

AN ABSTRACT OF THE THESIS OF

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Title: Dust Storm Transport of Pathogenic Microbes to Viking Scandinavia
A Query into Possible Environmental Vectors for Disease Pathogenesis in a
Closed Biological and Ecological System

Abstract approved:

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Roberta Hall

This thesis is an integrated study that links several disciplines- archaeology, anthropology, geography, atmospheric sciences, and microbiology. It attempts to generate an argument that central to climate change is disequilibrium in human ecologies- in my case, disease ecologies in Iceland during the 15th century.

This thesis investigates the environment's effect on human adaptability. The effect of the environment on Icelanders as they moved from settlement to later periods was disquieting. The climate of the world was changing- moving from the Medieval Warm Period to the colder Little Ice Age.

I analyze the disease ecology of the 15th century and also conduct an archeological and cultural analysis of the Icelandic people, to show the deficiencies in their adaptation, and submit that certain shortcomings in their physical environment, as well as the inadequate adaptive synthesis to the environment, led to a marginal adaptation. This was augmented by political unrest and problems with outside trade, which left them vulnerable and susceptible to disease pathogenesis.

I discuss the climate change during the Little Ice Age, and assert that this event is the crucible that crushed Iceland after 400 years of reasonably good fortune. Hundreds of epidemics, natural disasters, and hardships befall the Icelanders. One of them is the plague, which comes twice in the 15th century. The important observation here is that the epidemiological and archeological evidence does not always match up. The principal problem is that the traditional vector for the disease cannot have survived the climate as it was in the winters during the LIA. I offer an analysis that pontificates this issue and I examine the ongoing debate concerning The Black Death in Europe.

I introduce another possible explanation: the introduction of disease through environmental vectors. The creation of disease ecologies through climate change is important, in light of problems that we face today. I discuss the phenomenon of the dust storm and its connection to disease pathogenesis.

By showing several key examples of dust from Africa to disease pathogenesis in the Caribbean, I make the connection a good one. In addition to this connection is the atmospheric analysis that shows incontrovertibly that the dust found in Greenland ice cores is only from Asia. Finally, there is the fact that the inveterate loci of the plague bacterium is located in the same areas that Asian Dust Events occur and travel from.

I create a methodology for investigating this disease ecology and am able to show that the pathogen can be identified in situ- meaning that it can be found in geological deposits that can be properly dated. My pilot study creates a methodology for the examination of ice cores- the principal reservoir for atmospheric deposits made during the LIA.

Finally, I look at the aftermath. I introduce the idea of disease ecology, as opposed to that of a healthy ecology, and suggest by the end of the thesis that within the disease ecology are created many of the platforms for emergent biological changes that translate through evolution over time.

Like the bacterium in the ice core, I suggest that evidence for disease states in the history of a people can be found through laboratory techniques. The presence of the CCR5 gene mutation is indicative of such a presence. I believe that the presence of the delta 32 gene mutation found in Icelandic people is the result of being exposed to the plague in the 15th century.

This thesis is a platform for future synoptic scale disease studies.

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Dust Storm Transport of Pathogenic Microbes to Viking Scandinavia:
A Query into Possible Environmental Vectors for Disease Pathogenesis in a
Closed Biological and Ecological System

by

David Carter Boling

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request

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/_____
David Carter Boling, Author

ACKNOWLEDGEMENTS

This work has been a long time coming and it is finally good to have completed the writing and the merciless nights sweating it out and working through this vastly interdisciplinary endeavor. These kinds of endeavors are never easy and are not for the type that thinks shallowly, linearly, and those who are pinned to one department and one way of thinking.

I have always worked on several layers and much to the chagrin of others, managed to keep up with the plethora of subjects that interested me, whether it be medical studies, engineering, molecular science & biology, medieval and occult literature, archaeology and anthropology, GIS and geography, astronomy and climatology, cartography and multimedia mapping, applied visual arts. I have also tried to maintain rigorous language studies.

My wish for the future is that interdisciplinary research becomes the norm, rather than the exception and doors are swung open and a great willingness expressed from departments that sit at opposite ends of the campus. It is interesting to note just how close synthesis of ideas come and go, when academic politics, vested interests, and guarded isolation act to deride the efforts. As I have found in my research, the wall between human ecology, deoxyribonucleic acid, and dust storms is not as built up as you might think.

Following my graduation in 1992 from Berea College, I quickly moved into medical anthropology and archaeology. I wanted to work as a biological anthropologist and quickly realized I would need to take a ton of science classes and get lab experience before doing so. To make ends meet, I detoured through field archaeology for ten years.

In the off time, I pursued many other interests. I had a great fascination with the systems science and future human technology. With my keen design background, I wanted to incorporate this interest into a tenable working platform- one firmly grounded in biological and ecological parameters- where greenhouse technology, geodesic domes, underground building, and emergent technology are implemented to create total synthesis with exterior environment. These ideas fueled my fascination with sustainable systems and emergent technology.

I spent the summers doing archaeology all around the country, and the winters taking medical and biological classes, and off time working in labs and hospitals, horse farms, building greenhouses and water gardens, landscaping, working in various offices, libraries, an investment brokerage, and even construction from time to time. I also traveled the world and continued my study of languages (Spanish, German, Russian) and cultures specific to my interests, namely Scandinavian, Russian, and indigenous Arctic peoples.

I did archaeology digs in the summer and sat in cold classrooms in the winter. This was a 10 year endeavor and was not the easiest existence. I began taking biological anthropology classes at the University of Kentucky, chiefly under the guidance of Dr. Susan Abbott, and Dr. Deborah Crookes. To complement my work in biological anthropology, I also took classes at the medical school.

The friends that have watched me work over the past couple of years know the hardship that archaeology brings. Its tough miserable work and not everyone can tough it out. Mostly it's the constant travel and sleeping in mud huts and Motel 6's.

Many people have come into my life since the early nineties when I took my first anthropology class at Berea College in 1990 and did field school at the Shaker Village in Kentucky in the summer of 1992. Beginning in Berea, where my youthful naiveté was molded by thoughtful progressives and driven thinkers, especially the Farmhouse Crew- you know who you are- Thanks so much for the good times!

The days spent cycling through Appalachia gave me a lot of time to cogitate and begin my ecological thinking. The Friday discussions with Dr. Michael Berheide from Political Science were legendary (even in his own words). We discussed current political events, quantum physics, statistics, the meaning of life and death, religion, and emerging sciences. We even touched upon the strange and unusual world of the paranormal and metaphysics.

These discussions were something that were never planned; I usually felt the need to talk and talk I did. I would race over from wherever I was on campus and try to catch him around 3:30 or 4:00- before he left for the weekend. This serendipitous discussion usually left me in a state of epiphany. I find myself looking for the same thing- every Friday, wherever I am in the world. Thank you Mike!

I cannot talk about influences without talking of my friends- though some have come and gone, I would like to thank those who gave patience, guidance, and perseverance when I needed it. First of all, I want to thank my friends Barry McNees, Doug Owens, Rob Gibbs, and Jan Hunter. They have provided much in the last couple of years and have always been there when I needed to talk- or bitch as was mostly the case. They are all amazing funny and have been there through every bad idea, and failed romance I have had.

My creativity and spiritual aspects have been augmented by my friend Chris Eaton, a brilliant architect that fused quantum physics and design principles. He exclaimed one day that everything around us was in constant flux- a vibrating matrix of existential states. Nothing is materially permanent- everything is vibrating and moving in and out of various states of energy states. The electromagnetic spectrum is a most amazing and vexing phenomenon! He was able to show me how to take physical science precepts and apply them to design and systems science.

I understood this to mean that one could understand complexities of the universe, if one were to look at the smallest phenomenon and see its effects on the larger system around it. The simple fluttering and vibration of a butterfly's wings is a good example. The Butterfly Effect was something very intriguing to me, and the scientific visual of the Lorenz Strange Attractor forever turned my mind over to systems studies. This greatly influenced my thoughts concerning ecology and complex systems.

The biggest influence on my ideas concerning future adaptation is my friend Mike Mossey, whom I met wandering aimlessly on campus. We immediately hit it off. Mike's mind rests not only in the world of the present, but eagerly hungering for that of worlds to come. He is a humanist, a scientist, and true technologist. He has been able to do so much since I have known him- he runs World Technology Update, (a radio show dedicated to emerging sciences) builds computers and robots, remodels anything, and is involved with private space travel- Mike is a true renaissance man. Thanks for being there Mike!

Finally, a big thanks to my new friends- Anders Carlson and Faron Ainslee- from Glacial Geology. They have sucked down enough beer with me to float an oil tanker. In doing so, I learned to survive the horrific nightmare of the writing process. Special thanks to my roommate Steve Borrego, who has been one of the most inspiring persons I have ever known. His life has so many parallels to my own, but so many beautiful differences- he has roamed the earth, working as a wildlife biologist, tattoo artist, and punk rocker.

However different our lives were, the circumstances necessitated similar living arrangements. He is one of the most colorful and opinionated men I have ever been privileged to know. Thanks for all the help and making life on 5th street in Corvallis amazing.

Another local I want to thank is Kelly Tharp. She is a woman I met in a bookstore, while perusing the science fiction section. We immediately became friends since we shared this particular interest. Being a sci-fi writer herself, she could appreciate the tedium behind my own writing. She graciously opened her home to me for retreats from campus. The many hours of Farscape, Stargate, and the X-files were definitely needed after slaving away on the research. Kelly and her cats gave me wonderful home away from home!

I have also had a few girlfriends who have been influential. I particularly want to thank Hester Haverkamp for being who you were in 1991. You were exactly what I needed that winter. The many nights we spent talking and walking around the icy campus were legendary. I would also like to thank Cynthia Sims for making the early nineties a time never to be forgotten. The wine making, the nights spent carousing the city, the intense conversations and time together were unbelievable. I will never forget summer school in 1993's neurophysiology class where we did everything but pay attention to the instructor. That summer was the best I have ever had.

Finally, to Elizabeth Roberts for instilling in me the will to move my ideas forward and into graduate school, though it would, in the end, not include her. She was a lovely woman whom I wish I could have shared my successes with here in Oregon.

Though never a girlfriend per se, I want to thank my friend Piper Uhl for being one of the most mysterious, enticing, and “quantum” human beings I have encountered. I never know when I will hear from her- its random and usually NOT arranged. Thanks for being there for me in 2000. You are an amazing individual.

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In the Geosciences department, Jon Kimerling was my adviser for the Earth Information Sciences and Technology minor. Finding you in your office was sometimes a geographical challenge, but when I finally nailed you down, you were very kind, helpful, and amazingly rich in anecdotal humor and wit. I want to thank you for the amazingly intellectual yet fun classroom experiences that you created in the many classes I took under your guidance.

I took my first microbiology class in 2001 with Dan Rockey and it changed my focus completely at OSU. His patience and guidance that term gave me the platform that I could later build upon, where I could work on my ideas concerning ancient disease, environmental vectors, and genome reservoirs of past viral and bacterial exposure. Dan, I could not have done this without your help and your lab. The people in your lab were fantastic and I will never be able to thank you enough for the help given this past year.

Another person of note would be Court Smith, the ecological anthropology professor. He and I spent many hours elucidating upon complexity and chaos, and its applicability to anthropology. I learned a lot from your classes and I want to thank you for being there when others couldn't be. You were more helpful than you know!

There is one last person in the department that I would like to thank, and that is David McMurray. David, I never thanked you for allowing me to work for you in 2002, but I really had fun. Cultural studies of protest music- melodic expressions of social revolution- demonstrate another aspect of a chaotic system and illustrate the emotions that lie at the center of the human experience.

Finally, I also want to thank my family, while never really understanding exactly what I was doing, never regretted a minute of this lunacy. It all worked out Mom and Dad. I love you both! I would never have gotten anywhere in life without one other special lady. I want to thank my grandmother Edith Farmer, who has always believed in me and supported me without any hesitancy.

David Boling

Trestled twixt the butterfly wing-
Softly flutter, softly sing....



TABLE OF CONTENTS

I. THE IDEAS

Chapter 1: The Introduction and Ecological Premise	1
Ecological and Anthropological Framework	6
The Objective of the Study	13

II. BACKGROUND INFORMATION

Chapter 2: Dust Storm Phenomenon	16
The Mechanism	16
The Dust Storm and its Antecedents	18
Dust Distribution Worldwide	21
Evidence for Environmental Vectors for Disease	22
Chapter 3: Emergence of the Human Disease Ecology	31
European Disease Ecology at the Time of Viking Expanse	36
Chapter 4: Iceland Geography and Climate	41
The Climate in the North Atlantic	49
The Little Ice Age	55
The Asian Dust Event	57
Chapter 5: Scandinavian History and Archaeology	61
Icelandic Settlement and Ecology	71
The Change in Climate	80
Chapter 6: The Plague Bacterium	83
The Disease Ecology of Iceland: an Analysis	86
Chapter 7: Hypothesis and Postulation	102

III. INVESTIGATION OF DISEASE ECOLOGIES

Chapter 8: The Archaeological Investigation of Disease in Scandinavia	103
Chapter 9: Using PCR in the Determination of Disease Etiology	109
Preservation of DNA in Ice Cores	113
Variables behind Environmental Preservation.....	116
Chapter 10: Outline for Ice Core Examination and the Pilot Study	123
Thompson Extraction Method	126
The Pilot Study.....	129
Preparation of the Ice Cores	130
The Polymerase Chain Reactions.....	131
The First PCR Reaction.....	132
The Second PCR Reaction	136
The Third PCR Reaction	137
The Final Experiment	140
The Results.....	142
Chapter 11: The Next Step	143
Appendix: CAS Analysis of Icelandic Ecology	151
Literature References:	165

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1. Dust events originating from Asia and Africa	21
2. Geological Map of Iceland	43
3. Side View of atmospheric circulation	50
4. Planet view of atmospheric circulation	51
5. Estimated temperatures in Iceland through time.....	54
6. Number of weeks of sea ice in Iceland	54
7. Ratio of O_{18} and O_{16} in Greenland ice cores	55
8. Extent of La Tene culture.....	64
9. Europe at the time of Viking expanse	67
10. Viking settlement across the North Atlantic.....	71
11. Iceland Settlement	74
12. Icelandic History.....	76
13. The flea (<i>Xenopsylla cheopsis</i>) and <i>Yersinia pestis</i>	89
14. The longhouse	95
15. Interior of the longhouse	99
16. Another interior of the longhouse	100
17. Sources of nutrition for the Icelander	104
18. Polymerase Chain Reaction.....	110
19. Cycle of PCR amplification.....	111
20. Compounds, their susceptible bonds and preservation potential.....	120
21. Specimen DNA, their environment and preservation information.....	120
22. Ancient DNA protocol as given by Cooper.....	122
23. Map of Thompson sampling sites	126
24. Thompson ice core sampling device.....	128
25. PCR final gel run.....	141
26. Close up of final gel run	141

DEDICATION

This thesis is dedicated to my twin brother Kevin and brothers Eric and Brian.....Though we haven't always been able to be with one another and events have transpired that created great distance between ourselves, my thoughts have never wavered far from our days together...Sorry for the many days away, and the many holidays spent on opposite ends of phone lines.....

**"People will accept your ideas much more readily
if you tell them that Benjamin Franklin said it first."**

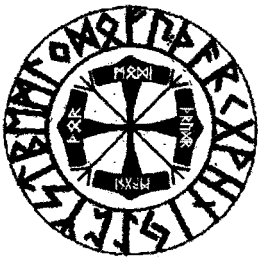
--Unknown

"Not all who wander are lost."

--J.R.R. Tolkein

**"I may not have gone where I intended to go,
but I think I have ended up where I intended to be."**

--Douglas Adams



**"He is truly wise
who has traveled far
and knows the ways of the
world."**

**He who has traveled
can tell what spirit
governs the men he
meets."**

**--Old Viking
Hávamál proverb**



"A furore normannorum libera nos domine!"

"Skona oss herre frá nördmännens raseri!"

Dust Storm Transport of Pathogenic Microbes into Viking Scandinavia

A query into possible environmental vectors for disease pathogenesis in a closed
biological and ecological system

Chapter 1: The Ideas The Introduction and Ecological Premise

Charles Lindbergh was a pioneer in aviation- crossing the Atlantic in 1927 by himself, a fact that is well known to most people. However, he was also an innovative amateur scientist, working in such disciplines as medical, biological and ecological research. In the 1930's, he assisted Dr Fred Meier – a scientist from the USDA- in collecting microorganisms from the arctic atmosphere. They were able to show that upper air masses between Maine and Denmark were full of microbial life- pollen, spores, fungi, bacteria, and viruses wafted high in air previously thought void of this kind of life. Lindbergh suggested that microbial life was not limited to the lower terrestrial air, but is conditioned to live well outside the limits previously thought. His paper, co-written with Dr. Fred Meier, was seminal in its efforts to locate and evaluate the microorganisms in the upper atmosphere. They also were the first to really pronounce the “tremendous consequences” that the potential of a world wide distribution of these microbial pathogens could be produced (Meier, 1935: 20).

However, by the late 1950's, all of the work was essentially forgotten, and dismissed. Even though it had, by this time, been demonstrated that the upper atmosphere would support the aeronautical transport of microorganisms, and that tropical air masses carried hundreds more than polar air masses, it was not taken seriously by the scientists of that era.

This dust storm phenomenon is something that has been studied for many decades; however, it was the 1990's and the early part of the 21st century that produced most of the work that led to my research. In its infancy, it was a curious synoptic and planetary event, but resolution on particulars concerning the dust clouds was not feasible early on in the century. It was speculated upon as early as the mid part of the 19th century. Charles Darwin noted as he sailed in the south Atlantic that dust surrounding his ship was creating dangerous haze, and he surreptitiously assumed that it was flowing out upon the ocean from the continent of Africa, judging by its rusty color (Darwin, 1845). This was taken further by JD Hooker, who proposed that similar island and continental biota was due to wind storms, which created a passive transport for seeds, pollen, and small animals (Hooker, 1845).

It was not until Lindbergh and Meier flew over the north Atlantic and took microbial readings that science concerning the dust events took shape. It was not until much later, in the late 1990's, that major research was conducted- no doubt due to advances in microbiology, molecular biology, GIS, and remote sensing.

Dr. Dale Griffin, from the USGS, demonstrated that African dust and its³ attendant microbial cast is carried across the Atlantic and is linked to pathogenesis in the Caribbean and in the southeastern part of the United States. He links the increase in this phenomenon to climate change and increasing desertification in the Saharan Desert. These ideas were corroborated by Dr. Joseph Prospero, who found that large quantities of African dust were carried into Florida airborne, and that this high rate of transfer can exceed up to 100 mg/m³. These synoptic scale events, events that are greater than hemispheric events, impact a high percentage of the southeastern portion of the United States with great regularity. By coupling these events with local air emission problems, he says that they could have very important implications for regional air quality. He also mentions that African Dust can efficiently penetrate into the human respiratory system (Griffin, 2002 A; Griffin, 2002 B; Prospero, 2003).

Many populations in Africa and Asia suffer pneumatic distress during the dust events, and asthma and bronchial disorders in the Caribbean are linked to African dust storms. Rainwater is also affected, and since this is the primary drinking water for many in developing countries, it becomes a problem in daily survival. In Asia, entire towns and villages are engulfed in dust clouds and breathing is hindered greatly (Pelig-Ba, 2001). For populations already living in marginal and ecologically challenged areas, the effect is more pronounced. A good example of this marginalization can be found on the island of Iceland.

Iceland is an island that has a nearly perfect written history of the human⁴ occupation from beginning to the present. This is very well documented by a people who are genetically homogenous, thus making studies of their biological adaptation allowable for control. The adaptation of settlers to this isolated island and the ecological consequences that emerge after a climatic upheaval make it a perfect platform for ecology studies.

Island communities have special and unique dynamics. The dynamics of an island operate on biological and ecological constraints that are put into place by spatial and distance variables. The first states that the proximity of an island to the source of founding population: the closer the better- this is the distance effect. The second states that the size of the island: the number of species doubles with every tenfold increase in the island's area- this is the area effect (Schneider, 1997). These two variables are very evident in the course of Iceland's human settlement. This kind of settlement has taken place several times over the course of humanity's evolution, usually through island hopping, or literally, moving over "linear continental fragments" called land bridges, such as the Aleutian chain in the north Pacific and the many island chains in the south Pacific (Menard, 1986).

Ecologically, the problems that humans encounter on islands often deal with the depletion of resources, and there are frequent adaptations made to marginal, limited ecologies. Iceland is a fantastic example. The isolation variable shapes the population and any change to the system can move the system into either chaos or equilibrium. This includes climate change.

The Little Ice Age (LIA), which occurred roughly between the late 13th century and the early part of the 19th century, was the major event that disrupted the delicate ecological balance in Europe, and indeed, Iceland. Climate change brought an end to very moderate climate and easy adaptation. The effects were much greater than any change that could be wrought through societal/cultural structures. The situation on the island would have been very different if the climate had remained optimal during the later Viking era. In fact, the people may have prospered and remained self-sustaining, if the climate did not change the fate of the island. Their inability to adapt was due to cultural maladaptation to systemic ecological change.

The debate over the amount, rate, and source of global climate change over the past several decades continues. However, we can investigate the effects of climate change on the people that experienced it in the past. Predictably, the studies that have been done demonstrate loss of natural resources. This loss is often due to overkill, overuse, or environmental degradation.

Adaptation to marginal and challenging environments is something that has been the running theme for all of human evolution. It is the shaper and broker for both genotype and phenotype of humanity. The early *Homo sapiens* in Europe experienced many hardships with the last Ice Age, and resource competition with Neanderthals, when their occupations overlapped. This historical ecological backdrop was something probably not on the forefront of the Icelandic settler's minds, as day to day survival was difficult.

Biological and cultural adaptation to extreme environments is ubiquitous⁶ with human evolution. In fact, this thesis is partly an investigation of the environment's affect on human adaptability and the synthesis that occurs there. Adaptation is key to any conceptualization in the study of ecological anthropology. I will base my analysis on systems thinking and the newer concepts in ecological anthropology- emergent and complex adaptive systems that lie at the center of ecology. The change from ecological stability to instability is the cornerstone of any analysis concerning systems, especially the creation of disease ecologies.

Ecological and Anthropological Framework

Thought concerning adaptation and ecological system analysis emerged in strength in the mid part of the 20th century, in large part, due to the work done by Boas and his students at Columbia University (McGee, 2000). One of the major accomplishments of Boas was his idea of culture and the cultural assemblage having its own specific history and the idea of culture being an "emergent system" (Hatch, 1973: 48). He goes on to espouse the idea of cultural determinism and the idea that culture is the refining tool upon humans. He extended this by saying that studies of any people need to be done under their terms and seen through culture specific lenses (Hatch, 1973). Adaptation was specific to every environment, but not necessarily one delimited by it. The idea of any limitation of the environment was, by Boas, considered to be too broad to be of any consequence to the development of culture and an adjudicator of human behavior (Hatch, 1973: 341). This is, of course, wrong.

However, his ideas concerning the emergent properties in cultural adaptation are critical to my research. Stasis in any system is equivalent to system death. Change is ubiquitous to all human/environmental interactions. Major emergent behaviors that cause instability within human/environmental systems create platforms for disease and unhealthy ecologies.

Ecological thinking within anthropology rebounded in the 1940's and 1950's as anthropologists began to see that the environment and external pressures had a strong if not bigger role in the shaping of a people and their adaptation to the external world. It was, and is, at least in this authors view, a viable and more sophisticated scientific standpoint, one that was less sanctimonious, antirational, and antievolutionary.

The early principle thinkers behind the movement were Julian Steward and Leslie White. These anthropologists "developed a techno-environmental approach to cultural change" and set the stage for the principle generation of true ecological anthropologists (McGee, 2000: 225). These anthropologists began the theoretical component of what would become ecological anthropology in later decades. For Steward, culture was responsive to the "exigencies of life" (Hatch, 1973: 344) and was integral to human relations with the external world. White was more functional and considered culture to be a collection of functional adaptations to the environment. His was a very utilitarian approach.

While White and Steward focused on cultures as their unit of analysis, later thinkers looked at populations and their interactions with the environment. However, while the former stated that the surrounding environment was 'a passive background' that shaped human culture while remaining unaffected, the new thinkers used the population and the environment as their unit of analysis- to take inconsideration, the significant effect of humans upon the environment (McGee, 2000). The level of resolution becomes an important one.

In doing so, anthropologists brought biological and ecological principles to the forefront of ecological thought. Anthropologists Steward, White, and Harris, brought attention back to the evolutionary principles of Darwin and others, and capitulated once again, the process of cultural evolution with respect to the mechanism found behind all environments.

This relationship was premised on the cycle of interaction, adaptation, and transmission through future evolution. One of the limits to cultural ecology was its overemphasis on stability and not how things change over time. This is a major problem, as variables do change and ecosystems can move quickly from stable to unstable. Despite these limits, there were four aspects of cultural ecology that are useful:

1. It focuses on the environment as presenting adaptive problems and opportunities.
 2. It uses adaptive processes that shape and mold patterns and methodologies that are best suited for specific environments, specifically technology and subsistence.
 3. It shows the effect of the cultural response to the vagaries of the environment, dependent on existing socio culture features that any particular population has at any point in time.
 4. This idea is one that can be used both with historical and prehistoric peoples.
- This makes it very important for archaeological modeling and theory.
(Smith, 2004)

The anthropologist, Roy Rappaport had his major impact on anthropology during this second phase of ecological thought. According to his thinking, “nature is seen by men through a screen composed of beliefs, knowledge, and purposes, and it is in terms of their cultural images of nature, rather than in terms of the actual structure of nature, that men act”. He goes on to say that, “in order to deal with discrepancy between cultural beliefs about the environment and the environment as it really is, the ecological anthropologist must construct two models of reality” (Rappaport, 1971: 246).

One is the cognized and ‘emic’ model, which is a construct that is built in terms meaningful to all members of a culture. The second is the operational and ‘etic’ model. This model provides a construct that is built in terms of creating logical and empirical interfaces with outside and abject reality (Theory Class, 2001).

Another way to look this is to see the terms as representing two models of reality- one is external and based on abject facts, the other stemming from cultural inheritance and custom. The Emic model- this is the conceptualized view of reality that is shared by the community- usually an insider’s viewpoint. The Etic model- this is the operational view; it is the logical and empirical interface with the external world- usually an informed viewpoint. When these operational cultural adaptive modalities are in concert, there is stability in the ecology; when they are not in concert, instability is created within the system. In my case, the emic knowledge is that found in the Scandinavian culture and conceptualized model of

the world as they saw it; the etic knowledge is found in abject reality- usually it is found outside the cultural boundary.

Two major developments from this new perspective were cultural functionalism and ecological cybernetics. Both of these tend to look at stabilizing mechanisms within society and feedback loops that give order and continuity over time and space. Gregory Bateson, a British anthropologist committed much thinking to cybernetics and emergent properties. This emergent property idea was something that had talked about by several early anthropologists.

The change from culture as the adaptive element against the harsh, but rigid elements that remain unchanging, to a concept of it as a dynamic relationship of utility and reflects the growing understanding of ecology and human impact on it.

Cultural expression by humans was, and is, a reaction to the strong molding constraints, limits, as well as refining factors, of the environment that holds a people engulfed in an ecological and biological matrix. Culture could not exist or develop without this effect. It is circumstance and not cultural responses to the environment that ultimately decides the fate of a human group. Depending on the biome to which these humans are adapted, the development of their culture is stunted, given germane grounds for growth, or stopped altogether.

The development of human cultures is relative to the environment that shaped them, and this does not equate them unequivocally to one another across the board. A gradient of adaptive success still exists. Humans are multifarious and have lucrative ways of adapting to most biomes of the world.

The biomes that they choose and how they adapt largely depends on circumstance, material resources available to them, and cultural communication of knowledge over time and space. Success is determined by genetic predisposition, cultural stability, and long-term compatibility of the biome. With respect to diversity, the beauty of cultural differences is amazing, but the truth- that it is an adaptation to adversity in the immediate environment- is one that needs to be seen. A good example of this kind of progressive thinking is Hutchins' idea of culture being a process rather than "mental content" (McGee, 2000). He believes that it involves the process of "thinking and interacting in and with the physical world" (Hutchins, 1994, in McGee, 2000; 372).

This way of thinking emphasizes another area that I believe to be a cornerstone in adaptive studies- that of cognitive and psychological interactions. How a culture chooses to understand the world around itself will stand as testament to its eventual modality and synthesis with its outer reality, never mind any discrepancy between the inner and outer abject reality. These interactions create a synthesis with the outer and inner worlds of humanity, and give a platform for thoughtful adaptation. Higher cognition is given a possibility that lower base mammalian adaptation cannot deliver.

Currently, ecological analysis is now being reconstituted in ways that take into consideration new ideas in the natural sciences concerning complexity and chaos theory. These new ideas are used now to investigate the interlacing systems found in the history and biological and ecological aspects of cultures.

Complexity theory addresses the multitude of forces at work in any human and environmental exchange. ¹²

To facilitate the study of the ecological and biological construct of the island, modern anthropologists use a cybernetic systems descriptor of sorts, one mainly derived from behavioral loops and analogous cycles in nature. Called a complex adaptive system (CAS), it is never identified by its parts, but rather from its entirety. The identity of the CAS system is always given by this wholeness because of amazing thing- it exhibits the rare exposition of emergent behavior, something never expected from the parts themselves. Depending on the changes of variable expression in the CAS system, the cycle moves from one behavioral extreme to another. They incorporate all variables of human existence- cultural, ecological, biological- and all are heavily interconnected.

Adaptation is a thoughtful process that involves conceptualization of the world. This translates to a dynamic system that is brokered on change and constant redevelopment through time. Adaptation is the one constant variable within the system. There are many layers to adaptation, and one of them is physiological. A result of this biological interface is the emergence and dispersal of disease ecologies.

