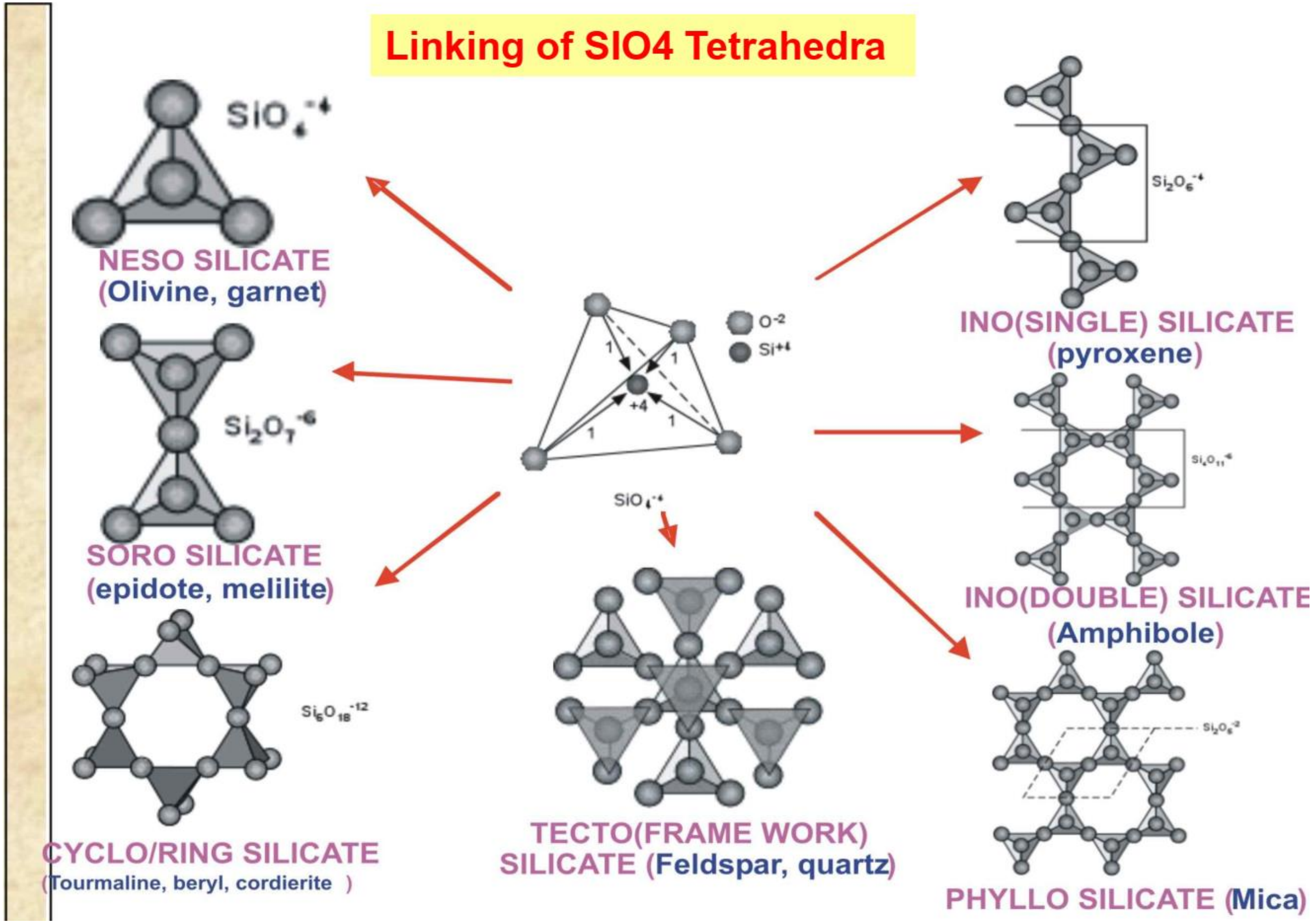
Earth and Planetary Sciences (ES1101)

(Minerals: Building Blocks of Rocks)

(Autumn 2020 by Gaurav Shukla)

Book: **1) Understanding Earth by Grotzinger & Jordan (Text Book)**
2) Earth: An introduction to Physical Geology by Tarbuck & Lutgens
3) The Solid Earth: An introduction to global geophysics by Fowler

Minerals Classification: Silicate Minerals



Minerals Classification: Silicate Minerals

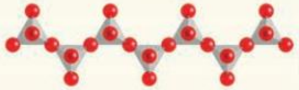
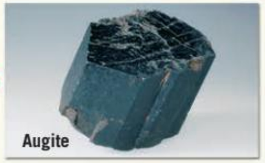
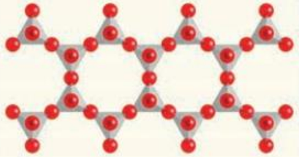
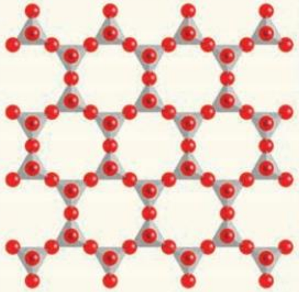
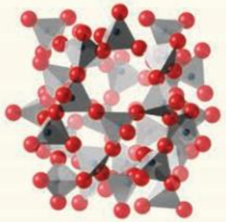
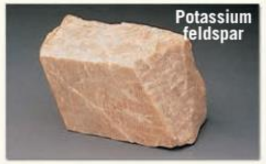
Table 11.1 Silicate Classification[a]

