Paleomagnetism of two Keweenawan alkalic complexes in northern Ontario, Canada.

Michael Terry Lewchuk

University of Windsor

Follow this and additional works at: https://scholar.uwindsor.ca/etd

Recommended Citation
NOTICE

The quality of this microform is heavily dependent upon the quality of the original thesis submitted for microfilming. Every effort has been made to ensure the highest quality of reproduction possible.

If pages are missing, contact the university which granted the degree.

Some pages may have indistinct print especially if the original pages were typed with a poor typewriter ribbon or if the university sent us an inferior photocopy.

Reproduction in full or in part of this microform is governed by the Canadian Copyright Act, R.S.C. 1970, c. C-30, and subsequent amendments.

AVIS

La qualité de cette microforme dépend grandement de la qualité de la thèse soumise au microfilmage. Nous avons tout fait pour assurer une qualité supérieure de reproduction.

S'il manque des pages, veuillez communiquer avec l'université qui a conféré le grade.

La qualité d'impression de certaines pages peut laisser à désirer, surtout si les pages originales ont été dactylographiées à l'aide d'un ruban usé ou si l'université nous a fait parvenir une photocopie de qualité inférieure.

PALEOMAGNETISM OF TWO KEWEENAWAN ALKALIC COMPLEXES IN NORTHERN ONTARIO, CANADA

by

( Michael Terry Lewchuk

A Thesis submitted to the Faculty of Graduate Studies and Research through the Department of Geology in partial fulfilment of the requirements for the Degree of Master of Science at the University of Windsor

Windsor, Ontario, Canada 1989
The author has granted an irrevocable non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of his/her thesis by any means and in any form or format, making this thesis available to interested persons.

The author retains ownership of the copyright in his/her thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without his/her permission.

L'auteur a accordé une licence irrévocable et non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de sa thèse de quelque manière et sous quelque forme que ce soit pour mettre des exemplaires de cette thèse à la disposition des personnes intéressées.

L'auteur conserve la propriété du droit d'auteur qui protège sa thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

PREFACE

The body of this thesis is composed of two papers of studies that have been submitted to recognized scientific journals for publication. Except for pagination they are "as submitted" and therefore some of the information on the experimental methods is duplicated. Thus there are two sets of "Abstracts, Figures, Tables and References". Also the explanations of the methods assume that the reader has a working knowledge of paleomagnetics. A more complete discussion of the methods used in the Windsor paleomagnetic laboratory can be found in Lewchuk (1987) and of paleomagnetism in general can be found in Tarling (1983) and Piper (1987).

In addition to the two papers, an operations manual was written for the paleomagnetics laboratory to provide a compendium of written instructions for future students working in it. This manual has been appended to the thesis (Appendix A) in order to provide some additional information on the methods employed. Both studies fairly closely followed the "standard" procedure as outlined in the manual.

The two studies are related in that both examine 1.1 Ga Keweenawan igneous alkalic complexes in the Superior Province of northcentral Ontario. Both complexes are products of the last major tectonic event in the Precambrian Shield, i.e., attempted rifting along the Mid Continental Rift system (MCR) (Halls, 1978). The MCR extends from Kansas,
north to Lake Superior, east across the lake and then south through Michigan forming a continuous arc of almost 180°.

The MCR was active from 1200 Ma to about 1000 Ma when it aborted, possibly as a distant effect of the collisional Grenville Orogen (Halls, 1978). The MCR produced extensive volumes of magmatism, particularly in the Lake Superior region where a volcanic pile of some 20 to 30 km thickness was extruded. Intrusive units such as the Logan sills, the Duluth Complex and the approximately 25 alkalic complexes in the area (including the two in this study) were also products of the MCR. The Logan sills, Duluth Complex and most of the volcanic units have been studied paleomagnetically and comprise a large portion of the database for the Keweenawan Apparent Polar Wander Path (APWP) of North America. Many of these results from this database have been important in the interpretation of the results of this research.

The first paper is entitled "Paleomagnetism of the Clay-Howells Carbonatite Complex: Constraints in Proterozoic Motion in the Kapuskasing Structural Zone, Superior Province, Canada". This unit was sampled as a result of the ongoing discussion concerning the timing and nature of the tectonic movement on the fault system that bounds the Kapuskasing Structural Zone (KSZ). Comparison of the Clay-Howells pole with the APWP has helped to define the movement on the KSZ since 1.1 Ga.
The specimens were collected in the summer of 1987 by field drilling with access provided by motor boat along the Mattagami and Kapuskasing rivers. The collection was prepared in the fall of 1987 and measured later that year using the Canadian Thin Film Systems Inc. (CTF) cryogenic magnetometer in the University of Windsor Paleomagnetic Laboratory. Excellent results were obtained which were presented in abstract form at a meeting of the Institute on Lake Superior Geology in May of 1988. The paper was completed and submitted to Tectonophysics in January of 1989.

The second paper is entitled "Age and Petrologic Evolution from Paleomagnetism of the Late Precambrian Coldwell Complex, Ontario, Canada". This is an "odd" Keweenawan alkalic intrusion because it consists of at least three phases, it is many times larger than the other complexes, and it is situated right on the apex of the rift. For these reasons it has been considered as a possible location for a "failed" third arm of the rift system (Weiblen, 1982).

It is a much larger study area which was originally collected in 1982 but, because of new petrologic information for the complex, several additional sites were collected in the summer of 1987 to augment the collection. The entire collection was prepared and measured at about the same time as the Clay-Howells study using the same equipment.
Subsequent analysis yielded excellent results and the paper was submitted to *Precambrian Research* in November 1988.

At present (February, 1989) both papers are in the hands of referees.
REFERENCES


# TABLE OF CONTENTS

**Preface** ........................................... iv

**List of Tables** ................................... xi

**List of Illustrations** ............................ xii

**Part I: Paleomagnetism of the Clay-Howells Complex**

**Abstract** ........................................ 3

**Introduction** .................................... 4

**Geology** .......................................... 6

**Methods** ......................................... 8

- Collecting and Measurement .................... 8
- Alternating Field Demagnetization .......... 8
- Thermal Demagnetization ...................... 11
- Bulk Demagnetization ............................ 13
- Contact Test .................................... 13
- SIRM Test ........................................ 16

**Results and Discussion** ....................... 19

**Conclusions** .................................... 23

**Acknowledgements** ............................. 25

**References** ...................................... 26

**Part II: Paleomagnetism of the Coldwell Complex**

**Abstract** ........................................ 35

**Introduction** .................................... 37

**Geology** .......................................... 39

**Sampling** ........................................ 42

**Measurement and Demagnetization** .......... 42

**Magnetic Mineralogy** ........................... 43

**Results** .......................................... 47
LIST OF TABLES

PART I

TABLE 1 - SITE AND UNIT MEANS ......................... 15

PART II

TABLE 1 - SITE AND UNIT MEANS - THIS STUDY .......... 48
TABLE 2 - SITE AND UNIT MEANS - ROBERTSON'S STUDY .... 54
TABLE 3 - MEAN REMANENCE STATISTICS ............... 56
LIST OF ILLUSTRATIONS

PART I

FIGURE 1 - LOCATION OF CLAY-HOWELELS COMPLEX .......... 5
FIGURE 2 - LOCATION OF SAMPLING SITES ................. 9
FIGURE 3 - NORMALIZED ORTHOGONAL DEMAGNETIZATION PLOTS OF AF PILOTS .......... 10
FIGURE 4 - NORMALIZED ORTHOGONAL DEMAGNETIZATION PLOTS OF THERMAL PILOTS ............... 12
FIGURE 5 - STEREONET PROJECTION OF SITE MEAN REMANENCE DIRECTIONS .................. 14
FIGURE 6 - SIRM TEST DATA .................................... 18
FIGURE 7 - APPARENT POLAR WANDER PATH ............... 20

PART II

FIGURE 1 - LOCATION OF COLDWELL COMPLEX ............ 38
FIGURE 2 - LOCATION OF SAMPLE SITES ............... 40
FIGURE 3 - NORMALIZED ORTHOGONAL DEMAGNETIZATION PLOTS OF AF PILOTS .......... 44
FIGURE 4 - NORMALIZED ORTHOGONAL DEMAGNETIZATION PLOTS OF THERMAL PILOTS .......... 45
FIGURE 5 - SIRM TEST DATA .................................... 46
FIGURE 6 - STEREONET PROJECTION OF SITE MEAN REMANENCE DIRECTIONS .................. 49
FIGURE 7 - APPARENT POLAR WANDER PATH ............... 57
PART I
PALEOMAGNETISM OF THE CLAY-HOWELLS CARBONATITE COMPLEX:

CONSTRAINTS IN PROTEROZOIC MOTION IN THE

KAPUSKASING STRUCTURAL ZONE, SUPERIOR PROVINCE, CANADA

M.T. LEWCHUK AND D.T.A. SYMONS

DEPARTMENT OF GEOLOGY, UNIVERSITY OF WINDSOR

WINDSOR, ONTARIO, CANADA N9B 3P4
ABSTRACT

The Clay-Howells Complex is located approximately 130 km east of Hearst, Ontario, at 49°50'N, 82°05'W near the north end of the Kapuskasing Structural Zone (KSZ) of the Superior Province in the Canadian Shield. The pluton is a large-oviform pluton of about 16 km² that is composed dominantly of syenite with minor carbonatite. It was emplaced into an Archean gneissic terrain of the amphibolite to granulite facies with Middle Precambrian diabase dikes. The complex is unmetamorphosed and Late Precambrian in age (Rb/Sr 1075±15 Ma). Multistep AF and thermal demagnetization was done on 194 specimens from 18 sites in the intrusion and three sites in the host rock dikes and gneisses. The 18 syenite sites give a unit mean direction of 294.2°, 27.1° (N=18, k=26, α₉₅=7.0°) which yields a pole position of 178.8°E, 26.5°N (δ_p=4.1°, δ_m=7.6°) for the Clay-Howells Complex. A rudimentary contact test using the three host rock sites proved inconclusive. The pole for the intrusion is concordant, falling at about 1080±10 Ma on the Keweenawan apparent polar wander path which agrees with the Rb/Sr age. Thus the complex has an untilted, primary remanence that indicates that there has been no significant uplift (<10 km) or rotation (<7°) on the KSZ since intrusion and therefore that all significant geotectonic activity on the KSZ must predate 1.1 Ga.
INTRODUCTION

The Superior Province of the Canadian Shield has been divided into several east-trending subprovinces. Two of these, the Quetico and Wawa Subprovinces are separated from the Opatica and Abitibi Subprovinces respectively by the NNE-trending Kapuskasing Structural Zone (KSZ) (Figure 1). The KSZ is a 500 km linear structure composed mostly of high-grade metamorphic rocks with a number of early to mid-Proterozoic carbonatitic intrusions. It is characterized by pronounced gravity and magnetic highs with several normal and low-angle thrust faults. There have been a number of hypotheses for the origin of this structure such as: a) an upwarp of the Conrad Discontinuity (Wilson and Brisbin, 1965); b) uplifted late Archean or Proterozoic horst (Bennet et al., 1967; McGlynn, 1970); c) a suture zone between plates (Gibb and Walcott, 1971); d) a failed arm of the Keweenawan Rift Structure (Burke and Dewey, 1973); e) a late Archean or early Proterozoic sinistral transcurrent fault (Watson, 1980); and, f) an uplifted deep crustal slice on a low-angle reverse or listric thrust fault (Percival and Card, 1983; Hoffman, 1988). The last hypothesis is presently favoured by most researchers although the timing of the uplift and tilting on the KSZ has been under investigation. Percival et al. (1988) have postulated that the minimum age for termination of tectonic activity on the
Figure 1. Location of the Clay-Howells alkalic syenite complex in northern Ontario. The solid circles indicate other alkalic complexes in the KSZ. Geology after Leclair and Nagerl, 1988.
KSZ is greater than the oldest carbonatite complex that cuts faults associated with the KSZ. The oldest such intrusions are the 1888±3 Ma Cargill Complex (Heaman et al., 1988, prelim. data) and the 1872±13 Ma Borden Complex (Bell et al., 1987). Hoffman (1988) proposes that the KSZ is a distant effect of the collision of the Archean Slave and Superior cratons to form the Trans-Hudson orogen (1.8-1.9 Ga) which agrees fairly well with Percival et al. (1988). However, Constanzo-Alvarez and Dunlop (1988) have suggested that reactivation at 1.1 Ga involved uplift and rifting based on paleomagnetic data from granulite gneisses and anorthosites in the KSZ.

The objective of this study was to obtain paleomagnetic data for the Clay-Howells Complex in the Quetico Subprovince and to compare its pole to the relatively well-defined apparent polar wander path (APWP) for contemporaneous Keweenawan units to look for any post-intrusive tectonic movement on the KSZ. Obviously some of the hypotheses for the origin of the KSZ involved substantial rotations and/or translations in addition to uplift that might be detected paleomagnetically.

GEOLOGY

The Clay-Howells alkalic syenite complex is located approximately 130 km east of Hearst, Ontario, at 49°50'N 82°05'W (Figure 1). It lies within the Quetico Subprovince of the Superior Province near the north end of the KSZ.
There is abundant outcrop along the Mattagami and Kapuskasing Rivers which cut the intrusion on the north and east sides. The south side and interior are accessible by a logging road although exposure is sparse.

The intrusion is comprised dominantly of fresh unmetamorphosed pyroxene syenite. It was emplaced into an Archean gneissic terrain of upper amphibolite to granulite facies that contains north-trending Middle Precambrian diabase dikes (Sage, 1983). The complex lies along the northeast-trending Lepage normal fault zone which is associated with the KSZ. A late NNW trending fault may also cut the northeast portion of the complex. Large country rock xenolithic blocks within the intrusive body generally lack significant rotations with respect to the host rock walls, suggesting that the mode of emplacement was probably passive and the depth of emplacement was probably shallow. Field evidence and aeromagnetic survey results indicate that the attitude of the intrusion is most likely vertical (ODM-GSC, 1964; West, 1988). The aeromagnetic results also led Sage (1983) to suggest the presence of three distinct intrusive lobes formed by three magmatic pulses of similar composition and age. Gittins et al. (1967, recalculated to modern decay constants) obtained a Late Precambrian K-Ar age on biotite of 1004 Ma and Bell et al. (1982) obtained an older Rb-Sr whole rock age of 1075±15 Ma for the intrusion.
METHODS

Collecting and Measurement

Five oriented core samples were obtained from each of 21 sites by field drilling (Figure 2). These include 18 sites from the complex, two from the country rock diabase dikes and one from the host gneisses. The cores were sliced into 2.5 cm diameter by 2.2 cm long specimens to give a total collection of 194 specimens.

The natural remanent magnetization (NRM) measurements were made using an automated two-axis Canadian Thin Film (CTF) cryogenic magnetometer operated within a magnetically shielded room to minimize viscous remanent magnetization (VRM) effects from the present Earth's magnetic field (PEMF).

Alternating Field Demagnetization

Two specimens from different cores for each site were selected as pilots for detailed alternating field (AF) demagnetization analysis. Each pilot specimen was demagnetized in 14 steps up to 160 mT using a Sapphire Instruments SI-4 AF demagnetizer. Normalized orthogonal vector demagnetization plots of their remanence indicate the isolation of a single characteristic remanence component after removal of an initial VRM component (Figure 3). The VRM component is generally removed by 20-30 mT of AF
Figure 2. Location of sampling sites in the Clay-Howells complex. MR and KR identify the Mattagami and Kapuskasing Rivers. The dashed line is the inferred contact from geophysical data after Sage (1983). The solid line is a logging road.
Figure 3. Normalized orthogonal vector plots of example specimens on AF step demagnetization from: a) site 19; b) site 3; and c) site 5. Treatment is in milliTesla (mT). Circles represent projections in the horizontal plane while triangles represent projections in the vertical plane. Open symbols indicate the use of an expanded axial scale as shown in brackets. Axial intensities are expressed as a ratio of the NRM intensity.
cleaning. Above that field the stable linear decay of a WNW moderately-dipping (20°-30°) stable component to the origin was observed in all 18 sites from the complex. The magnitude of the stable component varies from as much as 70% of the NRM intensity (Figure 3a) to as little as 10% (Figure 3c), indicating that the component is held by domains with a relatively wide spectrum of magnetic coercivities.