Disease ecologies are ecologies that are emergent features of a system such as a human settlement. It is self sustaining and brought on by a change in systemic variables that lead to major pathogenesis within the population. This type of event goes all the way back to human origins, and in some ways, it may be a major contributing factor to human evolution. How a population deals with

disease is tackled through modified physiology, behavior modification, but mostly, genetic polymorphism for our immune systems worldwide. Within the genome and its million or more lines of protein codes, we can find evidence for exposure over time. A good example would be the many immunoglobulin molecules that develop through exposure and are replicated and shared over time.

The Objective of the Study

This thesis is an integrated study that links several disciplines- archaeology, anthropology, geography, atmospheric sciences, and microbiology. I am arguing that dust storms, as an integral part of the earth's weather system, provide a microbial transport mechanism that can be found in the archaeological record of Iceland. By extension, I am hypothesizing that disease ecologies accompany major climate upheaval and that they have contributed to our evolution. I address the ecological cycles and specific adaptive strategies of Scandinavians during the Viking Age. I am looking, in particular at the occurrence of the plague- the 'Black Death'- in the 15th century, and I am suggesting that climate and environmental change may create disease ecologies. Environmental vectors may be responsible for the transmission of the *Yersina pestis* bacterium to Iceland.

The effect of environmental change on Icelanders was severe. The climate of the world was changing- moving from the Medieval Warm Period to the colder Little Ice Age. I focus on one century during the climate change, the 15th century, and look at two occurrences of the plague that occurred in 1402 and in

1494. The same study could be made in other island communities, save for the¹⁴ fact that preservation and non-contamination of microbial material is slim in the South Pacific and other island communities. Most importantly, the northern latitude of Iceland and its arctic climate provide the needed glacial ice for the preservation of atmospheric contents of air masses as they moved across the North Atlantic.

I analyze the historical record and describe the epidemiological and ecological facts- principally that the limited resource base, coupled with climate change, created a foundation that was not easily met with the cultural and technological adaptations used by the settlers. These climatic events also have to correspond to an ice record that could be found in the glaciers of Iceland and Greenland- both of which receive similar atmospheric inundations over time. This is then compared to the archeological record for epidemiological comparisons.

The cultural maladaptation to the volcanic island and the quick degeneration of the climate in the 15th century gave rise to disease propagation and epidemics that cannot be explained with conventional disease models. Using PCR techniques, I created a lab technique that could demonstrate the possibility of finding an environmental vector for this disease pathogenesis at a time when the climate and ecology changed immensely. I developed a pilot study to show that by using ice cores, a scientist could identify microbes in the ice that are linked to actual historical disease events. The disease ecology model is thus subject to empirical testing.

Through discussion of their adaptation to the arctic island, and the marginal existence that is found in this arctic climate- given the limiting factors present and the severe lack of natural resources, I reveal the effects of climate change, and related reasons for the disaster and disease cycles. I illustrate the limiting mechanism that ecology plays against Iceland's people who exemplify the elasticity of human adaptation.

This research contributes to the understanding of past, present, and perhaps future dissemination of diseases resulting from weather extremes and climatic change. The goal is to help scientists see how climate mechanisms become agents for disease and how other propagated energy transfers create an ecological and biological propensity for chaos, when change and perturbation are pushed to higher levels.

BACKGROUND INFORMATION

Chapter 2: The Dust Storm Phenomenon

The Mechanism

The vector of disease that I am looking at is found not terrestrially, nor bound to human cultural events. It is found in the space between the earth and the troposphere. An atmospheric vector is one that acts by itself and is the agent of microbial transfer, as opposed to one that acts as an intermediary and assists to another more predominant one. The force behind this vector is wind.

Wind is the motion of air measured relative to the rotating earth. The different pressures of air created around the globe create wind. The circumference of the wind's path decreases with increasing latitude north and south (Moran, 1994). The speed of the wind is relative to position. At the equator it moves at 1670 kph or 1035 mph and at 60 degrees north or south, it moves at 835 kph, or 517 mph (Lutgens, 2001).

These pressure cells have both a magnitude and a direction. Described as its vector quantity, it is measured in terms of one force per unit mass of air, which is one single kg. This one unit is further extrapolated to larger air masses, which become exponential expressions of wind force. These are measured on the Beaufort scale (Moran, 1994; Lutgens, 2001).

Several forces allocate power to the phenomenon of wind. They work together, but the dynamic is basically tension between the pressure gradients that are created by the differences between high and low pressure systems and the planetary forces (Moran, 1994; Lutgens, 2001).

Pressure Gradients: Air is moved around the globe primarily through the different pressures that exist both vertically and horizontally. Latitudinal differences in temperature and the amount of water vapor create the pressure gradients. Energy is transferred latitudinally by moving from areas of high pressure to areas of low pressure. Acceleration is a product of any change in either temperature or amount of water vapor (Moran, 1994; Lutgens, 2001).

Centripetal Force: the counter clockwise rotation of the planet pushes all the atmospheric winds in an easterly direction (Moran, 1994; Lutgens, 2001).

Coriolis Effect: It is a deflection of air to the right in the northern hemisphere and to the left in the southern hemisphere. The effect is more pronounced in the higher latitudes, with maximum effect at the poles. This is most important for large-scale circulation systems (Moran, 1994; Lutgens, 2001).

Friction: Affects the horizontal winds within one km of the surface, where obstacles slow the wind and create turbulence and shifts in direction.

Gravity: Accelerates wind direction downward and perpendicular to the surface. This force is responsible for vertical motion of air (Moran, 1994; Lutgens, 2001).

The entire set of variables really describes a tug of war. The pressure gradients created by variations in temperature and moisture content are in direct opposition to the gravitational forces and rotational forces. When there is a shift and alteration in these forces, air is shifted and is caused to accelerate up or down (Moran, 1994).

There are three types of wind. Surface winds are the main High and Low pressure systems that cycle and create weather. The higher geotrophic winds

are horizontal; they blow above the friction layer of the surface and therefore have high speeds. They are created by the equilibrium between the pressure gradient and the Coriolis effect. The last type is gradient winds which are horizontal winds that blow above the friction layer. They are created by disequilibrium between the pressure gradient and the Coriolis effect. These three types of winds are intrinsically tied together, in that planetary scale air circulation is intimately responsible for smaller scale weather systems (Moran, 1994; Lutgens, 2001).

The Dust Storm and its Antecedents

Dust storms are events that are created by atmospheric uplifting, and they move latitudinally by wind transport. They are not products of deserts themselves, but instead, are the result of the effect of climate on dry biomes of the world. Dust storm activity increases as the arid regions become drier, and vice versa.

There are nine areas of the world that are sources of dust: the Salton Sea in the desert southwest of North America, Patagonia in South America, the Altiplano in the Andes, the Sahel and Sahara deserts in Africa, the Namibian desert lands of Africa, the great Mongolian and Gobi deserts of Asia, and the Lake Eyre basin of Australia (Taylor, 2002; 83). However, dust storms occur in two principal areas of the world: the Saharan and Sahelian deserts of the African continent, and the huge desert regions of Asia. Seventy-five % of the world's dust is attributable to the deserts in these areas. Over 60% of Africa is composed of deserts and dry lands, whereas a little over 30% of Asia is composed of deserts. These deserts are getting bigger, as global warming increases. African

droughts were significant in the 1960's through the 1990's and Asia's rate of desertification is climbing. From 1975 to 1987, the annual rate of desertification there was 2100 km² per year (Griffin, 2001B; 25; Griffin, 2002B).

Desertification and tropical ecological degeneration have occurred at a very rapid rate in our lifetimes, due primarily to arid regions becoming more arid and suffering drought for 30 years or more. This action is due to two things:

1. Long term changes in natural processes.

Good examples are the glacial episodes that have occurred, as recently as the Pleistocene Era. These are caused by changes in the earth's tilt and axis, and the eccentricity of its orbit. Ice Core analysis indicates that around 14,000 to 16,000 yBP, airborne dust was deposited on glaciers more prevalently than during the previous 10,000 years, or from 16,000 to 25,000 yBP. The time period from 14K to 16K BP is a period of deglaciation. Much longer-term shifts in the relative positions of landmasses due to continental drift can also push various biomes around on the globe until major changes occur to its ecological parameters. At the other extreme, the changing rainfall patterns in the African Sahara and Sahel deserts affects the ecology of the area on a yearly cycle, yet another example of desertification caused by changes in the natural processes of the area. From these two examples, one can clearly see that changes on synoptic levels as well as regional levels can make huge changes to a biome (Griffin, 2001B; 23).

2. Short term changes in human occupancy and adaptive measures.

Major effects of human activity, particularly agriculture, are a relatively recent thing, as humans presumably have not been actively pursuing agriculture more than 10,000 years. Anthropogenic effects upon long term climate could have begun during the advent of agriculture 10,000 years ago. Most scholars put the heaviest build up of anthropogenic effects right around the beginnings of the Industrial Age, which coincides with the end of the LIA. Ruddiman argues that the effects extend much further in our evolution, specifically the early days of forest burning related to agriculture (Ruddiman, 2003).

Agriculture has created huge ecosystem devastation and loss of biome diversity, ultimately leading to desertification. A closely related human cultural adaptation is irrigation, which, in the beginning, did not affect the environment on such levels. However, over time we have created deserts out of watersheds and whole lakes have disappeared as humans have diverted natural water ways for their own needs. It is estimated that the planet loses 29 million acres of farmland per year to unsustainable farming methods (Griffin, 2001B; 24-5).

Desertification has increased the size and aridity of the deserts, due to an imbalance in the hydrological cycle. Many of these desert areas have one thing in common worldwide- where desert dust lay now, was a muddy lake during the Ice Ages. It is the microbial contents of these waterbeds, along with modern microbes that are being lifted into the atmosphere during dust events (Perkins, 2001). Other arid areas are created by human impact, and have their own anthropogenic aerosols, such as pesticides, and toxins (Penner, 2001). With

atmospheric uplift, these microorganisms and particulates are carried aloft in the dust and moved rapidly to other areas of the world.

Dust Distribution Worldwide

Dust storms are events that are a worldwide phenomenon created by weather systems in the few large desert areas of the planet.

Atmospherically, around 75% of the dust in the world comes from the deserts of Africa. Its dust events occur year round. From June to October, its dust impacts the Caribbean, Central and North America, and from November to May, the dust impacts South America, Europe, and the Middle East (Perry, 1997; Swap, 1996). In contrast, the dust events in Asia occur only part of the year. From February to April, its dust impacts the Pacific at large, North America, and eventually the entire Arctic region (Biscaye, 1996). (Figure. 1)

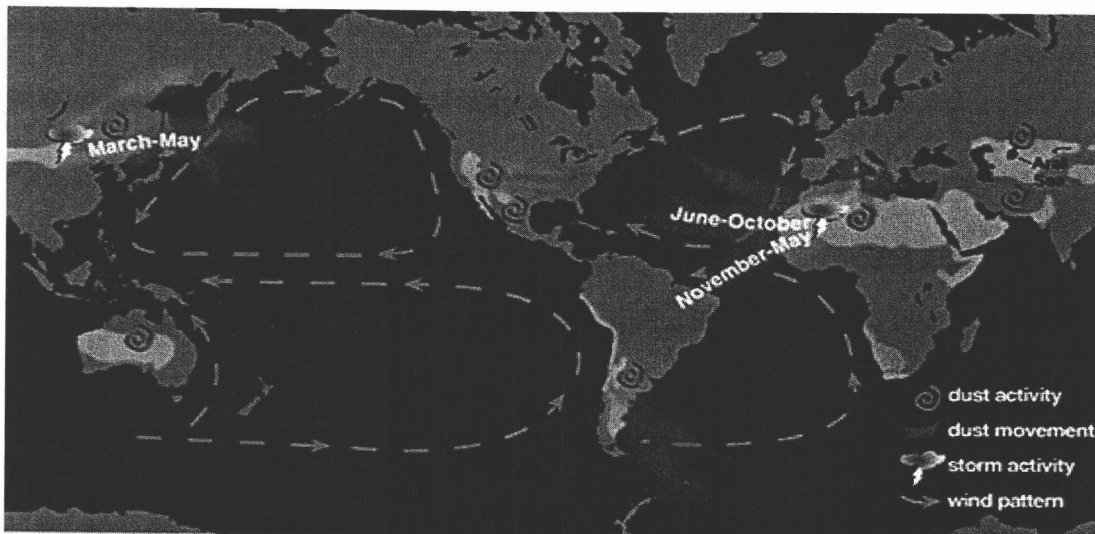


Figure 1: Dust events originating from Asia and Africa (Griffin, 2002 B: 232)

Dust particles are picked up through atmospheric uplifting and are thrown up into the upper level winds. Because of this, the deposition of dust occurs over a greater surface area than that of surface winds could provide. African winds can

generate about 700 teragrams (770 million US tons) of mineral dust and this is spread out across the world (Perkins, 2002).

Evidence for Environmental Vectors for Disease

Environmental vectors for disease propagation exempt the more traditional mechanisms that allow diseases ecologies to emerge. Basic to any disease ecology are pathogenic factors and transmission factors. The former refers to certain triggers, or mechanisms, that are disease causative. The latter refers to the fact that microbial life requires one or more hosts; one for reproduction and the other for transmission. Both of these factors are central to the microbe itself. However, microbes require a certain collective host ratio to cause pathogenesis in the organism. This host ratio is the inoculum size (Murray, 1998). Then there is the difference between infected and diseased states. The diseased state is one where pathogenesis has occurred and there is an obvious reaction to the presence of bacterial or viral contaminate. The infected state is ubiquitous with life itself. All creatures have microfaunal levels that rise and fall with the passing of time and change in the environment. The inoculum level dictates when this level goes from infected states to acute diseased states.

Outside the presence of the microbe are the influences of first and second order mechanisms. Social and cultural elements of a human group are good examples of this, as well as individual behavior and lifestyle, which affect the community as a whole. On a higher level is the environment itself (Harvard Working Group, 1995). Environmental change increases the contributing factors of the first and second order mechanisms.

First-order mechanisms such as air and water pollution have a direct association with disease occurrence; chronic pulmonary obstructive diseases and diseases of the digestive system are directly linked. The reduction in the ozone layer and its connection to a rise in incidence of skin cancer is another example. For first order mechanisms, correlation and cause and effect are very strong.

Second-order mechanisms provide conditions that enhance the development and proliferation of disease agents. One of these mechanisms is a greater extreme in weather and climate change. Good examples are the connection between cold and damp weather with the proliferation of pneumatic disorders. Hot and dry weather usually promotes allergen disorders. Greater frequency of extreme weather conditions will enhance the diffusion of disease organisms. This has been demonstrated for vector borne-diseases such as malaria and dengue fever.

Glaciations are a fine example of a second order mechanism. During glacial events there is rapid aridity in areas that are marginally humid. As water is suddenly frozen in glaciers, there is a change in hydrological changes around the planet. This desertification results in dust storm activity. By looking at dated dust layers and its cargo of microbes in glaciers and by correlating this with the epidemiological historic record, this atmospheric transport can be connected to real temporal events. It should be possible to determine if an isolated island such

as Iceland, whose nearest neighbor is 600 miles away, can be beset by disease propagation without other vectors for disease present.

Recent technological advances in remote sensing sciences and proxy analysis in atmospheric sciences, most notably using soil and ice cores, have given high resolution on long climatic events and more impressive- single occurrence events. Molecular science has given biology new resolution on the microbial world.

In the 1970's, Joseph Prospero conducted aerosol studies that were an attempt to correlate African dust storms and high dust concentrations that seemed to have cyclic occurrences in the Florida and in the Caribbean. This study was the foundation and basis for future research. He was able to show that the dust in the Americas was isotopically identical to that of the Sahelian deserts in Africa (Taylor, 2002).

In the last few decades, plant pathogenesis has been linked to long distant dust transport. Examples of the transcontinental movement of spores and fungus are numerous. In the 1970's and 1980's, a series of outbreaks in the United States of blue mold hit Connecticut, Kentucky, and North Carolina. It was determined that the spores had reached their destination atop high level winds that skirted past the Caribbean Sea, where the spores were picked up (Davis, 1987: 169; Griffin, 2001 B: 29). Later, still more fungal outbreaks were attributed to this phenomenon. In the early 1970's, a coffee rust pathogen outbreak was reexamined and it was attributed to upper atmospheric transport from Africa to Brazil. (Griffin, 2001 B: 29)

This was later found to take approximately five to seven days. A sugarcane rust pathogen that hit both North America and South America had come from the Caribbean, which had received the pathogens from the Cameroon in Africa. It arrived in a little over nine days. In the 1930's, a banana leaf spot epidemic was attributed to the worldwide transportation of the pathogen, beginning in Australia, moving onto Africa, and onto the Caribbean. This transit was over 15,000 miles long (Griffin, 2001 B: 29).

However, risks to humans were not appreciated until the late 1990's, when advances in molecular biology made analysis of pathogens easier. It was known and accepted that the dust transport mechanism existed (now called the Long Distance Dispersal Vehicle, LDDV), but its true connection to microbial transfer globally was not being looked at, due to the confinement of the research to that being done in agriculture and in atmospheric sciences. Obviously, the distribution of human pathogens through the mechanism of dust storms was something of a shock that scientists had not thought possible. The discovery by Lindbergh in the 1920's that spores and fungi were being distributed worldwide in the atmosphere was shocking, but it was not as surprising as the relatively recent discovery that bacteria and viruses were ostensibly doing the same thing.

In searching through literature of the last couple of decades, I found that the idea of aerial disease transport had been tossed around. The most impressive long-term study was a taxing 30-year examination of foot and mouth disease. Researchers found strong evidence that the virus had actually traveled over the sea and ocean in the European region, where infections were rampant and were being spread to areas separated by sea, ocean, and mountains (Gloster, 1982).

In 1988, a case occurred in Europe where viruses were literally jumping from one country to another- not by the usual routes of trade, and overland movement, but through atmospheric transfer. The swine disease, Aujeszky's Disease, occurred in Germany. It quickly spread to Denmark through airborne transport. In an earlier incident, from 1980 to 1981, Foot and Mouth Disease was found active in Scandinavia due to its transport from Germany via upper atmospheric lifting. During the same incident, pathogens from Germany were transported into France as well. Shortly after this, there were outbreaks across the channel in southern England (Griffin, 2001 B: 30).

A related event occurred in the Pacific Northwest in the 1990's. A fungus that is native to tropical areas of the south Pacific, most notably Australia, has been found to be growing in the higher latitudes of British Columbia. This fungus, *C. neoformans*, was first reported to the British Columbia Center for Disease Control in 1999, when there were a number of animal infections, both in the wild and in people's homes. This fungus is inhaled and causes pneumatic distress, and infection in the lungs and nervous system. From 1999 to 2003,

there were 77 human cases of cryptococcosis on Vancouver Island. This is a huge leap from a previous average of two or three cases per year. Five of these cases ended in death (Todd, 2003).

The total amount of dust and soil moving into the atmosphere is on the order of two billion metric tons per year. This converts to two quadrillion grams per year. It has been calculated that within each gram, there are 10,000 bacteria and many more viruses. This is enough microbial life to stretch from Earth to Jupiter end to end (Griffin, 2002 A: 2)!

In the late 1990's, Ginger Garrison and Dale Griffin, along with Garriet Smith, launched an investigation into coral reef and sea fan epidemics, and found that airborne dust was responsible, as opposed to currently held thoughts that terrestrial leaching brought the fungus and other contaminants into contact with the undersea ecology (Griffin, 2001 A). Griffin later cultivated the samples in the lab and was able to show that there were 200 viable pathogens in the dust collected in the Caribbean (Griffith, 2001 A).

Griffin followed up this study that same year when he extrapolated the ideas confirmed in the coral reef research to possible implications on human and ecological health (Griffin, 2001 A and B). One of the more important contributions by Griffin is his idea concerning transport and the effects of UV light. He speculates that the immense size of the dust storms actually provide cover- at least for the airborne particles tucked away in the lower layers of the storm. He also suspects that microbes find refuge in the cracks and crevices in the dust and sand itself (Griffin, 2001 A and B).

Toxins are also transported around the globe. The dust storms that come off the continent of Asia are so extensive that more than 4000 tons of dust per hour can be transported into the arctic regions. Microbes are transported as expected, but pesticides and herbicides are also carried aloft, to an otherwise, virgin territory. This transport results in bioaccumulation in the entire arctic food chain. Toxic levels have been confirmed in living tissue that has been assayed from people residing in China (Griffin, 2001 B: 25).

Most recently, many correlations between dust storms and pneumatic disorders have been published. In Barbados, hospital visits for asthma attacks and the dust in the atmosphere of the region have been correlated (Prospero, 1999, 2003). In the Aral Sea region, there is strong evidence that the drainage of this lake by the Soviets during the cold war exposed 3.5 million hectares of former lakebed to the atmosphere. Unfortunately, this also means that pesticides from years of Soviet monoculture and use of toxic agricultural products were left to become aerosols. These toxins have been linked to nervous disorders and lung impairments in the people surrounding the lake (O'Hara, 2000; Small, 2001).

In the United States, the former Owens Lake, located between Death Valley and Sequoia National Park, is a problem for life forms in the area. This lake was drained and rivers supplying the lake were diverted to Los Angeles. The lake dried up in 10 years and left the lakebed open to uplifting by the atmosphere. Like the Aral Sea, there are contaminants in the dry lake bed. During the Gold Rush, miners used the lake for their operations. One of their techniques called for arsenic, and it is this element that now taints the silt found at the lakebed. In a

normal 24-hour period, this arsenic-laced silt contributes soil particles at a concentration of 150 micrograms per cubic meter. This concentration far exceeds the national safe level of 15 micrograms per cubic meter. In an actual dust storm, the concentrations can grow exponentially to 40,000 micrograms per cubic meter. According to the researchers, this arsenic deposition has increased the rates of cancers in exposed individuals (Raloff, 2002).

These atmospheric events are also found in the archeological record. Verschuren, using dry lakebed sediment cores, found that desertification and associated dust storms occurred on a regular basis across larger geographical areas than we now experience. (Verschuren, 2000)

His study of northern Africa shows that it has experienced four major drought periods in the past 1,100 years. His data shows that over the past millennium, equatorial Africa has alternated between very contrasting climatic conditions. It had a very dry climate during the Medieval Warm Period (AD 800-1200), and a relatively wet climate during the Little Ice Age (AD 1200- 1900). However, this wet period was interrupted by three prolonged dry episodes (1380-1420; 1560-1620; 1760- 1840) that were more severe than any drought suffered in the 20th century. These periods are caused by interruptions in the hydrological cycle and growing glaciation in the northern latitudes. It disrupted the African cultures quite severely, creating obvious gaps in prosperity (Verschuren, 2000).

The important thing here is that the prevalence of drought occurred during the MWP and the time of highest rainfall occurred during the lowest LIA temperatures. This implies that the “latitudinal pattern of century scale climate anomalies during the past 1,100 years was opposite to that which occurred on millennial timescales during the last glaciation, the Younger Dryas, and the early Holocene” (Vershuren, 2000: 412).

These cyclic periods of desertification and humid conditions are important to my study, since they show that the climate the Icelanders experienced was an event that occurred globally. This global climate change created periods of major convulsion in disparate regions worldwide. If the connection between dust storms and microbes proves to be correct, and dust storms create worldwide distribution networks of microbial transport, then the disease ecologies that we are accustomed to studying need to be drastically altered, both in present studies, and in archaeological studies of the past.

The disease ecology in Iceland is an interesting case because the usual vectors for disease are not possible due to isolation and the climate itself. Is dust storm activity responsible for the extreme pathogenesis suffered by the Icelanders during the 15th century? This research creates a methodology for determining if the pathogenesis suffered by the Icelanders in their formative years, was the result of similar dust borne pathogenic agents.

Chapter 3: Emergence of the Human Disease Ecology

The emergence of human disease ecologies can be traced throughout the entire track of evolution. Depending on the environment and social construct, the synthesis between the human and the microbial world was either in equilibrium or a state of chaos. Regardless of what state the relationship is in, the process is a co-evolution. The development of the immune system is the product of the synthesis.

The development of the immune system involves the creation of a barrier between the outer and internal worlds, and this barrier becomes the demarcating line of self and non-self. This progression gave distinction and immediacy to self preservation and its antithesis, corruption and invasion. From this simple design, came the emergence of complex organisms. Cellular barriers and the defense mechanisms that develop through time give rise to our specific and non-specific immune systems within our anatomical and physiological construction. Moreover, the plasticity of viruses and bacteria is a testament to the constant surveillance provided by the human host.

The emergence of modern *Homo sapiens* 125,000 years BP came as its ecological circumstance and biological evolution converged. As the human brain developed, it “permitted the full development of culture in the modern sense” which became the primary means by which people responded to natural selective pressures”- the molding and shaping constraints of the environment (Klein, 1999: 494).

This permitted movement outward across landscapes and biomes that were untouched prior to that time. The cultural and behavioral innovations, though not thoroughly understood developmentally, did “propel the human species” from insignificance to worldwide significance by 50,000 BP (Klein, 1999: 572-3). This ‘competitive advantage’ led to developments in societal and psychological complexities, familial and group lineage, and certainly, ideas concerning regional identification, and later, national affinities. This led to the formation of nation-states and regional cultural centers.

Agriculture and urban settlements were offshoots for this biological and cultural development. Beginning perhaps as early as 20,000 years ago, the adoption of a more sedentary lifestyle gave rise to human populations that were “more geographically stable and [therefore the] populations grew”. This in turn affected the stratification of society, altered land use patterns, and increased competition for resources (Stinson, 2000: 225).

The major impact from this chain of events was an increase in population densities, which increased group-to-group and person-to-person contact, and the adoption of agriculture led to increased contact with disease vectors and the emergence of zootrophic crossovers from the newly domesticated animals (Stinson, 2000). The role of agriculture and animal husbandry in the microbial ecology of humans can be attested to by the fact that “humans share 65 different diseases with dogs; 50 with cattle; 46 with sheep and goats; 35 with horses; 32 with rats and mice and 26 with poultry” (Gottfried, 1983: 3).

Within this new disease ecology, humans changed their evolutionary heritage; genotypes specific to immunity functions that were coded in the genome as a result of long term exposure, or to the contrary, a long term of non exposure to varying microbial ecologies, were altered. These biochemical changes are primarily selected as a result of direct contact with specific microorganisms (Long, 1996).

Since the adoption of agriculture and urbanization, the synchrony of infectious microorganisms and human hosts has been slowly met over time. This happens through a complex relationship, one where the microorganism develops strategies “that enable it to use the hosts tissues and metabolic processes to propagate and spread” (Long, 1996: 83). The host evolves defensive mechanisms to prevent this exploitation. There are both mutualistic and antagonistic relationships; each organism has evolved with humans differently. Through synchrony and long periods of time, equilibrium develops, which is subsequently followed with a benign symbiotic relationship. Or, if there is no synchrony, then antagonism results and cycles of loss and gain are the result.

As long as the microorganisms have a time frame that is conducive for their dispersal, “there is no evolutionary benefit in sparing the health [or life] of its host” (Long, 1996: 83). This is ultimately an antagonist relationship. Many researchers now see the host defensive mechanism to an antagonistic relationship as synchronous with the biochemical pathways of the microorganisms, insomuch as they benefit their dispersal and propagation. Clearly, there is no benefit in pathogenesis for the host, given these parameters.

Human disease ecologies are specific to the location of the biomes inhabited by humans. The synthesis between the microbe and other animals, and cycles of climatic instability and stability has impacted the evolution of each community. Each biome has its own unique microflora and indeed, its own endemic disease. The humans within each biome develop specific responses and have evolved in response to this environmental stress. No two individuals within the human communities are equally susceptible- however the systemic nature of disease ecologies makes the effect of social and biological variables complex. The spread of any pathogen requires a 'vulnerable human population', and by vulnerability, I mean the state of health not only of the individual, but the community itself.

Vulnerability depends on two things: the contagious nature of the pathogen and the speed at which it is transmitted. The degree of contagion depends on two variables:

1. It depends on the number of pathogens that enter and leave an infected individual and enter the environment.
(Pathogenic factor)
2. It depends on the number of pathogens that survive in that environment and gain contact to ultimately infect other people.
(Transmission factor) (Harvard Working Group, (HWG), 1995: 26)

There is no one cause of infectious disease. Although the virulence factor of each microorganism, and its density within the host, create pathogenesis, it is the transmission and spread that both maintain the organism and continually challenge the human immune system.

On top of this is the multiplicity of social, ecological, and biological variables that aid in the depression of the immune system and/or the improvement of the pathogen in its efforts at compromising the human host (HWG, 1995).

The Harvard Working Group of New and Resurgent Diseases states that “all social and environmental changes are potentially reflected epidemiologically, since conditions can affect the opposing process of contagion and recovery, acquisition and loss of immunity” (HWG, 1995: 26) So infectious disease, a product of human co-evolution with microorganisms, is directly influenced by the ebb and flow of population density, cultural and social practices, and the ever changing nature of the biochemistry of the human and the microorganism.

European Disease Ecology at the Time of Viking Expanse

By the time of the Vikings, agriculture, animal domestication, and massive urbanization had slowly grown within Europe for 6,000 years. By the High Middle Ages (1050-1347), Europe had grown immensely and many groups had prospered. This resulted in a population growth of about 300%, up to around 75-80 million by 1250 AD. This growth was due to three things: agricultural technological improvement, political stability, and a disease ecology that had reached equilibrium. This growth came at a cost. The population density created situations where it was too high relative to their carrying capacity. It also ended their relatively disease free era (Gottfried, 1983:15).

Improvements in agriculture- plowing, soil turning and the use of fertilizing manure- increase contact with soil microbes and helminthes. The domestication of animals- butchering, herding, and the raising of cattle, sheep- increases the propensity for the zootrophic crossover of animal parasites and disease (Roberts, 1995; Gottfried, 1983).

