To the Graduate School:

The members of the Committee approve the thesis of Clinton C. Crago presented on April 28, 2003.

Charles A. Reher

Charles A. Reher, Chairman

Marcel Kornfeld

Marcel Kornfeld

William L. Baker

William L. Baker

APPROVED:

Audrey C Shalinsky

Audrey C. Shalinsky, Head, Department of Anthropology

Don Roth

Don Roth, Interim Dean, The Graduate School

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Climatic conditions of the Great Plains and Black Hills region over the past 500 years have been the focus of a number of investigations. These studies have examined a climatic episode known as the Little Ice Age which is generally believed to have been a colder and wetter period than the present. One investigation from the northern Black Hills occurred at the Vore Site (48CK302) where varved sediments were analyzed and determined to show precipitation peaks indicative of the Little Ice Age. Archaeological investigations have tried to establish the relationship between cultural behavior and the changing climate of the Little Ice Age on the Great Plains. Contrasting opinions have resulted in questions on the severity and importance of the Little Ice Age conditions and their affect on prehistoric cultures.

In this thesis an attempt is made to acquire high resolution dendroclimatic data to 1) refine the dates of the varved sediments of the Vore Site (48CK302), 2) reconstruct a basic precipitation record of the northern Black Hills, and 3) use the new data coupled with a review of past investigations on the Little Ice Age to examine the severity of the climatic episode for the Black Hills region and its effect on prehistoric cultures. The results have shown that the Vore Site varve sequence is actually discontinuous with gaps in the sequence caused from bison kill episodes or extreme drought. Accounting for the gaps in the varve series yields a date for the entire varve sequence of A.D. 1512-1663. This would date the first five bison kill events at the Vore Site to: A.D. 1553-1558; A.D. 1572; A.D. 1608; A.D. 1637-1642; and A.D. 1663. Analysis of dendroclimatic data for the Black Hills region covering the last 500 years has given relatively inconclusive results in regards to the proposed increase of precipitation during the period. These results, as well as the conclusions of previous investigations suggest that archaeological inquiries must take into account climatic, as well as cultural variables when investigating the Little Ice Age time period in the Black Hills.

CROSS-DATING REFINEMENT OF THE VORE SITE VARVES: LITTLE ICE AGE CLIMATE AND CULTURAL ADAPTATIONS IN THE NORTHERN BLACK HILLS

by
Clinton C. Crago

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CHAPTER I
INTRODUCTION

Paleoclimatic reconstructions covering the past 500 years for the Great Plains and Black Hills regions have been the focus of a number of investigations (Reher 1978; Reher and Frison 1980; Bamforth 1990; Meko 1982; Meko 1995; Sieg et al. 1996; Fredlund et al. 1985). These have dealt primarily with a climatic episode known as the Little Ice Age which is generally believed to have been a colder and wetter period than the present. According to Bamforth (1990:360), most often, these reconstructions of the Little Ice Age have applied broad climatic models to infer the paleoclimate of the Great Plains with little supporting local data. The alternative methodologies to the low resolution models are found in data derived from historical records, varve sequences and dendroclimatology (Bamforth 1990:360, Bradley and Jones 1995:3).

In the Black Hills specifically, paleoclimatic investigations have been somewhat limited, although according to Sundstrom (1996a:1d-6), paleoenvironmental reconstruction is the key to several anthropological research problems in the area. The limitation with such paleoenvironmental reconstructions, much like those from the Great Plains, is the lack of localized paleoclimatic data, especially regarding the last 500 years. One notable exception, were the paleoclimatic investigations at the Vore Site (48CK302), which is a Late Prehistoric period bison jump in the northern Black Hills. The site is located in the bottom of a large sinkhole that periodically held water concurrently with the first five bison jump episodes. The small pond allowed for the formation of varve-like deposits which were analyzed and determined to show precipitation peaks indicative of the Little Ice Age (Reher and Frison 1980).

In the initial cross-dating analysis of the Vore site varve sequence, Reher and Frison (1980:57) used the closest available comparative tree-ring chronologies, which were an extended distance from the Vore Site (North Platte River 250 miles/400km and Missouri River Basin 450miles/725km). Although positive cross-dating correlations were obtained, the authors suggest that a refinement of the varve dates should be possible with comparison of the varve data with tree-ring indices from areas of closer proximity. This is partly due to the varve series origination dates showing high sliding correlations to a number of years, including A.D. 1500-1505, 1573-1576, 1613-1614, and 1634-1635 (Reher and Frison 1980:58). However, the carbon-14 dates (A.D. 1580 ± 140) coupled with the strongest correlations from the nearer tree-ring chronology (North Platte), indicated that the varves originated in the first five years of the 1500's and extended into the 1640's (Reher and Frison 1980:58).

Varve cross-dating with tree-ring records has been successful elsewhere. Soutar and Crill (1977) established statistical correlations between varve chronologies and local tree-ring series in the Santa Barbara Basin of California. Schimmelmann and Lange (1996:127), in reference to the varve sequences of the Santa Barbara Basin (SBB), state that "For the purpose of cross-dating, one should rely on standardized tree-ring records which are sensitive to precipitation, comparable in time interval to the varve records, and which are located as close as possible to the SBB."

Although on a much smaller scale, it is presumed that the sedimentation processes that occurred at the Vore Site are analogous to such basin areas. As described by Reher (1978:32), the geologic setting of the Vore Site sinkhole is unique in that it sits atop a "slight knoll" creating a feature that "is essentially a rain gauge 100 ft. in diameter." It is therefore assumed that the Vore Site varves are an accurate representation of past precipitation.

Cultural adaptive strategies to changing environments in the Black Hills, and the Northwest Plains in general, have been the subject of speculation (Frison 1991; Reher and Frison 1980; Sundstrom 1989; Fawcett 1987; Driver 1983). Sundstrom (1996:1d-2) notes that in the Black Hills, as well as other parts of the Great Plains, "various changes in social organization, settlement pattern, population density, subsistence activities and even ideology have been explained as a human response to environmental conditions." The communal hunting of bison, such as that represented at the Vore Site, is a primary subsistence activity of prehistoric cultural groups of the Great Plains and Black Hills regions during the Late Prehistoric period (Sundstrom 1989). Models and theories of cultural adaptation to the changing environment of the Little Ice Age that consider the Vore Site have been presented by numerous authors including Reher and Frison (1980), Driver (1983), and Fawcett (1987).

Reher and Frison's (1980) study of the Vore Site is believed to be the only Black Hills project to date "that attempts to correlate archaeological and paleoenvironmental data to develop a model of human-environment interaction" (Sundstrom 1996a:1d-4). The Vore site model presented by Reher and Frison (1980) was developed as a research design for analysis of the archaeological materials recovered from the Vore Site. It considers four main operational areas relevant to "an ecosystemic interpretation of western Plains hunting adaptations; these include variation in 1) effective moisture, 2) the productivity of shortgrass, 3) the distribution of buffalo populations, and 4) the distribution, density and organizational complexity of Plains hunters" (Reher and Frison 1980:2). The implications of the model are the development of "measures of climate, buffalo populations, changes in ethnic affiliation, group size and organization, territory size and other aspects of cultural process on the shortgrass Plains" (Reher and Frison 1980:137). A more detailed discussion of the Vore site model will be presented in Chapter V.

Other archaeologists have also addressed the issue of human adaptation to the changing climatic conditions of the Little Ice Age in the Great Plains, Black Hills and elsewhere (Driver 1983; Fawcett 1987; Osborn 1983; Kennett and Kennett 2000; Koerper et al. 1985; Bamforth 1990; Lensink 1993). Driver (1983), Osborn (1983), and Kennett and Kennett (2000), believe that the climatic conditions of the Little Ice Age had a significant effect on prehistoric cultures. Conversely, Fawcett (1987), Koerper et al. (1985), Lensink (1993), and Martin and Szuter (1997) claim that other factors besides climate are influencing prehistoric cultures during the same time period. These contrasting opinions have resulted in questions on the severity and importance of the Little Ice Age conditions and their effect on prehistoric cultures. Bamforth (1990) suggests that the Little Ice Age may not have been as uniformly influential to culture change in all regions and that the high variability of the climate over the past 600 years cannot be applied to cultural studies using generalized climate models. High resolution data is recommended to not only better understand local and regional climate (Bradley and Jones 1995), but human adaptation to that climate, as well (Bamforth 1990).

The primary goals of this thesis are 1) to refine the dates of the Vore Site varves using existing dendroclimatic data from published tree-ring stations and newly acquired dendroclimatic data from the northern Black Hills, 2) to reconstruct a basic precipitation record of the Black Hills for the last 500 years, in order to examine the validity of using climatic data from differing elevations and, 3) to use the results of this study coupled with a review of previous paleoclimatic and anthropological investigations to evaluate the reality of the Little Ice Age climate and its subsequent influence on cultural adaptative processes in the northern Black Hills.

In regards to the second goal, a dendroclimatic analysis of the elevation gradient of the

Black Hills must be conducted to qualify the comparison of paleoclimatic data from differing elevations. The currently available dendroclimatic data in the Black Hills region is concentrated in the higher elevation Black Hills, while the Vore Site and other dendrochronological samples used in this research are located at lower elevations. Tree-ring properties are known to change with elevation due to the climatic influences of elevation on the growth of trees (Fritts et al. 1965; Schweingruber 1988; Splechtna et al. 2000). It is believed that the success or failure of cross-dating in this research will show the relevance of comparing the higher and lower elevation paleoclimatic data.

The research presented here offers the potential to refine the dates of one of the largest and most significant archaeological sites in North America. The ability to know the specific year that an archaeological site was occupied or used, is a resolution rarely found in archaeological investigations. Furthermore, tree-ring series provide a foundation for paleoclimatic reconstruction in that they record temperature and precipitation which is dateable to a specific time and place (Hughes et al. 1982:i). Dendroclimatic data is important for understanding the "statistical and physical understanding of climate," as well as the "interpretation of historical, archaeological, and other past events" (Pittock 1982:62). Different types of investigations require different types of paleoclimatic data for specific purposes (Pittock 1982:62) and "precipitation is the aspect of the Plains climate which plays the largest role in anthropological discussion of the effects of climate on human beings"(Bamforth 1990:361). Accordingly, the high resolution data used in this research emphasizes reconstruction of the precipitation record to not only date the Vore Site, but also increase the paleoclimatic knowledge base and potentially lead to a better understanding of the climatic and cultural processes of the northern Black Hills during the Little Ice Age.

CHAPTER II
THE RESEARCH AREA

The Black Hills

The area under study here is in the northern Black Hills of Wyoming and South Dakota (Figure 1). The Black Hills are an elliptical, domal uplift located in western South Dakota and northeastern Wyoming that measure approximately 80 km (50 miles) east to west and 190 km (120 miles) north to south, covering approximately 15,200 km^2 (6000 $miles^2$). The hills rise 900 to 1200 meters higher than the surrounding plains to a maximum of 2207 meters (asl) at Harney Peak (Knight 1994:242). The Black Hills are considered to be the easternmost extent of the Rocky Mountains, as they originated at approximately the same time (Knight 1994:242), and are structurally similar to other outliers of that mountain range (Sundstrom 1989:13). However, the Black Hills are also considered to be part of the northwestern portion of the Great Plains physiographic region (Frison and Mainfort 1996:3). This mixed nomenclature is due to the region showing environmental and biological characteristics of both mountains and plains, making the Black Hills unique and regarded a landscape of special interest (Knight 1994:242).

Geomorphic Regions

The topography of the Black Hills can be divided into four major geomorphic features (Knight 1994:244) (Figure 2). In the interior is the Central Area, which is comprised of the rugged granitic mountains. The highest peak elevations in the Black Hills are found in this area with a range of 1525 to 1830 meters (Knight 1994:246). Exterior to the central core and extending mainly to the west, is an area known as the Limestone Plateau, which is composed of sedimentary strata. The water permeable limestone in this region has led to the formation of

Figure 1 - Location of study area and research data sources in the northwest Great Plains. (1:Eagle Nest Canyon; 2: The Brakes; 3: The Vore Site; 4: Moskee, 5: Reno Gulch ; 6: Buckhorn Mountain; 7:Herbert Draw; 8: Pilger Mountain Lookout; 9: Pilger Mountain) (Adapted from Raisz 1939)

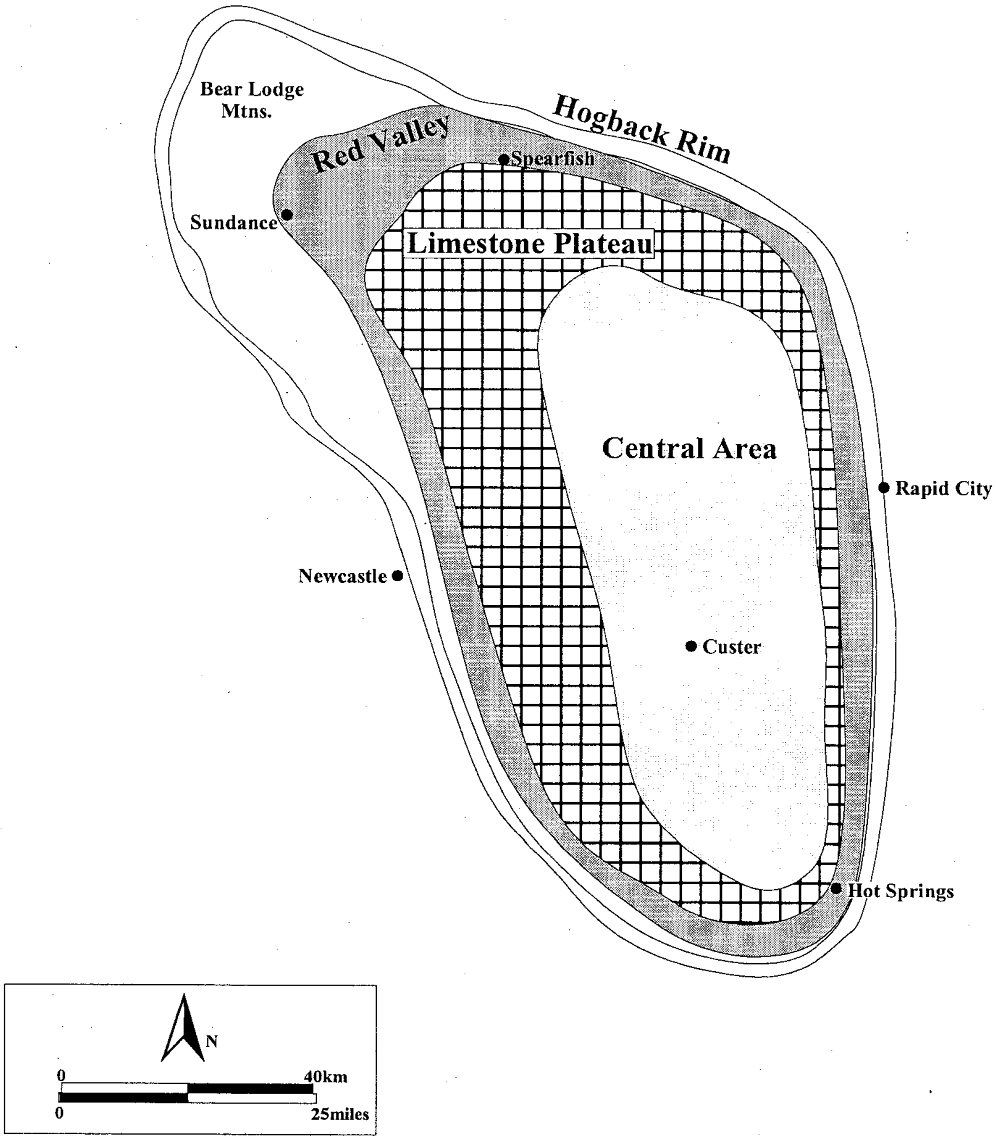

Figure 2 - Schematic map of Black Hills major geomorphic zones. (Adapted from Knight 1994, Froiland 1978)

numerous caves (Knight 1994:246). Encircling the Limestone Plateau, as well as the entire Black Hills, is the Red Valley, also known as the race track. This area is characterized by the red colored, eroded soft shales of the Spearfish and Sundance formations (Knight 1994:246). On the perimeter of the Black Hills, exterior to the Red Valley, is a resistant sedimentary formation known as the Hogback Rim. This pine-covered ridge is fairly continuous but broken intermittently by streams and drainages, which form natural passes into the Black Hills interior (Knight 1994:246). One notable break is Buffalo Gap in the southwestern Black Hills which, historically, was a passage for bison herds entering the Red Valley from the surrounding plains (Froiland 1978:13).