Silicate Class	Number of O^{2-} Shared per Tetrahedron	Z:O Ratio	Structural Configuration
Orthosilicates	0	1:4	Isolated tetrahedra
Disilicates	1	2:7	Double tetrahedra
Ring silicates	2	1:3	Rings of tetrahedra
Chain silicates			Chains of tetrahedra
Single chain	2	1:3	
Double chain	2 or 3	4:11	
Sheet silicates	3	2:5	Sheets of tetrahedra
Framework silicates	4	1:2	Framework of tetrahedra

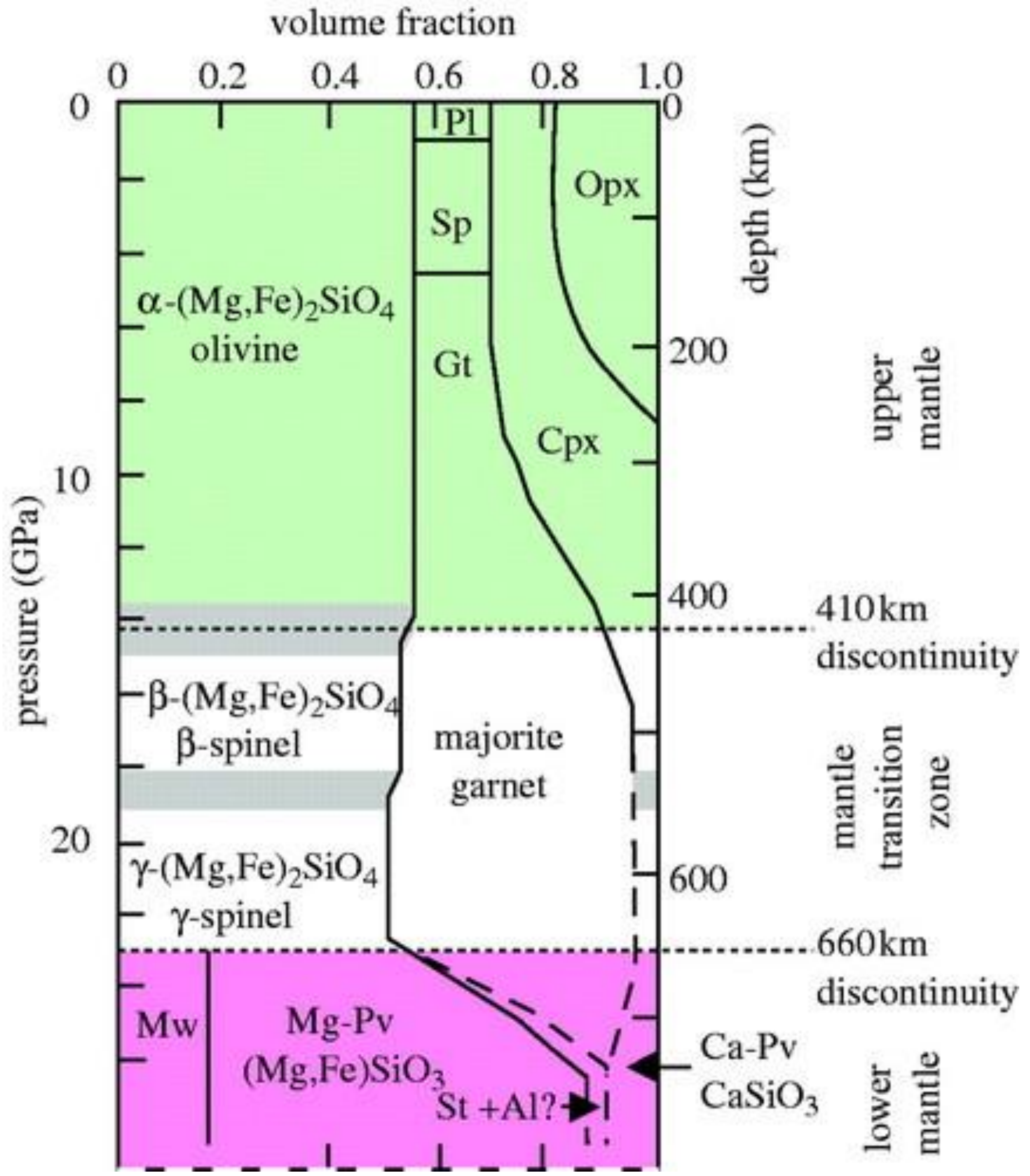
[a] Z refers to the cation(s), usually Si^{4+}, and also Al^{3+}, that occupy the tetrahedral sites.