These three variables combined to produce the perfect environment for epidemic outbreak- or at the least, unsustainable ecologies. As the High Middle Ages progressed, another change occurred. The climate began to shift and this ultimately affected agriculture and tilted European ecology in favor of malnutrition, starvation, disease and pestilence (Gottfried, 1983). The population centers, which were a product of agriculture, began to create the platforms on which disease ecologies would manifest:

- epidemics swept through cities, cleaning 10-20% of their population away.
- famine and starvation which hampered the immune system was very common.
- public hygiene was abysmal, even for royalty.
- butchered animals and decomposing bodies regularly festered in the streets and deep open pits were dug in which were laid the bodies of the poor. These were located near the city centers. (Stanard, 1992: 57-8)

These unclean practices created a “stench and vile aroma” that persisted incessantly. Obviously, it increased the conditions that were ripe for infectious disease and acute bouts of sickness. People usually had bouts with smallpox and other deforming diseases throughout their lifetime. This left virtually no one untouched by physical scars, deformities, and chronic conditions that festered throughout individuals and whole communities. Other persistent ailments included “suppurating ulcers, eczema, scabs, running sores” which lasted for months, if not years. This was the everyday, common health experience (Stanard, 1992: 57-8).

The pattern of disease ecology characteristic of the Middle Ages was in place in Europe by the 6th century. William McNeill argues that between 500 BC and 500 AD, the infectious diseases that Medieval Europe suffered from had arrived inherited from their Classical counterparts (McNeill, 1976). This was, of course due to the increasing contact between the civilizations of China, Central Asia, India, the Upper Nile, and the Mediterranean Basin. The confluence of disease pools brought “most of the important diseases that can survive in temperate climates” to the major population centers (Gottfried, 1983: 15). By the end of the 12th century, each area’s disease pool had stabilized. After a period of equilibrium and undisturbed growth and prosperity, the coming of the Little Ice

Age created a downward spiral, and the agriculture surplus and economic fortitude that Europe enjoyed was for all intents and purposes, finished.

By the end of the 13th century, “Europe was in the throes of a classic Malthusian subsistence crisis. Population growth was outstripping food production, and Europe was getting poorer and poorer” (Gottfried, 1983: 25) The lack of infectious disease in high levels at this point and high fertility rates led to this growth (Gottfried, 1983). However, with increased contact with foreign elements, a new disease ecology was being set in motion.

The origination of this disease ecology was put in place in ancient times. In fact it is the “peripatetic character of ancient empires [that] acted as a conduit and incubator for future disease patterns” in Europe (Gottfried, 1983; 5). During the classical era, there were very few major epidemics- save for three new disease pathogens- the smallpox virus, the measles, and the plague- that were introduced and did cause significant loss. Because of this overall stability, the civilizations lay intact and were able to create the foundation for trade routes, contacts, political and cultural patterns that would eventually become the Middle Ages (Gottfried, 1983).

Population growth and the building of infrastructures that connected distant peoples began this alteration. The contact changed the balance and pattern of infectious disease across the European Peninsula, as well as Asia and the Middle East. It is believed that the ruling Mongols in Asia had brought the plague to the Mongol headquarters in Karakorum, in the Gobi Desert. Through constant raiding and travels to and from east Africa and the Near East over a

number of centuries, Mongol horsemen and supply trains might have carried strains from the first outbreak home with them. Other researchers believe that the Gobi Desert itself was an inveterate locus of *Y. pestis*. However the bacterium arrived, it is generally accepted that the rodent population and the Mongols themselves were the initial carriers of the plague bacterium that would cause the second world pandemic in the Mediterranean, and later, the European Peninsula (Gottfried, 1983).

Another progenitor of disease ecologies is that of climate change. During the mid part of the 13th century, climate change began to alter insect and rodent distribution, and viral ecologies throughout the world. These changes were vectors of prime diseases like smallpox, measles, malaria, leprosy, and the plague. The climate change affected the Mongolian plain, across which the pastoralist cultures would have had to move east or west in search of pasture. As they moved, wild rodents likely followed, doing the same thing (Gottfried, 1983). Increasing contact between civilizations, plus climate change, began to alter the ancient disease ecologies that had formed when people were far more separated and settlement and civilization was much less grand (Gottfried, 1983).

The world of the middle ages in Europe was certainly harsh and the disease ecologies that were created most likely impacted their populations on a molecular level. Most certainly, when the Scandinavians settled Iceland, the geography and climate in the North Atlantic were added pressures in an already disturbed human ecology present in Europe.

After exploring the island's geography, I discuss the settlement of the island and the disease ecology that ensues there. I offer a new vector- that of the atmosphere itself. It may be the beginning of a new medical paradigm for disease proliferation that could be tested in the archaeological record.

Chapter 4: Iceland Geography and Climate

Lying between latitude 63° 24' and 66°33 ' North and between longitude 13° 30 ' and 24° 32' West, Iceland is the most northern of all Nordic countries, including Greenland. Iceland encompasses an area of almost 103.000 km². Most of this area consists of an uninhabited central region- a 500 to 800m high plateau with mountain ridges ringing this, ranging from 1200 to 2000 meters in height. From north to south at its greatest latitudinal distance, it stretches about 100 kms. Its greatest longitudinal distance east to west is around 300 kilometers. It is comparable to the size of the state of Kentucky (Somme, 1968; Ogilvie, 1981).

Landforms found in Iceland include desert plateaus, sandy deltas, volcanoes, lava fields, glacial icecaps, tundra, grassland, bogs, and coastal zones. The most fertile areas are the coastal lowlands and the valleys. Coasts are either indented with fjords in the north and northwest, or they are flat and sandy, as found in the south and the southeast (Ogilvie, 1981). Hydrographically, Iceland is not in want of water. Its high rainfall and relative lack of evaporation and subsequent water deficit insure numerous rivers and many lakes- more than enough water for the yearly hydrologic cycle. There are three types of Rivers:

1. the glacial river- consists of meltwater that drains from the many glaciers.
2. the direct runoff river- consists of water that is draining from the old basalt areas.
3. the spring fed rivers- consists of water drained in springs & permeable lava flows.

Other hydrographic features include magnificent waterfalls, underground water caverns and many small lakes. Lake Zungenbrechen is a kettle filled with water that reaches a depth of over 361 feet. This is most decidedly below sea level. This is much like Crater Lake in Oregon, USA.

Iceland is an immense bowl-shaped plateau averaging just 600 meters in height above sea level. This flat area is punctuated and ringed by high mountains and peaks, particularly to the south. Its over 6000 kilometers of coastline is indented with textbook examples of deep fjords and bays, starting from the northwest and moving east to the eastern shoreline, while the southern coast- being very low lying has no natural harbors. The northern coasts are also characterized by steep cliffs, which rise almost immediately as you move inland. The island has many high peaks, the highest being Hvannadalshnukur, located within the glacier named Vatnajökull in the southeast. It is 2119 meters high (Lacy, 1998). The island of Iceland from its inception geologically was isolated from human occupation. The age of the island depends on where you get your samples. The oldest rocks on the west coast are 14-16 million years old, whereas the oldest rocks on the east coast are at least 18 million years old (Bardarson, 1982).

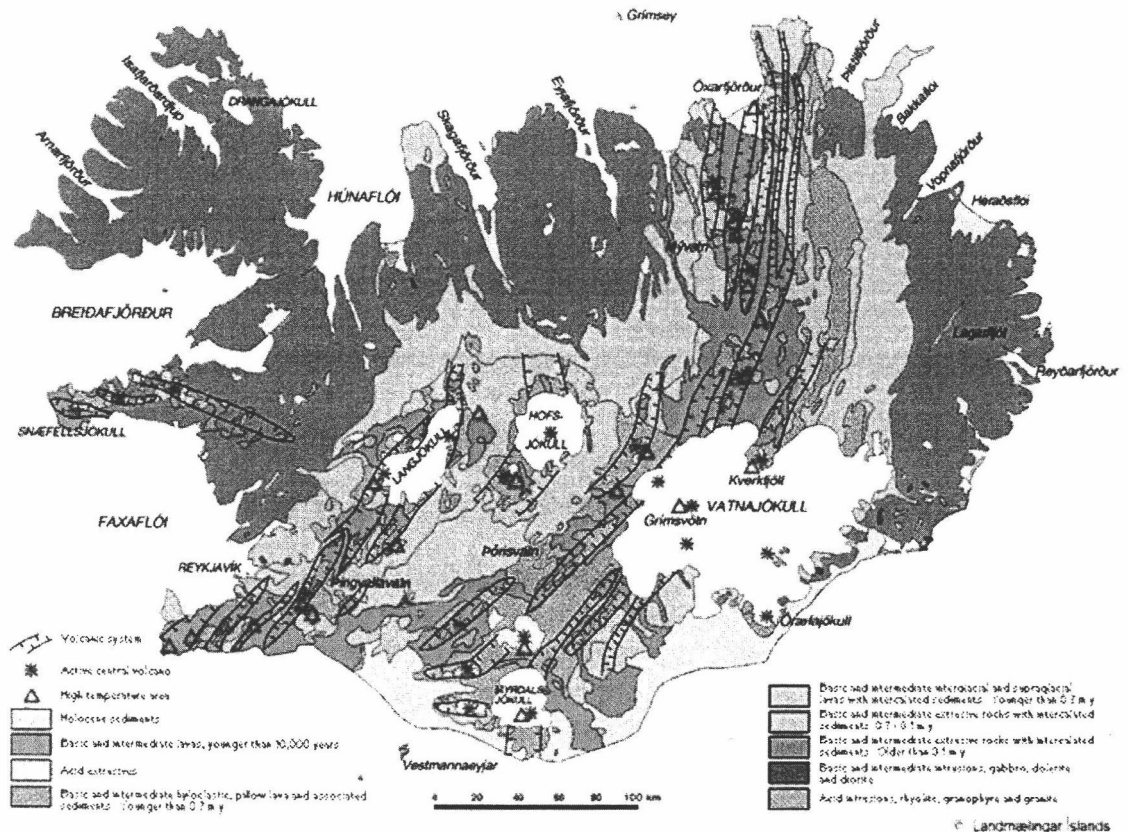


Figure 2: Geological map of Iceland (Landmælingar Íslands, 2004)

Iceland formed over a hotspot in the North Atlantic, which was previously occupied by Greenland. Continental drift and plate tectonics cause movement over the hotspot. As a result of the movement, continental Europe and Greenland have been separating and drifting away from one another for 30 to 40 million years (Bardarson, 1982).

The two plates create tension, moving the plates an average of seven centimeters a year. This sometimes results in earthquakes (Lacy, 1998). One of the more notable geological features that stems from the geological tension is volcanic activity- something the northern Europeans had not experienced. As a result of this outward spread, and volcanism, Iceland as an island was created on

the mid-Atlantic ridge. Over a period of 10 million years and 700 lava flows, an⁴⁴ island rising 8.5 km deep to the ocean floor was formed (Bardarson, 1982).

This ridge is slowly pulling and separating Iceland apart- straight down the middle. The ridge goes through the middle of the country, averaging 48 kilometers in width and covers up to 25% of the land. It exits Iceland and continues up to the Arctic Region. It provides the island a signature terrain of volcanic mountain chains that enter from the SW at two points and exit to the north, after joining up in the center of the island near Askja. For the people who live in Iceland, volcanic eruption and earthquakes are very common, and they are being looked at as possible variables in local climate change effects on a global scale.

Physically, Iceland is a land sculpted by the force of fire and ice and is an island replete with natural sources of energy. It is a peculiar finding that the natural basalt in the bedrock is on the average three times as hot as its natural temperature gradient should allow.

Vast ice fields cover the highest points of the mountain areas. These glacial fields are the remnants of the icesheet that covered the entire island up to 10,000 years ago. At the greatest extent of glaciation, the ice cap ranged from 500 meters to as much as 1500 meters thick (Lacy, 1998).

The action of ice and frost against soil and rock as the huge ice sheet cyclically retreated and disappeared carved and shaped today's Iceland. During the 21st century, the ice sheet is gone, but the remaining glaciers are some of the biggest icefields in all Europe, in particular the vast Vatnajökull glacier, which

covers most all of the southeast section of the island. It is 8400 km² and is the⁴⁵ biggest glacier outside the Polar Regions and Greenland, and is bigger than all the rest of Europe's glaciers put together. Iceland has over 11% of its surface covered by glaciers and has every type of glacier found on Earth (Bjonnsson, 1979; Ogilvie, 1981). They range in size, but they all make an impact on the climate in their respective regions. It is in these areas that extreme geological events occur. In addition to avalanches, heavy snow and icefall, freezing temperatures, and ice calving, there are glacial bursts, which produce extensive outwash plains and extreme erosion. These are a regular event in the history of Iceland (Lacy, 1998; Somme, 1968).

Just like the Scandinavian Peninsula, the island of Iceland had 20 glacial periods during the ice ages occurring during the Quaternary Period. The Quaternary period is broken down into two eras, the Pleistocene (the Ice Age) and the Holocene (the present). The former lasted from 2 million years ago to around 10,000 years ago. The latter marks the end of the last ice age and extends to the present time (Bardarson, 1982).

The last cold climatic phase in Europe, the Würm Glaciation, lasted from 70,000 years ago to 10,000 years ago. During this time, Iceland was covered by an immense ice sheet, which spread in all directions, from the central highlands outward. By 15,000 years ago, the climate began to warm considerably, though cold climate returned momentarily for 1300 years, beginning around 12.5 kya.

Glacial events over long periods of time had huge impacts on the landscape of Iceland. Two different types of mountains exist here. When the

island was free of ice, lava shield volcanic mountains were formed. As ice built up over time, table mountains were formed. When the last ice age ended, the downward pressure created by ice ended and isometric lifting, beginning around 9,000 years ago, began to raise the island to its present level. This is about the same time that Scandinavia was finally settled by humans (Bardarson, 1982). ⁴⁶

Along with the force of ice and snow is the awesome force of volcanism and the subsequent earthquakes that accompany volcanic activity. Iceland has every type of volcano known, especially crater rows and shield volcanoes. Iceland has more than 200 volcanoes and one third of the total global output of lava erupted since 1500 has come from Iceland. During this period there have been over 160 eruptions, one or two about every five or six years. These eruptions play an integral role in the settlement of Iceland (Somme, 1968: 207).

The eruptions during and after settlement by the Vikings have been a huge force on the demographics of the people. Since the 9th century, 1040 km squared, or 1% of the land, has been covered by lava flows. This creates havoc on farms and agricultural areas. Tephra falls, or pyroclastic ejecta, create a far worse situation, since resettlement is directly linked to how much tephra falls. The greater the depth, the longer that human usage is compromised. The volcanism on Iceland is predominately effusive, so it produces more lava than tephra (Lacy, 1998, Somme, 1968). Eighty percent of Iceland is composed of Basaltic Lava and its soils are of the Andisol variety, which develop from Volcanic Ash. Eleven percent of the surface is postglacial lava, a testament to relatively

recent geological activity. Similar conditions are found in some areas of the ⁴⁷ American Northwest (Lacy, 1998).

The volcanism of the island and its position over the mid Atlantic ridge has created an island that has bedrock that is consistently two or three times the natural temperature gradient found in similar areas of the world. This hot metabolism includes high and low temperature thermal activities, which are located near new volcanic areas (Somme, 1968). The high temperature areas include 14 solfatora fields made up of boiling springs, steamholes, mudpools, and sulphur vents. The average temperature is 200°C. The largest of these are located in the Torfajokull area and Grimsvotn areas. They have a total output of heat that registers around 500E6 cal/sec (Somme, 1968; 209-10).

The low temperature areas exist in the form of 800 individual springs. The average temperature is 100°C. Some of these springs are big enough to be geysirs (an Icelandic word). The most impressive is the Great Geysir and the Stokkur Geysir. A strange feature found in these new volcanic regions is the white vapor found exuding from soil and rock crevices (Somme, 1968). The water in each of these follows the laws of thermo dynamics. At great depths water remains in liquid state, but towards the surface, "a partial evaporation" occurs, with the result being a "a mixture of water and steam. The water in both of these hot areas is acid and the precipitation consists of sulphur (Somme, 1968).

Iceland's volcanic nature is thought to impact global climate. Several investigators have found that volcanism is responsible for worldwide climate changes that affect many regions of the world for short durations. One of the changes is an increase in cold, damp weather, due to eruptions, and this type of regional change is conducive to several pathogenic diseases. This phenomenon is further explored in upcoming chapters (Stothers, 1999). Benjamin Franklin, the eminent statesman and inventor who lived in the 18th century, originally espoused this idea. He laid out the premise that volcanic eruptions could temporarily cool the climate. Contemporary scientists have corroborated this (Franklin, 1785; Stothers, 1999).

Prehistorically, humans had never explored Iceland, during any of its, nor did they experience the incredible changes to its flora, fauna, and landform over time until they colonized the island in the ninth century. Yet it became an environment that challenged Scandinavians as they brokered a defiant settlement that raged against the power of land, sea, and air. This was met with success and failure. It was the most arduous environment adapted to by Europeans in their long history.

The Climate in the North Atlantic

Terrestrial energy on Iceland creates a terrific hotbed of activity. This translates into not only geological and glacial events, but contributes for the quizzical climate found here. Located near the Arctic Circle in the North Atlantic, Iceland should not be as warm or as temperate as it is. Geothermal contributions to the weather here are found in the volcanic events and the effect of the glaciers on the regional temperature. Atmospheric variables in the climate of the North Atlantic region are also unpredictable and vexing.

The standard behavior of atmospheric circulation in the middle latitudes of the North Atlantic is “prevailing westerly winds both in the upper air and on the surface” (Somme, 1968: 50). The westerlies are accompanied by the presence of “middle and high latitude cyclones formed along the Atlantic arctic and polar fronts which develop between the cold air masses from polar regions in the north and the tropical air masses in the south” (Somme, 1968: 50).

In Iceland, there is a constant conflict between three air masses; the Arctic High, the Icelandic Low, and the Azores High. The heaviest and coldest air comes from the Arctic high pressure air mass; this is followed by the Icelandic low pressure air mass. The Azores high pressure air mass is much lighter and more tropical. The conflict is played out daily, as the heavier, colder air of the Icelandic Low displaces the warmer air of the Azores High. Overall, cold, wet and humid conditions prevail (Somme, 1968; Lacy, 1998). The climate is moderated by the Gulf Stream as it crosses the Atlantic towards the European peninsula.

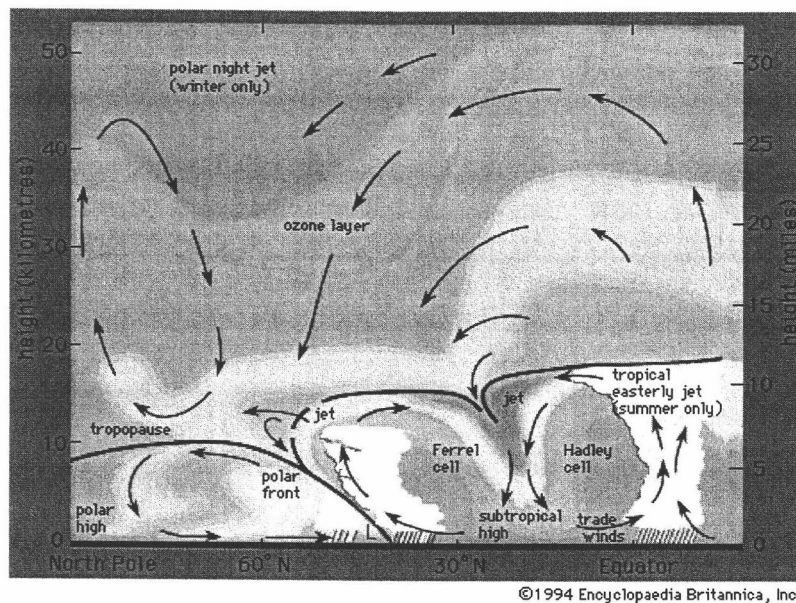


Figure 3: Side view of the atmospheric circulation. (Goddard Space Flight Center, 2004)

At the upper atmospheric levels, there are constant mid-latitude westerly jet streams that flow high above the earth (Somme, 1968). These are formed by the extreme temperature gradients created by the clash of the polar high pressure cells and the sub-polar low pressure cells. In the southern Hemisphere, the high and low pressure cells are formed around the planet and thus, the jet streams run the girth of the planet. However, in the northern hemisphere, the jet streams do not string themselves around the planet. This is due to the presence of larger land masses in the northern hemisphere which act to break up the flow, as opposed to the larger presence of hydrographically smooth water in the southern hemisphere. As a consequence, the sub-polar low pressure cells form pressure centers over large bodies of water and create cyclonic flow. The main low pressure centers in the northern hemisphere are the Aleutian low and the Icelandic low pressure cells.

The pressure gradients and the subsequent wind speeds rise with increasing height as long as the temperature gradients remain in the same direction. This dynamic continues upward to the troposphere. Once it reaches the troposphere, the temperature gradient reverses direction and the wind speeds diminish. Thus, jet streams are usually found in the upper troposphere between 9 and 18 kilometers. They are between 1.6 and 4.8 kilometers thick and can be 1609 to 4,828 kilometers long. They travel at tremendous speeds, often between 160 and 643 kilometers an hour.

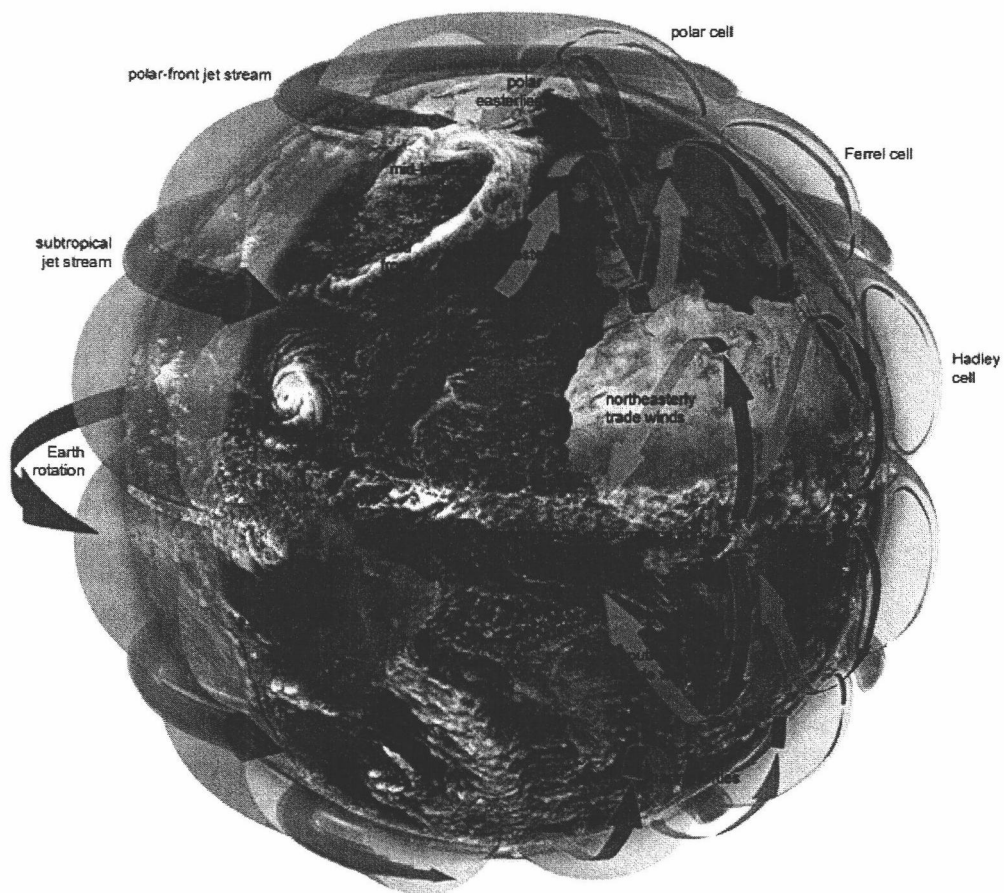


Figure 4: Planet view of atmospheric circulation: (Planetary Visions, 2004)

Iceland sits on the margin between the Arctic high pressure systems and the sub-polar low pressure systems; a location that drives its unique climate. At its high latitude, the climate should be much more 'arctic'. Due to the westerly flow of winds and the pronounced heat transport of the Gulf Stream, it remains moderate and habitable. Precipitation is heavy and many storms occur. Weather changes within the hour are not uncommon and pressure changes due to temperature changes and wind shifts can be amazingly fast. For example, in February 2001, on the Vestfjarda peninsula to the northwest, there was a drop in pressure of 28.4 millibars in less than three hours. Although not the fastest pressure change recorded, the pressure changes that challenge this one are found in the same north Atlantic region (Somme, 1968; Brown, 2001).

Four factors affect Iceland's climate: its situation between two huge low and high pressure air masses; the confluence of two different ocean currents; the moderating effects of the Gulf Stream; and the presence of Arctic drift ice, which lowers the temperature upon the land. The main variable is the passage of atmospheric depressions across the island over time. If it is dominated by high pressure systems, it is dry and bitter cold. If the island is dominated by low pressure systems, the weather will be wet and mild. This is reflected in the amount of snowfall that the island receives. The north typically gets 100 or more days of snowfall per year, whereas the south gets as little as 40 days a year (Somme, 1968).

The tension between the Arctic high and the Icelandic low notwithstanding, there is another important dynamic in the region. This is between the Icelandic Low and the Azores high to the south. Both of these pressure systems are present year round but their intensity is highest in the winter months. During the rest of the year, a north-south fluctuation between the two is created and the amount of warm air and moisture fluctuates latitudinally. When the Icelandic Low is stronger, the cold Arctic high pressure air mass from the north is forced southward to areas to the west of Greenland and Iceland, most notably Hudson Bay. This increases sea ice in this area and, in general, in all of the entire Arctic. Concurrently, this allows warm air from the southern Azores high pressure air mass to be pushed into the areas east of Iceland, leaving this area free from ice. When the tension creates a weak Icelandic Low, the same things happen at reduced intensity. This dynamic is called the North Atlantic Oscillation (Goddard Space Flight Center, 2004).

Over the many centuries that humans have occupied Iceland, the climate has gone through various climate changes. During the early period of Scandinavian movement into the north Atlantic, the climate was much more moderate compared to today's climate, warmer and more conducive to travel. The figures below show that the temperature in Iceland has changed considerably from the beginning of the Settlement Period (874 AD) to the late 20th century:

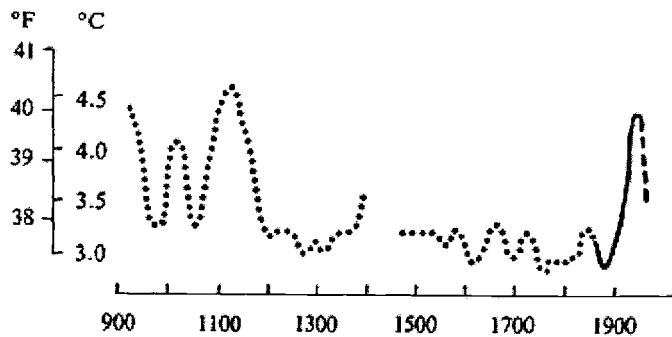


Figure 5: Estimated temperatures in Iceland through time (Bergthórsson, 1969)

The lack of records during the 15th century was due to the lack of record keeping during the century of the plague. There were no temperature records kept until much later in the late part of the 15th and early part of the 16th century, as the Icelanders did not have thermometers. However, other weather events were noted; most records did contain precipitation types and most importantly, the presence of ice in the fjords and coasts of the island

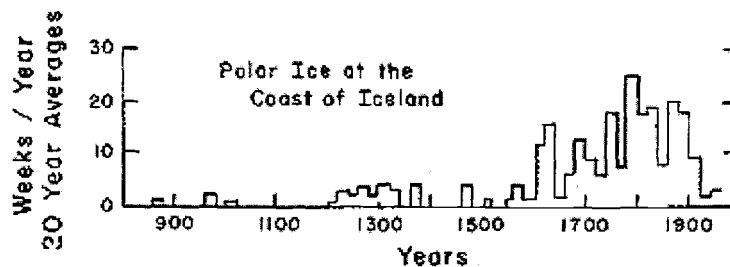


Figure 6: Number of weeks of sea ice in Iceland (Tkachuk, 1983)

Another temperature clue is given by ice core studies done in Greenland. The historical reference to the presence of ice is augmented by oxygen isotopic studies. Measurement of the ratio of O^{18} vs. O^{16} isotopes in ice indicates the temperature of the snow at the time it formed in the atmosphere. Higher ratios of the heavier O^{18} oxygen isotope indicate that the snow formed at a higher temperature while lower ratios indicate the snow formed at a lower temperature.

These studies show that there was a climatic shift at the end of the 13th century corresponding with the historical record. The years leading up to the climatic shift is the period that was optimal for the north Atlantic, hence the name- Medieval Warming Period (MWP). The years following the shift were very turbulent and unpredictable. This is the Little Ice Age (LIA):

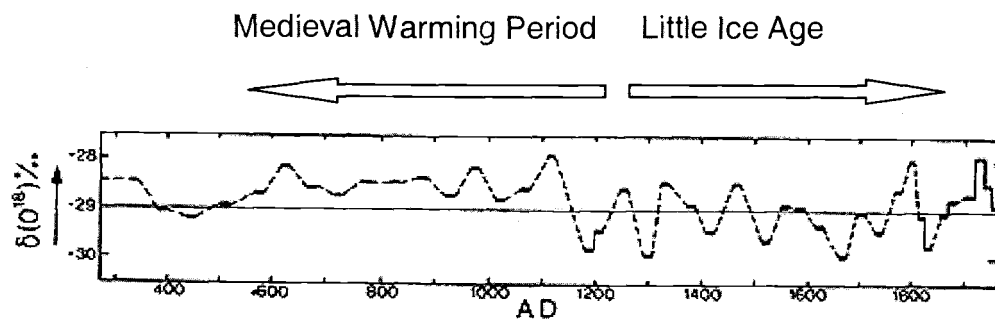


Figure 7: Ratio of O_{18} vs. O_{16} in Greenland ice core (Lamb, 1995)

The climate during the Little Ice Age was brutal for the humans living not only in marginal arctic climes, but also in desert areas. A study done by Vershuren demonstrates that during the LIA, desertification took place and significant droughts accompanied ages of prosperity in the eastern portion of Africa.

