U3A Geology

Evaporites

Introduction

- Evaporites are water-soluble mineral deposits that formed from brines
- brines form when the amount of water evaporated, exceeds total rainfall and influx via rivers and streams
- minerals in evaporites include carbonates (calcite, dolomite, magnesite), sulphates (gypsum, anhydrite), chlorides (halite, sylvite), borates and nitrates
- evaporites occur in both marine and non-marine environments

Occurrence of evaporites

- Evaporites are known from all continents and all ages including Precambrian
- one quarter of the continental areas of the world is underlain by evaporites, mostly in N. Hemisphere
- the Permian basin of NW Europe, underlies most of the sea and adjacent land including NE UK, Denmark and the Netherlands, the north German plain and extensions into Poland and beyond
- in 60% of cases, the evaporite sequences contain chlorides

Origin of evaporites

- All salt deposits are formed by precipitation from brine
- the ultimate source of brine is generally seawater
- brines may also form in interior basins of an arid region in which water has derived its salt from connate waters of marine sediments, older salt beds or airborne salt particles

Composition of evaporites

- >80 mineral species have been reported from marine evaporite deposits with only 12 of these major constituents
- in non-marine environments other species may be constituents e.g. trona, ($Na_2CO_3.Na_2HCO_3.H_2O$), mirabilite ($Na_2SO_4.10H_2O$) and glauberite [$Na_2Ca(SO_4)_2$]
- only the sulphates gypsum and anhydrite are likely to be seen in the field. Anhydrite converts to gypsum through hydration
- other salt minerals are so water soluble, they do not outcrop in humid regions

Constituents of seawater and natural water (Duff 1993)

The chief constituents of average seawater	‰	Average salinities of some natural waters	%
Na	10.56	seawater	3.5
Mg	1.30	river water	0.016
Ca	0.40	Baltic Sea	0.73
K	0.38	Caspian Sea	1.3
Cl	19.00	Gulf of Kara Bogaz	18.5
SO_4	2.65	Black Sea	2.0
HCO_3 } CO_3	0.14	Dead Sea	10.2
		Great Salt Lake	20.3

Composition of oceanic salts

Salt	%
$NaCl$	77.76
$MgCl_2$	10.88
$MgSO_4$	4.74
$CaSO_4$	3.60
K_2SO_4	2.46
$CaCO_3$	0.35
$MgBr_2$	0.22

Major mineral constituents of marine evaporites

Chlorides

halite	$NaCl$
sylvite	KCl
carnallite	$KMgCl_3.6H_2O$

Sulphates

anhydrite	$CaSO_4$
langbeinite	$K_2Mg_2(SO_4)_3$
polyhalite	$K_2Ca_2Mg(SO_4)_6.H_2O$
kieserite	$MgSO_4.2H_2O$
gypsum	$CaSO_4.2H_2O$
kainite	$KMg(SO_4)Cl.3H_2O$

Carbonates

calcite	$CaCO_3$
magnesite	$MgCO_3$
dolomite	$CaMg(CO_3)_2$

Economic importance

- Nitrate evaporative deposits are important in Peru and Chile. Nitrates are used in the production of fertilisers and explosives

- thick halite deposits are often mined for salt

Halides:	halite ($NaCl$), sylvite (KCl)
Sulphates:	gypsum ($CaSO_4.2H_2O$), anhydrite ($CASO_4$)
Nitrates:	nitratine ($NaNO_3$), niter (KNO_3)
Borates:	borax [$Na_2B_4O_5(OH_4).H_20$]
Carbonates:	trona [$Na_2(HCO_3)(CO_3).2H_2O$]

Environments of formation

- Fundamental factor in formation of evaporites → climate
- seawater becomes sufficiently concentrated for precipitation only when rate of water loss through evaporation exceeds input
- arid environments found mostly in sub-tropical regions → low rainfall
- modern marine evaporites are found in coastal settings where precipitation is isolated e.g. lagoons, sediments on coastal plains, where recharge of water is limited
- in the past, larger areas of evaporite precipitation → areas isolated from open ocean (epicontinental seas, small ocean basins)

Evaporite depositional environments

(1) Graben areas within continents with limited drainage, in tropical and subtropical environments e.g. Death Valley, California

(2) Internal drainage basins in arid to semi-arid temperate to sub-tropical environments fed by ephemeral drainage e.g. Great Salt Lake, Utah

(3) Non-basin areas fed exclusively by groundwater seepage from artesian waters e.g. seepage mounds in Great Victoria Desert

(4) Restricted coastal plains in regressive sea environments e.g. sabkha deposits of Saudi Arabia, Kara Bogaz, Caspian Sea

(5) Drainage basins flowing into extremely arid environments e.g. Sahara Desert, Chilean deserts

Precipitation order of evaporites from seawater

- Evaporite minerals start to precipitate when their concentration in water reaches such a level that they can no longer stay in solution

- minerals precipitate from seawater by evaporation in the reverse order of their solubilities

calcite	→ ~50% original water volume	Increasing evaporation ↓
gypsum	→ 20% original volume	
halite	→ 10% original volume	
K and Mg salts	→ $1/60^{th}$ original volume	

- most common marine evaporites are calcite, gypsum and anhydrite, halite, sylvite (KCl), carnallite ($KMgCl_3.6H_2O$)

