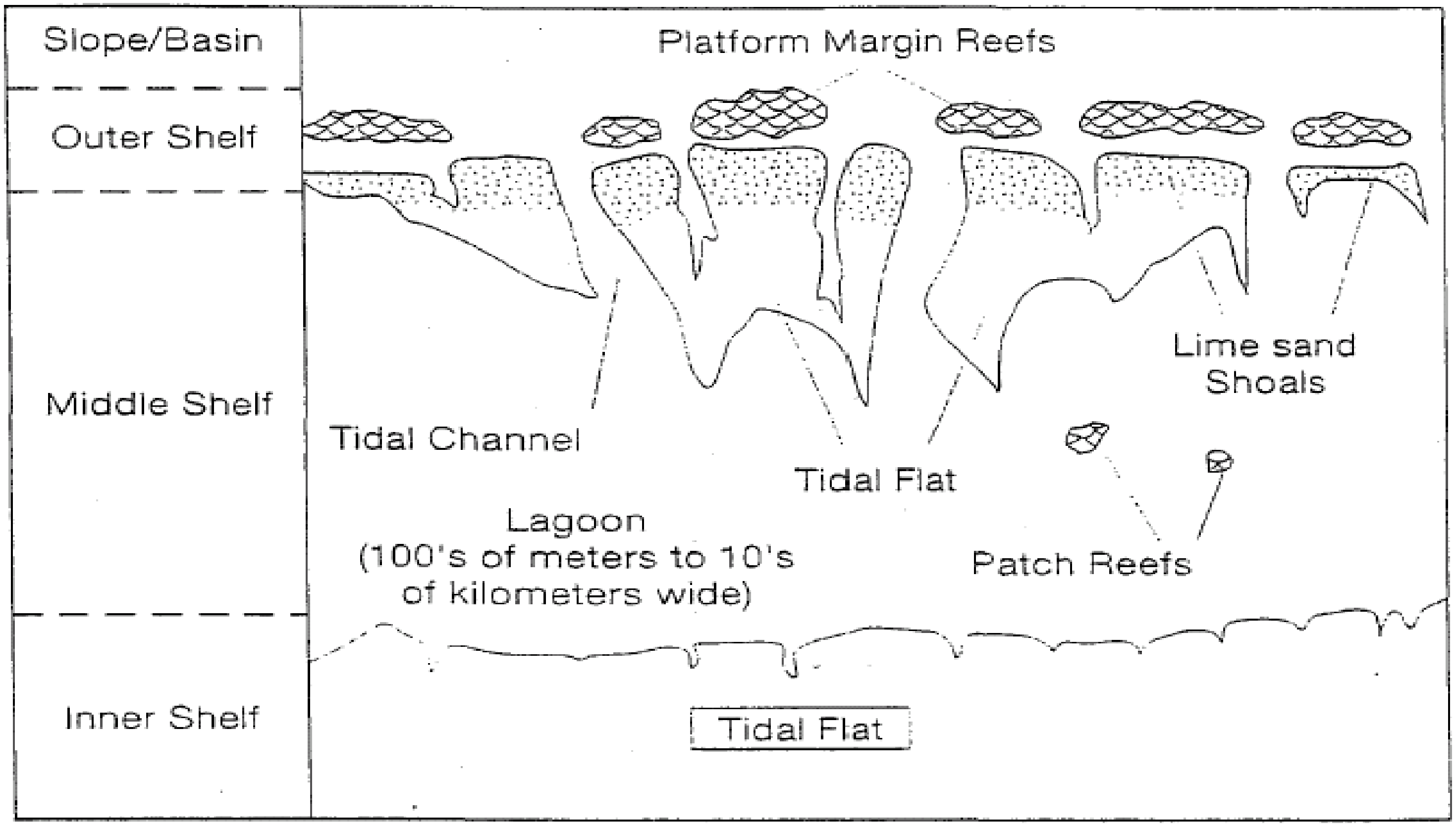
Carbonate Platforms - 5



Carbonate Platforms - 6



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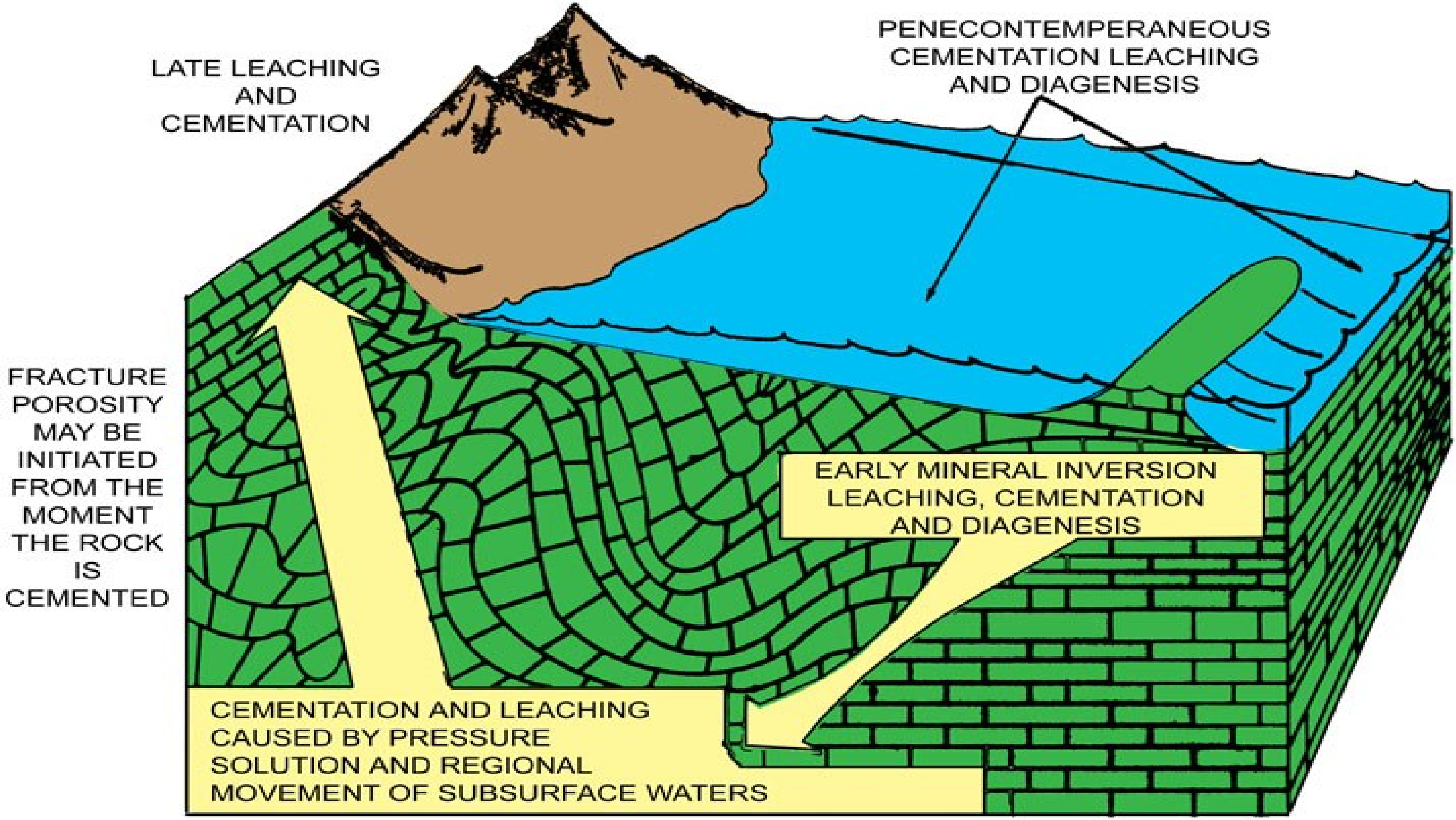

LATE LEACHING
AND
CEMENTATION
PENECONTEMPERANEOUS
CEMENTATION LEACHING
AND DIAGENESIS
FRACTURE
POROSITY
MAY BE
INITIATED
FROM THE
MOMENT
THE ROCK
IS
CEMENTED
EARLY MINERAL INVERSION
LEACHING, CEMENTATION
AND DIAGENESIS
CEMENTATION AND LEACHING
CAUSED BY PRESSURE
SOLUTION AND REGIONAL
MOVEMENT OF SUBSURFACE WATERS

DURING LIMESTONE

DEPOSITION

BURIAL

AND SUBSEQUENT UPLIFT

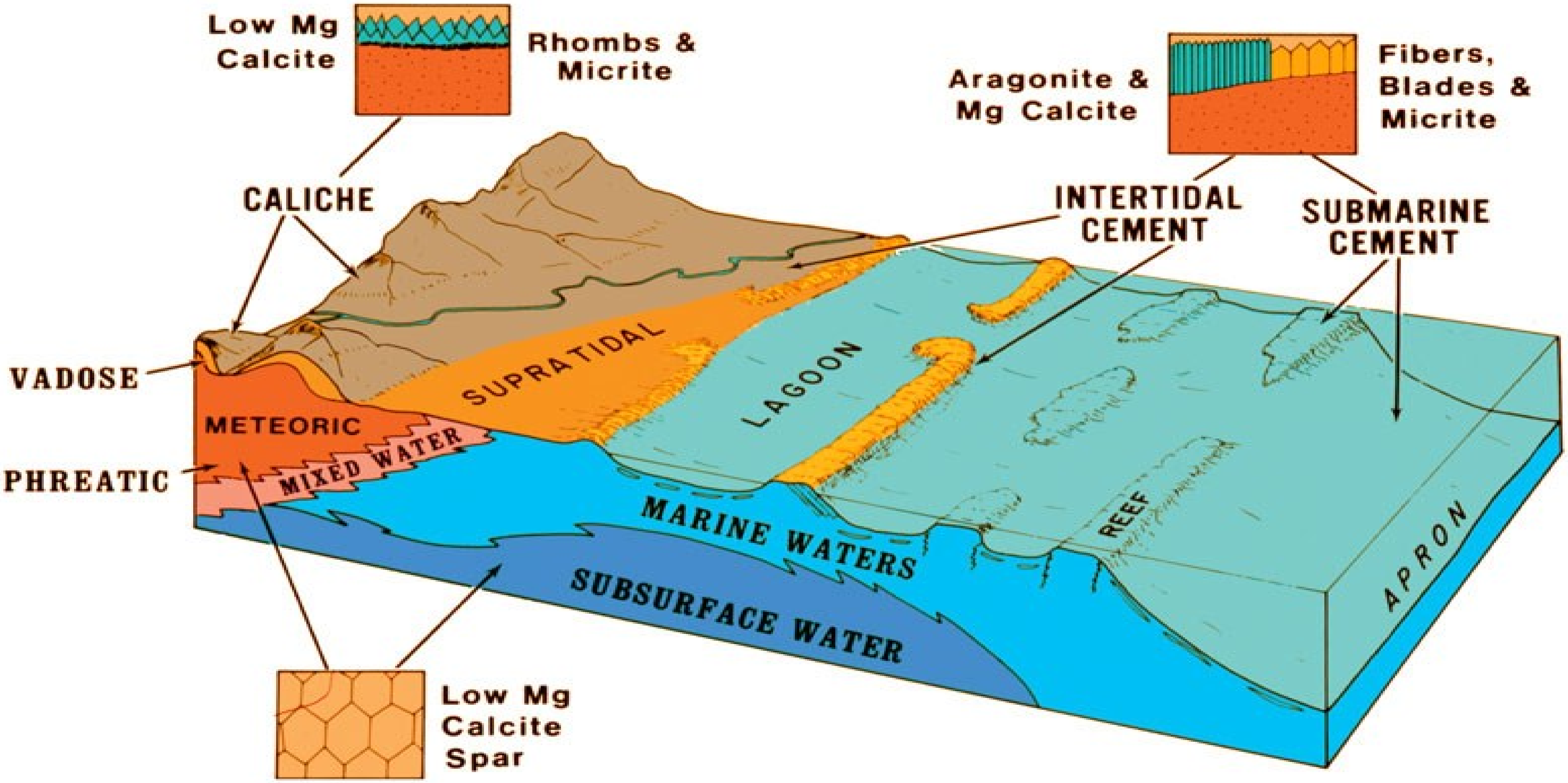
THEY UNDERGO

A. CEMENTATION

B. LEACHING

C. DIAGENESIS
   i) MINERAL ALTERATION
   ii) MINERAL INVERSION
   iii) NEOMORPHISM (RECRYSTALLIZATION GRAIN GROWTH)

Holocene Calcium Carbonate Cementation



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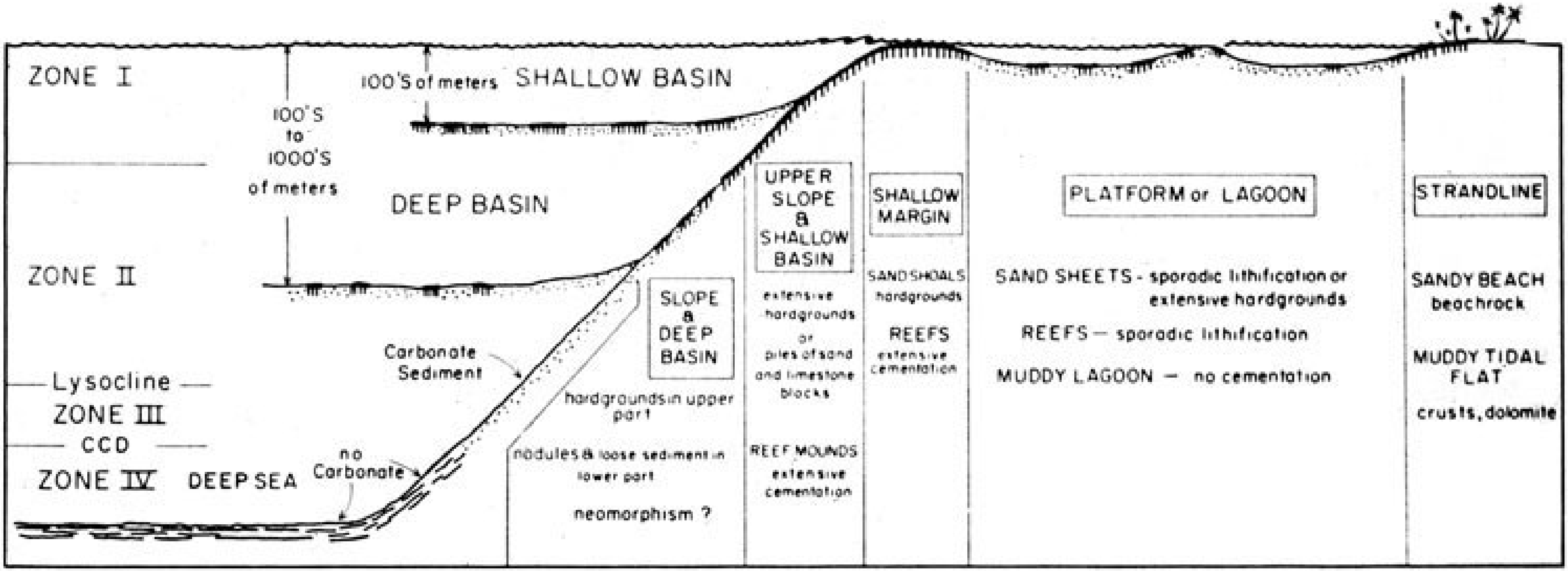


After James, 1984

Figure 5 *The locations of seafloor precipitation on a shallow, carbonate platform and in adjacent deep-water settings. In all of these habitats, most sediments are unlithified.*

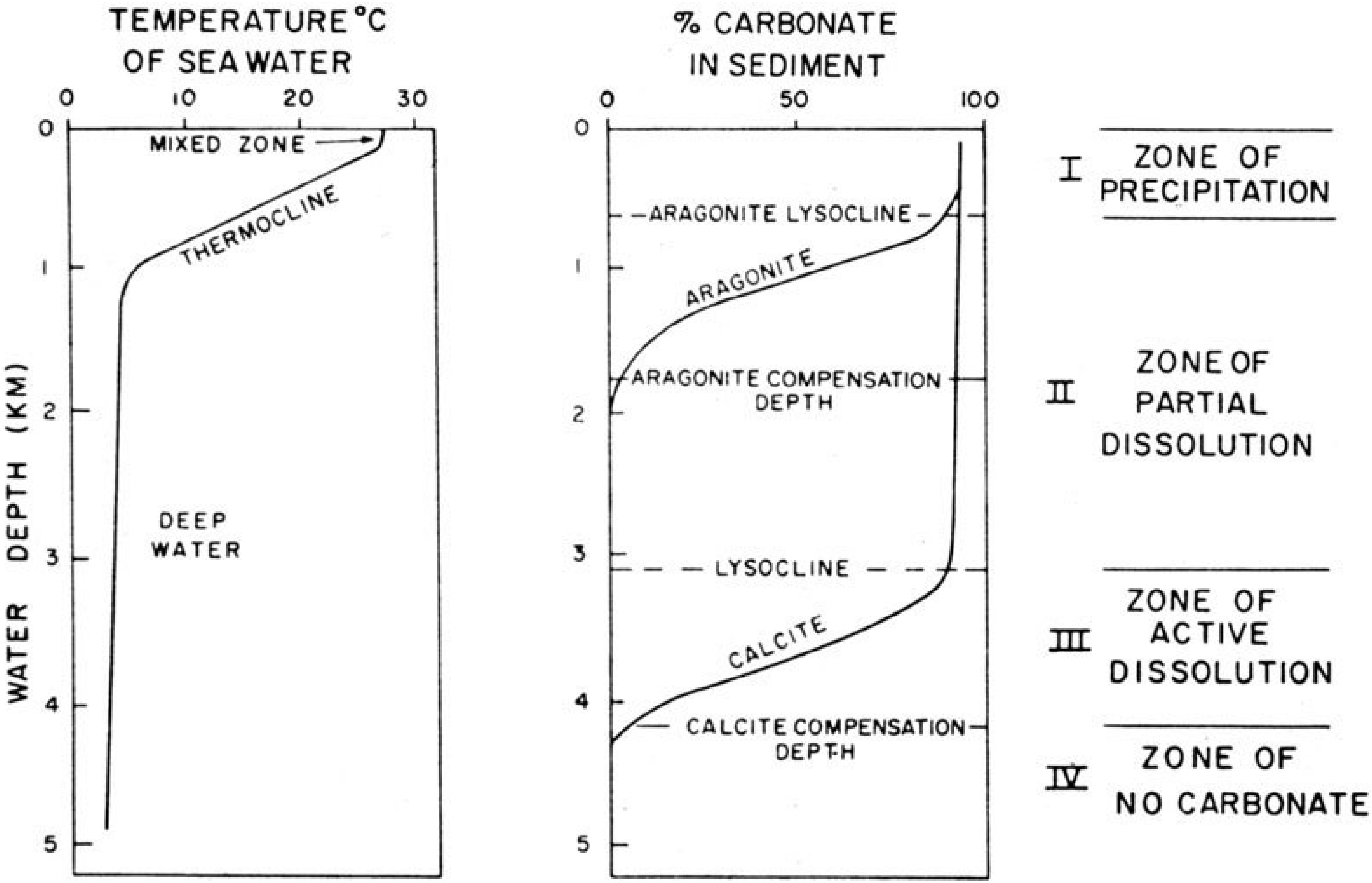
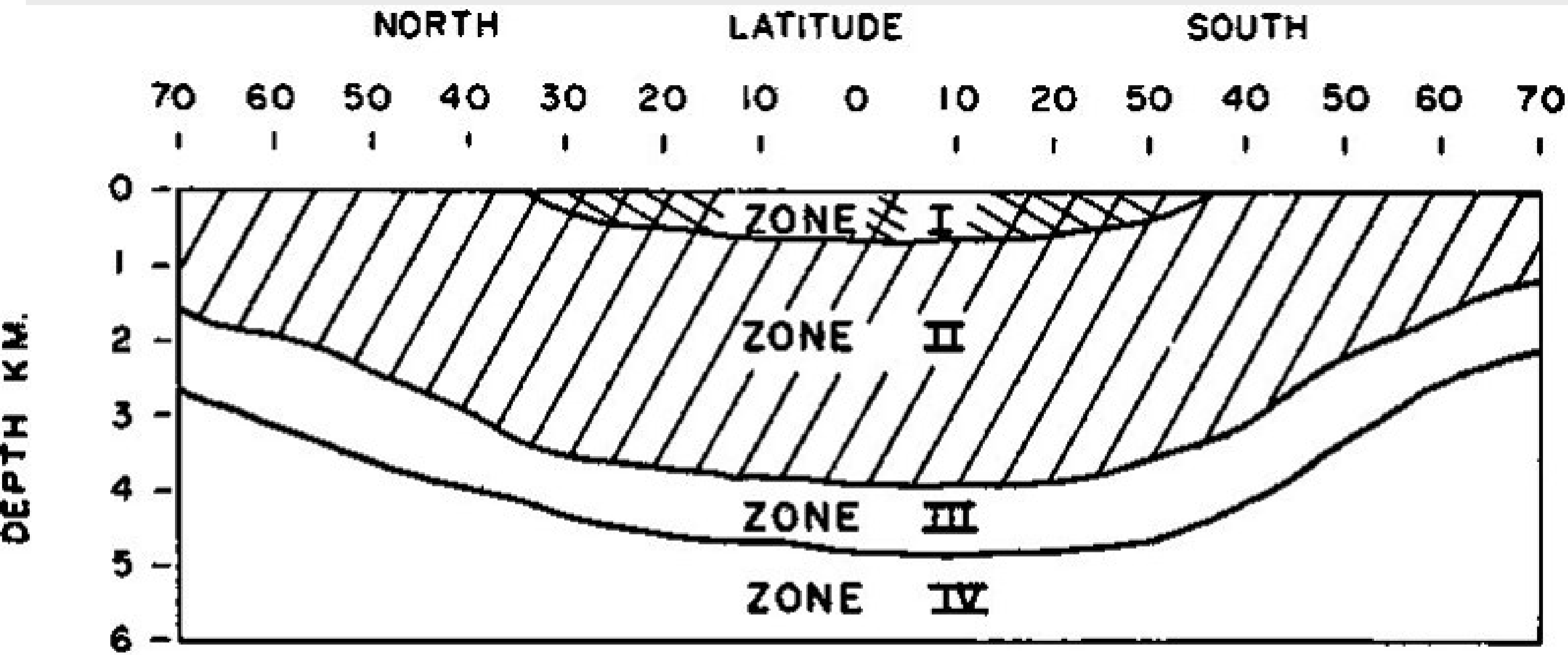


