[PS]Gypsum Stromatolites From Sawda Nathil: A Geological Relict From Salinas Along the Fourth Coastline of Qatar*

Christian J. Strohmenger[1] and Jeremy Jameson[1]

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[1]ExxonMobil Research Qatar, Doha, Qatar (user378313@aol.com)

Abstract

Sawda Nathil is one of a series of inland depressions (inland sabkhas and salinas) that extend nearly continuously along the Southern Qatar border with Saudi Arabia. Six to eight thousand years ago, these depressions were marine embayments that separated the peninsula of Qatar from the mainland. These embayments in-filled rapidly with marine sediments and dune sands, blown southeastward across Qatar. Since then, they have become progressively more evaporitic. Inland depressions like Sawda Nathil host a set of unique environments within Qatar. Most depressions are close to or below sea level, resulting in near-surface water tables in the driest parts of Qatar. Evaporation to salt saturation creates thick gypsum and salt crusts (sabkhas), as well as shallow hypersaline ponds (salinas) with spectacular domal microbial gypsum stromatolites. The present ground surface is a mosaic of relict marine facies, deflated dune sands, and inland sabkhas and salinas. Sediment from four short push cores was photographed, described, and sampled for petrographic thin-section and X-ray diffraction (XRD) analyses. Radiocarbon (AMS) as well as optically stimulated luminescence (OSL) age-dating were carried out on three samples. Scanning electron microscopy (SEM) was used to resolve the microbial-influence on gypsum precipitation. Radiocarbon dating of marine shells provides ages of approximately 6,600 un-calibrated ^{14}C years before present (yr BP), coinciding with a well-documented sea-level highstand, approximately 2 to 4 meters higher than present. During that time, Qatar was mostly an island, only connected in the south to the Arabian Peninsula by narrow isthmuses. SEM examinations of gypsum stromatolites show gypsum crystals developing in close spatial association with microbial biofilms. Whether this is a purely passive microbial-influenced gypsum mineralization process or an example where microorganisms actively control the gypsum crystal morphology in order to obtain ecological advantages, remains to be evaluated. Studying and documenting different types of microbial sedimentary structures preserved in gypsum is of particular interest, not only in the field of petroleum geology, but also in the field of exobiology. Whereas carbonate minerals quantitatively form the most important sediments for preserving morphological bio-signatures on Earth, the most relevant chemical sediments on Mars are likely formed by sulfate minerals, such as gypsum.

Gypsum Stromatolites from Sawda Nathil: A Geological Relict from Salinas along the Fourth Coastline of Qatar

مركز قطر للأبحاث الساحلية
Qatar Center for Coastal Research

Christian J. Strohmenger and Jeremy Jameson

ExxonMobil Research Qatar (EMRQ)

ExxonMobil

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Sediment from four short push cores was photographed, described, and sampled for petrographic thin-section and X-ray diffraction (XRD) analyses. Radiocarbon (AMS) as well as optically stimulated luminescence (OSL) age-dating were carried out on three samples. Scanning electron microscopy (SEM) was used to resolve the microbial-influence on gypsum precipitation.

Radiocarbon dating of marine shells provides ages of approximately 6,600 un-calibrated ^{14}C years before present (yr BP), coinciding with a well-documented sea-level highstand, approximately 2 to 4 meters higher than present. During that time, Qatar was mostly an island, only connected in the south to the Arabian Peninsula by narrow isthmuses.