Minerals Classification:
Silicate Minerals

Common Silicate Minerals and Mineral Groups

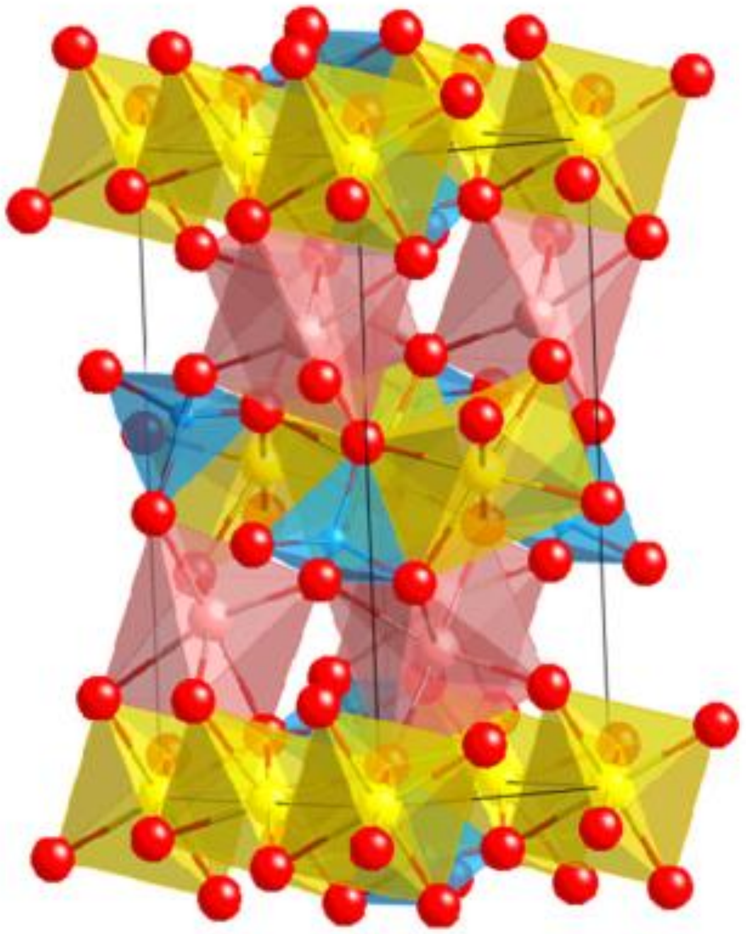
	Mineral/Formula	Cleavage	Silicate Structure	Example
	Olivine group $(Mg,Fe)_2SiO_4$	**None**	**Single tetrahedra** 	
	Pyroxene group (Augite) $(Mg,Fe,Ca,Na)AlSiO_3$	**Two planes at 90°**	**Single chains** 	
	Amphibole group (Hornblende) $Ca_2(Fe,Mg)_5Si_8O_{22}(OH)_2$	**Two planes at 60° and 120°**	**Double chains** 	
Micas	**Biotite** $K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$	**One plane**	**Sheets** 	
Micas	**Muscovite** $KAl_2(AlSi_3O_{10})(OH)_2$			
Feldspars	**Potassium feldspar (Orthoclase)** $KAlSi_3O_8$	**Two planes at 90°**	**Three-dimensional networks** 	
Feldspars	**Plagioclase** $(Ca,Na)AlSi_3O_8$			
	Quartz SiO_2	**None**		

