

spot on the photographic paper at a distance proportional to $\cot \theta$ from the turntable axis.

The constants r and p in the gnomonic relationship are represented by the length of the telescopic rod at the $\theta=0^\circ$ position, and the distance between the photographic paper and the axis of the larger gear, respectively. The latter may be varied to any convenient value by raising or lowering the turntable, but the value set for r must correspond to the film-to-crystal distance for the Laue photograph in question. In practice it has been found convenient to use values of $r=3$ cm, $p=1$ cm to record the maximum number of points on a paper of convenient size.

A Laue photograph of a complex orthorhombic crystal and its gnomonic projection produced in this manner are shown in Figs. 3 and 4.

The gnomonic projector has the advantages of improved accuracy and speed compared to manual plotting, and can be readily assembled from materials readily available from broken clocks and phonographs. The requirements for accuracy in the construction of the projector are few, and precision assembly is unnecessary except for the following points:

- a) The sliding bar and pointer must be arranged so that the pointer moves in a straight line radially outward from the spindle axis.
- b) The telescopic rod must be set vertical at the $\theta=0^\circ$ position, and the light beam must be set to be parallel with the plane of the turntable at this position.
- c) The axis of the turntable should intercept the axis of the larger gear, and be perpendicular to it, so that the light beam moves radially outward from the turntable axis.

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PARAGONITE FROM TÄSCH VALLEY NEAR ZERMATT, SWITZERLAND¹

E-AN ZEN, MALCOLM ROSS, *U. S. Geological Survey, Washington, D. C.*
AND PETER BEARTH, *University of Basel, Basel, Switzerland.*

INTRODUCTION

During a field trip in the upper Täsch valley near Zermatt, Switzerland, Zen and Bearth collected a specimen of a peculiar-looking white mica in a quartz-kyanite vein. This mica proved to consist of paragonite and little else. Because single-phase paragonite suitable for chemical analysis is extremely rare, the sample was investigated in detail; this note reports the mineralogical results.

The upper Täsch valley is in the Mesozoic ophiolite zone that tectonically overlies the Monte Rosa nappe and underlies the Dent Blanche

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nappe (Bearth, 1953). The quartz-kyanite vein from which we collected is in an eclogitic glaucophane schist of the ophiolite zone. The precise structural relations of the vein to the ophiolite are unknown. The vein is located on the southern ice margin of a rock island in the Längfluh glacier, at about 3000 meters elevation, immediately northeast of

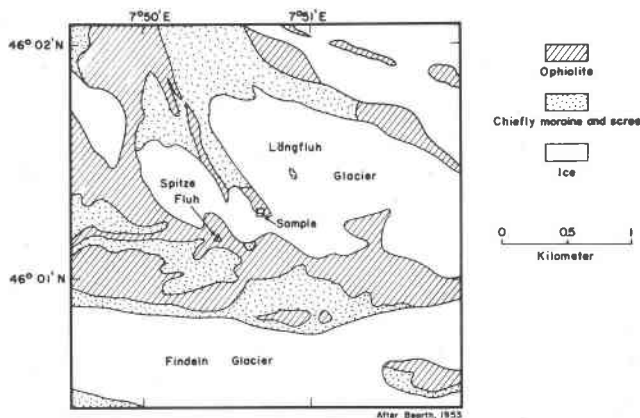


FIG. 1. Index map showing the paragonite locality, Täsch Valley, Switzerland.

Spitze Fluh (Fig. 1). The petrography and mineralogy of the eclogitic glaucophane schist and its associated rocks have been described by Bearth (1958, 1959).

SAMPLE DESCRIPTION

The vein consists predominantly of milky quartz and light-blue blades of kyanite as much as $\frac{1}{2}$ cm by 3 cm long. Many of the kyanite crystal faces are veneered with plates of white mica which proved to be a mixture of muscovite and paragonite. The analyzed paragonite, however, occurs as a compact nodule about $\frac{3}{4}$ by 1 by $1\frac{1}{2}$ cm, enclosed in vein quartz. Near the margin of the nodule, the mica flakes have rudely concentric orientation, but toward the core the mica plates are nearly perpendicular to the nodular surface. Much of the paragonite in this latter zone is in crystals as much as 2 mm across.

