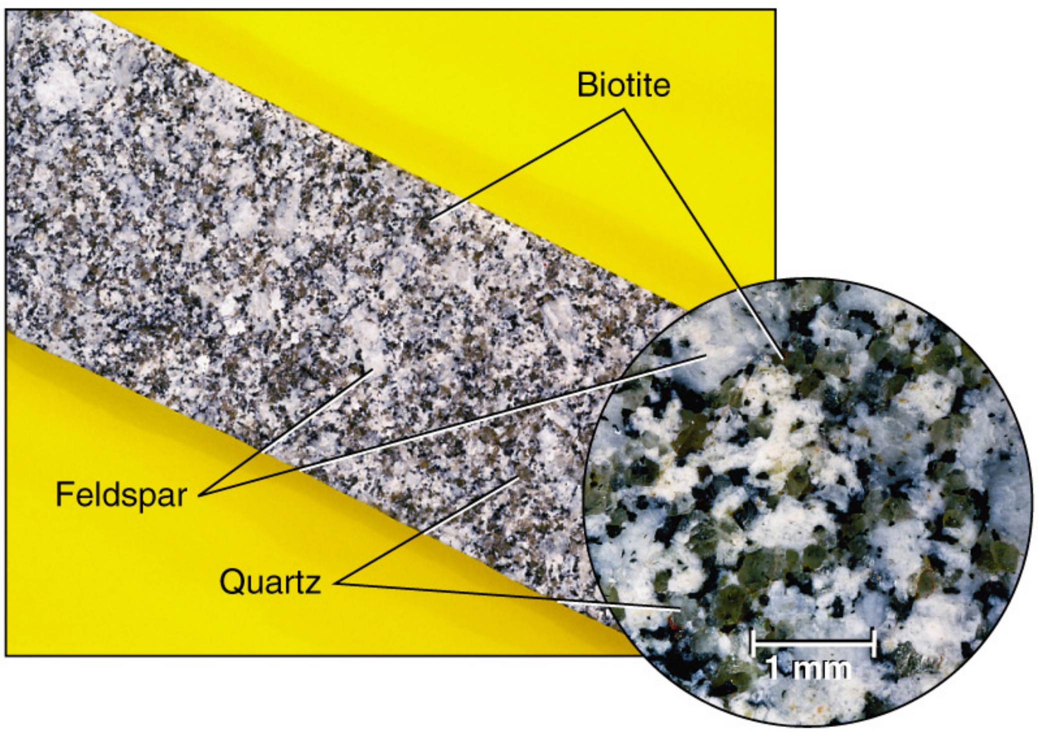
Three Types of Rock: Igneous, Sedimentary, Metamorphic

Rock: A solid, cohesive aggregate of grains of one or more MINERAL.

Mineral: A naturally occurring, solid, inorganic element or compound, with a definite composition (or range of compositions), usually possessing a regular, internal crystalline structure.



Example:

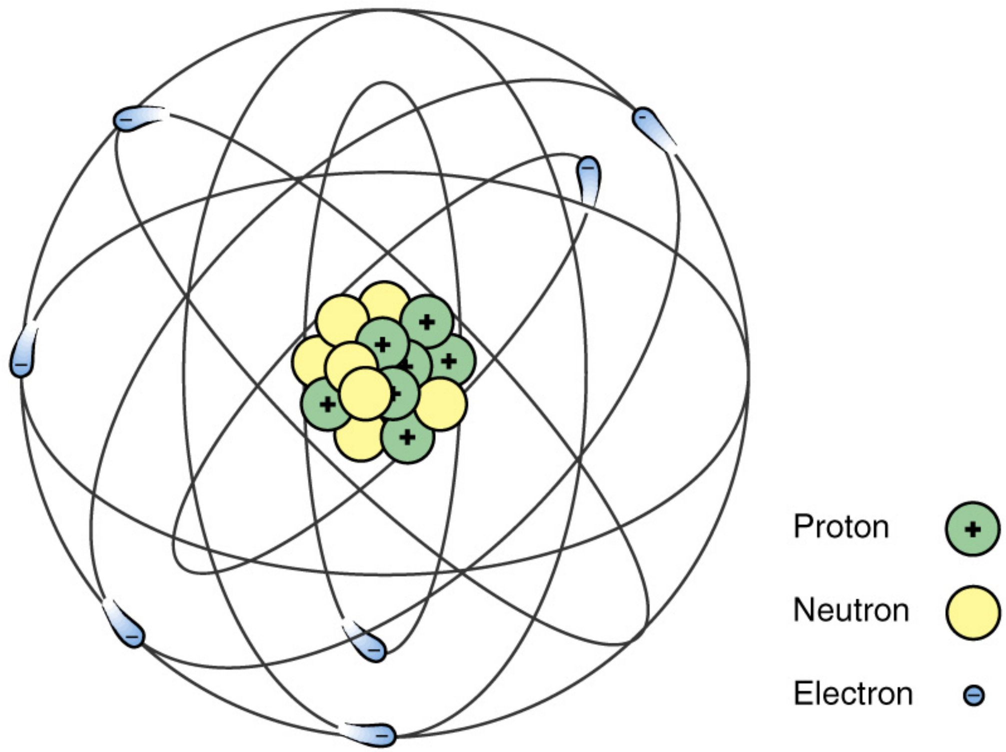
Rock = Granite

Minerals = Quartz, Feldspars, Biotite, etc.

CRYSTAL - A mineral grain displaying the characteristics of its atomic structure.

- almost 4000 different kinds of minerals

- differences result from the different elements used and the ways they are bonded

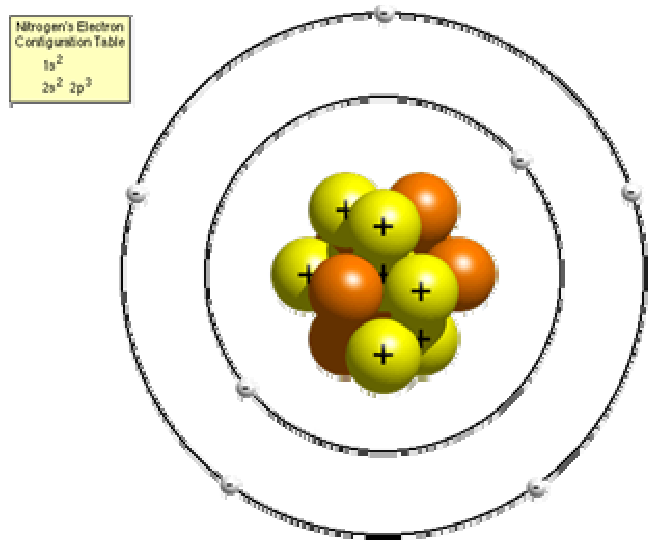


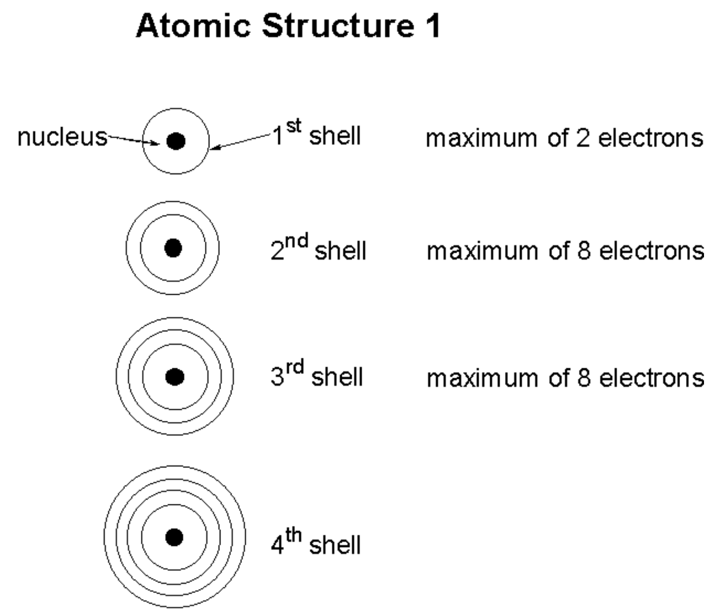
Chemistry Review :

An ELEMENT is determined by the number of PROTONS (+).

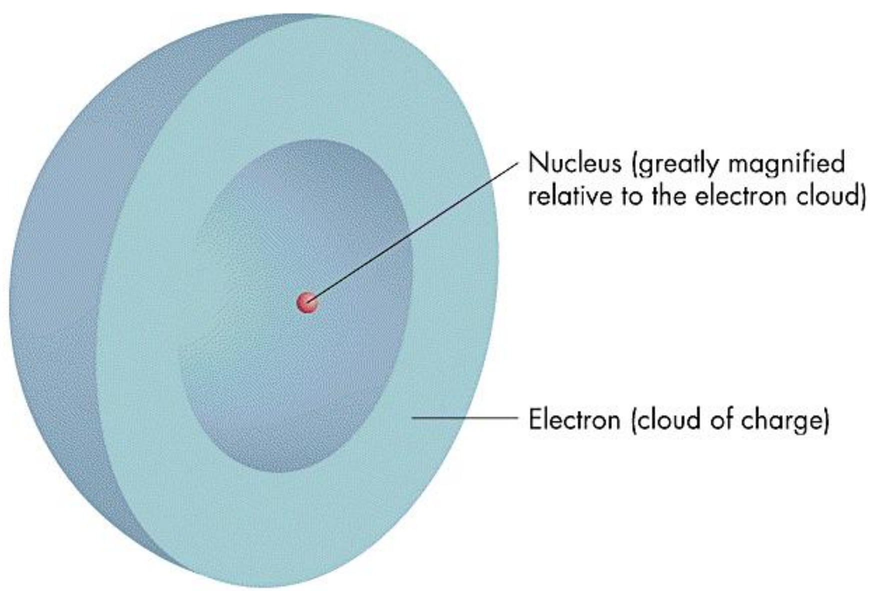
IONS - Atoms where the number of ELECTRONS (-) have been added or subtracted.

ISOTOPES - Atoms where the number of NEUTRONS have been added or subtracted.

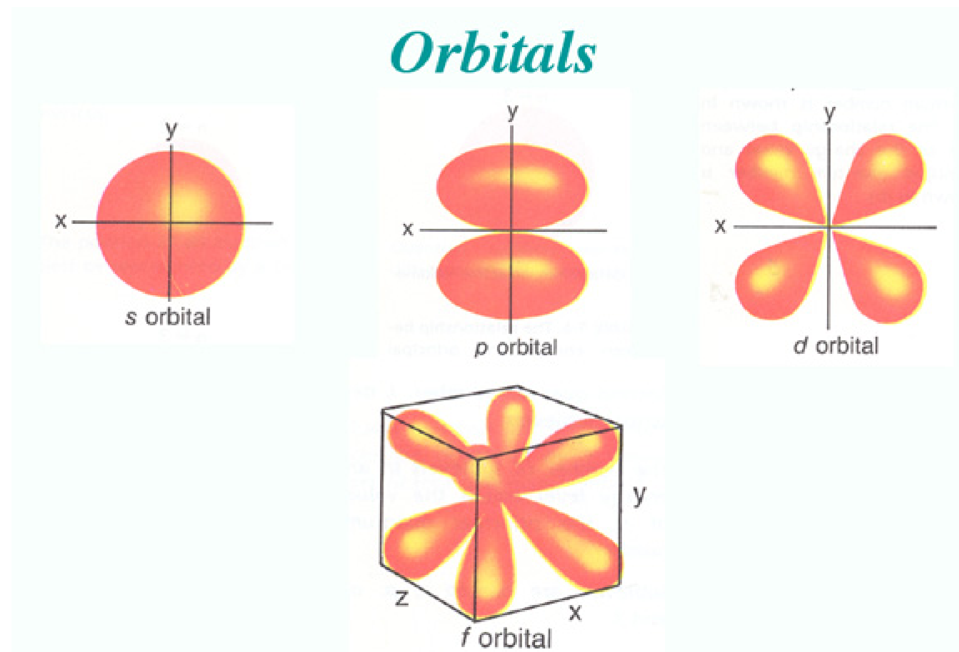




Changing Model of the Atom



Cross section of a hydrogen atom



Chemical Bonds – Forces that keep atoms together

Bonds are strong when the electron orbitals (“shells”) are complete.

# of electrons in Orbital	Total # of electrons
2	2
8	10
8	18
18	36
18	54
Etc.	

Strong tendency to lose electrons

8 O^{-2} 1.42 Oxygen	
8	Atomic number (protons)
-2	Ionic charge
O	Symbol
1.42	Ionic radius Å
Oxygen	Name of element

Tendency to share electrons or gain and lose electrons

Strong tendency to gain electrons

No tendency to gain or lose electrons

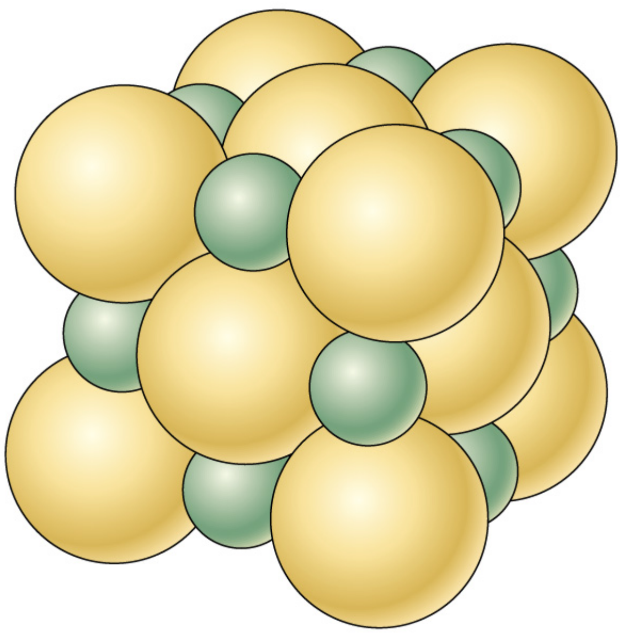
Darker colors are major constituents of crust

