Appendix

1.1 Conversions Between Common US Units and Metric Units

One of the most common conversions seen is the one for temperature (Fig. A1.1):

$$C = (F - 32) \times 5/9$$

$$F = C \times 9/5 + 32$$

where *C* stands for degrees Celsius (centigrade) and *F* for Fahrenheit

$$K = C + 273.2$$

where *K* stands for degrees Kelvin (absolute temperature).

Figure A1.1 Many thermometers can be read in °C or in °F, demonstrating a simple linearity in the conversion (see equations)

Length	
1 cm = 0.394 inch	1 inch = 2.54 cm
1 m = 3.281 feet	1 foot = 0.305 m
1 km =0.621 statute miles	1 mile = 1.609 km
	1 nautical mile = 1.852 km
Volume	
1 mm = 1000 μm (micrometer or microns) (international)	
1 liter (l) = 1000 milliliter (ml) = 0.264 US gallons	1 US gallon = 3.781 l
Mass	
1 barrel (oil) = 42 gallons =159.1 liter	
1 kilogram (kg) = 1000 grams (g) = 2.205 US pounds	1 pound = 0.454 kg
1 metric ton =1000 kg = 1.102 US short tons	1 short ton = 907.4 kg

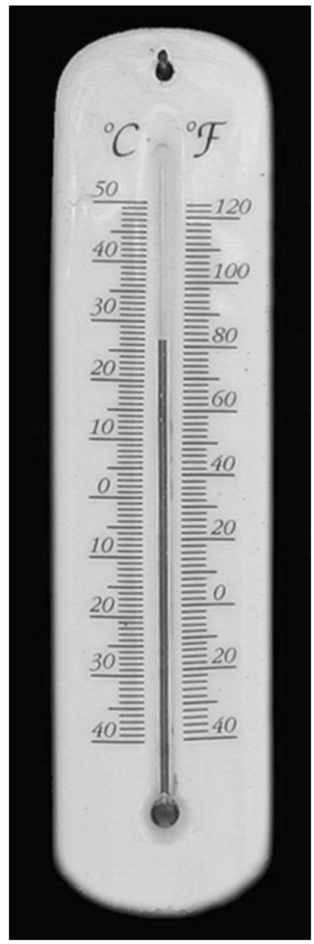

Fig. A1.1 Thermometer with two temperature scales (Photo W.H.B.)

E. Seibold, W. Berger, *The Sea Floor*, Springer Textbooks in Earth Sciences, Geography and Environment,
DOI 10.1007/978-3-319-51412-3

1.2 Topographic Statistics

Earth		
Equatorial radius = 6378 km	Polar radius = 6356 km	
Ocean		
Atlantic Ocean (incl. Arctic and marginal seas)		
Area = 106.5 million km^2	Volume = 354.7 million km^3	Mean depth = 3332 m
Indian Ocean (incl. Adjacent seas)		
Area = 74.9 million km^2	Volume = 291.9 million km^3	Mean depth = 3897 m
Pacific Ocean (incl. Adjacent seas)		
Area = 179.7 million km^2	Volume = 723.7 million km^3	Mean depth = 4028 m
Total Ocean (incl. Adjacent seas)		
Area = 361.1 million km^2	Volume = 1370.3 million km^3	Mean depth = 3795 m
(Source: E. Kossinna, 1921, as quoted in H.U. Sverdrup et al., 1942. The Oceans. Prentice-Hall, Englewood Cliffs, NJ)		
Shelf seas		
(Slightly over 3% of the total ocean area.) Collation of continental and oceanic areas in Kossinna's data prevents recognition of shelf sea properties. The data shown are from the compilation in Table 2.1 in the third edition of the present text		
Area = 11.4 million km^2	Volume = 2.28 million km^3	Depth (defined!) = 200 m

1.3 Geologic Time Scale

On the modern seafloor, ages greater than 100 million years are rare. Nevertheless, it is well to keep in mind that more ancient marine rocks are common on land. Shown: time scale for marine fossils for the entire Phanerozoic, beginning with the Cambrian (Figs. A3.1 and A3.2).

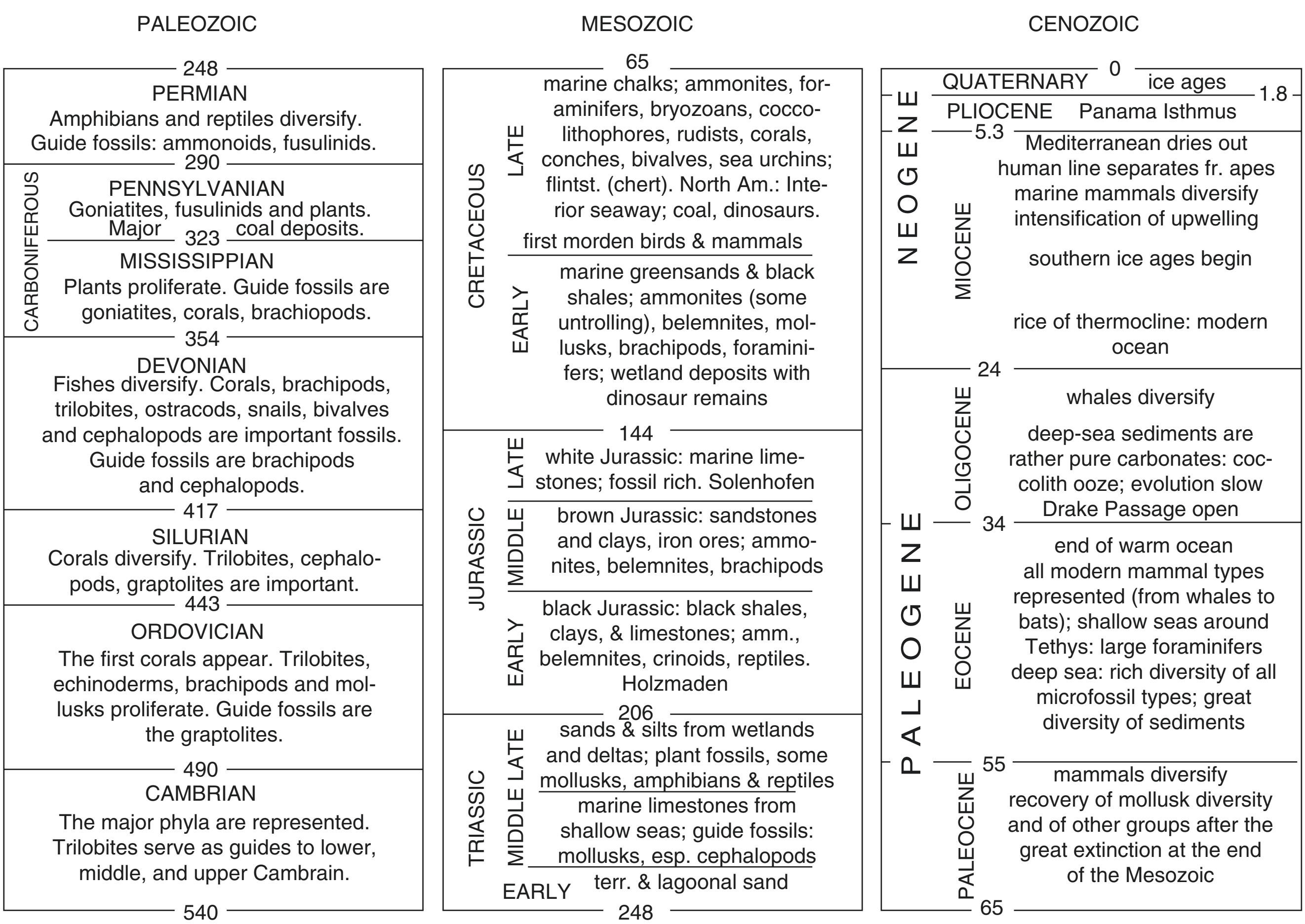

Fig. A3.1 Approximate time scale for the Phanerozoic (i.e., for rocks with marine fossils) in millions of years (Sources: The Geological Society of America, Boulder, Colorado and various geology textbooks)

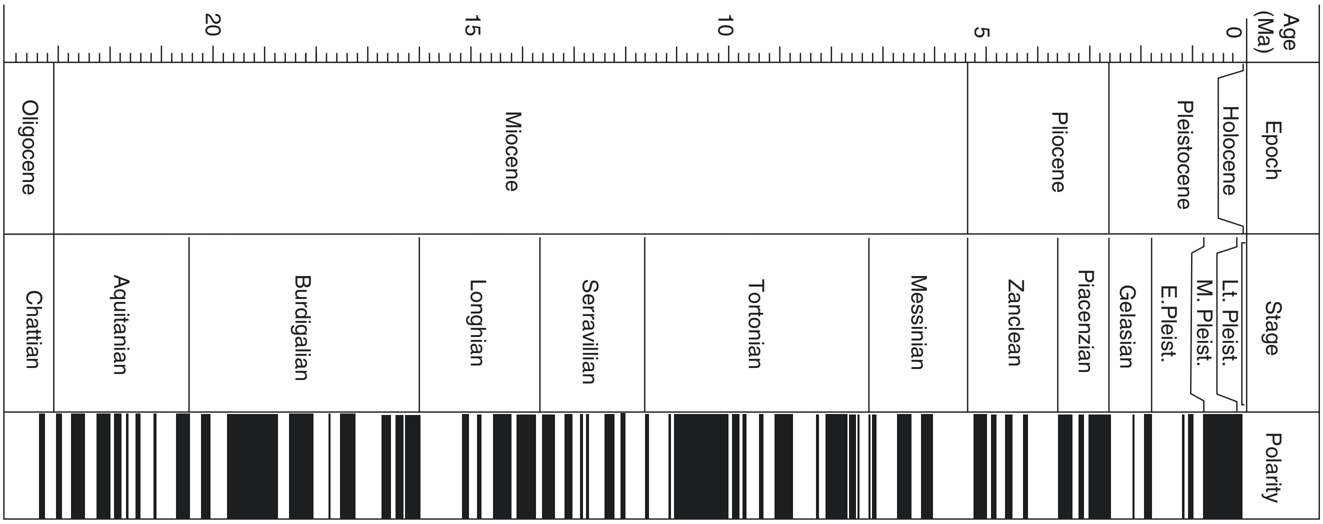

Fig. A3.2 Modern age assignments rely heavily on correlations using the geomagnetic time scale, especially in Neogene sediments (Sources: the Ocean Drilling Program after 1990)

1.4 Common Minerals

1.4.1 Silicate Minerals

Perhaps the most widely known mineral is the ubiquitous clear or white-colored glassy-looking *quartz,* with the formula SiO_2. It is common in granitic rocks (i.e., in continental crust) and is made of *silicon tetrahedra* (Fig. A4.1) such that each oxygen atom is shared by a neighboring tetrahedron (hence the formula, with two rather than four oxygen atoms for each silicon atom). "Opal" is the same but less well ordered and with plenty of water molecules accommodated between the silicate tetrahedra. By replacing some Si atoms with Al atoms, the tetrahedra structure retains a (negative) charge,

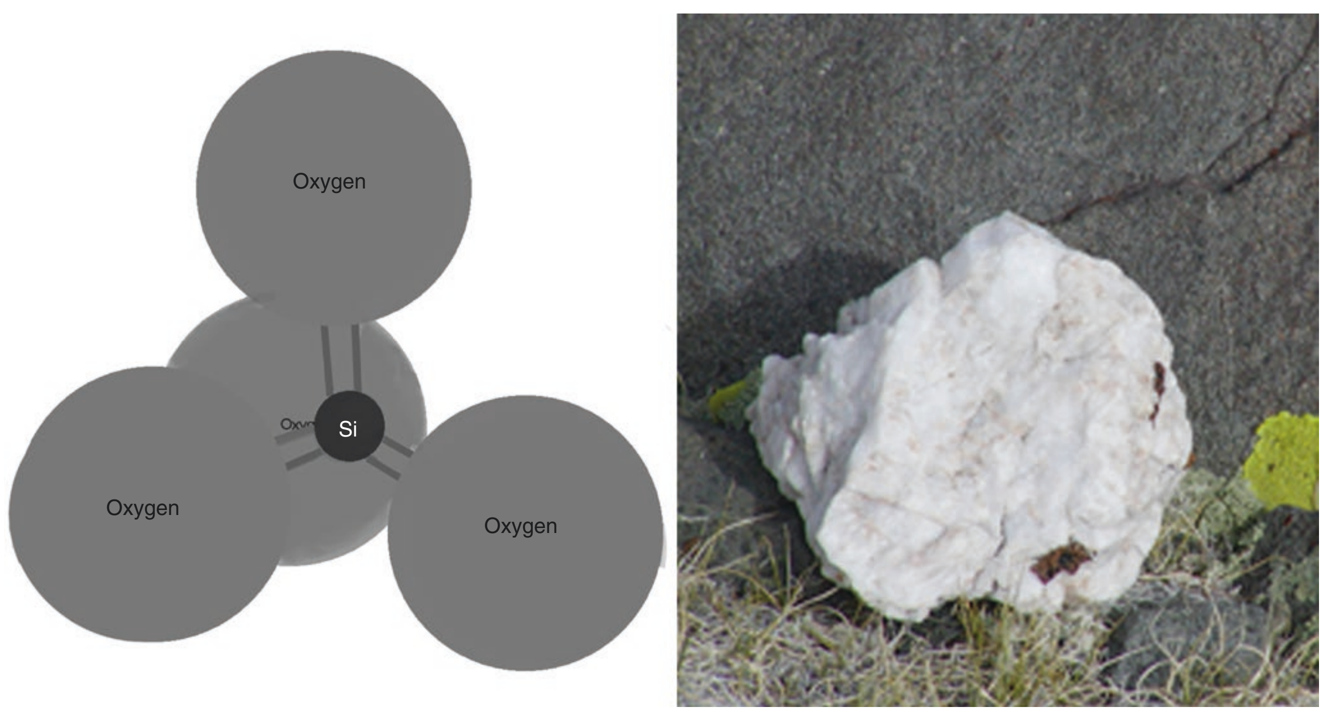

Fig. A4.1 Quartz, the most common silicate mineral on the surface of the planet and its structure. *Left*: silicate tetrahedron: a silicon atom surrounded by four oxygen atoms (fourth set of binding forces obscured). The spheres represent the atoms. [See any text book on minerals] *Right*: milky quartz crystal on White Mountain, near Bishop, Calif (Photo W.H.B.)

which is balanced by cations (Ca, Na, or K). This arrangement results in *feldspars* (e.g., albite, $NaAlSi_3O_8$, microcline and orthoclase, KAl Si_3O_8, anorthite, $CaAl_2Si_2O_8$). Feldspars are ubiquitous, with sodium and potassium feldspars common in granitic rocks and calcium feldspars in basaltic rocks.

The shimmering platy minerals commonly seen on sandy beaches are *mica*. Mica represents ubiquitous potassium-rich silicate minerals common in granitic rocks and in all marine sediments because of ease of transportation. Its sheet structure derives from the fact that its silicate tetrahedra are joined by three atoms in a plane, rather than by four oxygen atoms in a three-dimensional structure. Familiar examples of the mineral are the silvery "muscovite" (used, e.g., for windows into furnaces) and the dark magnesium- and iron-rich "biotite." Clay minerals are similar to "mica" but are deficient in cations. The most notable representatives are "smectite" (or "montmorillonite"), a weathering product of basaltic rocks; "illite" (somewhat similar, but commonly on a path toward "mica," with less water and more potassium than "smectite"); "chlorite," a weathering product of metamorphic continental crustal rock; and "kaolinite," a product of chemical weathering, stripped of cations.

Other minerals of note are the chain-like silicates in the "hornblende" group (double chains, "amphiboles") and those in the "augite" group (single chain, "pyroxenes"). "Pyroxenes" (note the reference to pyr = fire) are common in volcanic rocks, as are "olivines" (dark Mg- and Fe-rich silicates with tetrahedral in insular arrangement).

Zeolites (Fig. A4.2) are feldspar-like silicate minerals precipitated in places on the seafloor and within deep-sea clays, commonly in volcanogenic and other silica-rich environments. Unlike many other silicates, they are commonly fully marine in origin.

1.4.2 Nonsilicate Minerals

Carbonates. Bulk of biogenous sediments. Examples:
- Calcite ($CaCO_3$) calcareous shells and skeletons
- Aragonite ($CaCO_3$) ditto. Easily dissolved
- Dolomite (Ca Mg $(CaCO_3)_2$) product of diagenesis. Very resistant.

Evaporite minerals. Most common: calcium sulfate (anhydrite and gypsum)
- Commonly seen in drylands as a white cover of dried-up marine wetlands. Much less common: halite = sodium chloride Na Cl (kitchen salt)

Iron oxides and sulfides. Oxides and sulfides of iron are very common in marine sediments (here commonly hydroxides at the modern surface) and ubiquitous in all crustal rocks. The presence of sulfide minerals within sediments (mostly iron sulfides) indicates reduction of sulfate either on the surface or (mainly) after burial. Iron sulfide is abundant in organic-rich sediments, which also may have abundant diatoms (Fig. A4.3).

1.4.3 Heavy Minerals

The minerals listed here (excepting carbonates and evaporites) also are counted as heavy minerals if they are compact and make sand grains. Heavy minerals are useful as tracers for the sediment they are part of.

Details on minerals are in mineralogy textbooks and in textbooks on general geology.