About 1.5 g of the sample were carefully drilled out from near the core of the nodule. The same powdered sample was used for all the detailed studies except the single-crystal work. Microscopic check showed nothing but white mica in the sample; x-ray powder pattern showed that a little muscovite was the only contaminant. The amount of muscovite was estimated from the relative intensities of the (006)_{2M} peaks in the following manner.

A highly oriented mount of the powder, of effectively infinite thickness, was prepared by pressing the material into an aluminum holder. A preliminary chart was run to estimate the positions and intensities of the peaks. A Norelco diffractometer was used, with Cu/Ni radiation, at 35 kv and 15 ma tube current. Enough layers of nickel foil were placed in front of the Geiger tube window so that the tube response was well within the linear range during the entire counting routine (no more than about 700 cps encountered). The background intensity was counted at several goniometer positions which bracket the 006 peaks of muscovite and paragonite. The fixed-time technique was used with a 32-second interval; once the time switch was set it was not touched until the entire counting procedure was completed. At each goniometer position, the intensity was measured six times. The average for each position was plotted against the 2θ angle; interpolation of the data gives the background correction for the mica peaks.

A traverse across each mica 006 peak was made next in intervals of 0.01° to $0.02^\circ 2\theta$; the goniometer was held stationary at each position and the intensity counted in the manner described. The scale factor was adjusted, if necessary, to suit the peak intensity, but otherwise the instrument setting was not tampered with. As each peak was traversed, the results were plotted against the 2θ angle. After the interpolated background has been subtracted, the results give the peak intensities, and the positions of these peaks are checks on the d_{006} values.

Because the 4° and 0.006-inch slit system was used, the entire mount was bathed in the x-ray beam at all angular positions during the counting. At higher angles, the flux was denser; the measured intensities thus include a systematic error. Between 2θ values of 26.7° and 27.8° , however, the error was only 3%; it was felt that this error, which itself was a correction on a 2% correction term, was more than compensated by the larger sample size and therefore improved counting statistics.

The relative intensities of paragonite and of the muscovite contaminant are converted to relative amounts by means of calculated structure factors, F^2 , for end-member paragonite and end-member muscovite. For the analyzed sample, the observed intensity ratio was $I_{\text{musc}}/I_{\text{parag}} = 1:80$; this corresponds to 2 molar per cent of muscovite. No attempt was made to further purify the sample before it was chemically analyzed.

The chemical analysis of this paragonite is given in Table 1. All the oxides except H_2O were analyzed by methods similar to those described by Shapiro and Brannock (1962); because of the small sample size, H_2O was separately analyzed by Robert Meyrowitz using a modified, microchemical Penfield technique. The calculated chemical formula for the paragonite is given, after correcting for 2 atomic per cent of end-member K-muscovite that was present as a separate phase.

TABLE 1. CHEMICAL ANALYSIS OF PARAGONITE FROM TÄSCH VALLEY, SWITZERLAND¹

SiO ₂	47.0	Formula (after subtracting 2 atomic percent of stoichiometric K-muscovite as impurity), calculated on the basis of 11 oxygens in the anhydrous formula: 1.01 0.01 (Na _{.946} K _{.047} Ca _{.016})(Mn _{.001} Mg _{.010}) 2.98 (Al _{2.939} Fe ³⁺ _{.039} Ti _{.001})Si _{3.00} O ₁₀ (OH) ₂
Al ₂ O ₃	39.1	
Fe ₂ O ₃ (total iron)	0.78	
MgO	0.10	
MnO	0.02	
CaO	0.24	
Na ₂ O	7.5	
K ₂ O	0.81	
TiO ₂	0.02	
P ₂ O ₅	—	
H ₂ O ¹	4.3	
	99.87	
Total	99.87	

¹ Sample analyzed according to the procedure of Shapiro and Brannock (1962), except for H₂O, which was analyzed by the Penfield method using Pb₃O₄ as flux. P. Elmore, S. Botts, G. Chloe, and R. Meyrowitz, analysts.