**Thermal Demagnetization**

Two specimens from two cores that were not selected for AF step demagnetization were chosen from each site as pilots for detailed thermal demagnetization analysis. Each pilot specimen was demagnetized in 12 steps to 585°C using a Schonstedt TSD-1 thermal demagnetizer. An additional three steps to 640°C were added when deemed necessary. The normalized orthogonal vector demagnetization plots (Figure 4) were similar to those from the AF pilots. A VRM component was usually removed by 400°C. Above about 400°C linear decay to the origin was observed as a stable component was removed. This component had the same WNW and moderately downwards direction as found for the AF pilots, and it ranged in magnitude from 70% to 10% of the NRM intensity. The few thermal pilots that required additional steps above 585°C were found to retain a small hematite component. In all cases, the hematite component direction for a given specimen did not differ significantly from its observed magnetite direction.
Figure 4. Normalized orthogonal vector plots of example specimens on thermal step demagnetization from: (a) site 12; (b) site 2; and (c) site 1. Treatment is in degrees Celsius (°C). Plotting conventions as in Figure 3.
Bulk Demagnetization

The response of the Clay-Howells specimens to both detailed AF and thermal step demagnetization methods were very similar. Thus the rest of the specimens were AF demagnetized in four steps using 5, 30, 55, and 85 mT cleaning fields for most specimens. A coherent cluster of specimen remanence directions was observed for all 18 sites which, when averaged to give the site mean directions, have cones of 95% confidence ($\alpha_{95}$) (Fisher, 1953) that range from 3.5' to 13.4' (Table 1, Figure 5). Averaging the 18 site mean directions gives a unit mean direction of 294.2°, 27.1° (N=18, k=26, $\alpha_{95}$=7.0°). This represents a relatively reliable unit mean direction for the complex because all 18 site means were included in the analysis and because the same characteristic direction was observed over a relatively wide range of unblocking temperatures and AF coercivities. The scatter of the site means about the unit mean direction does not have a geographical bias suggesting that any postintrusive movement along the late NNW trending fault that cuts the complex did not produce tilting rotations. Also if three magma pulses formed the complex they did so over a short time interval.

Contact Test

A rudimentary contact test was attempted using the two diabase dike sites and one host rock gneiss site, but the
Figure 5. Steronet projection of site mean remanence directions. The circles represent the 18 syenite site directions, the square represents the unit mean direction circumscribed by its cone of 95% confidence after Fisher (1953) and the diamonds represent the three sites from the contact test. The star indicates the present Earth's magnetic field direction.
### TABLE 1. Site and Unit Mean Directions

<table>
<thead>
<tr>
<th>Site No.</th>
<th>N</th>
<th>Demagnetizing Level</th>
<th>R</th>
<th>Dec</th>
<th>Inc</th>
<th>α₀₅</th>
<th>k</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
<td>580/55</td>
<td>5.898</td>
<td>311.1</td>
<td>12.6</td>
<td>9.7</td>
<td>49</td>
</tr>
<tr>
<td>2</td>
<td>11</td>
<td>580/55</td>
<td>10.624</td>
<td>295.5</td>
<td>28.8</td>
<td>9.0</td>
<td>27</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>580/55,85</td>
<td>9.936</td>
<td>301.9</td>
<td>28.1</td>
<td>4.1</td>
<td>142</td>
</tr>
<tr>
<td>4</td>
<td>11</td>
<td>580/55,85</td>
<td>10.940</td>
<td>280.8</td>
<td>15.6</td>
<td>3.5</td>
<td>168</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>565,580/55,85</td>
<td>7.684</td>
<td>309.2</td>
<td>43.3</td>
<td>12.0</td>
<td>22</td>
</tr>
<tr>
<td>6</td>
<td>10</td>
<td>580/55,85</td>
<td>9.738</td>
<td>287.2</td>
<td>24.1</td>
<td>8.3</td>
<td>35</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>580/30,55</td>
<td>9.904</td>
<td>289.7</td>
<td>23.6</td>
<td>5.0</td>
<td>95</td>
</tr>
<tr>
<td>11</td>
<td>8</td>
<td>565/55,85</td>
<td>7.650</td>
<td>290.4</td>
<td>26.8</td>
<td>8.2</td>
<td>47</td>
</tr>
<tr>
<td>12</td>
<td>6</td>
<td>565/30,55</td>
<td>5.851</td>
<td>293.9</td>
<td>24.9</td>
<td>11.7</td>
<td>34</td>
</tr>
<tr>
<td>13</td>
<td>6</td>
<td>580/55</td>
<td>5.913</td>
<td>298.6</td>
<td>45.8</td>
<td>8.9</td>
<td>57</td>
</tr>
<tr>
<td>14</td>
<td>6</td>
<td>565,580/55,85</td>
<td>5.897</td>
<td>292.5</td>
<td>25.8</td>
<td>9.7</td>
<td>49</td>
</tr>
<tr>
<td>15</td>
<td>10</td>
<td>585/55,85</td>
<td>9.795</td>
<td>285.0</td>
<td>52.8</td>
<td>7.4</td>
<td>44</td>
</tr>
<tr>
<td>16</td>
<td>4</td>
<td>580/55</td>
<td>3.937</td>
<td>304.4</td>
<td>19.7</td>
<td>13.4</td>
<td>48</td>
</tr>
<tr>
<td>17</td>
<td>8</td>
<td>580/30,55</td>
<td>7.895</td>
<td>289.2</td>
<td>22.4</td>
<td>6.8</td>
<td>67</td>
</tr>
<tr>
<td>18</td>
<td>9</td>
<td>600/30,55,85</td>
<td>8.833</td>
<td>296.9</td>
<td>22.6</td>
<td>7.5</td>
<td>48</td>
</tr>
<tr>
<td>19</td>
<td>10</td>
<td>580/55,85</td>
<td>9.870</td>
<td>280.1</td>
<td>26.5</td>
<td>5.9</td>
<td>69</td>
</tr>
<tr>
<td>20</td>
<td>6</td>
<td>565/30,55,85</td>
<td>5.822</td>
<td>305.9</td>
<td>8.9</td>
<td>12.9</td>
<td>28</td>
</tr>
<tr>
<td>21</td>
<td>6</td>
<td>580/30,55</td>
<td>5.907</td>
<td>292.0</td>
<td>49.1</td>
<td>9.2</td>
<td>54</td>
</tr>
<tr>
<td>Mean 18</td>
<td></td>
<td>565-600/30-85</td>
<td>17.331</td>
<td>294.2</td>
<td>27.1</td>
<td>7.0</td>
<td>28</td>
</tr>
</tbody>
</table>

Notes: N is the number of specimens averaged for each site; R is the resultant vector obtained by the summation of the individual vectors; the mean-remanence direction is given by declination (Dec) and inclination (Inc) in degrees; α₀₅ is the radius of the cone of 95% confidence in degrees; and k is the precision parameter of Fisher (1953).
test proved inconclusive. The mean direction of these three sites is 278.7°, 30.2° (N=3, k=17.6, α95=30.3°). Although this direction differs distinctly from the unit mean direction for the complex, its large cone of 95% confidence from having only three data points precludes a statistically significant separation of this direction from the complex direction. The three sites used for the contact test are located much closer to the intrusion than is desirable (i.e. < 0.1 x complex diameter). The close proximity favours partial overprinting of the original remanence in these sites which would obscure their primary directions.

**SIRM Test**

Nine specimens with representative directions and demagnetization characteristics of the collection were selected for saturation isothermal remanence magnetization (SIRM) analysis to characterize better their magnetic minerals. The specimens were initially cleaned by AF demagnetization in a field of 160 mT. They were then progressively magnetized along one axis in a continuous field (CF) in six steps to 160 mT using the Sapphire Instruments SI-4 unit. As a last magnetization step, the specimens were saturated in a 900 mT CF using a large electromagnet. The specimens were then AF demagnetized once again in five steps to 30 mT. The remanence intensities were measured along the magnetizing axis after each step.
Normalized acquisition and decay curves were plotted for the nine specimens against type curves for coarse-grained hematite, fine-grained hematite, multidomain magnetite, pseudosingle domain magnetite and single domain magnetite (Dunlop 1971, 1972, 1973, 1981).

The acquisition curves indicate by their rapid increase in intensity that the remanence is dominantly contained in magnetite (Figure 6a). An increase in intensity from the 160 mT step to the 900 mT step of more than about 3% is indicative of the presence of hematite. A significant amount of hematite was observed in only two of the nine specimens. Detailed examination of the initial 80 mT of the acquisition curves shows that the magnetite carriers are generally multidomain (MD) to pseudosingle domain (PSD) in character (Figure 6b). The AF decay curves indicate most clearly that the remanence is carried mostly in MD to PSD magnetite (Figure 6c). These results agree with the range of NRM intensity decay rates observed during the initial AF step demagnetization of the collection. The intensity decay and Curie temperatures seen on thermal step demagnetization are also consistent with the remanence being carried for the most part in MD to PSD magnetite with minor hematite in a few specimens.
Figure 6. Saturation isothermal remanent magnetization (SIRM) test data for: a) acquisition of SIRM to 900 mT; b) initial acquisition of SIRM to 80 mT; and c) demagnetization of SIRM. The type curves for coarse-grained and fine-grained hematite (CRHM, FHM) and for multidomain (MD), pseudosingle domain (PSD) and single domain (SD) magnetite are from Dunlop (1971, 1972, 1973, 1981).
RESULTS AND DISCUSSION

The Clay-Howells unit mean direction of 294.2°, 27.1° corresponds to a pole position of 178.8°E, 26.5°N (δ_p=4.1°; δ_θ=7.6°). This pole fits directly on the Logan Loop of the APWP for Keweenawan rocks (1000-1200 Ma) of Palmer and Davis (1987) (Figure 7) which is probably the most intensely studied portion of the Precambrian APWP for North America. At least 60 individual paleomagnetic poles have been obtained for this time period (Halls and Pesonen, 1982). Combined with radiometric data, they provide a very good base for evaluating the age of magnetization. The Clay-Howells pole is located between the poles for the Nonesuch Shale (NN) dated at 1050 Ma (Henry et al., 1977, Halls and Pesonen, 1982) and the Upper Osler Group Volcanics (OS2) (Halls, 1974) dated at 1098 Ma (Davis and Sutcliff, 1985). It falls at the base of a dense cluster of poles that includes the Mamainse Point volcanics (MP, >1086 Ma) and Michipicoten Island volcanics (MI, <1086 Ma, Robertson, 1973; Palmer and Davis, 1987), the Portage Lake volcanics (PL, 1095 Ma; Paces and Davis, 1988), the Logan Dikes (< 1100 Ma, Robertson and Fahrig, 1971; Pesonen, 1979) and the Upper North Shore volcanics (<1098 Ma, Books, 1972). This places the pole for the Clay-Howells Complex at about 1080±10 Ma, which is in good agreement with the Rb/Sr whole rock isochron of 1075±15 Ma (Bell et al., 1982).
Figure 7. Apparent polar wander path for Keweenawan time from Halls and Pesonen (1982) and Palmer and Davis (1987). The added poles are for the Clay-Howells Complex (CH, this study, with its oval of 95% confidence), Nemegosenda Complex (NG, Symons and Garber, 1974) and the Lackner Lake Complex (LL, Symons, 1988). The Powder Mill pole (PM) is that of Palmer and Halls (1986).
The fact that the Clay-Howells pole is concordant to poles from contemporaneous units indicates that a tectonic correction is neither necessary nor likely, and that any significant tilting or translation on the Lepage fault was probably completed before intrusion at 1.1 Ga. However, a tilt correction of up to 15° NW about the trend of the Lepage fault could be applied before the Clay-Howells pole would fall outside the accepted boundaries of the APWP, but such a correction causes the pole to move in a "younging" direction subparallel to the path towards the 1050 Ma Nonesuch Shale position. Thus this tilt correction progressively degrades the pole's fit with the Rb/Sr radiometric data and hence the correction is unlikely. Further, SW or NE tilts of more than about 7°, caused by rotation in the fault plane, will move the Clay-Howells pole off the APWP at right angles to its trend. Therefore the Clay-Howells paleomagnetic result is consistent with the interpretations of Percival et al. (1988) and Hoffman (1988) that all significant motion on the KSZ is pre-Keweenawan in age.

The concordancy of the Clay-Howells primary component is consistent with the results from other 1.1 Ga alkalic syenite-carbonatite intrusions along the KSZ. The 1107 +6/-4 Ma Nemegosenda Carbonatite Complex (Heaman et al., 1988) records an intermediate WNW component (Symons and Garber, 1974) similar to Clay-Howells and the the 1108±10 Ma
Lackner Lake Complex (Symons, 1988) records a somewhat older concordant Keweenawan pole position. Preliminary data on the 1047 Ma Shenango Complex (Dunlop et al., 1988) indicates an intermediate ESE up component that is similar but antiparallel to the Clay-Howells direction. All four of these bodies are in or along the KSZ and give concordant pole positions that do not indicate significant postintrusive translation or rotation on the KSZ. Furthermore there is no evidence from their surface outcrop, magnetic anomaly pattern, distribution of petrologic phases or internal foliation fabric that any of these complexes have been tilted since emplacement. Thus all four appear to postdate the majority of uplift and tilting associated with the formation of the KSZ as suggested by West (1988) from their aeromagnetic anomalies. There is, however, permissive evidence in the paleomagnetic data for a small amount of postintrusive uplift along the KSZ. Geobarometric data by Percival and McGrath (1986) indicate a metamorphic pressure of 5.4±0.5 kbar for the Archean granulite host rocks surrounding Clay-Howells which is equivalent to a depth of about 18 km. They also conclude that there was at least 8 km of uplift before 1.9 Ga so that the maximum emplacement depth for Clay-Howells would be about 10 km. The paleomagnetic data for Clay-Howells is consistent with this estimate. Thermal step-demagnetization of the syenites revealed a VRM component up to about 400°C and a single
primary component thereafter. There was no indication of any secondary metamorphic overprinting in the collection. A 400°C laboratory heating temperature corresponds to a geological burial temperature of about 200°C (Pullaiah et al., 1975). In a stable shield environment a reasonable geothermal gradient would be about 25°C/km for the upper 10 km of the crust (Blackwell, 1971; Cermak and Jessop, 1971). Thus a 200°C burial temperature is equivalent to an emplacement depth of about 8 km and postintrusive uplift cannot have exceeded this value otherwise a secondary metamorphic overprint would have been preserved. Similarly, the other three well-studied Keweenawan intrusions in the KSZ - Nemegosenda, Lackner Lake and Shenango - also lack regional remanence overprints. This means that rifting and intrusion in the KSZ took place over a 35 Ma period from 1110 to 1075 Ma with no evidence for subsequent uplift or metamorphic activity. It is also evident that the steep reversed ENE component in the Archean host rocks that Constanzo-Alvarez and Dunlop (1988) attribute to thermochemical overprinting during Keweenawan rifting and volcanism is not found in these intrusions, and therefore is probably related to some earlier event.