Development of brines

- For the development of brines from which halite can be precipitated the mean relative humidity must be <76%
- for potassium salts the relative humidity must be <67%
- most coastal regions have relative humidity 70-80% however, low values do occur over land masses
- along many arid coastlines $CaCO_3$ will be the only precipitate
- best environment for halite and potassium salts will be marine basins surrounded by land

Evaporation of seawater

- If a column of seawater 1000m deep is evaporated, only 14-17m of evaporites (mainly halite) are deposited
- some evaporite successions are thick (several hundred metres) too thick to be simply the result of evaporation of a single water mass
- also their compositions would not result from a single event
- this indicates that multiple desiccation events have occurred alternating with seawater replenishment

Marine evaporites

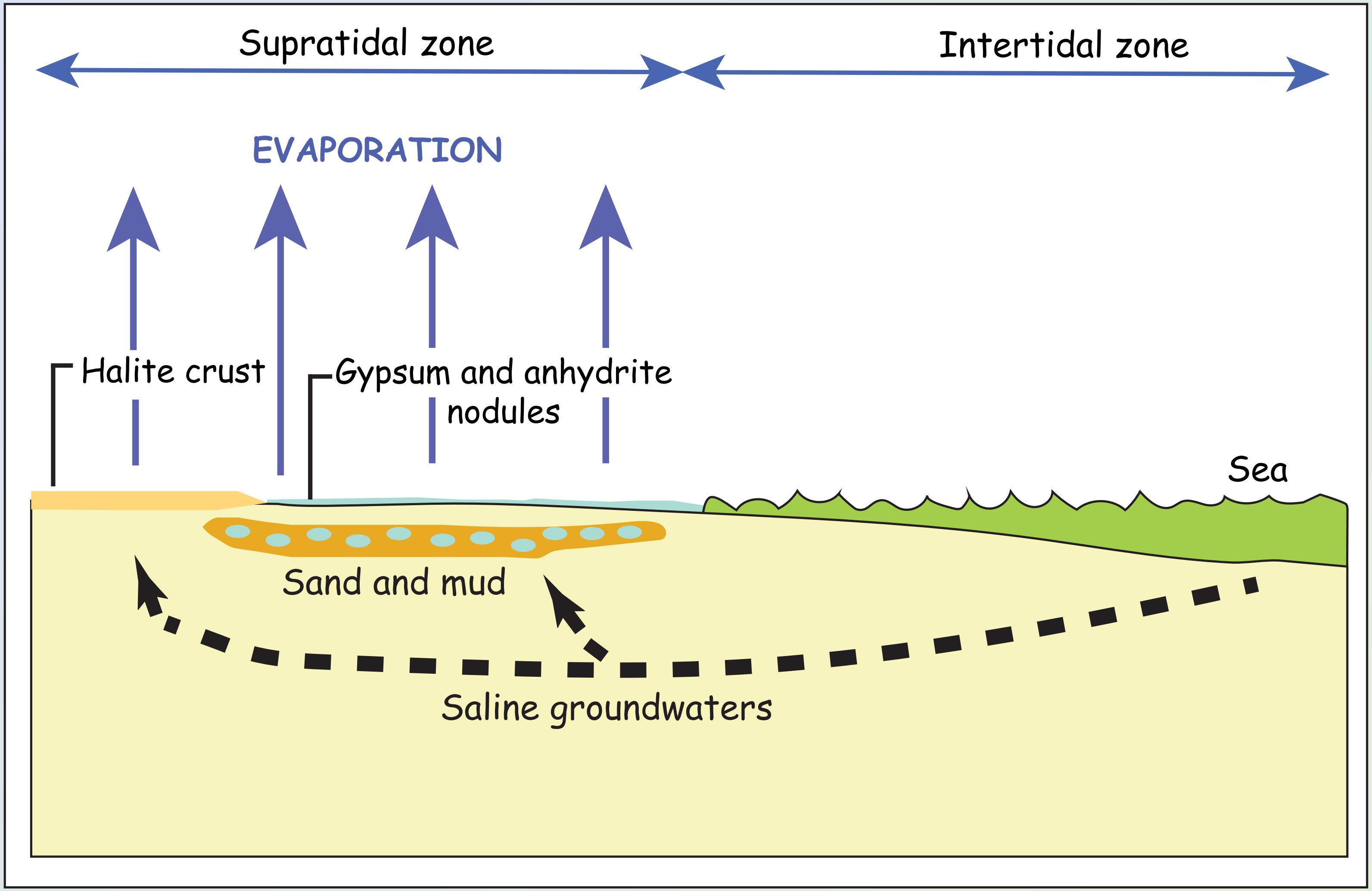
- Evaporites in modern marine environments are largely restricted to coastal regions such as sabkhas and tidal mudflats

- sabkha – coastal, supratidal mudflat or sandflat in which evaporite salt minerals accumulate as a result of semi-arid or arid environments e.g. Middle East

- sabkhas are gradational between land and intertidal zones

- however, evaporite successions in the stratigraphic record indicate that precipitation of evaporite minerals was at all times in more extensive marine settings

