Paleomagnetism of Volcanic Rocks from Niihau, Nihoa, and Necker Islands, Hawaii

RICHARD R. DOELL

U.S. Geological Survey, Menlo Park, California 94025

A paleomagnetic study of 39 lavas collected from the islands of Niihau, Nihoa, and Necker yields paleosecular variation values in agreement with the low values found from more extensive studies on the main islands of the Hawaiian group. A mean VGP (virtual geomagnetic pole) on the opposite side of the geographic pole was obtained from the Niihau data, but the Nihoa mean VGP is very close to the rotation axis. Unusual equatorial VGP were found in the lava flows from Necker Island.

Paleomagnetic studies of the Hawaiian Islands have been of primary interest in determining the long-term nature of geomagnetic secular variation in the central Pacific, because the secular variation (SV) is now anomalously low in this region [*Fisk*, 1931] and because the nondipole part of the geomagnetic field whose changes produce part of the SV is essentially missing [*Cox*, 1962; *Creer*, 1962; *Doell and Cox*, 1971, 1972]. Paleomagnetic studies made on rocks of the main Hawaiian group [*Tarling*, 1965; *Doell and Cox*, 1963, 1965; *Doell*, 1969, 1972*a*, *b*; R. R. Doell and G. B. Dalrymple, unpublished data, 1972] have established that these features, anomalously low secular variation and low nondipole field, have been characteristic of the geomagnetic field in the vicinity of the main Hawaiian Islands for about 5 m.y.

Through the courtesy of the U.S. Coast Guard and the U.S. Bureau of Sport Fisheries and Wildlife it was possible to make collections on two of the 'leeward' volcanic islands, Nihoa and Necker, in 1968, and during 1969 and 1970 collections were made from Niihau through the courtesy and generosity of the owners of the island. Although the collections are more restricted than those previously made on the main islands, they are of some interest in that they extend the mid-Pacific paleomagnetic coverage farther west.

Niihau lies about 27 km SW of Kauai. Niihau is composed of an older highland shield of layered basalts, surrounded on the north, west, and south by low-lying younger basalts and calcareous sands and sand dunes. The geology has been described by Stearns and the petrology by Macdonald [*Stearns and Macdonald*, 1947]. The older shield lavas make up the Paniau volcanic series and have an age of about 3.0 m.y. [*Jackson et al.*, 1972]. Some of the younger lavas, the Kiekie volcanic series, have yielded K-Ar ages in the range 0.3–0.7 m.y. (G. B. Dalrymple, oral communication, 1971).

The islands of Nihoa and Necker lie about 280 and 520 km, respectively, NW of Kauai. Both are remnants of shield volcanoes and have been described by *Palmer* [1927], who visited the islands during the Tanager expedition in 1923 and 1924. The K-Ar ages are about 3.0 m.y. for Nihoa Island and around 10.0 m.y. for Necker Island [*Jackson et al.*, 1972].

Reviews of the geology of these and other islands of the Hawaiian group are given by *Stearns* [1966] and *Macdonald and Abbott* [1970].

METHODS AND RESULTS

On the Island of Niihau five superposed lavas of the Paniau volcanic series, exposed at the base of the cliffs along the NE margin of the highlands, were sampled. Samples were also obtained from 13 exposures of the younger Kiekie volcanic series distributed over the length of the island. The sites are shown in Figure 1; site numbers correspond with the units in Table 1. Wherever lavas are superposed at any one

Copyright © 1972 by the American Geophysical Union.

