OBSERVATIONS ON ORDER-DISORDER RELATIONS OF NATURAL PLAGIOCLASE

II. Order-disorder Relations in Metavolcanic and Plutonic Rocks of the Prison Hill Area, Carson City, Nevada

By

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Introduction

This study was undertaken by Eisinger (1960) primarily to determine if a zonal distribution of plagioclase composition exists in the metamorphic rocks of the Prison Hill-Brunswick Canyon area, and if plagioclase composition is correlative with metamorphic grade. If these relationships could be established they might be used as a basis on which to map the outer boundary of the contact metamorphic aureole, which is generally narrow and obscure in the studied area.

J. N. Swinderman made optical studies of plagioclase feldspars from the Prison Hill pluton to determine whether there is increased disorder in the plagioclase of marginal zones. D. B. Slemmons made the X-ray diffraction study of the plagioclase.

Geologic setting

The oldest rocks in the Prison Hill area, near Carson City, Nevada, are metamorphosed sedimentary and volcanic rocks of Triassic and Jurassic age. The sedimentary rocks are limestone, shale, arenite, and water-laid volcanic tuff. The volcanic rocks were probably originally andesite, basalt, andesitic breccia, rhyolite, and intrusive lamprophyre and diorite. These older sedimentary and volcanic rocks were folded and subjected to greenschist facies regional metamorphism during the "Nevadan" orogeny. The sedimentary rocks were little affected by the regional metamorphism, but the volcanic rocks were uralitized and albitized.

After, or at a late stage of the regional metamorphism, the volcanic and sedimentary rocks were intruded by a granodioritic pluton. Sharp contacts, chilling effects, uniform hypidiomorphic texture, oscillatory zoning of plagioclase with cores more calcic than the rims, all indicate an intrusive igneous origin for the pluton. The intrusion imposed low to medium grade contact metamorphic effects upon the already regionally metamorphosed volcanic and sedimentary rocks, and caused the local development of contact schists in otherwise non-

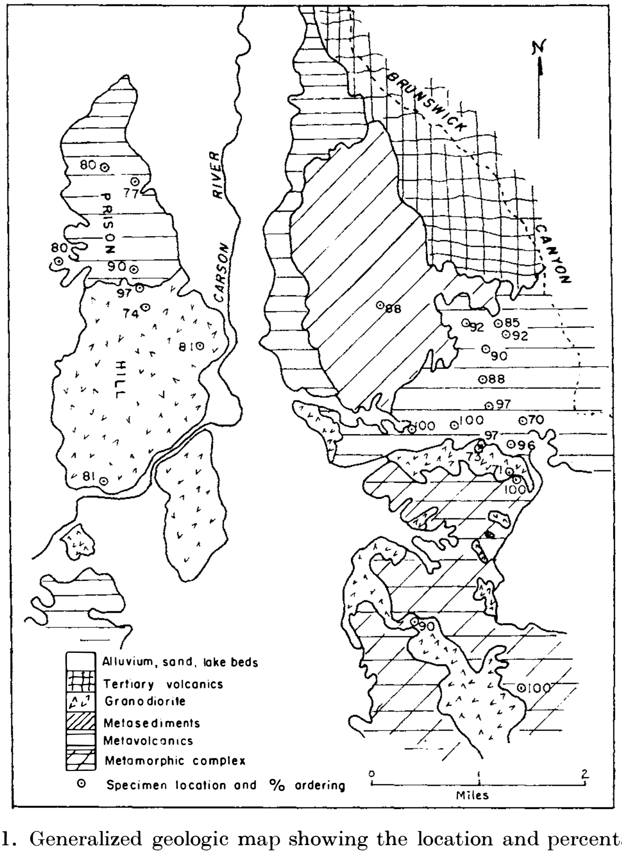

Figure 1. Generalized geologic map showing the location and percentage of anorthite in plagioclase of metavolcanic and plutonic rock specimens.

