DIFFUSE X-RAY SCATTERING BY LUNAR MINERALS

by H.Jagodzinski, Institut für Kristallographie und Mineralogie, Universität München, 8 München 2, Theresienstr.41, BRD and M.Korekawa, Institut für Kristallographie der Universität Frankfurt, 6 Frankfurt/Main, Senckenberganlage 3o, BRD.

1. Introduction

Diffuse X-ray scattering by lunar minerals may be caused by thermal motion, disorder phenomena due to growth, deformation or thermal activation and radiation damage. Since the most important rock-forming minerals have been studied very carefully in the last two decades, we hoped to be able to separate the three effects, because it seemed to be probable that the contribution of thermal and disorder diffuse scattering may be small at least for some of the minerals in question. Radiation damage caused by fast neutrons has been studied by Comès(1), it could be shown that an integrated flux of 10^{20} fast neutrons per square centimeter is sufficient to completely destroy the crystal structure of quartz, and it is evident that a recrystallisation begins at very high temperatures. On this reason there was a good chance of observing similar effects of radiation in lunar silicates having a chain-, layer- or framework-structure, but the expected effect is very small. It is well known that the temperature of forming lunar rocks is appreciably higher than the corresponding temperatures of terrestrial rocks with the same chemical composition. Therefore we had to check the question, which of the abundant lunar minerals are best suited for the intended separation of diffuse scattering. The most promising minerals were plagioclases, pyroxenes and tridymite. Single crystals of all three minerals have been found in the lunar rocks investigated so far, and their diffuse scattering will be described below.

2. Plagioclase

Plagioclase rich in anorthite is the most important lunar mineral. With respect to the diffuse scattering of X-rays three different types of single crystals have been found so far:

α) Plagioclases with 60-75 % An show a very diffuse two phase pattern of labradorite and bytownite (?), as described previously (2)

β) Plagioclase with 75-95 % An, shows (c)- and (d)-reflections [(c)-reflections in the Laves notation(3)] totally smeared out. It could be shown that the integrated intensity of the diffuse scattering is nearly independent from that of an anorthite crystal with sharp (c)- and (d)-reflections (4).

γ) Plagioclases having approximately 95-1oo % An show well defined (c)- and (d)-reflections. There is a very weak diffuse scattering in the immediate neighbourhood of Bragg-reflections dependent from their indices.

Crystals of type α and β were found in the lunar rocks 14310, type β was found in 15076, while crystals of type γ were very abundant in rock 68415.

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Because of their very diffuse diffraction pattern due to intergrowth phenomena, type α-crystals are inconvenient to study small radiation defects. Since diffuse scattering near to the (a)-reflection is much smaller, crystals of type β are much better suited. Unfortunately diffuse streaks accompanying all types of reflections makes a careful study of radiation defects more difficult, although not impossible. Only crystals of type γ, which are limited to a very small composition range are suited for determining low concentrations of radiation defects.

Point defects can best be studied at diffraction angles far from Bragg-reflections, while clusters of defects are typical for diffuse scattering in the immediate neighbourhood of Bragg-reflections. Since only very small crystals were available for our experiments with strictly monochromatic X-rays, a diffuse background was unavoidable. On this reason we focussed our attention on clusters of defects and their contribution to the diffuse scattering near the Bragg-reflections.

Some crystals were selected from a small specimen originating from the inner part of the rock (i-crystals) and another set of crystals was taken from the surface (s-crystals) which had been exposed to the radiation of the sun. Although the i-crystals showed diffraction pictures with slightly diffuse c- and d-reflections and one of the s-crystals did not, it was not sure that the diffuse anisotropic halo around the Bragg-spots observed for the s-crystal is really due to radiation or other types of defects. Unfortunately all crystals showed the typical diffration effects of submicroscopical twinning, which are streaks accompanying Bragg-spots in case of lamellar twins, but they may also be "halos" around Bragg-reflections if their shape differs from platelets.

The theory of lamellar intergrowth, given in a previous paper(2), has been worked out for symmetric and antisymmetric effects of the diffuse scattering caused by crystals containing submicroscopical domains with equal or different chemical composition and changed lattice constants differing by Δa, Δb, Δc (antiphase domains and twins are included as special cases).

a) As long as $h\Delta a + k\Delta b + l\Delta c$ is small against $1/L$, where L is the averaged number of unit cells vertical to the plane (hkl) of the crystal, a single reflection is observed. The diffuse streaks emerging from the Bragg-spot may be asymmetric if the averaged size of one type of domains is becoming small.
b) In all other cases two reflections are observed, having symmetrical streaks in the immediate neighbourhood of Bragg-reflections; if the two reflections are very close to each other, asymmetric diffuse scattering is generally observed.

The asymmetric halos observed for anorthite of rock 68415 exposed to the radiation of the sun may therefore also be caused by domains having a non-lamellar shape. Further experiments are neccessary to explain the origin of this diffuse scattering.

3. Pyroxene

Unfortunately no pyroxene single crystals, suited for the study of diffuse

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scattering have been found in rock 68415. Therefore only some very brief remarks shall be given here. The exsolution of augite in pigeonites of samples 1451o and 15o76 was very common. The averaged thickness of lamellae was in most cases not more than one or two unit cells. The complete study of the diffraction pattern showed, that only some few reflections are free from diffuse scattering generated by the thin exsolution lamellae. Therefore lunar pyroxenes with a very small Ca-contents are suited best for the study of radiation damage by diffraction methods.

4. Tridymite

Submicroscopically twinned single crystals of tridymite have been found in lunar rock 15o76. All crystals show the superstructure reflections of low-tridymite and a submicroscopical twinning of this superstructure. All crystals studied so far have a diffraction pattern with diffuse streaks typical for a one-dimensional disorder as described by Flörke(5).
In agreement with a theoretical treatment of this disorder phenomenon(6), (001)-reflections only are free from diffuse scattering.
Tridymite single crystals are well suited to study radiation damage by diffraction, since the diffuse streaks are well defined and may easily be separated from the diffuse halos, being more extended in reciprocal space. It should be pointed out that a periodic phase change from low to high-tridymite takes place every lunar day. There is no indication of an additional disorder correlated with this phase change.

References

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