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REMANENT MAGNETIZATION OF SOME INTRUSIVE ROCKS IN THE CASCADE RANGE, OREGON

by

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Abstract

This paper gives a preliminary report of paleomagnetic measurements of some small granitic intrusions which are several kilometers in diameter, exposed in the Cascade Range, Oregon. The directions of remanent magnetization of the samples were mostly scattered before magnetic cleaning. However, the directions of magnetization of samples obtained from three intrusive bodies were well grouped in each sampling site after treatment in the alternating current field. The samples taken from one intrusion had a large soft component of remanent magnetization and no detectable stable moment. The Curie points of these intrusive rocks are within range of 560°C and 575°C. The samples in the Laurel Hill, Detroit Dam and Vida intrusions possess stable remanent magnetization with an intensity greater than 10^{-4} emu/cc after A. C. demagnetization of 200 oe. The intensity of stable magnetization is less than one tenth of the soft component of the remanent magnetization. The Laurel Hill intrusion is reversely magnetized in the margin of the body and normally magnetized in the inner part. The sample in between the reversed and the normal rocks have an intermediate direction.

1) Introduction

It is well known that approximately 50 percent of the world's rocks are magnetized normally, that is, in directions consistent with the earth's dipole field in its present sense, and that the other 50 percent are magnetized reversely. Recent age determination work (Cox et al, 1964 ; McDougall and Chamalaun, 1966) has demonstrated that the earth's field changed its direction frequently during the late Tertiary time. However, the time required for a reversal of the field has not been obtained from the potassium-argon dating, because the time is likely to be within a standard deviation of precision of the method. There are three different approaches to the solution of this problem, of course, using the potassium-argon dating ; the first is paleomagnetic surveys of a sequence of successive lava flows (Dagley et al, 1967), the second is paleomagnetic measurements of deep sea sediments and the estimation of the rate of sedimentation (Harrison, 1966 ; Opdyke et al, 1966), and the third is systematic observations of the remanent magnetization of an intrusive body in view of a cooling rate of a small sized intrusion (Jaeger, 1957 ; Ito, 1965). A great advantage of the third method is that

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continuous records of the earth's magnetic ield during a change in polarity may be obtainable.

Some geologists think that more than 85 percent of all exposed granitic rocks were formed from cooling magmas (Wahlstron, 1950 ; Buddington, 1948). Such granitic rocks come to rest only after the transfer of magma from one place to another in the earth's crust. On the other hand, Kawai (1957) suggested from laboratory experiments and field evidences that the Curie temperature become lower with the increase in temperature and pressure at which the rocks were formed. According to these investigations, the natural remanent magnetization (NRM) of the granitic rocks is controlled by the depth of the formation of rocks, so the deep seated rocks are thought to have been disturbed over a long period of time at relatively highly temperature and pressure. On the contrary, small intrusion, such as stocks, dikes and plugs, almost were certainly formed by injection of magma to shallow place in the crust, and it is expected that they have a magnetization undisturbed as compared with the deep seated rocks.

The time required for cooling of the igneous body is one of the most important factors in a study of the reversal process of the earth's field. Larson (1945) stated that the time for complete crystallization of dikes, if the loss of heat were only by conduction through the walls, should be as follows ; 10 km, which is width of dike, is 700000 years and 1 km is 7000 years. Jaeger (1957) discussed the possibility of following the change in direction of the earth's field if it reversed during the cooling of an intrusive rock. Thus, the time for the cooling of a intrusion depends upon the dimension of the body. Accordingly, we attempted to collect samples from small intrusive rocks exposed in the Cascade Mountain Range, Oregon. The samples were successively collected from the margin to the center of their intrusive masses. Although the shape of the igneous bodies resulting from intrusion and solidification depends on many circumstances, the intrusions observed appear to take the shape of a stock (Baldwin, 1964). In this paper, the results of preliminary paleomagnetic studies will be described on four intrusive rocks.

2) Geological setting

The Cascade Range in Oregon is composed chiefly of volcanic rocks of Cenozic age. Small bodies of intrusive rock ranging in composition from rhyodacite to basalt cut the volcanic rocks of the western Cascade Range. The intrusive bodies are divided into three rock types according to Peck et al (1964). Of these rock types, medium grained rocks comprise diorite, quartz diorite, granodiorite or quartz monzonite, which occur as pipes, dikes or small stocks.

Laurel Hill intrusion

The intrusive rocks in this area consist apparently of two small bodies on the geological map of west Oregon (1961). One is exposed along the U. S. Route 26 passing through Laurel Hill, which has an apparent diameter of about 2 km but is overlain by younger lavas to the northeast, as shown in Fig. 1. The other of which is about 5 km in diameter is exposed in the area along Still Creek. The intrusive rocks are the quartz diorite stocks which intruded the upper and middle Miocene Sardine formation.

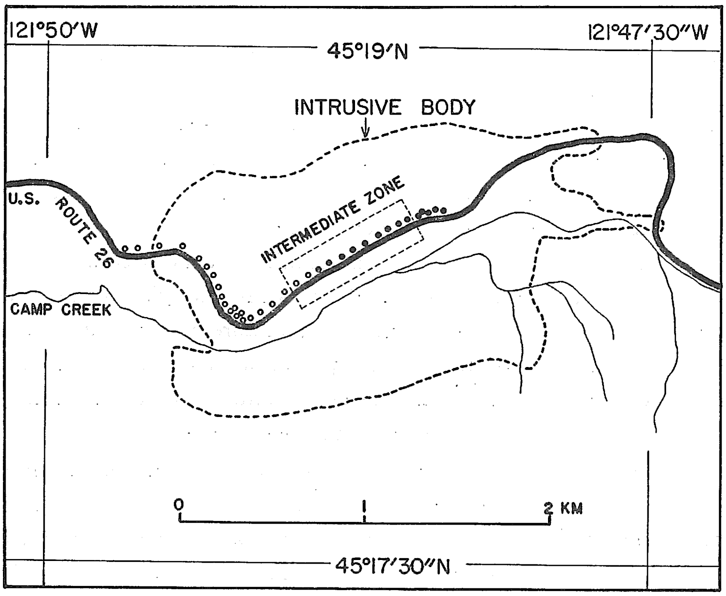

Fig. 1 Map showing locations sampled and area of Laurel Hill intrusion.

