Paleointensity study of McMurdo volcanic rocks, Antarctica

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Abstract

Paleointensity of the geomagnetic field was studied on lavas collected from 11 sites at McMurdo Sound. These rocks have K-Ar radiometric ages spanning the interval from 0.08 Ma to 4.2 Ma. The 61 specimens were analyzed, and indicate low paleointensities at Antarctica for the past 5 Ma.

Key words: paleointensity, geomagnetic field, Thelliers' method

1. Introduction

To understand the nature of the past geomagnetic field, it is necessary to study both the direction and intensity of the geomagnetic field. Concerning to the McMurdo volcanic rocks, several paleodirectional studies have been reported (e.g. Funaki, 1984; Mankinen and Cox,1988), but paleointensity study has not. The aim of the study is to obtain the paleointensity at Antarctica where a few paleointensity studies have been performed.

Various kinds of volcanic rocks, such as kenyte, ankaramite, olivine basalt, hornblende basalt and trachyte on which a directional study (Funaki, 1984) and K-Ar ages (Ueno et. al. 1994) had been reported were used in this study.

2. Samples

In McMurdo region, volcanism occurred sporadically in the Plio-Pleistocene (Mankinen and Cox, 1988). K-Ar radiometric ages were determined for the same 25 samples as the samples used in this study from the 11 sites. The results were in between 0.08 Ma and 4.15 Ma (Ueno et. al., 1994). Samples were collected by one of the authors (Funaki) in the 1977-1979 austral summer seasons with the support of the U. S. National Science Foundation, from Hut Point Peninsula and Cape Royds on Ross Island and from Taylor Valley (Fig.1). The sampling sites on the Hut Point Peninsula are illustrated in Fig.2. Petrographic descriptions for the samples of the same sampling area

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are listed in Ueno et. al. (1994). At Cape Royds, samples were collected from north of the Hut. In Taylor Valley, samples were collected from basaltic cones under the Marr Glacier in the middle of the Valley. Polarities of the specimens are normal except those from Observation Hills.

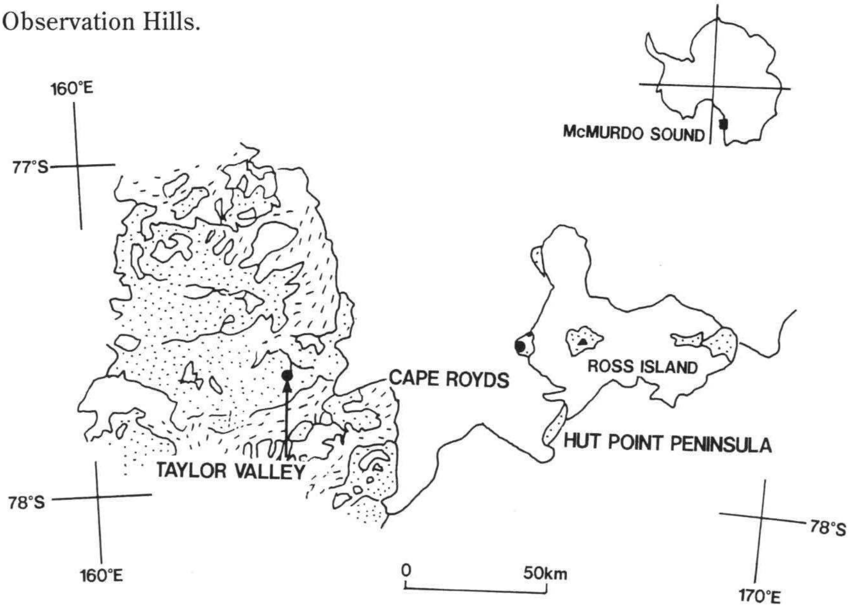

Fig. 1. Location map of the McMurdo Sound region and the sampling sites (modified after Funaki,1984).

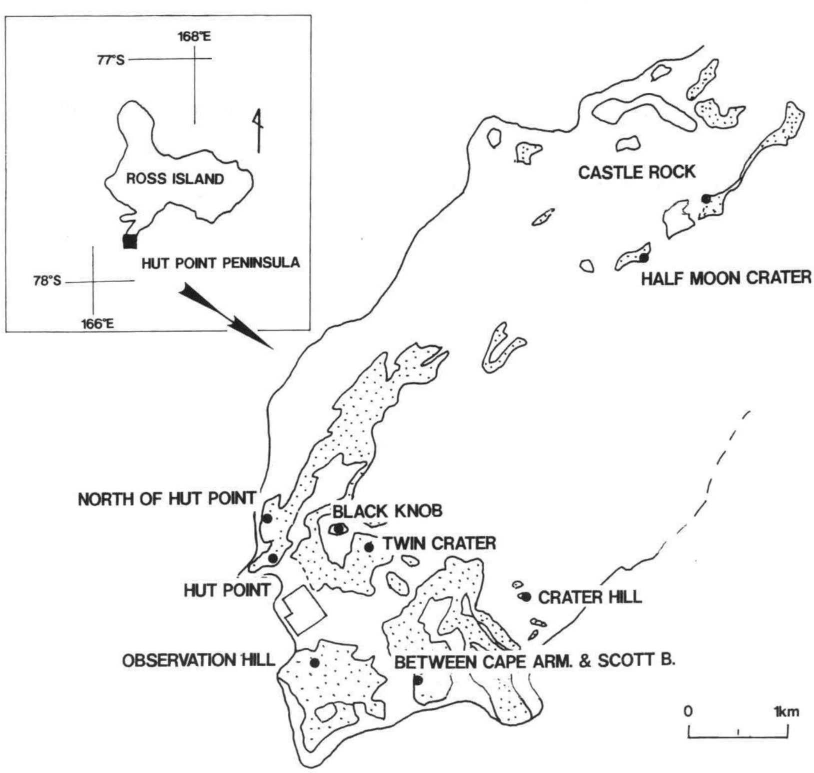

Fig.2. Sampling sites of Hut Point Peninsula (modified after Funaki, 1984).

3. Experimental Procedures

Coe's version of the Thelliers' method (Coe,1967) was applied to conventional paleomagnetic specimens (25mm in diameter). Samples varied in length from 10 to 22mm. Samples were treated in a series of paired heating-cooling cycles, repeated in zero and known laboratory field with progressively increasing temperature. Nitrogen gas was used at temperatures above 100 ℃. Initial magnetic susceptibility was measured after each step to detect any magnet-chemical changes. Applied laboratory fields were selected from 10 μT, 20 μT or 50 μT to match the paleointensity of the specimens. Partial thermo-remanent magnetization (PTRM) tests were employed to check the reproducibility of the PTRM. Specimens were set in the furnace horizontally or perpendicularly to the applied laboratory field. Variation on applied field magnitude and direction, and size of the specimens, produced no difference in results.

Natural Remanent Magnetizations (NRM) determined after demagnetization in zero field, and TRMs acquired in known field are plotted with the NRM on the ordinate and the TRM on the abscissa. The slope of a line is calculated by the method of Kono and Tanaka (1984), in which the least squares fitting of Williamson (1968) was used.

4. Results and Discussions

The experiments were made on 61 samples (Table1). NRM-TRM diagrams, Zijderveld diagrams and PTRM tests were mainly used to find linear segments in NRM-TRM diagrams to calculate paleointensity.

Summaries of the experiments for each sampling site are given below.

4-1 Cape Royds

Two Curie temperatures, 100-120 ℃ and 550-570 ℃, were reported for the samples from this site (Funaki, 1984). Results of this study are illustrated in Fig.3 (Fig.3-1, Fig.3-2). Large changes appeared around 100 ℃ and 500 ℃ in measurement of initial magnetic susceptibility (χ) during heating and cooling cycles in air. Low unblocking temperatures and the decrease of pTRM (partial TRM) in 300-400 ℃ was the characteristics of this area. Initial susceptibility in room temperature after each heating-cooling step varied within 20%. Averaged paleointensity of four samples, which have averaged age of 0.080 $\pm$ 0.02 Ma (Ueno et al, 1994), is 13 $\pm$ 2 μT.

4-2 Hut Point Peninsula

(1) **Crater Hill** : At this site, straight line segments were obtained both in NRM-TRM and Zijderveld diagrams (Fig.4-(1)). Curie temperatures of these rocks are approximately 310 ℃ and 560 ℃. Averaged paleointensity of five samples, which have the age of 0.39 $\pm$ 0.04 Ma, is 27 $\pm$ 9 μT.

(2) **Twin Crater** : Specimens from this area had straight line in NRM-TRM diagrams under the low temperatures as those from Cape Royds (Fig.4-(2)). Large changes

on initial susceptibility occurred during cooling. Averaged paleointensity of two samples, which have the age of 0.47 ± 0.01 Ma, is 18 ± 9 μT.

(3) **Between Cape Armitage and Scott Base** : Two Curie temperatures were observed, around 220-330 ℃ and 520 ℃ (Fig.4-(3)). Both NRM and pTRM change only in the high temperature steps. Averaged paleointensity of two samples, which have the age of 0.50 ± 0.05 Ma, is 19 ± 9 μT.

(4) **North of Hut Point** : Good results were obtained from this site. Reversible curve was obtained in χ / χ_0 measurement, that ran low at 540 ℃ (Fig.4-(4)). Averaged paleointensity of two samples, which have the age of 0.68 ± 0.03 Ma, is 19 ± 1 μT.

(5) **Hut Point** : Although good linear segments were obtained from the steps over 400 ℃ (Fig.4-(5)), both pTRM test and initial susceptibility measurement seem not so good. Averaged paleointensity of two samples, which have the age of 1.32 ± 0.63 Ma, is 15 ± 0 μT.

(6) **Castle Rock** : Double Curie temperatures were expected from χ / χ_0 curve (Fig.4-(6)). Both pTRM test and initial susceptibility measurement seem not so good. Averaged paleointensity of two samples, which have the age of 0.73 ± 0.02 Ma, is 80 ± 2 μT.