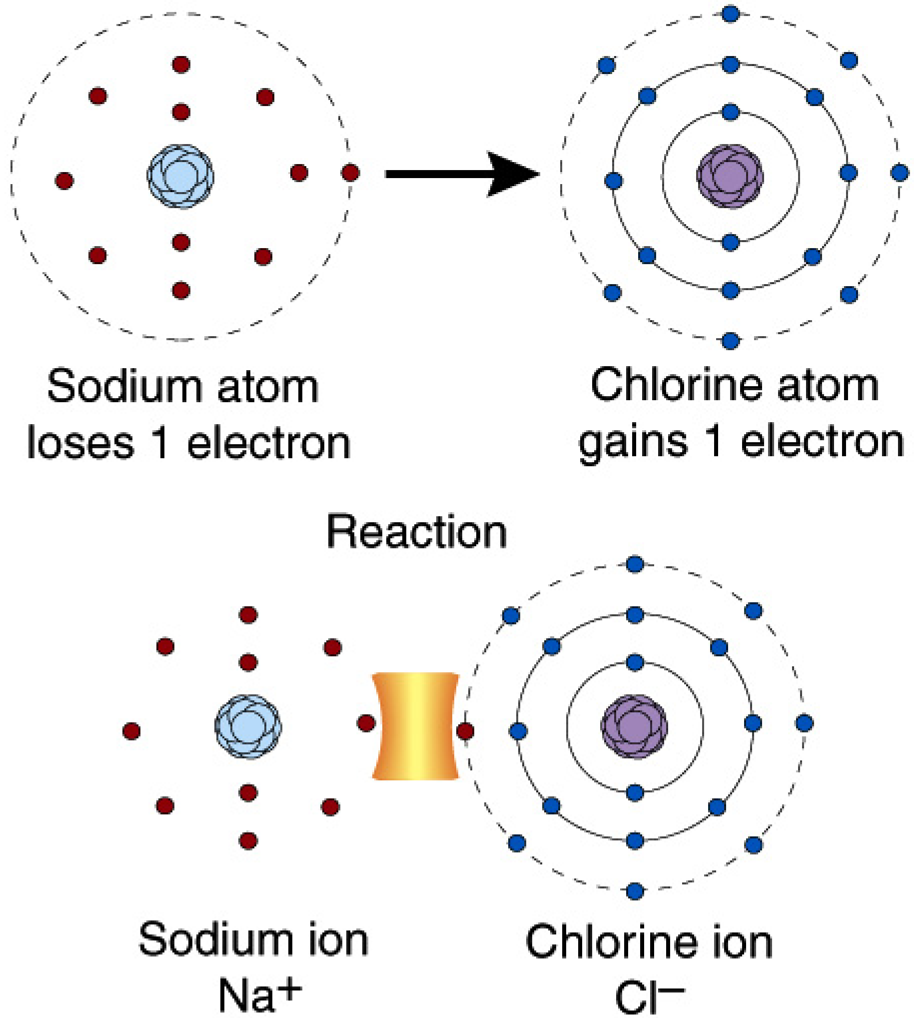
Tendency to lose electrons

1 H Hydrogen																	2 He Helium
3 Li^{1} 0.76 Lithium	4 Be^{2} 0.27 Beryllium											5 B^{3} 0.11 Boron	6 C^{4} 0.16 Carbon	7 N^{5} 0.13 Nitrogen	8 O^{-2} 1.42 Oxygen	9 F^{-1} 1.36 Fluorine	10 Ne Neon
11 Na^{1} 1.18 Sodium	12 Mg^{2} 0.72 Magnesium											13 Al^{3} 0.54 Aluminum	14 Si^{4} 0.40 Silicon	15 P^{5} 0.38 Phosphorus	16 S^{-2} 1.84 Sulfur	17 Cl^{-1} 1.81 Chlorine	18 Ar Argon
19 K^{1} 1.51 Potassium	20 Ca^{2} 1.12 Calcium	21 Sc^{3} 0.14 Scandium	22 Ti^{4} 0.74 Titanium	23 V^{3} 0.64 Vanadium	24 Cr^{3} 0.62 Chromium	25 Mn^{2} 0.83 Manganese	26 Fe^{2} 0.78 Iron	27 Co^{2} 0.74 Cobalt	28 Ni^{2} 0.69 Nickel	29 Cu^{2} 0.73 Copper	30 Zn^{2} 0.74 Zinc	31 Ga^{3} 0.62 Gallium	32 Ge^{4} 0.53 Germanium	33 As^{3} 0.46 Arsenic	34 Se^{6} 0.42 Selenium	35 Br^{-1} 1.95 Bromine	36 Kr Krypton
37 Rb^{1} 1.61 Rubidium	38 Sr^{2} 1.26 Strontium	39 Y^{3} 1.02 Yttrium	40 Zr^{4} 0.84 Zirconium	41 Nb^{5} 0.74 Niobium	42 Mo^{5} 0.61 Molybdenum	43 Tc Technetium	44 Ru^{4} 0.62 Ruthenium	45 Rh^{3} 0.67 Rhodium	46 Pd^{2} 0.86 Palladium	47 Ag^{1} 1.15 Silver	48 Cd^{2} 0.95 Cadmium	49 In^{3} 0.80 Indium	50 Sn^{4} 0.69 Tin	51 Sb^{3} 0.76 Antimony	52 Te^{6} 0.56 Tellurium	53 I^{-1} 2.16 Iodine	54 Xe Xenon
55 Cs^{1} 1.74 Cesium	56 Ba^{2} 1.42 Barium	57 TO 71	72 Hf^{4} 0.83 Hafnium	73 Ta^{5} 0.74 Tantalum	74 W^{6} 0.60 Tungsten	75 Re^{4} 0.63 Rhenium	76 Os^{6} 0.54 Osmium	77 Ir^{4} 0.62 Iridium	78 Pt^{2} 0.60 Platinum	79 Au^{1} 0.68 Gold	80 Hg^{2} 1.02 Mercury	81 Tl^{1} 1.59 Thallium	82 Pb^{2} 1.29 Lead	83 Bi^{3} 1.17 Bismuth	84 Po Polonium	85 At^{-1} Astatine	86 Rn Radon
87 Fr^{1} Francium	88 Ra^{2} 1.48 Radium	89 TO 92													Metals	Nonmetals	
			57 La^{3} 1.16 Lanthanum	58 Ce^{3} 1.14 Cerium	59 Pr^{3} Praseodymium	60 Nd^{3} 1.11 Neodymium	61 Pm^{3} 1.09 Promethium	62 Sm^{3} 1.08 Samarium	63 Eu^{2} 1.25 Europium	64 Gd^{3} 1.05 Gadolinium	65 Tb^{3} 1.04 Terbium	66 Dy^{3} 1.03 Dysprosium	67 Ho^{3} 1.02 Holmium	68 Er^{3} 1.00 Erbium	69 Tm^{3} 0.99 Thullium	70 Yb^{3} 0.98 Ytterbium	71 Lu^{3} 0.98 Lutetium
			89 Ac Actinium	90 Th^{4} 1.05 Thorium	91 Pa Protactinium	92 U^{4} 1.00 Uranium											

IONIC BOND

Ex: Halite (salt)





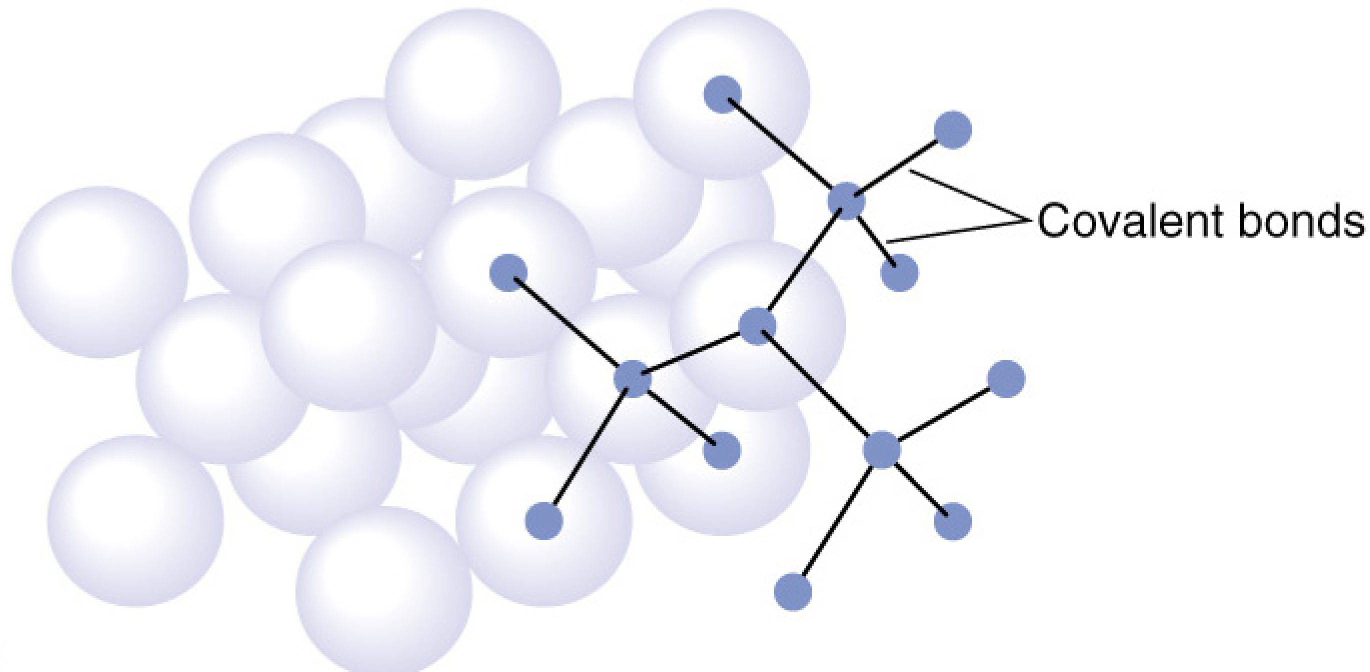
Compound sodium chloride forms by electrical attraction between Na^+ and Cl^-

Q: Which is Na? Cl?

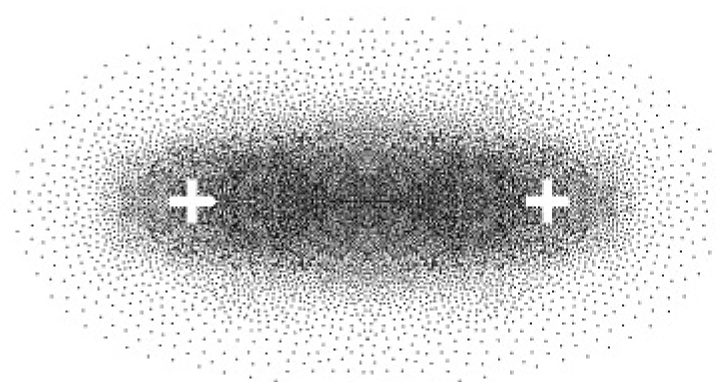
A: Cl is larger

COVALENT BOND

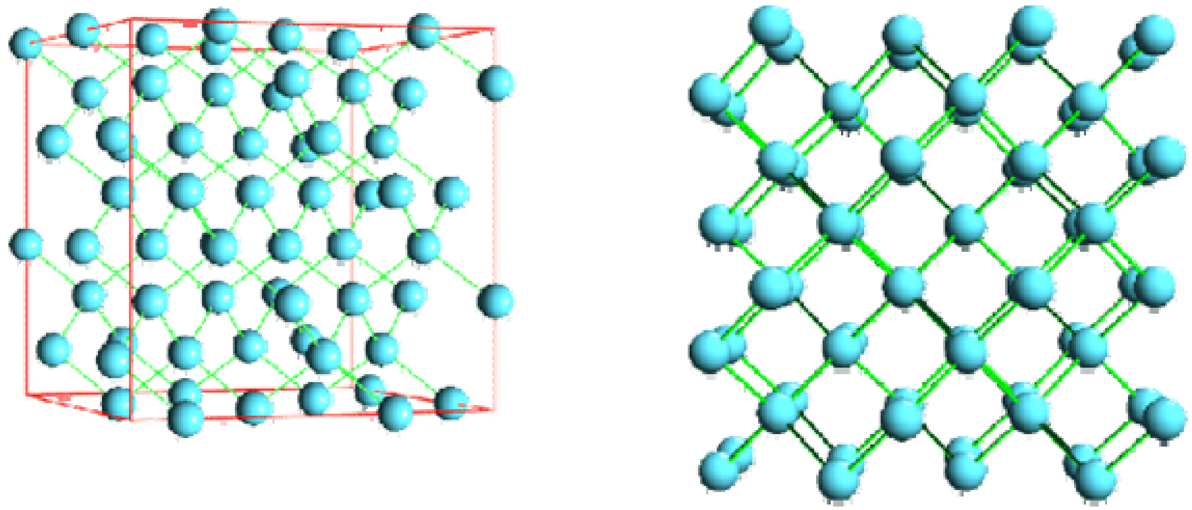
Ex: Diamond



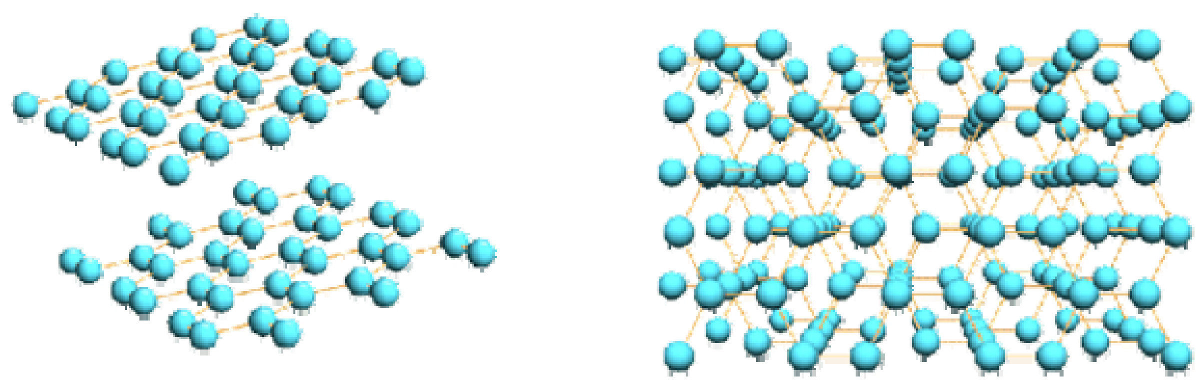
(a)



(b)



