OBSERVATIONS ON TWINNING OF PLAGIOCLASE IN METAMORPHIC ROCKS

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Abstract

Metamorphic plagioclase in general is characterized by: (1) comparative rarity of twinning; (2) prevalence (in low-grade schists) of simple twins consisting of few subindividuals; (3) predominance of albite and pericline twins, Carlsbad twins being subordinate; (4) absence of complex twin combinations. Comparison with twinning of plagioclase of igneous rocks and of migmatites yields evidence tending to support magmatic origin of most granites and diorites.

Introduction

Petrographic literature of the last twenty years includes a number of studies on occurrence, nature, and origin of twinning in plagioclase of igneous rocks (e.g., Coulson, 1931; Barber, 1936; Chapman, 1936; Emmons and Gates, 1943). Corresponding accounts of twinning in metamorphic plagioclase are few and meager, a notable exception being the observations of Phillips (1930) on plagioclase of the Green Bed group of the Scottish Dalradian schists. The purpose of this note is to record some of my own observations regarding the types of twinning commonly encountered in plagioclase of various metamorphic rocks and to draw attention to certain consistent differences in twinning between metamorphic and igneous plagioclase. Such differences, if confirmed by others working in this field, may possibly have some bearing on the vexed problems connected with the origins of granitic and dioritic rocks.

Twinning in Metamorphic Plagioclases

The generalizations which follow are based partly on recorded observations of other petrographers, partly on my own experience. The latter involves determination of twin laws by standard universal stage procedure (Turner, 1947) in all cases.

(1) Prevalence of untwinned plagioclase in metamorphic rocks of all types is too well known to merit further comment. There is scattered evidence in petrographic literature suggesting that twinning of plagioclase is more frequent in rocks of moderate to high metamorphic grade than in albite-bearing schists of the greenschist facies. Thus Phillips (1930, pp. 244, 245) records increasing abundance of twinned grains of albite in passing from the chlorite zone to the biotite zone of the Scottish Dalradian schists. My own observations confirm this general tendency:

(*a*) In even-grained greenschists and quartz-albite-muscovite-chlorite schists within the chlorite zone of regional metamorphism in New Zealand, untwinned grains of albite are very common in most thin sections and twinned grains typically are rare or absent. In porphyroblastic albite schists from the same region, simple twinning of albite is distinctly more common, though the majority of the porphyroblasts still are untwinned. The same generalization applies to suites of albite-quartz-piedmontite schists and porphyroblastic albite-chlorite schists of the Besshi series, Japan (cf. Suzuki, 1930) and to various German and Alpine greenschists which I have examined.

(*b*) In albite-bearing glaucophane schists from the Franciscan of California (believed to belong to the greenschist or the albite-epidote-amphibolite facies) albite seems to be somewhat more commonly twinned than in most other greenschists. The albite here tends to be porphyroblastic, and the twinned coarse grains in most cases consist of two to four subindividuals of nearly equal size.

(*c*) In amphibolites and quartz-biotite-oligoclase schists of the amphibolite facies in New Zealand (Westland; Manopouri), plagioclase ranging from An_{20} to An_{45} commonly shows lamellar twinning. In individual sections between 10% and 50% of the grains show obvious twinning.

(*d*) Preponderance of grains with lamellar twinning over untwinned grains has been observed in a number of hornfelses of the amphibolite facies (e.g., Bluff, New Zealand; Engel Mine, California) and in German pyroxene granulites.

(2) There seems to be no general correlation between abundance of twinning in metamorphic plagioclase and degree of deformation experienced by the enclosing rock. The most abundant twinning I have seen is in undeformed hornfelses and metasomatic rocks; and Goldschmidt (1911, pp. 293, 295) records plentiful albite twinning in oligoclase and andesine of the Oslo hornfelses. Moreover, the albite porphyroblasts of the post-tectonic stage in New Zealand schists are twinned to just the same extent as are rotated porphyroblasts of paratectonic origin. On the other hand discontinuous lamellar twinning has been observed at margins of residual large albites in strongly sheared and granulated albite-quartz rocks occurring as dikes in California serpentinites. Here metamorphism is local and strictly cataclastic.

