

Lesson 5 cont'd:

The Minerals and Rocks of the Earth

*5a: The minerals- special
mineralogy*

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In the previous lectures concerning the materials of the earth, we studied the most important silicates. We did so, because they make up more than 80% of our planet. We said, if we know them, we know much about our planet.

However, on the surface or near-surface areas of the earth 75% is covered by sedimentary rocks, almost 1/3 of which are not silicates. These are the carbonate rocks such as limestones, dolomites (Americans call them dolostones, which is inappropriate, because dolomite is the name of a person {Dolomieu}, after which the mineral dolomite, the rock dolomite and the Dolomite Mountains in Italy have been named; it is like calling the Dolomite Mountains Dolo Mountains!). Another important category of rocks, including parts of the carbonates, are the evaporites including halides and sulfates. So we need to look at the minerals forming these rocks too. Some of the iron oxides are important, because they are magnetic and impart magnetic properties on rocks. Some hydroxides are important weathering products. This final part of Lesson 5 will be devoted to a description of the most important of the carbonate, sulfate, halide and the iron oxide minerals, although they play a very little rôle in the total earth volume. Despite that, they play a critical rôle on the surface of the earth and some of them are also major climate controllers.

The carbonate minerals are those containing the carbonate ion CO_3^{-2}

The are divided into the following classes:

1. Anhydrous carbonates (i.e., waterless carbonates)
1. Anhydrous carbonates with compound formulae
2. Carbonates with hydroxyl or halogen parts
3. Hydrated carbonates (i.e., carbonates with water)

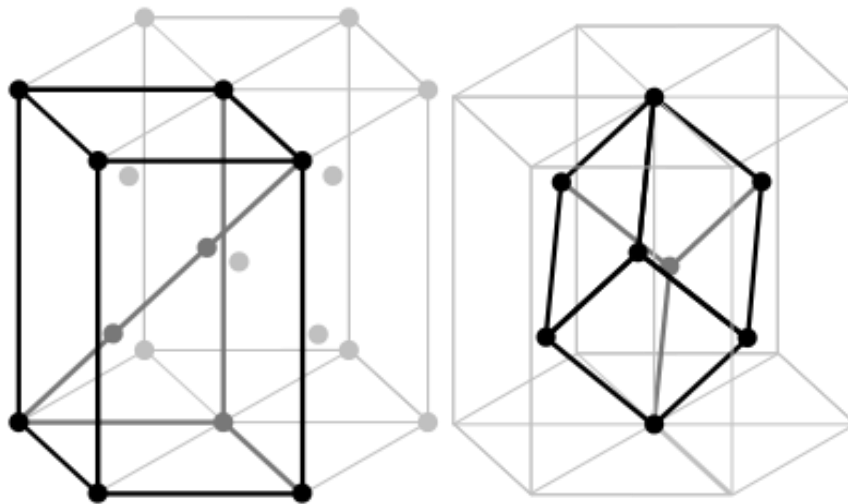
Carbonate minerals are numerous and some of them make beautiful gem- or decorative stones (such as malachyte). Not all of them are important rock-builders. In the following I describe only the important rock-builders and two decorative minerals, because they are often encountered in social life.

Anhydrous
carbonates
(i.e., waterless
carbonates)

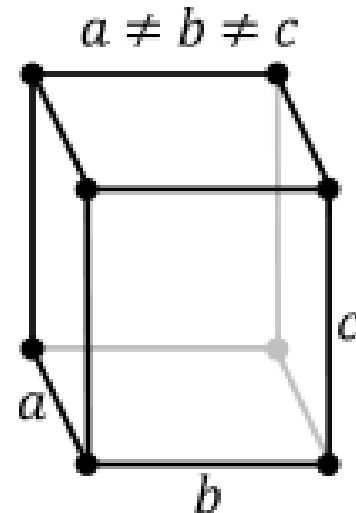
Anhydrous carbonates fall into two groups:

1. Calcite group
2. Aragonite group.

Aragonite and calcite have the same composition, but different crystal systems. Calcite and all calcite group minerals are trigonal (hexagonal), whereas aragonite and all the aragonite minerals are orthorhombic.



Trigonal geometry (=hexagonal geometry)



Orthorhombic geometry

Calcite group of carbonate minerals
(all trigonal, i.e., hexagonal):

Calcite CaCO_3

Gaspeite $(\text{Ni}, \text{Mg}, \text{Fe}_{2+})\text{CO}_3$

Magnesite MgCO_3

Otavite CdCO_3

Rhodochrosite MnCO_3

Siderite FeCO_3

Smithsonite ZnCO_3

Spherocobaltite CoCO_3

Of these, we shall look at only calcite, as it is by far the most important rock-builder among the calcite group of carbonate minerals



Clear calcite crystals
from the West
Cumberland iron
field, Cumbria,
England (copyright
by Kristalle and
Crystal Classics)

Calcite



Calcite is among the minerals that were known in antiquity. It was named by Pliny the elder (died during the famous eruption of the Vesuvius in 79 CE) from the Latin *calx* meaning lime.

Crystal system: triclinic-pinacoidal

Cleavage: $[10\bar{1}1]$ perfect, $[101\bar{1}]$ perfect, $[10\bar{1}\bar{1}]$ perfect (in three rhombohedrons!)

Colour: colourless, white, pink, yellow, brown

Average density: 2.71

Hardness: 3

Streak: white

Luster: vitreous-glassy

Fracture: brittle-conchoidal



Calcite effervesces when treated with dilute hydrochloric acid (about 10%):



Not all carbonate minerals fizz with the same vigour when in contact with cold hydrochloric acid. For example, dolomite barely fizzes. However, with warm hydrochloric acid, the dolomite will be seen to fizz more vigourously. This is because at higher temperatures the rock reacts more easily with the acid.

When in the field, always carry with you a bottle of 10% HCl fitted with a dropper such as the ones shown on the right.



Calcite also dissolves when in contact with carbonic acid (i.e. carbonated water):

The following is the main reaction sequence:



Water (from rain) + carbondioxide (from the atmosphere and from the soil) \rightarrow carbonic acid (i.e., carbonated water)



This is the cause of widespread limestone dissolution in areas underlain by extensive limestones. This dissolution creates a special group of landforms known as karst topography, which we shall study later this semester.











“Dog’s tooth” calcite crystals

Aragonite group of carbonate minerals (all orthorhombic):

Aragonite CaCO_3

Cerussite PbCO_3

Strontianite SrCO_3

Witherite BaCO_3

Rutherfordine UO_2CO_3

Natrite Na_2CO_3



Aragonite crystals
from an unknown
locality

Aragonite



Aragonite was named after Molina de Aragón, 25 km to Aragón in Guadalajara, Spain, by the great German mineralogist Abraham Gottlob Werner in 1797.

Crystal system: orthorhombic-dipyramidal

Cleavage: [010] distinct

Colour: colourless, white, grey, yellowish white, reddish white

Average density: 2.93

Hardness: 3.5-4

Streak: white

Luster: vitreous-glassy

Fracture: subconchoidal







Calcite and aragonite compensation depths in the oceans

Calcite is insoluble in the surface waters of the earth. As calcium carbonate sinks in the water column a level is reached where the dissolution dramatically increases. That depth is known as lysocline (from the Greek words λύσις {*lysis*=loosening, setting free, releasing} and κλίνω {*klino*=to lean, to exhibit a gradient}). When the calcite compensation depth (CCD) is reached, all the calcite is already dissolved according to the following reaction



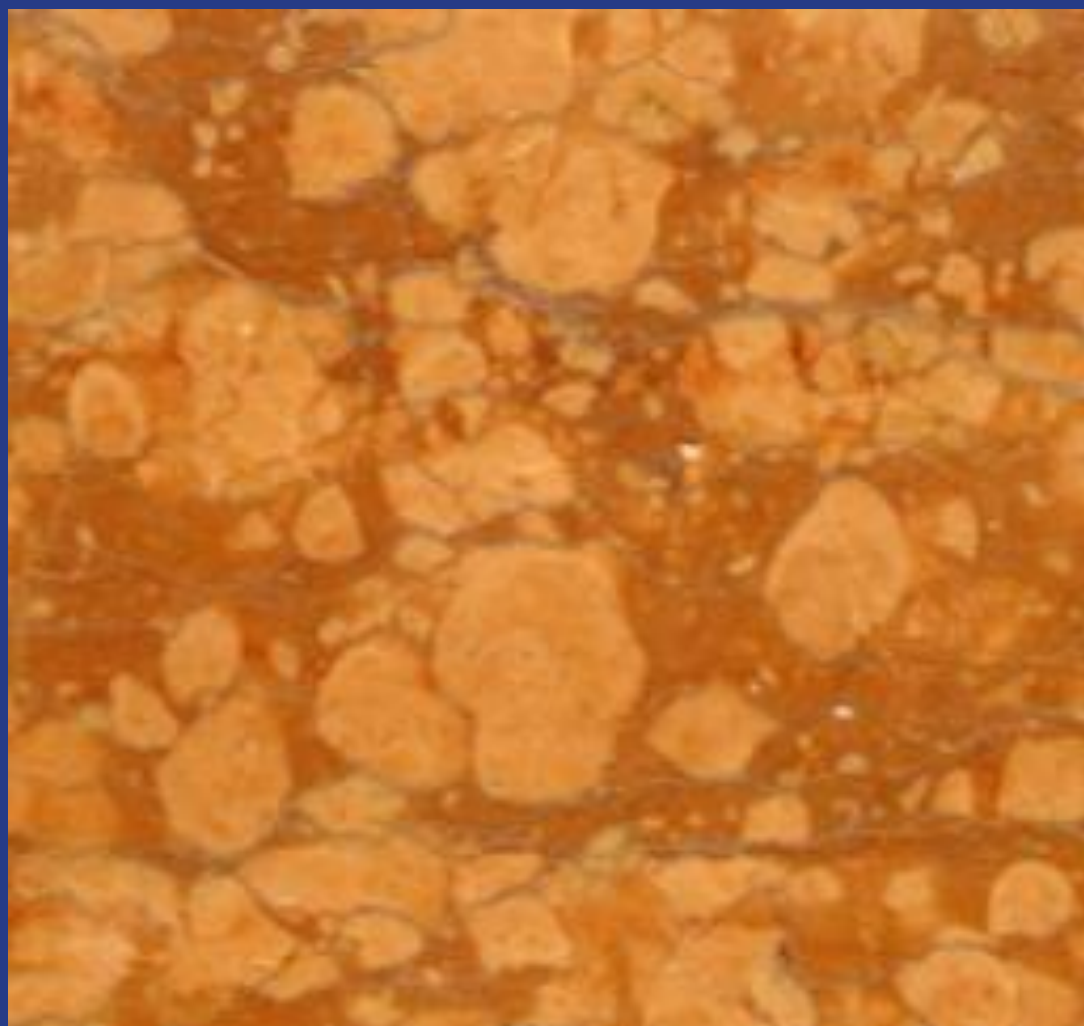
The dissolution of calcite is dependent on the chemical composition of the water, its temperature and pressure. Today, the CCD is at about 4.2 to 4.5 km depth in the world ocean. In upwelling zones it descends down to 5 km. The aragonite compensation (ACD) depth is shallower.