Figure 1 *Generalized diagrams illustrating the relative positions of calcite and aragonite solubility profiles in the modern tropical ocean and the variation in temperature with depth. The major zones of diagenesis are plotted to the right.*

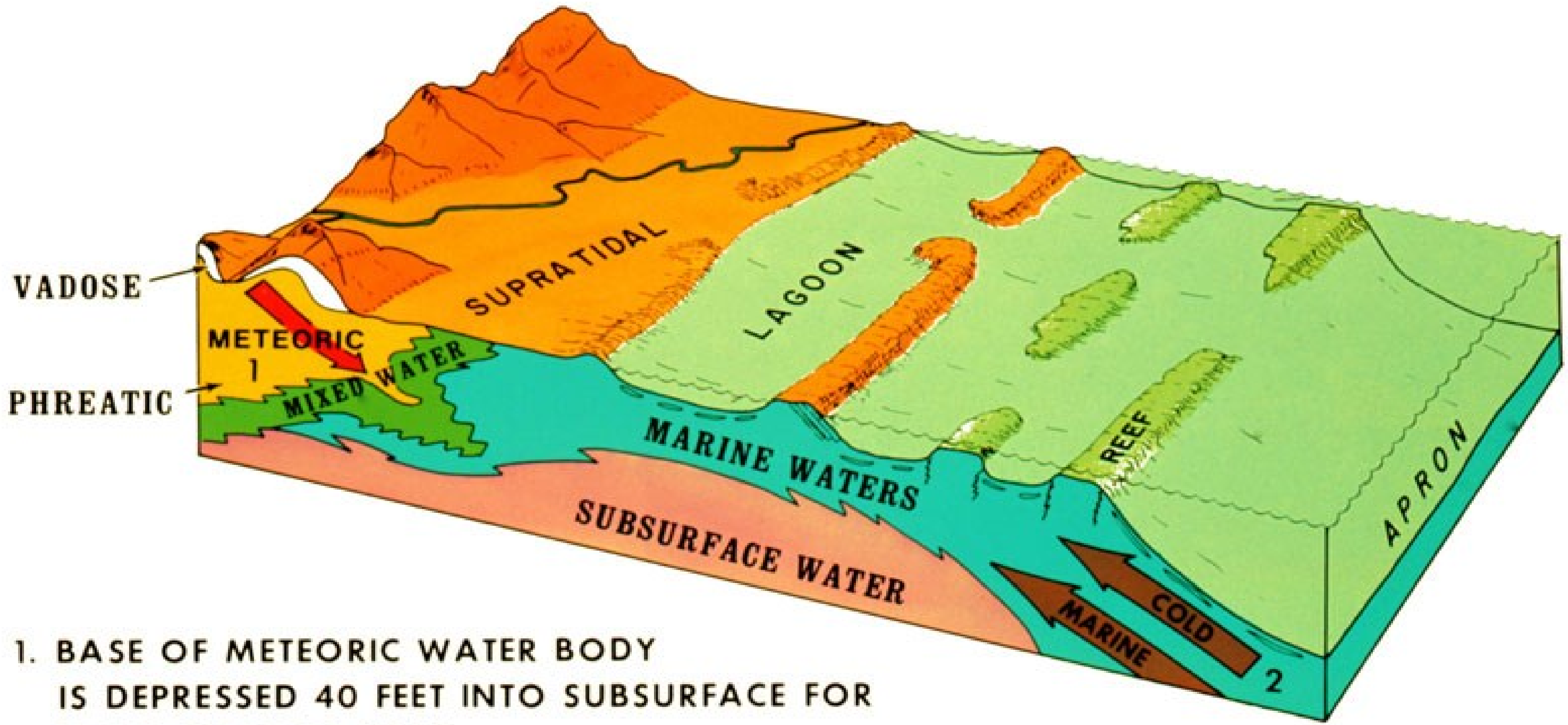
After James, 1984



After James, 1984

Figure 2 *Variations in the different zones of seafloor diagenesis in the modern ocean.*

Water Movement within Carbonate Sediments During and Just After Deposition

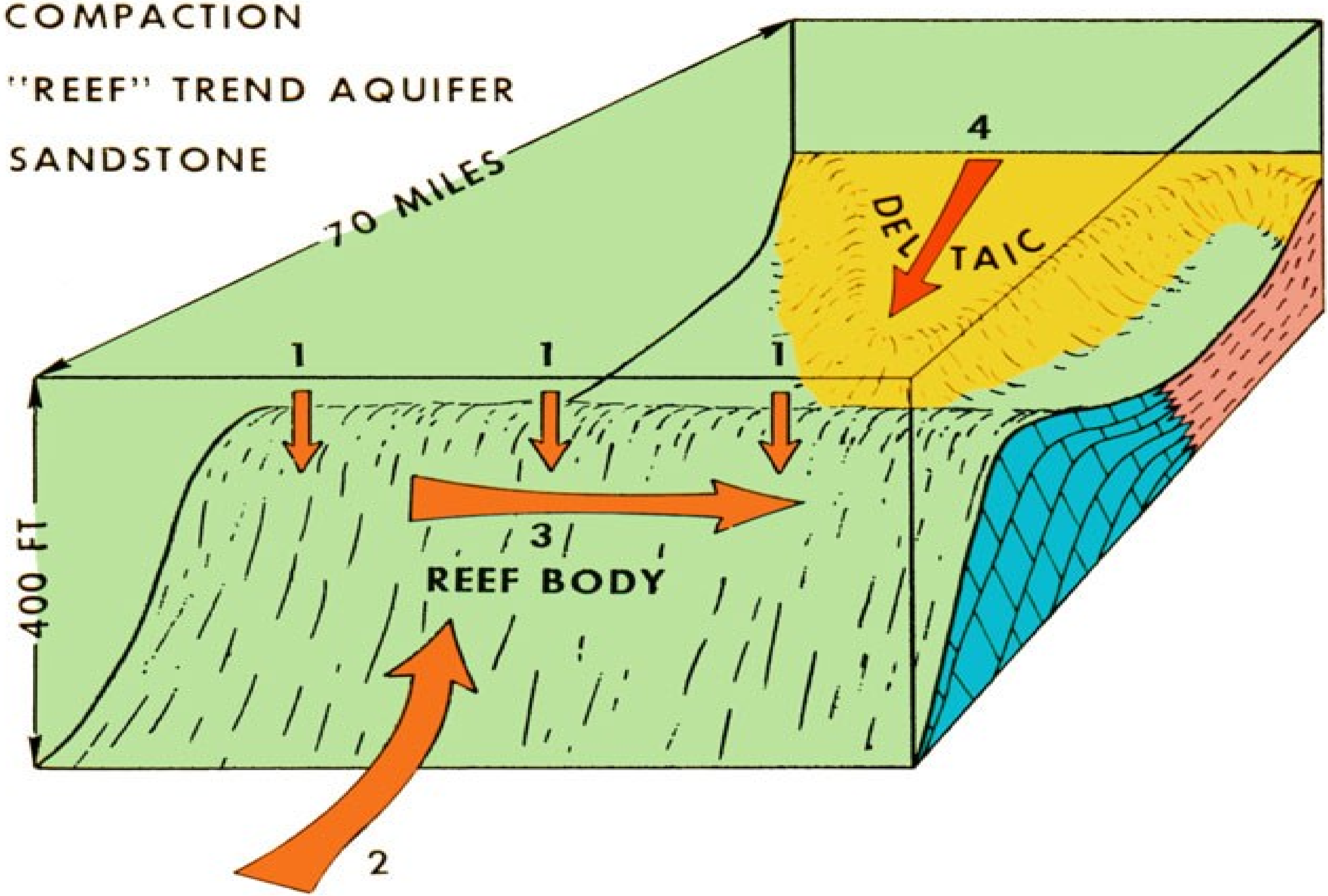


1. BASE OF METEORIC WATER BODY IS DEPRESSED 40 FEET INTO SUBSURFACE FOR EVERY FOOT OF HEAD

2. COLD MARINE WATER SUCKED INTO POROUS PLATFORM SEDIMENTS TO REPLACE CONVECTING WARM SURFACE WATERS

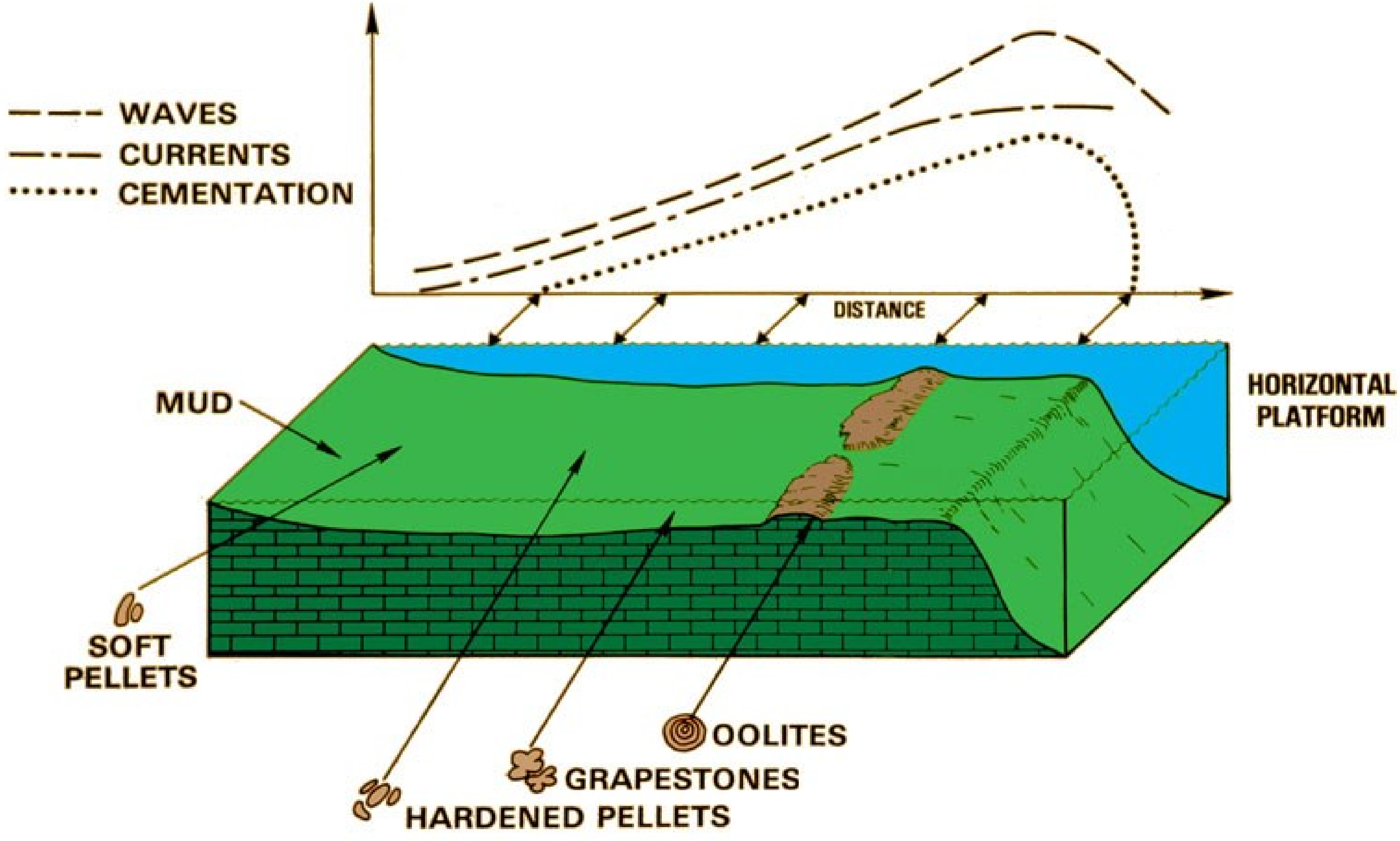
Possible Subsurface Water Movements

1. LOCAL METEORIC
2. OFFSHORE COMPACTION
3. REGIONAL "REEF" TREND AQUIFER
4. REGIONAL SANDSTONE AQUIFER



THERE CAN ALSO BE STRUCTURALLY CONTROLLED REGIONAL MOVEMENTS OF WATER UNRELATED TO LITHOLOGY

RELATIONSHIP OF GRAIN MORPHOLOGY TO CEMENTATION AND WAVE AND CURRENT REGIME



CEMENTATION DURING SEDIMENT DEPOSITION

MARINE ENVIRONMENT:

1. FORMATION OF { OOLITES, GRAPESTONES, PELLET HARDENING }
2. SUBMARINE
   - A. REEF CAVITY CEMENT
   - B. SEDIMENT SURFACE CRUSTS
3. INTERTIDAL
   - A. SUBSURFACE CRUSTS
   - B. SEDIMENT SURFACE CRUSTS

STABLE MARINE CEMENTS:

ARAGONITE —— FIBERS, AND MICRITE

HIGH MAGNESIUM CALCITE —— FIBERS, BLADES AND MICRITE

OOLITE FORMATION

ALGAE AND BACTERIA INVEST OOLITE
IN MUCILAGENOUS ENVELOPE

STAGE 1 | STAGE 2 | STAGE 3

OOLITE COMES TO REST

ARAGONITE FIBERS ARE PRECIPITATED ON SURFACE

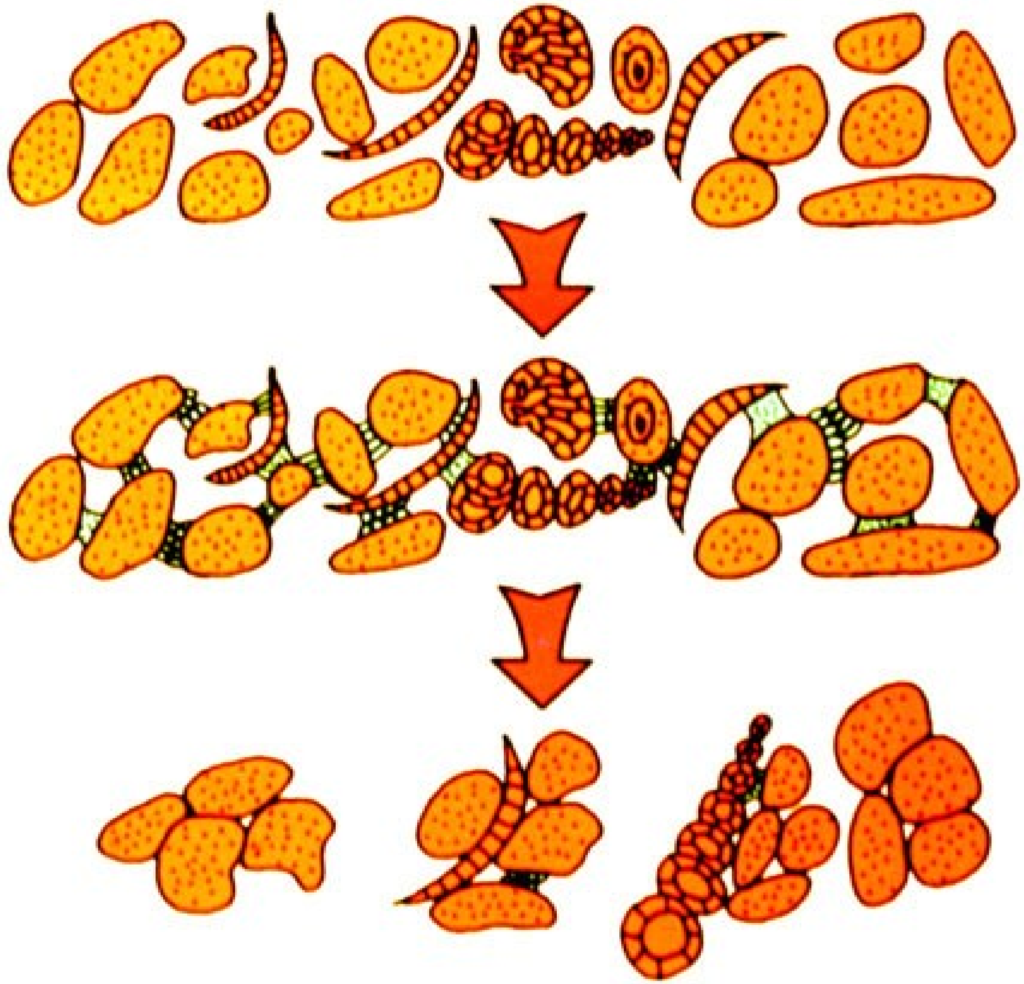
ABRASION FLATTENS TANGENTIAL CRYSTALS AND REMOVES OTHERS. POLISHED ORIENTED SURFACE PRODUCED