CONCLUSIONS

The Clay-Howells alkalic syenite-carbonatite complex records a primary remanence. Although tectonic rotation (<7°) cannot be entirely ruled out, the preferred
interpretation is that the complex has not been tilted and the remanence records the Earth's magnetic field at the time of intrusion at about 1080±10 Ma. This result agrees with both the available radiometric dating for Clay-Howells and the paleomagnetic results from other 1.1 Ga complexes in the KSZ. Therefore translation, thrust-fault rotation, or vertical axis rotation associated with tectonic activity on the KSZ, regardless of the hypothesis involved for its origin, had ceased by prior to 1.1 Ga although about 8 km of postintrusion uplift and erosion is probable.
ACKNOWLEDGEMENTS

We wish to thank A. Chiasson and L. DeBrouwer who assisted in the collection and preparation of the specimens. We also wish to acknowledge the financial support of the Natural Sciences and Engineering Research Council of Canada through a Lithoprobe grant to D. Symons.
REFERENCES


26


Heaman, L.M., N. Machado, and T.E. Krogh, Combined U-Pb and Sm-Nd studies on carbonatites, lamprophyre and diabase


Percival, J.A., R.R. Parrish, T.E. Krogh, and Z.E. Peterman,  
When did the Kapuskasing zone come up? Project  
Lithoprobe-Kapuskasing Structural Zone Transect.  

Pesonen, L.J., Paleomagnetism of late Precambrian Keweenawan  
igneous and baked contact rocks from the Thunder Bay  
District, northern Lake Superior, Geol. Soc.  

Pullaiah, G., E. Irving, K.L. Buchan, and D.J. Dunlop,  
Magnetization changes caused by burial and uplift.  

Robertson, W.A.; Pole positions from Mamainse Point lavas  
and their bearing on a Keweenawan pole path and  

Robertson, W.A., and W.F. Fahrig, The great Logan  
paleomagnetic loop - the polar wandering path from  
Canadian Shield rocks during the Neohelikian era. Can.  


PART II
AGE AND PETROLOGIC EVOLUTION FROM PALEOMAGNETISM

OF THE LATE PRECAMBRIAN COLDWELL

COMPLEX, ONTARIO, CANADA

M.T. Lewchuk and D.T.A. Symons
Department of Geology, University of Windsor,
Windsor, Ontario, Canada N9B 3P4
ABSTRACT

The Coldwell Complex is a large multiphase alkaline intrusion found on the north shore of Lake Superior in northern Ontario. It was emplaced into Archean metavolcanics in at least three distinct magmatic episodes. The complex is Late Precambrian giving Keweenawan isotopic ages ranging from 1010 Ma (K/Ar) to 1188 Ma (U/Pb). Detailed AF and thermal demagnetization was done on 416 specimens from 33 sites in all petrologic phases of the complex. Additional data are included from an unpublished 1972 study by W.A. Robertson. Three separate magnetizations were observed. The oldest, FCA, was found in 19 episode I sites from both studies and gives a reversed mean direction of $D=121.0^\circ$, $I=-70.9^\circ$ ($N=19$, $k=104$, $\alpha_{95}=3.3^\circ$). This corresponds to a pole position of $143.0^\circW, 54.2^\circN$ which is concordant to the Keweenawan APWP at an age of $1109\pm5$ Ma for the magnetization. The second magnetization, PCB, was found in 11 sites from both studies and gives a normal mean direction of $D=301.8^\circ$, $I=60.1^\circ$ ($N=11$, $k=49$, $\alpha_{95}=5.8^\circ$). Its pole position of $164.9^\circW, 49.1^\circN$ is also concordant to the Keweenawan APWP at a slightly younger age of $1103\pm5$ Ma. The third and youngest magnetization, PCC, was found in nine episode III sites from our study and gives a reversed mean direction of $D=119.1^\circ$, $I=-54.3^\circ$ ($N=9$, $k=101$, $\alpha_{95}=5.1^\circ$). Its pole position of $170.4^\circW, 43.3^\circN$ is on the Keweenawan APWP and indicates an age of $1095\pm5$ Ma. The paleomagnetic ages
agree closely with recent U/Pb zircon ages but are distinctly older than the K/Ar and Rb/Sr ages. The results require some changes in the existing magmatic evolution models for the Coldwell Complex. Since all three poles are concordant it is evident that the complex has not been substantially tilted or deformed since emplacement at about 1.1 Ga. The age difference between the oldest and the youngest magnetizations is about 15 Ma, indicating that the complex cooled relatively quickly to below about 200°C after each magmatic episode.
INTRODUCTION

The Coldwell Complex is located on the north shore of Lake Superior in northern Ontario (Figure 1). It is a very large subcircular alkaline intrusion of about 500 km² with more than 30% of the pluton under the lake. It was emplaced into doubly-folded greenschist to amphibolite grade Archean metavolcanics of the Wawa Subprovince in the Superior Province of the Canadian Shield. The complex is roughly bisected by HWY 17 providing for easy access to outcrop for sampling (Figure 2). It is Late Precambrian in age giving Keweenawan isotopic ages ranging from 1010 Ma (K/Ar biotite, Currie, 1980) to 1188±56 Ma (U/Pb zircon, Turek et al., 1985) indicating either slow cooling or analytical problems in one or more of the isotopic systems.

The cooling history of the Coldwell Complex has been debated. Turek et al. (1985) suggested that the complex was emplaced at about 1188 Ma, the closure of the Rb/Sr system at about 1050 Ma coincided with cooling through 600°C, and the closure of the K/Ar system at about 1035 Ma coincided with cooling through 400°C thus making the entire cooling period in excess of 150 million years. Heaman and Machado (1987) have suggested a much shorter cooling time of not more than 20 million years after emplacement at 1108 Ma.

At least three separate intrusive episodes have been recognized although the areal extent and order of each has
Figure 1. Location of the Coldwell Complex in Ontario.
been argued (Mitchell and Platt, 1978, 1982; Currie, 1980). The available radiometric evidence has been of little help in resolving the argument.

This study was undertaken on the premise that paleomagnetism might help solve some of the geologic and age problems associated with the Coldwell Complex. W.A. (Bill) Robertson had undertaken a paleomagnetic study in 1972 for much the same reasons but unfortunately his results were never published. With his generous consent we have included his table of results and, because the results of both his and our studies proved to be similar, we have combined both data sets in our conclusions.

**GEOLOGY**

The detailed geology of the Coldwell Complex is complicated. Both Mitchell and Platt (1978, 1982) and Currie (1980) have suggested that the complex was formed as the result of three magmatic episodes that were separated by relatively short periods of time as the magma source deepened and migrated westward.

According to Mitchell and Platt (1978, 1982) magmatic episode I resulted in the emplacement of the dominant eastern and subordinate western gabbros as well as an extensive volume of associated ferroaugite syenites (Figure 2). After the western migration of the source magma, episode II resulted in the formation of a ring of biotite
Robertston from this study while the alphabetical sites are from the unpublished study of M.A.

Figure 2: Geology and site locations in the Coldwell Complex. The numbered sites are

red syenite to granite
neptunite syenite
biotite gabbro
ferroan gabbro
eastern gabbro
gabbro with associated nepheline syenite within the ring and to the south on Pic Island. Their final episode III involved the emplacement of red syenites, quartz syenites and granitic rocks containing large xenolithic blocks of assimilated country rock.

Currie (1980) identified essentially the same units in episodes I and II with minor exceptions. According to his interpretation the subordinate western border gabbros are similar to the ring of biotite gabbro so that they belong to episode II rather than episode I. Also he considers the syenites of Pic Island to record episode III rather than episode II. Further Currie (1980) believes that the red syenite to granite suite of Mitchell and Platt's (1978, 1982) episode III is extensively metasomatized roof rock material, and therefore not a primary unit of the complex.

A large number of isotopic age determinations have been done on the complex with a rather wide spectrum of results. Only the more reliable results are mentioned here. Turek et al. (1985) give a more complete discussion. All ages reported in this paper have been corrected to the decay constants recommended by Steiger and Jaeger (1977). Whole rock K/Ar dates of 1074±39 and 1116±41 Ma have been obtained by Stevens et al. (1982). Hurley (1958) obtained biotite K/Ar dates of 1075 and 1065±50 Ma. The most reliable Rb/Sr dates are whole rock isochrons of 1045±6 Ma reported by Platt and Mitchell (1982) and of 1070±15 Ma reported by Bell
and Blenkinsop (1980). Upper limit U/Pb ages of 1188±56 Ma on zircon and 1126±6 Ma on tritomite have been given by Turek et al. (1985). Recently Heaman and Machado (1987) analyzed 10 U/Pb zircon/baddeleyite fractions from the three intrusive episodes of Mitchell and Platt (1978, 1982). They found an age of 1108±1 Ma for episodes I and II while episode II appears to be about 10 Ma younger.

**SAMPLING**

The complex was sampled mostly in roadcuts along HWY 17 with a few sites along secondary roads (Figure 2). Five oriented core samples were obtained by field drilling at each of 25 sites. Each core was sliced in the laboratory into one to three standard specimens of 2.5 cm diameter by 2.2 cm long. An additional eight sites were collected by taking four oriented hand samples per site. These samples were drilled and cut in the laboratory with each sample yielding from two to four specimens. The complete collection consisted of 416 specimens from 33 sites. An attempt was made to select sites from each of the recognized petrologic phases.

**MEASUREMENT AND DEMAGNETIZATION**

The natural remanence magnetism (NRM) of all specimens was measured using an automated two-axis Canadian Thin Film Systems (CTF) cryogenic magnetometer operated within a shielded room to minimize the effects of the present Earth's magnetic field (PEMF).
For each site four specimens from different cores were selected as pilots for detailed demagnetization analysis. Two of the pilots were alternating field (AF) demagnetized in 14 steps to 160 mT using a Sapphire Instruments SI-4 AF demagnetizer. The other two pilots were thermally demagnetized in 12 steps to 585°C using a Schonstedt TSD-1 thermal demagnetizer. The behavior of the the AF and thermal pilots was essentially the same for each site (Figures 3 and 4). Therefore the remaining specimens were AF demagnetized in three assigned fields based on the demagnetization behavior of their respective pilots.

MAGNETIC MINERALOGY

Fifteen representative specimens were selected for saturation isothermal remanent magnetization (SIRM) analysis in order to characterize better the magnetic minerals. Each specimen was AF demagnetized at 200 mT and then saturated in a direct current field of 200 mT using a Sapphire Instruments SI-4 DC magnetizer. The specimens were then progressively AF demagnetized in steps of 5, 10, 15, 20 and 30 mT. Normalized intensity decay curves are plotted in Figure 5. All 15 specimens fall in the pseudosingle (PSD) to multidomain (MD) field defined by the type curves for magnetite. In general the ferroaugite syenite and gabbro samples from episode I fall closer to the PSD type curve than the samples from episodes II and III implying either...
Figure 3. Normalized orthogonal demagnetization plots of example specimens on AF step demagnetization from: a) Site 1, A component; b) Site 17, B component; and c) Site 21, C component. Treatment is in milliTesla (mT). Circles represent projections in the horizontal plane while crosses represent projections in the vertical plane. Axial intensities are expressed as a ratio of the NRM intensity.
Figure 4. Normalized orthogonal demagnetization plots of example specimens on thermal step demagnetization from: a) Site 3, A component; b) Site 26, B component; and c) Site 22, C component. Treatment is in degrees celsius (°C). Plotting conventions as in Figure 3.
Figure 5. Saturation isothermal remanence magnetization (SIRM) test data showing the progressive demagnetization of saturated specimens as indicated by site number from all three components. The type curves for single domain (SD) pseudosingle domain (PSD) and multidomain (MD) magnetite are from Dunlop (1972, 1973, and 1981).
faster cooling or less titanium in the magnetite of the more mafic episode I rocks.

**RESULTS**

A coherent remanence with a mean direction having an $\alpha_{95} < 30^\circ$ (Fisher, 1953) was observed in the specimens from 27 sites. Six sites (#12, 16, 18, 25, 30 and 32) were characterized by inconsistent decay patterns and large $\alpha_{95}$ values. Of these six rejected sites, sites 12, 30 and 32 were located in the syenite to granite suite of Mitchell and Platt (1978, 1982), sites 16 and 18 were in the gabbro on the extreme west side of the complex and site 25 was in nepheline syenite. Two of the rejected sites (#25 and 32) were near a fault in the center of the complex which may account for their poor results. Also the incoherence in three of the 12 granitic episode III sites may indicate that they were located in assimilated xenoliths instead of a primary phase. Of the remaining 27 sites with coherent within-site remanence directions, two sites (#4 and 11) resolved mean directions which were anomalous to the rest of the collection and were therefore rejected. Each of the remaining 25 sites displayed one of three paleomagnetically distinct primary remanence directions (Figure 6) that are designated components A, B and C in Table 1.

The A component was observed in the 11 sites (Table 1a) on the eastern side of the complex (Figure 2) in the units
TABLE 1: Site and unit means - this study

<table>
<thead>
<tr>
<th>Site No</th>
<th>Rock Type</th>
<th>Demagnetizing Level °C/mT</th>
<th>N (N)</th>
<th>R</th>
<th>Dec</th>
<th>Inc</th>
<th>α95</th>
<th>k</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A COMPONENT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>570/30,60</td>
<td>15</td>
<td>14.897</td>
<td>110</td>
<td>-72</td>
<td>3</td>
<td>136</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>560/80,125</td>
<td>14</td>
<td>13.625</td>
<td>125</td>
<td>-63</td>
<td>7</td>
<td>35</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>585/30,80</td>
<td>10</td>
<td>9.954</td>
<td>130</td>
<td>-81</td>
<td>3</td>
<td>195</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>585/40,60</td>
<td>17</td>
<td>16.843</td>
<td>92</td>
<td>-64</td>
<td>4</td>
<td>101</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>570/30,40</td>
<td>12</td>
<td>11.847</td>
<td>124</td>
<td>-74</td>
<td>5</td>
<td>72</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>570/40,80</td>
<td>10</td>
<td>9.930</td>
<td>110</td>
<td>-76</td>
<td>4</td>
<td>129</td>
</tr>
<tr>
<td>8</td>
<td>2</td>
<td>585/60,80</td>
<td>6</td>
<td>5.947</td>
<td>115</td>
<td>-70</td>
<td>7</td>
<td>95</td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td>585/80,100,125</td>
<td>9</td>
<td>8.931</td>
<td>111</td>
<td>-71</td>
<td>5</td>
<td>117</td>
</tr>
<tr>
<td>10</td>
<td>2</td>
<td>570/30,40,60</td>
<td>6</td>
<td>5.950</td>
<td>117</td>
<td>-72</td>
<td>7</td>
<td>100</td>
</tr>
<tr>
<td>14</td>
<td>2</td>
<td>570,60,80</td>
<td>15</td>
<td>14.941</td>
<td>126</td>
<td>-63</td>
<td>3</td>
<td>236</td>
</tr>
<tr>
<td>15</td>
<td>2</td>
<td>570/10,30</td>
<td>9</td>
<td>8.930</td>
<td>145</td>
<td>-71</td>
<td>5</td>
<td>114</td>
</tr>
<tr>
<td><strong>MEAN</strong></td>
<td></td>
<td></td>
<td>(11)</td>
<td>10.9241</td>
<td>117.8</td>
<td>-71.1</td>
<td>4.0</td>
<td>132</td>
</tr>
</tbody>
</table>

| **B COMPONENT** | | | | | | | | |
| 17 | 3 | 540/10,15,20 | 8 | 7.804 | 339 | 68 | 9 | 36 |
| 19 | 3 | /30,40 | 5 | 4.803 | 329 | 64 | 17 | 20 |
| 20 | 3 | 570/20,60 | 6 | 5.876 | 27 | 63 | 11 | 40 |
| 26 | 2 | 525/10,20 | 10 | 9.672 | 328 | 68 | 9 | 27 |
| 27 | 2 | 570/20,40,60 | 8 | 7.612 | 306 | 55 | 13 | 18 |
| **MEAN** | | | (5) | 4.9142 | 313.9 | 65.3 | 11.3 | 47 |

| **C COMPONENT** | | | | | | | | |
| 13 | 6 | 540/20,40,60 | 13 | 12.967 | 300 | 57 | 2 | 366 |
| 21 | 7 | 570/60,80 | 14 | 13.943 | 120 | -59 | 3 | 228 |
| 22 | 7 | 560,570/60 | 8 | 7.960 | 120 | -53 | 4 | 174 |
| 23 | 7 | 560/40,80 | 11 | 10.898 | 118 | -56 | 5 | 98 |
| 24 | 4 | 585/20,40 | 11 | 10.934 | 122 | -62 | 4 | 151 |
| 28 | 2 | 585/20,40,80 | 10 | 9.914 | 119 | -53 | 5 | 105 |
| 29 | 7 | 585/15,30 | 10 | 9.805 | 116 | -41 | 7 | 46 |
| 31 | 7 | 585/40 | 7 | 6.621 | 137 | -52 | 16 | 16 |
| 33 | 3 | 570,585/20,40 | 15 | 14.768 | 102 | -52 | 5 | 60 |
| **MEAN** | | | (9) | 8.9213 | 119.1 | -54.3 | 5.1 | 101 |