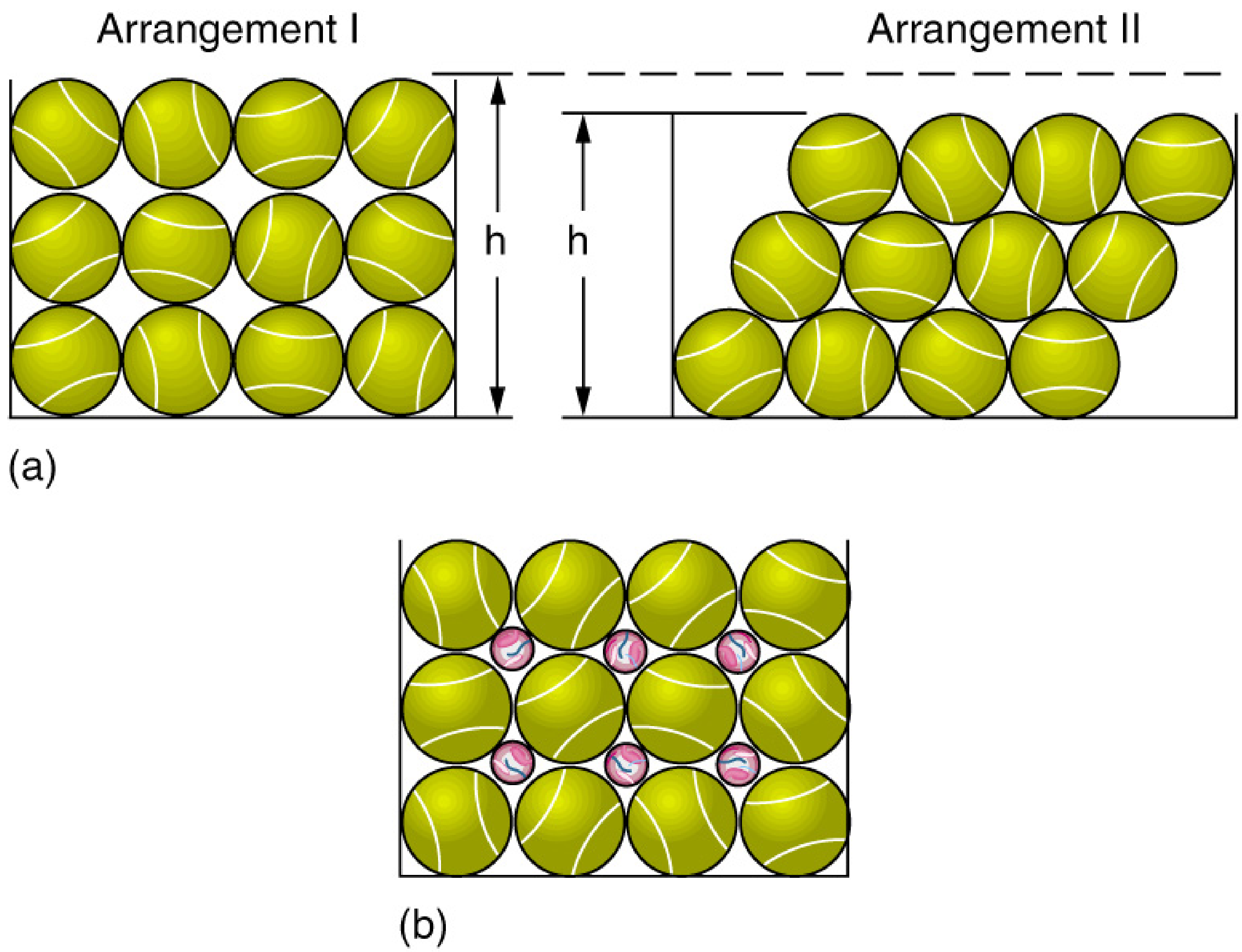
Diamond lattice

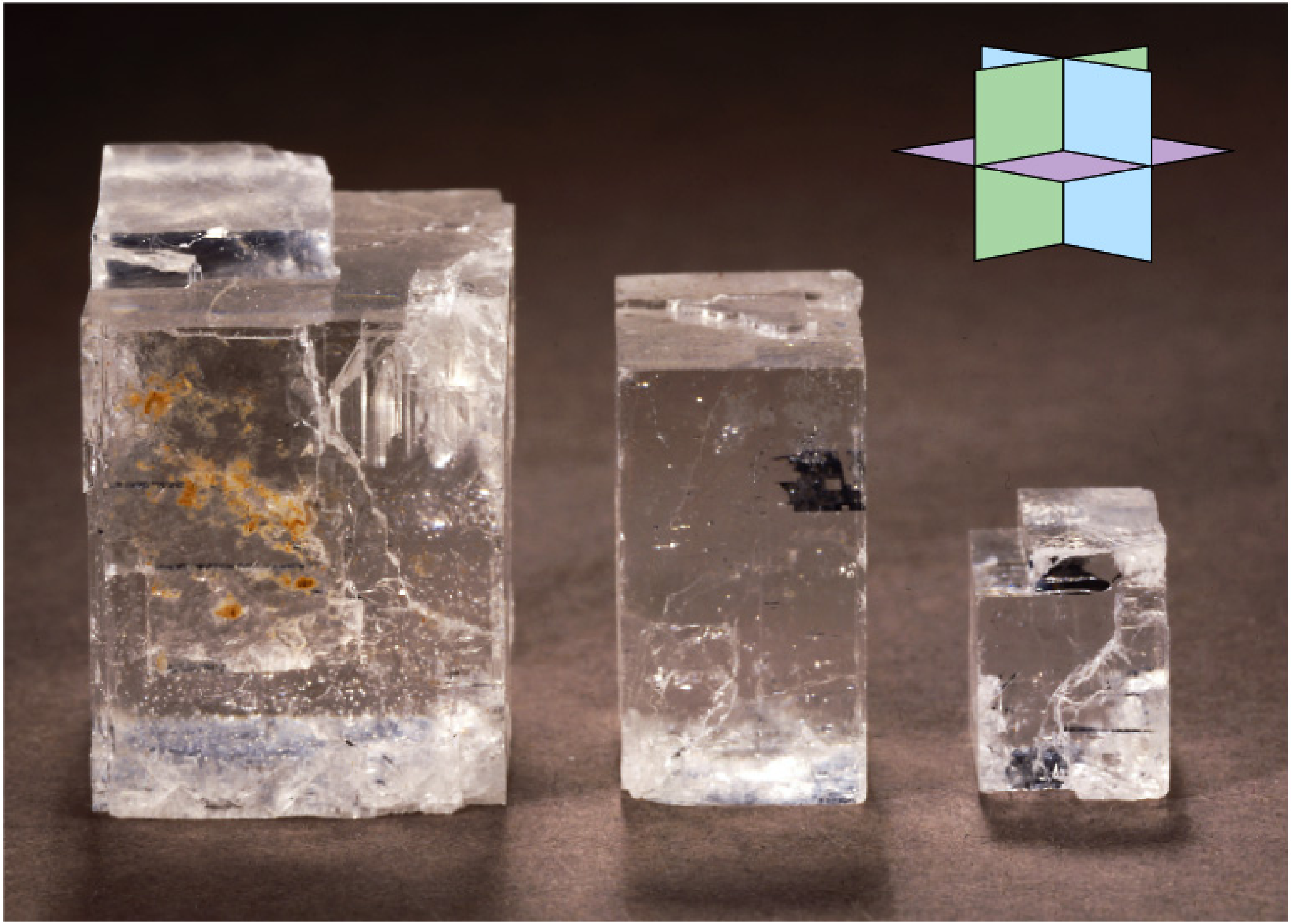


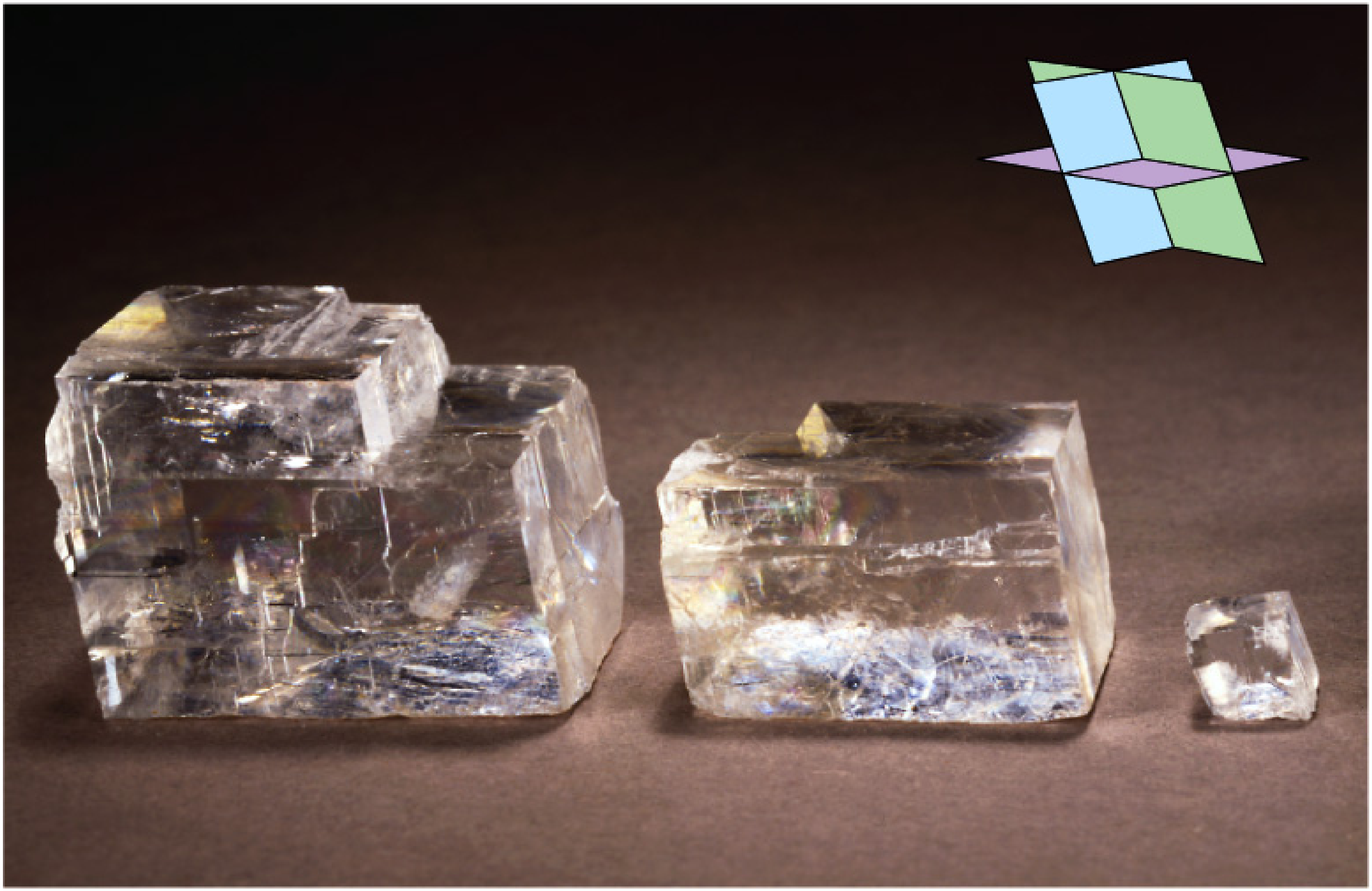
Graphite lattice

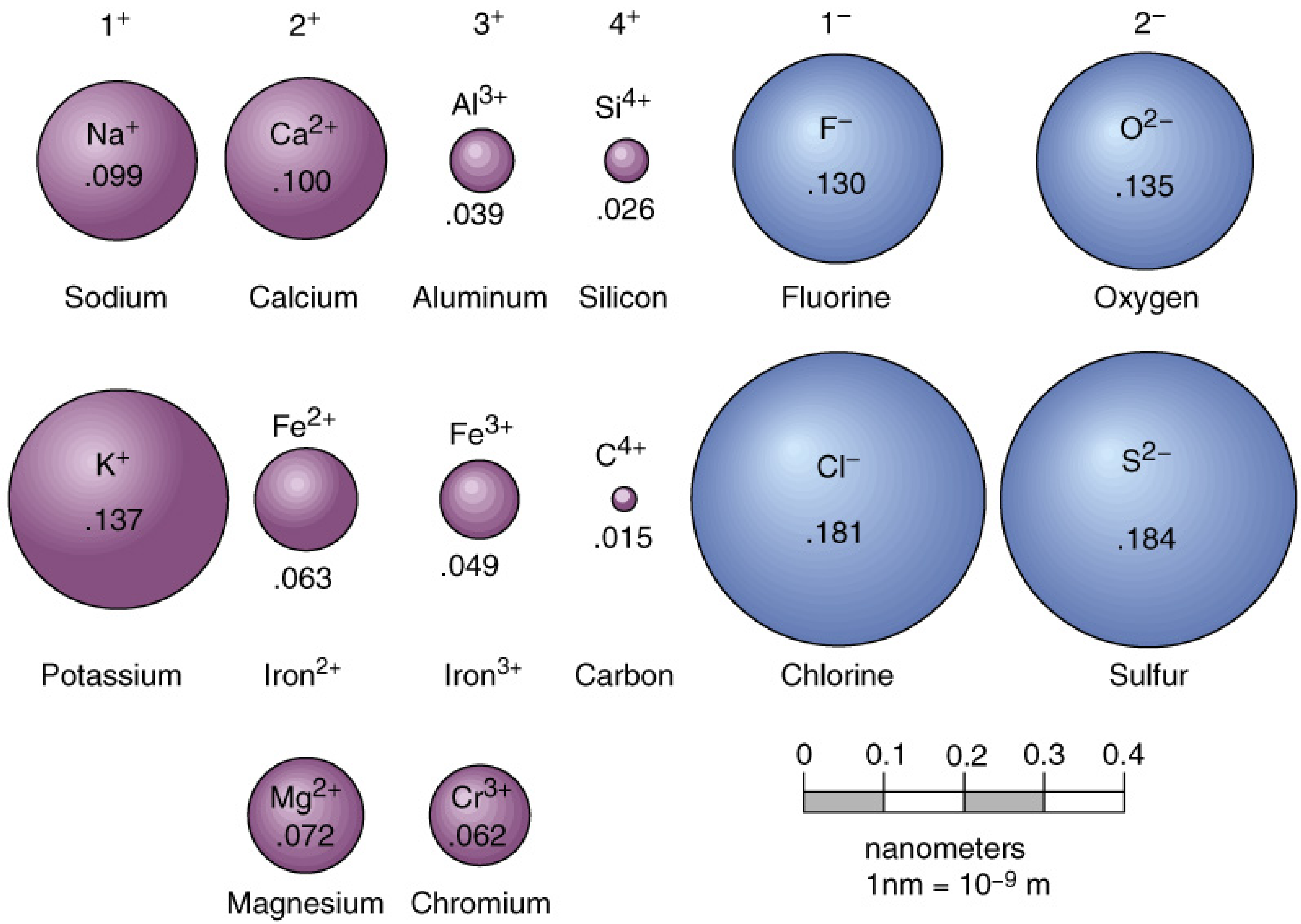
For a Mineral to be Stable:

1. Ionic charges sum to ZERO
2. Ion sizes must be compatible (sizes determined by electron cloud)





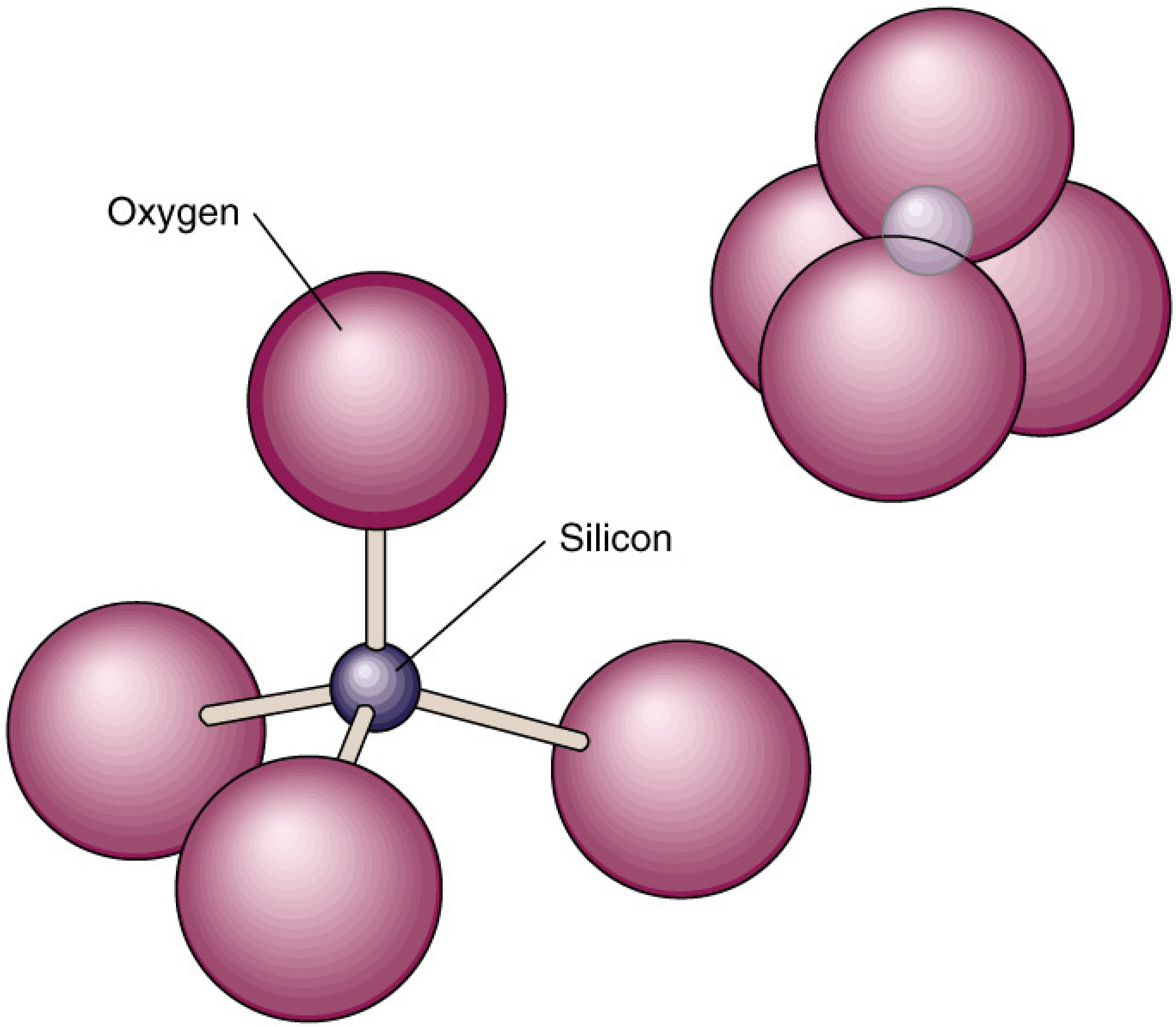




1+
2+
3+
4+
1−
2−
Na+
.099
Ca2+
.100
Al3+
.039
Si4+
.026
F−
.130
O2−
.135
Sodium
Calcium
Aluminum
Silicon
Fluorine
Oxygen
K+
.137
Fe2+
.063
Fe3+
.049
C4+
.015
Cl−
.181
S2−
.184
Potassium
Iron2+
Iron3+
Carbon
Chlorine
Sulfur
Mg2+
.072
Cr3+
.062
Magnesium
Chromium
0
0.1
0.2
0.3
0.4
nanometers
1nm = 10−9 m

Most rocks are variations on silicon and oxygen: *silicates*

Silica Tetrahedron:

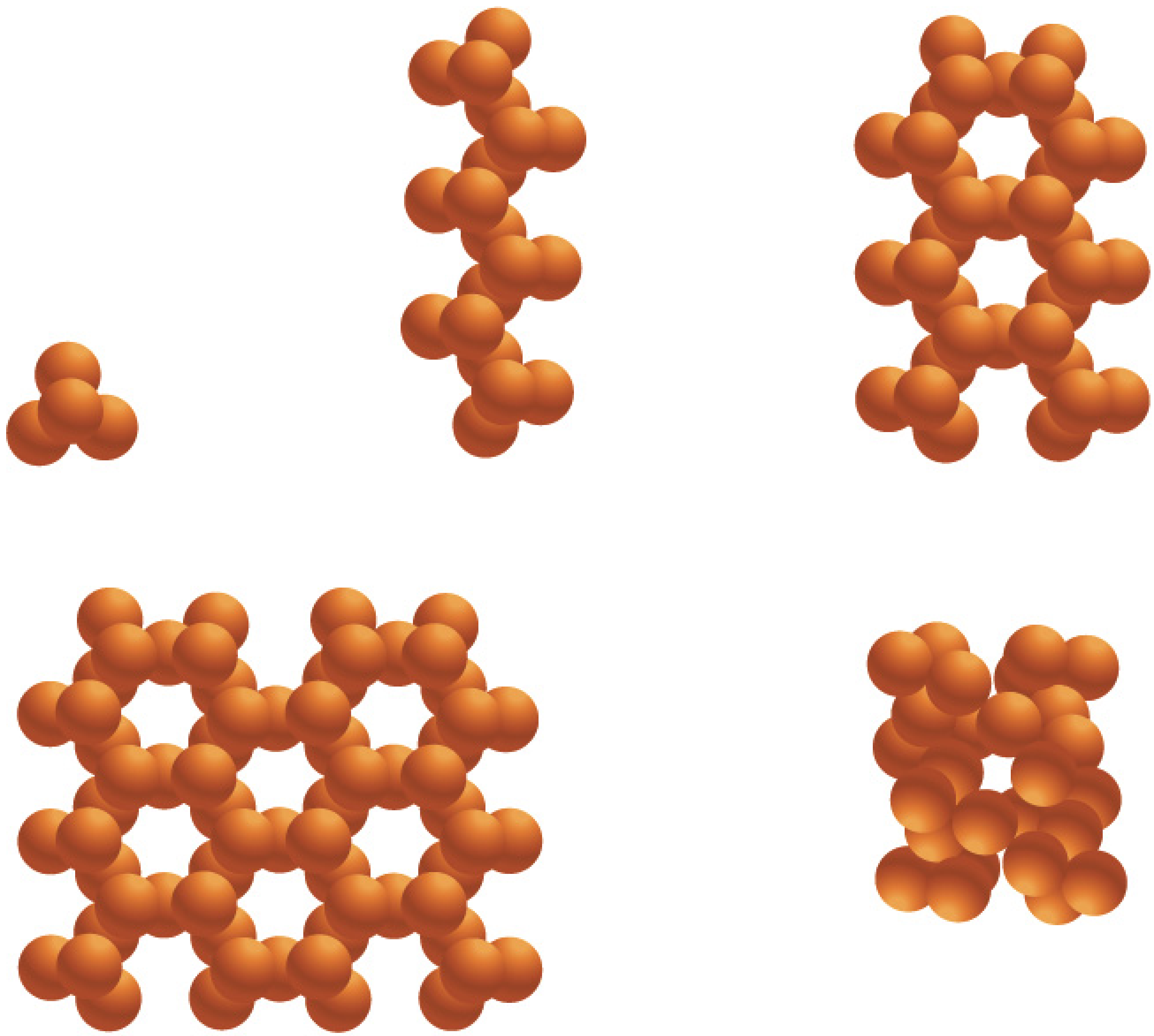


Oxygen - normally should have 8 protons, neutrons, electrons, but prefers to grab two electrons to exist as a NEGATIVE ION - O^{-2} (completing second orbital with 10 electrons)

Silicon ---> 14 protons, neutrons, electrons. Could GO EITHER WAY! But prefers to lose 4 electrons to end up with 10 electrons - POSITIVE ION - Si^{+4}

>>instead of the Silicon and Oxygen forming an ionic bond, the Si^{+4} COVALENTLY bonds with FOUR O^{-2} ions, making an $SiO_4(^{-4})$ TETRAHEDRON, which bonds ionically with other cations (positive ions).

Different silicate structures: single tetrahedra, single chains, double chains, sheets, 3D structures (other atoms fill in the spaces in between).



Slightly changing the different elements that combine with silica greatly changes the mineral that results, or the characteristics of the mineral.