Phase Transitions in Olivine

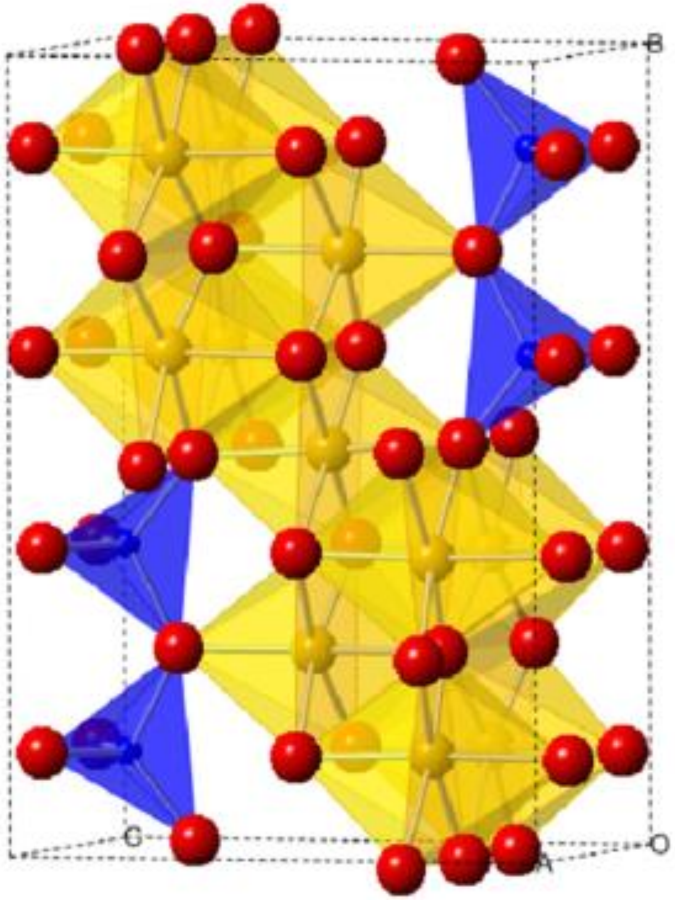


https://royalsocietypublishing.org/doi/10.1098/rsta.2005.1675

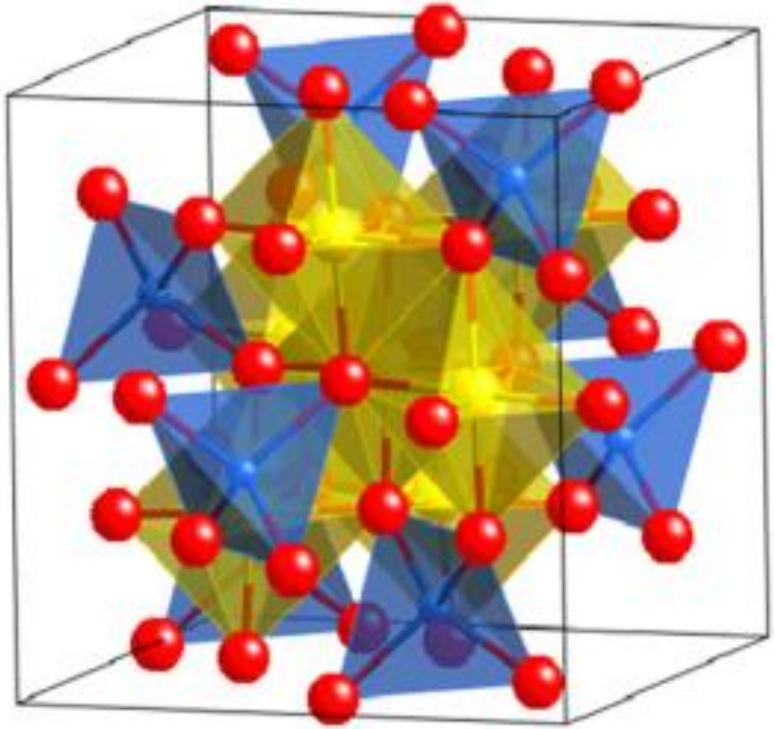
Phase Transitions in Olivine



olivine

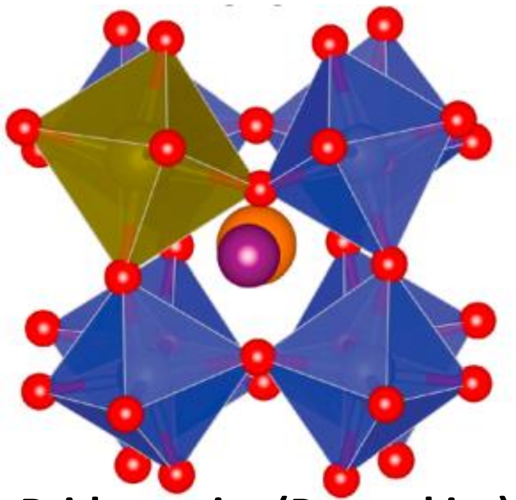


wadsleyite

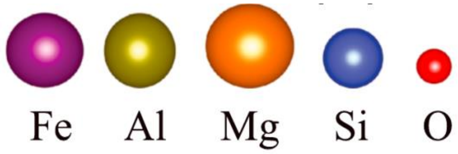


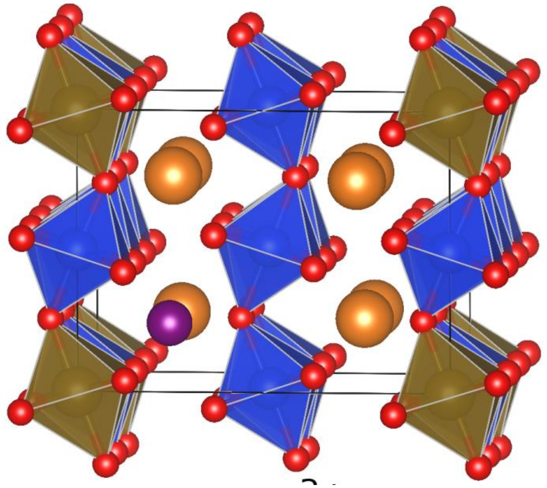
ringwoodite

Phase Transitions in Bridgmanite



Bridgmanite (Perovskite), Orthorhombic





Post-perovskite, Orthorhombic (expected to be in the D'' region)

Exploring Earth’s Interior using Seismic Waves

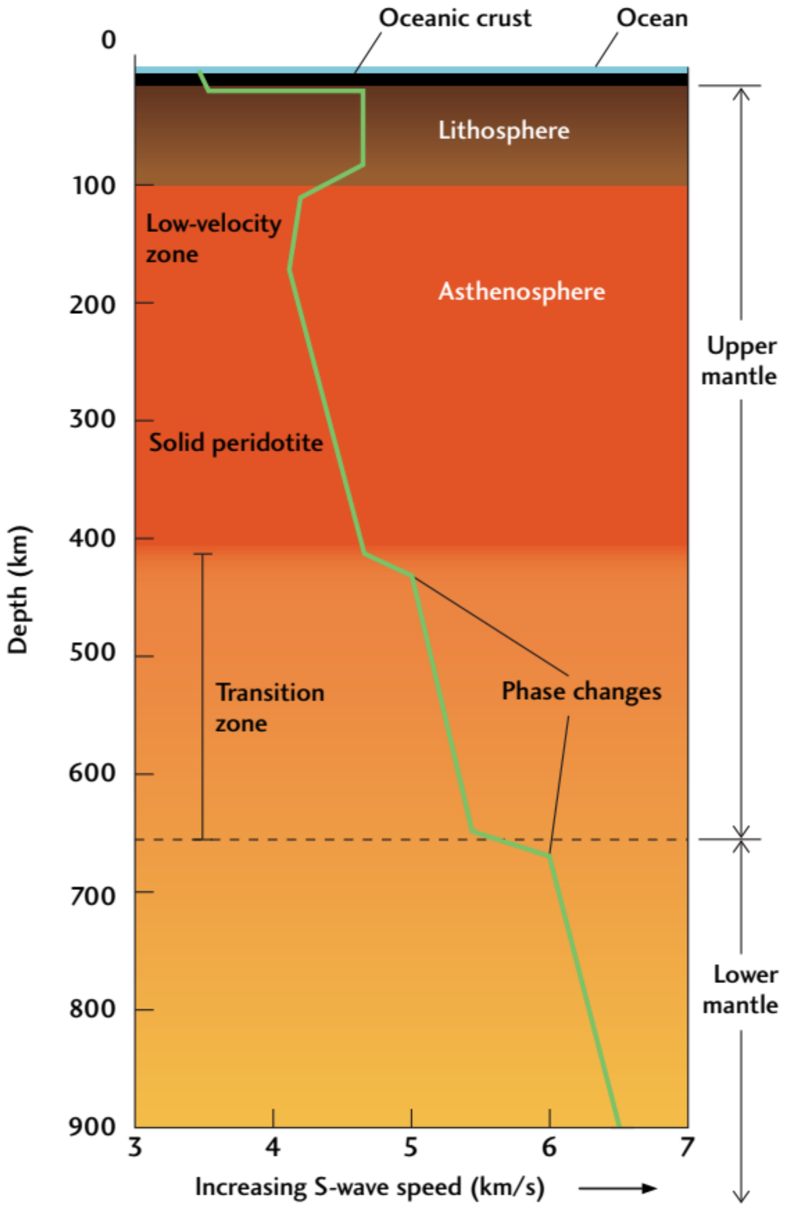


FIGURE 14.8 ■ The structure of the mantle beneath old oceanic lithosphere, showing S-wave velocities to a depth of 900 km. Changes in S-wave velocity mark the strong, brittle lithosphere, the weak, ductile asthenosphere, and a transition zone, in which increasing pressure forces rearrangements of atoms into denser and more compact crystal structures (phase changes).