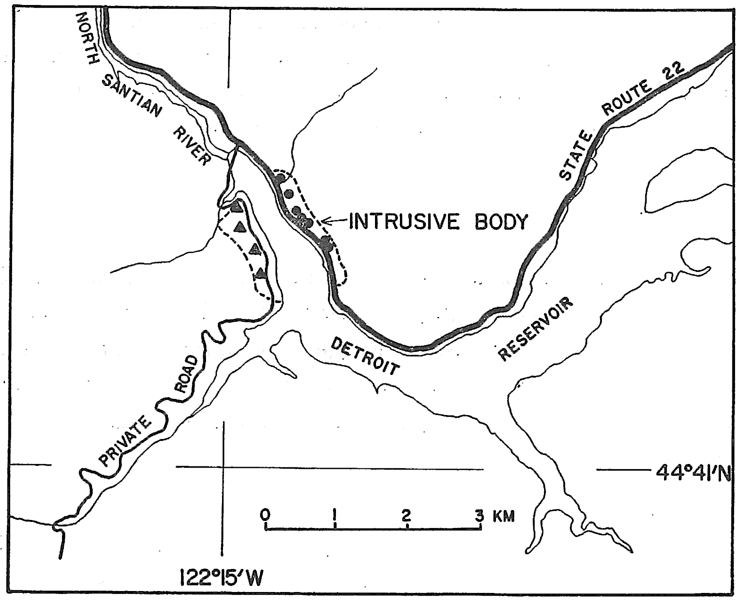

Fig. 2 Map showing locations sampled and area of Detroit Dam intrusion.

Detroit Dam intrusion

An intrusive body located at the Detroit Dam forms a granodiorite stock and it has a flat roof. The body crops out in the northeast and the southwest sides of the Dam reservoir as seen in Fig. 2. It intrudes lavas in Sardine Mountain formation (Baldwin, 1964). The age obtained by zircon method is 25 ± 10 million years, which places the age in the early Miocene (Jaffe, 1959).

Vida intrusion

A small intrusive body locate a short distance to the west of Vida along the McKenzie River. It is an apparent dimension of about 1 km in diameter and forms a granodiorite stock (Fig. 3).

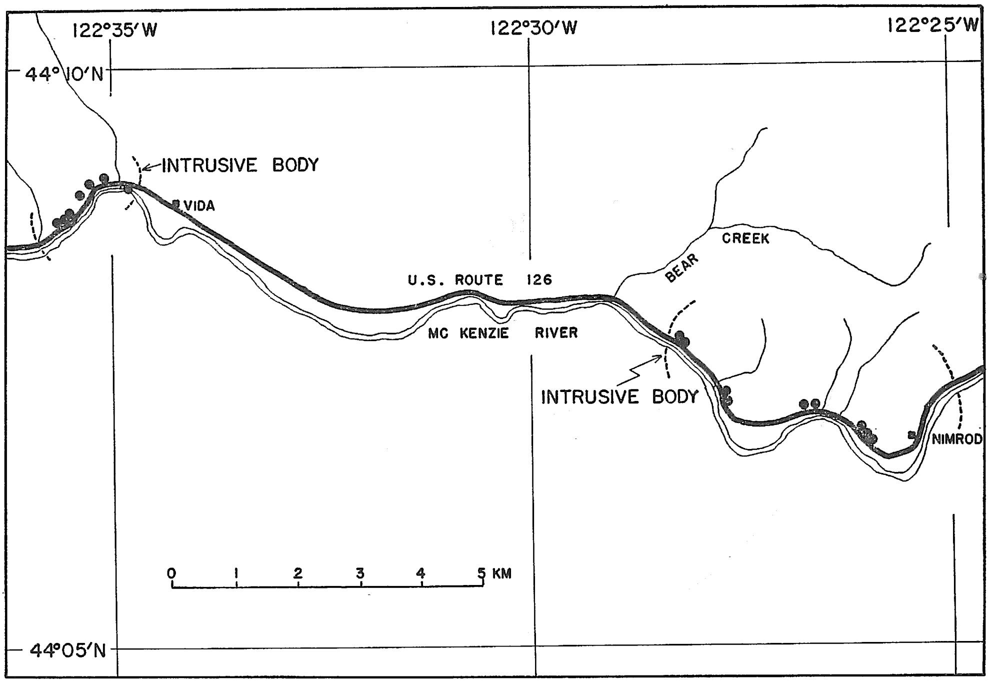

Fig. 3 Map showing locations sampled and area of Vida and Nimrod intrusions.

Nimrod intrusion

A granitic intrusion crops out near Nimrod along the McKenzie River. This intrusion penetrates the flows and tuffs of the western Cascade Range. The body is apparently about 5 km in diameter as shown in Fig. 3. Zircon from a sample of the body has a lead content corresponding to an age of 35 ± 10 million years. This data is very early in the Oligocene (Jaffe, 1959).

3) Sampling and laboratory procedures

Oriented samples were collected at several sites of apparent margin and center of each body as shown in Figs. 1, 2 and 3. The samples were taken either as oriented blocks or as cores using portable drilling apparatus similar to be described by Doell and Cox (1967). Some core samples were cut from the block in the laboratory with an electricpowered diamond drill. Two or three core samples of 23 mm in diameter were taken from a site and they were cut into one or two specimens of 23 mm long.

