# Feldspars

Orthoclase

Amazonite

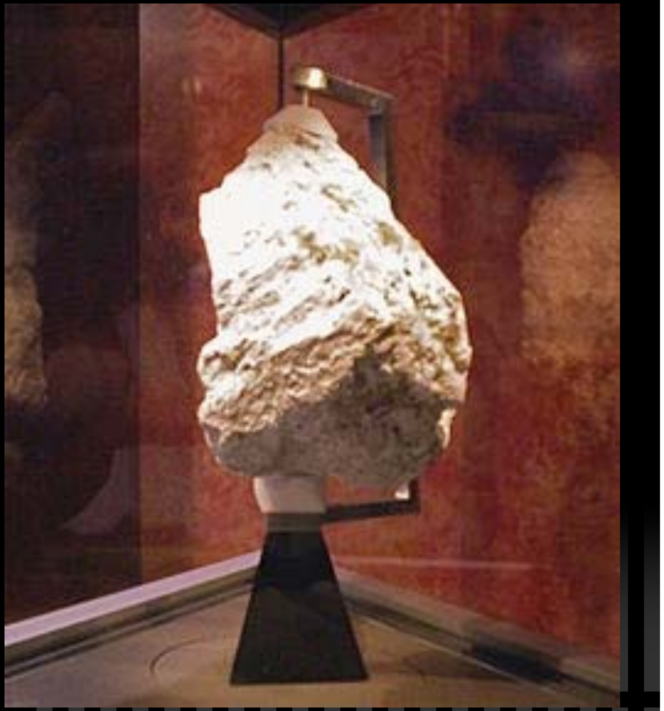
Green microcline

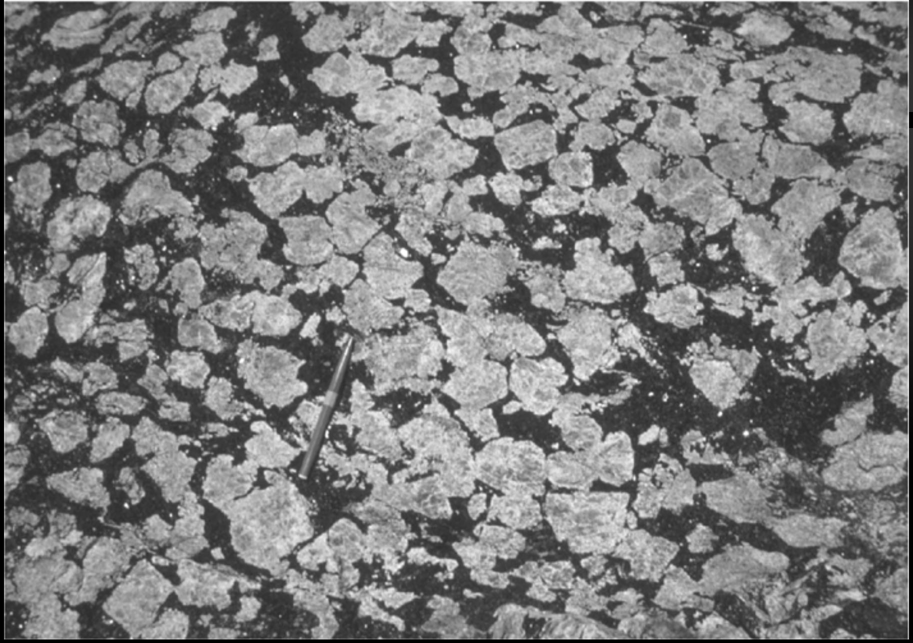
Orthoclase

Carlsbad
twinning

Sanidine

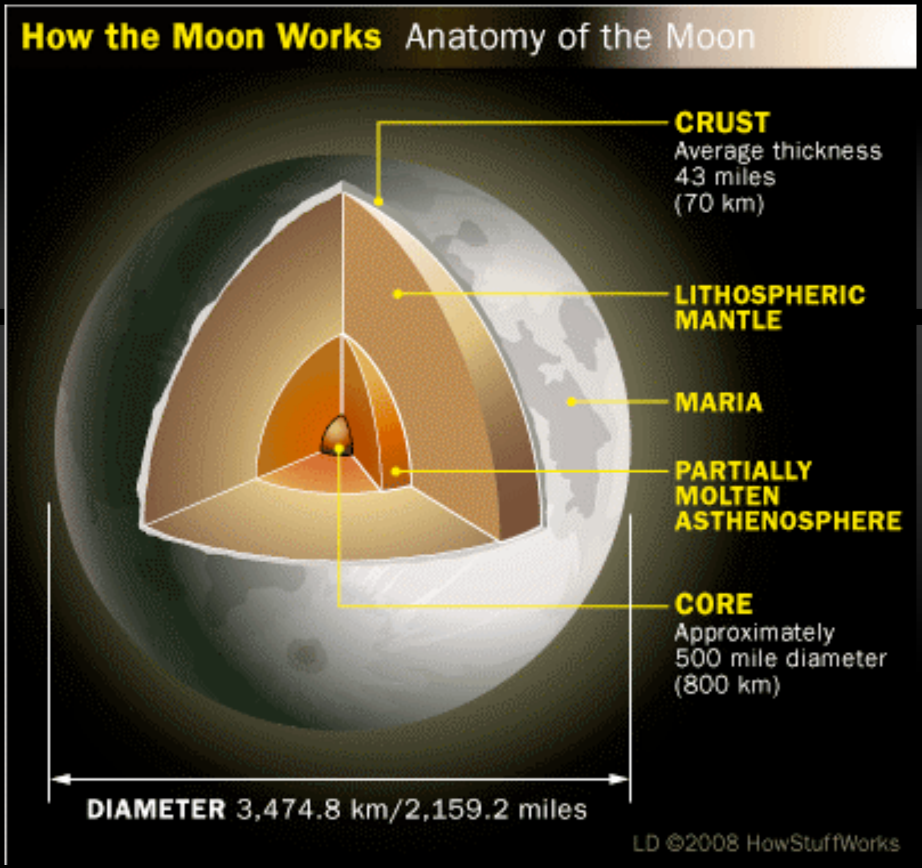
# Anorthosites

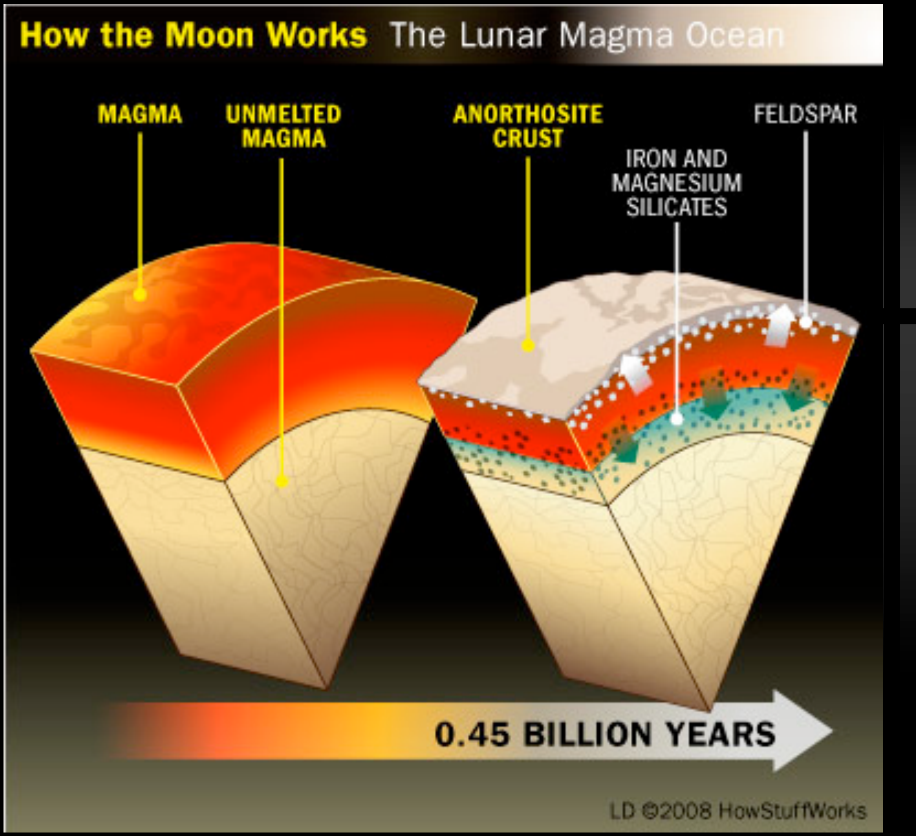




Nearly 100 % feldspar!!!

# Moon


How the Moon Works Anatomy of the Moon
CRUST
Average thickness 43 miles (70 km)
LITHOSPHERIC MANTLE
MARIA
PARTIALLY MOLTEN ASTHENOSPHERE
CORE
Approximately 500 mile diameter (800 km)
DIAMETER 3,474.8 km/2,159.2 miles
LD ©2008 HowStuffWorks


How the Moon Works The Lunar Magma Ocean
MAGMA
UNMELTED MAGMA
ANORTHOSITE CRUST
IRON AND MAGNESIUM SILICATES
FELDSPAR
0.45 BILLION YEARS
LD ©2008 HowStuffWorks

# Structure and chemistry of the feldspars

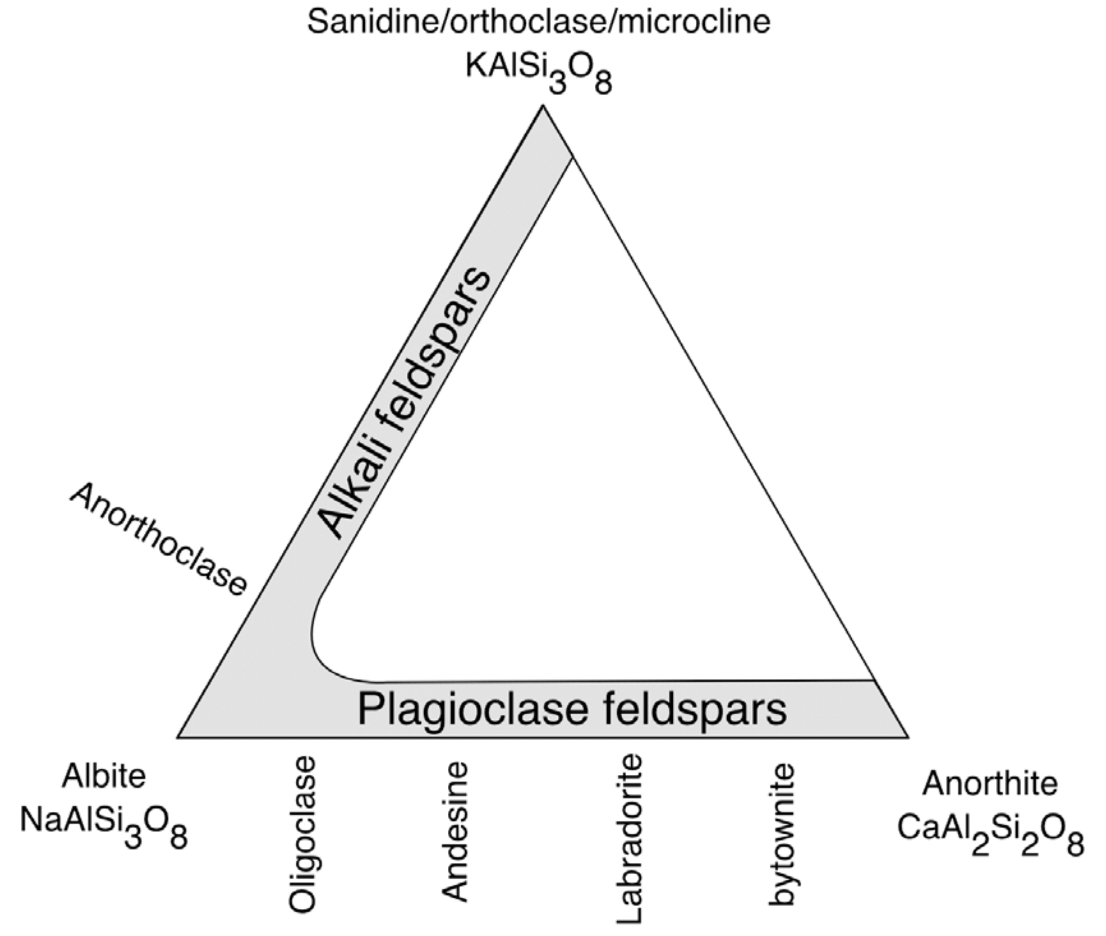
The feldspars are ***aluminosilicates***, consisting of a 3D framework of Si and Al tetrahedra