This study uses correlated information from atmospheric CO₂, lake depth and the salinity levels of Lake Naivasha, in Kenya. It “suggests that equatorial Africa was generally drier than today during the MWP, and that fairly wet conditions during the LIA were interrupted around 1380-1420, 1560- 1620, and 1760- 1840, by episodes of persistent aridity more severe than any recorded drought of the 20th century” (Vershuren, 2000: 412). He also says:

The inferred prevalence of drought in tropical Africa during the MWP, and the highest rainfall broadly coincide with the lowest LIA temperatures in mid-latitudinal regions of the northern hemisphere, implies that the latitudinal pattern of century scale climate anomalies during the past 1,100 years was opposite to that which occurred on millennial timescales during the last glaciation, the Younger Dryas, and early Holocene.(Vershuren, 2000: 412)

This aridity is also connected to dust storms, especially in the eastern portions of Africa. Desertification can be a regional event or global event. If glaciation changed the hydrological cycle enough, Asia would be no exception to the events during the process of desertification. Desertification occurs during glaciation periods because the hydrological cycle is altered and more water is frozen in glaciers and ice sheets. Although the data suggest that Africa- at least in the east- was considerably wetter, there were three periods of intense drought. The periods of drought correspond with the increasing cold period in the north Atlantic. If increased desertification did occur, it would have contributed to the creation of larger deserts and the possibility of dust storms.

Ice core studies indicate that a higher concentration of dust was in the atmosphere during the periods being studied by Vershuren. In a study done in 1996, Yung was able to demonstrate that during the Last Glacial Maximum, there

was a considerable change in the hydrological cycle and this was correlated with an increase in dust in the ice cores being studied (Yung, 1996). This increase is not only an indicator of climate change, but “is an agent of climate change” (Yung, 1996: 963). During the LGM, the northern hemisphere had more “deserts and large areas of land that were covered by ice sheets” (Yung, 1996: 963) It is obvious that a change in the hydrological cycle can create conditions for increases in aridity and desertification.

The Asian Dust Event

Studies thus correlate dust events in Africa to dust landfall patterns across the globe and their connection to pathogenesis. What I next do is to discuss an Asian dust event, and describe its path.

In April 1998, there was an Asian Dust Event (ADE) that literally knocked ‘the dust off’ the last 10 years of dust events. On April 15th and 19th, two sizable dust storms in the Gobi Desert were created by the pressure systems discussed earlier. The uplift pressure gradient was swift and the two dust events were eventually lifted out of their terrestrial confinement and driven west by precipitating weather systems. The dust from the April 15th storm was ameliorated by the precipitation, but the April 19th dust storm continued its ascent into the jet streams and thus, was unaffected (Husar, 2000: 1).

The dust storm took five days to get across the Pacific Ocean, flying, as it were, on the jet stream in elevated layers. It did three things when landfall occurred. Some portion of the dust stayed aloft and moved into the American Midwest. Another portion turned south along the West Coast and continued its traverse at

a height of 5 to 10 kilometers in height. The last portion subsided to the surface between British Columbia and California.

What were the effects of this aerosol event? It reduced the solar radiation input by 30-40% and doubled diffuse radiation. This was instantly discerned by the discontinuance of the blue sky and subsequent white discoloration. The dust event created a dust concentration level of 20-50 mg/m³ and it peaked at levels >100 µg/m³ throughout the valleys of the West Coast. The morphological signature (particle size 2- 3 µm) and the chemical signature were found from California to Minnesota (Husar, 2000).

This dust storm was two or three times bigger than any other event since 1988. It was fast and carried desert microfauna across the Pacific Ocean to North America. The human loss was significant in the Gobi Desert area and the storm was significant enough to warrant several state agencies to issue air pollution advisories and shut down prescribed burning. The size of the particles is particularly important for health considerations, since they are easily inhaled.

The important aspect of this Asian Dust event is that it penetrated as far as it did, into North America. If the world were in the grip of an ice age, what would this storm have achieved? High level winds and the jet stream is usually farther north during the winter, and during glaciation periods. Going back to the events in Africa during the LIA, it is interesting to imagine what this huge storm could have achieved during increased desertification.

If an Asian Dust Event occurred while the jet stream was located farther north during the LIA, the dust storm would have been carried further north and would have passed over Alaska and British Columbia and continued across Canada and the Plains States. If its power was increased by the increase in aridity and terrestrial storm strength, this same storm could go as far as Greenland and Iceland (Biscaye, 1996).

This is no imaginary situation. Work on ice cores has demonstrated that this occurred in the past, repeatedly during past ice ages. In 1996, an international team found that tiny particles trapped in a Greenland glacier during the last ice age traveled to their resting place not from the nearest desert in Africa, but from the Asian Gobi Desert. By looking at 3,000 years of ice core data, Biscaye was able to show that in the ups and downs of climate through this time period, the upper level winds over Asia were the only harbingers of dust going to Greenland. Fluctuations in atmospheric circulation were not the reason behind varying dust amounts. Instead, Biscaye postulates that the pressure cells governing the high level winds decreased in their strength, resulting in the movement of more and less dust (Biscaye, 1996).

These facts are corroborated by another study done in 2003 by Bory and⁶⁰ Biscaye, who repeated the experiment. They compared the mineralogical and isotopic (Sr and Nd) composition of mineral dust extracted from Greenland ice cores to possible terrestrial source areas (PSA) and found that Asia is the sole source of dust to Greenland. This was so for the many periods of glaciation during the last ice age, two intervals of the Holocene, and the present day (Bory, 2003).

A discussion of the Scandinavian settlement of Iceland would be remiss without summarizing their archaeological history and settlement of the Fenno-Scandinavian peninsula. This region of the world has experienced climatic extremes and it has never been static ecologically. The 20 glaciations of the Pleistocene were moderated by interglacial periods where climate was ameliorated significantly. The complete cycle of glaciations and interglacial periods took place over a million years during the Pleistocene period. The last major glacial maximum (LGM) took place 20 thousand years ago. After the 1300 cold years of the Younger Dryas episode, which occurred around 13 thousand years ago, the next major glaciation to occur in Northern Europe was the LIA, which occurred from the end of the 13th to beginning of the 19th centuries (Geispel, 1968; Alley, et al, 1993)

Neanderthals evolved in Europe from 500,000 years ago to around 30,000 years ago. Modern *Homo sapiens* arrived around the end of the first interglacial of the Würm Ice Age. This occurred around 40,000 to 50,000 years ago in Eastern Europe. Cold intensified from about 24,000 years ago, and again limited habitable land and resources. This led to their expansion towards the west, towards the Iberian Peninsula. They shared the region for some time with the Neanderthal.

From this point in time, various cultures and groups begin migrating towards northern Europe. However, the glacial ice sheet was a demarcating margin to any settlement further north. The Scandinavians are descended from people who migrated across the German plains as the glacier retreated northward over time (Fitzhugh, 2000).

Genetic work on these northern populations has linked them to a small group of Paleolithic hunter gatherers. This group, which numbered from 50 to 1000 persons, is thought to have come from a larger group who had first retreated south to escape the last advance of the Würm glaciation. This glacial advance created a bottleneck, or a founder effect, and they were forced to the south, either to the Balkans or Spain. This study also suggests that northern Europeans diverged from an African group of *Homo sapiens* around 27kya to 53kya (Reich, 2001).

Archaeologically, the material evidence shows that by the 18th millennium BC, the Solutrean culture was dominant in Western Europe and by 15kya, the Magdalenian culture rose to preeminence. It expanded to geographical limits not seen in human cultures on the European peninsula. It is from this material culture that archaic forms of Scandinavian cultures developed (Geispel, 1968).

Both genetics and archaeology suggest that a Scandinavian founder population came from Spain, and with more fieldwork, a better understanding of the exact material cultures- their conception and transmission- may be analyzed and developed.

By 10,000 BP Scandinavia was settled by humans who followed the retreating ice. These humans crossed what then was an “arctic” Denmark and moved over the land bridge that connected the European continent to the Scandinavian Peninsula. It is evident at least in Denmark that rudimentary agriculture was in place in southern Scandinavia by 7000 BP. This shows that Neolithic influences from the south were making their way to the north. By 1800 BP, the main culture groups that are known in the 21st century seem to have been firmly established in Scandinavia (Geispel, 1968: 149). This relatively quick settlement seems clearly possible since the “prospects for human life and settlement underwent far reaching changes as the environment responded to the onset of Post Glacial conditions” (Clark, 1975: 99).

The Neolithic or early farming period of European history was transformed as urbanization and metallurgical manufacturing became established. This prompted the Bronze Age which lasted from around 1500 to 500 BC. This was a time of flourishing culture, trade, manufacturing, and political growth for the Scandinavian peoples and was followed by the Iron Age. The early period of this age, known as the Halstatt period, was dominated by the Celts, whose movements, especially around 2500 BP, proved to be very influential. These people lived in the Upper Rhine and Danube initially, but migrated throughout eastern France, Spain, Italy, Hungary, the Balkans, and much of Asia Minor.

This migration dominated much of European history, and the Celts, at least for this time, were the dominant cultural group in Europe. Scandinavians were dominated and controlled by the Celtic culture (Jones, 1984). During the latter part of the Iron Age, the Celts developed the La Tene culture which soon spread its influence to Scandinavia.

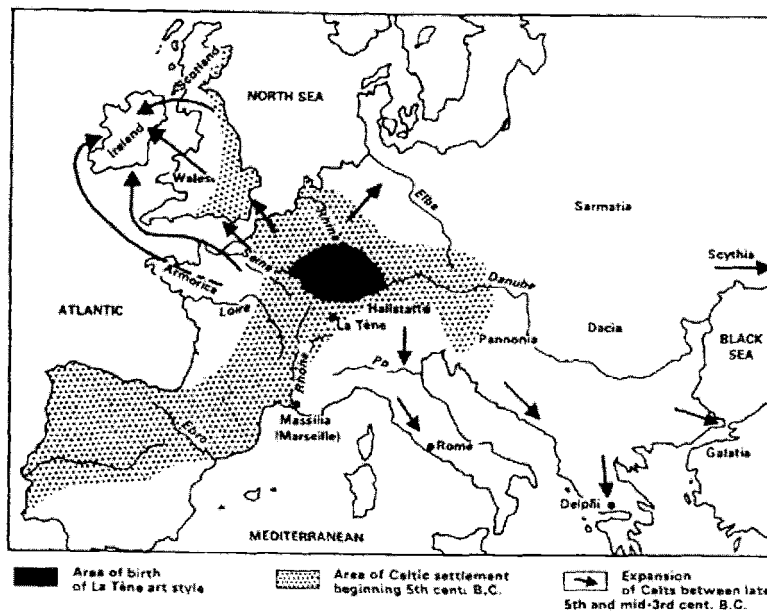


Figure: 8: Extent of La Tene culture. (Rubba, 2004)

For the most part, the Iron Age brokered the basic economic innovations of the previous age and laid the foundations for the feudal system in the Middle Ages. The Scandinavians, being so close to the Arctic, were challenged further by the environment, and so, took longer to gain the economic foothold that the rest of Neolithic Europe had made. During the Iron Age, they also faced a slight climate change that made things much more difficult for their former way of life to exist consistently year to year (Childe, 1962), (Alsop, 1964), (A. Jones, 1975).

The Celts utilized the crops and domesticated animals introduced during the agricultural revolution in the Middle East, in addition to using ox-drawn plows

and wheeled vehicles. This gave them the ability to effectively adapt to the heavily forested land. Villages were built with fortifications, transportation had improved, and this translated into conflict resolution as well. Warfare was conducted on horseback and on chariots. Finally, alphabetic writing based on the Phoenician script became widespread throughout the various groups living in Europe. This intellectual jump also expressed itself in the distinctive styles that were now quintessential for the style of pottery, stoneware, and wood work (Childe, 1962; Alsop, 1964; A. Jones, 1975).

After the Roman Empire rose to dominance, and culminated in collapse after 1000 years, the movement of European tribal groups began to occur. The years from 400 to 575 AD are known collectively as the Great Migration Period. These Germanic and Slavic peoples all moved into former Roman Empire lands. These groups did not displace the culture, but rather they absorbed it (Bronstead, 1965). They implemented much of the Roman culture and supplemented it with contributions from conquered people from former empire lands (Bronstead, 1965).

By the end of the of the migration period, “the face of Europe had changed but slightly under the new rulers”. (Bronstead, 1965) From this emerged the powerful Frankish Kingdom in what is now known as France, Belgium, and the Netherlands. The Germanic tribes were less organized and stayed pretty much tribal and loosely confederated (Bronstead, 1965: 12).

The population in Scandinavia was very similar to the Franks and Germanic people, and drew much cultural inspiration from them. This was the time of Charlemagne and his empire grew immensely strong, especially in lieu of

a new emerging threat of Arab invaders from the south. The Muslim nation who was advancing upon Europe, however Charlemagne was able to extinguish this threat.

The fall of the Roman Empire was an open door for Arab invasion and it was the strength of Charlemagne and his kingdom over time was directly linked to the emergence of Mohammed (Pirenne, 1939). However, unlike the great German migration period, where toleration was practiced, the Arab invaders waged a religious war against Mediterranean and European people and forced cultural change and adherence to the new religion.

With the death of Charlemagne and the division of his Kingdom into three parts, the power of the Scandinavians to the north emerged. Beginning with raids on the northern coast of France, England, and Ireland, the age of Scandinavia began (Bronstead, 1965).

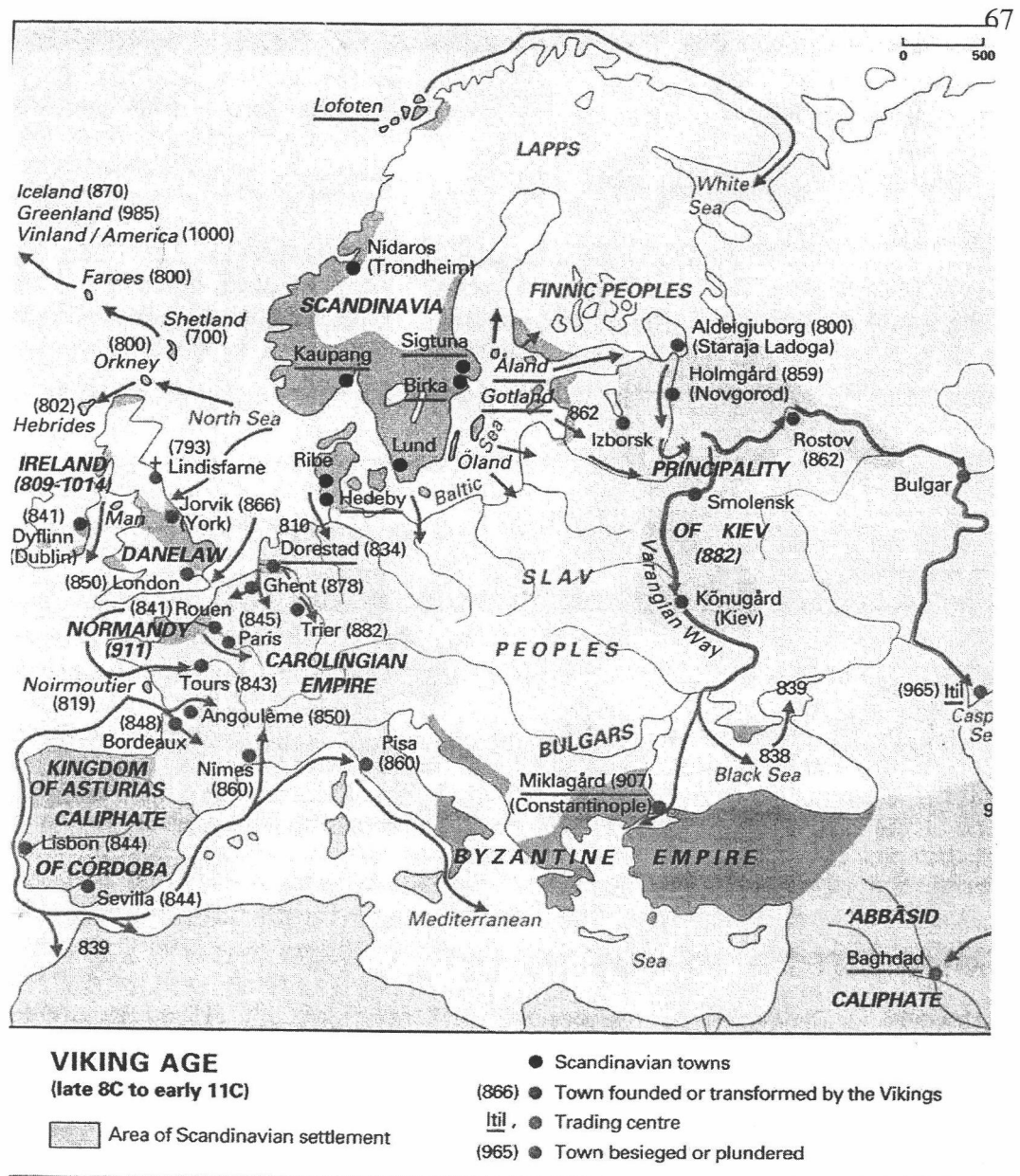


Figure: 9: Europe at time of Viking Expanse. (Michelin Corporation, 1998: 34)

The Scandinavian Age was not dissimilar to the earlier environmental and climatic conditions that the earlier groups of humans experienced. Most scholars put the beginning of the Viking Age at around 780 AD, but there is no single date to which this event is attributable. Most historians consider the many centuries of raids upon the European continent as the beginning of the Viking Age.

The Scandinavian Vikings were in competition with three great powers- the Carolingian Empire on the continent, and the Arabian and Byzantine empires to the far south. The latter two were too remote to be of any consequence, but the Frankish group that made up the Carolingians made large culture impacts upon the northern peoples. The origin of the Carolingians was Celtic, and this sharing of culture had been going on since the time that the Celts had their preeminence. The west of Norway was mostly influenced by the people in France and England, and their Merovingian culture, whereas the eastern peoples of Scandinavia were primarily influenced by tribes located in central Europe, the German Teutonic people. Also, there was a constant transmission of knowledge and material culture between these two sides of the Scandinavian Peninsula (Shetelig, 1937).

The emergence of a Scandinavian people distinct from the other northerners, the Franks and Saxons, came between 600 AD and 800 AD when the languages became sufficiently different between the southern and northern Germanic peoples. The language common to all Scandinavians underwent fundamental phonological changes, so that it "became less and less like the languages of their Germanic neighbors to the south and the west" (Foote, 1970: 2). On the whole, the new language change created a speech that was germane throughout the whole of Scandinavia. This speech, called *donsk tung*, *vox danica*, was used all over the Nordic area. This is indicative of a wholly subsistent culture taking root (Foote, 1970).

The Scandinavian culture put a major emphasis on the group and clan, and much less on the sole individual. Though their stories and religion (Beowulf, and the legends of the Aesir) do impart greatness to the single individual, the main prerogatives for the groups were family strength and pride (Foote, 1970). This is imparted in the law and ordinances given out in this time. Payment was often tied to honor, and pride in one's family and obligation to the family came first above all things. This codification of thought became a predominant problem in later times. Differences were settled through group revenge and quick passing of judgment, usually through blood loss. This method of dealing with tension translates from the level of the individual to the level of the regional culture group (Foote, 1970).

Tension and differences between culture groups existing in Norway, Sweden, Denmark, and Finland took place as resources were fought over. As each group became cohesive and self sustaining, they began to coalesce around resources and the power to control them is seen as the most important object for each group. Still, at least in the beginning, the various culture groups spoke a common language. Over time, language changes demarcate the differences between these groups.

However, the differences were minor at the time of the Scandinavian expanse, better known as the Viking Age. As the kingdoms of the great Charlemagne fell into the less capable hands of his sons, the Vikings raids increased and the power over the southern lands increased. The conquest of Europe and the North Atlantic had begun.

During the time after the Roman Empire fell, there was an obvious drop in scholarly writing about the northern lands, primarily due to the illiteracy that dominated Europe. However, after “an unbroken silence of 400 years”, great writers from the south began to write again (Jones, 1984: 25). This was during the great migrations of Europe. This literary tradition continued and Scandinavians, adopting writing and the Latin alphabet, soon began to write about themselves (Jones, 1984).

The period between 800 to around 1200 was a period of great stability for the Scandinavians. The amalgamation of groups into regional identities increased and the complexities of these groups continued to grow. By the end of this period, there existed a sense of nationality in the individuals living in what is now Denmark, Norway, Sweden, Finland, and eventually, Iceland (Foote, 1970).

Icelandic Settlement and Ecology

The constant raiding by the Vikings over a few centuries before the 9th century brought huge wealth to the Scandinavian people. This wealth began to coalesce around emerging nation states. Paradoxically, the countries of Sweden and Denmark were unified and made strong by an emergent tribe, the Sverige, among the many others, whereas the Norwegian realm did not coalesce so easily. It took the emergence of one man, as opposed to one tribe, to bring about the unification of the entire country. It was this single act that encouraged the Viking diasporas across the north Atlantic, in the case of this study, to the western island of Iceland (Magnusson, 1977).

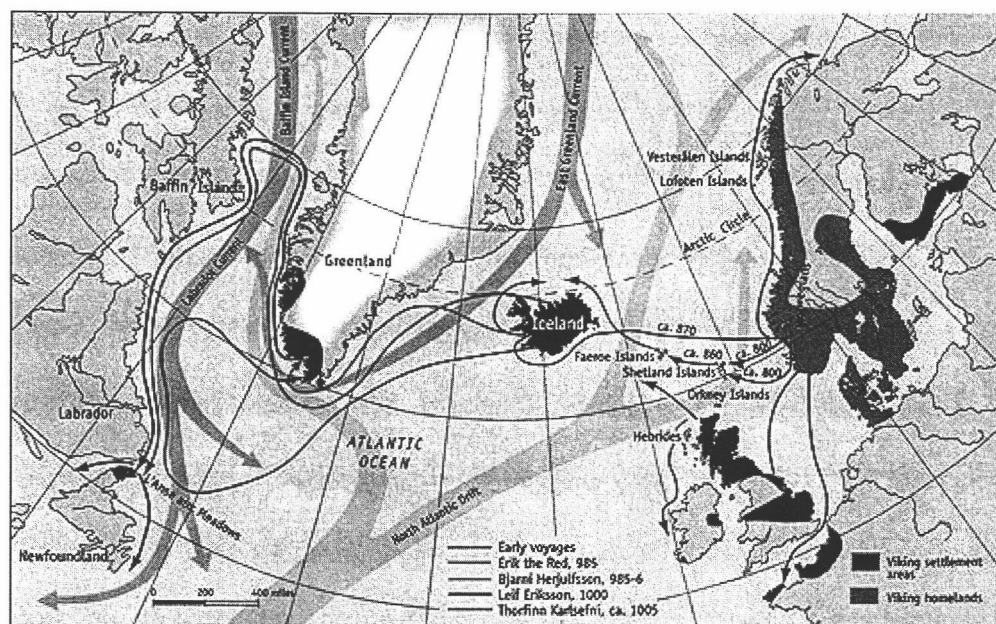


Figure 10: Viking settlement across the North Atlantic (McGovern and Perdikaris, 2000: 51)

The key social rule that drove people to further exploration was the law of inheritance that was firmly in place in Scandinavia, particularly in Norway. By the late 8th century, there was little land left for younger sons not eligible to inherit. If they wanted a life for themselves, they went looking for new lands. Moreover, political and social pressures aside, the climate was the biggest conduit for this movement.

Two things pushed the move out of Scandinavia: the climate of the early middle ages and the technological culture of the Scandinavians. They were primed for this kind of maritime adaptation. Trade with southern Europe and the Mediterranean region had given them contact with sea faring cultures and they quickly adapted and then surpassed these people in the art of sea navigation and sailing (Lacy, 1998). They had plenty of timber and an advanced iron industry that rivaled any other in Europe. The ships that the Vikings built, the Knörr, were so much more advanced, that the Scandinavians were the only people at the time in this region to sail across the oceans and large seas; the rest of Europe hugged the coastlines. However, during this time, Irish monks were leaving Ireland and sailing in leather skinned boats called currachs to Iceland to find refuge. This report is augmented by the appearance of old place names that refer to monks. Clearly, the Vikings who came to Iceland must have known about the monks since it is in their written record. The monks did not stay long though and did not continue the sailing tradition. The Vikings, however, continued their utilization of the sea. Viking longships traveled “faster than any vessels built before the invention of the steamship, a millennium later” (Tomasson, 1980; 5).

Even though they lacked the compass these Scandinavians were the most advanced ocean going people in all of Europe. They used astronomical observations to navigate the oceans. They rivaled the Phoenicians to the south. The rest of Europe did not reach this proficiency in technology until after the 15th century. This domination brought new lands to find and new resources as a result (Lacy, 1998; Byock, 2001; Bardarson, 1982).

Iceland was explored as early as 800 AD, but it was not settled then (Foote, 1970). The first Viking settlers, moving from the British Isles, Ireland, the Faroese Islands and Norway, finally reached Iceland in 870 AD and began establishing settlements after another four years. The time of settlement ended in 930 AD, when they declared themselves settled (Foote, 1970). The first 400 years were years of societal and cultural growth and they provided the historical context and reference that people return to for principle and cultural foundation.

Hrafna Flokia, who explored a particular fjord in the south in the first spring of settlement, gave the name 'Iceland'. He was noticeably impressed with the icebergs still floating in the harbor. In fact, many of the place names given by the settlers are attributable to the environment; the prefix endings 'eld', 'varm', 'reyk', (fire, warm, smoke) obviously referred to geothermal events never before experienced by Scandinavians before (Bardarson, 1980).

Volcanic eruptions and occasional glacial floods, as well as cold weather snaps occurred but they were never severe enough to dissuade settlement. The environment of Iceland is extremely harsh, tenuous, and susceptible to small changes in the many variables that create the ecology of the arctic island.

However, the climate at the time of settlement was moderate and very mild compared to earlier periods of Scandinavian history and this made even the terrestrial problems easy to deal with and adapt to (Shalins, 1976; Hastrup, 1985; Tomasson, 1980). Below is a map illustrating the settlement years and placement of towns in early Iceland:

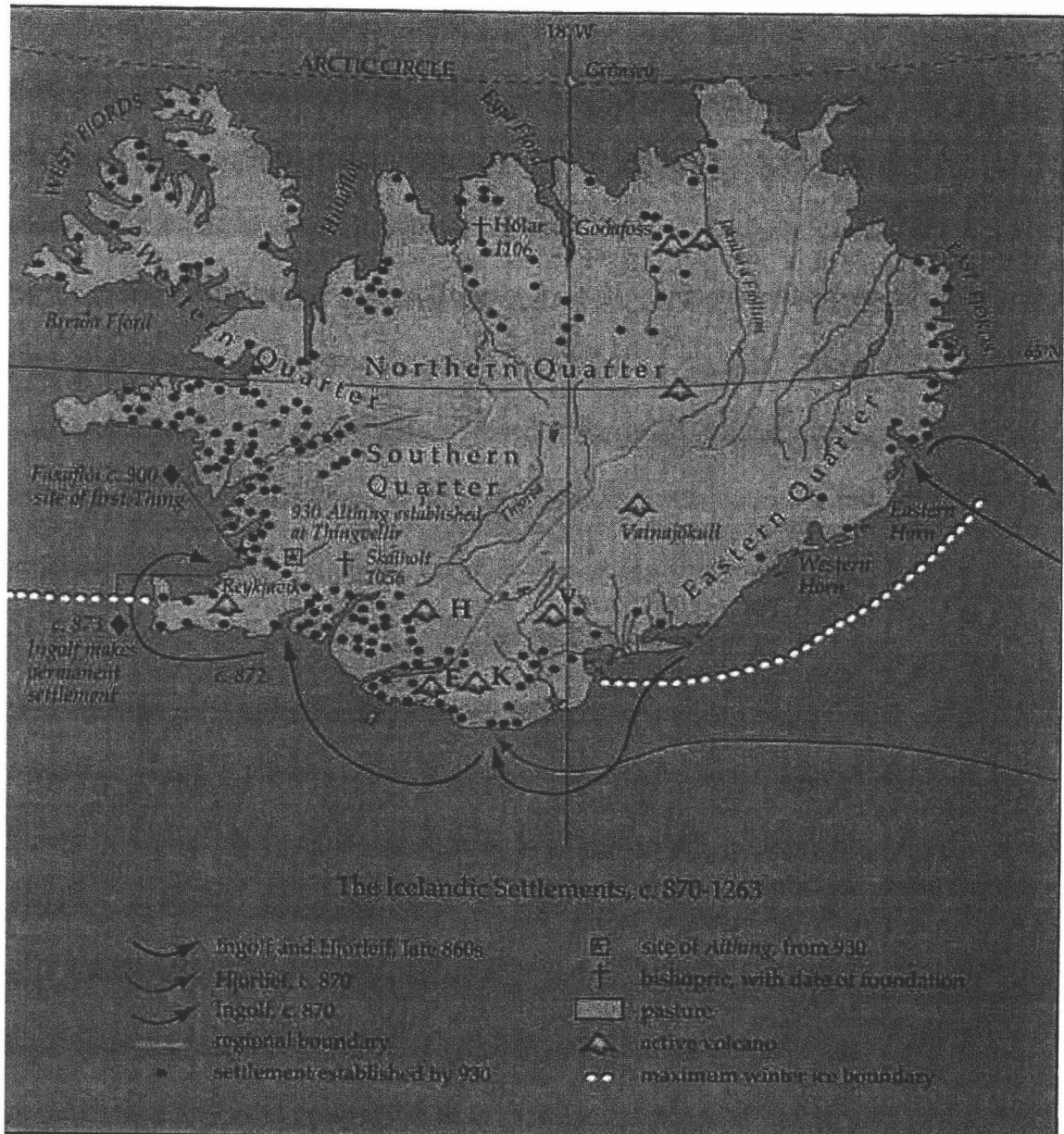


Figure: 11: Iceland Settlement. (Fitzhugh, 2000: 165)

The extreme nature of Iceland's ecology and geography "represents the most extremely inhospitable environment in which a European people has been able to survive and maintain its culture" (Tomasson, 1980; 57) and it is this fact that has interested me as a biological archaeologist and anthropologist. The success of Iceland this century is a welcome accolade following a very rough and tumble journey.