The NRM of the specimens was measured on the spinner magnetometer purchased from the Princeton Applied Research Corporation. The direction of NRM of these intrusions were very scattered on the Schmidt's projection. Therefore, all samples were progressively demagnetized in the A. C. demagnetization device of three-axis rotation system.

a) A. C. demagnetization

The procedure is to subject a rock sample to an alternating field which is reduced smoothly. The sample is tumbled around three perpendicular axes with slightly different rate by a gear system made of plastic material. A solenoid coil provide a magnetic field smaller than 2000 oe. The A. C. field is changed smoothly by means of a G. E. Inductorol voltage regulator from maximum value to zero. The external earth's field is

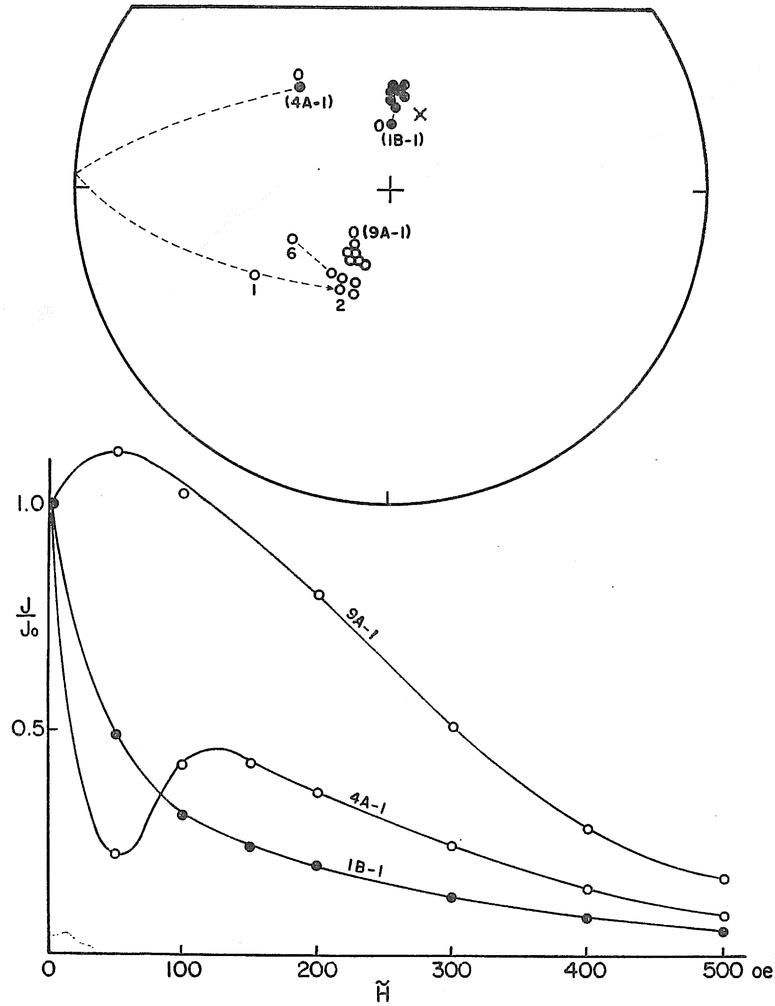

Fig. 4 A. C. demagnetization of samples of Laurel Hill intrusion.

cancelled by a Helmholtz coil set parallel to the earth's field direction.

We demagnetized at least one sample from each site in field progressively increased up to 500 oe. The field at which the directions of NRM remained constant while the intensity of magnetization decreased was chosen as the demagnetizing field for all the other specimens from the site. It was about 200 oe for samples of these intrusive bodies.

The directions of NRM of the Laurel Hill intrusion were scattered on the upper and the lower hemisphere of the equal area net. After the A. C. treatment of 200 oe, some samples remained constant their directions, but some samples changed their directions to opposite side against the initial directions. Typical examples of these treatments are shown in Fig. 4.

The directions of NRM of the Detroit Dam intrusion were grouped two positions on the equal area projection. The samples from the northeastern side of the Dam reservoir remained constant the directions of NRM, but the samples from the southwestern side slightly changed in directions of NRM to the north at the peak field of 100 oe and the drections become closed to the present direction of the earth's field. Fig. 5 shows

