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Heather Hilchey
Carleton College,

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A Signal of Abrupt Climate Change in Alaska

Heather L. Hilchey
Senior Integrative Exercise
March 10, 2004

Submitted in partial fulfillment of the requirements for a
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Heather L. Hilchey
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Clint Cowan, Advisor

Abstract

Hysteresis and ARM parameters for the top two meters of the 20 meter loess profile located at Gold Hill Steps, Alaska, indicate that variation in susceptibility, within the profile, is due to concentration and not composition of ferromagnetic grains, below the modern soil, and that this signal is not being influenced by pedogenic processes. As a result, the susceptibility profile can be used as a proxy for climate change, indicating that the region of increased susceptibility spanning a depth of 1.32-1.50m is part of a climate signal. Correlation between Gold Hill Steps and the Halfway House site, 50km away, whose susceptibility profile displays a similar increase in susceptibility dated at 11.6kyr ± 1.3kyr, provides preliminary evidence for the presence of the Younger Dryas climate change in Alaska.

Keywords: Younger Dryas, Magnetic Susceptibility, Alaska, Loess, Climate

Introduction:

Climate Change and the Younger Dryas

There are a number of factors that govern climate change; these include, for example, the amount of solar radiation received by the earth as part of the Milankovitch cycle, solar insolation, and the positions of the continents, among others. These factors operate cyclically yet independently and on different time scales. As a result, the interpretation of climate change is very difficult. Within recent geologic history there have been instances of abrupt climate change that do not fit well into any known cyclic patterns. These short-term fluctuations, some of the most recent being Younger Dryas and the Little Ice age, do not fit into regular modes of climate change, they are quick to occur and involve drastic changes in temperature. As a result, scientists must focus on the mechanisms for generating abrupt climate change and address the likely hood of such an event occurring in the near future. To do this they must first be able to see the extent of this climate change on a global scale, making research in less documented areas, like Alaska, very necessary.

The Younger Dryas was a 1,000 year interval of near-glacial conditions at the Pleistocene - Holocene boundary. This climatic change is well documented in ice cores from Greenland, and in the terminal moraines and pollen records of Northern Europe (Hajdas et al. 1998; Alley, 2000). The transition into the colder climate of the Younger Drays was originally thought to have taken roughly forty years (Taylor et al., 1997) but new research indicates that this change took place within only 5-10 years (Rutter et al., 2000). The implications of this are immense when you consider that the mean temperature dropped anywhere from 5°C to 10°C (Severinghaus et al. 1998) in only a few years, not a lifetime as some had previously assumed. In Greenland the temperature was 15± 3°C colder than today placing the temperature at –46±3°C (Severinghaus et al. 1998). It has been shown that this climate change was coeval with changes in both atmospheric composition and sea-surface temperatures in the north Atlantic (Mayewski et al. 1993; 1994; Rahmstorf, 2002). Though the Younger Dryas was first thought to be unique to the north Atlantic, it is now generally accepted to be global in scale (Denton & Hendy, 199; Rutter et al, 2000; Easterbrook, 2002)(Fig. 1). This has occurred only recently although scientists have been researching the presence of this interval in other parts of the world for the past decade. Everyday, as technology advances and techniques are refined, new discoveries are made pertaining to the impact of this abrupt climate change.

Although scientists now consider the Younger Dryas to be a global event, they have had some difficulty in constraining the causal mechanisms for a change of this magnitude on a global scale. As a result, sites that indicate the presence of the Younger Dryas need to be well documented and contain reliable data.

It appears that the Younger Dryas was felt globally but that does not mean that the climate change was simultaneous or that it was a global "cooling" (Rutter et al. 2000). For the most part, mechanisms generated to explain this event indicate that its occurrence was relatively simultaneous. Furthermore, it can no longer be assumed that the Younger Dryas was a worldwide cold snap. Increasing evidence in southern regions, like Antarctica, indicate that warming was felt during this time (Sowers and Bender, 1995, Alley, 2000) and that this warming was a result of the Younger Dryas climate change (Rutter et al., 2000). These findings both attest to and contribute to the difficulty in

