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COMBINATION TWINNING IN PLAGIOCLASE FELSPARS

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ABSTRACT. In many igneous rocks, the concentric zoning of the individuals shows that small plagioclase crystals have combined to form large aggregates of crystals. Crystals combine along smooth composition planes, normally (010), and their combination is governed by either the Carlsbad, the Albite-Carlsbad, or the Albite-Ala law. Combination of plagioclase crystals, as described, is believed to be characteristic of truly magmatic rocks, and thus may be a useful criterion for separating magmatic from metamorphic or metasomatic rocks.

INTRODUCTION

The present study originated from a suggestion by Dr. W. H. Mathews, who, while describing a series of volcanic rocks from the Garibaldi region of British Columbia, noticed that many of the plagioclase felspars within the lavas occurred as aggregates of crystals, and that many of the individuals comprising these aggregates were in twin relationships. These crystals are distinguished by distinct nuclei outlined by concentric zones, with outer-zones encompassing all parts of the aggregate, by smooth composition planes, and by zig-zag outlines. It was therefore decided to investigate crystal associations of this type to see if they are the result of simple crystallization, or whether they result from the combination of two or more crystals after crystallization, and what laws govern these combinations.

Literature describing previous work related to the twinning and optics of plagioclase felspars is extensive, but very few data dealing with post-crystallization combination and parallel growth of plagioclase have been recorded. Hence, it is thought that a statement concerning the nature and possible petrological significance of combination and parallel growth in plagioclase felspars should be placed on record.

SOURCE OF MATERIAL

Since the study required rocks with many crystals of plagioclase felspar, a suite of porphyritic volcanic rocks from the Garibaldi area, western British Columbia, was taken, and the characters of the plagioclase felspars compared with those belonging to a suite of granitic rocks from the Caulfeild, Vancouver area of the Coast Range Batholith.

UNIVERSAL-STAGE MEASUREMENTS

The observations and measurements of the plagioclase felspars in the various rocks studied were made with the Leitz 4-axis stage[1]. Aggregates, of all sizes, of plagioclase crystals, were examined, and in each combination of crystals the composition plane between the crystals was identified, and the twin law relating the crystals was determined by the method and diagrams shown by Turner (1947).

[1] Index of hemisphere used was 1.516, and that of the immersion liquid was 1.519 at 18°C. The observations with the universal-stage and the plotting of same on a Wulff's net were carried out simultaneously. The twin laws and compositions of the plagioclase felspars were determined according to Turner's (1947) methods and diagrams, and checked by v.d. Kaaden's (1951) curves.

A). *The Garibaldi volcanics*—are a suite of rocks that range in composition from basalt through andesite to dacite, the two latter types forming the bulk of the rocks seen; they have been described by W. H. Mathews (1948). All the rocks are porphyritic, with concentrically zoned phenocrysts of plagioclase felspars varying in size from one to three millimeters in length, set in a groundmass of fine-grained microlites of zoned plagioclase that rarely attain a size of one millimeter, and they commonly exhibit flow structure.

Combinations of crystals of plagioclase have been observed in both the phenocrysts and groundmass plagioclase; the term combination being used here to denote a coalescence of two, three, or four concentrically zoned individuals, as shown in figure 1. Some hundred and fifty-five of these combinations have been noted and the optic and crystallographic relations between individuals within the combinations determined. In all instances individuals within a combination are related by some common twin relationship, and in the majority of relations the plane joining two individuals is (010). However, although the composition plane of two individuals is relatively constant, the twin axis relating individuals varies considerably. From the readings shown in table 1 it will be seen that three twin axes are common, namely, [001], $\perp$ [001]/(010), and $\perp$ [100]/(010), and since the composi-