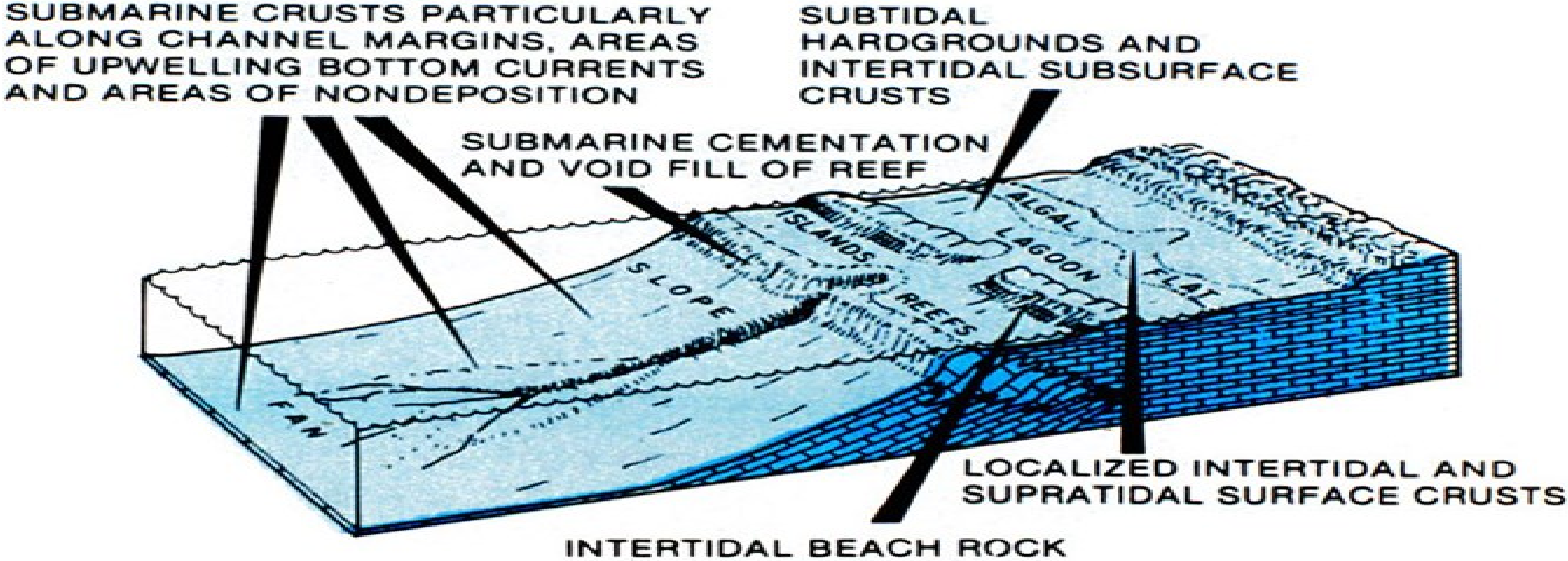
SOURCE OF CARBONATE LUMPS

1. ACCUMULATION OF LOOSE CARBONATE SAND

2. PRECIPITATION OF MARINE CARBONATE CEMENT WHILE AT REST

3. BREAK UP OF LAYER BY STORM INTO LUMPS





DIAGENETIC EFFECTS OF MARINE WATERS

MICRITIZATION

NEOMORPHIC GRAIN GROWTH

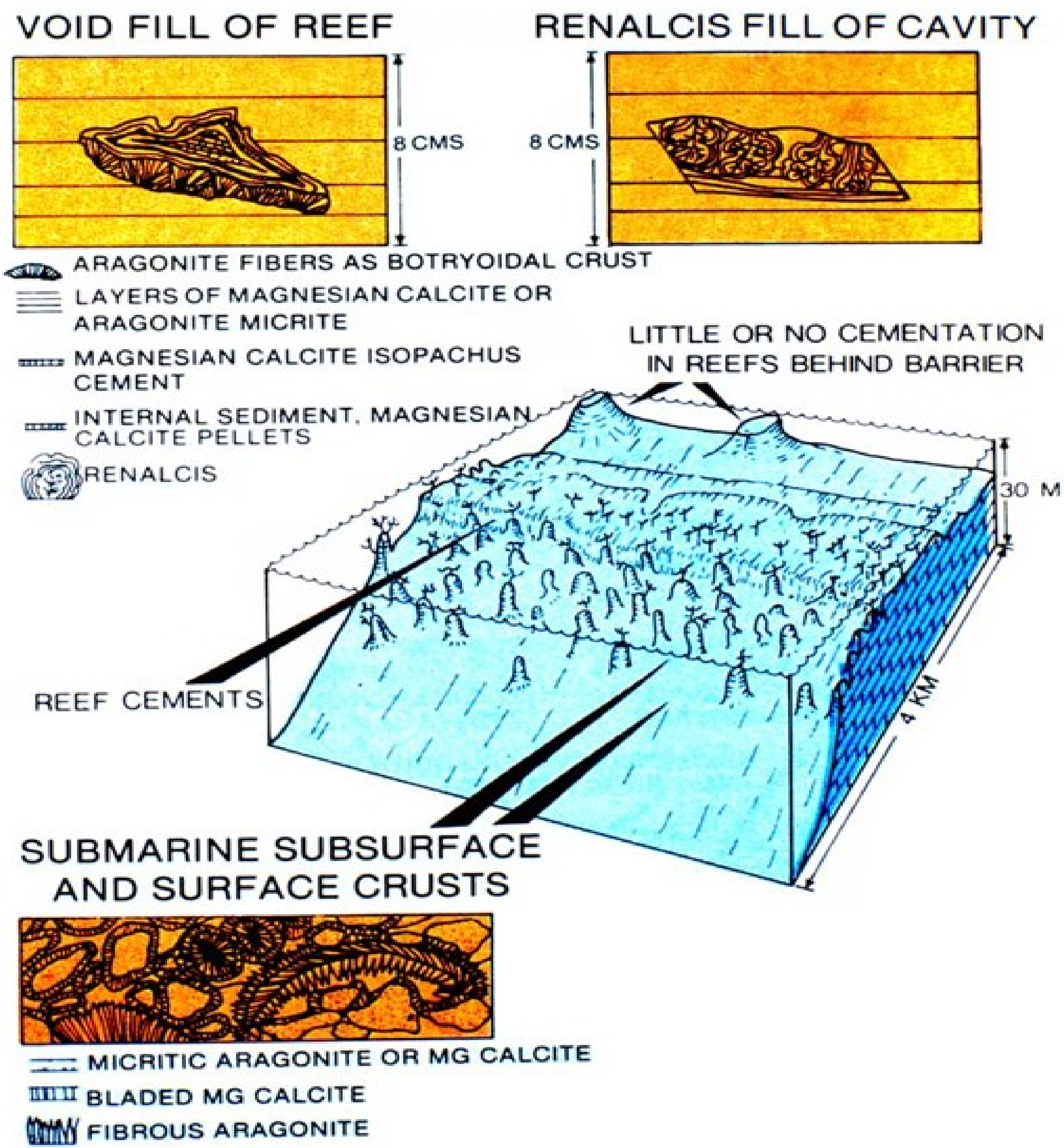
CEMENTATION DURING SEDIMENT DEPOSITION

FORMATION OF { OOLITES, GRAPESTONES, PELLET HARDENING

SUBMARINE, INTERTIDAL { CRUSTS

STABLE MARINE CEMENTS

ARAGONITE — FIBERS AND MICRITE
MG CALCITE — FIBERS. BLADES AND MICRITE



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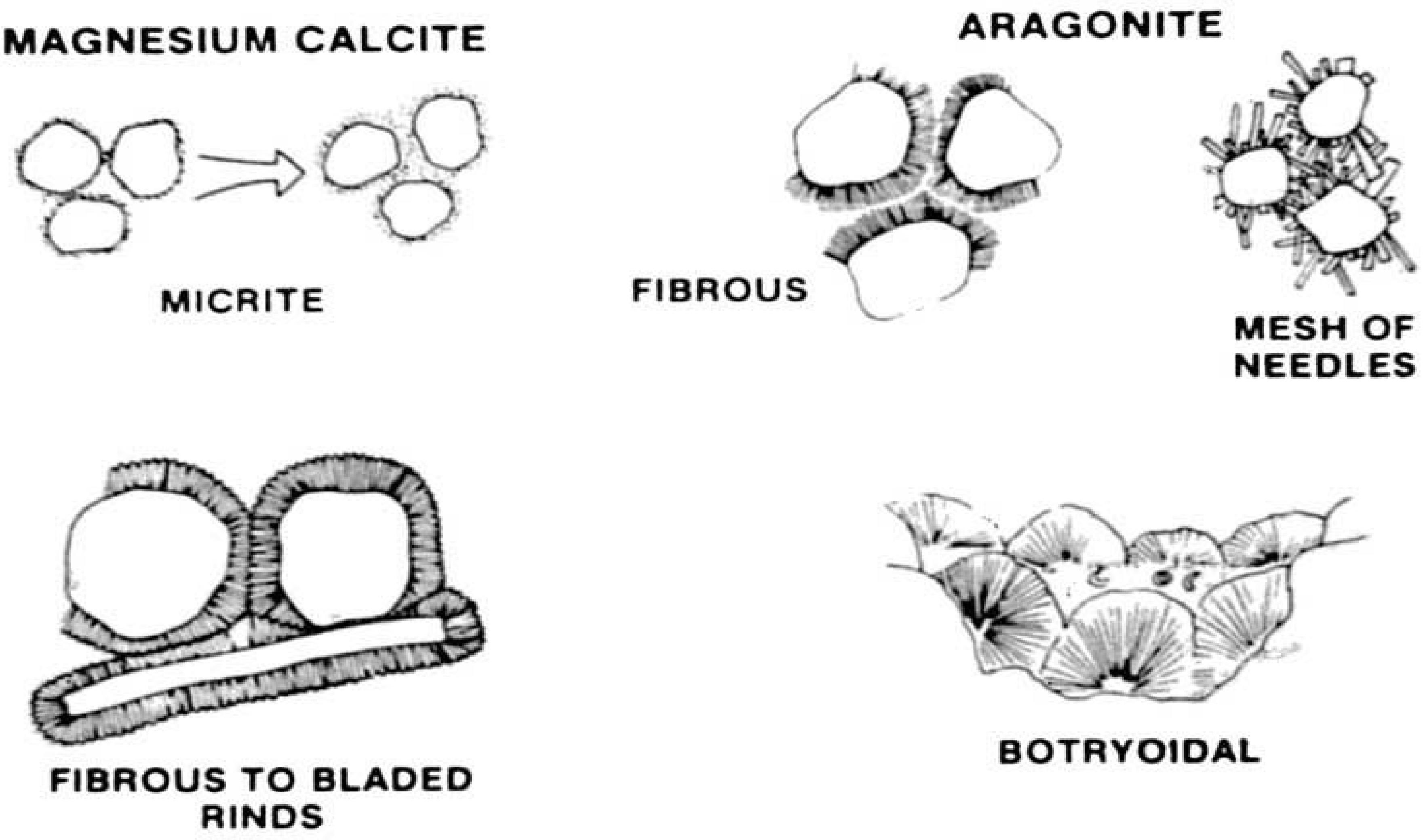


Figure 3 *Different types of modern seafloor carbonate cements.*

After James, 1984

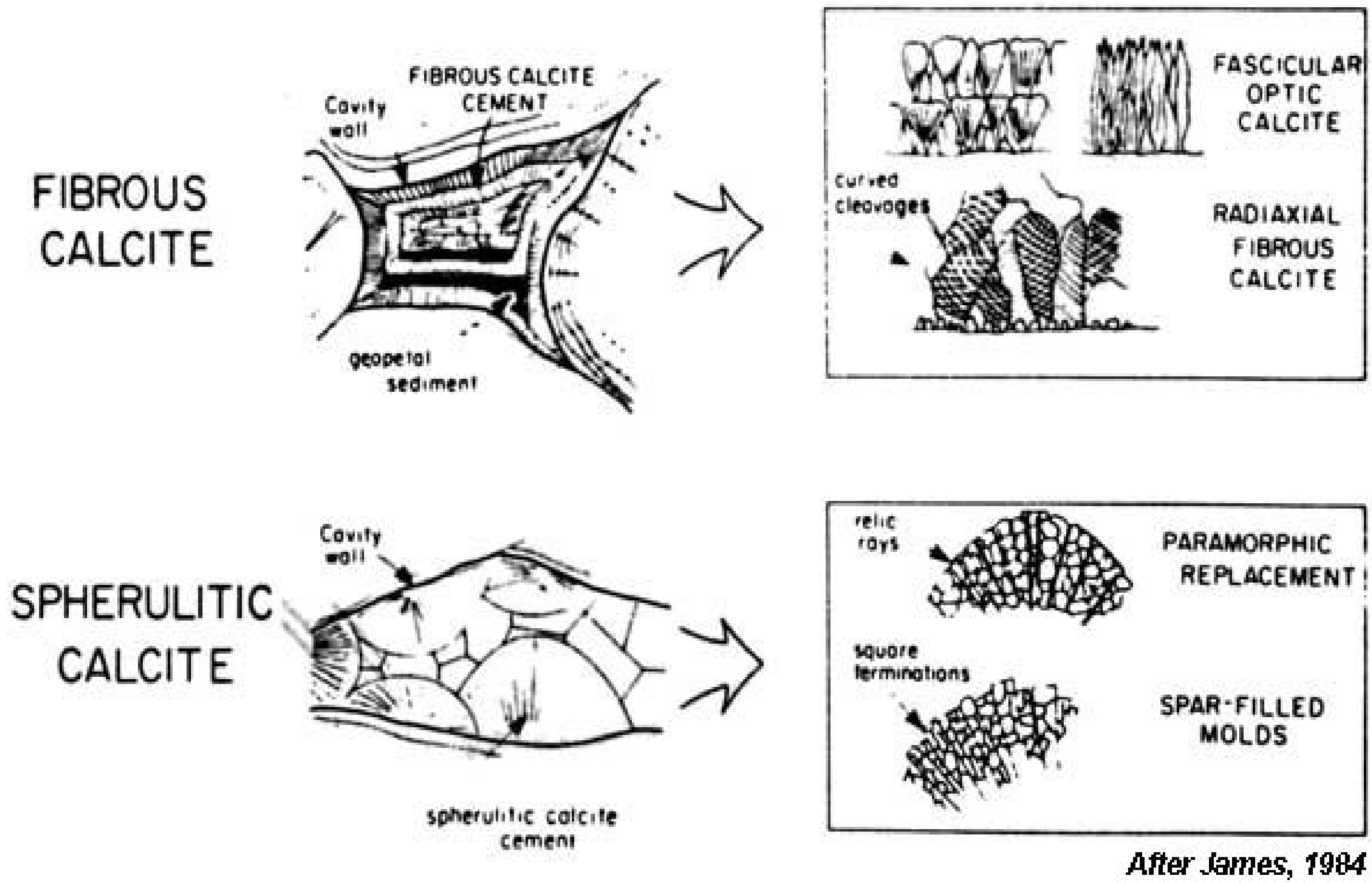
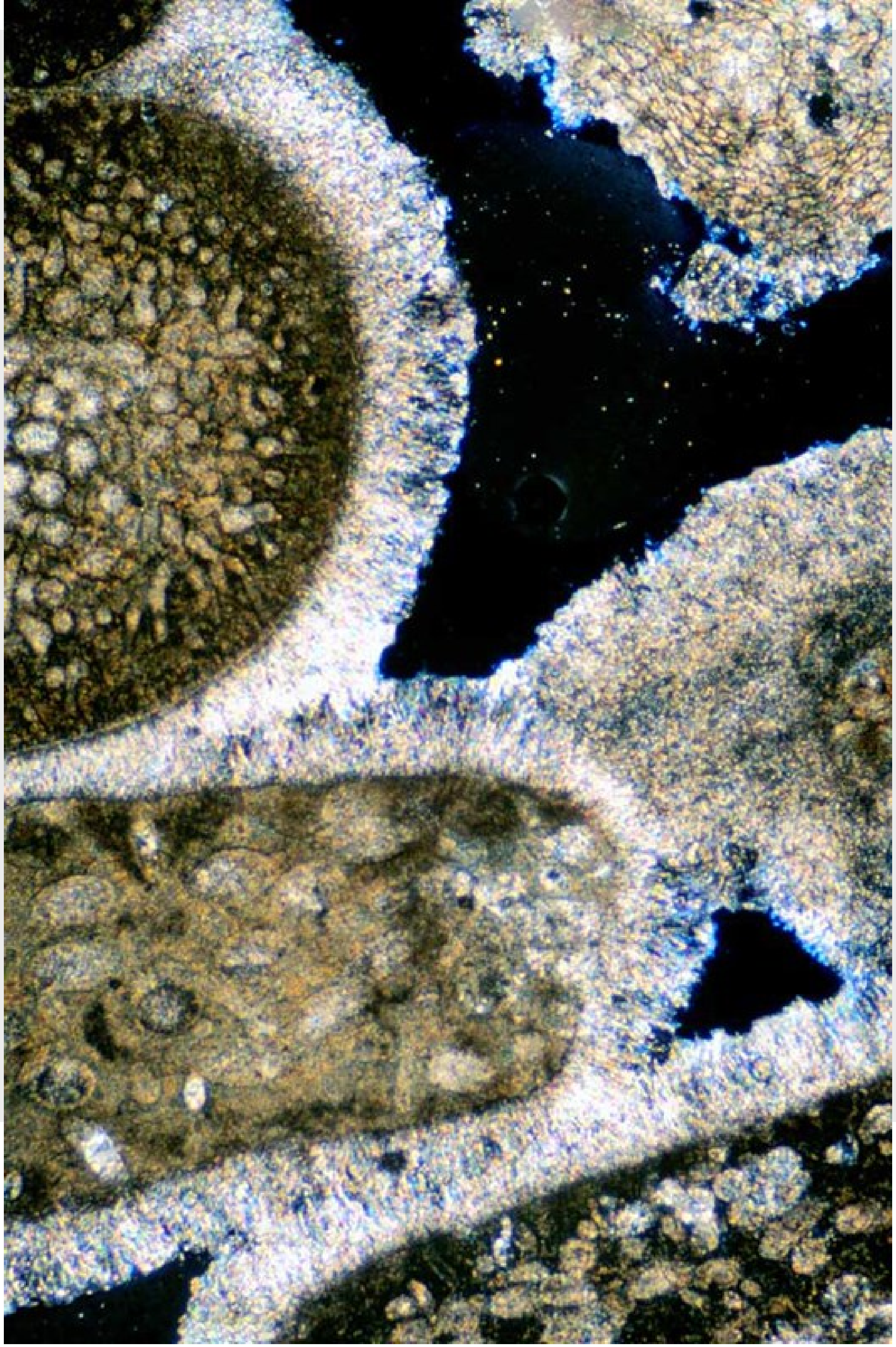


Figure 16 *Fabrics and morphologies of coarse marine cements. Fibrous calcite is generally interpreted as derived from Mg-calcite and spherulitic calcite from botryoidal aragonite.*