Two important solid solution series:

***The alkali feldspars***:
$Na(AlSi_3)O_8$ - $K(AlSi_3)O_8$

and

***The plagioclase feldspars***:
$Na(AlSi_3)O_8$-$Ca(Al_2Si_2)O_8$



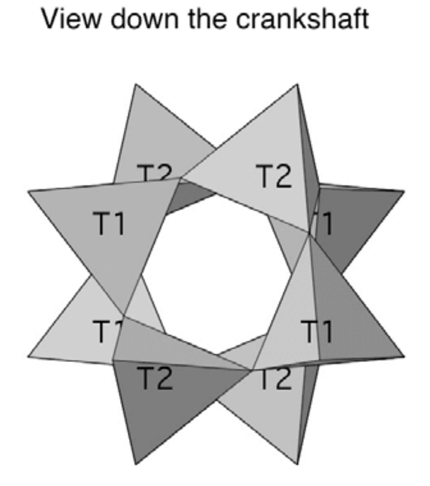
# Structure of sanidine $KAlSi_3O_8$

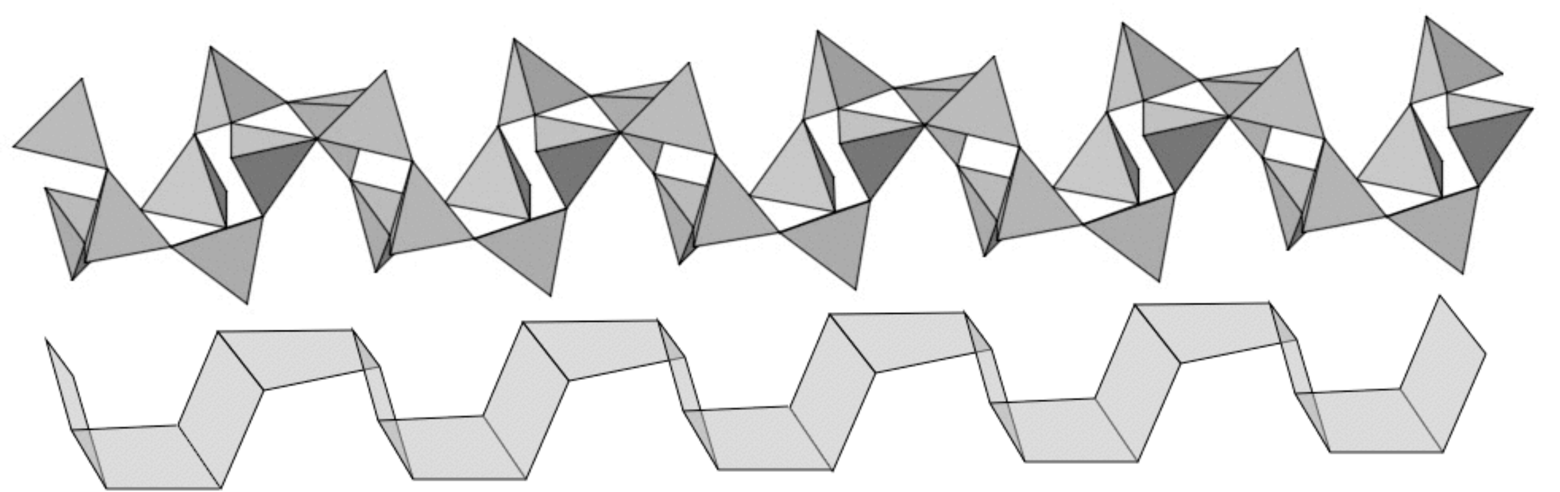
Sanidine has the highest symmetry feldspar structure

Crystal system: Monoclinic

Structure consists of a 3D framework of corner-sharing Si and Al tetrahedra

***Al and Si are randomly distributed throughout the framework!***





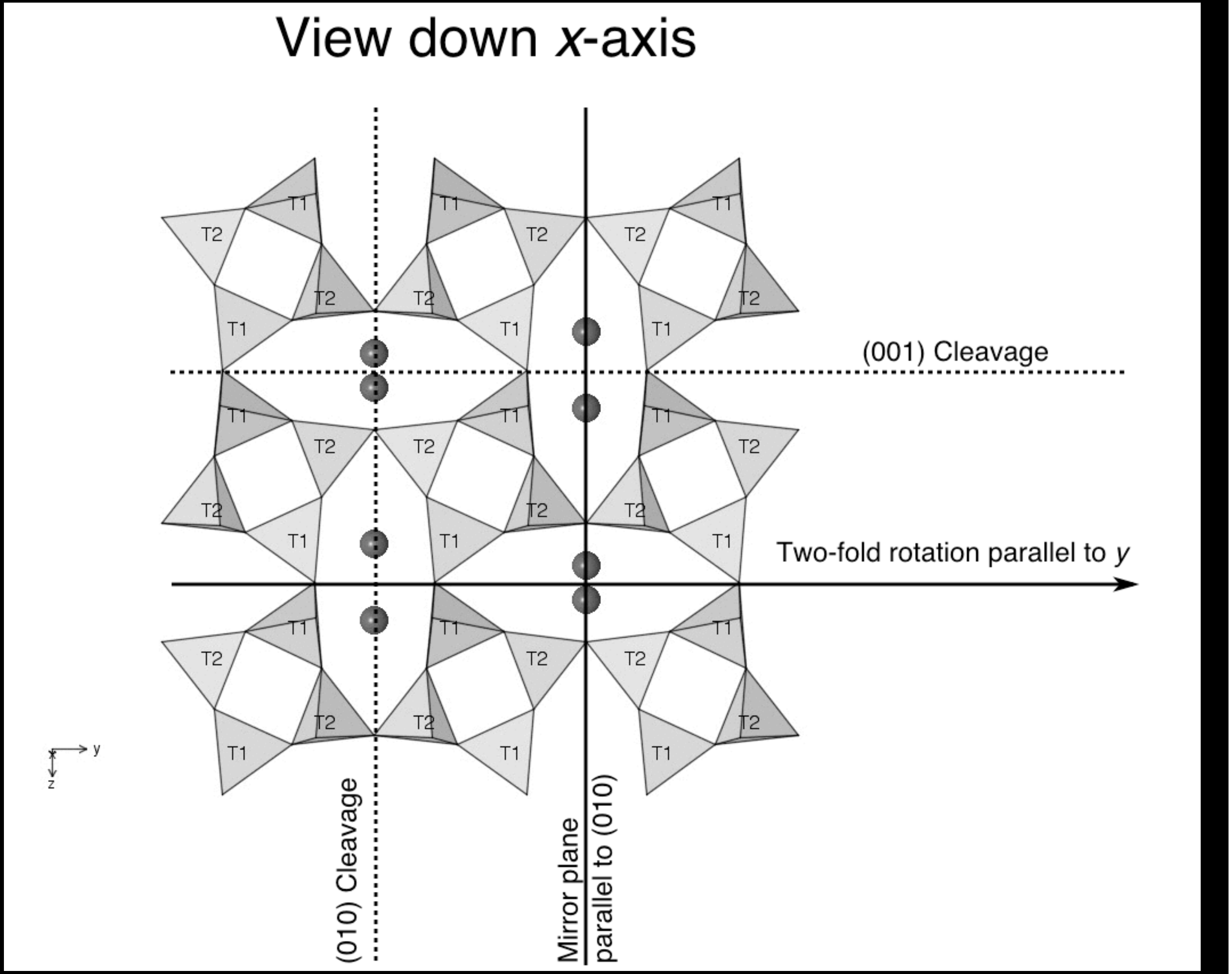
Framework can be build from crenulated structure “crankshafts”

# Structure of sanidine $KAlSi_3O_8$

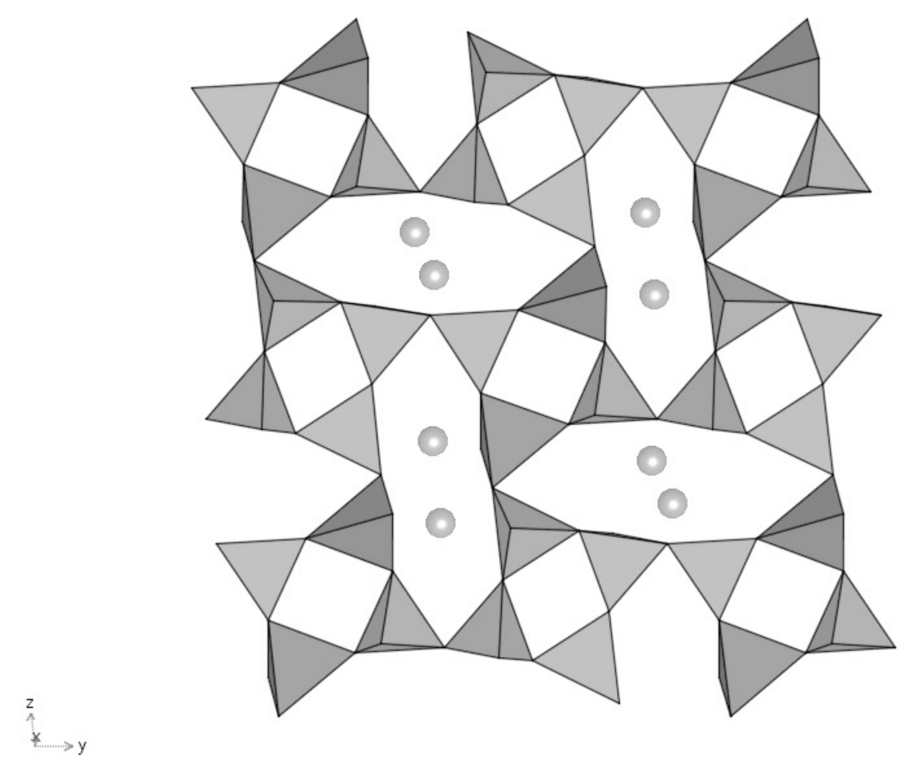
Two types of tetrahedral sites **T1** and **T2**. There are very similar, but ***symmetrically distinct*** sets of tetrahedra.