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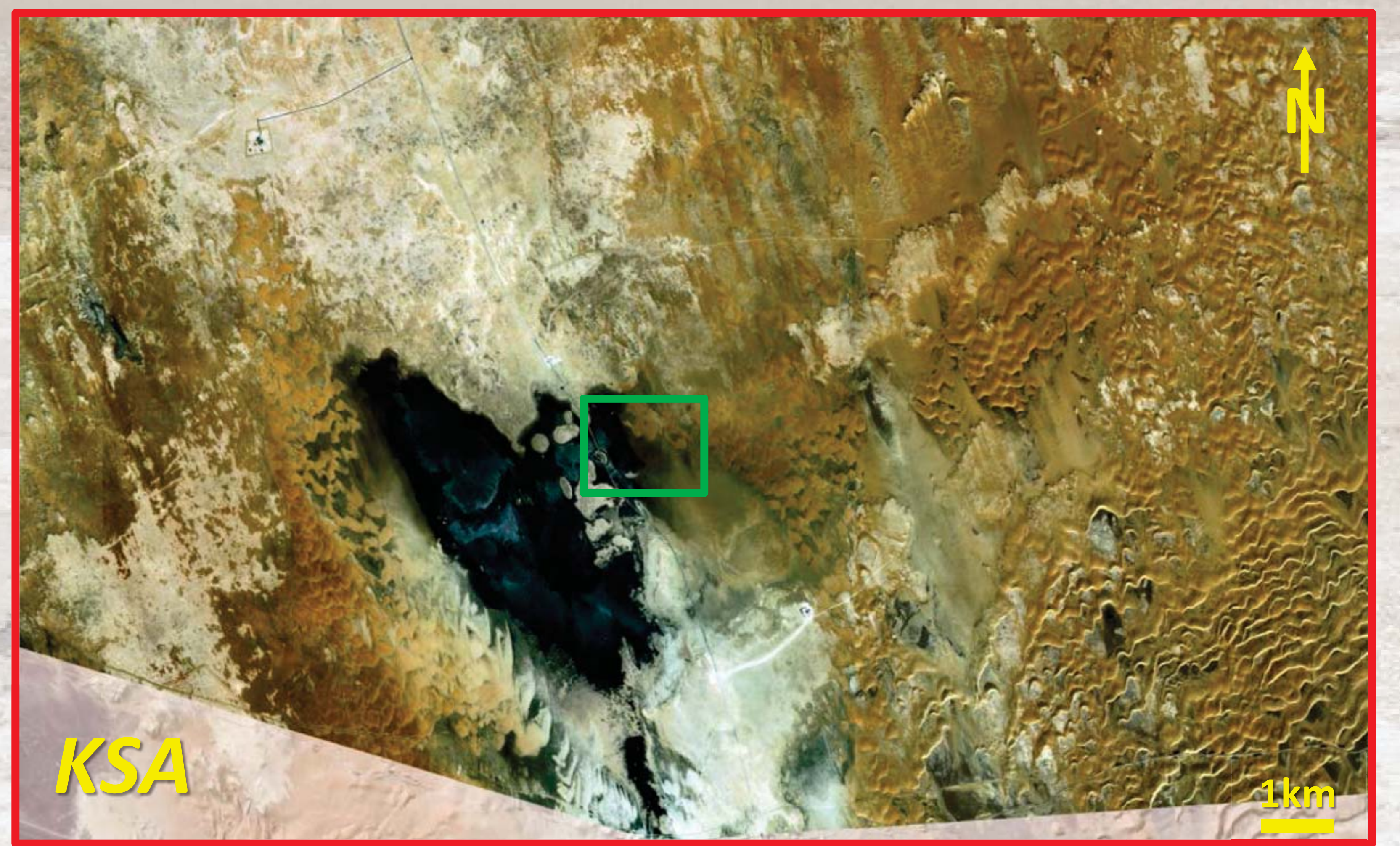
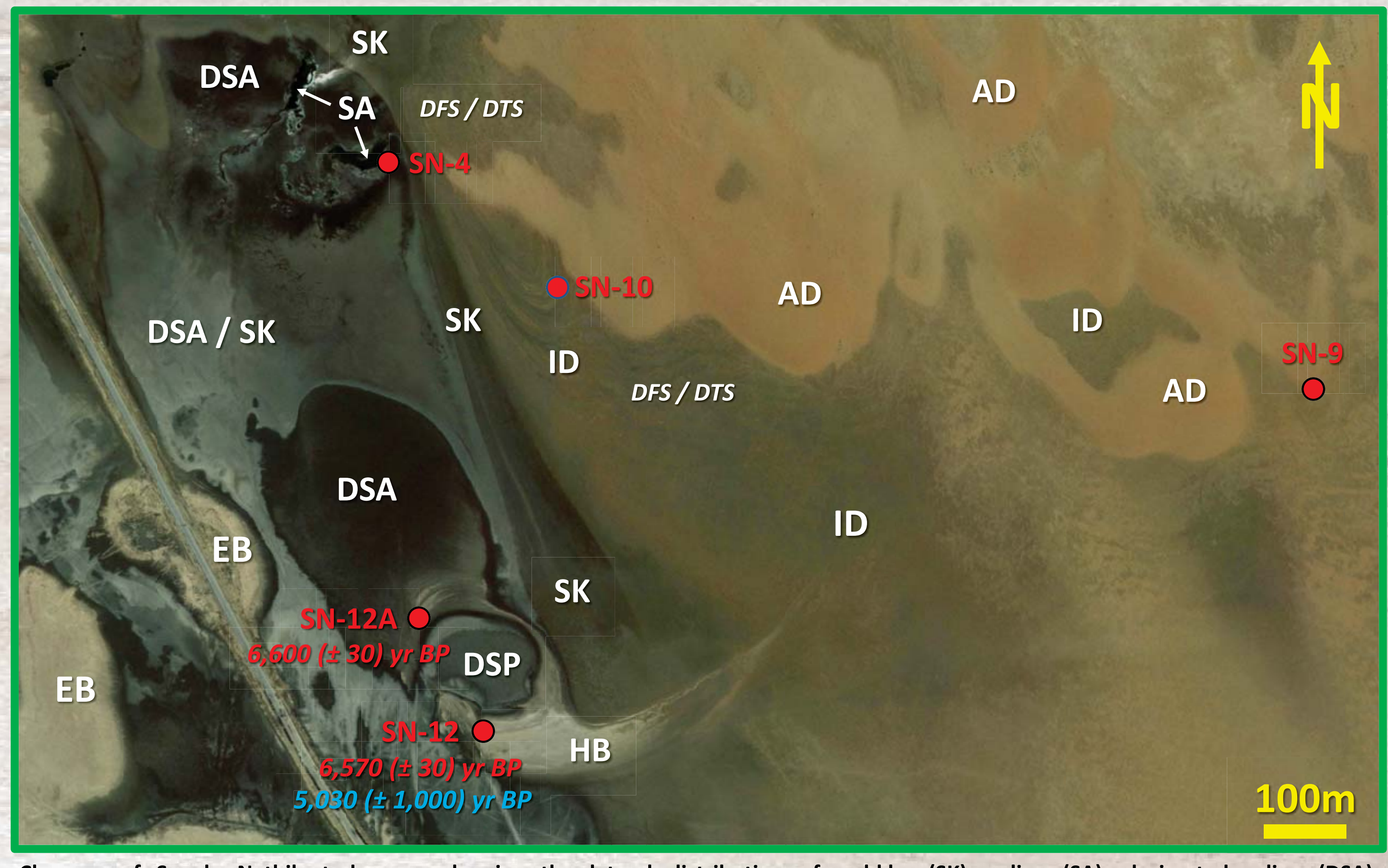
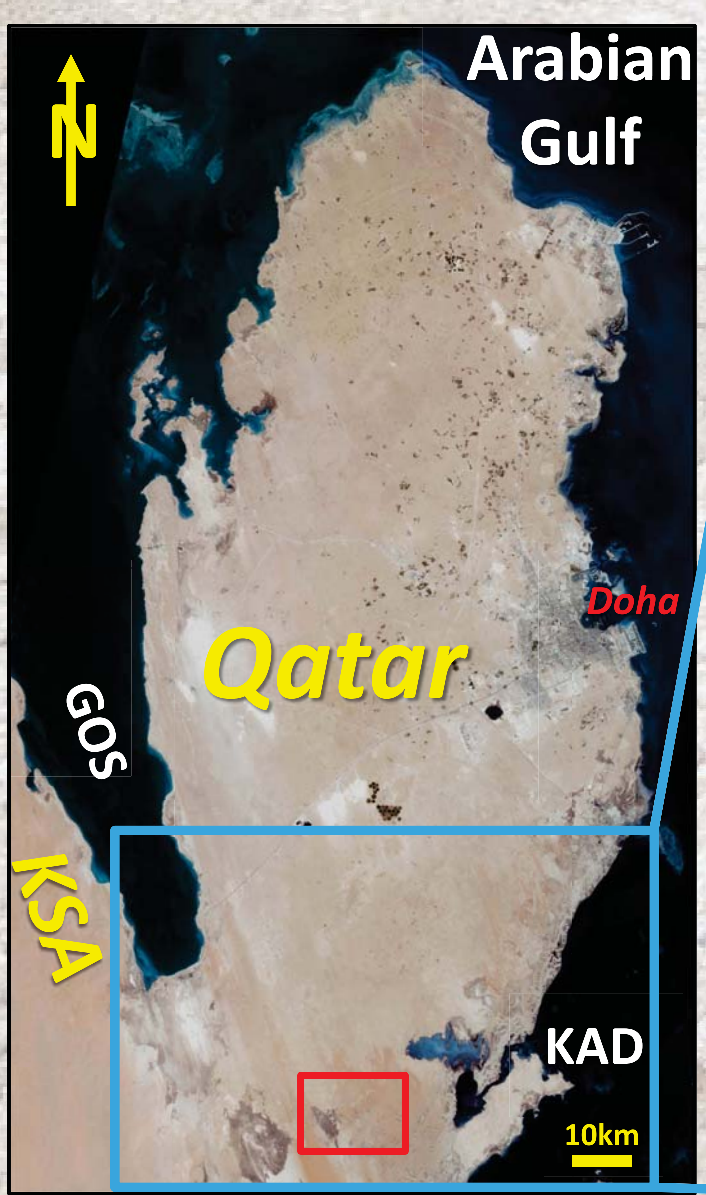
Studying and documenting different types of microbial sedimentary structures preserved in gypsum is of particular interest, not only in the field of petroleum geology, but also in the field of exobiology. Whereas carbonate minerals quantitatively form the most important sediments for preserving morphological bio-signatures on Earth, the most relevant chemical sediments on Mars are likely formed by sulfate minerals, such as gypsum.