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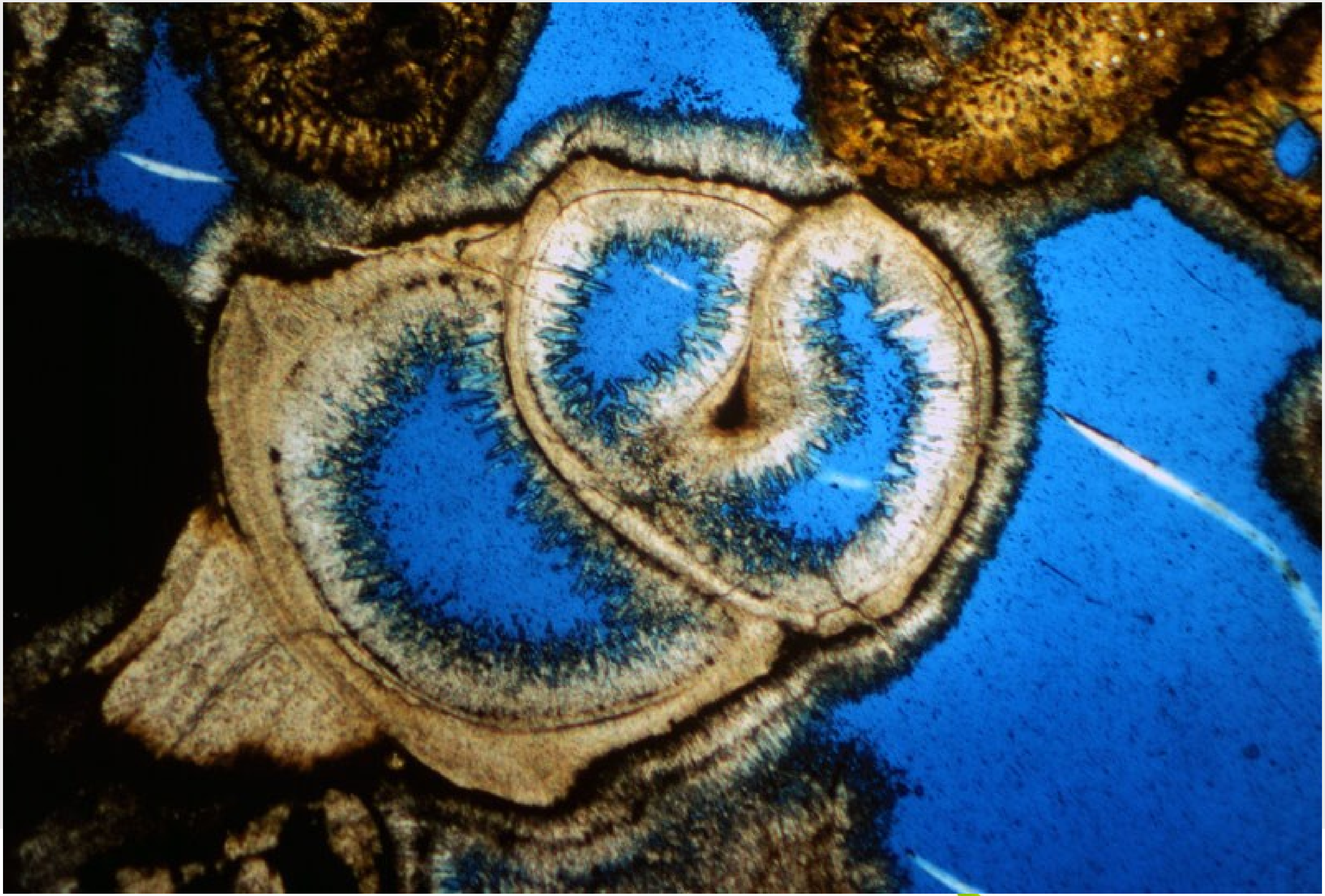

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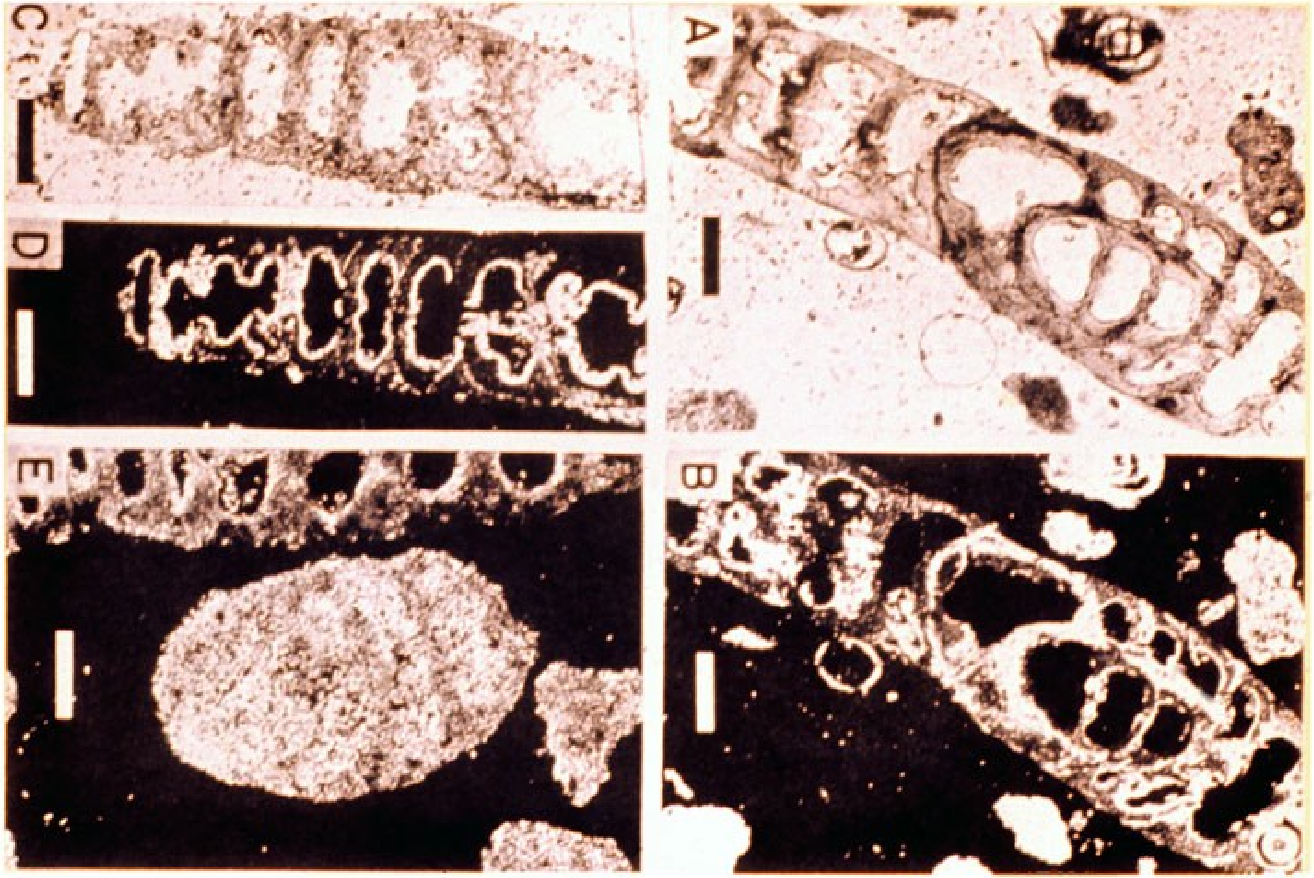
CRYPTOCRYSTALLINE GRAIN ALTERATION



Pusey, 1964

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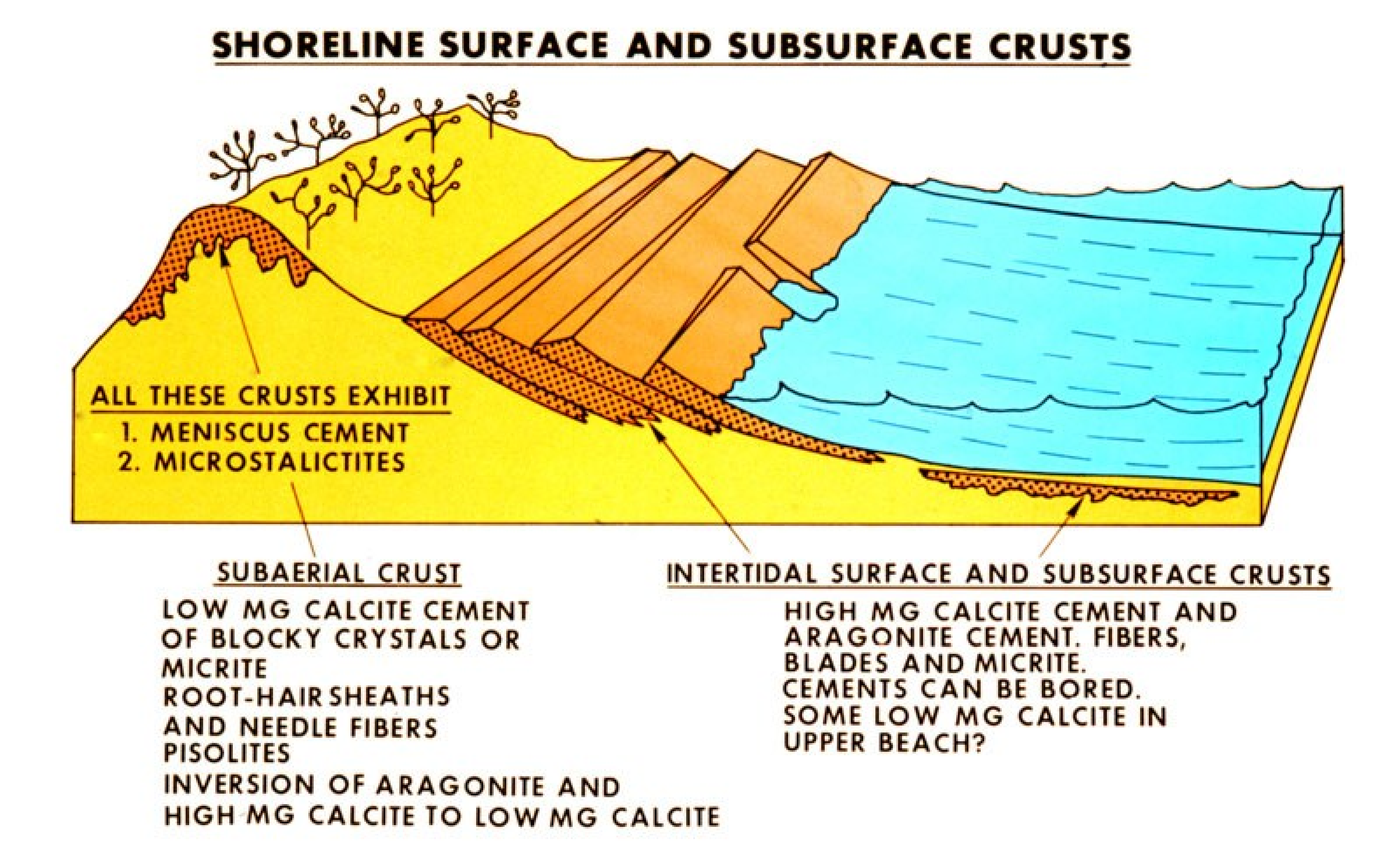
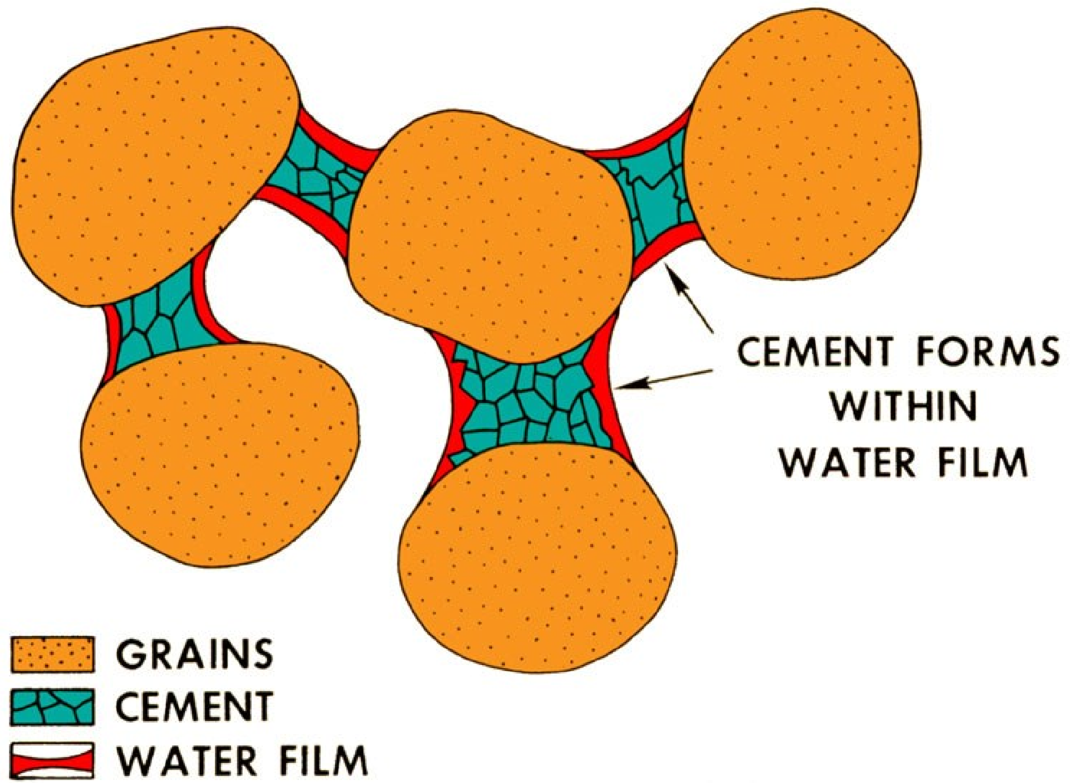
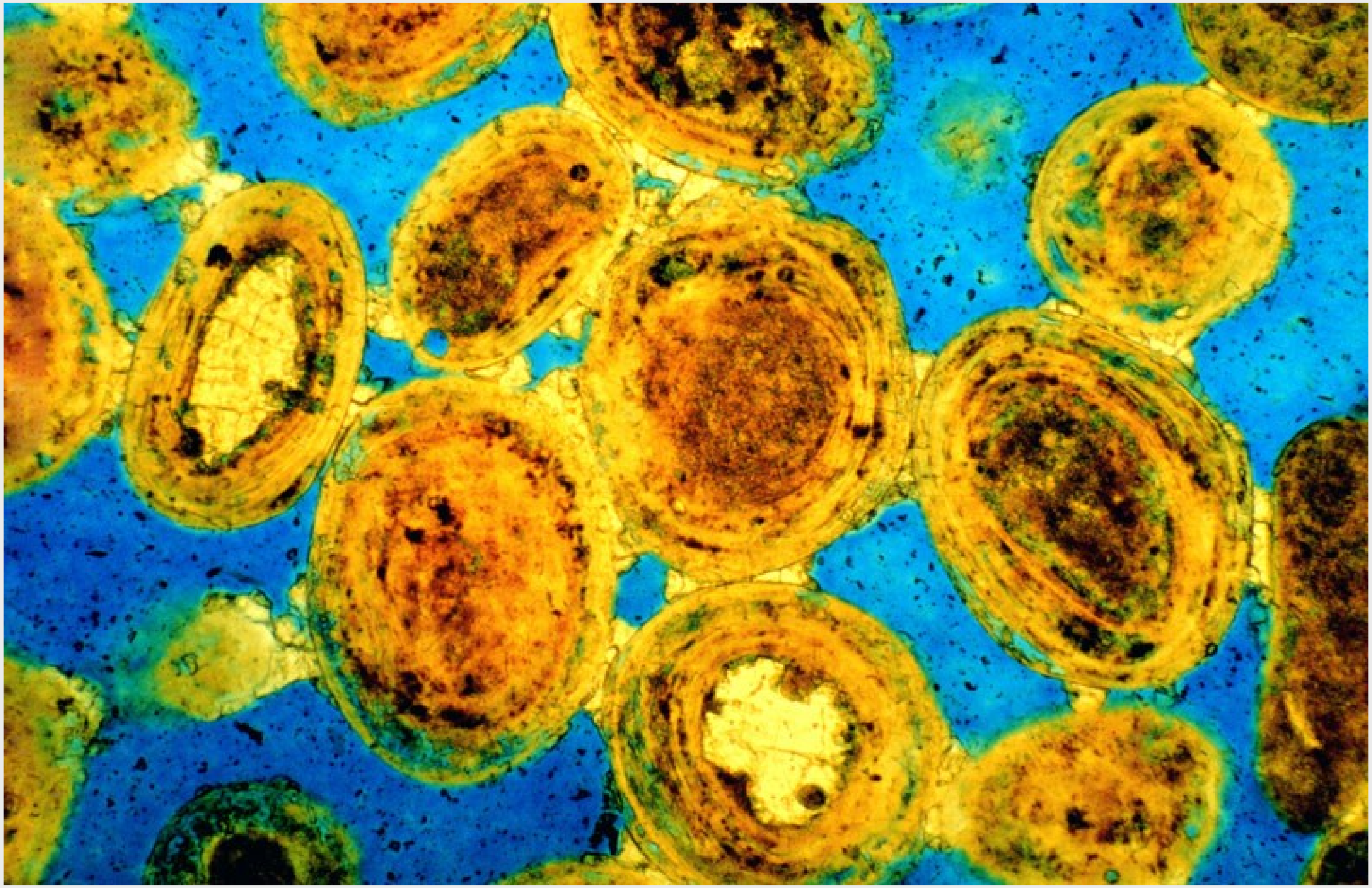

SHORELINE SURFACE AND SUBSURFACE CRUSTS
ALL THESE CRUSTS EXHIBIT
1. MENISCUS CEMENT
2. MICROSTALICTITES
SUBAERIAL CRUST
LOW MG CALCITE CEMENT
OF BLOCKY CRYSTALS OR
MICRITE
ROOT-HAIR SHEATHS
AND NEEDLE FIBERS
PISOLITES
INVERSION OF ARAGONITE AND
HIGH MG CALCITE TO LOW MG CALCITE
INTERTIDAL SURFACE AND SUBSURFACE CRUSTS
HIGH MG CALCITE CEMENT AND
ARAGONITE CEMENT. FIBERS,
BLADES AND MICRITE.
CEMENTS CAN BE BORED.
SOME LOW MG CALCITE IN
UPPER BEACH?