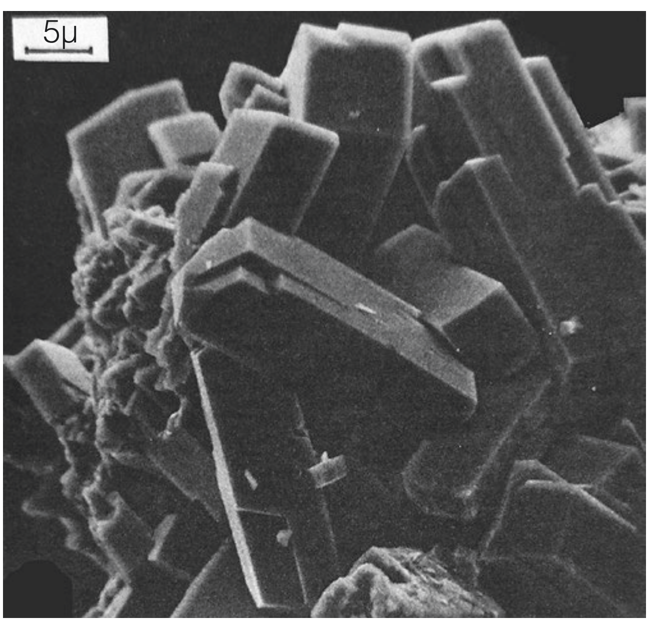

Fig. A4.2 Silt-size zeolite crystals from Paleocene sediments in the central Atlantic (clinoptilolite) (W.H.B. and U. von Rad, 1971. DSDP Leg 14; SEM by C. Samtleben, Kiel)

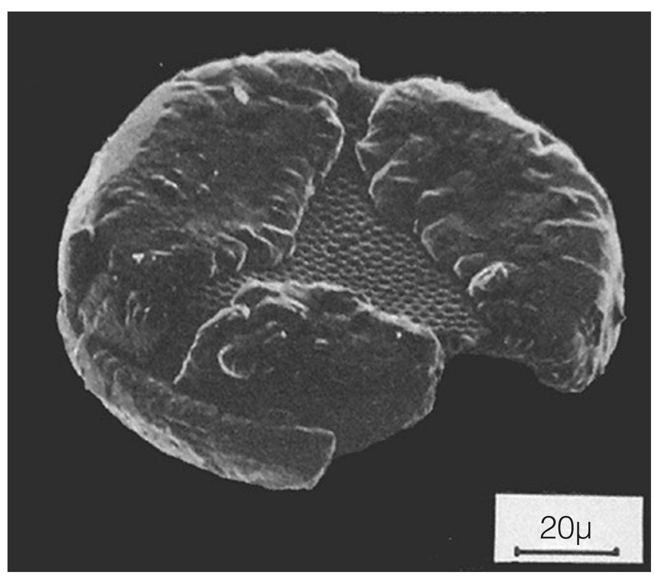

Fig. A4.3 Miocene diatom shell from sediments in the central Atlantic, with iron sulfide precipitation (W.H.B and U. von Rad, 1971. DSDP Leg 14. SEM by C. Samtleben, Kiel)

1.5 Grain Size Classification for Sediments

Boulder	Gravel	Sand	Silt	Clay
mm	256	2	0.063	0.004

In some classifications, 0.002 mm separates silt from clay. Also see Sect. 4.5.1 and Chap. 5.

1.6 Common Rock Types

1.6.1 Igneous Rocks

The Earth is hot inside (Fig. A6.1), in and below the lowermost crust, oceanic, and continental. It is here one finds igneous rocks, that is, rocks that are crystallized from hot melt (Engl. cognate: ignition). Igneous rocks make up the bulk of the Earth's crust and much of the uppermost mantle material (some of which is soft, being very hot). Continental crust: largely granitic, rich in silicate minerals (large ones typical for slow cooling). Granitic rock is commonly seen in uplifted roots of mountains, such as the Sierra Nevada and peninsular extension in Southern California (Fig. A6.2). In contrast, all of the oceanic crust is basaltic (rocks seen on the surface are in large part from ash, some welded, or from volcanic extrusions; see Figs. A6.3 and A6.4). The fundamental difference in rock types of continental and oceanic crust was used by A. Wegener in his arguments for continental drift, early in the twentieth century. The classification of igneous rocks is based on silicate content (high for granitic rocks, low for basalt) and on crystal size (coarse crystals for intrusive rocks and microscopic ones for extrusive rocks).

Fig. A6.1 Evidence that Earth is hot inside: geysirs in Iceland (Photo W.H.B.)

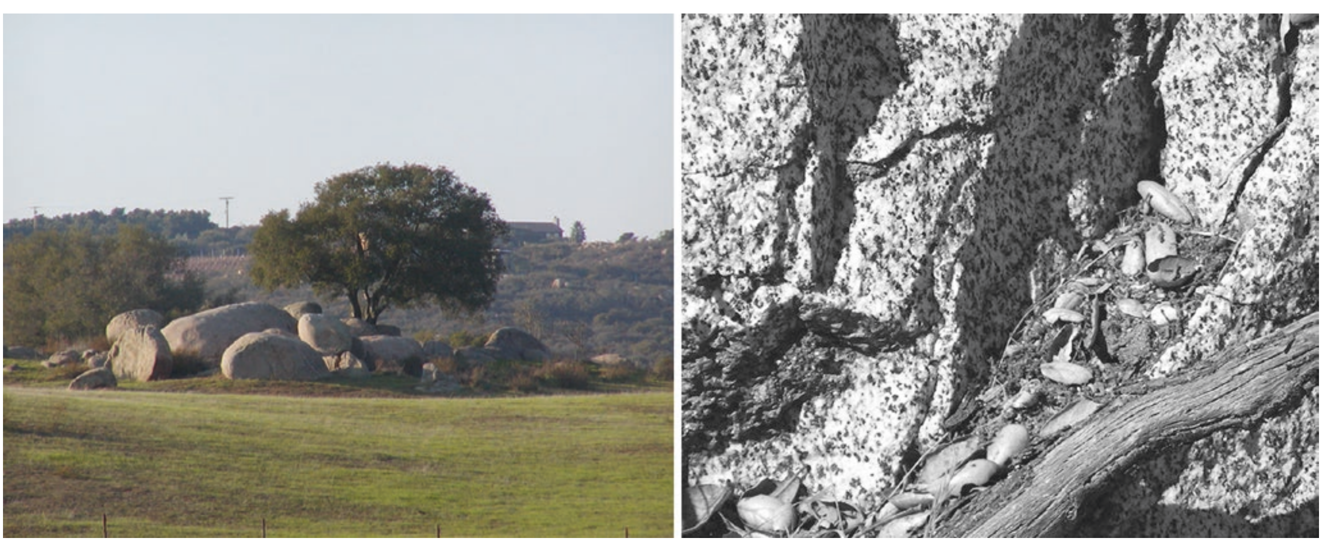

Fig. A6.2 Light-colored granitic rock, mountain roots exposed after removal of "overburden," San Diego County (Photos W.H.B.)

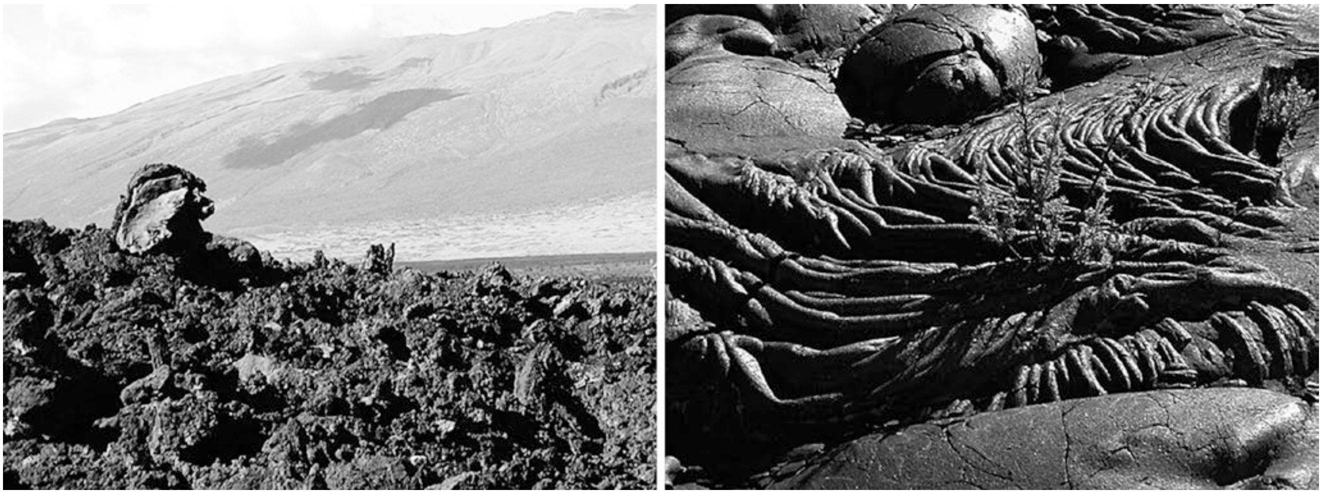

Fig. A6.3 Dark basaltic lava rocks, Hawaii (*Left*: rough aa lava; right: smooth pahoehoe flow) (Photos W.H.B.)

Fig. A6.4 Volcanogenic boulders (scoriaceous basalt; two light gray and white coral pieces, beach, Honolulu) (Photo W.H.B.) "scoria" = slag

Fig. A6.5 Basalt columns in Iceland. The entire island is made of volcanic rock (Photo W.H.B.)

Much of the seafloor basement is on oceanic crust and made of basaltic volcanic rock, some apparently derived from eruptions and intrusions (as in Hawaii and in Iceland. Much deep-sea sand, especially where influenced by the volcanic "Ring of Fire," has a strong showing of volcanic debris (Figs. A6.5 and A6.6).

On land, one can find ash deposits surrounding explosive volcanoes (Fig. A6.7). Examples are abundant in the Andes (here: Chile, Villarica). Layers of ash (seen on the flanks of the volcano) mark eruptions.

"Andesites" are intermediate in composition between granitic and basaltic rocks. The intermediate composition presumably is the result of mixing materials from the two major types of crust in Andes-type mixing machines (as in Peruvian mountains) next to subduction zones. The "andesite" line separates andesitic volcanoes and their rocks from (oceanic) basaltic ones. It is parallel to the Pacific "Ring of Fire" for much of its course. It was first mentioned (and named) in the nineteenth century.

1.6.2 Sedimentary Rocks

The most abundant types of sedimentary rock are "shale," "sandstone," and "limestone." "Limestone" refers to rocks made of calcium carbonate. The rock can be massive (Fig. 13.1) or layered (Fig. A6.8). Shale derives from siltstone, claystone, or mudstone. Commonly, it parts along very thin bedding planes. Much of it presumably originates from once widespread anaerobic marine sediments – sequences of ancient seafloor horizons deficient in oxygen. Examples are especially common in the Paleozoic and Mesozoic, but they also are seen in the Cenozoic. In the Paleozoic, some ancient shales have delicate marine fossils (presumably once drifting organisms) preserved as pyrite structures. The pieces show in X-ray graphs. Geologically young black shales may be well lithified or else still contain considerable water. An outstanding Mesozoic example is provided

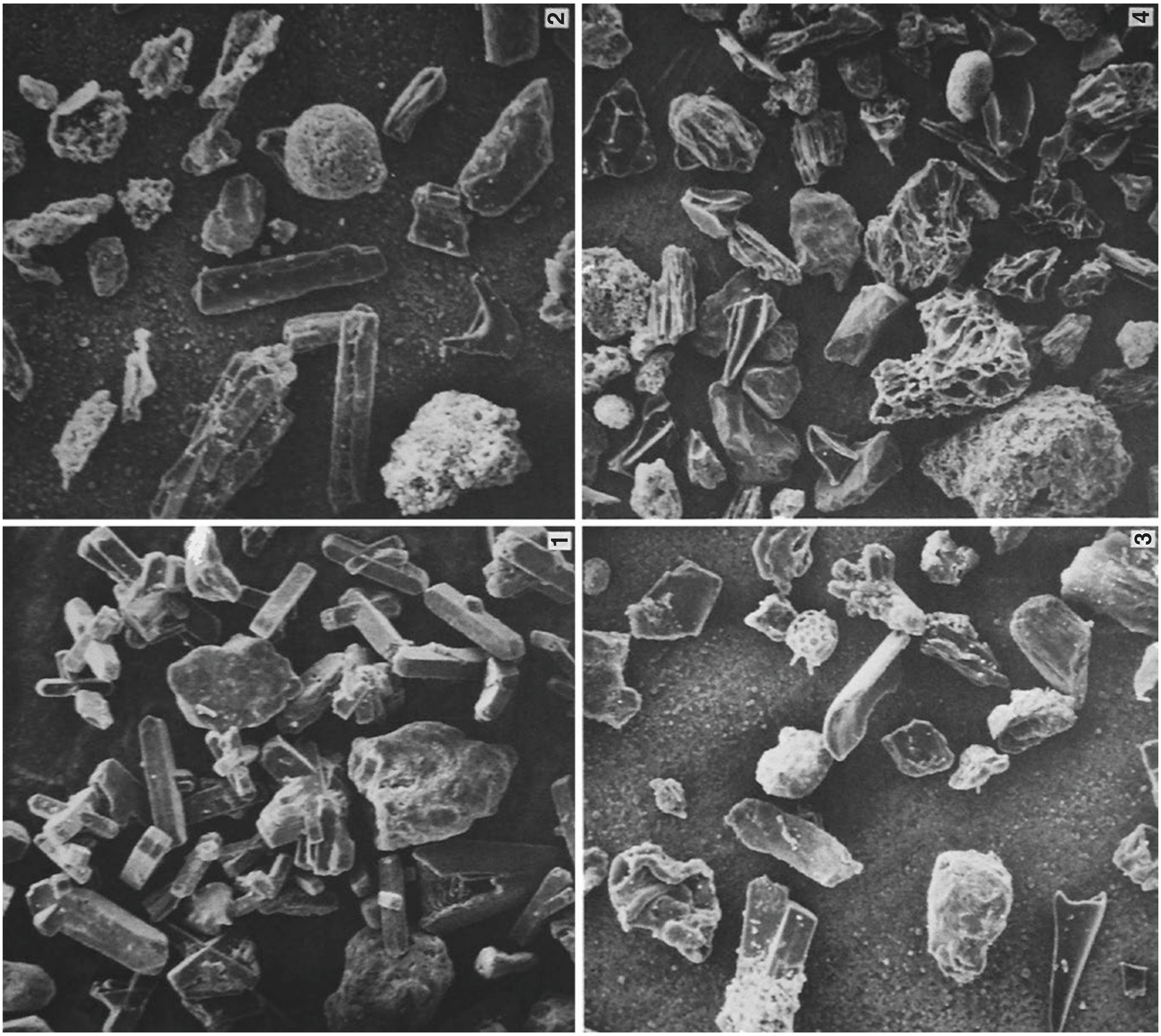

Fig. A6.6 Deep-sea sand with strong volcanogenic affinity (From A.C. Pimm, DSDP Leg 6. Northwestern Pacific. Images provided by S.A. Kling (then S.I.O.))

Fig. A6.7 Volcanic ash layers on the road to Villarica Volcano, Chile (Photo W.H.B.)

Fig. A6.8 Jurassic bedded limestone. Quarry near Crailsheim in Southern Germany (Photo W.H.B.)

by the Black Jurassic. Many fine examples of various types of Cretaceous marine sedimentary rock are now on land (Fig. 13.1).

Bedded (layered) limestones are familiar from Mesozoic sequences (Fig. A6.8) but occur abundantly all through the Phanerozoic and in earlier sequences. The bulk of this rock type is of marine origin, although other types do occur also, notably varieties derived from lake deposits ("limnic" sediments).

Among common but not dominant sedimentary rocks are cherts, coal, and phosphorites. Chert is typified by microcrystalline quartz, the latter presumably largely of biogenous origin (although this is difficult to document, especially in ancient rocks). The rocks range from silicified mudstones to very fine-grained quartzite. Coal usually contains terrestrial plant fossils. Phosphorite, a rock originating from phosphatic deposits, apparently is largely of marine origin: many phosphorites have marine fossils.

A widespread sedimentary rock (albeit not necessarily recognized as such) is ice, both in glaciers and at sea. On land, it originates from snow, that is, from sedimentary particles (frozen water) settling through the air. When close to its melting point, the ice is mobile and flows downhill. Being less dense than water, it floats at sea. For marine geologists, floating ice incorporating rock particles is very important as a transportation agent for IRD (*ice-rafted debris*). Sea ice results from freezing seawater at the surface. On and just below the seafloor, there can be methane ice, which is a type of water ice accommodating large amounts of methane. Upon melting, methane ice (*clathrate*) releases large amounts of combustible gas with strong greenhouse properties.

1.6.3 Metamorphic Rocks

Metamorphic rocks are mineral assemblages produced by deformation and recrystallization of igneous or sedimentary rocks, through elevated temperature and pressure, with or without addition of material through injection of solutions. Metamorphic rocks occur preferentially at collision margins, such as the ones in California, Alaska, or Japan, along the rim of the Pacific. Classification by origin (the most useful kind) is commonly very difficult, and thus classification tends to be descriptive in many cases (e.g., based on properties such as types of foliation, minerals present, grain size). Ages of metamorphic rocks on land have a large range, with a strong link to mountain building. Uplift and removal of overburden (some by polar ice masses) exposes ancient mountain roots with abundant metamorphic rocks (Figs. A6.9, A6.10, and A6.11). The resulting labels include the terms hornfels, amphibolite, granulite, slate, schist, and gneiss. In contrast, the labels marble and quartzite point to an origin from carbonate rocks or quartz sandstone, respectively.

Fig. A6.9 Metamorphic rock in Southern California, presumably of igneous origin. San Diego County (Photo W.H.B.) (US five-cent piece for scale.)

