POTASH-OLIGOCLASE IN HAWAIIAN LAVAS*

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ABSTRACT

Interstitial feldspar in Hawaiian lavas with the refractive indices of oligoclase or andesine has an abnormally small positive optical angle. The abnormalities have previously been attributed to an isomorphous admixture of nepheline or carnegieite, but this is made doubtful by the discovery of the material in rocks with normative quartz. It is concluded that the abnormal properties are caused by an admixture of potash feldspar, the compound being unstable at ordinary temperatures but prevented from unmixing by the rapid cooling of the enclosing rocks.

INTRODUCTION

Many Hawaiian lavas contain feldspar which differs notably in some of its optical properties from any commonly recognized variety. This feldspar was first described by Barth, who found it widely distributed in Hawaiian lavas.[1] Its properties, as described by Barth, include a range of refractive index generally between 1.53 and 1.55, and a positive optic angle ranging as low as 10°. Observations by the writer are in close agreement with those of Barth. The mineral commonly has refractive indices within the range of oligoclase and sodic andesine, and $+2V$ varying from large to nearly uniaxial. The estimated optic angle may show a range of 20° or more in different grains in the same thin section.

This peculiar feldspar was found by Barth in lavas in which nepheline is present in the norm, but not in the mode. He concluded, as a result of calculations of its theoretical composition based on the chemical and modal analyses, that it is a soda-lime feldspar containing a variable isomorphous admixture of alkali feldspar and nepheline, the latter probably in the form of carnegieite. On the basis of its apparent nepheline content, he suggested its identity with anemousite, a feldspar containing nepheline which had previously been described from the island of Linosa.[2] It has recently been doubtfully identified by Stark and Howland in lavas from Borabora.[3]

Identical feldspar from basaltic lavas of Japan and neighboring parts of

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[1] Barth, T. F. W., Pacificite, an anemousite basalt: *Jour. Washington Acad. Sci.*, **20**, 60–68 (1930); Mineralogical petrography of Pacific lavas: *Am. Jour. Sci.*, 5th ser., **21**, 401–402, 510–513 (1931).

[2] Washington, H. S., and Wright, F. E., A feldspar from Linosa and the existence of soda anorthite (carnegieite): *Am. Jour. Sci.*, 4th ser., **29**, 52–70 (1910).

[3] Stark, J. T., and Howland, A. L., Geology of Borabora, Society Islands: *B. P. Bishop Mus., Bull.* **169**, 34 (1941).

the Asiatic mainland has been described by Tomita,[4] who concluded that it is a potash-rich, high-temperature variety of andesine.

Occurrence of the Feldspar

In Hawaiian lavas, the anomalous feldspar is largely confined to the interstices of the groundmass. Nearly all phenocrysts and most of the groundmass feldspar appear to be entirely normal soda-lime plagioclase. The anomalous feldspar is generally absent in rocks with a glassy base, presumably being retained in the glass. Thus in most rocks, it is restricted to the portion that crystallized last. The percentage is generally small, ranging from 2 or 3 to 15 or 20 per cent, the amount being typically greater in rocks of basaltic andesite or andesite composition than in the basalts. In many basalts it is entirely absent.

In a few andesites a large proportion of the feldspar grains exhibit abnormal properties. This is true of the andesite constituting White Hill, on the edge of the summit depression of Haleakala volcano, in which most of the feldspar shows a positive sign and an optic angle estimated at 45° to 55°, combined with refractive indices in the range of sodic andesine and calcic oligoclase. A chemical analysis of this rock is reproduced as number 15 in the accompanying table, and a micrometric analysis yields the following modal composition: feldspar 62.3%, monoclinic pyroxene 19.8%, olivine 7.5%, and magnetite 10.4%. In rocks which contain large amounts of the abnormal feldspar, the optic angles appear to be larger, and the deviation from normal therefore less extreme, than in many rocks containing less of the material.