Crankshafts are stacked together to form large cavity sites, where the large alkali cations Na, K, and Ca are placed.

Two cleavages develop through the cavity sites at 90° to each other parallel to (010) and (001).



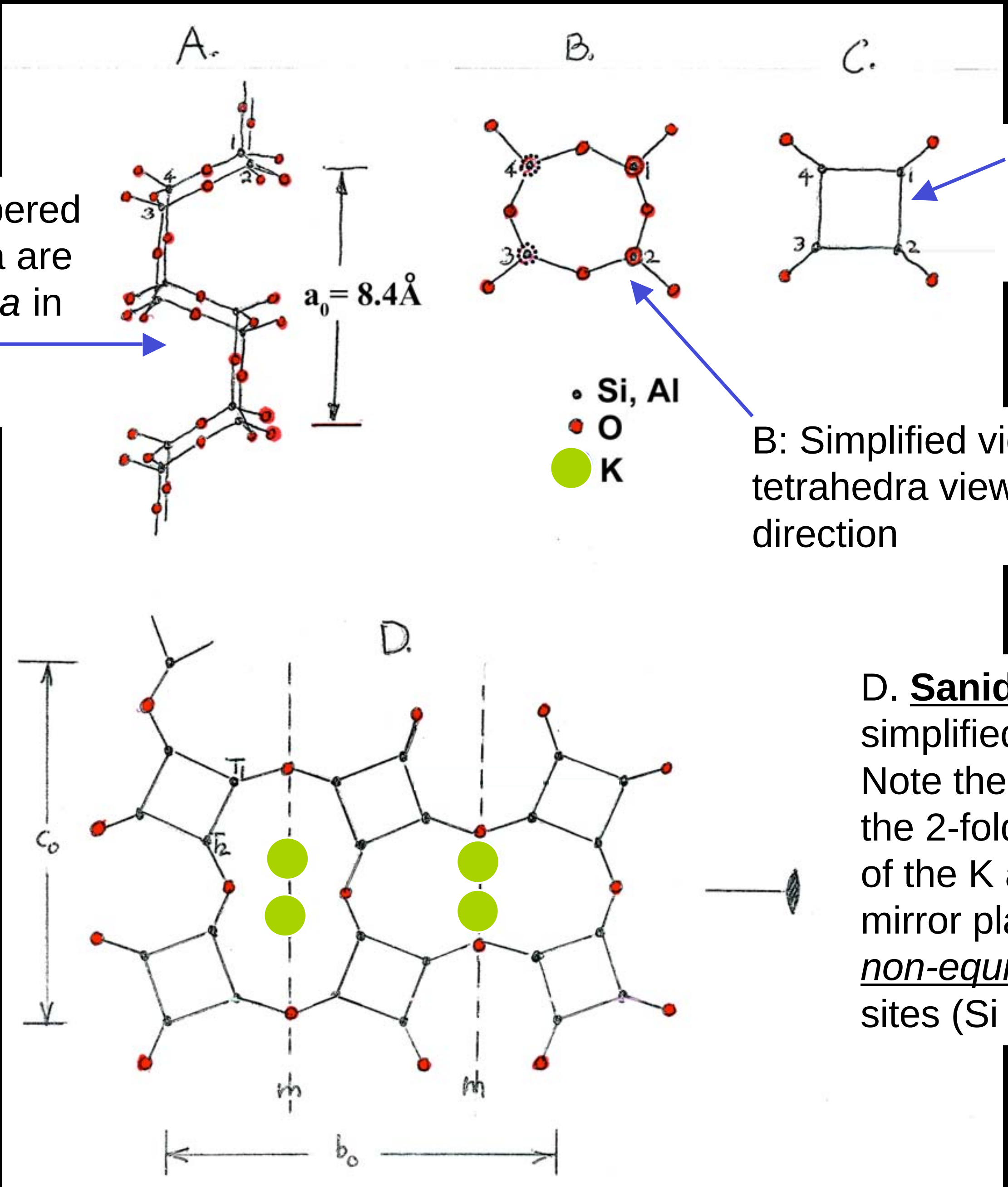
# Structure of albite $NaAlSi_3O_8$



At T > 980 °C albite is isostructural with sanidine.

Since Na is smaller than K, at lower temperatures the framework distorts to reduce the size of the cavity site.

# Simplified view of sanidine structure



A. The four-membered rings of tetrahedra are linked in chains // *a* in a crankshaft-like arrangement

C: same as B with bridging oxygens not shown

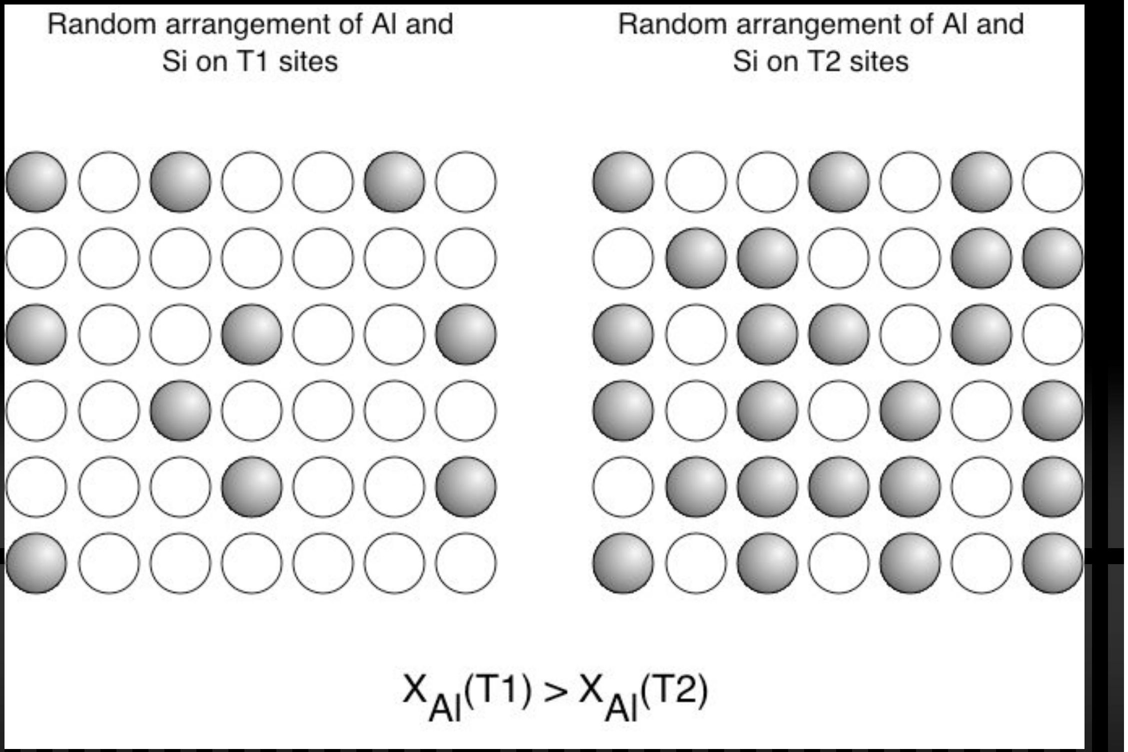
B: Simplified view of feldspar tetrahedra viewed along the ***a*** direction

D. **Sanidine** structure (greatly simplified) viewed along ***a***. Note the mirror planes (m) and the 2-fold axis and the position of the K atoms (lying on the mirror planes). $T_1$ and $T_2$ are *non-equivalent* tetrahedral sites (Si and Al positions).

# Aluminium-silicon ordering

In monoclinic sanidine there are two types of tetrahedral sites, T1 and T2

Al and Si are randomly distributed on T1 and T2 (high temperature).



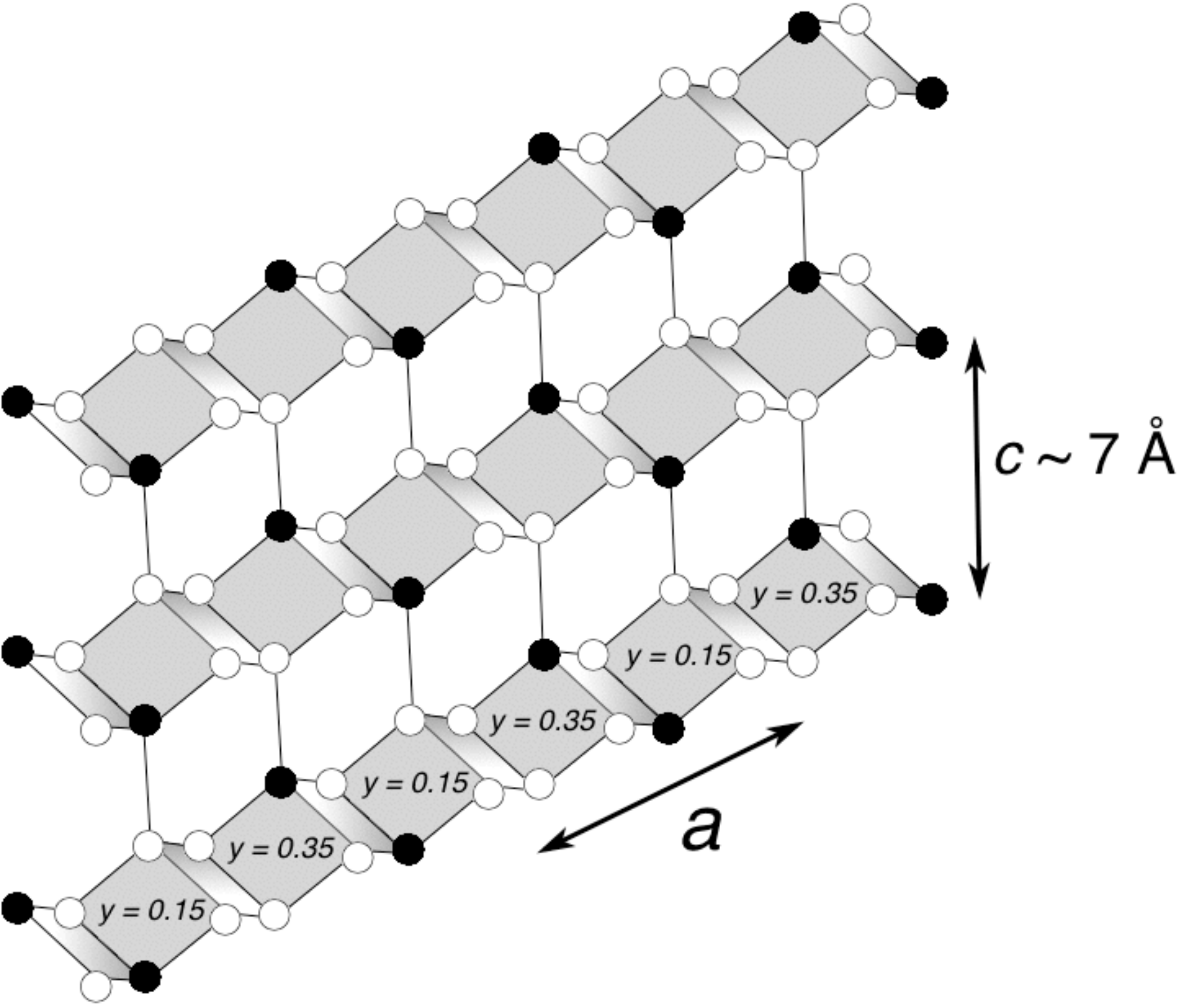
However, there is a preference for Al to be on T1 => ordering of Al onto T1 at low temperatures (similar to the Mg-Fe ordering in orthopyroxenes).