(7) **Black Knob** : Complicated NRM-TRM diagrams were obtained at temperature above 300 ℃ (Fig.4-(7)). PTRM test were performed for the steps under 300 ℃ where linear segments were obtained. Averaged paleointensity of two samples, which have the age of 0.55 ± 0.25 Ma, is 4 ± 0 μT.

(8) **Half moon Crater** : Two segments with successful pTRM tests were obtained from both the low and the high temperature components (Fig.4-(8)). The initial susceptibility curves were reversible with temperature, and changes of initial susceptibility after each step were small except those for one specimen. We had no reason to reject both of them. From four samples, which have the averaged age of 0.83 ± 0.12 Ma, two averaged paleointensities obtained are 27 ± 6 μT from the lower temperature portion in NRM-TRM diagrams, and 47 ± 9 μT from the higher portion.

(9) **Observation Hills** : Good segments were obtained (Fig.4-(9)) from the high temperature steps. Averaged paleointensity of five samples, which have the age of 1.28 ± 0.03 Ma, is 20 ± 4 μT.

4-3 Taylor Valley

Very low paleointensities were obtained from this site. A sharp decrease between 450 ℃ and 550 ℃ and reversibility on cooling are the distinctive features in measurement of temperature dependent susceptibility (Fig.5). Averaged paleointensity of three samples, which have the age of 3.51 ± 0.64 Ma, is 5 ± 1 μT.

4-4 Magnetic mineralogy

The magnetic mineralogy of pilot samples from Crater Hill and Half Moon Crater is dominated by hematite. The main magnetic minerals for samples from other sites are titanomagnetite and magnetite. Among the samples dominated by titanomagnetite and magnetite, those from North Hut Point, Observation Hill and Taylor Valley had ilmenite lamellae. Coercive force (Hc), saturation magnetization (Ms) and ratio of saturation remanence (Mrs) to saturation magnetization were also determined by vibrating sample magnetometer for some specimens (Table 1). Magnetic coercivity was over 20 mT except for Crater Hill and Half Moon Crater. All of the Mrs/Ms values were over 0.12, acceptable value for sample selection (Thomas, 1993).

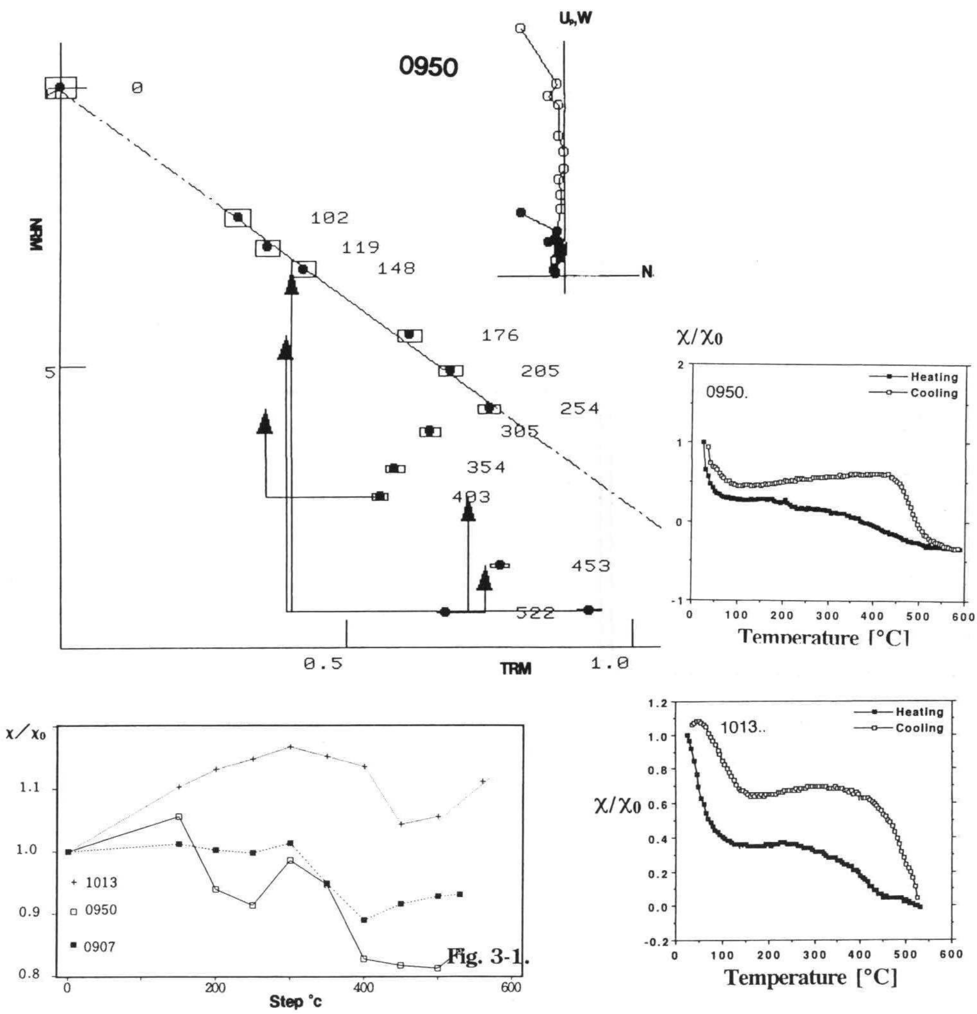

Fig. 3-1.

Fig.3. Representative examples of Cape Royds. (Fig.3-1, Fig.3-2)
NRM-TRM diagram : vertical and horizontal axes are normalized to the NRM intensity, triangles show PTRM test.
Zijderveld diagram: orthogonal plot of zero field steps.
Change of initial susceptibility (χ) after each steps.
Initial susceptibility (χ) change with temperature.

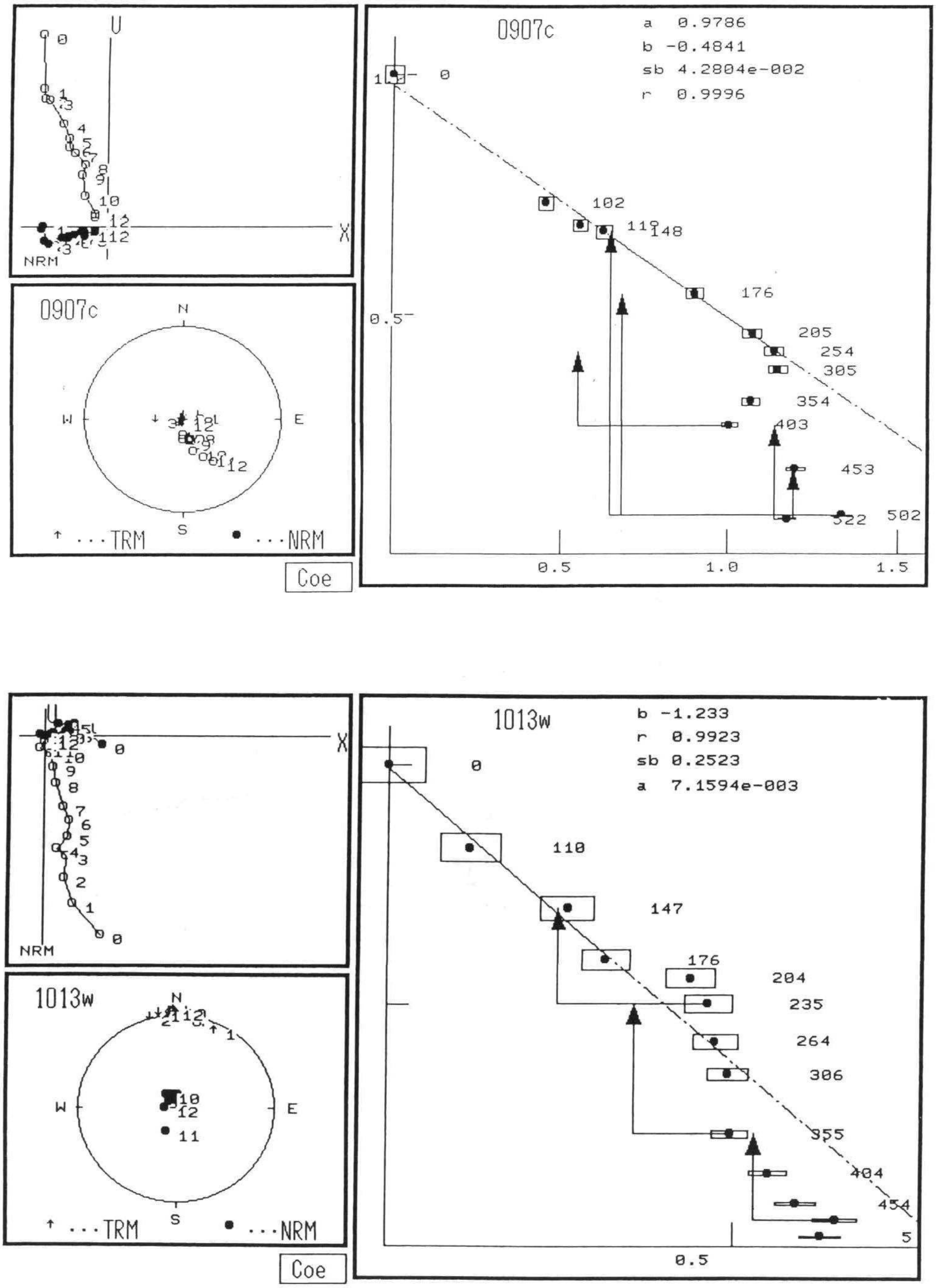
0907c
a 0.9786
b -0.4841
sb 4.2804e-002
r 0.9996
102
176
205
254
305
354
403
453
502
0.5
1.0
1.5
U
X
NRM
N
W
E
S
↑ ...TRM
● ...NRM
Coe
1013w
b -1.233
r 0.9923
sb 0.2523
a 7.1594e-003
110
147
176
204
235
264
306
355
404
0.5
Coe

Fig. 3-2.