Typical of the Hawaiian basaltic andesites is a lava collected in Hanawi Gulch, on the northern side of Haleakala volcano. It is aphyric, with an intergranular texture, and is composed of calcic andesine, 30%; interstitial feldspar with the refractive indices of calcic oligoclase, 20%; monoclinic pyroxene, 25%; olivine, 5%; magnetite, 20%; and a few minute needles of apatite. The interstitial oligoclase has a positive axial angle estimated from optic axis and bisectrix figures to range from 10° to 50°. Its refractive indices determined by immersion are: $\alpha = 1.545$, $\beta = 1.547$, $\gamma = 1.550$ ($\pm .003$). Although the estimated optic axial angles may be in error possibly by as much as 10°, it is obvious that the values are abnormally low for feldspar with these refractive indices.

In its usual interstitial occurrence, the anomalous feldspar is anhedral and untwinned. A few grains show poor cleavage. The extinction is fre-

[4] Tomita, T., Geological and petrological study of Dogo, Oki, part 12 (in Japanese): *Jour. Geol. Soc. Tokyo.*, **38,** 413 (1931); Olivine-trachyandesitic basalt from Hsueh-hua-shan Hill, Ching-hsing District, North China: *Jour. Shanghai Sci. Inst.*, sec. 2, **1,** 1–10 (1933).

quently irregular or undulatory.[5] The birefringence is low, estimated as between 0.004 and 0.008. A few grains show carlsbad or albite twinning, but twinning is rare. The mineral is generally anhedral and contains numerous inclusions of all the other minerals, showing that it was the last constituent to crystallize. Especially characteristic are very abundant included highly acicular, minute crystals of apatite.

Effect of Overlapping Grains

Sugi has recently described soda-lime feldspar with apparent small positive optic angle in olivine dolerite from Fu-shun, in Manchuria.[6] He clearly demonstrates that in this material the abnormal properties of the feldspar are caused by the superposition of two thin plates of feldspar. The plates are approximately parallel to 010, and their combination is probably the result of twinning on the carlsbad or albite law. The feldspar is sodic labradorite or calcic andesine. Crystals are commonly found to consist of two parts in which the orientation of the X vibration directions are nearly opposite. The abnormal properties are restricted to certain areas within the crystals in which the two parts of contrasted optic orientation overlap, and they are shown to be the result of the partial compensation of the double refraction in one layer by the other layer of nearly opposite orientation.

As the result of special search similar occurrences have been found in a few Hawaiian lavas. In the specimen from Molokai (no. 13, in the table), certain low-birefringent zones in phenocrysts have been found to have small optic angle although the rest of the crystal appears normal. In these instances the crystal consists of two parts, in which the directions of the faster ray are nearly opposite. However, in the same rock the groundmass feldspars, many of which also have a small optic angle, show no evidence of being compound. The same is true in most of the Hawaiian lavas which contain the anomalous feldspar. Owing to the smallness of many of the grains, an overlap of one over another is common, but no regular relationship between the overlapping flakes is detectable. Their optic orientations are haphazard with regard to one another. Moreover, there is frequently no evidence of an overlapping condition, the grains with small 2V appearing to be single homogeneous crystals. Twinning, on the carlsbad and especially on the albite law can rarely be recognized. Irregular

[5] Macdonald, G. A., Petrography of Kahoolawe, in Stearns, H. T., Geology and groundwater resources of the islands of Lanai and Kahoolawe, Hawaii: *Hawaii Div. of Hydrography, Bull.*, **6**, 151–153 (1940).

[6] Sugi, Ken-ichi, On the nature of some plagioclase apparently with small optical angle, with special reference to the plagioclase in olivine-dolerite from Fu-shun, Manchuria: *Kyushu Imp. Univ., Fac. Sci. Mem., ser. D*, **1**, 1–22 (1940).

or undulatory extinction, which is typical of these feldspars, might, and undoubtedly in part does, result from the irregular overlapping of the thin flakes, but it might also, as in the quartz of many granitic rocks, be the result of the strains set up in the last crystallized minerals which are forced to adjust themselves to the residual spaces between the earlier-crystallized grains. Moreover, the clearest conoscopic figures are generally obtained on grains which show the most regular extinction and no evidence of overlap of one grain by another, suggesting that the abnormally small optic angle is unrelated to either overlap or strain.

The possibility that the abnormal properties of the groundmass feldspars are due to superimposed plates with contrasted optic orientation is difficult to rule out entirely, but in view of the above facts is regarded as very unlikely.

