Some unusual alkali-felspars in the Central Australian charnockitic rocks.

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I. Introduction.

DURING a universal stage investigation of the pegmatitic felspars in the Central Australian charnockites, several alkali-felspars were found which, according to the stereograms published by Emmons (3, pl. 12), should have been near 'anorthoclase' in composition. This identification, based purely on optical properties, was questioned in the first instance because of the absence of other evidence for a soda-rich suite of minerals in these apparently potassic pegmatites. Two felspars which suggested a high soda-content were chemically analysed. Neither proved to be notably high in soda.

II. Microcline-microperthite with cross-hatched twinning (4750).[1]

This mineral occurs in the central part of a narrow pegmatite which cuts charnockitic granodiorite 2·8 miles N. 37° E. of Ernabella in the Musgrave Ranges. Excepting the dolerites, this pegmatite is representative of the latest phase of igneous activity in this region. Associated minerals are haematite, zircon, biotite, hornblende, and tourmaline (a rare mineral in the Musgrave Ranges). No orthite was seen, as this mineral appears to be confined to somewhat earlier pegmatites of the same batholith (10, p. 208). The felspar is a very pale flesh-coloured perthitic microperthite with the perthite recognizable in hand-specimen only on careful scrutiny. The mineral fluoresces pink under intense ultra-violet radiation of wave-length 2537 Å. Under the microscope the felspar is found to contain 18 % by volume of perthitic material arranged in the normal way.

[1] Numbers refer to specimens in the mineral collection of the University of Adelaide.

Optical properties.—Work with the universal stage gave the amount of rotation needed to obtain α, β, and γ from the readings of α' and β' on (010) and α'' and γ' on (001). With use of Emmons's refractive index variation diagram (3, pl. 10), the appropriate corrections were obtained. In both specimens 4750 and 4760 these are very small, being of the order of 0·00003 for (010), and 0·00006 for (001) readings. The corrected values were checked by comparison of calculated and measured 2V, and some by direct measurement. Even so, it is doubtful whether the readings can be more accurate than $\pm 0{\cdot}0003$. Hot-water control was used in conjunction with a modern Bellingham-Stanley Abbe refractometer.

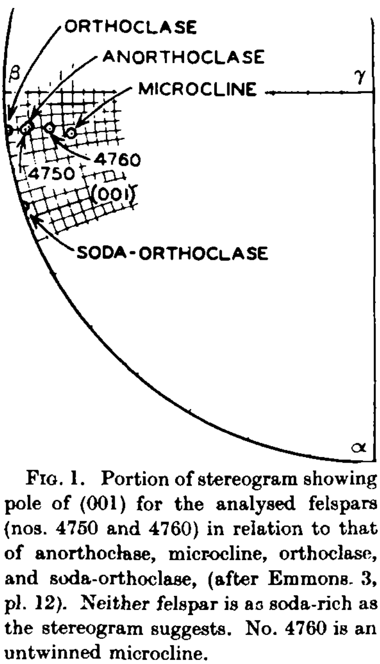

FIG. 1. Portion of stereogram showing pole of (001) for the analysed felspars (nos. 4750 and 4760) in relation to that of anorthoclase, microcline, orthoclase, and soda-orthoclase, (after Emmons. 3, pl. 12). Neither felspar is as soda-rich as the stereogram suggests. No. 4760 is an untwinned microcline.

Interference figures in convergent light on (010) flakes are more off-centred for microcline than for the albite of the perthitic veins. 2V was measured with the universal stage on both (100) and (010) sections. Stereographic plots of poles of cleavages visible on (010), (001), and (100) fall near 'anorthoclase' in all cases, although the mineral is not soda-rich (fig. 1). Extinction angles on (001) and (010) are set out with the other data in table I. The extinction angle on (001) is much smaller than the so-called usual extinction of 15° of microcline. A regular and very fine cross-hatched twinning is seen on (001).

Chemical analysis.—The analysis was carried out primarily to confirm or otherwise the high soda-content of this felspar, and for this purpose it was considered unnecessary to attempt the tedious separation of the perthite from the microperthitic material. The analysis was carried out on a 0·5-gram sample of powder. Alkalis were determined on a separate 0·5-gram sample by fusion with anhydrous $BaCl_2$ and $CaCO_3$ and subsequent precipitation of K_2PtCl_6. Total iron was determined on another 0·5-gram sample. The analysis and calculations based thereon appear in table I.