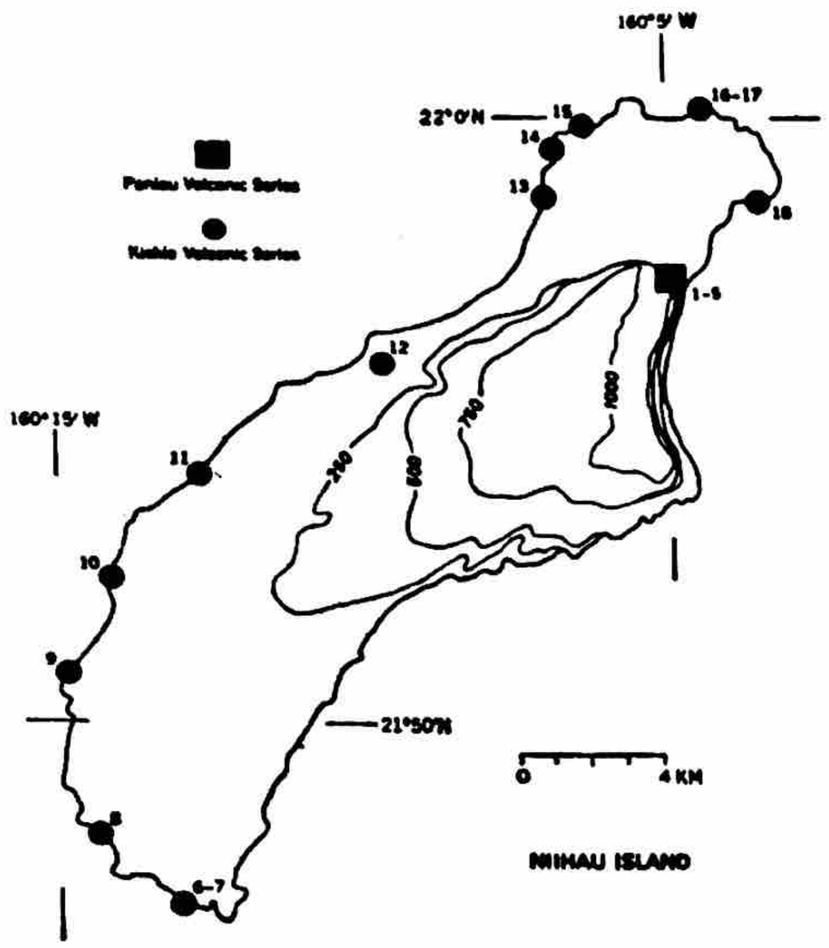


Fig. 1. Generalized contour map of Niihau showing location of sampling sites. Sample site numbers correspond to lava flow numbers in Table 1. The contour interval is 250 feet (76 meters).

locality, the older (lower) lavas have the smaller numbers.

On Nihoa Island a section of 14 superposed lavas was sampled in the shallow ravine that runs from Adam's Bay nearly to the top of Miller's Peak (Figure 2). On Necker Island seven superposed lavas on the north side of Annexation Peak were sampled (Figure 2).

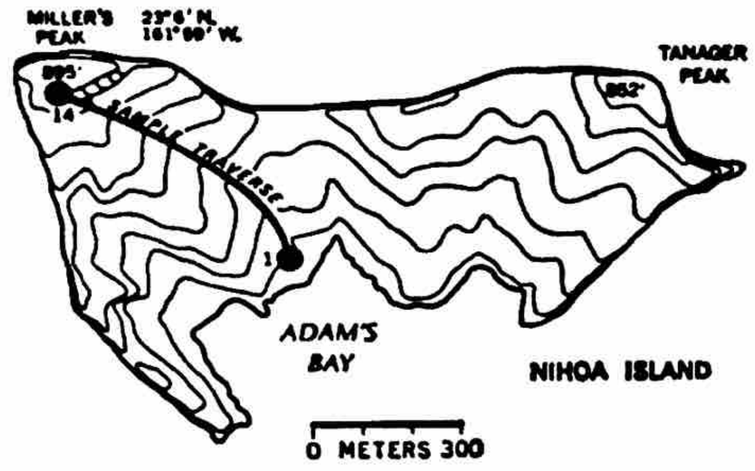
In all instances about eight cores 2.5 cm in diameter by 10–15 cm long were drilled from each lava flow, spanning lateral distances from 5–29 meters (average 13 meters). One specimen about 2.3 cm long was cut from each core, and its magnetic remanence was measured and analyzed with spinner magnetometers and alternating-field (af) demagnetization equipment. The methods of measurement and analysis are described in detail in the works of Doell and Cox cited above and by *Collinson et al.* [1967].