Fig. A6.10 Metamorphic rock, Norway (Photo W.H.B.)

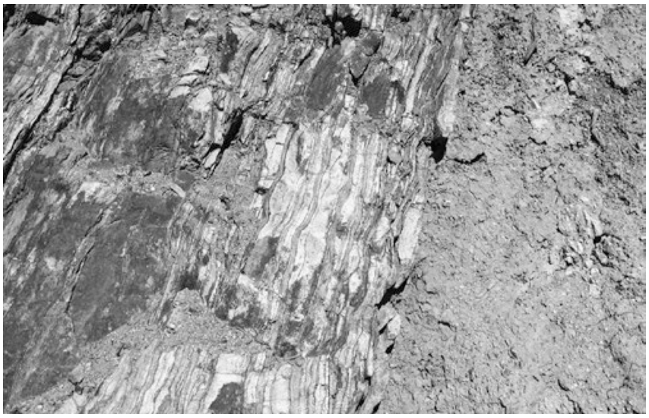

Fig. A6.11 Metamorphic sedimentary rocks from the mountain root zone in San Diego County, Southern California (Photo W.H.B.)

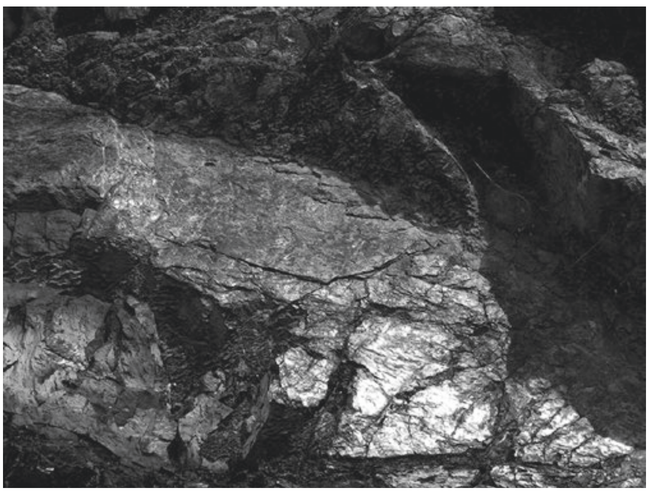

Fig. A6.12 Ophiolite (serpentinized basalt). *Top*: in a road cut near Santa Barbara, Southern California (*gray*). *Bottom*: road cut, Big Sur, California (Photos W.H.B.)

For marine geologists, metamorphosed and chemically altered basalt ("serpentinite," "ophiolite") is of special interest. It represents pieces of basaltic seafloor that ended up within active margin mountains (Fig. A6.12).

(Consult any general geology textbook or petrology text for details on rock types and their distribution.)

1.7 Geochemical Statistics

The Earth's crust mainly consists of aluminum silicates (oxygen, silicon, aluminum), with alkaline and earth alkaline elements for cations (Na, K, Ca, Mg) and with iron (Fe) ubiquitous within silicate or as sulfides and oxides mostly (see Table A7.1). Continental crust has a composition resembling that of granodiorite (a granitic rock with a reduced content of quartz, compared with classic granite, a feldspathic rock rich in mica and quartz). Ocean crust is mainly basalt (no quartz, rich in Fe and Mg). Seawater is largely a watery solution of kitchen salt (Na, Cl) with a bit of Epsom salt mixed in (Mg SO_4). The atmosphere is a mixture of nitrogen and oxygen gas (N_2, O_2), both intimately tied to biological cycling (i.e., to the carbon cycle) (see Table A7.1).

On the whole, igneous rocks and the sediments derived from them (mainly shale-type sediments) have very similar composition (Table A7.2). Sodium tends to be depleted in the sediment; much of it ends up in seawater. The high content in carbon in sediments is owing to the presence of carbonates and also of organic carbon (most of it finely dispersed). The sulfur content is largely linked to evaporites (e.g., gypsum). Compared with marine sediments on land, "Red Clay" is enriched in highly oxidized iron and manganese. Also it is unusually low in carbon (carbonate is dissolved; organic carbon is oxidized) but relatively high in water content**.** Differences in crustal composition (used by

Table A7.1 Chemical ingredients in crust, ocean, and atmosphere (weight %)

	Cont. crust	Ocean crust	Seawater	Atmosphere
O	46.3	43.6	85.8	21.0
Si	28.1	23.9	–	–
Al	8.2	8.8	–	–
Fe	5.6	8.6	–	–
Ca	4.2	6.7	0.04	–
Na	2.4	1.9	1.1	–
Mg	2.3	4.5	0.14	–
K	2.1	0.8	0.04	–
Ti	0.6	0.9	–	
H	0.14	0.2	10.7	–
P	0.10	0.14	–	–
Cl	–	–	2.0	–
N	–	–	–	78.1
Ar	–	–	–	0.9
CO_2	–	–	tr	0.04

Data of geochemistry. Sources for the tables: mainly R.W. Fairbridge (ed) 1972. The Encyclopedia of Geochemistry and Environmental Sciences. Van Nostrand Reinhold, New York.; and A.E.J. Engel and C.G. Engel, 1971. In A. Maxwell (ed) The Sea vol. 4, pt. 1. Wiley, New York

Table A7.2 Composition of igneous and sedimentary rocks and of Red Clay (percent)

	Igneous (continent)	Sedimentary (continent)	Tholeiite (deep-sea basalt)	Alkali basalt	Red Clay (deep seafloor)
SiO_2	59.1	57.9	50.2	48.2	53.7
Al_2O_3	15.3	13.3	16.2	16.5	17.4
FeO	3.8	2.1	7.1	7.6	0.5
Fe_2O_3	3.1	3.5	2.6	4.2	8.5
CaO	5.1	5.9	11.4	9.1	1.6
Na_2O	3.8	1.1	2.8	3.7	1.3
MgO	3.5	2.7	7.7	5.3	4.6
K_2O	3.1	2.9	0.2	1.9	3.7
H_2O	1.1	3.2	<1	<1	6.3
TiO_2	1.1	0.6	1.5	2.9	1.0
MnO	–	0.1	0.2	0.2	0.8
P_2O_5	0.3	0.1	0.1	0.5	0.1
CO_2	0.1	5.4	–	–	0.4
C(org)	–	0.7	–	–	0.1
SO_3	–	0.5	–	–	–

For details on the chemical composition of Earth and its crust, see any textbook on general geology or a text on geochemistry

A. Wegener in his arguments concerning continental drift) are quite obvious (see Table A7.1, columns 1 and 2).

1.8 Radioisotopes and Dating

Atoms of the same kind are called *isotopes* (a label referring to the fact that they take up the same place in the "periodic table"). The atoms that emit radiation are *radioactive isotopes* or r*adioisotopes.* Such isotopes may emit alpha, beta, or gamma radiation. An alpha particle is a helium nucleus (i.e., it consists of two protons and two neutrons) and is commonly ejected from the nucleus of a large element in the uranium series. A beta particle is a high-speed electron, commonly ejected from radioactive carbon. Gamma rays are electromagnetic waves similar to X-rays, except much more energetic.

Over the ranges of temperature and pressure investigated, radioisotopes were found to emit radiation independently of conditions, including chemical configuration. Thus, emissions from an element are considered to be only dependent on the number of radioactive atoms present. From this, it follows that the number of atoms remaining after time t from an initial number of radioisotopes is given by a simple decay formula, which may be written

$$N / N_0 = e^{-\lambda t} \qquad \text{(A8.1)}$$

Solving for "t" yields the time of decay that reduced N_0 to N. The decay constant λ obviously must be known before the solution can be found. For radiocarbon, it is near 0.00012.

$$\ln(N_0 / N) = \lambda \times t; \qquad \text{(A8.2)}$$

$$t = \ln(N_0 / N) / \lambda. \qquad \text{(A8.3)}$$

Setting N/N_0 equal to 1/2 and then solving for t yields the *half-life* of a radioactive isotope. Half-lives vary greatly. For radiocarbon (^{14}C), it is close to 6000 years. (Radiocarbon decays back to ^{14}N, from which it arose through cosmic ray bombardment of the air.) The half-life for the most common uranium (^{238}U) is near 4.5 billion years (close to the age of the Earth, it is thought). It decays to lead which is at the end of a long decay series involving several different types of radioactive elements.

After ten half-lives, only about one tenth of a percent is still present of the original number of radioisotopes. Thus, some radioisotopes become unsuitable for dating at some point. For the "short-lived" radiocarbon, with its 6000-year half-life, the point is reached near 40,000 years. Beyond about seven half-lives, the decay signal is very vulnerable to contamination. For the dating of older products (e.g., oceanic crust and also sediments), there are long-lived radioisotopes. Examples are potassium-40 (which decays to several elements, notably its daughter element argon-40). Dating by potassium-40 decay delivered the time scale for seafloor ages. (Transfer of such ages from one place to another is by correlation, including correlation using magnetic reversal sequences.) Other commonly used long-lived radioisotopes, besides potassium-40 (^{40}K), are rubidium-87, thorium-232, uranium-235, and uranium-238 (^{87}Rb, ^{232}Th, ^{235}U, ^{238}U). Their decay (in some cases involving decay series – a cascade of radioisotopes ending up in stable elements) has been studied in some detail and applied to the dating of rocks and sediments.

Man-made radioisotopes (such as plutonium and other bomb-related products) carry information not normally an important part of routine dating: their appearance is geologically extremely young.

Details on radioactivity in the sea and on the seafloor and its use in the study of seafloor age and sedimentation processes are available in any geochemistry text and in many textbooks in general geology.

1.9 Marine Organisms Involved in Seafloor Processes

1.9.1 General Remarks

There are many more different species on land than at sea, mainly owing to the proliferation of insects (phylum arthropods) on land. The number of *noninsect* species in the sea outnumbers those on land in the ratio of roughly 2 is to 1 (as does area of the sea to area of land). Marine benthic species greatly outnumber planktonic ones in practically all categories by various factors. It is a factor of more than 100 for foraminifers (not subtle). In the phylum echinoderms, the ratio approaches infinity for certain crinoids, adult forms being extinct in the plankton (they are still seen as plankton fossils in rocks of Mesozoic age, having been reported from quarries in Solnhofen and from DSDP Leg 11). Infinity is avoided if one counts larvae as establishing presence. Similarly poorly defined ratios obtain in some holothurians floating close to the bottom and of questionable affiliation, benthic or planktonic or both, like many a flatfish (phylum chordates).

On the basis of similarity of appearance (and most recently of chemistry), organisms are classified into species, which are grouped into *genera* (plural of *genus*), which in turn are grouped into *families,* then *orders*, then *classes*, and finally *phyla* (plural of *phylum*). The classification is a legacy of the Swedish naturalist Carolus Linnaeus (Carl von Linné), working in the eighteenth century.

Phyla that are similar to each other make up a *kingdom*. To establish similarity between different phyla can be a bit of a challenge: the groupings at this high level can be arbitrary. Commonly cell properties are being compared. Presumably, a kingdom has implications for common ancestry deep in the Precambrian, while classes imply ancestry in the early Paleozoic, with successively younger geologic ancestors for the groupings' orders, families, and genera, at least in large multicellular organisms. The discovery of a new kingdom in recent decades (the "archaea," by the biologist C. Woese, 1928–2012, working in Urbana, Illinois) suggests that the task of proper classification of organisms has by no means ended, especially when contemplating bacteria and archaea. The life-forms in question (prokaryotic microbes) are greatly involved in many geochemical processes, including those on the seafloor.

At this highest level of classification (kingdoms), there is a choice between fundamentally different ways of viewing life-forms. Some scientists are still aware of the ancient divisions of "animals," "plants," "fungi," "protists," and "monera," a classification that goes back to the early nineteenth century and has no biochemistry in it. The category "monera," once used for prokaryotic microbes such as bacteria, is now obsolete. Many biologists prefer to consider only prokaryotes (cells without a membrane-enclosed nucleus) and eukaryotes (cells with a well-defined nucleus) as of fundamental importance. In such a simplified scheme, the eukaryotes include animals, plants, fungi, and microscopic "protists" such as foraminifers, coccolithophores, and radiolarians, while the prokaryotes contain the bacteria and the archaea. The latter apparently are ancient life-forms now found abundantly in hot springs and salty environments and involved in anaerobic reactions. They may superficially resemble bacteria but are quite different from them biochemically.

In the modern threefold fundamental classification, there are then three "domains" (kingdoms) – bacteria, archaea, and eukaryotes. All are abundant on the seafloor. Whether eukaryotes are derived from prokaryotes by complexification or prokaryotes originate (at least in part) from eukaryotes by simplification is a matter of research and discussion. In the marine rock record, eukaryotes apparently are the younger group of organisms, arising hundreds of millions of years later than prokaryotes. Also, eukaryotes are organisms with plenty of multicellular representatives (i.e., with animals, plants, and fungi), which are not much in evidence before the Phanerozoic (although multicellular remains, presumably marine, are indeed present as fossils in certain late Precambrian rocks prior to the Cambrian).

When we discuss life on the seafloor, we tend to emphasize the types of organisms one finds at the shore and in the fish markets, that is, multicellular eukaryotes. But it is microbes that dominate the marine environment. Their remains cover most of the seafloor. Also, members of the group "microbes" perform the photosynthesis in corals. The sedimentary reactions on and within the seafloor, including decay of organic matter and recycling of nutrients, are largely performed by bacteria and archaea.

1.9.2 Microbes and Marine Sediments

Archaea and bacteria largely appear in their products (e.g., methane ice, iron sulfides, ferromanganese nodules) and more generally in chemical reactions in seawater and on the seafloor (e.g., photosynthesis, nitrogen reduction, many types of mineral precipitation, early diagenesis). Their activities dominate the marine environment. Nevertheless, the chief targets of microbial studies by marine geologists classically have been eukaryotes, especially foraminifers. All of the eukaryotic microbes are useful in stratigraphy, as well as in assessment of environmental conditions, since they normally leave recognizable skeletal remains in marine sediments (Fig. A9.1).

Much of micropaleontology is in fact focused on the contents of the fine sand fraction of marine sediments. Study targets include the ubiquitous foraminifers (Fig. A9.2) and other microbes. Nannofossils, the one group of microbes studied roughly equally intensely as foraminifers, are mainly in the fine silt, however. Occasionally, one sees fish teeth in marine sediments. Such remains, while difficult to identify, can be of some use for stratigraphic purposes, especially where other fossils are lacking.

1.9.3 Dominant Marine Organisms

Multicellular marine creatures are eukaryotic, as mentioned. The ones of relevance in marine geology make fossils or produce bioturbation. The best-known examples of the former are in coral reefs and include calcareous

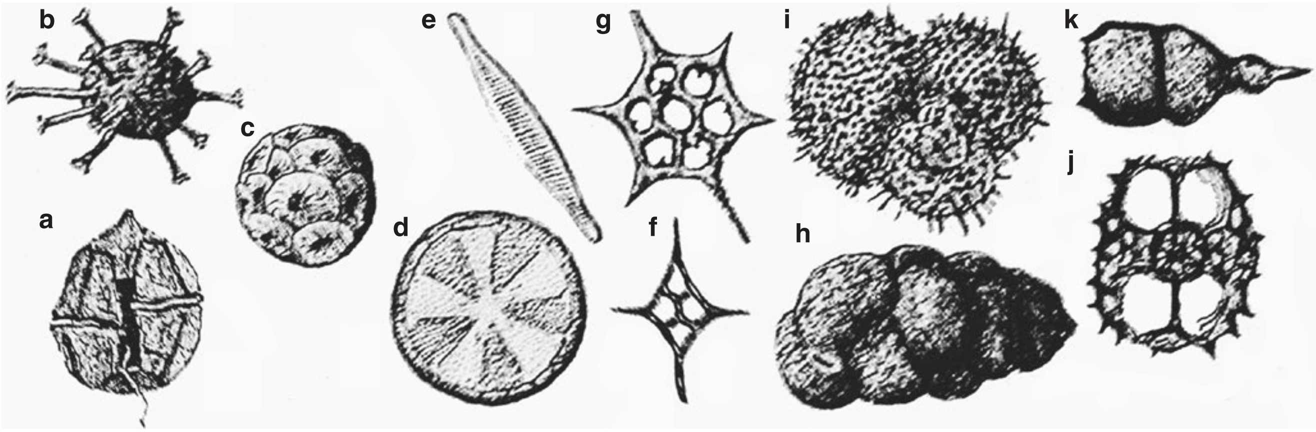

Fig. A9.1 Eukaryotic microbes found in marine sediments: fossils of micropaleontology. (**a**) and (**b**) dinoflagellates. Photosynthesizing. Common as symbionts in various organisms, including certain other microbes. (**c**) Coccolithophore (nannofossil). Photosynthesizing. Remains are ubiquitous in calcareous sediments; rock forming in many places. (**d**, **e**) Diatoms. Photosynthesizing. Siliceous skeletons. Colonial forms abundant in marine plankton. Can be rock forming. (**f**, **g**) Silicoflagellates. Similar to diatoms but with an internal skeleton. (**h**, **i**) Foraminifers. Heterotrophic plankton and benthos. Remains are common in "*Globigerina* ooze." Can be rock forming. (**j**, **k**) Radiolarians. Heterotrophic. Internal skeleton of silica. "Radiolarian ooze" in places. Ancient fossils (Drawings from the third edition, after various sources)