Flora

The Black Hills are unique in their biological makeup in that different regional floral communities coexist. The four main vegetative complexes represented consist primarily of species from the Rocky Mountains, eastern deciduous woodlands, northern coniferous forest, and northern Great Plains (Froiland 1978:81). As summarized by Froiland (1978:81), the vegetational diversity of the Black Hills was studied in the early 1900's by Hayward (1928) and MacIntosh (1931), who concluded that the Black Hills vegetation was composed of 30% Rocky Mountain species, 17% Great Plains species, 9% eastern species, 6% northern species, 4.5% southwestern species and the remainder being widespread or introduced species.

The grassland vegetation of the Black Hills consists of many species of grasses and forbs with ratios dependant on local moisture and soil conditions (Froiland 1978:92). The dominant grass species are western wheatgrass (*Agropyron*), needle-and-thread (*Stipa comata*), little bluestem (*Andropogon scoparius*), blue grama (*Boutelona gracilis*), buffalo grass (*Buchloe* *dactyloides*), Japanese brome (*Bromus japonicus*), prairie junegrass (*Koeleria pyramidata*), side oats grama (*Bouteloua gracilis*) and green needlegrass (*S. viridula*) (Froiland 1978:92). Forbs include prickly pear (*Opuntia* spp.), yucca (*Yucca glauca*), and purple coneflower (*Echinacea angustifolia*) (Froiland 1978:92-93). Sagebrush (*Artemesia* spp.) occurs on the peripheries of the Black Hills, but is particularly well established around the southwestern hills (Froiland 1978:92-93).

Forest vegetation, as well as the Black Hills landscape in general, is dominated by ponderosa pine (*Pinus ponderosa*), although Rocky Mountain Juniper (also known as western red cedar) (*Juniperus scopulorum*), quaking aspen (*Populus tremuloides*), white spruce (*Picea glauca*), burr oak (*Quercus macrocarpa*), elm (*Ulmus americanus*), aspen (*Populus tremuloides*), birch (*Betula*), ash (*Fraxinus pennsylvanica*), cottonwood (*Populus deltoides*) and boxelder (*Acer negundo*) are common (Froiland 1978:82-89). The forest understory includes common ground juniper (*Juniperus communis*), kinnikinnik or bear-berry (*Arctostaphylos uva-ursi*), and creeping cedar (*Juniperus horizontalis*) in the coniferous forests, and shrub communities composed of willow species (*Salix* spp.), river birch (*Betula papyrifera*), red osier dogwood (*Cornus stolonifera*), wild rose (*Rosa* spp.), raspberry (*Rubus* spp.), currant (*Ribes* spp.) and buffalo berry (*Shepherdia canadensis*) in the deciduous forests (Froiland 1978:82-91). The drier southern hills are dominated by a shrub community of mountain mahogany (*Cercocarpus montanus*), buffalo berry (*Shepherdia* spp.), currant (*Ribes* spp.), and sumac (*Rhus* spp.) (Froiland 1978:84).

Fauna

The fauna of the Black Hills consists of many native, as well as introduced animals

(Sundstrom 1989:21). Large herbivores include white-tail deer (*O. virginianus dacotensis*), mule deer (*Odocoileus hemionus hemionus*), pronghorn antelope (*Antilocapra americana americana*), and elk *(Cervus canadensis canadensis*). Historically, bison (*B. bison bison*) and mountain sheep (*Ovis canadensis*) inhabited the Black Hills (Sundstrom 1989:21). Extant carnivores include coyote (*Canis latrans latrans*), red fox (*Vulpes vulpes*), bobcat (*Felis rufus*), and mountain lion (*Felis concolor*), while historically black bear (*Ursus americanus*) and grizzly bear (*Ursus arctos*) and gray wolf *(Canis lupis irremotus)* inhabited the region (Froiland 1978:136-146).

Other wildlife species include smaller mammals such as rabbit (*Lepus* spp. and *Sylvilagus* spp.), mice (*Peromyscus* sp.), squirrel (*Tamias* sp. *Eutamias* sp.), prairie dog (*Cynomys ludovicanus*), beaver (*Castor canadensis missouriensis*), muskrat (*Ondatra zibethicus*), porcupine (*Erethizon dorsatum bruneri*), skunk (*Mephitus mephitus*), and raccoon (*Procyon lotor hirtus*) (Sundstrom 1989:22). Reptiles include frogs, snakes, turtles, lizards and numerous species of snakes, including the venomous prairie rattlesnake (*Crotalus viridis viridis*) (Froiland 1978:99-105). Avifauna include various species of eagles (*Aquilla* spp. and *Haliaeetus* spp.), hawks (*Buteo* spp.), owls (Order Strigiformes), and falcons (*Falco* spp.), as well as the turkey vulture (*Cathartes aura*), ruffled grouse (*Bonasa umbellus*), sharp-tailed grouse (*Pedioecetes phasianelles*), ring-necked pheasant (*Phasianus colchicus*), turkey (*Meleagris gallopavo*), and various species of songbirds and waterfowl (Froiland 1978:106-135).

Contemporary Climate

The contemporary climate of the Black Hills is a combination of a semi-arid continental type with a foothills-mountain type, creating a highly variable yet milder climate when compared to the surrounding plains (Froiland 1978:34, Sundstrom 1989:19). The climate of the Black Hills changes from north to south and Froiland (1978:36) notes the differences by dividing the region into northern and southern climatic zones. The northern Black Hills are cooler and have higher annual precipitation from heavier snowfalls and intense thunderstorms, while the southern hills are warmer throughout the year and have a lower annual precipitation (Froiland 1978:36). The northern Black Hills actually receive the highest snowfall amounts for the entire northern plains (Sieg et al. 1996:295).

The annual precipitation in the northern Black Hills ranges from 43 to 74 centimeters (17-29 inches), while the southern hills receive an average of 43 to 48 centimeters (17-19 inches) (Sundstrom 1989:19). Frequent droughts occur and may be severe, especially in the southern hills (Sundstrom 1989:19). Most of the precipitation for the entire region falls between April and September with summer precipitation in the form of scattered rainfall and intense thunderstorms (Sieg et al. 1996:295), while winter and spring precipitation is most often in the form of snow (Sundstrom 1989:19).

Natural Resources

The Black Hills contain abundant natural resources today, much like they probably did prehistorically. As described by Sundstrom (1989:22-23) and summarized above, the Black Hills have good water, edible plants and forbs, many rockshelters and caves, and abundant small and large game. Extensive lithic resources, suitable for flintknapping, can be found throughout the Black Hills (Church 1996:3e-17). Orthoquartzites, cherts and silicified wood can be found in the Hogback Rim, chert in the Red Valley and orthoquartzites and cherts in the Limestone Plateau (Church 1996:3e-17). Chert, metaquartzite, and hematite are also available in the Central interior of the Black Hills. (Church 1996:3e-17).

Cultural Chronology

The cultural chronology of the Black Hills extends from the Paleoindian period to the present (Sundstrom 1989; Kornfeld and Reher 1992), with sites representative of culture groups from the Northwest, Central, and Northern Plains and Middle Missouri area (Sundstrom 1989:25) (Figure 3). The Black Hills have long been considered a possible "oasis-like" area which allowed inhabitation by prehistoric peoples during intervals of unfavorable climate over the past 12,000 years (Frison 1991:191). However, for purposes of this discussion, the focus will be on the Late Prehistoric period (1500 - 350 years B.P.) (Frison 1991:111), with some overlap with the subsequent Protohistoric period.

According to Sundstrom (1989:107-108), the Late Prehistoric period in the Black Hills experienced an increased amount of ethnic and economic diversity, relative to earlier periods. Three major cultural adaptations occurred in this period: large scale communal bison hunting, plains village settlement, and specialized local subsistence adaptations (Sundstrom 1989:63-73). The most common localized adaptation was the warm-season deer and mountain sheep hunting in the Limestone Plateau and the cold-season camping in the Hogback (Tratebas 1986). Based on analysis of surface collections, Late Prehistoric archaeological sites in the Black Hills are concentrated in the Hogback, relative to the inner regions (Sundstrom 1989:100). Kornfeld and Reher (1992:241), also determined that the Black Hills foothills have an "over representation" of sites from the Late Prehistoric period.

It is the advent of the bow and arrow and the resulting change in projectile point type that marks the beginning of the Late Prehistoric period in the Black Hills as well as the Northwestern Plains in general (Frison 1991:111; Sundstrom 1989:63). The first culture group to possibly use

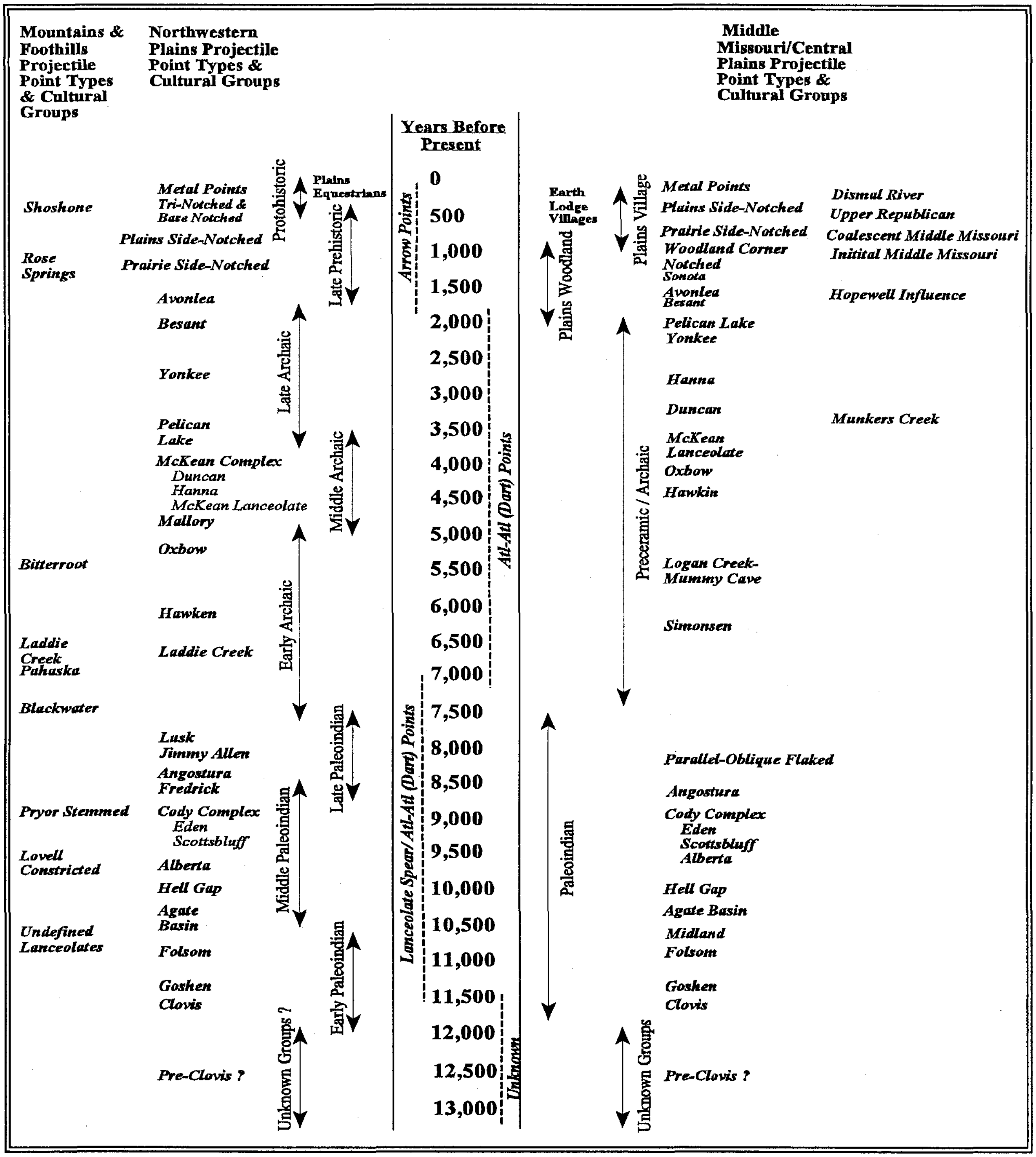

Figure 3 - Cultural chronology for the Black Hills and surrounding areas. Adapted from Frison 1991, Sundstrom 1989, Tratebas 1986, Kornfeld et al. 1995, Husted and Edgar 2002. (Figure 2, page 19 in Weathermon 2002, © Rick L. Weathermon, December, 2002) Used with permission of author (March, 2003).

the bow and arrow on the Northwest Plains is the Avonlea, whose presence in the Black Hills has been debated (Noisant and Sundstrom 1996:2e-2). However, small triangular arrow points similar to other Avonlea projectile points have been found in the hills (Noisant and Sundstrom 1996:2e-2). Subsequent complexes and culture groups in the Northwest Plains and Black Hills also share the characteristics of small triangular corner or side notched arrow points, as well as tipi habitation and subsistence based on bison hunting, much like the Avonlea complex (Sundstrom 1989:64).