The results of the laboratory measurements are given in Table 1 for the Paniau and Kiekie volcanic series of Niihau and in Table 2 for volcanic rocks of Nihoa and Necker islands. Various amounts of magnetic cleaning were required to remove anomalous magnetization from the lava flows (Table 1, column 5; Table 2, column 3). Anomalous magnetization could not

TABLE 1. Flow-Average Data for Paniau and Kiekie Volcanic Series of Niihau

Unit	Site Lat., °N	Site Long., °E	No. of Samples*	af Cleaning, oe	RM Declin., °E	RM Inclin., ° dn	Resultant R	95% Confidence, deg
			Kiekie Volcanic Series, Niihau					
18	21.98	199.95	8 (8)	50	352.2	26.0	7.9715	3.6
17	22.00	199.93	8 (8)	50	346.2	23.9	7.9709	3.6
16	22.00	199.93	4 (8)	400	348.3	30.1	3.9725	8.8
15	22.00	199.90	5 (8)	200	7.7	19.2	4.9560	8.1
14	21.99	199.90	8 (8)	100	352.3	23.7	7.9378	5.2
13	21.98	199.90	7 (8)	200	352.5	24.1	6.9490	5.6
12	21.93	199.84	8 (8)	400	0.4	22.9	7.9441	5.0
11	21.90	199.79	8 (8)	50	342.0	20.8	7.9859	2.5
10	21.87	199.76	6 (6)	50	348.2	20.1	5.9806	4.2
9	21.85	199.75	8 (8)	100	0.4	41.3	7.9531	4.6
8	21.80	199.76	5 (8)	400	351.0	40.9	4.9729	6.3
7	21.78	199.78	8 (8)	NRM	192.3	-36.4	7.9700	3.6
6			8 (8)	50	184.5	-37.0	7.9858	2.5
			Paniau Volcanic Series, Niihau					
5	21.96	199.92	8 (8)	NRM	191.8	-27.8	7.9636	4.0
4	21.96	199.92	8 (8)	NRM	191.9	-33.7	7.9246	5.8
3	21.96	199.92	8 (8)	NRM	187.6	-42.0	7.9709	3.6
2	21.96	199.92	8 (8)	NRM	181.4	-43.0	7.9793	3.0
1	21.96	199.92	7 (8)	NRM	191.2	-44.4	6.9787	3.6

*Number of samples used in analysis is given first; number in parentheses is number of samples collected.



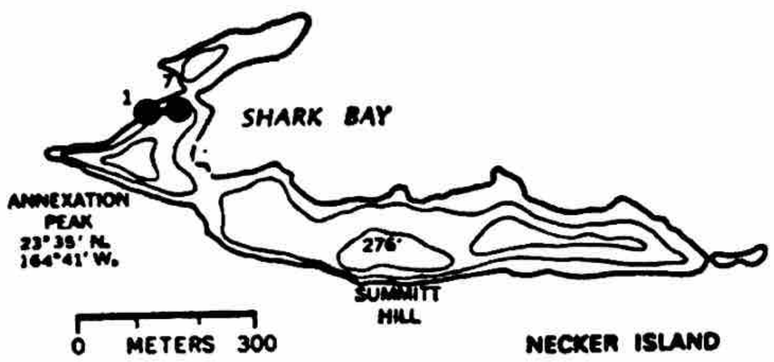


Fig. 2. Generalized contour map of Nihoa and Necker islands showing location of sampling sites. Sample site numbers correspond to lava flow numbers in Table 2. The contour interval is 100 feet (30 meters).

be removed from all specimens, and those in which it persisted were excluded from analysis. The rationale and criteria for these exclusions were discussed in an earlier paper [*Doell*, 1970]. The data given in Tables 1 and 2 are considered to be the best paleomagnetic representation of the geomagnetic field that can be obtained from these samples. The method of *Fisher* [1953] was used in calculating the flow-average data.