Evidence from Chemical Analyses

In the accompanying table are shown the chemical and normative compositions of 15 Hawaiian lavas, all of which contain feldspar exhibiting the abnormal properties described above. The analyses are arranged in the order of increasing content of the abnormal feldspar. All have been studied microscopically by the writer, and several were described by Barth.[7] The table also shows the percentage of anomalous feldspar in the modal composition; the values quoted from Barth and several of those determined by the writer are micrometric determinations, but most by the writer are estimates. Similar estimates have been checked against micrometric determinations and found to agree within a few per cent. Reliable estimates or measurements of the amount of anomalous feldspar are difficult of attainment because of the interstitial nature of the material, the fine grain of the rocks, and the overlapping of thin grains in the groundmass. However, the figures are believed to be close enough to give valuable results. Partly glassy lavas were avoided because of the uncertainty of the composition of the glass, and because few of them contain much of the peculiar feldspar.

Barth observed the anomalous material only in rocks that contain normative nepheline, and concluded as a result of calculations of the composition of the mineral, based on the chemical and modal analyses, that the feldspar is anemousite and the abnormal properties are the result of the presence of nepheline or carnegieite. However, the writer has found the abnormal feldspar in several rocks containing normative quartz.[8] This discovery appears to rule out the presence of admixed nepheline as essential to the abnormal properties of the feldspar. More-

[7] Barth, T. F. W., *op. cit.*

[8] Macdonald, G. A., *op. cit.*, p. 152.

over, the investigations of Bowen,[9] and more recently of Dittler and Kohler,[10] indicate that only a very small amount of nepheline or carnegieite can be held in solid solution in soda-lime feldspars.

Figure 1*A* is a graph showing the percentages of modal anomalous feldspar plotted against the percentages of normative quartz and nepheline. The distribution is essentially random, the abnormal properties being exhibited by both rocks with normative quartz and rocks with normative nepheline. There is, however, a general trend downward toward the right, which suggests a remote if not a direct control. This remote influencing factor is probably the tendency of rocks richer in normative orthoclase to be less saturated in silica than those in which normative orthoclase is less abundant. This tendency is demonstrated by a comparison of parts *A* and *B* of Fig. 1. It is concluded, therefore, that the occurrence of the abnormal feldspar is independent of the presence of nepheline. Moreover, in the Linosa feldspar described by Washington and Wright, in which admixed nepheline or carnegieite was demonstrated to exist, the measured values for the optic angle[11] are not smaller than would be expected in normal feldspar with the determined indices.[12]

If the admixture of nepheline is not the cause of the abnormal properties observed in the feldspars in Pacific lavas, it becomes necessary to seek some other factor which might be the cause. The only other component not accounted for in the modal constitution of the rocks is normative orthoclase. Consequently, in Fig. 1*B*, the percentages of abnormal feldspar have been plotted against those of normative orthoclase. A definite linear trend is immediately obvious, and is taken to indicate that an admixture of the potash feldspar molecule in the soda-lime feldspar is probably responsible for the lowering of the optic angle. The deviation of the points in the diagram from a single line is probably the result of different amounts of potash feldspar being combined with a unit amount of soda-lime feldspar. Such a variation in the amount of potash feldspar in the anomalous soda-lime feldspar would preclude the possibility of an exact linear distribution of the points in the diagram. That such a variation does occur is also suggested by the variability of the properties of the mineral, especially of the size of the optic angle. Tomita found a fairly regular decrease in the size of 2V with the decrease of the β refractive index. He suggested that the mineral might form part of a reaction

[9] Bowen, N. L., The binary system: $Na_2Al_2Si_2O_8$ (nephelite-carnegieite)—$CaAl_2Si_2O_8$ (Anorthite): *Am. Jour. Sci.*, 4th ser., **33,** 551 (1912).

[10] Dittler, E., and Kohler, A., Über Mischkristallbildung im ternären System An-Ab-Cg: *Min. pet. Mitt.*, *Bd.* **43,** Heft 4/5 (1932). Cited by Tomita, T., *op. cit.*, p. 9.

[11] *Op. cit.*, p. 53.

[12] Winchell, A. N., Elements of Optical Mineralogy, Part 2, p. 318, New York **(1933)**.