Ammonitico Rosso=
Adneter Kalk=Knollenkalk=nodular limestone





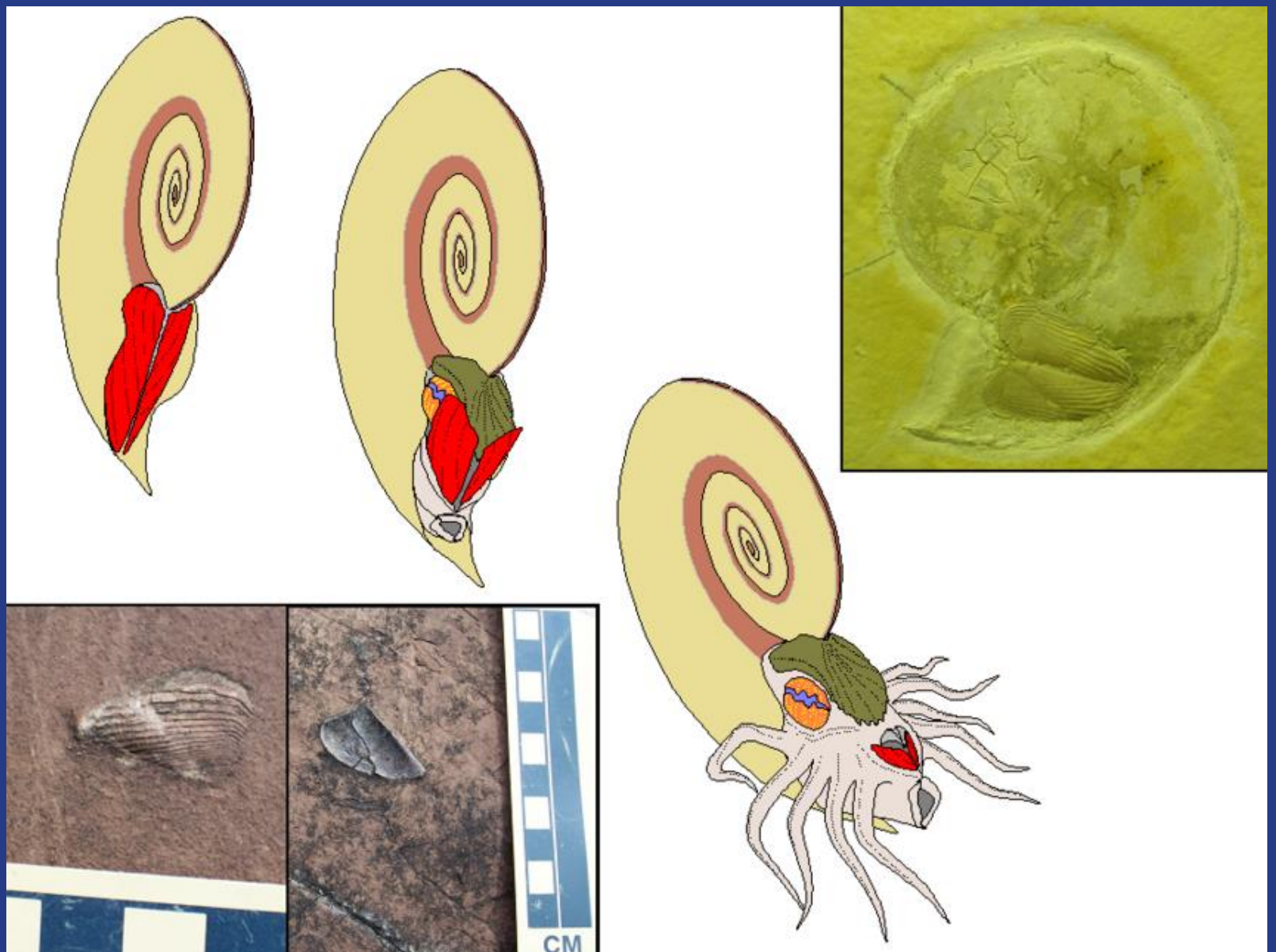




A pair of ammonite aptychi (singular: aptychus)



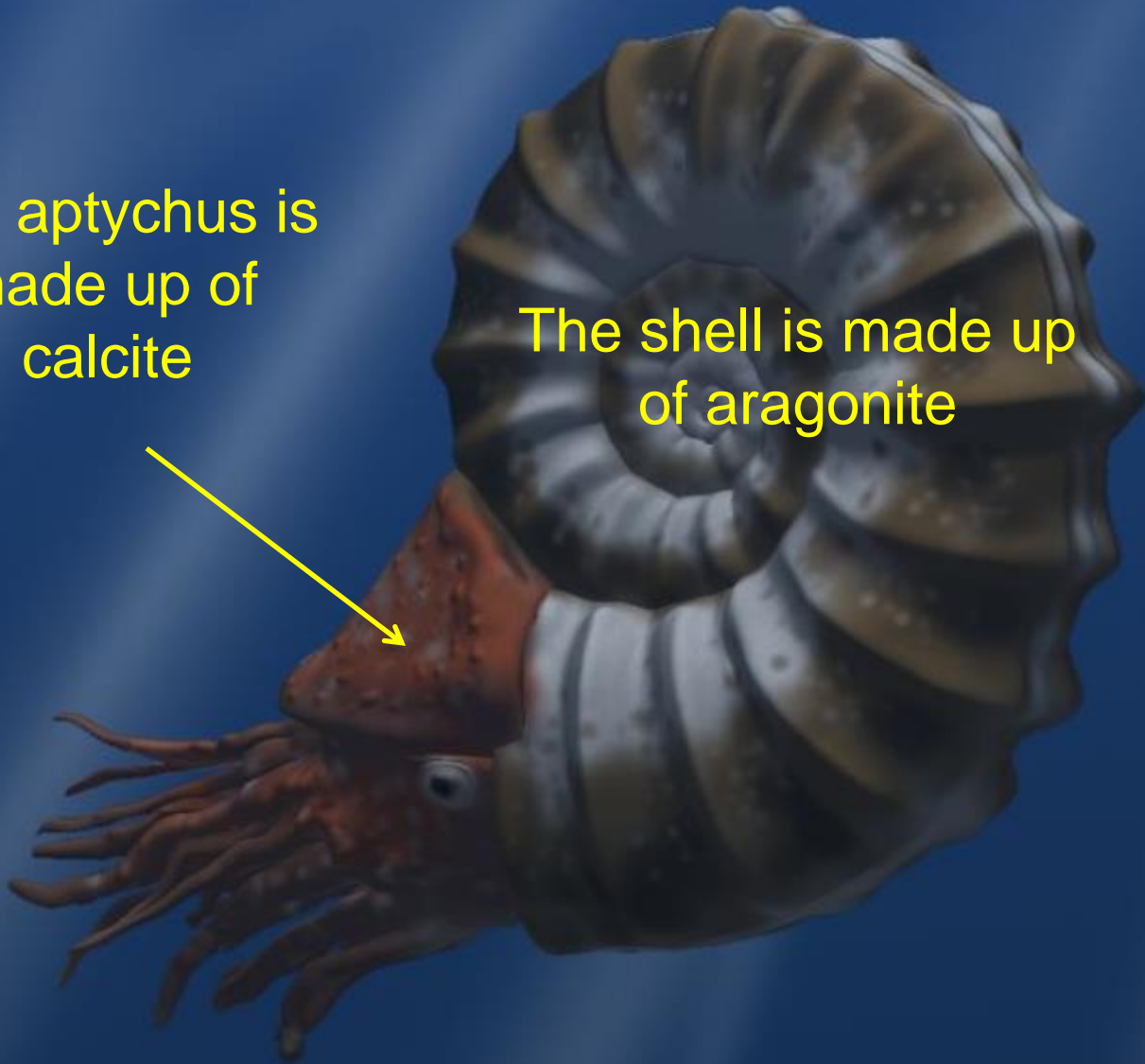
Different ammonite aptychi



Aptychi in the anatomy of an ammonite.
The three insets show aptychus fossils.

The aptychus is
made up of
calcite

The shell is made up
of aragonite



A swimming ammonite

Sea level



Ammonites lived in the upper 100m or so of the water column

ACD



Ammonitico
Rosso=Adneterkalk

CCD



Calcari e marni ad aptici=Aptychenkalk=
Maiolica=aptychus limestone

No calcareous fossils preserved

SEA BOTTOM

Silicious ooze, radiolarian
cherts etc.

Therefore the behaviour of calcite and aragonite profoundly influences the pattern of sedimentation in the deep ocean.

Anhydrous carbonates with compound formulae

Anhydrous carbonates with compound formulae

Ankerite $\text{CaFe}(\text{CO}_3)_2$

Dolomite $\text{CaMg}(\text{CO}_3)_2$

Huntite $\text{Mg}_3\text{Ca}(\text{CO}_3)_4$

Minrecordite $\text{CaZn}(\text{CO}_3)_2$

Baryoctide $\text{BaCa}(\text{CO}_3)_2$



Dolomite



Dolomite was first named by Nicolas-Théodore de Saussure in 1792 in honour of the great French geologist Déodat Gratet de Dolomieu who first recognised it as a rock-builder first in the buildings of Rome and then in what later became known as the Dolomites in the Southern Alps

Dolomite crystals from an unknown locality.

Crystal system: trigonal-rhombohedral

Cleavage: $[10\bar{1}1]$ perfect, $[10\bar{1}1]$ perfect, $[10\bar{1}1]$

Colour: white, grey, reddish white, brownish grey

Average density: 2.84

Hardness: 3.5-4

Streak: white

Luster: vitreous-glassy

Fracture: brittle conchoidal



The Dolomites, also known as the “Pale Mountains”.



The location of *The Dolomites* in the Southern Alps

The name of the mountains, as “The Dolomites” appeared first in a guidebook published in London in 1837 to describe the mountainous area around the valleys of Fassa, Gardena, Badia and Pusteria as well as the Venetian Alps. In 1864 two Englishman, Josiah Gilbert and G. C. Churchill, published a book called *The Dolomite Mountains* which introduced the term into a larger European audience.

The name “Pale Mountains” comes from an old tale of the marriage of the Prince of these mountains with the Princess of the Moon. The Prince of these mountains, which then had the same colour as the rest of the Alps, fell in love with the Princess of the Moon. But the Princess of the Moon could not live amidst the dark mountains. Neither could the Prince go to the Moon which was too bright for him. So, one day, when wondering hopeless in his mountains he came across the King of the Salvani, a nice little gnome, who was looking for a place for his people to live. When the Prince told him of his problem, the King offered to help him in exchange for the right to live in the forests of the mountains. The Prince granted it and the Salvani then weaved the light of the Moon onto the mountains, making them pale, so that the Princess of the Moon could come and live there. When the Princess saw the bright, pale coloured mountains, she was overjoyed and came there and lived with the Prince of the Pale Mountains ever after!