Close-up showing the Sawda Nathil depression (dark area), surrounded by aeolian dunes (brownish areas), and Eocene bedrock (whitish areas). Also shown is parallel striping of the surface caused by wind erosion (northerly and northwesterly blowing Shamal winds). Location of the study area is shown by green box. KSA: Kingdom of Saudi Arabia. *WorldView-2 imagery (2012).*



Close-up of Sawda Nathil study area showing the lateral distribution of: sabkha (SK), salina (SA), desiccated salina (DSA), desiccated salt pan (DSP), Holocene beach bar / tidal bar (HB), aeolian dune (AD), interdune (ID) with deflated dune foresets (*DFS*) and dune toesets (*DTS*), and Eocene bedrock (EB). Location of studied push cores SN-4, SN-9, SN-10, and SN-12, as well as radiocarbon age dating samples (red color) and OSL sample (blue color) are also marked . *WorldView-2 imagery (2012).*



Satellite imagery showing the Qatar Peninsular and the area of Sawda Nathil (red box).

KSA: Kingdom of Saudi Arabia. GOS: Gulf of Salwa. KAD: Khor Al-Adaid.

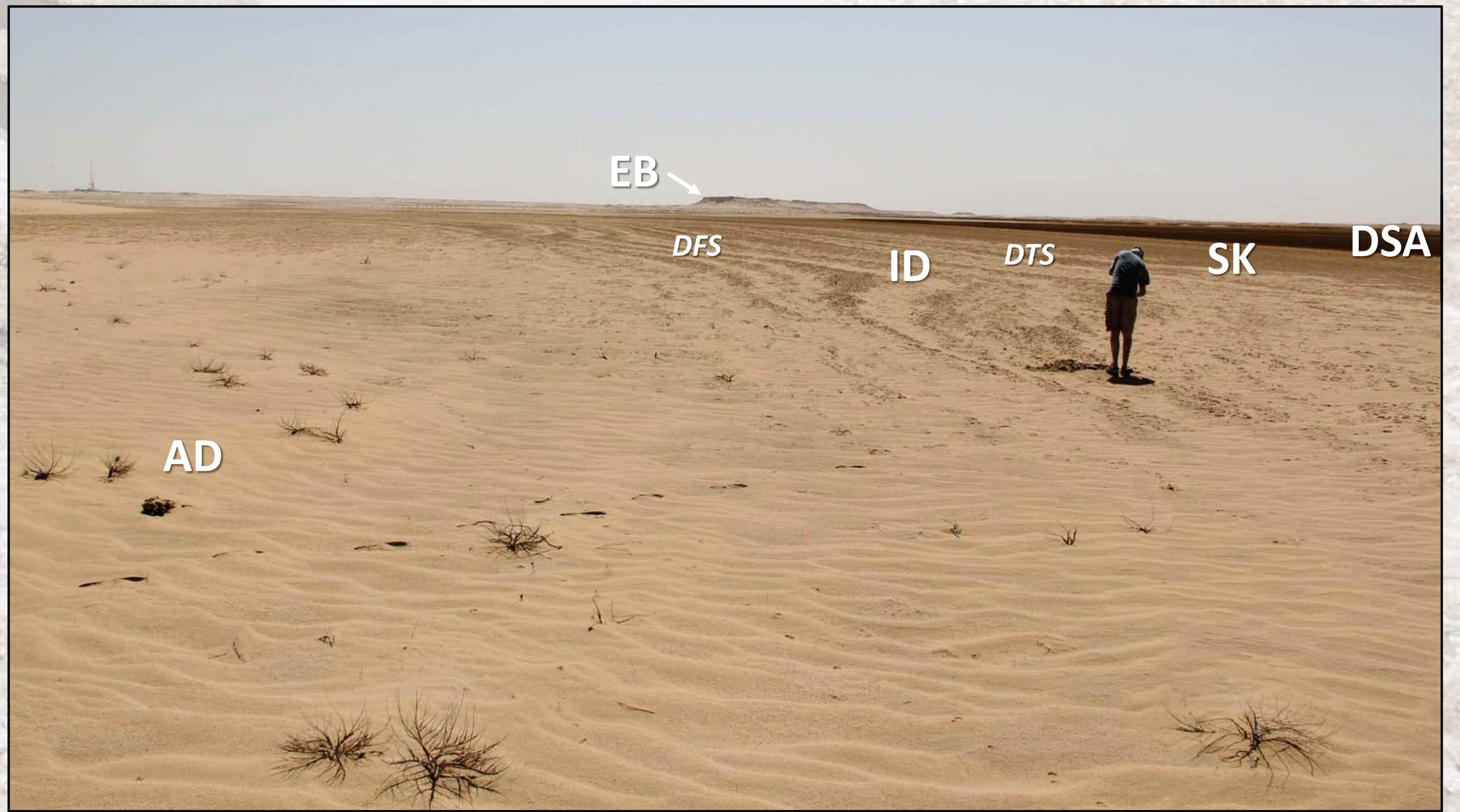
Spot-5 imagery (2010) draped over Qatar Digital Elevation Model (DEM, CGIS 2010).

Merged single elevation and bathymetry multi-scale terrain model (*DEM, CGIS 2010 and GEBCO bathymetry, Gebco_08*), used for simulating a 4m higher than today sea level.

Simulation shows flooding of the South Qatar coastlines (light blue area) during 6,000 yr BP sea-level highstand.

At that time, Qatar is mostly an island, only connected with the Arabian Peninsula in the south by narrow isthmuses.

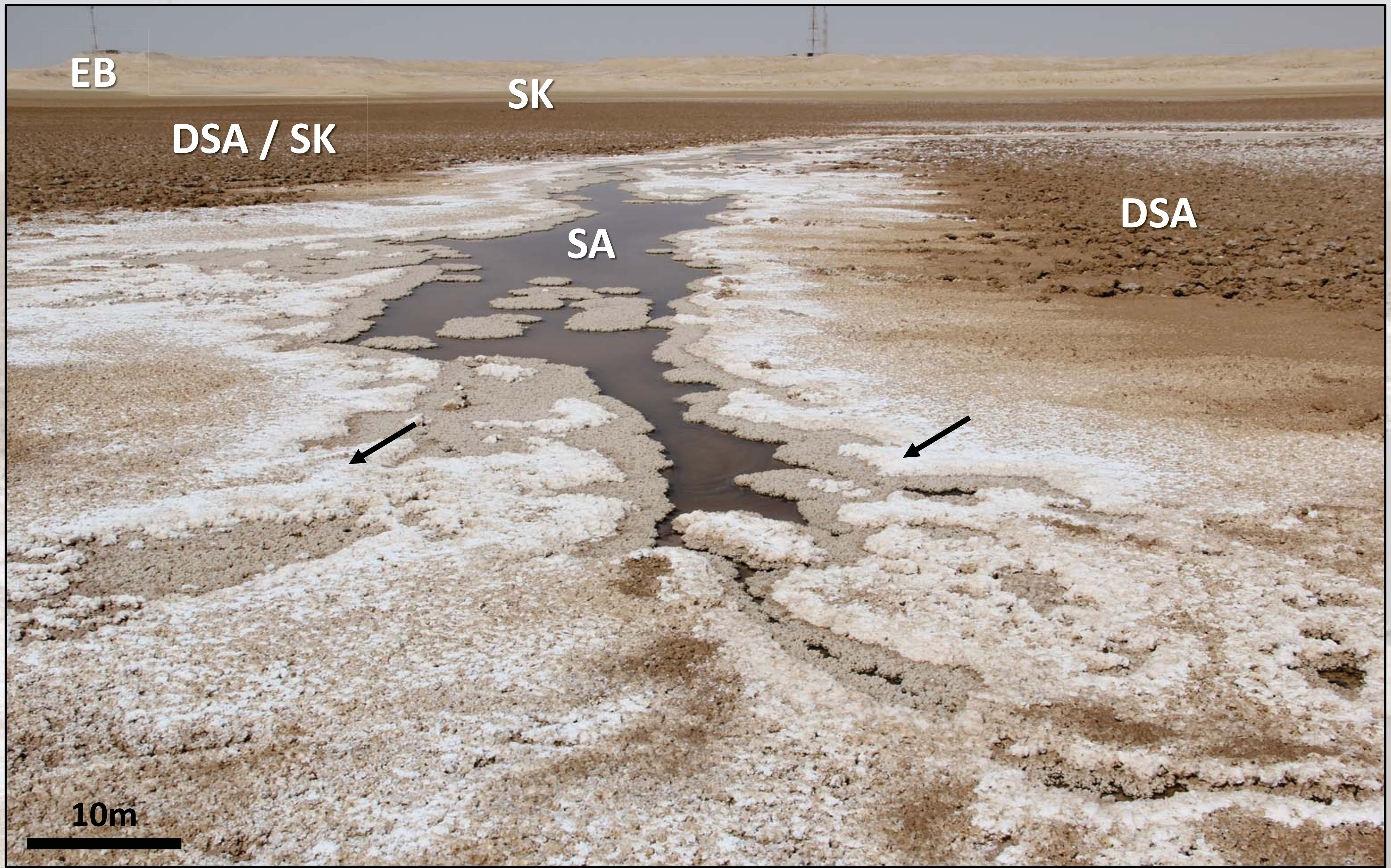
Black box depicts location of Sawda Nathil area.