The composition of the original felspar (i.e. before exsolution of the perthite and microperthite) was Or 74·72, Ab 22·91, An 2·37. Modal percentages were measured by the Rosiwal method in sections cut parallel to (010), (001), and (100), and the average taken after recalculation to 100 % to eliminate 2·2 % of quartz and epidote. The values are microcline-microperthite 81·5 %, perthitic albite 18·5 %. The figure for microcline-microperthite is in excess of the Or as calculated from the analysis. This is due to the difficulty of measuring modal proportions on microperthitic material as well as of possible incomplete exsolution. It is clear, however, that the stereograms and other optical properties are misleading when they suggest that this microcline (which is rather rich in potash) is almost pure anorthoclase.

TABLE I. Chemical analysis and optical data of two Central Australian microclines. (Analyses by A. F. Wilson.)

4750. Perthitic microcline-microperthite, near Ernabella, Musgrave Ranges.
4760. Untwinned microcline-microperthite, Koli-Koli rock-hole, Musgrave Ranges.

	4750.	4760.		4750.	4760.
SiO_2	64·95	64·66	Or	74·72	60·53
Al_2O_3	20·11	20·10	Ab	22·91	35·59
Fe_2O_3	trace	0·35*	An	2·37	3·88
CaO	0·45	0·60	Sp. gr.	2·565	2·569
MgO	trace	0·12	α	1·5178	1·5210
BaO	nil	nil	β	1·5209	1·5247
K_2O	11·85	10·19	γ	1·5232	1·5273
Na_2O	2·55	4·21	$\gamma-\alpha$	0·0054	0·0063
MnO	nil	trace	$2V_\alpha$ (obs.)	81° ± 1°	80° ± 1°
Loss	0·12	0·11	$2V_\alpha$ (calc.)	81° 20′	79° 26′
	100·03	100·34	Extn. on (010) ...	4½°	5½–6°
			,, (001) ...	5°	4–5°

* Total iron, mainly ferric.

III. UNTWINNED MICROCLINE-MICROPERTHITE (4760).

This mineral occurs in a narrow pegmatite in the gneissic and granulitic charnockites at the Koli-Koli rock-hole, 6½ miles WSW. of Ernabella in the Musgrave Ranges (10, p. 208). The pegmatite contains hornblende, haematite, and the weakly radioactive minerals zircon and orthite. The pegmatite is one of those responsible for the felspathization of the rocks of the Koli-Koli ridge, and is typical of many such concordant veins among the gneissic charnockites. The felspar in the pegmatite is very variable in colour (pale dove-grey to purplish-grey) and possesses a marked moonstone schiller. No perthitic veins are present, although along certain cracks a much later bleaching has taken place yielding albitic material. The felspar is non-fluorescent under intense ultra-violet radiation of 2537 Å. The mineral is an untwinned microperthitic microcline.

Under the microscope the felspar is found to contain a large number of microperthitic inclusions. These are best seen on (010) cleavage flakes, and an attempt was made to estimate (by the Rosiwal method) the proportions of the two felspars. These exsolution lenses of albite appear to comprise about 40 % by volume of the microperthite. On (010) the lenses are usually $0{\cdot}3 \times 0{\cdot}006$ mm. and tightly packed with about one hundred bands per mm. On (001) the microperthite is less regularly spaced. Some lenses measure $0{\cdot}04 \times 0{\cdot}02$ mm., but most appear as wisps only $0{\cdot}02 \times 0{\cdot}002$ mm.

Non-felspathic inclusions are important in this microcline. On (010) tiny dark inclusions occur in the albite exsolution lenses. About twelve grains appear in each lens and each grain is about 0·004 mm. in diameter. The inclusions probably amount to between 2 and 3 % of the total mineral. They are reddish and almost opaque, but are probably an iron-rich silicate rather than haematite, since only 0·35 % of Fe_2O_3 was found chemically. It seems likely that the iron was held in solution by the original alkali-felspar (a soda-orthoclase?) but preferred to follow through with the soda component when exsolution of the microperthitic material took place (the potash component is free from the inclusions). Later cooling (and perhaps diminished pressure) has apparently caused this iron compound to exsolve from the microperthitic albite lenses.

Optical properties.—Refractive indices α, β, and γ were determined as in no. 4750. Owing to the confused mass of microperthitic particles on (001) sections the measurement of γ is the least reliable. However, calculated and measured 2V are in good agreement. In convergent light the obtuse bisectrix is somewhat off-centred on (010) flakes. If this untwinned alkali-felspar were orthoclase the Bx_0 would be perfectly centred. Plots of poles of cleavages visible on (010), (001), and (100) fall between anorthoclase and microcline. This is not what was expected, and also indicates that the mineral is triclinic (fig. 1). Extinction angles on (001) and (010) are set out in table I. On (001), α': (010) is between 4° and 5°. If the mineral were orthoclase there would be straight extinction.