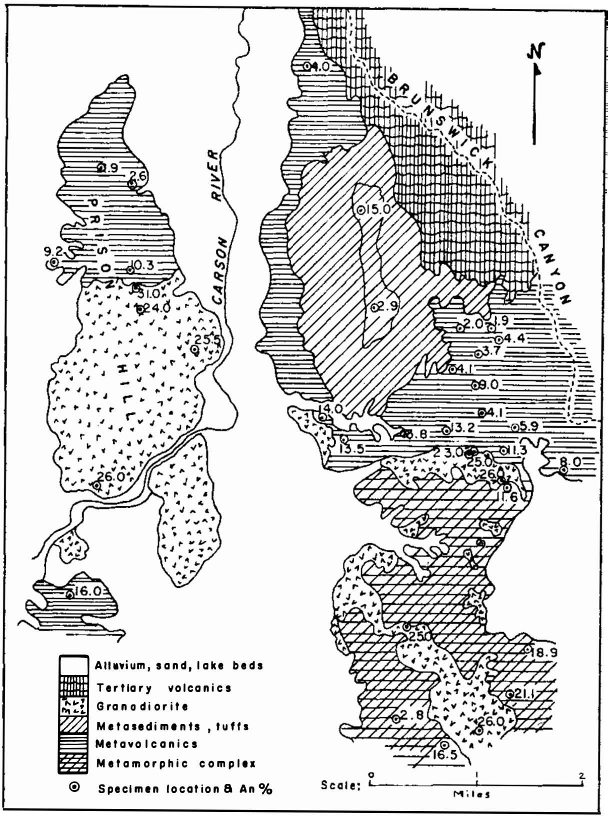

Figure 2. Generalized geological map showing location and intermediacy index of the metavolcanic and plutonic plagioclase specimens.

schistose country rock. The results of a study of the plagioclase feldspar in the metavolcanic rocks immediately surrounding the pluton indicate that the albite (An 0–5) in the regionally metamorphosed rocks has been reconstituted to more calcic plagioclase (An 8–21), and that the anorthite content of the plagioclase is related to metamorphic zoning. The pluton was emplaced by a combination of forceful injection and magmatic stoping. Aplitic and pegmatitic dikes and quartz veins that normally contain tourmaline are later than the intrusion of the main granodioritic mass.

The contact aureole is obscure in most cases, but hornfels, mica schist, marble, and skarn have been formed in a zone having a maxi-

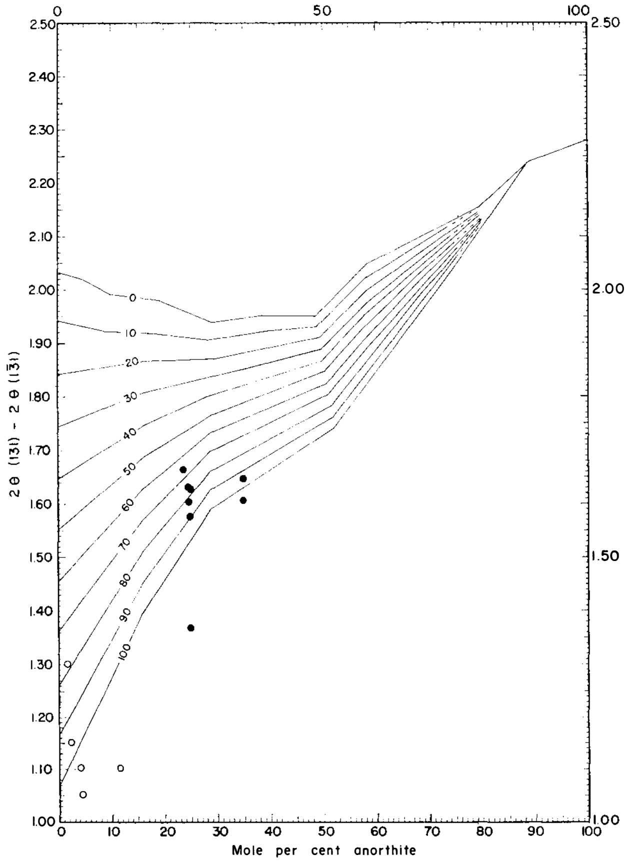

Figure 3. Intermediacy indices of plagioclase in metavolcanic rocks (open circles) and plutonic rocks (solid circles) derived from $2\theta(131)-2\theta(1\bar{3}1)$.