(3) Various writers have contrasted the simple twinning of metamorphic plagioclase with the characteristically complex twinning of plagioclase in igneous rocks (e.g., Phillips, 1930, p. 247; Harker, 1932, p. 213). In the great majority of metamorphic rocks which I have examined, twinned grains of plagioclase consist of few subindividuals, and only one twin law is represented in most grains. This contrasts very strikingly

with the variety and complexity of twinning exhibited by igneous plagioclase and with the large number of lamellae that occur in many grains in igneous rocks. There are, however, certain exceptions. In pyroxene granulites and in certain hornfelses of relatively high grade, grains of plagioclase may consist of many closely-spaced lamellae, though there is still a marked tendency for only one twin law to be represented in any grain. In amphibolites of igneous origin, coarse plagioclase (in some cases retaining relict idiomorphic outlines) is liable to show twinning just as complex as that of igneous plagioclase—albite-Carlsbad-pericline combinations especially. The twinned condition and crystal habit of such plagioclase are considered to be relict and afford good evidence of igneous parentage of the amphibolite in which they are observed.

(4) Phillips (1930, p. 247) records the percentage frequencies of various types of twinning observed by him in plagioclase of schists belonging to the Dalradian Green Bed group as follows: albite 60%, pericline (mainly in oligoclase and andesine) 17%, Carlsbad 16%, other laws 7%. My observations confirm the great prevalence of albite and pericline twinning in metamorphic plagioclase (cf. also Goldschmidt, 1911, pp. 292–300; Ambrose, 1936, pp. 262, 264, etc.); but I would rate pericline twinning as being more frequent and Carlsbad twinning much less frequent than the figures given by Phillips would indicate. Some further generalizations in this connection may be noted:

(*a*) Albite porphyroblasts in greenschists and related rocks of low to moderate metamorphic grade rather commonly consist of two twinned subindividuals of approximately equal size with {010} as composition plane. These have been identified as Carlsbad twins by most writers (e.g., Knopf and Jonas, 1929, p. 29; Hietanen, 1941, p. 102; Turner and Hutton, 1941, p. 224). I have examined many sections of porphyroblastic albite schists from New Zealand, Japan, and California and have found in every case that the majority of these simple twins are actually composed of two subindividuals twinned on the albite, not the Carlsbad, law. Carlsbad twins are also present in some rocks but always in subordinate numbers. Carlsbad and albite twinning in pure albite are optically indistinguishable from each other. Since X is almost parallel to the composition plane {010} and at the same time is almost perpendicular to the crystal axis [001], there are two possible solutions to the problem of identifying the twin axis from the respective positions of X, Y and Z in each of the twinned subindividuals. Either [001] or $\perp\{010\}$ as twin axis will satisfy the optical data within the limits of probable experimental error. However, the ambiguity may be resolved if the {001} cleavage plane is measured in both subindividuals; for the angle between the two {001} poles is 7° in the case of albite twins, 53° in Carlsbad twins. Even without a universal stage the twin axis of suitably oriented albite porphyroblasts may be identified microscopically as ⊥{010} from the fact that the transverse {001} cleavage continues across both subindividuals with but slight deflection where it crosses the composition plane. If {001} cleavage is clearly visible in one half of a section of a Carlsbad twin, it is invisible in the adjoining half—though by appropriate tilting on a universal stage it may be found and identified in most cases.

(*b*) My experience agrees with that of Phillips (1930, pp. 247, 248) that albite twinning greatly predominates over other types of twinning in sodic plagioclase (An_0 to An_7) of rocks within the greenschist facies. There are other records, however, of predominant pericline twinning in nearly pure albite of such rocks (e.g., Ambrose, 1936, p. 262). With certain exceptions (e.g., the pyroxene granulite and the hornfels noted at the bottom of Table 1), pericline twinning of plagioclase is at least as common as albite twinning in rocks of higher metamorphic grades. Some illustrative examples, from my own measurements, are appended in Table 1.

TABLE 1: TWIN LAWS FOR PLAGIOCLASE OF METAMORPHIC ROCKS, MAINLY IN AMPHIBOLITE FACIES

Rock		Plagioclase	Number of measured twinned grains		
			Albite twin	Pericline twin	Combined albite-pericline twin
Amphibolites,	2461	An_{24}	8	6	1
Lake Manopouri,	7512	An_{20-25}	8	7	2
New Zealand	8014	An_{33-38}	12	24	4
Biotite-plagioclase schists	7531	An_{20-25}	—	3	—
Westland, New Zealand	7533	An_{29-33}	6	9	2
Almandine-mica schists,	22	An_{30}	—	3	—
European Alps	24	An_3	—	3	—
Plagioclase-garnet-epidote hornfels, Engel Mine, California	E64	An_{75-80}	—	10	—
Plagioclase-diopside hornfels, Bluff, New Zealand	7488	An_{45}	10	—	—
Pyroxene granulite, Germany	314	An_{50-55}	12	—	2

(*c*) Albite (An_{0-5}) of Californian glaucophane schists commonly shows simple or very coarsely lamellar twinning on the albite law. Pericline twinning is generally lacking. I have seen no cases of undoubted Carlsbad twins in these rocks.