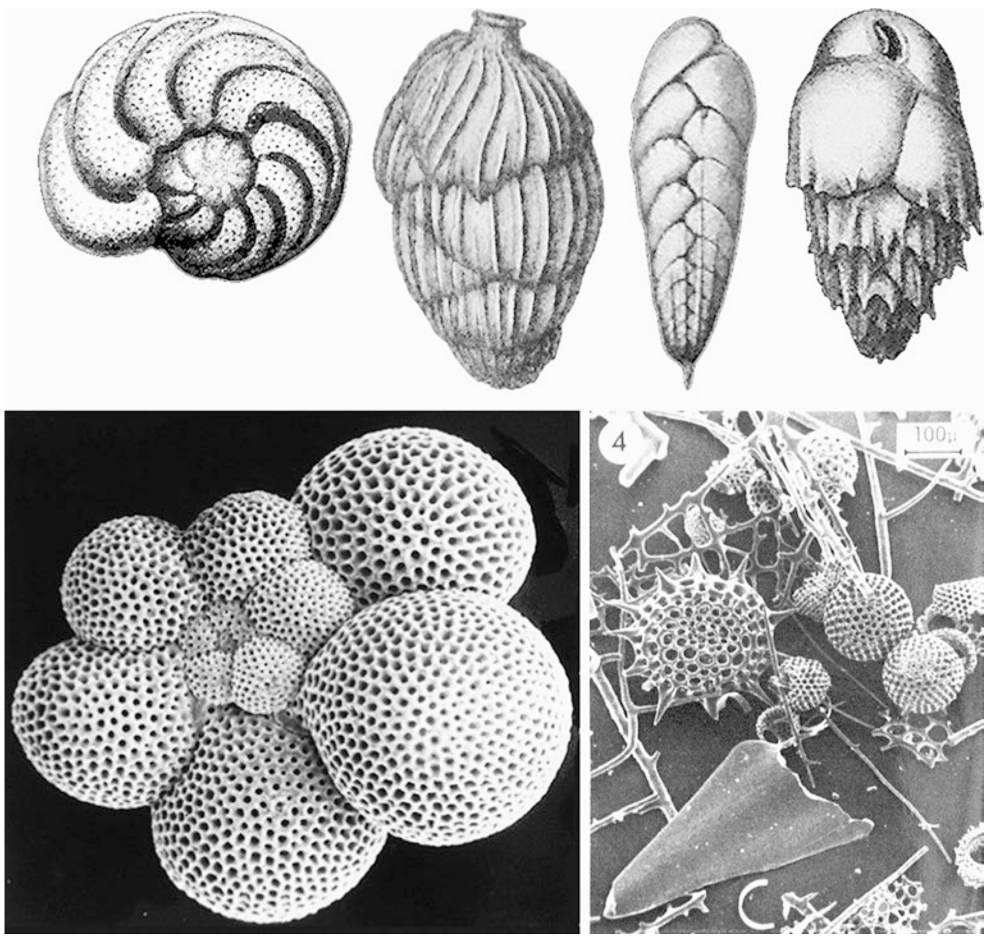

Fig. A9.2 Favorite objects of marine micropaleontology. *Top row*, benthic foraminifers from the Challenger Expedition; leftmost: dominant information carrier for stable isotopes; rightmost three: indicators of low-oxygen conditions. *Bottom row*, SEM photos (leftmost: planktonic foraminifer species, deep tow off California, S.I.O.; right: Neogene sediment sampled during DSDP Leg 14, SEM Kiel University) algae, sponges, corals, lamp shells, bryozoans, and a host of mollusks and arthropods, as well as echinoderms. In addition, there is a great variety of fishes. A similar assemblage (on the level of class and phylum) is seen at any shore, again with mollusks, arthropods, and echinoderms dominant, and with coral relatives and large algae much in evidence. At the shorelines of Southern California, we also have plenty of barnacles (a shell-bound sessile arthropod and in the same class as the crabs scurrying underfoot and the somewhat annoying kelp flies nearby). Mollusks, arthropods, and vertebrates, of course, dominate the biosphere not only at sea but on land as well. Echinoderms and cnidarians are found mainly in seawater, as is true for the phyla of many other creatures.

We might well ask whether the more restricted phyla are the more ancient ones or vice versa.

The question is difficult to tackle. With few exceptions, only fossil makers can be shown to have existed in the distant past. That is, for many organisms, we cannot even think of documenting the first appearance (not to mention the time of origin which is a near-impossible challenge even for organisms with hard parts). This is true not just for phyla but for any type of organism, actually, right down to the species level. (Neither do we know the time of last occurrence on the planet. What is known is what was found in what rock.) Another problem is that so many animals first appear in the Cambrian (hence the label “Phanerozoic,” which is the time since the beginning of the Cambrian). The coincidence of first appearances suggests that environmental forces were at work in forcing geologic history at the time; the relevant changes are not known but much discussed. A third problem is that evolution changes the phyla. Just what we are talking about when discussing the origin of a phylum is not necessarily clear.

1.9.4 A Note on Large Marine Plants

Not all marine photosynthesizing algae are minute and reside in the marine plankton. Some live on the seafloor and some are large, like the calcareous algae, or very large, like certain species indicative of upwelling conditions (“kelp”).

Details on marine organisms are available in any marine biology text and in many general biology texts.

Glossary

Marine geology, like many related disciplines of science, has experienced major changes within the twentieth century, and also in the twenty-first. One result is an index in flux, that is, one that reflects arbitrary preferences of authors regarding entries more strongly than desirable. [→ means "see entry for"]

Abyssal hill morphology: Sect. 2.3.6

Abyssal plains, deep seafloor usually covered by erosion products (→ Turbidites), commonly from extension of certain types of "continental rise." Sects. 1.3.3, 2.2.2, and 3.8; Figs. 2.2, 2.7, and 3.18.

Abyssal storms, pulsed deep-sea currents (transporting silt): Sect. 5.3.4.

Accelerated sinking (biological pump): Sects. 7.2.4 and 10.2.5; Figs. 7.6 and 10.7.

Acidification of seawater: Sects. 4.7.1., 13.1.1, 13.3.1, and 14.2.3.

Acoustic impedance (Eocene rocks, → chert), commonly associated with a change in density of the medium carrying sound: Sect. 10.4.3, Fig. 10.12.

Acropora, bushy calcareous coral genus, common in Caribbean, apparently selected for fast growth: Figs. 8.9 and 9.11; Sect.9.3.2.

Active margin (Pacific-type margin, collision margin): mountain-building region, factory of continental crust, → Trench, → Ring of Fire, Sect. 3.3, Figs.1.2, 2.9, 2.10, 2.11, 3.2, 3.9, and 3.10.

AFS (Auversian Facies Shift) also see → Auversian Facies Change, Eocene → CCD drop, → Plate stratigraphy: Sects. 12.2.2 and 12.2.3; Figs. 3, 1.7, 12.4, and 12.15.

Air gun records (sub-seafloor → echo sounding, also see → seismic profiling → side scan): Figs. 2.7, 3.6, and 3.14.

Albatross Expedition: Sects. 1.3.4 and 11.1.1; Fig. 11.6.

Alfred-Wegener-Institut, marine institute in Bremerhaven, Germany, focused on polar studies.

Algal mats, desiccation cracks, tidal flat deposits: Fig. 6.3.

Alvarez, L., pioneer, Calif. physicist, proposed bolide impact for end of Mesozoic (→ K-T): Sect. 1.1.1.

Alvarez, W., pioneer, Calif. geologist (son of L.), co-proposed → K-T impact: Sects. 1.1.1 and 1.1.5.

ALVIN, scientific submarine of Woods Hole (also see → hot vents): Sect. 1.2.1; Figs. 1.8 and 1.9.

Anaerobic (anoxic) and dysaerobic (low oxygen) conditions, humid sedimentation, and human impact: Sects. 8.2.3 and 9.5.2; Figs. 8.5, 8.6, 9.15, and 9.16.

Anaerobic conditions: result of complete → oxygen loss.

Anaerobic feedback in ocean productivity: Sect. 7.1.2.

Ancient sea-level fluctuations (reconstruction): Sects. 6.5 and 15.4.7; Figs. 6.10, 6.11, 6.12, 6.15, 11.9, 12.3, and 15.4.

Andrusov, N.I.: Sect. 1.3.6.

Anhydrite, $CaSO_4$, soft mineral, ("La Dame Blanche"): Sect. 14.4.3.

Anomalies (temperature, surface water): Figs. 7.10, 7.13, and 9.7; Sect. 9.1.5.

Anoxic conditions: Sects. 11.6.3, 13.2.2, 13.2.3, and 13.2.4; Figs. 13.8 and 13.9 (also see → Oceanic Anoxic Events).

Antarctic bottom water (AABW): Sect. 5.3.4; Figs. 5.15 and 7.12.

Antarctic deposition patterns in the Cenozoic: Sect. 12.2.3 (also see → Drake Passage opening).

Antarctic opal deposition: Sect. 10.4.2; Fig. 10.11 (also see → Siliceous ooze and mud).

Antarctic upwelling: Sect. 7.5.4; Fig. 7.12.

Anthropocene, Carbon Cycle Modified: Sect. 15.5.

Anthropocene, the Central Problem: Sect. 15.1.

Anti-estuarine circulation (margins): Sect. 5.3.5.

Aragonite vs. calcite: Sect. 4.6.2.

Archaea: Sect.1.2.2 (also see → methane and → Woese).

Arid and humid sedimentation: Preface, Fig. 2; Sect. 9.5.1; Figs.9.14, 9.15, 9.16, and 9.17.

Arrhenius, G.O.S, chemist on the *Albatross* discovered deep-sea carbonate cycles: Sect. 10.1; Fig. 11.5.

Asaro, F., co-proposer bolide impact at end of Cretaceous: Sect. 1.1.1.

Asymmetries in ocean circulation: Sect. 12.2.6; Fig.12.10 (also see → Basin-basin fractionation).

E. Seibold, W. Berger, *The Sea Floor*, Springer Textbooks in Earth Sciences, Geography and Environment,
DOI 10.1007/978-3-319-51412-3

Atlantic-type margins (passive margins, trailing edge, sinking edge of continent): Sect. 3.2.

Atolls: Sect. 9.3.3.

Auversian Facies Shift (→ AFS, → Eocene-Oligocene silica sedimentation).

Back-arc spreading (spreading in collision margins): Sect. 3.3 (→ Active margin), Fig. 3.9.

Bacterial mat: Sect. 4.5.4 (also see → Bioturbation).

Bahamas (carbonate sedimentation): Sect. 4.7.2; Figs. 4.14 and 4.15. (Also see → Carbonate).

Baleen whale evolution (length of food chain argument, link to diatoms): Sect. 12.2.4.

Baltic Sea (humid circulation example): Sect. 9.5.2.

Baltic Sea (depth stratification of benthic foraminifers): Sect. 9.5.2; Fig. 9.16.

Barrier-type coast: Sect. 6.3.3; Fig. 6.9 (Galveston).

Barron, J.A., USGS, diatom expert (coauthor in reporting the mid-Miocene silica switch → Monterey).

Basin-basin exchange, (between Atlantic and Pacific, → Monterey): Sect. 10.2.3.

Basin-basin fractionation (corollaries of exchange circulation between Pacific and Atlantic): Sect. 10.2.3.

Basin-shelf fractionation (and AFS): Sect. 12.4.2.

Beach (morphology, California): Sect. 3.1.2; Fig. 3.3.

Bed load (vs. → suspension load): Sect. 5.1.3; Figs. 5.4 and 5.5 (Also see → Hjulström Diagram).

Bengal Fan (largest sediment wedge on the planet): Sect. 3.1.3.

Benthic boundary layer, water layer in contact with the seafloor: Sect. 5.3.4.

Benthic foraminifers (examples by E. Haeckel): Fig. 4.13.

Benthic organisms on and in the seafloor: for all major groups, benthic organisms are more diverse than planktonic ones, by far.

Benthic-organism-derived sediments: Sect. 4.6.2; Fig. 9.11.

Benthic life styles (infauna, epifauna, sessile, vagile, suspension feeder, etc.): Sect. 8.3.

Berger, A., Belgian astronomer and climatologist, recalculated Milankovitch input to high precision:

Sects. 1.1.1 and 11.1.2.

Berger, W.H., S.I.O./UCSD; junior coauthor of this textbook, worked on → CCD fluctuations, on ice-age history, and on selective preservation of deep-sea fossils (calcareous foraminifers).

Berggren, W.A., pioneer. Woods Hole geologist, worked on Cenozoic biostratigraphy: Preface, Fig. 5.

Bermuda coral (coral growth and solar cycles): Sect. 15.6.4.

Biodiversity (long time to recover from destruction): Sect. 15.4.4.

Biogenic sedimentary structures (trace fossils, bioturbation): Figs. 8.6, 8.7, 8.13, 8.14, 8.15, and 8.16.

Biogenous sediment: Sects. 4.4, 4.6, and 10.2.2; Figs. 10.5 (plankton), 10.2, 10.11, 4.7, 4.12, 4.13, 4.14, 4.15, 7.9, 8.1, 8.2, 13.3, and 13.4.

Biological pump: Sect. 7.2.4; Figs. 7.5, and 7.6.

Bioturbation (disturbance): Sects. 8.4.1 and 8.5.

Bioturbation (and the low abundance of thin layers in oxygenated sediments): Sect. 8.5.2.

Black sediment (modern seafloor): Sect. 13.2.2; Fig. 13.7.

Black shale, Cretaceous: Sect. 13.2.1; Fig. 13.6. (Also see → “Oceanic Anoxic Events”).

Bleaching of coral reefs: Sect. 9.3.5.

“Blue” vs. “green” ocean: Figs. 7.4 and 7.7.

Bohrmann, G., marine geochemist, Bemen University: Sect. 1.2.2; Fig. 1.10.

Bolin, B., Swedish meteorologist and biogeochemist, founder of the IPCC: Sect. 15.5.2.

Bottom shear stress: Sect. 5.1.3; Fig. 5.4.

Bottom-water circulation (global ocean): Sects. 5.3.3 and 5.3.4; Figs.5.15 and 5.16.

Bottom-water formation on Tethys shelf: Sects. 5.3.3 and 13.2.6.

Bottom-water production (NADW): Sect. 5.3.3; Fig. 5.15.

Bouma sequence = graded layer (turbidite): Sect. 3.7.

Bourcart, J., French marine geologist: Sect. 1.3.6.

Box-core (artificial outcrop of deep-sea ooze): Fig. 10.8.

Brittle stars: abundant in some muddy places offshore: Fig. 8.11.

Broecker, W.S., Lamont geologist and ocean chemist, involved in a great number of concepts and activities of interest to marine geology (radiocarbon dating, radioisotope dating of last warm time, terminations, differential dissolution, carbon isotopes, conveyor-belt circulation, Dansgaard-Oeschger Oscillations, Heinrich Events, and others).

BSR (“bottom-simulating reflector”): Figs. 3.10 and 4.5; (also see → methane clathrate).

Bullard, E.C.: Sect. 1.3.8; Fig. 1.14.

Burning coal and oil (recovery by carbonate dissolution): Sect. 10.3.4.

Burrows and trails: Sects. 8.4 and 8.5.

Burrows in “Red Clay”: Fig. 8.13 (X-ray shadow graph).

Calcareous ooze: Sect. 10.3; Figs. 4.7, 10.2, 10.3, 10.4, 10.5, 10.6, 10.8, and 10.9.

Calcareous shell (resource): Sect. 14.3.2.

Calcium sulfate deposit (resource, vent chimney): Sect. 14.4.3.

Calibration (distribution patterns vs. environmental parameters}: Sect. 9.2.1.

Californian margin (active, uplift, Big Sur): Fig. 3.2.

Carbon dioxide (effects of rise, basic considerations): Sect. 15.4.3.

Carbon dioxide (uptake by the sea); Revelle and Suess, 1957: Sect. 15.4.1.

Carbon dioxide (warming effect; discussions): Sect. 15.4.1; Fig. 15.2.

Carbon dioxide consumption (during dissolution of carbonates): Sect. 4.7.1.

Carbon dioxide release (during precipitation of carbonates): Sect. 4.7.1.

Carbon isotope signal, Cretaceous OAEs: Sect.13.2.4; Figs. 13.8 and 13.9.

Carbon isotopes, indicators of carbon cycle: Sect. 9.4.2.

Carbon system state and changes: Sect. 15.5.1.

Carbon transfer, sea surface to seafloor, schematic, estimated (blue vs. green ocean contrast): Fig. 7.7.

Carbonate crash (short-lived CCD rise, end of middle Miocene): Sect. 12.4.2; Fig. 12.15.

Carbonate cycles: Sect. 11.4.2; Fig. 11.5.

Carbonate rate of production: Sect. 8.3.3; Figs. 8.8, 8.9, and 8.10.

Carbonate saturation and precipitation (focus on geochemical definition): Sect. 4.7.1.

Carbonate (types of calcareous matter): Sects. 4.6, 4.7, and 4.8; Figs. 4.7, 4.11, 4.12, 4.13, 4.14, and 4.15.

Carbonate deposits with no recognizable biological structure: Sect. 4.7.

CCD and “Red Clay”: Sects. 10.1, 10.2, and 10.3; Fig. 10.2.

CCD drop at end of Eocene (→ AFS, → Drake Passage opening): Sect. 12.2.3.

CCD, Cenozoic fluctuations: Sects. 12.4.1 and 12.4.2; Fig. 12.15.

CCD map: Fig. 10.10.

Cementation during early diagenesis: Sect. 4.3.2.

Cenozoic history from deep-ocean drilling: Sects. 12.1 and 12.2; Figs. 12.3 and 12.5.

Cenozoic stepwise cooling: Fig. 1.7.

Cenozoic time scale: Preface, Fig. 5.

Central gyres: Sect. 5.3.2; Fig.5.14. (Also see “Gulf Stream”).