Notes: N is the number of specimens averaged for each site mean and (N) is the number of site means averaged for the component mean; R is the resultant vector obtained by the summation of the individual vectors; the mean remanence direction is given by declination (Dec) and inclination (Inc) in degrees; α95 is the radius of the cone of 95% confidence in degrees; and k is the precision parameter of Fisher (1953). The rock types are as follows: 1-eastern gabbro; 2-ferroaugite syenite; 3-biotite gabbro; 4-nephele syenite; 5-red syenite; 6-quartz syenite; and 7-granite. For purposes of calculating the mean for the C component the antiparallel direction of site 13 (i.e., 120, -57) was used.
Figure 6. Stereonet projection of site mean remanence directions from: a) this study; and b) W.A. Robertson. Open triangles represent the A component, solid circles represent the B component and open circles represent the C component. Small symbols indicate the individual site means while the larger symbols indicate the component means which are circumscribed by their cones of 95% confidence after Fisher (1953). The star indicates the present Earth's magnetic field direction.
that both Mitchell and Platt (1978, 1982) and Currie (1980) consider to be episode I. Normalized orthogonal demagnetization plots of the AF (Figure 3a) and thermal (Figure 4a) pilots show the A component to be steeply reversed to the east-southeast and univectorial after the removal of a very small viscous remanent magnetization (VRM) component that is characteristic of all 11 sites. When averaged together these 11 sites give a mean direction of D=117.8°, I=-71.1° (N=11, k=132, α95=4.0°).

The B component is the most distinct because, with one exception, all of the other 20 sites are of reversed polarity. This component is defined by only five sites (Table 1b) of normal polarity on the western edge of the complex in rocks that Mitchell and Platt (1978, 1982) consider to be part of episode I but Currie (1980) considers to be part of episode II. Normalized orthogonal demagnetization plots of the AF (Figure 3b) and thermal (Figure 4b) pilots show, again after the initial removal of a minor normal VRM component, the steep normal WNW univectorial component that is characteristic of these sites. These five normal sites combine to define a mean direction of D=313.9°, I=65.3° (N=5, k=47, α95=11.3°).

The C component was observed in nine sites (Table 1c) in the northern and central portion of the Coldwell Complex. Six sites (#13, 21, 22, 23, 29 and 31) are in the red syenite to granite suite that Mitchell and Platt (1978,
1982) consider to be episode III but Currie considers to be metasomatized roof rock. Two sites (#24 and 33) are in the nepheline syenite and biotite gabbro suite that both Mitchell and Platt (1978, 1982) and Currie (1980) believe to be episode II. The final site (#28) is located in ferroaugite syenite near B component sites in the west of the complex. Again both sets of authors agree that this unit belongs to episode I. The existence of one magmatic signature spanning all three rock suites is somewhat problematic. There are three possible explanations for this based on three different assumptions. It can be assumed that: a) the interpretation of Currie (1980) is correct; b) the interpretation of Mitchell and Platt (1978, 1982) is correct; or c) both interpretations are incorrect.

If Currie (1980) is correct then the two episode II sites (#24 and 33) should retain their primary signature. The episode I site could have been remagnetized and it is also possible that the roof rock sites were remagnetized at the same time. Thus the nine sites would all be recording an episode II magnetic signature. There are two problems with this model. First, at least three of the six roof rock sites (#13, 23 and 31) are a good distance from any episode II material at the surface. To envoke a remagnetization model for these sites would require the unproven existence of a large mass of episode II material at a shallow depth beneath the roof rock. Second, if Currie's correlations are
correct then why doesn't the magnetization correlate with the normal B polarity found in the rest of his episode II rocks on the extreme western side of the complex?

If Mitchell and Platt (1978,1982) are correct, then the six sites in the granitic suite should be recording a primary episode III magnetic signature. The other three sites (#24, 28 and 33) are all sufficiently close to large bodies of the granitic suite so that they might have been completely remagnetized. Under this model all nine sites would be recording an episode III magnetic signature, thereby removing the problem of the three sites not correlating with the other B component sites.

The third and more likely possibility is that both Mitchell and Platt (1978, 1982) and Currie (1980) are wrong and that the central area of the complex with the C component represents only one intrusive episode.

Normalized orthogonal demagnetization plots of the AF (Figure 3c) and thermal (Figure 4c) pilots illustrate that the C component is similar to the A component in declination but that it has a shallower reversed inclination. They also show the isolation of C as a univectorial reversed component only after the removal of an initial VRM component. One site (#13) in the population displayed an antiparallel normal polarity. Since this site is clearly in the granite to red syenite unit it is thought to reflect a short normal event in a predominently reversed polarity period. When
averaged with site #13 reversed to its antiparallel direction, the nine sites give a mean remanence direction of D=119.1°, I=-54.3° (N=9, k=101, α95=5.1°).

DISCUSSION

Introduction

W.A. Robertson's previously unpublished site mean data from 1972 for the Coldwell Complex are given in Table 2 and his site locations are shown on Figure 2. It is evident from the table and figure that both studies followed similar sampling strategies.

The first conclusion to be reached upon comparison of the two data sets is that the sites which we rejected as incoherent reflect the inherent nature of the rock and are not a function of the sampling or measurement procedures. Of the nine sites (B, F, G, P, V, W, X, Y and Z) that Robertson considered incoherent five (B, F, G, P and W) were at or near the location of five (#18, 32, 12, 16, and 25) of our six rejected sites.

The only normal polarity site that we found to the east of the Little Pic River (site 13) is confirmed by Robertson's data in that his site CC at about the same location also gives a normal polarity direction.

We divided Robertson's site mean data into the three geographic groups (Table 2) (Figure 6) indicated by our data to try to reproduce the three distinct A, B and C components that we found. Each will be discussed in turn.
### TABLE 2: Site and unit means - Robertson's study

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Rock Type</th>
<th>Demagnet. mT</th>
<th>N</th>
<th>R</th>
<th>Dec</th>
<th>ε Inc</th>
<th>α°95</th>
<th>k</th>
</tr>
</thead>
<tbody>
<tr>
<td>A COMPONENT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H 1</td>
<td>20</td>
<td>5</td>
<td>4.991</td>
<td>104</td>
<td>-59</td>
<td>4</td>
<td>465</td>
<td></td>
</tr>
<tr>
<td>I 1</td>
<td>20</td>
<td>7</td>
<td>6.879</td>
<td>127</td>
<td>-68</td>
<td>9</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>K 2</td>
<td>20</td>
<td>6</td>
<td>5.714</td>
<td>164</td>
<td>-81</td>
<td>18</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>L 2</td>
<td>40</td>
<td>7</td>
<td>6.670</td>
<td>145</td>
<td>-71</td>
<td>15</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>M 2</td>
<td>20</td>
<td>3</td>
<td>2.976</td>
<td>125</td>
<td>-74</td>
<td>13</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>N 2</td>
<td>20</td>
<td>3</td>
<td>2.954</td>
<td>143</td>
<td>-75</td>
<td>19</td>
<td>44</td>
<td></td>
</tr>
<tr>
<td>O 1</td>
<td>10</td>
<td>5</td>
<td>4.965</td>
<td>108</td>
<td>-66</td>
<td>7</td>
<td>114</td>
<td></td>
</tr>
<tr>
<td>P 2</td>
<td>20</td>
<td>4</td>
<td>3.963</td>
<td>127</td>
<td>-64</td>
<td>10</td>
<td>81</td>
<td></td>
</tr>
<tr>
<td>MEAN</td>
<td></td>
<td></td>
<td>7.9078</td>
<td>125.3</td>
<td>-70.6</td>
<td>6.4</td>
<td>76</td>
<td></td>
</tr>
</tbody>
</table>

| B COMPONENT |
| A 3 | 20 | 3 | 2.992 | 291 | 58 | 8 | 270 |
| C 3 | 20 | 3 | 2.974 | 303 | 49 | 14 | 79  |
| D 3 | 20 | 3 | 2.844 | 301 | 51 | 36 | 13  |
| S 3 | 10 | 4 | 3.948 | 302 | 53 | 12 | 58  |
| T 2 | 20 | 4 | 3.948 | 280 | 58 | 20 | 22  |
| U 3 | 40 | 5 | 4.000 | 285 | 60 | 44 | 4   |
| MEAN  | (6) |   | 5.9614 | 294.5 | 55.2 | 5.9 | 129 |

| C COMPONENT |
| E 4 | 40 | 5 | 4.484 | 81  | -85 | 29 | 8   |
| J 7 | 20 | 5 | 4.989 | 113 | -62 | 4  | 363 |
| O 4 | 20 | 4 | 3.3953 | 118 | -73 | 13 | 64  |
| AA 5 | 20 | 4 | 3.993 | 111 | -68 | 5  | 426 |
| BB 3 | 20 | 6 | 5.913 | 121 | -68 | 9  | 57  |
| CC 6 | 20 | 7 | 6.965 | 298 | 66 | 5 | 172 |
| MEAN  | (6) |   | 5.9449 | 114.6 | -70.5 | 7.1 | 91  |

Notes: Symbols as in Table 1. For purposes of calculating the mean for the C component the antiparallel direction of site CC (i.e. 118, -66) was used.
A Component

Eight of Robertson's sites were located in the area of our reversed A component and all eight were also reversed. When averaged they yield a mean of D=125.3°, I=-70.6° (N=8, k=76, α95=6.4°). This mean is very close to our A component mean with both falling well within the cone of 95% confidence of the other study. This indicates that both A populations are statistically similar and can be validly combined. When combined the two groups yield a mean direction of D=121.0°, I=-70.9° (N=19, k=104, α95=3.3°) for the A component (Table 3) which corresponds to a pole position of 143.0°W, 54.2°N (δp=5.0°, δm=5.7°). This pole (PCA) falls directly onto the Late Precambrian or Keweenawan portion of the apparent polar wander path (APWP) (Halls and Pesonen, 1982, Lewchuk and Symons, 1988) near the apex of the "Logan Loop" (Robertson and Fabrig, 1971) (Figure 7). PCA lies very close to a number of similarly reversed poles from contemporaneous units. The mean pole for the Logan Sills (LS, Halls and Pesonen, 1982) dated at 1109 ±4/-2 Ma (U/Pb-zircon, Davis and Suttcliffe, 1985), the pole for the reversed Logan Dikes (LD4, Pesonen, 1979) that are stratigraphically younger than the Logan Sills, and the Lower Osler Group volcanics pole (OS3, Palmer, 1970) dated at 1108 ±4/-2 Ma (U/Pb-zircon, Davis and Suttcliffe, 1985) are all very close to the mean pole for the Coldwell Complex
TABLE 3: Mean remanence statistics

<table>
<thead>
<tr>
<th>Component</th>
<th>Mean remanence direction</th>
<th>Pole position</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Dec.</td>
</tr>
<tr>
<td>A - this study</td>
<td>11</td>
<td>117.8</td>
</tr>
<tr>
<td>A - Robertson</td>
<td>8</td>
<td>125.3</td>
</tr>
<tr>
<td>A - combined</td>
<td>19</td>
<td>121.0</td>
</tr>
<tr>
<td>B - this study</td>
<td>5</td>
<td>313.9</td>
</tr>
<tr>
<td>B - Robertson</td>
<td>6</td>
<td>294.5</td>
</tr>
<tr>
<td>B - combined</td>
<td>11</td>
<td>301.8</td>
</tr>
<tr>
<td>C - this study</td>
<td>9</td>
<td>119.1</td>
</tr>
<tr>
<td>C - Robertson</td>
<td>6</td>
<td>114.6</td>
</tr>
</tbody>
</table>

Notes: $N$ is the number of site means averaged for each component; $R$ is the resultant vector obtained by the summation of the individual vectors; the mean remanence direction is given by declination (Dec) and inclination (Inc) in degrees; $\alpha_{95}$ is the radius of the cone of 95% confidence in degrees; $\delta_p$ and $\delta_m$ are the radii of the ellipsoid of 95% confidence about the pole.
Figure 7. Apparent polar wander path for Keweenawan time from Halls and Pesonen (1982) and Lewchuk and Symons (1988) showing the A, B and C component pole positions circumscribed by their ovals of 95% confidence after Fisher (1953). The added poles are for the Clay-Howells Complex (CH, Lewchuk and Symons, 1988), Nemegosenda Complex (NG, Symons and Garber, 1974) and the Lackner Lake Complex (LL, Symons, 1988). The Powder Mill pole (PM) is from the study of Palmer and Halls (1986).
A component. The PCA pole is also close to the pole for the Marquette Dikes (MD, Pesonen and Halls, 1979) which are undated but are thought to be related to the same intrusive event that led to the emplacement of the Logan Dikes (Pesonen and Halls, 1979). In addition the PCA pole is close to the normal polarity pole for the Lackner Lake complex (LL, Symons, 1988) which has a pooled whole rock Rb/Sr isochron age of 1095±30 Ma (Bell et al., 1982) and an inferred age from paleomagnetism of 1108±10 Ma (Symons, 1988). This evidence indicates that the A component is a primary untilted magnetic vector that records the direction of the Earth's magnetic field (EMF) at the time of cooling, i.e. about 1109±5 Ma. The magnetic age agrees well with the isotopic dating for episode I of Heaman and Machado (1987) who assign an age of 1108±1 Ma from U/Pb zircon. The A component and its PCA pole correspond to episode I in both the Mitchell and Platt (1978, 1982) and Currie (1980) models.

B component

The normal B component observed in our study is also confirmed by Robertson's data. He identified six normal polarity sites in the western portion of the complex that have a mean direction of D=294.5°, I=55.2° (N=6, k=129, \( \alpha_{95}=5.9 \)). This is similar but not identical to our result. The cones of 95% confidence overlap slightly but do not include the mean of the other study. However both
populations are sufficiently small, with only five and six sites included, that the addition or subtraction of one site from either population will significantly alter their means and cones of confidence. Thus, although the McFadden and Jones (1981) test indicates that they are marginally statistically different at the 95% confidence level, we believe that they are recording the same magnetic signature and have opted to combine them to yield a mean direction for all 11 sites of \( D=301.8^\circ, I=60.1^\circ \) (\( N=11, k=49, \alpha_95=5.8^\circ \)) (Table 3) which corresponds to a paleopole (PCB) at \( 164.9^\circ W, 49.1^\circ N \) (\( \delta_p=7.5^\circ, \delta_n=10.0^\circ \)). This PCB pole also falls directly on the Keweenawan APWP (Figure 7), although at a slightly younger age. It falls between two poles of reversed polarity from the upper and lower Osler Group Volcanics (OS3, Halls, 1974; OS2, Palmer, 1970) which have given U/Pb zircon ages of \( 1097.6\pm3.7 \) and \( 1008 \pm4\pm2 \) Ma respectively (Davis and Sutcliffe, 1985). We therefore consider the B component to be primary and untitled also with an acquisition age of about \( 1103\pm5 \) Ma. The rocks retaining the B component are confined to a portion of the complex that is as yet undated by any isotopic method.