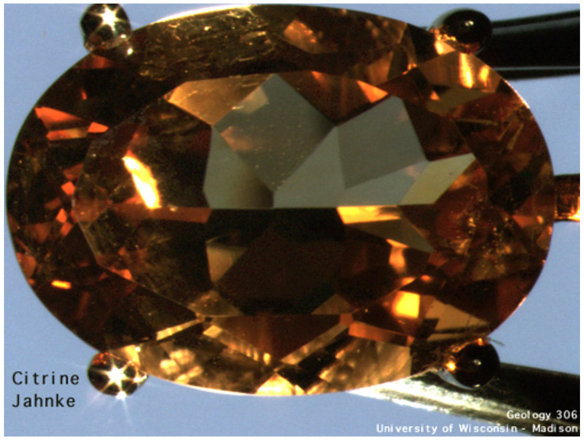
Ex/ Different forms of quartz

Pure Quartz

Cat's Eye

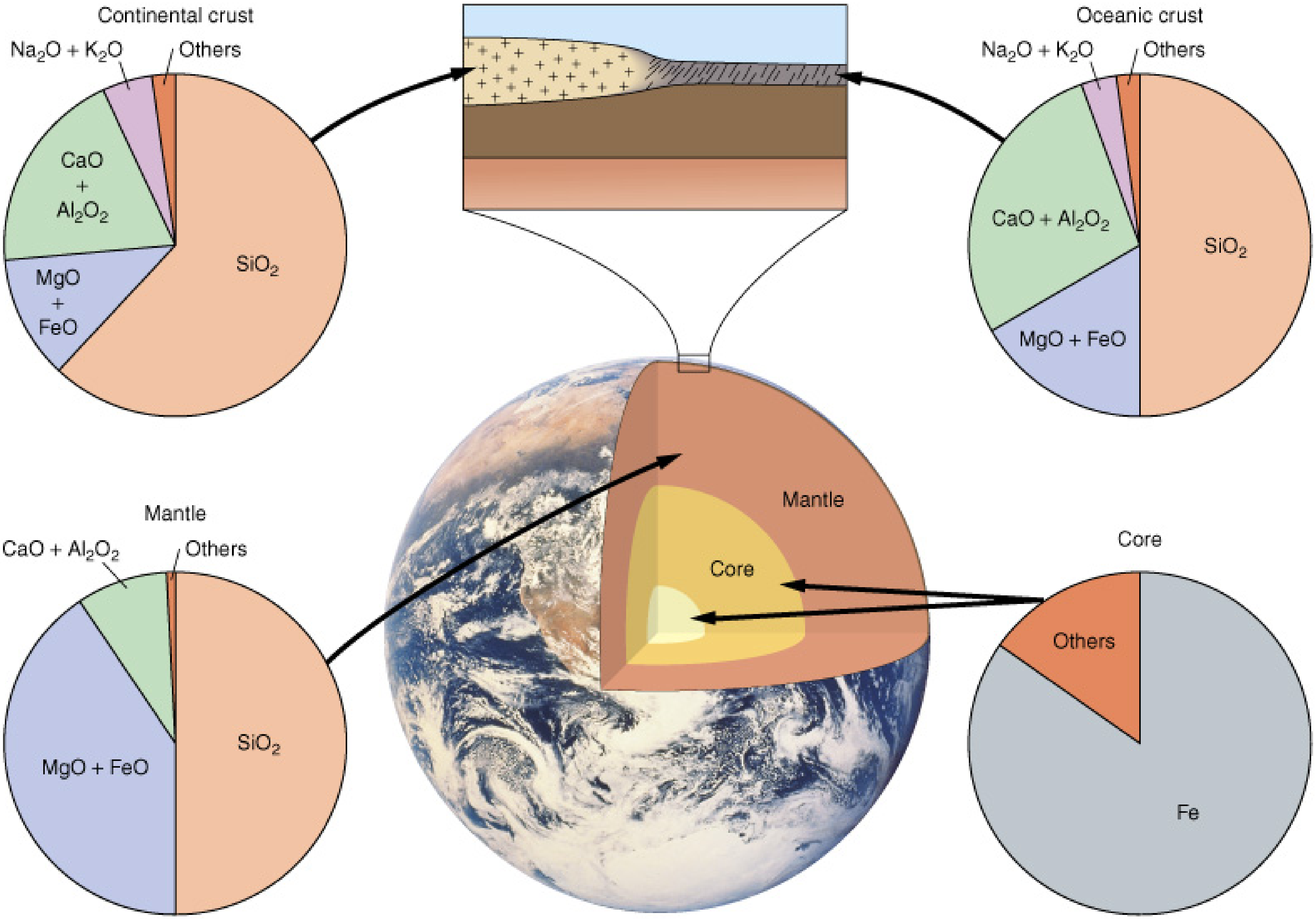
Amethyst (+manganese, iron)

Citrine (+iron)

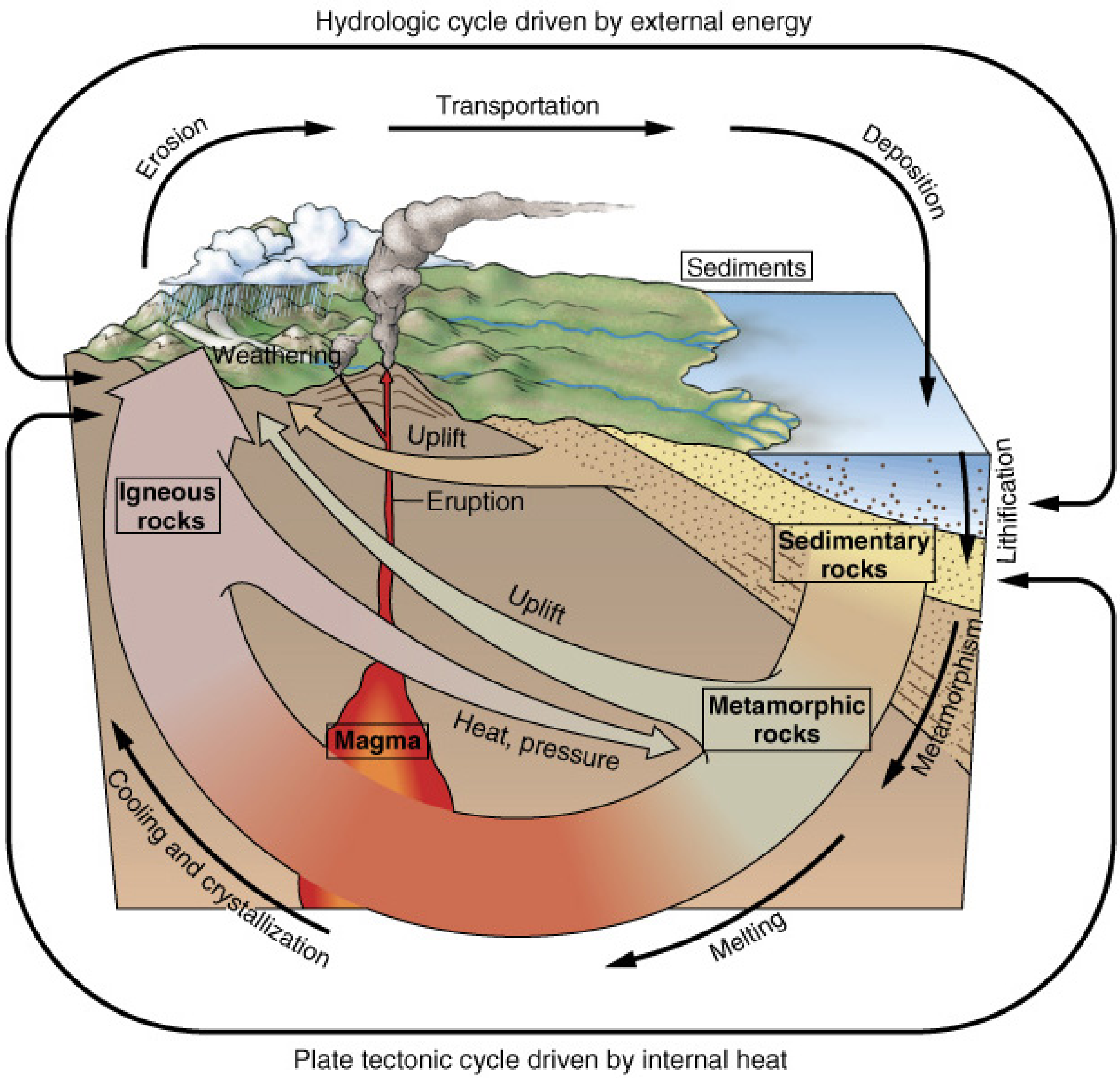


Rose Quartz (+titanium)

Smoky Quartz (+aluminum)



Continental crust
$Na_2O + K_2O$
Others
CaO + Al_2O_2
MgO + FeO
SiO_2
Oceanic crust
$Na_2O + K_2O$
Others
CaO + Al_2O_2
MgO + FeO
SiO_2
Mantle
CaO + Al_2O_2
Others
MgO + FeO
SiO_2
Mantle
Core
Core
Others
Fe



Hydrologic cycle driven by external energy
Erosion
Transportation
Deposition
Sediments
Weathering
Uplift
Eruption
Igneous rocks
Sedimentary rocks
Lithification
Uplift
Metamorphic rocks
Metamorphism
Magma
Heat, pressure
Cooling and crystallization
Melting
Plate tectonic cycle driven by internal heat

MAGMA is molten rock, but is not just liquid - also contains bits of rock crystals and gas. It ranges in consistency from wet concrete to thick oatmeal.

Rock that crystallizes from a magma is IGNEOUS ROCK.

The most important factors controlling the behavior of the magma are

1. amount of **WATER**
2. amount of **SILICA**
3. **TEMPERATURE**

VISCOSITY = resistance to flow

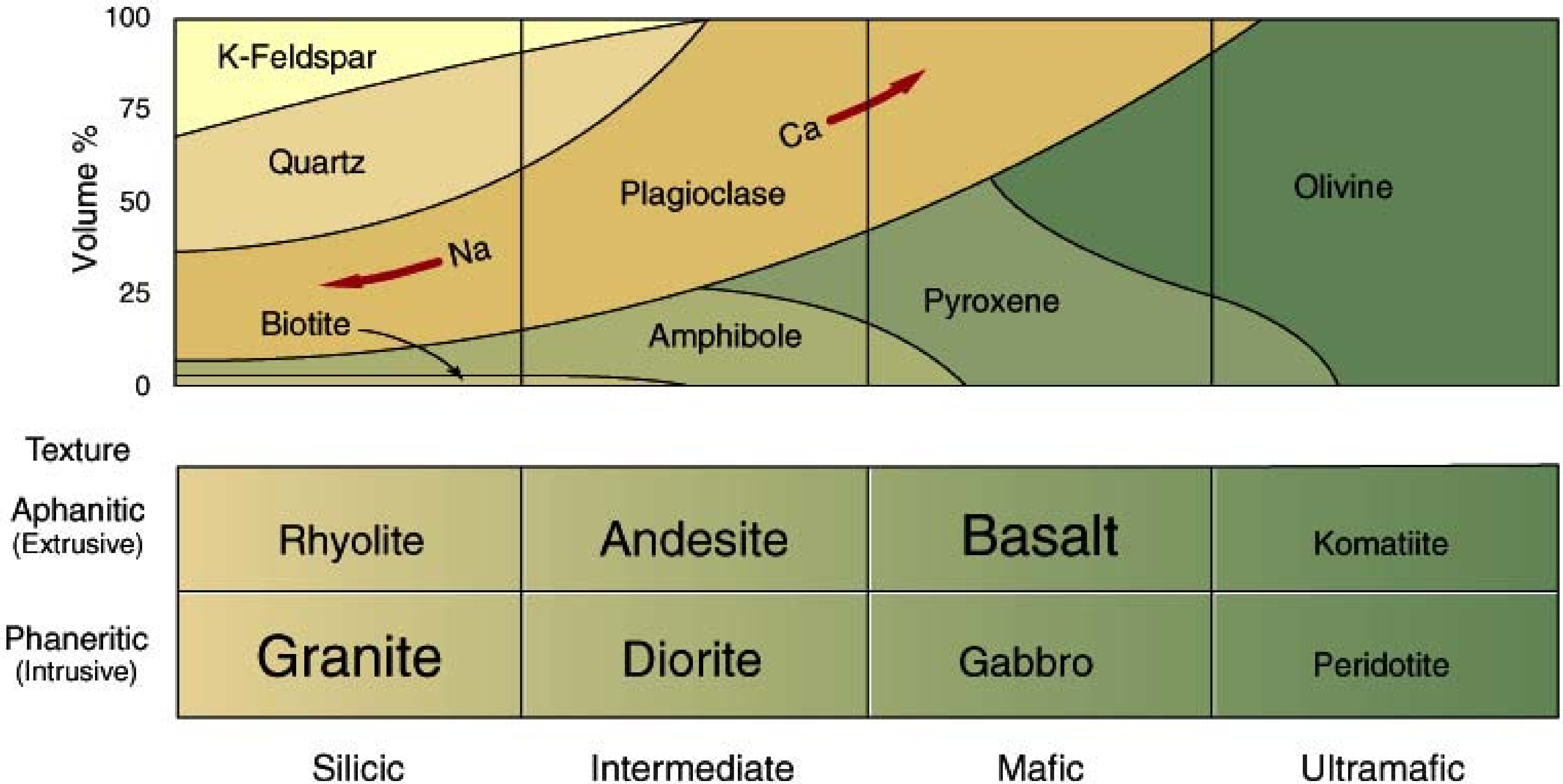
Viscosity increases with

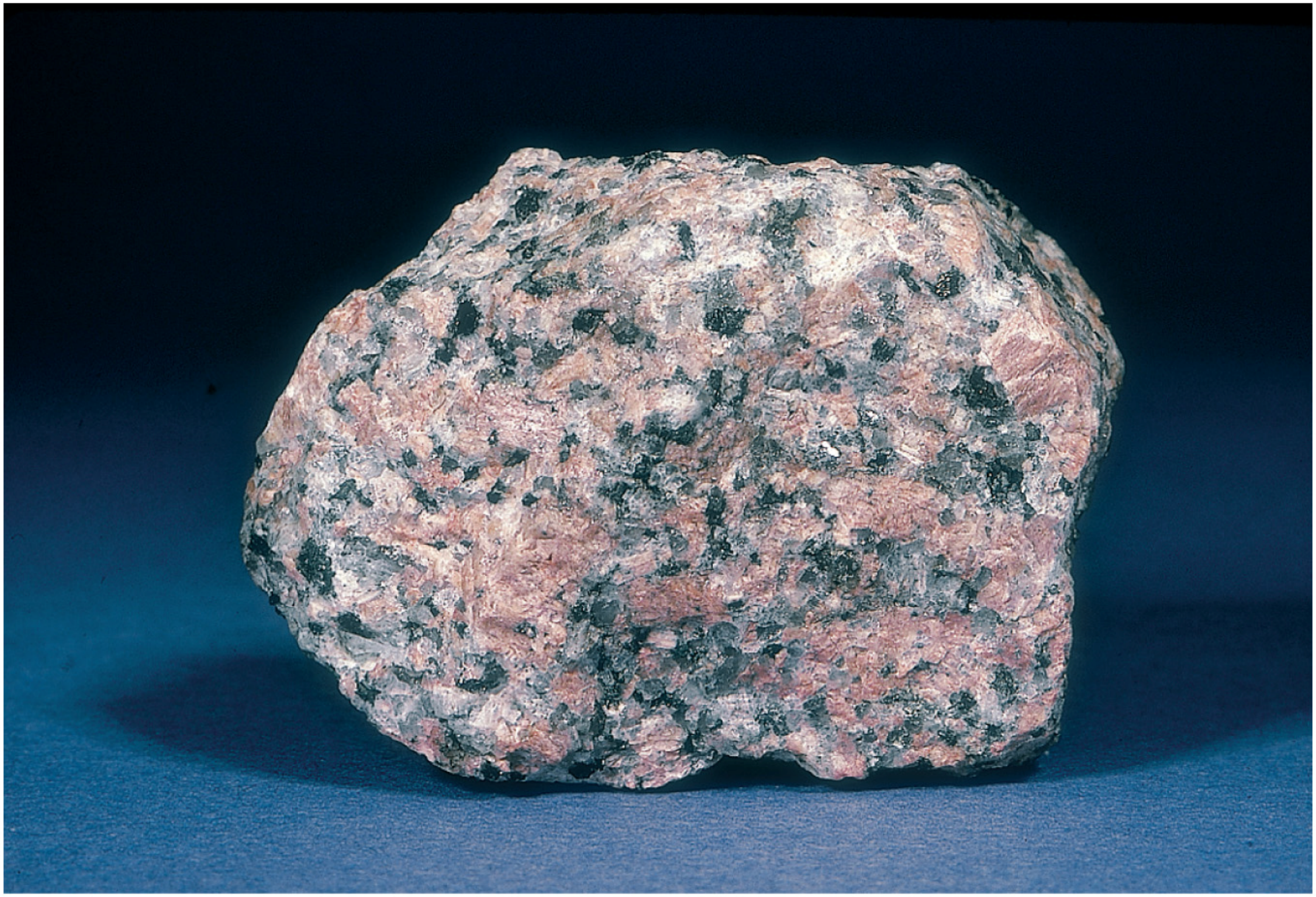
1. increase in SiO_2 (silica), because of the strong covalent silicon-oxygen bonds.
2. decrease in temperature.
3. decrease in water. (water has a lubricating effect, breaking bonds, making melting easier)

HOWEVER, added water causes explosive eruptions due to the rapid expansion of water into steam (Subduction Zones).