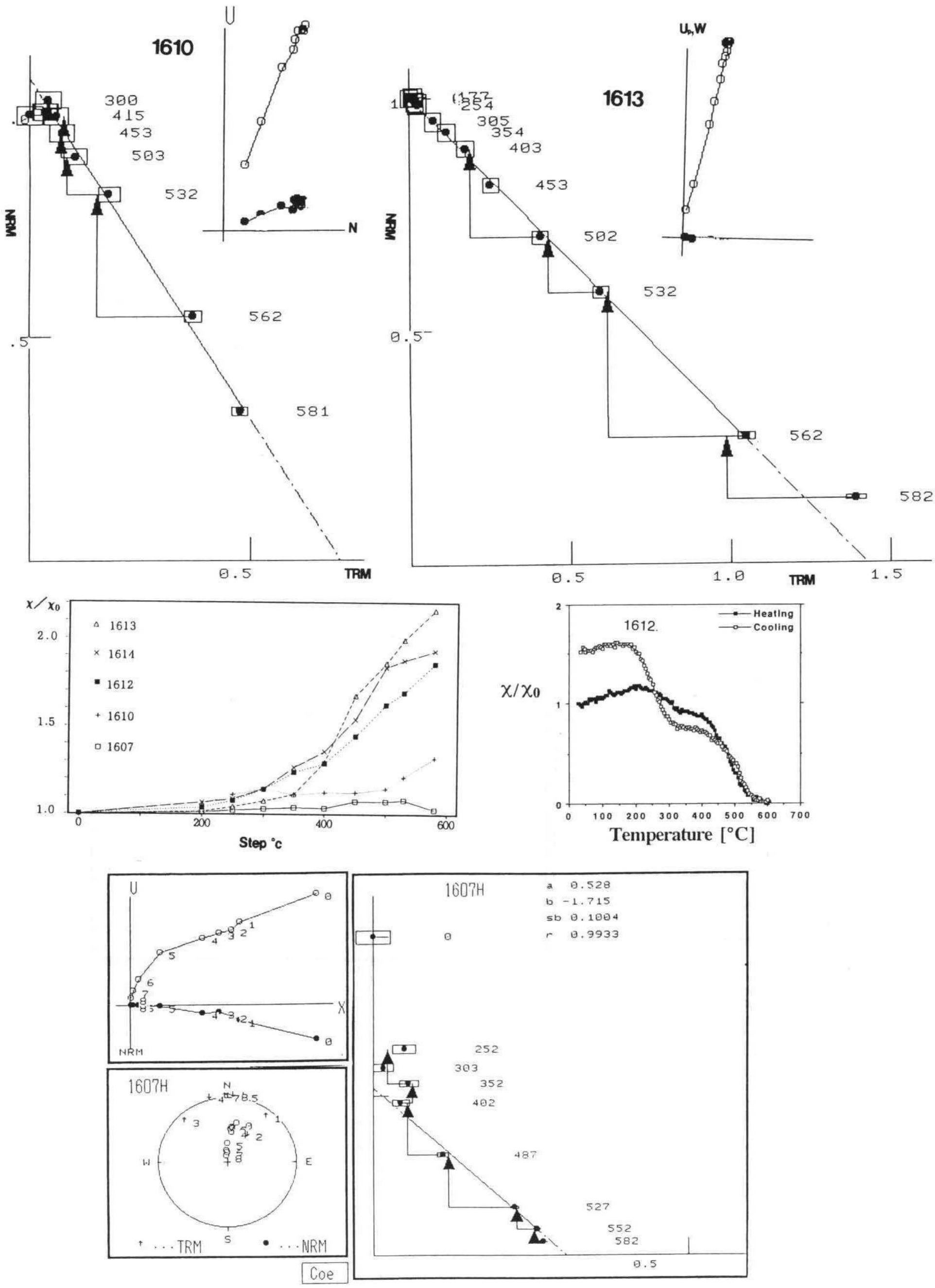

Fig. 4-(1)-1.

Fig.4-(1). Crater Hill. (Fig.4-(1)-1, Fig.4-(1)-2)

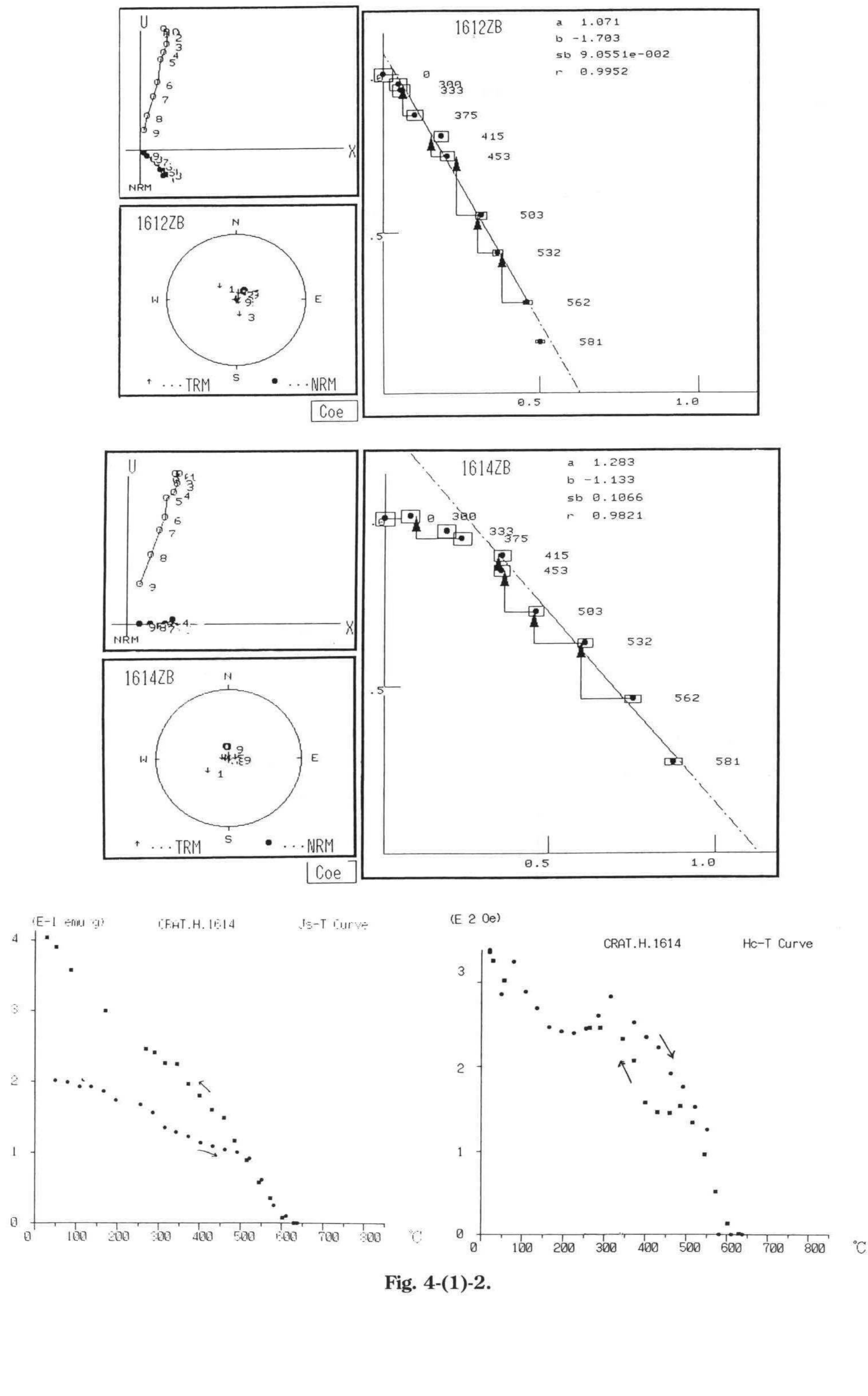
1612ZB
a 1.071
b -1.703
sb 9.0551e-002
r 0.9952
0
300
333
375
415
453
503
532
562
581
0.5
1.0
.5
U
X
NRM
N
W
E
S
↑ ...TRM
● ...NRM
Coe
1614ZB
a 1.283
b -1.133
sb 0.1066
r 0.9821
(E-1 emu/g)
CRAT.H.1614
Js-T Curve
(E 2 Oe)
Hc-T Curve
℃

Fig. 4-(1)-2.