The separation of the A and B components on the APWP as well as the polarity difference argue strongly against the eastern and western border phases of gabbro and syenite being from the same magmatic episode. We consider the B component to record a second magmatic event that is confined
to the western edge of the complex. This second episode probably occurred at about 1103±5 Ma or about six million years after the initial A magmatic pulse. The normal B component was not observed in any of the gabbro or nepheline syenite sites in the center of the Coldwell Complex that were supposed to be related to episode II of either Mitchell and Platt (1978, 1982) or Currie (1980) and thus it likely predates episode II in both of their versions. It is conceivable, however, that the episode II sites in the center of the complex could have been completely reset by the episode III magmatic event in the Mitchell and Platt (1978, 1982) version.

C Component

The analysis of Robertson's sites that correspond to our C component was not successful in confirming C as a distinct component. Six sites from Robertson's study, including the one normal polarity site (site CC), come from the same geographic area as our C component and their mean remanence direction is D=114.6°, I=-70.5° (N=6, k=91, α95=7.1°) (Table 3). This mean direction is coincident with the A component means of both studies and is statistically significantly different from our C component at the 95% confidence level. Therefore the existence of the two discrete reversed components seen in our study is not confirmed by Robertson's data. The explanation for this difference is unclear. A systematic bias in the collecting
or analytical procedures of either party would have shown itself in the A and B components also but this is not the case. The possibility of less complete demagnetization cleaning in one of the studies is also unlikely. His C component mean is more steeply inclined than ours, and yet we generally used more intense AF cleaning intensities but found that the directions track to their final position from shallower inclinations without passing through his mean direction. Unfortunately a more detailed comparison with Robertson's data is not possible because the demagnetization data for his individual specimens are no longer available.

The C component, although not confirmed by the data of Robertson, was nevertheless clearly isolated by our study. It's mean direction of D=119.1°, I= -54.3° using only our data corresponds to a paleopole position of 170.4°W, 43.3°N (δp =5.0°, δm =7.1°). Like the A and B component paleopoles this PCC pole also falls directly onto the Logan Loop to indicate the youngest age of the three components (Figure 7). It falls between the 1098 Ma OS2 pole and the two poles for the Mamainse Point volcanics (MP1 and MP2, Robertson, 1973; Palmer and Davis, 1987) that are directly overlain by a porphyry dated at 1086 ±1/-3 Ma (U/Pb zircon, Palmer and Davis, 1987). We believe the C component to be a primary component recording the EMF at the time of cooling of magmatic episode III in the Coldwell Complex. This episode III occurred at about 1095±5 Ma which also agrees with the
isotopic results of Heaman and Machado (1987) who suggest that this phase is about 10 Ma younger than the 1108 Ma episode I.

Episode III was a period of dominantly reversed polarity although it must have spanned at least one reversal because one of the nine sites (#13) records a normal polarity. The polarity transition likely happened either very early or very late in the cooling sequence. If early then site 13 could record the transition from the normal B polarity period. If late then site 13 could record the onset of the widely-discussed prolonged normal interval beginning at about 1090 Ma (Halls and Pesonen, 1982). Thus our episode III corresponds to Mitchell and Platt's (1978, 1982) episodes II and III and to Currie's (1980) episode II in which case his Pió Island episode III would represent a fourth episode.

Cooling Rates and Burial Depth

All three components track to their primary direction directly after the removal of randomly oriented VRM components by about 400°C of laboratory heating. This corresponds to a maximum burial temperature of about 200°C (Pullaiah et al., 1975). Using a geothermal gradient of 35 °C/km for a rift zone (Morgan, 1983) the maximum 200°C burial temperature suggests that the burial depth upon intrusion was no greater than 6 km. This represents a conservative estimate as it has been suggested that
geothermal gradients may be as high as 175°C/km in this type of tectonic regime above active plutonism (Miyashiro, 1973).

Post-emplacement Keweenawan volcanism in the Lake Superior area, associated with the Mid Continental Rift System, resulted in the deposition of as much as 32 km thickness of flows and sediments (Behrendt et al., 1988). The 6 km burial constraint for the Coldwell Complex implies that it was located at the margin of the rift zone where deposition would be minimal. The acquisition of each of the characteristic A, B and C remanence components within essentially one polarity period plus the absence of any secondary overprint components indicates that the magma for each episode cooled from the 585°C Curie temperature of magnetite to the 200°C burial temperature or less in a relatively short period of time, probably before the emplacement of the next episode.

The 150 Ma cooling model suggested by Turek et al (1985) does not agree with the paleomagnetic results. Similarly the majority of the Rb/Sr isochron and mineral ages that fall in the 1030-1070 Ma range appear to be too young and cannot be argued to be cooling ages if the paleomagnetism is correct. It is hard to imagine any cooling model in which the three magnetization components are locked in by 1090 Ma and the Rb/Sr system remains open for another 20 to 60 million years, and this implies a problem in the Rb/Sr systematics.
CONCLUSIONS

The rocks of the Coldwell Complex retain three distinct untitled primary remanence components. Their definition supports in part the interpretations of Mitchell and Platt (1978, 1982) and Currie (1980) who believe that the complex formed as a result of three magmatic pulses.

The oldest magnetization, the A component of episode I, is found in the gabbros and ferroaugite syenites on the eastern side of the complex. It records a concordant pole position with reversed polarity of about 1109±5 Ma which agrees precisely with the U/Pb zircon age of 1108±1 Ma obtained by Heaman and Machado (1987).

The B component of episode II, is found in the gabbros and nepheline syenites on the extreme western side of the complex. It records a concordant pole with normal polarity of about 1103±5 Ma.

The C component magnetization of episode III, is held in the biotite gabbros, nepheline syenites and the red syenite to granite suite that comprise the youngest rocks in the center of the complex. Whether the rocks on Pic Island correlate with our episode III or represent a fourth magmatic episode remains open to investigation. The pole for the C component indicates an age of 1095±5 Ma when the Earth's field was dominantly reversed. The age also agrees
with the U/Pb zircon age of about 1098 Ma obtained by Heaman and Machado (1987) for these rocks.

Because all three poles are concordant with the poles from contemporaneous Keweenawan units in the Lake Superior region, it is evident that the Coldwell Complex has not been substantially tilted or deformed with the exception of up to 6 km of simple uplift and unroofing since emplacement.

The presence of a normal component chronologically between two reversed components is evidence for another polarity epoch in the Keweenawan portion of the APWP at about 1.1 Ga and indicates that the EMF reversal record for this time period is more complex than originally thought by Pesonen and Halls (1982).

The univectorial behavior of all three components and the agreement of the paleomagnetic data with the U/Pb ages of Heaman and Machado (1987) suggests rapid cooling from 700°C to 200°C of the three intrusive episodes over a 5 to 7 Ma interval each within a total time interval of about 15 to 20 Ma.
ACKNOWLEDGEMENTS

We wish to thank A. Chiasson, L. DeBrouwer, B. Symons and A. Timmins who assisted in the collection and preparation of the specimens as well as J. Kulhanek who assisted in the measurement of the collection. We are particularly indebted to W.A. Robertson for allowing us to publish the results from his 1972 study. Finally we would like to thank the Natural Sciences and Engineering Research Council of Canada for providing support for this project through an operating grant to D. Symons.
REFERENCES


Hurley, P.M., 1958. Age investigations of syenites from


PALEOMAGNETIC MEASUREMENT MANUAL
UNIVERSITY OF WINDSOR
PALEOMAGNETIC LABORATORY
JANUARY, 1989

MICHAEL T. LEWCHUK
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTRODUCTION</td>
<td>76</td>
</tr>
<tr>
<td>GETTING STARTED</td>
<td>77</td>
</tr>
<tr>
<td>SELECTING, COLLECTING AND ORGANIZING THE COLLECTION</td>
<td>79</td>
</tr>
<tr>
<td>PREPARATION AND STARTUP</td>
<td>80</td>
</tr>
<tr>
<td>Using the computer and accessing the Master disk</td>
<td>80</td>
</tr>
<tr>
<td>Initializing blank diskettes</td>
<td>81</td>
</tr>
<tr>
<td>Storing orient data on file</td>
<td>82</td>
</tr>
<tr>
<td>Copying disks and files</td>
<td>85</td>
</tr>
<tr>
<td>THE MEASUREMENT PROCEDURE</td>
<td>86</td>
</tr>
<tr>
<td>NRM measurement</td>
<td>86</td>
</tr>
<tr>
<td>AF pilot demagnetization</td>
<td>91</td>
</tr>
<tr>
<td>Checking space on disk</td>
<td>94</td>
</tr>
<tr>
<td>Thermal pilot demagnetization</td>
<td>95</td>
</tr>
<tr>
<td>Bulk demagnetization</td>
<td>99</td>
</tr>
<tr>
<td>INSERTING SPECIMEN INTO SHAFT</td>
<td>103</td>
</tr>
<tr>
<td>COMMON PROBLEMS</td>
<td>104</td>
</tr>
</tbody>
</table>
INTRODUCTION

Welcome to the University of Windsor Paleomagnetic Laboratory. This manual was prepared to help guide you through the system and end up with a complete set of data which is organized in a manner to allow for efficient analysis.

As you read through the manual you will find numerous references to and data for a collection called SW88. The SW88 data were obtained by completing an actual measurement sequence. Therefore a diskette is available with this manual which contains all the data files which would normally appear in a real study. It may be helpful to use this diskette as you read through the manual, to help familiarize yourself with the system.

Please remember that, as in any scientific laboratory, the equipment and software are continually evolving as technology advances. The instructions are written using the software available as of January 1, 1989. Later versions may be slightly different. If there are any problems or confusion be sure to clarify it before continuing.

Although there are two operational magnetometers (Schonstedt and CTF) in the lab, the latter is used most frequently. Therefore this manual will concentrate on it almost exclusively. However, the software for both is similar and the manual can be adapted to the Schonstedt if necessary.

Much of the information in this manual is similar to that found in a manual made in 1984 entitled MEASUREMENT AND ANALYSIS PROGRAMS FOR CTF AND SSM-1A MAGNETOMETERS. If there are any problems understanding the information here it is suggested that you consult the 1984 manual.
GETTING STARTED

The first thing you should do is familiarize yourself with the equipment that you will be using. It is contained within a magnetically shielded room in the front office of Room 102, Memorial Hall. The magnetic shielding in the walls of this lab effectively reduces the intensity of the Earth's magnetic field from about 60,000 gammas to about a couple of hundred gammas, which helps eliminate unwanted errors from viscous remanence (VRM) acquisition in the measurement procedure.

When you are sitting at the chair in the lab, directly in front of you should be an Apple II plus, or similar computer. This is the heart of the lab. Virtually all peripheral equipment can be run from and controlled by the computer. The programs necessary for this can be found on a "Master Disk". Several versions of the "Master Disk" are probably available. It is suggested that you consult Dr. Symons regarding the version best suited to the work you will be doing.

Directly to the left of the computer is the signal analyzer for the Schonstedt Spinner Magnetometer (Model SSM-1A). Directly to the left of the chair and connected to the signal analyzer is the detector for the SSM-1A. It is nested in a series of grey cylinders, which provide additional magnetic shielding during measurement. This is a very accurate and effective magnetometer, although the measurement process is somewhat slow, and it is not capable of handling weakly magnetized specimens. It does, however, have the ability to run any day of the year with only a few moments preparation under normal circumstances.

To the right of the chair, in a large vertical blue cylinder is the Canadian Thin Film Systems Inc. (CTF) Cryogenic Magnetometer. It measures the remanence using two mutually perpendicular sensors called superconducting quantum interference detectors or SQUIDS. In order to make these detectors superconductive, they have to be cooled to about 5º Kelvin or -268ºC. This is achieved through the use of liquid helium as a coolant. It is very expensive to achieve and maintain this temperature, therefore the CTF magnetometer is only operational about 1 or 2 months a year.

The SQUIDS are monitored by a pair of digital SQUID controllers (DSQ-400's) which are located to the right of the computer. The DSQ-400's are interfaced directly to the computer and the results are converted by software to Declination, Inclination and Intensity data. Detailed instructions for these devices may be found in separate manuals available from Dr. Symons.
A complete paleomagnetic analysis at the University of Windsor normally consists of the following routine:

1. Selection of topic or study area and the subsequent collection and preparation of the "collection".

2. Preparation of Diskettes.


7. Bulk measurement of remaining specimens.

Each of these steps will be explained in detail on the following pages.
SELECTING, COLLECTING AND ORGANIZING THE COLLECTION

When a paleomagnetic study is done at the U. of W., it is normally in the form of a collection of 200 to 300 specimens which are representative of a particular rock type, age or tectonic setting. The collection is divided into a number of sites (normally 20-30). From each site, four to six cores (if drilling was done in the field) or three or four blocks (if drilling was done in the lab) are normally obtained with the in situ orientation of each core or block recorded in the field. For the sake of convenience, whenever the word "core" is used in this text or in the computer commands, it means either core or block, whichever is appropriate. From each core, one to six specimens are cut. Each specimen is assigned a 10 character code, which consists of two letters followed by eight numbers. The first four characters (2 letters and 2 numbers) will be common to the collection as they will represent the name and year in which it was collected. For example if you made a collection in the summer of 1988 by drilling a number of sites in the walls of Dr. Symons' office, a suitable collection name would be SW88 (Symons'. Walls, 1988). This would be followed by a six digit numerical sequence which would be unique for each specimen in the collection. The first two digits indicate the site number, the middle two indicate the core number and the final two digits indicate the specimen number. The complete 10 digit identification code should appear on all specimens. In addition to the ID code, a line should be present across the top and down one side of the specimen. These lines will be used to properly orient the specimen in accordance with the measurements taken in the field.
PREPARATION AND STARTUP

Using the computer and accessing the "Master Disk"

The paleomagnetic equipment at the University of Windsor is completely computer controlled. All programs are stored on one "Master Disk" which is set up with menus and prompts to help guide you through the system. The master diskette should always be put in Disk Drive 1.

When the computer is turned on, it automatically reads the diskette in Disk Drive 1. If the master diskette is placed in Drive 1 before the computer is turned on the first menu will appear on the screen. The 1st or main menu can be called upon in the following manner if the computer is already on:

1. Press CRTL and RESET simultaneously to exit any existing program mode the computer may be in.

2. Type in PR#6 then press RETURN; the following menu will appear on the screen:

   PROGRAMMES FOR THE PALEOMAGNETIC LAB
   SAPPHIRE SOFTWARE
   DEPARTMENT OF GEOLOGY
   UNIVERSITY OF WINDSOR

   ***1 STORE ORIENT DATA ON FILE
   2 READ ORIENT DATA FILES
   3 SPINNER MAGNETIC MEASUREMENT
   4 CRYOGENIC MAGNETIC MEASUREMENT
   5 UTILITIES
   6 COPY DISKS AND FILES
   7 QUIT GO TO BASIC
   USE THE TWO ARROW KEYS TO SELECT A PROGRAM

   ***HIT RETURN TO MAKE SELECTION***

   All other menus and individual programs may be accessed through this menu.
Initializing blank diskettes

Each new diskette must be initialized before it can be used to store data.

To initialize a diskette call up the main menu, select 7 QUIT GO TO BASIC then type the following, inserting your collection name and date where appropriate.