Prehistoric ceramic artifacts recovered in the Black Hills from the Late Prehistoric period suggest use of the area by a number of other cultural groups. These ceramic traditions include the Middle Missouri Tradition and Prairie/Plains Side Notch Complex of the Plains Village cultures from the east of the Black Hills, and the Crow and possibly Shoshone from west of the Black Hills (Noisant and Sundstrom 1996:2e-8 - 2e-12). The Prairie /Plains Side Notch Complex is more recognized for its projectile point type of small, triangular side notched arrow points, but it does have a diagnostic ceramic type as well (Noisant and Sundstrom 1996:2e-13).

The Protohistoric period on the Northwestern Plains is usually marked by the introduction of the horse and European trade goods to the Native Americans, somewhere around A.D. 1700 - 1750 (Frison 1991:122, Sundstrom 1989:74). A number of identifiable ethnic groups inhabited the Black Hills and surrounding areas starting in the mid 18th century (Reher and Frison 1980:34). The earlier groups include Crow, Kiowa, Kiowa-Apache, Comanche, Suhtai, Ponca, and Arikara, while the later groups include Lakota, Arapaho, and Cheyenne (Sundstrom 1989:74; Reher 1977). By A.D. 1770 and up to the historic period, the Lakota controlled the Black Hills (Sundstrom 1989:75).

The Vore Site

The Vore Site (48CK302) is a Late Prehistoric bison jump located in the northern Black Hills of Wyoming (Figure 4). Initial investigation of the site took place in the early 1970's after the discovery of the site from activities surrounding the construction of Interstate-90. The main site area is located in the bottom of a large, naturally occurring pseudokarst sinkhole that is approximately 31 meters (100 feet) wide at the bottom and 15 meters (50 feet) deep (Reher and Frison 1980:1) (Figure 5). Drive lines and other evidence suggest that bison were driven into the hole from different directions, although one side has a perpendicular jump point, while the rest has a steep talus slope (Frison 1991:226). The top cultural levels at the bottom of the sink are buried by 1.2 meters of recent deposition, with the bottom levels extending down to 5.2 meters below the surface (Reher and Frison 1980:1) (Figure 6). There are at least 22 bone levels with their thickness ranging from a single bone to 1 meter thick zones where three bone levels converge. It is estimated that the remains of 10 to 20,000 bison may be present in the site.

The dating of the Vore Site is primarily based on artifact typology and radiocarbon assays, however, the presence of varved sediments allowed further dating refinement (Reher and Frison 1980:53) (Figure 7). Investigation of the laminated sediments revealed that they occurred in the lower site levels, between 3.6 and 6.1 meters below the surface (Reher and Frison 1980:53). Reher measured the thicknesses of 282 laminations intervening with bison bone beds, representing 141 years of varved sediments (Reher and Frison 1980:55). As mentioned earlier, the varves were determined to have originated in the first five years of the 1500's and extended through to the 1640's. The varve sequence helped determine that the buffalo jump was used between A.D. 1500 and A.D.1800 (Reher and Frison 1980:1).

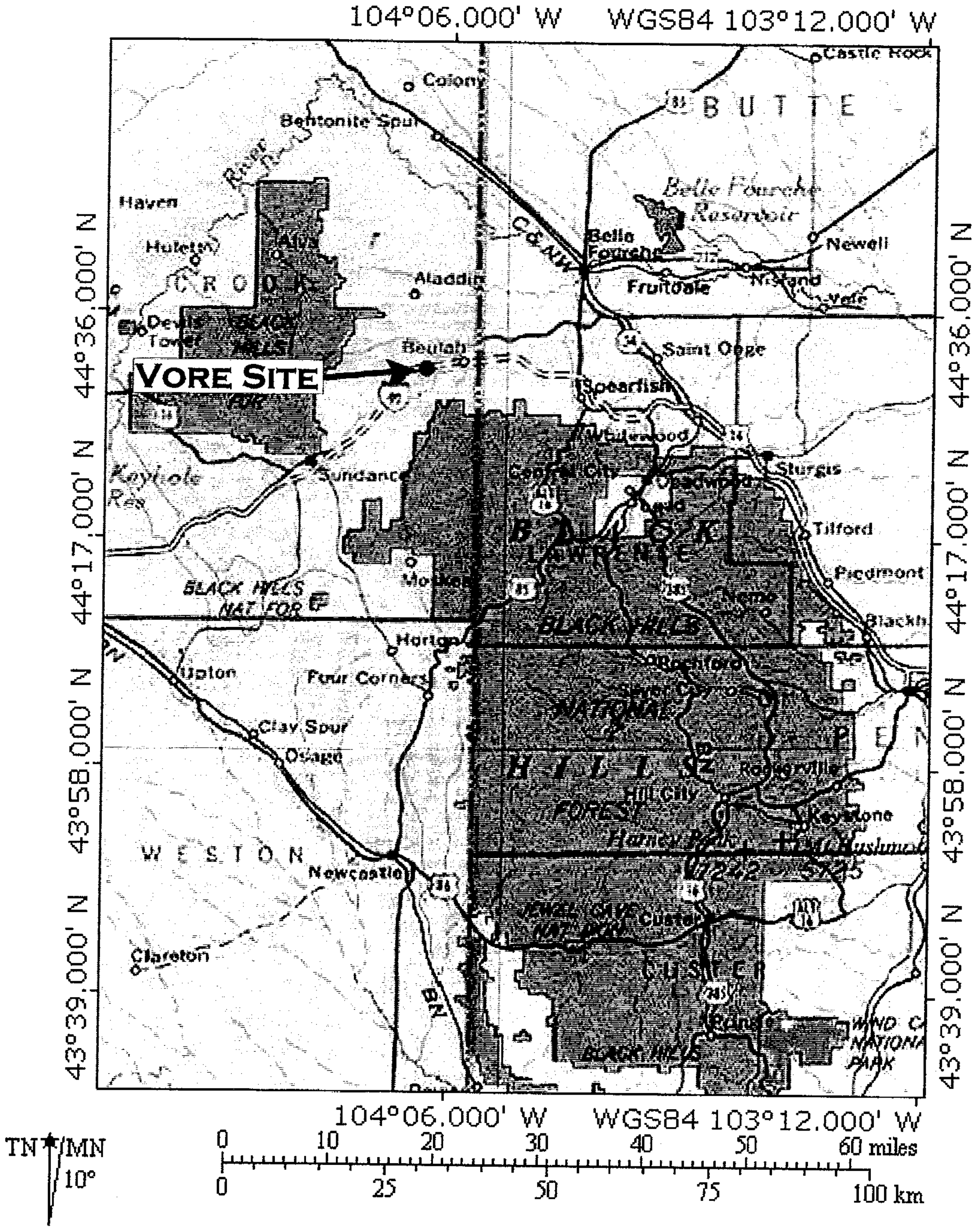

Figure 4 - Location of Vore Site in the northern Black Hills.

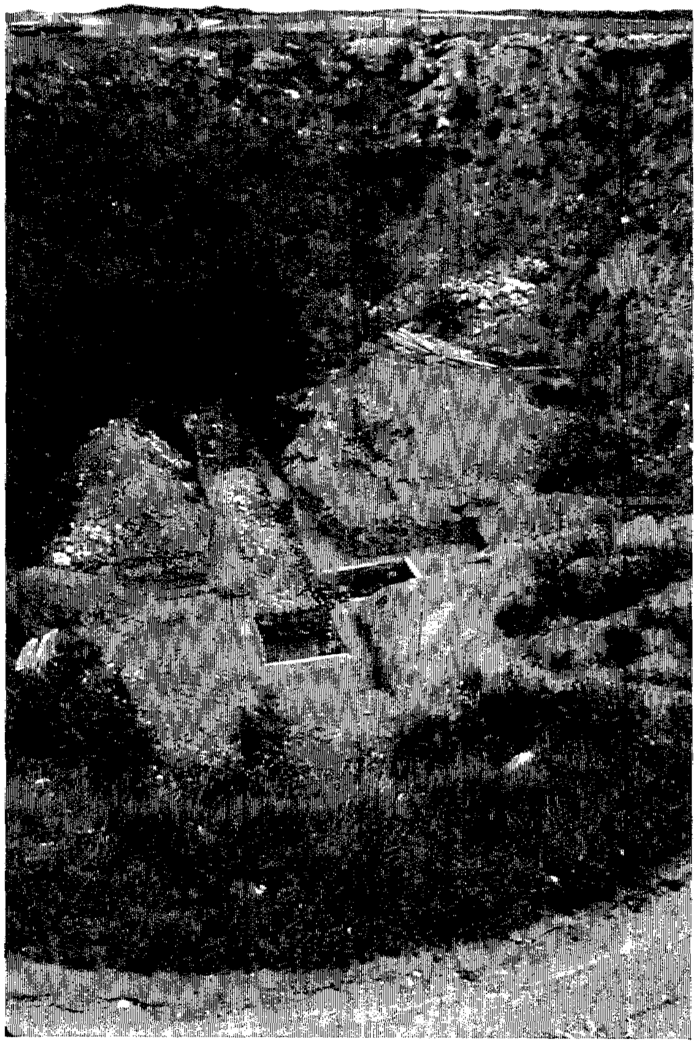

Figure 5 - View of sinkhole at the Vore Site

Figure 6 - View of bone middens in the Vore Site

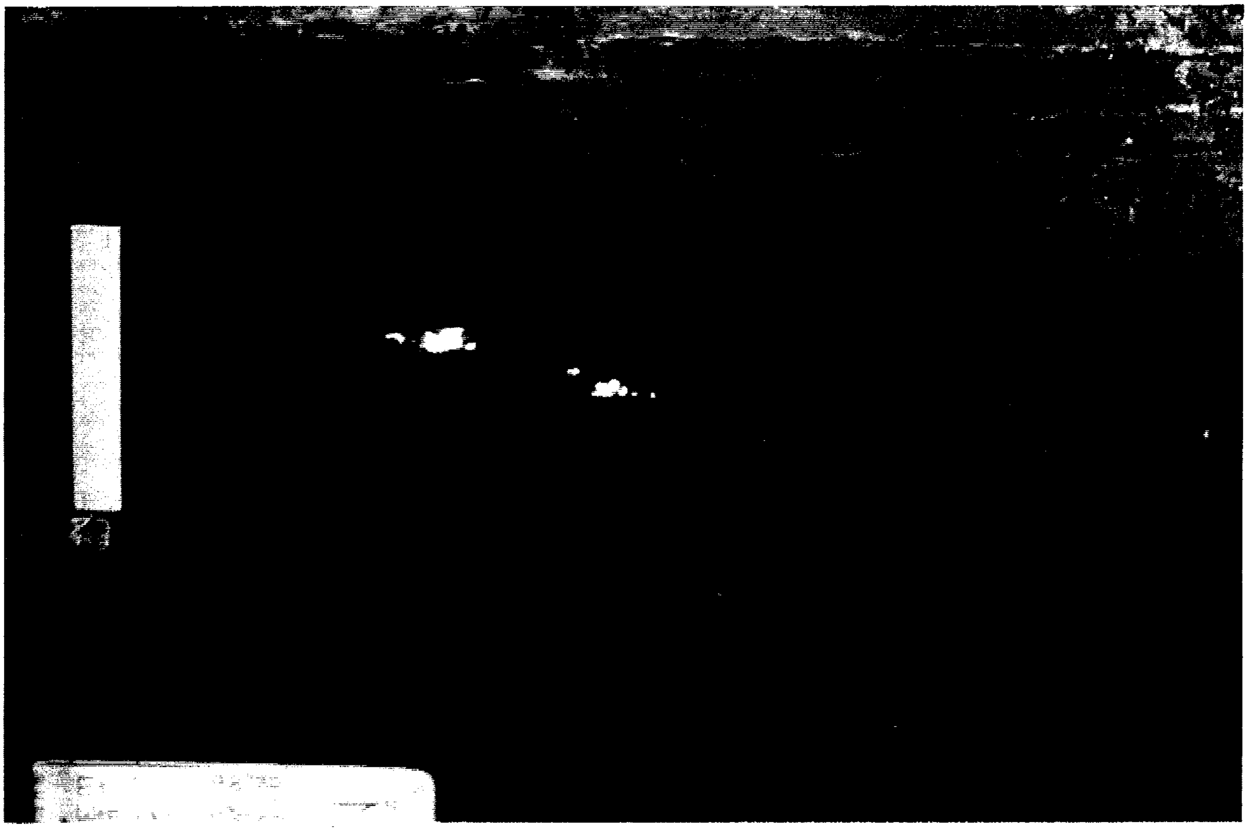

Figure 7 - View of the Vore Site varves. (Figure 34a, page 54 in Reher and Frison 1980)
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Cultural affiliation of the upper cultural levels in the Vore Site have been attributed to the Cheyenne culture group (Sundstrom 1996b:2f-13). Two Cheyenne ethnographic sources suggest possible reference to the buffalo jump activities at the Vore Site. One ethnographic account is told by John Stands In Timber, who remembers being told by old Northern Cheyenne men, of a buffalo trapping pit located near the existing highway between Sundance, Wyoming and Lead, South Dakota (Stands in Timber and Liberty 1967:86). Another possible reference to the site is seen in the painted imagery on a Cheyenne medicine blanket curated at the Heye Foundation Museum of the American Indian in New York (Sundstrom 1996b:2f-13). Wildschut (1926), who acquired the robe, learned from a Cheyenne informant that the images on the blanket symbolically depict bison being stampeded into a sinkhole. It is believed that these illustrations represent activities at the Vore Site in the northern Black Hills.

CHAPTER III
THE LITTLE ICE AGE

The term "Little Ice Age" was first used by Matthes (1939:520) who stated, "We are living in an epoch of renewed but moderate glaciation--a 'little ice age' that already has lasted about 4,000 years." In a later report, Matthes (1940:397) notes that the glacial oscillations of the last few centuries were the greatest during that 4000 year period, and "the greatest since the end of the Pleistocene ice age." It is these recent centuries of glacial oscillations that the term Little Ice Age is now generally applied by most researchers (Jones and Bradley 1995:658). Numerous authors (Bamforth 1990; Bradley and Jones 1995; Reher 1978; Reher and Frison 1980) agree that the Little Ice Age climatic episode occurred from the middle 1400's to the middle 1800's A.D. However, some researchers claim that the Little Ice Age began anywhere from A.D.1250 (Porter 1986) to A.D. 1550 (Lamb 1977). The differences in the starting dates can be attributed to "locational experience of individual workers and the volume and accuracy of the evidence available to them (Grove 1988:4).

The Little Ice Age was notably a worldwide event with the global average temperature 1-2°C cooler than today (Grove 1988:5). Cold climate and glacier expansion during the Little Ice Age are documented from many continents (Table 1).