# Aluminium-silicon ordering

$AlO_4$ and $SiO_4$ tetrahedra have different charges and different sizes (the **$AlO_4$ tetrahedron is larger**).

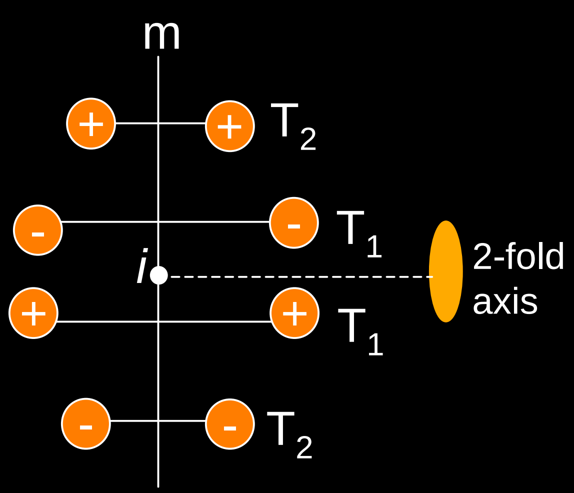
There is a large energy penalty to be paid for having two large $AlO_4$ tetrahedra next to each other. The system will always try to avoid having Al-Al nearest neighbours. This is known as the ***aluminium avoidance principle***

Al-avoidance in albite can be achieved by reducing the symmetry.

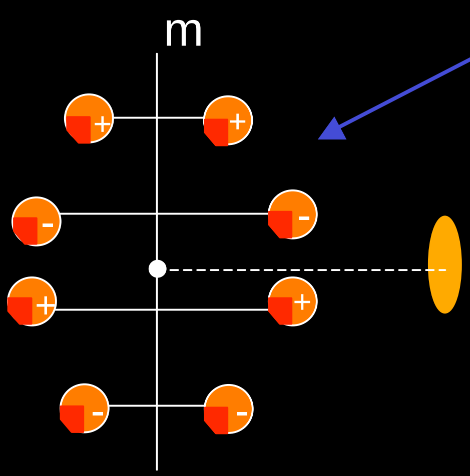


Albite $C\bar{1}$ Ordering Scheme
Al:Si = 1:3

# Al-Si order-disorder in K-feldspars



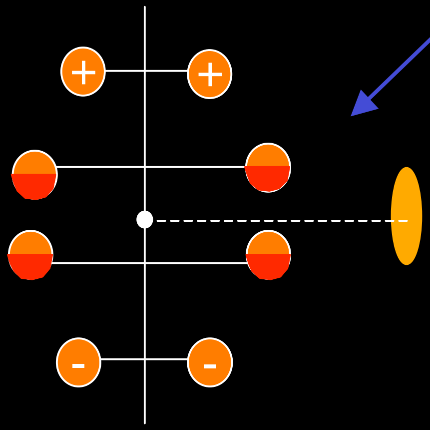
T site nomenclature: (+) above page (-) below



Probability of each T site containing Al (shown in red) is 0.25 and Si (shown in green) is 0.75

Totally disordered structure: high T

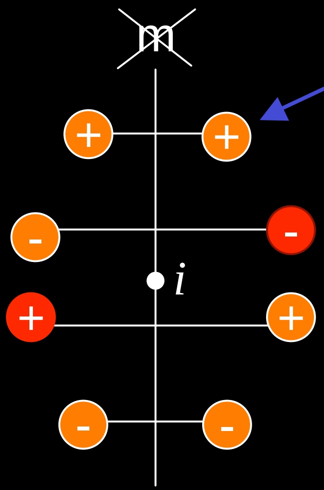
**Sanidine (Mon.)**



Probability of each $T_2$ site containing Al = 0. Probability of each $T_1$ site containing Al = 0.5, Si = 0.5

Partially ordered structure

**Orthoclase (Mon)**



Now, there are *__four__* *non-equivalent* T sites. All Al is concentrated into only one of the four T sites. M plane and 2-fold axes are lost.

Totally ordered (low T)

**Microcline (Tricl.)**

## How can we tell the extent of ordering in a feldspar?

A. By doing a precise 3D structure refinement which enable us to determine precise atom positions in the structure, and hence to determine bond lengths.

Si—O bond length = 1.60Å and Al—O bond length = 1.80Å

For example, in K-feldspar we might discover that:

(1) $T_1$—O = $T_2$—O = 1.65Å This would be: ? sanidine

$T_2$—O = 1.60Å and $T_1$—O = 1.70Å? orthoclase

$T_1$—O = $T_2$—O = $T_3$—O = 1.60Å and $T_4$—O = 1. 80Å? Microcline

Degree of ordering can also be determined by a simple powder x-ray method by measuring the 2θ difference between diffraction peaks

## Plagioclase Feldspar (Triclinic)

**Albite $NaAlSi_3O_8$ Anorthite $CaAl_2Si_2O_8$**

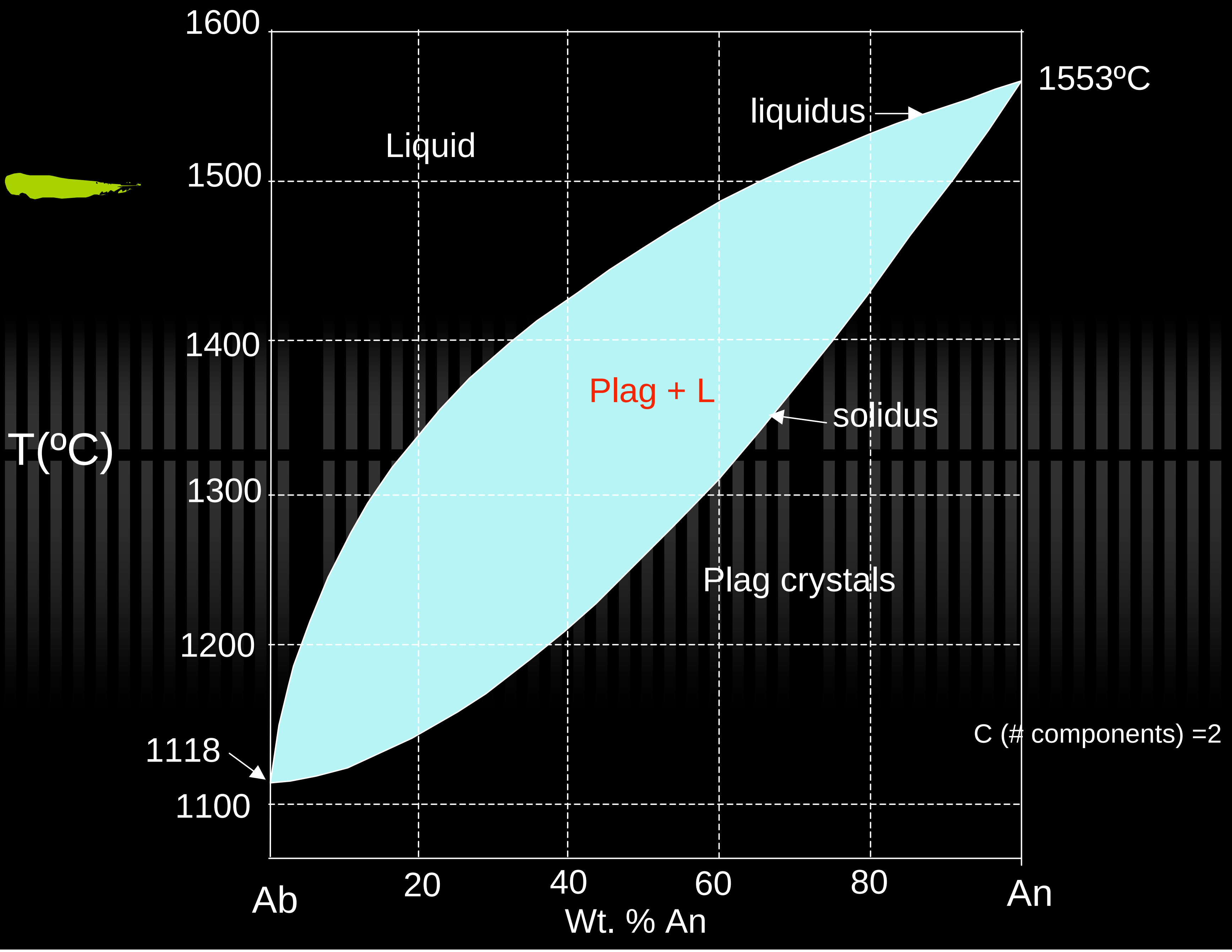
There is a complete solid solution between albite and anorthite at high temperatures. This solid solution also unmixes at lower T in a complex series of immiscibility gaps.

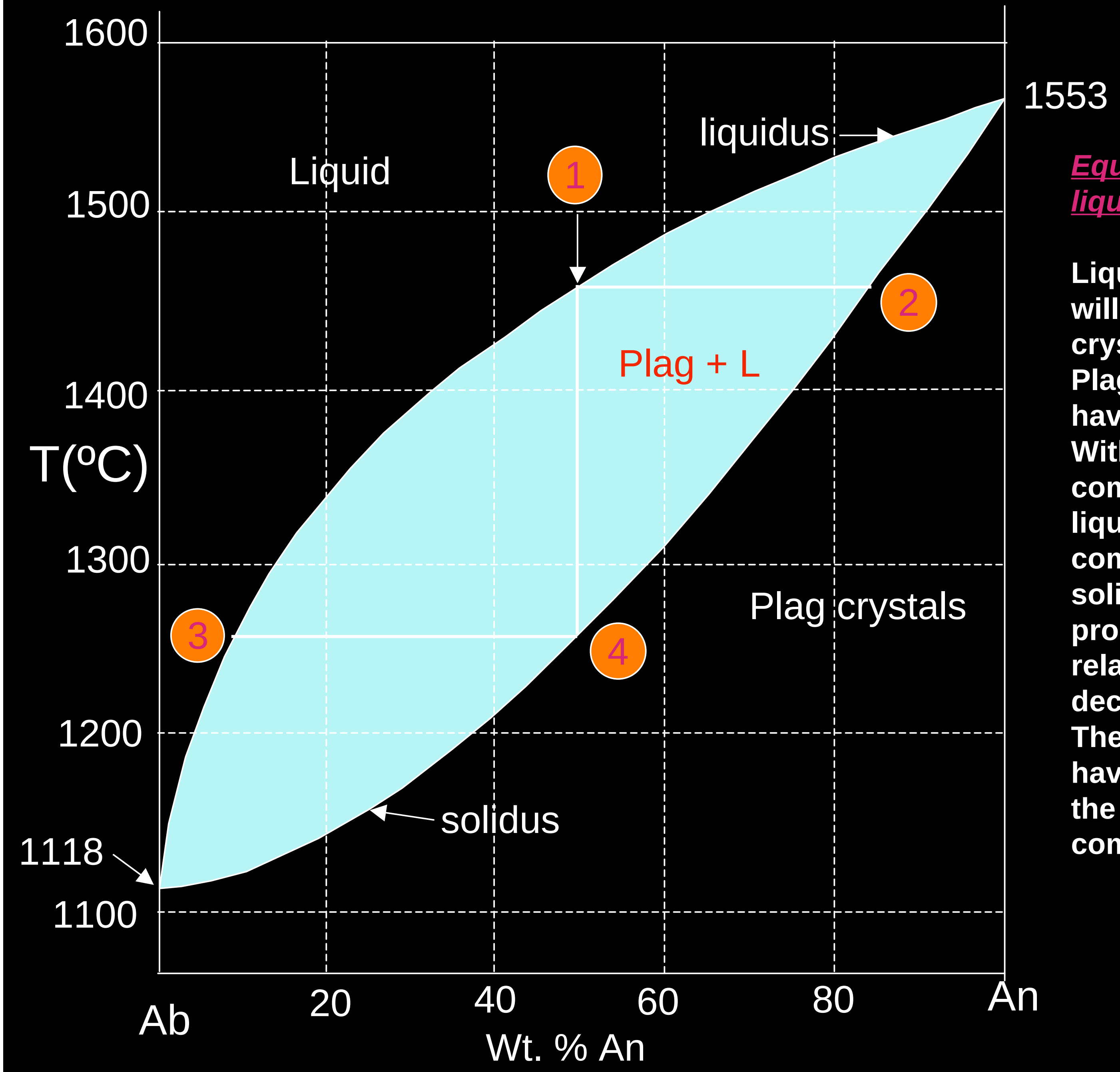
Plagioclase feldspar (the most common mineral in the earth's crust) shows variable "structural state", i.e., they are "disordered" at high temperature and become more "ordered" at lower temperature (coupled substitution $(CaAl)^{5+} \Leftrightarrow (NaSi)^{5+}$)

