

# **An occurrence of zeolites at Kragerø, southern Norway.**

By

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## **Introduction.**

The purpose of this paper is to report the occurrence and discuss the paragenesis of some zeolites which we found near Kragerø, southern Norway. The zeolites were found along two joint surfaces in an outcrop along the side road which crosses Kalstadkilen. The place name is Østland; it is located 1.5 km NW of the railroad station in Kragerø.

The rock in which the joints occur is a quartz rich gneiss. The gneissic structure is primarily due to a vaguely layered distribution of quartz and microcline, from layers very poor in microcline to layers less poor in microcline, and rather poorly oriented, evenly distributed biotite. The layers are generally about 2 mm broad. The rock is medium-grained, consisting primarily of quartz with interstitial microcline and plagioclase, and a little biotite. The grain size is markedly unequal, quartz occurring in moderate sized grains (up to ca. 1 mm in largest dimension) with highly irregular boundaries, while the feldspars occur as small (up to ca. 0.5 mm), interstitial grains. The quartz usually shows undulatory-mosaic extinction; microcline shows very well developed polysynthetic cross-hatch twinning (hence, high degree of triclinity?); plagioclase is intensely sericitized; biotite occurs in small grains, partly altered to pennine. The accessory minerals are: muscovite, frequent; apatite, frequent; sphene, rather frequent; opaques, very rare.

Quartz is so abundant that it seems probable that the rock is an intensely metamorphosed, slightly arkosic sandstone, or possibly, a slightly granitized quartzite. No signs of original sedimentary grains

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or structures are visible. The strike in the outcrop is N 25 E and the dip 50° S<sup>1</sup>, but dip and strike are variable in the rocks in this area.

In the outcrop at Østland there can be seen two joint surfaces along which there occur late-formed minerals. Joint 1 strikes N 68 W and dips 90° S, and joint 2 strikes N 25 E and dips 50° S. Along joint 1 we have identified the following minerals, all zeolites: natrolite, stilbite (*desmine*), heulandite, and laumontite. Along joint 2 we have identified calcite, epidote, albite, quartz, and laumontite. X-ray powder patterns have been obtained for all four zeolites.

## Mineralogy.

### Joint No. 1.

*Natrolite.* Natrolite is the most abundant mineral along the joint. It occurs as acicular, vertically striated grains in radiating aggregates (rosettes) which are up to 1 cm in diameter. The surfaces of the grains are usually chalky pink, but fresh surfaces are yellowish-pink and the grains can be seen to be transparent. Optically (—).  $\gamma = 1.486 \pm 0.003$ . An analysis for alkalis was performed on the natrolite (the material analysed was somewhat contaminated with quartz). The results of the analysis are:

Na <sub>2</sub> O	14.18 %	Analyst: Liv Bolkesjø, N.G.U. laboratory.
K <sub>2</sub> O	0.21 %	

In all of the zeolites the ratio (Na<sub>2</sub>O + CaO) : Al<sub>2</sub>O<sub>3</sub> = 1. In natrolite SiO<sub>2</sub>:Al<sub>2</sub>O<sub>3</sub> = 3 and CaO:Na<sub>2</sub>O = 0. (The formulas used as the basis for the ratios given are taken from Winchell (1951), with the limits being those indicated by the optical data.)

*Stilbite (desmine).* Two types of stilbite are present. Type 1 occurs as reddish, sheaflike aggregates at the periphery of the natrolite rosettes. Optically (—).  $\gamma = 1.500 \pm 0.003$ .  $\alpha \wedge c = 3^\circ - 4^\circ$ . Type 2 occurs as rare, scattered, small, colorless individuals which are flattened parallel to 010. The crystals are always twinned with (100) as the twin plane. Optically (—).  $\gamma = 1.500 \pm 0.004$ .  $\alpha \wedge c = 3^\circ$ . SiO<sub>2</sub> : Al<sub>2</sub>O<sub>3</sub> = 4.5 — 5.2. CaO : Na<sub>2</sub>O = 10 — 4.

<sup>1</sup> When the symbol g is used the angle is given with reference to a circle of 400 degrees. The symbol ° is used for angles referred to a 360 degree circle.

*Heulandite.* Heulandite is rather rare along the joint. It occurs as colorless, individual, tabular crystals parallel to 010, up to 1 mm in length. It is generally found within the periferal stilbite zone of the natrolite-stilbite rosettes. Optically (+).  $\gamma = 1.500 \pm 0.003$ .  $2V < 40^\circ$ . Dispersion:  $\gamma > V$ .  $\alpha \wedge c = 32^\circ - 34^\circ$ .