mum width of 2000 feet. Some of the contact metamorphic rocks, primarily the skarn and hornfels, are intricately intermingled with the granodioritic intrusive rocks and are apparently small roof pendants. This mixed zone of rocks has been mapped as a separate unit, the contact metamorphic complex. The presence of large quantities of skarn and associated iron deposits suggests that metasomatic processes have operated extensively at least in local areas. Tourmaline found in some of the schist and hornfels implies that material has been transferred across the igneous-metamorphic contact.

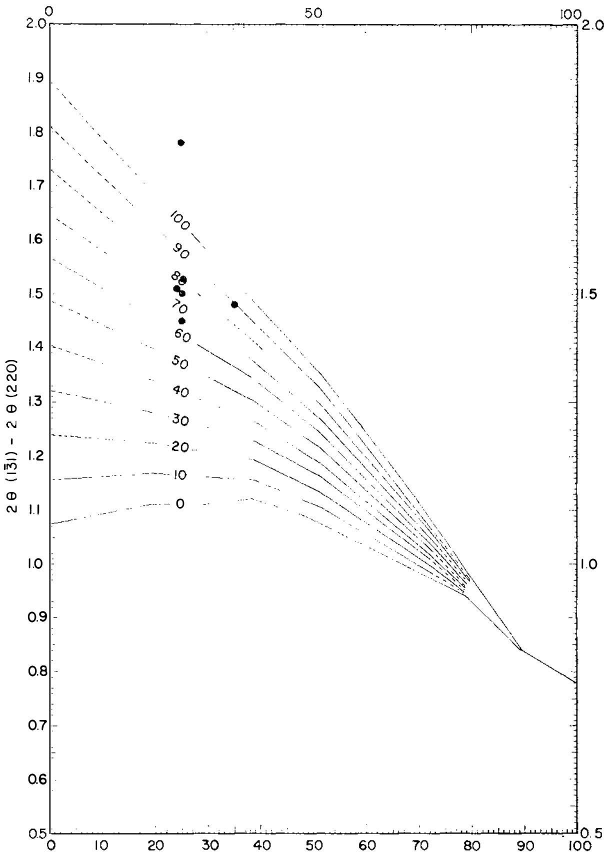

Figure 4. Intermediacy indices of plagioclase in plutonic rocks derived from $2\theta(1\bar{3}1)-2\theta(220)$.

Plagioclase mineralogy

Regional Metavolcanic Rocks

The regionally metamorphosed volcanic rocks are blastoporphyritic in texture, and contain phenocrysts of unzoned euhedral albite as well as epidote and calcite. The albite phenocrysts are commonly twinned according to both the albite and the Carlsbad-albite twin laws, a feature which Turner and Verhoogen (1960) interpret as a suggestion of magmatic rather than metamorphic origin. These relationships suggest that the more calcic volcanic plagioclases typical of calc-alkaline rocks have been pseudomorphously replaced during the