Schematic sabkha



Qanatir sabkha, UAE

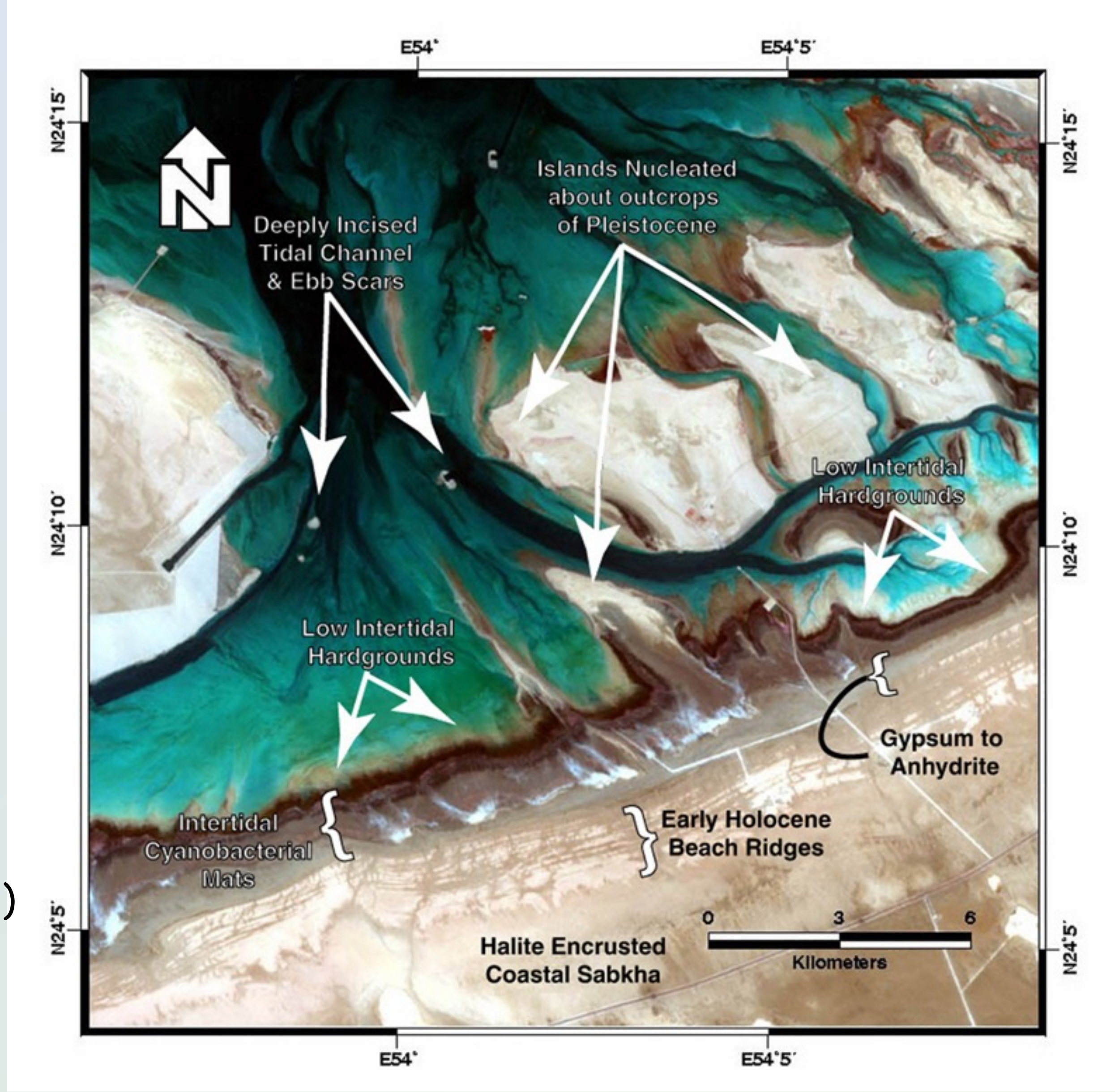
Lower intertidal to shallow lagoon carbonate

Series of cyanobacterial mat surfaces (upper intertidal)

Moist carbonate mud and gypsum mush(lower supratidal)

Halite crust on lower salt flat (mid supratidal)

Thin polygonal cracked halite on upper salt flat (upper supratidal)