Meniscus Cement Formed in "Wet" Sediment Above Water Table





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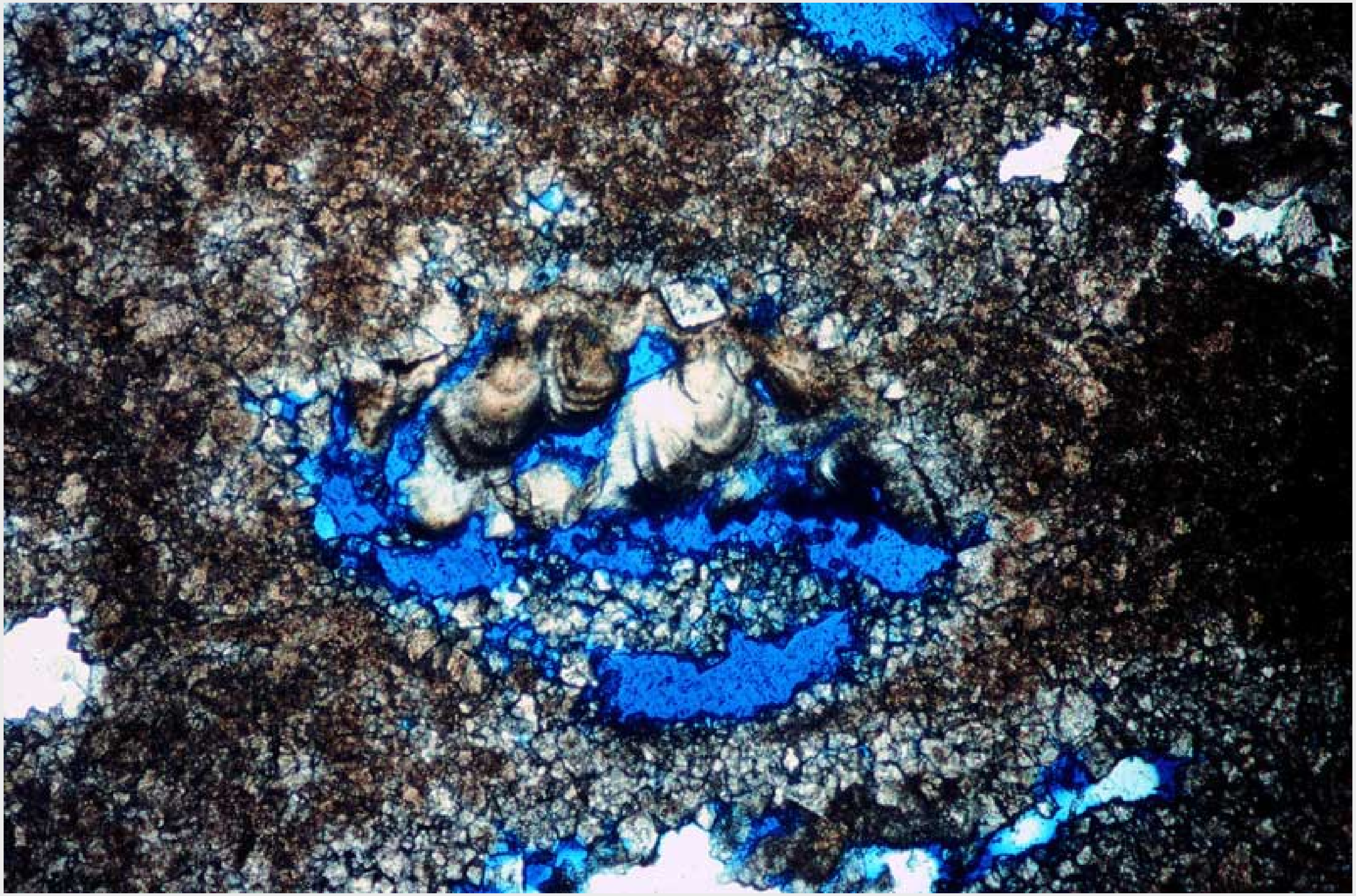

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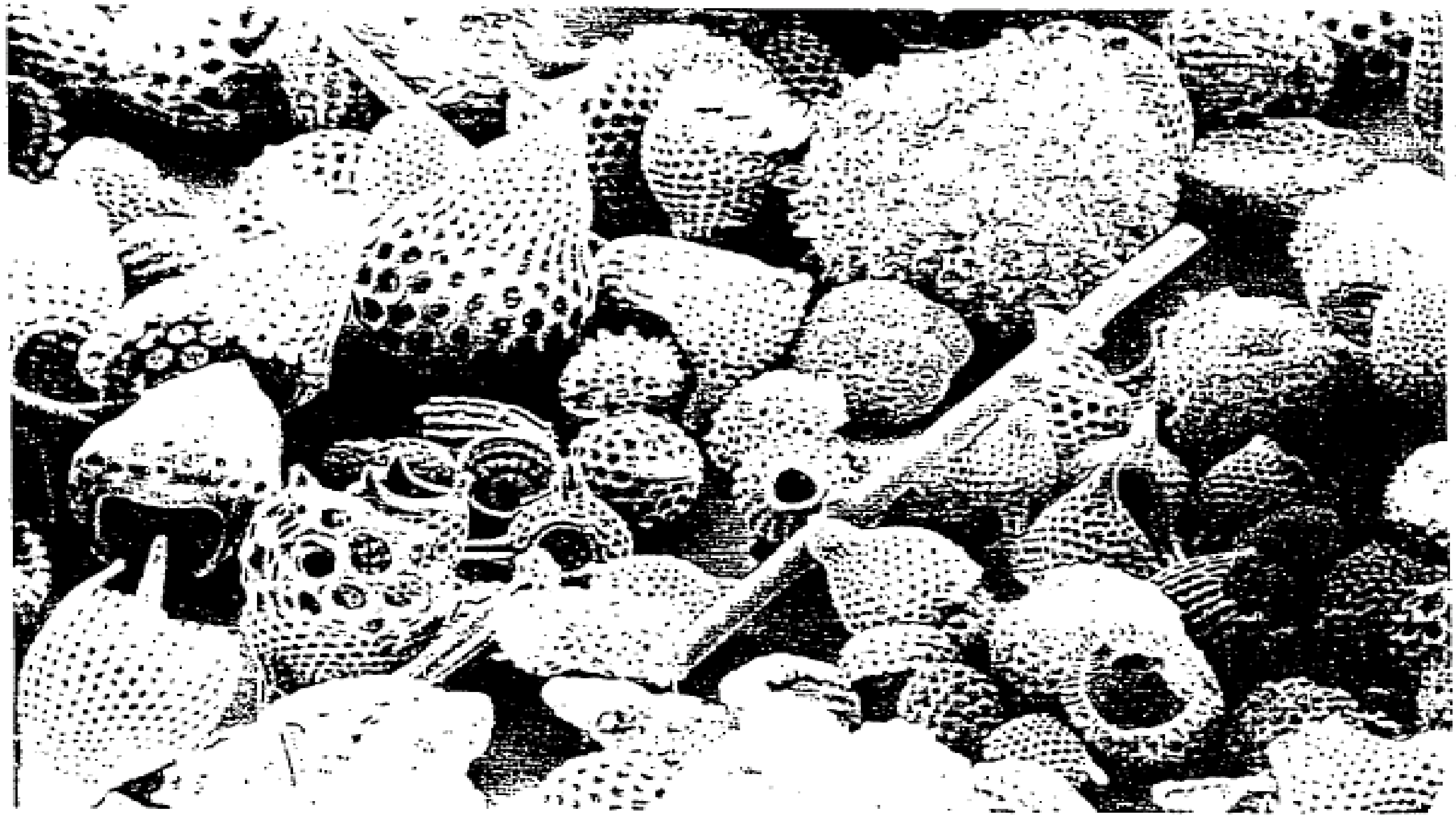

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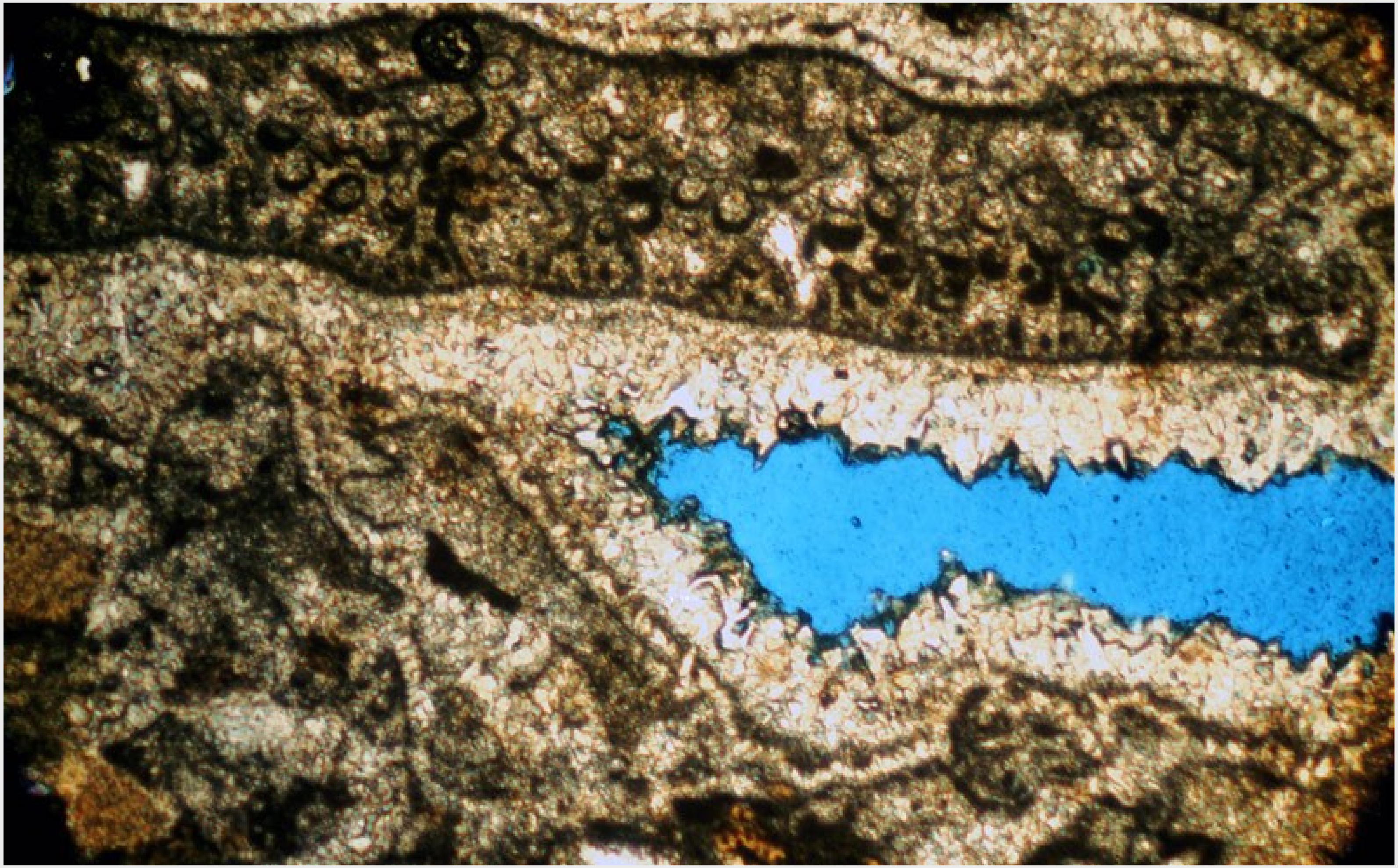
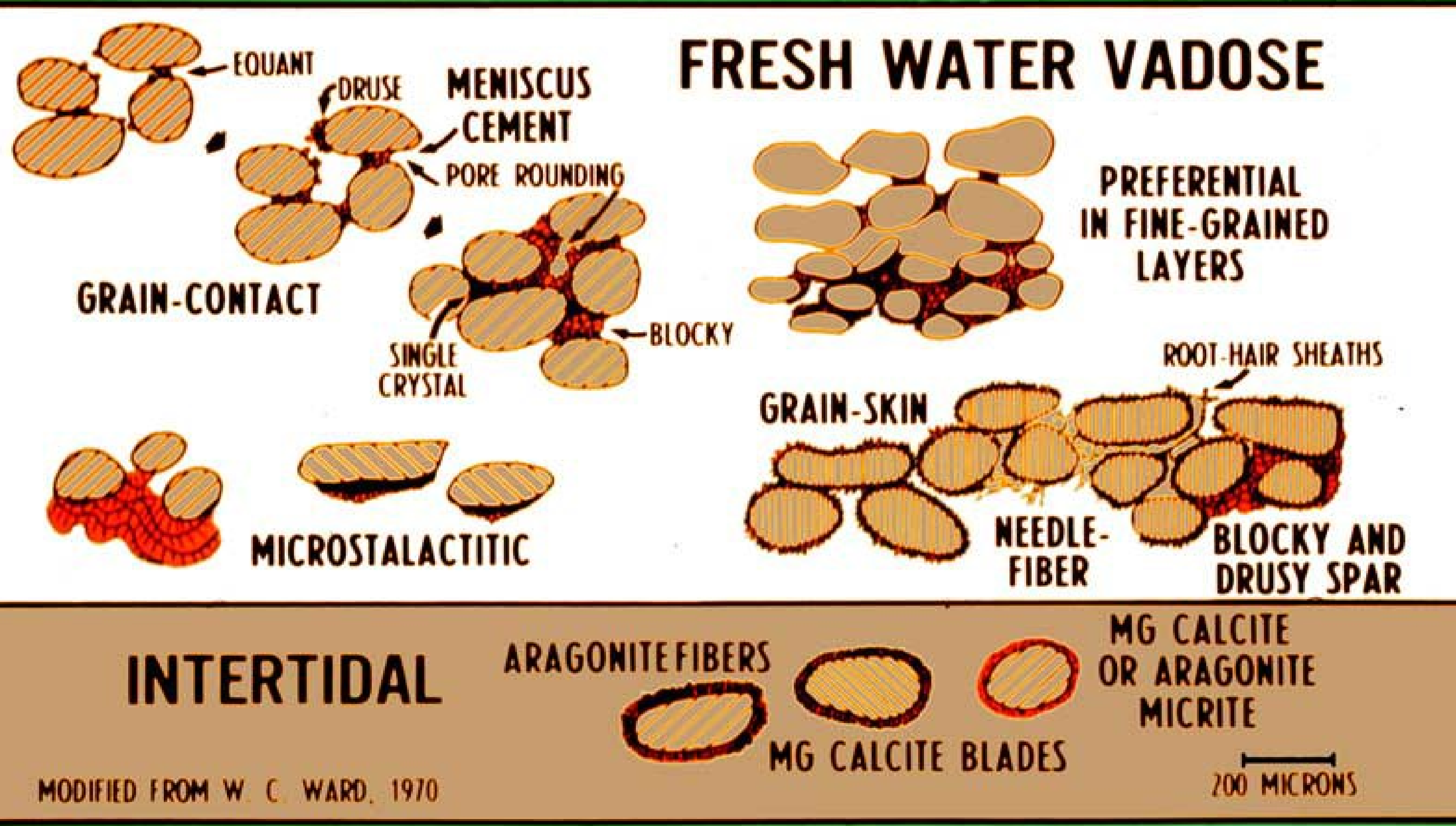
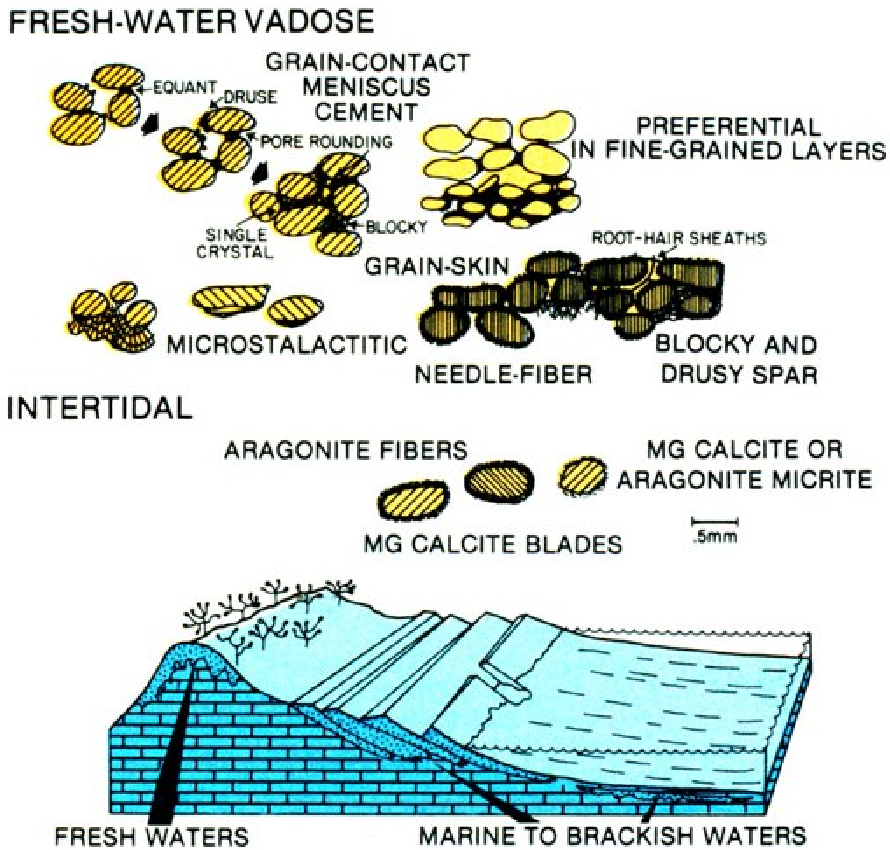


Near Shore Cementation



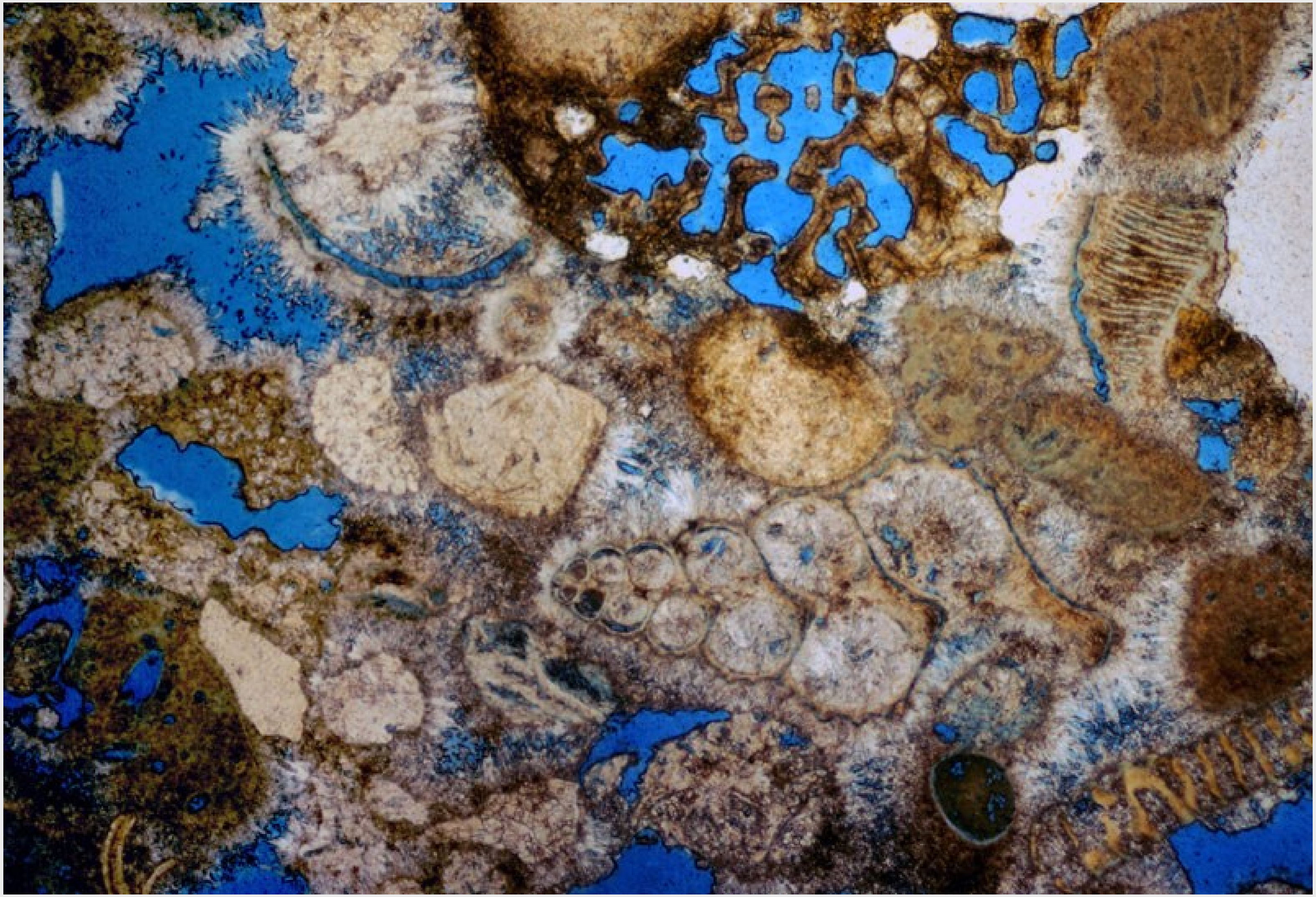


SUBAERIAL CRUSTS, CALICHE, CONCRETIONS AND CEMENT

- CALCITE BLOCKY CRYSTALS OR MICRITE WITH MENISCUS OR MICROSTALACTITIC FABRIC
- ROOT-HAIR SHEATHS AND NEEDLE FIBERS
- PISOLITES
- INVERSION OF ARAGONITE AND MG CALCITE TO CALCITE

INTERTIDAL SURFACE AND SUBSURFACE CRUSTS

- MG CALCITE CEMENT AND ARAGONITE CEMENT, FIBERS, BLADES AND MICRITE
- CEMENTS CAN BE BORED
- SOME CALCITE IN UPPER BEACH



