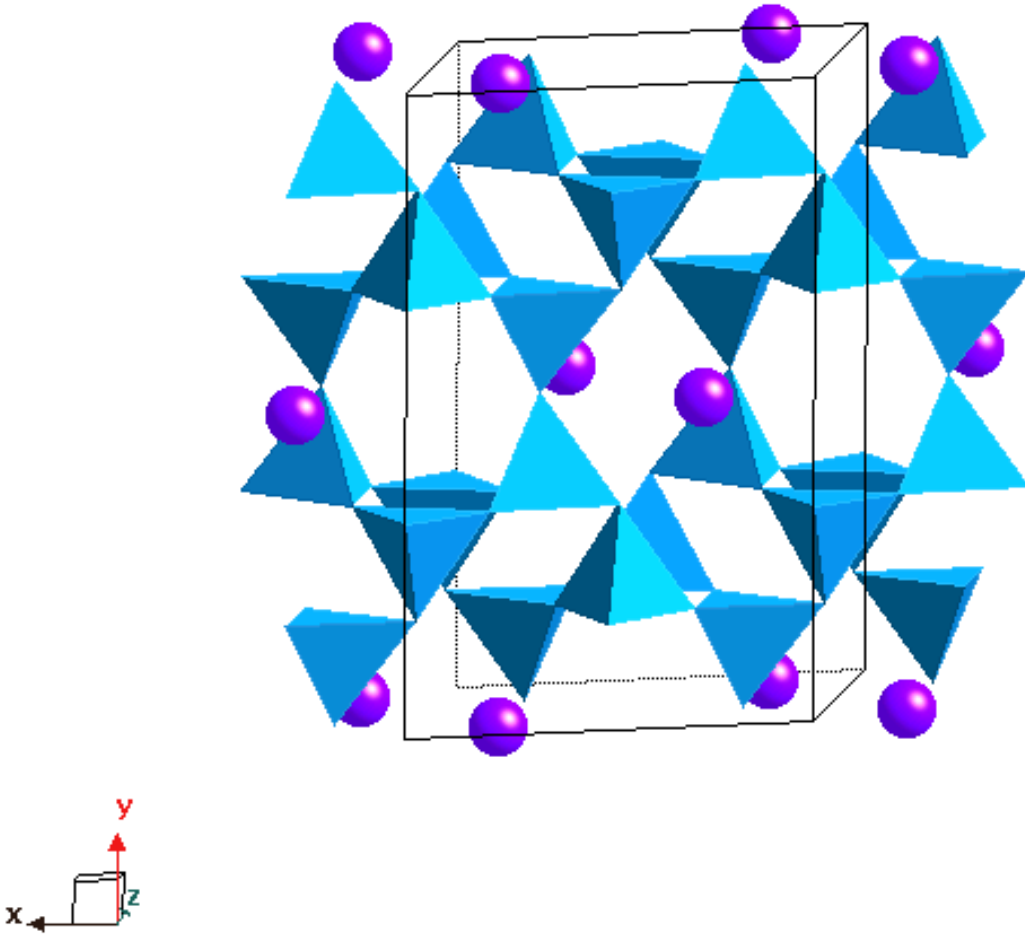


## Lecture Notes - Feldspars

- If quantity is of any significance, the **feldspar minerals** are the most important minerals for geologists studying the crust of the earth. By volume (or mass!) there is more feldspar in the crust of the earth than there is water in the oceans. Feldspars may be divided into two compositional series: the **alkali feldspars** and the **plagioclase feldspars**. The alkali feldspars have chemical compositions that form a solid solution principally between the two **end member** compositions **orthoclase** ( $\text{KAlSi}_3\text{O}_8 \equiv \text{Or}$ ) and **albite** ( $\text{NaAlSi}_3\text{O}_8 \equiv \text{Ab}$ ). The plagioclase feldspars have chemical compositions that form a solid solution principally between the two end member compositions **albite** ( $\text{NaAlSi}_3\text{O}_8 \equiv \text{Ab}$ ) and **anorthite** ( $\text{CaAl}_2\text{Si}_2\text{O}_8 \equiv \text{An}$ ). Compositions for alkali feldspars are commonly described in terms of mole percents of the end member components (*e.g.*  $\text{Or}_{85}\text{Ab}_{15}$ ,  $\text{An}_{54}\text{Ab}_{39}\text{Or}_7$ ). Most natural feldspars have minor amounts of other components in their composition. The major third component for alkali feldspars is An. The major third component for plagioclase feldspars is Or. Thus, to show graphically the variation in chemical composition of the feldspars, a ternary composition diagram is needed with two independent **composition axes** and three end member components: Or, Ab, and An (see attached diagram). Note that the feldspar compositions follow closely two sides of the composition triangle and that the observed proportion of a third component increases with increasing temperature. This is true for many minerals: the observed range of chemical composition is greater at higher temperatures.
- All feldspars are tectosilicates with every oxygen atom shared by adjacent silicon or aluminum tetrahedra. The tetrahedra are arranged in four-member rings that are stacked to form “crankshafts” parallel to the **a**-axis of the monoclinic or triclinic structure. The crankshafts are joined together in an open structure with large voids to hold the alkalis or calcium (see attached drawing). The structures of individual feldspar varieties are all based on this model, although a number of important variations are possible.
- Sanidine, orthoclase, and microcline are all polymorphs of potassium-rich alkali feldspar. **Sanidine** is restricted in occurrence to volcanic rocks. **Microcline** is found mainly in plutonic igneous rocks and in metamorphic rocks. **Orthoclase** can be found in either plutonic or volcanic igneous rocks. Sanidine and orthoclase are monoclinic; microcline is triclinic. The structures of these three minerals differ principally in the **ordering** of aluminum and silicon among the four tetrahedra in each tetrahedral ring. High sanidine is fully **disordered** with a statistically random Al-Si distribution: each tetrahedron has, on averaging over a reasonable volume, 0.25 Al atoms and 0.75 Si atoms. This is an example of **statistical symmetry**, where the symmetry of the pattern as a whole actually exceeds the symmetry of the unit cell.
- If a sanidine crystal is cooled slowly from high temperature, Al-Si ordering will occur with the Al atoms preferring one of the two pairs of tetrahedra in each ring. Low sanidine and orthoclase are successively more ordered versions of the high sanidine structure. For these minerals to be monoclinic (which they are), the center of symmetry in each ring must be preserved. This requires a random distribution of Al and Si on each distinct tetrahedral site ( $\mathbf{t}_1$  or  $\mathbf{t}_2$ ). For example, 80% of the Al might be in  $\mathbf{t}_1$  tetrahedra and 20% of the Al in  $\mathbf{t}_2$  tetrahedra. To maintain the center of symmetry, the 80% of the Al must be distributed randomly among all of the  $\mathbf{t}_1$