Halite margin to sabkha, Qanatir, UAE

Evaporitic basins

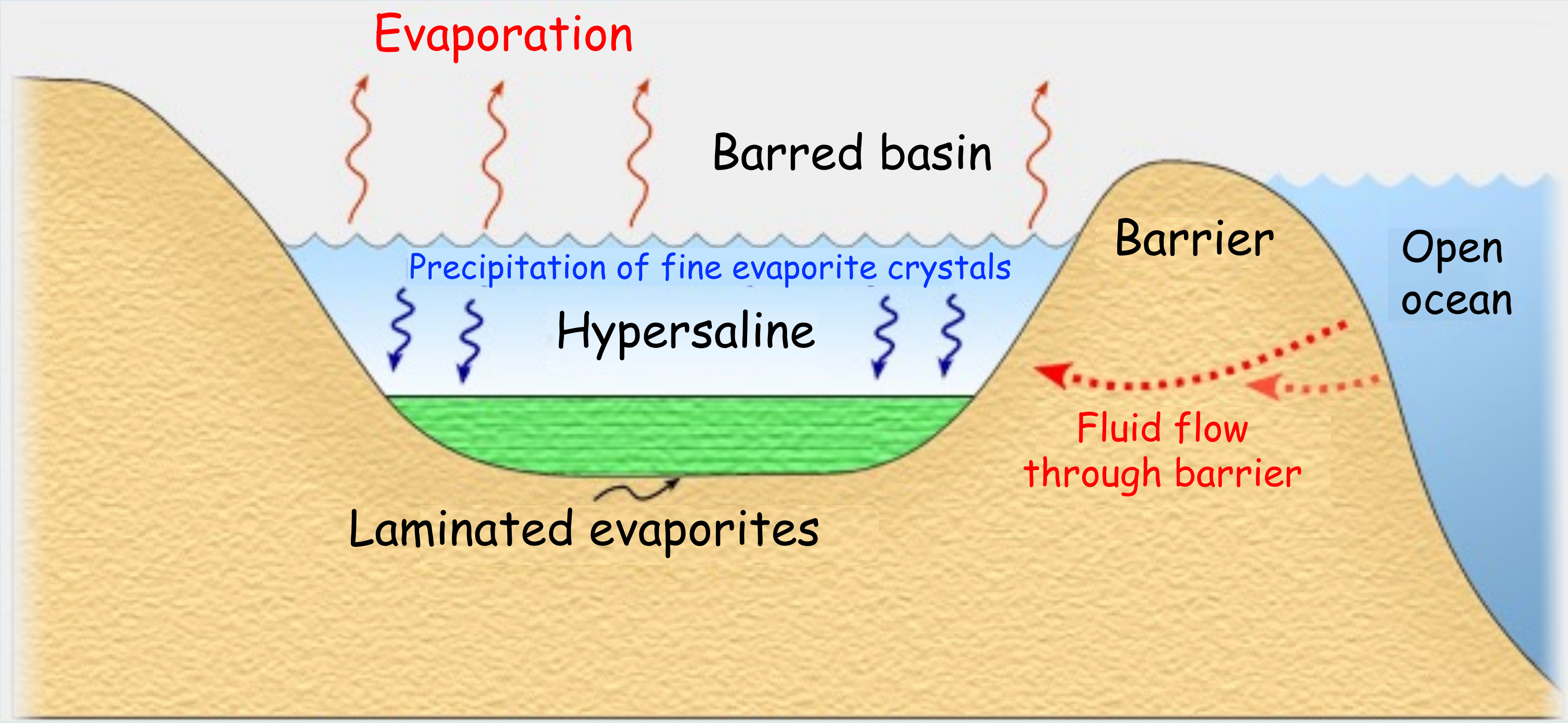
- Evaporite sedimentation occurs only in situations where a body of water becomes partly isolated from the ocean and salinity increases to the point of supersaturation → precipitation

- this can occur in epicontinental seas or small basins that are connected to the ocean by a strait that can be blocked, by fall in sea level or by tectonic uplift

- these are called basal basins and are capable of accumulating hundreds of metres of evaporite sediment e.g. Kara Bogaz

Evaporitic basins

Barred basin where the water level in the restricted area is lower than that of the open sea. Water is slowly recharged to The restricted area through the barrier



Laminated evaporites

The light laminations are anhydrite (deposited as gypsum). Darker laminae are calcite that precipitated as the basin was replenished at times

Laminated Permian Castille evaporite from SE New Mexico.

Halite sedimentation

- To produce a metre thickness of halite, a column of seawater over 75m deep must be evaporated