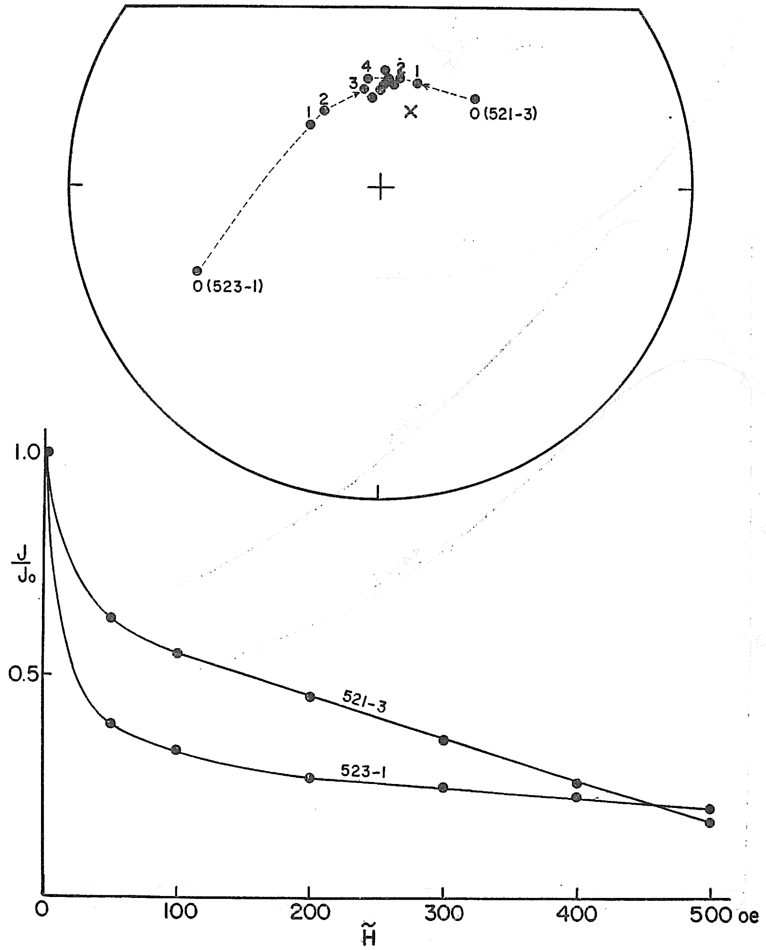

Fig. 5 A. C. demagnetization of samples of Detroit Dam intrusion.

typical change in direction of magnetization and demagnetization curves during progressive A. C. demagnetization.

Samples of the Vida intrusion were magnetized reversely and the directions of NRM were slightly scattered. After the A. C. demagnetization, the directions of magnetization were well grouped as seen in Fig. 6.

All specimens of the Nimrod intrusion before the A. C. demagnetization showed random directions of magnetization on the equal area net. After the A. C. treatments

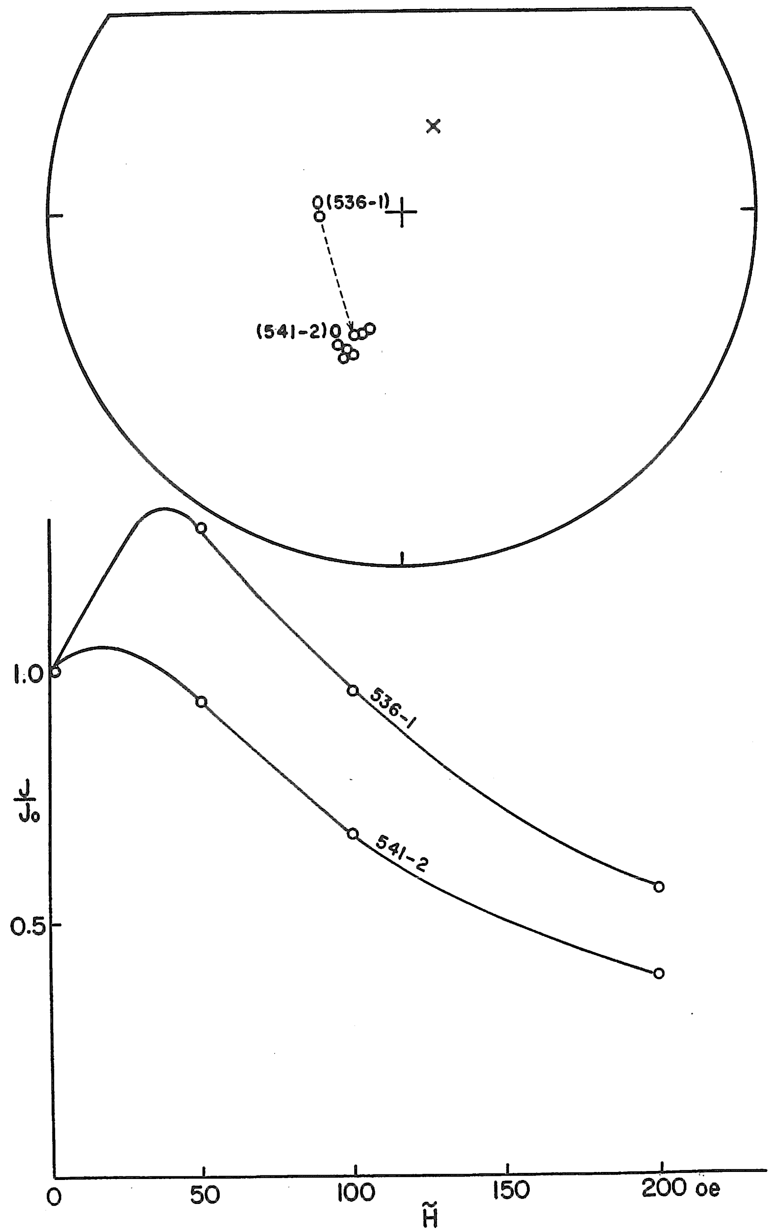

Fig. 6 A. C. demagnetization of samples of Vida intrusion.

of 200 oe, the specimens at some sites decreased the intensity of magnetization to zero or the directions dispersed randomly as shown in Fig. 7. Therefore, we could not find reliable direction of magnetization of this intrusive rock.

b) Thermomagnetic and x-ray analyses

To identify the ferromagnetic minerals in all intrusive bodies, thermomagnetic analysis for one or two specimens at several sites in a body were carried out in air by a quartz spring magnetic balance. Typical examples of the thermomagnetic curves in a magnetic field of about 2000 oe are shown in Fig. 8. The Curie temperatures Tc of the intrusions are within limits of 560°C and 575°C. The x-ray analysis of ferromagnetic minerals represents to be iron oxides having a spinnel structure such as magnetite. This shows