Photograph showing area covered by remnants of aeolian dune deposits (AD; foreground) laterally interfingering with interdune (ID) area, showing deflated dune foresets (*DFS*) and dune toesets (*DTS*).

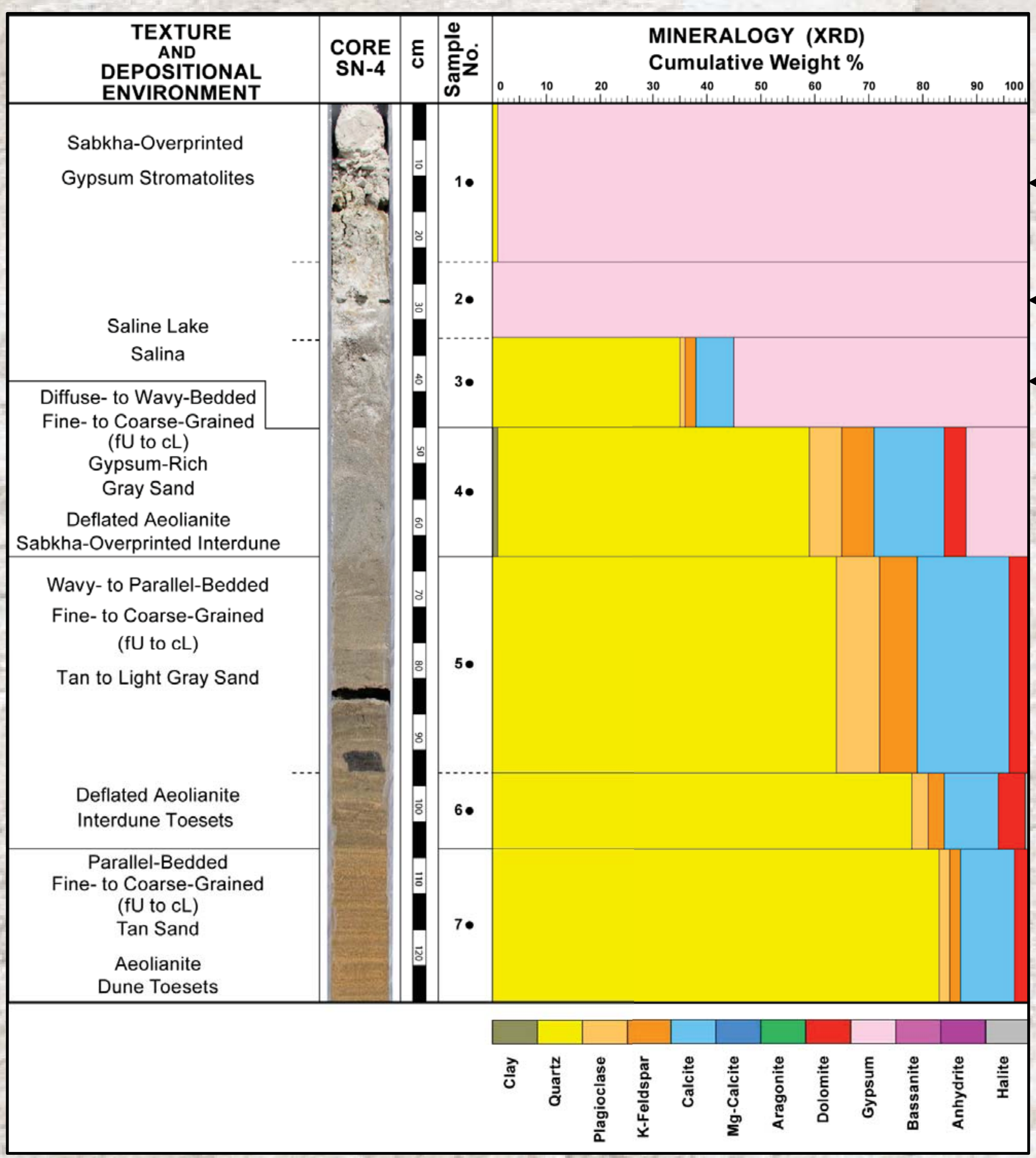
Towards the center of the depression (upper right hand corner), deflated interdune deposits laterally grade into sabkha (SK), and desiccated salina (DSA; dark area). Topographic high in the far distance is Eocene bedrock (EB).

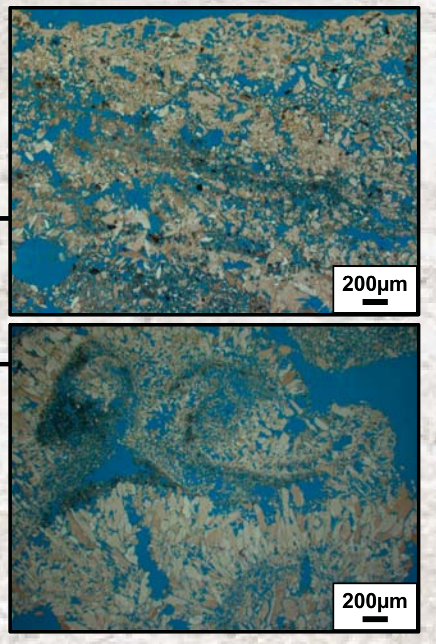
The Sawda Nathil modern aeolian dune and interdune environments, together with the salina deposits and the sabkha-type diagenetic overprint of the sediments represent excellent modern analogues to ancient dune sand reservoirs like the Lower Permian Rotliegend Formation of Northern Europe.