Challenger Expedition (1872–1876): Sects. 1.3.2 and 10.1; Figs. 10.1 and 10.2.

Charles Darwin (1809–1882), geologist, naturalist, and polymath known in marine geology for his amazing contributions to paleontology and biology, for his speculations about atolls, and his observations on dust at sea (among other things).

Chemistry of seawater (geochemistry of sediments): Sect. 4.3.

Chert (microcrystalline quartz): Sects. 4.6.2 and 10.4.3; Fig. 10.13.

Classification of sediments on the seafloor: Box 4.1.

Clathrate (→ methane ice): Sect. 1.2.2; Figs. 1.10 and 4.5.

Clay (clay size): Sects. 4.5.1 and 4.5.4.

Clay (mineral composition): Sect. 10.5.2; Fig. 10.14; Appendix A4, A5.

Cliff erosion: Fig. 5.9; Sects. 5.2.1, 5.2.2, and 5.2.3.

CLIMAP reconstruction, last glacial maximum (LGM): Sect. 9.2.2; Fig. 9.9.

Climate change (ongoing) and the seafloor: Sect. 15.4.

Climate change, short-term marine record: Sect. 15.6 (also see → Santa Barbara).

Climate indicators other than coral reefs, physical and biological indicators: Sect. 9.4.

Climate system (complexity): Sect. 15.4.2; Fig. 15.2.

Climate zonation (marine sediments and fossils): Sects. 9.1 and 9.1.2; Figs. 9.2, 9.3, 9.4, 9.5, and 9.6.

Climatic change vs. the economy (prevailing argument): Sect. 15.4.5.

Climatic clues from restricted seas: arid and humid zones on shelves: Sect. 9.5; Figs. 9.14 and 9.15. Climatic transgression (pattern of temperature): Sect. 9.2.2.

Coastal erosion: Figs. 5.8 and 5.9.

Coastal morphology and sea level: Sect. 6.3; Figs. 6.2, 6.3, 6.4, 6.5, 6.6, 6.7, 6.8, and 6.9.

Coastal upwelling and high production off California: Sect. 7.2.1; Figs. 7.2 and 7.10.

Coccolithophores (temperature reconstruction): Sect. 9.2.1.

Coccoliths, parts of → coccolithophores, the most abundant fossils on the planet (also called nannofossils because of their minute size): Sect. 4.4; Figs. 4.7 and 4.11; Table 10.1.

Cold seeps: Sect. 1.2.2.

Collision margin: see → Active margin.

Comet mark: Fig. 5.13.

Continental drift: Sect. 1.3.7; Figs. 1.13, 1.14, and 13.5 (Also see → Wegener).

Continental margins, general features: Sect. 3.1. (Also see → Cont. rise and → Cont. slope, → Shelf)

Continental rise and slope, coalescing fan deposits off continents. Differ by rates of sedimentation, steepness (both have gentle slopes) and type of underlying crust (continental or oceanic): Sect. 3.5.

Continental rise: Sect. 3.5; Figs. 3.13, 3.14, and 3.15.

Continental slope: Sects. 3.5 and 3.1.1; Figs. 3.13, 3.14, and 3.15.

Continental uplift: Sect. 2.1.2; Figs. 2.1 and 3.2 (Western Big Sur vs. East Coast).

Contour currents: Sect. 5.3.4.

Contourites: sediment layers formed by → contour currents.

Conversions for temperature, length, volume, mass: Appendix A1.

Conveyor belt circulation: Sects. 5.3.3 and 9.1.5; Fig. 5.15. (Also see → Bottom water and → Silica Switch).

Cooling and mountain building: Sects. 2.1.2 and 12.2.2.

Cooling trends (evidence from oxygen isotopes): Fig. 12.3; Sect. 12.1.3.

Cooling in the Cenozoic: Preface, Fig. 3; Figs. 12.1, 12.3, 12.4, 12.9, and 12.13; Sect. 12.1.1.

Coquina deposits: Sect. 8.3.5.

Coral reef stress: Sect. 9.3.5.

Coral reef, associated organisms: Fig. 9.11; Sects. 2.2.2 and 9.3.1 (Great Barrier Reef: Sects. 2.2.2 and 9.3.4).

Coral reefs (general distribution): Sect. 9.3.1; Fig. 9.10.

Coral reefs, markers of tropical climate: the response of reefs to a warm climate is not obvious because a warm ocean differs from a cold one not just in temperature: Sect. 9.3.

Coral symbiosis: Sects. 2.2.2 and 9.3.1.

Coring (the first collection of long cores was from the *Albatross* Expedition, 1940s): Sect. 10.1.

Coring (the first cores from the seafloor were from the *Meteor* Expedition, 1920s): Sect. 10.1.

Coring: widespread use of piston cores taken by Lamont's RS *Vema* (see → *Vema*).

Coring and drilling: drilling vessels *Glomar Challenger* and *JOIDES Resolution*. (See → Drilling, deep sea).

Coriolis force (discussed with upwelling): Sects. 7.5.1 and 7.5.3; Figs. 7.10 and 7.11.

Corliss, J., pioneer, S.I.O.-trained marine geologist, Oregon, discovered the first → hot vent: Sect. 1.2.1.

Cox, A., pioneer, USGS geologist who worked on → magnetic reversals: Sect. 2.3.3.

Crest (MOR): Sect. 2.3.5; Figs. 2.4 and 2.5.

Cretaceous carbon energy (background): Sect. 13.1.1.

Cretaceous carbonate reefs (why they matter): Sect. 13.3.1.

Cretaceous environments (evidence from land and from deep-ocean drilling): Sects. 13.1 and 13.2.

Cretaceous leitmotif: Sect. 13.2.

Cretaceous marine fossils (background): Sect. 13.1.2.

Cretaceous marine rocks (background): Sect. 13.1.1.

Cretaceous Milankovitch cycles: Fig. 13.12; Sect. 13.2.6.

Cretaceous rudist reefs: Sect. 13.3.2; Fig. 13.13.

Croll vs. Milankovitch (emphasis on ice buildup vs. melting): Sect. 11.1.4.

Croll, J., Scottish pioneer geologist and climatologist of the nineteenth century (a brilliant but failed) Proposed orbital theory of ice ages: Sect. 11.4.1. Also see Sect. 9.1.5 (Gulf Stream heat transport).

Crust (continental and oceanic): Sect. 3.1.1; Fig. 3.1.

Cryptic predation: Sect. 8.5.1.

Currents and sediments (the faster the current, the larger the particles moved): Sects. 5.1, 5.2, and 5.3.

Cyanobacteria (blue-green algae, stromatolites): Sect. 6.2.2.

Cycles of the Pleistocene: Sect. 11.4.

Dalrymple, G.B., pioneer, USGS geologist who worked on magnetic reversals: Sect. 2.3.3.

Daly, R.A., pioneer, Harvard geologist, examined reef growth and ice-age sea level: Sects. 6.4.3 and 1.3.3.

Dansgaard-Qeschger oscillations (found in ice and in lake sediments) are named after physicists in Copenhagen and in Berne, who discovered long-term (millennia-long) regular climate variations in the Pleistocene: Sect. 11.6.2 (Also see → Heinrich Events).

Dead lakes on the Cretaceous seafloor: Sect. 13.2.7.

Dead zones (→ oxygen loss): Sect. 7.2.4, final paragraph.

Décollement, major fault system in collision systems, nearly horizontal; commonly greased by methane-bearing fluids: Fig. 3.10 (Also see → Active margin).

Deep biosphere; prokaryotic microbes are everywhere, even deep within sediments: Fig. 1.11; Sect. 8.6.

Deep-ocean drilling and the ice-age target: Sect. 11.5.

Deep-sea fans and abyssal plains: fans are found off valleys carved into → shelf and slope; abyssal plains are, in essence, extensions of rises and fans: Sect. 3.8; Figs. 3.13, 3.14, 3.15, 3.16, 3.17, and 3.18 (Also see → Turbidites).

Deep seafloor morphology: Sect. 2.3.6; Figs. 2.7 and 2.8.

Deep-sea sediment cycles (ice ages): Sects. 1.3.4 and 11.4.

Deep-sea sediments – patterns and processes. Three major facies (types of rock or sediment) exist – calcareous ooze and "Red Clay" (separated by the → CCD) and the mud (commonly siliceous) of the coastal ocean (mainly on cont. slope): Sects. 10.1 and 10.2.

Deglaciation: sea-level rise and coastal morphology: Sects. 11.6; Figs. 6.5, 6.6, and 6.7.

Delta deposit structure: Fig. 6.7.

Deposit feeders, interference with suspension feeders: Sect. 8.3.5, fourth paragraph.

Depth of the sea: Sect. 2.1.

Desert at gyre center: Sect. 7.2.2; Figs. 7.3 and 7.4.

Desiccation cracks, algal mats, tidal flat deposits: Sect. 6.2.1; Fig. 6.3.

Diagenesis in coral reefs and other carbonate deposits: Sects. 9.3.2, 4.3.2, and 4.7.3.

Diagenesis, chemical modification of deposits: Sects. 4.3.2, 7.6, and 4.7.3; Fig. 7.15.

Diatoms, shelled siliceous plankton – weakly silicified in some species, strongly in other instances.

Diatoms (marine): Sects. 4.4 and 7.4.2; Figs. 4.7 and 7.9.

Diatoms (size and length of food chain): Sect. 7.4.2.

Diatom distribution pattern: Fig.7.4.

Diatom crash, Santa Barbara Basin: Sect. 9.1.7; Fig. 9.8.

Diester-Haass, L., Kiel-trained marine geologist (then at Saarbruecken) discovered the Pleistocene silica paradox (more production, less silica during glacials, off Namibia): Sects. 11.4.4 and 7.4.2.

Dietz, R.S., pioneer, US Navy, San Diego, proposed seafloor spreading: Sect. 1.3.9.

Discussing the future (a task for marine geology in the modern world) Sect. 15.7.

Dissolution of calcareous shells on the seafloor: Sect. 10.3.2; Figs. 10.9 and 10.10.

Dissolution of siliceous fossils: Sects. 10.4.2 (first paragraph) and 10.4.3; Fig. 7.15.

Diversity of marine organisms (benthos far more diverse than plankton): Sect. 8.1; Fig. 4.13.

Diversity (benthic foraminifers, different ways of building a shell): Sect. 8.1.2; Fig. 8.10.

Diversity of calcareous shells (benthic mollusks and other macrofauna): Sect. 8.1.2.

Diversity (link to differences in habitat): Sect. 8.2.

Diversity (link to food supply, may be counterintuitive): Sect. 8.2.1, first and last paragraph.

Diversity of microplankton (Cenozoic changes): Fig. 12.2.

Doell, R.R., pioneer, USGS geologist who worked on magnetic reversals, Sect. 2.3.3.

Dolomite, a product of diagenesis: Sect. 4.7.3.

Douglas, R., geologist, USC Los Angeles, codiscovered stepped cooling: Sect. 1.1.1.

Drake Passage opening: Sect. 12.2.3; Fig. 12.9.

Drilling, deep sea: Sects. 1.1.4, 1.3.5, and 11.5; Figs. 3, 1.6, 1.7, 6.16, 11.10, 12.2, 12.3, 12.5, 12.9, 12.10, 12.11, 12.13, 12.15, 13.4, 13.6, 13.8, 13.9, 13.11, 13.12, and 13.15.

Earthquakes (mantle motion): Sect. 2.4.3; Fig. 2.12. Also see → MOR (shallow quakes).

Earthquakes in continental margins: Sect. 3.5; Fig. 3.14.

Eccentricity, frequency of variation: Sect. 1.1.3, second paragraph; Fig. 11.10.

Echo-sounding records: Sect. 2.3.1; Figs. 2.2, 2.7, 3.6, 3.10, 3.14, 10.6, 10.12 (side scan), 4.6, 5.13, and 5.16.

EEZ (exclusive economic zone): Sect. 14.1.2.

Elevations: Sect. 2.1.1 (first paragraph); Fig. 2.1.

Emiliani, C, (isotope record principle): Fig. 1.5; Sect. 11.4.5.

Emiliani, C. (isotopic stages in the Pleistocene): Figs. 1.4 and 11.10.

Emiliani, C., pioneer paleoceanographer, introduced oxygen isotopes to reading the record of ocean history: Sects. 11.1.1 and 1.1.3; Fig. 1.5.

End of the Mesozoic: Sect. 13.4; Figs. 13.14 and13.15.

Endogenic and exogenic processes: Sect. 2.2; Figs. 1.2, 1.14, and 4.9.

Endogenic forcing (tectonic forcing largely controlled by processes in Earth's mantle): Sect. 2.2.1.

"Engineering Fixes": Sect. 15.5.4.

ENSO (El Niño-Southern Oscillation): Sect. 9.1.6 (Also see → Warm Pool).

Environments at sea (main depth habitat labels): Sect. 8.2.1; Fig. 8.3.

Eocene-Oligocene silica drop: Sect. 10.4.3; Fig. 10.12. Also see "AFS" and "chert."

Epsom salt, magnesium sulfate, is made of the second most abundant metal ion and the second most abundant base (sulfate) in seawater; yet, seawater evaporation is not the foremost source of the salt.

Epstein, S., pioneer Canadian-US isotope geochemist and paleontologist: Sects. 8.2.2; 11.4.5.

Equatorial upwelling (high production and silica deposition): Sects. 7.2.3 and 7.5.3; Fig. 7.11.

Ericson, D.B., twentieth-century Lamont geologist: last use (1960s) of Penck scheme of ice ages by a prominent marine geologist.

Erosion, coastal: Figs. 5.8, 5.9, 5.10, and 5.11.

Erosion (mechanical vs. chemical): Sect. 4.2.1.

Erratics, boulders important in the discovery of ice ages, rare on the global seafloor: Sect. 4.5.1 (last paragraph).

Error discussion (estimating past temperatures): Sect. 9.2.1.

Estuarine and anti-estuarine circulation: Sects. 5.3.5 and 9.5.1; Preface, Fig. 2; Figs. 9.14, and 9.15.

Eukaryotes: organisms with one or more cells with a well-defined nucleus. Appendix A9.1, A9.2, and A9.3. Others are "prokaryotes," i.e., bacteria and archaea.

Euler's theorem: Sect. 1.4.2 (Also see → Bullard and → Morgan).

Eustatic sea-level change: Sect. 6.1.2 (first paragraph).

Evaporites (marine): Sect. 4.8.1.

Events (forced suspension in sediment transport): Sect. 5.1.4.

Evidence for an impact at the K-T boundary: Sect. 13.4.2; Fig. 13.15.

Ewing, M., pioneer US geophysicist: Sects. 1.3.8 and 1.3.3; also see → Lamont (Ewing was the founder).

Exogenic forcing: Forcing of processes on Earth that is ascribed to solar energy (including erosion, but which obviously depends on tectonic uplift as well; i.e., on tectonic forcing): Sect. 2.2.

Facies, type of rock formation, one of any number of types at several levels of classification.

Facies pattern as function of depth of deposition in the sea: Sect. 6.1.1.

Fairbanks, R.G., pioneer Lamont geologist worked on → deglaciation (Fig. 6.5) and Cenozoic evolution.

Fecal pellet transport (→ accelerated settling in the water column): Sects. 10.2.5 and 4.5.4; Figs. 7.6 and 10.7.

Feedback, negative, stabilizing: Sect. 1.1.1. (Also see → Le Chatelier, → Vernadsky.)

Feedback, positive, run-away: Sect. 1.1.1. (Also see → Milankovitch.)

Felspars = certain common Ca−, Na−, and K-silicates (Ca− in basaltic rock; Na− and K− in granitic rocks (e.g., continental crust).

Ferromanganese nodules: Sect. 14.4; Figs. 14.10 and 14.11 (table).

Feynman, R., famous Calif. physicist, erstwhile CalTech and Berkeley: Preface.

Fiddler crab (benthic, California wetland): Fig. 8.6.

Fischer, A., pioneer Alpine geologist (Wisconsin-trained), worked on ancient marine shelf sediments.

Flank sinking, MOR: Fig. 2.6.

Flooded shelves vs. exposed shelves (albedo): Sect. 6.1.2 (second paragraph).

Flysch = Alpine turbidite sequences (local Swiss name): Sect. 3.7.

Food chain (or food web): Sect. 7.4.1.

Food chain: the order of being eaten, top consumer at the top. Also web and pyramid. Since there is much loss from one eating level (→ trophic level) to the next, a long food chain (starting with extremely small organisms) produces less for top consumers than a short one: Sect. 7.4.

Fool's gold: golden-yellow iron sulfide. Can conceivably be confused with real gold.

Foraminiferal ooze, calcareous ooze with planktonic foraminifers: Fig. 10.1; Table 10.1.

Fossil information (biased recording): Sect. 8.2.2 (fourth paragraph).

Fourier analysis (statistics): Sects. 15.6.3 and 15.6.2.

Fracture zones: Sects. 1.4.2 and 2.3.4.

Framework and fill (coral reef): Sect. 9.3.2.

Fusulinids, grain-shaped Paleozoic benthic foraminifers, presumably bore light-processing symbionts.

Future problems: Sect. 15.7.

Gabbro, basaltic dark rock above the → "Moho," made of large crystals: Sect. 2.3.4; Fig. 2.5.

Gaia hypothesis, so named by the British engineer and chemist J. Lovelock, negative feedback: Sect. 1.1.1 (last paragraph).

Galveston Bay: Fig. 6.9.

Garbage in the deep sea: Sect. 15.3.4.

General cooling and productivity: Sect. 7.1.3.

Geochemical climate indicators: Sect. 9.4.1.

Geochemical statistics (element distributions): A7 (table).