Before the beginning of the twentieth century, it was much different in Iceland- it came very close to becoming a vanished history. This change in luck, in the 13th century was due to change in climate, ecological change, and biology. On top of this was an isolation/dependency problem created by the lack of resources on the island and the leverage created by outsiders that created trade monopolies and controlled the Icelandic people severely. These changes brought disease, pestilence, dearth, and terrible threats to survival. (Tomasson, 1980)

This early history of Iceland and its Viking settlers was dependent on an amicable climate, good trade and contact with the homeland, and appropriate resource management. Despite that the animal population on the island consisted of arctic fox, seals, walrus, whale, ocean and freshwater fish- primarily trout and salmon- the first settlers were farmers first and fishermen second.

This led to overgrazing of unindigenous animals which produced erosion that was ten times that before colonization. The optimal climate gave them borrowed time and an artificial sense of sustainable adaptation.

Though they recognized that they needed to change their agricultural practices during these times, it was not enough (Ogilvie, 1980). The disease ecology that eventually affected Iceland is one that came as a direct result of the complete reversal of the climate and social situation that opened the seas to the Vikings.

Their misfortune was an exaggeration of that which the Europeans faced at the end of the 13th century, when the Medieval Warm Period ended. Like the Europeans, they did not see how their adaptive practices encouraged further degeneration, and could not foresee climatic changes and the terrible calamities before them. A table of Icelandic History follows:

I. Early Period	THE COMMONWEALTH PERIOD	(840-1262- Freestate)
840-930- Age of Settlement	This is the period when many of the disenfranchised and disinherited come to find new lives. They also create the world's oldest democratic state of governance, the Althing.	
930-1030- Age of Sagas	This is the period when many of first great works of the Germanic family of languages were written.	
1030-1220- Age of Peace	This is the period of great democracy and high Viking culture. Their use of the surrounding environment begins to show signs of resource depletion. The lack of wood requires the use of Peat instead. It is found in plentiful stock, but can only be harvested in moderate climate.	
1220-1262- Age of Sturlungs	Political unrest, treachery, murder, mutilation, the island tightly controlled by 6 families.	
II. Norwegian Takeover	LOSS OF SELF RULE	(1262- 1380- Norwegian Rule)
Climate change creates total dependency on Norway for trade goods which is a diminishing reality over time due to European conflicts and merciless outbreaks of epidemics, including Black Death, which kills two thirds of Norway's population, rendering them useless for trade and supplies.		
III. Intermediate Period	THE DARK AGES	(1380-1918- Danish Rule)
Entire culture is supplanted by German one and is controlled by Danish merchants which causes very inhumane economic oppression. All social activity is controlled and farms abandoned due to lack of barter and trade. Whole families die off. The great history writing that began as a national obsession withers away. Danish impose complete monopoly of trade upon the island, making trade impossible with any other nation. This bankrupts any surviving landowner and destroys the Icelandic Culture.		

Figure: 12: Icelandic History

Upon settling the island, the climate was quite moderate, and the settlers grew grains and raised cattle as they did back in the homeland of Norway and the colonies located in the British Isles. Sheep provided a good deal of the protein in the diet, and it also contributed wool as a trade item which was the main export to the mainland. However, the bleak natural resources on the island caused the settlers to have a high import requirement. They were forced to import all of their timber, meal, and malt. They also felt compelled to bring in all the niceties of the Scandinavian homeland, such items as “iron, linen, fine cloth, pitch, wax, [smithy tools], soapstone vessels, weapons, and jewelry” Foote, 1970: 55). This kind of economic trade situation is not unfamiliar to modern people in the 21st century. Indeed, many societies live marginally and basically import or create a lifestyle not conducive to the reality of their physical environment.

Observing the nature of island ecology is important in understanding Iceland and its settlement by humans. According to Marshall Sahlins, “[island] ecology is brought into cultural play as a set of limiting conditions, a range of tolerance in the exploitation of [an] environment or the satisfaction of biological requirements beyond which the system as constituted can no longer function” (Sahlins, 1976; 208). If people exceed this limit, they are selected against by natural selection. This is much like Rappaport’s view. (Rappaport, 1971) Hastrup continues:

Natural ecological situation does impose certain limits beyond which the exploitation of nature cannot move, yet these limits will to a large extent depend on the limitations inherent in the conceptualization of the environment (Hastrup, 1985:159).

This last concept is very important, because it exemplifies the ecological situation that the settlers found, and suggests how the Icelanders were able to move so quickly into step with their counterparts in Norway. They had a preconceived notion of the natural world, and with this conceptual reality, they moved quickly to use the resources in much the same manner as in Norway. This quick adaptation was a result of the similarity of the northern position of Scandinavia to Iceland, which encouraged their conceived environmental views, despite the abject reality of Iceland. This 'constant dialectical interplay' between the ecology of Iceland and the Nordic culture dictated their resource use strategies and their social/cultural development. These spatial and temporal conceptualizations were not challenged, primarily because the situation at the time was not objectionable to them. It was the change in climate and good fortune that brought major cultural challenges (Hastrup, 1985). The ecological limitations to the exploitation of Iceland were not being approached in the early period, so their limiting effects were not experienced. It was not until the middle of the 13th century that limitations were readily felt, due to a progressively colder climate, interrupted by occasional warming periods.

Towards the end of the Commonwealth Period, there was an end to temperate climate and a return to conditions similar to the Pleistocene Ice Ages which these northern Europeans had not experienced in several millennia. The Little Ice Age (LIA) began by the beginning of the 15th century and ended in the 19th century. It altered not just the immediate climate and environment, but as a consequence to this, several changes followed:

1. Winds were shifted from eastern prevailing winds to those coming from the west, which are primarily unstable (Ahlman, 1970; Larsen, 1969, 1975; Wallen, 1970).
2. Climate worsened, becoming colder and wetter (Hastrup, 1985).
3. Resource depletion hastened even further (Hastrup, 1985).
4. Epidemics and hard times ensued (Hastrup, 1985).
5. Social/cultural systems were thrown into disarray (Ogilvie, 1981).
6. Contact was diminished with Scandinavia (Hastrup, 1985).

The winds carrying the settlers to Iceland for several centuries originated from the east- a fact known from reading the tacking instructions left by the Vikings in their manuscripts. A study done by the *Journal of Navigation* in 2002 showed that the instructions given in the early Commonwealth Period were for winds coming from the east (Thirslund, 1997; Power, 2002). More importantly, the research showed that “the average weather conditions over the past century (20th) are not too much different from those in the early Middle Ages” (Powers, 2002: 110). When the dominant wind direction changed to the west during the LIA, it crippled the ability of Norwegian and Danish ships, and anyone else interested in trade with the Icelanders, from entering. The trade situation was also deleterious due to the stranglehold that the warring Chieftains, the Norwegians, and later, the Danish, had upon the island.

Because of the LIA and its effect on climate, the Icelandic people lost central authority and the island was inundated by economic monopolies created by Norway in 1262 and again by Denmark in 1380. There also were pirates and Arab marauders who raided the island after being daring enough to sail through the almost constant presence of sea ice around the island.

At this time, the two Viking colonies in Greenland were depleted and lost. Studies suggest similar lack of contact and depletions of resources and trade goods as the major contributing cause for the Greenlander demise (Ahlman, 1970; Ogilvie, 1981).

The causes of both colonies' suffering seem to be a string of events that cascaded and became bigger and bigger problems. This cascade of events created social disillusionment, upheaval, and most certainly several disease ecologies that ensued, putting the Icelandic and Greenland populations at terrible risk. Alongside these climate changes there was also an increase in volcanic activity and glacial disturbances, adding to the general inhospitable nature of Iceland. As a consequence, whole sections of the country were deserted, owing mostly to inability to foster any grain production, and destruction of habitat by volcanic events. This prompted an increase in dependence on imported grain. This occurred as the woody areas of Iceland ceased to be replenished with new growth, due to the insufficiencies of the climate, and the incessant cutting by the islanders.

Depletion of timber impeded ship repair and production and this further reduced the ability to import grain and maintain trade with the rest of Europe. Finally, the lack of timber led to the use of manure for fuel. This use, while necessary, took a valuable fertilizer away from agricultural use, since it could have been used for the remaining areas of agricultural production. Hastrup says this about the cascade of events:

Thus we see how the societal exploitation of nature not only gradually changed the natural environment, resulting in a worsening of living conditions, but at the same time precluded the alternatives which might have improved the critical situation (Hastrup, 1985:164).

This emic construct of the environment, a constant need to further exploit a dwindling resource base, was further crippled by abject reality- the world as it existed around the Vikings. Their etic construct was hampered by their ill conceived emic analysis of the environment. This interrelationship between the cognized view of reality and the more objective operational view is one that Rappaport would view as the necessary creations of an ecological analysis of any system. Adaptation is constrained harshly. Ogilvie writes in her dissertation about the unfortunate problem in Iceland:

The fact that the Icelanders' lives were so tightly controlled by foreign economic and political interests must have given little incentive or motivation for change and adaptation amongst the majority of the people (Ogilvie, 1981: 304).

Hastrup continues by stating:

Icelandic society is part of the ecosystem, just as ecology is part of the social system. These systemic properties imply that the interrelationship between natural and cultural systems is governed by complex processes of positive and negative feedback (Wilden, 1972, in Hastrup, 1985; 165).

One of the results of the cultural and ecological failure on the island is depleted immunity to disease and nutritional deficit, leading to several periods of death and distress to disease and starvation. Disease ecologies ensue and begin to wipe out the prosperity that once favored the island.

This thesis focuses on one of the many disease epidemics, the Plague, or Black Death- that hit Iceland twice. I hypothesize that the epidemiology of the disease outbreaks and the archaeological record do not fit neatly together. From 1402 to 1404, the plague killed two thirds of the population. All farming was abandoned and all families were stricken. Regrettably, it sometimes killed entire villages. The plague made a return visit in 1494-95.

Chapter 6: The Plague Bacterium

The plague bacterium is a gram negative, aerobic bacillus that is non-motile and non-spore forming. *Yersinia pestis*, the bacterium, is native to certain areas of the world. These “permanent reservoirs are called inveterate loci”, and include central Asia, Siberia, the Yunan region of China, parts of Iran and Libya, the Arabian Peninsula, and East Africa (Gottfried, 1983; 9). This terminology is based on the geographical location of the primary vector, the rat, and certain environmental considerations.

The plague is a disease primarily found in rodents and sometimes in other small mammals. Typically, the disease occurs within the rodent population and rarely crosses over to humans. The principal vectors are fleas, and the rodents act as secondary or corollary vectors. The flea most commonly found in association with this bacterium is the oriental rat flea (*Xenopsylla cheops*). The bacterium usually crosses over to human populations when fleas leave infected or dead animals and move onto a human host. This transfer and disease pathogenesis is called a zootrophic crossover. The rodents themselves can act as the vector per se when they move into human settlements (CBWinfo, 1999).

There are two main types of the plague, the bubonic and pneumatic varieties. The bubonic variety is transmitted from bites delivered by fleas living on the hide of rodents. The bubonic form is characterized by buboes, and pathologically inflamed lymph nodes in the armpit and groin. It spreads rapidly through the body cells by moving via the lymphatic system. This system pushes fluid that drains out of the body's capillary beds, back into the body through

various filters. It enters the bloodstream and is delivered throughout the body, and back into the intracellular spaces. When the body is infected with this bacterium, it generally leads to infections of the spleen, lungs, and the brains' meninges. Mortality can be as high as 50 percent, but it is usually less than this (CBWinfo, 1999).

The pneumatic variety is transmitted through animal to human, and then human-to-human transmission. The pneumatic form is characterized by tightness in the thoracic area, dyspnea, and bloody sputum production. The first sign is a fever and rapidly worsening cough, mixed with difficulty in breathing. The infection rapidly engulfs the lungs, creating hemorrhages that eventually fill the lungs with fluid. Associated symptoms include nausea, diarrhea, vomiting, abdominal pain, and buboes on the neck. Death is almost always certain without treatment (CBWinfo, 1999). The plague bacteria is very easily killed by exposure to UV light for three to five hours and in high heat, and in its biological enzymatic window, it is highly contagious and lethal (CBWinfo, 1999).

For modern humans, this bacterium is treated with antibiotics, usually in combinations of tetracycline, streptomycin, gentamicin, and fluorquinones prophylaxis. However, for earlier human populations, the plague meant death most of the time.

After climate changed to colder conditions, it brought scourges and disease that took advantage of the weakened people already bereft of agriculture industry, outside trade, and contact with the outside world. The health and immunocompetence of the Icelandic people suffered and pronounced disease

ecology emerged. The plague events in 1404 and 1494 were the worst disease outbreaks that hit Iceland in its history. Three smallpox epidemics hit during the 1300's and again in the year 1431, but they did not have the death rate that the plague did (Lacy, 1998).

By the beginning of the 15th century (1400), the old culture of Iceland and the ways of life of the Viking were largely finished (Lacy, 1998). The end of the Commonwealth in 1260, and the rule of Norway up to 1380, and the subsequent rule by Denmark afterwards left an indelible foreign element in Iceland. Local custom departed and strict control imposed by the foreign governments took a toll on the people. No longer able to make their own trade decisions and discuss their own politics, they were little more than puppets in a tug of war between far off Scandinavian countries. This was ameliorated by the appearance of English and German Hanseatic traders who began illegal trade with the Icelanders after the huge monopolies were put in place by the Norwegian and Danish kingdoms (Lacy, 1998).

Foreign domination came about the same time as the first epidemic of the plague. It is speculated that it arrived through trade and it is documented that a ship from England sailing into the harbors of Hvalfjörður which lies in the southwestern part of the island, came soon before the first victim fell (Karlsson, 1996; Lacy, 1998).

The Disease Ecology of Iceland: an Analysis

Studies of the epidemiology and the archaeology of the plague in Iceland do not agree with one another and this has led to much speculation about the epidemics. Gunnar Karlsson outlines the current ideas about the cause of the plague in Iceland, as well as in Europe and the rest of the world during the Middle Ages, and he is quick to discard the standard theories based on one key item: the absence of rats in the archaeological record of Iceland up to the 18th century (Karlsson, 1996). Lacking a rodent population, bubonic plague is not a realistic disease.

Karlsson reviews the research that was done before him. He is quick to point out that the ideas are very paradoxical. The authors Karlsson cites have produced volumes of work over that last couple of decades. However, the work is very contentious and does not produce any consensus. Shrewsbury (1971) denies that the disease outbreak could be pneumatic plague, and believes that England, from whose shores Iceland is professed to have received the bacterium, was too cold at this time, and was too under populated by rats to be the source of *Yersinia pestis*. Next, he states that the whole of the Great Pestilence is wrongly diagnosed and that it was more probably typhus fever (Shrewsbury, 1971). This position is greatly criticized by Morris who believes that pneumatic plague, and not bubonic plague, was the culprit in Iceland (Morris, 1971). Shrewsbury's ideas are supported again when Twigg suggests that the disease was actually anthrax (Twigg, 1984).

Finally, Benedictow, a Norwegian historian, argues very aggressively that the epidemics that affected the northern countries, including Iceland, were nothing more than the bubonic plague itself. He does not offer another diagnosis, and is belligerent about his point of view (Benedictow, 1992). This abrupt and defensive posture is countered by Horrox, who states eloquently that the pneumatic variety of the plague could have occurred “at least in southern and western Europe”. She follows this by agreeing with Benedictow about “another situation in the north of Europe” (Horrox, 1994: 6). Another idea was a suggestion that the human flea and not the flea usually associated with the rat vector, was responsible (Oeding, 1988).

The end result is a situation that would have “the mode of infection considered most likely in cool temperatures [occurring] in the warmer parts of Europe, and the heat loving black rat and its even more heat dependent flea spread [the disease] in the coolest of regions [of Europe]” (Karlsson, 1996; 264).

The proponents of pneumatic plague, including this researcher, follow the lead of the late physician and medical writer, Jon Steffensen, who wrote in 1975, that the disease that hit Iceland was indeed pneumatic plague (Thorlacius, 1990).

Research contributed by Karlsson is my prime source since I believe it to have more validity than all others concerning Iceland. His line of reasoning is based on the demonstration of the epidemic dispersal across the island, the mortality rate, the lack of any rats in the archaeological record, and lastly, the symptoms that were exhibited by the islanders during the epidemic in 1402 and in 1494.

1. The lack of rats:

The presence of rats in Iceland appears impossible due to the climate and the natural behavior of rats and fleas. The black rat does not naturally acclimate to cold regions and migrates to warmer areas, or uses the heat given off by human settlement structures in tightly packed human cities. In terms of migration in Iceland, this would have been impossible, given the temperature extremes. Also, the size of the villages would make rat domiciles negligible since most people lived in farmsteads in great isolation. Transport to and from these remote buildings would have been very difficult for rats. Finally, there have not been any rats found in any archaeological dig that is dated prior to the 18th century (Lacy, 1998; Twigg, 2003).

The written records of Iceland do not provide any mention of rats at all. In modern Icelandic, the two words used in modern parlance are 'valska' and 'rotta'. The former is a loan word from the French, and the latter is a loan word from the Germans or the Danes. On the other hand, the word for mice occurs over 20 times in ancient Icelandic and Norwegian texts- and these are the texts that have survived! Karlsson's final statement is one of assertion; he states, that "it is hardly conceivable either that a rat which could have been present to spread a plague to and within practically every nook and corner of the country in the 15th century could have died out" (Karlsson, 1996; 280). This rat, if it existed, would have certainly gone against the biology and behavior known to black rats and would have certainly continued its dominion on Iceland.

The activity and natural disposition of the flea pose the next problem.

Karlsson argues that the environmental conditions were not feasible or viable for the flea during this time in Iceland. Research has demonstrated that the metabolic activity of the flea is greatly affected by cold temperatures. When the temperature of the ambient air reaches below 18.3°C, the activity of the flea is decreased.

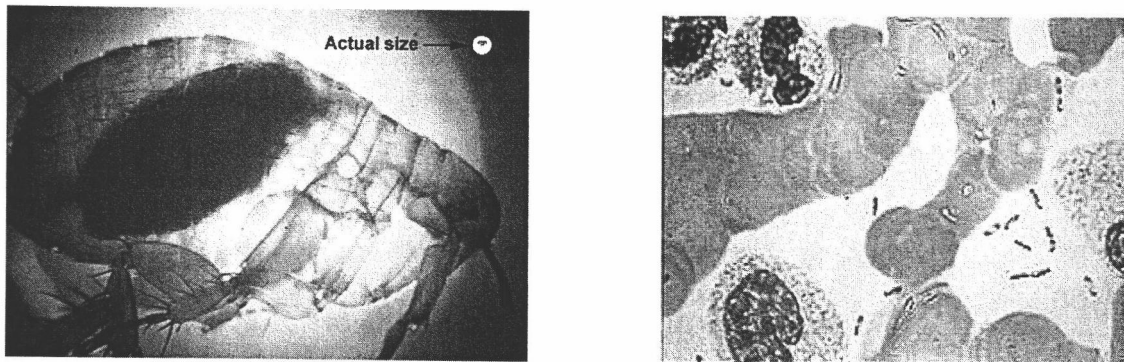


Figure: 13 : The flea, (*Xenopsylla cheopis*), and *Yersinia Pestis*. (CDC, 2004)

Paradoxically, the temperature needed for the spread of the bubonic variety is 10°C. In cooler weather, the eggs of the flea cannot hatch. Upon the arrival of snow and frost, the flea hibernates. In both cases of the plague outbreaks in Iceland, the first occurrence took place during the winter months (Karlsson, 1996).

2. The spread of the disease:

The European outbreak began between 1330 and 1346, as the bacterium made its way into the European region. In Europe, there were around 22 million victims (Twigg, 2003). It entered Scandinavia in May of 1349, through the port city of Bergen, in southern Norway. By the end of 1350, the plague had run completely through Scandinavia. As for its spread through the rest of Viking Europe, most traditional scholars consider trade as the primary vector for the rat

and its fleas. The North Atlantic route most often understood to be is from Bergen, to Iceland, to the Hebrides, the Orkneys, and the Shetlands. It then moved on to Greenland. According to this viewpoint, this movement occurred over the next several decades and caused outbreaks throughout the Viking World (Gottfried, 1983). Regardless of the vector bringing it to Iceland, the disease did come. The first outbreak in Iceland occurred in 1402 and lasted for 19 months, ending in 1404. The second outbreak occurred in 1494 and lasted for less than a year, ending in 1495. Iceland lost 2/3 of its population (Karlsson, 1996). The spread of the disease presupposes an epizootic outbreak in the rat population. The rat population could not have been at levels that would allow this due to the climate and to the living arrangements of the human settlers, which could have provided some shelter. According to the reports from the first outbreak, the speed of the disease was around three kilometers a day. This is based on the distance between the north and south of Iceland, which is about 300 kilometers. This speed is close to that of the plague outbreak in mainland Europe, where the climate was much more conducive for the bubonic plague. Its rate of travel was, according to Benedictow, around .65 kilometers a day (Karlsson, 1996). This is too fast a rate for bubonic plague to travel through an entirely agricultural society (Twigg, 2003).

3. The mortality rate:

The mortality rate for the 1402 outbreak in Iceland was 60% and the rate of farm desertion was 50%; the mortality rate for the 1494 outbreak was 53% and the rate of desertion was 38%. These rates are based on historical documents from the time period, and from periods thereafter, written about retrospectively. Admittedly, the 15th century was the only century in the 1200 years of Icelandic history that “had no extensive narratives” (Karlsson, 1996: 265). However, the annals that do supply information do so in a very informative fashion. The first plague is revealed in the ‘Nyi Annali’, or New Annual, which was written in the 1430’s. A few fragments found in a document written for 13 years around the year 1400 provide other information (Karlsson, 1996). The second plague epidemic comes to us from a document immediately following the ‘New Annual’ in 1430, called Gottskalk’s Annual. This information is augmented by documents from the 17th century (Karlsson, 1996).

4. The symptoms:

According to Karlsson, “there is nothing in the Icelandic sources that seem to support Graham Twigg’s theory that the medieval plague was in fact anthrax” (Karlsson, 1996: 264). This pathogen is spore forming, aerobic, and gram positive. They are usually saprophytic and are found in soils worldwide. What makes anthrax special is its tenacity to endure indefinitely without having to reproduce and its ability to hibernate. There are three basic types of defense that it uses for survival; a protective antigen, a lethal factor, and a toxin specific to

itself, called the edema factor. The former, plus either one of the latter, will cause pathogenesis. The toxins also inhibit phagocytosis and leukocyte oxidative activity. This combination makes it very adaptable and able to demobilize a physiology, but it was not likely to have been the bacteria responsible for the two mysterious outbreaks in Iceland. One of the principal reasons is that this disease is primarily a herbivore disease. Ninety-five percent of the disease occurrences in humans result from inoculation through the skin. Furthermore, the organism is not highly contagious, and transmission from one person to another does not occur.

This is a key element, since the research obviously shows that the disease was rampant and was vectored in a way that created a quick pathogenesis within whole communities across the country (Murray, 1998). It was a classic Reed and Frost dynamic “where infections rose sharply to a single mortality peak before decaying” (Twigg, 2003).

Documents show that at least during these two outbreaks, there was no great mortality within the animal groups on the island. The main economic activity on the island was animal husbandry; thus animal butchery and harvesting of hide and wool took place often. If the disease outbreak was anthrax, there would have been a demonstrable dying off of both animals and humans (Karlsson, 1996).

The strange thing about anthrax is that it is considered rare and curiously, one where the infected individual dies sterile- all the pathogenic organisms are eliminated during the disease process and the toxicity is lethal to the end (Tierney, 2002).

This would make DNA comparison to samples found in bone, tissue, etc, a virtual impossibility. The evidence for the pathogenesis is literally processed out of the body physiologically, through the disease process. Archaeological evidence for anthrax would be null. This makes testing this causal mechanism very difficult.

Other clues for the mysterious outbreaks in Iceland are to be found in the symptoms described in the annals. In one of the passages there is a clause that many epidemiologists and translators have wrestled with: The whole phrase goes like this:

The nature of the sickness was such that men lived not more than one day or two, **with great pleuritic pain** (með hörðum stinga), whereupon they began to vomit blood and then the spirit passed on its way (Karlsson, 1996: 281).

Translated, it can be understood in various ways. The first historians thought it meant “with great pleuritic pain”. This understanding comes from Steffensen who believes that it obviates the nature of the illness as that of pneumatic plague (Steffensen, 1990; 43). Benedictow, who instead believes that the definition of “stinga” is more general, challenges this translation and he translates the phrase as “with sharp pangs of pain” (Karlsson, 1996: 281; Benedictow, 1992).

This is wrong, however. According to Icelandic language etiology, the word ‘stinga’ is understood as a severe incapacitating pain. The Norwegian medical historian, Reichborn-Kjennerud, believes this pain to be the result of the causative agent, pneumatic plague. In the Icelandic Sagas, there are two occurrences of this word and in both instances, the word is in reference to a pain “in the side and over the chest, and “under the arm” (Kaupmannahöfn, 1858;

182). Finally, the modern Icelandic word, *stingur*, refers to a pain in the chest.

This etiological extension from the past probably has a predecessor that meant the same thing (Karlsson, 1996).

In addition to the argument given by Karlsson, there are archaeological data that show with no uncertainty that the living arrangements of the settlers in the mid part of the Middle Ages were very conducive to epidemic pathogenesis of every kind. As noted earlier, the climate was temperate in the beginning of colonization. The people thus were able to maintain a typical Scandinavian lifestyle. Even though the growing season was short, they depended greatly on livestock- cattle, sheep, rams, goats, and swine- to sustain them (Fitzhugh, 2000). Food crops were generally scarce, and this could very well have hurt their overall daily healthy regimen of nutritive caloric intake. The little vegetative intake was limited to barley, cabbage, onions, peas, and beans. Beer and mead were the favored drinks (Fitzhugh, 2000). Goats, sheep and rams were maintained for their wool. Based on archaeological research of the island, rams were the favorite wool producers. The sheep and goats were used mostly for milk, which was used to make cheese (Fitzhugh, 2000). The Norse farm was traditionally centered on the long house and the surrounding pit houses that were living quarters, stalls, and storage areas over time (Lacy, 1998). The building of these structures required new methods and different materials than were used in Scandinavia. They built mud and turf houses, augmented by rock for foundations. Vikings also used peat blocks instead of mud when this was an option (Fitzhugh, 2000). Dirt floors were ubiquitous (Fitzhugh, 2000).

These floors were subject to constant deposition generated by daily tasks. The illustration below provides insights about the micro-ecology that existed in Icelandic farm sites:

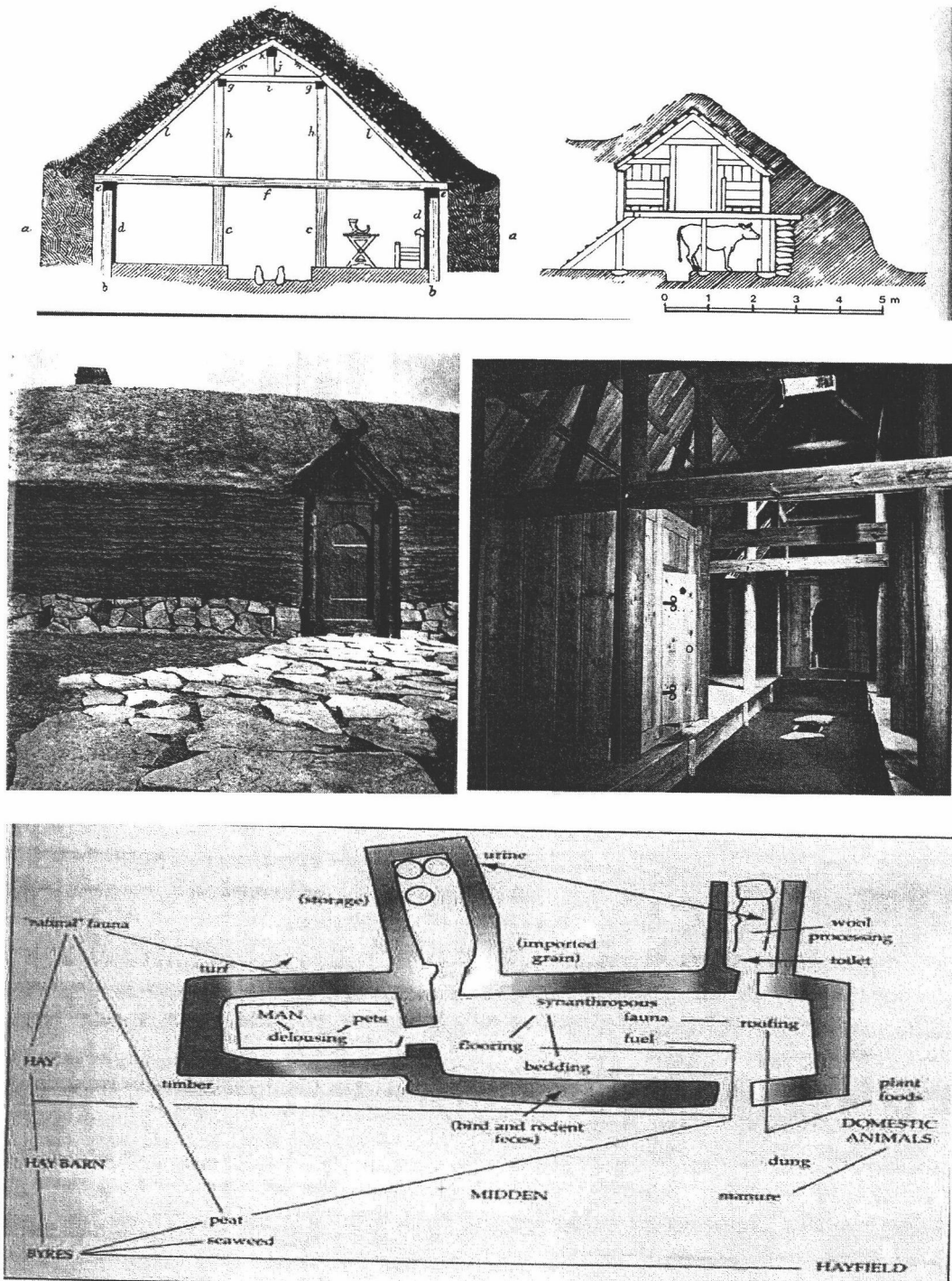


Figure: 14: The Longhouse (Bardarsson, 1983; 57 & 60; Fitzhugh, 2000; 149)

In addition to the hair combs and ear spoons and other artifacts which are found at Norse sites, there is an abundant macrofossil record. This record is helped in part by the preservation of key farm sites. However, the main factor was that the Viking settlers occupied farm sites for generations, and the floors inside the farm houses would consist of hay or turf, scattered over previous layers. This was sufficient to cover food remains and dirt, and to absorb moisture (Fitzhugh, 2000). In the later Greenland colonies that came later, the lack of hay, and need to keep the permafrost somewhat frozen forced settlers to throw down a special layer of twigs, wood chips, and moss, as well as hay (Buckland et al, 1993; Fitzhugh, 2000).