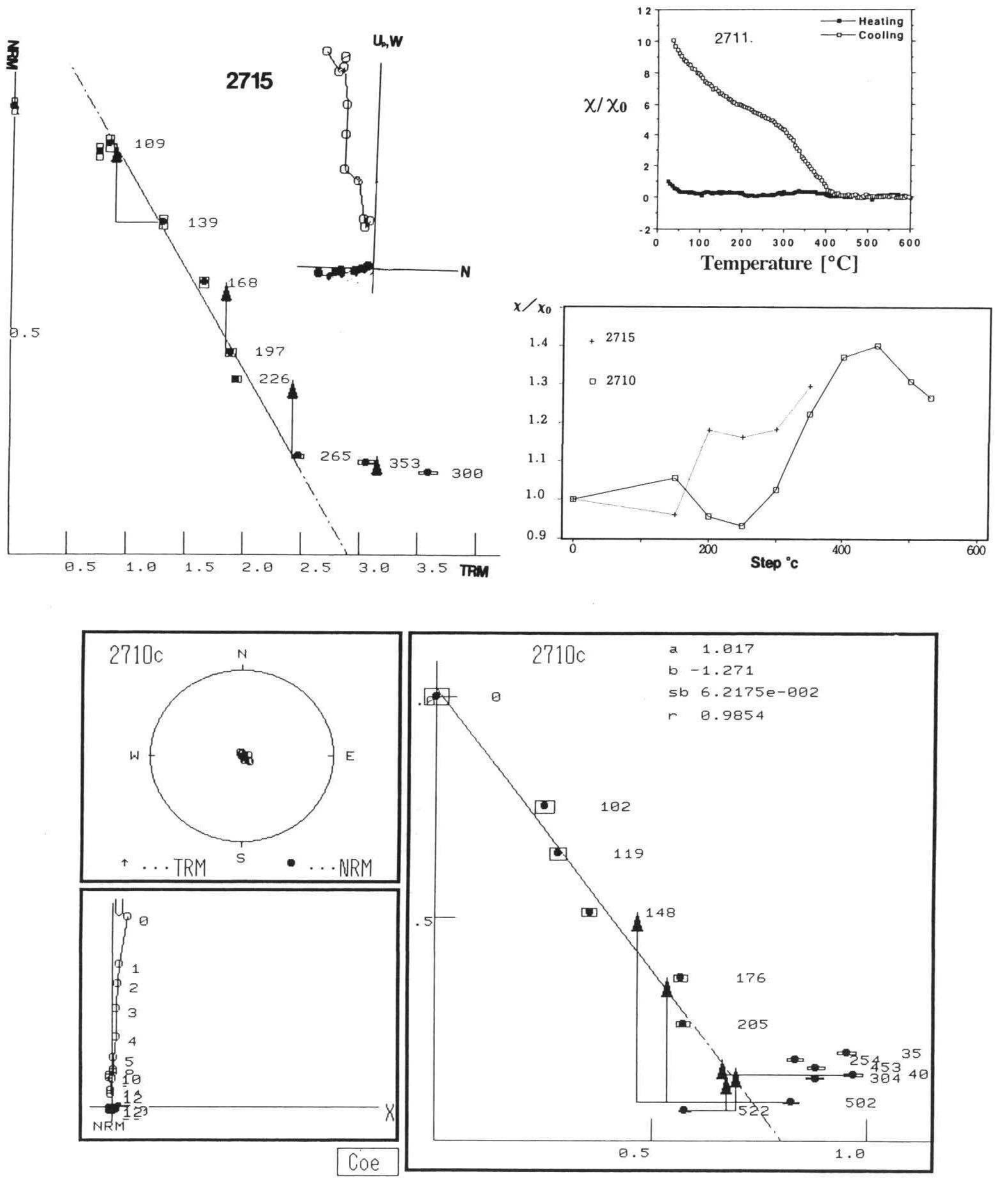

Fig.4-(2). Twin Crater

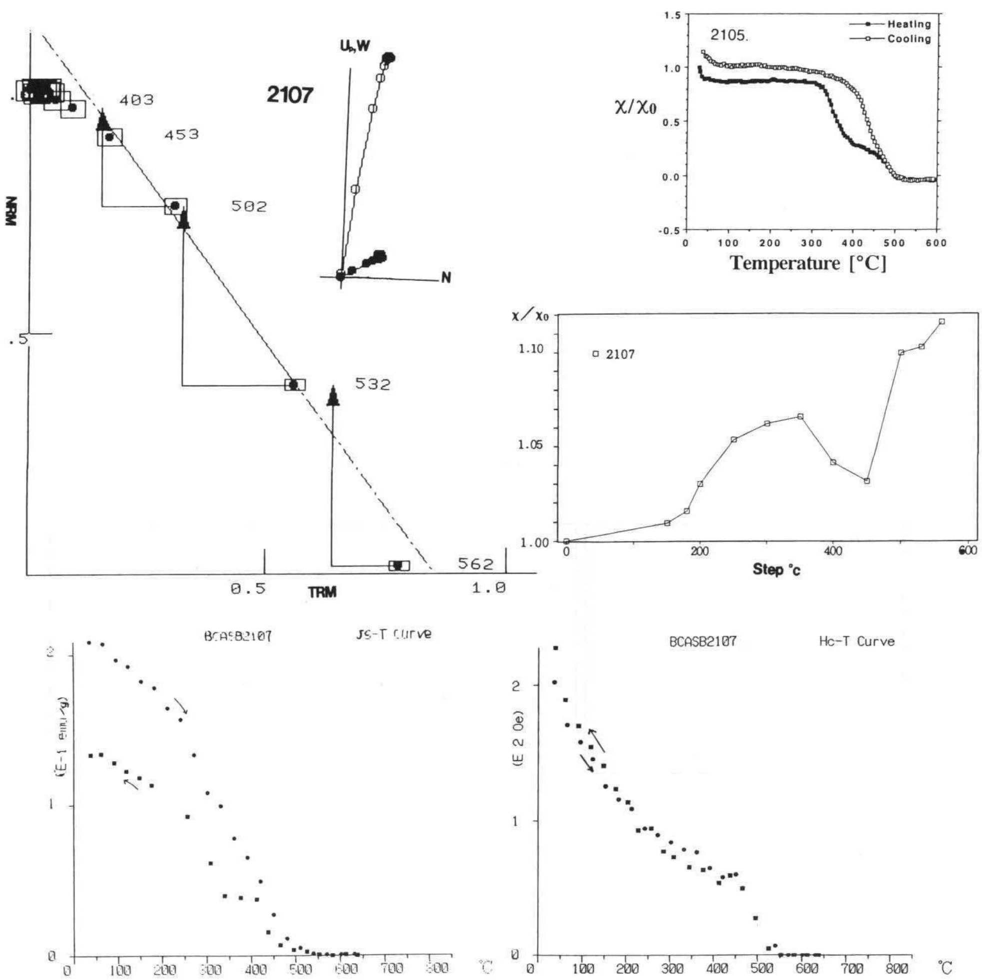

Fig.4-(3). Between Armitage and Scott Base

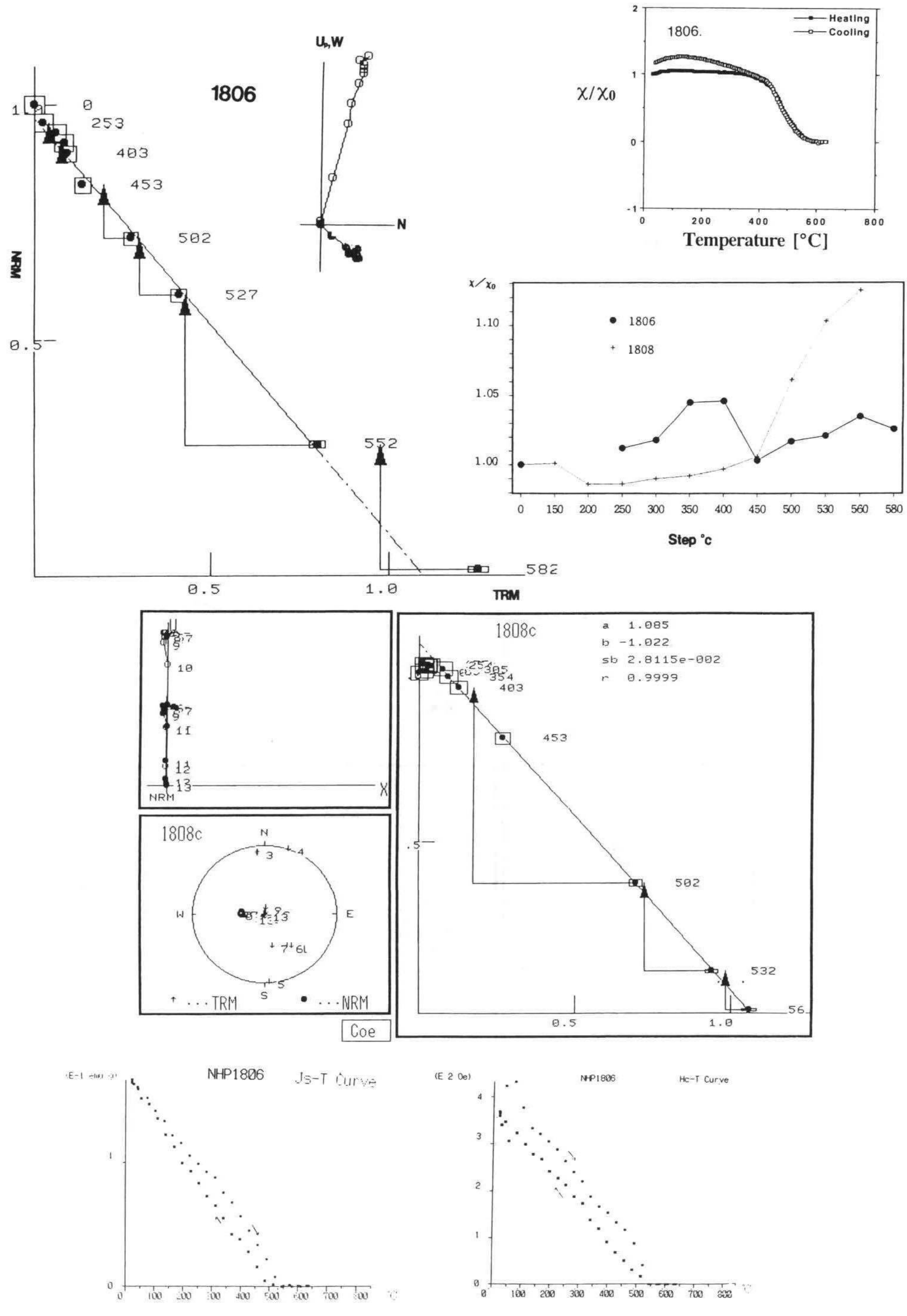

Fig.4-(4). North of Hut Point

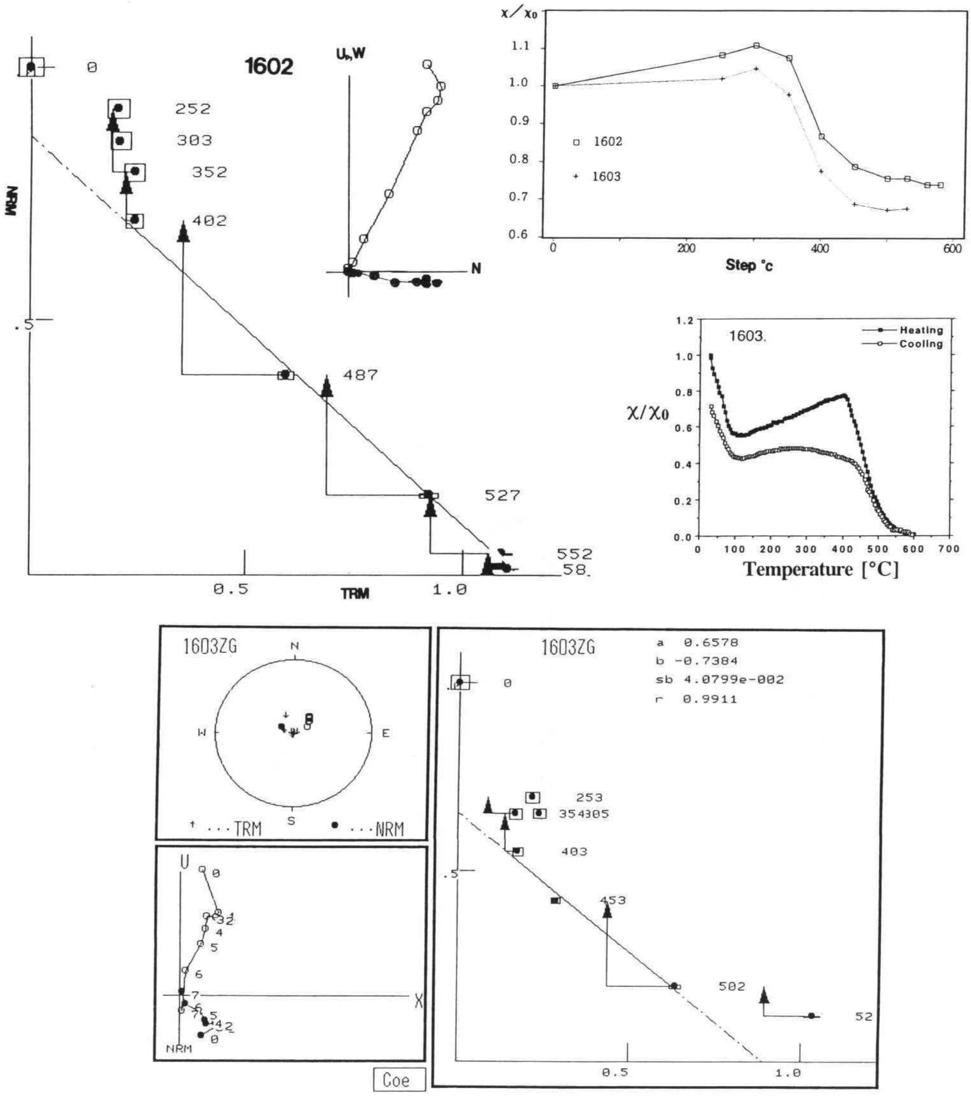

Fig.4-(5). Hut Point