(5) There are many records of widely prevalent lamellar albite twinning in albite and oligoclase porphyroblasts formed by soda metasomatism. Becke (1913, pp. 124, 125) considered the interrupted blocky {010} twinning of "chessboard albite" to be a criterion of replacement of original potash feldspar by albite of this type (cf. also Anderson, 1937, pp. 62, 63). Goldschmidt (1911, pp. 301, 303, 305) has described "chessboard albite" as a constituent of various metasomatic rocks, including albite veins and impregnated skarns; but he states that in his experience this type of plagioclase does not occur in "normal contact rocks formed without introduction of material." Details of twinning are not recorded in most of the numerous accounts of feldspathized porphyroblastic albite and oligoclase gneisses occurring in migmatites adjacent to granitic bodies. From such data as are available (e.g., Goldschmidt, 1921, pp. 81, 82; Read, 1927, p. 338; Anderson 1934, p. 386, figs. 6, 7) it would seem that lamellar twinning on one law (probably albite law) is common in metasomatically formed sodic plagioclase. There are also references (e.g., Koch, 1939, p. 71) to occurrence of simply twinned oligoclase porphyroblasts in metasomatically affected rocks of this type. Complex combinations of albite, Carlsbad and pericline twinning in albite of sodic granites is probably a relict feature inherited from originally more calcic igneous plagioclase now replaced by albite.

Interpretation

Plagioclase of schists and hornfelses differs in a number of respects from plagioclase of undoubtedly igneous rocks as regards twinning phenomena:

(1) Absence or rarity of twinning in many groups of rocks.

(2) Prevalence, especially in low-grade schists, of simple twins consisting of a few (in many cases only two) subindividuals. Note, however, that in some sodic granites also simple albite twins of two subindividuals may occur.

(3) Lack of variety in types of twin commonly represented; albite and pericline twins greatly predominate, Carlsbad twins are much rarer, other types (including complex combinations) are very rare; even albite-pericline combinations in one crystal are infrequent.

(4) Frequent development, and in some rocks great preponderance, of pericline twinning, even in sodic plagioclases ranging from An_{10} to An_{30}.

There are exceptions to all of these rules. But their general validity is striking in view of the great range of composition and physical conditions of origin represented by metamorphic rocks. Reference to the detailed accounts of Duparc and Reinhard (1924, pp. 8–10), Coulson (1931), Barber (1936) and Chapman (1936) will make obvious the generally contrasted twinning behavior of igneous plagioclase.

It seems likely that the differences noted above may reflect generally prevalent differences in the respective physical conditions of magmatic and metamorphic crystallization. It is possible, for example, that twinning behavior, as well as crystal habit and the nature of the crystal boundaries, is affected differently by metamorphic crystallization of plagioclase in an essentially solid medium and by magmatic crystallization in a liquid medium. Temperature may well exert an even more important influence. Metamorphic temperatures in general are lower than magmatic temperatures. It is now known that sodic plagioclase (An_0 to An_{35}) inverts from a high- to a low-temperature form at temperatures a little below 700° C.; and it has been suggested (Tuttle and Bowen, 1950, p. 583) that "the nature of the twinning should certainly be different when the crystals are grown below the inversion, as compared with that developed when they are inverted from the high-temperature modification." Much of magmatic crystallization must take place above the inversion temperature, and most if not all metamorphic processes must be governed by temperatures considerably below it. Moreover, the optical properties of metamorphic plagioclase consistently conform to "low-temperature optics," rather than to the "high-temperature optics" now recognized (e.g., Barber, 1936, pp. 247–249; Oftedahl, 1948, pp. 10–15) as characteristic of phenocrysts in volcanic rocks. According to the French theory of twinning (Donnay, 1943) differences in twinning behavior of similar minerals are much more probably due to differences in space-lattice structure than to direct influence of external conditions such as temperature.