No undoubted cross-hatched twinning is seen on (001), although in a large number of crushings a few (001) flakes were seen with shadowy extinction resembling incipient twinning. The mineral is essentially an untwinned microcline-microperthite.

Chemical analysis.—Owing to the several coloured varieties of microcline in this pegmatite, great care was taken to select material for analysis of the same colour (dark dove-grey) and similar appearance under the microscope. Owing to the abundance of microperthitic material, no attempt was made to separate the two felspars. The analysis was carried out as for no. 4750, and the results with calculations based thereon are set out in table I.

The composition of the original felspar (i.e. prior to any exsolution) was Or 60·53, Ab 35·59, An 3·88. An estimation, by the Rosiwal method, of the amount of exsolved albite was undertaken (extinction of the fast ray of the lenses on (010) measured to (001) suggested a composition of Ab 92, An 8). The albite lenses comprise about 40 % by volume of the whole, which compares favourably with the 39 % by weight of plagioclase calculated from the analysis. Exsolution seems to be fairly complete and indicates that the felspar, whose optical properties suggested a high soda-content, is notably rich in potash.

IV. Discussion.

(1) *Cross-hatched twinning of microcline.*

The cross-hatched twinning of microcline seems to be a combination of albite and pericline twin-lamellae with twin-laws (010) and [010]. A monoclinic crystal with a diad axis of symmetry *b* and the plane of symmetry || (010) cannot show twinning on either of these two laws. Although the *presence* of true cross-hatching[1] in a potash-felspar may be taken as proof of triclinic symmetry (i.e. the mineral is microcline and not orthoclase), the *absence* of such twinning on (001) cannot be taken as sufficient evidence that the felspar is the monoclinic mineral orthoclase. In this paper alkali-felspars are described which, although showing no cross-hatched twinning on (001), are not monoclinic. They are therefore called untwinned microclines.

Many petrologists, it appears, are not aware that untwinned microcline can exist and indeed is very common in certain rocks. It has been the custom, therefore, to accept as microcline any potash-felspar which shows cross-hatching on (001) and to relegate all other potash-felspars to the orthoclases. Indeed, for routine work such a criterion is useful.

Several years ago Alling (1, p. 256) drew attention to the fact that

[1] Certain highly microperthitic potash-felspars of the charnockites may display a 'pseudo-twinning' due to an intimate interlocking of exsolution lenses. The difference in relief when viewed under reduced illumination serves to distinguish these lenses from the 'true' twinning.

'the term "orthoclase" is used in a very loose manner, quite inconsistent with present-day standards'. He suggests, moreover, that 'orthoclase (nearly pure potash-feldspar without microclinic characteristics) is very rare in nature'.[1] Nevertheless, it appears that many well-twinned microclines are still described as orthoclases, and most untwinned microclines are overlooked.

In a recent paper on certain alkali-felspars (Jayaraman, 4, p. 118) a pegmatitic felspar is called a 'white orthoclase' presumably because of its lack of twinning on (001) and $2V_{\alpha}$ 58°; yet the author gives the extinction α':(010) on (001), not as 0°, but as 4° 30′. Such an extinction would suggest that the mineral is triclinic and therefore likely to be microcline. Moreover, he states that 'It shows no twinning and only in one case was a very faint incipient microcline twinning noticeable'. In two other 'orthoclases' of similar type a 'very faint cross-hatching' was noticed. The optic axial angle is low (58°) but falls on the continuation of the 2V 'line' for the microclines as suggested by Spencer (6, fig. 4*b*). The mineral, therefore, does not appear to be orthoclase but rather an untwinned (or poorly twinned) microcline. E. Spencer, however, has recorded a similar oblique extinction on (001) (5, p. 333) but in his case he found 'no trace of microcline twinning either on cleaved or ground sections' and heat-treatment suggested that the mineral was orthoclase.

It appears that in the absence of the typical cross-hatching on (001) another petrographic criterion for distinguishing between orthoclase and microcline is needed. The extinction angle α':(010) on (001) is often listed for microcline as 15°, but actually varies from near 15° to near 0° (usually 5–6°). Thus a potash-felspar which has oblique extinction on (001) should be taken as triclinic whether or not it shows twinning on that face.