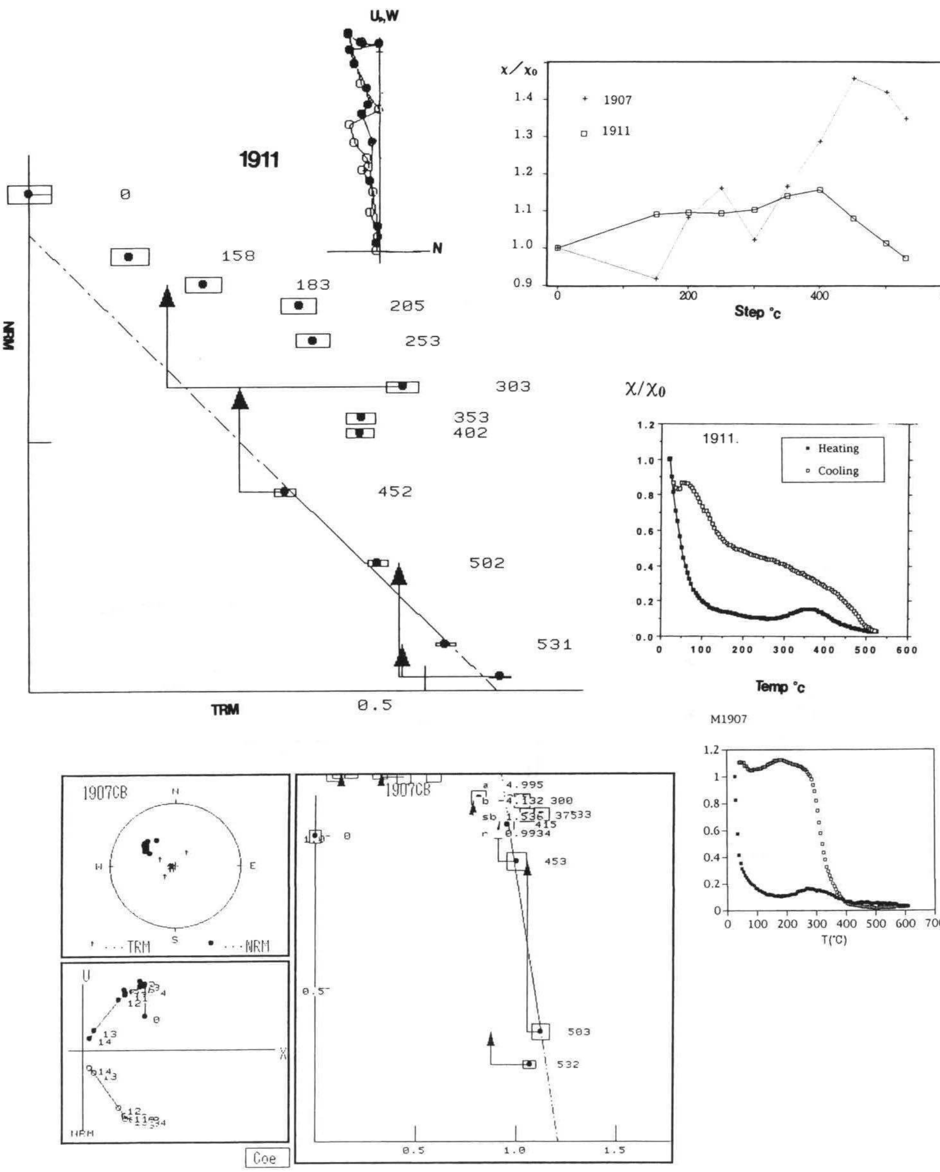

Fig.4-(6). Castle Rock

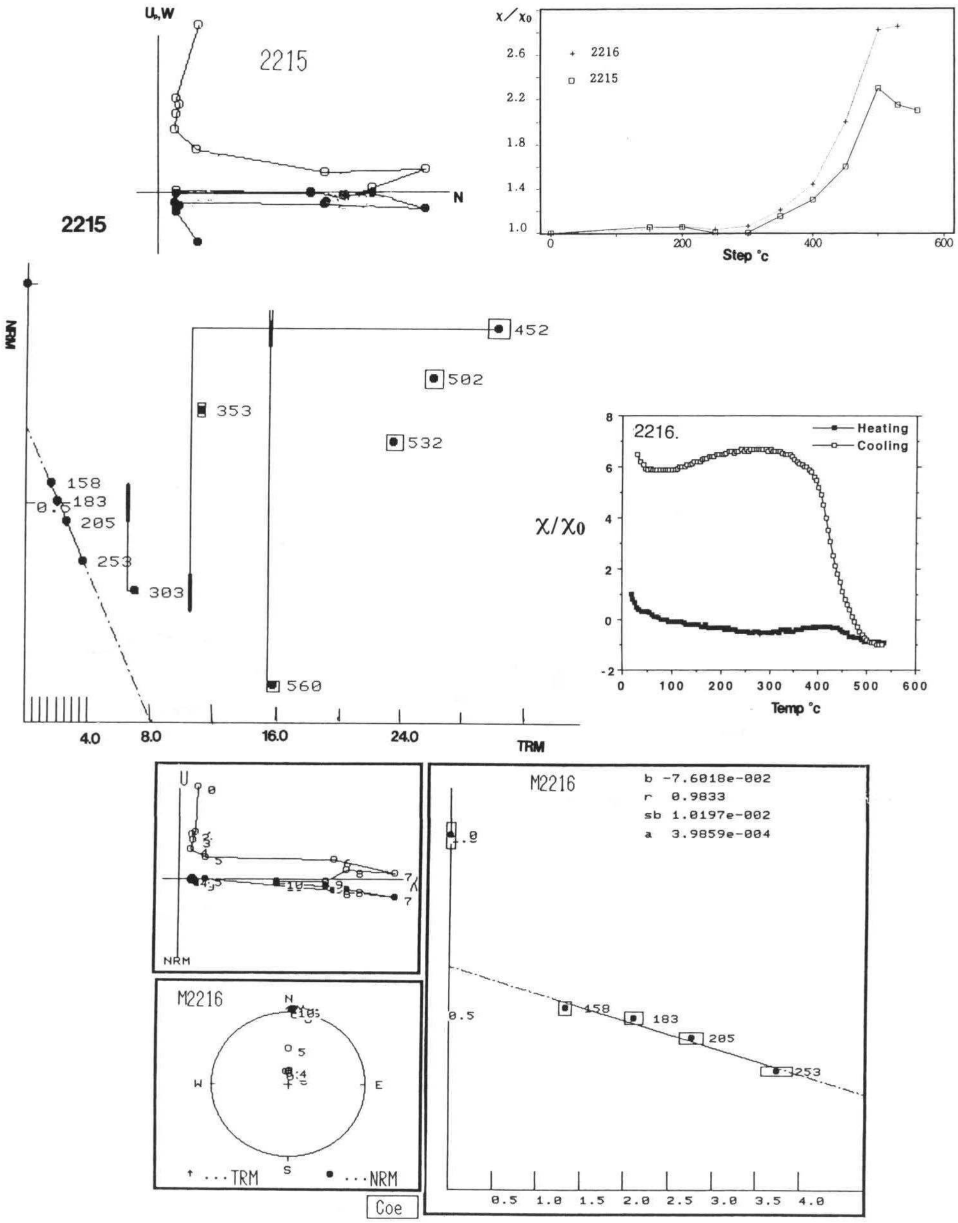

Fig.4-(7). Black Knob

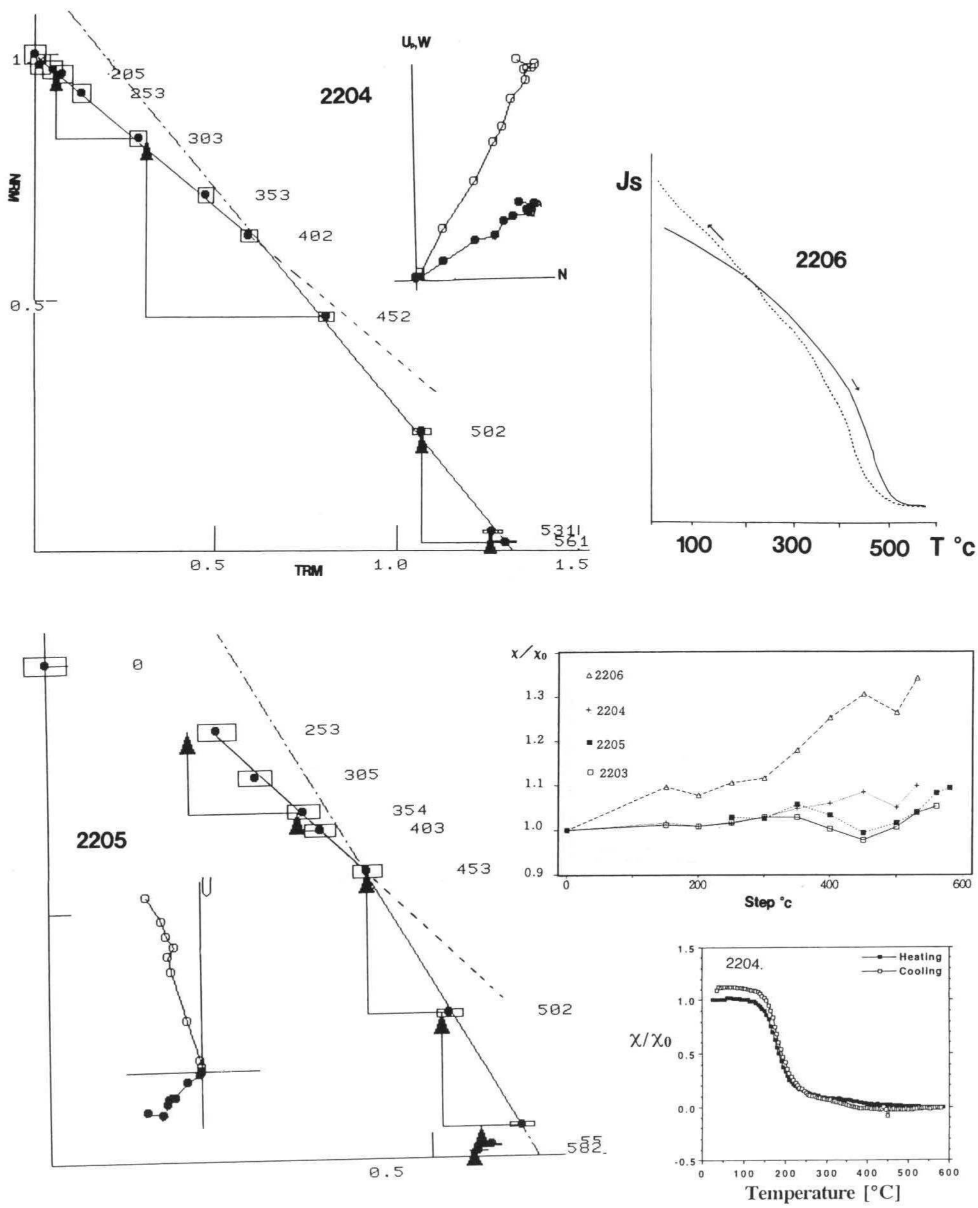

Fig. 4-(8)-1.

Fig.4-(8). Half Moon Crater (Fig.4-(8)-1,Fig.4-(8)-2)

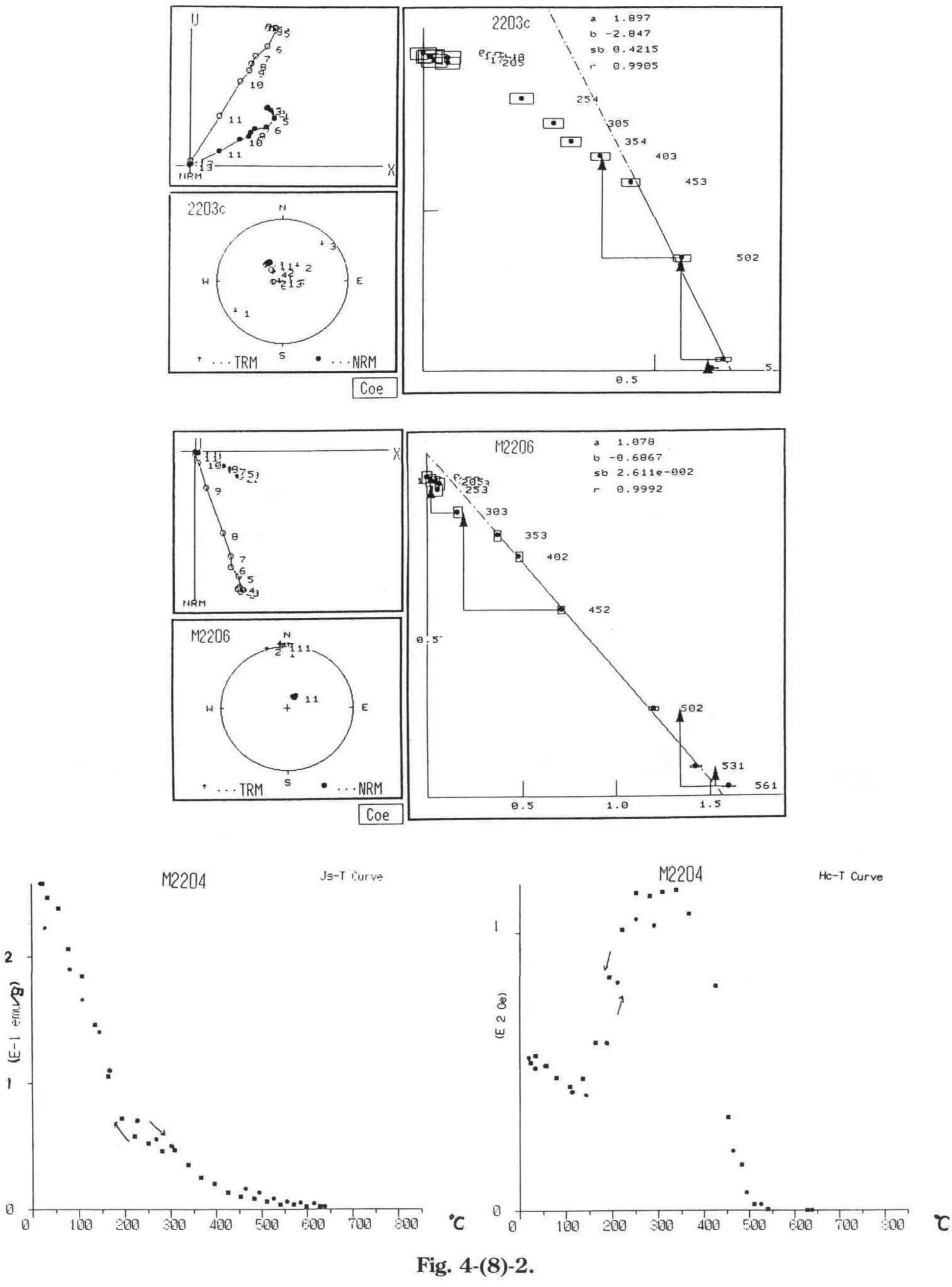
2203c
a 1.897
b -2.847
sb 0.4215
r 0.9905
254