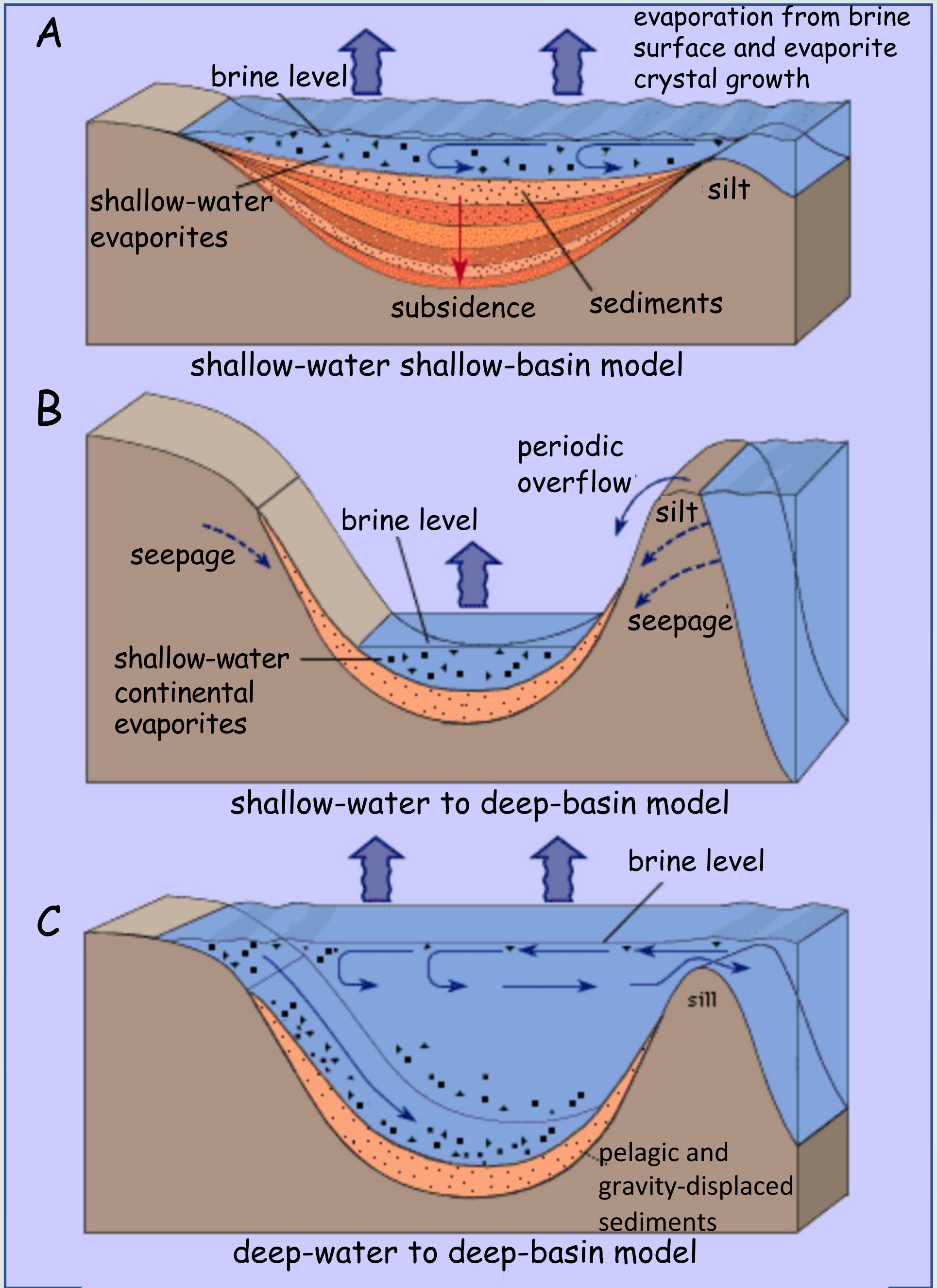
- deposition of thick succession can be produced in three ways:

(1) shallow water to shallow basin setting → evaporites are deposited in salterns, continued deposition → thick succession

(2) shallow water to deep-basin setting where a basin is only partly filled with evaporating seawater → periodically replenished

(3) deep-water to deep-basin filled with hypersaline water in which evaporite deposits form on shallow margins and are deposited by gravity flows into deeper part of basin

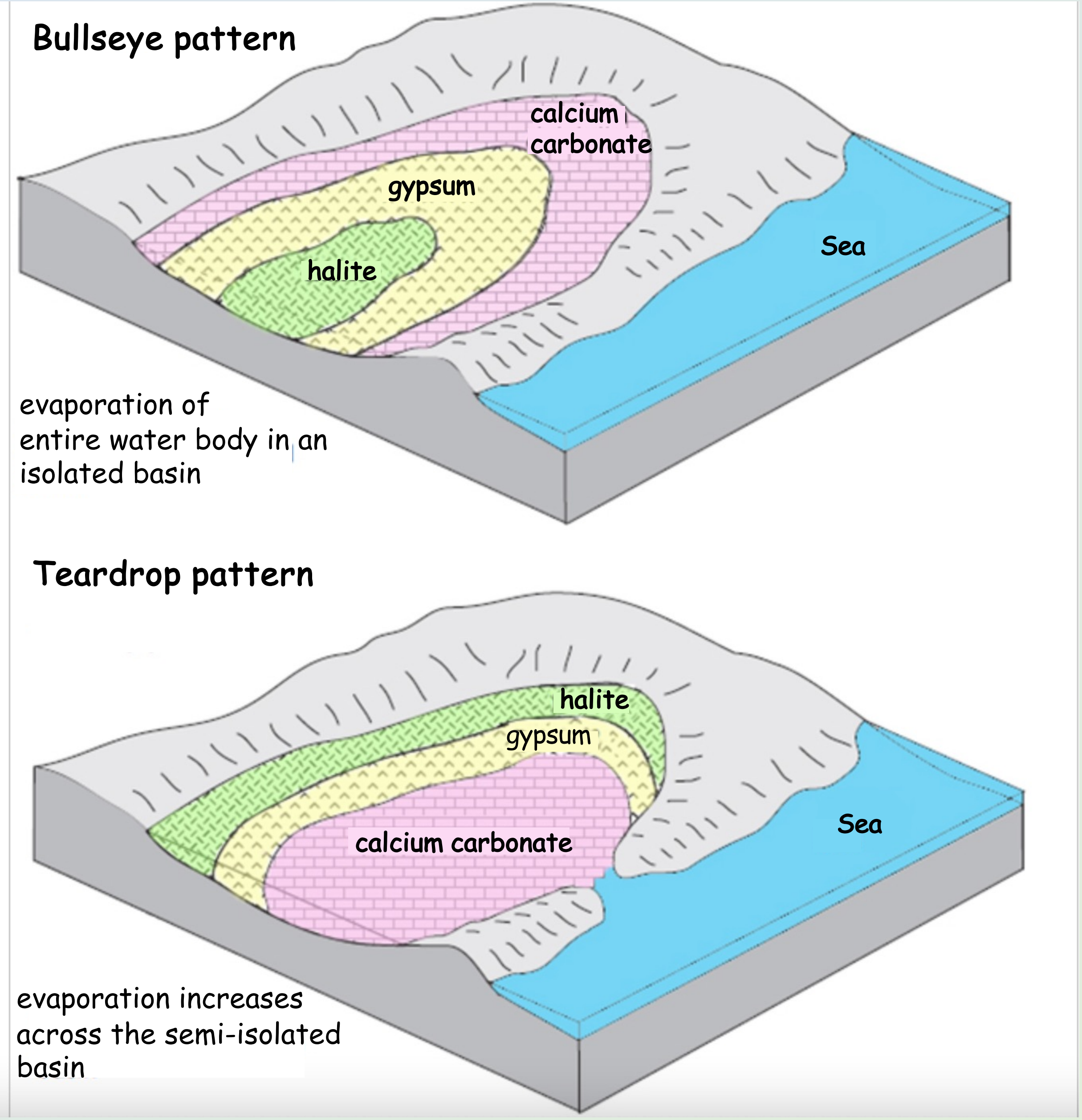
Basin models (Encyclopaedia Britannica)