Compositional Variation in Minerals

- During chemical analysis of different samples of *a mineral*, it is routinely found that these samples do not have same chemical composition (Definite but not a fixed chemical composition).

- Composition variation is possible because different cations can interchangeably occupy the various sites. The term applied to this compositional variation is **solid solution**.

- Practically all naturally occurring minerals containing Fe-Mg-Mn-Ca or Na-K etc. are solid solutions.

- Quartz (SiO_2) is not a solid solution.

Compositional Variation in Minerals

Substitution Solid Solution: Substitution of one cation for another.

- ➢ Requirement for substitution solid solution:
  - Ion sizes must be similar
  - Charge neutrality must be maintained
  - Similar electronegativity

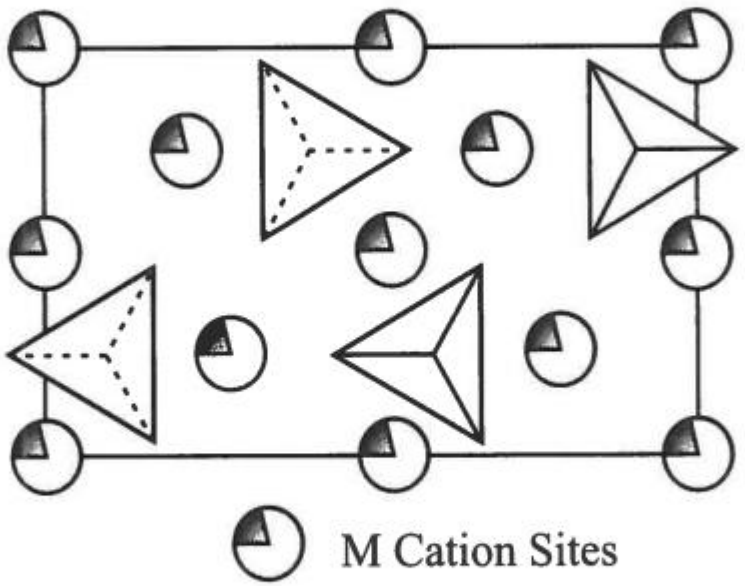
- ✓ If the difference in ion size is less than 15%, extensive substitution is possible.
- ✓ If the size difference is ~15-30%, limited substitution possible.
- ✓ If the size difference is greater than 30%, substitution is very unlikely.

- ➢ ***Temperature*** has a substantial influence on the degree to which ions of different sizes may substitute for each other.

Compositional Variation in Minerals

Substitution Solid Solution: Substitution of one cation for another.

- **Simple substitution:**
  Olivine, Forsterite (Mg_2SiO_4)-Fayalite (Fe_2SiO_4) end members



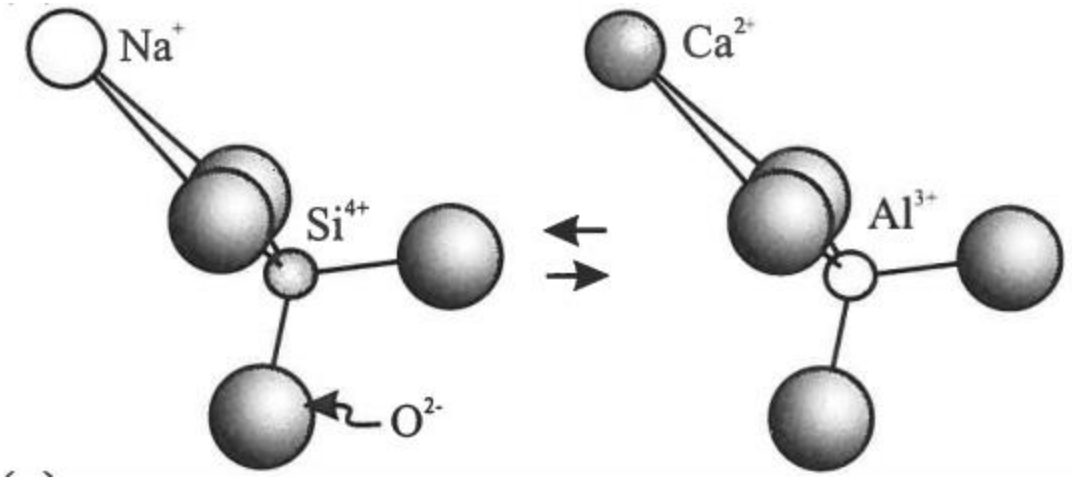
- The structure is viewed down the a-axis
- Octahedral M-sites or occupied by Mg^{2+} or Fe^{2+}
- The shaded wedge shown on M-sites represents the occupation of Fe^{2+}. In this case 22%.

Compositional Variation in Minerals

- **Coupled substitution:** Coupled substitution maintains a charge balance by coupling one substitution that increases the charge with another that reduces the charge.
  Example: Plagioclase: Albite (NaAlSi3O8)-Anorthite (CaAl2Si2O8) end members

- Ca^{2+} and Na^{+} both occupy distorted 8-fold coordination sites.
- Si^{4+} and Al^{3+} both occupy tetrahedral coordination sites.