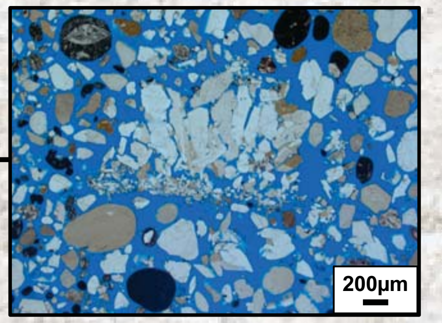
Photograph showing salina (SA) with water-covered gypsum stromatolites, temporarily exposed gypsum stromatolites covered by halite crust ("whitish" area, black arrows), and desiccated salina / sabkha (DSA / SK), displaying buckled gypsum-halite surface crust (brownish area), fringed by sabkha (SK) buckled gypsum-halite surface crust. Topographic highs in background are Eocene bedrock (EB).

Photograph showing close-up of shallow water salina with gypsum stromatolites and temporarily exposed gypsum stromatolites, displaying whitish halite crust.



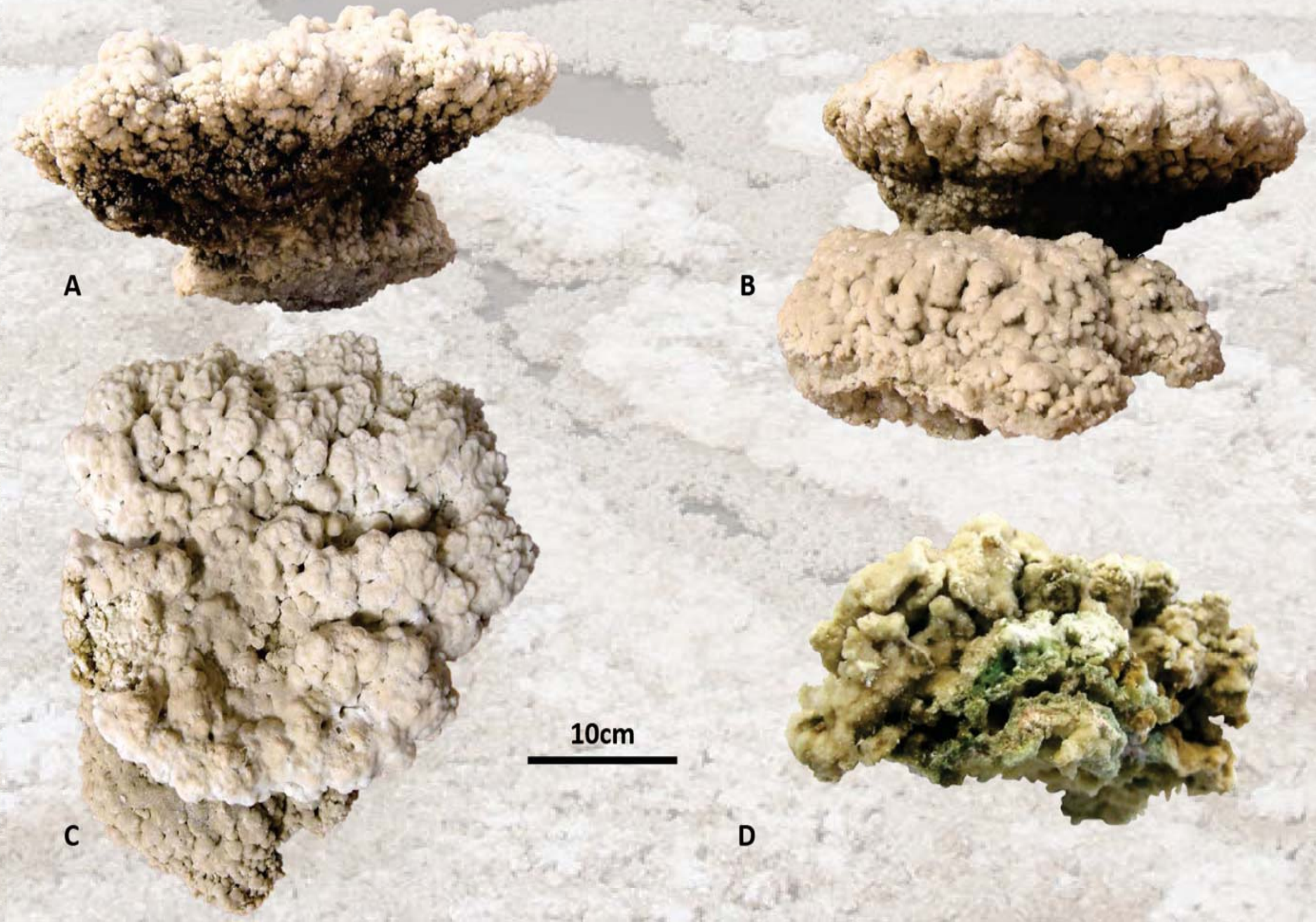


Gypsum crystals (µm- to mm-size) growing on thin dark organic (microbial) layers.
Partly crossed polarized light.



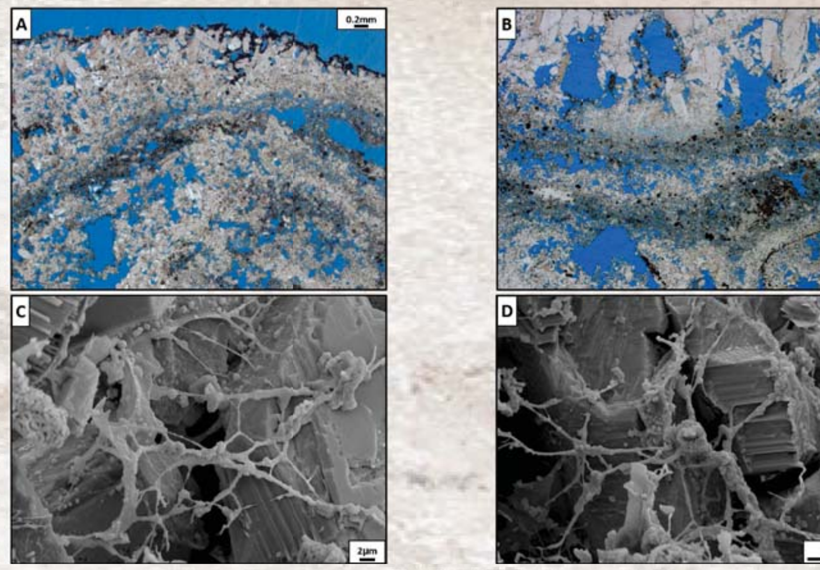
Fine- to coarse-grained sand and subaqueous precipitated prismatic gypsum crystals. Micrometer-size crystals replacing horizontal organic layers are overgrown by millimeter-size crystals showing palisades fabric.
Partly crossed polarized light.

Core photograph (SN-4), mineralogical composition determined by X-ray diffraction (XRD), reported as cumulative weight percentage, and thin section photomicrographs.



Photographs showing different views of single, mushroom-like looking, gypsum stromatolite.