Time Period	**Glacial Activity**
■1560-1610 A.D.	-Major advances by all glaciers
■1640-1650 A.D.	-Glacial maximum in Switzerland
■1670-1705 A.D.	-Glacial maximum in Austria
■1720-1750 A.D.	-Glacial maximum in Norway
■1816-1825 A.D.	-Minor advances by all glaciers
■1850-1890 A.D.	-Glacial maximum in Canada/Iceland

Table 1 - Glacial Activity During the Little Ice Age. (Adapted from Grove 1988:352)

As Table 1 illustrates, the Little Ice Age was not a single, uniformly cold climatic episode. Distinct variations in climate and in glacial activity occurred on a region-wide scale. In Europe, for example, the 17th century was cold, 16th and 18th centuries warm, and the 19th century experienced the most widespread climatic anomalies, up to A.D. 1915 (Bradley and Jones 1995:659). Contrastingly, in North America, the 17th century was cold in the north, but warmer than 20th century normals in the west, with the 19th century being the coldest (Bradley and Jones 1995:659). The Little Ice Age climate has been linked as a causal factor of such events as the failure of many North American colonies of the 1600's and the Irish potato famine of the 1840's (Fagan 2000:96-97,181-197).

CHAPTER IV

PALEOENVIRONMENTAL RECONSTRUCTION OF THE LITTLE ICE AGE IN THE GREAT PLAINS AND BLACK HILLS REGIONS

Low Resolution Data

According to Bamforth (1990:360), many early reconstructions of the Great Plains climate relied on theoretical analyses of global atmospheric circulation patterns. Although theoretical investigations are "essential to achieving a causal understanding of how and why climates change," they are not as useful for "reconstructing specific climate changes in specific places" (Bamforth 1990:360). Kutzbach (1976:471) states that theoretical climate models are most accurate for time spans over one thousand years. Therefore, investigating the Little Ice Age using global atmospheric circulation models would theoretically be limited, since the climatic episode is significantly shorter than one thousand years in duration.

Hall (1988) has investigated the complexity of using climatic models on the Southern Plains. According to Hall (1988:204), climatologists in an earlier study, using climatic data from Europe, theorized on the precipitation of the Central and Southern Plains during the thirteenth century A. D. The data indicate global circulation patterns that would have reduced precipitation on the Central Plains, but increased it on the Southern Plains (Hall 1988:204). Hall (1988:206) argues that supporting data show that drier conditions dominated both regions, which is contrary to the expected results from the theoretical model.

According to Sundstrom (1996a:1d-6), regional climatic models are also unacceptable for paleoenvironmental reconstruction in the Black Hills, since the region cannot be assumed to be climatically homogenous with the surrounding Great Plains. Archaeological investigations, in and around the Black Hills, have yielded low resolution data in the form of pollen, phytolith, sediment, and faunal samples (Sundstrom 1996a:1d-6). However, most data has come from the peripheries of the Black Hills creating data gaps and making the paleoenvironment of the whole region poorly understood (Sundstrom 1996a:1d-6).

One paleoclimatic investigation from the southeast edge of the Black Hills in the Capes Cave rockshelter (39FA205) uses geomorphological, sedimentological and palynological data from an archaeological context (Fredlund et al. 1985). In an interdisciplinary study, the researchers concluded that sometime during the Late Prehistoric period there was a sudden expansion of the pine forest in the southern Black Hills (Fredlund et al. 1985:9). It is hypothesized that this expansion occurred within a time span of 200 years and is a vegetational response to the increased precipitation of the Little Ice Age climatic episode (Fredlund et al. 1985:9).

High Resolution Data

A number of methods exist to gather paleoclimatic data that allow a sufficiently high resolution to detect annual climatic variability (Bradley and Jones 1995:3) (Table 2).

Data Source	Potential information
■Historical documents	-almost all aspects of climate
■Tree-rings	-temperature, precipitation, pressure patterns, drought, runoff
■Ice cores	-temperature, precipitation, atmospheric aerosols, atmospheric composition
■Varved sediments	-temperature, precipitation, solar radiation
■Corals	-sea surface, temperatures, adjacent continental rainfall

Table 2 - Types of High Resolution Data For Paleoclimatic Investigations (Adapted from Bradley and Jones 1995:3).

Of these five types of high resolution data, those that can be acquired for the Great Plains region are historical documentation, tree-rings (dendrochronology), and varved sediments. Bamforth (1990:360) believes these three data sources form the primary data useful for reconstructing the Little Ice Age climate of the Great Plains.

Historical Records

Bradley and Jones (1995:6) identify three categories of historical data used for paleoclimatic reconstruction.

1. Direct observation of weather phenomena: (i.e. rainfall, snowfall, frost).
2. Records of weather-dependent natural phenomena (i.e. droughts, floods).
3. Records of weather dependent biological phenomena.

One study that uses historical data to infer climate change over the past century is Wahl and Lawson's (1970) examination of rainfall totals at military forts across the western United States between A.D. 1850 and 1870. Wahl and Lawson (1970) compared the annual precipitation of the period (A.D. 1850-1870) to the modern standard annual precipitation (A.D. 1931-1960) for the same locations in the western United States. They found that the precipitation of the Great Plains from 1850 to 1870 was 5 percent greater than the modern period annual precipitation normal.

Historic records are considered to be very useful, but advised by some researchers to be used with caution (Bradley and Jones 1995:6; Bamforth 1987:1). Location, timing and severity of a climatic event can be lost in the possibly biased documentation of an individual, whereas long term climatic trends are outside of their perception entirely (Bradley and Jones 1995:6). Likewise, external effects on the data being studied, are also outside the perception of an individual observer, and must be accounted for (Bamforth 1987:13).

Dendrochronology

Dendrochronology, the study of tree-rings, has largely focused on climatic reconstruction and archaeological dating throughout its history as a discipline (Dean et al. 1996:v). Environmental data from dendrochronology come from two sources: 1) the comparison of species in archaeological wood collections with modern plant distributions and 2) dendroclimatic analysis of tree-ring series (Dean 1996:463). It is the dendroclimatic reconstructions derived from the tree-ring series that "help evaluate the effects of past climatic variability on human adaptive behavior" (Dean 1996:463).

However, according to Meko (1982:321), tree-ring studies of the Great Plains region have been hindered by a lack of tree-ring chronologies, because of the scarcity of trees in the central parts of the Plains. According to Sieg et al. (1996:295), low precipitation, severe winters and recurring droughts restrict tree-growth to ravines and flood plains or areas of higher elevation, such as the Black Hills or wooded escarpments, which receive more rainfall. Sieg et al. (1996:295) determined that the dendroclimatic potential of the northern Great Plains is limited to the early 1600's (as the oldest chronologies) based on the tree-ring chronologies currently developed.

Addressing the suggestion that drought cycles in the region occurred every 20 to 30 years, Meko (1995) used tree-ring chronologies to study the drought history of the Great Plains from A.D. 1750-1964. The paleoclimatic reconstructions revealed that drought fluctuations during this period occurred irregularly, with the possibility of 60 year drought cycles (Meko 1995:312). Meko's (1995:312) study revealed that the 1930's drought was minor when compared with major droughts of the 1750's, 1820's and 1860's.

Varves

Varves can be simply defined as laminated sediments deposited in bodies of water (Kemp 1996:vii). Often, these laminated bands are formed seasonally by "a coarse terrigenous lamina (resulting from spring meltwater discharge) alternating with finer sediment," to form a couplet, and are interpreted to represent the deposition of a single year (Kemp 1996:viii). Varves are analogous to tree-rings in that the thickness of annual layers is "significantly controlled by precipitation" (Schimmelmann and Lange 1996:127).

Much like tree-ring data, other factors of paleoclimate besides precipitation and temperature, can be determined from varved sediments. Climatic change can be determined from such things as the climate sensitive biological, chemical and mineral components of the sediments (Dean et al. 1984:1191). More specifically, the salinity and proportions of minerals and organics in the sediments can drastically change varve formation, as well as their thicknesses (Dean et al. 1984:1192). This is similar to such things as soil conditions, canopy release, and other growth limiting factors in trees.

Dean and Schwalb (2000) extracted sediment cores from Pickerel Lake, South Dakota, in the 1960s and again in 1995. The cores were analyzed for such things as magnetic susceptibility, percent organic matter and percent calcium carbonate, in order to make climatic and environmental inferences (Dean and Schwalb 2000:5). For example, a high percentage of organic matter in a year of sediment is indicative of an abundance of vegetation in the previous year, which is related to higher precipitation (Dean and Schwalb 2000:9). Dean and Schwalb (2000:18) determined that over the past two thousand years, major droughts have recurred on the Northern Great Plains of the United States at approximately 400-year intervals. According, to Dean and

Schwalb (2000:18), the most recent of these drought periods occurred between 200 and 400 years ago.

As previously mentioned, the only varve study from the Black Hills occurred at the Vore Site by Reher and Frison (1980). The 141 years of varved sediments, cross-dated with tree-ring sequences showed increased precipitation during the 1500's and 1600's. The authors attributed the increase in moisture to the effects of the Little Ice Age climate and determined that peaks in precipitation occurred with a 10-year periodicity with increasing frequency and amplitude between A.D. 1500 and 1640 (Reher and Frison 1980:59).

CHAPTER V

LITTLE ICE AGE ARCHAEOLOGICAL STUDIES

A number of investigations have addressed the idea of culture change as a function of climate change during the Little Ice Age climatic episode (Reher 1978; Reher and Frison 1980; Osborn 1983; Kennett and Kennett 2000; Koerper et al. 1985; Bamforth 1990; Lensink 1993). “Climatic conditions are often considered to be critical determinants of human adaptations on the Plains” (Bamforth 1990:359). Researchers such as Reher (1978), Reher and Frison (1980), Driver (1983) and Osborn (1983), believe that the Little Ice Age had a significant effect on the Plains aboriginal groups. Other climatic studies by researchers outside of the Plains region (Koerper et al. 1985; Kennett and Kennett 2000) also emphasize the influence of climate on cultural adaptations. Lensink (1993), Fawcett (1987) and Martin and Szuter (1997) offer research that minimizes the climatic effects on aboriginal life ways.

Reher (1978) and Reher and Frison (1980) proposed the Vore model discussed earlier, which emphasizes the increased moisture of the Little Ice Age as a driving cause behind the communal bison hunts represented at the Vore site. The model includes variation in 1) effective moisture, 2) the productivity of shortgrass, 3) the distribution of buffalo populations, and 4) the distribution, density and organizational complexity of Plains hunters” (Reher and Frison 1980:2). Preliminary analysis of the Vore Site varves suggested a series of peaks in moisture with a 10-year periodicity, with greater frequency and amplitude, during part of the Little Ice Age (A.D. 1500-1640's) (Reher and Frison 1980:59). Kill episodes occurred an average four years after peaks in precipitation, although a kill did not occur after every peak. The hiatus in site use is theorized to be the time needed for increased grass productivity to translate into increased bison weight and numbers as young calves matured and were able to produce calves of their own (Reher and Frison 1980:59). This suggests that bison populations fluctuated on a roughly ten-year cycle and consequently the bison jump was used during periods of increased precipitation (Reher and Frison 1980:59).

Reher and Frison (1980) use many types of evidence from the Vore Site, such as lithic technology, lithic source analysis, and bison population dynamics to explain proposed changes in human population dynamics and use of the Vore Site between A.D. 1500-1800. For example, analysis of the projectile point assemblage suggested that the lower cultural levels "might represent an ethnic group" and "the upper levels may reflect intrusion of more than one cultural assemblage" (later determined to be up to four cultural assemblages in the upper level) (Reher and Frison 1980:121). It is the suggestion that this is a reflection of increasing competition of resources and increasing social complexity "with an increasing ability to support part time technological specialists" (Reher and Frison 1980:137), as has been reported for the Cheyenne Tribe (Grinnell 1923).

The Vore model proposes the cultural evolution of plains aboriginal groups from bands "to suprafamilial production and consumption, to institutions vested with true power and authority (such as the warrior-police societies) and to exclusive, ethnically defined territories" (Reher and Frison 1980:48). Again, this is suggested as a reflection of increasing competition for resources due to increased human population densities on the Great Plains (Reher and Frison 1980:137). Furthermore, it is suggested by Reher and Frison (1980:137) that the "Vore sequence seems to document an increasing frequency of social aggregation at the kill site." As Reher (1978:30) states, "occasional or local buffalo population 'highs' should define an increase from family-level local groups to temporary aggregations, larger group size during the jumping season, and perhaps longer duration of the semi-sedentary behavior associated with the kills."

Contrary to the Vore model, Driver (1983) proposes that communal bison hunts were conducted during droughts. Driver (1983:150) concurs with Reher and Frison on the unpredictability and variability of the Great Plains climate and he notes that the kills at the Vore Site occurring four years after a peak in precipitation would put them at the low point of the 10-year precipitation cycle. He suggests that young animals have higher mortality than adults during drought periods and that bison less than three years of age account for only 7-35% of the specimens in kill sites, whereas they account for 50% of the population in a living herd (Driver 1983:Table 1). Driver (1983) also states that concentrations of bison around watering holes during dry periods would allow for communal hunting. However, Reher (2003 personal communication) suggests that although the kills at the Vore Site occurred during low points of the 10-year precipitation cycle, the climatic trends indicate that these low points were not actual severe droughts.

Osborn (1983) considers the Little Ice Age in developing an ecologically based model of horse herd size of aboriginal groups. Osborn (1983:572) hypothesizes that "if winter forage and its availability is a limiting factor for horse populations in western North America, horse herd size (tribal herds) should decrease as winter severity increases." The author tested this hypothesis with ethnohistorical records of horse populations in aboriginal societies of the Great Plains in comparison with a weather severity index for the region (Osborn 1983:572-581). Osborn (1983:579) states his interpretation of the Little Ice Age as, "For the Great Plains, climatic conditions probably included increased summer precipitation, lower evaporation levels, cooler annual temperatures, increased summer storm and tornado activity, shortening of the growing season, more frequent frosts, lower snowlines, and more severe winters (at least in terms of temperature)." Osborn (1983:581-586) concludes that due to increased winter severity, a cultural adaptive response occurs with increased labor costs involving care given to the horse herd. "Considerable labor would be allocated to provisioning the herds with adequate forage and fresh water, and to protecting horses from animal and human predators" (Osborn 1983:584).

Although not from the Great Plains, a recent study by Kennett and Kennett (2000) examined the effect of climate on hunter-gatherer societies in the southern California coastal region. The study tests the hypothesis that the cultural complexity of the aboriginal groups changed rapidly around A.D. 1300 due to changing climatic conditions (Kennett and Kennett 2000:379). Archaeological evidence shows that at this time, the aboriginal groups of southern California subsisted less on maritime resources than at other times (Kennett and Kennett 2000: 389). Although Kennett and Kennett (2000) were not addressing the Little Ice Age specifically, the time frame of this study corresponds with what some believe as the earliest dates of the Little Ice Age. Kennett and Kennett (2000: 391) concluded that good evidence exists to support the conclusion that a climate change in the past affected resource availability and cultural complexity was changed as a result.

Another study in southern California by Koerper et al. (1985) investigates a region similar to Kennett and Kennett's (2000), within the Little Ice Age time period (A.D. 1400-1850). Koerper et al. (1985) conclude that the Little Ice Age, although impacting the resources of the area, had a limited influence on the aboriginal cultures. Koerper et al. (1985:102) suggest that the "broad base of subsistence resources and hunter-gatherer adaptive strategies" lessened the impact of the climatic change.