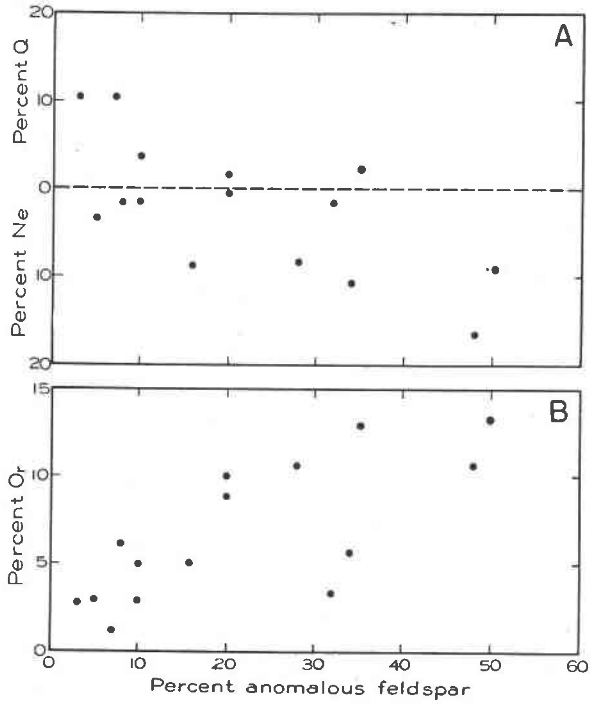

FIG. 1. Graph showing approximate percentage of modal anomalous feldspar plotted against (*A*) percentage of normative quartz and nepheline, and (*B*) percentage of normative orthoclase, in holocrystalline Hawaiian lavas.

series including potash-oligoclase, anorthoclase, and potash feldspar.[13] Benson and Turner suggest that abnormalities in the extinction angle of certain feldspars in mugearites of the Dunedin district, New Zealand, may be due to the presence of potash feldspar in solid solution in the soda lime feldspar, but do not describe the optic angle or sign of the anomalous feldspars.[14]

EVIDENCE FROM INTRUSIVE ROCKS

The feldspar with abnormal properties appears to be restricted entirely to extrusive rocks or fine grained intrusive rocks which cooled quickly at shallow depths, or in small bodies. It has not been found in any of the coarse-grained intrusive bodies in Hawaii. Conversely, however, the gabbros contain another feldspar only very rarely encountered in the lavas. In many of these coarse-grained bodies, notably the gabbro stocks in

[13] *Op. cit.*, pp. 8, 10.

[14] Benson, W. N., and Turner, F. J., Mugearites in the Dunedin district: *Trans. Royal Soc. New Zealand*, **70**, pt. 3, 188–199 (1940).