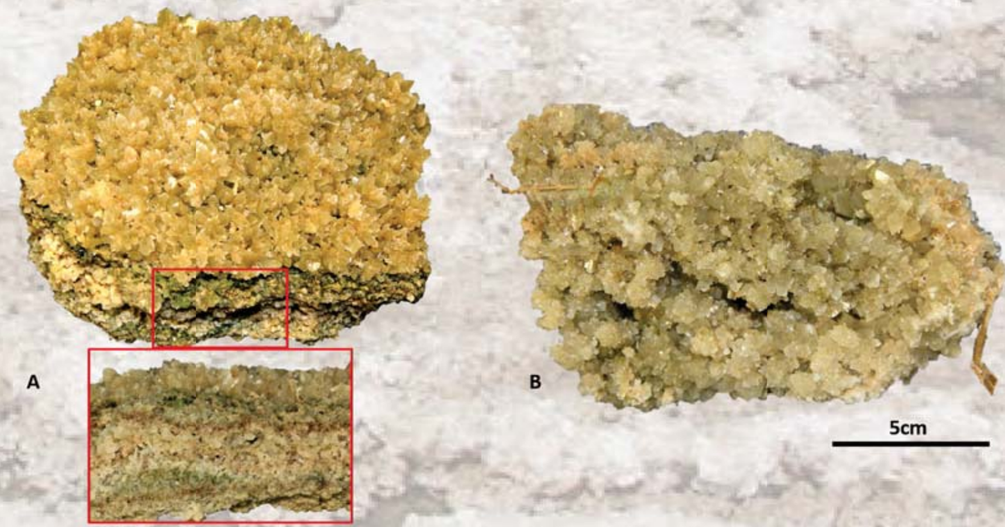
A: Side view.
B: Side view.
C: Top view.
D: Cross-section through stromatolite showing gypsum-encapsulated green cyanobacteria, indicating photosynthesis.



Thin section (A and B) and SEM (C and D) photomicrographs of gypsum stromatolite.

A and B: Alternation of oriented gypsum crystals and microbial-lamination (darker bands). *Partly crossed polarized light.*

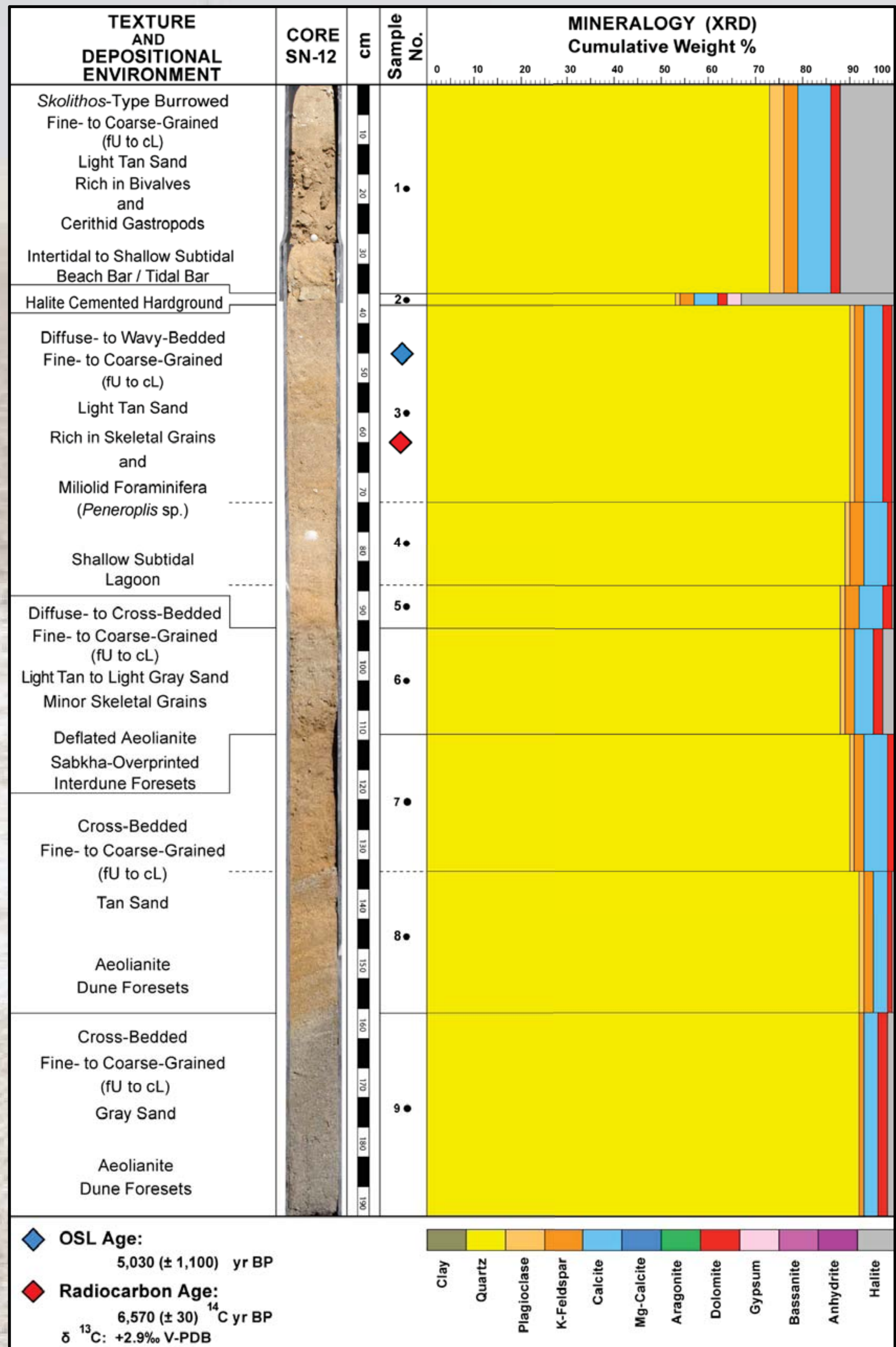
C and D: Gypsum crystals developed in close spatial association with microbial biofilms (microbial filaments).
SEM photomicrographs provided by Tomaso Bontognali (ETH Zurich, Switzerland).

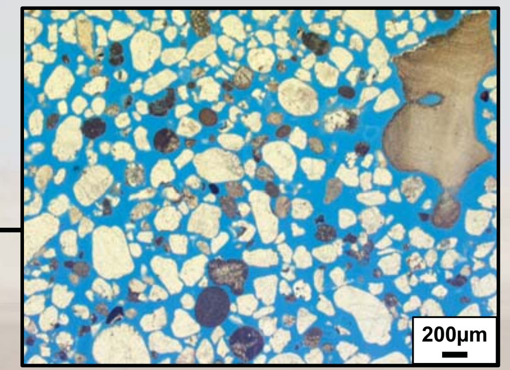


Photographs showing subaqueous precipitated gypsum crust and gypsum encrustation.

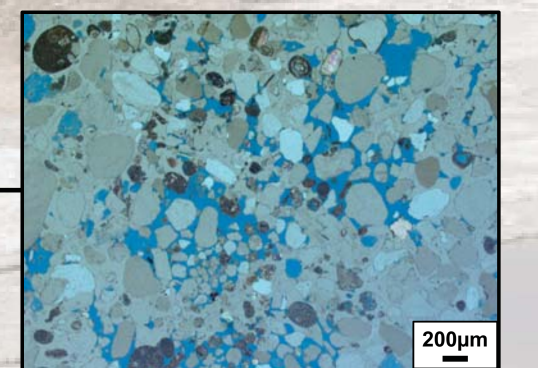
A: Prismatic gypsum crystals (swallow-tails) forming multi-layered gypsum crust, covering salina floor. Gypsum growth seems to be triggered / mediated by cyanobacteria-rich, greenish layers (close-up, red box).