A contrasting study to those discussed above is seen in Lensink's (1993) investigation of the Mill Creek culture in Iowa. Previous studies of the area, most using broad climatic models, determined that a climatic episode around A.D. 1200 decreased precipitation (Lensink 1993:195). As a result, agricultural productivity decreased and a cultural adaptation of increased ungulate (bison and deer) procurement occurred (Lensink 1993:195). Lensink (1993:192) reinvestigated the paleoclimatic data (in the pollen record) for the Mill Creek area and determined that no apparent change in climate occurred around A.D. 1200. Lensink (1993:189) argues that the climate models used by previous researchers of the Mill Creek culture fail to account for all the variables, such as regional climatic differences. Lensink (1993:189) concludes that the changes seen in the archaeological evidence of the Mill Creek culture sites circa. A.D. 1200 are due to resource depletion and a shift to distant big game hunting, as explained by a central-place foraging model.

Fawcett (1987) investigated communal bison hunting on the Great Plains, in part, as a possible outcome of climatic change. Examining several types of evidence, Fawcett (1987:154) determined that "all evidence indicates that communal drives were successfully organized and executed without regard to bison conditions." He also concluded that "the frequency of communal hunts is not simply a response to changes in the physical environment. The peaks in kills transcend short term variation in climatic and grazing conditions" (Fawcett 1987:210). Fawcett (1987:210) suggests that communal hunts "served to mediate a number of socio-political tensions . . . Some hunts were probably organized to either obtain bison products for redistribution or to feed large numbers of people at redistributions. Others were acts of resistance and defiance to leaders and groups."

Another recent investigation that partly incorporates the Great Plains does not consider climatic effects at all. Martin and Szuter (1997) evaluated Lewis and Clark's journals to determine that hunting strategies of the Native Americans changed considerably due to human influences rather than climate. Martin and Szuter (1997) contend that enormous populations of bison existed in some areas for two reasons. First, the decrease of the Native American population from diseases introduced by Euro-Americans, and second, inter-tribal warfare, what Martin and Szuter (1997:38) call the "war zone" phenomenon. Territorial boundaries between warring tribes would theoretically offer a safe haven for herds of bison.

CHAPTER VI

METHODOLOGY

Varve Data

The Vore Site varve data being used in this study was collected by Charles Reher during the excavations at the Vore Site in the early 1970's. Measurements of the laminae were taken with calipers (to the nearest millimeter) on three vertical columns in the wall of one unit, and additional documentation was conducted with photographs and drawings of the profiles (drawn to scale) (Reher, personal communication 2003). The data from the three columns were averaged together, and this along with the actual profiles and associated notes, constitutes the final data set used in this investigation (Appendix I -Vore site varve measurements).

One potential problem in the varve data, as pointed out by Reher and Frison (1980:55), is that there were a number of couplets associated with the cultural levels which contained extra sediments and organic materials. These extra materials are obviously from the disturbance of the vegetation and soils on the sides of the sinkhole during the bison jump episode. According to Reher and Frison (1980:55), these "bone varves" around the cultural levels seemed to obscure the seasonal lamination, but it was initially determined that these did not significantly change the varve formation otherwise. In the cross-dating analysis presented here, data sets including and excluding the bone varves were used to determine the influence of the bison jumping episode on the formation of the varves.

Dendrochronological Data

Several tree-ring stations have been established in the Black Hills region over the last few decades (Table 3) and the data is held within the International Tree Ring Databank (ITRDB).

The data is accessible and freely available from the National Oceanic and Atmospheric Association (NOAA) Paleoclimatology Home Page at (www.ngdc.noaa.gov). Although established tree-ring chronologies were emphasized in this research, there are only a few chronologies that overlap with the initial dates of the Vore Site varves (A.D. 1500-1640). As Table 3 shows, only the Pilger Mountain Lookout (SD-1), Buckhorn Mountain (SD-2) and Reno Gulch (SD-17) chronologies incorporate all or part of the proposed varve chronology. The Eagle Nest Canyon (SD-8) and Pilger Mountain (SD-16) chronologies were also kept with the comparative data sets, just in case the varve sequence was determined to be more recent.

Tree-Ring Station	**Location**	**Tree species**	**Elevation (m)/(ft)**	**Chronology (A.D.)**	**Distance to Vore Site (km/miles)**
SD-1:Pilger Mtn. Lookout, SD[1]	43°28' N 103°54'W	Ponderosa Pine	1402/4600	1520-1964	121/74.9
SD-2:Buckhorn Mountain, SD[3]	43°47' N 103°36'W	Ponderosa Pine	1768/5800	1600-1991	94.7/58.8
SD-3:Blair, SD[2]	44°20' N 103°26'W	Burr Oak	1097/3600	1753-1990	61.7/38.3
SD-6:Crystal Cave, SD[2]	43°57' N 103°18'W	Burr Oak	1230/4035	1833-1990	94.4/58.6
SD-7:Custer State Park, SD[2]	43°45' N 103°23'W	Burr Oak	1340/4396	1775-1990	107/66.4
SD-8:Eagle Nest Canyon, SD[2]	45°21' N 103°08'W	Ponderosa Pine	1090/3576	1651-1990	121/75.3
SD-9:Frawley Dairy Farm, SD[2]	44°28' N 103°40'W	Burr Oak	1130/3707	1807-1990	39.7/24.6
SD-10:Frawley Oak, SD[2]	44°29' N 103°41'W	Burr Oak	1230/4035	1892-1990	38/23.6
SD-12:Grace Coolidge Pine, SD[2]	43°45' N 103°21'W	Ponderosa Pine	1234/4049	1703-1990	109/67.4
SD-13:Hankins Group, SD[2]	44°20' N 103°41'W	Burr Oak	1520/4987	1875-1990	43.8/27.2
SD-16:Pilger Mountain, SD[3]	43°30' N 103°53'W	Ponderosa Pine	1392/4567	1646-1991	117/72.8
SD-17:Reno Gulch, SD[3]	43°54' N 103°36'W	Ponderosa Pine	1658/5440	1281-1991	83.5/51.9
SD-18:Rockerville, SD[2]	43°56' N 103°22'W	Burr Oak	1370/4495	1717-1990	92/57.1
SD-19:Thompson, SD[2]	44°35' N 104°00'W	Burr Oak	1036/3399	1747-1990	13.5/8.4
Vore Site[4]	44°32' N 104°09'W	**varves**	1180/3871	~1500-1640	----------

Table 3 - ITRDB tree-ring stations in and around the Black Hills area and Vore Site. ([1] Fritts 1964; [2]Meko and Sieg 1990; [3]Meko and Sieg 1991, [4]Reher and Frison 1980)

Closer inspection of the tree-ring stations reveal that all but The Eagle Nest Canyon (SD-8) chronology are higher elevation sites when compared to the Vore Site. This is potentially problematic since tree-ring properties are known to change with elevation due to the climatic influences of elevation on the growth of trees (Fritts et al. 1965; Schweingruber 1988; Splechtna et al. 2000). Schweingruber (1988:138) suggests that attempts should be made to only compare chronologies that are uniformly from comparable elevations. However, he also states that the response functions of individual trees of differing elevations are similar in years of extreme climatic conditions (Schweingruber 1988:138). Therefore, it is presumed that the tree-ring station data will be useful for cross-dating purposes, since extreme conditions (especially drought) are considered important for dendrochronological cross-dating (Schweingruber 1988:48). The five ITRDB chronologies constituted the primary cross-dating data for comparison with the varves (Figure 8), however supplemental data was also sought (See Appendix II for detailed tree-ring station information).

To augment the cross-dating data, individual tree chronologies were produced from existing Black Hills dendrochronology samples at the University of Wyoming Archaeology Laboratory. Two large, cross-sectioned Ponderosa pine (*Pinus ponderosa*) samples from Herbert Draw, South Dakota and Moskee, Wyoming were acquired by Reher in years past (refer to Figure 8). The higher elevation Herbert Draw sample had been previously measured with a glass micrometer (to the nearest .1 inch) and its chronology extends back to the A.D.1500's, which would place it within the proposed varve chronology. Although previously measured, a cross-dating analysis was considered necessary to confirm the chronology of the Herbert Draw sample. The Moskee sample from a lower elevation area had never been measured and required full

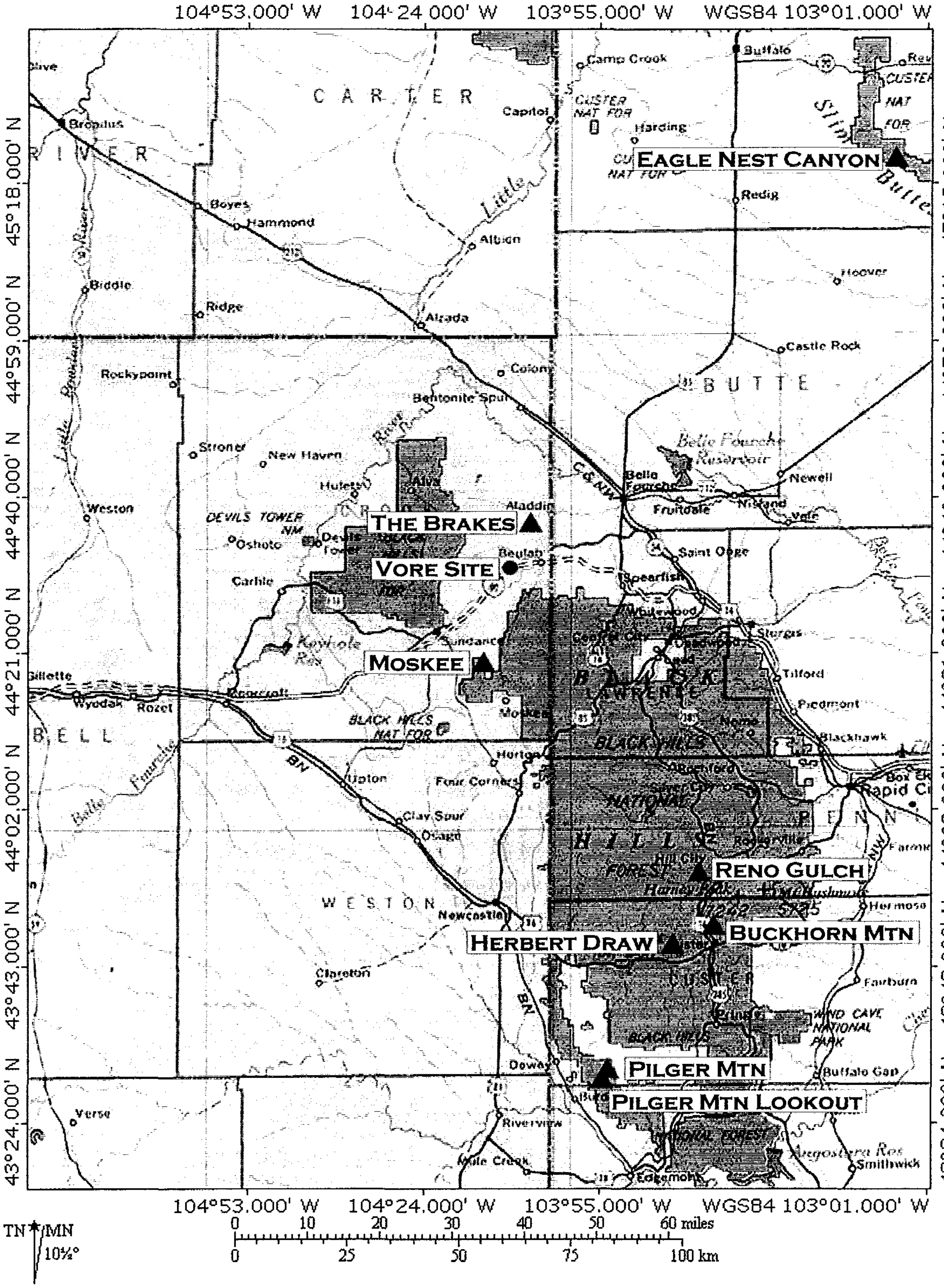


Figure 8 - Location of ITRDB tree ring stations, Vore Site, and dendrochronological samples used in this research.

analysis.

To further augment the comparative data, an attempt was made to acquire new samples from the northern Black Hills with a few field outings. The Brakes area of the northern Black Hills was chosen for its accessibility, since my family owns a ranch there, as well as its proximity to the Vore site (approximately 7.5km/5 miles) (refer to Figure 8). The Brakes, despite the unusual spelling, are a portion of the pine-covered, Hogback Rim immediately north of the Red Valley. Ponderosa Pine (*Pinus ponderosa*) is the dominant tree species in The Brakes area, although burr oak (*Quercus macrocarpa*) and Rocky Mountain juniper *(Juniperus scopulorum*) are also available. Field sampling in this investigation was limited to pine, since the junipers were relatively sparse and as determined by Sieg et al. (1996:301), oak chronologies in the region are rarely older than A. D. 1800. Table 4 lists basic details of the dendrochronology samples.

Tree Sample	**Location**	**Tree species**	**Number of samples**	**Elevation (m)/(ft)**	**Distance to Vore Site (km/miles)**
Moskee, WY	44°22' N 104°14'W*	Ponderosa Pine	8	1500*/4921*	12.2*/19.7*
The Brakes, WY	44°36' N 104°08'W	Ponderosa Pine	1	1230/4035	4.7/7.5
Herbert Draw, SD	43°45' N 103°42'W*	Ponderosa Pine	1	1400*/4593*	92*/57*

Table 4 - Dendrochronology samples used in this study. (* estimated)

Field Methods

Standard dendrochronological field techniques were used in the sampling of The Brakes trees (Schweingruber 1988:16-17, 42-43), except that rather than attempting a high "sampling variability" (LaMarche 1982:6), older trees (i.e., larger with flat crowns) were specifically looked for. This strategy was implemented since it was not feasible to establish a full tree-ring station and the intent was to find temporally comparable samples in consideration of the Vore Site varve chronology.

Eight older and possibly more sensitive trees were selected for sampling, seven of which were living (Figure 9). The one dead tree (TB-6) was standing deadfall prior to a forest fire in 1997 when it was cut down during firefighting operations. TB-6 was cross-sectioned with a chainsaw, while the living trees were sampled with an increment corer (5 mm outer diameter - 4 mm core). Two radii from each tree were taken, roughly perpendicular to each other and deep enough to include the center of the tree. However, in three instances, only one radius was taken from a specimen due to the inner pith of these trees being too soft (sometimes known as heart-rot) to allow the increment corer to bore any further into the tree. This suggests that the tree-ring sequence from these trees would be truncated since the center of the tree was not acquired.

The University of Wyoming Anthropology Dendrochronology Laboratory field forms were used to detail such things as the location, dimensions and characteristics of the tree, surrounding vegetation, topography, and soil type (Appendix III - Dendrochronology Field Form). The tree location was marked on a USGS 7.5 minute Quadrangle map (refer to Figure 9) , and photographs were taken of each individual tree. Plastic straws were used to transport the extracted cores and labeled accordingly. Although pine is a resin-rich species and tends to resist disease in core holes or other damaged areas (Schweingruber 1988:44), all holes were plugged with dowels or a small tree branch.