These layers also harbored hundreds, if not thousands, of parasites, insects and microbes (Buckland et al, 1993; Skidmore, 1996). Many of these insects and parasites live only in squalid conditions, chiefly in carrion and feces, and it is to be assumed that these were inside the farmhouse because the fauna are there (Fitzhugh, 2000). Along with hay and dung fauna introduced by the Vikings, there were also the entire micro fauna found on humans and animals. This includes viruses, bacteria, and other types of microbes.

Many of these insects and microbes were used to the warmer conditions found in Scandinavia, and they would not have survived in the harsher winters and cooler summers in Iceland or Greenland except for the warmth found in the farm houses themselves (Fitzhugh, 2000). This fact however, does not detract from the earlier argument that the fleas could not have survived in Iceland. The distance between farmhouses, and the fact that no house is heated continually,

augments my argument. In fact, as the climate deteriorated, the ability of the fauna to quickly adapt is obviously a moot point; they don't.

The chief importance of faunal remains is that they suggest a colder trend at the end of the Medieval Warming Period (Fitzhugh, 2000) and the beginning of the Little Ice Age that immediately follows it (Atkinson et al, 1996; Barlow et al, 1997; Bocher, 1998; Bocher and Bennike, 1996). Species adapted to temperate climate diminished in numbers and were sometimes replaced with heartier arctic varieties. The environment of Iceland provides keys to the climate including not just glaciers, but a faunal record that gives monumental evidence of climate change. This evidence comes from various remains sediment cores (Dugmore, and Buckland, 1991). The ecosystems that are literally found 'under the living room' rug provide a plethora of evidence not just of the insect and parasites that lived there, but the scourge of microbes that infested the animals and humans as well.

Many researchers and historical architects who have participated in reconstruction of the living structures on Nordic farms have remarked at how similar living conditions of the early settlers were to Icelanders living much later, in the 19th century. Kristjan Eldjarn says that the farmers living during the 19th century were essentially Iron Age people and would have had little trouble recognizing and implementing the material culture of the early settlers. Farming techniques and building techniques were essentially the same (Lacy, 1998).

By the end of the 10th century, there were about 4000 farms scattered about the island. These population concentrations were no European sized towns. They consisted of farm structures and out buildings. During the settlement years, these buildings were quite comfortable and provided “good protection from the weather” (Lacy, 1998: 96). However, climate change made these adaptations inefficient. The Icelandic historian, Jon Adils, described the conditions as dark and dank, and when the rains came, as often is the case in Iceland, the roofs would leak, and the floors would become “pools of mud”. Due to the constant wet conditions, a grey coat of mildew and green slime was constantly trickling down the walls of the structures (Magnusson, 1977; 120; Adils, 1925).

In addition to the weather’s effect on the structures is the presence of animals inside the dwellings. This addition occurred after the climate change, and it is assumed that this was to maximize heat for both animals and humans. This likely contributed to zootrophic crossovers of animal diseases, especially in such harsh conditions.

Structural components aside, it is most important to discuss the living arrangements inside the domicile during the period of the climate change from the warm period to the Little Ice Age. Before the climate change, there were outdoor privies, or special places within the longhouse. After the climate change, people began to abandon the outdoor privy altogether. Access to fresh water was severely limited and cleanliness, so much a virtue in their society during the Commonwealth Period, was compromised. They bathed, urinated, defecated, ate, and recreated inside the longhouses for many hours of the day (Lacy, 1998;

Magnusson, 1977). Smoking cooking fires within the structure filled the air, along with body odor and the stench of the filth inside the longhouse (Magnusson, 1977). Another problem is the constant winter darkness, which is not good for mental and emotional health.

Another Icelandic writer, Magnus Olafsson wrote “that one can understand how these miserably constructed houses...contribute to the spread of all sorts of diseases.” He continues by stating that “the air is so impure that a stranger...can scarcely endure it...as it is corrupted by the smoke, and the respiration and perspiration of the people, many of whom are affected with scurvy and other diseases” (Magnusson, 1977: 121). In addition to this is the biota of insects and vermin nestled in the habitat which made the environment a breeding ground for infectious disease. The paintings below, done in later centuries, historically reflect this:



Figure: 15: The interior of a Longhouse: (Bardarsson, 1980: 70)



Figure: 16: Another interior of the longhouse: (Bardarsson, 1980: 62)

These are people living at the extremes of the northern Atlantic frontier- isolated and resource-challenged. There is evidence to show that they did try and control resource use and had various ways of dealing with over population (Ogilvie, 1981). The climate change, the many disasters and blights against their health, and threats against their continued settlement were a product of circumstance and not a consequence of their culture. However, the situation was difficult and there appears to have been no options. Their situation reflects other situations forced by other populations living in marginal environments.

Humans living in marginal environments are very often put to the test when slight changes occur. Icelanders community health was on a slippery slope and this put them at greater risk for infectious disease and opportunistic infections.

Adaptation must be quick and clever enough to maintain vigorous synthesis with the external world. Though they did see disruption, they were not able to put major changes into effect. The CAS model in the appendix will shed more light upon this dynamic.

Chapter 7: Hypothesis and Postulation

The key problem to understanding this 15th century Icelandic epidemiology is that the climate was not conducive to the tolerance levels of the rat or the flea. Still, there was a rapid and deadly pace at which the pathogenesis spread out upon the island. Contributing to these facts about the epidemiology are the living conditions that the Icelanders dealt with during the climate change in the LIA.

My hypothesis is that the climate change produced an ecology that was ideal for pathogenic microbes to fester and be viable. Climate change also curtailed the customary social and cultural adaptations on the island. The material evidence left in the archaeological record allows an assessment of the living conditions for the majority of people.

I believe that the pneumatic form of the plague, *Yersinia pestis*, arrived during a time when atmospheric winds would have been able to translocate it from Asia on high altitude winds above the terrestrial limits of ground weather.

I devised a pilot study to show how molecular biology and Polymerase Chain Reaction (PCR) techniques can provide a way to explore this event in 15th century Iceland. Although I do not use an ice core from Greenland or Iceland, I expect that my success in identifying bacterium at various concentrations will translate to the study of an ice core from Greenland or Iceland that will determine whether there was an environmental vector for the plague.

My hope is that such a future study could shed light on a time of human history that experienced a climate change that may have created a global epidemic of interconnected disease ecologies.

Investigation of Disease Ecologies

Chapter 8: The Archaeological Investigation of Disease in Scandinavia

The health of a people indicates the measure of success that they have had in adapting to their environment. By looking at archeological evidence left behind, a linear history of disease and pathology emerges. Most evidence is found in skeletal remains, since very little tissue usually remains. From the skeletal remains, one can see readily the evidence left by the scourge of polio, leprosy, tuberculosis, syphilis, as well as lymphomas. Congenital diseases and anomalies are also observed in both children and adult skeletons. Lastly, nutritional deficits are evidenced in grave sites. This is corroborated by instances of starvation and famine that were part of the local historical record.

The health status of the Scandinavian people prior to the LIA appears to be quite good, according to several researchers. The population's diet was sufficient in nutritive quality. They consumed a large quantity of milk products, beef, and mutton, fish, geese, chicken, and pork (Lacy, 1998; Poertner, 1971). This high protein and high fat diet was very nourishing and appropriate for the labor intensive lifestyle they had in meeting the adaptive circumstances in the far north. Their cooking processes did not destroy vitamins and minerals, since they usually boiled their meat and vegetables. If the meat were being preserved, they would use drying and salting techniques that would not degenerate the nutritive quality of the food (Lacy, 1998). Their intake of the more important vitamins is illustrated below:

Vitamin A- came from fats that were obtained from animals
 Vitamin B- came from the meats and the fish
 Vitamin C- came from raw onions, angelica, crowberries, and blueberries
 Vitamin D- came from fish, milk, butter, and in a physiological process by the sun
 Vitamin E- came from the fish oil, and milk fat that was consumed

Figure 17: Sources of nutrition for the Iclander (Source: Lacy, 1988)

The Scandinavians had to supplement their diet with hunting and fishing and could not allow themselves the luxury of agriculture as the dominant food supplier. The Norwegians, in particular, were extremely adept hunters and fishermen, as opposed to the Danes and the Swedes, who had more arable land and used agriculture more extensively (Poertner, 1975). This research, however, is based on analysis of historical records of food and diet that have been gleaned from written records through time. The archaeological record, specifically, the biological record, should be more specific. The romanticized notion of the Viking and the reality that is found in gravesites is far more revealing.

The archaeological record of the Scandinavian region is interesting in that cultural practices make a sizable impact on preservation and number of remnant skeletal remains. They also show the changes that occur over time to the people as they endure hardships, hardships that make the lifestyle mentioned above, much harder to obtain. Fewer than 400 individuals have been found and studied in the region: 300 from Denmark, 60 from Norway, and less than 20 from Sweden (Roesdahl and Wilson; 1992: 116).

Geographically, the skeletal material found in Denmark comes from all over the three principal islands, plus areas which are now part of Germany. The material from Norway comes from the northern parts of the country. Sweden has very few interments anywhere in the pre Christian archaeological record. This reflects the culture, as the early Swedes practiced cremation much more than their Scandinavian neighbors to the west. This is obviated by the influences given by the surrounding cultures around each (Roesdahl and Wilson, 1975).

Findings by biological anthropologists show that, for the most part, people died as mature adults and had a comparatively high standard of living, compared to other groups. There are very few graves of children, probably reflecting the practice of infanticide and lack of ceremonial significance to young death (Roesdahl & Wilson; 1992). The bones have very few traces of fatal wounding and many have traces of healed wounds. Almost all gravesites contained the typical Scandinavian features, i.e. long narrow skulls of medium height and robust, strong appendicular frames and strong limbs (Roesdahl & Wilson; 1992).

The stature of the individuals is as follows: Denmark males ranged from 163- 185 cm, with a mean of 172.6 cm; Norway males ranged from 175.6 with a range from 120-181 cm; females in Denmark averaged 158.1 cm with a range of 150- 167 cm, and in Norway, the females averaged 159.6 with a range of 149- 164 cm.

There are no measurements from Sweden, as their interment practices were such that no remains are found. The overall average stature is 10cm below today's Scandinavian average. The propensity for tall stature is probably the same then as it is now, which suggests that caloric and lifestyle differences found in post-industrial populations after the 19th century, exhibiting the same improvement, demonstrate the exceedingly good living conditions.

Else Roesdahl believes that the Danes had a homogeneity that surpassed the northern Scandinavians. The Danish skeletal remains showed no signs of intermingling with outside peoples, including the Celts and the Germanic tribes that they subjugated from time to time. Norway has more variability and the presentation of brachycephalic, or broader, skulls, indicate definitive admixing with the Saami population to the north of the Norwegian area of Scandinavia (Roesdahl & Wilson; 1992).

For Iceland, a recent excavation in the Mosfell Valley has shed light on the lives of the Norwegian settlers that came there. Dating from the early settlement period, roughly the 10th and 11th centuries, the researchers found that these people suffered much more derogatory conditions, than their kin in Scandinavia (Walker, 2004). Analysis of the skeletal remains of 14 individuals shows considerable stress is evident in the bones. The most pronounced finding is the evidence for traumatic injury and infectious disease that is present.

As mentioned in previous sections, Lacy demonstrated the typical diet for the Icелander, which from all appearances, had adequate nutritional value. However, from the finds at this cemetery, it appears that these people did suffer much more than Lacy's statements concerning diet could allow for. Certainly, a diet rich in these vitamins and the associated antioxidants and bio-flavonoids, especially Vitamin C, would have given a physiological barrier to much of the evidenced infectious disease.

Blueberries are considered to be one of the plant kingdoms largest sources of antioxidants. Its ORAC (oxygen radical absorbance capacity) is the third highest, down from prunes and raisins. In fact, berries represent a food source that is abundant with health promoting substances (Moneysmith, 2002).

The excavations at Mosfell valley suggest that the marginal environment was not conducive for consistent agriculture production of highly nutritive foods especially towards the beginnings of the LIA. Infectious disease preys upon the weak and starved, and it appears that even in the good years of the Commonwealth Period and the climatic optimum that benefited most of Europe, Icelandic settlers experienced a rougher life than their counterparts in Scandinavia. This became increasing clearer after the climate shifted.

The causative organism for infectious disease suggested in archaeological skeletal remains was not determined. The wake of the disease is manifest, but concurrent etiologies are hard to determine, largely because bone responds similarly to a variety of stresses, including microbial infection, so it takes additional data to identify one cause among several possibilities. For example,

tuberculosis was considered a possible disease to have been in the Americas before European contact, but it took the identification of the TB bacillus in mummies in Peru to definitely establish its presence. Once in a great while, archeologists find the disease-causing microbe in the teeth roots.

This was demonstrated by the French archaeologists Raoult, Drancourt and Cause in 2002, when they were able to analyze the dental pulp from an individual who lived in the 14th century. These remains, found in a French graveyard, allowed the use of PCR in identifying microbial life and an excellent venue for forensic research into disease etiology. This individual was determined to indeed have *Yersinia pestis* DNA in his dental pulp, and this was used to argue that the Medieval Black Death was the plague (Raoult, et al, 2002). Their conclusions were challenged- due to epidemiological concerns, but their methods and technique were not (Twigg, 2003).

This kind of find is rare. Having found source material, the bioarchaeologist controls for contamination and moves into the laboratory. The process used for the extraction of DNA is usually done through PCR.

PCR stands for polymerase chain reaction. It is a technique that is basically a primer extension reaction for amplifying specific nucleic acids in found samples. The useful and important thing about this procedure is that it allows the technician to “produce enormous numbers of copies of a specified sequence without resorting to cloning”, which involves whole genomes (Ausubel, 1999).

PCR has revolutionized the research of the biological community. Not only has it found uses in molecular sciences, forensics, disease studies, astrobiology, medicine and genetic research, but it has become the cornerstone of emerging biological technologies that have been put to use in biological archaeology. Molecular science is increasingly useful in understanding the dynamics of the force of evolution. The inventor of the genetic process, Kary Mullis, wrote this about his invention:

Beginning with a single molecule of the genetic material DNA, the PCR can generate 100 billion similar molecules in an afternoon. The reaction is easy to execute. It requires no more than a test tube, a few simple reagents and a source of heat. The DNA sample that one wishes to copy can be pure, or it can be a minute part of an extremely complex mixture of biological materials. The DNA may come from a hospital tissue specimen, from a single human hair, from a drop of dried blood at the scene of a crime, from the tissues of a mummified brain or from a 40,000-year-old woolly mammoth frozen in a glacier

(K. B. Mullis, 1990; 56-6)

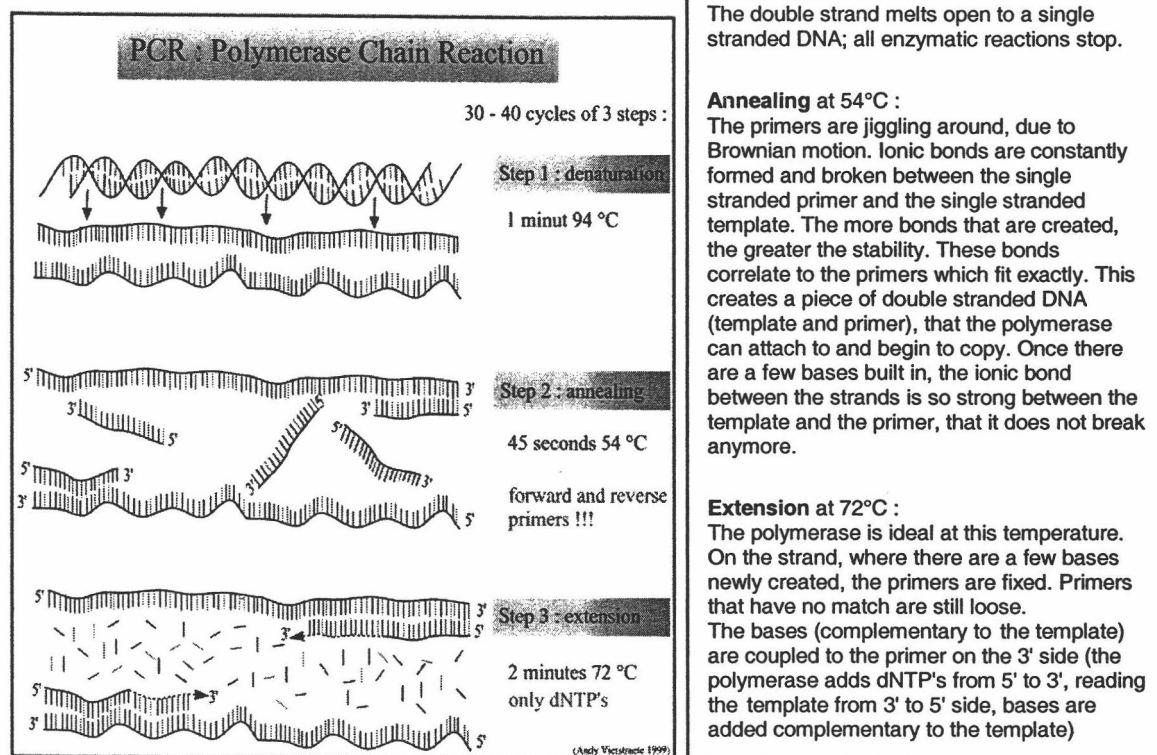


Figure: 18: Polymerase Chain Reaction (Source: Vierstraete, 1999)

Owing to the unusual simplicity of the technique is the fact that anything that has any amount of the macromolecule can be copied and identified. Once a biological remnant is found, several techniques can be used to identify it.

Afterwards, you can use it much as you would any biological product in the lab.

Identifying a biological specimen usually requires that you know something of the organism, and have a whole genome against which to compare. In the event that the organism is extinct, you can compare two extinct biological specimens and compare them to a living relative. In 2004, when this research was done, several ready-made primer sets were available for many organisms.

This known genetic codon is called the target sequence, and is identified by a specific pair of DNA primers, oligonucleotides which are usually about 20 nucleotides in length. If they are any longer they are called polynucleotides. The DNA between the added primers undergoes exponential duplication. This is due to the fact that the primers are specific to that gene. They flank the area to be copied and generally are referred to as upstream and downstream primer sets.

The duplication is repeated 30 or 40 cycles on an electronic automated cycler, which can heat and cool the tubes with the reaction mixture in a very short time. Duplication takes place through the subsequent annealing or hybridization of primers to the target sequence which has minimal loss of enzymatic activity. This technique allows short stretches of DNA (usually fewer than 3000 bp) to be amplified to about a million fold so that one can determine its size, nucleotide sequence, etc.

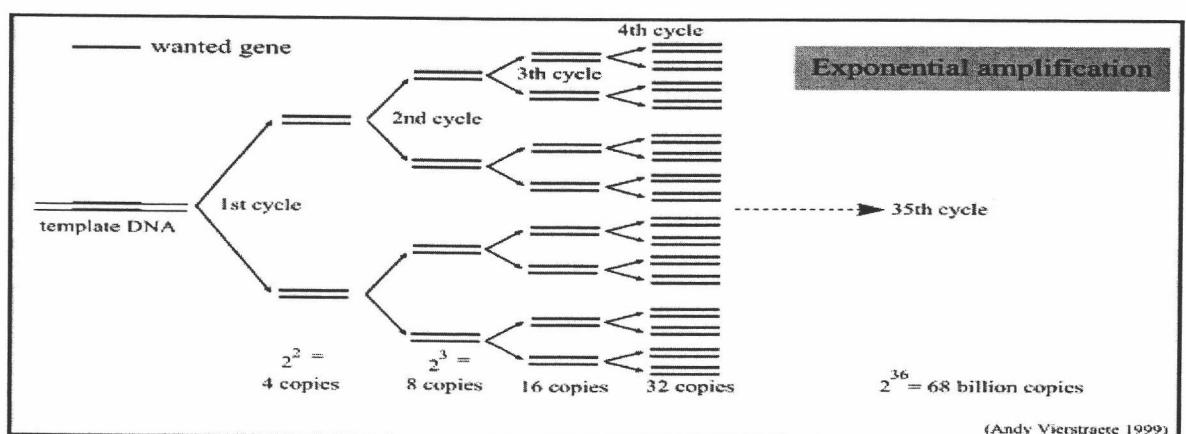


Figure: 19: Cycle of PCR amplification (Source: Vierstraete, 1999)

PCR analysis in any genetic material begins with the source material found at the archaeological site. Archaeological sites are the places that we traditionally go to for information regarding human past. However, it is probably important to remember that they become sites upon investigation, so saying that these sites are principal sources for biological artifacts is somewhat of an error. Biological evidence is relative to the investigation itself.

The proposed investigation following the pilot study involves the recovery of pathogenic bacteria from ice cores in Greenland, or ideally, Iceland. This is not the most commonly studied reservoir of DNA for archaeologists and their studies however. Most DNA is found in two types of reservoirs. The primary sources are the creators of the DNA itself. These would include tissue, bone, teeth, and in rare instances, other artifacts. Insofar as Viking Archaeology is concerned, these rare artifacts would include hair combs and ear spoons, which are found all over Viking Age sites in all of Scandinavia. These material remains contain various DNA from the past. It is simply a matter of choosing 'what' to look for in the DNA study- whether it be human, animal, or microbe targeted sequences. In archaeology it is still widely found that in most studies, the DNA is usually found in primary biological reservoirs and not secondary artifactual remains. Bone and tissue produce the DNA, so it is not surprising that this is the recoverable ratio.

Several things can be gleaned from a DNA recovery at an archaeological site. One can sex burial remains, based on chromosome morphology, especially when the bones are too deteriorated for typical osteological analysis. Disease identity can also be made, in some cases, when body fluids or tissue are present. Most importantly though, is the huge library of human evolution that is contained in the biological compendium of the human genome. At the present, researchers use mitochondrial DNA (mtDNA) for most of their studies, since there is more of it in every cell. Nuclear DNA is much more difficult to find.

Preservation of DNA in Ice Cores

For studies concerning environmental vectors, as does mine, there are other reservoirs of DNA. In high altitudes and northern and southern polar extremes, DNA from microbes and animals deposited by atmospheric winds is found in glaciers and ice sheets. These massive geological features contain much of the planet's water and generously affect the world's climate through the albedo effects, hydrological changes, water salinity values, and many others. Many national and international studies have been conducted on ice cores obtained from all over the world, since glaciers are "sensitive barometers" of climate change, growing and wasting in response to changes in temperature and snowfall [precipitation]" (Benn & Evans, 1998: 4). However, in addition to the trappings of atmospheric gases, they also trap airborne particles and microorganisms. It is these particles that contain dust and it is upon this dust that microorganisms are found (Benn & Evans, 1998: 66).

Equally important is the fact that ice and colder temperatures slow chemical and enzymatic reaction rates, decreasing them at a factor of three to four times for every 10°C in temperature (Poinar, 1998).

Glaciers are windows to our recent climatic past. The atmospheric trappings contain scientific proxy variables that can be analyzed to create an understanding of past features of the geosphere, biosphere, and atmosphere (Thompson, 1997). These proxies are important because they are an indirect way to study aspects of the terrestrial history that are no longer temporally available and are physically restricted from observation directly. This is complicated however, because climate affects and controls glacier precipitation accumulation and ablation, and ultimately, its mass balance. This is the ratio between snowfall and its depletion through evaporation and melting. Thus picking glaciers that are consistently cold and have long temporal records is essential for this kind of proxy research. The morphology of the glacier is also an important consideration. There are two areas of the glacier: the zone of accumulation and the zone of ablation, which is located towards the glacier terminus. These two zones are demarcated by the line of equilibrium (ELA). Everything towards the front of the glacier- the terminus- is not appropriate for data recovery, since it is characterized by runoff and melting on a yearly cycle. The ice cores for this type of coring must come from the area on the other side of the ELA, where there is little melting and no layer admixing (Benn and Evans; 1998; 67).

For the North Atlantic area, Greenland and Iceland are the prime sources for ice cores. However, Greenland has a bigger accumulation zone and thus it is not victim to great cycles of evaporative melting and refreezing. Using the ice cores that have already been drilled over the past 30 years is the most sensible choice, as the cost of even one core at a relatively shallow depth is very high. Iceland's geophysical nature is not conducive for ice coring but Greenland – the neighboring island continent – has a vast ice sheet that is so immense that it creates its own climate. This ice sheet is permanent, not tenable like Iceland's glaciers, which have too much melting to maintain intact records. Greenland has been intensely studied over the past several decades and all ice cores drilled by the US based projects or US funded projects are stored at the United States National Ice Core Laboratory (NICL) at the Denver Federal Center in Lakewood, Colorado (Mayewski and White, 2002).

Variables behind Environmental Preservation

The first step, having received the ice core section, is to isolate and protect the core from modern contaminants. The condition that the genetic material is in beforehand is a significant factor. This condition is extended throughout its domicile in the ice and is further complicated after extraction. To understand this, we have to look at the variables related to preservation in the environment.

Although DNA and RNA are preserved at archaeological sites, the preservation of the DNA's viability and structural integrity is affected by both macro and micro variables.

The Macro Variables:

1. The immediate environment at the archaeological site.
2. The source of the DNA (Tissue, Bone, Fluid)

The Micro Variables:

1. The condition of the molecular environment
2. The source of the DNA (nuclear, mitochondrial)

For the most part, preservation in the archaeological record is a “function of molecular makeup and structure of an organism and the environment in which it is preserved particularly in regard to the availability of water and oxygen” (Poinar, 1998; 142). Since ice and freezing cryogenically stop all biological reactions, it is safe to assume that this is best. However, this is optimal only under specific perfect conditions.

The Macro Variables:

The macro variable most important to the preservation of DNA is temperature. However, humidity and aridity display important augmented roles. Low temperatures and humidity coupled with high aridity provide the best conditions. Planetary biomes that best exemplify these conditions are high altitudes like the Andes Mountains in Chile and Peru, the high desert plateaus of China and Siberia, and the North and South Polar areas. Included in this group are the many glaciers and ice sheets that cover 10% of the earth's surface (Poinar, 1998; Benn and Evans, 1998).

Another important macro variable involved in the preservation of genetic material is acidity. To the exclusion of the other variables, acidity protects against degradation from the bacterial flora surrounding a deposit. Consequently, peat bogs are excellent reservoirs. Noteworthy examples include the Lindow Man and Tollund Man found in the bogs of England and Denmark. Essentially, the anaerobic environment prevents oxidation degradation and the acidity prevents bacterial degradation (Brothwell, 1986).

The Micro Variables:

The source of genetic material is critical: it affects how it is studied and whether it can be retrieved. DNA extracted from bone is likely to be in better condition than that taken from epithelial tissue or mucosal tissue, and genetic material taken from teeth is likely to be in even better condition. Nuclear DNA- not mitochondrial DNA- is the source material most often searched for since it is protected by histones- proteins in the chromatin of all eukaryotic cells. The significance of this protein encasement clearly indicates that the genome structure was optimized very early on in evolution. Mitochondrial DNA is more numerous but it is not well protected. In evolution, mitochondria were separate organisms, and through endosymbiosis, these mitochondria were “engulfed” into the somatic cells of a higher animal species. It has not evolved the protective measures that nuclear DNA has evolved (Johnson, 2002: 101; Poinar, 2000; Lodish, 2000).

The polymer structures of both DNA and RNA are relatively weak and unstable when compared to other macromolecules. The perfect survival of the integral structure of genetic material in most environments is limited to 10,000 years. Hendrick Poinar, a zoological expert at the University of Munich, suggests that this instability “enables its deconstruction and reconstruction by repair enzymes so that the 100,000 degradations that occur almost daily can be fixed” (Poinar, 1998; 133). For the study of bacteria in ice cores in temporal layers correlated to Medieval Iceland, DNA integrity is reasonably expected, since reservoirs do not exceed one thousand years.

To better understand the archeological and microbiological research and investigation of ancient DNA, one must understand completely that “ancient DNA research presents extreme technical difficulties because of the minute amounts and degraded nature of surviving DNA and the exceptional risk of contamination” (Cooper, 2000: 1139). According to Poinar, two types of damage can critically dissociate a DNA macromolecule:

Hydrolytic damage: damage that is caused by the addition of a hydrogen ion. This is due to the presence of water at the archaeological site. Usually, this results in the cleavage of the phosphate ester links between the DNA strands. Deamination can also occur. This effectively changes the base constituency completely. Cytosine, adenine, and guanine change to that of uracil, hypoxanthine and xanthine, respectively (Poinar, 1998).