Plagioclase of porphyroblastic albite and oligoclase schists in migmatite areas seems, from such records as are available, to resemble metamorphic rather than undoubtedly igneous plagioclase as regards twinning. That of most granites, grandiorites, and diorites which I have examined shows the profusion and great variety of twinning typical of igneous plagioclase as developed in phenocrysts of volcanic rocks. Especially characteristic is the common appearance of the Carlsbad-albite combination, and the less frequent but still by no means rare occurrence of twins on Manebach and Ala laws. All of these are typically unrepresented or rare in plagioclase of metamorphic rocks. This is one more piece of evidence suggesting that the evolution of most granites, granodiorites, and diorites involves crystallization of feldspar from a magmatic liquid (silicate-melt phase); and that the porphyroblasts of sodic plagioclase in many migmatitic schists and gneisses are products of metasomatism (a phase of metamorphism) in essentially solid rocks permeated by aqueous fluids introduced from igneous or other sources.

Much has been written on the problem of primary origin of plagioclase twins during crystal growth, versus secondary origin by deformation of the fully grown crystal. Most of the discussion centers around observations on twinning in igneous plagioclase. Barber (1936, pp. 256–258), from detailed observations on a wide range of plagioclases, found that there is a marked tendency for the composition plane of lamellar albite twins to be a vicinal face inclined to {010} at an angle of $\frac{1}{2}°$ to 3°. From this and from consideration of external morphology he concluded that it was possible to recognize "many examples of twininng, including albite and pericline twinning, which it is considered must be primary." He found no conclusive evidence of secondary twinning in the material which he examined. Donnay (1940, 1943) explained the close relation, observed by many petrographers, between composition of plagioclase and mean width of albite twin lamellae, by assuming that twinning of plagioclase is a phenomenon of crystal growth and is controlled mainly by the geometry of the space lattice (which varies with variation in composition). The opposite view, that lamellar twinning of plagioclase is essentially secondary, has been stated by Emmons and Gates (1943) on the evidence of microscopic texture of igneous rocks. The observations on metamorphic plagioclase recorded in this paper support in two respects the view that much twinning in plagioclase is primary:

(1) Prevalence of simple albite twins, consisting of only two or three subindividuals of equal size, in almost pure albite of low-grade schists, confirms Donnay's (1940, p. 584) prediction that "in the short range from oligoclase to albite, one should expect a rapid widening of the lamellae, to such an extent that for pure or almost pure albite, twinning [on the albite law] may cease to be polysynthetic at all."

(2) In plagioclase of schists with strongly developed tectonite fabrics, resulting from continuous deformation proceeding simultaneously with crystallization, lamellar twinning is on the whole much less generally developed than in phenocrysts of volcanic rocks.

Postscript—M. Gorai's Observations on Twinning on Plagioclase

Since this paper was accepted for publication, Dr. K. Yagi drew my attention to a recent important contribution to the same problem by

M. Gorai.* Gorai has made a statistical study (based on several thousand universal-stage determinations) of the relative abundance of various kinds of twins in plagioclase of common igneous and metamorphic rocks, and has reached the following conclusions:

(1) Plagioclase twins commonly observed in volcanic and many plutonic rocks fall into two groups, both typically well represented in rocks of these classes: *C-twins*, including Carlsbad, Carlsbad-albite, and the much rarer Manebach, Baveno, Ala, and albite-Ala types; *A-twins*, including albite and pericline twins (and acline, which in plagioclase of intermediate composition is indistinguishable from pericline). In all undoubtedly igneous rocks untwinned plagioclase is subordinate to twinned plagioclase. These generalizations are demonstrated statistically by plotting, for each rock examined, the relative abundance of grains of three types (untwinned, A-twins and C-twins) on a triangular UAC diagram.

(2) In schists and hornfelses of undoubted metamorphic origin, only A-twins are commonly developed. In some rocks untwinned crystals greatly predominate; but in other rocks the majority of the grains may be twinned. C-twins are absent or inconspicuous in all cases.

(3) Development of C-twins is controlled partly by crystallization from a melt phase but apparently is influenced too by composition of plagioclase, in that C-twins seem to be more plentiful in calcic than in sodic plagioclase of volcanic rocks.

(4) Relative abundance of untwinned grains, A-twins, and C-twins in granites in some cases corresponds to that typical of igneous rocks; but in others, exemplified by granitic rocks of certain migmatites and tonalite-gneiss contact zones in Japan, the statistical pattern of plagioclase twinning is identical with that of metamorphic rocks. The type of twinning shown by plagioclase of granitic rocks is therefore considered to be a valuable criterion by which metasomatic granites can be distinguished from granites of magmatic origin.

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