Albite

Anorthite

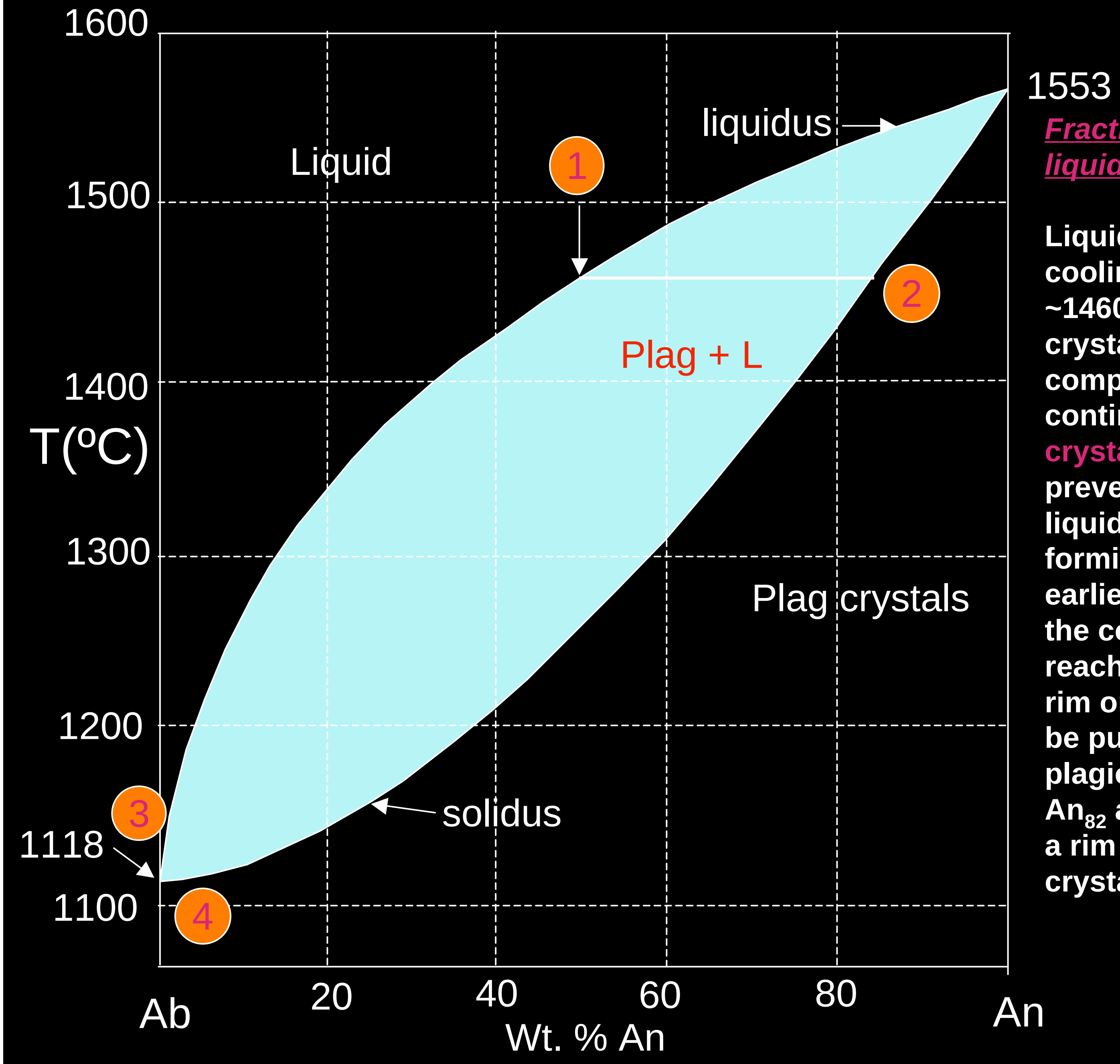
# Phase equilibria in the plagioclase system at P = 1 bar (Bowen, 1913)





***Equilibrium crystallization of a liquid of bulk composition 1.***

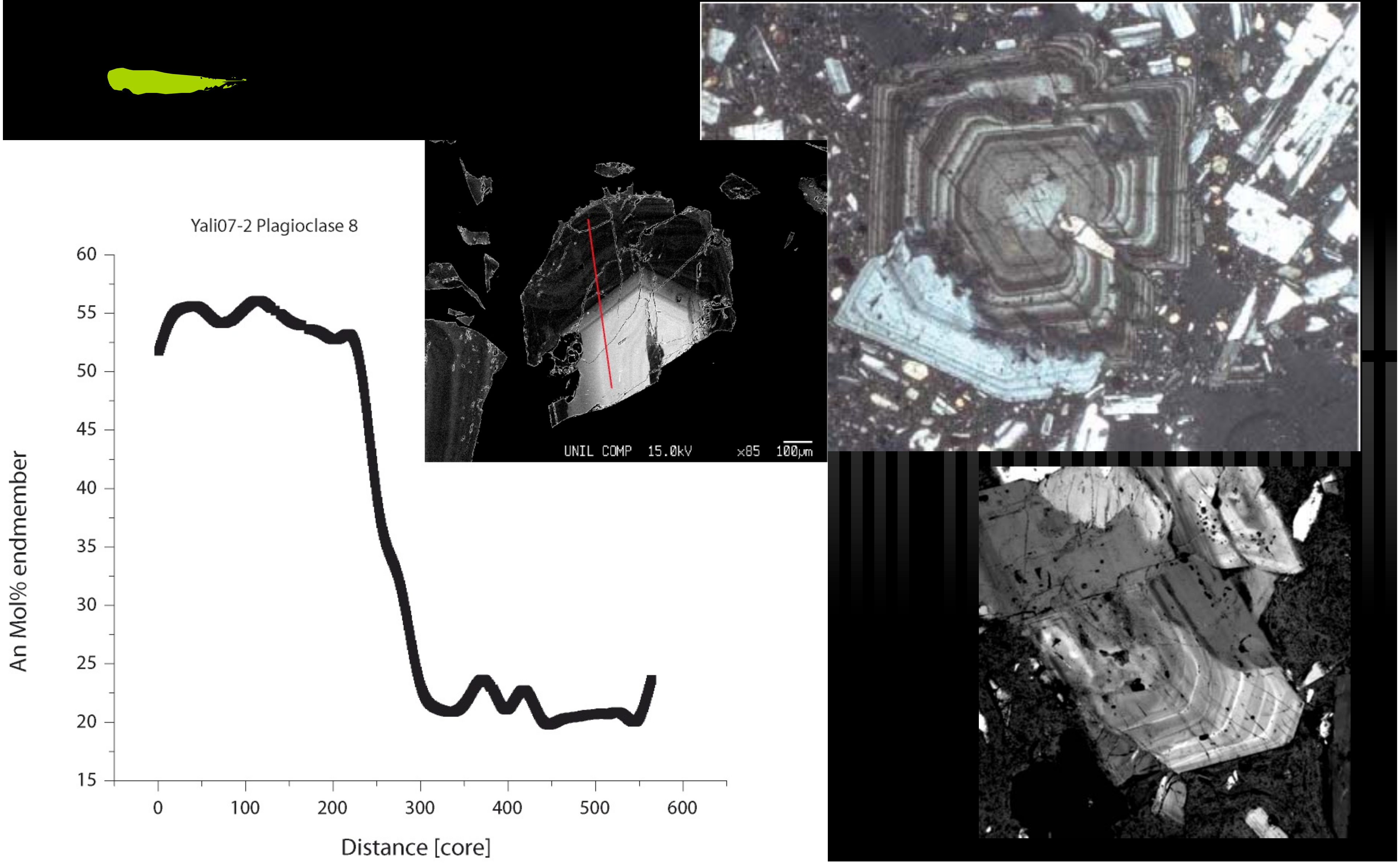
**Liquid of composition 1 ($An_{50}$) will, on cooling, begin to crystallize at ~1460ºC. Plagioclase crystals that form have composition 2 ($An_{82}$). With continued cooling, liquid composition changes along the liquidus from 1→3 and crystal composition changes along the solidus from 2→4. During this process, the mass of liquid relative to the mass of crystals decreases.**
**The last tiny part of liquid will have composition (3) because the bulk composition (1) is now completely crystalline (4).**



***Fractional crystallization of a liquid of bulk composition 1.***

**Liquid of composition 1 will, on cooling, begin to crystallize at ~1460ºC as before. Plagioclase crystals that form have composition 2 ($An_{82}$). With continued cooling and fractional crystallization, crystals are prevented from reacting with the liquid either by removal or by forming a new zone around an earlier-formed zone. In this case the composition of the liquid will reach the lowest T (3) and the last rim on the zoned plagioclase will be pure albite. The zoned plagioclase will have a core of $An_{82}$ and change continuously to a rim of $An_0$. This is fractional crystallization**