Oxidative damage: contact with oxygen can subject the DNA molecule to free radical induced damage. The presence of metal ions creates the formation of these free radicals. When this kind of damage occurs, it usually affects the pyrimidine bases. PCR analysis is effectively marred when this occurs (Poinar, 1998). Finally, after these cycles of damage are finished, the DNA could leach away into its organic matrix, becoming part of the “overall organic debris, such as humic acids, and eventually kerogen” (Poinar, 1998: 141). Following this paragraph is a chart showing comparatively how weak DNA is compared to other macromolecules:

Compound Class	Susceptible Bonds	Susceptible Groups	Preserving Potential*
<u>Nucleic acids:</u> RNA DNA	Phosphate esters; Glycosidic.; 5,6- C,C bond of pyrimidines	Heterocyclic rings Amino, Methyl	- +
<u>Proteins</u>	Peptide bond	Side chain functionalites Chiral center	-/+
<u>Carbohydrates</u>	Acetal C-O	Hydroxy, amide	+
<u>Lipids</u> glycolipids	Ester, Ether, C-O Amide, C-N	Hydroxyl, carboxyl ester	++
<u>Cutin</u>	Ester, Ether, C-O	Hydroxyl, carboxyl	+++
<u>Lignin</u>	Ether, C-O	Methoxyl aromatic rings	++++

- to ++++ (weakest to strongest) a rough estimate on the preservation potential.

Figure 20: Compounds, their Susceptible Bonds and Preservation Potential (Poinar, 1998: 133)

Environmentally, frozen reservoirs are the ideal matrix for protein preservation.

Other environments do not do so well, as evidenced from this table:

SOURCE NAME Scientific, and common	AGE Kys	TISSUE type	SITE	DNA bp	PRESERVATIONAL COMMENTS	ADDITIONAL INFO	REFS.
<i>Thylacynus cynocephalus</i> Marsupial wolf	0.08	Muscle	Museum	411	museum dried specimen no treatment, natural drying	proteins, antigenic response	50, 51, 52
<i>Equus quagga</i> Quagga	0.140	Muscle	Museum, Mainz Germany	117*	preserved with salts	proteins, antigenic response	3, 53
<i>Zea mays</i> Corn	.980	Seeds	Huari Tomb, Peru	130	dessication and Seed coating as protection	NA	54
<i>Megalapteryx didinus</i> Moa	3.5	Bone Tissue	Mt. Owen New Zealand	438 B 150 T	cooler temps higher elevation?	low race	17, 18
<i>Homo sapiens</i> Ice Man	5.0	Tissue	Tyrolean Alps Austria Italy?	394	glacier <0°C freeze dried (dessicated) low bacteria	low race	11
<i>Homo sapiens</i> Windover samples	7.0	Brain	Windover Pond Windover Florida	200	waterlogged, acidic, or alkaline, anoxic, high humic acids, demineralization	protein, no DNA controversy? fatty acids. degraded TAGs	36, 38, 55
<i>Myiodon darwini</i> Ground sloth	13.0	Bone	Cave, Ultima Esperanza Patagonia, Chile	140 -	cold cave, magnesium sulfate (Epsom salts, hygroscopic drying) low bacterial content	hide preservation hist. excellent low race	28, 18, 57
<i>Smilodon fatalis</i> Sabre tooth tiger	14.0	Bone	LaBrea Tar pits Los Angeles, CA	200	anaerobic asphalt, oils and salts involved in dessication. Low humidity, low bacteria	protein& chitin preservation collagen, varying aa race	57, 60, 61
<i>Equus hemionus</i> Selerikan horse	27.0	Bone	Tundra Fairbanks, Alaska	140	permafrost <0°C, freeze dried (dessicated) (humics)	low race Hist= 5, %N = 4.80	18, 30 63
<i>Mammot primigenius</i> Wolly mammoth	50.0	Tissue	Khatanga, Siberia	200	permafrost <0°C, freeze dried dessicated tissues	protein, lipids albumin good histology, low race	5, 18, 52, 62, 63

DNA preservation in tissues of varying ages and locations. Maximum length PCR product or Cloned* DNA product indicated in base pairs (bp). Histology (Hist) and Percent Nitrogen (%N) based on ref 63. Abbreviations: TAG = Triacylglycerides; Low race = low amino acid (aa) racemization, REFS = References.

Figure 21: Specimen DNA, their Environments and Preservation Information. (Poinar, 1998: 134)

Another problem faced by the researcher is the risk of contamination and possible admixing with modern contaminants in the laboratory.

Contamination, dissemination, and possible temporal micro flora admixing, are important issues to consider before and after any field work. This is especially true because the extracted DNA could prove to be problematic for humans and other animals, since the possibility exists that an ancient pathogen could become a modern Prometheus. Alan Cooper describes nine steps that should be taken to do exceedingly good PCR: (Cooper, 2000:1139)

PHYSICALLY ISOLATED WORK AREA

It is essential that prior to the amplification stage, all ancient DNA research is carried out in a dedicated and isolated environment.

CONTROL AMPLIFICATIONS

Multiple extractions and PCR controls must be performed to detect sporadic or low copy number contamination. Positive controls should be avoided.

APPROPRIATE MOLECULAR BEHAVIOR

PCR amplification strength should be inversely related to product size. Reproducible mtDNA should be obtainable if single copy nuclear or pathogen DNA is detected.

REPRODUCIBILITY

Results should be repeatable from the same, and different, DNA extracts of a specimen.

CLONING

Direct PCR sequences must be verified by cloning amplified products to determine the ratio of endogenous to exogenous sequences, damage-induced errors, and to detect the presence of numts.

INDEPENDENT REPLICATION

Intra-laboratory contamination can only be discounted when separate samples of a specimen are extracted and sequenced in independent labs.

BIOCHEMICAL PRESERVATION

Indirect evidence for DNA survival in a specimen can be provided by assessing the total amount, composition, and relative extent of diagenetic change in amino acids and other residues.

QUANTIFICATION

The copy number of the DNA target should be assessed using competitive PCR

ASSOCIATED REMAINS

In studies of human remains where contamination is especially problematic, evidence that similar DNA targets survive in associated faunal material is critical supporting evidence.

Figure: 22: Ancient DNA protocol as given by Cooper (Source: Cooper, 2000: 1139)

I conducted a pilot study to determine the efficacy of such an archaeological and microbiological assessment, should a researcher in the future gain an ice core from the NICL. I used a lab- made core with a pathogenic microorganism inserted into the core. My lab work consisted of a resolution and dilution study to show the maximum and minimum biological signature for *Escherichia. coli*, using PCR methodology. This shows the feasibility of demonstrating the hypothesis of atmospheric dust transport. The next chapter is the protocol that would be used for the actual study of an ice core from the subject area, followed by the protocols used in the pilot study.

The future investigation of the dust storm pathogen transport hypothesis can be done using the PCR methods described in the previous chapter. The pilot study demonstrates the PCR method for extracting the microbial DNA from ice, but in addition to these methods, there are protocols that need to be followed when working with a real ice core before it gets to the lab. The researcher will receive ice core samples from the National Ice Core Laboratory. Determining which sector of ice to use is the first step. The selection is based on isotopic dating of the cores from the Greenland DYE ice core collection.

The sectors of ice that are taken from the ice core will be chosen to represent the target time period, which is the 14th century, according to the isotopic dates already obtained from the core. Samples will be transported as ice to ensure that contamination and new growth does not occur, as it is possible that some of these micro-organisms could return to viable condition upon melting.

The ice cores that a researcher will use have been in cold storage in situ on the glaciers and in ice storage at the National Ice Core Laboratory. The environment of the DNA at the time of deposition is still preserved. There are three cores in storage that have some value to my study. Drilled throughout the seventies, they are core projects DYE 77, DYE 71, and DYE 79-81. They are from the southern and southwestern parts of Greenland. With respect to my work in Iceland, these cores will serve well because they have regional compatibility (Mayewski and White, 2002).

The Vikings had two settlements in Greenland that lasted several hundred years. The core material recovered from the three ice core project areas is regionally quite close and gives proxy information about the climate, as well as information on atmospheric residents at the time of the Viking expansion into the North Atlantic. The settlement of Greenland also matches the temporal record of Iceland during Iceland's two plague outbreaks of 1404 and 1494.

The ice core is handled by principles set down at a NSF national science workshop that took place in Oregon in 2001. This workshop was specifically put together to discuss ideas from "experts studying ice, permafrost, ancient life, biological preservation, evolution, and astrobiology" and "to assess current and future research that would extend our knowledge of life in ancient frozen matrices". At this conference, several methods were presented concerning contamination and decontamination of cores, as well as isolating and identification of microorganisms (Rogers and Costella, 2001).

The methods used to minimize contamination at the drill site and in transport, as well as methods of decontamination inside the lab, are explicitly outlined in the conference material. The first thing to consider is the type of drilling that was used to extract the core. Drilling fluids have often been seen as a contributor to contamination, but dry drilling has also recently been criticized because the drilling produces too many cracks in the core. Confounding this is the fact that deeper cores often crack as they are brought to the surface, and are compromised, scientifically. This cracking is due to the change in pressure surrounding the core as it is brought to the surface. Using liquid to drill creates a

viscous layer that buffers the core from the surrounding ice. Though it does introduce contamination to the outside layer, it protects the core from breakup, as it refreezes in the drilling process, creating a veneer layer on the original ice. These two methods need to be compared before one is selected. The important thing to measure is the infiltration of outside contaminants to the core- where the ancient atmospheric elements are suspended (Rogers and Costella, 2000).

The next consideration is the transport to the lab. The workshop group suggests that while sterility in the field is next to impossible to guarantee, it can be achieved at the next stage. The cores should be wrapped in black plastic, and then covered in aluminum foil. They should then be placed inside PVC pipe or metal tubing that is a little bigger than the cores themselves. This packaging will protect against the ravages of light (UV), humidity changes, contaminations, and most importantly, the accidental breakage that could easily occur (Rogers and Costella, 2000).

The group suggests the following to be performed in the laboratory. In addition to clear labeling and provenience, the scientist should keep labels on both ends of the core, as well as any sectors that are taken for sampling. The samples that are taken from the core need additional care. They should be covered in the original sheathing until transported into either a hood box or a glove box- both of which should have been previously cleaned and decontaminated. The hoods should be illuminated with UV lamps that will provide constant decontamination. The surfaces of the hoods need to be sterilized with Clorox and ethanol each time a sample is placed into its quarantine. The sample

should remain covered during such treatments as the UV and Clorox will naturally affect the proteins and DNA inside the core as well, defeating the purpose of the work. To further guarantee uncontaminated samples, the core sector should be scraped and treated with ethanol on the surface. During the melting, which is required in PCR analysis, all the equipment should be brought to the same temperature, so the core does not crack or explode (Rogers and Costella, 2000).

Thompson Extraction Method

In the laboratory the extraction must be handled in a manner duplicative of Thompson's work in 1999, when he created an extraction system that could isolate for contamination, but still melt and collect water aseptically. Although his ultimate goal for this study was to provide a corollary study for future Mars missions, this work provides an excellent method for extraction. His goal was to identify and cultivate microbes found in cores that were drilled at five sites around the world: Greenland, China, Peru, and Antarctica. The dates ranged from 5 to 20,000 years in age:

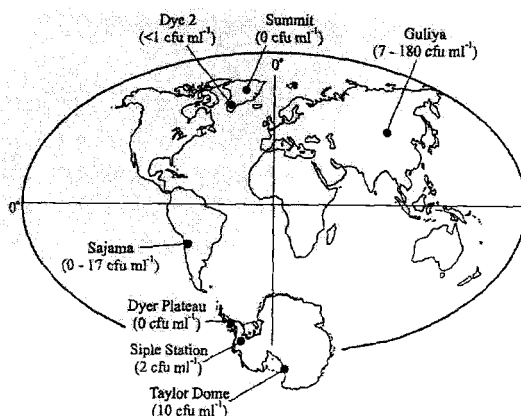


Figure 23: Map of Thompson sampling sites with the number of colony forming units (cfu) per milliliter isolated from ice cores. (Source: Christner, 2000: 480)

The findings were predictable. Ice samples from non-polar, low-latitude,¹²⁷ high altitude glaciers located in the Andes and Himalayas “generally contained a larger number of colony forming units and greater variety of bacterial species than that of polar ice samples, as predicted by their closer proximity to major biological ecosystems”. This is in stark contrast to polar samples, which had less variety and fewer colony forming units (Christner, 2000: 484). As is with all ice cores, he finds that the number of “recoverable bacteria at different positions in ice cores reflect the prevalent climate and wind direction and individual events at the time of deposition” (Christner, 2000: 484).

Although my study does not involve culturing microbes, it will benefit from this autoclavable sampling system. This device ensures positive results and sterile condition for the core as it melts. After melting, the analysis consists of performing polymerase chain reaction (PCR) techniques on each sample. Having done the PCR, the researcher sequences and identifies the microbe. This is followed by a comparison of the microbial signatures to those diseases experienced in the historical epidemiological record. Following this paragraph is an illustration of the system.

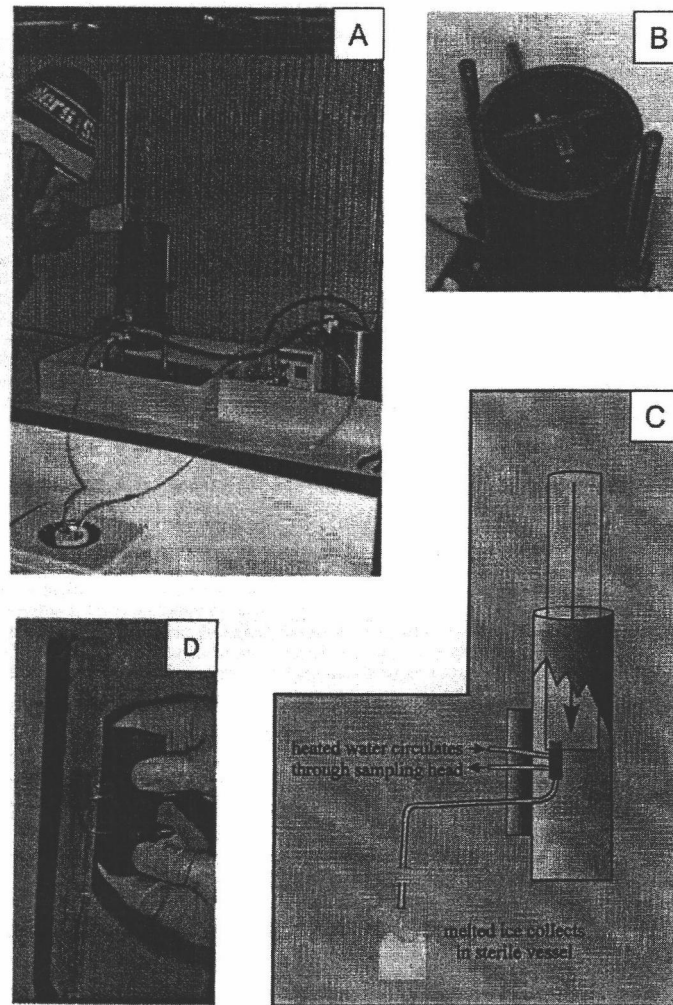


FIG. 2. Ice-core sampler. (A) The complete unit with an ice core inserted perpendicularly into the ice-melting unit. All components of the system are sterilized by autoclaving and then assembled inside a laminar flow hood housed in a -20°C walk-in freezer. (B) Moveable separation flanges facilitate melting half or quarter core sections and allow duplicate samples to be collected from parallel regions through the same core. (C) An ethanol-treated cut core surface is placed in contact with the funnel-shaped sampling head which is heated by circulating water and melted upward through the ice. The water generated is collected directly through a hole in the center of the melting head and pumped into an external sterile container. (D) The sampling head after movement through a core and removal of a cylindrical section of the core interior.

Figure: 24: Thompson ice core sampling device (Source: Christner, 2000: 481)

After performing these tests, this researcher will examine climatic models and¹²⁹ historical dust samples, and determine if desertification in more southerly latitudes is responsible for the dust and its attached microbes. It will be important to show that this is a transcontinental pathogenesis event, and not a regional signature of a local outbreak. The goal is to demonstrate a link between climate change and the production of disease ecologies.

The Pilot Study

The study was begun on March 3, 2004. Jae Dugan, of the Microbiology and Veterinary Science department, assisted me, along with guidance provided by his supervisor, Dr. Daniel Rockey. It was conducted in Nash Hall laboratories on the Oregon State University campus. My study is a concentration study and not a recovery and culture study like Thompson's. The study will test my ability to use PCR in the recovery and identification of DNA found in artificial ice cores of different concentration ratios. I prepared artificial ice cores and did a number of PCR reactions to best articulate the DNA and express it accurately.

Preparation of the Ice Cores

I first prepared the artificial ice cores. Ten falcon tubes were used, along with prepared, cultured *E. coli* bacterium. Cultured bacterium is grown in glass tubes in an LB (Luria Bertani) broth, which consists of carbon, ammonium, and trace elements. This nutritive matrix allows for a controlled colony of bacterium to be grown. Two test tubes with 10 ml each of LB broth were cultured and used. The total between the two is 20 ml.

A spectrometer was used to obtain concentration ratios for each tube. Five hundred micro liters (μl) of the cultured sample was pipetted automatically into the cuvette housed in the spectrometer. This cuvette is made of quartz, rather than glass, since glass is impermeable to UV. This machine gives a count of the total number of bacteria in the sample. It does this by measuring the absorption of the solution optimal density at 560 nm. The spectrometer used is the Smart Spec 3000 TM (Biorad corporation). The machine takes the ratio and converts it into real numbers that represent the true presence and numbers in the sample.

I used two tubes containing different ratios of bacteria that have been colonized. I combined them to create the starter tube on which all measured dilutions were made. The first cultured tube contains 1.26×10^9 bacteria. The second cultured tube contains 1.44×10^9 bacteria. These two are added together and poured into the first 50 ml falcon tubes. The addition of these two tubes created a total bacterial concentration of 1.35×10^9 .

To this tube I added 20 ml of sterile water. This brought the total volume of the starter tube to 40 ml. From this tube, a serial ten fold dilution was made. To do this, 4ml of the contents in the starter tube were pipetted into the second tube. Afterwards, 36 ml of sterile water was added. This same dilution was carried out down the line of falcon tubes, until nine tubes were filled with 40 ml of cultured bacteria and sterile water. The concentration levels were as follows:

1. Tube 1- 6.75×10^8 , per ml
2. Tube 2- 6.75×10^7 , per ml
3. Tube 3- 6.75×10^6 , per ml
4. Tube 4- 6.75×10^5 , per ml
5. Tube 5- 6.75×10^4 , per ml
6. Tube 6- 6.75×10^3 , per ml
7. Tube 7- 6.75×10^2 , per ml
8. Tube 8- 6.75×10^1 , per ml
9. Tube 9- 6.75×10^0 , per ml

A control tube was also created by pipetting 40 ml of sterile water into a falcon tube. All ten tubes were then put on a Styrofoam rack and loaded into a -20° Celsius freezer, and were kept frozen for three weeks.

The Polymerase Chain Reactions

I conducted four PCR runs and was able to recover remnants of *Escherichia. coli* DNA from very low concentrations. It was predicted that I would get positive hits on the first four tubes and that complications would arise as the concentration gradient became less and less. I got around these problems by tweaking the amounts of the various components of each PCR run. Almost all

biological and molecular methods require that the technician be committed to constant change and surveillance of results and methods.

The First PCR Reaction

On March 26th, I conducted the first PCR reaction. The ten tubes previously frozen were left to thaw until the ice was loose and its constitution watery. During this thawing process, the PCR master mix was created. This mixture was created for both 30 and 40 cycle reaction runs.

The makeup of these master mixes is based on total number of samples being run; specific ratios of each reagent need specific representation. The total volume needed for 20 samples is 205 μ l. The following describes the reagents used in the Master Mix.

Sterile water- 93 μ l: provides the matrix for the reaction.

Buffer- 50 μ l: provides control for pH.

MgCl₂- 30 μ l: provides salts for enzymatic reaction.

dNTPS- 15 μ l: these are the additional nucleotides that are used for DNA building.

taq polymerase- 5 μ l: the agent of regeneration

#1 Primer- 6 μ l: the upstream DNA extension

#2 Primer- 6 μ l: the downstream DNA extension

The total volume: 205 μ l.

Primers are particular reagents (chemicals) that are very specific and are catalogued in publications dedicated to gene markers (signatures). A universal gene marker (16s rRNA) can also be used to show the presence of principal bacteria presence, but I used gene markers that are taxon specific for *E. coli*. In addition to this, it must be noted that these primers will be specific to plasmid DNA and not the chromosomal DNA. This is done because there are

approximately 200 plasmids for every chromosome. Consequently, resolution¹³³ and identification were improved.

The total volume for each of the 20 PCR reactions was 25 μ l. Fifteen μ l of the melted ice was pipetted from the center of the falcon tubes. To this was added a total of 10 μ l of master mix. The 20 PCR tubes were then ready for the PCR process. Ten tubes were placed into the 30 cycle machine and ten are placed into the 40 cycle machine. The standard temperatures were used for denaturation (94° C), annealing (52° C), and extension (72° C). The process varies for each, since they are running at different cycles, but it is approximately two hours.

After the PCR was complete, the tubes were removed from the thermocyclers and a 1% agarose gel electrophoresis was performed. Electrophoresis is based on two principles: the mobility of nucleic acid being relative to its size (number of base pairs), and that DNA being negatively charged, due to phosphate groups located on the nucleotides. This creates an electrical gradient that flows from negative to positive.

The gel is made out of agarose, a polysaccharide polymer that was found and extracted from seaweed- red algae in particular. When agarose is dissolved in hot water and promptly cooled, it becomes gelatinous. Ethidium Bromide (EB) is added to the gel at this point to fluoresce the DNA. This works because EB is strongly attracted to proteins and will attach itself to any found in the gel. Basically, the EB intercolates between the nucleic acids.

This gelatinous liquid was poured into a mold and a comb is placed on the top, which creates slots, or lanes. These are the holes within the gel matrix that the DNA is pipetted into for the electrophoresis. A DNA ladder was added along with the PCR reactions. This is used for comparison.

Applying voltage to both sides of the gel dish creates a current from which the negatively charged DNA is pushed. Higher voltages move the macromolecule at a faster rate. However, a slower pace creates a better picture. The time frame for a gel run varies with respect to the charge, but a charge of 100 volts is typically a half hour.

After finishing the gel, it has to be fluoresced with UV light in order to see the EB tainted DNA. The ladder that was added along with the PCR samples shows the exact base pair location that should be evidenced, if the reaction for that particular chunk of DNA is successful. After inspecting the gel sample, a picture was taken. The lanes fluoresce when the DNA produced in the PCR reaction comes into contact with ethidium bromide.

The 30 cycle gel run:

The lab process in my experiment went as described and the results of the reaction were mixed. As expected, the first three lanes, having a concentration ratio greater than what would ever be found naturally, fluoresced with huge abundance. The PCR parameters were sufficient to express these three lanes.

Lane four failed and lane five did not fluoresce enough. These were remixed and rerun. This is common in PCR; reactions do not always take place successfully. All biological reactions are governed by chance but laboratory skill can improve this. Lanes six through nine were failures and were repeated in the next PCR reaction. This is likely due to inadequate sampling at such small numbers. Lane 10 is the control lane and is negative.

The problems with the PCR are obvious. The sample size taken from each of the falcon tubes was too small for reactions coming from tubes 8 and 9, and the reactions for 4 and 5 simply failed. The failure could also be due to the number of cycles that the samples are run at.

The 40 cycle gel run:

As in the 30 cycle run, lanes one through three naturally fluoresced and were not repeated. Lanes four through six were successful- though six was very faint; however, lanes seven through nine failed. Lane 10, being the control, was negative.

The Second PCR Reaction:

This reaction was completed on April 1st. The second PCR reaction was modified from the first run. The key thing being looked at was the amount of sample that was added to the PCR reactions; this amount is relative to the ratio present in the falcon tubes.

The difficulties in the first reaction were a problem with the number of cycles, and the amount of DNA being extracted from the falcon ice cores. As in the first reaction, the second reaction had two cycles; falcon tubes one through five run on 30 cycles and falcon tubes six through 10 run at 40 cycles. The total volume of the PCR reaction tubes is increased to 100 μ l. Because of this, the master mix ratio was altered. The alteration is seen in the following list:

Sterile water- this will vary depending on how much DNA sample is used

DNA sample- this will vary depending on the falcon sample

Buffer- 200 μ l: provides control for pH.

MgCl₂- 120 μ l: provides salts for enzymatic reactions.

dNTPS- 60 μ l: these are the additional nucleotides that are used for DNA building.

taq polymerase- 10 μ l: the agent of regeneration

#1 Primer- 30 μ l: the upstream DNA extension

#2 Primer- 30 μ l: the downstream DNA extension

The total volume: 2000 μ l.

The master mix totaled 2000 μ l. Each tube received 25 μ l of the master mix and the sample size from each DNA sample increased as the concentration increased. Depending on this amount, the water addition varied.

Falcon tube one received 2 μ l from the original sample, whereas tubes two and three received 10 μ l. Tubes four and five received 15 μ l.

Tubes six through nine received 70 μ l. The control tube received 15 μ l. The difference between the total volume and the amount of DNA used will be made up by the addition of water.

The results of this reaction confirmed that DNA sample tubes one through three were amplified sufficiently. However, it was obvious that sample tubes four through nine need additional PCR reactions. The failure of lane four was due to an error in pipetting; lane five failed due to a diminutive size of sample and also the number of cycles. However, sample tubes six and seven were successful, due to the increase in sample size. Lane eight was finally amplified, though the fluorescence was faint. The increase in DNA sample size worked. Lane nine was a failure. The control lane was again, negative. I decided that sample tubes four through nine needed to be confirmed again in another PCR reaction.

The Third PCR Reaction:

This reaction was done on April 7th. The reaction was again modified by the introduction of a technique that is used to increase the concentration ratio in tubes of eight and nine. Sample tubes four through seven were not treated in the same fashion. This technique involves the use of a centrifuge and 10ml of falcon tubes eight and nine. By spinning these samples down at 9,000 rpms (this produces 12 G forces), the DNA inside the sample was forced into the bottom of the tube; this results in a concentrated amount of DNA sample in the form of a pellet, which was then resuspended in liquid.

As the pellet was resuspended in liquid, its volume was increased, since the ratio was now smaller. This concentrated DNA was purified by dropping it through two columns. The filters inside the columns bind to DNA and the rest of the contents were allowed to drain into a tube in a rack underneath the columns. The contents were then ready for the PCR reaction. Falcon tubes four through seven are processed in the usual manner, but the amounts taken from the sample tubes was increased.

For DNA sample tubes four through six, the total volume was 50 μl . For DNA sample tubes seven through nine, the total volume is 200 μl . I did each PCR reaction in two Master Mix groups, rather than creating a Master Mix for all PCR tubes. Both groups of reactions, tubes four through six and tubes seven through nine, were at 40 cycles.

#1: REACTION 4-6; 10

Sterile water- this varies depending on how much DNA sample is used

DNA sample- this varies depending on the falcon sample

Buffer- 20 μl : provides control for pH.

MgCl₂- 12 μl : provides salts for enzymatic reactions.

dNTPS- 6 μl : these are the additional nucleotides that are used for DNA building.

taq polymerase- 1 μl : the agent of regeneration

#1 Primer- 6 μl : the upstream DNA extension

#2 Primer- 6 μl : the downstream DNA extension

The total volume: 109 μl .

#2: REACTION 7-9

Sterile water- this varies depending on how much DNA sample is used

DNA sample- this varies depending on the falcon sample

Buffer- 80 μ l: provides control for pH.

MgCl₂- 48 μ l: provides salts for enzymatic reactions.

dNTPS- 32 μ l: these are the additional nucleotides that are used for DNA building.

taq polymerase- 1 μ l: the agent of regeneration

#1 Primer- 28 μ l: the upstream DNA extension

#2 Primer- 28 μ l: the downstream DNA extension

The total volume: 362 μ l.

There were two PCR reactions. The first PCR reaction included DNA sample tubes one through nine. This one also included the control tube number ten. For the first reaction, each PCR tube is given 20 μ l of the Master Mix. This is followed by the addition of 30 μ l of DNA sample from each tube. The second PCR reaction, each PCR tube received 55 μ l from the Master Mix and 145 μ l from the DNA sample tubes. For tubes eight and nine, I use the concentrated versions created by the column and centrifuge procedure. Both reactions were run at 40 cycles. After the reaction I changed the amounts introduced into the gel.

From reaction tubes four through six I used 10 μ l. I used 15 μ l for samples seven through nine. The results achieved were interesting. Tubes four through six were very successful and the fluorescence is quite good. Tubes seven through nine completely failed. The concentration efforts with samples eight and nine are not successful.

The success of four through six is important because I effectively isolated and amplified a bacterium in increasingly smaller ratios. The method of increasing the sample size in the reaction and using the step up procedure worked; increasing the number of cycles also is attributed to the success of samples four through six. However, samples seven through nine did not succeed.

The Final Experiment

The final experiment was completed on April 15th. This experiment combined the best attributes of previous PCR runs, running a gel with the addition of no new PCR reaction. The answer to getting the gel fluorescence to work was the increase in the amount of PCR reaction being introduced into the gel lanes. I wanted to get samples eight and nine to amplify and be expressed in the gel, to obtain a final print for the concentration study. In order to do this, I used PCR reaction tubes from previous reactions and changed the amounts being pipetted in the gel lanes.

To represent sample tubes one through three, I used the PCR reaction tubes from the first reaction conducted on April 1st. For sample tubes four through six, I used PCR reaction tubes from the reaction conducted on April 13th. To represent sample tubes seven through nine, I used PCR reaction tubes from the reaction conducted on April 13th.