Geologic time: not available before the end of the nineteenth century: Sect. 4.9.

Glacial sea level (also see → shelf break): Fig. 6.5 (range of variation during last deglaciation).

Glauconite: greenish iron-bearing silicate mineral, common in certain continental margins: Sect. 4.8.3.

Global conveyor (deep-basin exchange circulation): Sects. 5.3.3 and 9.1.5.

Global warming, methane release (concern, positive feedback): Sect. 1.2.2.

GLOMAR Challenger, first ship employed for scientific drilling, 1968: Sects. 1.1.4; Figs. 1.6 and 12.5.

Graded layers: → turbidites; Sect. 3.7.

Grain size and sediment transport: Sects. 4.5.1 (last paragraph), 5.1.2, A5; Box 4.1; Figs. 5.4 and 14.9.

Great Barrier Reef: Sects. 9.3.4 (specific) and 4.6.2 (general).

Great Man Drowning: Storm flooding A.D.1362, North Sea: Sect. 6.2.1 (fourth paragraph).

Greenhouse effect: Sects. 9.1.1 (last paragraph) and 15.7.

Greenland ice today: Fig. 11.4 (air photo, 10 km up).

Gubbio: Sect. 1.1.5.

Gulf Stream: Sect. 5.3.2; Fig. 5.14.

Guyot = flat-topped seamount (so named by H. Hess, whose office was in Guyot Hall, Princeton University): Sects. 2.6.1 and 2.6.2.

Halite = kitchen salt mineral, NaCl.

Hawaiian island chain: Sect. 2.6.2; Figs. 2.14 and 2.15.

Heat anomaly (ocean): Sect. 5.3.3.

Heat piracy (ocean, N Atlantic): Sects. 5.3.3 and 9.1.6; Fig. 9.7.

Heat transfer, link to → NADW production: Sect. 9.1.5.

Heavy metals on the deep seafloor: Sect. 14.4.

Heavy minerals: A4.3.

Heezen, B.C., pioneer marine geologist (Lamont), morphology of the seafloor, seafloor spreading: Sects. 1.1.1, 1.3.3, 1.3.6, and 1.3.9; Fig. 1.12.

Heinrich events (geologically short-lived cooling events somewhat similar to the Younger Dryas cold spell, seen in deep-sea cores, named after the geologist who is credited with seeing them first and with dating the relevant layers): Sect. 11.6.2.

Heirtzler, J.R., Lamont geophysicist who documented the symmetry of magnetic anomalies across the mid-ocean ridge south of Iceland: Sect. 2.3.3; Fig. 2.4.

Hemipelagic mud ("hemi-"= Greek for "semi-"; "pelagic" = pertaining to the sea well away from land: Sect. 10.6.

Hertogen, J., Belgian physicist (Gent University); proposed a bolide impact for the end of the Mesozoic, offering evidence from exposed marine sediments in Spain.

Hess, H.H., geologist (Princeton) and US Navy officer, discovered numerous flat-topped seamounts in the Pacific (he named them → "guyots"), proposed seafloor spreading in 1960 (unpublished ms), subsequently proposed SFS in a publication (1962): Sect. 1.3.9.

Hessler, R., marine biologist, helped explore hot vents, Woods Hole, and S.I.O.: Sect. 1.2.1; Fig. 1.20.

Hiatus development: Sect. 10.2.4.

Hilgen, F.J., Dutch geologist (Utrecht), extended orbital stratigraphy back into the Miocene: Sect. 11.6.3.

Hjulström diagram: the standard textbook link between transport of particles of different sizes and current speed. Not entirely clear: Sects. 5.1, 5.2, and 5.3; Fig. 5.4.

"Hockey stick" (description of the graph containing an unusual temperature excursion upward near the end of the last century.): Sect. 15.4.1.

Hot spots, island chains, seamounts: Sect. 2.6.

Hot vents: Sect. 1.2.1; Figs. 1.8 and 1.9.

How fast did sea level rise? Illustration of an ice-age data analysis based on oxygen isotope ratios in foraminifer shells: Sects. 6.7 and 15.4.7; Fig. 6.16.

Human time scale vs. geologic time scale: Sects. 15.4.5 and 11.2.2.

Humid and arid deposits in shelf basins: Sects. 9.5.1 and 5.3.5; Figs. 9.14 and 9.15.

Hydrate (methane): Sect. 1.2.2; Fig. 1.11.

Hydrocarbon pollution: Sect. 15.3.5.

Hydrogen sulfide produced in early diagenesis: Sect. 4.3.2.

Hydrogenous sediment, made in in situ, in water or below the seafloor (not including → biogenous): Sects. 4.4 and 4.8; Fig. A4.2; Box 4.1.

Hydrological cycle: Sect. 4.5; Fig. 4.9.

Ice-age fluctuations: Sects. 6.4.2 and 11.4.6; Figs. 6.10, 11.9, 11.10, 11.11, and 11.12.

Ice age – a confusing term used in more than one way: Sect. 11.2.2 – cycles (multiple) and Sect. 11.4.1 (background).

Ice-age carbon cycles: Sect. 11.4.7; Figs. 11.6, 11.7, and 11.8.

Ice-age carbonate productivity cycles: Sects. 11.4.2 and 11.4.3.

Ice-age lessons re-climate change: Sects. 11.2.1, 11.2.2, and 11.2.3.

Ice-age lessons: Lessons other than broad principles are difficult to extract from the geologic record, largely owing to timescale problems. The melting of large ice masses is of considerable interest, however. Crucially important clues to climate-relevant processes can emerge from Pleistocene sea-level studies: Sects. 11.2 and 11.4; Figs. 11.10, 6.16, and 15.4.

Ice-age oceans: upper waters were colder in an ice age, and currents were altered: Sect. 11.1.

Ice-age silica productivity cycles (Walvis Paradox): Sect. 11.4.4.

Ice-ages onset: Sect. 12.3.1; Fig. 12.13.

Ice input (→ IRD, ice-rafted debris) Sect. 4.2.2; Figs. 4.2 and 9.13.

Ice-age studies by deep-ocean drilling: Sect. 11.5.1.

Ice-driven sea-level fluctuations: Only 20,000 years ago, ice forming on land had bound some 200 m worth of seawater; much shelf area was exposed or had but a thin water cover. Even now (during an interglacial time period) there is still about 80 m worth of sea-level rise bound up in ice. Notable sea-level fluctuations have been recorded for the last several million years using oxygen isotopes. Suggested corresponding variations in ice mass: Sect. 6.4; all of Chap. 11.

Iceland low: Sect. 9.1.6.

Igneous rocks: crystalline rocks made inside the Earth: Sect. A6.1.

Imbrie, J., Brown Univ. geologist, pioneer of a system approach to marine geology and to ice-age temperature reconstruction, Preface, Fig. 4, Sect. 9.2.1 (leader, CLIMAP group). Also see Chap. 11.

Impact (end of Cretaceous, Cretaceous-Tertiary boundary): Sects. 1.1.1 (first paragraph) and 13.4; Figs. 13.14 and 13.15.

Imprinting of zonal (temperature) pattern on planktonic foraminifers: Sect. 9.1.3; Figs. 9.3 and 9.5.

Inman, D.L. (1921–2016), S.I.O., marine geologist who discovered beach sand transport cells in Southern California, in the 1950s. Cells commonly end in a → submarine canyon: Figs. 3.16 and 5.1.

Interstitial water, chemical modification of deposits: Sect. 4.3.2.

Intertidal zone: Sect. 6.2.1; Figs. 6.3, 8.6, and 8.7.

IRD (ice-rafted debris), indicator of polar conditions: Sect. 9.4.3; Fig. 9.13.

Iron sulfide: Sect. 4.3.2.

Iron, abundance linked to that of oxygen: Sect. 4.8.3.

Island chain: a label applied to islands in a row. Within the central ocean islands are of volcanic origin, without exception. The iconic example in the Pacific is Hawaii: Sects. 2.6.1 and 2.6.2; Figs. 2.14 and 2.15.

Island chains, seamounts, hot spots: Sect. 2.6.

Isostasy (vertical motion of crust from loading or unloading): Sect. 3.4.

Jannasch, H., Woods Hole biologist, studied hot vent organisms and related forms: Sect. 1.2.1.

Japan Trench: trench system off Japan, parts of which serve to illustrate important processes related to subduction (volcanism, earthquakes, mélange formation, submarine landslides, tectonic erosion, décollement, expulsion of fluids, and others): Sect. 3.3.

Jenkyns, H.C., British geologist, Oxford, studied "ocean anaerobic events:" Sect. 13.2.3; Fig. 13.8.

JOIDES Resolution: Sect. 1.1.4; Fig. 1.6.

Karig, D.E., Prof. em. Cornell, erstwhile grad student at S.I.O., UCSD, discovered → back-arc spreading.

Kastner, M., Israeli-US geochemist and general marine geologist, UCSD, studied reactions at hot vents, changing productivity of the oceans, methane formation, and other fundamental processes recorded on the seafloor: Sects. 1.2.1 and 1.2.2; Figs. 1.8 and 1.10.

Keller, G., Swiss-US marine geologist, Princeton, codiscovered the mid-Miocene → silica switch in deep-sea sediments. Also, she questions the end-of-Cretaceous → impact scenario as the final word on the matter of ending the Mesozoic.

Kennett, J.P., pioneer of Cenozoic ocean history, N-Z trained (Wellington), Prof. em. UCSB, studied Cenozoic cooling, deglaciation, methane, and the role of impact in the origin of the → Younger Dryas: Sects. 1.1.1 and 12.1.3.

Klenova, M.B.: Russian pioneer marine geologist, wrote one of the earliest textbooks in the field of marine geology (1948), documenting abundant Russian contributions: Sect. 1.3.6.

Köppen, W., German pioneer climatologist born in St. Petersburg, used vegetation to classify climate types. Earliest supporter of Milankovitch Theory.

K-T event (bolide impact, massive extinctions): Sect. 1.1.5.

K-T event (end of Mesozoic): Sect. 13.4.

K-T event boundary Denmark (Stevn's Clint): Fig. 13.14.

K-T event boundary Gubbio: a section described by H. Luterbacher and I. Premoli-Silva, (marine pelagic record) and subsequently analyzed by → L. Alvarez and associates.

Kuenen, Ph.H., pioneer marine geologist, studied → turbidites: Sects. 1.3.3 and 3.7.

Kullenberg, B., Swedish oceanographer on the *Albatross* Expedition invented the piston corer: Sect. 11.1.1.

Lagoon: Sects. 6.3.3 and 3.1.1; Figs. 3.2, 3.4, and 6.8.

Lamont Geological Observatory; later Lamont-Doherty Earth Observatory: Marine geological institute that played a major role in the evolution of plate tectonics. Founded 1949 by the US geophysicist Maurice → Ewing, erstwhile professor at Columbia University in New York. Many marine geologists refer to the institute as "Lamont."

Lancelot, Y. (1938–2016), French marine geologist, studied deep-sea corollaries of plate tectonics, anoxic deep-sea sedimentation, and other fundamental issues of deep-sea geology: Sect. 12.4.1; Fig. 13.6.

Laplace, P.-S., famous French mathematician and astronomer: Sect. 1.1.3.

Larson, R., Scripps-trained marine geophysicist, URI, discovered various parallelisms in endogenic processes, sedimentation, and environment: Fig. 13.11.

Last Glacial Maximum (LGM): Sect. 11.3; Fig. 11.3.

Le Chatelier, H.L., French chemist and engineer, gave his name to negative feedback in chemistry, asserting that reactions minimize any change: Sect. 1.1.1.

Lebensspuren (trace fossils): Fig. 8.14.

Leitmotif of the Cenozoic (cooling): Sect. 12.1.

Le Pichon, X., French marine geophycisist who determined plate sizes and motions, chiefly at Lamont (Columbia University, New York).

Levin, L., S.I.O.-trained biogeochemist, studies the biology and chemistry of cold seeps and of the dysaerobic and anaerobic seafloor: Sects.1.2.1 and 1.2.2.

Limiting nutrients (phosphate, nitrate, silicate, iron, and various other compounds and trace elements): nutrients whose abundance is sufficiently restricted to limit growth: Sect. 7.1.1.

Lister, C.R.B., marine geophysicist, (U. Washington), early proposed hydrothermal processes at spreading centers: Sect. 1.2.1; Fig. 1.9.

Lithogenous sediment, continent-derived or volcanogenic particles: Sects. 4.4 and 4.5; Figs. 4.8, 4.9, and 4.10.

Living on the seafloor: requirements differ for mobile and sessile organisms and for those that live exposed to the environment or that make burrows in sediments or in rocks: Sects. 8.2 and 8.3.

Lonsdale, P., marine geologist, studied morphology of deep seafloor, using deep-towed, side-ways looking echo-sounding equipment designed by physicist and engineer Fred N. Spiess (erstwhile short-term multiple director of S.I.O.): Sect. 1.2.1; Fig. 5.16.

Lovelock, J., British environmental chemist, creator of "Gaia hypothesis" and "daisy world;" see → feedback, negative.

Lugworm (benthic, wadden): Sect. 8.3.2; Fig. 8.7.

Luterbacher, H., German-Swiss geologist (paleontology), co-described (with Isabella Premoli-Silva) in some detail the pelagic K-T section near Gubbio, Italy: Sects. 1.1.1 and 1.1.5; Fig. 13.15.

Lyell, C., uniformitarianism: Sect. 1.1.1 (third paragraph).

Lysocline (differential dissolution, selective preservation): Sects. 10.3.2 and 10.3.3; Fig. 10.10.

Magma chambers (MOR): Sect. 2.3.4; Fig.2.6.

Magnesium, abundant ionic metal in seawater, homologous to calcium: Sect. 4.1.2.

Magnetic anomalies: widely greeted as proof of seafloor spreading; notably the symmetry of anomalies across certain spreading ridges. The ultimate cause of the pattern of magnetic anomalies on the seafloor are reversals of the Earth's magnetic field: Sect. 2.3.3; Figs. A3.2, 13.11, and 2.4.

Magnetic reversal scale, Neogene: Sect. A3; Figs. A3.2, 7.14 (back to Gilbert, side bar), 2.4 (J.R.Heirtzler).

Mammoth extinction during deglaciation (along with many other large mammals): Sect. 11.6.2.

Manganese deposits (composition, origin): Sect. 14.4; Figs. 14.10, 14.11, and 14.12.

Mangrove thicket, brush and forest at the beach: Fig. 3.4; Sects. 3.1.2 and 6.3.4.

Mantle of Earth: Sects. 1.1.2 and 2.5.2; Fig. 1.1.

Margin (continental): Sects. 3.1.1 and 3.2; Figs. 3.1, 3.2, and 3.5.

Margins (organic matter): Sect. 3.1.3.

Margins (origin of passive margins): Sect. 3.2; Figs. 3.5, 3.6, and 3.8.

Marine organisms: A9.

Marine record of short-term climate change: Sect. 15.6.

Martin, J., erstwhile Calif. ocean chemist, proposed a strong role for iron in diatom growth: Sect. 10.4.2 (fourth paragraph).

Mass extinction (at → K-T boundary): Sect. 13.4.

Matuyama Diatom Maximum (ODP Leg 175): Sect. 7.5.5 (fourth paragraph); Fig. 7.14.

Mediterranean drying out (end of Miocene): Sect. 12.2.5.

Mediterranean sapropels (recovered by drilling): Sect. 11.6.3.

Mélange (mixture; applied to landslide rock mixtures in active margins): Sect. 3.3; Figs. 1.2, 3.9, and 3.10.

Mesozoic fossils and rocks: Figs. 13.1, 13.3, 13.4, 13.6, 13.12, 13.13, 13.14, and A6.8.

Mesozoic seafloor abundance: Sect. 13.1.3.

Meteor Expedition (1925–1927): Sects. 1.3.4 and 5.3.4; Figs. 2.2 and 5.15.

Methane clathrates, methane-bearing ice-like substance: Figs. 4.5, 12.16, and 11.2.2.

Methane ice and deglaciation (also see → permafrost): Sect. 11.6.2 (third paragraph).

Methane ice in the Cenozoic: Sect. 12.5; Fig. 12.16.

Methane offshore: Sect. 14.2.6.

Methane runaway feedback potential: Sect. 15.7.

Methane, produced in early diagenesis and by fermentation: Sects. 4.3.2 and 8.6.

Methane (burning ice): Sects. 1.2.2 and 11.2.2; Fig. 1.10.

Michel, H., was on the Alvarez team, involved in the K-T revolution: Sect. 1.1.1.

Micrite = lime mud and silt, commonly made in carbonate reefs and platforms.

Microbes (archaea and bacteria) deep below seafloor: Fig. 1.11.

Microfossils (eukaryotic microbes): A9.2.

Mid-ocean ridge morphology: Sect. 2.3.

Mid-Pleistocene climate shift: Sect. 11.5.2; Fig. 11.10.

Milankovitch theory (principles): Sects. 1.1.3 and 11.1.3; Fig. 11.2.

Milankovitch theory of the ice ages: support from deep-sea sediments: Sects. 11.1.2; Fig. 1.4.

Milankovitch, M., Serbian civil engineer, pioneer ice-age student, orbital theory: Sects. 1.1.1 and 11.1.2.

Milankovitch cycles in the Cretaceous: Sect. 13.2.6; Fig. 13.12.

Miller, K.G., pioneer marine geologist, Rutgers U., plotted isotopic core data from the Atlantic for an early view of Cenozoic cooling and ice buildup: Preface, Fig. 3; Fig. 12.3.

Minamata disease: Sect. 15.3.7.

Minerals, silicates: A4.1 and nonsilicates A.4.2.