# Zoning in plagioclase

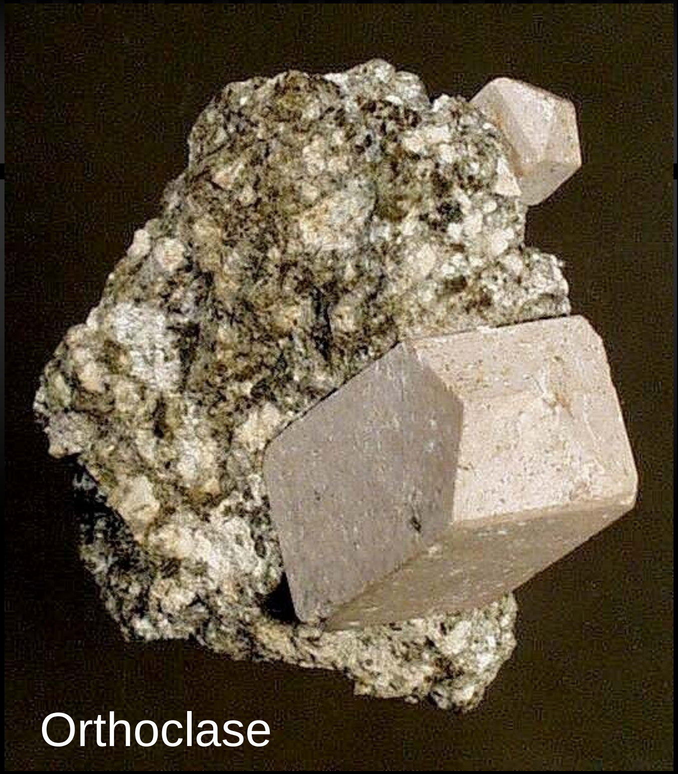


# Feldspars - Potassium feldspars

**Sanidine, orthoclase, microcline - $KAlSi_3O_8$**

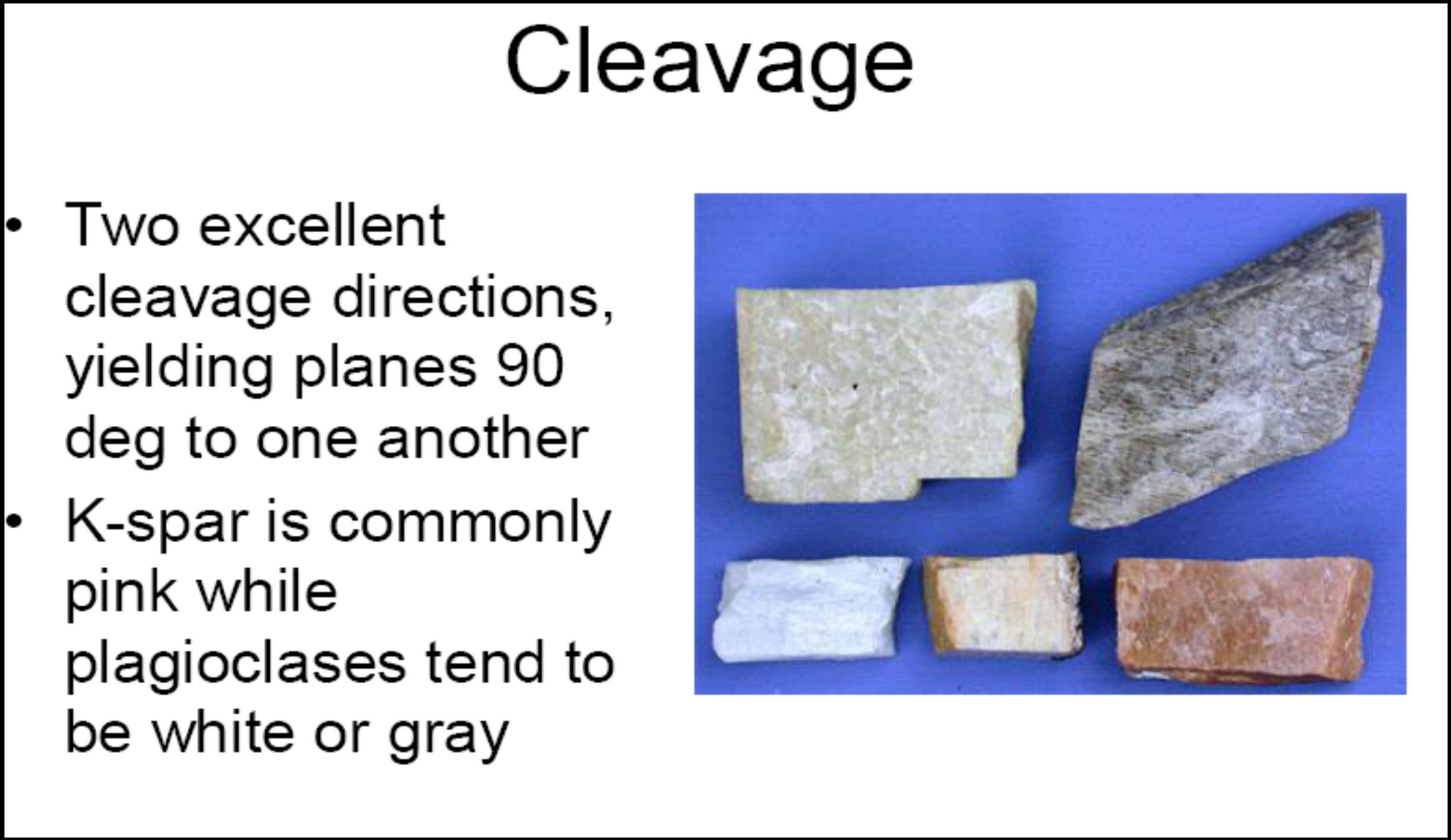
Order- disorder polymorphs

Sanidine



Orthoclase

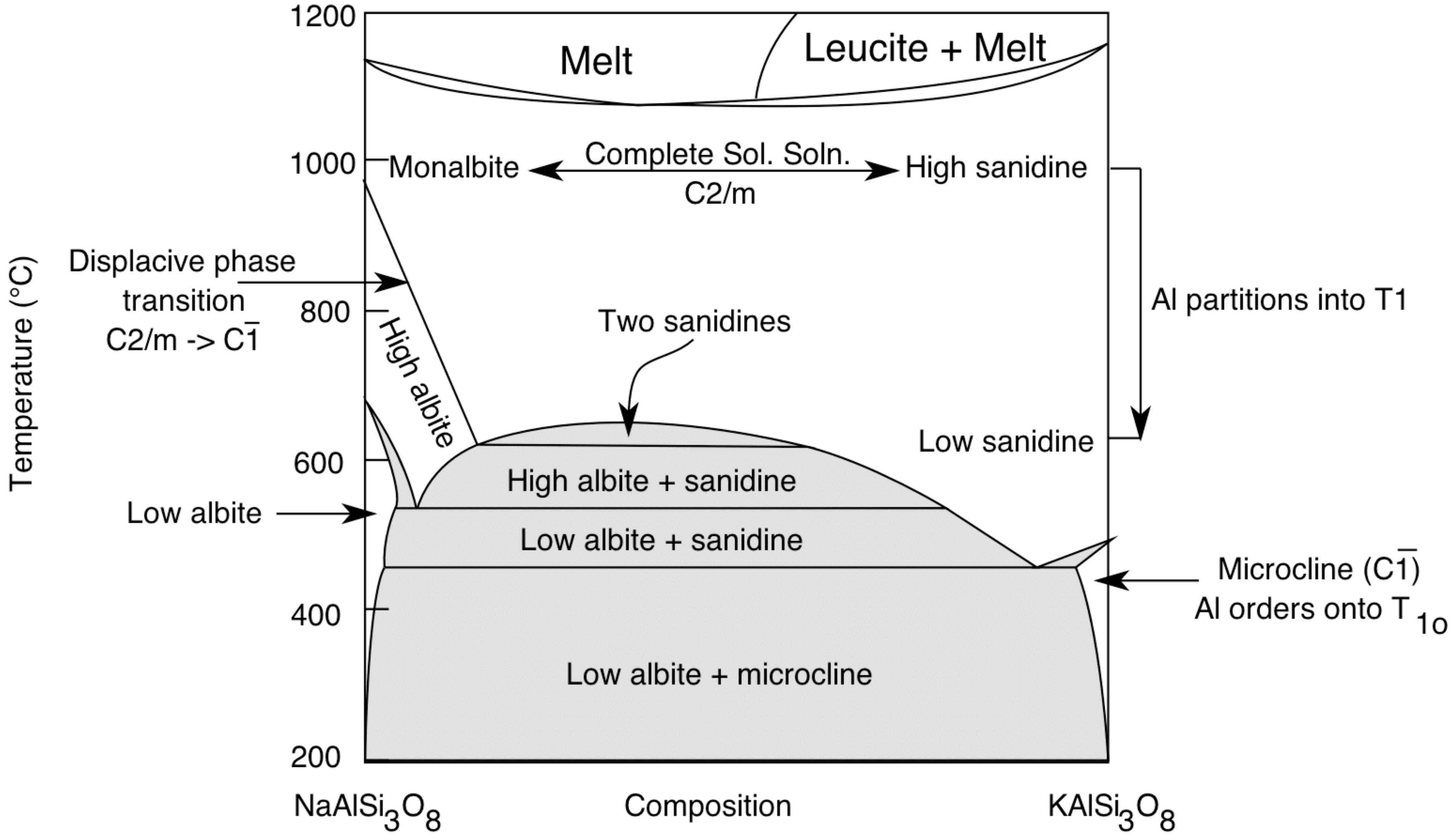
# Cleavage



## Cleavage

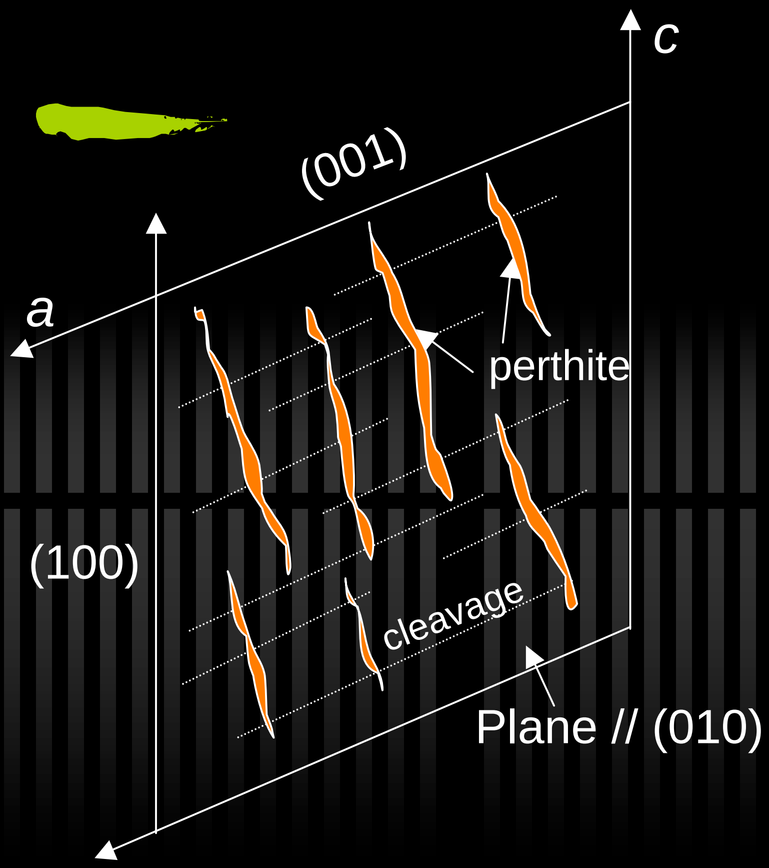
- Two excellent cleavage directions, yielding planes 90 deg to one another
- K-spar is commonly pink while plagioclases tend to be white or gray