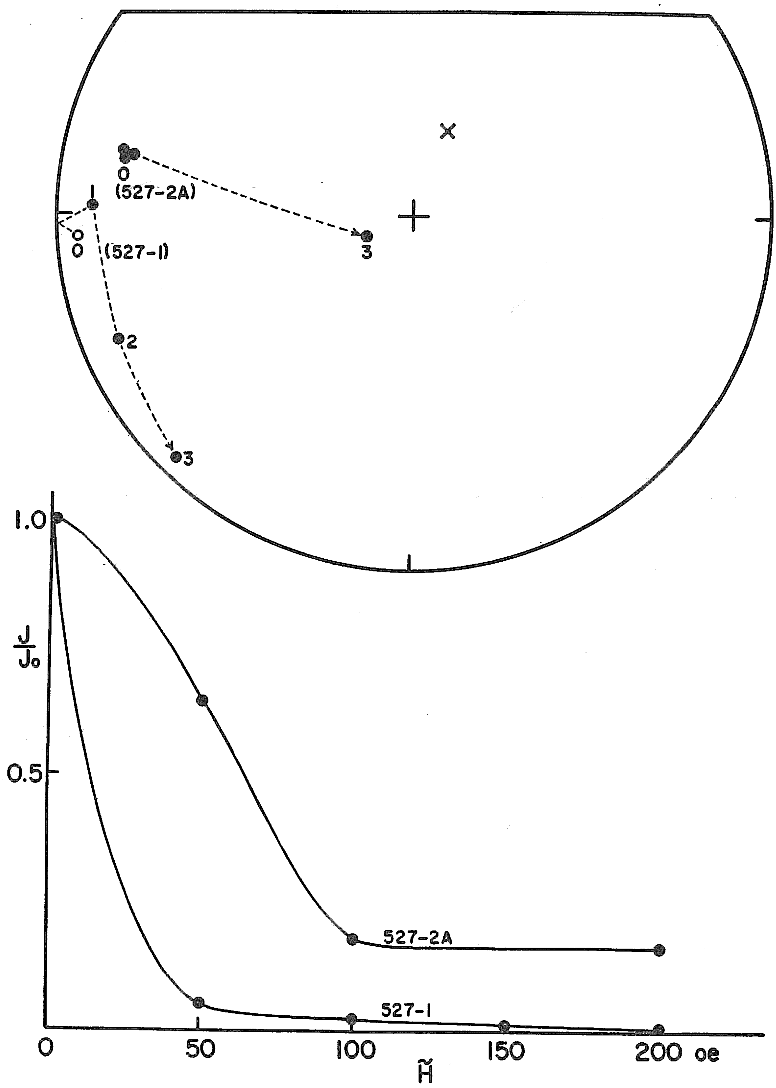

Fig. 7 A. C. demagnetization of samples of Nimrod intrusion.

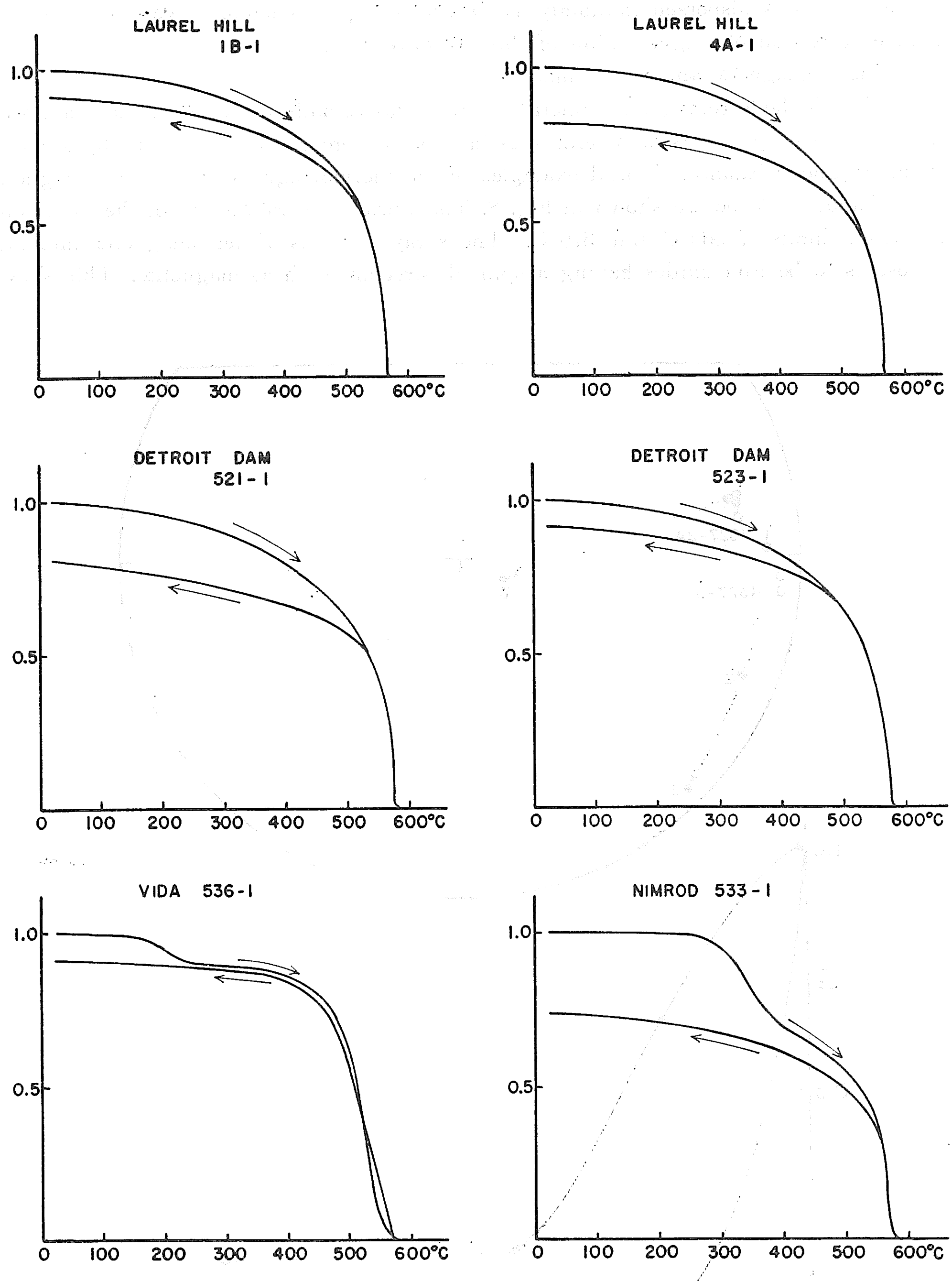

Fig. 8 Thermomagnetic curves.

that the ferromagnetic minerals of these intrusions are nearly the same.