Although microclines usually have an extinction angle of 5–6° on (001), some have been recorded with the angle nearly zero. If the mineral is untwinned and α':(010) on (001) = 0°, it should, of course, be called orthoclase, but if the mineral is cross-hatched twinned and has apparently 'straight extinction' it must still be microcline. In several finely cross-hatched twinned microclines which show a superficially straight extinction I have found an extinction which is never 0° but from 1° to 1½°.[2]

[1] Although E. Spencer (6) has since established his 'orthoclase-microperthite series', microcline seems to be the more common form.

[2] The (010) is the poorer of the two main cleavages in felspar, and on (001) sections it is sometimes difficult to find satisfactory cleavages. This, no doubt, accounts for many 'anomalous' extinctions in the potash-felspars.

Jayaraman (4, p. 121), in discussing some green perthitic microperthites from India, states that mainly 'Because of the very fine cross-hatching exhibited . . . these have so far been *wrongly* considered to be microcline perthites'. 'The potash member of this feldspar appears to be an *orthoclase*. . . . It shows the presence of very fine cross-hatching on (001) face, but sections or cleavages parallel to this face give *almost straight extinction* . . .' (4, p. 120) (the italics are mine). But even if the cross-hatching is a very fine variety (it is carefully described) it appears to be essentially a combination of typical albite and pericline twins. In that case the mineral is triclinic, which is further borne out by the fact that the author had to record that the extinction after all was only 'almost' straight. The author supported his claim that the mineral was orthoclase by stating that in convergent light it gave a centred obtuse bisectrix figure on (010). As a routine test this usually serves to distinguish microcline (twinned or otherwise) from orthoclase, but when the extinction is nearly straight on (001) a more critical test is needed.

I have studied with a universal stage several Central Australian felspars similar to this Indian mineral, both as regards fineness of cross-hatching and nearly straight extinction. These on (010) show a small but marked separation of b from γ, although they gave sensibly centred obtuse bisectrix figures in convergent light. I submit, therefore, that the so-called cross-hatched 'orthoclases' are microclines.

(2) *Relations between composition and physical properties.*

Spencer (6, figs. 1 and 3) has published graphs indicating the relationship between chemical composition and refractive indices, extinction angle on (010), and optic axial angle of the orthoclase-microperthite series. After much investigation he is convinced that felspars of this series should conform fairly closely to these relationships.

But it is apparent that no such regular relationships exist for the microclines. For most microclines the extinction angle on (010) is $6°\pm1\frac{1}{2}°$, but many occur with α':(001) on (010) = 1 or 2° for no apparent reason. Likewise, on (001) in both twinned and untwinned microclines there is a great variety of extinction angles, again for no apparent reason. For instance, while many microclines rich in potash have α':(010) on (001) = 15°, many others of almost identical composition have values ranging from 15° to almost zero. Refractive index is a little more useful, but the increase in the indices with increase of soda-content is only a trend. There are very many examples of microclines whose refractive indices, for no apparent reason, deviate strongly from this trend. 2V, likewise, shows a tendency to increase with the increase of soda, but there are so many anomalies that an optic axial angle determination has no diagnostic value.

(3) *The occurrence of microcline.*

The researches of E. Spencer (7, pp. 90–91, &c.), Vogt (9, pp. 64–68, &c.), and others show that the first potash-felspar to slowly crystallize at temperatures of 1100–950° C. is a schillerized orthoclase of the moonstone type. In a lower temperature range (950–750° C.) the normal microperthitic orthoclase is probably the stable form, but from 750–400° C. a primary microcline appears. While this appears to be so, in addition a microcline is very often found taking the place, either wholly or in part, of an original (but now less stable) orthoclase. Certain agents may govern this change, viz. (*a*) crush-metamorphism, (*b*) age, and (*c*) volatile concentration at the time of crystallization of the original orthoclase.

(*a*) *The role of crush-metamorphism.*—Alling (1, p. 275) has shown that microcline is common in shear zones, and suggested that careful study of the felspars could assist in deciphering structural problems. Study of the felspars in the great crush zones of the Musgrave Ranges (10, p. 209) shows that both poorly cross-hatched and untwinned microclines have replaced the original orthoclases in almost all cases. In some of the rocks the crushing is obviously the promoter of the twinning of microcline.