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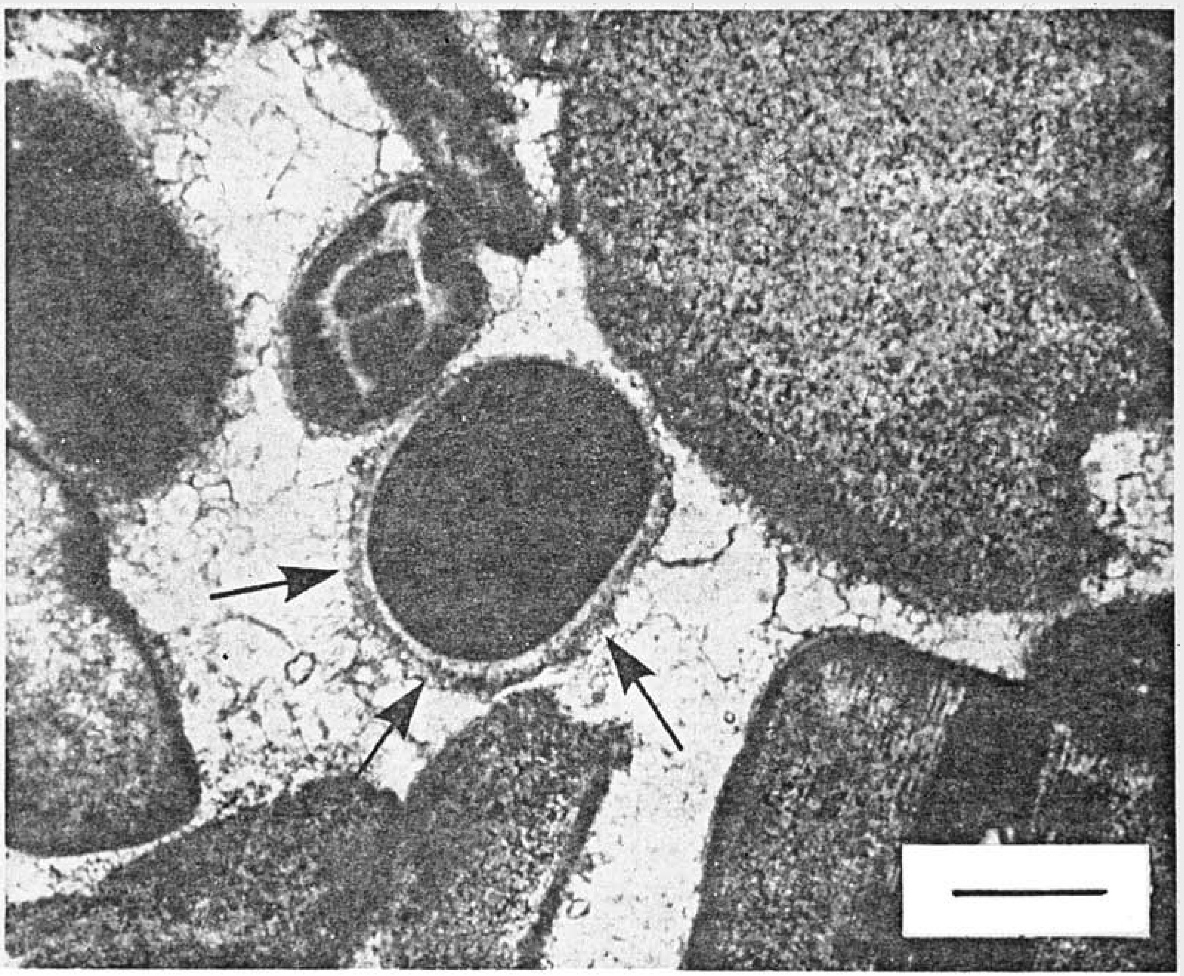


Figure 15 *Photomicrograph of a bioclastic grainstone from the Ste. Genevieve Formation (Mississippian) Bridgeport Field, Illinois Basin, in which the first cement is a fringe of fibrous calcite that is thickest on the undersides of grains (arrows) resembling small stalagtites. This early cement probably developed while the sediment was beachrock. (scale 2 mm).*

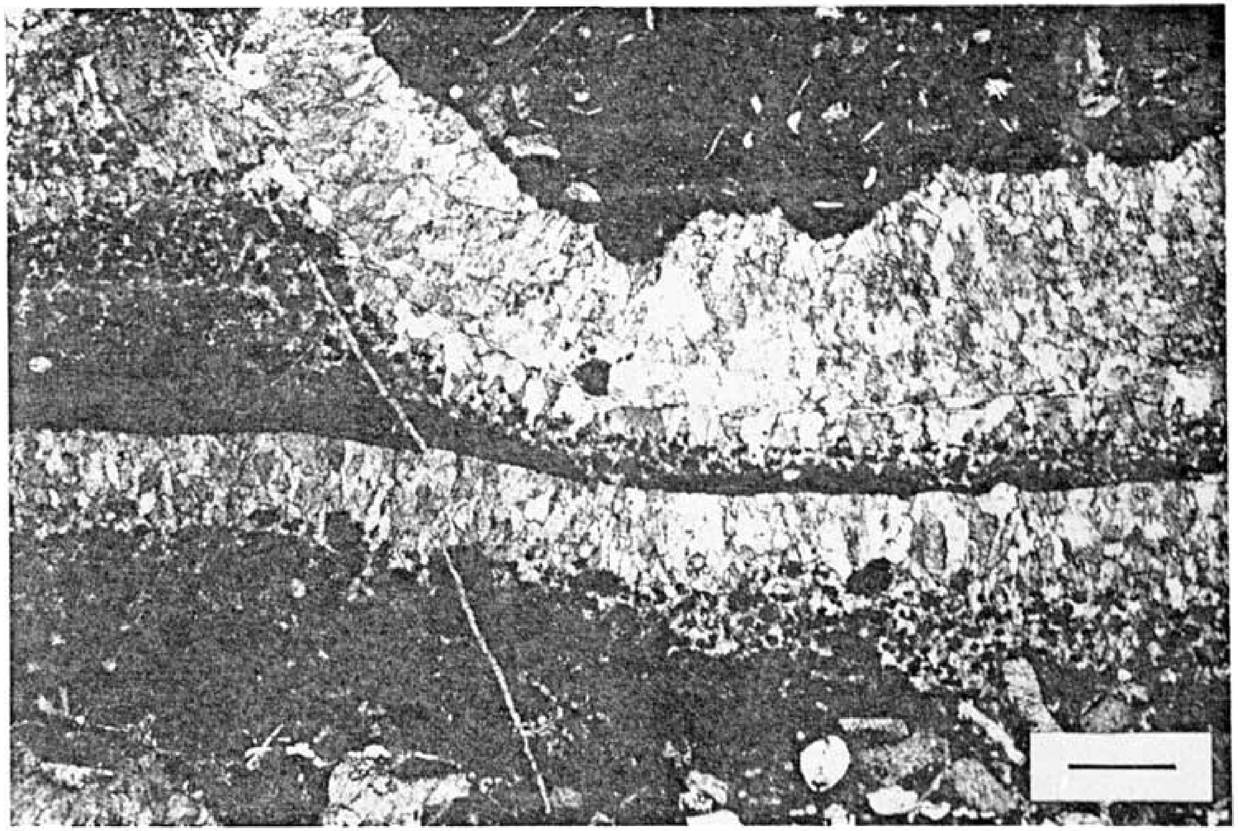


Figure 13 *Photomicrograph of interlayered marine sediment and radiaxial fibrous calcite cement in laminar cavities from a Middle Ordovician reef mound at Meiklejohn Peak, Nevada (scale 1 mm).*

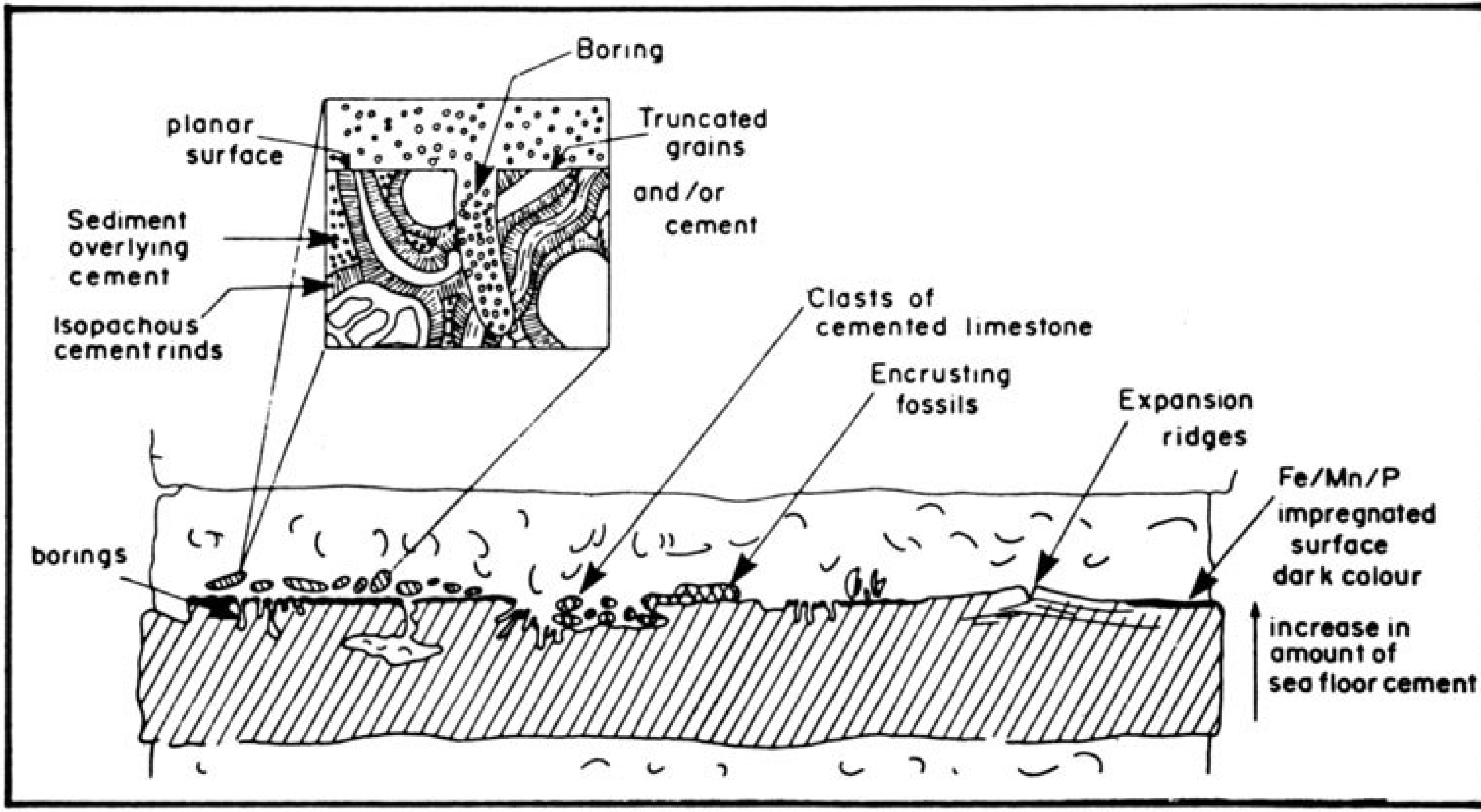


Figure 12 *Criteria for the recognition of seafloor cementation.*

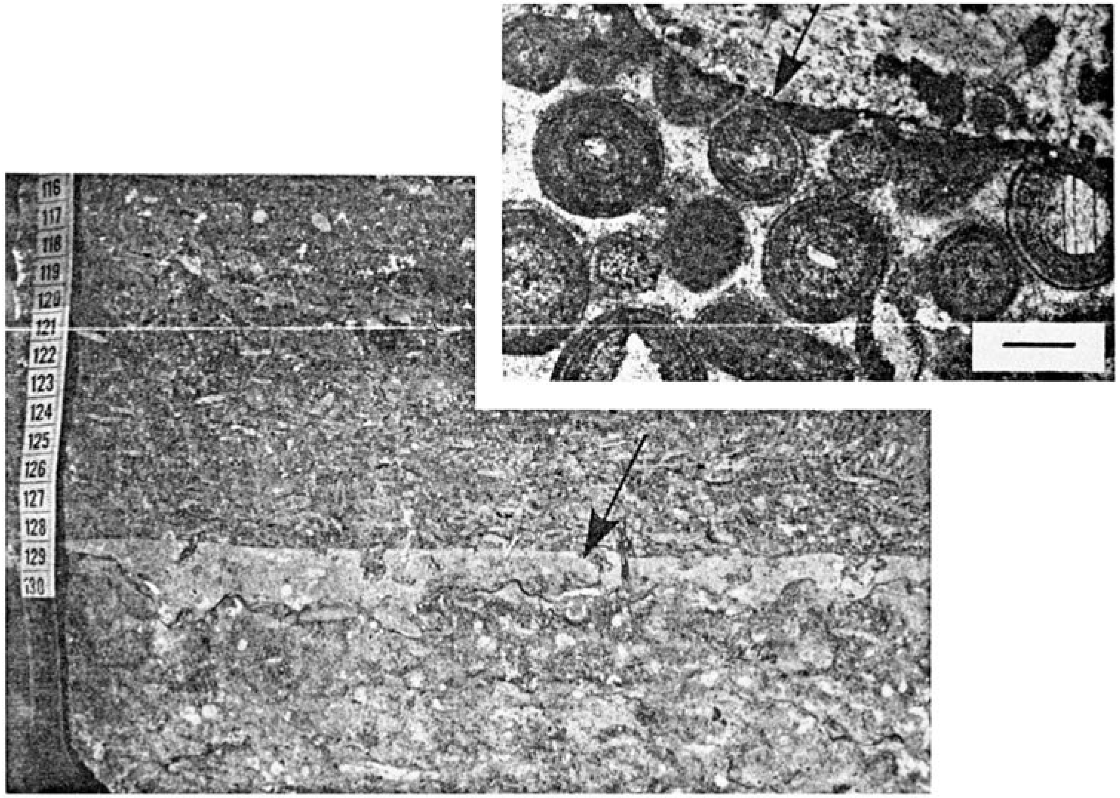
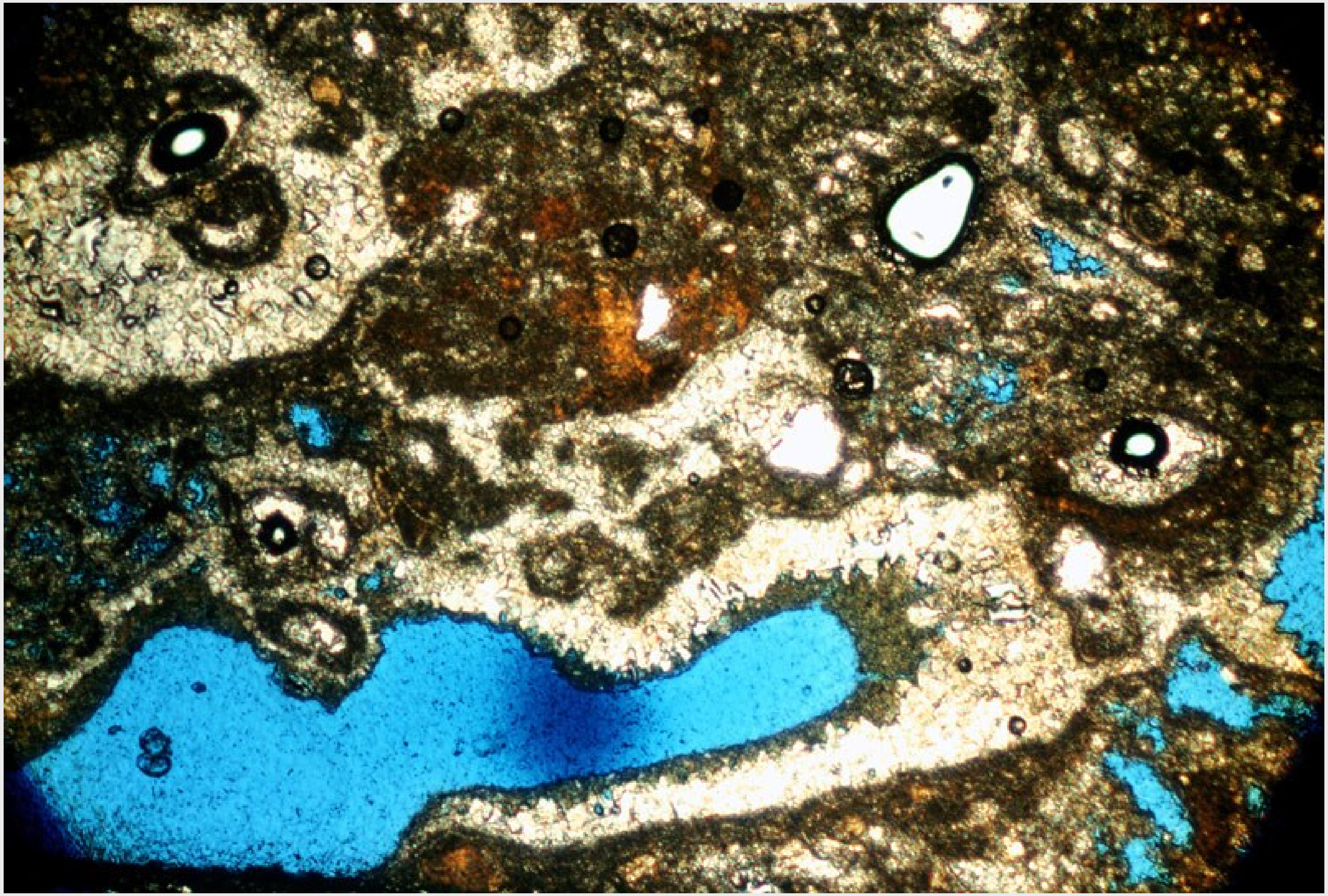


Figure 6 *An irregular submarine hardground (between 129 and 128 cm. on the tape) developed in Lower Cambrian ooid limestones of the Forteau Formation, western Newfoundland. The photomicrograph illustrates the truncated ooids and cements at the hardground surface (arrow indicates location; scale bar 0.5 mm).*



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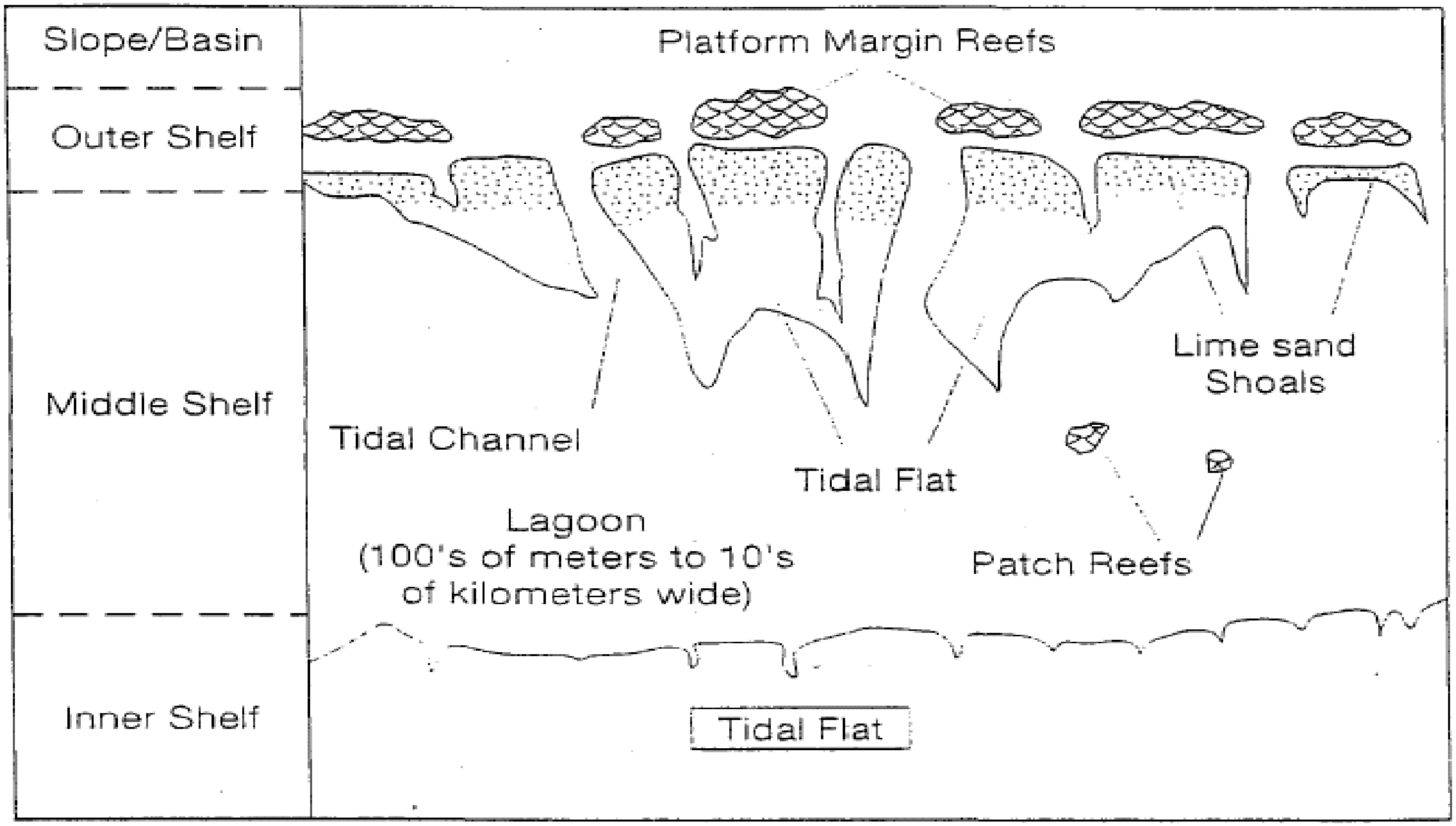
Carbonate Platforms - 6



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Evaporites

Evaporites comprise all rocks that have formed by precipitation from saline solutions concentrated by evaporation. Evaporates have formed under both marine and nonmarine conditions, although the nonmarine formations tend to be much thinner. Marine sequences in the Mediterranean are up to 1km thick.