The crystals generally show zonal structure almost identical to that described by Bugge (1954), the zones having slightly varying optical orientation. The interference colors of the inner part are often anomalous blue and those of the outer zones normal and slightly higher.  $\text{SiO}_2 : \text{Al}_2\text{O}_3 = 4.5 - 6$ .  $\text{CaO} : \text{Na}_2\text{O} = 10 - 2$ .

*Laumontite.* Laumontite was observed as a few, tiny crystals lying on the surface of type 2 stilbite grains. So little of the material was available that no optical data could be obtained. The visual identification was verified by the x-ray powder pattern.  $\text{SiO}_2 : \text{Al}_2\text{O}_3 = 3.7 - 4.7$ .  $\text{CaO} : \text{Na}_2\text{O} = \infty - 5$ .

#### Joint No. 2.

The joint is mainly filled by calcite with abundant epidote, some quartz, albite sporadically along the sides of the joint, and laumontite.

*Calcite.* Yellowish-white calcite is the most abundant mineral along the joint, occurring in crystals up to ca. 1 cm.

*Epidote.* Epidote occurs in slightly elongate to equant grains which are bright green in color and often have well developed crystal faces. The grains are up to ca. 2—3 mm in size.  $2V$  is close to  $90^\circ$  and the epidote is therefore rather Fe poor.

*Albite.* Albite occurs as small (up to 2 mm), colorless grains at some places along the sides of the joint, largely intimately associated with epidote.

*Quartz.* Quartz is seen as clear grains up to ca. 1 cm in length. Crystal faces are excellently developed. Where it was possible to make the determination it was identified as right-handed quartz which had originally crystallized as  $\alpha$ -(low temperature) quartz.

*Laumontite.* Laumontite occurs as prismatic, elongate, vertically striated, colorless crystals which are up to ca. 1 mm in length. Optic-

ally (—).  $\gamma = 1.514 \pm 0.003$ .  $\gamma \wedge c \sim 27^\circ$ . The low refractive index probably indicates some loss of Ca by base exchange (Winchell, 1951, p. 542).  $\text{SiO}_2 : \text{Al}_2\text{O}_3 = 3.7 - 4.7$ .  $\text{CaO} : \text{Na}_2\text{O} = \infty - 5$ .

### Results of spectrographic analyses.

Spectrographic analyses were made of the minerals natrolite, stilbite, and heulandite from joint No. 1, and of albite from joint No. 2.

In all of the minerals  $\text{K}_2\text{O}$  was found to be present in amounts considerably less than 1 % by weight; probably less than 0.4 %. Natrolite contains very little Ca and very little BaO and SrO (less than 10 ppm.). Heulandite and stilbite contain a little  $\text{Na}_2\text{O}$ , ca. 0.3 %. The stilbite is so poor in  $\text{Na}_2\text{O}$  that it might more properly be called stellerite. The optical data more closely agree with stilbite (Winchell, 1951, p. 345) but the chemical composition is apparently quite like that of stellerite (Neumann, 1944, p. 108—109). Of more genetic interest is the ratio SrO:BaO in the heulandite and stilbite. Heulandite contains ca. 3 % SrO (Dana, 1932, p. 645, says that strontia is usually present, sometimes up to 3.6 per cent) and ca. 1 % BaO, SrO : BaO  $\sim$  3. Stilbite contains ca. 0.1 % SrO and ca. 0.03 % BaO, SrO : BaO  $\sim$  3. This similarity in the ratio SrO : BaO would indicate that the two minerals formed from the same or chemically similar environments.

Albite contained  $\ll$  1 %  $\text{K}_2\text{O}$ , 0.05 % SrO, 0.01 % BaO, and very little CaO, thereby indicating formation at quite low temperature.

### Mineral paragenesis.

#### Joint No. 1.

The study of the minerals along joint No. 1 under the binocular microscope has indicated the following mineral paragenesis along the joint. The mineral formed first was natrolite. It was never seen to surround or include the other zeolites. Stilbite and heulandite formed next, probably largely coincidentally. The likelihood of coincident formation is substantiated by the similarity of the SrO : BaO ratio in the two minerals. Both occur in the periferal zone of the rosettes. Stilbite of type 1 can often be seen to surround heulandite which, in turn, has been seen to have irregular crystal boundaries against stilbite where contact occurs only on one side. Stilbite of type 2 was not seen in contact with the other zeolites except for laumontite which lay on

its surfaces. This would indicate that laumontite formed after stilbite (and consequently also after heulandite) and was the latest mineral formed in the paragenesis along joint No. 1.