305
354
403
453
502
0.5
U
X
NRM
N
W
E
S
+ ...TRM
• ...NRM
Coe
M2206
a 1.078
b -0.6867
sb 2.611e-002
r 0.9992
253
303
353
402
452
502
531
561
0.5
1.0
1.5
M2204
Js-T Curve
(E-1 emu/g)
Hc-T Curve
(E 2 Oe)
0
100
200
300
400
500
600
700
800
℃

Fig. 4-(8)-2.

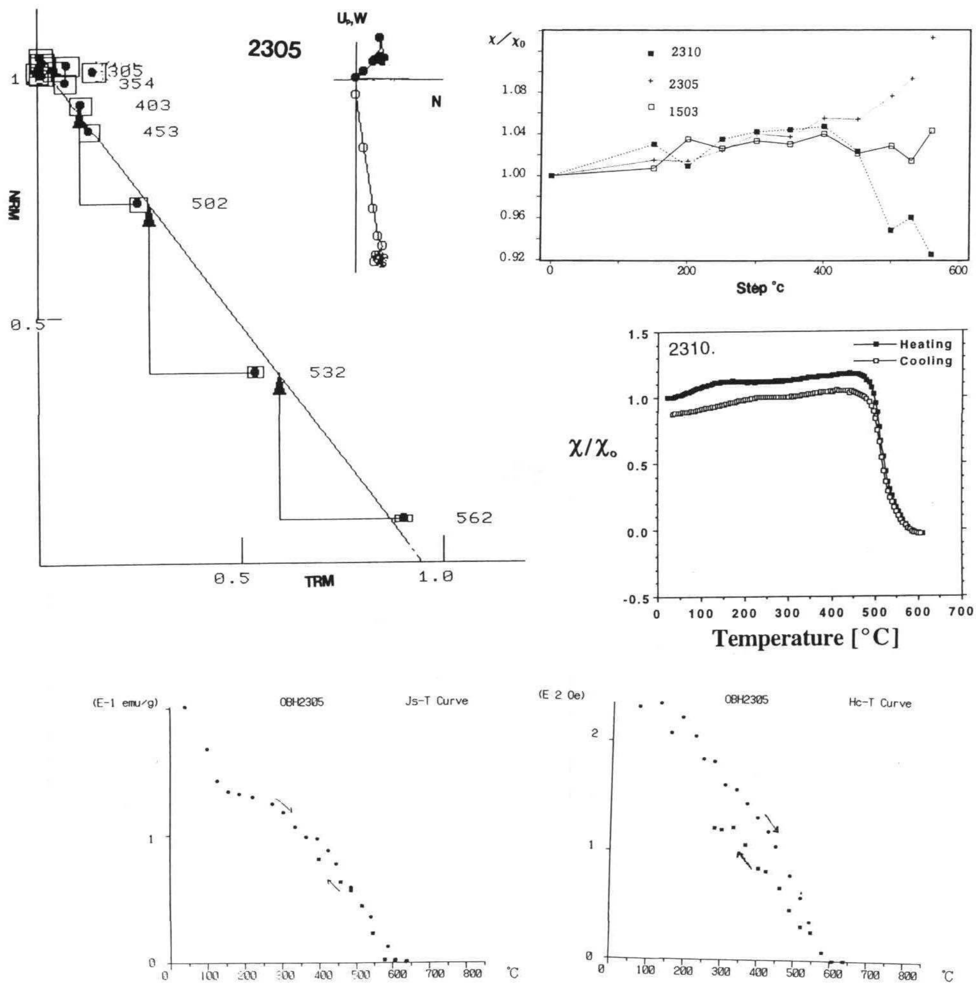

Fig. 4-(9)-1.