Laboratory Methods

Sample Preparation

The cores were allowed to dry for at least a week, then glued into pre-grooved core

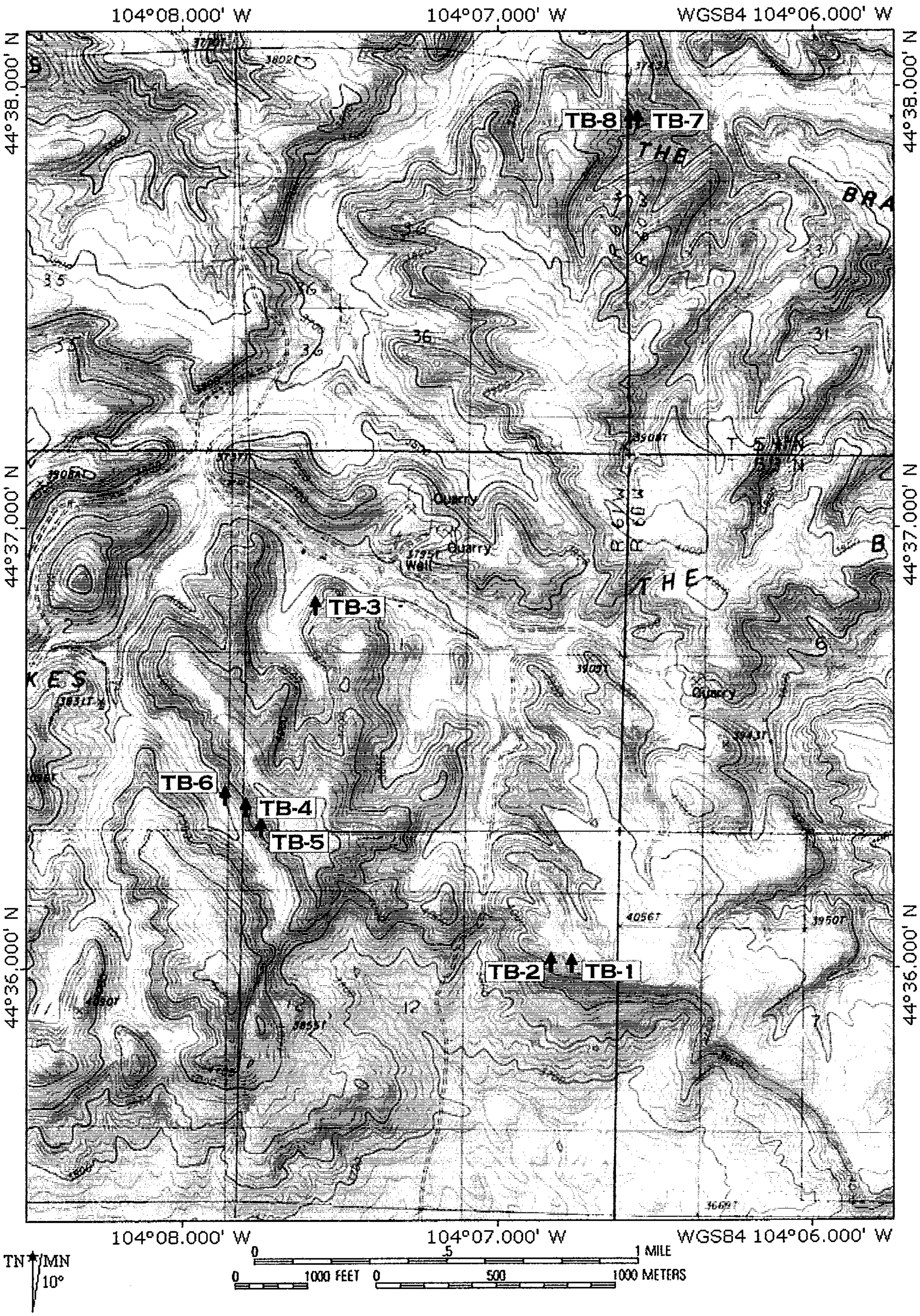


Figure 9 - Topographic map showing locations of The Brakes (TB) dendrochronology samples. (Aladdin, Slaughter Reservoir, Schoomarm Butte, and Beulah Quadrangles)

holders with wood glue. After sufficient drying (at least one day), the cores were first sanded by hand with 150 grit sand paper, then finished with 400 grit. The tree-rings became identifiable and adequately visible for the measuring process after only a little finishing with the finer grain sand paper. Experimentation revealed that the cores became highly polished with too much finishing, which led to a distractive glare in the microscope; making lighter rings harder to distinguish in the measuring process. The one deadfall cross-section (TB-6) was sanded with a palm sander with 40 grit sand paper to start and then finished with 220 grit.

Measurement Technique

The cores and cross-section (TB-6) were measured with a Henson Optical Rotary Encoder located in the Anthropology Department Dendrochronology Laboratory at the University of Wyoming. This measuring device uses a binocular microscope, in order to view a sample on a table which is movable by a rotating spindle. A cross-hair in the binocular lens allows measurement of tree-rings from the extent of early wood to late wood by hitting a trigger interface after every ring. The ring width data, to the nearest one-hundredth of a millimeter, is exported to the computer via serial port interface with an interface device and computer program developed by Reher, Reher, and Rich (1993). The resulting raw measurement (*.rm) file and data (*.dat) file can be used and/or manipulated with the ITRDB program library (DPL) or its suite of programs.

The Moskee sample was measured by drawing two straight line radii with a ruler and using a digital camera mounted on a tripod to take pictures along each radius. It was necessary to take a number of sequential pictures with some overlap in order to obtain all rings. The *.jpg images stored in the camera were downloaded to a computer and the files were opened in

SigmaScan Pro which is a computer measurement program designed for measuring screen images. The presence of a scale in each photograph allowed measurement calibration of the program on each individual image to the nearest millimeter, therefore allowing an approximate measurement quality to within .1 mm.

Measurement Verification

For measurement verification, the radii from each tree were first visually compared to each other using the program ITRVIEW 2.0 (Varem-Sanders 1996). The ITRVIEW 2.0 program allows two plots to be viewed at the same time and gives the user the ability to slide one plot against the other. This sliding correlation used for visual cross-dating (discussed in detail below) also allows for locating of anomalous or erroneous data by optically aligning the graphs and looking for discrepancies. However, it only accepts decadal (horizontal by decade), compact (space saving file) or chronology (complete tree-ring chronology - *.crn) files and not column-wise files. The decadal file is the standard format for all data held by the ITRDB (Grissino-Mayer 1995a), therefore conversion of the column-wise raw data (*.rm) file to a decadal file (*.m) was executed through the program Convert 5 (Grissino-Mayer 1995a) from the ITRDB suite of programs.

In the comparison of data sets, when a questionable tree-ring was found in the raw ring width sequence, its number was marked on the core and visual inspection under the microscope was necessary. Sometimes extra rings were determined to be false rings (rings caused from an early or late frost - Fritts 1976:20-21), while sometimes a ring was missed in measurement. Re-measurement of sections of a core were sometimes necessary until all problems were worked out.

After each radius was verified against the other radius from the same tree, the same process of cross-dating comparison and reexamination was conducted between each tree. Some of the same problems existed as before; missing or extra rings, which can be attributed to technical errors or biological faults caused by different environmental factors (climatological or pathological) affecting different trees (Schweingruber 1988:72). Re-measurement and reworking was conducted until the best fit was achieved for all samples.

Statistical Analysis

Although the visual inspection was emphasized in the verification of measurements in this research, the ITRDB program Verify 5 (Grissino-Mayer 1995b) was also used to check the results and obtain preliminary statistics. The Verify 5 program uses a basic linear regression analysis to compare two raw measurement files and the output gives statistics such as mean width, standard deviation, coefficient of variation, and mean sensitivity to name a few (Grissino-Mayer 1995b). In The Brakes samples, the Verify 5 program was used to compare radii from the same tree to determine basic statistics and verify measurements. In the Moskee and Herbert Draw samples, the individual sample was checked against itself to obtain these basic statistics (Appendix IV).

The mean sensitivity was of interest in this study, as it has long been associated with cross-dating, chronology development, and climatic responsiveness (LaMarche 1982:5). The "sensitivity" of a tree is only a statistical concept whereas a high sensitivity describes a "time series high, relative, year to year differences in ring width" (LaMarche 1982:5). Complacent trees, or those with a low mean sensitivity, do not show much inter-annual difference, are harder to cross-date and are therefore usually selected against in tree-ring sampling strategies. According to Fritts (1976:258), the statistical "values of mean sensitivity range from 0 where there is no difference" in ring widths, "to 2 where a zero value occurs next to a nonzero value in the time sequence." By rule of thumb, a mean sensitivity value around .3 is considered to be adequately significant.

The verified raw data was then converted to standardized indices by using the ARSTAN (Cook and Holmes 1986) program from the ITRDB suite. The ARSTAN program creates chronologies from a set of tree-ring data series by detrending with a negative exponential curve, standardizing each series, and then applying a robust estimation of the mean value to remove endogenous stand disturbances(Cook and Holmes 1986). The primary goal of standardization is to remove non-climatic signals in a tree-ring series that may include either a biological growth trend, tree disturbance signals, or both (Graybill 1982:22). Tree disturbance signals include unique events affecting an individual tree or widespread events affecting numerous trees such as fire or insect damage (Graybill 1982:21).

Skeleton Plotting

The method of skeleton plotting can simply be defined as "a graphic representation of those rings considered important in cross-dating" (Cook and Kairiukstis 1990:43). Generally, dendrochronology is concerned with the narrowest rings in a sequence, where a single particularly dry year is considered to be "pointer" year, and a grouping of notably dry years are called "signature" years (Schweingruber 1988:49). The skeleton plot is an "outline" or the "skeleton" of a tree-ring sequence, such that only the narrowest rings of individual samples are graphed for comparison (Schweingruber 1988:49) (See Results section for an example).

Historically, skeleton plotting was a subjective technique where individual rings in a tree-ring sequence were visually compared to adjacent rings in order to specify the locations of the narrowest rings (Stokes and Smiley 1968:47). With the advancement of computer technology over the past few decades, skeleton plotting has become less subjective and more efficient. Cropper (1979) established a computer-based skeleton plotting technique to aid in cross-dating that allows for a computer program to determine the narrowest rings in a tree-ring series and plot the results. Cropper's technique (1979) calculates running means (5 years) and subtracts .5 to .75 standard deviations below the mean to compute and plot only the narrowest rings in a series.

Similar to Cropper's methods (1979), I developed a formula for Microsoft Excel to calculate the narrowest rings of the standardized tree-ring series for graphing in a skeleton plot. However, rather than using a running mean for segments of each series, the mean for the entire series was used, with the expectation that this would adequately determine the driest years (narrowest rings) which would be sufficient for cross-dating.

The formula calculates the mean ($\bar{x}$) of the series and then subtracts either one or two standard deviations (σ) below the mean, allocating a zero (in a specified column) if the indice is equal to or greater than $\bar{x} - \sigma$, a one if the indice is less than $\bar{x} - \sigma$ and greater than $\bar{x} - 2\sigma$, and a 3 if the indice is equal to or less than $\bar{x} - 2\sigma$. Bivariate bar charts were created from the resulting data to simulate skeleton plotting.

Bivariate Graph Cross-Dating

Visual correlation with bivariate graphs was also utilized to help support the results of the skeleton plotting cross-dating. The ITRVIEW 2.0 program was employed for this purpose. The ITRVIEW 2.0 program buffer allows for 10 files, which can contain up to 1000 samples of a maximum 8000 years each (Varem-Sanders 1996:1). It also gives preliminary correlation coefficients based on the visible range of data on the screen and the degree to which the two data sets overlap (Varem-Sanders 1996:1). According to Fritts (1976:257), the correlation coefficient between two data sets can range from "an upper value of +1, which indicates perfect and direct agreement, to a value of -1, which indicates perfect and inverse agreement."

In the ITRVIEW 2.0 interface, three coefficients are calculated and displayed at the bottom of the screen. The coefficient in the middle is a comparison of the graphs year for year, the left coefficient is the result if the bottom graph is shifted left one year, and the right coefficient is the result if the bottom graph is shifted right one year. The program developer (Varem-Sanders 1996:1) cautions that these statistics are "ad hoc" and do not replace "a vigorous statistical analysis," but does offer a preliminary comparative analysis of numerous data sets.

The varve raw data series was plotted on the upper graph and each tree-ring station indices and individual sample indices were plotted on the lower graph. One graph window is always active while the other remains stationary. For purposes here, the plot of varve data remained stationary, while the other series graphs were scrolled through for comparative purposes.

CHAPTER VII

RESULTS

Dendrochronology Samples

The skeleton plotting cross-dating of the dendrochronology samples worked to a limited extent (Figure 10). Cross-dating of The Brakes samples was not as necessary since live trees were sampled which gave the samples a confirmed ending date of 2001. However, a skeleton plot was created of The Brakes series to see how well the skeleton plotting technique would work. As seen in Figure 10, The Brakes samples fit well into the Pilger Mtn. Lookout (SD-1) and Buckhorn Mountain (SD-2) chronologies with signature years in the 1650's, 1710's, 1730's and 1760's, to name a few. The Brakes samples have a mean sensitivity of .307 and date from A.D.1617-2001 (Table 5 - Also refer to Appendix IV for listings of other basic statistics).

Conversely, the Moskee, and Herbert Draw skeleton plots do not align well with the other tree-ring chronologies. The Moskee series has a possible fit with some narrow rings around the 1930's, but not many matching rings elsewhere. Likewise, the Herbert Draw sample overall does not have many matching narrow rings when compared to the other tree-ring series. This is possibly due to the level of sensitivity of the trees or other individual growth factors (refer to Table 5).