We classify Igneous Rocks by Texture and Composition

> Large XLs → SLOW cool-down (visible) → Intrusive Rocks
> Small XLs → FAST cool down (microscopic) → Extrusive Rocks

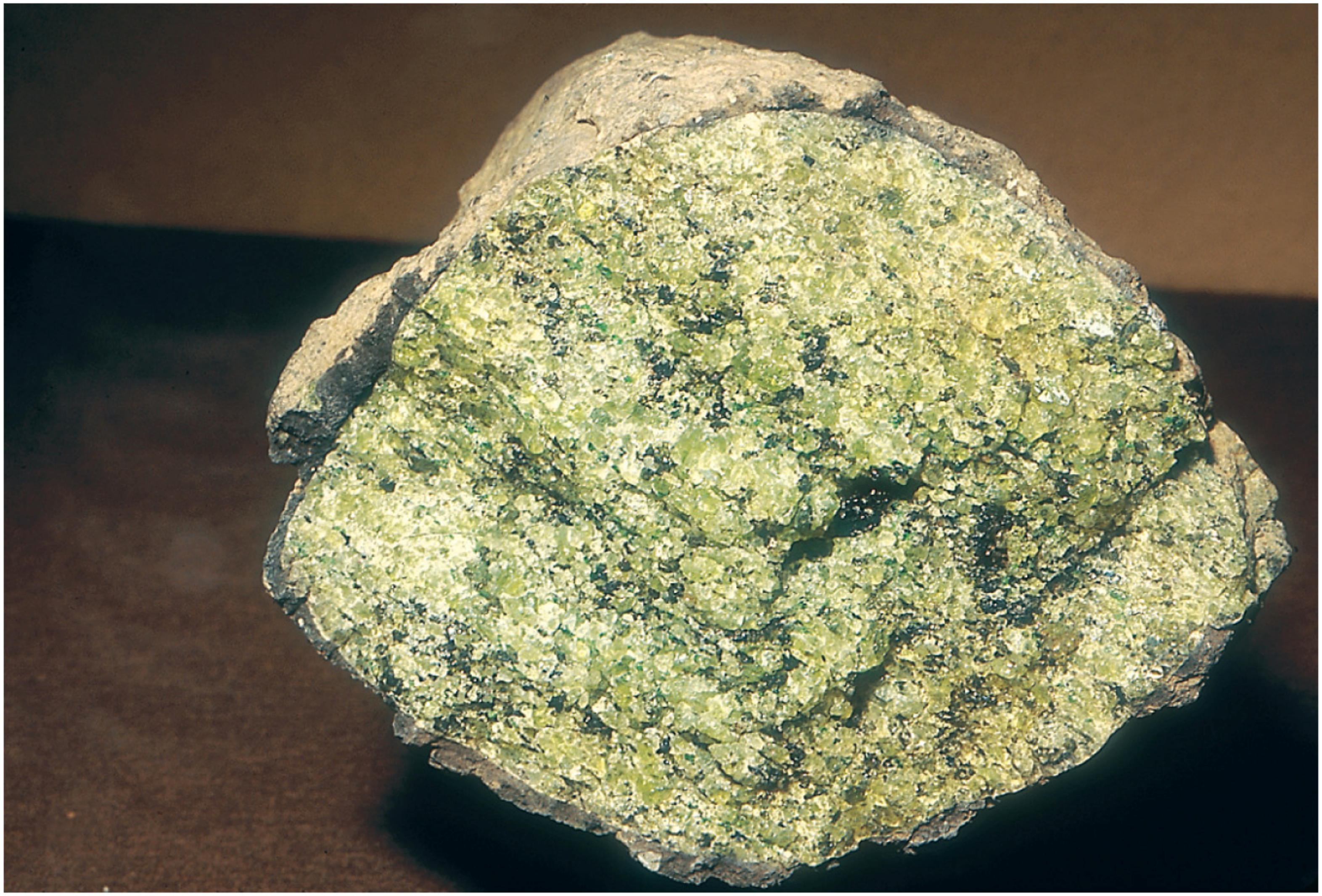




Granite

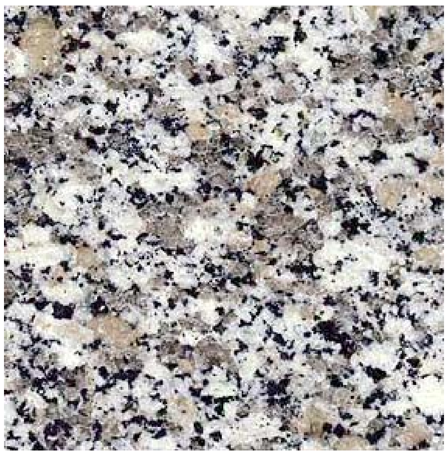
Diorite

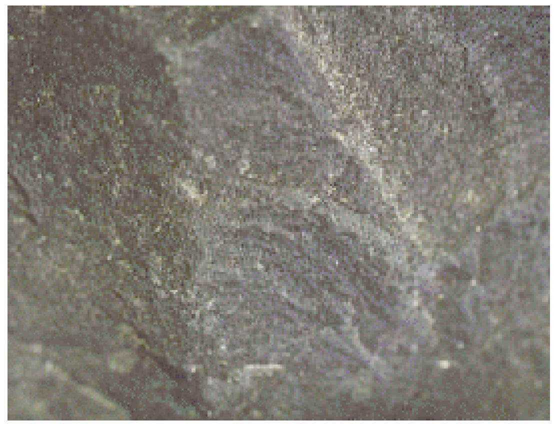
Gabbro



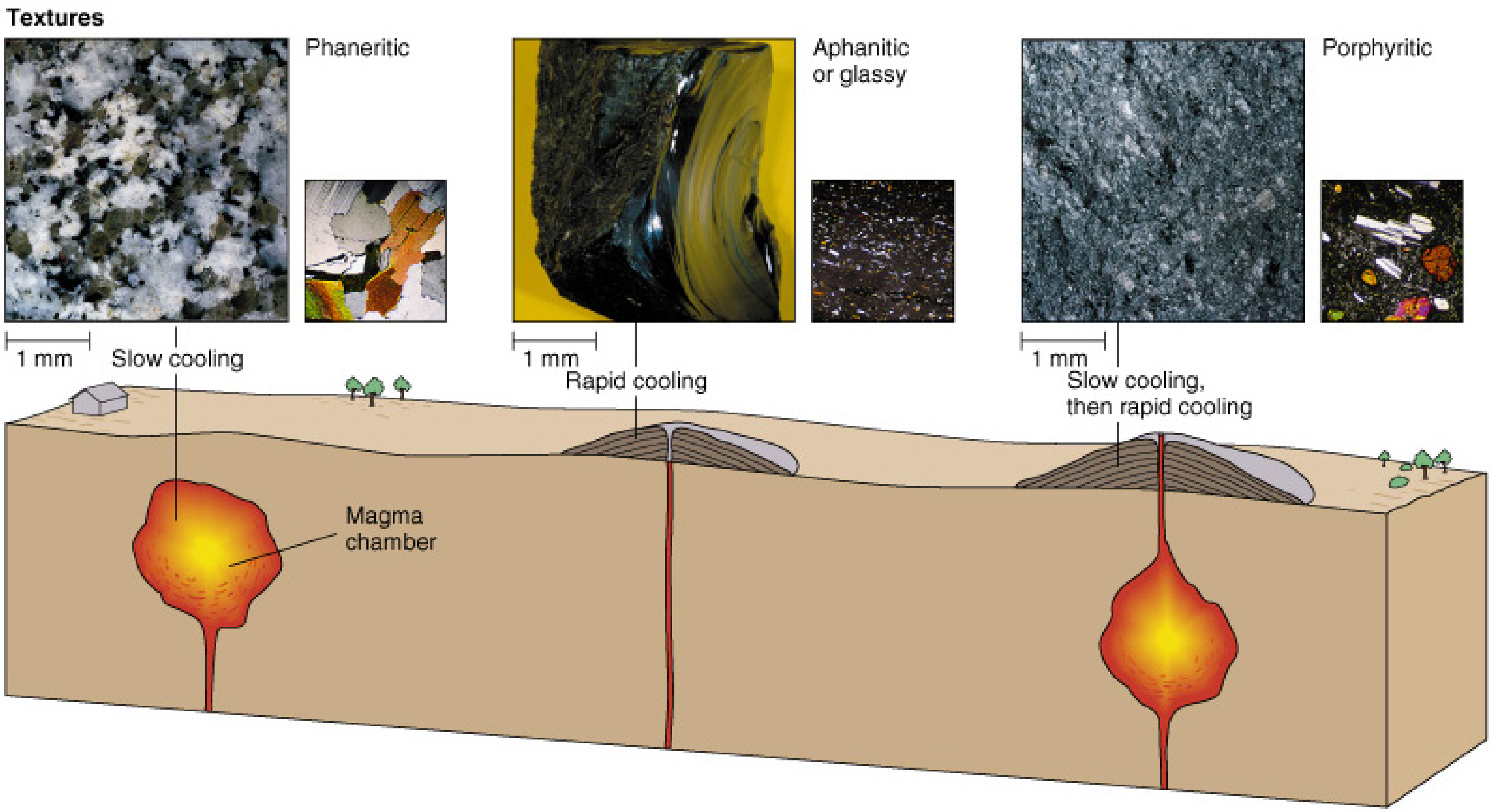
Peridotite

Phaneritic	Aphanitic	Glassy
large xls	tiny xls	no xls
slow cooling	fast	*very* fast





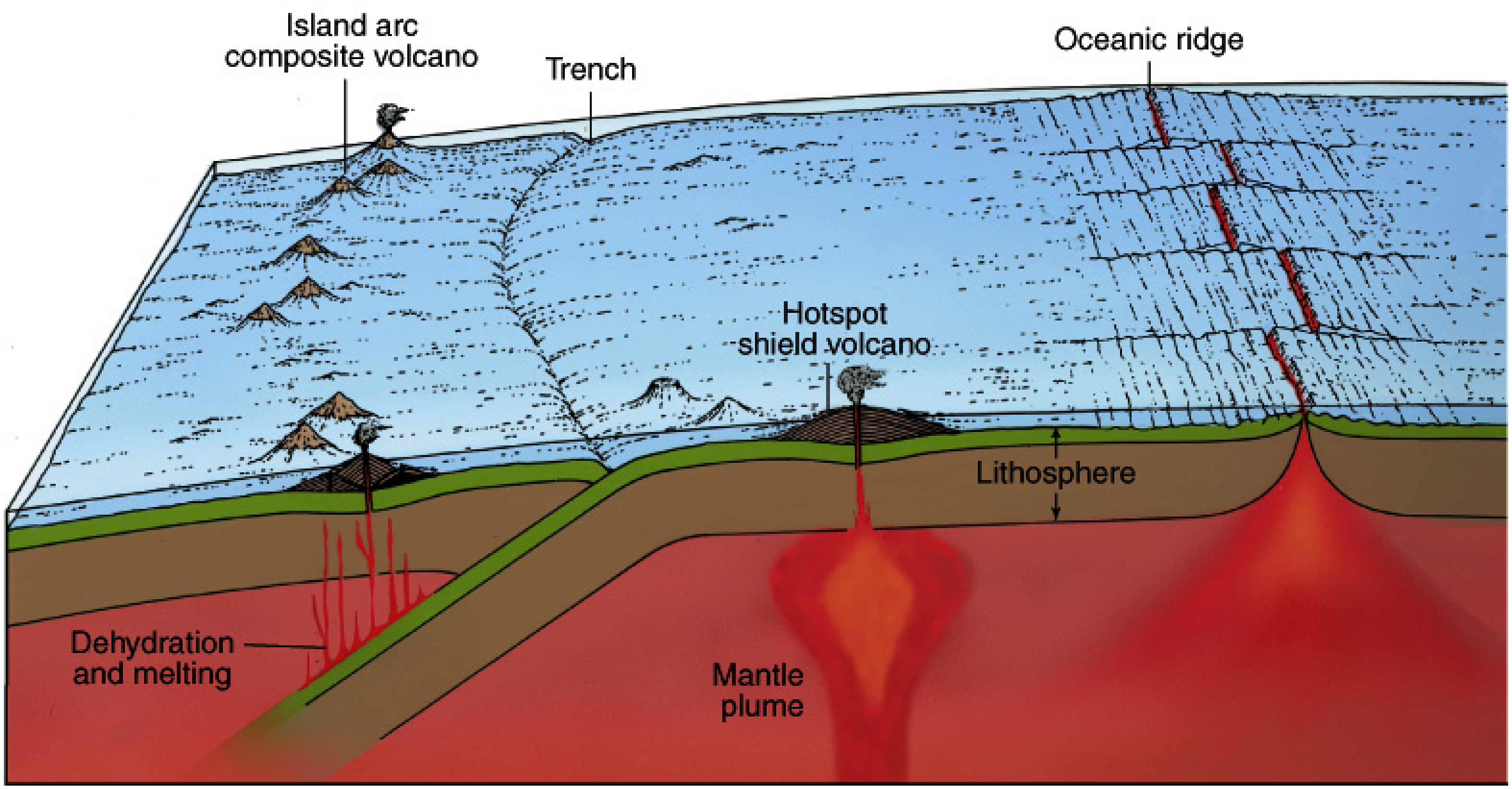
Also: porphyritic, pyroclastic



Textures
Phaneritic
Aphanitic
or glassy
Porphyritic
1 mm
Slow cooling
1 mm
Rapid cooling
1 mm
Slow cooling,
then rapid cooling
Magma
chamber

Rock melts when the temperature within the earth (**geotherm**) exceeds the melting point (**solidus**) of rock.

This happens for **different reasons** at (1) subduction zone volcanoes, (2) mid-ocean ridge volcanoes, and (3) hotspot volcanoes.



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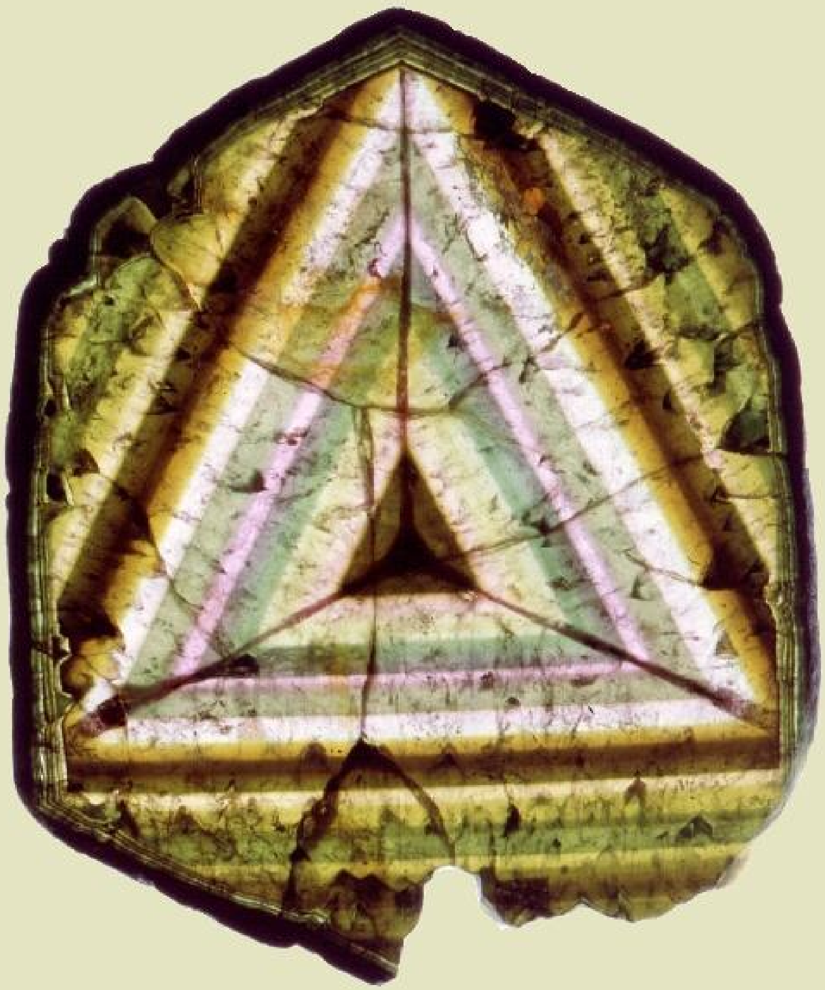
VERY IMPORTANT!!!

Minerals crystallize at different temperatures!!

Some are more stable than others.