# Phase diagram for the alkali feldspars



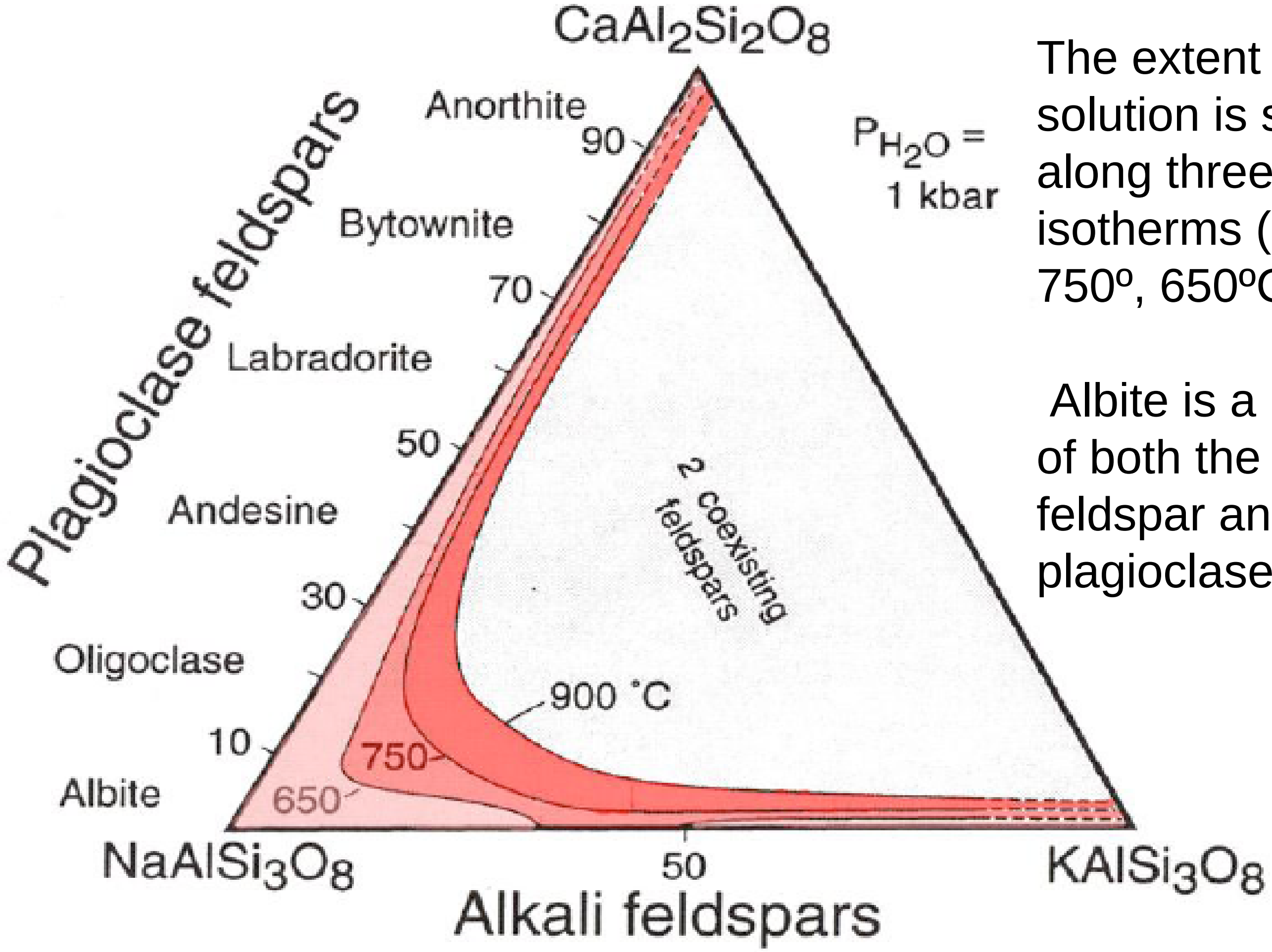
Compare with pyroxene phase diagram

Perthite (oriented lamellae of albite (light streaks) exsolved from orthoclase



**Perthite:** exsolution texture is visible in hand sample (or with hand lens)
**Microperthite:** exsolution visible in optical microscope
**Cryptoperthite:** exsolution detectable only with x-rays or TEM

# Feldspar compositions (expressed in a ternary diagram)

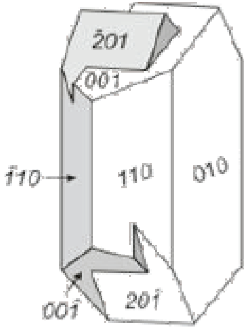


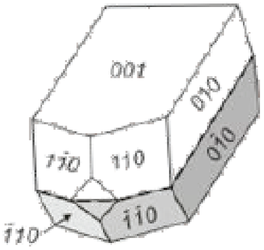
The extent of solid solution is shown along three isotherms (900º, 750º, 650ºC).

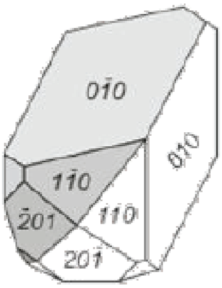
Albite is a member of both the alkali feldspar and the plagioclase series

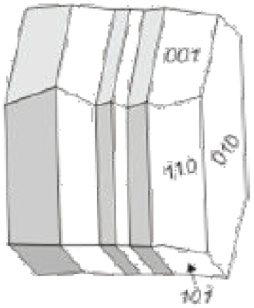
# Twinning

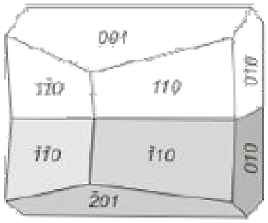
- **Carlsbad** **Manebach** **Baveno** **Albite**





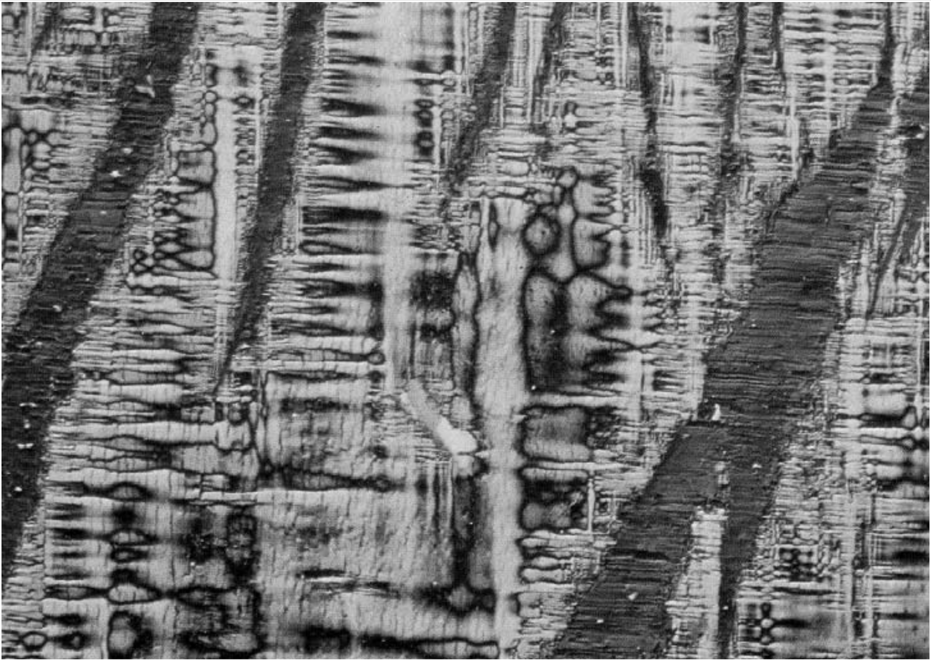






Pericline

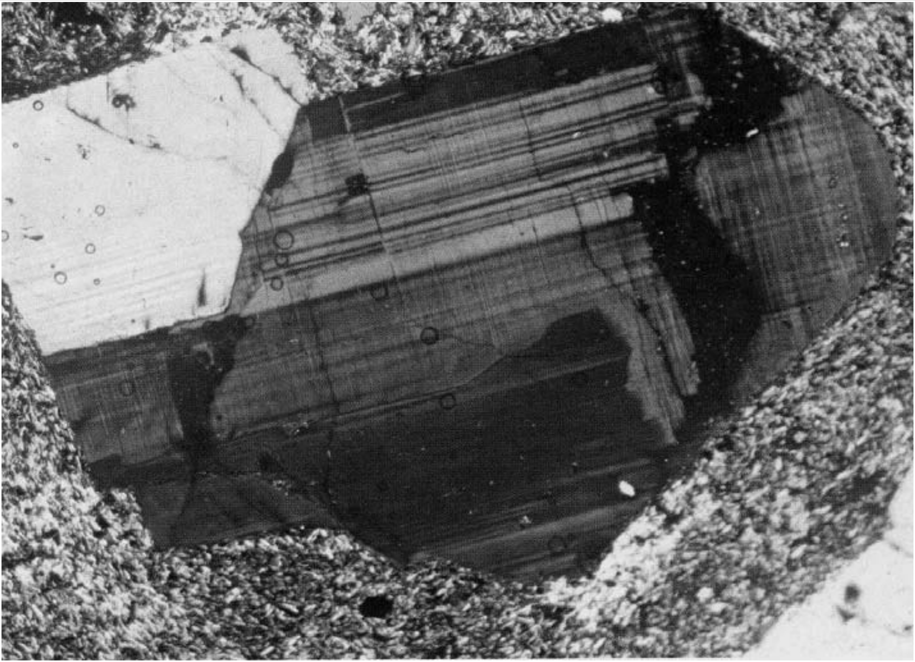
# Transformation twinning in alkali feldspars