DISCUSSION

Virtual geomagnetic poles (VGP) as calculated from the flow-average data of Tables 1 and 2 are plotted on Figures 3 and 4, respectively. Except for those from Necker Island, all VGP are grouped near the present polar regions.

Wilson [1970] analyzed worldwide Tertiary and Quaternary paleomagnetic data and noted a tendency for mean VGP to be located on the opposite side of the geographic pole from the sampling locality. He suggested that this could be due to a northward displacement of the main geomagnetic dipole along the rotation axis.

TABLE 2. Flow-Average Data for Volcanic Rocks

Unit	No. of Samples*	af Cleaning, oe	RM Declin., °E	RM Inclin., ° dn	Resultant, *R*	95% Confidence, deg
			Nihoa Island			
14	8 (8)	NRM	4.6	50.3	7.9861	2.5
13	8 (8)	NRM	357.5	48.0	7.9923	1.8
12	8 (8)	NRM	6.6	50.2	7.9947	1.5
11	8 (8)	NRM	359.2	19.3	7.9742	3.4
10	7 (7)	NRM	3.1	21.0	6.9936	2.0
9	8 (8)	NRM	4.0	24.2	7.9921	1.9
8	7 (8)	NRM	353.9	36.9	6.9988	0.8
7	7 (8)	NRM	6.1	36.3	6.9913	2.3
6	8 (8)	NRM	350.9	38.4	7.9904	2.0
5	8 (8)	NRM	2.5	55.0	7.9722	3.5
4	9 (9)	NRM	1.6	58.0	8.9873	2.0
3	8 (8)	NRM	2.7	34.1	7.9841	2.6
2	8 (8)	NRM	24.4	17.7	7.9811	2.9
1	8 (8)	100	358.2	4.9	7.9935	1.7
			Necker Island			
7	8 (8)	200	56.8	-49.4	7.9708	3.6
6	8 (8)	100	58.2	-46.0	7.9532	4.6
5	6 (8)	400	62.0	-50.3	5.8692	11.0
4	8 (8)	200	59.0	-42.3	7.9147	6.2
3	7 (8)	100	52.8	-45.9	6.9397	6.1
2	8 (8)	50	313.0	-76.6	7.9436	5.0
1	6 (8)	200	274.2	-78.6	5.9406	7.4

Location of site at Nihoa Island, 23.1°N, 198.0°E; location of site at Necker Island, 23.6°N, 195.3°E.

*Number of samples used in analysis is given first; number in parentheses is number of samples collected.