Minette ores, oolitic iron (hydr)oxide pellets, abundant in certain Jurassic shelf deposits but apparently not forming at present: Sect. 4.8.3.

Mining the seafloor: Sect. 14.1.1.

Mixing intensity and upwelling, bringing nutrients: Sect. 7.2.4 (last two paragraphs).

Mljet Island (varved sediments): Sect. 15.6.1; Fig. 15.6.

"Moho," Mohorovičić discontinuity, referring to a sudden change in speed of sound within the Earth. The sound speed is relatively low in the crust and high in the mantle, the boundary being near 10 km below the deep-ocean floor (and deeper below the continents): Sect. 2.3.4; Fig. 2.5.

Mollusk diversity (large species): Sect. 8.1.1; Fig. 8.1.

Mollusk diversity (snails, benthic vs. pelagic): Sect. 8.1.2, Fig. 8.2.

Monterey Canyon: extremely large Grand Canyon size → submarine canyon: Fig. 3.16.

Monterey climate event (Monterey C isotope shift; also "silica switch"): Figs. 12.10, 12.11, and 12.12.

MOR (mid-ocean ridge): Sect. 1.3.9; Figs. 1.12, 2.2, 2.3, 2.4, 2.5, and 2.6.

Moraines (and other inherited shelf sediments): Sect. 3.4.

Morgan, W.J., pioneer geophysicist, Princeton U., contributor to plate tectonics: Sects. 1.4.2 and 2.6.2.

Morphology, deep seafloor, MOR to abyssal plain: Sect. 2.3.6; Fig. 2.7.

Mountain making: → subduction.

Mountain, G.S., Rutgers Univ., marine geologist, codiscovered general Cenozoic cooling: Preface, Fig. 3.

Mud volcanoes, holes in the seafloor, presumably made from strong gas sources: Sect. 4.3.2; Fig. 4.6.

Mud, hemipelagic ("continental slope" sediments, mainly): Sect. 10.6.

Murray, W., Scotsman, naturalist on R/V *Challenger* (1872–1876), discovered the chief patterns of sediment distribution on the deep seafloor: Sects. 1.3.2 and 10.1.

Natland, M.L., pioneer geologist, Los Angeles, proposed Pliocene turbidites in Ventura Basin: Sect. 1.3.3.

Namibia upwelling (ODP Leg 175): Sect. 7.5.5, Fig. 7.13.

Nannofossils, geologic label for → coccoliths and → coccolithophores.

Neogene time scale: Fig. 5.

Neogene-type seasonal productivity effects (guess): Sect. 15.5.3.

New York margin: Fig. 3.2.

Nonsilicate minerals: A4.2.

Non-skeletal carbonate: calcareous deposit with no recognizable biological structure: Sect. 4.7.

North Sea oil (occurrence): Sect. 14.2.5; Fig. 14.5.

North-Atlantic Deepwater production (NADW production): Sect. 9.1.5.

Nutrients and waste: Sects. 15.3.1 and 15.3.2; Fig. 15.1.

Obliquity, tilt of Earth axis, frequency of variation: Sect. 1.1.3.

Oceanic anoxic events (OAEs): Sects. 13.2.3 and 13.2.4; Figs. 13.8 and 13.9.

Oil production from the seafloor (ballpark estimates): Sect. 14.2.1.

Olausson diagram, deep-sea sediments, example tropical eastern Pacific: Fig. 10.4.

Onset of the ice ages: Sect. 12.3.

Ontong Java Plateau (Cretaceous sequence, link to volcanism): Sect. 13.2.5; Fig. 13.11.

Oolites, Bahamas, precipitation aided by microbes: Sect. 4.7.2; Fig. 4.15.

Ooze → biogenous sediment made of microscopic shells, commonly seen on and below the deep seafloor: Fig. 4.7.

Ophiolite ("snake rock"): Sects. 2.4.4 and 3.3 (third paragraph); Figs. 2.12 and A6.11.

Orbital ice-age revolution: Sect. 1.1.1.

Organic matter distribution pattern: Fig. 7.4.

Organisms, marine (dominant forms, high-level taxonomy, common-language terms): A9.3.

Organisms associated with coral reefs, Fig. 9.11.

Oscillations (and anomalies): Sect. 9.1.6.

Overwash fan: Fig. 6.8.

Oxygen and carbon isotopes (as climate indicators): Sect. 9.4.2.

Oxygen deficiency (various localities): Sect. 8.2.3.

Oxygen isotope cycles (Urey, Emiliani): Sect. 11.4.5.

Oxygen loss from sediment (early diagenesis): Sect. 7.6; Fig. 7.15.

Oxygen minimum: Sect. 7.3.1.

Oxygen reconstruction in the environment: Sect. 8.2.3; Fig. 8.5.

Oxygen supply vs. marine production in the Cretaceous: Sect. 13.2.1.

Oxygen utilization (AOU): 10.2.5.

Pacific-type (active) margin: mountain-building, factory of continental crust: Sect. 3.3; Fig. 3.2.

Paleoceanography and piston coring: Sect. 11.1.1; Fig. 11.1.

Paleogene ocean environments (guesses): Sect. 12.2.1.

Paleomagnetism on the seafloor: Sect. 2.3.3; Figs. 2.4, 7.14, 13.11, and A3.2.

Paleotemperature and climate zonation: the reconstruction of temperature patterns is fraught with difficulties stemming from partial preservation, from continuing adaptation, and from the applicability of greatly differing time scales depending on record resolution, among other problems: Sect. 9.2.

Panama Paradox: Sect. 12.3.2 (also see → onset).

Parker, F.L., pioneer paleontologist and interpreter of foraminiferal distributions: Figs. 8.5 and A9.2.

Partial preservation of the record and bioturbation: Sect. 8.5.

Passive margin: sinking edge of continent: Sect. 3.2.

Pause (in temperature rise): Sect. 15.4.2.

Pebble beaches: Sect. 5.2.1 (fourth paragraph).

Penck, A., pioneer Alpine ice-age expert, proposed multiple ice ages (4 or 5): Sect. 11.4.1 (third paragraph).

Peridotite, black pyroxene-rich rock of the upper mantle: Sect. 2.3.4 (last paragraph).

Permafrost (on land and in shallow water, in high latitudes) shrinks during deglaciation: Sect. 11.6.2.

Persian Gulf: shelf basin in the arid realm, effects on incoming plankton: Sect. 9.5.3; Fig. 9.17.

Peterson, M.N.A., S.I.O. geochemist in charge of the first deep-sea drilling program: Sect. 10.3.2.

PETM (Paleocene-Eocene Temperature Maximum): Sect. 12.5; Fig. 12.17.

Petroleum (origin and Gulf of Mexico): Sects. 14.2.4 and 14.2.5; Figs. 14.2 and 14.4.

Petroleum (off Southern California): Sect. 3.1.3; Fig. 14.1.

Pettersson, H., Swedish marine geophysicist, led the *Albatross* Expedition: Sect. 1.3.4.

Phanerozoic time scale: Fig. A3.1.

Phosphorites (upwelling, resource): Sect. 14.3.1; Fig. 14.7.

Photosynthesis as sea-level indicator: Sect. 6.2.2.

Phylum, phyla (high-level grouping of orgs., e.g., mollusks, arthropods): Sects. A9.1 and A9.3.

Pillow basalt, lava frozen in water in the shape of pillows: Sect. 2.3.4.

Pioneers of marine geology: Sect. 1.3.

Pioneers of paleoceanography: Sect. 11.1.1.

Piston coring (Kullenberg machine and subsequent modifications): Sect. 11.1.1; Figs. 11.1.

Pitman, W., Lamont geophysicist, proposed flooded shelves from increased seafloor spreading.

Pitman hypothesis (seafloor heat content determines depth of shelf): Sect. 6.5.2.

Placer deposits (beach, resource): Sect. 14.3.3; Figs. 14.8 and 14.9.

Plagioclase, Ca felspar, mineral common in → tholeiite: Sect. 2.4.4.

Plankton fossils: → coccoliths, → planktonic foraminifers, → diatoms, → radiolarians. Also Sect. 4.6.3.

Planktonic foraminifers (temperature reconstruction): Sect. 9.2.1.

Planktonic foraminifers, important part of calcareous → ooze, besides → coccoliths: Fig. 4.7.

Plate stratigraphy and CCD fluctuations: Sect. 12.4.

Plate tectonics revolution: Sect. 1.1.1.

Plate tectonics, forcing: Sect. 1.1.2.

Plate tectonics (pioneers): Sect. 1.3.8.

Plate tectonics (summary): Sects.1.4.1, 2.5.1, 2.5.2, and 2.6; Figs.1.2, 2.3, 2.11, and 2.13.

Plate tectonics (open questions): Sect. 2.6.3.

Plate tectonics (seismology): Fig. 2.11.

Pock marks, gas-spewing holes in the seafloor: Sect. 4.3.2 (last paragraph); Fig. 4.6.

Pollution of the seafloor: Sect. 15.3.

Postglacial sea-level rise and coastal morphology: Sect. 6.3; Figs. 6.5 and 6.6.

Premoli-Silva, I., Italian geologist, co-described (with Hans → Luterbacher) the Gubbio K-T transition.

Preservation effects (planktonic foraminifers}: Sect. 9.2.1; Fig. 10.10.

Problems ahead: Sect. 15.1.

Production patterns in the sea: Sect. 7.2.

Productivity and temperature: Sect. 9.1.3; Fig. 9.4.

Productivity and thermocline: Sect. 7.3.2.

Productivity controlling factors: wind stirring and nutrient abundance: Sect. 7.1.3.

Productivity indicators: Sect. 7.2.3; Fig. 7.4.

Productivity of the ocean: a misnomer; what is meant is *production.* It is controlled by nutrients and amount of sunlight. An alternation of mixing and stratification favors production. Thus, the structure of the water column and circulation are important, as well as seasonal change between stirring the uppermost waters and stable stratification.

Productivity, blue-green dichotomy: Sect. 7.2.2.

Prokaryotes: Sects. A9.1 (third paragraph) and A9.2.

Prokaryotic microbes deep below the seafloor: Sect. 8.6.

Protective structures (coastal): Sect. 5.2.2; Fig. 5.10.

Pteropod ooze, small pelagic snails, aragonitic, shallow parts of the seafloor, easily dissolved: Fig. 10.1.

Pumice, vuggy volcanic rock (gas-filled floats): Sect. 4.2.4 (second paragraph).

Radiation balance: Sect. 9.1.1; Fig. 9.1.

Radiocarbon and bioturbation: Sect. 8.5.2; Fig. 8.16.

Radioisotopes and age assignment: A8.

Radiolarians, geologically the oldest of planktonic microfossils: Sect. 4.4; Fig. 4.7.

Radiolarian (siliceous) distribution pattern (esp. equatorial upwelling): Fig. 7.4.

Rapid burrowing: Sect. 8.3.5 (second paragraph).

Rate of sea-level rise (evidence from ice-age data): Sects. 6.7, 15.4.6, 15.4.7, and 15.7; Figs. 6.16, 11.9, and 15.4.

Rates of sedimentation: indicator of global erosion rates. The range of rates of deposition (more than a factor of ten) reflects intensity (decreases with distance from continent): Sects. 4.2.1 and 4.9; Fig. 4.16.

Raw material, solids from shelves: Sect. 14.3.

Reconstruction of ancient sea-level fluctuations from physical and biological indicators: Sect. 6.5.

Reconstruction of the tertiary: Sect. 12.2.

"Red Clay" and "clay minerals": Sect. 10.5.

"Red Clay" vs. off-margin mud: Sect. 10.2.1; Fig. 10.3.

Red Sea (ore-bearing mud): Sect. 14.4.4 (rifting, NASA satellite photo): Fig. 3.5.

Redox reactions during early diagenesis: Sect. 4.3.2 (second paragraph).

Reef structure (Mg, chert): Sects. 4.6.2 (reef talus and reservoir rock) and 8.3.4 (last paragraph).

Regression (retreat of sea from shelf): Sect. 6.1.2.

Relict sediments, legacy sediments, offer clues to past environments: Sect. 5.1.3 (last paragraph).

Renard, A.F., Belgian naturalist, authored (with John → Murray) the *Challenger* Report on geology.

Residence time: Sect. 4.3.3.

Resource, shallow vs. deep (shallow is cheaper to obtain): Sect. 14.1.1 (fourth paragraph).

Resources from the ocean floor: Sect. 14.1 (introduction to resource chapter).

Revelle, R.R. (The *"Great Experiment"*): Sect. 15.4.1.

Revelle, R.R., Californian geologist and oceanographer, flagged differences in the carbon systems of Pacific and Atlantic (Sect. 10.2.3). Chiefly known as a pioneer of early warnings concerning input into atmosphere and ocean of excess carbon dioxide after the Industrial Revolution. Erstwhile Director of S.I.O.; i.e., Vice Chancellor for Marine Sciences at UCSD.

Revolutions in geobiology and geochemistry: Sect. 1.2.

Revolutions in geology of the twentieth century: Sect. 1.1; also see Chap. 2 for plate tectonics.

Ring of Fire morphology: Sects. 2.4 and 3.3; Figs. 1.3, 2.9, 2.10, and 2.11.

Rip rap, → protective rubble (against wave attack): Sect. 5.2.2 (last paragraph), Fig. 5.10.

Ripple marks: Figs. 5.2, 5.3, and 5.11.

Risk assessment (and human impacts on the seafloor): Sect. 15.3.7.

Risk assessment (and oil spillage): Sect. 14.2.3 (second paragraph).

River input (sediment cycle): Sect. 4.2.1.

Rocky seafloor as habitat: Sect. 8.3.4.

Salinity and temperature reconstruction: Sect. 8.2.2; Fig. 8.4.

Salt age of the ocean: → residence time.

Salt deposits (rift deposits): Fig. 3.7.

Sand and pebbles (beach, resource): Sect. 14.3.4.

Sand, a familiar term, strictly denoting grain size in marine geology: Sect. 4.4.2; Fig. 4.8.

Santa Barbara Basin (varves): Sects. 15.6.2; 15.6.3.

Satellite remote sensing by camera from space is heavily focused on everything that is visible from space, including ocean production. The processes seen belong to a short-term time scale.

Savin, S., pioneer geochemist, Ohio, codiscovered stepwise Cenozoic cooling: Sect. 1.1.1; Fig. 1.7.

Schlager, W., Austrian-Dutch geologist, made important contributions to carbonate platform knowledge.

Schlanger, S.O., pioneer geologist, expert on Pacific islands, codiscovered (with H. → Jenkyns) evidence for anaerobic conditions in the Cretaceous Pacific.

Schott, W., German geologist on the original *Meteor* Expedition: Sects. 1.3.4, 9.2.1, and 10.1.

Seafloor exploration, deep-sea history: Sect. 1.3.4; Fig. 10.1.

Sea level in geology, rise and fall define sustained "transgression" and "regression," which provide the calendar of geologic history: Sect. 6.1; Fig. 6.1.

Sea level and coastal morphology: Sect. 6.3.

Sea level and reef growth: Sect. 6.4.3.

Sea level and the fate of Venice: Sect. 6.6.

Sea-level fluctuations, ice driven: Only 20,000 years ago, ice forming on land had bound some 200 m worth of water from the sea. Even now there is still some 80 m worth of sea-level rise bound up in ice.

Notable fluctuations have been recorded for several million years: Sect. 6.4.

Sea-level indicators: Tidal wetlands occur where the land runs (gently) into the sea: Sect. 6.2.

Sea-level reconstruction, lacking ice: proceeds from physical and biological indicators. The result may have large uncertainties measured in tens of meters: Sect. 6.5.

Sea-level rise (asymmetric ice, Neogene type): Fig. 15.5.

Sea-level rise (ice-age data from the seafloor): Sect. 15.4.7; Figs. 6.15 and 15.4. Also see Sects. 15.4.6 and 15.7; Fig. 15.3.

Sea-level fall in the Cenozoic, albedo change, and other corollaries of cooling: Sect. 12.2.2.

Sea-level rise, postglacial: Fig. 6.5.

Sea level, how fast did it rise? Illustration of a sediment analysis based on oxygen isotope ratios in foraminifer shells from the late Pleistocene: Sects. 6.7 and 15.4.7; Fig. 6.15.

Seafloor as habitat: requirements differ for mobile and sessile organisms, and for those that live exposed to the environment or that make burrows in sediments or in rocks: Sects. 8.2 and 8.3.

Seafloor as waste receptacle: Sect. 15.3.

Seafloor spreading: Sects. 1.3.9 (second paragraph), 1.4, 2.3, and 3.2; Fig. 1.2.

Seamounts, island chains, and hot spots: Sect. 2.6.

Seasonal flux, trapping: Sects. 7.2.4 and 10.2.5; Figs. 7.6 and 10.7.

Seawater chemistry and sediment: reactions of rocks and deposits with seawater: Sect. 4.3.

Sediment cycle: pathways of sediments, some recycled: Sect. 4.1; Fig. 3.1.

Sediment sources: (erosion, weathering vs. production, productivity): Sect. 4.2.

Sediment thickness distribution and offshore oil: Fig. 14.6; Sect. 14.2.5.

Sediment transport and grain size: Sect. 5.1.2; Fig. 5.4.

Sediment transport offshore, Southern California: Fig. 5.1.

Sediment transport, shallow water, ripples, and subsea dunes: Fig. 5.2.

Sediment types (on the seafloor): Sect. 4.4; Box 4.1.

Sediment wedges (continental margins): Sect. 3.1.3, Figs. 3.6.

Sedimentary rocks: A6.2.

Sedimentation (and erosion) rates: Sect. 4.2.1 and 4.9; Fig. 4.16.