  $Ca^{2+} + Al^{3+} = Na^{+} + Si^{4+}$



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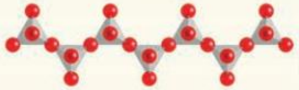
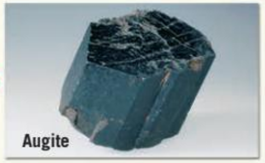
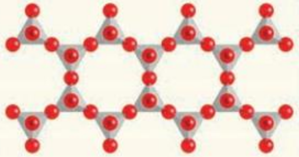
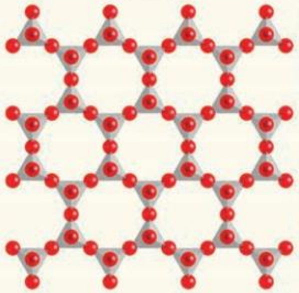
	Pyroxene group (Augite) $(Mg,Fe,Ca,Na)AlSiO_3$	Two planes at 90°	Single chains 	
	Amphibole group (Hornblende) $Ca_2(Fe,Mg)_5Si_8O_{22}(OH)_2$	Two planes at 60° and 120°	Double chains 	
Micas	**Biotite** $K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$	One plane	Sheets 	
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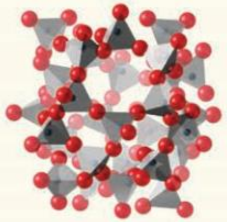
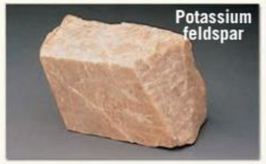
Feldspars	**Potassium feldspar (Orthoclase)** $KAlSi_3O_8$	Two planes at 90°	Three-dimensional networks 	
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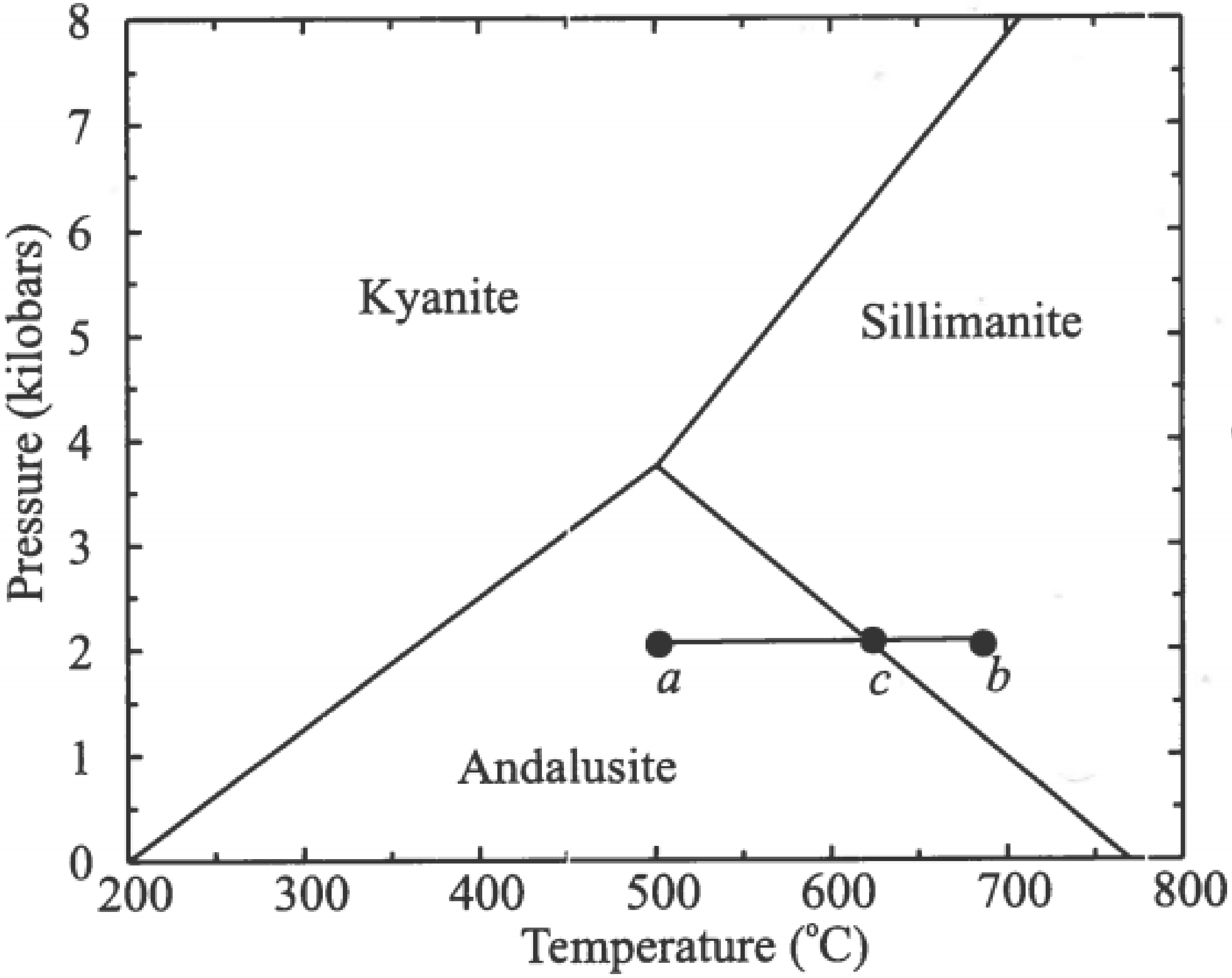
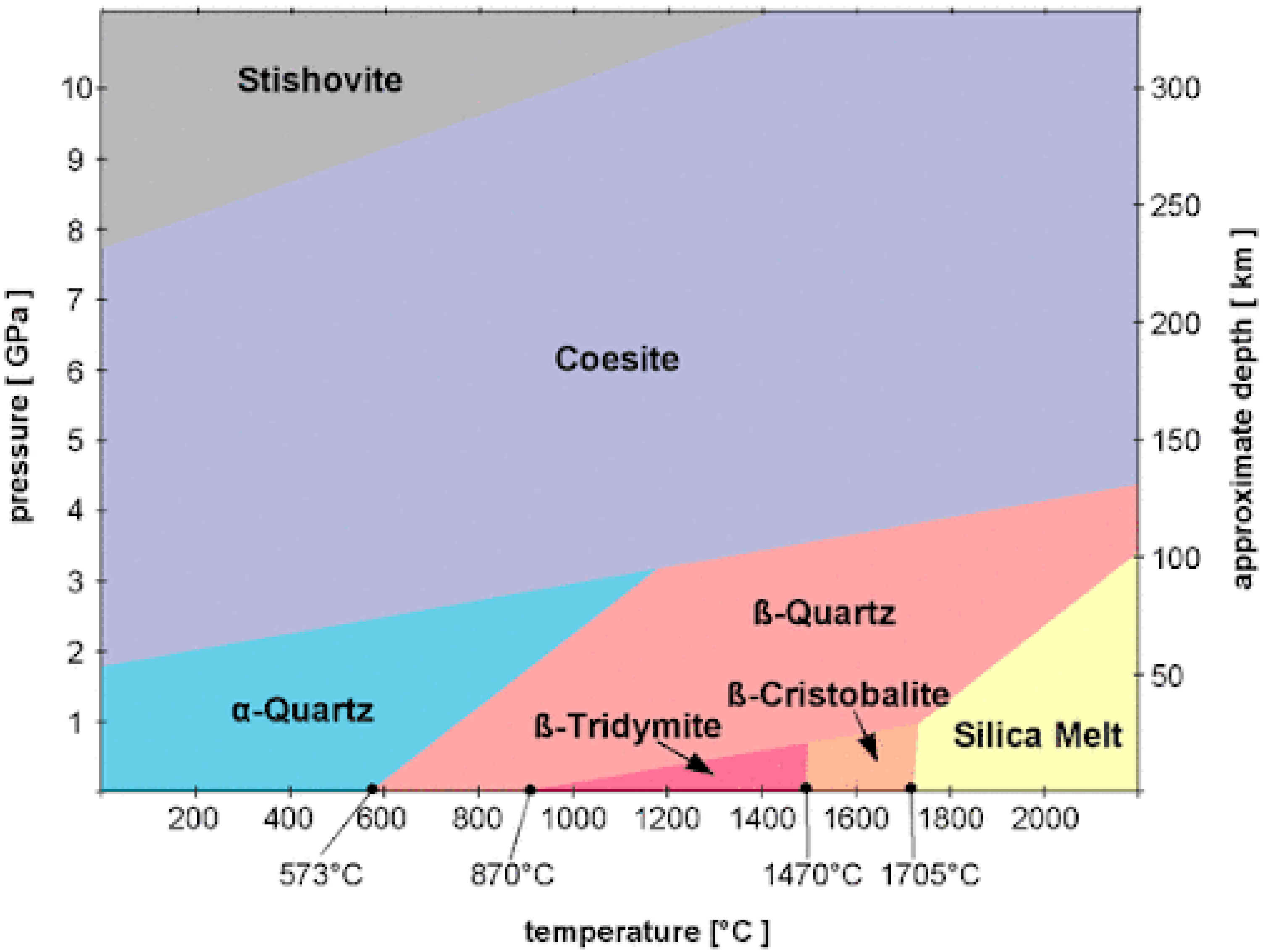
	Quartz SiO_2	None		