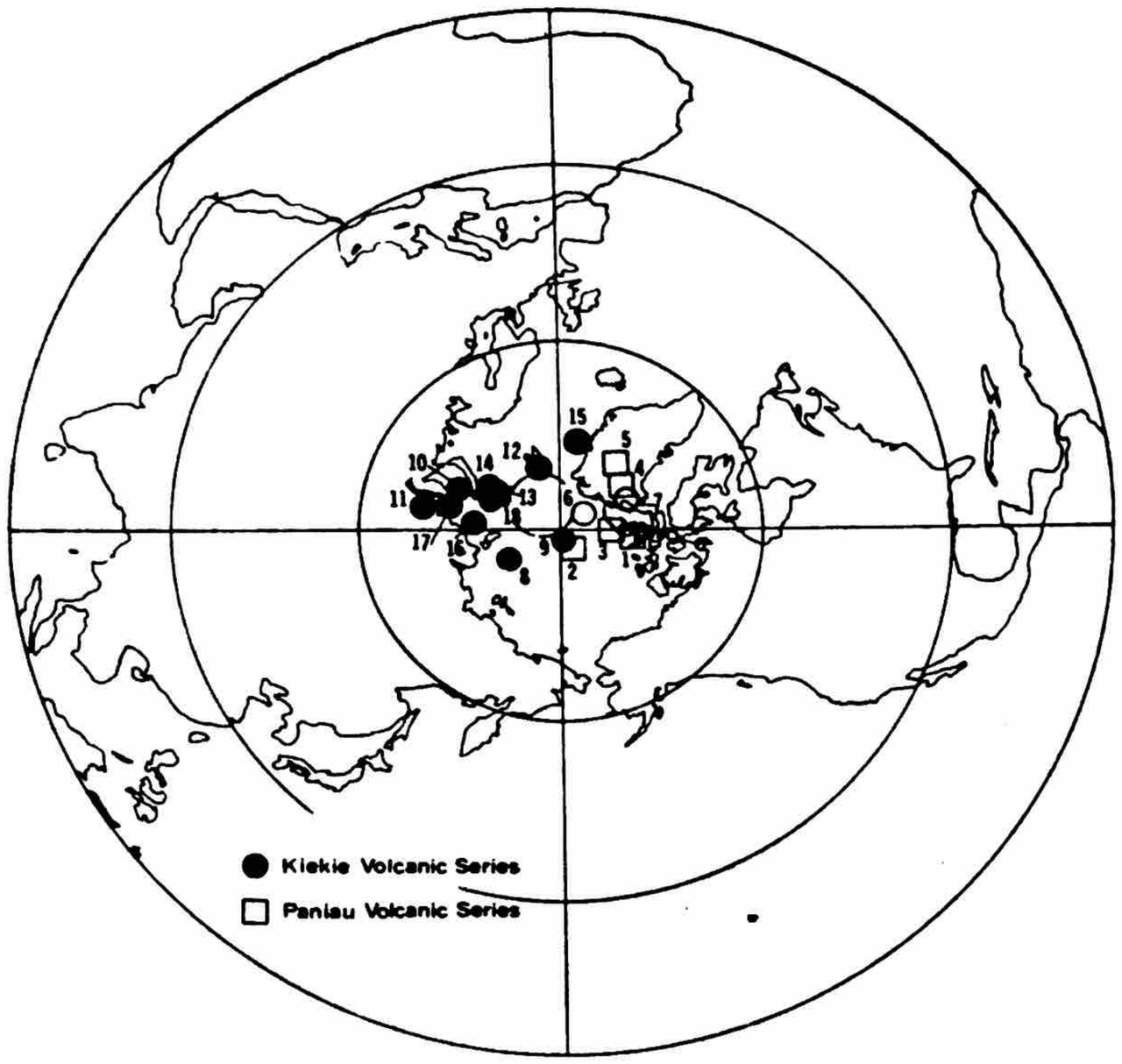


Fig. 3. VGP positions calculated from the paleomagnetic directions of lavas from Niihau Island. The solid symbols are south-seeking VGP, open symbols are north-seeking VGP (the present geomagnetic field yields a south-seeking VGP), and the large circle is the 95% confidence about mean VGP. Numbers correspond to those in Table 1. Lambert equal-area projection.

This feature appears to obtain for the Niihau lavas, where most of the VGP are more distant from Niihau than the geographic pole is. On the other hand, the Nihoa VGP yield a mean quite close to the rotational pole. The individual flow-average VGP are few in number, however, and should probably be given significance only in conjunction with other similar data. The mean VGP for all Niihau data is at 85.2°N, 33.1°E, and has a 95% confidence cone semi-angle α_{95} [*Fisher*, 1953] of 4.8°. The Nihoa mean VGP is at 86.8°N, 329.2°E; its α_{95} is 6.6°.