The *Tre Cime di Lavaredo* (in German *Die Drei Zinnen*)
in the Dolomites.

Carbonates
with hydroxyl
or halogen

Carbonates with hydroxyl or halogens (all except Phosgenite are monoclinic; phosgenite is hexagonal (or triclinic in American terminology))

Azurite $\text{Cu}_3(\text{CO}_3)_2(\text{OH})_2$

Hydrocerussite $\text{Pb}_3(\text{CO}_3)_2(\text{OH})_2$

Malachite $\text{Cu}_2\text{CO}_3(\text{OH})_2$

Rosasite $(\text{Cu},\text{Zn})_2\text{CO}_3(\text{OH})_2$

Phosgenite $\text{Pb}_2(\text{CO}_3)\text{Cl}_2$

Hydrozincite $\text{Zn}_5(\text{CO}_3)_2(\text{OH})_6$

Aurichalcite $(\text{Zn},\text{Cu})_5(\text{CO}_3)_2(\text{OH})_6$



Azurite from the Shilu
Copper Mine,
Guangdong Province,
South China.

Azurite



It used to be known as lazward. Name changed to Azurite by the French geologist François Sulpis Beudant in 1824.

Crystal system: monoclinic-prismatic

Cleavage: [011] perfect, [100] fair

Colour: azure blue, blue, light blue, dark blue

Average density: 3.83

Hardness: 3.5-4

Streak: light blue

Luster: vitreous-glassy

Fracture: brittle conchoidal



Azurite from the historic Laurion mines in Greece (Copyright by Michael Pfeil)



Azurite from Namibia, Southwest Africa



Malachite from the
Congo, Africa



Layered malachite from an unknown locality

Malachite



The name was mentioned already in antiquity by Pliny the elder. The name comes from the Greek *μαλαχή* (*malakhe*=mallows).

Crystal system: monoclinic-prismatic

Cleavage: [201] perfect, [101] fair

Colour: green, dark green, bluish green

Average density: 3.8

Hardness: 3.5-4

Streak: light blue

Luster: vitreous-silky

Fracture: uneven

Hydrated carbonates

Hydrated carbonates:

Hydromagnesite $\text{Mg}_5(\text{CO}_3)_4(\text{OH})_2 \cdot 4\text{H}_2\text{O}$

Ikaite $\text{CaCO}_3 \cdot 6(\text{H}_2\text{O})$

Lansfordite $\text{MgCO}_3 \cdot 5(\text{H}_2\text{O})$

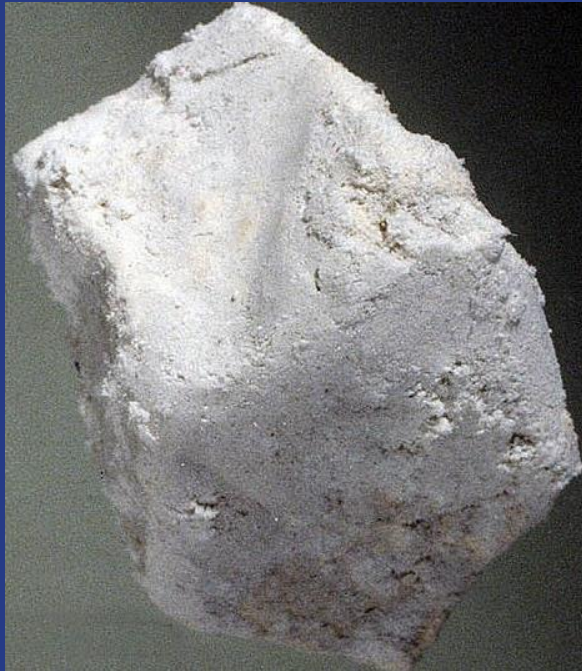
Monohydrocalcite $\text{CaCO}_3 \cdot \text{H}_2\text{O}$

Natron $\text{Na}_2\text{CO}_3 \cdot 10(\text{H}_2\text{O})$

Zellerite $\text{Ca}(\text{UO}_2)(\text{CO}_3)_2 \cdot 5(\text{H}_2\text{O})$



Natron from Wyoming, USA



Natron from British
Columbia, Canada

Natron



An ancient name, from the Latin *natrium* = soda. The name actually is derived from the Wadi al-Natron in Egypt, near Cairo.

Crystal system: monoclinic-domatic

Cleavage: [001] distinct, [010] imperfect

Colour: colourless, white, grey, yellow

Average density: 1.44

Hardness: 1

Streak: white

Luster: vitreous-glassy

Fracture: brittle conchoidal

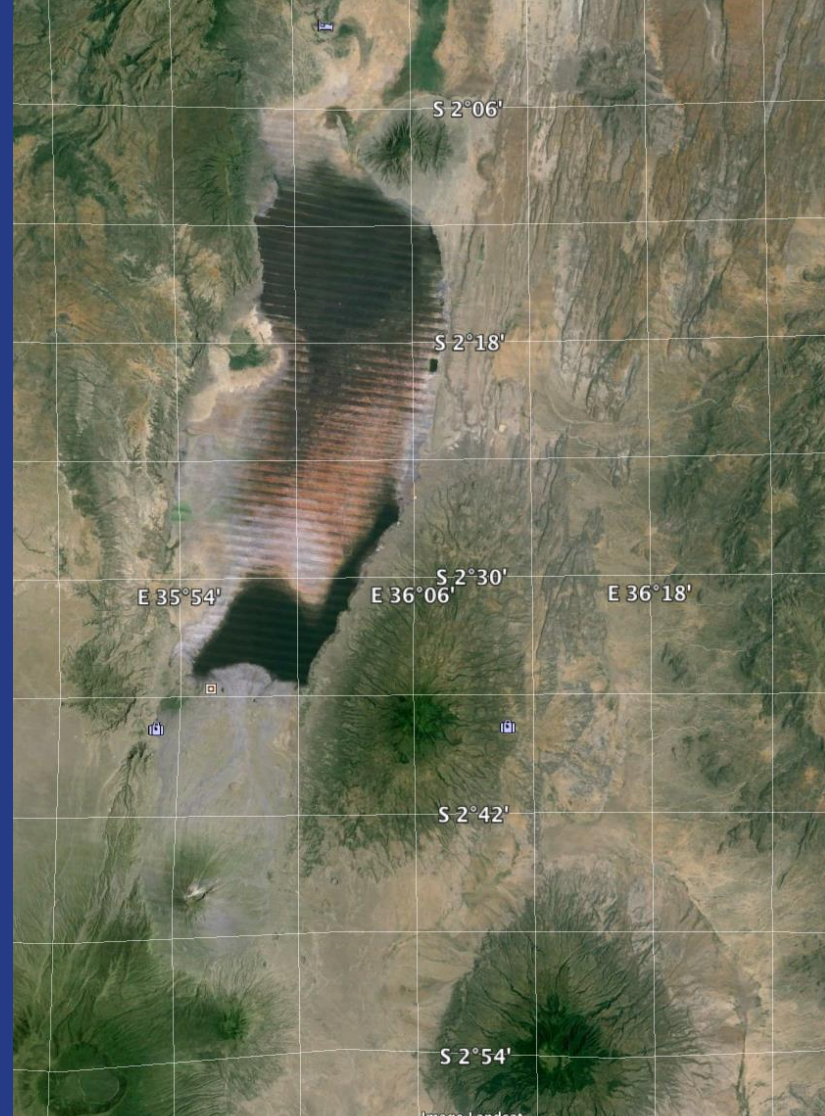


Modern exploitation of evaporite minerals
near Wadi al-Natron, Egypt



Lake Natron in Tanzania, East Africa





Ol Doinyo Lengai
erupting natro-
carbonatite lava



Sulfate minerals

The sulfate minerals constitute a numerous family. Below I list their most important members. Of these I shall describe only the anhydrite and the gypsum, because they are important rock-builders and are widely used in the industry:

Anhydrous sulfates (waterless sulfates)

Barite BaSO_4

Celestite SrSO_4

Anglesite PbSO_4

Anhydrite CaSO_4

Hanksite $\text{Na}_{22}\text{K}(\text{SO}_4)_9(\text{CO}_3)_2\text{Cl}$

Hydroxide and hydrous sulfates (wet sulfates)

Gypsum $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$

Chalcanthite $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$

Kieserite $\text{MgSO}_4 \cdot \text{H}_2\text{O}$

Starkeyite $\text{MgSO}_4 \cdot 4\text{H}_2\text{O}$

Hexahydrate $\text{MgSO}_4 \cdot 6\text{H}_2\text{O}$

Epsomite $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$

Mediraniite $\text{MgSO}_4 \cdot 11\text{H}_2\text{O}$

Melanterite $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$

Antlerite $\text{Cu}_3\text{SO}_4(\text{OH})_4$

Brochantite $\text{Cu}_4\text{SO}_4(\text{OH})_6$

Alunite $\text{KAl}_3(\text{SO}_4)_2(\text{OH})_6$

Jarosite $\text{KFe}_3(\text{SO}_4)_2(\text{OH})_6$

Anhydrous
sulfates
(waterless
sulfates)



Anhydrite from
Chihuahua, Mexico
(copyright by Rob
Lavinsky and irocks.com)

Anhydrite

(CaSO_4)

Anhydrite was named in 1804 by the great German mineralogist Abraham Gottlob Werner

Crystal system: orthorhombic-dipyramidal

Cleavage: [010] perfect, [100] perfect, [001] good

Colour: colourless, white, bluish white, violet white, dark grey

Average density: 2.97

Hardness: 3.5

Streak: white

Luster: vitreous-pearly

Fracture: brittle conchoidal

Hydroxide and
hydrous
sulfates
(wet sulfates)



Gypsum crystals from
Maramureș, Romania.

Gypsum



The earliest occurrence of the name is in Theophrastos' stone book (4th century BCE) after γυψοζ (gipsoz=plaster)

Crystal system: monoclinic-prismatic

Cleavage: [010] perfect, [100] distinct, [011] distinct

Colour: colourless, white, bluish white, violet white, dark grey

Average density: 2.3

Hardness: 2

Streak: white

Luster: pearly

Fracture: fibrous



Gypsum “fishtail” twin from the Cave of Swords, Naica, Mexico



A gypsum "rose" from Manitoba, Canada



The largest crystals so far discovered on earth are gypsum crystals in the Cave of Swords or Cave of Crystals in Chihuahua in Mexico.

Halides

Halides include our table salt (NaCl) and form important evaporite deposits and cap rocks in petroleum reservoirs. Of them I shall describe only halite, i.e. the common table salt, which is by far the most important mineral of the halite group.