B: Subaqueous precipitated, prismatic gypsum crystals encrusting plant material.

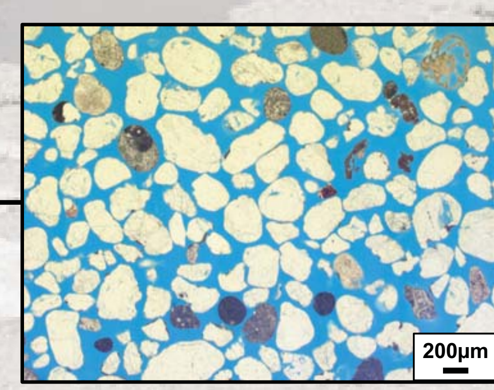




Fine- to coarse-grained quartz-dominated sand with skeletal fragments.
Plane polarized light.

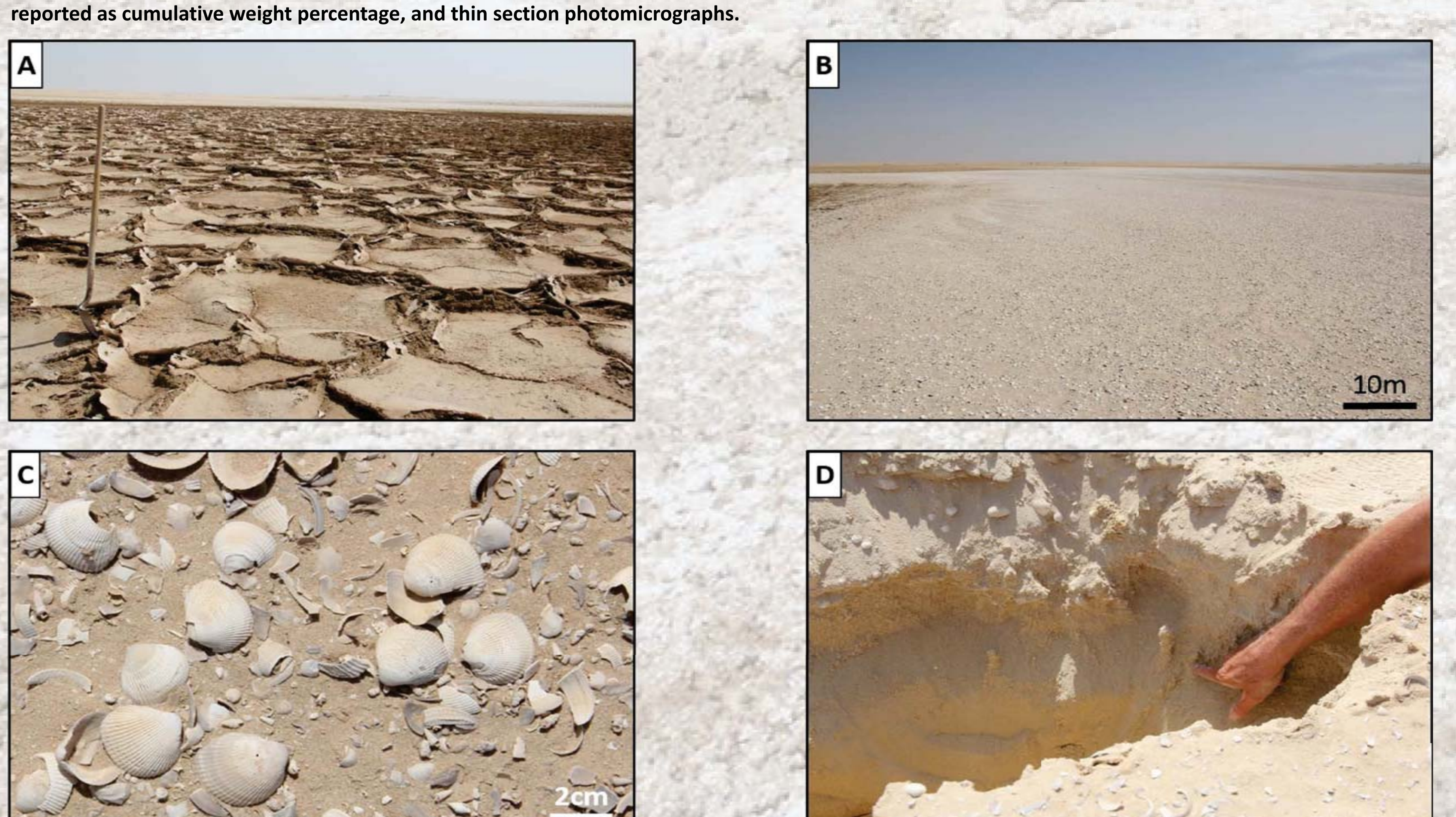


Halite cemented fine- to coarse-grained quartz-dominated sand.
Partly crossed polarized light.



Fine- to coarse-grained quartz-dominated sand with miliolid foraminifera (*Peneroplis* sp.).
Plane polarized light.

Core photograph (SN-12), mineralogical composition determined by X-ray diffraction (XRD), reported as cumulative weight percentage, and thin section photomicrographs.