Typical samples were polished and examined in reflected light. The most abundant opaque mineral in all samples is magnetite. Secondary hematite occurs in several samples as an alteration product around margin of magnetite grains. The occurrence of secondary hematite was unrelated to intensity or stability of the remanent magnetization.

c) A. C. demagnetization on the saturation IRM

Several samples in each intrusive rock were magnetized in a magnetic field of 3000 oe and then were demagnetized with the A. C. field up to 500 oe to compare the magnetic charateristics of different samples. The intensity of the saturation IRM was 5×10^{-1} emu/cc. Fig. 9 shows the demagnetization curves of the saturation IRM ($H=$ 3000 oe) of some samples. As seen in the figure, the demagnetization curves of IRM appear to correspond to the stability of the NRM of the samples. However, a distinction between the curves is not known whether or not due to a difference in grain sizes of magnetite, because the systematic distinction between the unstable and the stable specimens was not found microscopically.

4) **Directions of NRM**

Laurel Hill intrusion

Although initial directions of NRM were random, they were well grouped after the A. C. treatment of 200 oe. The mean directions of NRM from the eighteen sites near the margin are in good agreement with each other, and all of the samples were magnetized reversely. On the contrary, the samples from the five sites in the center were magnetized normally. We could find an intermediate zone between the normally and the reversely magnetized rocks, which it suggests that the earth' field changed

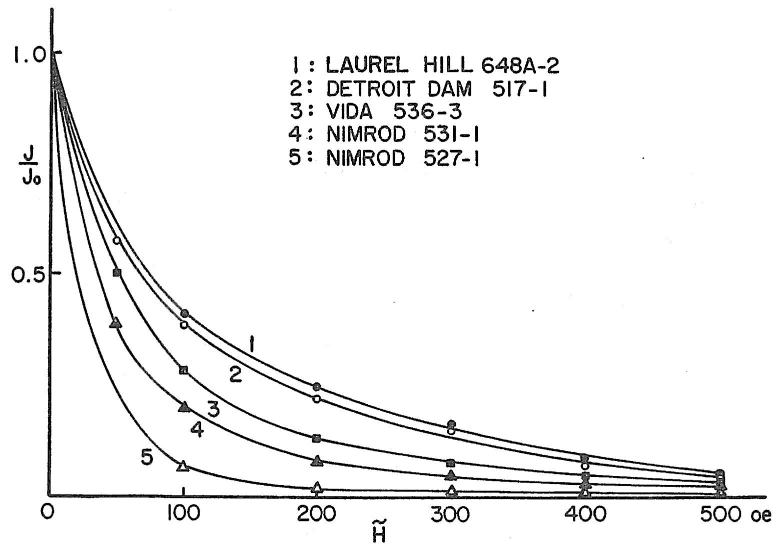

Fig. 9 Demagnetization curves of IRM magnetized in a field of 3000 oe.

its polarity from the reversed to the normal magnetization during cooling process of the body. Most of the samples obtained from the intermediate zone was not as stable against the A. C. field treatment as the samples from the normal and the reversed regions. The directions of NRM before and after the A. C. treatment of 200 oe are shown in Fig. 10.

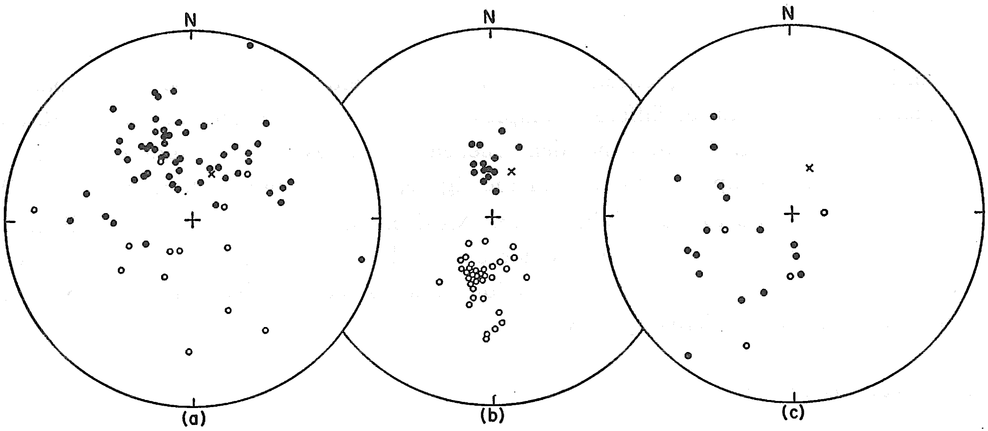

Fig. 10 Directions of NRM and of remanent magnetization after A. C. demagnetization of 200 oe for Laurel Hill intrusion.
a) Directions of NRM
b) Directions of the normal and reversed remanent magnetizations after treatment of 200 oe
c) Directions of intermediate remanent magnetization after treatment of 200 oe
● : Lower hemisphere
○ : Upper hemisphere
× : Direction of the present geomagnetic field in Oregon

Detroit Dam intrusion

The directions of NRM in the intrusive rock form two groups on the equal area projection. Fig. 11 (a) shows the direction of NRM before the A. C. demagnetization. In the figure, dots give the directions of magnetization of samples from northeastern side of the Dam reservoir and triangles are those from southwestern side. After the A. C. demagnetization of 200 oe of all the sites, the samples from northeastern side were no change in directions of NRM, but the samples from the southwestern side changed to the NRM directions obtained from the northeastern side. This shows that the intrusion was magnetized normally and the directions of NRM were well grouped.