However, in other cases a potash-felspar has undergone serious crushing (as seen both in the field and under the microscope) and yet has no sign of the cross-hatched twinning. For instance, no. 4755 is a pale pink microperthitic microcline which occurs in a mylonitized medium-temperature pegmatite near the summit of Mt. Carruthers in the Musgrave Ranges. No cross-hatched twinning is seen on (001) although there is ample evidence of considerable crushing. The extinction angle on (001) is very large (16½–19°), and on (010) the obtuse bisectrix is well off-centred.

Alling (1, p. 292) observed that the process of section grinding could develop the cross-hatching of microcline. It is doubtful whether this is very common.

(*b*) *The role of age.*—In large areas of the Australian pre-Cambrian shield alkali-felspars in igneous bodies which appear to have been emplaced 'magmatically' have been free from noticeable crushing since their initial crystallization. The original orthoclase-microperthite in many cases shows on (001) a peculiar wavy extinction (with incipient cross-hatched twinning) departing in places from the 0° of orthoclase to about 6°. This transformation from orthoclase to a poorly twinned microcline is best attributed, for the time being, to the 'ageing' of these ancient and stable rocks.

(c) *The role of volatiles.*—Empirically a relation is suggested between the ease of transformation of orthoclase to microcline and development of cross-hatched twinning, and the ability of volatiles to enter into the structures of minerals formed at the time of crystallization of the original orthoclase.

In deep-seated rocks with no obvious signs of shearing it appears that if the original orthoclase has crystallized in the presence of 'dry' minerals like hypersthene and diopsidic augite, it inverts on ageing to an untwinned microcline. The extinction angle on (001) is inclined (about 5° is common) and in convergent light the obtuse bisectrix is off-centred with the optic axial angle usually several degrees larger than the corresponding original orthoclase. Such untwinned microclines may develop a ragged cross-hatching due to subsequent crushing. This is seen in the charnockitic granites and granodiorites of Ernabella in the Musgrave Ranges.

In the cupola facies of the same 'batholith' (e.g., Bald Hill, 14 miles east of Ernabella) the original orthoclase has crystallized in the presence of hornblende and biotite (both 'wet' minerals). These orthoclases, though unstressed, have inverted to microclines which are finely cross-hatched on (001). This cross-hatched microcline displays a notable pink fluorescence under 2537 Å. radiation, whereas the untwinned or poorly twinned microclines and original orthoclases of the major igneous body do not fluoresce. This indicates that the pressure-temperature conditions which allowed the volatile to enter into the structure of the ferromagnesian minerals in the cupola facies may have allowed some trace element to enter into the structure of the original orthoclase, thus leading to a distorted structure on cooling, and a more facile inversion to a cross-hatched twinned and fluorescing microcline.[1]

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[1] These and other fluorescence phenomena are treated more fully in the following paper (p. 225).

References.

1. ALLING (H. L.), 1921. The mineralography of the feldspars. Part I. Journ. Geol. Chicago, vol. 29, pp. 193–294. [M.A. 3–33.]
2. —— 1923. The mineralography of the feldspars. Part II. Ibid., vol. 31, pp. 282–305 and 353–375. [M.A. 3–33.]
3. EMMONS (R. C.), 1943. The universal stage. Mem. Geol. Soc. America, no. 8. [M.A. 9–18.]
4. JAYARAMAN (N.), 1940. A chemical and mineralogical study of the feldspars from the mica-pegmatites of Nellore, Madras. Proc. Indian Acad. Sci., Sect. A, vol. 11, pp. 117–137. [M.A. 8–16.]
5. SPENCER (E.), 1930. A contribution to the study of moonstone from Ceylon. Min. Mag., vol. 22, pp. 291–367.
6. —— 1937. The potash-soda-felspars. I, Thermal stability. Ibid., vol. 24, pp. 453–494.
7. —— 1938. The potash-soda-felspars—II, Some applications to petrogenesis. Ibid., vol. 25, pp. 87–118.
8. —— 1945. Myrmekite in graphic granite and in vein perthite. Ibid., vol. 27, pp. 79–98.
9. VOGT (J. H. L.), 1926. The physical chemistry of magmatic differentiation of igneous rocks—II. Skrift. Norske Vidensk.-Akad., Mat.-naturv. Kl., no. 4, pp. 1–101. [M.A. 3–379.]
10. WILSON (A. F.), 1947. The charnockitic and associated rocks of north-western South Australia. Part I. The Musgrave Ranges. An introductory account. Trans. Roy. Soc. S. Australia, vol. 71, pp. 195–211. [M.A. 10–438.]
11. —— 1950. Fluorescent felspar and zircon as petrological aids. Min. Mag., vol. 29, p. 225.