To cross-date the Moskee and Herbert Draw samples, the ITRVIEW 2.0 program was used to compare the tree-ring series with the ITRDB station series. As discussed earlier, this program will enable the user to define a time interval for comparison and the program will calculate a correlation coefficient for the visible interval. As Figure 11 shows, The Brakes series (A.D. 1617-2001) has a high correlation coefficient of .34076 (p = .001, Thomas 1986:508) when

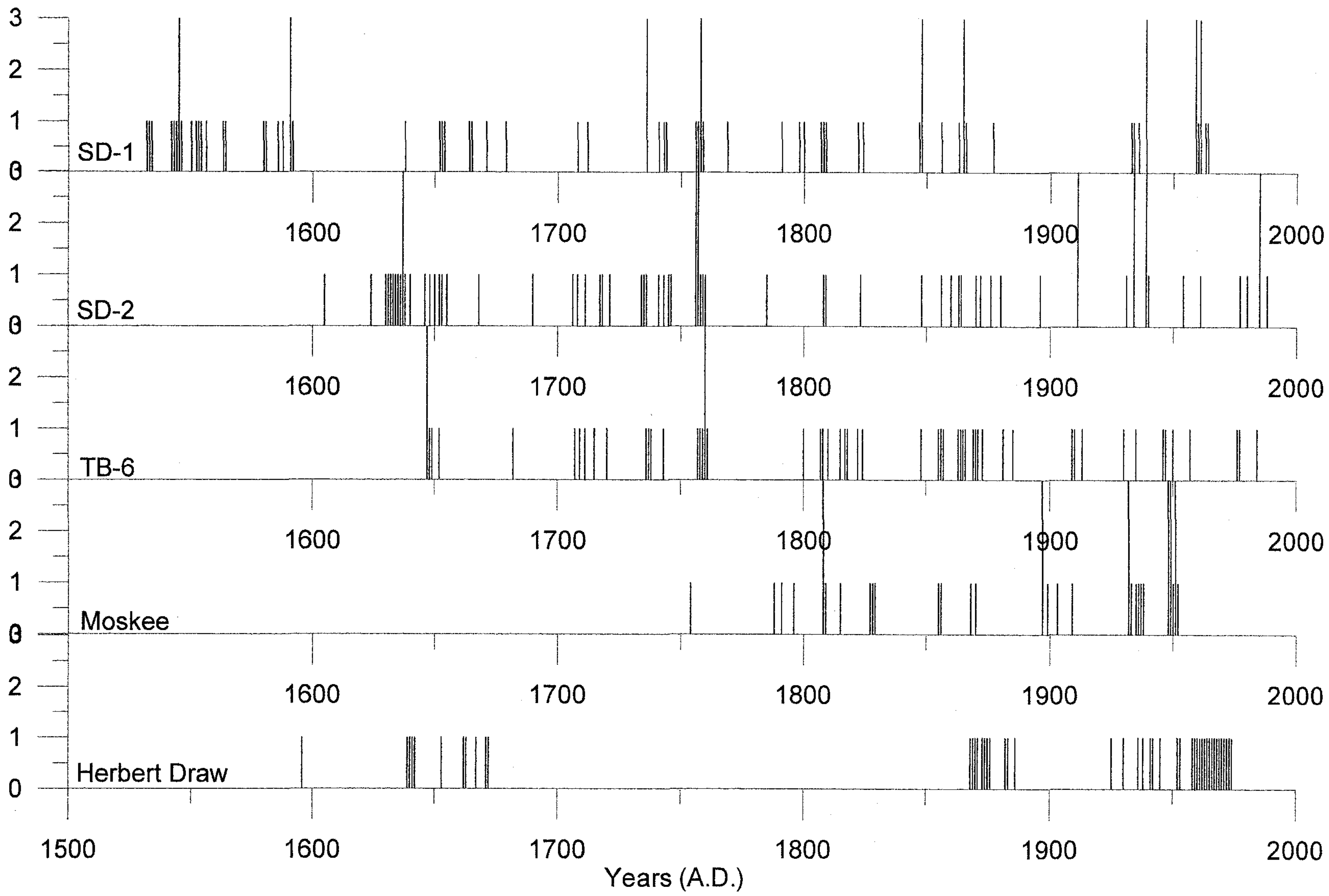
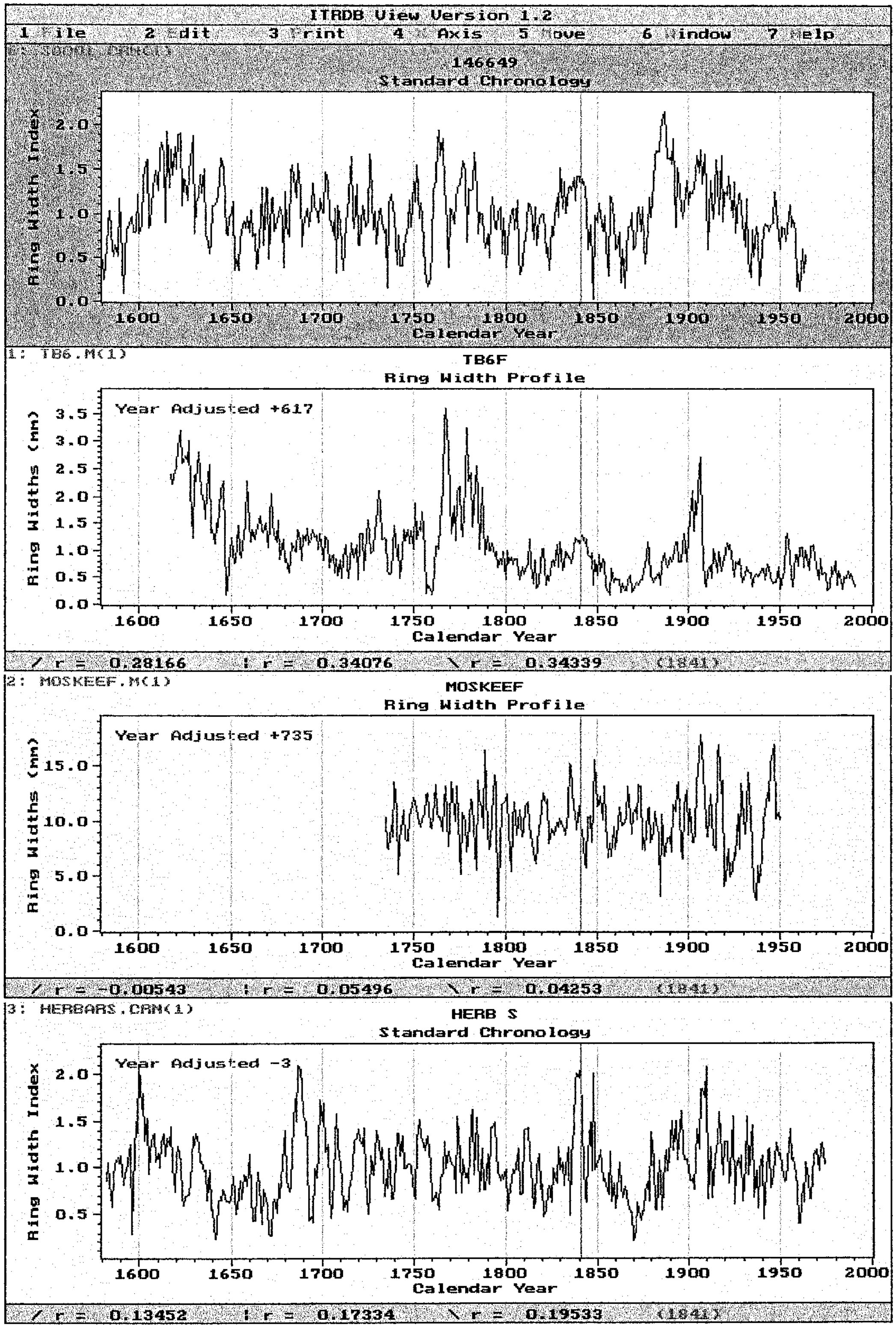


Figure 10 - Skeleton plots of TB-6, Moskee, and Herbert Draw dendrochronological samples cross-dated with SD-1 and SD-2.



```
/ r =  0.28166    ! r =  0.34076    \ r =  0.34339    (1841)
```

```
/ r = -0.00543    ! r =  0.05496    \ r =  0.04253    (1841)
```

```
/ r =  0.13452    ! r =  0.17334    \ r =  0.19533    (1841)
```

Figure 11 - Bivariate plot comparisons of TB-6, Moskee, and Herbert Draw dendrochronological samples (raw ring widths) and tree ring chronology, SD-1 (A.D. 1600-2000).

compared to the Pilger Mtn. Lookout (SD-1) series. The highest correlations for the Moskee and Herbert Draw samples in comparison to SD-1, were determined to be with the Moskee series set to A.D. 1735-1950, and the Herbert Draw sample set to A.D. 1582-1974. These dates were also compared to the Buckhorn Mtn. (SD-2) chronology with the results listed in Table 5. The correlation coefficients were much lower, but for the most part still statistically significant.

Samples	**Years (A.D.)**	**Species**	**Mean Sensitivity**	**r value (SD-1)/p**	**r value (SD-2)/p**
The Brakes	1617-2001	Pond. Pine	.307	.34076/.001	.14821/.01
Moskee	1735-1950	Pond. Pine	.235	.05496/.1	.14626/.05
Herbert Draw	1582-1974	Pond. Pine	.264	.17334/.01	.17055/.01

Table 5 - Final chronology and mean sensitivity of dendrochronology samples, with correlation coefficients (r) and significance probabilities (p) for cross-dating comparison with Pilger Mtn. Lookout (SD-1) and Buckhorn Mtn. (SD-2) tree-ring chronologies.

Vore Site Varve Dates

The Vore Site varve sequence was not easily cross-dated with the skeleton plots (Figure 12). No discernible pattern to the data was observed in either varve data set, other than a few matching narrow rings here and there. The best fit was achieved with the varve origination date set at A.D. 1518, although it was not a strong visual correlation. Adding to the clutter, the published tree-ring indices only match each other in a few areas such as the signature years near A.D. 1520 and A.D. 1760.

The question arose as to the continuity of the varve sequence, although one would suspect that a distinct division in the varve sequences would be visible if there were years that the pond did not hold water. Visual inspection of the original varve illustrations and notes (Reher 1972) suggested that gaps in the series could be possible around bone varves of the first and third

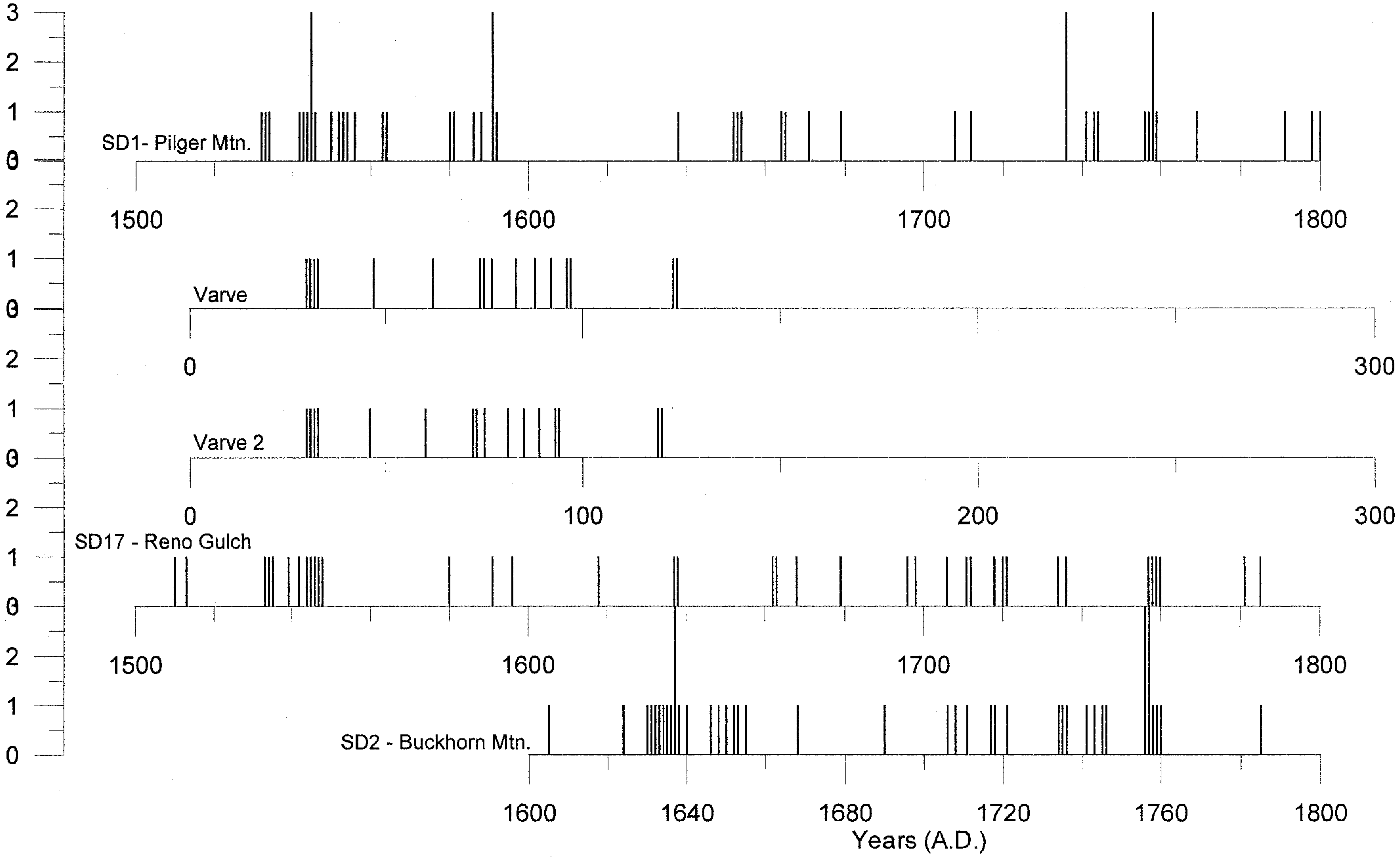
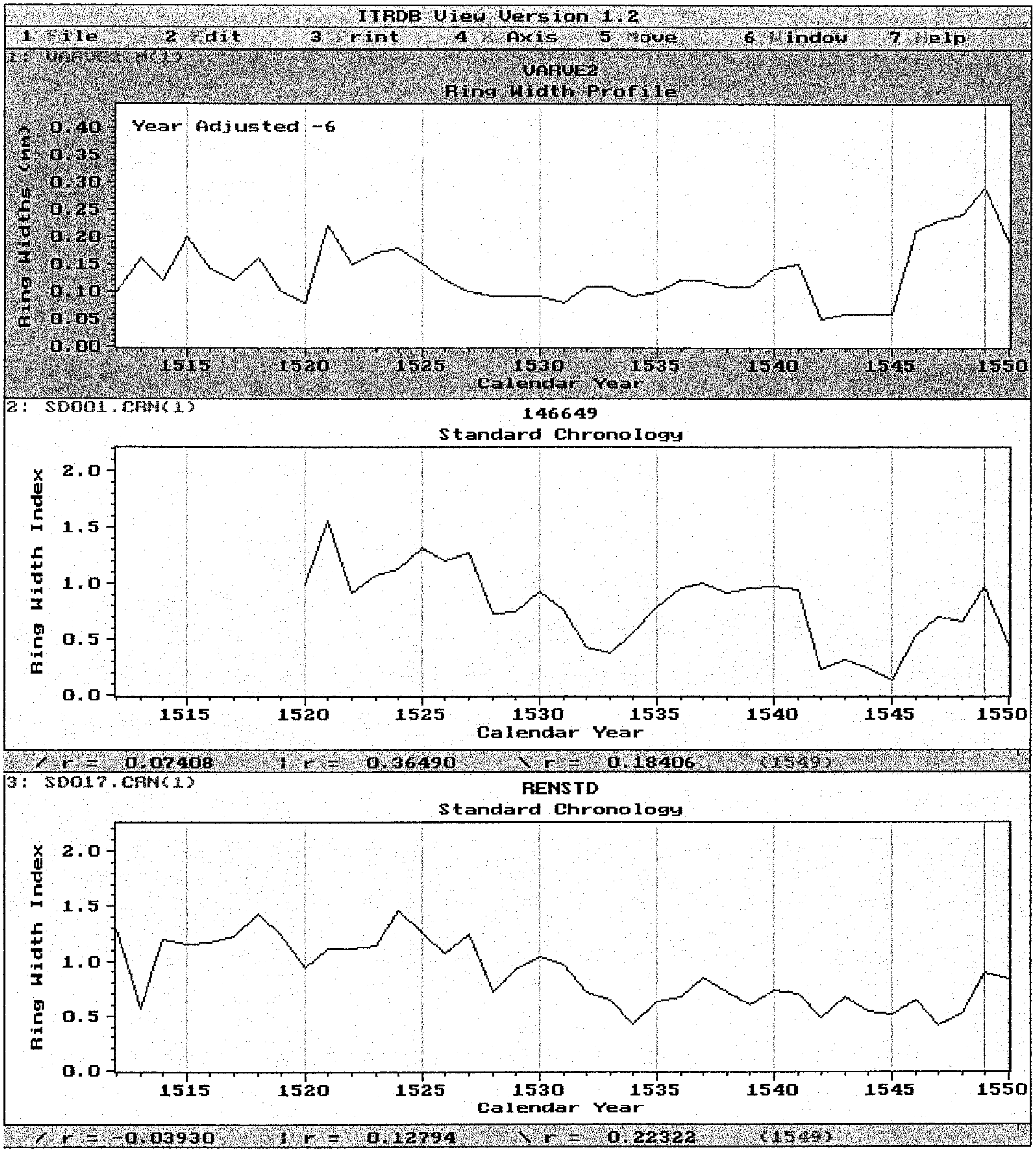