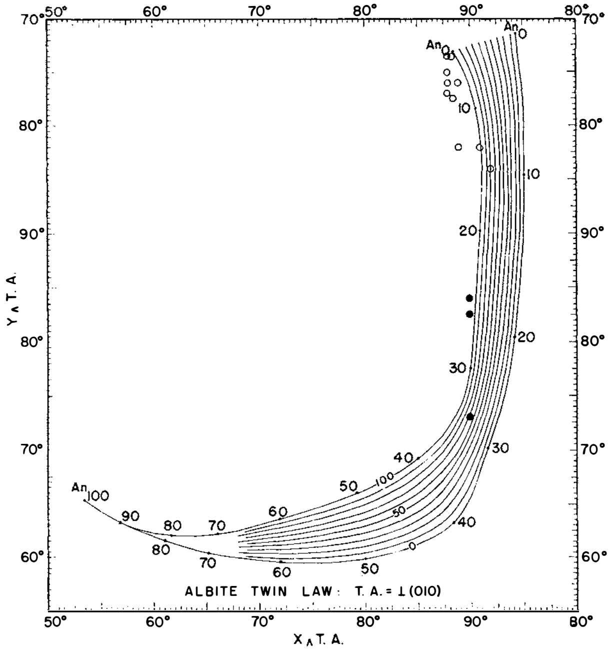

Figure 5. Intermediacy indices of plagioclase in metavolcanic rocks (open circles) and plutonic rocks (solid circles) derived from orientation.

metamorphism by albite, but that the original twin lamellae and twin laws have been preserved. The lime released during this process is present, at least in part, in the calcite, actinolite, and the ubiquitous epidote.

The composition, determined both by N_x' on cleavage fragments and universal stage measurements, normally ranges fron An 2 to An 5 (Figure 1). The compositions are in the same range as those of the Usu Massif in Western Indonesia (de Waard, (1959)), where the upper limit of the greenschist facies was clearly defined by the An 10 isopleth. Only one composition, An 15 for specimen 2600, is above the range and this may be a rare relict grain. D. C. Noble (personal communication) has noted relict disordered plagioclase from similar rocks a few miles south of the Prison Hill area.

The intermediacy index, I.I. (for definition see Part I of this paper), for these rocks ranges from 77 to 92 and averages 86 (Figure 2). Three methods were used to obtain the I.I. (Figures 3, 4, 5, 6), and the data have been tabulated in Tables 1 and 2.

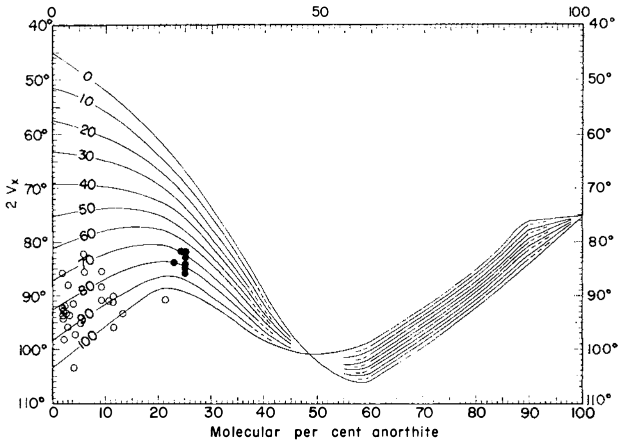

Figure 6. Intermediacy indices of plagioclase in metavolcanic rocks (open circles) and plutonic rocks (solid circles) derived from 2 *V*x.

Contact Metavolcanic Rocks

The contact zones are generally schistose; but the degree of schistosity varies greatly. The albitized plagioclase phenorcrysts are usually destroyed, the present plagioclase being a neomineral.

The composition of the plagioclase ranges from An 9 to An 21 (Figure 1), and nearly all specimens contain actinolite, hornblende, epidote, or calcite in contact with the plagioclase. The precence of actinolite and epidote with plagioclase of composition greater than An 10 in all recrystallized, or partly recrystallized, contact hornfels specimens studied indicates that An 10 can be used as an isopleth to define the contact aureole. It should be noted that all compositions from this zone fall in the range An 10 to An 21, which de Waard (1959) noted as being extremely rare in the Usu rocks. The presence of other lime minerals suggests either that stability was not reached in the contact rocks, or that in contact metamorphic rocks in contrast to the regional metamorphic rocks, sodic oligoclase may develop.