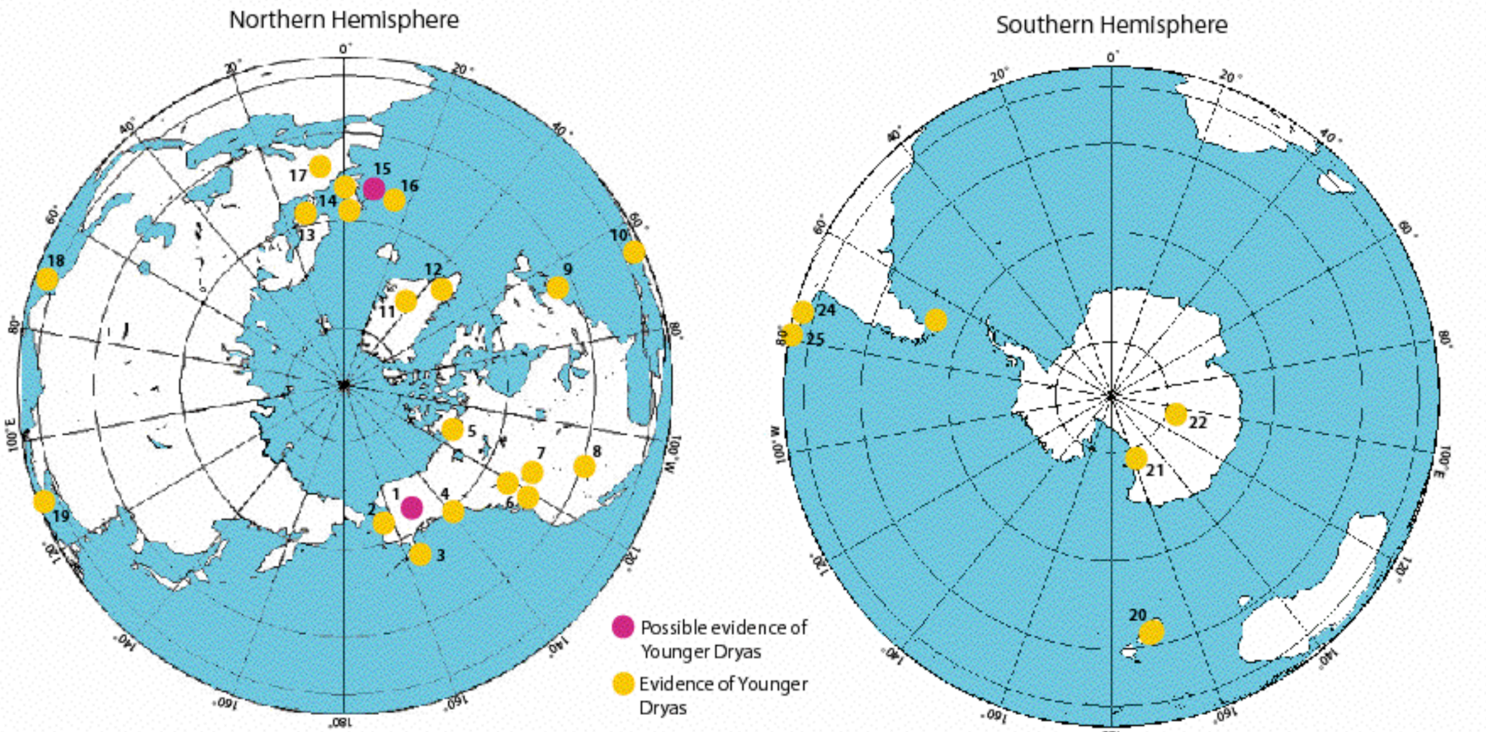

Figure 1: A map of the global distribution of Younger Dryas sites encountered in the research for this paper. Both northern and southern hemispheres are represented and a distinction is made between multiply sited locations and those either less sited or first mentioned in this paper (denoted by either yellow or magenta circles). The sites are numbered on the map and are cited as such. **1.** Gold Hill Steps (the subject of this paper), Central Alaska (Dry Creek, Walker Road) (Bigelow, et al. 1989). **2.** Arolik lake (59° 28′ N, 161 07′W) (Hu, et al., 2003). **3.** Kodiak Island (Hajdas, et al., 1998). **4.** Glacier Bay (Engstrom, et al., 1990). **5.** Wollaston Penninsula, Victoria Island (Dyke & Savelle, 2000). **6.** British Columbia, Canada (Easterbrook & Kovanen, 1997). **7.** Crowfoot and Bow Lakes, Canadian Rocky Mts. (Reasoner, et al., 1994). **8.** Titcomb basin, Wind River, WY. (Easterbrook, 2002). **9.** Splan Pond, (45° 15′15″N, 67° 19′50″W) (Walker, et al., 1991). **10.** Cariaco Basin, Tropical Atlantic Ocean (10° 40′N, 65 W) (Hughen, et al., 1996). **11.** GRIP and GISP-2 (72.6° N, 38.5° W) (Dansgaard, et al., 1993), Summit, Greenland (Taylor, et al., 1993). **12.** Dye-3, Greenland (Taylor, et al., 1997). **13.** Solberga, Sweden (Hajdas, et al. 1998). **14.** (two dots) Scotland and England, (Ruddiman, 2001) **15.** Lough Inchiquin, Galway, Ireland (Doebbert, 2002). **16.** V23-81 (off the coast of Ireland) (Lehman & Keigwin, 1992). **17.** Julier Pass, Switzerland (46° 28′21″N, 009° 43′41″E) (Ivy-Oches, et al., 1999) and Lake Gerzensee, Switzerland (Lehman & Keigwin, 1992). **18.** North Eastern Arabian Sea (Schulz, et al., 1998). **19.** Sulu Sea, South China (Kudrass, et al., 1991). **20.** Franz Josef Glacier, Southern Alps, New Zealand (Denton & Hendy, 1994) (Newnham & Lowe, 2000). **21.** Taylor Dome, Antarctica (77° 47′47″S, 158° 43′26″E) (Bender, et al., 1994). **22.** Vostok, Antarctica, (78° 28′S, 106° 48′E) (Sowers & Bender, 1995). **23.** **24.** Huascaran, Peru (Thompson, et al., 1995). **25.** Papallacta Valley, Ecuador (Clapperton, et al., 1997).

identifying a Younger Dryas climate signal within a climatological record.

The Younger Dryas is generally considered to have taken place between 13,000 and 11,500 calendar years before present, which is 11,000 to 10,000 years BP (radiocarbon)(Rutter et al., 2000). In Greenland it is well documented at 12,820±260 to 11,640±230 years ago (Rutter et al., 2000). Accurately dating climate change proves to be a difficult procedure, in part due to variations in sampling procedures. Rutter et al. (2000) suggest that variation in dates from one site to another may be a result of the time necessary for the climate change to propogate, but this is impossible to say without knowing the causal mechanism. Until then, dates that fall in or around this period are generally accepted.

Location

There has been a notable amount of paleoclimate research conducted in Alaska (Engstrom et al, 1990; Walker et al, 1991; Hajdas et al, 1998) and much of it has focused on the loess of the Tanana and Nenana river valleys (Begét and Hawkins, 1989; Bigelow et al., 1990; Begét et al.,1990; Waythomas and Kaufman, 1991; Begét, 2001). The loess of this region is considered to be a continuous record of local paleoclimate (Begét, 2001) that in some areas dates back to 140,000±10,000 years before present (Vlag et. al, 1999). This is mostly a result of its slow accumulation and deposition in an unglaciated corridor. Loess has also been found to be an accurate means for recording climate change. Through the use of rock magnetism, Begét et al. (1990) first discovered that magnetic concentration and corresponding magnetic susceptibility variations in Alaskan loess are proxy for wind strength.

Of particular interest, to this paper, are the loess sections at Halfway House and

Gold Hill Steps (Fig. 2). These two locations have been well researched by way of rock magnetism (Begét et al, 1990; Begét, 1990; Hamilton, 1991; Vlag et al, 1999; Lagroix and Banerjee, 2000). During the summer of 2003, I participated in an REU program at the University of Minnesota. While there I worked under Subir Banerjee and graduate student France Lagroix of the Institute for Rock Magnetism. As part of my internship I analyzed the modern profile or surficial two meters of a 20 meter loess profile located at Gold Hill Steps (2km northwest of Faribanks, Alaska)(Vlag et. al, 1999, Lagroix & Banerjee, 2000). The purpose of my research was to use rock magnetism to assess this two meter profile and identify any possible climate signals. This research was spurred by the indication that a signal, suspected to be the Younger Dryas, was present within the surficial two meters of the loess profile at Halfway House (50km southwest of Faribanks, Alaska).