CHEMICAL ANALYSES OF HAWAIIAN LAVAS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SiO_2	51.77	42.99	50.12	48.59	48.00	47.06	43.28	48.27	48.78	48.04	46.43	47.19	53.14	45.46	49.55
Al_2O_3	14.33	10.21	12.35	9.83	14.12	10.26	14.43	16.52	14.18	17.95	10.91	10.95	14.60	16.18	17.78
Fe_2O_3	2.76	3.01	4.41	7.62	5.42	2.14	0.70	3.72	5.81	4.28	3.15	3.31	5.74	4.40	4.65
FeO	7.85	10.28	8.71	5.27	8.05	6.60	10.92	6.71	6.57	7.21	10.26	10.21	7.72	7.38	5.89
MgO	6.77	14.61	7.96	7.15	4.94	17.76	11.68	3.63	3.63	2.79	11.08	10.52	2.50	4.07	2.49
CaO	9.74	12.54	10.28	8.27	9.43	8.62	11.22	6.24	6.98	7.52	10.09	9.73	5.44	8.56	7.01
Na_2O	1.75	1.40	1.22	4.96	3.23	2.80	2.49	4.14	5.03	5.55	3.16	4.69	4.64	6.06	6.12
K_2O	0.51	0.52	0.17	1.00	0.48	0.84	0.83	1.52	1.71	1.91	0.54	0.93	2.20	1.82	2.29
H_2O+	0.52	1.10	0.76	1.36	1.27	0.63	0.05	1.91	1.00	0.14	0.66	0.17	0.38	0.06	0.34
H_2O-	0.34	0.82	0.57	1.01	0.49	0.65	0.03	1.47	0.52	0.08	0.15	0.07	0.22	0.03	0.29
TiO_2	3.17	2.52	3.30	4.42	3.90	2.62	4.12	4.43	4.64	3.27	2.59	2.27	2.74	5.10	2.09
P_2O_5	0.49	0.29	0.22	0.84	0.52	0.50	0.31	1.03	0.89	0.88	0.67	0.55	1.03	0.51	1.10
MnO	0.18	0.17	0.21	0.16	0.19	0.16	0.13	0.18	0.23	0.39	0.09	0.16	0.26	0.24	0.28
Total	100.18	100.46	100.28	100.48	100.04	100.64	100.19	99.77	99.97	100.01	99.78	100.75	100.61	99.87	99.88
Norms															
Quartz	10.4	—	10.4	—	3.9	—	—	1.8	—	—	—	—	2.2	—	—
Orthoclase	2.8	2.8	1.1	6.1	2.8	5.0	5.0	8.9	10.0	11.1	3.3	5.6	12.8	10.6	13.3
Albite	14.7	6.3	10.0	39.3	27.2	21.0	4.7	35.1	41.9	32.0	23.8	19.9	39.3	21.0	34.6
Anorthite	29.8	20.0	27.8	1.4	22.5	13.1	36.7	22.0	11.1	18.4	13.9	6.1	12.5	11.7	15.0
Nepheline	—	3.1	—	1.4	—	1.4	8.8	—	0.3	8.2	1.6	10.8	—	16.5	9.1
Diopside	12.1	32.3	18.0	26.7	16.7	20.6	8.7	2.2	14.0	10.9	25.3	31.0	15.6	21.5	10.4
Hypersthene	18.2	—	18.5	—	8.6	—	—	10.4	—	—	—	—	4.0	—	—
Olivine	—	24.2	—	4.0	—	29.1	25.7	—	1.8	4.9	20.0	17.3	—	1.4	3.8
Magnetite	4.2	4.4	6.5	4.6	7.9	3.0	0.9	5.3	8.4	6.3	4.6	4.9	8.4	6.5	6.7
Ilmenite	6.1	4.7	6.2	8.4	7.4	5.0	7.8	8.4	8.8	6.2	4.9	4.3	5.2	9.7	3.9
Hematite	—	—	—	4.5	—	—	—	—	—	—	—	—	—	—	—
Apatite	1.3	0.7	0.3	2.0	1.3	1.3	0.7	2.4	2.0	2.0	1.7	1.3	2.4	1.3	2.7
Approximate model percentage of anomalous feldspar															
	3	5	7	8	10	10	[a]16	20	20	[a]28	[a]32	[a]34	35	[a]48	50

[a] Percentage quoted from Barth, T. F. W., Mineralogical petrography of Pacific lavas: *Am. Jour. Sci.*, 5th ser., **21,** 511 (1931).