Microcline

$KAlSi_3O_8$

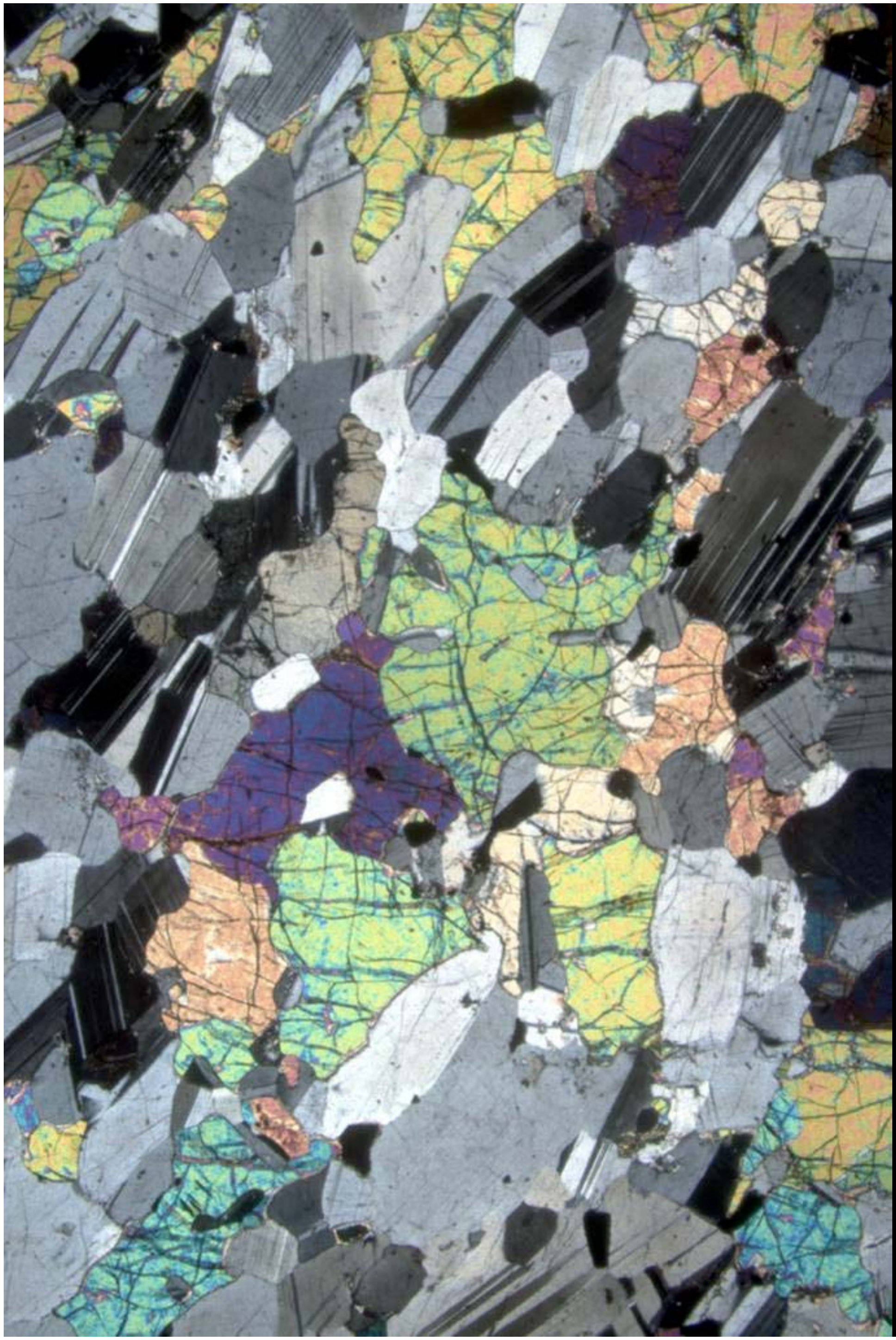
Twinning caused ***Al-Si cation ordering*** phase transition.



Anorthoclase

Na-rich $(Na,K)AlSi_3O_8$

Twinning caused by ***displacive*** phase transition during loss of symmetry.



Photomicrograph of olivine gabbro showing twinned plagioclase (gray/white mineral), olivine (brightly colored mineral). The colors are not “real” in the sense that they are produced by an interference phenomenon. Identification of minerals and textures is greatly enhanced by optical microscopic study of thin sections and polished sections.

# Occurrence of feldspars

## Alkali feldspars (orthoclase, sanidine, microcline)

• Essential constituents of alkalic and siliceous igneous rock (plutonic and volcanic), i.e., syenites, granites, granodiorites, trachyte, rhyolite and dacite. Usually perthitic, microperthitic or cryptoperthitic

•High grade regional metamorphic rocks (metapelites…). K-feldspar forms primarily from the breakdown of muscovite and biotite.

## Plagioclase feldspars

• Most abundant mineral in earth's crust. Occurs as phenocrysts in almost all volcanic rocks ranging from basalt–-andesite—dacite—rhyolite. Plagioclase is usually strongly zoned in volcanic rocks

• Abundant in equivalent plutonic rocks:
gabbro—diorite—granodiorite—granite. Also commonly zoned. Minor mineral in ultramafic rocks.

• Prominent mineral in all metamorphic grades from lowest T to highest T. In general, plagioclase become more An-rich as the temperature increases.

# Feldspathoids

- ✓ Anhydrous framework silicates
- ✓ Similar composition to feldspars with 6-membered rings leading to more open structures and lower densities
- ✓ Only 1/3 to 2/3 of the $SiO_2$ that feldspars have
- ✓ Some feldspathoids contain unusual anions such as $Cl^-$, $S^{2-}$, $SO_4^{-2}$, and $CO_3^{-2}$
- ✓ Found in silica-poor rocks (high alkali melts)

# Alkaline Provinces in the Mediterranean Region

# Leucite

- KAlSi2O6 ( vs. K-spar KAlSi3O8)
- Tetragonal (but looks like trapezohedron garnet). Truly isometric at high T, but undergoes a displacive phase transition to tetragonal at 605˚C, and keeps its isometric outer shell (just like high Quartz!!!)
- Never found with quartz
- White to gray, softer than garnet (5.5-6), no cleavage

# Nepheline

- ✓ (Na,K)AlSiO4 (vs (Na,K)AlSi3O8)
- ✓ Characteristic of alkaline igneous rocks (e.g., Mt Vesuvius)
- ✓ White, grey, yellowish

Tamazeght complex, High Atlas Mts, Atlas Mts, Morocco

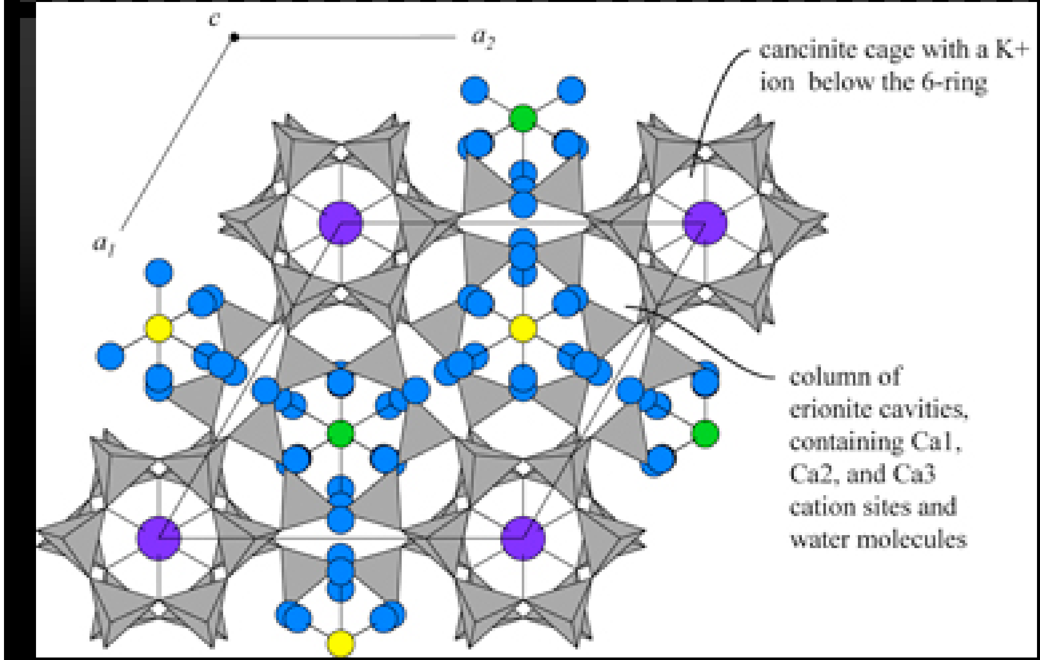
A big crystal of Nepheline from Canaã Massif, Brazil

# Sodalite

- Na4Al3(SiO4)3Cl (vs. NaAlSi3O8)
- Isometric, but single crystal are rare (forms masses
- Blue (sometimes grey or white)
- Often found with other feldspathoids (e.g., Mt Vesuvius)

# Zeolites = boiling stone

- $K_2(K,Na,Ca_{0.5})_7(H_2O)_{30}|\,[Al_9Si_{27}O_{72}]$ **= Erionite**
- Replace rhyolitic ash when in contact with alkaline waters
- Molecular sieves (used in fuel processing)

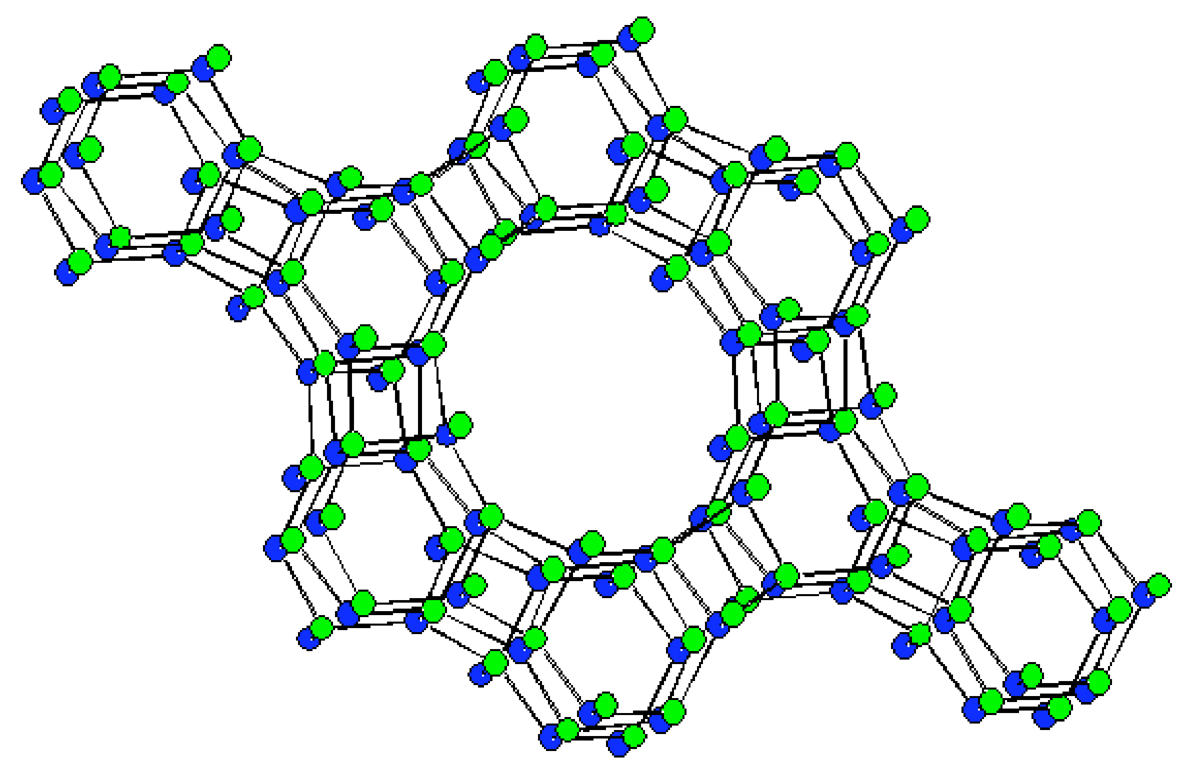


cancinite cage with a K+ ion below the 6-ring

column of erionite cavities, containing Ca1, Ca2, and Ca3 cation sites and water molecules

Erionite sprays, Agate Beach, Oregon, USA. Width 9 mm.

# Zeolites / Molecular sieves



Large cages or channels accessible to molecules