Loess and Magnetic Susceptibility

Magnetic susceptibility is the measure of the extent of perturbation of an applied magnetic field by a substance or magnetic mineral (Begét et al., 1990). This property is both concentration and composition dependent. Magnetic susceptibility was first used as a proxy for wind strength by Begét et al. (1990) who proposed that loess deposited near the source or carried by stronger winds will have higher susceptibilities and distal loess will be relatively depleted in magnetic minerals thus having a lower susceptibility. The higher susceptibility is due to winnowing of transported sediments which results in higher concentrations of denser magnetic minerals. As a result, in regions where cold periods are characterized by dryer windier weather, such as Alaska, higher susceptibility values should indicate a change to a colder climate.

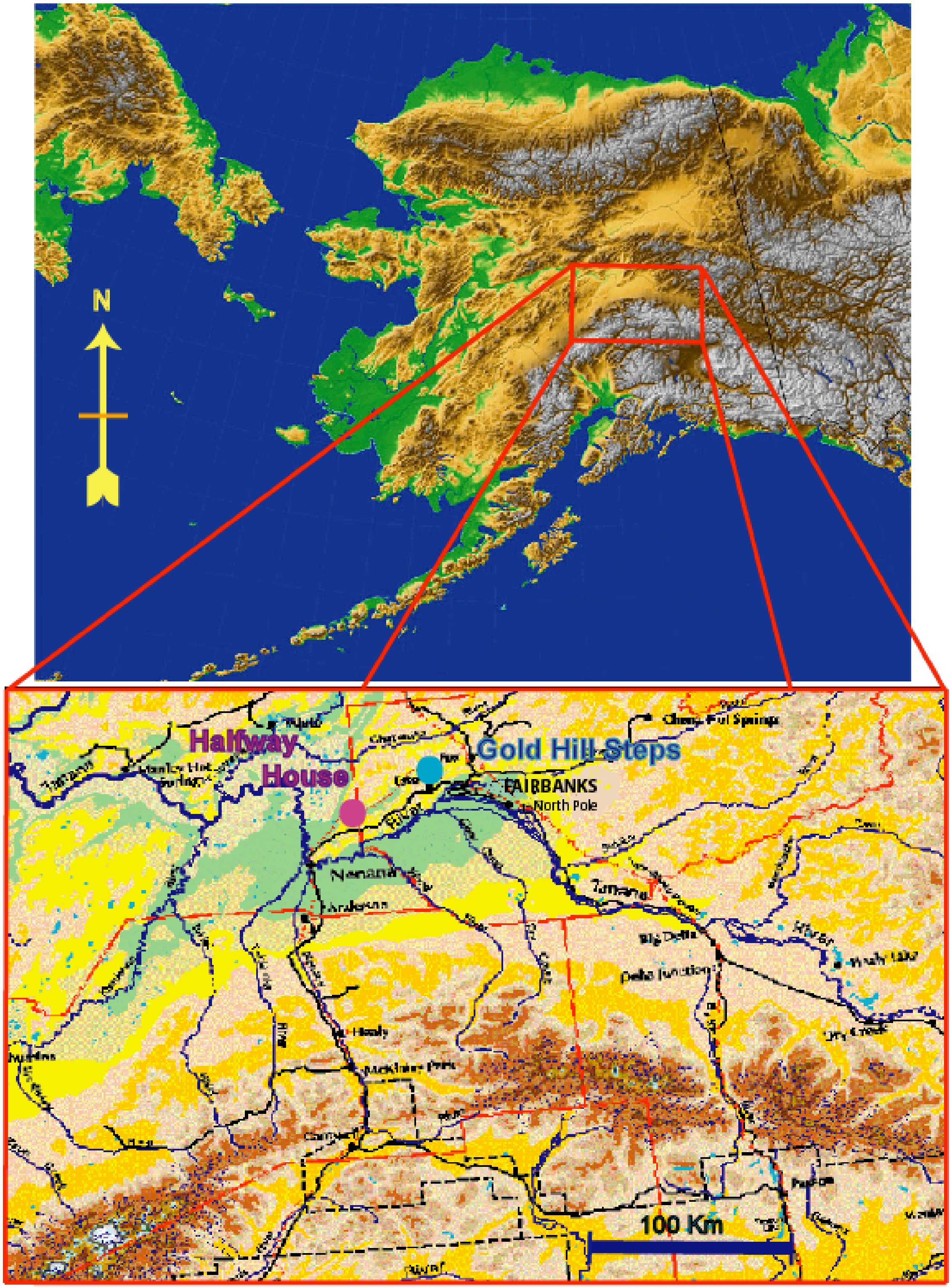

Figure 2: Topographic map of Alaska and enlargement of the Tanana and Nenana river valley region. Gold Hill Steps (64° 51' 22" N, 147° 55' 37" W) is located roughly 2km northwest of the city of Fairbanks. A similar loess profile, Halfway House, is about 50km southwest of Fairbanks. Both sites are found along the George Parks Highway.

Measurements and Analysis

Sample Collection

The samples were collected in 2002 by France Lagroix, of the University of Minnesota, and Peter Solheid, of the Institute for Rock Magnetism, University of Minnesota. Samples were taken from the Gold Hill Steps (GHS) site at 2cm intervals along a 20m loess profile. Steps were dug into the hillside to aid in sample collection and the steps were then carefully correlated to generate the complete profile. All measurements to be discussed in this paper were taken during the summer of 2003 at the Institute for Rock Magnetism, in Shepherd Laboratories, on the University of Minnesota campus.

Figure 3a is an illustration of the stratigraphy for the top two meters of loess at the GHS site. Each soil horizon represents a different stage in the formation of the modern soil in which chemical processes such as oxidation and reduction occur (Dunlop and Özdemir, 1997). These processes play a significant role in affecting the susceptibility profile and other magnetic parameters. For this reason most paleoclimatic profiles exclude the top 2 meters. Here the final soil horizon (C_{ox}) ends at a depth of 65cm, as determined by the lack of sand and distinct coloration associated with soil horizons, therefore these processes should only be of concern for the first portion of the profile. It is important to consider the stratigraphy because it provides an independent framework for interpreting the analytical data.