In formally calculating dispersion statistics of paleomagnetic data as a measure of paleosecular variation [*Cox*, 1970], it is necessary that all data used be independent. As has been discussed in detail elsewhere [*Doell*, 1972*a*, *b*; *Doell and Cox*, 1971], it is often difficult to show independence in sequential data such as those reported here for Nihoa Island. Moreover, by using the test of *Watson and Beran* [1967], it was found that this particular sequence was significantly more serially correlated (at 2 standard deviations) than a random sequence of the same data would be. This problem does not arise with the widely separated lavas from several vents that make up the Kiekie volcanic series on Niihau, the other data set reported here that was analyzed for paleosecular variation. On the other hand, because of extensive sand dune cover, it is not certain that different Kiekie lava flows were sampled at each site. This is particularly true for sites 13, 14, and 15 and may be true for the pair of sites 10 and 11. From Figure 3 it is apparent that sites 13 and 14 could be the same lava, as could 10 and 11, and that 15 is certainly a different lava than either 13 or 14. It is unlikely that a single lava was sampled at any other two sites, but the possibility cannot defi-

nitely be ruled out. The formal confidence limits calculated for the mean dispersion values given below are therefore smaller than the correct ones and should be considered minimums.

The angular dispersion of the Kiekie volcanic series is of interest because of the K-Ar ages that fall within the Brunhes normal polarity epoch, for which there are other paleosecular variation data from the Hawaiian Islands [*Doell and Cox,* 1971; *Doell,* 1972*b*]. It is obvious, however, that the reversely magnetized lavas 6 and 7 from Niihau (for which there are no K-Ar data) are older; they were therefore not included in the paleosecular variation analyses. As has been discussed previously [*Doell,* 1970, 1972*a*, *b*], it is preferable to calculate angular dispersion of the flow-average VGP about the geographic pole as a measure of paleosecular variation. For the 11 Kiekie lavas we calculate a value of 13.2° with a 95% confidence [*Cox,* 1969] between 18.1° and 10.4°. Although this is a higher mean value than the 11° mean for the considerably larger data set from the Island of Hawaii, it is not significantly higher. The data are in agreement with a low paleosecular variation for the central Pacific region during the Brunhes epoch.

The angular variance of the 14 Nihoa lavas is 13.5° with 95% confidence limits between 17.9° and 10.8°. This value is similar to the values of the Makaweli formation and Napali formation [*Doell,* 1972*a*], whose K-Ar ages are 3.5–4.0 m.y. and 4.5–5.6 m.y., respectively [*McDougall,* 1964]. Like the Makaweli and Napali data, the Nihoa angular variance suggests a somewhat larger paleosecular variation before the Brunhes epoch (but not significantly larger at the 95% confidence level).

The VGP positions calculated from the seven lavas sampled on Necker Island are a real surprise. The exposures on the north side of Annexation Peak are excellent, and there is no