The powder pattern of the paragonite is that of a 2M₁ mica (Yoder and Eugster, 1955, p. 245). The basal spacing, d_{001} (Copper K α radiation, $\lambda = 1.5418 \text{ \AA}$, nickel filter, quartz internal standard), is $19.246 \pm 0.006 \text{ \AA}$. The reference quartz line is the (10.1) peak.

Complete unit-cell data were obtained from single crystals of the paragonite.

TABLE 2. UNIT CELL AND OPTICAL DATA FOR THE ANALYZED PARAGONITE FROM TÄSCH VALLEY, SWITZERLAND
Cu K α radiation, $\lambda = 1.5418 \text{ \AA}$

Monoclinic	
<i>a</i>	$5.13 \pm 0.03 \text{ \AA}$
<i>b</i>	$8.89 \pm 0.05 \text{ \AA}$
<i>c</i>	$19.32 \pm 0.10 \text{ \AA}$
β	$95^\circ 10' \pm 30'$
Space group:	<i>C2/c</i> or <i>Cc</i>
V	877.5 \AA^3
d_{001}	$19.24 \pm 0.10 \text{ \AA}$ (single crystal)
d_{001}	$19.246 \pm .006 \text{ \AA}$ (powder)
Z	4
Density (calc.)	2.907 g/cm^3
Structure type	2M ₁
Optical properties (Na light; temperature at 22° C.):	
α	1.571 ± 0.003
β	1.603 ± 0.002
γ	1.606 ± 0.002
2V(-)	$\approx 30^\circ$
2V(-) _{calc}	33°

onite by using the Buerger precession technique. In Table 2 are listed the x-ray and optical data. The mineral has a unit cell with $a=5.13 \text{ \AA}$, $b=8.89 \text{ \AA}$, $c=19.32 \text{ \AA}$, and $\beta=95^\circ 10'$. The conditions limiting the possible reflections are:

$$hkl:h+k=2n$$

and

$$h0l:l=2n(h=2n)$$

thus the space group is $C2/c$ or Cc . The structure type is $2M_1$. The basal spacing, d_{001} , of 19.24 \AA , as determined from the precession photographs, compares favorably with the basal spacing of 19.246 \AA determined from the powder sample. The precession photographs show that the paragonite crystals are twinned by a rotation of 180° about $[310]$ or $[\bar{3}\bar{1}0]$. This type of twinning, known as spiral twinning, can also be described as the rotation of adjoining individuals 120° about the c^* axis (Sadanaga and Takéuchi, 1961).

A complete indexed powder pattern of the paragonite is given in Table 3.

ADDITIONAL COMMENTS

As mentioned, the kyanite in the hand specimen is locally coated with an intimate mixture of paragonite and muscovite. The nature and amount of the sample precluded its separation into pure phases for chemical analysis. X-ray diffraction chart of the sample, however, yielded the following fundamental basal repeat distances:

$$\text{muscovite} = 9.942 \text{ \AA}$$

$$\text{paragonite} = 9.637 \text{ \AA}$$

This paragonite spacing is much larger than that of the analyzed nodular paragonite, for which $d_{002}=9.623 \text{ \AA}$ (powder mount), and the difference, 0.014 \AA , is not accounted for by observational errors. The two paragonites must be out of mutual chemical equilibrium.

The trace of muscovite associated with the analyzed paragonite yielded a basal spacing of $\approx 9.947 \text{ \AA}$, but because of the weak peak the value is only approximate. It is not distinguishable from the value of 9.942 \AA for the kyanite-coating muscovite; indeed the muscovite could be contamination from material that occurs on the surface of the nodule.

This last possibility is supported by the observation that for the kyanite veneer, the difference between muscovite and paragonite basal spacings is 0.305 \AA , whereas for the nodular material this difference is 0.324 \AA . The latter value corresponds to metamorphism in the low garnet grade, but the former value corresponds to the kyanite grade (Rosenfeld *et al.*, 1958), which agrees with the occurrence of the micas in a kyanite vein.