Total Magnetic Susceptibility χ and Ferromagnetic Susceptibility χ_f

Low field susceptibility measurements were taken using a Geofyzika KLY-2 KappaBridge AC Susceptibility Bridge, in range 1. The one hundred susceptibility values

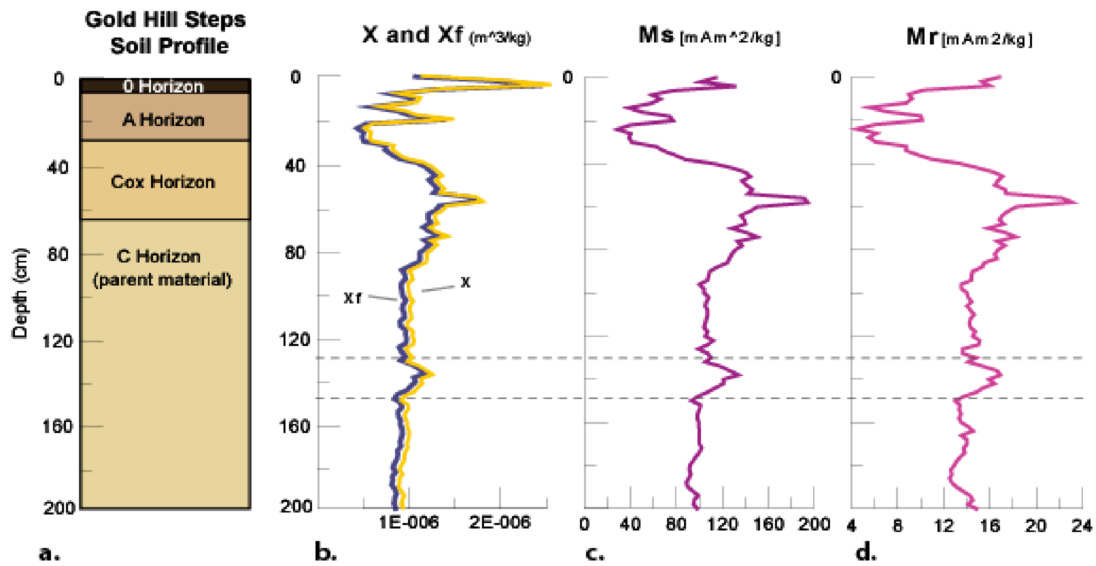

Figure 3: Soil profile and magnetic analysis of the first two meters at Gold Hill Steps, with sampling intervals of every two centimeters. **a.** Stratigraphy of the loess profile displays well defined soil horizons with the O-Cox horizons containing organic material and the area below Cox containing tan to brown silt. **b.** Susceptibility and Ferromagnetic susceptibility (light line and dark line respectively) are concentration dependent. The profiles show identical covariation indicating that the bulk of the susceptibility is due to ferromagnetic grains. **c.** Saturation Magnetization and **d.** Saturation Remanance Magnetization are composition and concentration dependent parameters. The similarity in shape of the 3 profiles (four graphs) suggests that the area of increased susceptibility (enclosed by the dashed lines) is due to variation in concentration of ferromagnetic grains.

were converted from volume to mass and plotted with depth (Fig. 3b). The susceptibility is quite variable within the modern soil but remains constant within the parent material, with the exception of the increase in χ through the 1.32 - 1.50 m interval. This increase in susceptibility is the suspected Younger Dryas signal.

Ferromagnetic Susceptibility χ_f is a parameter that is derived from subtracting High Field Susceptibility (χ_{hf}) from Susceptibility (χ). High Field Susceptibility along with Mr, Ms, Hc and %S-ratio (to be discussed later) were measured at room temperature on gelcap samples using a Princeton Measurements Micro-Mag Vibrating Sample Magnetometer (Micro-VSM) in an applied field of 1 Tesla. It is clear through comparison of the χ profile and χ_f profiles (Fig. 3b) that the variation in the curves is identical and that both show an increase in susceptibility within the parent material. Since ferromagnetic susceptibility is a parameter that singles out ferromagnetic grains (see appendix), this indicates that the bulk of the total susceptibility is due to the ferromagnetic particles within the section.

Saturation Magnetization M_s and Saturation Remanance Magnetization M_r

A sample's Saturation magnetization (M_s) is the magnetization at which all the ferromagnetic minerals of the sample, in a large applied field, become saturated. M_s is an intrinsic magnetic property of each individual ferromagnetic mineral (Moskowitz, 1991). A bulk sample's M_s will be composition and concentration dependent (Fig. 3c)(Vlag et al., 1999).

Saturation Remanance Magnetization is the remanance that is left when the field applied in Hysteresis (see appendix) is reduced to zero. This property is grainsize independent but is generally not used alone. M_r (Fig. 3d) becomes important when divided by M_s and this parameter will be discussed below.

The covariance between M_s, M_r and χ (Fig. 3b-d) suggest that the fluctuations within the parent material (below ~40 cm) do in fact result from variations in the concentrations of grains and that these grains are mostly ferromagnetic grains.

Ferromagnetic Susceptibility over Saturation Magnetization, χ_f/M_s

The plot of ferromagnetic susceptibility over saturation magnetization (χ_f/M_s) (Fig. 4a) shows that the increase in susceptibility in the soil profile (0-40cm) is due to a concentration of superparamagnetic (SP) grains (most likely of magnetite)(see appendix). These SP grains are formed in-situ within the modern soil due to soil forming processes, such as decomposition and oxidation (Dunlop and Özdemir, 1997). Greater values of χ_f/M_s indicate a greater concentration of ultra-fine particles (< 0.03μm) or SP grains (Moskowitz, 1991). In figure 4a it can be seen that the values are very high in the first 40