The I.I.'s in the contact zone range from 80 to 100 and average 94. The 94 value is slightly higher than the average value for the regionally metamorphosed rocks. Moreover, the plagioclase from the pluton also has a lower average I.I. of 83. The higher I.I. suggests either that metasomatism facilitates ordering in the contact zone, or that the

Table 1. Summary of plagioclase data

Spec. no.	Index liquid meas.		Universal stage measurements						X-ray data		Av. Comp. All Meas.
	Av. N_x' on Cleavages	An % from N_x'	Z/CP	X/TA	Y/TA	$2V@Z$	Twin Law	An % from U-Stage	$2\theta(131)-2\theta(1\bar{3}1)$	$2\theta(1\bar{3}1)-2\theta(220)$	
Plagioclases from the Prison Hill Pluton, Carson City Area, Nevada.											
2504			18.0	90.0	73.0	86.0	ab	35.0	1.60	—	35.0
2507			5.0	90.0	84.0	98.0	ab	24.2	1.63	1.49	24.2
2508			77.5	88.0	11.0	88.0	Ma	25.0	1.57	1.50	25.0
2509			6.5	24.0	66.0	96.0	ab–Cb	25.0	1.58	1.53	25.0
2530			7.0	90.0	83.0	88.0	ab	25.0	1.35	1.78	25.0
2532			6.0	68.0	21.5	84.0	Cb	25.0	1.64	1.51	25.0
2537			3.0	64.0	26.0	98.0	Cb	25.0	1.62	1.45	25.0
2550			7.0	67.5	24.0	88.0	Cb	25.0	1.64	1.48	25.0
Plagioclases from metavolcanic rocks associated with the Prison Hill Pluton, Carson City Area, Nevada.											
2501	1.530	2.5	17.0	88.0	77.0	87.0	ab	1.0			2.6
			16.0	83.5	15.5	—	Cb	4.3			
2502	1.531	4.0	17.0	84.0	21.0	86.0	Cb	0.6	1.30		1.9
			16.0	88.5	73.0	—	ab	0.8			
			16.5	83.7	20.0	88.0	Cb	2.0			
2503	1.533	10.5	13.0	80.5	14.0	92.0	Cb	9.0			9.2
			12.0	81.5	14.0	94.0	Cb	8.1			
2505	1.532	8.5	13.0	77.0	18.0	—	Cb	10.5			10.3
			11.0	88.0	76.0	89.0	ab	12.0			
2524	1.529+	3.5	13.0	89.0	76.0	—	ab	4.3			3.8
			14.0	88.0	76.0	—	ab	3.6			
2536	1.532+	9.0	84.0	16.0	74.0	84.0	ab–Cb	14.0			11.6
			9.0	89.0	82.0	—	ab	12.0			
2547	1.529	2.5	15.0	87.0	15.0	104.0	Cb	2.5			1.8
			16.0	86.0	17.0	86.0	Cb	0.5			
2548	1.531−	6.5	14.5	84.5	17.0	85.0	Cb	2.8			5.1

			24.0	80.0	16.5	—	Cb	6.0		
2556	1.530	4.0						—		4.0
2558	1.530+	4.5	13.5	88.5	77.5	88.0	ab	4.6	1.10	3.7
			12.5	87.0	12.0	76.0	Cb	3.0		
			13.5	85.5	14.5	14.5	Cb	2.6		
2559	1.531−	6.5	15.5	84.5	17.0	88.0	Cb	0.0	1.15	2.0
			16.5	88.0	73.5	87.0	ab	0.3		
			11.5	88.0	84.0	82.0	ab	1.0		
2560	1.534+	14.0						—		14.0
2561	1.534−	13.5						—		13.5
2563	1.531	7.0	12.5	84.5	15.0	94.0	Cb	5.3		5.9
			13.0	6.0	82.0	98.0	ab–Cb	5.4		
2565	1.533+	11.0	10.5	77.0	16.5	89.0	Cb	11.0	1.10	11.3
			11.0	89.0	82.0	90.0	ab	12.0		
2566	1.532−	8.0						—		8.0
2572	1.530	4.0						—		4.0
2575	1.532	9.0	15.5	77.5	18.0	91.5	Cb	9.0		9.0
2577	1.531−	6.0	17.0	81.5	18.0	83.0	Cb	3.0	1.05	4.1
			16.0	88.0	75.0	—	ab	3.3		
2581	1.531	7.0	10.5	81.0	14.0	86.0	Cb	9.3		13.2
			9.0	69.0	22.5	—	Cb	23.3		
2585	1.539+	22.0	4.5	72.0	17.5	88.5	Cb	20.2		21.1
2587	1.536	16.5						—		16.5
2589	1.529	2.8						—		2.8
2595	1.531−	6.0	19.5	88.0	73.5	92.0	ab	1.0		2.9
			15.5	87.0	14.0	84.0	Cb	1.0		
			15.0	84.5	16.0	86.0	Cb	2.6		
2598	1.538	19.0						—		19.0
2600	1.535	15.0						—		15.0
2602	1.536	16.0						—		16.0