Evaporites are particularly common in the Cambrian, Permian, Jurassic and Miocene eras.

Evaporite deposits mostly comprise gypsum, halite (rock salt) and anhydrite. Although these rocks are volumetrically much less significant than carbonates they nevertheless are very significant in engineering terms because of their peculiar properties.

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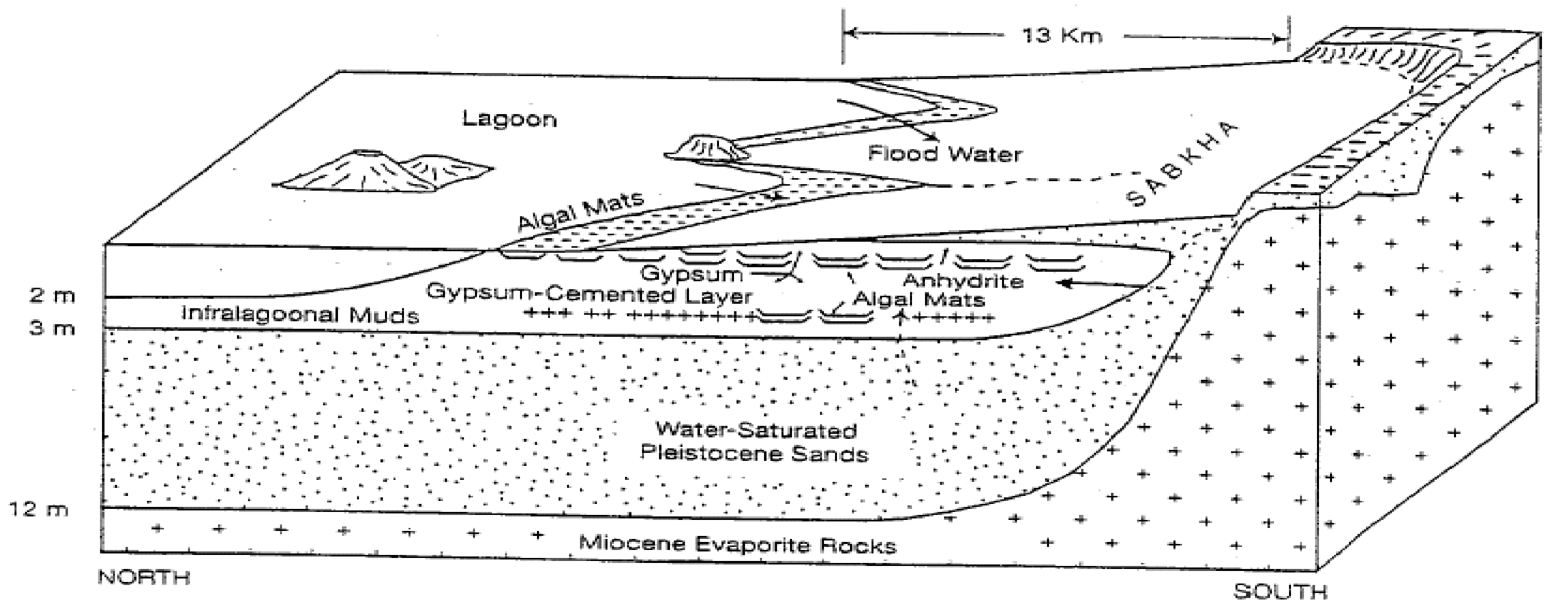
Evaporites – Rock Types

Evaporites may be classified as chlorides sulphates or carbonates on the basis of their chemical composition, Table 2.

Calcium Sulphates (gypsum and anhydrite) are deposited mainly as gypsum, which can then be altered to anhydrite with burial. This process is associated with a 30 to 40% loss of volume. Hence most old deposits are anhydrite. However the process is reversible and uplift and exposure to low-salinity water results in gypsum with a corresponding increase in volume.

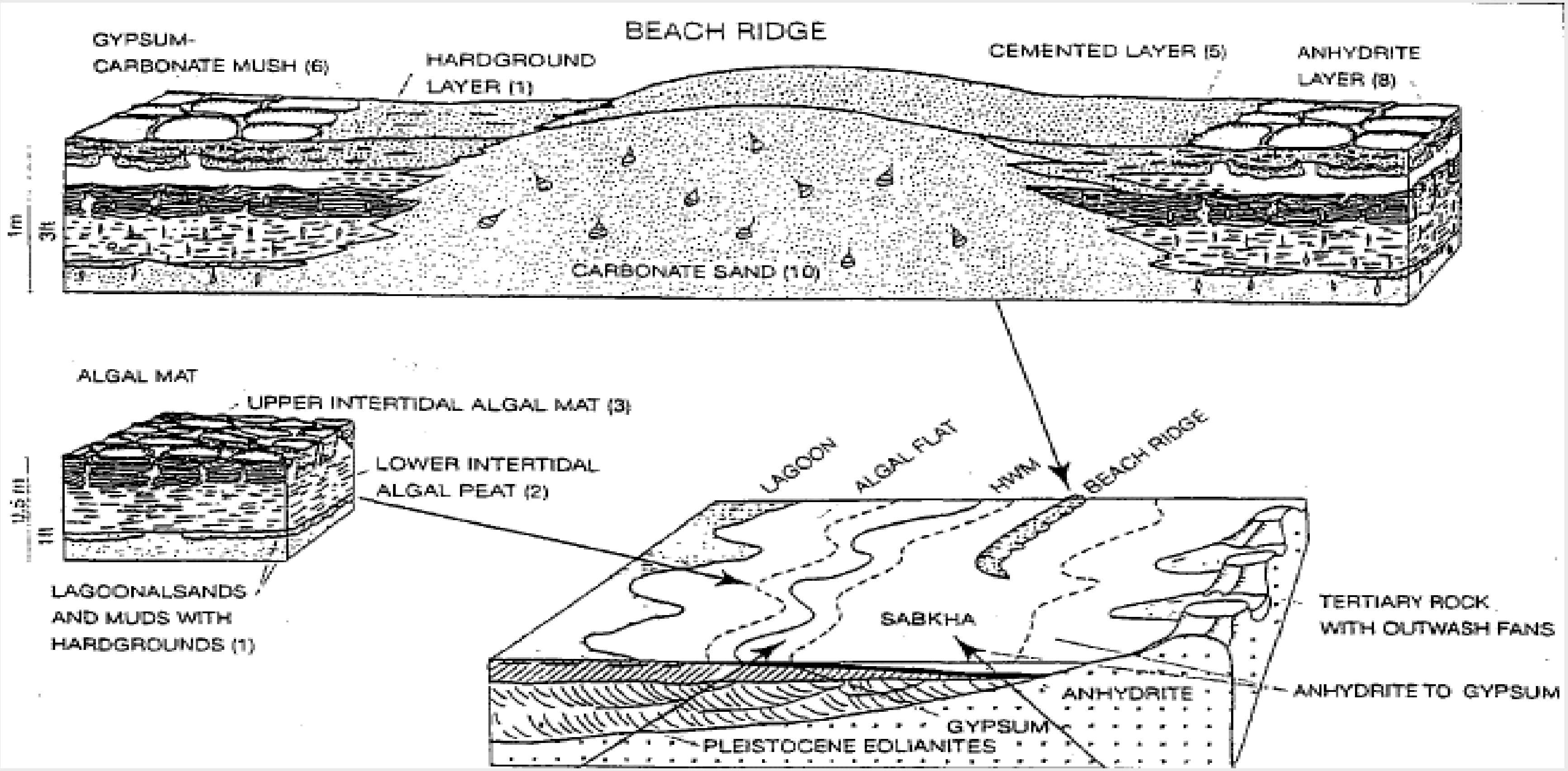
Halite forms as crusts in shallow water or as finely laminated deposits in deeper water.

Evaporites – Rock Types



Abu Dhabi sabkha, Persian Gulf. Schematic representation of a typical sabkha environment in which penecontemporaneous dolomite forms, commonly in association with gypsum and anhydrite, owing to evaporitic concentration of Mg. [After Butler, G. P., 1969, Modern evaporite deposition and geochemistry of coexisting brines, the sabkha, Trucial Coast, Arabian Gulf: Jour. Sed. Petrology, v. 39, Fig. 2, p. 72, reprinted by permission of SEPM, Tulsa, OK.]

Evaporites – Rock Types



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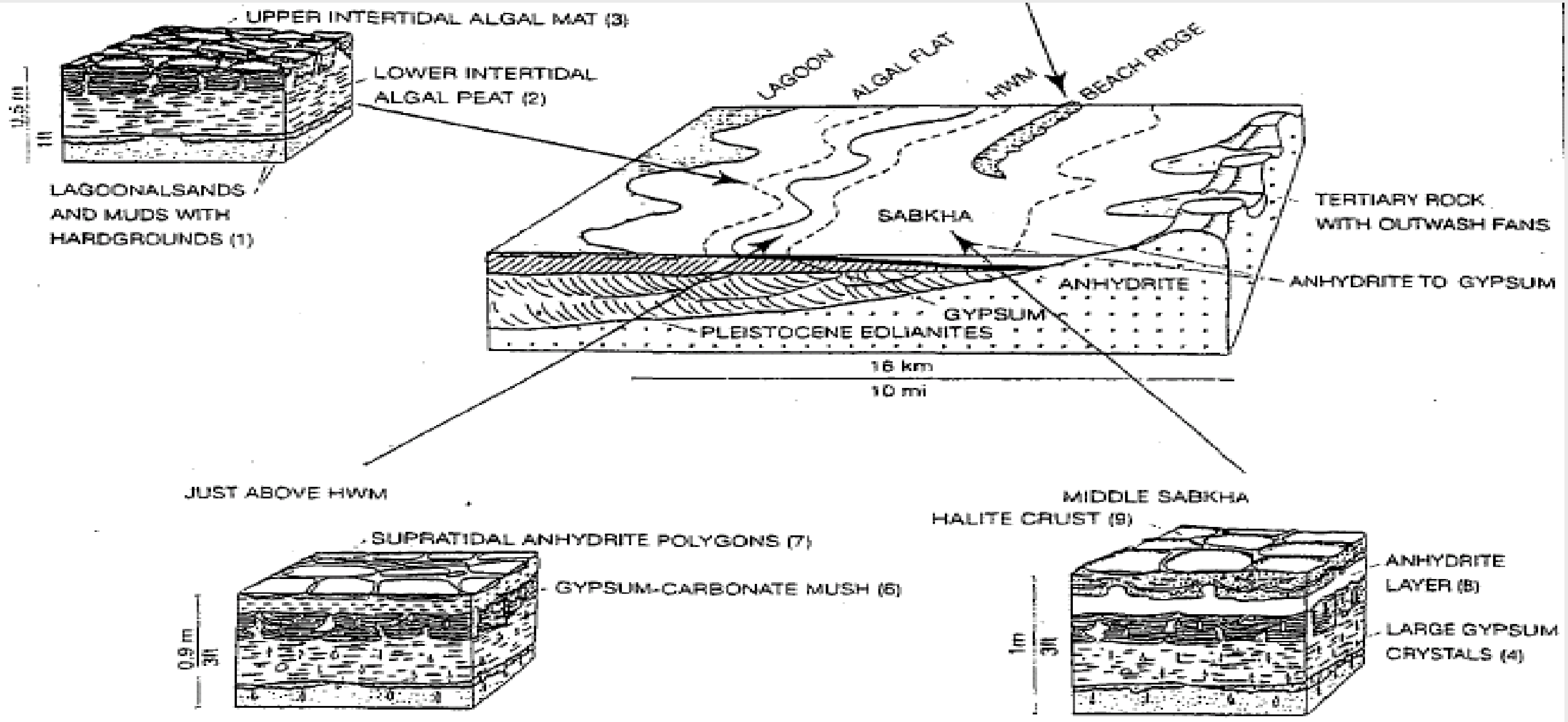
Evaporites – Rock Types



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Engineering Characteristics of Carbonates Structural

The main characteristics are:

1. Long-term solubility.
2. Effects of past solution.
3. Presence of thin argillaceous layers.

The classic problems associated with carbonate rocks include:

- Collapse and subsidence due to sinkholes.
- Questions over whether long-term solution could affect the engineering performance of the rocks.
- Poor foundation conditions, due to high void ratio, low-density granular materials of low strength and high compressibility; and grains themselves, which are of low strength. These features can also result in potential for collapse type behaviour.
- Large-scale landsliding on thin low strength layers that have weathered or been altered at great depth in conjunction with deep solution processes.
- Solution features often occur well below the groundwater table and therefore caves at depth should be expected.

Engineering Characteristics of Carbonates Hydrogeologic

Some hydrogeological implications of limestone/dolomite rocks include:

1. Subhorizontal solution features are usually of more importance than subvertical features, although this may be a sampling issue, Figure 36.

2. Experience has shown that major lineaments and lineament intersections are high success targets for groundwater wells, Figure 37. However deep soils and weathering/solution may make these sites difficult and expensive to drill.

3. Tension zones, eg anticlinal axes, often show more solution features, Figure 38.

4. Permeability may be almost infinite, due to karstic formation.

Engineering Characteristics of Evaporites

Because of their limited distribution as rocks on the earth evapoites are not associated with same widespread issues as carbonates, but there are some particular issues, which practitioners need to be aware of. The main issues are:

1. Volume changes associated with hydration changes.
2. Reaction with other minerals.
3. Solution, often down to depths of 700 to 1000m.

Firstly the volume changes:

ANHYDRITE	+	WATER	=	GYPSUM
Ca SO4	+	2H2O	=	Ca SO4 2H2O
100 Vol. Units	+	78	=	163

Anhydrite is generally deeply buried and drill through Gypsum at the surface into anhydrite at great depth.

The volume changes can be dramatic with significant stresses and uplift, this is one of the formation issues with Sabka's.

The big question is has the volume change from Gypsum to anhydrite fully occurred? When tunnelling through these rocks there could be volume changes 20 years ater construction is completed, leading to collapse of the tunnel sides.

Solubility

Materials	Solubility in pure water—c_s (kg/m^3) at 10°C
Gypsum	2.5
Halite	360.0
Limestone	0.015
Anhydrite	2.0
Quartz	0.01

Solubility

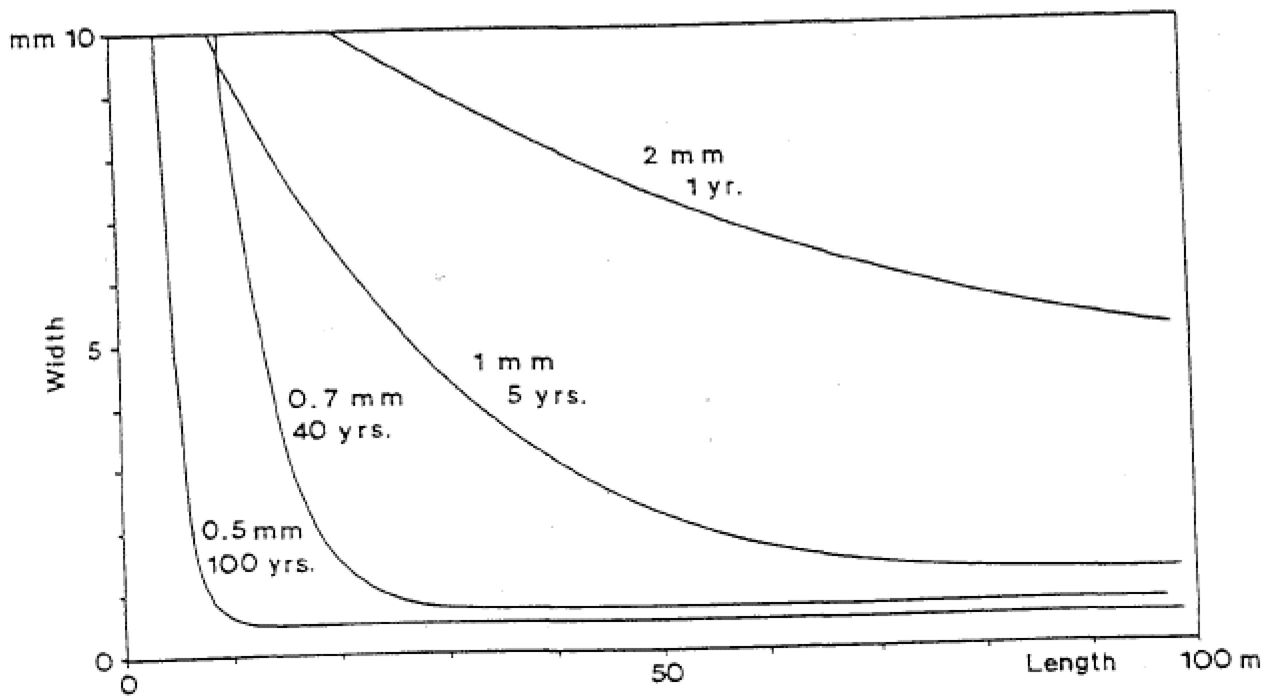

FIG. 3. Enlargement of fissures in calcium carbonate rock by pure flowing water.

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Solubility & Grouting

TABLE 3. *Fissure width and seepage control*

	Fissure width (mm)		
	For stable inlet face retreat	For a rate of retreat of 0.1 m/year	Suggested preventive measures
Gypsum	0.2	0.3	Grouting
Anhydrite	0.1	0.2	Cut-off—eg. plastic concrete
Halite	0.05	0.05	Cut-off—eg. plastic concrete
Limestone	0.5	1.5	Grouting

These values are for pure water; at fissure spacing on one every metre and an hydraulic gradient of 0.2.

