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SODA-RICH SANIDINE OF PYROCLASTIC ORIGIN FROM THE  
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## INTRODUCTION

It is now well known that the ordering, unmixing, and optical properties of the alkali feldspars are closely dependent on the conditions and rate of cooling. As yet, however, little attention has been given to the properties and composition of sanidine discharged in ash clouds, which should have a thermal history rather similar to sanidine formed synthetically. This paper describes the pyroclastic soda-rich sanidine crystals from a tuff bed in the John Day formation of Oregon.

## DESCRIPTION AND LOCATION OF TUFF BED

The sanidine occurs in a bed of vitric tuff in the John Day formation (Upper Oligocene-Lower Miocene) between Mitchell and the John Day River in north-central Oregon. The tuff is generally 1 to 3 feet thick and lies about 800 to 850 feet above the base of the formation and 200 to 400 feet below a widespread rhyolitic ash flow tuff which forms the middle member of the formation. In places the sanidine-bearing tuff is a massive bed of uniform thickness which is graded from coarse particles of ash up to fine ones; here it has probably remained undisturbed after settling from an ash cloud. Where reworked by running water, the tuff is stratified and may attain a thickness of 35 feet.

Sanidine crystals 1 to 5 mm long generally form 5 to 10 per cent of the tuff bed, and most of the remainder consists of delicate vitric shards, either fresh or altered to clinoptilolite or montmorillonite, or both. A small amount of sodic plagioclase, quartz, and iron-rich clinopyroxene crystals (or their altered equivalent) can be identified in most samples.

## PHYSICAL PROPERTIES OF SANIDINE

The sanidine crystals are commonly euhedral or broken and perfectly clear and colorless. Most of them appear optically uniform, but some of the larger crystals contain small cores of more sodic composition, a few of which display the grid twinning characteristic of anorthoclase. Small crystals of magnetite and pyroxene and inclusions of pale brown glass occur in some of the crystals, and a few of the crystals contain a myrmekitic mantle, 0.03 to 0.35 mm thick, of quartz intergrown with sanidine.

The sanidine is optically monoclinic, judging from universal-stage

measurements on twinned crystals. Refractive indices are as follows:  $\alpha=1.523 (\pm .002)$ ,  $\beta=1.529$ , and  $\gamma=1.530$ . The extinction angle on (010) cleavage flakes is 8 degrees, and  $2V_{\alpha}$  is 35 to 40 degrees. The specific gravity of the sanidine is  $2.568 (\pm .005)$ , determined with a Berman balance.

The sanidine is a single-phase monoclinic feldspar, as determined both from precession patterns of single crystals and diffractometer patterns of powdered samples. Precession patterns give  $\beta=116^{\circ}10'$ ,  $a=8.354 \pm .016$ ,  $b=12.985 \pm .015$ , and  $c=7.163 \pm .008$  (A. Pabst, personal comm.). The  $d(201)$  spacing, measured with a diffractometer and calibrated against  $d(10\bar{1}0)$  of quartz, indicating on the graph of Tuttle and Bowen (1958, p. 13) a composition of about  $Or_{40}(Ab+An)_{60}$ .

#### CHEMICAL COMPOSITION

A 10-gram sample of the sanidine was analyzed by H. Asari (Table 1) using gravimetric and flame-photometric methods. The analyzed crystals were obtained from the basal 3 inches of a 1-foot thickness of tuff in the  $NE\frac{1}{4} SE\frac{1}{4}$  Sec. 13, T. 10 S., R. 20 E. Quartz was first removed with heavy liquids from a crushed sample of hand-picked sanidine crystals; inclusions of glass, magnetite, and altered pyroxene were removed with a Franz magnetic separator. A few fragments of anorthoclase and very small amounts of glass included in sanidine are the only impurities noted under the microscope in a powdered part of the analyzed sample.

The feldspar composition calculated from this analysis is  $Or_{41.2} Ab_{55.5} An_{3.3}$  (in molecular per cent); barium feldspar forms .011 per cent, and strontium feldspar .0096 per cent. Calculated excess values for silica and alumina are 4.46 and 1.57 per cent, respectively, assuming no substitution of  $Fe^{2+}$  and Mg for Ca in the feldspar structure.

#### POTASSIUM-ARGON AGE

Dates of 16 and 24 m.y. were obtained from the sanidine by the potassium-argon method (G. H. Curtis, personal comm.). The 24 m.y. date appears to be the more reliable of the two as it embodies a recent improvement in purifying argon for measurement. This date is concordant with other dates from the John Day formation (Hay, in press), within the limits of analytical error, suggesting that the feldspar crystals have retained all or nearly all of their radiogenic argon.