Patterns of deep basin deposition

- Deep basin succession can show two distinct patterns of deposition
- if the barred basin is completely enclosed, the water body will gradually shrink in volume and area → bullseye pattern of deposition with most soluble salt in the centre of the basin (concentric zonation)
- if equilibrium is reached between inflow and evaporative loss, then stable conditions will exist across the basin → thick sequences of a single mineral can be deposited in one place → teardrop pattern
- changes in salinity and amount of seawater in basins results in variations of evaporative minerals precipitated

Patterns of deep basin deposition



Large ancient barred evaporitic basins

- There are no modern examples of very large, barred evaporitive basins
- evidence for seas precipitating evaporite minerals over hundreds of thousands of Km^2 exist in the geological record
- these saline giants have over 1000m thickness of evaporite sediments in them → products of evaporation of large quantities of seawater
- evaporites of late Miocene age in the Mediterranean Sea → evidence of evaporative conditions produced by partial isolation from Atlantic ocean
- this period of hypersaline conditions in the Mediterranean → Messinian Salinity Crisis

Messinian Salinity Crisis

- Messinian Salinity Crisis → geological event in which the Mediterranean went into a cycle of partial to nearly complete desiccation
- occurred in Late Miocene (5.96–5.33Ma) and ended with a flood that reclaimed the basin
- the precursor of the Strait of Gibraltar sealed the Mediterranean from the Atlantic Ocean
- basin reached a depth of 3-5km below normal sea level
- ended with the re-opening of the Strait of Gibraltar
- resultant salt layer (mostly gypsum, anhydrite, halite) → tens of metres thick

Messinian Salinity Crisis

Artistic interpretation of the Mediterranean at some time of the Messinian Salinity Crisis