1. Olivine basalt, on ridge on south side of Nanakuli Valley, Waianae volcano, Oahu; S. Iwashita, analyst. Macdonald, G. A., Petrography of the Waianae Range, Oahu, in Stearns, H. T., Supplement to the geology and ground-water resources of the island of Oahu, Hawaii: *Hawaii Div. of Hydrography, Bull.* **5,** 91 (1940).
2. Picritic basalt, northwest base of Namanaokeakua Hill in summit depression of Haleakala volcano; G. Steiger, analyst. Cross, W., Lavas of Hawaii and their relations: *U.S. Geol. Survey, Prof. Paper* **88,** 29 (1915).
3. Olivine basalt, on ridge on south side of Nanakuli Valley, Waianae volcano, Oahu: S. Iwashita, analyst. Macdonald, G. A., *op. cit.*
4. Biotite-bearing andesitic basalt, top of Puu Palailai; S. Iwashita, analyst. *Ibid.*
5. Olivine basalt, just north of saddle on north side of Puu Haleakala, Waianae volcano, Oahu; S. Iwashita, analyst. *Ibid.*
6. Olivine basalt transitional to picritic basalt, at junction of Amalu and Honokowai Streams, West Maui; S. Iwashita, analyst. Stearns, H. T., and Macdonald, G. A., Geology and ground-water resources of the island of Maui, Hawaii: *Hawaii Div. of Hydrography*, Bull. **7,** in press.
7. Picritic basalt, 1750(?) lava flow near Makena, on Haleakala volcano; M. G. Keyes, analyst. Washington, H. S., and Keyes, M. G., Petrology of the Hawaiian Islands; VI. Maui: *Am. Jour. Sci.*, 5th ser., **15,** 214–215 (1928).
8. Basaltic andesite, on ridge on south side of Nanakuli Valley, Waianae volcano, Oahu; S. Iwashita, analyst. Macdonald, G. A., *op. cit.*
9. Biotite-bearing basaltic andesite, on ridge east of Makaiwa Gulch, Waianae volcano, Oahu; S. Iwashita, analyst. *Ibid.*
10. Andesite, at rest house on rim of summit depression of Haleakala volcano; M. G. Keyes, analyst. Washington, H. S., and Keyes, M. G., *op. cit.*, pp. 211–212.
11. Olivine basalt, lava of 1801, Hualalai volcano; Washington, analyst. Washingson, H. S., Petrology of the Hawaiian Islands; II. Hualalai and Mauna Loa: *Am. Jour. Sci.*, 5th ser., **6,** 102 (1923).
12. "Chrysophyric oligoclase basalt," Kaula Gulch, above Ookala, Mauna Kea; Washington, analyst. Washington, H. S., Petrology of the Hawaiian Islands; I. Kohala and Mauna Kea: *Am. Jour. Sci*, 5th ser., **5,** 500 (1923).
13. Andesite, on highway at 380 feet altitude on northwest bank of Manawai Gulch, East Molokai volcano; S. Iwashita, analyst.
14. Basaltic andesite, three miles from rest house, Olinda trail, north slope of Haleakala volcano; M. G. Keyes, analyst. Washington, H. S., and Keyes, M. G.; *op. cit.*, pp. 211–212.
15. Andesite, White Hill, on rim of summit depression of Haleakala volcano; W. F. Hillebrand, analyst. Cross W., *op. cit.*, pp. 31–32.

West Maui volcano, the Palolo boss in the Koolau volcano of Oahu,[15] and certain gabbros from Kahoolawe,[16] there is found a small amount of interstitial orthoclase and sanidine, associated with oligoclase and in one instance with albite. The potash and soda-lime feldspars are often intergrown as antiperthite, which has the appearance of having resulted from the unmixing of two phases formerly in solid solution.

The apparent reciprocal relationship of antiperthite in the gabbros and the abnormal feldspar in the extrusive rocks supports the supposition that the latter may be a solid solution of potash feldspar in soda-lime feldspar, stable at high temperatures but metastable at low temperatures. In the gabbros, slower cooling would permit the unmixing of the solid solution forming antiperthite, or the direct crystallization of the two components as separate but closely associated minerals.

Conclusions

The small positive optic angle of interstitial feldspars with the refractive indices of andesine and oligoclase, found in many Hawaiian lavas, is not the result of an admixture of nepheline or carnegieite, as has previously been suggested. In some phenocrysts the abnormally small optic angle apparently is caused by the superposition of feldspar plates, probably by twinning on the carlsbad or albite laws, the corresponding vibration directions in the superimposed plates being approximately at right angles. In most of the groundmass feldspar, however, there is no evidence that the abnormal properties are the result of such overlapping of differently oriented plates. On the other hand, there is a definite correlation of the amount of abnormal feldspar in the rock with the percentage of normative orthoclase. Therefore, it appears probable that the feldspar with the small optic angle is an andesine or oligoclase containing more or less potash feldspar, in solid solution, stable at high temperatures, but metastable at ordinary temperatures. Following Tomita, it may be termed potash-oligoclase or potash-andesine.[17]

Acknowledgments

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[15] Stearns, H. T., and Vaksvik, K. N., Geology and ground-water resources of the island of Oahu, Hawaii: *Hawaii Div. of Hydrography, Bull.*, **1**, 21, (1935).

Wentworth, C. K., and Jones, A. E., Intrusive rocks of the leeward slope of the Koolau Range, Oahu: *Jour. Geology*, **48**, 986–988 (1940).

[16] Macdonald, G. A., *op. cit.*, p. 153.

[17] *Op. cit.*, pp. 7–10.