Fig.4-(9). Observation Hill (Fig.4-(9)-1, Fig.4-(9)-2)

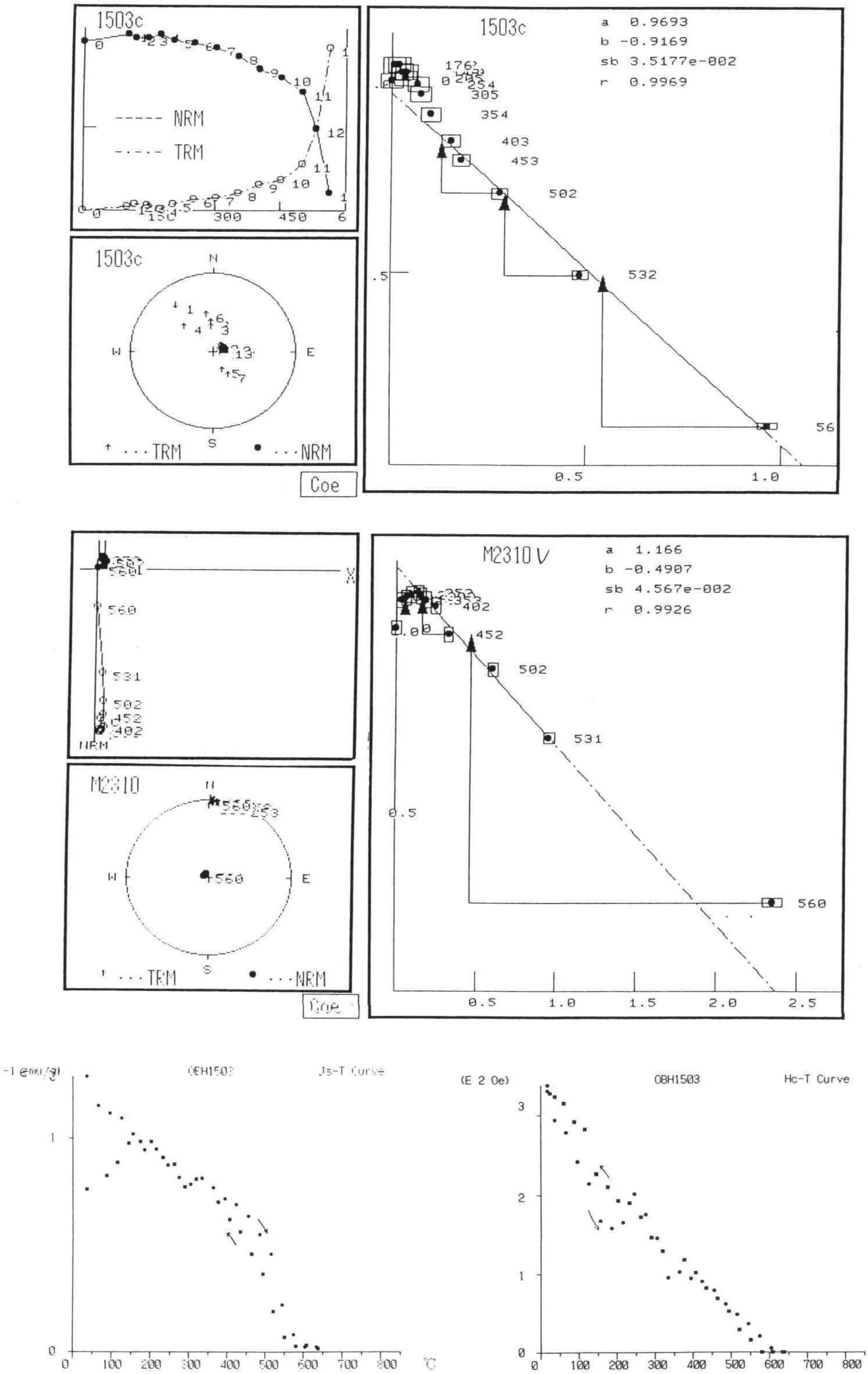
1503c
NRM
TRM
150
300
450
1503c
N
W
E
S
↑ ...TRM
• ...NRM
Coe
1503c
a 0.9693
b -0.9169
sb 3.5177e-002
r 0.9969
305
354
403
453
502
532
56
.5
0.5
1.0
X
560
531
502
452
402
NRM
M2310
N
W
E
S
560
↑ ...TRM
• ...NRM
M2310V
a 1.166
b -0.4907
sb 4.567e-002
r 0.9926
402
452
502
531
560
0.5
1.0
1.5
2.0
2.5
Js-T Curve
(E 2 Oe)
OBH1503
Hc-T Curve
0
100
200
300
400
500
600
700
800

Fig. 4-(9)-2.

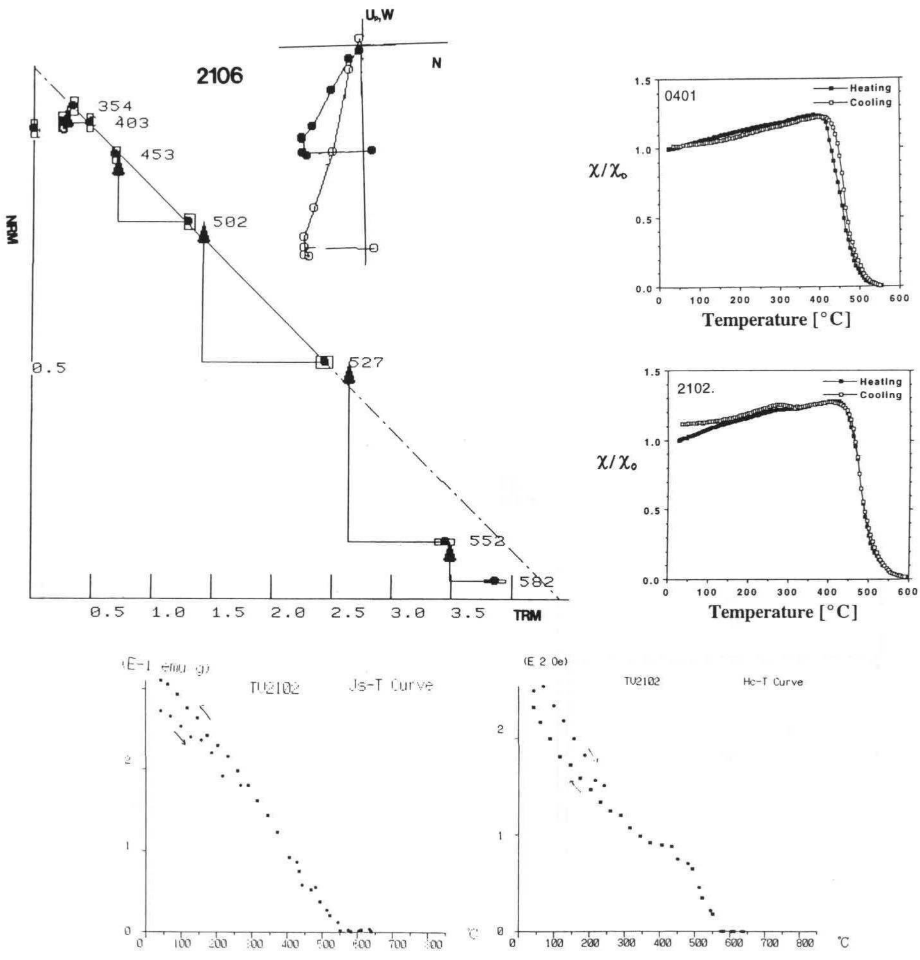

Fig. 5-1.