Halite NaCl

Sylvite KCl

Chlorargyrite AgCl

Bromargyrite AgBr

Fluorite CaF_2

Atacamite $\text{Cu}_2\text{Cl}(\text{OH})_3$

Bischofite $(\text{MgCl}_2 \cdot 6\text{H}_2\text{O})$

Carnallite $\text{KMgCl}_3 \cdot 6\text{H}_2\text{O}$

Cryolite Na_3AlF_6

Cryptohalite $(\text{NH}_4)_2\text{SiF}_6$

Bararite $(\text{NH}_4)_2\text{SiF}_6$

Halite

(NaCl)

From the Greek ἅλς (als=salt), changed by the American geologist James Dwight Dana to halite in 1837.

Crystal system: isometric-hexoctahedral

Cleavage: [100] perfect, [010] perfect, [001] perfect

Colour: white, colourless, light blue, dark blue, pink, reddish brown

Average density: 2.17

Hardness: 2.5

Streak: white

Luster: vitreous

Fracture: brittle

Halite crystals from an unknown locality



The evaporation sequence

Most
soluble

Mineral Class	Mineral Name	Chemical formula
Chlorides	Halite	NaCl
	Sylvite	KCl
	Carnallite	$\text{KMgCl}_3 \cdot 6\text{H}_2\text{O}$
	Kainite	$\text{KMg}(\text{SO}_4)_5$
Sulfates	Anhydrite	CaSO_4
	Gypsum	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$
	Kieserite	$\text{MgSO}_4 \cdot \text{H}_2\text{O}$
	Langbeinite	$\text{K}_2\text{Mg}_2(\text{SO}_4)_3$
	Polyhalite	$\text{K}_2\text{Ca}_2\text{Mg}(\text{SO}_4)_6 \cdot \text{H}_2\text{O}$
Carbonates	Dolomite	$\text{CaMg}(\text{CO}_3)_2$
	Calcite	CaCO_3
	Magnesite	MgCO_3