    NEW - press RETURN
    2 PRINT "collection name, P.MAG.DATA" - press RETURN
    4 PRINT "date" - press RETURN

Place your blank diskette in Drive 2 and type

    INIT HELLO,D2 - press RETURN

Drive 2 should come on and after about a minute, the initialization is complete. At least four diskettes should be initialized in this manner.
Storing Orient Data on File

1. Call up main menu and insert a blank, initialized diskette in Drive 2.

2. Select 1 STORE ORIENT DATA ON FILE and press RETURN; the following will appear on the screen:

READ MANUAL INSTRUCTIONS FOR THE SOD PROGRAM BEFORE CONTINUING

HIT ANY KEY
ENTER COLLECTION NAME CODE=

3. Enter your collection name (in this case it is SW88) and press RETURN. The collection name should consist of two letters which identify the particular unit being studied, followed by two numbers which indicate the year the collection was made.

4. Enter the site number and press RETURN.

5. Enter the site longitude (SLONG), site latitude (SLAT), Strike (STR), Dip, Plunge direction (PLUNGE), and plunge dip (PDIP) then press RETURN. The screen will appear as follows:

SITE NO. = (ENTER 0 IF YOUR FINISHED) 1
SLONG, SLAT, STR, DIP, PLUNGE, PDIP = 83.067, 42.317, 0, 0, 0, 0

83.067 and 42.317 are the longitude and latitude of Dr. Symons office in W and N with minutes and seconds converted to decimal notation. The rest of the values are 0 because the stratification in his walls is horizontal.

6. You are now ready to input the declination and inclination for each core number. After the last core has been typed in, type 0,0,0 to finish. The screen will appear similar to what follows.

CORE NUMBER, DECLINATION, INCLINATION (0, 0, 0 FOR NEXT SITE) = 1, 88, 40

CORE NUMBER, DECLINATION, INCLINATION (0, 0, 0 FOR NEXT SITE) = 2, 110, 36

CORE NUMBER, DECLINATION, INCLINATION (0, 0, 0 FOR NEXT SITE) = 3, 95, 38

CORE NUMBER, DECLINATION, INCLINATION (0, 0, 0 FOR NEXT SITE) = 0, 0, 0
COLLECTION=SW88 SITE=1 SLONG=83.067 SLAT =42.317 STR=0 DIP=0 PLUNGE=0 PDIP=0

J  CORE  CDEC  CINC
1   1    88.0  40.0
2   2    110.0 36.0
3   3    95.0  38.0
CORRECTIONS? (Y/N)=

If there are no corrections, type N and press RETURN.
The orientation data for site 1 is stored on the Disk Drive 2. In the SW88 collection site 1 contains 3 cores with orientations of 88,40, 110,36 and 95,38. You can now move to site 2.

SITE NO. = (ENTER 0 IF YOUR FINISHED) 2
SLONG,SLAT,STR,DIP,PLUNGE,PDIP=83.067,42 .317,0,0,0,0

CORE NUMBER,DECLINATION, INCLINATION (0, 0,0 FOR NEXT SITE)=1,106,39

CORE NUMBER,DECLINATION, INCLINATION (0, 0,0 FOR NEXT SITE)=2,111,41

CORE NUMBER,DECLINATION, INCLINATION (0, 0,0 FOR NEXT SITE)=3,82,40

CORE NUMBER,DECLINATION, INCLINATION (0, 0,0 FOR NEXT SITE)=0,0,0
COLLECTION=SW88 SITE=2 SLONG=83.067 SLAT =42.317 STR=0 DIP=0 PLUNGE=0 PDIP=0

J  CORE  CDEC  CINC
1   1    106.0 39.0
2   2    111.0 41.0
3   3    82.0  40.0
CORRECTIONS? (Y/N)=N

The orientation data for site 2 is now complete. Move to Site 3. Notice in this site an error has been made in the third core. The desired inclination is 77 not 7 and therefore it had to be corrected.

SITE NO. = (ENTER 0 IF YOUR FINISHED) 3
SLONG,SLAT,STR,DIP,PLUNGE,PDIP=83.067,42 .317,0,0,0,0
CORE NUMBER, DECLINATION, INCLINATION (0, 0, 0 FOR NEXT SITE)=1,210,778

CORE NUMBER, DECLINATION, INCLINATION (0, 0, 0 FOR NEXT SITE)=2,345,89

CORE NUMBER, DECLINATION, INCLINATION (0, 0, 0 FOR NEXT SITE)=3,003,7

CORE NUMBER, DECLINATION, INCLINATION (0, 0, 0 FOR NEXT SITE)=0,0,0

COLLECTION=SW88 SITE=3 SLONG=83.067 SLAT =42.317 STR=0 DIP=0 PLUNGE=0 PDIP=0

<table>
<thead>
<tr>
<th>J</th>
<th>CORE</th>
<th>CDEC</th>
<th>CINC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>210.0</td>
<td>78.0</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>345.0</td>
<td>89.0</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>3.0</td>
<td>7.0</td>
</tr>
</tbody>
</table>

CORRECTIONS? (Y/N)=Y

WHICH ROW?
ENTER J VALUE (J=0 TO END CORRECTIONS)=3

ENTER NEW CORE NO,=, CDEC=, CINC= 3,3,77
COLLECTION=SW88 SITE=3 SLONG=83.067 SLAT =42.317 STR=0 DIP=0 PLUNGE=0 PDIP=0

<table>
<thead>
<tr>
<th>J</th>
<th>CORE</th>
<th>CDEC</th>
<th>CINC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>210.0</td>
<td>78.0</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>345.0</td>
<td>89.0</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>3.0</td>
<td>7.0</td>
</tr>
</tbody>
</table>

CORRECTIONS? (Y/N)=N

After the correction was made the corrected orientation data for site 3 was printed on the screen and the option to make further corrections was given. Since there were no more corrections "N" was typed and the correct data for the site was stored on the data diskette.

SITE NO.= (ENTER 0 IF YOUR FINISHED) 0

The SW88 collection has only 3 sites so 0 was typed in for site number, and the orientation data file was complete.

The presence of the file in drive II can be checked by typing:

CATALOG,D2.
The following should appear

```
DISK     VOLUME  254
A  002    HELLO
T  004    ODSW88
```

The data file is automatically called ODSW88, for Orientation Data, Symons Walls, 1988.

This file should be copied onto all diskettes belonging to this collection.

---

**Copying disks and files**

1. Type PR#6 -press return
2. Select 6. COPY DISKS AND FILES
3. Select either 1 COPY WHOLE DISK or 2 COPY INDIVIDUAL FILES
4. Answer remaining questions appropriately.

```
SOURCE SLOT=6
DRIVE=1
DESTINATION SLOT=6
DRIVE=2
FILENAME -type in file name if necessary
```

5. Insert the original diskette into Drive 1 and the diskette onto which the files will be copied in Drive 2.
6. Press RETURN and the copying will be completed.

For safety purposes two copies of all data should be kept.
THE MEASUREMENT PROCEDURE

NRM measurement

In any paleomagnetic study, the first measurement involves measuring all the specimens to get their virgin or Natural Remanent Magnetization (NRM). Use the following procedure to measure the NRM's.

1. Call up main menu.

2. Select 4 CRYOGENIC MAGNETIC MEASUREMENT - press RETURN; the following menu will appear:

   PROGRAMS FOR THE CRYOGENIC MAGNETOMETER
   SAPPHIRE SOFTWARE

   ***1 NRM AND BULK REM MEASUREMENT
   2 AF STEP REMANENCE MEASUREMENT
   3 THERMAL STEP REM MEASUREMENT
   4 UTILITIES
   5 RETURN TO MAIN MENU

   USE THE TWO ARROW KEYS TO SELECT A PROGRAM

   ***HIT RETURN TO MAKE SELECTION***

3. Select 1 NRM AND BULK REM MEASUREMENT - press RETURN, the following will appear:

   READ MANUAL INSTRUCTIONS FOR CTFRD
   PROGRAM BEFORE CONTINUING

   HIT RETURN TO CONTINUE

4. Press RETURN. One at a time the following questions will appear. Answer each one accordingly and press RETURN.

   COLLECTION NAME=
   1 OR 2 ORIENTATION SEQUENCE=
   TREATMENT=
   SITE NO.=(0 TO FINISH)
   DEMAG. FIELD=

   In this case the collection name was SW88. 1 orientation sequence is always selected unless you are instructed otherwise by Dr. Symons. TREATMENT is NRM at
this step, SITE NO. is 1 and DEMAG. FIELD is 0 because no demagnetization has been done. It is very important that the collection name and treatment be exactly the same each time they are typed in. All the NRM data will be stored on a file named RDSW88NRM which the computer obtains by combining RD + "collection name" + "treatment".

If you stop measuring your NRM's midway through the collection and complete it another day, the only way to get NRM's for the entire collection onto one file, is to input the exact collection name and treatment both times.

5. After you input the value for DEMAG. FIELD the following will appear:

COLLECTION=SW88 SITE=1 S LONG.=83.067 S LA 
T=42.317 CLEAN=0

C S DEC INC INTENSITY R95 
CDEC CINC 
MEASURE SHAFT REMANENCE
IS DEWAR COVER OFF? PRESS RETURN

The "shaft remanence" is a measurement sequence without a specimen in the holder. By doing this, you will be able to find out how much the shaft is contributing to your answer. An acceptable shaft remanence is anything less than 5.0E-08 EMU/cc, unless very weak specimens (such as those with an intensity of less than 1.0E-06 EMU/cc) are to be measured.

Make sure that the shaft and specimen holder are clean and free of debris. Check that the elevator control panel is turned on. It is a silver box on the right wall with a switch and 3 buttons which are marked LOWER, RAISE, ROTATE. The control panel is on when the red LED beside the switch is lit up. Remove the dewar cover and press RETURN. The shaft should descend, rotate by 90° 3 times, return to the top and rotate a fourth time over a period of about 60 seconds. As this proceeds, five values should appear on the screen: Z, -Y, -X, Y and X. These represent the measured intensities in each direction (+ and -) along the three mutually perpendicular axes X, Y, and Z. The means of each are printed, then they are combined to give the resulting shaft intensity. If the shaft intensity is acceptable, you can proceed to measure your first specimen. The screen up to this point should look similar to this:
\$8\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}\\phantom{8}
Proceed to the next specimen. In this case, it is SW88 010102.

CN,SN (99,99 FOR NEXT SITE)=1,2
I=1 CD=88 CI=40
IS SHAFT AT TOP? IS SHAFT AT ODEG.?
IS DEWAR COVER OOF? PRESS RETURN
Z=1.93419214E-04
-Y=-1.79965826E-03
-X=.017993455
Y=4.63550142E-03
X= .0243390758

MX=-.0211662654 MY=-1.41792158E-03 MZ=
-1.93419214E-04

1 2 182.9 39.3 1.928E-03 8.6
182.9 39.3

CN,SN. (99,99 FOR NEXT SITE)=

This process should be repeated until all specimens from the site are measured. When the final specimen has been measured, input 99,99 to finish the site. At this point the data for that site will be stored on the diskette in Drive 2. The actual hardcopy printout should look like this:

<p>| COLLECTION=SW88 SITE=1 S LONG.=83.067 SLAT=42.317 CLEAN=0 |
|-----------------|--------|-------|----------------|--------|--------|--------|</p>
<table>
<thead>
<tr>
<th>C</th>
<th>S</th>
<th>DEC</th>
<th>INC</th>
<th>INTENSITY</th>
<th>R95</th>
<th>CDEC</th>
<th>CINC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>190.3</td>
<td>41.3</td>
<td>1.847E-04</td>
<td>.2</td>
<td>190.3</td>
<td>41.3</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>182.9</td>
<td>39.3</td>
<td>1.928E-03</td>
<td>8.6</td>
<td>182.9</td>
<td>39.3</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>192.5</td>
<td>39.3</td>
<td>6.660E-05</td>
<td>000</td>
<td>192.4</td>
<td>39.3</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>349.3</td>
<td>67.5</td>
<td>4.809E-07</td>
<td>11.3</td>
<td>349.3</td>
<td>67.5</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>218.6</td>
<td>32.9</td>
<td>1.466E-04</td>
<td>000</td>
<td>218.6</td>
<td>32.9</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>138.8</td>
<td>28.9</td>
<td>1.022E-04</td>
<td>000</td>
<td>138.8</td>
<td>28.9</td>
</tr>
<tr>
<td>8</td>
<td>2</td>
<td>215.6</td>
<td>33.0</td>
<td>1.459E-03</td>
<td>.2</td>
<td>215.6</td>
<td>33.0</td>
</tr>
</tbody>
</table>

7. The computer will ask for the next site number and cleaning. In this case it was site 2 and cleaning=0.

A printout of the NRM data for two more sites is shown below:
COLLECTION=SW88 SITE=2 S LONG.=83.067 SLAT=42.317 CLEAN=0
C S DEC INC INTENSITY R95 CDEC CINC
1 1 171.7 35.6 7.902E-05 000 171.7 35.6
1 2 185.6 30.7 5.495E-04 000 185.5 30.7
2 1 191.2 43.1 5.264E-05 0.2 191.2 43.1
2 2 222.6 40.7 4.225 0.9 222.6 40.5
2 3 248.6 32.1 2.904E-05 000 248.6 32.1
3 1 252.2 87.4 2.319E-03 0.55 252.2 87.4
3 2 177.6 27.1 2.453E-03 0.22 177.6 27.1

COLLECTION=SW88 SITE=3 S LONG.=83.067 SLAT=42.317 CLEAN=0
C S DEC INC INTENSITY R95 CDEC CINC
1 1 140.3 79.6 4.232E-03 8.7 140.2 79.5
2 1 145.4 65.2 9.665E-04 000 145.4 65.2
3 1 49.7 72.6 7.648E-04 0.1 49.7 72.6
3 2 79.3 81.0 2.823E-03 0.9 79.3 81.0

8. When you have measured the NRM's of all specimens in the collection, or are finished for the day, type in 0 for site number and the computer will automatically display the menu for the various cryogenic programs (See page 11). Go back to the main menu and select 7 QUIT GO TO BASIC. Once in basic, type CATALOG,D2 and something similar to this should appear:

DISK VOLUME 254

A 002 HELLO
T 004 ODSW88
T 008 RDSW88NRM

With the addition of the third file you have now completed your NRM measurement.

If the NRM file is not complete, i.e. several sites remain to be measured the next day, start over at step 1 the next day making sure to input the correct collection name (SW88) and treatment (NRM) so that the additional sites can be saved on the same file. In addition be sure that the same data disk is put in Drive 2.
AF Pilot Demagnetization

Ideally, in any paleomagnetic study, each specimen in the collection should have its remanence measured after each of 10 to 15 demagnetization steps. However, measuring all specimens up to 15 times can be extremely time-consuming. Therefore a few specimens known as "pilots" are selected from each site. These pilots are analyzed in detail by a 10 to 15 step pilot demagnetization process. Hopefully, these pilots will indicate two or three optimum cleaning fields and the remainder or bulk of the specimens from the pilot's site will be treated at those fields only in a process known as "bulk demagnetization". Using the "pilot-bulk" approach saves a tremendous amount of time while still producing high quality data.

In a normal situation (i.e. unless Dr. Symons says otherwise), two AF and two thermal pilots are selected from each site. The "pilots" are specimens that have typical NRM directions and intensities for the site. It is desirable to select the four pilots from four different cores if possible. However, note that any specimens which have been glued using epoxy cannot be treated thermally.

Under normal circumstances, the AF pilots will be the first to be measured. The procedure for AF pilot demagnetization is as follows:

1. Select the first two AF pilot specimens. The program is configured to allow pilots to be measured in pairs. Obtain a step demagnetization scheme from Dr. Symons. An example of this would be 0, 5, 10, 15, 20, 30, 40, 50, 60, 100, 130 and 160 mT.