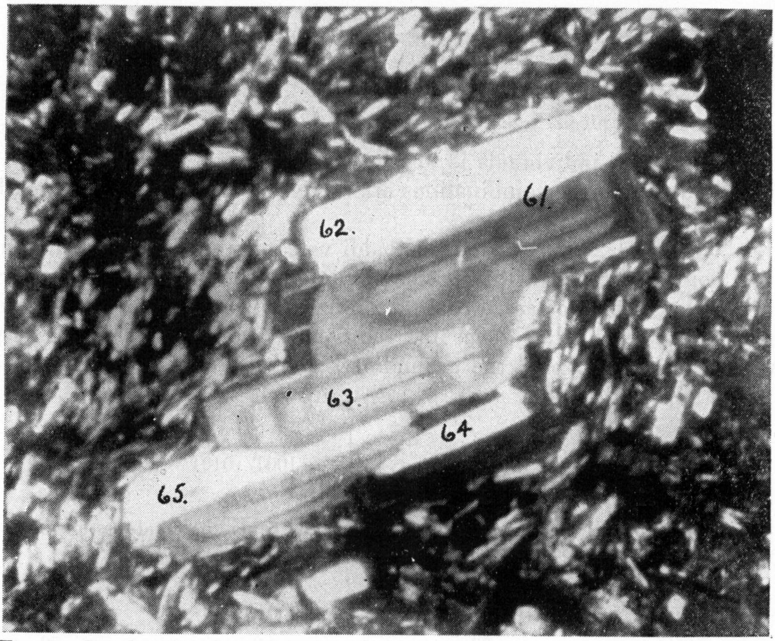

Fig. 1. **Porphyritic plagioclase aggregation.**
62:61—Carlsbad.
61:63—Albite.
63:64—Albite-Carlsbad.
63:65—Carlsbad.
Crossed nicols. x 60. Andesite, Garibaldi.

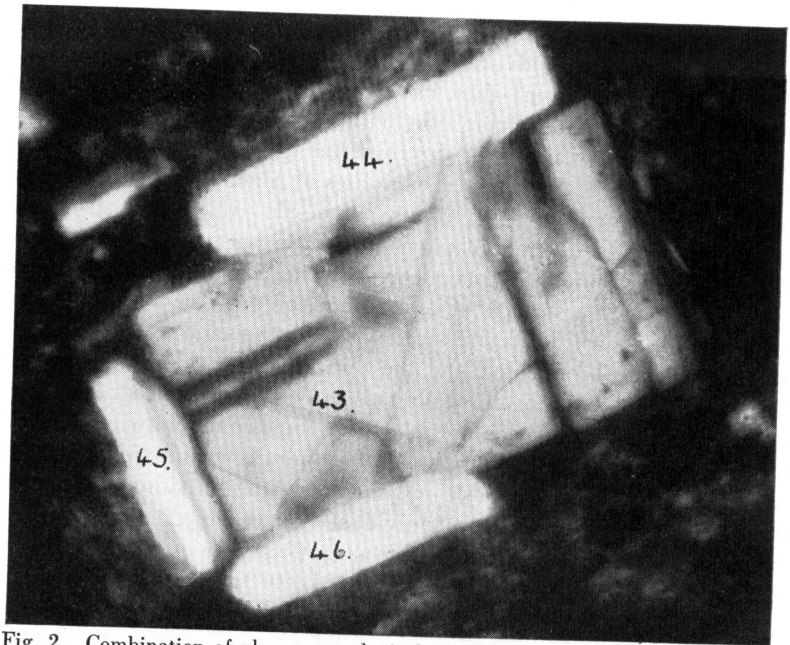

Fig. 2. Combination of phenocryst plagioclase with groundmass microlites.
43:44—Albite-Carlsbad.
43:45—Ala-A.
43:46—Carlsbad.
Crossed nicols. x 225. Andesite, Garibaldi.

tion plane for two individuals is in nearly every example always (010), the twin laws governing the combinations are therefore Carlsbad, Albite-Carlsbad, and Albite-Ala.

Tables 1 and 2 refer to the Garibaldi volcanics and show the frequency of twin types developed within the combinations examined in the phenocryst and groundmass plagioclase. From these tables it would appear that the most common type of twin law governing the combination of plagioclase felspars is Albite-Carlsbad, in both the groundmass and phenocrysts. However, there are exceptions to this rule.