Sediments and seawater chemistry: reactions of rocks and deposits with seawater: Sect. 4.3.

Sediments, hydrogenous: produced by mineral precipitation: Sect. 4.8.

Sediments, lithogenous: (rock produced, from erosion): Sect. 4.5.

Seibold, E., pioneer of marine geology, Kiel and Freiburg, senior coauthor of the present book: Preface, Fig. 1, post-Preface essay (obituary).

Seismic profiling: Figs. 3.6, 3.7, 3.10, 3.14, 3.18, 6.11, 10.6, 10.12, 13.6, 14.4, and 14.5.

Sensitivity (variability of conditions, ease of forcing): Sects. 9.1.4 and 9.1.5.

Sensitivity of climate system and safe levels of carbon dioxide: Sect. 15.5.2.

Settling a matter of particle size: Sect. 5.3. (Also see → accelerated sinking.)

Sewage and sludge: Sect. 15.3.3.

Shackleton, N.J., British geophysicist and pioneer isotope geochemist (Cambridge), applied Milankovitch Theory to the ice ages and extended Milankovitch dating deep into the Cenozoic, using oxygen isotope stratigraphy: Sect. 1.1; Fig. 6.10.

Shear (downhill soil creep): Sect. 8.4.2 (second paragraph), Fig. 10.8.

Shelf (approximate area in percent of seafloor): Sect. 3.1.1 (third paragraph). (Continental shelf): Sect. 3.4; Figs. 3.1, 3.10, 3.11, 3.12, and 3.13.

Shelf currents: Sect. 5.3.1.

Shelf sediments as zonal climate indicators (distribution): Sect. 9.4.3; Fig. 9.12.

Shelves and shelf break: continent covered by the sea and edge: Sect. 3.4.

Shepard, F.P., pioneer marine geologist, S.I.O., focused attention on marine sedimentation off California and on submarine canyons worldwide: Sects. 1.3.3 and 1.3.6.

Shoemaker, E., pioneer NASA geologist, contributions to understanding impact events: Sect. 1.1.5.

Short-term climate change in the marine record: Sect. 15.6.

Side-scan echo sounding: Figs. 4.6, 5.12, 5.13, and 5.16; Sect. 3.8 (second paragraph).

Silica loss from sediment (early diagenesis): Sect. 7.6; Fig. 7.15.

Silica Paradox see → Diester-Haass.

Silica Switch: a major event in the Middle Miocene involving basin-basin exchange and the silica cycle. Discovered by the geologists G. Keller of Princeton and J. Barron of the USGS. (See Monterey.)

Silicate minerals: A4.1.

Siliceous ooze and mud: Sects. 4.4, 10.4; Figs. 4.7 and 10.11.

Silt (beyond the shelf break): Fig. 4.11.

Sink, technical term in geochemistry, process that balances “source:” Sect. 4.3.3.

Sinking of MOR (mid-ocean ridge) flanks: Sect. 2.3.5; Fig. 2.7.

Siphon (clams), adaptation (obtaining oxygen and food while hiding): Sect. 8.3.2; Fig. 8.7.

Size classification, sediments: A5.

Slope → continental slope.

Slump: incoherent landslide, also see → submarine landslides.

Smit, J., geologist and paleontologist (Amsterdam), made fundamental contributions to K-T knowledge.

Soft bottom (mud, sand) as habitat: Sect. 8.3.5.

Solar cycles (in the marine record): Sects. 15.6.4 and 15.6.5.

Solid raw material from shelves: Sect. 14.3.

Southern California Borderland: Sect. 3.5; Fig. 3.13.

Spiess, F.N., pioneer oceanographer, geophysicist and engineer (S.I.O.), made important contributions to identifying the location of hot vents: Sect. 1.2.1.

Stability field (T & P, methane hydrate): Fig. 4.5.

Stacking (combining of data points, commonly averaging them, limiting resolution): Sect. 8.5.3.

Stepwise Cenozoic cooling (revolution): Sects. 1.1.1 and 12.2; Fig. 1.7.

Storm damage (coastal): Sect. 5.2.2.

Stott, L., marine geologist (USC, Los Angeles) codiscovered (with Jim → Kennett) the Paleocene-Eocene temperature maximum event (PETM): Sect. 12.5 (fourth paragraph).

Strakhov, N.M., Russian pioneer geologist, studied (with A.D. Arkhangel'sky) the geological history of the Black Sea: Sect. 1.3.6 (first paragraph).

Stratigraphy, nannofossils: Sect. 12.2.1; Fig. 12.6.

Stromatolites, organic structures, commonly finely laminated mounds, football size. Among oldest marine fossils, the presence indicates shallow water cover. Sect. 6.2.2; Fig. 6.4 (Precambrian).

Strontium isotopes. Fig. 12.4; Sect. 12.1.4.

Subcrustal erosion (collision margin): Sect. 3.5 (fifth paragraph).

Subduction: Fig. 1.2, Sect. 3.3.

Submarine canyons: Sects. 3.6 and 5.2.1; Figs. 3.16 and 3.17.

Submarine dunes (giant): Sect. 5.3.4; Fig. 5.16.

Submarine landslides: Sect. 3.5; sixth paragraph and following; Figs. 3.14 and 3.15.

Suess, E., pioneer German-US American geochemist (Kiel and Oregon), studied export of organic matter from the sea surface by trapping, and methane release from the seafloor: Figs. 7.6 and 4.5.

Suess, H., solar chemist (S.I.O.). A 205-y solar cycle has his name: Sect. 15.6.3.

Suspension feeders (common at continental margin): Figs. 8.11 and 8.12.

Suspension load, settling velocity: Fig. 5.5.

Swedish Deep-Sea Expedition (*Albatross*): Sect. 1.3.4.

Symbiosis in benthic foraminifers: Fig. 8.10.

System concept: Preface, Fig. 4.

Taira, A., marine geophysicist, Japan, plate collision studies: Fig. 3.10.

Tektites, glassy objects, usually sand size, commonly classified as objects from space. Occasionally abundant: Sect. 4.9 (penultimate and last paragraphs).

Tectonic erosion, removal of material of a growing active margin: Sect. 3.3 (fourth paragraph), Fig. 3.10.

Temperature and productivity: Sect. 9.1.3; Fig. 9.4.

Temperature and salinity reconstruction: Sect. 8.2.2; Figs. 8.4 and 9.14.

Temperature history reconstruction: Sect. 9.2.1; Fig. 8.4.

Tempestites, storm-produced layers on the seafloor: Sect. 5.1.4 (second paragraph).

Tephra aprons (volcanogenic eruption deposits): Sect. 4.2.4; Fig. 4.4.

Terminations (geologically fast, major melting seen in the ice-age record): Fig. 11.11.

Terraces (California): Sect. 3.4.

"Terrigenous" = from continents: Sects. 2.2.2, esp. second paragraph, 4.1.1, and 4.1.2. Also see Sect. 4.2.

Tethys, an ancient tropical seaway: Sect. 4.6.2, second paragraph, Figs. 12.8 and 13.5.

Tethys closing toward end of Eocene: Sects. 12.2.3 and 12.2.5.

Tetrapods = certain protective structures against breaking waves: Sect. 5.2.2; Fig. 5.10.

Tharp, M., Lamont geomorphologist who worked with Bruce → Heezen to prepare the famous "physiographic map" of the seafloor: Sects. 1.3.6 and 1.3.9 (second paragraph); Fig. 1.12.

Thera eruption (Santorini volcano) in the Aegean Sea may have ended the Minoan culture about 3600 y ago: Fig. 4.4.

Thermocline: the transition layer between shallow (light) water and deep (heavy) water. In the modern ocean, the transition is between warm and cold water and commonly comprises several hundred m of water below 100 m of depth: Sect. 7.3; Fig. 7.8. The thermocline contains the oxygen minimum.

Thickness of deep-sea sediments: Sect. 10.2.4.

Thierstein, H.R., Swiss marine geologist and nannofossil expert, prof. em.ETH, Zurich, erstwhile prof. at S.I.O.: Figs. 1.7 and 12.2.

Tholeiite, type of basaltic rock, common on the mid-ocean ridge: Sect. 2.4.4.

Tidal flats: Sect. 6.2.1; Fig. 5.11 (wadden, North Sea).

Tides, large waves produced by gravitational interaction of moon and sun with a rotating Earth and its complicated morphology: Sect. 5.2.3.

Time scale: there are (at least) three: a human-relevant scale (decades to a few centuries: varves etc., Sect. 15.4.2), the ice-age scale (millennia, Chap. 11), and the geological scale (millions of years, Sects. 12.1.4, 8.1.1, and A3; Fig. 12.4).

Toba volcanism: perhaps the largest witnessed by humans, eruption 73,500 years ago: Sect. 4.2.4.

Topographic statistics, Earth and ocean: A2.

Trace fossils, trails and burrows, bioturbation: Sects. 8.4, 8.5. (Also see → lebensspuren).

Tragedy of the Commons hypothesis (G. Hardin): Sect. 14.1.1.

Transform fault: Sect. 2.5.1

Transgression: Sect. 6.1.2.

Trask, P.D., editor of a famous book with classic articles in early marine geology: Sect. 1.3.1.

Trenches: Sects. 2.4.1., 2.4.2, and 3.3; Figs. 1.2 (lower panel), 2.9, and 2.10.

Trophic level: habitat level in the → food chain.

Tsunami: a wave or a series of waves generated in the deep sea (e.g., by an earthquake), traveling at very high speed and growing to great size upon hitting the shelf: Sect. 3.4.

Turbidity currents, turbidites: muddy flows traveling downslope and deposits of same. Sects. 1.3.3, 3.5, 3.6, 3.7, and 3.8; Figs. 3.16 and 3.18. Also see → Kuenen, → submarine canyons, and → abyssal plain.

Upwelling (coastal): Sects. 3.1.3 and 7.5.1; Fig. 7.10. "Upwelling" pertains to vertical circulation of the upper 300 m or so, in certain coastal waters (e.g., off California, off Portugal, off Peru, off Namibia) and also along the equator. Around Antarctica, deeper waters are involved. Upwelling waters bring nutrients into sunlit depths, thus enabling high production: Sect. 7.5. Upwelling sediments commonly contain much gas (owing to oxygen shortage and fermentation): methane may be made here, resulting in → methane ice and a bottom-simulating reflector or "BDR" (→"clathrate").

Urey, H.C., outstanding physical chemist, Chicago, invented the use of oxygen isotopes for reconstruction of temperature: Sect. 9.4.2. Geologists use the method on calcareous fossils.

Uyeda, S., Japanese marine geophysicist, 1978 textbook on the new tectonics: Fig. 3.1.

Vail sea-level reconstruction: Fig, 6.11.

Vail, Hardenbol, and Haq sea-level curves for the Cenozoic: Fig. 6.12.

Van Dover, C.L., marine biologist, authored a book on the ecology of hydrothermal vents: Sect. 1.2.1.

Varves, annual layers deposited at a high rate with relatively little disturbance from bioturbation (lack of oxygen for large benthic organisms): Sects. 4.9, 9.1.7, and 15.6.1.

Vema, Lamont ship, took a comprehensive early collection of cores: Sects. 1.3.4 and 10.1 (second paragraph).

Venice (sea-level problems): Sect. 6.6.

Vening-Meinesz, F.A., Dutch geophysicist, pioneered gravity measurements in trenches: Sect. 1.3.9.

Vernadsky, V., pioneer Ukrainian geochemist, founder of biogeochemistry, identified negative feedback in geological processes: Sect. 1.1.1.

Vincent, E., French-US micropaleontologist, USC, Los Angeles and S.I.O, expert in Neogene stratigraphy, proposed (with W.H.B.) the → Monterey Event: Figs. 12.11 and 12.12.

Vine, F.J., British geophysicist, proposed (in 1963, with D.H. Matthews, his advisor) magnetic lineations on the seafloor as a corollary of seafloor spreading and magnetic reversals: Sects. 1.1.1 and 2.3.3.

Volcanism, → Ring of Fire, → subduction: Sects. 3.3 and 4.2.4; Figs.1.3 and 4.4. Also see → Trench, → Tephra.

Volcanism and Cretaceous sediments, western Pacific: Sect. 13.2.5; Figs. 13.10 and 13.11.

Volcanogenic beach sand, common on and around oceanic islands, largely black: Sect. 4.5.2; Fig. 4.10.

Volcanogenic margins: Sects. 3.2 and 3.3.

Von Herzen, R.P., Woods Hole geophysicist, studied heat flow patterns on the seafloor: Sect. 1.2.1.

von Humboldt, A., eighteenth- to nineteenth-century naturalist, noted similarity of opposing Atlantic margins: Sect. 1.3.7.

Walther, J., German pioneer geologist, studied environments of marine sedimentation: Sect. 1.3.1.

Walvis Paradox: Silica Paradox (Pleistocene silica cycles off Namibia, higher production during glacial periods resulting in lower sedimentation of siliceous fossils (see → Diester- Haass).

Warm ocean and dearth of oxygen (Cretaceous): Sect. 13.2.

Warm Pool: mass of warm surface water in the west of the equatorial Pacific, created by trade winds, collapses whenever trades become weak or cease (El Niño): Fig. 9.4. (Also see → ENSO.)

Waste (seafloor as waste receptacle, human-derived sediment): Sect. 15.3.1.

Wave base: Sect. 5.2.1 (last paragraph).

Wave-cut terrace: Fig. 6.2.

Waves and sediment transport: Sect. 5.2; Figs. 5.6 and 5.7.

Wegener, A., German-Austrian geophysicist, proposed the hypothesis of continental drift (rejected for many decades, now widely seen as corollary of plate tectonics): Sects. 1.1.1, 1.3.7, and 1.4.1; Fig.1.14.

Wilson Cycle, opening and closing of Atlantic (switching from rifting to collision, proposed by the Canadian geologist J.T. Wilson): Sect. 3.2, last paragraph.

Wilson, J.T. (Toronto), geologist who proposed the ruling hypothesis regarding the origin of the Hawaiian island chain and other chains like it: Sect. 2.6.2; Figs. 2.8 and 2.15. Also see → Wilson Cycle.

Wind input, eolian deposits: Sect. 4.2.3; Fig. 4.3.

Winogradsky, S., Russian microbiologist, early flagged the role of microbes in soil chemistry: Sect. 1.2.3.

Winterer, E.L., (S.I.O.), expert on Alpine and Pacific geology, co-proponent of → plate stratigraphy: Sects. 12.4 and 6.4.3; Figs. 12.15 and 12.14.

Woese, C., (Illinois) microbiologist who realized that prokaryotic microbes come in two very different versions, archaea and bacteria: Sect. 1.2.3, A9.1 (third paragraph).

Wuerm (last glacial period): Sect. 6.4.1.

Younger Dryas: Sect. 11.6.1 (third paragraph); Fig. 11.12.

Suggestions for Further Reading

Sundquist, E.T., and W.S. Broecker (eds.) 1985. The Carbon Cycle and Atmospheric CO_2: Natural Variations Archean to Present. Geophys. Monogr. Ser., 32.

Bolin, B., et al., (eds.) 1986. The Greenhouse Effect, Climatic Change, and Ecosystems. *SCOPE Report No.* 29. John Wiley, Chichester.

Hsü, K.J. (ed.) 1986. Mesozoic and Cenozoic Oceans. AGU & GSA Geodynamics Series vol. 15.

Rampino, M.R., J.E. Sanders, W.S. Newman, and L.K. Königsson (eds) 1987. Climate – History, Periodicity, and Predictability. Van Nostrand Reinhold, New York.

Berger, A., Schneider, S., and J.C. Duplessy (eds.) 1989. Climate and Geo-Sciences. Kluwer Academic, Dordrecht.

Ittekkot, V., S. Kempe, W. Michaelis, and A. Spitzy (eds.) 1990. Facets of Modern Biogeochemistry. Springer, Berlin & Heidelberg.

Betancourt, J.L. (ed.) 1991. Proceedings of the Seventh Annual Pacific Climate (PACLIM) Workshop. Dept. of Water Resources, Sacramento, CA.

Jones, P.D., R.S. Bradley and J. Jouzel (eds.) 1992. Climatic variations and forcing mechanisms of the last 2000 years. Springer, Berlin & Heidelberg.

Kemp, A.E.S, (ed.) 1996. Paleoclimatology and Paleoceanography from Laminated Sediments. The Geological Society, London.

Hoyt, D.V., and K. H. Schatten, 1997. The Role of the Sun in Climate Change. Oxford University Press, New York & Oxford.

Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. Van der Linden, and D. Xiaosu, 2001. Climate Change 2001: The Scientific Basis. Cambridge University Press, Cambridge, UK.

Alverson, K.D., R.S. Bradley, and T.F. Pedersen (eds.) 2003. Paleoclimate, Global Change and the Future. Springer, Berlin.

Wefer, G., F. Lamy, and F. Mantoura (eds.) 2003. Marine Science Frontiers for Europe. Springer, Heidelberg & Berlin.

Shiyomi, M., H. Kawahata, H. Koizumi, A. Tsuda, and Y. Awaya (eds.) 2003. Global Environmental Change in the Ocean and on Land. Terrapub, Tokyo.

Solomon, S., et al. (eds.) 2007. Climate Change 2007: the Physical Science Basis; Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Mann, M.E., and L.R. Kump, 2009. Dire Predictions – Understanding Global Warming. Dorling Kindersley, New York.

IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva.

http://geology.com/rocks/granite.shtml

https://www.nps.gov/goga/learn/education/serpentinite-faq.htm

Index

E. Seibold, W. Berger, *The Sea Floor*, Springer Textbooks in Earth Sciences, Geography and Environment,
DOI 10.1007/978-3-319-51412-3