2. Turn on the AF demagnetizer. It is a Sapphire Instruments (SI-4 or similar) AF demagnetizer instrument box which is located below the two DSQ 400's. Immediately beneath the instrument box, and connected to it, is a coil within a series of three grey cylindrical shields. The specimen is placed in this coil in order to be demagnetized at each step. Detailed instructions on the performance and operation of this device may be found in a separate manual provided by Sapphire Instruments Inc. Instruction on the methods for operating this device should be obtained from it. During routine operation the only LED that should be on continuously is the one for DR MODE which indicates computer control of the decay rate. The three decay rate LED's should be changing from off to on as the intensity of demagnetization increases. Also, if milliTesla (mT) are selected as FIELD UNITS it's LED will be on.
3. Call up main menu (PR#6). Put your data diskette in drive II. Note: the OD-data must be on this diskette.

4. Select 4 CRYOGENIC MAGNETIC MEASUREMENT

5. Select 2 AF STEP REMANENCE MEASUREMENT

6. Input your collection name (SW88).

7. Select 1 cycle measurement (unless told otherwise).

8. Select 2 specimen measurement sequence.

9. Select the appropriate procedure in accordance with the Sapphire manual.

10. Input the ID code (last 6 numbers) for both specimens. A specimen with an ID code of SW88 020103 would be input in the following manner: 2,1,3.

11. The program is now ready to measure the shaft remanence. You should be familiar with this procedure by now. If so, continue as before. If not, see step 5 of the "NRM measurement".

12. If the shaft remanence is satisfactory, enter 0 for TREATMENT FIELD? and measure the first specimen that you entered in step 10. This result should be similar to your NRM measurement for that specimen since it is essentially a repeat of it.

13. Repeat this process with the second specimen. While the second specimen is being measured, the first specimen should receive its initial demagnetization.

14. Set the demagnetizer to the first field in the demagnetization scheme. Insert the first specimen as instructed by the Sapphire Instruments manual and demagnetize it according to the same instructions.

The length of time it takes to measure one specimen is slightly longer than the length of time required to demagnetize the other. Therefore, when the first specimen has been demagnetized, remove it from the coil and prepare it to be placed in the shaft. When the NRM of the second specimen has been measured, it can be removed and demagnetized while the first is being remeasured. At this point, the computer should ask the question TREATMENT FIELD? again. Input the demagnetization level in Oersteds or milliTesla (10 Oe=1mT, the demagnetizer can attain a maximum field of 1600 Oe or 160 mT but the program only allows values up to 999.9 for
TREATMENT FIELD?). Press RETURN. The computer automatically knows the first specimen is being remeasured.

Continue this "leapfrogging" of the specimens until all the steps assigned have been completed. You may stop sooner if both the specimens have a $J/J_0$ value of less than 0.01. This means that there is less than 1% of the original intensity remaining, and the specimens are virtually completely demagnetized.

As each specimen is measured, the computer will print a hardcopy of data similar to the NRM printout.

When the last demagnetization step is completed, input 9999 for "TREATMENT FIELD" The data will be saved on the diskette in Drive 2.

After the data is saved, the computer will provide a printout of all the data, in order, for the first specimen, followed by all the data for the second specimen. This printout is much easier to read and analyze than the original, and therefore very useful. An example of the total printout is shown below.

<table>
<thead>
<tr>
<th>SPEC #</th>
<th>SW#</th>
<th>1</th>
<th>2</th>
<th>83.067</th>
<th>.42317</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>88</td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>88</td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SP</th>
<th>ID</th>
<th>#</th>
<th>CLEAN</th>
<th>DEC</th>
<th>INC</th>
<th>INTENSITY</th>
<th>R95</th>
<th>J/JO</th>
<th>CDEC</th>
<th>CINC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>2</td>
<td>000</td>
<td>168.0</td>
<td>37.6</td>
<td>9.656E-04</td>
<td>13.2</td>
<td>1.000</td>
<td>168.0</td>
<td>37.6</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>2</td>
<td>000</td>
<td>191.6</td>
<td>30.8</td>
<td>1.399E-04</td>
<td>0.00</td>
<td>1.000</td>
<td>191.6</td>
<td>30.8</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>2</td>
<td>10.0</td>
<td>173.4</td>
<td>39.3</td>
<td>1.026E-03</td>
<td>5.6</td>
<td>1.662</td>
<td>173.4</td>
<td>39.3</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>2</td>
<td>10.0</td>
<td>198.3</td>
<td>29.7</td>
<td>1.211E-04</td>
<td>0.00</td>
<td>0.865</td>
<td>198.3</td>
<td>29.7</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>2</td>
<td>20.0</td>
<td>179.3</td>
<td>39.5</td>
<td>7.491E-04</td>
<td>3.4</td>
<td>0.775</td>
<td>179.3</td>
<td>29.5</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>2</td>
<td>20.0</td>
<td>187.2</td>
<td>32.5</td>
<td>9.703E-05</td>
<td>0.00</td>
<td>0.693</td>
<td>187.1</td>
<td>32.5</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>2</td>
<td>40.0</td>
<td>168.6</td>
<td>39.8</td>
<td>2.533E-04</td>
<td>0.00</td>
<td>0.262</td>
<td>168.6</td>
<td>39.8</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>2</td>
<td>40.0</td>
<td>196.2</td>
<td>32.2</td>
<td>5.513E-05</td>
<td>0.00</td>
<td>0.394</td>
<td>196.2</td>
<td>32.2</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>2</td>
<td>80.0</td>
<td>182.3</td>
<td>43.0</td>
<td>4.934E-05</td>
<td>0.5</td>
<td>0.051</td>
<td>182.3</td>
<td>43.0</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>2</td>
<td>80.0</td>
<td>188.3</td>
<td>32.7</td>
<td>2.370E-05</td>
<td>0.1</td>
<td>0.169</td>
<td>188.3</td>
<td>32.7</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>2</td>
<td>120.0</td>
<td>188.3</td>
<td>47.5</td>
<td>1.455E-05</td>
<td>0.8</td>
<td>0.015</td>
<td>188.2</td>
<td>47.5</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>2</td>
<td>120.0</td>
<td>207.4</td>
<td>36.5</td>
<td>1.277E-05</td>
<td>0.00</td>
<td>0.091</td>
<td>207.4</td>
<td>36.5</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>2</td>
<td>160.0</td>
<td>216.9</td>
<td>52.3</td>
<td>7.060E-06</td>
<td>1.6</td>
<td>0.001</td>
<td>216.8</td>
<td>52.4</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>2</td>
<td>160.0</td>
<td>192.5</td>
<td>42.4</td>
<td>5.424E-06</td>
<td>0.9</td>
<td>0.038</td>
<td>192.4</td>
<td>42.4</td>
</tr>
<tr>
<td>SITE=1</td>
<td>CN=1</td>
<td>SN=2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>------</td>
<td>------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>FIELD</strong></td>
<td>DEC</td>
<td>INC</td>
<td>J/JO</td>
<td>R95</td>
<td>INTENSITY</td>
<td>X/J</td>
<td>Y/J</td>
<td>Z/J</td>
<td></td>
<td></td>
</tr>
<tr>
<td>000.0</td>
<td>168.0</td>
<td>37.6</td>
<td>1.000</td>
<td>13.2</td>
<td>9.656E-04</td>
<td>-.775</td>
<td>.165</td>
<td>.610</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.0</td>
<td>173.4</td>
<td>39.3</td>
<td>1.062</td>
<td>5.6</td>
<td>1.026E-03</td>
<td>-.817</td>
<td>.095</td>
<td>.673</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20.0</td>
<td>179.3</td>
<td>39.5</td>
<td>.775</td>
<td>3.4</td>
<td>7.491E-04</td>
<td>-.599</td>
<td>.001</td>
<td>.493</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40.0</td>
<td>168.6</td>
<td>39.8</td>
<td>.262</td>
<td>6.00</td>
<td>2.533E-04</td>
<td>-.198</td>
<td>.040</td>
<td>.168</td>
<td></td>
<td></td>
</tr>
<tr>
<td>80.0</td>
<td>182.3</td>
<td>43.0</td>
<td>.051</td>
<td>6.5</td>
<td>4.934E-05</td>
<td>-.037</td>
<td>.000</td>
<td>.035</td>
<td></td>
<td></td>
</tr>
<tr>
<td>120.0</td>
<td>188.3</td>
<td>47.5</td>
<td>.015</td>
<td>6.8</td>
<td>1.455E-05</td>
<td>-.010</td>
<td>.000</td>
<td>.011</td>
<td></td>
<td></td>
</tr>
<tr>
<td>160.0</td>
<td>216.9</td>
<td>52.3</td>
<td>.001</td>
<td>6.1</td>
<td>7.060E-06</td>
<td>-.001</td>
<td>.000</td>
<td>.001</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SITE=1</th>
<th>CN=2</th>
<th>SN=2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FIELD</strong></td>
<td>DEC</td>
<td>INC</td>
</tr>
<tr>
<td>000.0</td>
<td>191.6</td>
<td>30.8</td>
</tr>
<tr>
<td>10.0</td>
<td>198.3</td>
<td>29.7</td>
</tr>
<tr>
<td>20.0</td>
<td>187.2</td>
<td>32.5</td>
</tr>
<tr>
<td>40.0</td>
<td>196.2</td>
<td>32.2</td>
</tr>
<tr>
<td>80.0</td>
<td>188.3</td>
<td>32.7</td>
</tr>
<tr>
<td>120.0</td>
<td>207.4</td>
<td>36.5</td>
</tr>
<tr>
<td>160.0</td>
<td>192.5</td>
<td>42.4</td>
</tr>
</tbody>
</table>

This demagnetization process is repeated until all AF pilots have been demagnetized.

After completion, a catalog of your data diskette should look something like this:

```
A 002 HELLO    - diskette title
T 004 ODSW88   - orientation data
T 008 RDSW88NRM -NRM data
T 008 AFSSW88   - AF step data
```

Your files should be much longer than the size of these sample files. This is a good time to check and see how much space there is left on the diskette.

**Checking space on disk**

1. Call up main menu. (PR#6)
2. Select COPY DISKS AND FILES
3. Select COPY INDIVIDUAL FILES
4. Select <3> SPACE ON DISK
5. Input 6 for SOURCE SLOT
6. Input the drive number that your diskette is in (usually 2)
The computer will tell you the number of sectors free and the number of sectors used. If there is enough space, you can put your thermal pilot data on this diskette. If there is not much space remaining, the thermal data should be put on a separate diskette. In general the same number of thermal pilots will use about half of the space that was required for the AF pilots.

**Thermal Pilot Demagnetization**

Thermal pilot demagnetization is very similar to AF pilot demagnetization, although the measurement order is different. As for the AF pilots, two specimens per site, preferably from different cores than were selected as AF pilots are demagnetized in 10-15 steps. They are demagnetized using the Schonstedt (TSD-1) thermal demagnetizer. The thermal demagnetizer is a long (>1m) black cylinder, located above the spinner magnetometer.

The measurement sequence is different than that for AF pilots, largely due to the restrictions of the oven. During thermal step demagnetization, all specimens are treated and measured at one step before proceeding to the next. Therefore it is necessary to have all the pilots ready at once. The routine is as follows:

1. Obtain a thermal demagnetization scheme from Dr. Symons. An example of this is 200, 400, 500, 525, 550, 570, 585, 600, 615, 630, 660 °C. If the main magnetic carrier is likely to be only magnetite, the final step will be around 600°C, just past the 585°C Currie temperature of magnetite with more steps below 600°C. If there is significant hematite in the collection, the final temperature will be about 700°C, which is just past the Neél temperature for hematite with fewer steps below 600°C and more in the 600 to 700°C range.

2. Turn the TSD-1 unit on by pressing the white plastic button on the control panel in front of the oven. Turn on the heating elements by pressing the red plastic button. Both of these buttons should now be lit.

3. Set the temperature control to the value for the first temperature in your demagnetization scheme.

4. Select your pilots and divide them into groups of 7 or 8 specimens. *Important*: Do not select specimens which have been glued. Place each group of pilots into a separate box. Mark the first box as "BOAT 1", and the rest of the boxes sequentially thereafter.
5. Find a slotted metal tube (about 40 cm long and slightly larger in diameter than a specimen) and insert the first "boat" of specimens into the tube. Do not use the outer 10 cm on each side of the tube and, slightly separate each specimen. The edges are not used because of the thermal gradient i.e. the ends of the oven do not reach the desired temperature. The specimens are spaced to allow for quicker and more complete heating.

6. Find a "boat" to place the tube on. A "boat" consists of two parallel metal dowels cemented to a grey cylindrical asbestos insulating block at each end.

7. Put the tube on the boat and place it inside the heating chamber of the oven using the port nearest the entrance of the room, and close the cover.

8. After about 20-30 minutes, this boat can be pushed through to the cooling chamber side of the oven with a long metal dowel, which should be beside the oven. Once there is a boat in the cooling chamber, the fan for the oven should be turned on. This is done by pressing the blue button on the control panel. It should light up and air should begin blowing out of the other end of the oven.

9. Prepare the next boat of specimens, and place them in the oven as before.

10. As each boatload has cooled to within a few degrees of room temperature, it can be removed from the cooling chamber and measured. The heating and cooling process will continue, increasing the temperature appropriately, until the final step has been completed.

11. Once each boat of specimens is cooled, they should be either measured immediately or stored in a shield to avoid the acquisition of unwanted viscous remanence components. The measurement sequence is as follows:

12. Call the main menu (PR#6) and select 4 CRYOGENIC MAGNETIC MEASUREMENT

13. Select 3 THERMAL STEP REM MEASUREMENT


15. Input your collection name code (SW88).

16. Select 1 orientation sequence.

17. Input the first site number of the collection (1).
18. Input the last site number of the collection.

19. Delete any sites numbers between the first and last sites for which there are no orientation data on your diskette.

20. Input the temperature at which the specimens were demagnetized. Press RETURN.

21. Insert the specimen into the holder and measure as in the previous programs.

22. Repeat the measurement process until all the specimens in the first boat have been measured.

23. Input 0,0,0 when the last specimen in the boat has been measured. The computer will store the data from this boat on a file named TS + "collection name" (ie TSSW88).

24. The program will revert to step 20 and ask you for the temperature again. The rest of the thermal demagnetization process consists of cycling through steps 20-23 as the boats come out of the oven.

The printout for the thermal step program should look similar to what appears below. Note that you will probably have more than one boat for each temperature (only one boat per temperature is shown) and you will probably have more steps than are shown.