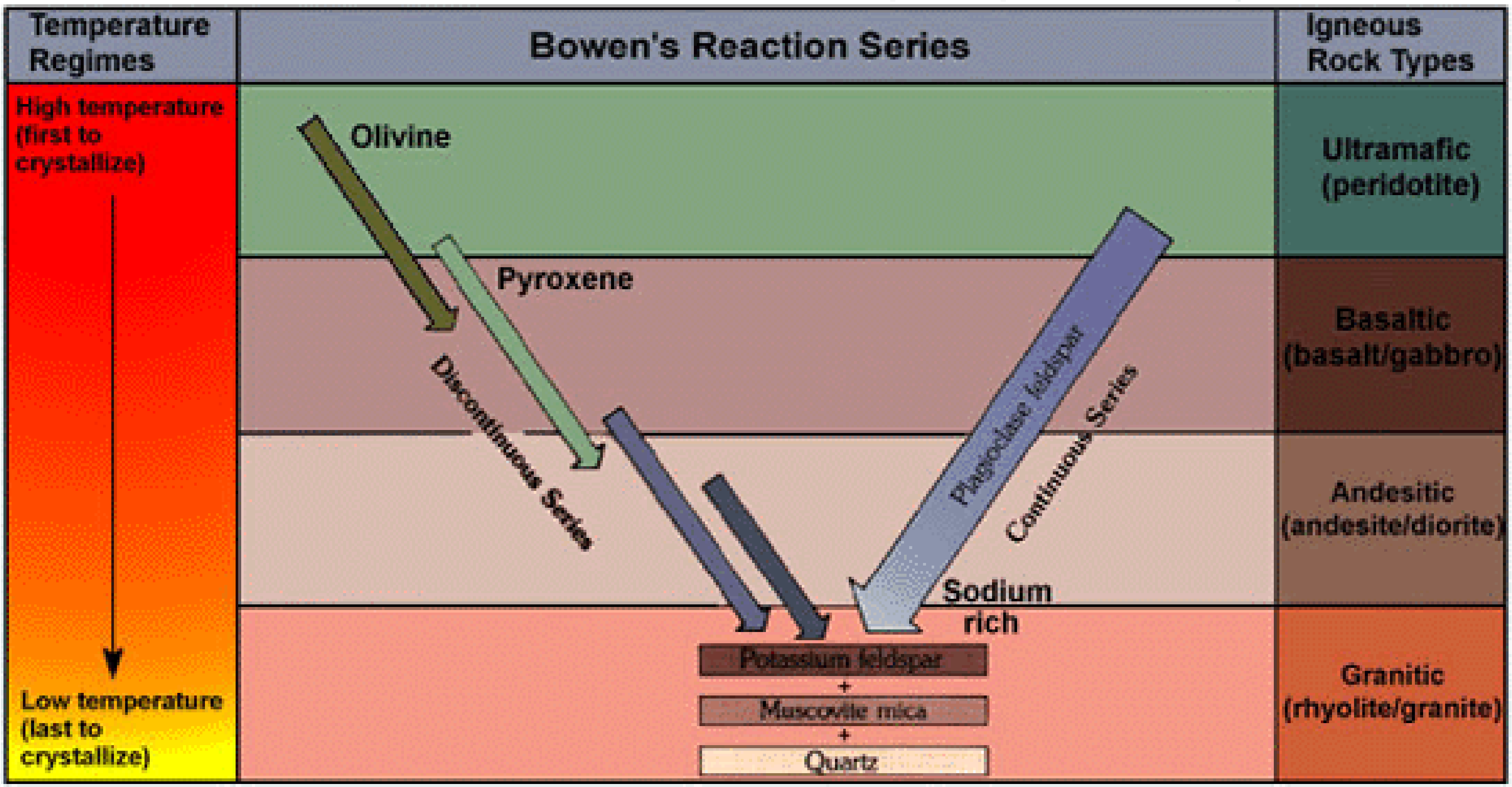
As a magma begins to cool, some minerals crystallize first, changing the composition of the magma.

Like game of Musical Chairs.



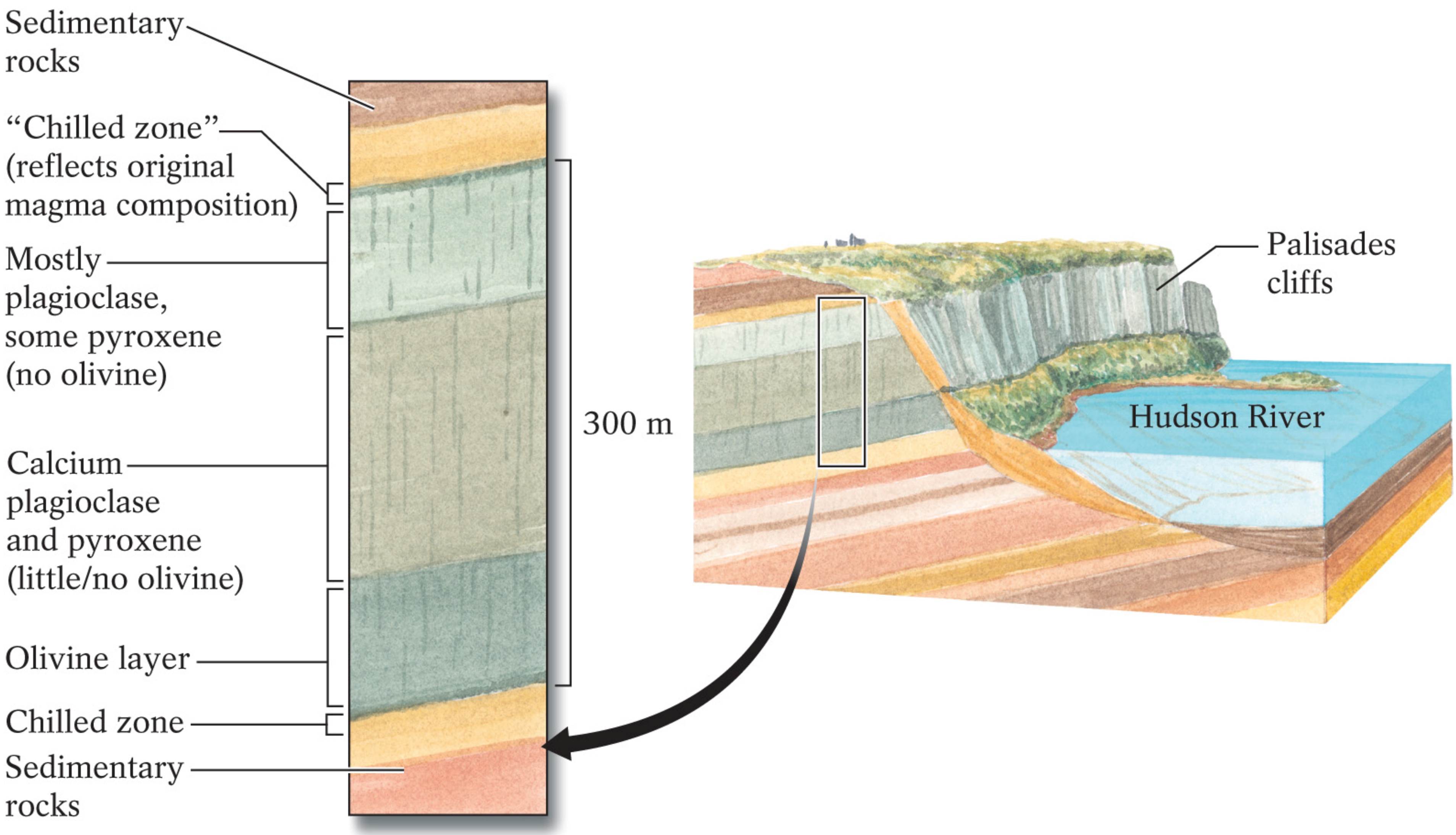
“Zoned” crystal

This also happens across different minerals. The last minerals to crystallize are quartz, sodium- and potassium-rich feldspars, and amphibole → granite!



See this in the Palisades Cliffs in NJ, along the Hudson River.

* 50 miles long, 1000 ft. thick, 200 MA
* Sill intruded into (cold) sediments
* Top and bottom show chilled basalt
* bottom layer is OLIVINE
* Layer above is PYROXENE rich
* top third is rich in Sodium-PLAGIOCLASE (Albite)


Sedimentary rocks
"Chilled zone" (reflects original magma composition)
Mostly plagioclase, some pyroxene (no olivine)
Calcium plagioclase and pyroxene (little/no olivine)
Olivine layer
Chilled zone
Sedimentary rocks
300 m
Palisades cliffs
Hudson River

Q. Why is it that there are large bodies of granite (batholiths) in the cores of mountain ranges?

Q. Why is it that there are large bodies of granite (batholiths) in the cores of mountain ranges? A. *Reversed* Bowen reaction series.

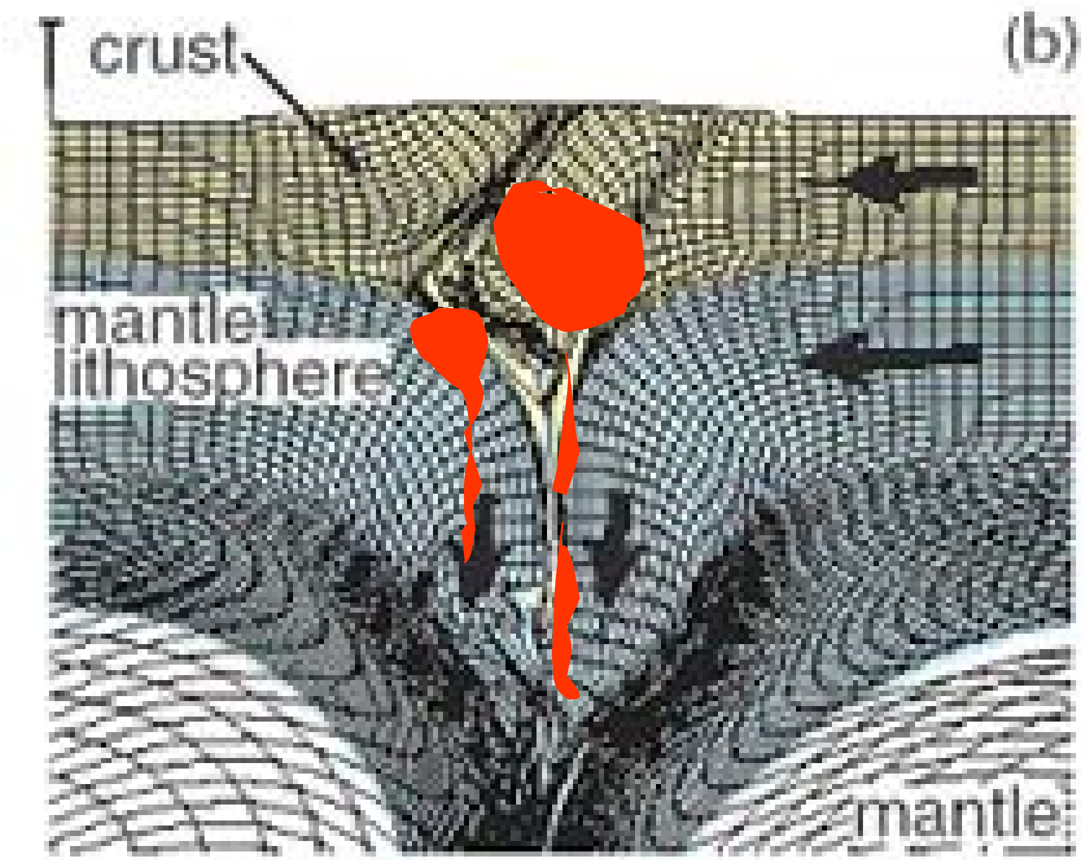
As continents collide, crust is pushed down, and melting begins.

The first minerals to melt are “granitic.”

They rise up, but often cool, before reaching the top of the mountain.

These granitic batholiths become exposed at surface when mountains erode.

Magma flows up



(b)

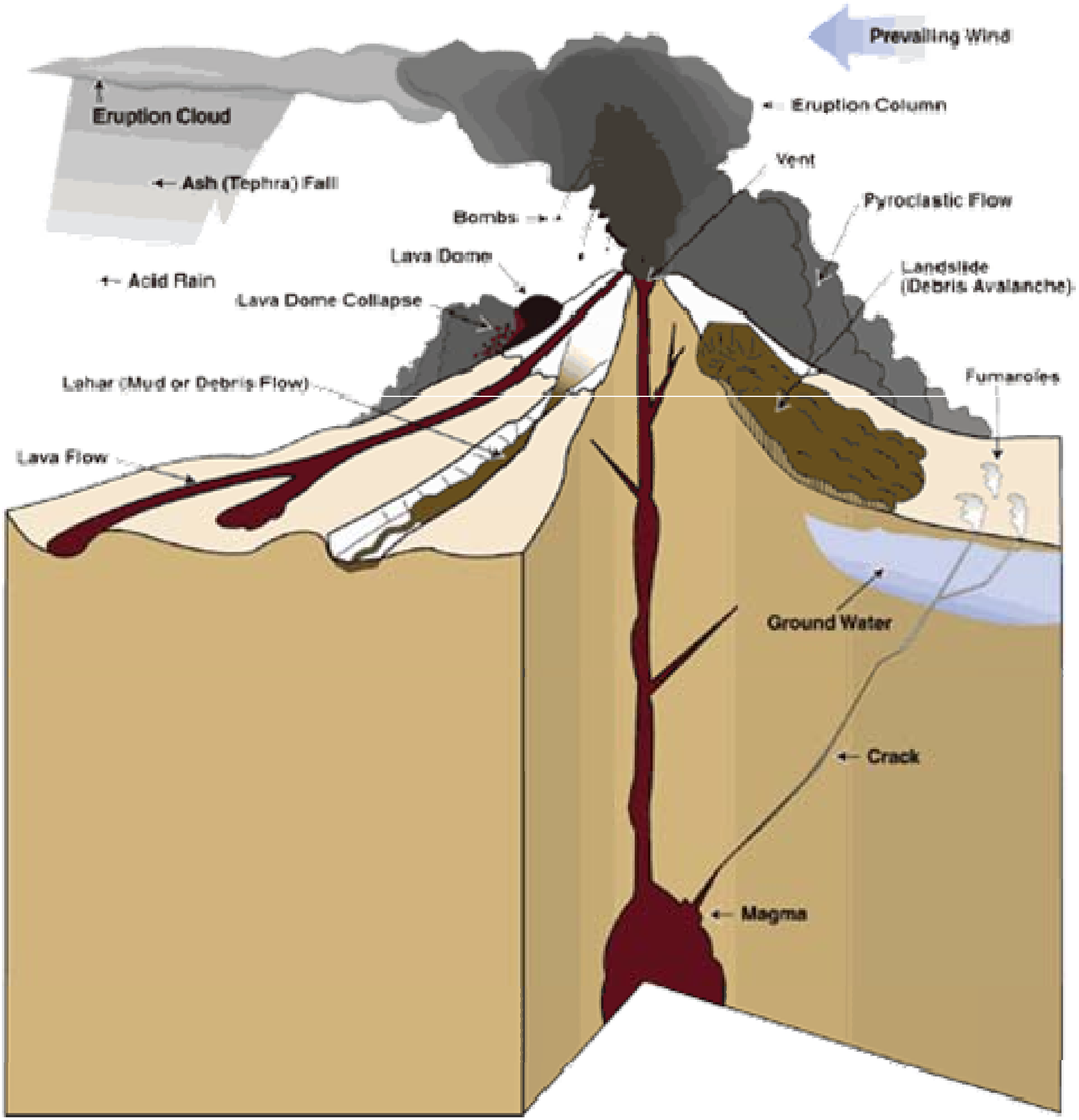
Pahoehoe lava, Hawaii

“Aa” lava flow, Kilauea, Hawaii

(b)

(c)

(b)



Prevailing Wind
Eruption Cloud
Eruption Column
Ash (Tephra) Fall
Vent
Pyroclastic Flow
Bombs
Lava Dome
Acid Rain
Landslide
(Debris Avalanche)
Lava Dome Collapse
Lahar (Mud or Debris Flow)
Fumaroles
Lava Flow
Ground Water
Crack
Magma

Pyroclastic flow
sweeps down the side of Mayon Volcano, Philippines, 1984.

Mt. Pinatubo, Philippines, 1991.

A small *lahar* triggered by rainfall in Guatemala, 1989.