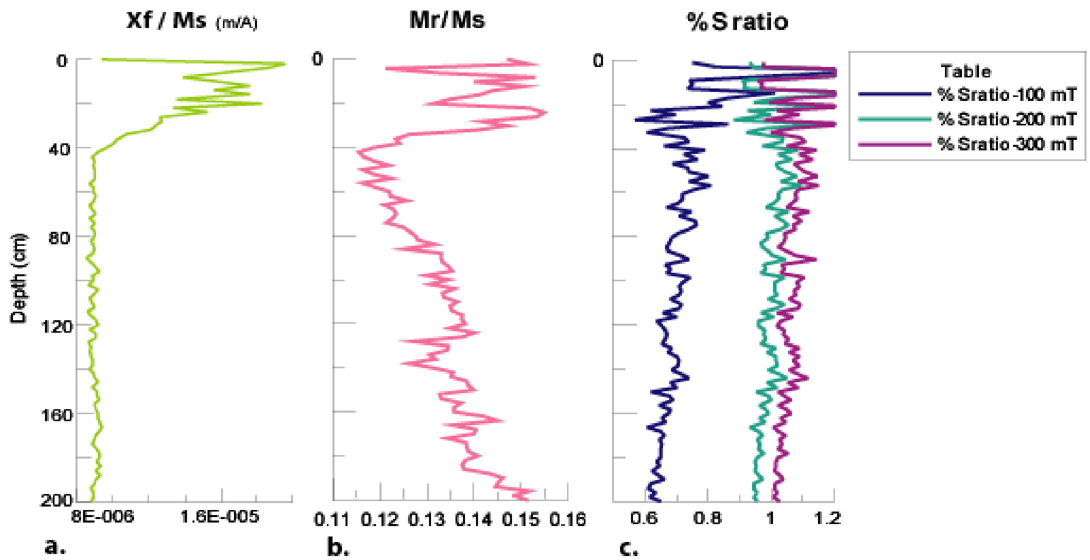

Figure 4: a. The graph of Xf/Ms shows SP grains above 40cm and a rather constant grainsize below this region. **b.** Mr/Ms displays the fraction of PSD grains. From this plot it appears that all of the samples fall within the PSD grainsize range The graph also indicates an trend of increasing coercivity from about 40cm on, which may be attributed to maghematization. **c.** The % S-ratio gives an indication of the types of minerals present in the section. Values near one denote magnetically soft minerals like Maghemite and Magnetite. Values less than one are attributed to harder minerals like Goethite and Hematite. The S-ratio near 1 indicates that the main minerals contributing to coercivity are probably Maghemite and Magnetite.

cm and then drop off sharply to remain around a value of $8x10^{-6}$m/A. There appears to be relatively no variation in grainsize in the section after 40cm indicating that the increased values of susceptibility, mentioned before, are a result of variation in concentration.

M_r over M_s, and %S-ratio

M_r over M_s is a definitive means of distinguishing between particle sizes. For magnetite pseudo-single domain (PSD) grains (see appendix) plot in the range of 0.1-0.5 M_r/M_s (Moskowitz, 1991), but usually remanance ratios between values of 0.1 and 0.4 are considered to denote PSD grains (Banerjee, 1981). The plot of M_r/M_s for GHS (Fig. 4b) falls well within this range of values which is expected since most natural samples plot within the PSD range of values (Moskowitz, 1991).

From the graph of χ_f/M_s we know that due to soil forming processes the first 40 centimeters consists mostly of SD grains. A steady increase in M_r/M_s (after 40 cm) indicates that alteration is occurring but it seems likely that this alteration is diagenetic and not pedogenic since it steadily increases throughout the parent material. Furthermore, none of the other parameters indicate any change in grain size or chemical variation within this region. If the process appeared to be pedogenic this would be of concern because it would directly affect the climate signal seen within the profile. There were no visual indications of any pedogenic processes at the outcrop and there appears to be no indication of any unusual chemical process within the parameters. As a result, it is most likely that this alteration is maghematization (see appendix). This process would cause magnetite grains to appear larger and have higher coercivities, but show no variation in actual grain size. This idea is also supported by previous research conducted at GHS (Vlag et al., 1999). They found that the top interval corresponds with that of maghemite because the low temperature curves for this portion of the profile are interpreted as indication of maghematization. In addition to this, oxidation to maghemite is not an unknown occurrence within loess profiles (Dunlop and Özdemir, 1997).

This idea is supported by the %S-ratio (Fig. 4c), which was measured on the Micro VSM in an applied field of 1 Tesla and backfields of -100, -200, and -300mT respectively. This ratio demonstrates that the increased coercivity is certainly not goethite or hematite (the values are too high) and most likely maghemite. The magnetically hard minerals like hematite and goethite have values less than 1 (Geiss, et al., 2003) and magnetically soft minerals like magnetite and maghemite have values close to 1. From the plot of S-ratios we can see that values are close to 1 for backfields of 300mT suggesting that magnetically soft minerals like maghemite and magnetite are the main carriers of magnetic remanence in these samples (Geiss, et al., 2003).