**COLLECTION=SW88 TEMP.=200**

<table>
<thead>
<tr>
<th>SITE</th>
<th>CN</th>
<th>SN</th>
<th>DEC</th>
<th>INC</th>
<th>INTENSITY</th>
<th>R95</th>
<th>CDEC</th>
<th>CINC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>1</td>
<td>318.3</td>
<td>61.9</td>
<td>2.277E-07</td>
<td>20.9</td>
<td>318.3</td>
<td>61.9</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>1</td>
<td>150.0</td>
<td>30.7</td>
<td>7.813E-05</td>
<td>000</td>
<td>150.0</td>
<td>30.7</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>2</td>
<td>197.9</td>
<td>42.1</td>
<td>1.529E-03</td>
<td>000</td>
<td>197.9</td>
<td>42.1</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>1</td>
<td>162.1</td>
<td>48.9</td>
<td>.011</td>
<td>.6</td>
<td>162.1</td>
<td>48.9</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>1</td>
<td>149.6</td>
<td>54.1</td>
<td>6.580E-04</td>
<td>.1</td>
<td>149.5</td>
<td>54.1</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>2</td>
<td>117.8</td>
<td>77.8</td>
<td>9.503E-03</td>
<td>.4</td>
<td>117.8</td>
<td>77.8</td>
</tr>
</tbody>
</table>

**COLLECTION=SW88 TEMP.=400**

<table>
<thead>
<tr>
<th>SITE</th>
<th>CN</th>
<th>SN</th>
<th>DEC</th>
<th>INC</th>
<th>INTENSITY</th>
<th>R95</th>
<th>CDEC</th>
<th>CINC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>1</td>
<td>252.3</td>
<td>21.7</td>
<td>1.450E-07</td>
<td>27.0</td>
<td>252.3</td>
<td>21.7</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>1</td>
<td>146.6</td>
<td>29.6</td>
<td>5.695E-05</td>
<td>000</td>
<td>146.6</td>
<td>29.6</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>2</td>
<td>186.0</td>
<td>40.5</td>
<td>5.320E-04</td>
<td>.1</td>
<td>186.0</td>
<td>40.5</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>1</td>
<td>217.6</td>
<td>38.1</td>
<td>3.753E-03</td>
<td>.3</td>
<td>217.6</td>
<td>38.1</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>1</td>
<td>149.2</td>
<td>48.7</td>
<td>5.758E-04</td>
<td>.1</td>
<td>149.2</td>
<td>48.7</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>2</td>
<td>41.3</td>
<td>68.4</td>
<td>6.881E-03</td>
<td>1.0</td>
<td>41.3</td>
<td>68.4</td>
</tr>
</tbody>
</table>
If you catalog your diskette at this time, it should look similar to this:

<table>
<thead>
<tr>
<th>SITE</th>
<th>CN</th>
<th>SN</th>
<th>DEC</th>
<th>INC</th>
<th>INTENSITY</th>
<th>R95</th>
<th>CDEC</th>
<th>CINC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>1</td>
<td>291.8</td>
<td>41.9</td>
<td>2.179E-07</td>
<td>25.6</td>
<td>291.8</td>
<td>41.9</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>1</td>
<td>134.1</td>
<td>24.5</td>
<td>3.346E-05</td>
<td>.2</td>
<td>134.1</td>
<td>24.5</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>2</td>
<td>223.6</td>
<td>34.6</td>
<td>1.515E-04</td>
<td>.5</td>
<td>223.6</td>
<td>34.6</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>1</td>
<td>226.7</td>
<td>34.5</td>
<td>1.042E-03</td>
<td>.4</td>
<td>226.7</td>
<td>34.5</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>1</td>
<td>149.0</td>
<td>41.8</td>
<td>5.101E-04</td>
<td>.1</td>
<td>148.9</td>
<td>41.8</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>2</td>
<td>171.0</td>
<td>45.9</td>
<td>1.290E-03</td>
<td>.2</td>
<td>170.9</td>
<td>45.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SITE</th>
<th>CN</th>
<th>SN</th>
<th>DEC</th>
<th>INC</th>
<th>INTENSITY</th>
<th>R95</th>
<th>CDEC</th>
<th>CINC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>1</td>
<td>244.4</td>
<td>56.8</td>
<td>2.400E-07</td>
<td>21.8</td>
<td>244.4</td>
<td>56.8</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>1</td>
<td>120.8</td>
<td>18.1</td>
<td>1.436E-05</td>
<td>.3</td>
<td>120.8</td>
<td>18.1</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>2</td>
<td>179.6</td>
<td>41.7</td>
<td>1.344E-05</td>
<td>8.7</td>
<td>179.5</td>
<td>41.7</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>1</td>
<td>108.5</td>
<td>64.4</td>
<td>9.191E-05</td>
<td>9.6</td>
<td>108.4</td>
<td>64.4</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>1</td>
<td>150.2</td>
<td>27.3</td>
<td>4.393E-04</td>
<td>.2</td>
<td>150.2</td>
<td>27.3</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>2</td>
<td>179.9</td>
<td>62.4</td>
<td>4.882E-05</td>
<td>7.5</td>
<td>179.8</td>
<td>62.4</td>
</tr>
</tbody>
</table>
Bulk Demagnetization

Once the AF and thermal pilot work is completed, the remaining specimens are usually subjected to three steps of bulk demagnetization. The steps selected are based on the results of the pilots. The steps will most likely vary from one site to another.

It is desirable to have the first bulk cleaning from all the sites on one file, the second bulk cleaning on a separate file and the third bulk cleaning on a third file. The instructions below are designed to achieve this result. If you follow the instructions carefully, three files similar to the following should appear on the data diskette:

RDSW88B1
RDSW88B2
RDSW88B3

1. Call up the main menu and select
   4 CRYOGENIC MAGNETIC MEASUREMENT

2. Select 1 NRM AND BULK REM MEASUREMENT

   Notice that you are using the same program that you used to measure the NRM's of the collection.

3. Input your collection name (eg. SW88)

4. Select 1 orientation sequence

5. Input B1 for treatment. This string is used to name the file, along with the collection name. Therefore both must be typed in the same way, each time you start this program during the first bulk cleaning. When you are ready to begin the second bulk cleaning level, B2 should be typed in for the treatment, and likewise B3 at the third bulk cleaning level. Sometimes more bulk treatments are required which can be labelled B4, B5, B6 etc.

6. Input your first site number (usually 1).

7. Input the appropriate demagnetization field for that site (eg. 50 for 50mT or 580 for 580 C).

8. Measure the shaft intensity.

9. Measure in turn the specimens in the site as in step 6 of the NRM instructions after each has been properly demagnetized.
10. Continue demagnetizing and measuring the sites until they all have been treated at the first bulk cleaning level and measured.

11. Return to step number 1 and begin the cycle at the next cleaning level (B2). After the second level is completed do the same for the third cleaning level (B3) and fourth (B4), fifth (B5), sixth (B6), etc. as necessary.

The printout should look similar to the NRM reading, except that the heading CLEAN=0 will read the cleaning value that was entered in step 7 (eg. CLEAN=50 for 50 mT or CLEAN=580 for 580°C).

A sample printout from the SW88 collection appears below. Notice that there are four less specimens in each site than there were at the NRM stage. These are the two AF and two thermal pilots. Since there were only four specimens to begin with in the third site, there were no specimens left to bulk clean.

The following bulk cleanings were selected for SW88:

<table>
<thead>
<tr>
<th>Site</th>
<th>B1</th>
<th>B2</th>
<th>B3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10mT</td>
<td>60mT</td>
<td>600°C</td>
</tr>
<tr>
<td>2</td>
<td>30mT</td>
<td>80mT</td>
<td>160mT</td>
</tr>
<tr>
<td>3</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>COLLECTION=SW88</td>
<td>SITE=1</td>
<td>S LONG.=83.067</td>
<td>S LAT=42.317</td>
</tr>
<tr>
<td>-----------------</td>
<td>--------</td>
<td>----------------</td>
<td>--------------</td>
</tr>
<tr>
<td>C S DEC</td>
<td>INC</td>
<td>INTENSITY</td>
<td>R95</td>
</tr>
<tr>
<td>1 1</td>
<td>177.9</td>
<td>39.2</td>
<td>1.536E-04</td>
</tr>
<tr>
<td>1 3</td>
<td>202.8</td>
<td>36.1</td>
<td>5.223E-05</td>
</tr>
<tr>
<td>3 2</td>
<td>193.2</td>
<td>36.3</td>
<td>1.112E-03</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>COLLECTION=SW88</th>
<th>SITE=2</th>
<th>S LONG.=83.067</th>
<th>S LAT=42.317</th>
<th>CLEAN=30</th>
</tr>
</thead>
<tbody>
<tr>
<td>C S DEC</td>
<td>INC</td>
<td>INTENSITY</td>
<td>R95</td>
<td>CDEC</td>
</tr>
<tr>
<td>1 2</td>
<td>197.5</td>
<td>25.4</td>
<td>1.094E-04</td>
<td>.1</td>
</tr>
<tr>
<td>2 3</td>
<td>242.8</td>
<td>32.0</td>
<td>9.182E-06</td>
<td>000</td>
</tr>
<tr>
<td>3 2</td>
<td>190.6</td>
<td>33.6</td>
<td>.010</td>
<td>10.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>COLLECTION=SW88</th>
<th>SITE=1</th>
<th>S LONG.=83.067</th>
<th>S LAT=42.317</th>
<th>CLEAN=60</th>
</tr>
</thead>
<tbody>
<tr>
<td>C S DEC</td>
<td>INC</td>
<td>INTENSITY</td>
<td>R95</td>
<td>CDEC</td>
</tr>
<tr>
<td>1 1</td>
<td>181.1</td>
<td>45.5</td>
<td>5.579E-05</td>
<td>.1</td>
</tr>
<tr>
<td>1 3</td>
<td>211.3</td>
<td>33.8</td>
<td>2.592E-05</td>
<td>.3</td>
</tr>
<tr>
<td>3 2</td>
<td>208.0</td>
<td>35.4</td>
<td>2.219E-04</td>
<td>.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>COLLECTION=SW88</th>
<th>SITE=2</th>
<th>S LONG.=83.067</th>
<th>S LAT=42.317</th>
<th>CLEAN=80</th>
</tr>
</thead>
<tbody>
<tr>
<td>C S DEC</td>
<td>INC</td>
<td>INTENSITY</td>
<td>R95</td>
<td>CDEC</td>
</tr>
<tr>
<td>1 2</td>
<td>176.7</td>
<td>22.4</td>
<td>2.555E-05</td>
<td>.1</td>
</tr>
<tr>
<td>2 3</td>
<td>251.9</td>
<td>29.5</td>
<td>3.963E-06</td>
<td>.2</td>
</tr>
<tr>
<td>3 2</td>
<td>227.6</td>
<td>21.4</td>
<td>8.307E-03</td>
<td>25.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>COLLECTION=SW88</th>
<th>SITE=1</th>
<th>S LONG.=83.067</th>
<th>S LAT=42.317</th>
<th>CLEAN=600</th>
</tr>
</thead>
<tbody>
<tr>
<td>C S DEC</td>
<td>INC</td>
<td>INTENSITY</td>
<td>R95</td>
<td>CDEC</td>
</tr>
<tr>
<td>1 1</td>
<td>167.7</td>
<td>69.9</td>
<td>1.505E-05</td>
<td>000</td>
</tr>
<tr>
<td>1 3</td>
<td>224.2</td>
<td>30.8</td>
<td>8.557E-06</td>
<td>000</td>
</tr>
<tr>
<td>3 2</td>
<td>206.4</td>
<td>48.3</td>
<td>1.198E-05</td>
<td>.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>COLLECTION=SW88</th>
<th>SITE=2</th>
<th>S LONG.=83.067</th>
<th>S LAT=42.317</th>
<th>CLEAN=160</th>
</tr>
</thead>
<tbody>
<tr>
<td>C S DEC</td>
<td>INC</td>
<td>INTENSITY</td>
<td>R95</td>
<td>CDEC</td>
</tr>
<tr>
<td>1 2</td>
<td>220.8</td>
<td>52.8</td>
<td>7.116E-07</td>
<td>9.7</td>
</tr>
<tr>
<td>2 3</td>
<td>264.2</td>
<td>24.3</td>
<td>9.487E-07</td>
<td>1.3</td>
</tr>
<tr>
<td>3 2</td>
<td>243.0</td>
<td>13.8</td>
<td>2.095E-03</td>
<td>.1</td>
</tr>
</tbody>
</table>
The bulk demagnetization process is now complete. A catalog of the data diskette should appear similar to what follows:

**DISK VOLUME 254**

<table>
<thead>
<tr>
<th>File Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A002 HELLO</td>
<td>introduction</td>
</tr>
<tr>
<td>T004 ODSW88</td>
<td>orientation data</td>
</tr>
<tr>
<td>T008 RDSW88NRM</td>
<td>NRM data</td>
</tr>
<tr>
<td>T005 AFSSW88</td>
<td>AF step data</td>
</tr>
<tr>
<td>T005 TSSW88</td>
<td>thermal step data</td>
</tr>
<tr>
<td>T005 RDSW88B1</td>
<td>first bulk step</td>
</tr>
<tr>
<td>T005 RDSW88B2</td>
<td>second bulk step</td>
</tr>
<tr>
<td>T005 RDSW88B3</td>
<td>third bulk step</td>
</tr>
</tbody>
</table>

In a normal-sized collection all of these files will not fit on one diskette. They would probably have to be divided amongst two or more diskettes. However the files HELLO and ODSW88 would appear on all diskettes.
INSERTING SPECIMEN INTO SHAFT

The measurement process is useless unless the shaft and specimen are properly oriented. Each specimen should have a line across the top and continuing down one side. When the specimen is placed in the shaft these lines should be at the top and front respectively.

The holder is properly oriented when the 0 degree mark at the top of the shaft is facing the computer (approx. north west). There should also be a vertical line or scratch on the shaft where the specimen is inserted with the same orientation. When the specimen is placed in the shaft this scratch should be aligned with the line on the front of the specimen. When all of the above have been completed correctly the shaft and specimen are in proper orientation for measurement.

To deter movement of the specimen during measurement a piece of Scotch tape is usually attached to the top of the specimen and the front of the holder thus fixing the specimen in place.

Be careful to keep the dewar porthole covered while removing and inserting specimens. A specimen which falls down the porthole is very difficult to retrieve. The permanent dewar cover is a heavy circular green plastic device which is inconvenient to use during routine measurement. A small (10cm x 10cm) piece of cardboard is much easier to work with.
COMMON PROBLEMS

The range of errors which may occur are infinite. Therefore it is impossible to provide a comprehensive list of errors and solutions. However some of the more common errors are listed below.

1. The screen flashes NOT SELECTED

   This usually occurs when the printer is not set in the ON LINE mode. Check the printer.

2. OUT OF DATA or END OF DATA ERROR is listed

   This usually occurs when the computer is instructed to read information from a diskette file and it cannot find what it is looking for. Check that there is a diskette in both drives. Is the proper data diskette in? Is the orientation data stored correctly?

3. I/O error

   I/O or input/output errors usually occur when the port for one of the drives was left open. Check the diskette drives.

4. Computer stops with no explanation

   This usually occurs when the computer sends a command to a peripheral device and is waiting for a reply. If the peripheral device is not turned on it can't reply so the computer just waits. Check the printer, elevator control panel and the DSQ-400's to be sure that they are all on.

5. The shaft stops in the middle of a measurement

   A sudden momentary power surge caused from plugging in or unplugging another device in the room is usually the cause. Kicking a cord on the floor may also cause this problem. The solution is to simply set it in motion again using the manual controls on the small grey box and the rotation should continue as before.

6. BAD SUBSCRIPT ERROR BREAK IN ...

   This problem originates in the software. It is designed to only allow a limited amount of data in the current memory. If the amount is exceeded the error message appears and that portion of the data file is lost. This commonly occurs when there are more than 20 specimens in a site, or more than 15 thermal pilot specimens are
measured without pausing to save them on the data disk. It can also occur if more than 20 AF steps are required. BAD SUBSCRIPT ERROR means that you have exceeded the amount of data that a variable was subscripted for. If you are familiar with BASIC programming you can change the variable subscripts in the error line. If not, you must change the organization of the collection, i.e., divide the offending site into two sites, etc. If the thermal step data is stored after each boat this error should not appear during thermal step demagnetization.

7. Specimen falls in shaft

Big trouble. There really is not a good method of retrieving specimens. The best idea so far is to remove the shaft by undoing the three set screws at the top. Find a piece of plasticine, attach it securely to the end of the one inch dowel rod and try to fish out the specimen by getting it stuck to the plasticine. It isn't easy, good luck. If that doesn't work you're on your own!
VITA AUCTORIS

BORN
December 02, 1964

EDUCATION
Walkerville Collegiate Institute 1978-1983
Ontario Secondary School Diploma

University of Windsor 1983-1987
Bachelor of Science (Geology)

University of Windsor 1987-1989
Master of Science (Geology)

REFERENCES