TABLE 1

T.A.	[001]	⊥[001]/(010)	⊥[100]/(010)	Total
C.P.	(010) 31	53	19	103

Table showing the variation of twin laws governing the combination of phenocryst plagioclase felspars within the Garibaldi volcanics.

TABLE 2

T.A.	[001]	⊥[001]/(010)	⊥[100]/(010)	Total
C.P.	(010) 6	37	9	52

Table showing the variation of twin laws governing the combination of groundmass plagioclase felspars within the Garibaldi volcanics.

In some instances it has been observed that first generation phenocrysts have combined with second generation microlites, and in this latter case the plane

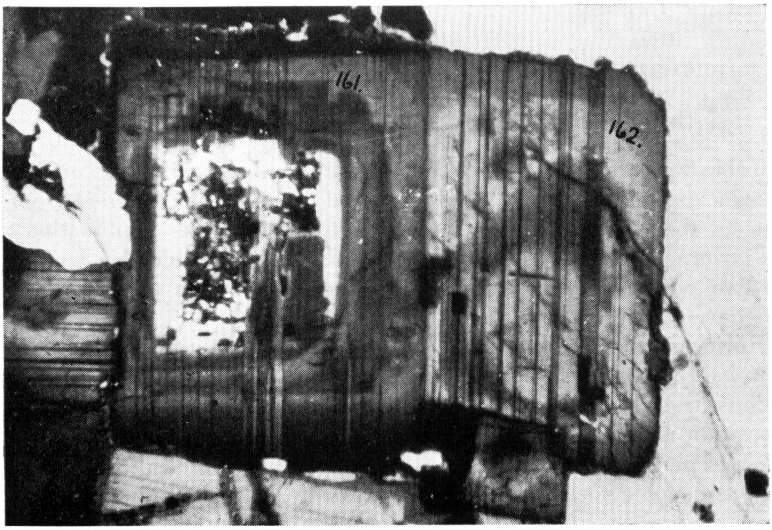

Fig. 3. Shows combination of plagioclase crystals.
161:162—Carlsbad.
Small, dark border encloses the combination twin, which is followed by a small zone of acid plagioclase. The formation of this combination twin took place before the formation of this reaction zone.
Crossed nicols. x 60. Diorite, Caulfeild.

joining the individuals is either (001) or (010), as shown in figure 2. Under these conditions of combination the twin axes are $\perp$ [001]/(010) and [100], so that the twin laws governing the combinations are Albite-Carlsbad and Ala-A, with the former being the dominant type of combination.

B). *The Caulfeild Quartz Diorite*—is a reasonably coarse-grained rock with crystals ranging in size from two to four millimeters. It consists almost wholly of plagioclase and hornblende, the former constituting about sixty-five percent of the rock. A small amount of quartz and some biotite are the other primary constituents, with some accessory sphene and magnetite. The plagioclase is commonly strongly zoned with the composition varying from basic andesine up to albite.

Combinations of two or more plagioclase felspars have been observed within these dioritic rocks, but their frequency of occurrence is relatively small when compared with that of combinations in the Garibaldi volcanics. Only twenty-four combinations of plagioclase felspars have been observed from approximately the same number of thin sections as were available for the Garibaldi volcanics. In all instances the composition plane for each composition is (010), and the twin axes determined are [001], $\perp$ [001]/(010), and $\perp$ [100]/(010). The twin laws governing the combinations of the plagioclase felspars are therefore Carlsbad, Albite-Carlsbad, and Albite-Ala. These are the same twin laws as were determined for the volcanic rocks, and their numerical occurrences are shown in table 3.

TABLE 3

T.A.	[001]	⊥[001]/(010)	⊥[100]/(010)	Total
C.P.	(010) 12	7	5	24

Table showing the variation of twin laws governing the combination of plagioclase felspars within the Caulfeild Quartz Diorite.