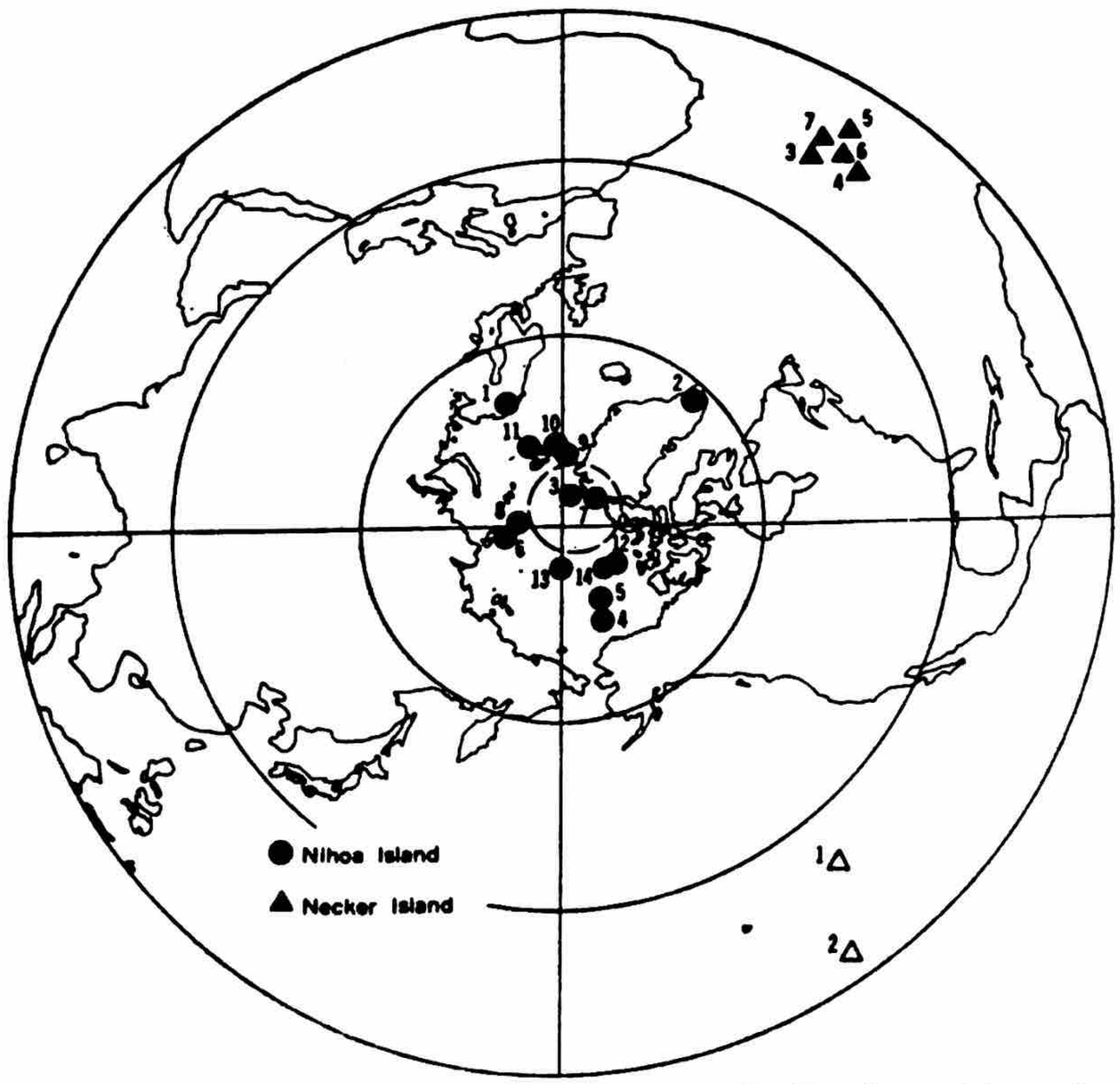


Fig. 4. VGP positions calculated from the paleomagnetic directions of lavas from Nihoa and Necker islands. Symbol convention is the same as that in Figure 3. The large circle is the 95% confidence about the Nihoa mean VGP. Numbers correspond to those in Table 2. Lambert equal-area projection.

doubt that these are separate superposed lava flows. The flows are between ½ and 2 meters thick and are separated from each other by scoria, rubble, and other flows. Total separation distances range from 3 to 6 meters (except for a total of 1–1½ meters between lavas 6 and 7). It seems that the VGP occupied two different low-latitude positions during the eruption of these lavas. It would be very interesting to study other lavas within this sequence should we have an opportunity to visit Necker Island again.

From the data reported here we find supporting evidence for the low secular variation and nondipole field components that have been found from studies of other islands in the Hawaiian group.

Acknowledgments. Permission to visit Nihoa and Necker islands of the Hawaiian National Wildlife Refuge was kindly provided by Eugene Kridler, U.S. Bureau of Sport Fisheries and Wildlife, who accompanied the party visiting these islands in 1968. We are very grateful for his assistance. Transportation to and landings on these islands were provided by personnel of the Coast Guard Cutter *Buttonwood*, and we wish to acknowledge our debt to the Commanding Officer, CDR Henry Haugen, and crew. Permission to visit the Island of Niihau in 1969 was granted by the late Lester B. Robinson and in 1970 by Bruce B. Robinson. These gentlemen provided transportation to and from the island as well as surface transportation and assistance while on Niihau. We are deeply grateful to them for making our visits possible. G. B. Dalrymple helped with the field collections, and the magnetic measurements were carried out by E. Mankinen.