Vide intrusion

This intrusive body was magnetized reversely before the magnetic cleaning. After the A. C. treatment of 200 oe, good group of directions were observed for all the sites and the results are shown in Fig. 12. In this case, the change in direction of magnetization is attributed to the gradual removal of a viscous component of magnetization which approximately opposed the stable component of NRM.

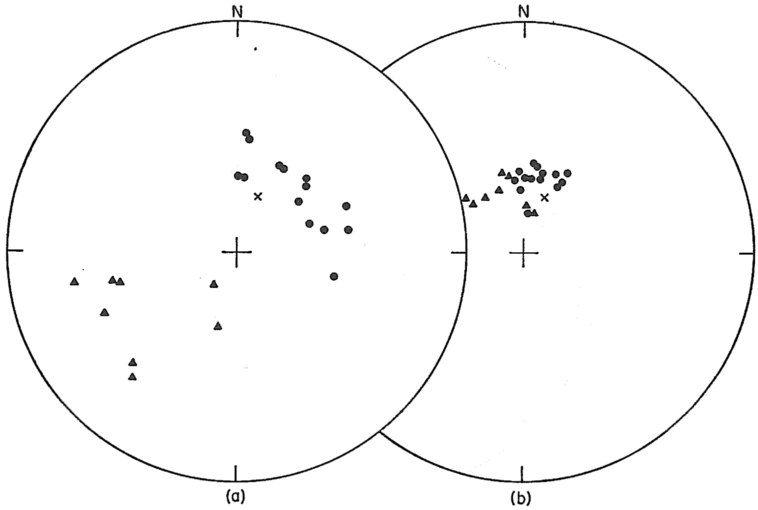

Fig. 11 Directions of NRM and of remanent magnetization after A. C. demagnetization of 200 oe for Detroit Dam intrusion.
a) Directions of NRM
b) Directions of remanent magnetization after treatment of 200 oe
● : Directions of NRM of samples collected from the northeastern side of the Dam reservior
▲ : Directions of NRM of samples collected from the southwestern side of the Dam reservior
× : Directions of the present geomagnetic field in Oregon

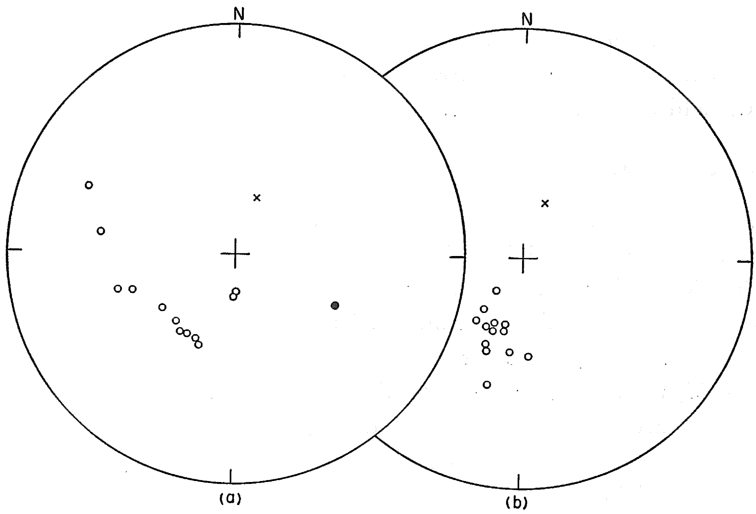

Fig. 12 Directions of NRM and of remanent magnetization after A. C. demagnetization of 200 oe for Vida intrusion.
a) Directions of NRM
b) Directions of remanent magnetization after treatment of 200 oe
● : Lower hemisphere
○ : Upper hemisphere
× : Direction of the present geomagnetic field in Oregon

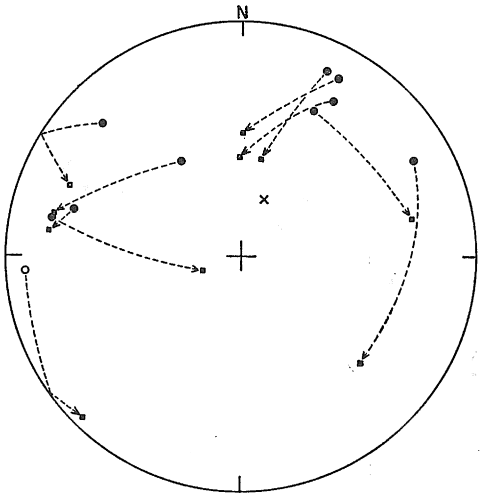

Fig. 13 Directions of NRM and of remanent magnetization after A. C. demagnetization of 200 oe for Nimrod intrusion.
● : Directions of NRM on lower hemisphere
○ : Directinos of NRM on upper hemisphere
■ : Directions of remanent magnetization on lower hemisphere after treatment of 200 oe
□ : Directions of remanent magnetization on upper hemisphere after treatment of 200 oe
× : Directions of the present geomagnetic field in Oregon

Nimrod intrusion

Samples from this intrusion showed the scattered directions of NRM before the A. C. demagnetization. The directions of NRM of the samples were random after the treatment in the A. C. field as seen in Fig. 13.