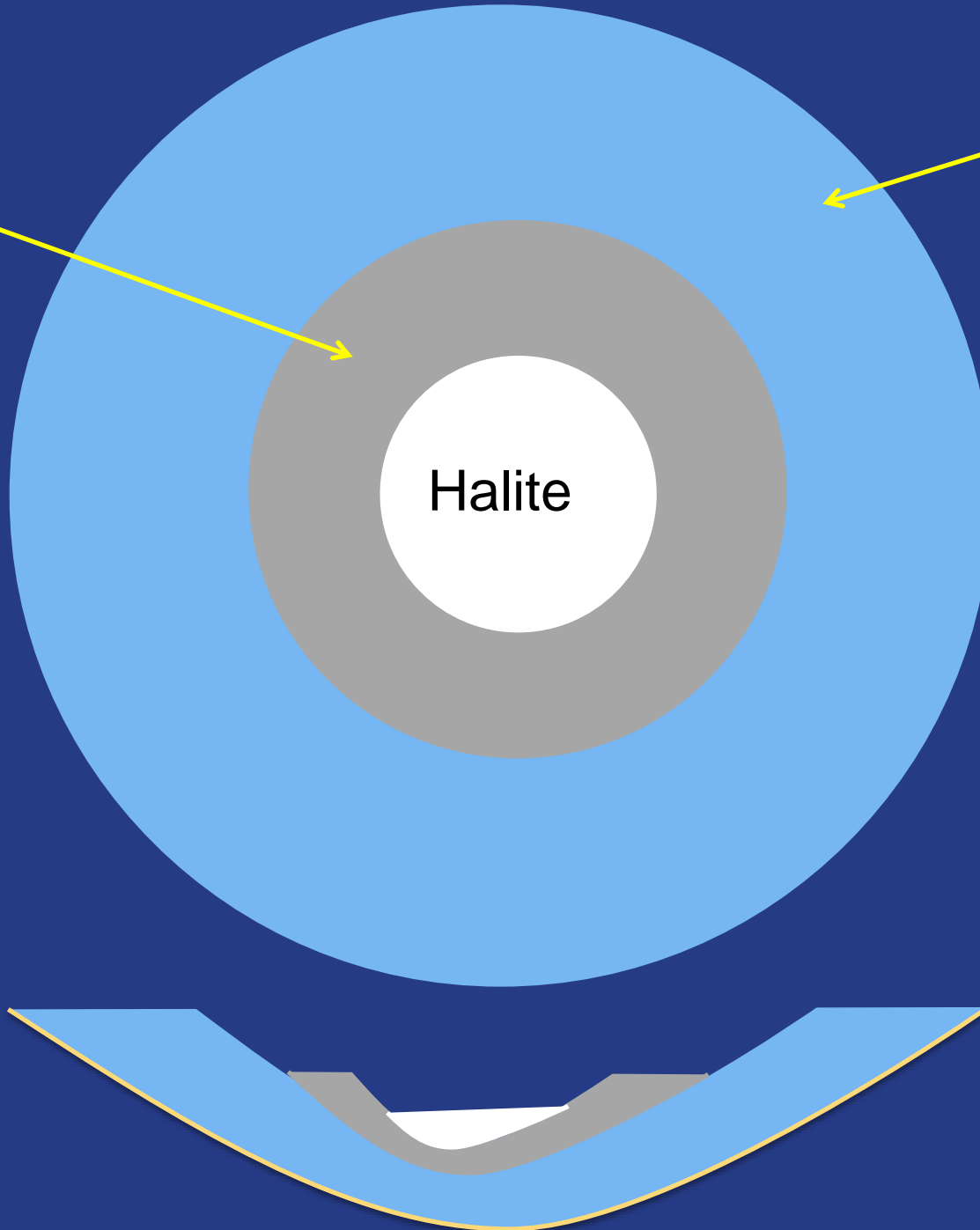
Least
soluble

Gypsum

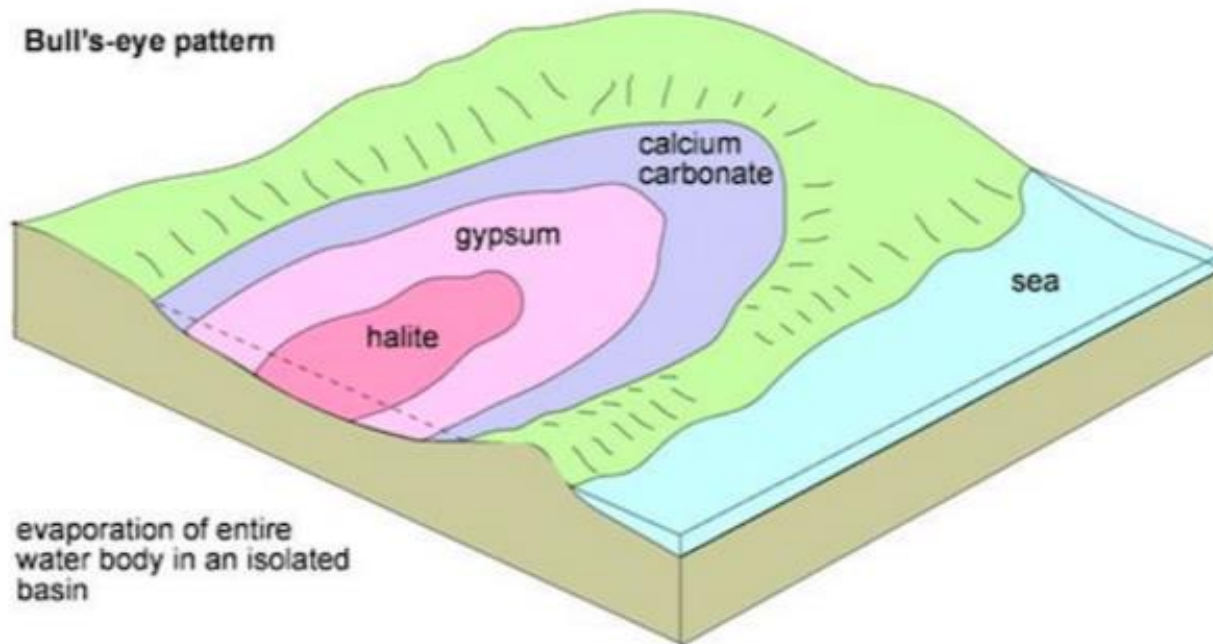
Carbonates

Halite

The “bull’s
eye” model
of evaporite
deposition

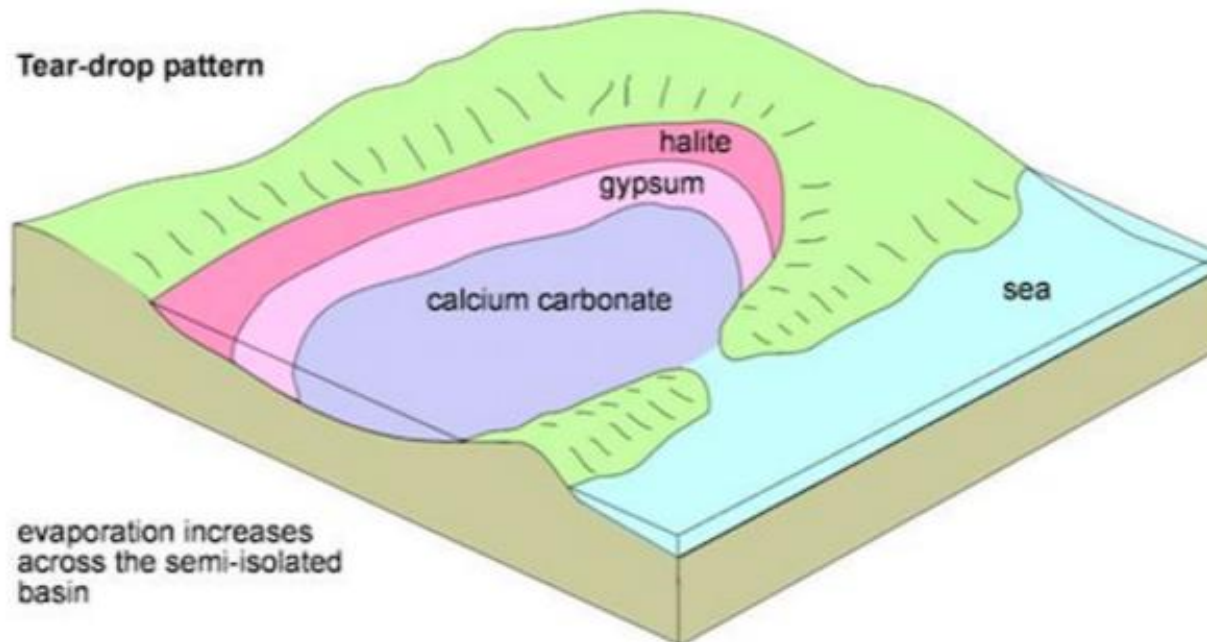


Bull's-eye pattern



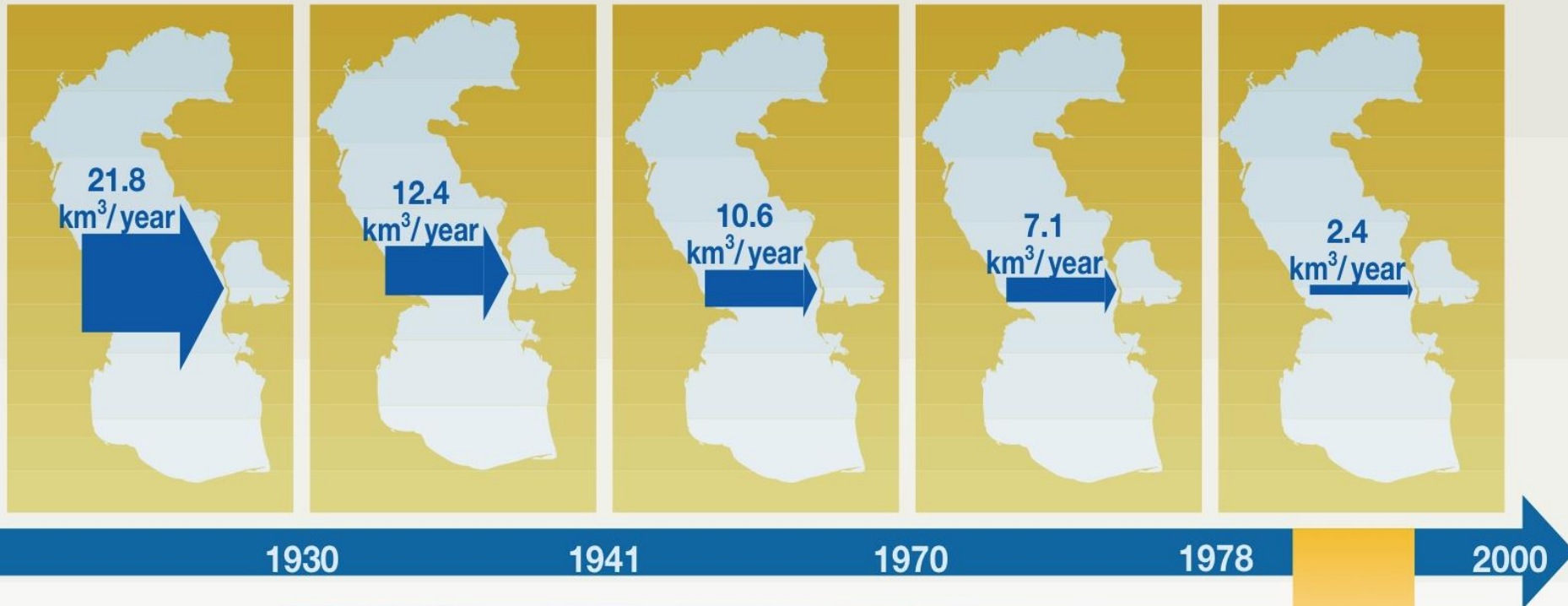
evaporation of entire
water body in an isolated
basin

Tear-drop pattern



evaporation increases
across the semi-isolated
basin

A century of outflow into Kara Bogaz Gol, km³/ year



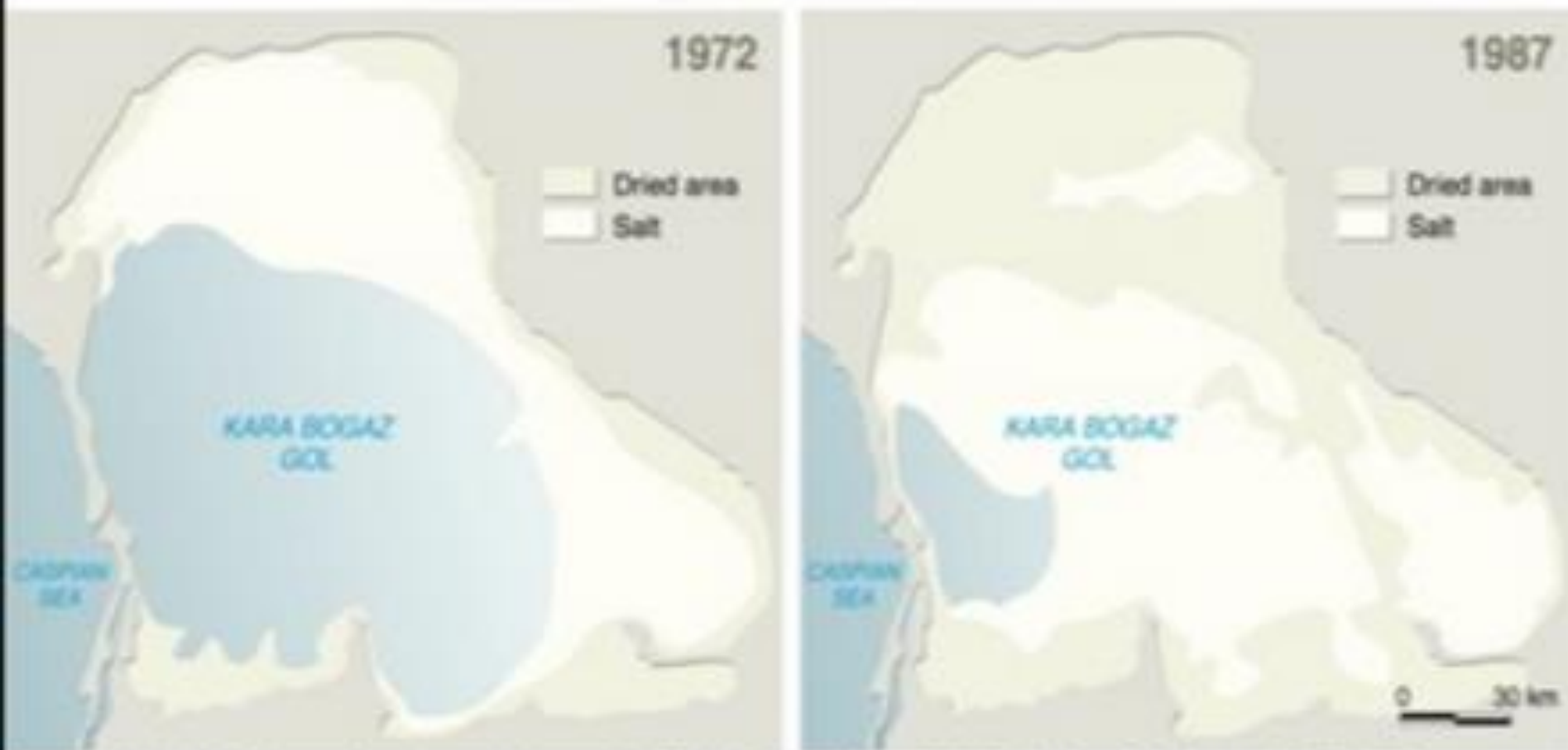
The channel between the Caspian Sea and Kara Bogaz Gol was closed between 1982 and 1992. Water stopped flowing into the Kara Bogaz Gol which dried up within three years.

Source: Frank Westerman, *Ingenieurs van de ziel*, Atlas, Amsterdam, 2002.