Publication authorized by the Director, U.S. Geological Survey.

REFERENCES

Collinson, D. W., K. M. Creer, and S. K. Runcorn (Eds.), *Developments in Solid Earth Geophysics*, vol. 3, *Methods in Paleomagnetism*, 609 pp., Elsevier, New York, 1967.

Cox, A., Analysis of present geomagnetic field for comparison with paleomagnetic results, *J. Geomagn. Geoelec., 13*, 101, 1962.

Cox, A., Confidence limits for the precision parameter κ, *Geophys. J., 17*, 545, 1969.

Cox, A., Latitude dependence of the angular dispersion of the geomagnetic field, *Geophys. J., 20*, 253, 1970.

Creer, K. M., An analysis of the geomagnetic field using paleomagnetic methods, *J. Geomagn. Geoelec., 13*, 113, 1962.

Doell, R. R., Paleomagnetism of the Kau volcanic series, Hawaii, *J. Geophys. Res., 74*, 4857, 1969.

Doell, R. R., Paleomagnetic secular variation study of lavas from the Massif Central, France, *Earth Planet. Sci. Lett., 8*, 352, 1970.

Doell, R. R., Paleomagnetism of lava flows from Kauai, Hawaii, *J. Geophys. Res., 77*, 862, 1972*a*.

Doell, R. R., Paleosecular variation of the Honolulu volcanic series, Oahu, Hawaii, *J. Geophys. Res., 77*, 2129, 1972*b*.

Doell, R. R., and A. Cox, The accuracy of the paleomagnetic method as evaluated from historic Hawaiian lava flows, *J. Geophys. Res., 68*, 1997, 1963.

Doell, R. R., and A. Cox, Paleomagnetism of Hawaiian lava flows, *J. Geophys. Res., 70*, 3377, 1965.

Doell, R. R., and A. Cox, Pacific geomagnetic secular variation, *Science, 71*, 248, 1971.

Doell, R. R., and A. Cox, The Pacific geomagnetic secular variation anomaly and the question of lateral uniformity in the lower mantle, in *The Nature of the Solid Earth*, pp. 245–284, McGraw-Hill, New York, 1972.

Fisher, R. A., Dispersion on a sphere, *Proc. Roy. Soc. London, Ser. A, 217*, 295, 1953.

Fisk, H. W., Isopors and isoporic movement, *Bull. Int. Geod. Geophys. Union*, no. 8, 280, 1931.

Jackson, E. D., E. A. Silver, and G. B. Dalrymple, The Hawaiian-Emperor chain and its relation to mid-Tertiary circumPacific tectonics, *Bull. Geol. Soc. Amer., 83*, 601, 1972.

Macdonald, G. A., and A. T. Abbott, *Volcanoes in the Sea*, 441 pp., Hawaii University Press, Honolulu, 1970.

McDougall, I., Potassium-argon ages from lavas of the Hawaiian Islands, *Bull. Geol. Soc. Amer., 75*, 107, 1964.

Palmer, H. S., Geology of Kaula, Nihoa, Necker, and Gardner islands, and French Frigates Shoal, *Bernice P. Bishop Mus. Bull., 35*, 35 pp., 1927.

Stearns, H. T., *Geology of the State of Hawaii*, 266 pp., Pacific Books, Palo Alto, Calif., 1966.

Stearns, H. T., and G. A. Macdonald, Geology and ground-water resources of the Island of Niihau, Hawaii, *Bull. Hawaii Div. Hydrogr., 12*, 51 pp., 1947.

Tarling, D. H., The paleomagnetism of some of the Hawaiian Islands, *Geophys. J., 10*, 93, 1965.

Watson, G. S., and R. J. Beran, Testing a sequence of unit vectors for serial correlation, *J. Geophys. Res., 72*, 5655, 1967.

Wilson, R. L., Permanent aspects of the earth's non-dipole magnetic field over upper Tertiary times, *Geophys. J., 19*, 417, 1970.

(Received November 12, 1971.)