5) Viscous magnetization

The viscous magnetization acquired in situ before the samples are collected should lie in a plane containing the initial direction of the remanence and the present direction of the earth's field, while the viscous magnetization acquired during storage of samples in the laboratory would tend to be random. However, such viscous components in rocks could be easily erased by A. C. or thermal demagnetization. The samples with hard and stable NRM, although it is weak tend to group its direction throughout the A. C. field treatment. From the laboratory examinations for samples collected from these intrusions, it is concluded that the samples have stable remanent magnetization except those of the Nimrod intrusion. If we give attention to the viscous magnetization which was erased by the A. C. demagnetization, it may be a clue to reveal some previous history of the intrusions.

The magnitude of the viscous component of magnetization of granite is dependent upon grain size (Ozima, 1966), but the direction of the viscous magnetization could be independent on the grain size. The viscous components of magnetization of the Laurel Hill and Vida intrusions, generally speaking, are in a plane containing the initial direction of remanent magnetization and the present direction of the earth's field. This can be explained by the phenomenon of "trainage" (Thellier, 1938). The directions of the viscous magnetization of the Detroit Dam intrusion are not parallel to the present direction of the earth's field. A vector of the viscous magnetization has been produced to a direction away from the present direction of the earth's field. This component is thought to be produced by other phenomena without the trainage. The initial directions of NRM of samples collected from the southwestern side of the intrusion lay in a place different from the northeastern side. After the A. C. demagnetization of 200 oe, their directions were nearly parallel to the present direction of the earth's field and the intensity decreased to one tenth of initial one. This is explained as a viscous component of magnetization is added in opposite sense to the present field direction as seen in Fig. 14. Nagata and Carleton (1968) pointed out that the IRM of natural rocks in a weak field considerably change its intensity under a uni-axial compression. Taking account of this result, the acquisition of the viscous magnetization of this intrusion is considered to be due to a uni-directional compression after the formation of the body.

The remanent magnetization of samples of the Nimrod intrusion is randomly scattered

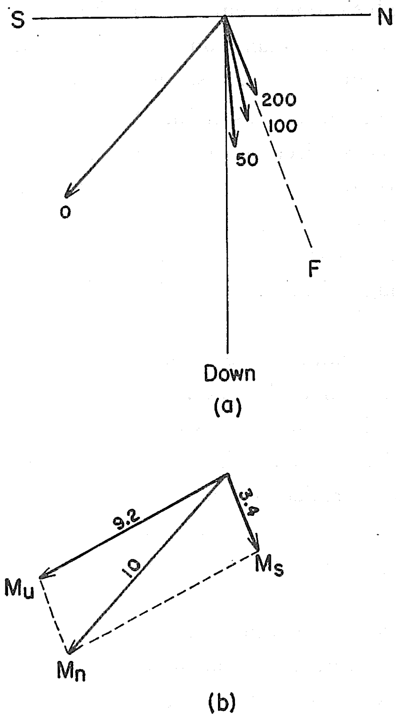

Fig. 14 (a) Change in direction of remanent magnetization during A. C. demagnetization.
O : Direction of NRM
F : Direction of the present geomagnetic field
(b) M_s : Stable component of remanent magnetization
M_u : Unstable component demagnetized after treatment of 200 oe
M_n : Initial direction of remanent magnetization

before or after the A. C. demagnetization. The intensity of magnetization was weak and less than one hundredth of initial one after the treatment in the A. C. field. The demagnetization curves are very similar to those of IRM of the same sample induced in the laboratory. This may show that the unstable samples contain mostly coarse ferromagnetic mineral grains.

6) Discussion

The small sized intrusive rocks from Cascade Range possess relatively stable remanent magnetization except the Nimrod intrusion. The ferromagnetic minerals of these four intrusive rocks examined are nearly same and almost pure magnetite. As all samples taken from the Nimrod intrusion had weak and unstable NRM, it may show that they contain mostly coarse magnetite grains.

The samples from the Laurel Hill and Vida intrusions have soft components of magnetization, which is easily removed using an A. C. demagnetization. The soft components are temporary magnetization as termed by Creer (1957). The remanent magnetization of samples from the Detroit Dam intrusion is obviously separated two components, primary and secondary. The secondary component is acquired different in direction from primary (stable) component or in the present direction of the earth's field. If magnetic particles with relaxation times less than the geological age of the rock are present in these intrusions, a viscous component is acquired approximately along the present direction of the earth's field. On the other hand, if a rock containing such magnetic particles was subject to a uni-directional compression, a direction of secondary magnetization could be dependent on magnitude of such a compression. The Detroit Dam intrusion may suggest to have been under the influence of the compression within a period less than a relaxation time of the magnetic minerals. The direction of viscous magnetization could be a clue to solve a previous history of rock bodies.

These intrusions, strictly speaking, were formed in different age because they have different directions of NRM with each other. The rock at Laurel Hill had both of the reversed near the margin and the normal NRM in the inner part after the A. C. treatment of 200 oe. The samples collected from Detroit Dam were magnetized normally, the body indicates to have intruded at the time when the earth's field was in the present sense. The Vida intrusion was formed at a time when the direction of the earth's field was nearly antiparallel to the present one. The Vida and Nimrod intrusions are unknown whether they were formed at the same time or not.

The samples collected from the intermediate region at Laurel Hill have weaker intensity of NRM than the reversed or the normal rocks. The directions of NRM are likely to indicate that the earth's field changed its direction in succession from the south to the north pole. This preliminary result shows that the granitic rock at Laurel Hill is suitable to trace the transition of the earth's field by prefering the intrusions with small dimension of the Tertiary age.

Acknowledgements

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