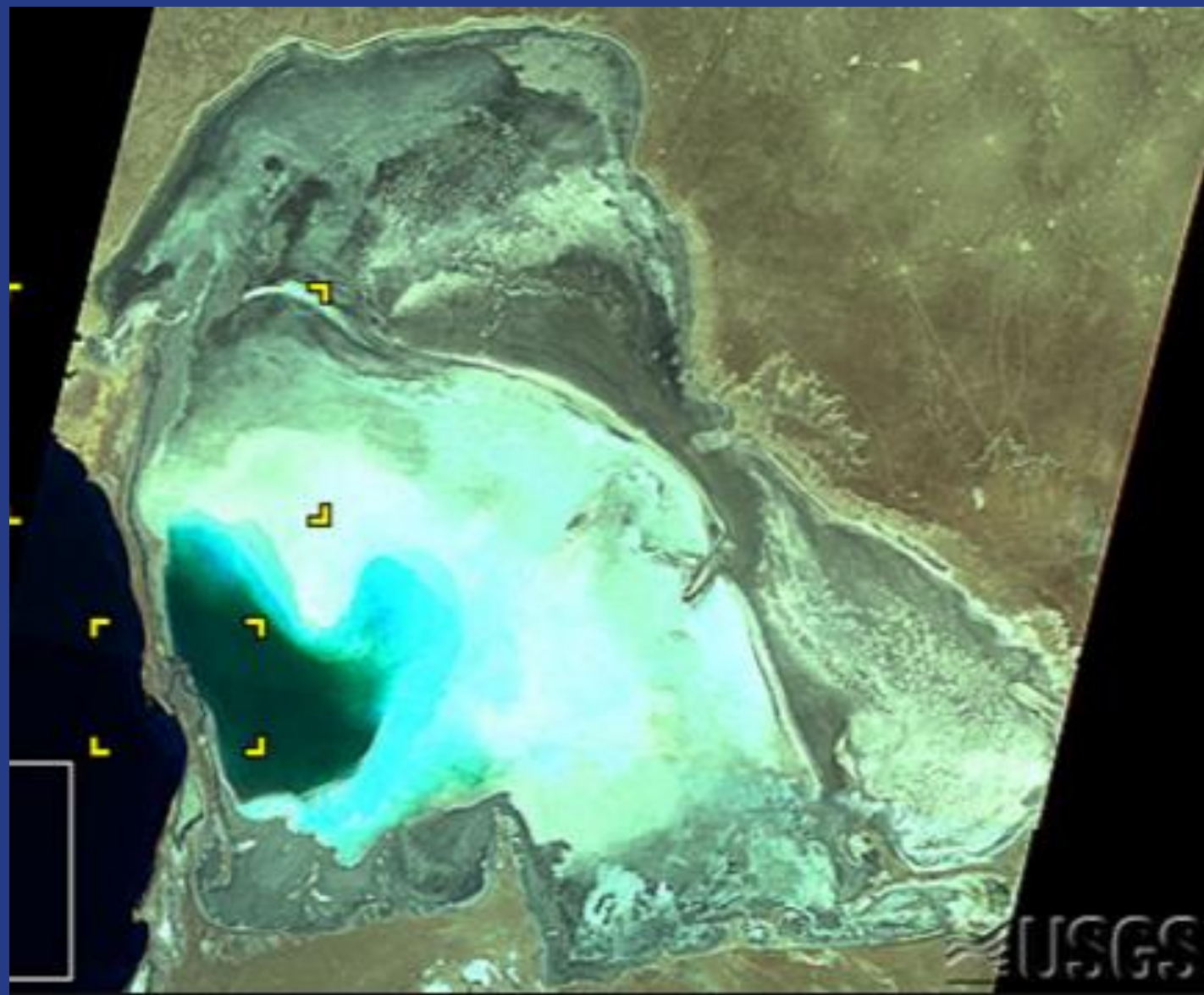


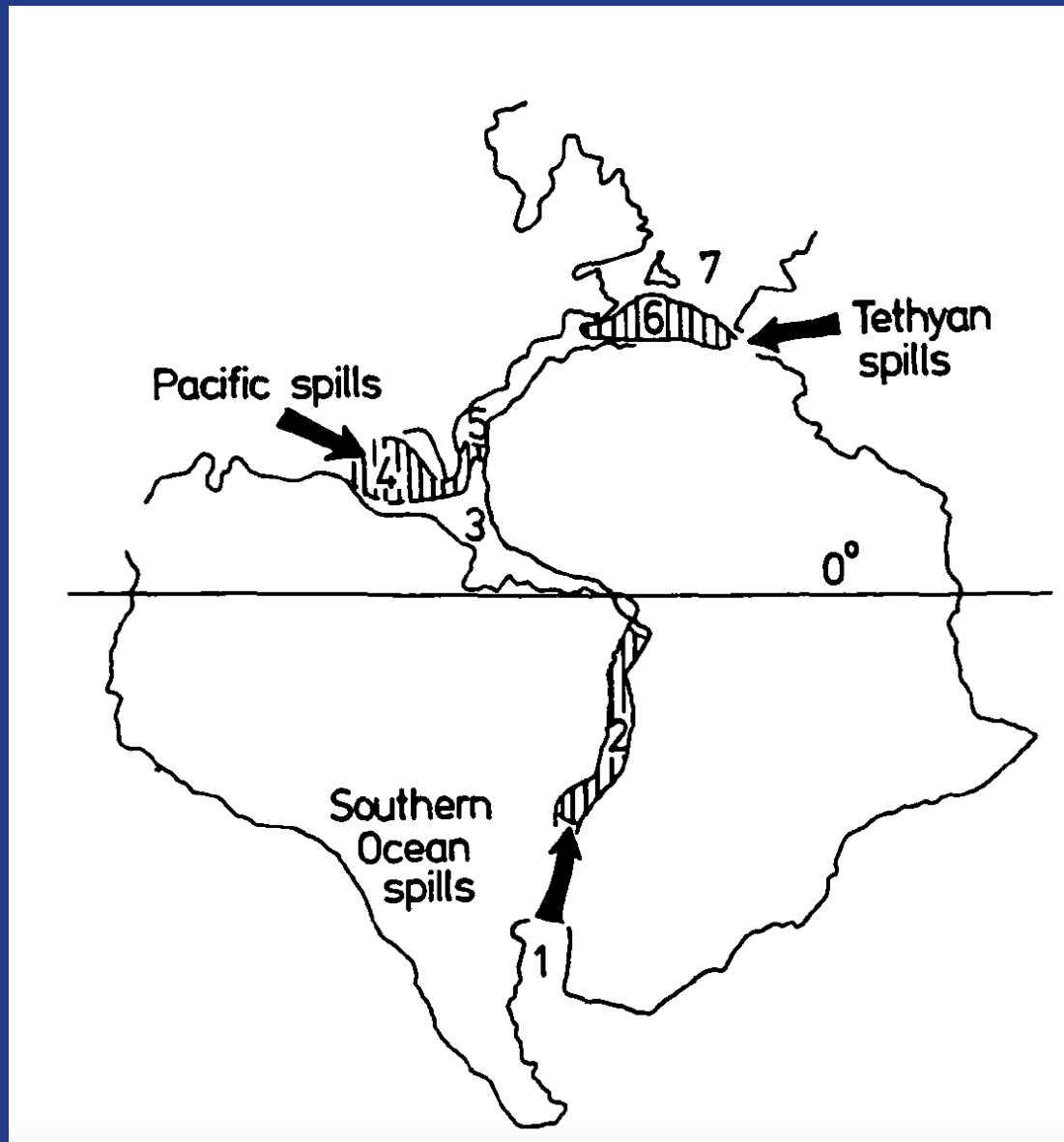
Kara Boğaz Gölü, Turkmenistan

When the Kara Bogaz Gol vanishes



Source: Earthshots: Satellite images for environmental change, United States Geological Survey (USGS): Kara Bogaz Gol, Turkmenistan 1972, 1987





Major salt deposits around the Atlantic Ocean
(from Burke, 1975)

Oxide minerals

The oxide minerals are very rich in members and many are important as iron-ores and industrial materials. Of this numerous group, I shall describe only the following: ice, corundum, hematite, spinel, magnetite and goethite.

The oxide minerals are commonly studied in two groups: simple oxides and hydroxides.

Simple oxides:

Cuprite Cu_2O

Ice H_2O

Periclase MgO

Manganosite MnO

Zincite ZnO

Bromellite BeO

Tenorite CuO

Litharge PbO

Corundum Al_2O_3

Hematite Fe_2O_3

Ilmenite FeTiO_3

Rutile TiO_2

Pyrolusite MnO_2

Cassiterite SnO_2

Baddeleyite ZrO_2

Uraninite UO_2

Thorianite ThO_2

Spinel MgAl_2O_4

Gahnite ZnAl_2O_4

Magnetite $\text{Fe}_3\text{O}_4(\text{Fe}^{2+}\text{Fe}^{3+}_2\text{O}_4)$

Franklinite $(\text{Zn}, \text{Fe}, \text{Mn})(\text{Fe}, \text{Mn})_2\text{O}_4$

Chromite FeCr_2O_4

Chrsoberyl BeAl_2O_4

Columbite $(\text{Fe}, \text{Mn})(\text{Nb}, \text{Ta})_2\text{O}_6$

Goethite $\text{FeO}(\text{OH})$

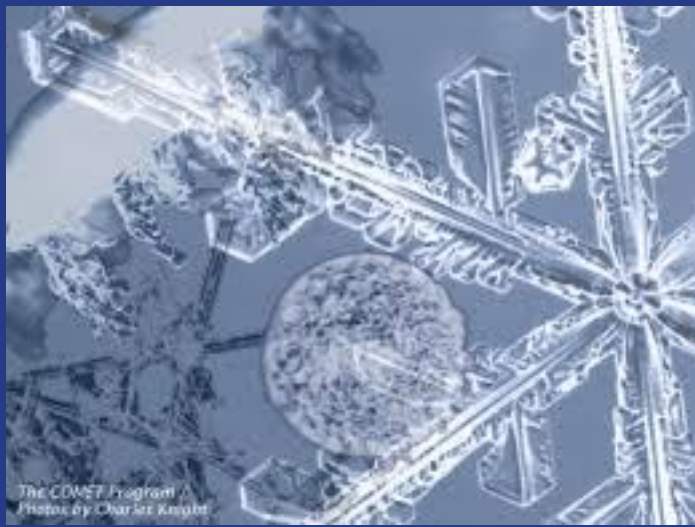
Diaspore $\text{AlO}(\text{OH})$

Hydroxide subgroup:

Brucite $\text{Mg}(\text{OH})_2$

Manganite $\text{MnO}(\text{OH})$

Romanechite $\text{BaMn}_2+\text{Mn}^{4+}_8\text{O}_{16}(\text{OH})_4$



Ice crystals



Ice



Ice is the only mineral that has a different name in almost every language on the globe, as its knowledge is as old as mankind.

Crystal system: hexagonal-dihexagonal-dipyramidal

Cleavage: none

Colour: colourless, pale blue, greenish blue, white

Average density: 0.9167

Hardness: 2.5

Streak: white

Luster: vitreous-dull

Fracture: brittle, conchoidal



Corundum crystals from an unknown locality

Corundum



Named corunvindum in 1725 by the English geologist John Woodward from the Sanskrit *kuruvinda* (=ruby)

Crystal system: trigonal-hexagonal-scalenohedral

Cleavage: none

Colour: blue, red, yellow, brown, grey

Average density: 4.05

Hardness: 9

Streak: none

Luster: vitreous-glassy

Fracture: tough



Corundum crystal (=ruby) from the Yen Bai Province,
Vietnam



Black, platy hematite
and minor white
magnesite from bahia,
Brazil.

Hematite



Originally named by Theophrastos (4th century BCE) as αιματίτις λίθος from αιματος (*aimatos*=blood) and λίθος (lithos=stone), meaning “blood-stone” in reference to its blood-red colour.

Crystal system: trigonal-hexagonal-scalenohedral

Cleavage: none

Colour: Reddish grey, black, blackish red

Average density: 5.3

Hardness: 9

Streak: reddish brown

Luster: metallic

Fracture: conchoidal



Hematite from an unknown locality



Hematite from the Zhoudoukian Cave
near Beijing, PRC.



Spinel from
Mandalay, northern
Burma (Myanmar
today)

Spinel



Spinel was named in 1779 by the Belgian chemist and military physician Jean Demeste after the Latin word *spinella* meaning a thorn alluding to its sharp octahedral corners.

Crystal system: isometric-hexoctahedral

Cleavage: none

Colour: colourless, blue, red, brown, grey

Average density: 3.64

Hardness: 8

Streak: greyish white

Luster: vitreous-glassy

Fracture: uneven

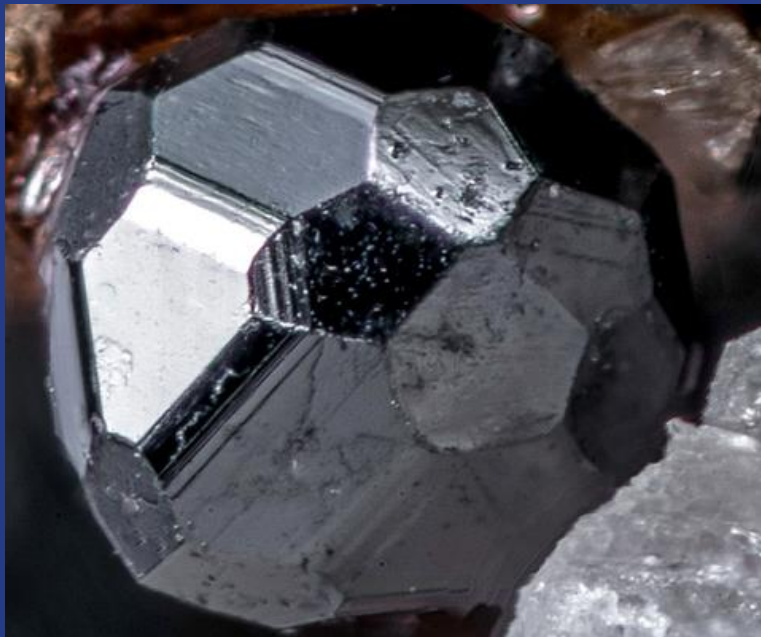
Many gemstones in even crown jewels around the world that are presented as rubies (i.e. corundum) are actually spinels. So the spinel is called “the greatest impostor in the gem world that has fooled many kings and queens.”

I think somebody should check the “rubies” in the Topkapı Palace Museum to see whether they are real rubies or just spinels!

Here is a mineralogy project I would recommend!



Spinel from New Jersey, USA



Magnetite (Loadstone)



Named in 1845 by the Austrian mineralogist Wilhelm Karl Ritter von Haidinger after Magnesia (Manisa) in Turkey, where in Antiquity this mineral was mined.