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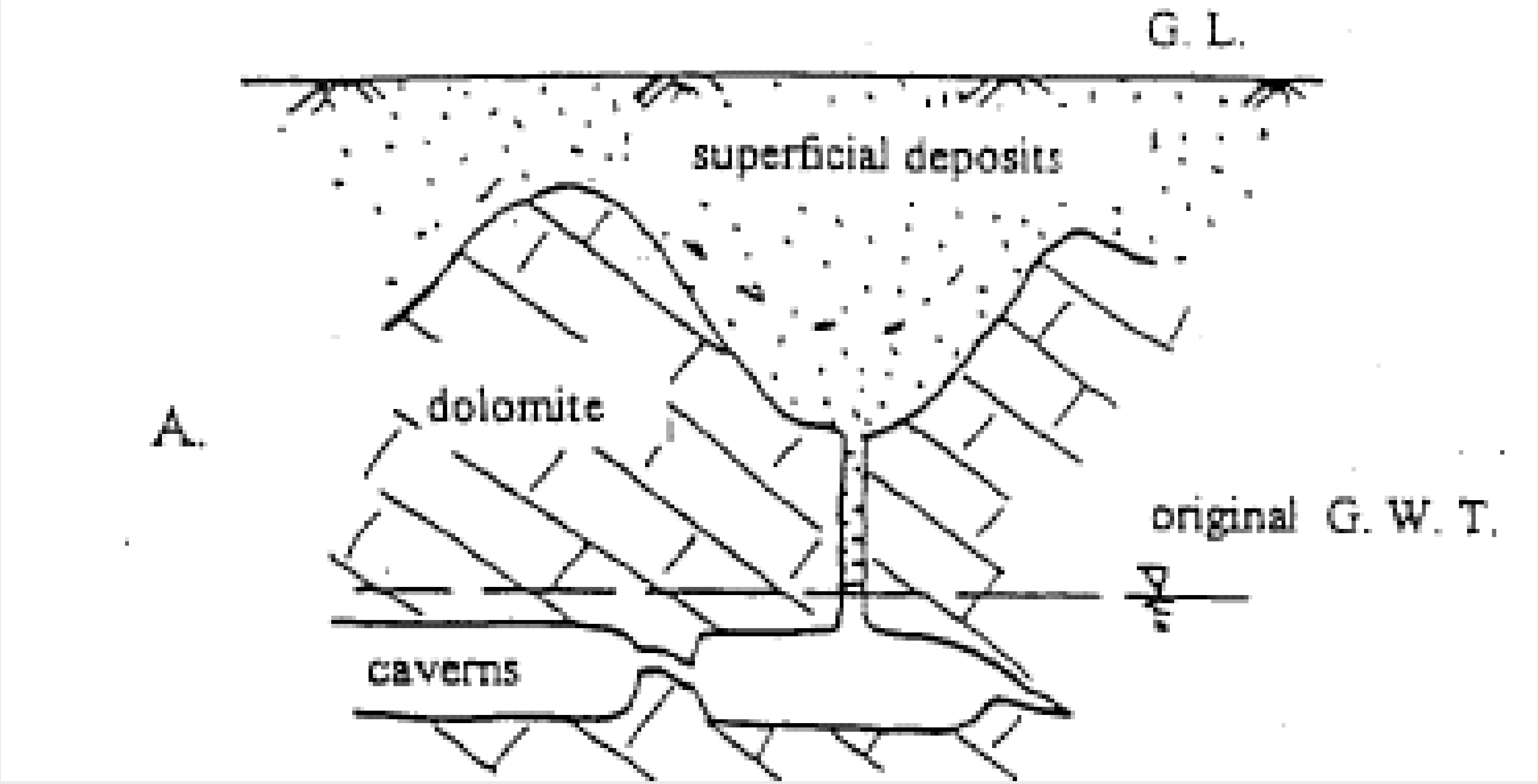
Sinkholes – Stage 1



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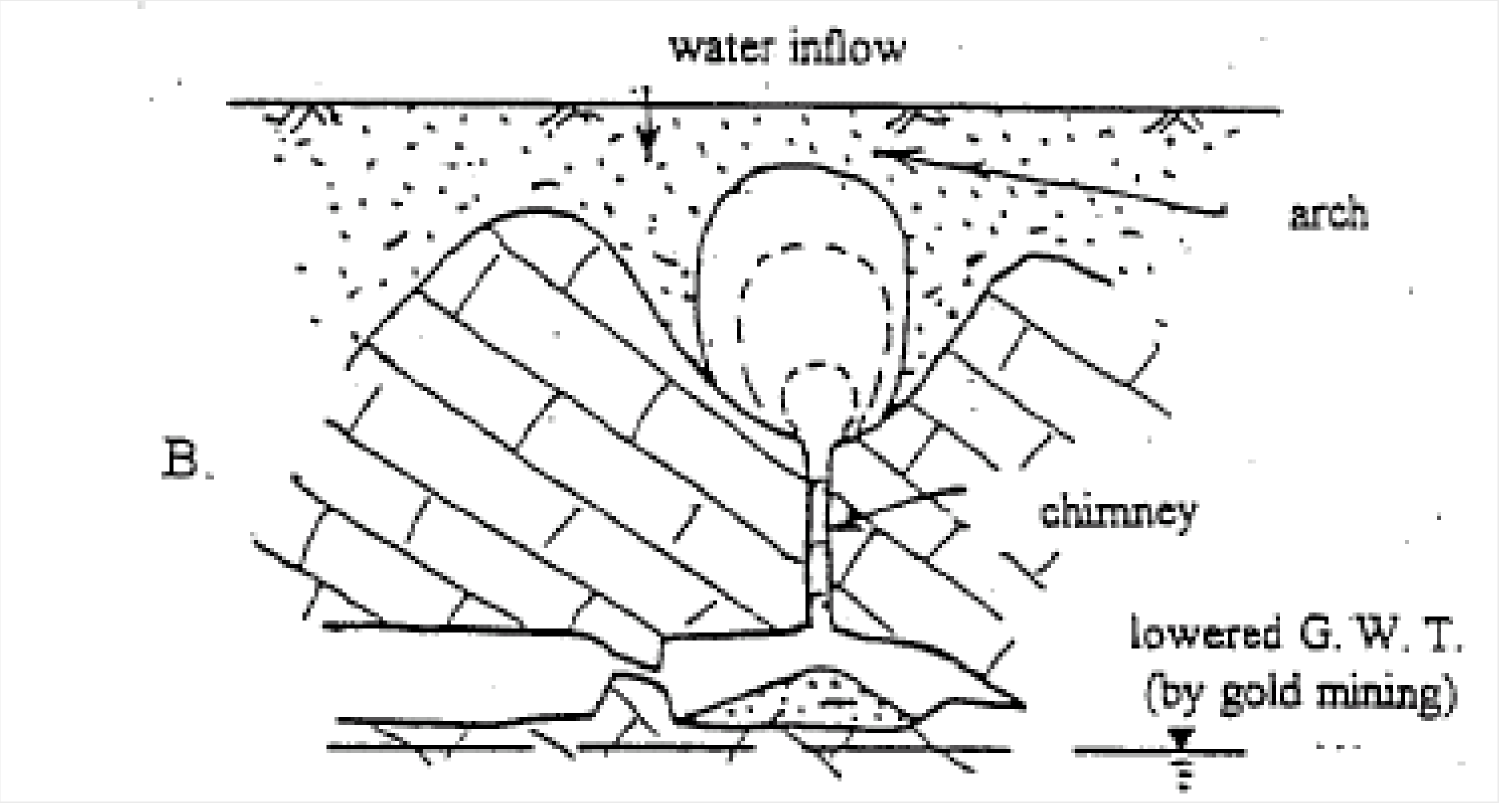
Sinkholes – Stage 2



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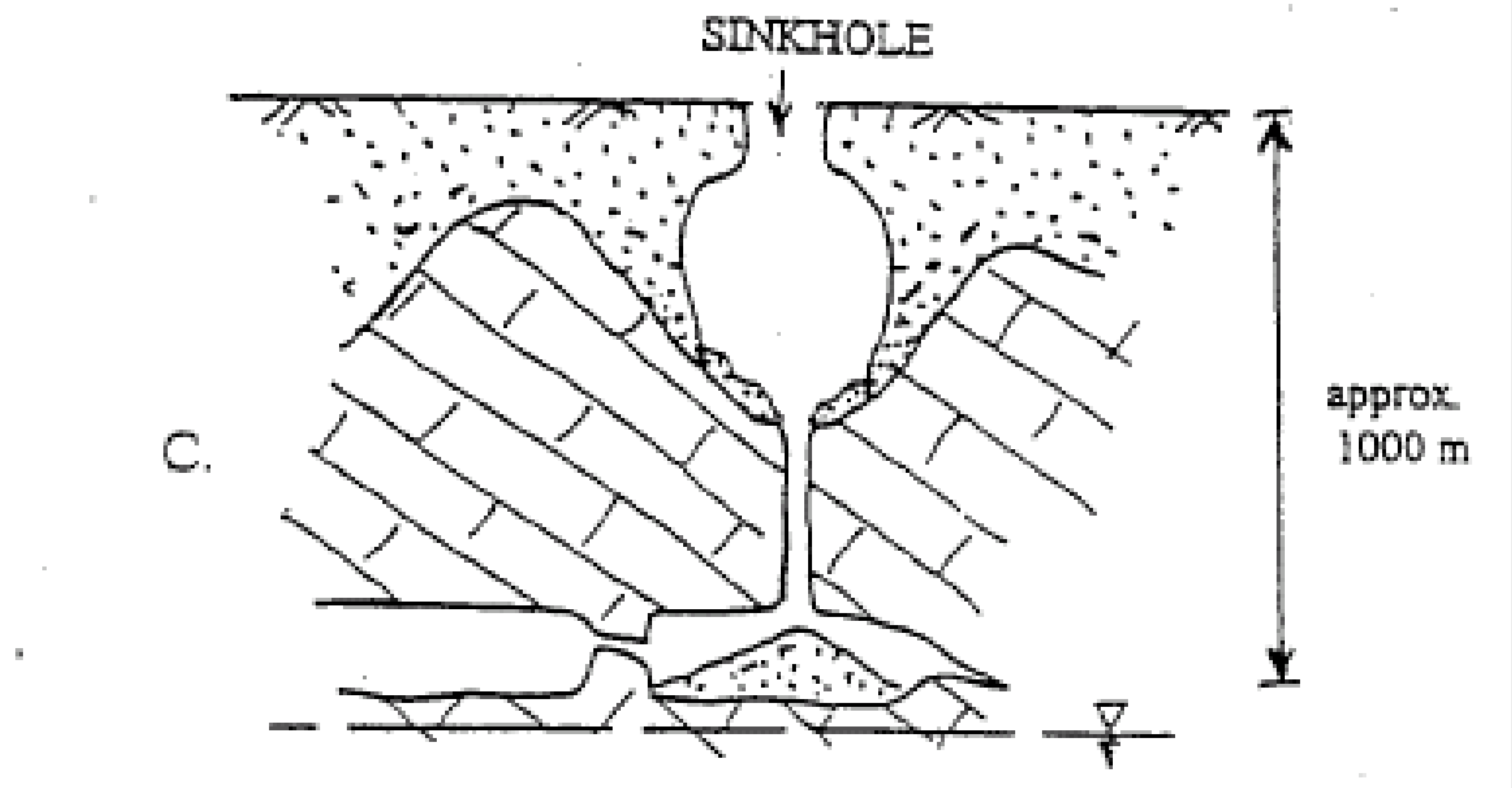
Sinkholes – Stage 3



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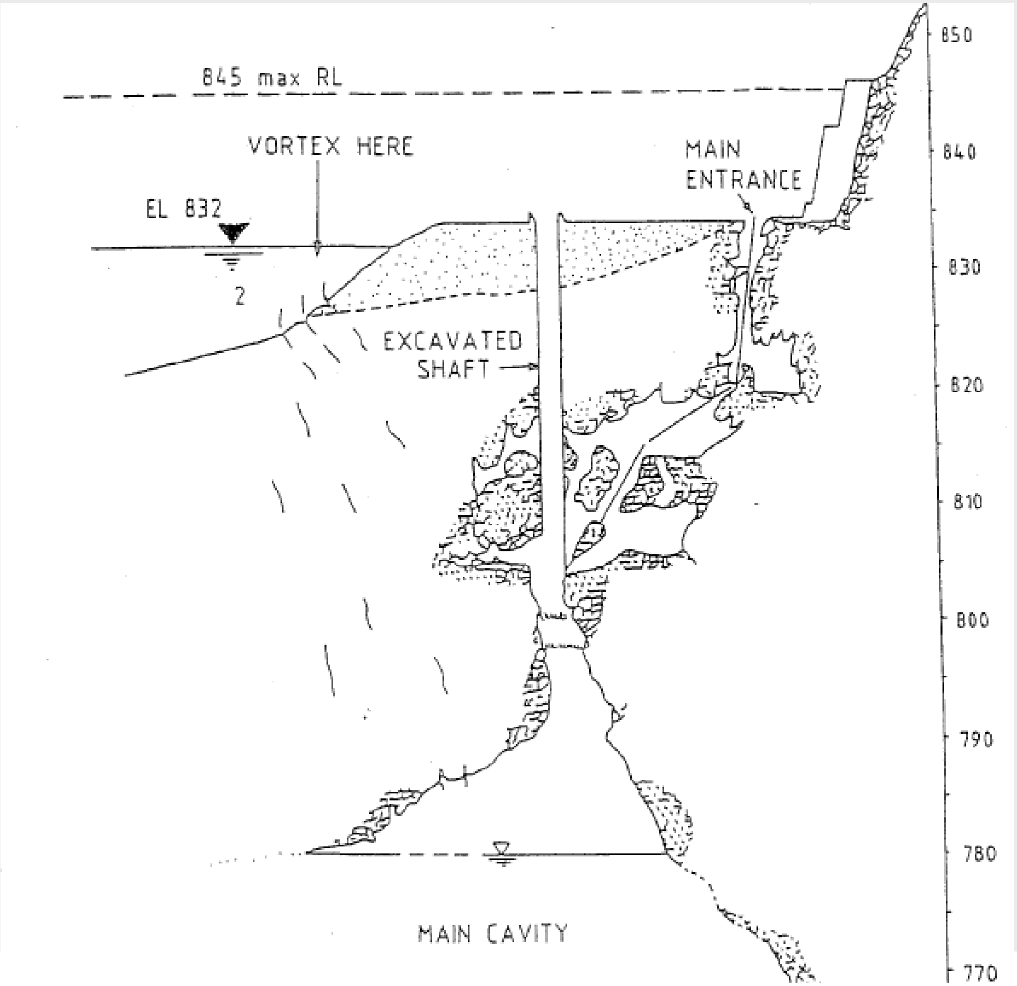
Sinkholes – Dam Abutments



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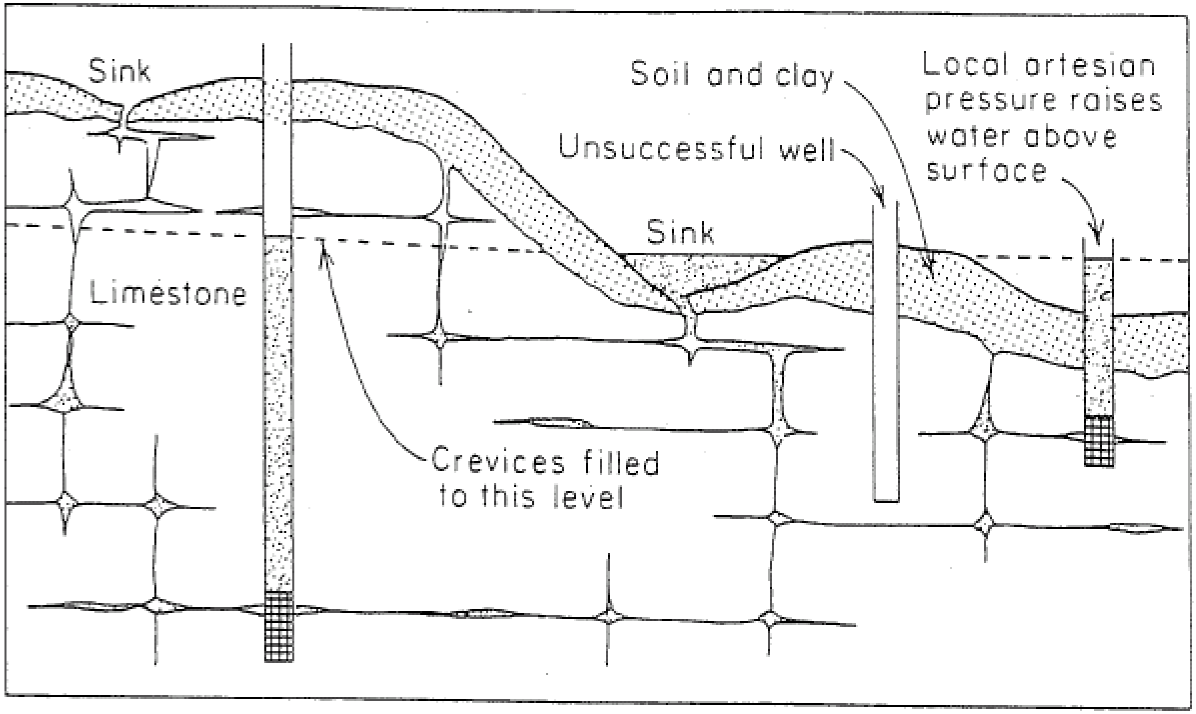
Carbontaes – Groundwater



Schematic illustration of the occurrence of groundwater in carbonate rock in which secondary permeability occurs along enlarged fractures and bedding plane openings (after Walker, 1956; Davis and De Wiest, 1966).

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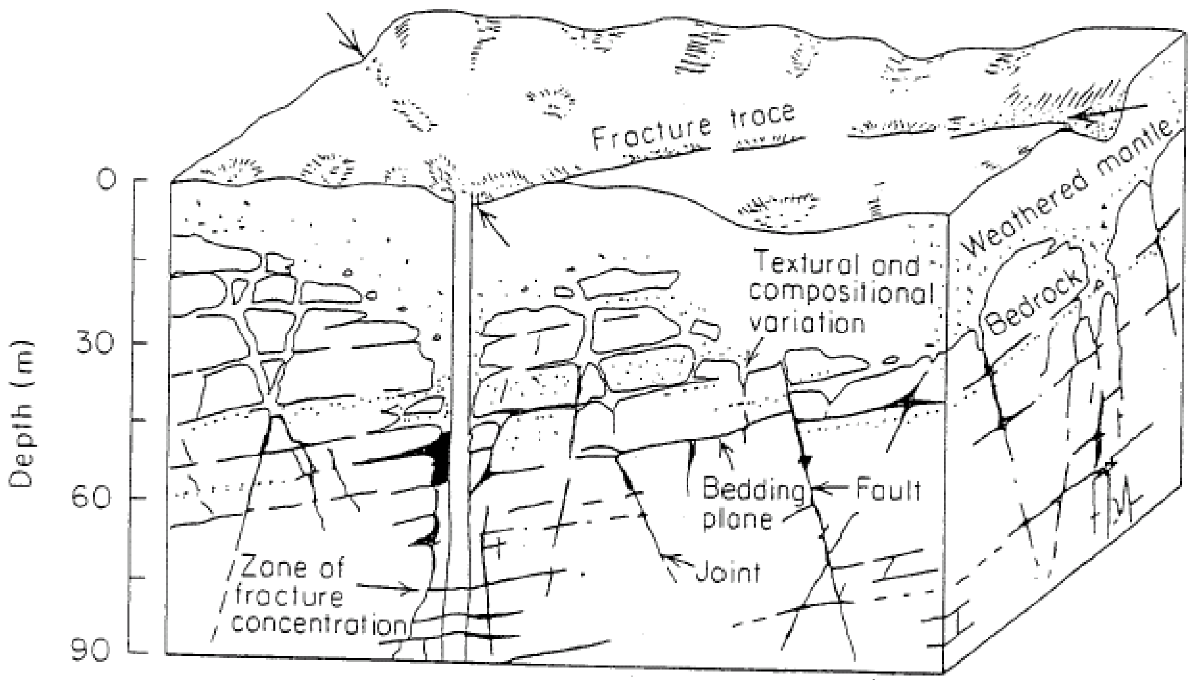
Carbonates – Groundwater



Occurrence of permeability zones in fractured carbonate rock. Highest well yields occur in fracture intersection zones (after Lattman and Parizek, 1964).