Note: ab denotes albite twins; Cb denotes Carlsbad twins; ab–Cb denotes albite–Carlsbad twins; and Ma denotes Manebach twins. All angles are in degrees.

Table 2. Intermediacy indices for Plagiclase from Plutonic and Metavolcanic Rocks, Prison Hill Area, Carson City, Nevada

Spec. No.	$2\theta(131)-2\theta(1\bar{3}1)$	$2\theta(1\bar{3}1)-2\theta(220)$	Orientation	$2V_x$	I.I. Weighted AVG. All methods
2504	100	—	65	100	97
2507	74	72	100	70	74
2508	90	75	—	72	81
2509	82	80	—	79	81
2530	100	100	100	85	97
2532	66	76	—	80	73
2537	78	66	—	68	71
2550	95	90	—	81	90
2501	—	—	100	85	77
2502	78	—	100	82, 85	80
2503	—	—	—	77, 82	80
2505	—	—	100	89	90
2524	—	—	100	—	100
2536	—	—	100	100	100
2547	—	—	—	85	85
2548	—	—	—	92	92
2558	100	—	100	83	90
2559	96	—	100, 80	92, 83	92
2563	—	—	—	68, 72	70
2565	100	—	100	89, 92	96
2575	—	—	—	88	88
2577	100	—	100	93	97
2581	—	—	—	100	100
2585	—	—	—	100	100
2595	—	—	100	85, 90	88

plagioclase of the regionally metamorphosed rocks retain some of the disorder of the volcanic plagioclase they replace.

Plutonic Rocks

The plagioclase grains are subhedral with quartz, orthoclase, and microcline in antiperthitic or myrmekitic intergrowths in granodiorite and quartz monzonite. The plagioclase ranges in composition from An 23 to An 31 (Figure 1). The I.I. ranges from 71 to 97 and averages 83. The two recorded occurrences of I.I. 97 are in contact zones, one with abundant pegmatites and the other in an area affected by metasomatism. The I.I.'s were determined by three methods (Figures 3, 4, 5 and 6).

The ordering indicies for this pluton, which is typical of many smaller mesozonal plutons of the Sierra Nevada batholithic belt, are nearly the same as the I.I.'s of the Conway granite of the White Mountain Magma series (see Part IV of this paper).

Conclusions

1. The relict plagioclase phenocrysts in the Mesozoic metavolcanic rocks of the greenschist facies in the Prison Hill area are well-ordered albite, I.I. 86. The contact metamorphic zone plagioclases are principally oligoclase with an average intermediacy index of 94.
2. There is a suggestion that the I.I.'s of the plagioclase phenocrysts in metasomatically affected or pegmatitic areas, are higher than their counterparts outside of such areas. This may provide field data to support the hypothesis of Donnay, Wyart, and Sabatier (1960), who indicate that water might play a major role in ordering processes.
3. The granodiorite body, apparently a shallow, isolated mesozonal intrusion (Buddington (1959)), has, except for the border zones, I.I.'s ranging from 71 to 81. This range of values may be common mesozonal intrusions of similar size.
4. The increased order in the contact zones, together with the absence of field and textural evidence for chilling, suggests a similar cooling history for the bulk of the intrusion.
5. Contact metamorphic plagioclase may develop with high ordering indices in the An 8 to An 21 range, a range that apparently is rare or lacking in regional metamorphic rocks (de Waard(1959)). They do not appear to be peristerites.

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