TABLE 3. X-RAY POWDER DATA FOR PARAGONITE FROM TÄSCH VALLEY, SWITZERLAND

Calculated ¹		Measured ²	
hkl	d _{hkl} (Å)	d(Å)	I ³
002	9.621	9.65	S
004	4.810	4.82	MS
020	4.445	4.41	MS
110	4.430		
$\bar{1}11$	4.392		
021	4.331		
111	4.245	4.25	VW
$\bar{1}12$	4.149	4.13	VW
022	4.035	4.04	M
112	3.909		
$\bar{1}13$	3.786	3.77	M
023	3.653	3.65	WM
113	3.519	3.54	W
$\bar{1}14$	3.393	3.37	WM
024	3.265	3.25	W
006	3.207	3.21	VS
114	3.139	3.14	VW
$\bar{1}15$	3.024		
025	2.909	2.91	M
115	2.799	2.81	M
$\bar{1}16$	2.700	2.68	WM
026	2.601		
130	2.563	2.56	WM
$\bar{1}31$	2.556		
200	2.555		
202	2.526		
131	2.526	2.52	S
116	2.506		
$\bar{1}32$	2.505		
132	2.450		
$\bar{1}17$	2.422		
$\bar{1}33$	2.418	2.42	M
202	2.416		
008	2.405		
204	2.345		
133	2.344	2.34	M
027	2.338		

¹ Monoclinic, $C2/c$ or Cc , $a=5.13$ Å, $b=8.89$ Å, $c=19.32$ Å, $\beta=95^\circ 10'$.

² $\text{CuK}\alpha$ radiation, Ni filter ($\lambda=1.5418$ Å). Camera diameter: 114.59 mm. Lower limit 2θ measurable: approximately 8° (11.0 Å). No muscovite lines are observable.

³ VS (very strong), S (strong), M (medium), WM (weak medium), W (weak), VW (very weak), b (broad).

TABLE 3—(Continued)

Calculated ¹		Measured	
hkl	$d_{hkl}(\text{Å})$	$d(\text{Å})$	I ²
134	2.306		
117	2.258		
040	2.223		
134	2.221		
221	2.220	2.21	VW
220	2.215		
041	2.208		
222	2.196		
118	2.187		
221	2.181		
135	2.179		
204	2.176		
042	2.165	2.172	W
223	2.146		
222	2.122		
028	2.115	2.13	VW
043	2.100		
206	2.092	2.094	M
135	2.090		
224	2.074		
136	2.048		
118	2.048		
223	2.045		
044	2.018		
		1.922	S
		1.838	W
		1.678	WM-b
		1.605	M-b
		1.481	M
		1.471	W
		1.372	WM
		1.34	VW-b
		1.304	WM-b

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RECALCULATION OF PYROXENE ANALYSES

M. G. BOWN, *Department of Mineralogy and Petrology,
University of Cambridge, England.*

In the crystal structure of any pyroxene there are three sets of cation sites which we may designate A (coordination 6 or more), A' (coordination 6), and B (4-coordinated), in the ratio represented by A'AB₂O₆, for example CaMgSi₂O₆ (Warren and Bragg, 1929; Warren and Modell, 1930; Morimoto, *et al.*, 1960). For the present purpose A' and A are not differentiated, so that the formula may be written A₂B₂O₆. In rock-forming pyroxenes the B sites contain mainly Si, with usually some Al, and apparently occasionally a few Fe³⁺ and Ti ions if the B sites are not filled by the available Si and Al ions. To save repetition the ability of Fe³⁺ and Ti to act as Al in some circumstances will not be mentioned again. All cations other than Si may occupy the A sites. Al can thus be present in both A and B positions.

After recalculating to six oxygens the ionic proportions obtained from the chemical analysis of a pyroxene, the cations may be assigned to A and B positions. All the Si must go in B, all other cations except Al in A. There are three ways which have been used to partition the Al ions between A and B:

1. to split the Al ions so that $\Sigma A = \Sigma B$.
2. to make $\Sigma B = 2$ by adding Al, the rest of the Al (if any) falling into A.
3. by the method proposed by Hess (1949), in which the ions are allocated in stages corresponding to the building of formula units such as NaCrSi₂O₆, etc. The (WXY) group of Hess corresponds to A above, the Z group to B.

In practice with a good analysis there is little difference between the