#### Joint No. 2.

Calcite is the dominant mineral along joint No. 2 and surrounds and includes all of the other minerals, shaping itself to conform to their crystal boundaries. This indicates that the silicates formed before calcite. The age relations between the silicates are difficult to determine, but it appears to be the case that albite and epidote are about contemporaneous, epidote having begun crystallizing later than albite and having continued to form after albite had stopped, and that laumontite is later than epidote. Quartz quite probably began to form later than epidote.

#### Discussion.

The parageneses along the two joints are almost certainly not simultaneous. In both cases an early influx of Na is apparent, but in the one case natrolite was the first mineral and in the other case albite. We must then propose that the Na-rich minerals formed in environments in which the H<sub>2</sub>O vapor pressure was different. Therefore the discussion of the parageneses in the two joints will treat them as independent.

*Joint No. 1.* By noting the ratios SiO<sub>2</sub> : Al<sub>2</sub>O<sub>3</sub> and CaO : Na<sub>2</sub>O in the zeolites (p. 175—176) it can be seen that the ratio SiO<sub>2</sub>:Al<sub>2</sub>O<sub>3</sub> increases at first, but then almost certainly decrease again, as laumontite, which is clearly the latest mineral, is generally relatively poorer in Si than stilbite and heulandite. The ratio CaO:Na<sub>2</sub>O, however, apparently consistently increases with time. This purely zeolite paragenesis is therefore different from the zeolite paragenesis near Arendal described by Bugge (1954). In that paragenesis there is no consistent variation of the ratio CaO : Na<sub>2</sub>O, but an increase of the ratio SiO<sub>2</sub> : Al<sub>2</sub>O<sub>3</sub> with time. Neumann (1944) in his study at Kongsberg, though able to describe a number of zeolites, found only two zeolites together, viz., harmontone and laumontite. Of these two harmontone, which has the higher SiO<sub>2</sub> : Al<sub>2</sub>O<sub>3</sub> ratio, is the younger.

*Joint No. 2.* In joint No. 2 the uncertainties regarding the order of appearance of the silicates make it difficult to determine how the environment from which the minerals grew changed with time. However, the most probable order is: albite; albite with a little epidote; less

albite, more epidote, and some quartz; epidote and quartz; laumontite; and finally calcite. If such is the case then the change of the ratios  $\text{SiO}_2:\text{Al}_2\text{O}_3$  and  $\text{CaO}:\text{Na}_2\text{O}$  are quite constant. The ratio  $\text{SiO}_2:\text{Al}_2\text{O}_3$  steadily decreases from 6 (albite) to between 3.7 and 4.7 (laumontite) while the ratio  $\text{CaO}:\text{Na}_2\text{O}$  steadily increases from almost zero (the albite  $\sim \text{An}_0$ ) to infinity (calcite), while the  $\text{H}_2\text{O}$  pressure increased such that non-hydrated silicates formed first and were followed by the zeolite. In this case, therefore, the ratio  $\text{SiO}_2:\text{Al}_2\text{O}_3$  diminished with time while the ratio  $\text{CaO}:\text{Na}_2\text{O}$  increased. The age relations of the minerals along this joint differ from those of the same minerals found by Bugge (1954, p. 17); albite is primarily before rather than after epidote and quartz, and calcite is the latest mineral instead of being an intermediate mineral.

Our study indicates that the ratio  $\text{CaO}:\text{Na}_2\text{O}$  increases with time in the two assemblages of low temperature, joint-filling minerals. We believe that this change was the primary determinative factor in the change of mineralogy with time.

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### **Norsk sammendrag.**

#### *Et funn av zeoliter nær Kragerø, Syd-Norge.*

Zeolitene ble funnet på to slepper i en kvartsrik gneis ved Østland, ca. 1,5 km NV for Kragerø. Sleppe nr. 1 (strøk N68V, fall 90° S) inneholder natrolit, desmin, heulandit og laumontit, alle zeoliter. Sleppe nr. 2 (strøk N25Ø, fall 50° S) inneholder kalkspat, epidot, albit, kvarts og laumontit.

Optiske og kjemiske undersøkelser tyder på at mineralene er blitt dannet i følgende rekkefølge: sleppe nr. 1, natrolit, deretter desmin og heulandit samtidig, og til slutt laumontit; sleppe nr. 2, albit, — albit og litt epidot, — mindre albit med epidot og kvarts, — epidot og kvarts, — laumontit, — og til slutt kalkspat.

Våre undersøkelser tyder på at forholdet  $\text{CaO}:\text{Na}_2\text{O}$  øker med tiden. Vi tror at denne endring var den viktigste bestemmende faktor for dannelsen av disse parageneser.

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