Crystal system: isometric-hexaoctahedral

Cleavage: none

Colour: greyish black, iron black

Average density: 5.15

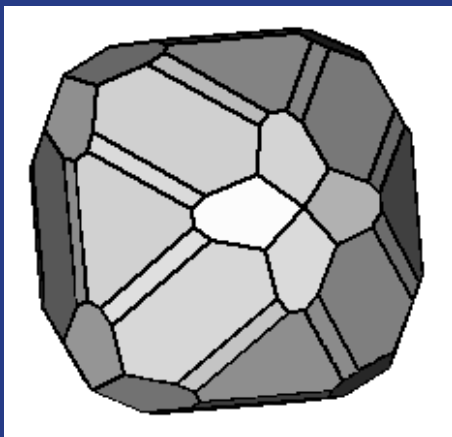
Hardness: 5.5-6

Streak: black

Luster: metallic

Fracture: subconchoidal

Magnetite crystal from
the Latium Province in
Italy





Magnetite crystals from St. Lawrence County, New York



Magnetite crystals from the Andes Mountains, Bolivia

Magnetite contributes very strongly to rock magnetism. Although rock magnetism can have a number of sources, only the magnetism contributed by magnetite is seen to be a remanent magnetism, i.e. it remains locked up in the rock and when the rock is moved, it can tell us about where, how and when the rock may have formed. The theory of plate tectonics could not have been used for the geological past, if it were not for magnetite.

There are five types of what is called magnetic order. These are:

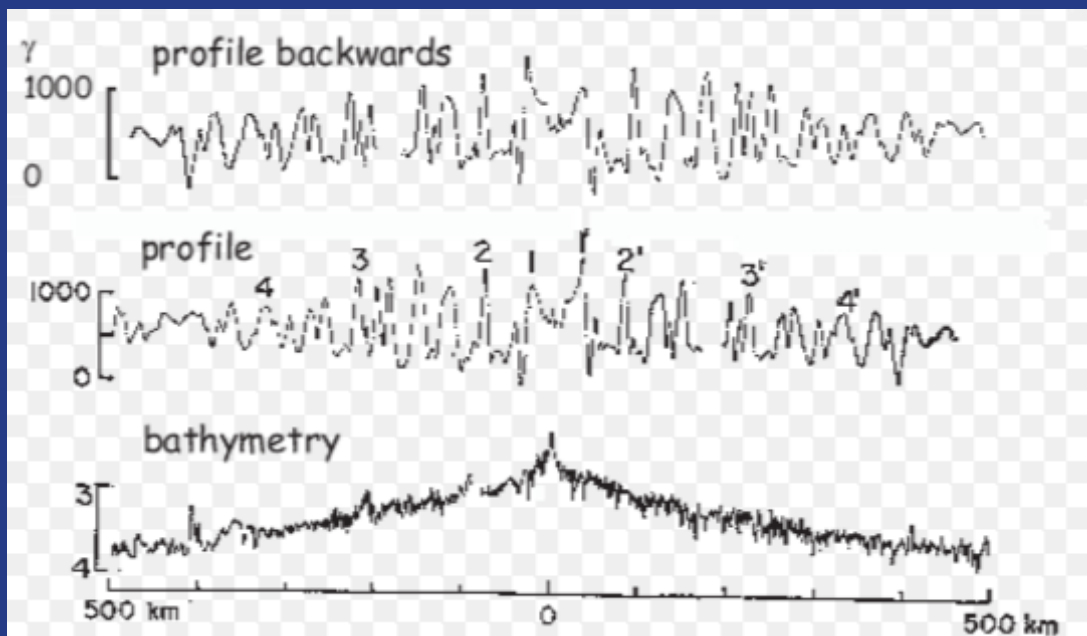
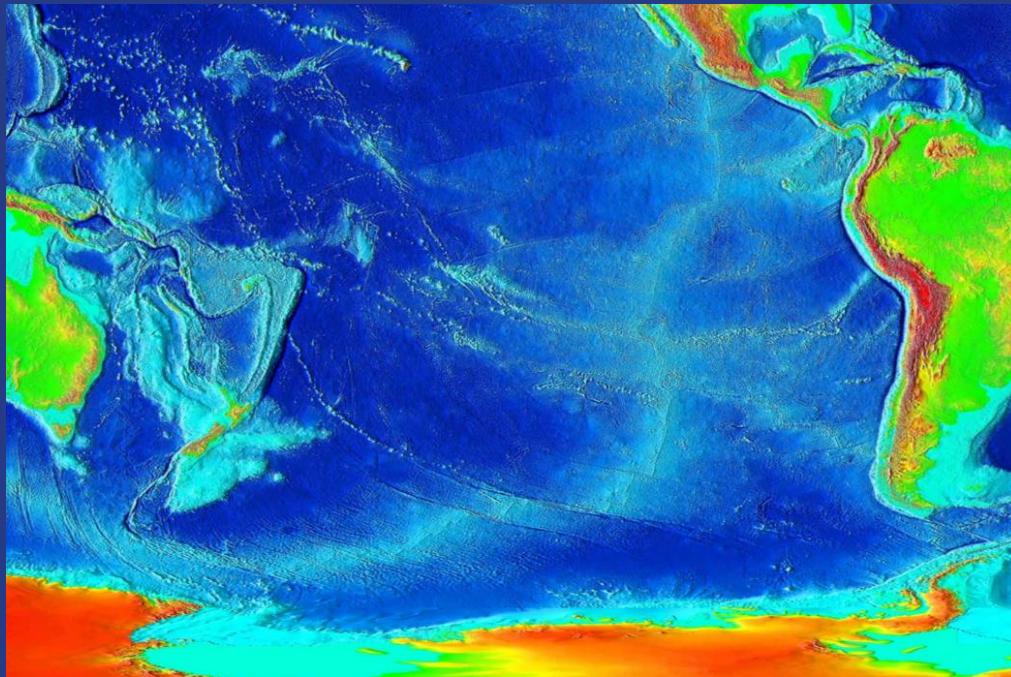
Diamagnetism is a property of any body that tends to induce magnetism in a direction at 180° to the applied magnetic field. The term was coined by the British physicist Michael Faraday from the Greek *διά* (*thia*=through) and magnetic meaning cross-magnetic. All substances have this property which consists of the electrons precessing under the influence of an applied magnetic field so as to protect the interior of the body from the magnetic field. It is a weak response and naturally has no remanence.

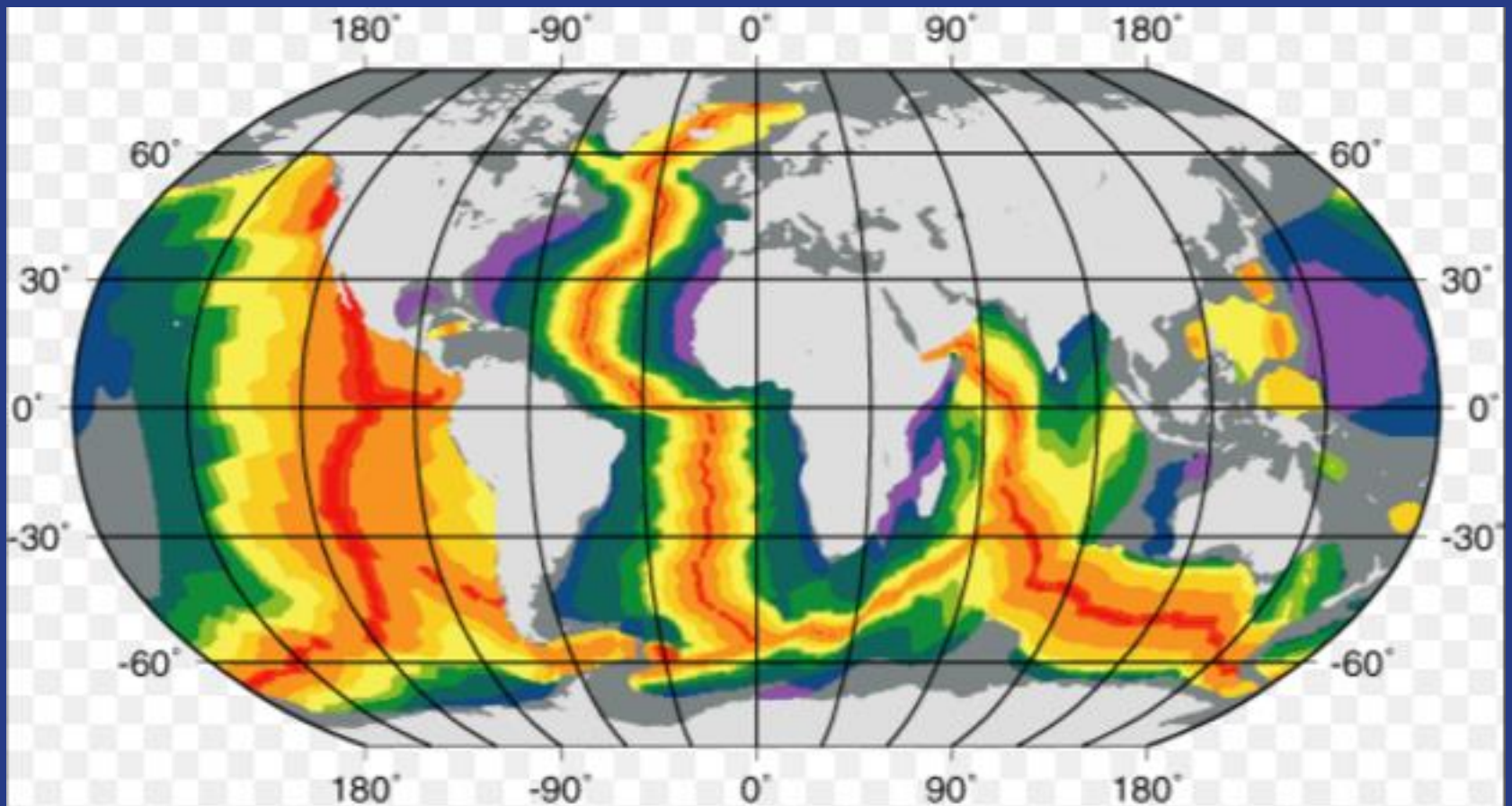
Paramagnetism is a weak positive response to a magnetic field. This positive response results from having one unpaired electron on one of the shells that makes the atom susceptible to the magnetic field. When the field is present the atoms align themselves with the field. Paramagnetic substances retain no magnetism when the field is removed. The prefix para- is from the Greek *παρά* (*para*=near, together, at once).

Ferromagnetic materials are the strongly magnetic materials such as nickel that lose their magnetism above a critical temperature called the Curie temperature after the French physicist Pierre Curie who showed that above certain temperatures magnetic substances lose their magnetism and become susceptible to the prevailing magnetic field.