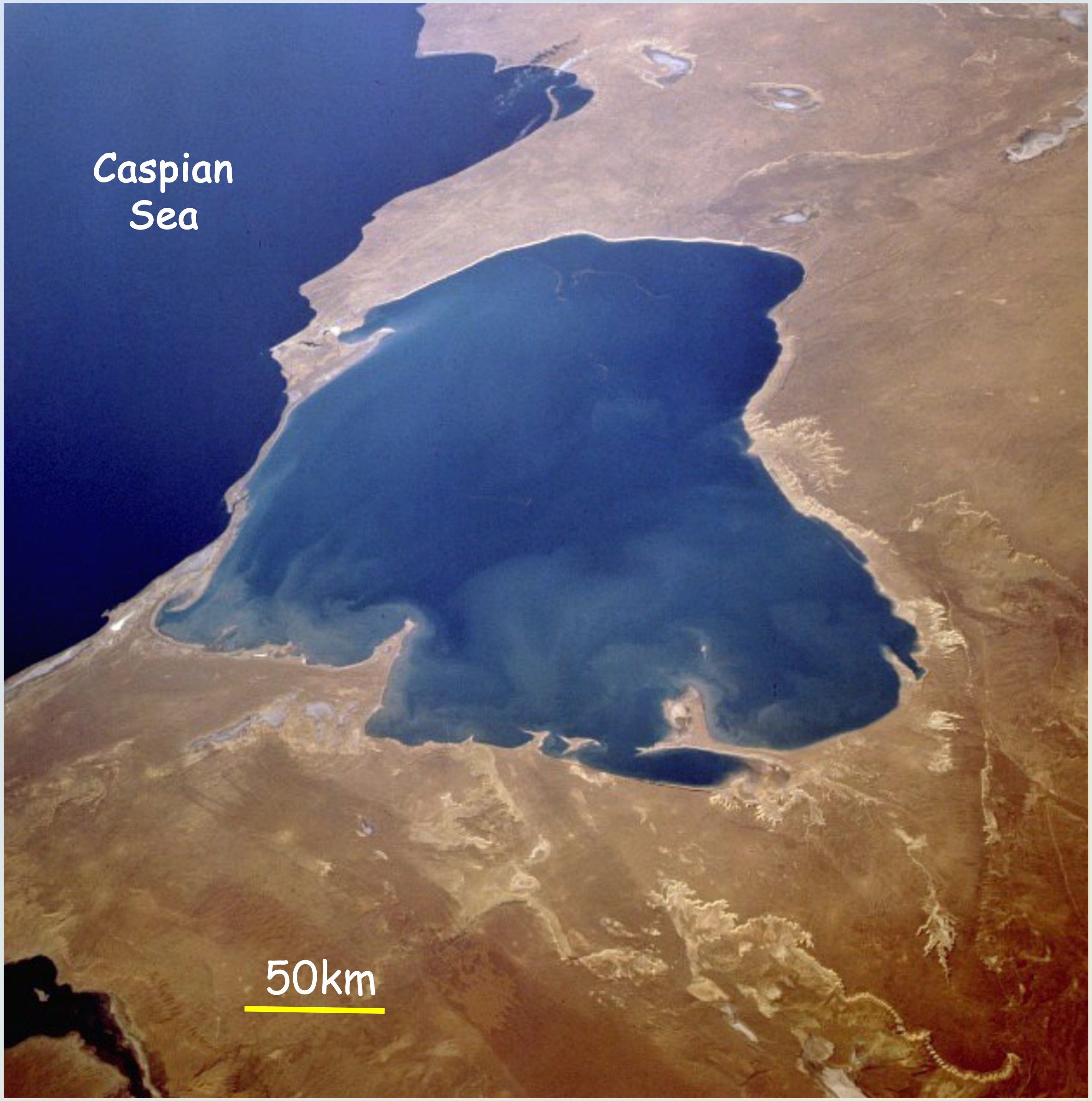
Arid lagoons

- In hot dry climates loss of water from surface of a lagoon is high
- if not balanced by the influx of water → salinity of lagoon will rise and become hypersaline → more concentrated in salts than normal water
- an area of hypersaline shallow water that precipitates evaporite minerals is called a saltern
- deposits are typically layered gypsum and/or halite occurring in units metres to tens of metres thick

Kara Bogaz

- Kara Bogaz → highly saline lagoon off the Caspian Sea with variable surface area ~18,000Km^2, its volume fluctuates
- it is separated from the Caspian Sea by a narrow ridge having a narrow opening
- salinity of lagoon is an average 35%, salt builds up on S shore
- in 1980 workers blocked the Caspian Sea → resultant dust bowl caused blowing of salt, soil poisoning and health problems
- in 1984 the lake became completely dry
- in 1992 the barrier was removed → influx of Caspian Sea

Kara Bogaz, Turkmenistan



Ancient basinal basins

- Thought to have developed in shallow and deep water environments
- shallow water evaporites tend to occur as massive beds with considerable lateral continuity (tens of Km)
- deep water evaporites also have great horizontal continuity
- they are thinly bedded to laminar and may contain sulphate and halite sections tens to hundreds of metres in thickness
- the majority of these saline giants formed within interior basins, others occur in rift valley settings

Genesis of basinal basins

Two principal models have been proposed for the genesis of basinal saline giants:

(1) Desiccated basin model

(2) Brine-filled model

Desiccated basin model

- In this model, there are several basin filling and drying out events since one drying out event would produce only a thin section

- each evaporitic event gives rise to concentric zones of carbonate, sulphate and chloride

Genesis of basinal basins

Brine-filled model

- Evaporating water in modern evaporites, replenished by continuous inflow of normal seawater (most commonly used to explain saline giants)
- the more saline water is dense and sinks below each inflow and is trapped within the bar at the inlet
- a variation proposes that precipitation of less soluble minerals occurs close to inflow and more soluble minerals further away → teardrop pattern