Table 3 shows that the frequency of twin laws governing the combination of plagioclase felspars in the Caulfeild rocks is somewhat different from that shown for the Garibaldi rocks. Within the Caulfeild rocks combination tends to be governed by the Carlsbad, Albite-Carlsbad, and Albite-Ala laws, in the respective ratio of 5:3:2, while the combinations within the Garibaldi volcanics have a ratio of 3:5:2.

However, combination twins within these dioritic rocks are few and are probably formed early in the history of the rock since many of the combinations have partial or complete overgrowths of plagioclase felspar, whose composition is very acid and is comparable to the outer zones of many single crystals of plagioclase (fig. 3).

Metamorphic rocks have been examined for combinations of plagioclase felspars in specimens from the North of Scotland and from the Caulfeild area. but none has been observed.

DISCUSSION

Combinations of plagioclase felspars in twin relationships have rarely been described in the literature dealing with the crystallography and optics of plagioclase. Kohler and Raaz (1947, p. 165), when describing Carlsbad twinning in the plagioclase of some volcanic rocks, noticed that "in addition to common occurrence of Carlsbad twins in individuals, there are also contact twins whose halves are united by the composition plane (010)", and showed that the law governing their combination is Albite-Carlsbad. The results shown in tables 1 and 2 for combination twins from the Garibaldi rocks also show that the common law governing combination is Albite-Carlsbad.

That the plagioclase in the Garibaldi rocks is magmatic in origin is unquestionable. Therefore, since these rocks have a high percentage of phenocrysts of plagioclase there must have been a stage in the crystallization of the lavas when large plagioclase crystals were floating about in a fluid medium, and it is thought that under these conditions combinations of crystals is most likely. Combination is also likely to be governed by other factors such as time taken for complete crystallization of the melt, the viscosity of the melt (which may possibly account for the difference in numbers of combination twins seen in granitic rocks and volcanic rocks), and the shape and form of the crystals.

The shape and form of the plagioclase crystals in the Garibaldi volcanics can be shown to be largely tabular in the a/c plane, such that the (010) face has the greatest surface area, and this, coupled with the fact that the rocks commonly exhibit flow structures, would account for crystal combinations having a composition plane of (010). It is likely that the mode of combination of crystals is one partly determined by chance, but from the frequency of twin laws within the volcanic rocks it would seem that Albite-Carlsbad and Carlsbad combinations are favoured above all others.

Within the Caulfeild dioritic rocks the shape and form of the plagioclase crystals is not so marked as in the Garibaldi volcanics. However, while the (010) face appears to be well-developed, the other faces, (001) and (100), are not developed to the same degree, and therefore any combination that occurs is again likely to have a composition plane of (010).

Relatively few combinations are observed in these dioritic rocks, and many of those that have been examined have a complete overgrowth of plagioclase that is comparable in composition to many of the single crystals of plagioclase. Thus, combination of early formed crystals has occurred, and table 3 shows that the Carlsbad and Albite-Carlsbad are again the favored laws. Possibly the paucity of combinations in the dioritic rocks is due to two factors. In this type of rock centers of crystallization occur throughout the melt and the rate of growth is fairly uniform, as shown by the equigranular texture. Also, the melt is likely to have a relatively high viscosity, such that combination and alignment of crystals is likely to be at a minimum, while random orientation and interpenetration of crystals are at a maximum—the reverse state of affairs probably existing within rocks of the Garibaldi type.

As mentioned earlier, no combination twins were observed in metamorphic or metasomatic rocks, which fact may have some petrogenetic significance. Recently, Gorai (1951) suggested a method whereby metamorphic rocks may be distinguished from truly igneous rocks on the basis of the type of twinning in the plagioclase present in those rocks. If, as is believed by the present author, combination twins in plagioclase result only by combination of crystals suspended in a melt, then the presence or absence of such twins, used in conjunction with the method proposed by Gorai, would be useful in separating truly magmatic rocks from those of metasomatic or metamorphic origin.

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