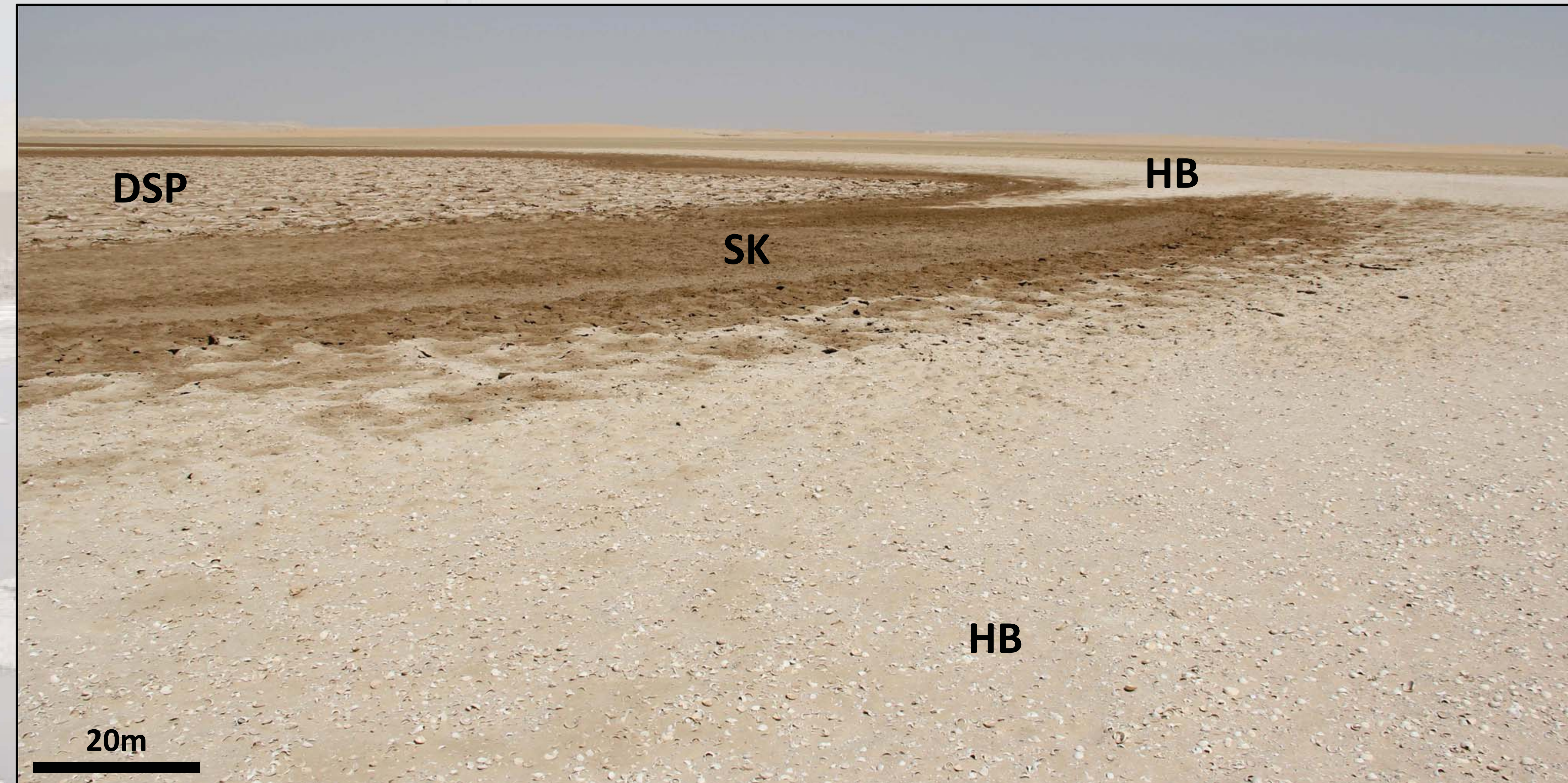
Photographs showing close ups of salt pan and Holocene beach bar / tidal bar area.

A: Dry (desiccated) salt pan (DSP) displaying halite crust polygons with upturned edges.

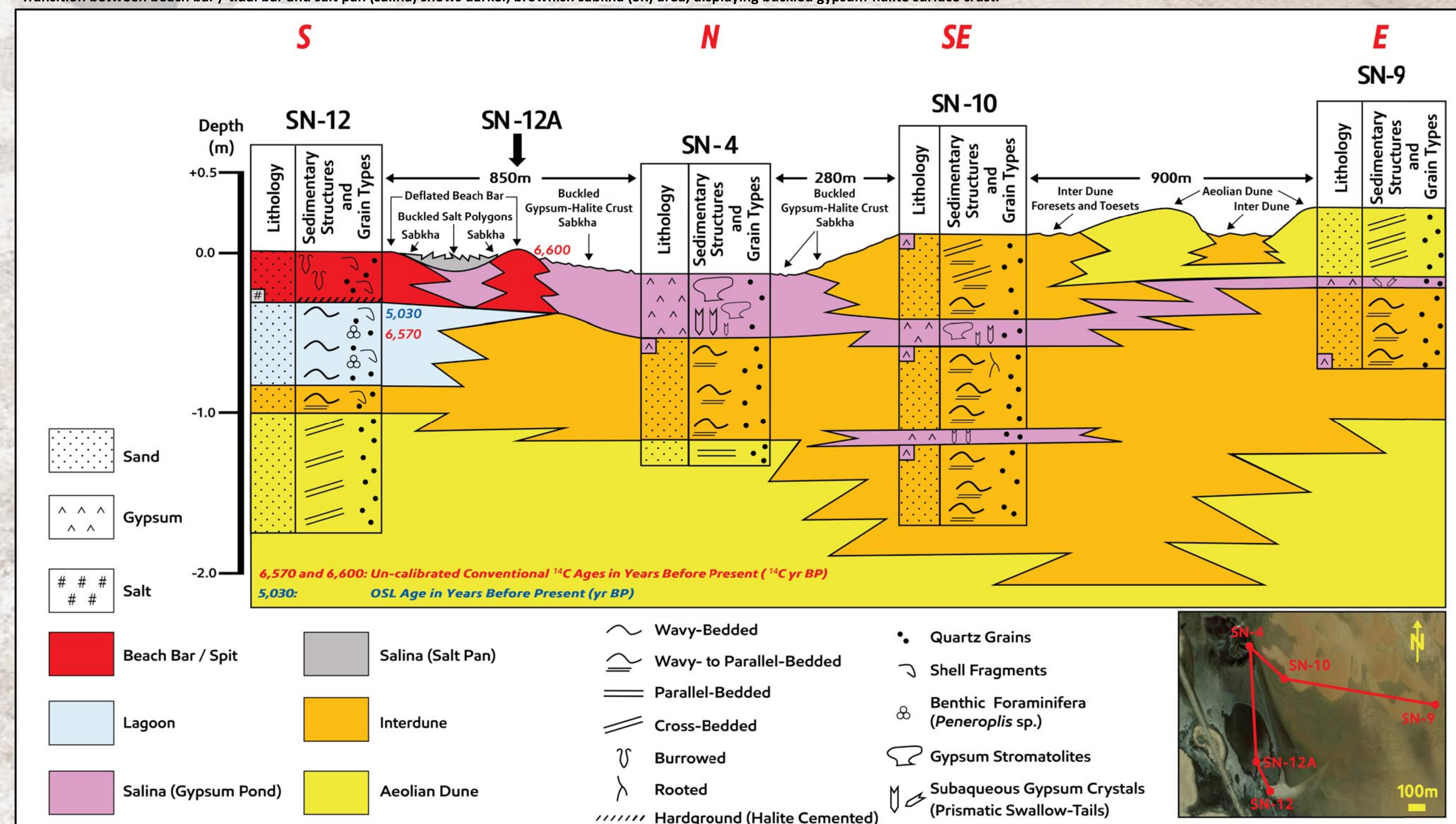
B: Deflated Holocene beach bar / tidal bar (HB) forming slight topographic highs.

C: Deflated Holocene beach bar / tidal bar (HB) showing predominantly cardiid bivalves and cerithid gastropods.

D: Holocene beach bar / tidal bar (HB) trench showing intertidal to shallow subtidal bivalves, gastropods (cerithids), and vertical *Skolithos*-type burrows.



Photograph showing Holocene beach bar / tidal bar (HB; foreground, "whitish" area) dipping towards back bar desiccated salt pan (DSP, background, "whitish" area), displaying warped-up halite polygons. Transition between beach bar / tidal bar and salt pan (salina) shows darker, brownish sabkha (SK) area, displaying buckled gypsum-halite surface crust.



Cross-section, correlating push cores SN-12, SN-4, SN-10, and SN-9. Shown is lithology, sedimentary structures, major grain types, and vertical facies successions for each push core. Also shown are interpreted lateral and vertical environment of deposition (facies) transitions between push cores (not to scale). Radiocarbon age-dating results show un-calibrated conventional ^{14}C ages of approx. 6,600 ^{14}C yr BP.