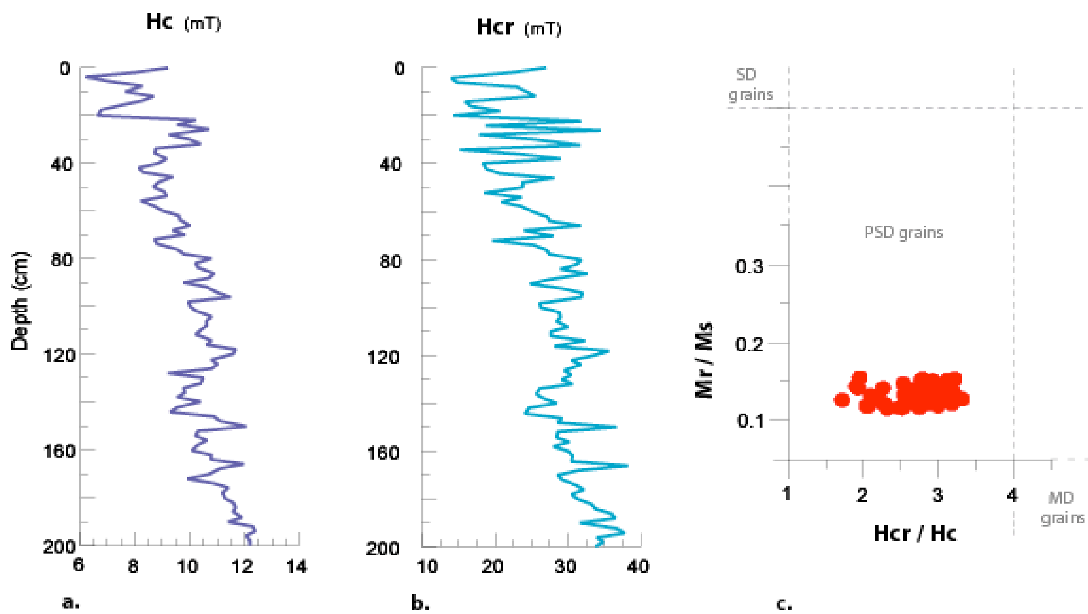

Figure 5: **a.** Coercivity and **b.** Coercivity of Remanance are grain size dependant properties. The graphs display an increasing coercivity with depth. This is an indicator of the occurance of chemical processes, and could be attributed to maghematization. **c.** The graph of Mr / Ms vs Hcr / Hc superimposed on the Day Plot (Day, et al 1977). From the plot it can be seen that all the points fall under a PSD grains size.

Coercivity H_c and Coercivity of Remanance H_{cr}

Both Coercivity and Coercivity of Remanance are grainsize dependant properties. A range of 10-15mT for H_c of synthetic magnetite samples denotes PSD grains (Moskowitz, 1991). About half of the samples in the GHS-2 section fall into this category (Fig. 5a), and they are mostly those in the lower portion of the profile. There is a high level of variability in the coercivity (Fig. 5a,b) line but it is possible that this is due to variations in testing procedure. The relevance of this graph is to show the trend of increasing coercivity with depth as was seen in the graph of M_r/M_s and is seen in both the H_c and H_{cr} lines. This trend indicates that something within the profile changes with depth, and this is considered to be most likely maghematization of the grains.

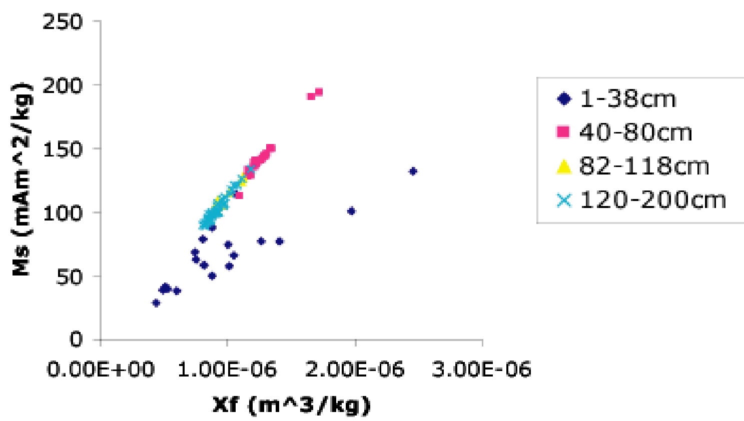

Figure 6: The plot of Ms vs. Xf. These two parameters are indicators of grain size and the split in the graph is a clear indicator of different grain sizes present in the profile. The points that plot on the lower part of the graph are the smaller grains or SD grains. These points fall within the first 40cm of the profile (denoted by the diamond shape). This was previously indicated by the graph of Xf / Ms.

M_r/M_s vs. H_{cr}/H_c and M_s vs. χ_f

The majority of the grains within this section are PSD grains, as is the case with most natural sediments. This is evidenced by the plot of M_r/M_s vs. H_{cr}/H_c (Fig. 5c) which shows that the samples fall within the range 1.5 to 3.5 Hcr/Hc and from 0.1 to ~0.15 Mr/Ms. According to the Day plot (Day, et al., 1977) these values are within the range denoting PSD grains. A plot of M_s vs. χ_f is also used to denote grain size (Fig. 6) and in this instance there is actually a split in the series plot. The points that show up on the lower half of the graph (labeled diamonds) should be the smaller grains within the profile, the SP grains. These points should be the ones with higher values of χ_f/M_s (see page 9). Since all the points on the lower part of the graph fall within the first 40cm as indicated by the diamonds, the data of M_s vs. χ_f supports that of the graph of χ_f/M_s.

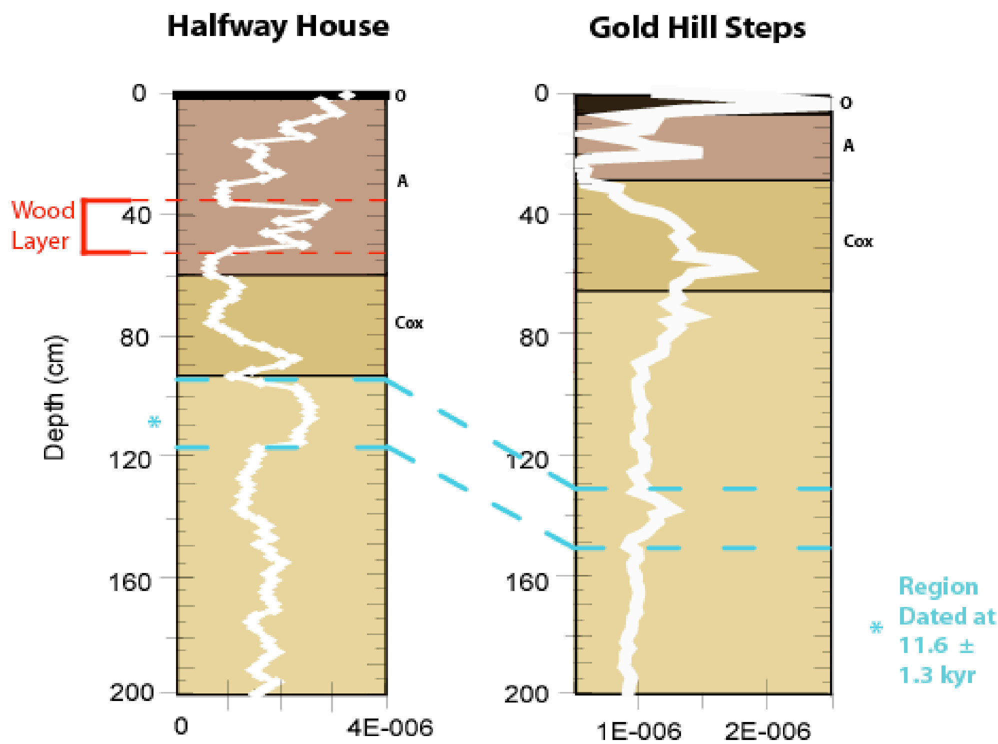

Figure 7: Chronology for Halfway House and correlation with Gold Hill Steps. The susceptibility profiles (in white) for each location are superimposed on their respective stratigraphic columns with the soil horizons labeled. The increased susceptibility attributed to a fallen log present at the Halfway House site is labeled as "Wood Layer". The area of increased suscetibility at Halfway House, suscpected to be the Younger Dryas, was dated at 11.6 ± 1.3kyr (labeled by an asterisk). This date corresponds to that of the Younger Dryas. This area of increased susceptibility is correlated with that of the Gold Hill Steps profile as indicated by the thick dashed lines.