The change introduced here was the amount of sample pipetted into the gel lanes. For tube samples one through three, I used 20 μ l of the DNA reaction. For tube samples four through six, I used 20 μ l of the DNA reaction. For the last three tubes- seven through nine, I used 30 μ l of the DNA reaction. This is an

increase by two to three folds. For the control tube, number ten, only 10 μ l of ¹⁴¹ the reaction was introduced into the gel lane. The results of the changes can be seen below in the gel prints:

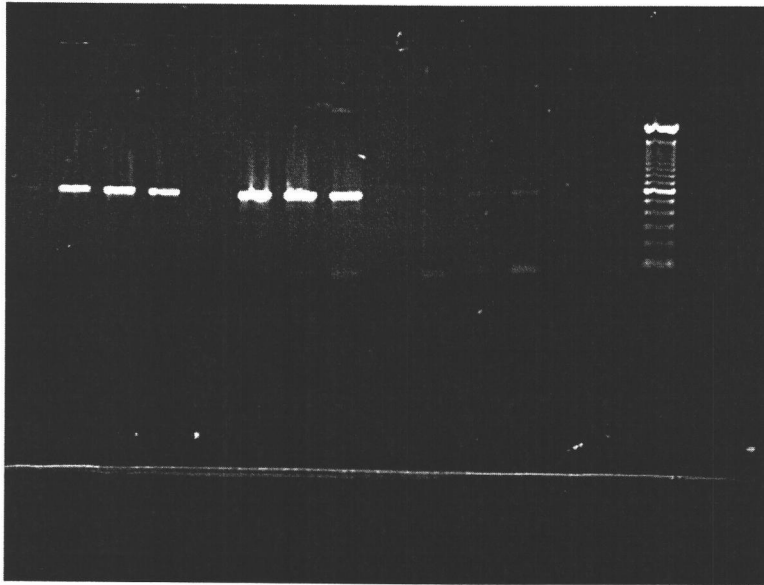


Figure 25: PCR final gel run

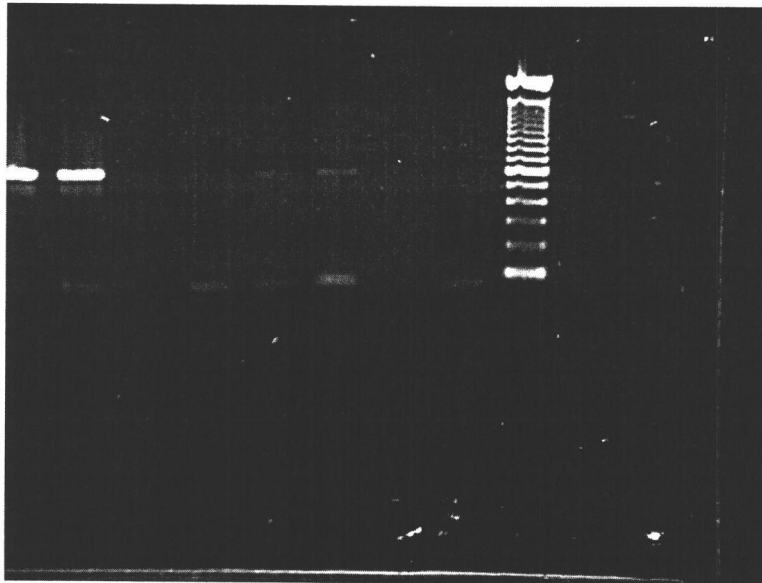


Figure 26: Close up of final gel run

The Results

The results were exactly what I had been looking for. Lanes one through six fluoresced perfectly. With the additional amount of sample from tubes seven through nine inserted into the lanes, I was able to achieve two faint fluorescent bands for lanes representing eight and nine. Tube seven did not express itself at all. The success of DNA sample tubes eight and nine confirmed that in the case of low concentration of bacteria- in this case, *E. coli*, a high amount of PCR reaction sample is required to attract the ethidium bromide inside the gel. By increasing the sample size in the gel, there was enough to produce fluorescence.

Though sample seven did not succeed, it did work in the PCR reaction done on April 1. Its failure to fluoresce in the final gel was disappointing, but being able to achieve results for tube nine is a far better achievement, since it contained the lowest concentration level of the bacterium.

These methods can be used on real samples taken from glacier cores. PCR methodology is no longer in its infancy. The quintessential aspects of PCR- that of patience, careful analysis, and continual upgrading- are not changed. It is not a perfect methodology, but a methodology that works with guidance augmented by human ingenuity.

The final resolution of tube number nine can be used as a model for working with an ice core sample. An ice core sample that is 10cm high and 10 cm in diameter will have a total volume of 785 cm³. This amount, multiplied by the concentration density of the final tube (6.75), is 5298. So, in a typical ice core section, I would be able to resolve to the level of 5298 bacterial cells per ml. This is excellent resolution for the identification of atmospheric samples frozen in glacial ice.

According to a study done by Allen in 2003, the bacterial counts in “polar ice and snow consistently range from 10² to 10⁴ bacterial cells per ml” (Allen, 2003: 4). I resolved for much less than this, showing that PCR could, in fact, be used to accurately isolate and identify the plague bacterium in Greenland ice cores, if it is present. Careful scrutiny of archaeological sites and the discovery of tissue or bone samples could complement this and further validate my proposal. By comparing the microbial signatures in the glacial ice to that found at an archaeological site, the question of whether the occurrence of the plague in 1404 and 1494 was truly due to *Yersinia pestis* could be resolved. If this bacterium is in the ice, the hypothesis of wind transport can be confirmed.

The creation of a disease ecology during the 15th century is not an event that is questionable. The change in climate, and quick turn of events in Scandinavian politics left the islanders vulnerable and susceptible to disease pathogenesis. The real question is the identity of the disease causing microbe. My thesis is one alternative, an alternative that has a number of variables that corroborate and strengthen my hypothesis. Certainly, the connection of dust storms by Dale Griffin, to pathogenesis in both floral and faunal life is a strong consideration. In addition to this is the atmospheric analysis that shows incontrovertibly that the dust found in Greenland ice cores is only from Asia. Finally, there is the fact that the inveterate loci of the plague bacterium is located in the same areas that Asian Dust Events occur and stem from. The argument is an interesting one, and one that can be taken further. It can be tested.

I was able to resolve my PCR lens- so to speak- to a finer concentration that that which is expected for naturally occurring bacteria in glaciers. The next step is to obtain the ice core and do the PCR analysis. New research done by Thorsteinsson in 2003 shows that ice coring in Iceland is not only possible, but good data can be gleaned from these endeavors. Greenland ice cores are also invaluable since they are regionally compatible. In addition to this would be the use of an archeological site which contains human remains. By looking at skeletal and tissue remains for comparison and correlation, my study would be corroborated.

There are numerous sites that have not looked at in Iceland and this could be exploited (Thorsteinsson, 2003). The use of PCR is continually being improved on and so, the re-investigation of skeletal and tissue samples already studied can be just as illuminating.

Several key events in biological archaeological research have moved the science along exponentially. During the past ten years, PCR and other related techniques have been perfected. Most DNA analysis is done on tissue and bone, so it is not surprising that most of the advances are coming from this kind of research. Most research is taking molecular science beyond the limits of traditional laboratory techniques that have been in place since the advent of microbiology.

Good examples would include the study done by Parrish in 1995, where he created the extraction and purifying technique used for DNA procured in dental plaque. He was able to culture over 325 bacterial species. This technique is important because it bypasses the labor intensive bacteria culturing that was used before. (Parrish, 1995)

Concentration ratios and the ability to rid oneself of impurities and inhibitory agents are very important for this type of research. A study done by Kalmar improves upon the extraction techniques formulated just years before that. He demonstrates that the extraction of aDNA from human bones can be done without hazardous chemicals or special devices. For the first, he introduces ethanol precipitation, which concentrates the DNA and leaves the DNA free from inhibitory impurities. He based his thinking on the isopropanol

based precipitation techniques developed by Hanni, et al. (Hanni, et al, 1995) He tests his new technique on 10 bones dating from the 7th to the 15th century and is successful. (Kalmar, 2000)

Finally, a good example of paleogenetic research is the sex determination study done by Cunha. She studies two skeletons that are impossible to sex with conventional forensic techniques. She uses primer sets that are specific to the amelogenin gene found in both X and Y chromosomes outside the recombining areas. The size of the base pairs is the key: 106bp for the X chromosome and 112 bp for the Y chromosome. Another method used is the use of primer sets specific to the SRY gene. This is related to testes development, and therefore is only applicable to the identification of male skeletons (Cunha, 2000).

This is not the only reservoir of DNA being studied. Willerslev, et al was able to procure quite a diverse array of DNA from sediment found in both permafrost and temperate areas of Siberia and New Zealand, respectively. The team was able to identify micro and macro flora and fauna from prehistory and historical strata (Willerslev, 2003). This is important for correlation studies and would be very useful in looking at vegetation changes that occurred in Iceland during the LIA. Another creative analysis looked at human coprolites in North and South America. This was specifically geared towards obtaining a signal from parasitological invasion. Using enzymatic amplification on human mtDNA, they were able to show that the sample was indeed human. Following this, they did PCR on the samples successfully

(Iñiguez, 2003). This study piggy backed on the parasite studies done on 147 mummies found in Peru. Ferreira used PCR techniques for the first time, instead of the microscope (Ferreira, et al, 2000).

Viruses are also the target of investigation. A study is being done in the permafrost region of Russia at the Neolithic site of Gorny Altai, as well as a collection of graves from the 19th century, where identification and studies of known viruses (smallpox) found in the graves are being made. PCR and genetic studies of the viral proteins will be analyzed and “the evolutionary process of the viral genome will be reconstructed” (Sandakhchiev, 2004).

Filter techniques have also been developed that concentrate the DNA to very low levels that remain detectable by PCR techniques. In a landmark study done a decade ago, Bej et al did a comparison study of several popular filters used in the microbiological community, and showed that Teflon filters were the best. Like all filters, they concentrate cells in the structural matrix of the filter. Through repetitive freeze/thaw cycles and the actual PCR being conducted with filter intact, very low concentrations of bacterial cells could be identified. This is extremely important for environmental sampling, such as that done by Griffin and others in the Caribbean. It is also good for sediment DNA analysis. For ice core studies, it would be invaluable for organism specific studies, such as mine.

Though there is an average for bacterial cell presence, the number¹⁴⁸ for any organism by itself could be anywhere from zero to infinity. Filtering techniques, as well as ethanol precipitation techniques, and running columns (as in my study), are all terribly important techniques that can make research on ancient DNA an easier task.

Epidemiological work on historical disease ecologies is ongoing. It seems that nothing is stagnant. Facts taken for granted in the past are giving way to new ideas like my own. Susan Scott and Christopher Duncan have recently worked on an epidemiological analysis of the Black Death events in 1346 and the London outbreak of 1665 and have shown through computer modeling and biochemical and etiological analysis- much like my own- and suggest that the 100 year old assumption that insisted on the etiological link for the epidemics be the plague bacterium is not the case. Like other researchers, they have their own suggestion for the disease ecology- that of hemorrhagic fever (Scott and Duncan, 2001).

Regardless of the etiological nature of the historical disease ecologies, the Icelanders have gone through many endeavors in their quest to adapt and remain culturally viable on the island. The effects of these ecologies are found in the genotype of the population.

Genetic studies being done on the Icelanders themselves has shown that their exposure through time to pathogens and disease ecologies has left many Icelanders with genetic changes that give some measure of protection against many new pathogens, such as HIV. Polymorphism in the Beta chemokine receptor gene CCR5 deflects HIV entry into the cell, its transmission throughout the body, and eventual outcome. The people that are homozygous for a CCR5 gene mutation- basically a 32 base pair deletion ($\Delta 32/\Delta 32$) are highly resistant to HIV infection (Liu, 1996; Samson, 1996; Dean, 1996).

The presence of this genetic mutation seems to have a gradient that lies on a north and south axis- its presence is not ubiquitous to the north, but is much higher in ratio, compared to its virtual non existence in the Mediterranean, Africa and the Americas. The spread of this mutation is also attributed to the Scandinavians as they colonized and settled throughout the world during the eighth and ninth centuries (Lucotte, 2002).

This protection was selected by some pathogen or pathogens present in Europe at the time. This is a good example of a genetic change that has augmented the immune system through exposure to pathogenic microbes. This genomic change is not not ubiquitous throughout humanity. This particularism shows the regional aspect of many mutations and their relation to the environment. The genetic mutations of Africans and Asians to the ravages of malaria are excellent examples of this type of regionalism that has occurred in response to pathogens.

I expect that lab results and archaeological analysis from the proposed research will substantiate other research that has implicated dust storms, specifically African Dust Storms, in several pathogenic episodes in the Caribbean and in the southeast of the United States. The practical applications are profound. By demonstrating past climatic change and how it creates a platform for disease propagation in the North Atlantic, and through more research on disease ecologies associated with desertification and dust storms, it may be shown that dust may be more than an indicator of climate change or carrier of microbes; it may be an agent for ecological and biological change itself. Whole animal microflora and microbial attendants may have a substantial contribution to our genomic makeup. The diffusion of microbes into the atmosphere through desertification and subsequent dust storms has probably occurred repeatedly, and has no doubt affected and altered the course of the human genome and our biochemistry.

Presently, infectious diseases currently endemic to many areas are leaving their traditional ecological limits and moving further out of their known ranges (McMichael, 1997). The areas they are moving to hold populations not biologically associated with these disease ecologies at any point in their evolution. These changes will increase the propensity for the creation of disease ecologies.

Emerging infectious disease (EID) has, in the past couple of years,¹⁵¹ become a buzzword in the American medical community for good reason- it has become increasingly clear that infectious disease, already the third leading cause for death, will worsen and show and increase in its virulence with increasing climatic and environmental instability (McMichael, 1997). EID and its link to environmental vectors need to be investigated.

This research creates a new medical paradigm- one that is synoptic in scale and one that is far reaching. World-wide disease pathogenesis being linked to climatic events and particular mechanisms within the atmosphere is hugely important for many disciplines and needs to be looked at. My hope is that is that the suffering of past civilizations- in my case, the Icelanders- will be vindicated and understood finally.

Appendix

Modeling Icelandic Ecology using CAS systems

To understand this ecological state as it has progressed through time, I suggested in the forward that the use of C. S. Hollings work and the new work being done with CAS systems be used as a model and corollary. I want to introduce the ideas behind Hollings work and the CAS, or complex adaptive systems, first. I want to show that real understanding of human systems, whether they be social, biological, or ecological- all are given a more resolute and refined characterization when observed through the lenses of system thinking and non-linear dynamics.

The new direction that many ecological anthropologists have taken is one that departs from the confines of scientific predicate altogether. When I say predicate, I do not mean to move away from validity or logical and reasoned thinking. Scientific precept is maintained but other characteristics less befitting their endeavors are thrown out. Instead of pummeling themselves against the platform of scientific materialism, they deliberately align themselves with a new stream of scientific thought found in holistic, emergent science- a science that has its roots in chaos and later, in complexity studies. Both of these are very much related to post modern thought, although they both have emerged from physical sciences.

provides a description of this transition:

For over twenty years scientists like Holling and Prigogine have been arguing that the first stream of science (western science) is limited to certain problem sets. They contend that a science of complexity has fundamentally different features, and is the proper approach to other problem sets....In fact, anthropologists have argued their case for understanding cultures in terms that sound remarkably like those advocated by the new science of complexity. We have been fighting to resemble the ideal of science, while a second form [of science] is coming to look like us!

(Abel, 1998: 6)

The conflict between the two types of science can be summed up as follows:

- 1 . scientific ideal- **experimental, synchronic, reductionist, materialist, narrowly multidisciplinary, hegemonous**
2. science of complexity- **comparative, diachronic, integrative, interdisciplinary, rank and order are not as important**

CS Holling, an ecologist who works with anthropologists extensively, describes this dichotomy, saying that the former is a “science of parts, and the latter, a science of the integration of parts”. This integration is a perfect vehicle for the discussion of cultural adaptations and biological and ecological processes. In fact, the whole of culture expression is studied as a whole system- more specifically a complex adaptive system (CAS) (Abel, 1998).

CAS systems are derived from cybernetics, ecology, human behavioral loops, and physical and biological cycles. Primarily, they also have roots in systems science, which has provided the foundation for all emerging sciences

and the advancement of many of the traditional fields of thought. The specific systems are never understood with respect to their parts, but rather from their entirety. The identity of the CAS system is always given by this wholeness because of one amazing thing. They exhibit the exceptional ability to create the foundation for emergent behavior. This is behavior that is not designed for or expected. It is something that comes as a result of learning and adaptation. Modification and the creation of new self limiting parameters is ongoing feature in the emergent behavior of a CAS system.

This emergent behavior can be compared to human cultural adaptation: adaptation is the essence of CAS systems and as we have seen, most decidedly in ecological thinking. As we move through the history of ecological anthropology, it is apparent that the principal essence behind ecology is initial adaptation, modification over time and space, and emergent form, structure, and process. Exactly like the CAS systems!

Kiersten Johnson, of the University of Maryland, has written an essay that explores this new idea as it is applied to human systems. In order to progress with her ideas on “progressive and sustainable human complex adaptive systems” she first asserts three assumptions that make up her foundation:

1. The sustained existence of all human populations is deemed desirable
2. Progressive human systems are characterized by economic and social equality
3. Human systems must be progressive in order to be sustainable in the final moment

(Johnson, 2004)

It is important to realize that she bases these three requirements on emerging sciences behind complexity and contemporary physical sciences. Basically the derivative of complexity is chaos theory. It has the following characteristics:

irregular uncertain, unpredictable forms
 unpredictable change
 study of the dynamics of change and develop ways of understanding all systems (natural and social) change

The study of chaos is really the study of process; the flux between states of being on the space time continuum. The traditional scientific empirical tradition focuses on the study of form in both macro and micro scale.

Abel demonstrates beautifully in his essay, that anthropology needs to embrace the new science of chaos and complexity. Total abandonment of scientific empiricism is not the issue, but balance of both and a clear method for doing so. From the study of form and process, we get states of being, namely:

1. Chaotic state- **a state of being that allows for innovation and change**
2. Equilibrium state- **a state that allows for uniformity and stasis.**

The chaotic state is negentropic, meaning that it moves away from a minimum state of order and towards greater and greater structure. The equilibrium state moves towards a maximum state of disorder, a process

called entropy. All natural systems have a mixture of these two states of being, in fact it is “the natural form of all living systems”. (Merry, 1995: 13)

The edge of chaos, and not chaos itself, is where complex adaptive systems are most adaptive. The natural form for all systems that are maintained is a mixture of disorder and order. From the tension found between these two emerge two states of being:

1. An accumulation of structure and free energy brings increased negentropy! THIS IS A STATE OF INCREASING EQUILIBRIUM AND ORDER: this is the platform for regularity, conservation, and continuity.
2. An accumulation of waste energy and formlessness brings increased entropy! THIS IS A STATE OF INCREASING CHAOS AND DISORDER: this is the platform for creativity, change, and innovation.

(Harvey and Reed, 1997: 302)

This tension is a descriptor of a higher order predicate called the dissipative state. The dynamic tension between the states of chaos and equilibrium is its most obvious characterization. Dissipative states are “materially and thermodynamically constituted entities, which mean that their internal structuring and development, as well as the processes by which they are born, evolve, and die, are regulated by transfers of energies from their immediate environment” (Johnson, 2004; Harvey & Reed, 1997: 302).

All living systems, including human ecological and cultural expressions have a tendency for dissipative behavior. This type of system has a tendency to gravitate to entropy, rather than negentropy. Not to say that the latter is not present. It tends to move to the state of equilibrium as the system moves through its various processes. It swings back but does not remain long in chaos. Change and flux are constant.

To put it in another way, dissipative systems are systems that find themselves in the midst of a tug of war: in one direction, the tension of the system is pulling it towards entropy, and on the flipside, the system is being prodded to transfer its positive entropy into the environment. It is this transfer that allows for negentropy to occur. This process allows the CAS system, or dissipative system to transform free environmental energy (positive entropy) into increasingly complex structuration. Entropy is the arbiter and predicate for all living things (Johnson, 2004; Harvey & Reed, 1997)!

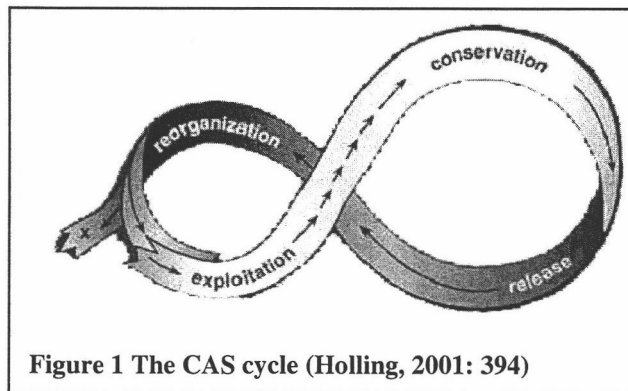
Holling has developed a system that shows the path of CAS systems as they move through time and space. Calling it the regenerative cycle, or adaptive cycle, it has various stages that occur, all of which are dependent on changes in the various spheres that make up any number of CAS systems. This cycle is also referred to as the Panarchy theory, which some say is a most “revolutionary concept” (Holling, 2001).

There are three properties that give structure to the adaptive cycle, and shape the responses of the systems to moments of critical change:

1. **An inherent potential of the system that can create change- this determines the future possibilities. It sets the limits for what is necessarily feasible for a given system in a given point in time and space.**
 2. **An internal controllability of the system and degree of connectedness between the internal controlling variables and processes-it determines and reflects the degree of flexibility or rigidity of such controls and their sensitivity to outside or inside perturbation. This connectedness determines the degree of control over destiny.**
 3. **An adaptive capacity and resilience capacity of the system- it shows the vulnerability to unexpected and unpredictable changes.**
- (Holling, 2001: 393)

A figure eight is the shape of the cycle, and it is given four defined aspects, or expressions that hold dominion over four areas of the shape:

1. alpha- reorganization
2. omega- release
3. r- exploitation
4. K- conservation



They wrap around two axis that represent two of the characterizations given to the adaptive cycle above.

- **The y-axis- represents that actual potential inherent in the system,**
- **x-axis that represents that degree of connectedness among the many variables inside a system.**

The four separate states take place over two time periods- a short period of time that creates opportunities for innovation (from release to reorganization) and a longer period of time of slow accumulation and transformation of natural resources (from exploitation to conservation). These four periods reflect the four ecosystem functions- alpha & omega behaviors, and r & K behaviors.

These new ways of looking at things can readily be applied to the story of Iceland's human occupation, subsequent ecological development, and historical epidemiology. In applying the Panarchy model, I first divide the periods of history into the various stages of pronounced change and perturbation, which is one of the quintessential features of the adaptive cycle.

The situation of Iceland and its history can be held up as a textbook example of Holling's adaptive cycle and is a great example of CAS systems interacting together. The CAS systems that are interacting here are not static; they move, rearrange their articulations, and are constantly changing their dimensions!

The CAS systems move around the Holling adaptive cycle and it moves from a chaotic state to one more characterized by equilibrium. This is what is described in Johnson's paper, where the states of chaos and equilibrium create a dynamic tension. As mentioned before, each of these extreme states creates situations where either change ensues or stasis and a limbo state occurs. This is what is called the tendency for dissipative behavior. Change and flux are constant! This can be applied to the adaptive history of Iceland beautifully.

Remembering that the states of change occur over a trajectory passing through two movements of behavior, one can readily apply Iceland's history to the cycle:

Exploitation- The first period of history belongs to the “r” state of ecology, when total settlement of the island was occurring at the beginning of the island’s human occupancy from 840 to 1262. The culture is blossoming and society and the ecology are in good balance. The great intellectual movements occur and the foundations for the fledgling island community are laid.

Conservation- The second period of history, the period from 1262- 1380, is one that characterizes the K period. This is characterized by stiff competition for resources and a controlling interest held by fewer individuals than would be considered democratic in nature. After the Iceland society fails to control its increasing problems with resources and political problems ensue, Norway controls the island, since the Icelanders failed in continual governance. There is a high degree of connectedness here and it results in a highly constricted society. These parameters naturally do not lend themselves to an evolved state of society, and this would unfortunately deteriorate further.

This change is usually “triggered by agents of disturbance, such as wind, fire, disease, insect outbreak, and drought”. (Holling, 2001: 394) Iceland has many of these and more that come to plague it. In fact, Norway is done in by the same ailments, and Denmark comes to hold the reigns of the political and economic steerage for most of Scandinavia, including Iceland. This introduces more of the same oppressive autocracy and huge dependency on outside non-indigenous resources, all of which is necessary since they had depleted the island of all trees and the climate change effectively froze the

peat in the ground. This reduced their ability to heat their homes and reduced new building supplies.

The climate change and the lack of self determined paths- provoked by the ostensible political control by Denmark, pushed the island further and further into limbo state (Holling, 2001).

The definition of limbo befits the degraded state of Iceland:

“state of oblivion and neglect”

“state of arrested possibility”

“condition of unknowable outcome”

It also fits the state Johnson speaks of when describing the tension of the CAS systems as they move around the adaptive cycle. They are in a static state, a state of equilibrium, one that is left without recourse and any chance of change or innovation. It is total entropy.

Release- The period of history from 1380-1900 characterizes the Omega state, one where things are still quite bad, but a time when resiliency is huge. The Icelanders put up with climate change, disease outbreaks, natural calamities, and political oppression. They never experience complete collapse, like their brothers in Greenland, but they do suffer severe blows to their population. This lasts up to about the end of the 19th century. They begin to feel the need for change and finally achieve some measure of home rule in the early 20th century.

Reorganization- the last period of history begins in the early 20th century 161
and is in the Alpha period of the adaptive cycle. It is currently being staged at the moment. This is the stage that total abandonment occurs and the shackles of the past are thrown away. The CAS system is thrown into chaos as disorder and waste energy increase. This increased entropy brings innovation and major change. Complete societal and political turn around occur very quickly, as well as a self-determined resource import, and the building of the renewable energy plants.

This adaptive cycle and its attendant CAS systems are now in the midst of completing one cycle around the Holling model. This will occur many more times, some being shorter than others- some being much longer. It depends on the three characterizations of the adaptive cycle mentioned earlier. The various attempts at innovation during the Alpha stage have to succeed to push the system into the next period of the adaptive cycle. It then can evolve and become better adapted to the environment and provoke the emergent property of sustainability.

The tension that pulls a system back and forth from chaos to stasis can be found throughout nature. No model can really capture the entirety of any system, but Holling does make the best effort I know. He even acknowledges that no system is going to have an exact fit, no matter how hard the investigator tries to do so. I believe that Iceland is one that has several properties that may put it in this category.

The extreme nature of its latitude with respect to most regions of hospitable land for human adaptation makes it tenuous and very oppressive. This makes it a system that can destabilize quickly, when given the appropriate stimuli.

There are also the many instances of struggle during the third period that could be shown to have a systemic characterization of their own, since the static conditions provoked certain adaptations that ensured future survival. These show some innovation in the face of major environmental challenge.

Another thought is the question whether some stochastic event triggered some instant collapse within that Omega period, and a new adaptive cycle began. An event that involved a random variable could have very well knocked it down the various layers of successful CAS systems that had been developed to deal with the ever-changing environmental conditions. It is an entirely plausible suggestion, but the fact that Iceland has only a one thousand years of human occupational history, does limit the number of cycles within cycles, and “sudden death/new beginning” episodes that can occur. (Tomasson, 1980; Holling 2001: 401)

Holling mentions that democratic nations create “smaller cycles of renewal and change through periodic political elections”. I would add also the various cultural stabilizers like marriage and social hegemony. These processes create diplomatic possibilities, and create allowances for the dissipation of negative energy that could cause a complete collapse of a system. Being an island nation does enable Iceland to be as it were, its own

system- one that allows connectivity to the outside world to be minimized. ¹⁶³

The isolation variable found in Iceland is both a detriment and something that can “provide the context for long term historical continuity” (Tomasson, 1980; Holling, 2001: 399).

Along with this continuity one can also add the fact that natural selection acts “not upon [the system] but rather upon the individual living things”. Although many individuals die, there remains some form of social continuity. The unit for analysis may be wrong here. It is not the system itself and its interactions that are “expressing self-organizing properties of [the] system, but instead they can be seen as the consequences of the various and variable adaptive strategies of individual organisms living in restricted spaces” (Vayda & McCay, 1975: 300).

The survival of the Icelanders may have more to do with individual actions rather than the group as a whole- which would introduce many adaptive cycles that would intersect here and there but would be separate for most of the time. The tendency for the behavior of the individual to begin creating the characteristics of the group is one that still perplexes social and behavioral scientists.

Most change and innovation begins with the individual and it moves to the larger plane of group dynamics, once the scope of success grows large enough. The CAS systems may have had intersecting adaptive cycles of individuals that would harmonize when an adaptation was significantly great enough to warrant full group participation (Vayda & McCay, 1975).

The application of this model to my thesis is pretty convincing. It is obvious from history alone that the Icelanders were robbed, if one can use this word, of the amazing climate and conditions that the 8th century brought their Scandinavian culture. The climate change put an even deeper wedge between the homeland and the colonies, created harsher ecological conditions, which served as a foundation for disaster and calamity. The diseases and death that they faced came as a result of two things. Their adaptation to the island- save for the first 400 years, was inadequate and quite useless, given the deleterious conditions. Their choice in resource use, shelter building, and increasingly hierarchal societal structure, and other cultural mainstays from the homeland also contributed to the widespread misery that constitutes much of her history. The second thing that contributed to their suffering is climate related. In the years following the LIA, there seems to be no doubt of the increase in disease pathogenesis.

My thesis suggests that the instigation of this disease ecology could have as its etiological platform, an environmental vector that gave rise to the proliferation of microbes which led to the massive disease pathogenesis. This would be a fine example of world wide systems being thrown against one another, and having the net result of system collapse on both ecological and biological levels. Using complexity and chaos models such as the one created by Holling is an emerging trend in ecological and medical circles and my analysis, though short, is indicative of the direction that academics are taking in the 21st century.

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