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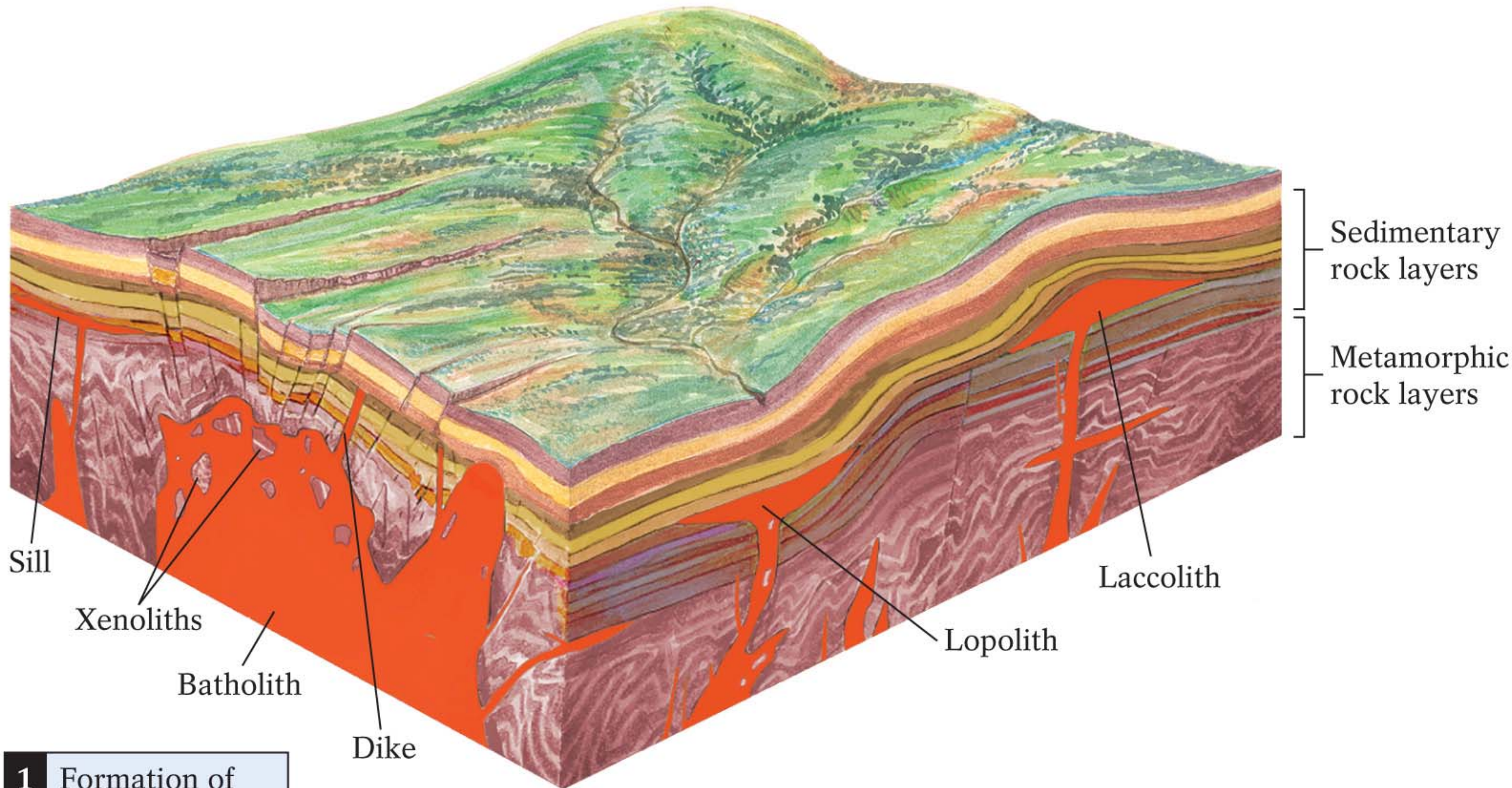
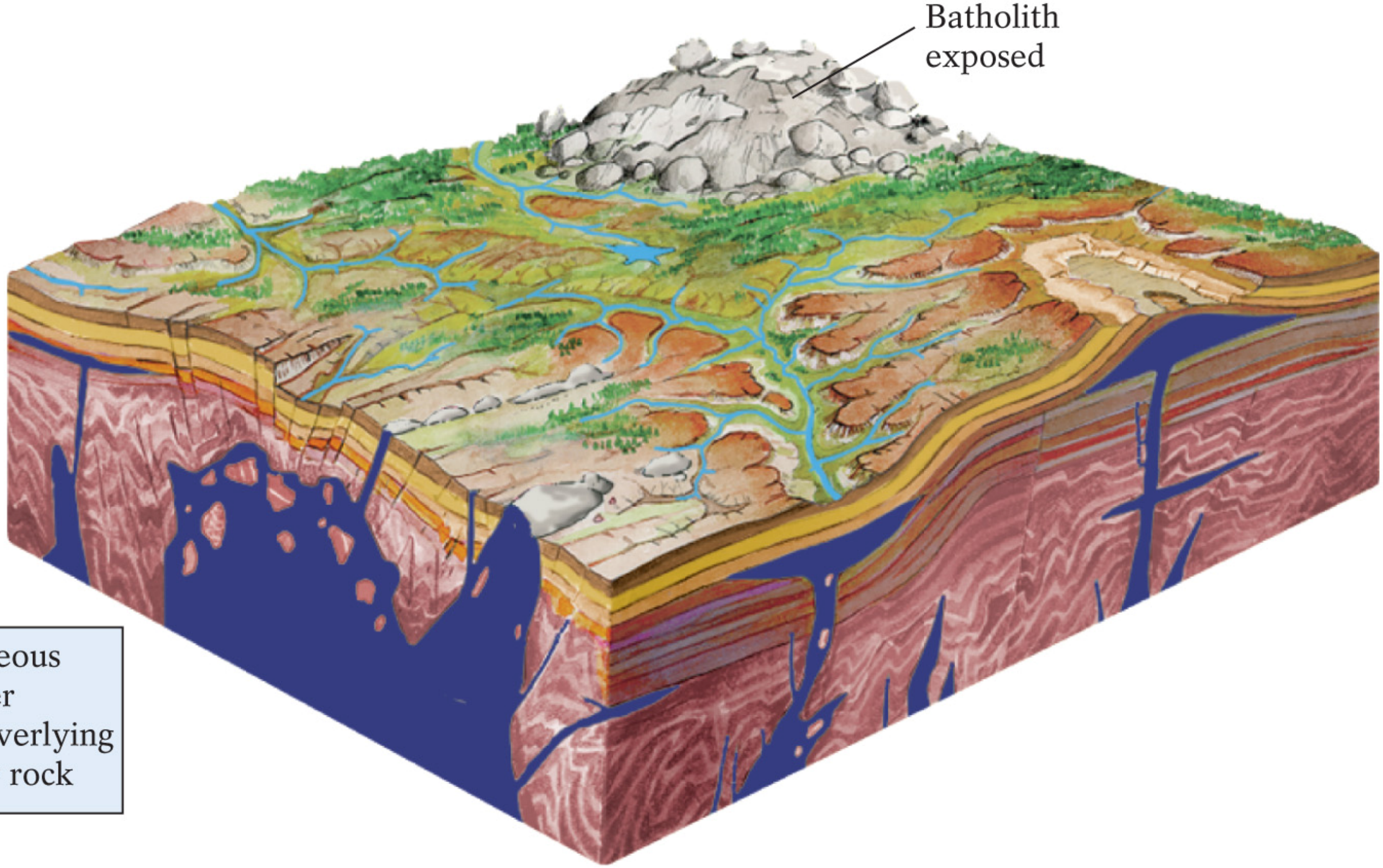
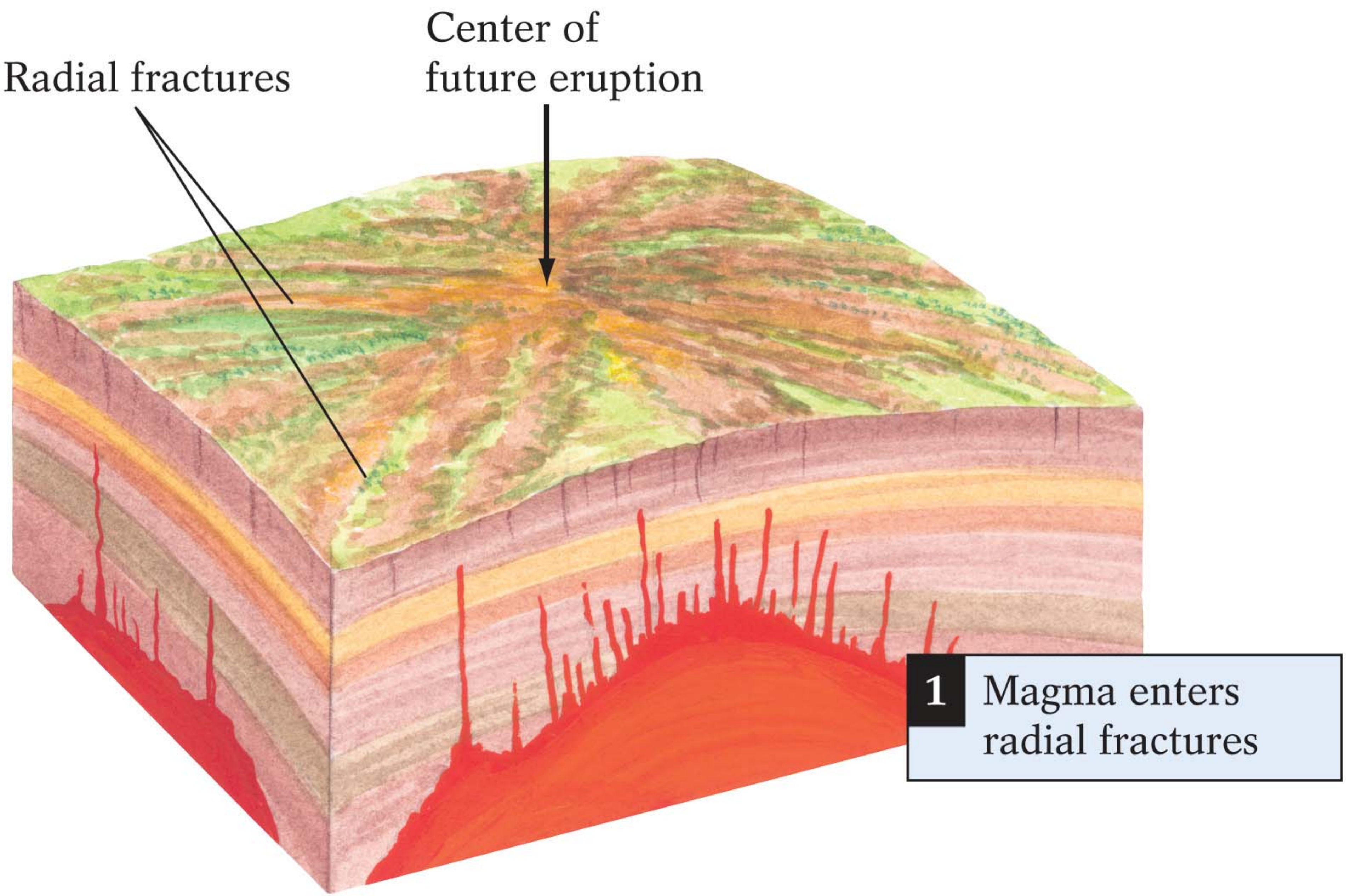


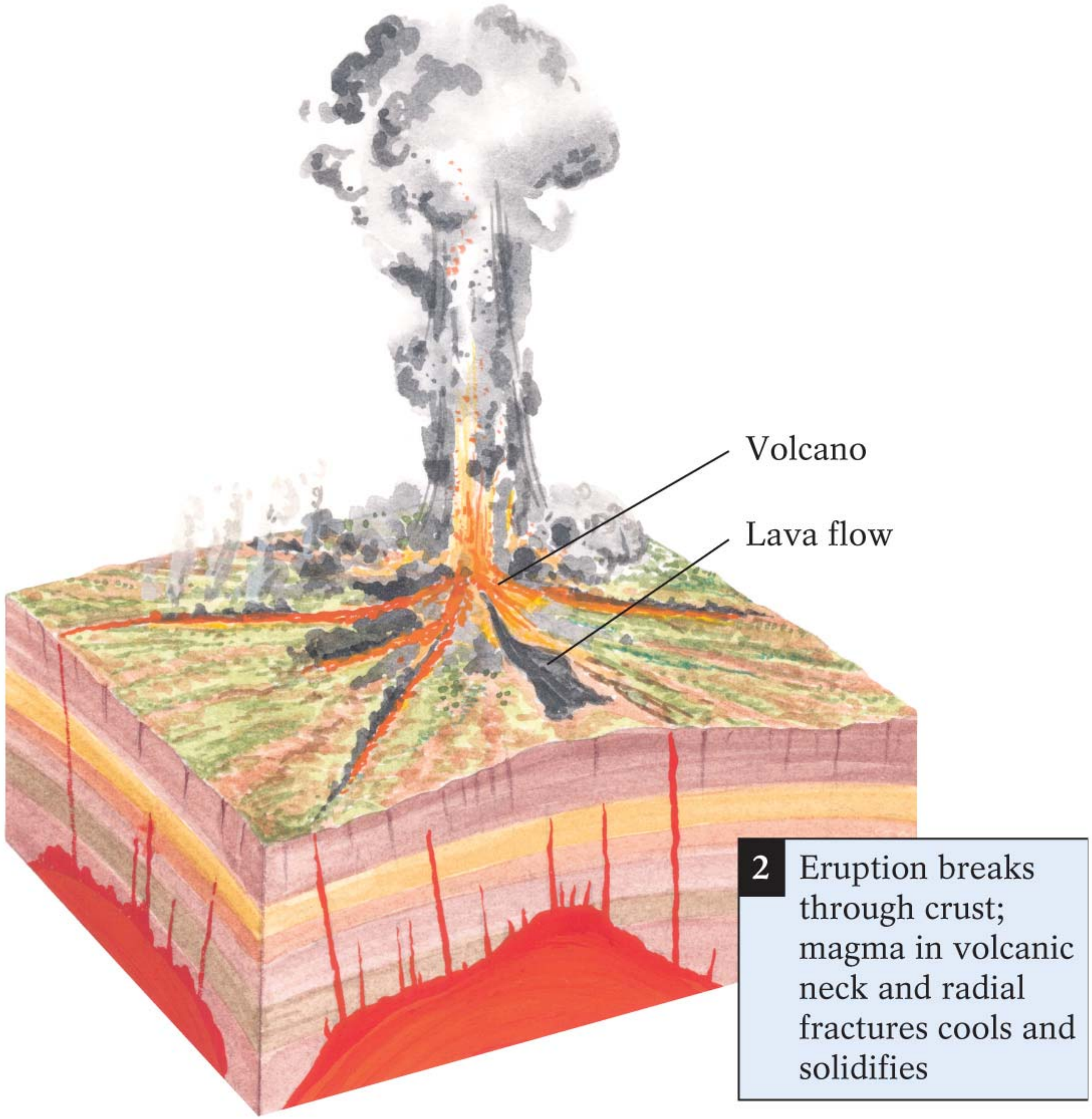
1 Formation of igneous features

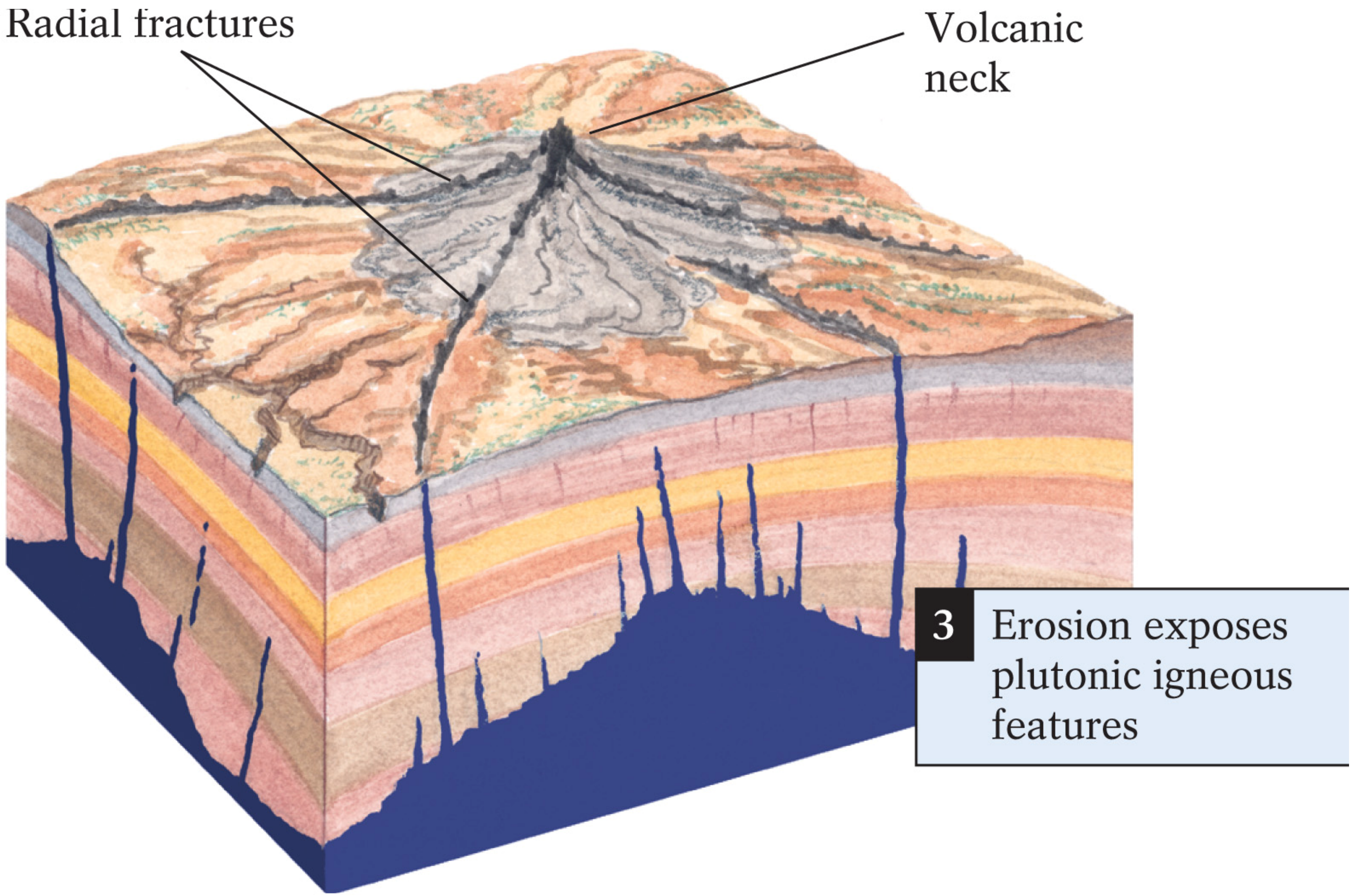


2 Plutonic igneous features after erosion of overlying sedimentary rock

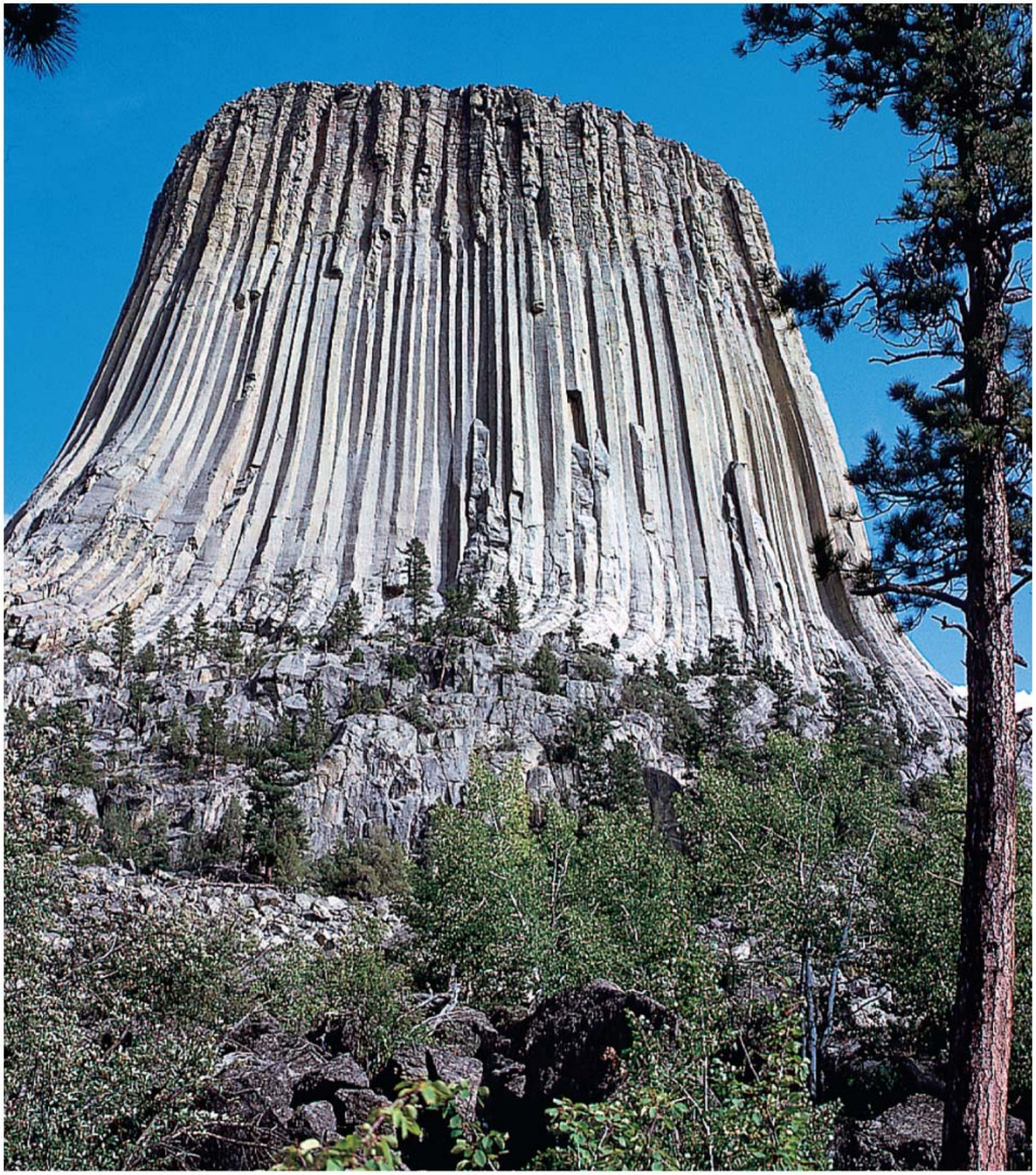
Migmatite


Radial fractures
Center of
future eruption
1
Magma enters
radial fractures


Volcano
Lava flow
2
Eruption breaks through crust; magma in volcanic neck and radial fractures cools and solidifies