Chronology

No chronology is available for Gold Hill Steps but one does exist for Halfway House (50 km southwest of Fairbanks, Alaska). Due to the similarities in magnetic signals between the two locations it is possible to make comparisons. Both of these profiles show similar trends in χ, M_s, M_r, M_r/M_s, χ_f/M_s, and H_c within the C-horizon and with respect to the interval of increased susceptibility (Fig. 7). It is apparent that the soil horizons are not a perfect match, but the presence of a fallen log in the interval of 35cm to 55cm is the source of the displacement within the Halfway House profile. Both profiles have a moderately steady susceptibility value within the C-horizon except for a region roughly 20cm thick where susceptibility values are higher. In the Halfway House profile this region has a thermoluminescence date of 11.6kyr ± 1.3kyr (Oches, et al, 1998). This is the date corresponds with the date generally accepted for the Younger Dryas.

Discussion and Conclusion

Evidence shows that most regions experienced the Younger Dryas as a cold, dry period of about 1,000 years in length. The data from Alaska, at Gold Hill Steps, displays a region of increased susceptibility that, in loess of this region, is indicative of a period of dry weather with greater wind in intensity. Environmental magnetic experiments conducted on this region, such as □ and hysteresis, indicate that the increase in susceptibility is due to an increase in concentration of ferromagnetic grains and not a change in magnetic mineral assemblage. During cold periods, such as the Younger Dryas, greater wind strength is able to carry and deposit denser particles, such as magnetite, resulting in higher susceptibility.

Although susceptibility is most often used to denote variation in concentration, it can also be affected by changes in the composition of magnetic grains. Because of this, other tests are needed to verify a possible climate signal. At GHS the covariation of M_s, M_r, and □ indicates that variation in the susceptibility profile is due to concentration of grains and the similarity between □ and $\square_f$ shows that these grains are mostly ferromagnetic grains. Furthermore, the lack of variation in $\square_f/M_s$ below 40cm signifies that there is no variation in grain size within the parent material. An in depth look at the ARM analysis (see appendix) of these samples would provide further information as to the grainsize distribution of the minerals in this section. There does appear to be a chemical process occurring within the parent material evidenced in the graphs M_r/M_s, H_c and H_{cr} and this process is most likely maghematization because it would explain both the increasing coercivities and the lack of variation in grain size. Maghematization is a common process that occurs within loess and has been identified within the topsoil at this location (Dunlop and Özdemir, 1997; Vlag et al., 1999). In addition to this, it is important to note that although maghematization might be occuring it is a process that does not necessarily disrupt the climate signature of the original magnetic minerals.

It is possible to guess at the mineralogical assemblage of this section based on the % S-ratio. For GHS, the signal near 1 at backfields of 300 mT, is most likely an indicator of magnetite and maghemite (Geiss et al., 2003). Values less than 1 usually indicate the presence of hematite and goethite. Since this section also has values of less than 1 for the %S-ratio it is likely that there are small amounts of hematite and goethite present within the profile (Geiss et al., 2003). Nevertheless, the main contributors to these samples are most likely magnetite and maghemite. To truly address the mineralogical assemblage of this section, further tests, such as conducting high and low temperature analysis on a Mössbauer spectrometer, would be necessary.

There are many similarities between this profile and the profile at Halfway House. Both regions are similarly vegetated and similarly situated. Their susceptibility profiles are also similar, with the same rise and then drop in susceptibility just before the end of the C_{ox} horizon and the same high initial susceptibility values in the A horizon. Due to this, it appears that the two regions are undergoing the same chemical processes of fermentation and oxidation within their respective soil horizons. Taking these similarities into account it is possible to say that the date for the region of increased susceptibility at Halfway House is the same as for that of Gold Hill Steps. If this can be assumed than it provides strong preliminary evidence that the Younger Dryas was felt in Alaska. Optical Stimulated luminescence tests have been run on the GHS section in an attempt to date the profile but until these dates are available (they are still being analyzed) it is necessary to rely on the correlation with Halfway House for a chronology.

There are few documented cases of the Younger Dryas in Alaska. Hajdas et al. (1998) found evidence of the climate change in Midge fossils and Engstrom et al. (1990) in pollen from lake cores, but besides these the cases are few. It is possible there are so few documented cases because there are few records. The northern half of Alaska fluctuates between periods of permafrost and glaciations. These events would remove climate signals and in some cases make it impossible for preservation to occur. It is also possible that there are few documented cases because the records just do not exist. Nevertheless, the loess of the Tenana and Nenana river valleys are ideal testing grounds for addressing the presence of the Younger Dryas in Alaska, because they have been proven to provide both local and regional paleoclimate records (Begét and Hawkins, 1989; Bigelow et al., 1990; Begét et al.,1990; Begét, 1990; Hamilton, 1991; Waythomas and Kaufman, 1991; Vlag et al, 1999; Lagroix and Banerjee, 2000; Begét, 2001). These climate records, whose susceptibility profiles have been correlated with marine _^{18}O, extend beyond 140,000±10,000 years. Heinrich events and other climate change events have been identified within these profiles but none have noted the presence of the Younger Dryas. This is probably because the climate change is recent enough that it is still within the portion of the profile considered “modern soil” and usually excluded from analysis. This study, however, suggests that climate signals, which are not being influenced by chemical processes, can be present within these upper most portions of loess profiles. If scientists include the "modern soil" within their future climate studies of this region they could provide insight into the presence of the Younger Dryas abrupt climate change in Alaska.