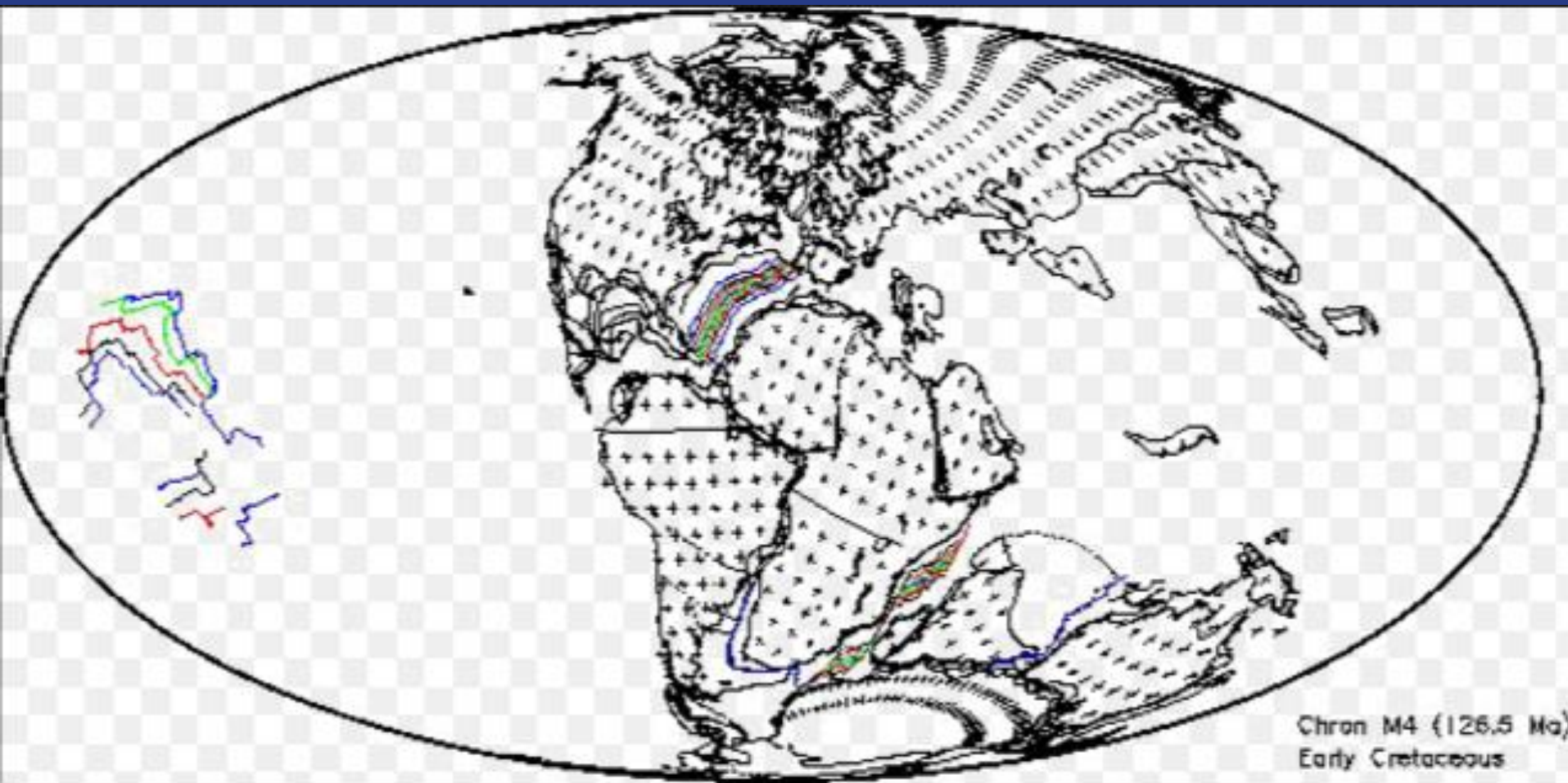
Ferrimagnetic materials have two lattices with opposing moments and one of these is stronger. So there is a net imbalance as, for example in magnetite. Although ferrimagnets behave much like the ferromagnets, their response to temperature is more complex, and, critically, involves a reversal of magnetism!

Antiferromagnetic minerals have two opposing lattices of equal strength and therefore cannot acquire any remanent magnetism. But if the lattices are tilted with respect to one another they can acquire remanent magnetism. Hematite is one such substance.

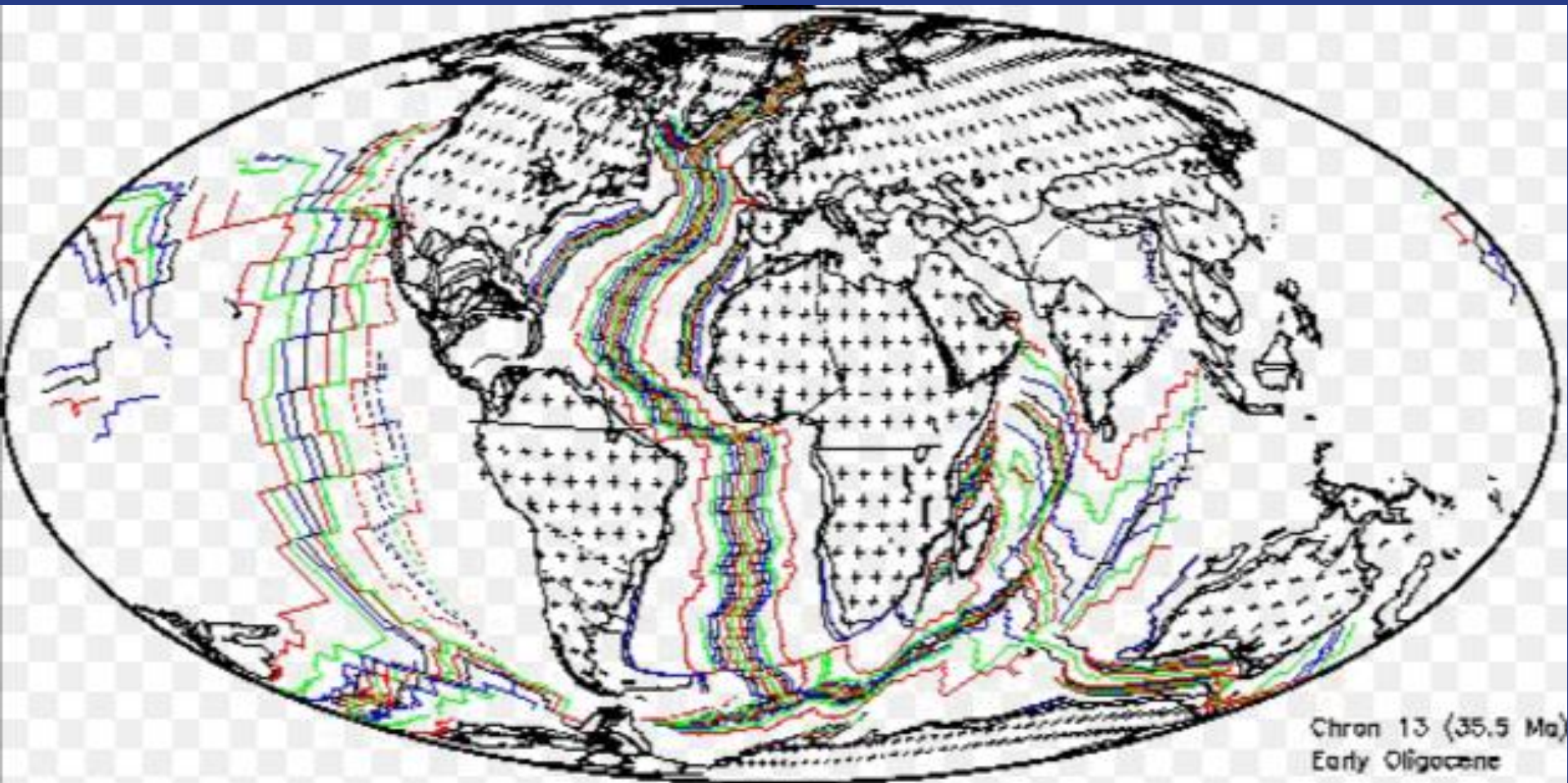




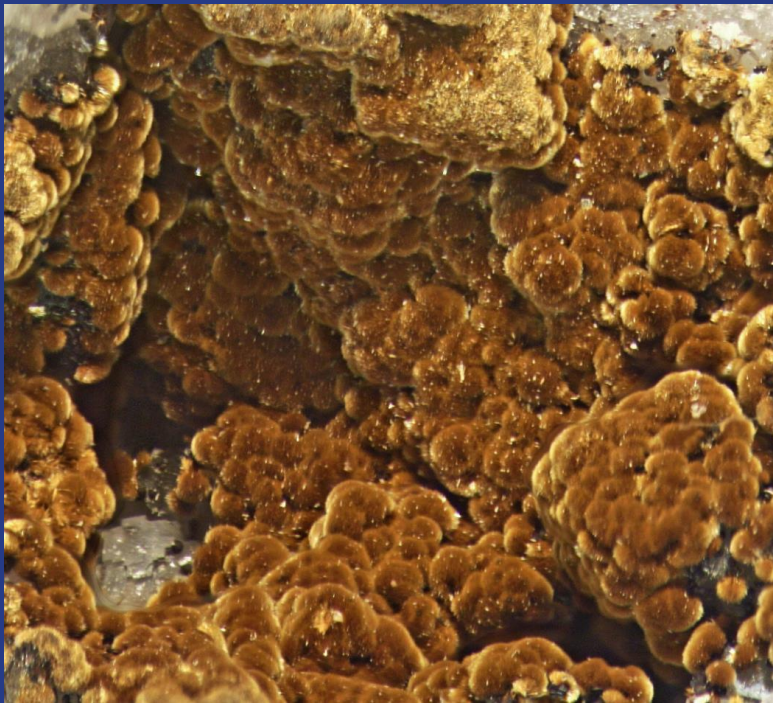
Age provinces (magnetic stripes) calculated from the disposition of magnetic anomalies in the oceanic crust in the world oceans



The continents and oceans 126.5 million years ago (Chron M4 time)



The continents and oceans 35.5million years ago
(Chron 13 time)



Goethite from New York, USA

Goethite

(FeO (OH))

Named by the German mineralogist Johann Georg Lenz in honour of the great German poet and polymath Johann Wolfgang von Goethe in 1806. Goethe had a strong interest in mineralogy.

Crystal system: orthorhombic-dipyramidal

Cleavage: [010] perfect, [100] distinct

Colour: brown, reddish brown, yellowish brown, brownish yellow, ochre yellow

Average density: 3.8

Hardness: 5-5.5

Streak: yellowish brown

Luster: adamantine-silky

Fracture: hackly-jagged



Goethite from Park County, Colorado, USA.

I wish to end the survey of the minerals with a mineraloid that has been very important as an iron ore and is an important product of chemical weathering of iron-bearing minerals:

It is limonite consisting of iron(III) oxides and hydroxides in such varying proportions that no single valid formula can be written for all limonites, although its generic formula is usually given as $\text{FeO}(\text{OH}) \cdot n\text{H}_2\text{O}$.



Limonite from Austria



Limonite from Brazil



Limonite deposited from an iron ore mine runoff