#### DISCUSSION

Several examples of soda-rich sanidine from large dikes and flows have previously been described (e.g., Tuttle, 1952). According to Smith (1960, p. 187), all of these feldspars between  $Or_{20}(Ab+An)_{80}$  and

TABLE 1. CHEMICAL COMPOSITION OF SANIDINE CRYSTALS FROM THE JOHN DAY FORMATION<sup>1</sup>

|                                      |        |                        |        |
|--------------------------------------|--------|------------------------|--------|
| SiO <sub>2</sub> .....               | 65.50% | K <sub>2</sub> O ..... | 6.65   |
| Al <sub>2</sub> O <sub>3</sub> ..... | 19.61  | TiO <sub>2</sub> ..... | 0.08   |
| Fe <sub>2</sub> O <sub>3</sub> ..... | 0.20   | Ig. loss .....         | 0.73   |
| FeO .....                            | 0.07   | SrO .....              | 0.0034 |
| CaO .....                            | 0.64   | BaO .....              | 0.0056 |
| MgO .....                            | 0.06   |                        |        |
| Na <sub>2</sub> O .....              | 5.89   | Total .....            | 99.44  |

<sup>1</sup> In a spectroscopic analysis, H. Asari detected traces of Cu, Tl, and Ga, in addition to the elements given above.

Or<sub>60</sub>(Ab+An)<sub>40</sub> are unmixed to a greater or lesser degree into potash-rich and soda-rich phases—*i.e.*, are cryptoperthitic. Smith (1960) suggested that rapid quenching of feldspar of this composition in volcanic ejecta might give a single-phase high-temperature feldspar. The sanidine described in this paper is indeed a single-phase feldspar, but its optic properties are those of the ["low"] sanidine-cryptoperthite series of Tuttle (1952), not those of "high" sanidine as represented on the Smith's phase diagram (1960, Fig. 1).

#### ADDENDUM

Single-crystal  $x$ -ray study by Adolf Pabst of additional cleavage fragments of the analyzed sanidine from the John Day formation modify the original conclusion that none of this sanidine is unmixed. Two of the six fragments Pabst studied show indications of unmixing, and he has described the evidence in the following personal communication.

"Exsolution is indicated in the  $b$  axis oscillation patterns by the appearance of diffuse brushes along the layer lines on either side of certain spots. Examination of  $h0l$  Weissenberg and precession patterns of these fragments shows that the brushes are approximately normal to  $c^*$ . The spots with which the brushes are associated are sharp and the brushes are separated from them by a clear interval corresponding to about  $0.8^\circ$   $2\theta$ . Cell dimensions determined from spots on patterns of the fragment yielding the most prominent brushes are within the limits of error of those found for the homogeneous fragments."

"Measurement of the densest part of the brushes about 600 on a calibrated Weissenberg from the fragment just mentioned suggest compositions of about Ab<sub>39</sub>Or<sub>61</sub> and Ab<sub>77</sub>Or<sub>23</sub> for the two phases represented by the brushes. The dimensions of the brushes are presumably determined not only by compositional variation but also by the smallness of the segregated volumes which conditions diffuseness of diffracted beams.

The 600 brushes measured extend over about a degree or two of  $2\theta$ , brushes on the Ab-rich side being somewhat more extended. The disposition of brushes for  $h00$  and  $00l$  indicates an increase of  $\beta$  for the Ab-rich phase and a decrease for the Ab-poor phase relative to the principal and supposedly original phase. This is in accord with requirements."

"An initially homogeneous fragment was annealed at 500° C. After this treatment it yielded a  $b$ -axis oscillation pattern showing brushes similar to those described above."

#### ACKNOWLEDGMENTS

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#### AGE OF AUTHIGENIC BIOTITE IN THE UTICA SHALE<sup>1</sup>

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Biotite suspected to be of authigenic origin has recently been reported in the bottom few feet of the Utica shale where it overlies the Trenton limestone near L'Epiphanie, Quebec, 25 miles north of Montreal (Clark and Stevenson, 1960). It occurs as scattered, euhedral, pseudo-hexagonal, thin books averaging 0.4 mm in diameter and 0.1 mm in thickness, and makes up as much as one per cent of the shale just above the Trenton-Utica boundary.

Factors suggesting authigenic development of the mica crystals in-

<sup>1</sup> M.I.T. Age Studies No. 35.