Radial fractures
Volcanic neck
3 Erosion exposes plutonic igneous features

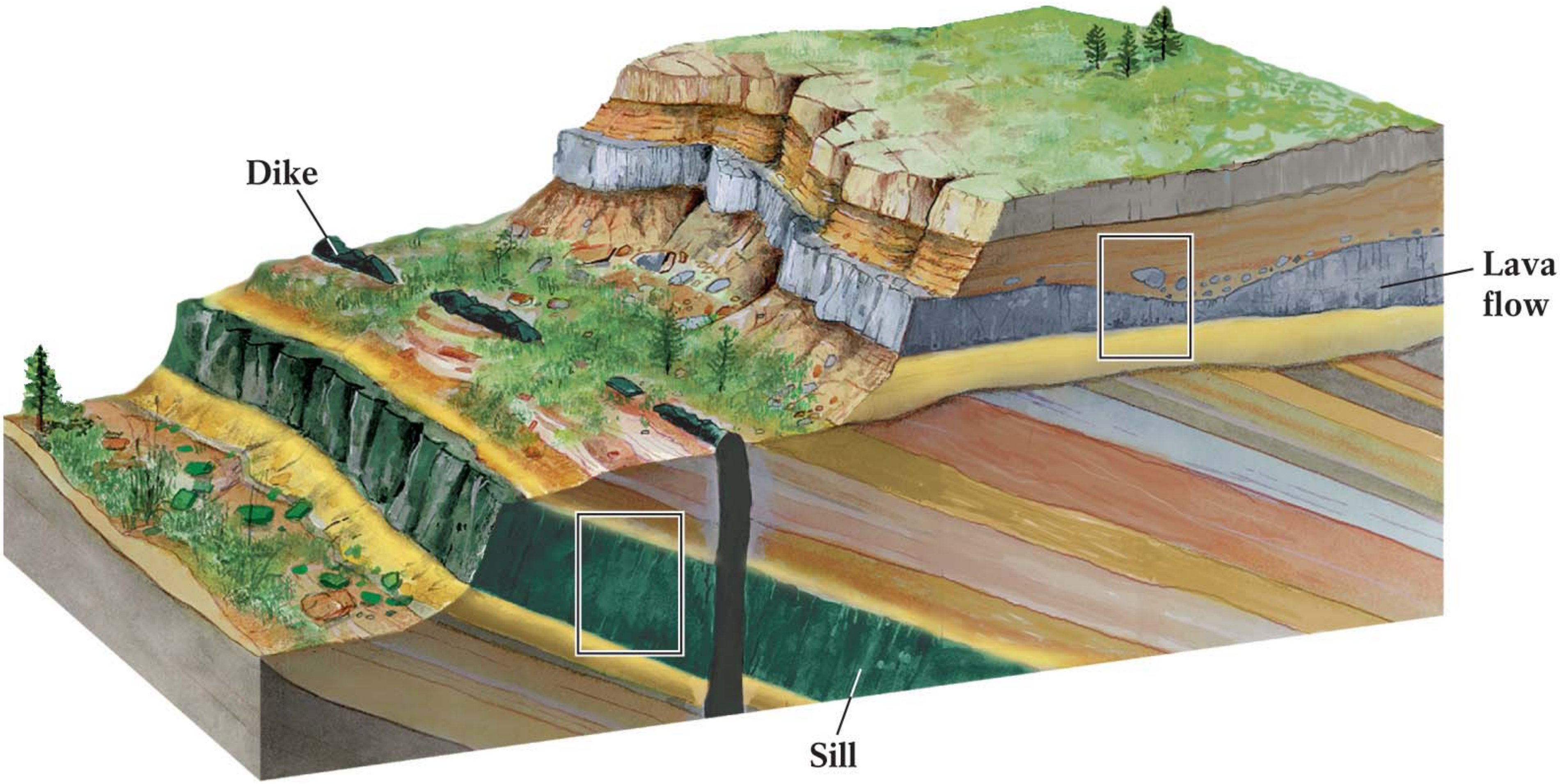
“Shiprock” (New Mexico)



(b)

(c)

Fingal's Cave, Island of Staffa


Dike
Lava flow
Sill

“Arthur’s Seat” (Edinburgh)

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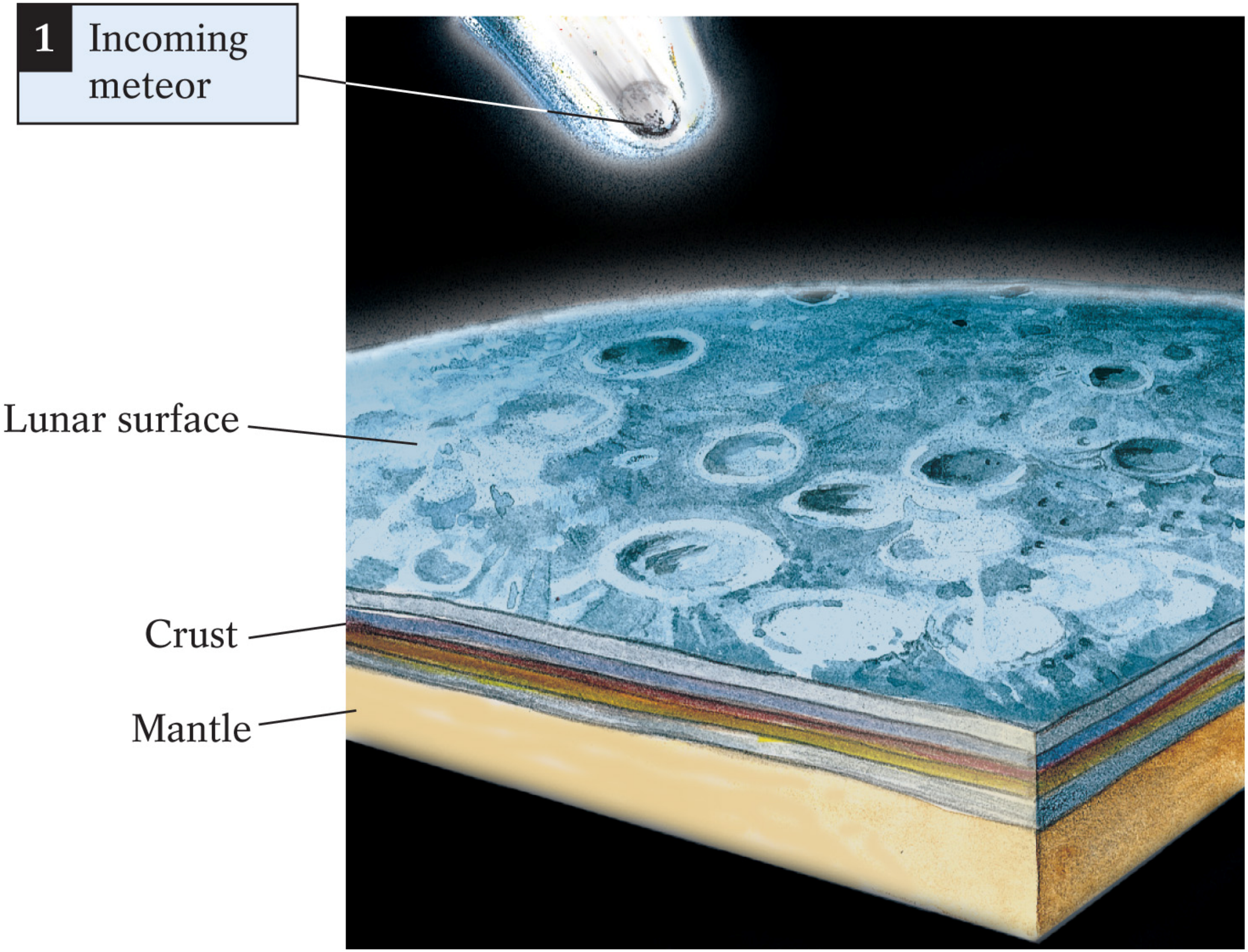
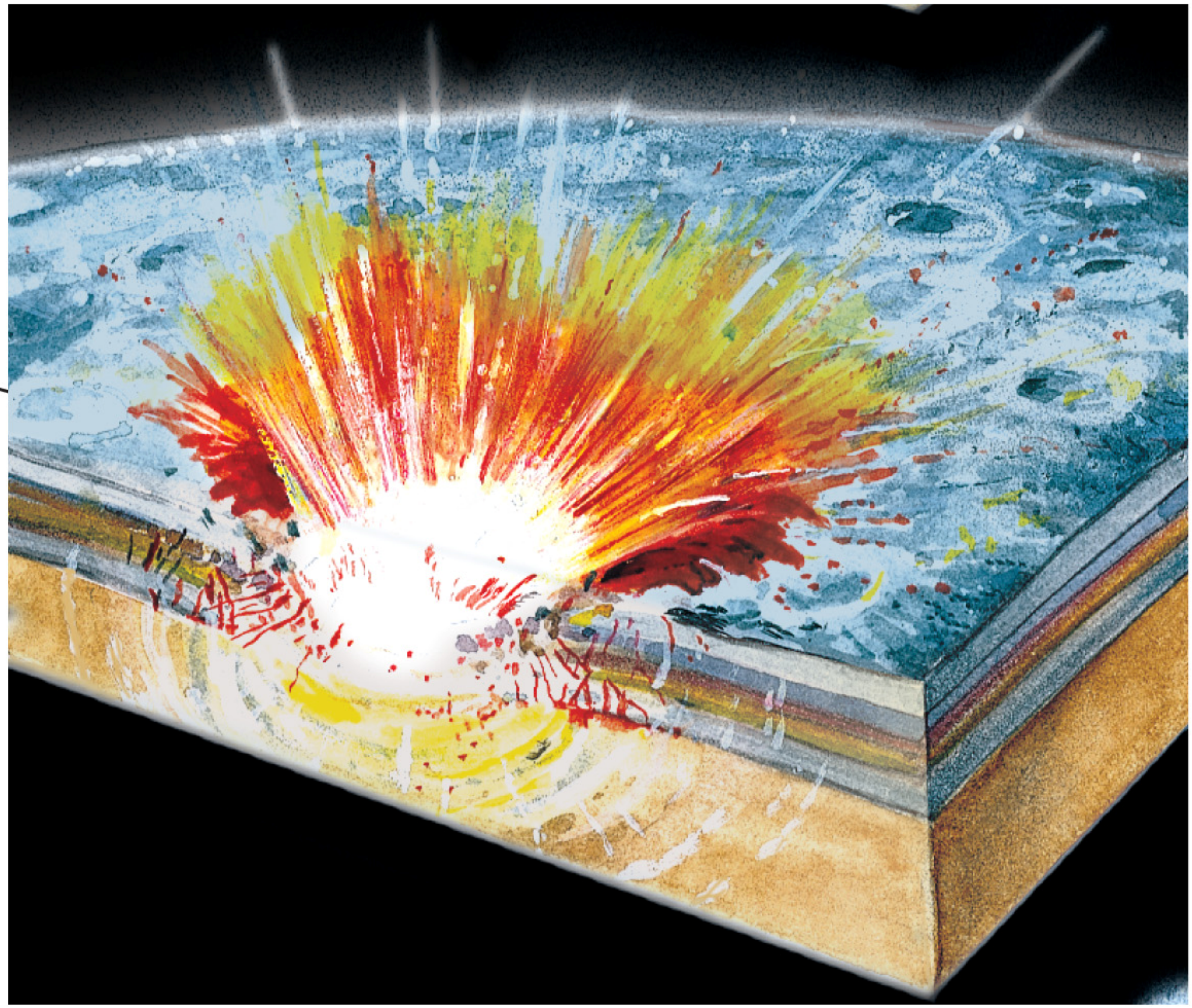
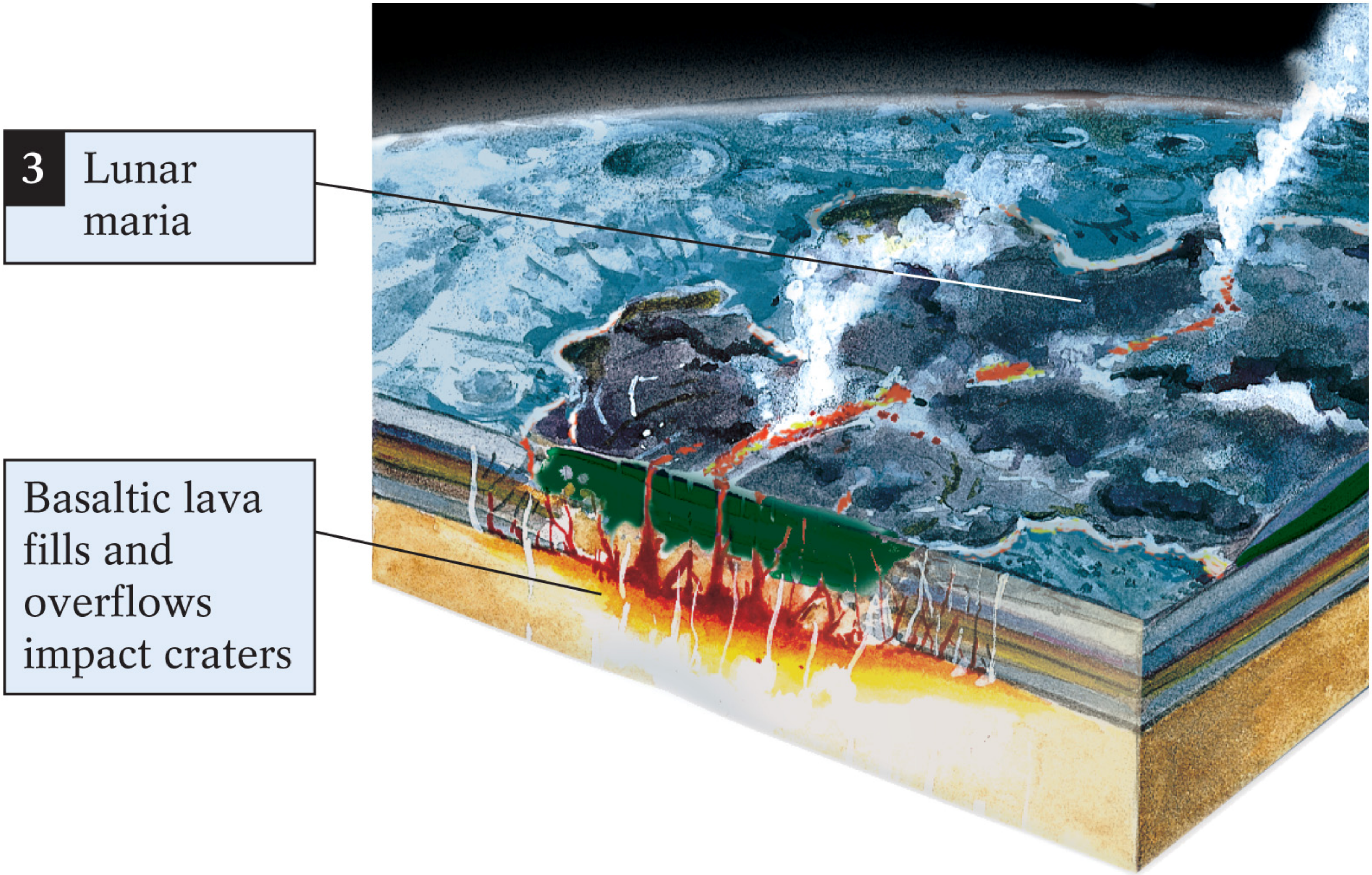
Crater Lake, Oregon


1 Incoming meteor
Lunar surface
Crust
Mantle

2 Meteor impact

Lunar crust broken and melted by impact. Upper mantle melts and wells up into fractured crust




3 Lunar maria
Basaltic lava fills and overflows impact craters