Polymorphism: Al_2SiO_5



Polymorphism: SiO_2



Polymorphism: SiO_2

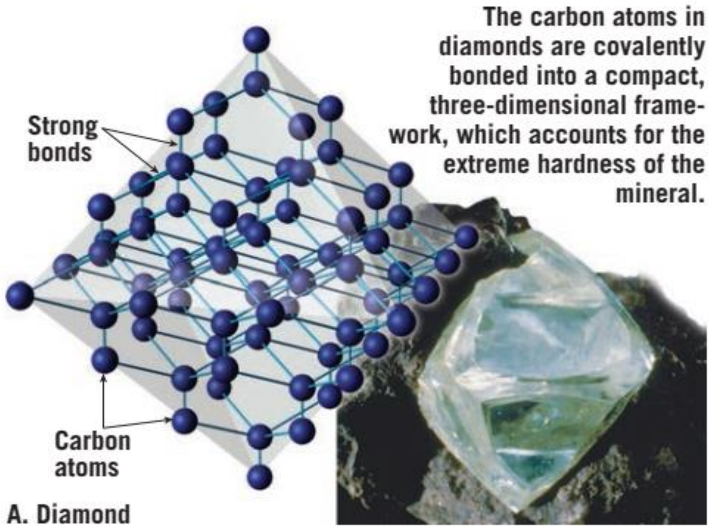
Meteor Crater, also known as Barringer Crater (Arizona, USA)