Zechstein

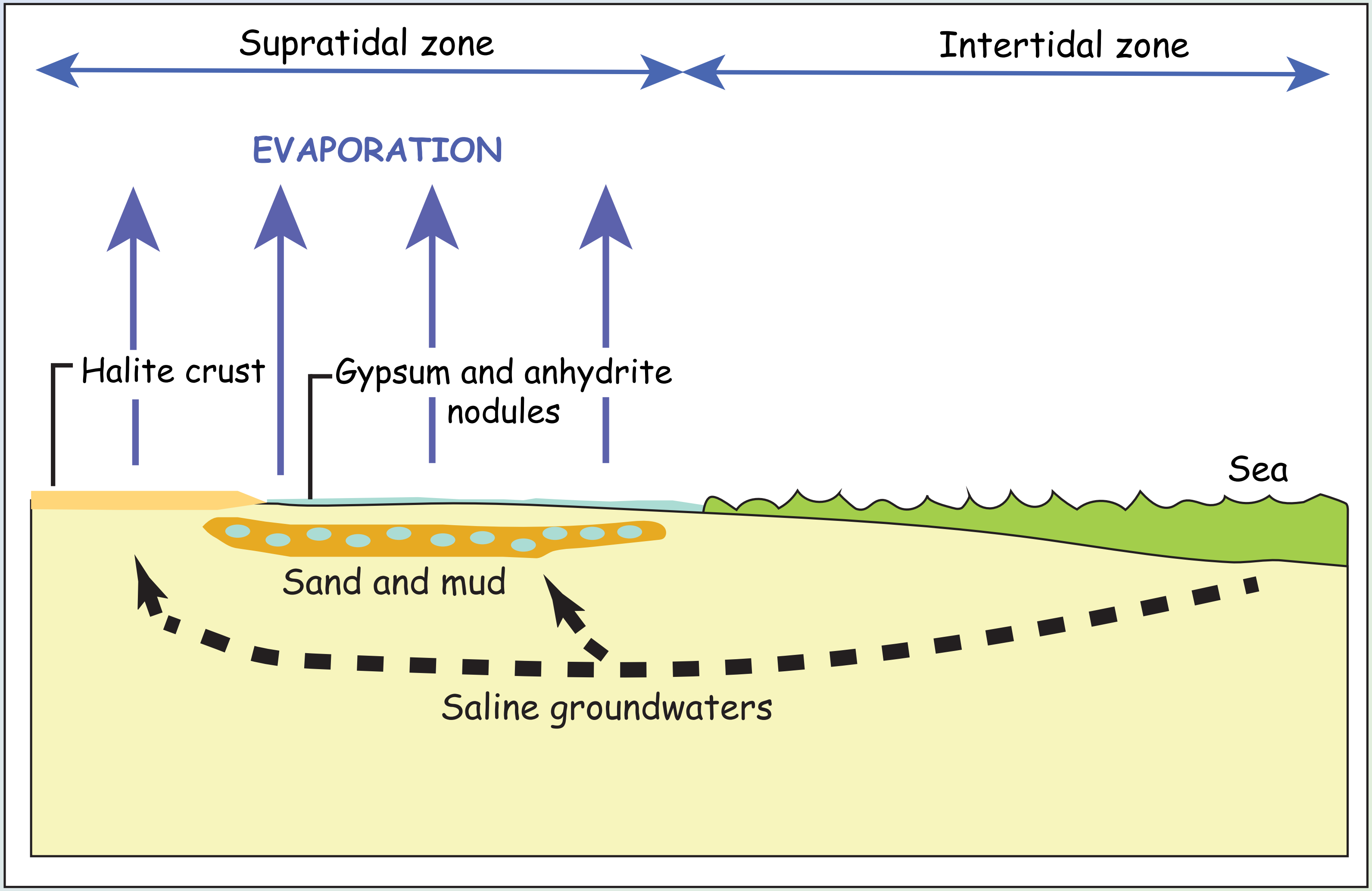
- The Zechstein is a formation of sedimentary rock layers of Late Permian age located in the European Permian Basin
- the basin stretches from the east coast of the UK to northern Poland
- the water level in the Zechstein Sea is believed to be controlled by eustatic change
- at a low level it became a completely enclosed basin leading to a high degree of desiccation
- evaporite rocks of the Zechstein Formation were deposited by the Zechstein Sea, an epicontinental sea that was situated near the equator in the Permian

Zechstein Sea

Arid sabkha flats

- Arid shorelines are formed today in places like the Persian Gulf where there are evaporites within coastal sediments
- those coasts are called sabkhas
- sabkhas typically have very low relief and there is not always a well-defined beach
- the coastal plain of a sabkha is occasionally wetted by seawater during very high tides and onshore storm winds
- most important water supply is groundwater seepage from the sea

Schematic sabkha



Gypsum and anhydrite growth

- Gypsum and anhydrite grow within sediment while a crust of halite forms at the surface
- gypsum grows within clusters and the anhydrite forms amorphous nodules with original sediment in between
- in general anhydrite forms in hotter drier sabkhas and gypsum where temperatures are lower and where there is a supply of fresh continental water to the sabkhas
- layers of anhydrite with remnants of other sediments have a characteristic chicken-wire structure
- halite crusts are rarely preserved because they are removed by any water flows

Anhydrite evaporites

Nodular anhydrite, Dukan sabkha

Chicken-wire structure in anhydrite

Non-marine evaporites

- Non-marine evaporites may contain halite, gypsum and anhydrite
- evaporite deposition in non-marine environments includes closed lakes in arid and semi-arid regions
- such lakes form in closed interior basins or shallow depressions on land where drainage is internal and runoff does not reach the sea
- if water depths are shallow and the lake is ephemeral, the term playa or playa lake is commonly used
- modern examples include The Great Salt Lake, Utah; Dead Sea

Non-marine evaporites - salinity

- Changing lake levels and water volumes lead to fluctuating salinity values
- variations in salinity lead to much solution and subsequent re-precipitation of evaporites
- non-marine evaporite deposits contain many minerals that are uncommon in marine evaporites e.g. borax [$Na_2B_4O_5(OH)_4.8H_2O$], epsomite ($MgSO_4.7H_2O$), trona [$Na_3(HCO_3)(CO_3).2H_2O$], mirabilite ($Na_2SO_4.10H_2O$)

Great Salt Lake, Utah

- Great Salt Lake → world's largest salt lake, surface area fluctuates due to its low average depth of 4.9m
- lake's three major tributaries (Jordan, Weber, Bear rivers) deposit ~1.1 million tonnes of minerals annually
- since lake has no outlet other than evaporation minerals accumulate → high salinity
- salinity of lake's main basin is variable ranging from 5 to 27% c.f. 3.5% for seawater and 33.7% Dead Sea
- the Great Salt Lake water is rich in K and depleted in Ca

Great Salt Lake, Utah