Fig.5. Taylor Valley (Fig.5-1, Fig.5-2)

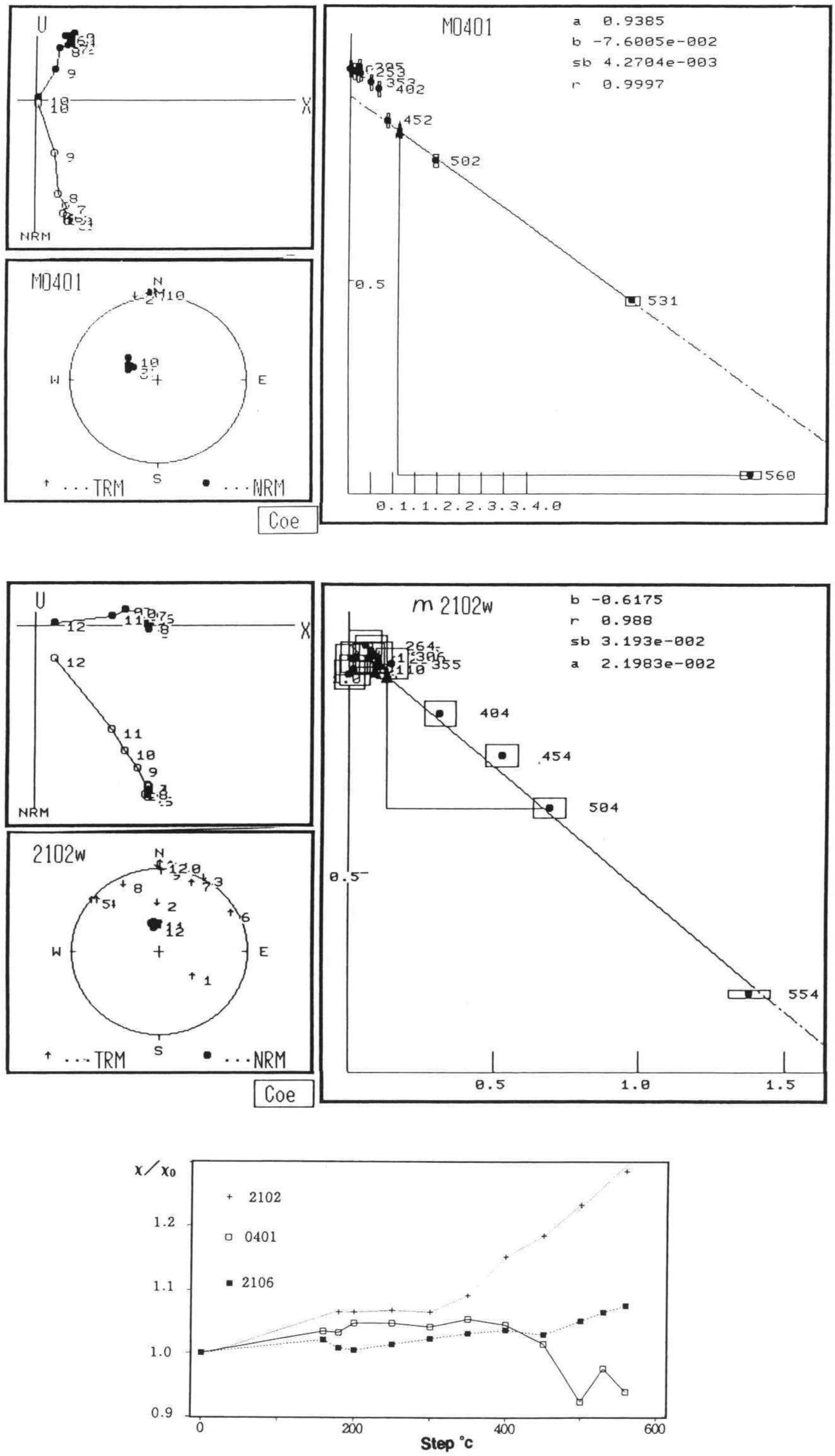
U
X
NRM
M0401
N
W
E
S
+ ...TRM
● ...NRM
Coe
M0401
a 0.9385
b -7.6005e-002
sb 4.2704e-003
r 0.9997
452
502
531
560
0.5
0.1.1.2.2.3.3.4.0
U
X
NRM
2102w
m 2102w
b -0.6175
r 0.988
sb 3.193e-002
a 2.1983e-002
404
454
504
554
0.5
1.0
1.5
χ/χ0
+ 2102
□ 0401
■ 2106
1.2
1.1
1.0
0.9
0
200
400
600
Step °c

Fig. 5-2.

Sampling site	Sample No.	J (E-3 Am²/kg)	χ (E-6m³/kg)	Hc mT	Ms (E-1 Am²/kg)	Mrs/Ms	T °C	N	fraction	F μT
Cape Royds	79010950	0.46	35				102-254	6	0.4	15
0.080±0.002Ma	79011013	0.62	26				30-147	4	0.4	12
	79010907	0.43	41				102-254	6	0.4	10
	79011011	0.98	17				158-253	4	0.2	13
									averaged F	12.5±2.1
Crater Hill	77121607	2.7	22				402-552	4	0.4	34
0.39±0.04Ma	77121610	1.5	11				415-581	6	0.7	31
	77121612	3.1	19				333-562	7	0.7	34
	77121613	1.2	22				254-562	8	0.7	14
	77121614	1.7	20	28.5	2.0	0.40	503-581	4	0.5	23
									averaged F	27.2±8.6
Twin Crater	77112710	0.32	4.6	3.0	7.9	0.14	30-205	6	0.7	26
0.47±0.01Ma	77112715	0.37	17				109-265	6	0.7	9
									averaged F	17.5±8.5
Between Cape	78012107	14.2	115	20.3	2.1	0.23	453-532	3	0.5	27
Arm. & Scott B.	78012105	2.0	37				487-552	3	0.2	10
0.50±0.05Ma									averaged F	18.5±8.5
North of Hut Point	78011806	7.0	85	42.3	1.6	0.37	253-552	7	0.7	18
0.68±0.03Ma	78011808	7.7	113				354-562	5	0.9	20
									averaged F	19.0±1.0
Hut Point	77121602	4.5	115				403-552	4	0.7	15
1.32±0.63Ma	77121603	4.6	113				403-502	3	0.3	15
									averaged F	15.0±0.0
Castle Rock	77121911	6.9	67				452-531	3	0.3	78
0.73±0.02Ma	77121907	2.5	67				415-503	3	0.6	82
									averaged F	80.0±2.0
Black Knob	78012215	0.033	2.0				158-253	4	0.2	4
0.55±0.25Ma	78012216	0.032	1.7	12.9	0.1	0.29	158-253	4	0.2	4
									averaged F	4.0±0.0
Half Moon Crater	78012203	3.1	93				205-453	6	0.4	20
0.83±0.12Ma	78012204	4.1	74	4.6	2.2	0.19	158-402	6	0.3	34
	78012205	2.8	78				253-453	5	0.3	29
	78012206	4.3	39				253-353	3	0.2	26
									averaged F	27.3±5.9
(high temp. segment	78012203						453-532	3	0.5	57
	78012204						402-531	4	0.6	45
	78012205						453-531	3	0.5	51
	78012206						353-531	5	0.7	35
									averaged F	47.0±9.4
Observation Hill	77121404	0.62	50				102-351	7	0.4	21
1.28±0.03Ma	77121503	0.68	33	29.4	1.3	0.18	403-562	5	0.8	18
	78122305	1.3	32	23.1	2.0	0.16	354-562	6	0.9	21
	78122310	1.2	46	20.5	14.5	0.18	402-531	4	0.3	25
	78122306	1.1	37				451-542	4	0.3	13
									averaged F	19.6±4.4
Taylor Valley	79010401	1.4	128				452-531	3	0.4	4
	77122102	1.4	63	24.9	2.7	0.32	355-554	5	0.8	6
	77122106	0.65	234				354-527	5	0.4	5
									averaged F	5.0±1.0

Table 1 Summary of data
J: NRM intensity χ:initial susceptibility Hc: coecivity Ms: saturation magnetization
Mrs: saturation remanence T: temperature range in which F was calculated
N: number of data points over which F was calculated F:calculated paleointensity from NRM-TRM diagram.

5. Summary and Conclusions

A summary of the results is shown in Table 1. Calculated VDMs from averaged paleointensities and the inclination data of the same samples obtained by Funaki (1984) are listed in Table 2. While VDMs for the past 5 my have been reported as being close to the present-day value (McFadden and McElhinny, 1982; Prevot et. al.,1990; Otake et.al.,1993), VDMs from the successful data of this study are very low, 0.86 to 3.8 $\times 10^{22}$ Am^2. The reason for this is unknown, but the effects of local non-dipole fields are probable.

Sampling site	Age Ma	N	F μT	VDM 10^{22} Am^2
Crater Hill	0.39±0.04	5	27.2±8.6	3.8±1.2
Cape Arm-Scott B	0.50±0.05	2	18.5±8.5	2.5±1.1
North of Hut Pt	0.68±0.03	2	19.0±1.0	2.5±0.1
Obsevation Hill	1.28±0.03	5	19.6±4.4	2.6±0.6
Taylor Vally	3.51±0.64	3	5.0±1.0	0.86±0.09

Table 2 Virtual Dipole Moment calculated
N: number of specimens F: site mean paleointensity VDM: Virtual Dipole Moment in unit of $10^{22}Am^2$.

In conclusion, Coe's version of the Thelliers' method was applied to volcanic rocks from the McMurdo region which have K-Ar ages covering the interval from 0.08 to 4.2 Ma. We obtained successful results from samples that meet the following criteria; linear segments in NRM-TRM diagrams and Zijderveld diagrams, PTRM tests, initial susceptibility after each demagnetization steps, initial susceptibility with temperature, microscopic observations, Hc and Mrs/Ms. Low geomagnetic paleointensity values were characteristic of the units sampled at McMurdo Sounds for the interval from 0.08-4.2 Ma.

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要 旨

上野直子・船木　實：南極マクマード地域の火山岩による古地球磁場強度

南極マクマードサウンドの11箇所から採取した溶岩について，テリエ法Coeバージョンを適用して，古地球磁場強度をもとめた。試料は直径1インチの円柱に整形したものを61個使用した。ある温度で試料を無磁場中で加熱・冷却した残留磁化と，同温度で無磁場中で加熱後，定磁場中で冷却して付加した熱残留磁化を測定した．加熱する温度は段階的に上昇させ，100℃以上では加熱・冷却中に窒素ガスを炉内に流した．採取試料は，カリウムーアルゴン年代法による測定で，8万年から420万年の生成年代が報告されている．代表的試料については，初期帯磁率の温度変化，振動試料型磁力計による飽和磁化の温度変化，保磁力などを測定して，岩石磁気的立場からの検討を加えた。保磁力が小さすぎる採取地点の結果は除き5箇所の試料からダイポールモーメント0.9～3.8×$10^{22}$$Am^2$をもとめた．この値は現在値8×$10^{22}$$Am^2$に比べて，明らかに小さい値である．