Research concerning the presence of the Younger Dryas in Alaska and other regions is important because it would solidify the view that this well known climatic perturbation was of a global scale. The extent of this event felt in other regions assists in generating more accurate models of climate change and the mechanisms that govern them.

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Appendix

Magnetic Susceptibility, χ

Magnetic susceptibility or χ is defined as the magnetic moment per mass of the sample divided by the induced magnetic field ($\chi = M / H$) and is expressed in units m^3/kg. It is a measure of the magnetic response of a mineral to an induced magnetic field and displays how easy or hard (magnetically) a sample is. Susceptibility values are subject to the magnetizations of all of the magnetic minerals in a sample, as a result grain size and concentration contribute to the final value. Even though this is the case, more often than not variations in susceptibility can be attributed to variations in concentration.

Susceptibility can be measured by subjecting the sample to a low field on the order of 0.1mT - 1mT. At such low values the effects of the magnetic field are reversible and the sample experiences processes such as domain wall translation, domain wall rotation, and rotation of magnetization in single domain grains (Banerjee, 1981).

Low field susceptibility can also be measured as a function of temperature. The process is the same although the material is heated to a peak temperature and then cooled. High temperature susceptibility is valuable because peaks in susceptibility can be seen at temperatures characteristic to certain minerals. In natural samples interpretation of the susceptibility peaks can be difficult because these characteristic temperatures can be suppressed or shifted due to the presence of multiple mineral types, prior chemical processes, or variations in magnetic mineral grain size. Although there are many things that can complicate the interpretation of the data, this measurement is helpful in determining mineralogical assemblage.

Ferromagnetic susceptibility χ_f

Ferromagnetism is the type of magnetism that is generally conceived of as "magnetism". A Ferromagnetic mineral has a parallel alignment of moments that gives it a strong magnetization in one direction outside the presence of a magnetic field (Moskowitz, 1991). Ferromagnetic susceptibility is the susceptibility that results from subtracting High Field Susceptibility (χ_{hf}) from Susceptibility (χ). This parameter singles out the susceptibility signal that is a result of ferromagnetic minerals.

Hysteresis

Hysteresis is the property of a magnetic mineral (Ferromagnetic mineral) to retain memory of an applied field (Moskowitz, 1991). If the variation of magnetization with applied field is plotted it creates what is called a "hysteresis loop". Generation of hysteresis requires an applied steady magnetic field that is varied from a peak value (+) to the opposite peak value (-) and then back again. One hysteresis measurement can give you important parameters like saturation magnetization (Ms), saturation remanance magnetization (Mr), coercivity (Hc), and coercivity of remanance (Hcr). These parameters are important because they are dependant on grain size and therefore useful in the grain sizing natural samples.

The underlying magnetic processes involved in obtaining hysteresis are as follows. A natural sample can contain multiple types of magnetic minerals with various domain states. If the sample is subjected to an applied peak field of say 1T in a particular direction this saturates the material and aligns all the magnetic moments (domains) in that direction (Ms). As the field is reduced to zero the domains begin to orient themselves accordingly. A magnetic remanance (Mr) will persist past the point where the field is zero due to magnetization retained by some of the minerals. The field is then flipped in the other direction and increased to the opposite peak value. At some point before the peak field is reached the magnetization of the sample will become zero this is the coercivity or Hc. Then the domains flip and begin orienting along with the applied field and saturation is reached in the opposite direction. A plot of the variation of magnetization along with the magnetic field generates what is called a hysteresis loop.

Superparamagnetic (SP) and Pseudo-single domain (PSD) grains

There are four subdivisions of magnetic behavior based on grain size: these are superparamagnetic (SP), single domain (SD), pseudo-single domain (PSD), and multidomain (MD) (Moskowitz, 1991). The main premis for these subdivisions is the idea that a magnetic mineral is composed of small regions (1-100's microns) called magnetic domains which have a local magnetization that is saturated but not necessarily parallel.

For this study the primary focus is on SP and PSD grains. Superparamagnetism results when the particle size is on the small end of the single domain size range (where the grain is uniformly magnetized to its saturation magnetization). Eventually a threshold is reached where the coercivity and remanance values become zero and the small grains are considered SP grains.

Pseudo-single domain grains (PSD) exist between single domain (SD) and multidomain (MD) grains. For magnetite this size range is 0.1-20μm. These grains exhibit properties of both SD and MD grains such as high remanance and low coercivity respectively.

Maghematization

Maghemite (_-Fe_2O_3) is formed when magnetite undergoes low-temperature oxidation and lattice vacancies are left in the mineral structure due to the oxidation of

Fe^{2+} ions to Fe^{3+} ions (Stacey and Banerjee, 1974). If this process proceeds undisturbed, a crystal of maghemite will form from the original microcrystal of magnetite without the generation of any new crystals. If any hematite is present within the initial magnetite grain an additional process will occur where an autocatalytic growth of hematite is included within the mixed crystal (Stacey and Banerjee, 1974). Maghemite's chemical composition is identical to hematite (_-Fe_2O_3) although it is denoted as _-Fe_2O_3 because its crystal structure (cubic spinel) and magnetization are similar to that of magnetite.

Anhysteretic Remanance Magnetization, ARM

Anhysteretic remanance magnetization is the magnetization acquired by subjecting a sample to the combined effect of a large AF field and a small DC field (Stacey & Banerjee, 1974). As the alternating field is reduced to zero the sample retains a remanance that is proportional to the strength of the DC field imposed (Moskowitz, 1991).

Often before imparting an ARM the sample is first demagnetized. This is accomplished by inducing an alternating field, the process being very similar to acquiring ARM but without the steady DC field (Stacey and Banerjee, 1974). The orientation of the minerals in the sample will follow the alternation of the field and as it is reduced the minerals of higher coercivity will be locked in a fixed orientation (Irving, 1964). As the field nears zero all the minerals will be left in some 'random' fixed orientation leaving the sample as a whole magnetically impotent.

ARM is useful because it provides information on the grain size domain of the magnetic minerals present. Since SD and PSD grains are better carriers of ARM than MD grains (Butler, 1992) they are the ones of most concern in this process.