tetrahedra and the 20% of the Al must be distributed randomly among all of the  $t_2$  tetrahedra. At still lower temperatures, the ordering between  $t_1$  and  $t_2$  will be complete and there will begin to be ordering of the Al on the two (formerly) equivalent  $t_1$  tetrahedra. This ordering will destroy the center of symmetry and the mineral will become triclinic microcline. Maximum microcline would be a fully ordered mineral with all of the Al on one of the two sites  $t_{1a}$  or  $t_{1b}$ .

- The solid solution between Or and Ab is complete at high temperatures, but is limited at lower temperatures. Thus, in volcanic igneous rocks and many plutonic igneous rocks, there is only one alkali feldspar. In other plutonic igneous rocks, there may be two alkali feldspars: orthoclase (or microcline) rich in K and albite rich in Na. Alkali feldspars of intermediate composition that are cooled slowly from high temperatures may **unmix** or **exsolve** to form **perthite**, a “stringy” (non-lamellar) intergrowth of orthoclase and albite or microcline and albite. **Microp-erthite** and **cryptoperthite** are perthites with a scale of **exsolution** features that is microscopic and submicroscopic, respectively. Exsolution requires the breaking of bonds and, therefore, is an example of a reconstructive transformation. In some cases, exsolution occurs by a process called **spinodal decomposition**, compositional waves whose amplitude grows by “uphill diffusion.” Spinodal decomposition leads to a **coherent** intergrowth of the Na- and K-rich phases. In others cases, exsolution occurs by **nucleation** and **growth** of the exsolved phase. Either process may be followed by **coarsening** of the resulting texture (to eliminate interface area) during isothermal annealing or slow cooling, leading to micro- or even macro-perthite. A graphical representation of observed alkali feldspar compositions as a function of temperature delineates a hill-shaped, two-feldspar (or no feldspar!) region at intermediate compositions. The curve bounding this region is called a **solvus**. The solvus marks the limit of solubility of the Ab component in potassium feldspar and the limit of Or solubility in sodium feldspar as a function of temperature. Micron-scale exsolution features lead to the “play of colors” visible in the building stone “Larvakite,” which contains mostly anorthoclase antiperthite feldspars.
- Plagioclase feldspars exhibit features similar to those of alkali feldspars, but in most cases the features are more complicated. Ordering is a factor as is exsolution. There may be as many as three or four solvi in the plagioclase series. Plagioclase exsolution is responsible for the “play of colors” observed in many laboradorite crystals. However, plagioclase exsolution features are rarely observed on a microscopic scale due to the fact that Al and Si must be rearranged in addition to Na and Ca. The breaking of tetrahedral bonds does not occur easily, even at fairly high temperatures. Plagioclase feldspars commonly twin upon cooling, mechanically, according to the albite [twin axis  $\perp$  (010), composition plane (010)] or pericline [twin axis = b, composition plane = “rhombic section” ( $h0l$ )] twin laws. These are both lamellar twin sets and are responsible for the twin striations visible in feldspar crystals. Carlsbad twinning [twin axis = c, composition plane = (010), usually] may be observed in either alkali or plagioclase feldspars.



The crystal structure of sanidine as drawn by CrystalMaker © looking perpendicular to (001).

# Idealized Structure of Sanidine Projected on $(\bar{2}01)$