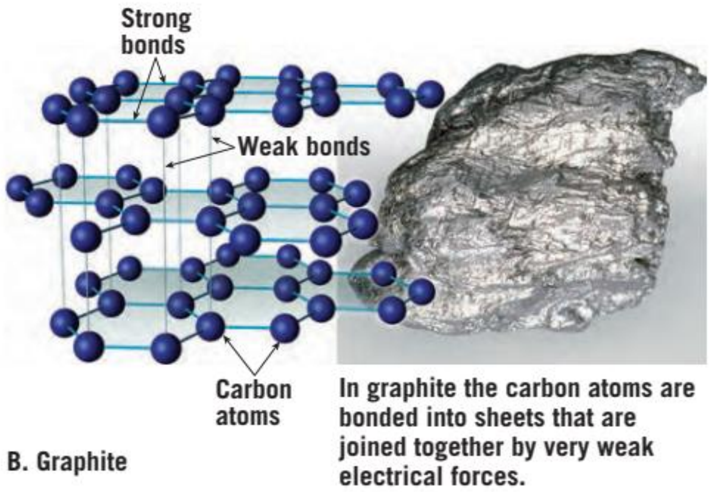
https://en.wikipedia.org/wiki/Meteor_Crater

Impact crater/structure	
Confidence	Confirmed[1]
Diameter	0.737 miles (1.186 km)
Depth	560 feet (170 m)
Rise	148 feet (45 m)
Impactor diameter	160 feet (50 m)
Age	50,000 years

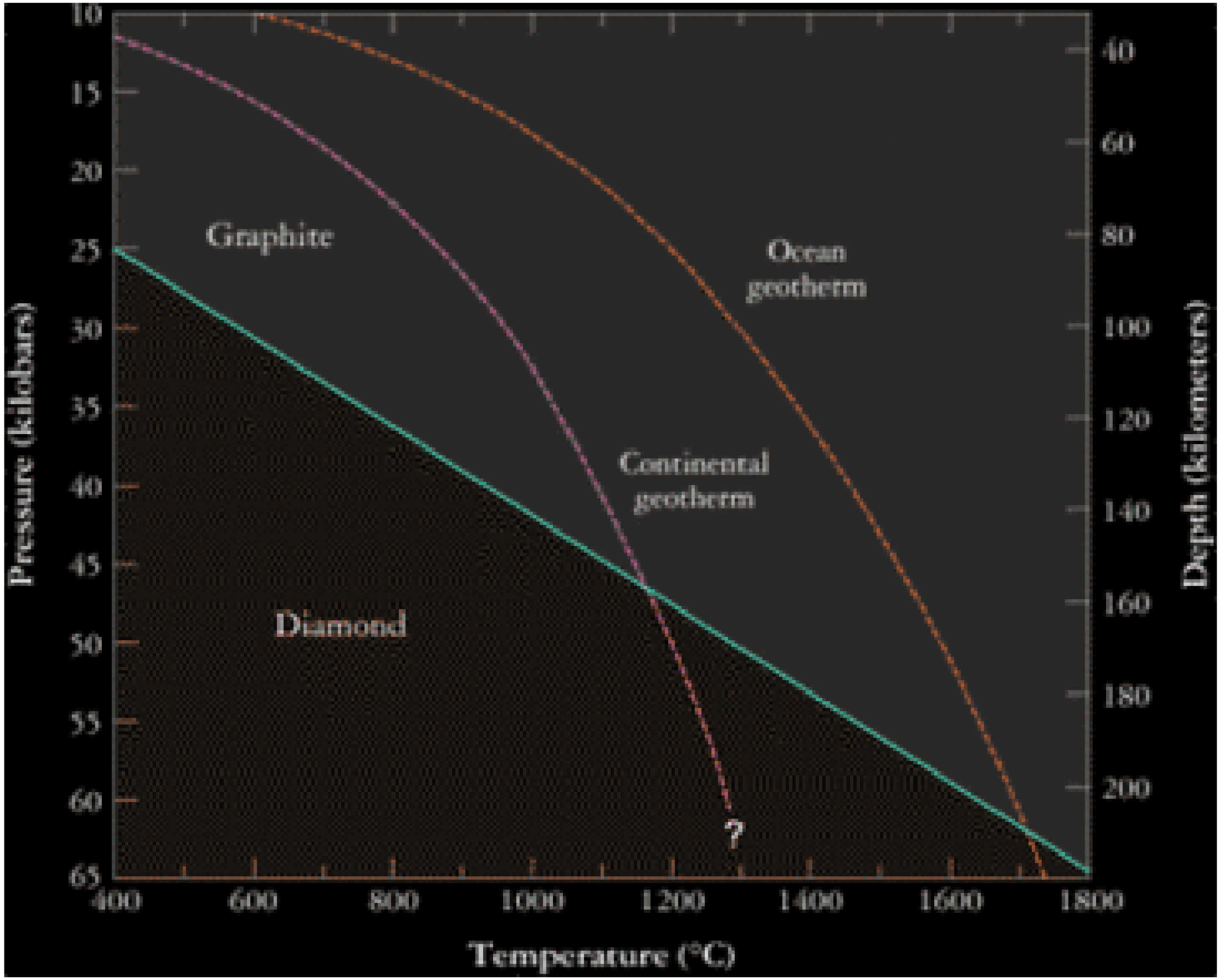
Polymorphism: Carbon

Figure 3.29
Diamond versus graphite
Both diamond and graphite are natural substances with the same chemical composition: carbon atoms. Nevertheless, their internal structures and physical properties reflect the fact that each formed in a very different environment. (Photo A Marcel Clemens/Shutterstock; photo B by E. J. Tarbuck)





Polymorphism: Carbon



Polymorphism

Table 4.4 Common Polymorphic Mineral Groups

Chemical Composition	Mineral Name
SiO_2	α-Quartz
	β-Quartz
	α-Tridymite
	β-Tridymite
	Cristobalite
	Coesite
	Stishovite
FeS_2	Pyrite
	Marcasite
C	Graphite
	Diamond
$AlAlOSiO_4$	Andalusite
	Sillimanite
	Kyanite
$KAlSi_3O_8$	Sanidine
	Orthoclase
	Microcline