Figure 12 - Initial skeleton plot results for Vore Site varve cross-dating. (A.D. 1500-1800)
Varve = with bone varves, Varve2 = without bone varves

cultural levels. Specifically, directly above bone varve 1, a band of silty deposit (totaling 11 millimeters) was not included in the original varve measurements. Likewise, directly above bone varve 3, another band of silty deposit (totaling 17 millimeters) was not included in the original varve measurements (Reher 1972).

In consideration of these findings, it was decided to use the Varve2 (without bone varves) data set to test the continuity of the varve sequence with the presumption that each bone varve represents some mixing of surrounding laminae. To test the hypothesis that the varve sequence was discontinuous, the ITRVIEW 2 program was used to compare segments of the varve chronology to the tree-ring sequences. The varve series was plotted as the stationary graph on the top and the tree-ring series were scrolled along the bottom.

Starting with the SD1 chronology (A.D. 1520-1990), the visible graph interval was defined arbitrarily at A.D. 1520 -1500 with the assumption that the varve origination dates (first five years of the 1500's) proposed by Reher and Frison (1980) and skeleton plot results from this research were reasonably accurate. The varve sequences were adjusted left or right to receive the highest positive correlation (as discussed above in Methodology-Bivariate graph cross-dating). When the highest positive correlation was achieved, the time interval was increased, one more year to the left and/or right until the correlation coefficient declined. Trial and error demonstrated that the interval of A.D. 1512-1550 had a high correlation coefficient ($r = .36490$, $p = .02$) between the SD-1 and varve series (Figure 13). Furthermore, the visual similarities of the series are very distinctive. The only other tree-ring sequence of adequate age was SD-17, which was not as similar, but did have a positive correlation ($r = .12794$, $p >.1$) (refer to Figure 13).



/ r = 0.07408 : r = 0.36490 \ r = 0.18406 (1549)

/ r = -0.03930 : r = 0.12794 \ r = 0.22322 (1549)

Figure 13 - Bivariate plot comparisons of varve series and tree ring chronologies, SD-1 and SD-17 (A.D. 1512-1550).

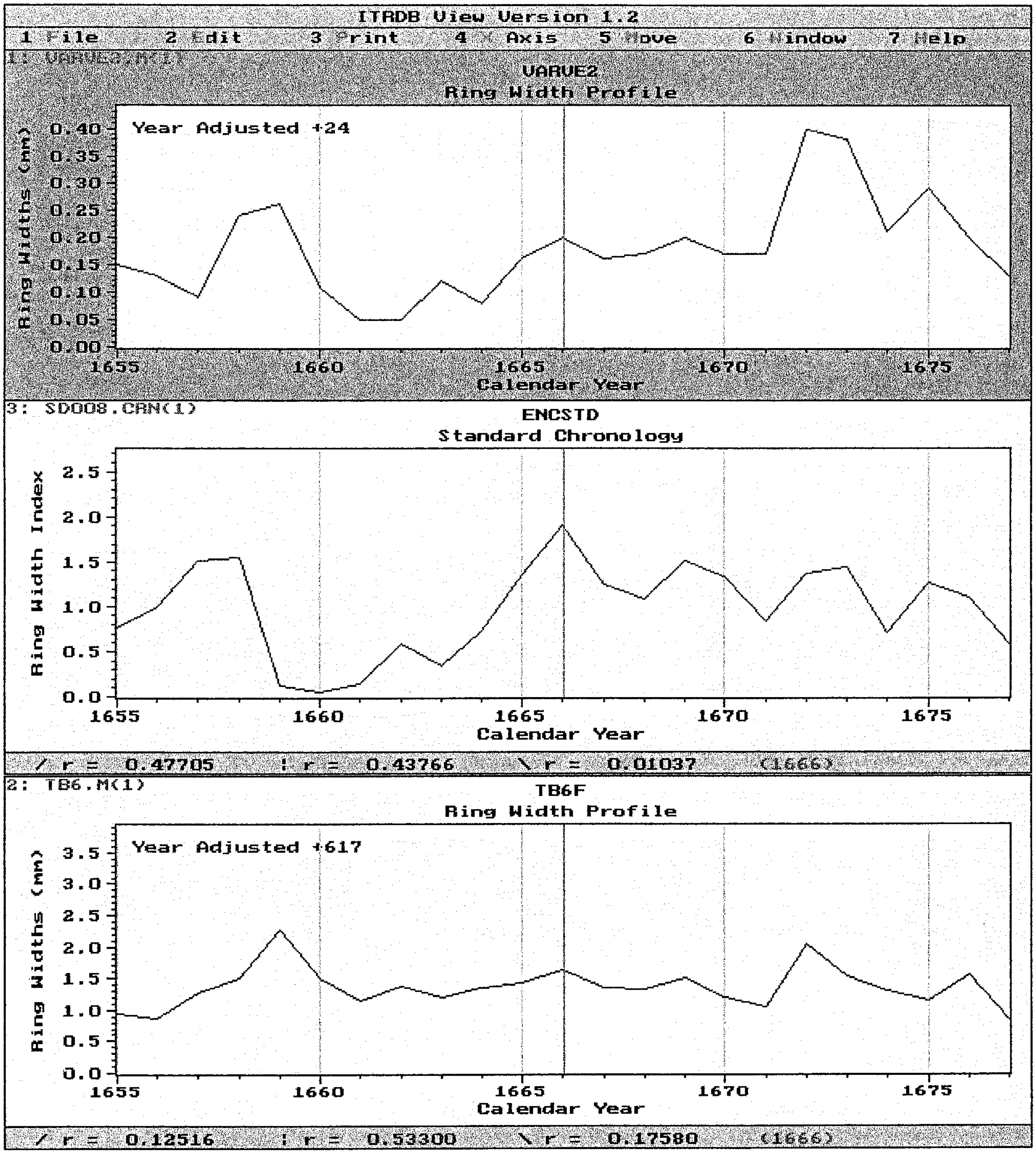
The period after A.D. 1550 did not correlate well between the varve sequences, SD-1 or SD-17. Using the premise that dating of the first interval was correct, data from that interval (<A.D. 1551) was not compared to any other series. Establishing the varve origination date at A.D. 1512, dictates A.D. 1551 to be the first year when the varve sequence ceases resembling the tree-ring series, which is coincidentally within a few years of the first bone varve.

Further graph comparisons of the varve series and dendroclimatic data revealed positive visual and statistical correlations between the intervals of A.D. 1568 -1591, 1596-1638, and 1638-1663 (Table 6, Appendix V - Cross-dating graphs).

	Interval (Years A.D.)				
	1512-1550	1568-1591	1596-1638	1642-1663	1655-1677*
SD-1: Pilger Mtn.	r=.36490/p=.05	r=.44714/p=.04	r=.22915/p>.1	r=.06767/p>.1	r=.39775/p=.06
SD-17: Reno Gulch	r=.12794/p>.01	r=.51520/p=.02	r=.26484/p=.1	r=.12022/p>.1	r=.56992/p=.01
SD-2: Buckhorn Mtn.	-------------	-------------	r=.09117/p>.1	r=.20210/p>.1	r=.33395/p=.1
SD-16:Pilger Mtn. Lookout	-------------	-------------	-------------	r=.25221/p>.1	r=.21822/p>.1
Herbert Draw	-------------	-------------	r=.06150/p>.1	r=.12308/p>.1	r=.06331/p>.1
SD-8: Eagle Nest Canyon	-------------	-------------	-------------	r=.03546/p>.1	r=.43776/p=.04
The Brakes	-------------	-------------	-------------	r=.51795/p=.01	r=.53300/p=.01

Table 6 - Correlation coefficients (r) and statistical probabilities (p) of compared intervals (years A.D.) for the Vore Site varve series and Black Hills area tree-ring series. (p>.1 = not statistically significant) - * optional dating of last varve interval

Although the intervals are positively correlated with one another throughout these results, some are not statistically significant (p>.1). Likewise, some intervals are positively correlated with many different periods. These results are similar to those determined by Reher and Frison (1980:55) in that "similar periodicities in the samples can result in statistically significant correlations not reflective of the true date, as the samples slide 'in phase' at several points." For example, in the last varve interval, one other possibility occurs with the interval set to A.D. 1655-1677 (Figure 14). The very strong visual and statistical correlations would suggest that there are 3 gaps totaling 28 missing years in the varve sequence from the origination date of A.D. 1512 and an ending date of A.D. 1674 (refer to Table 6). However, this cannot be substantiated at this time. The final proposed varve series would date the first five bison kill events at the Vore Site to: A.D. 1553-1562; A.D. 1572; A.D. 1608; A.D. 1637-1642; and A.D. 1663. Figures 15, and 16 show the final suggested solution for the varve series with comparison against SD-1 and The Brakes tree-ring series.



```
/ r = 0.47705     ! r = 0.43766     \ r = 0.01037     (1666)
```

```
/ r = 0.12516     ! r = 0.53300     \ r = 0.17580     (1666)
```

Figure 14 - Bivariate plot comparisons of varve series and lower elevation tree ring chronologies, SD-8 and TB-6 (A.D. 1655-1677).

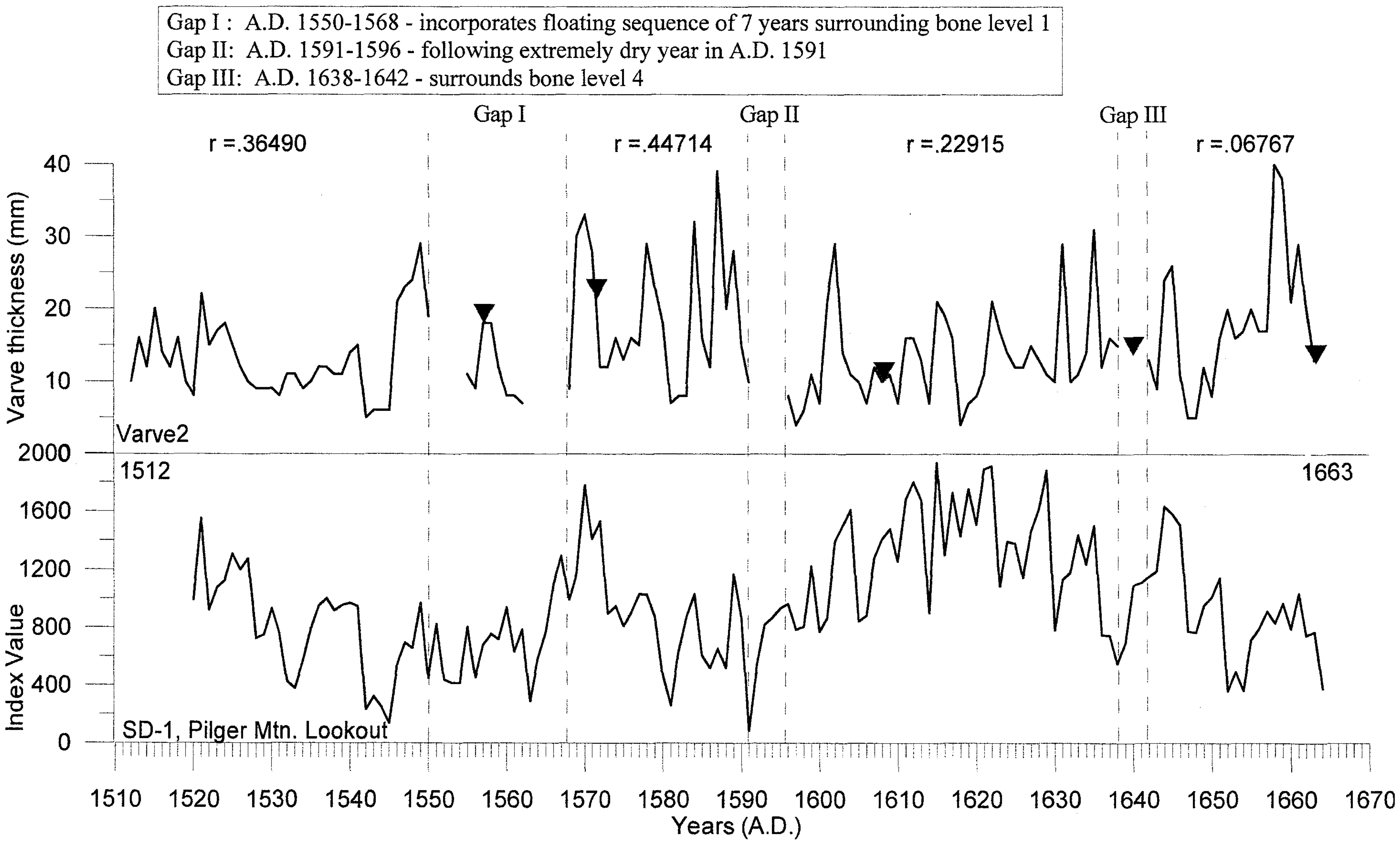


Figure 15 - Line graph comparisons of proposed varve series and SD-1 tree ring series. (r = correlation coefficient for given interval of years, ▼= Bone level)

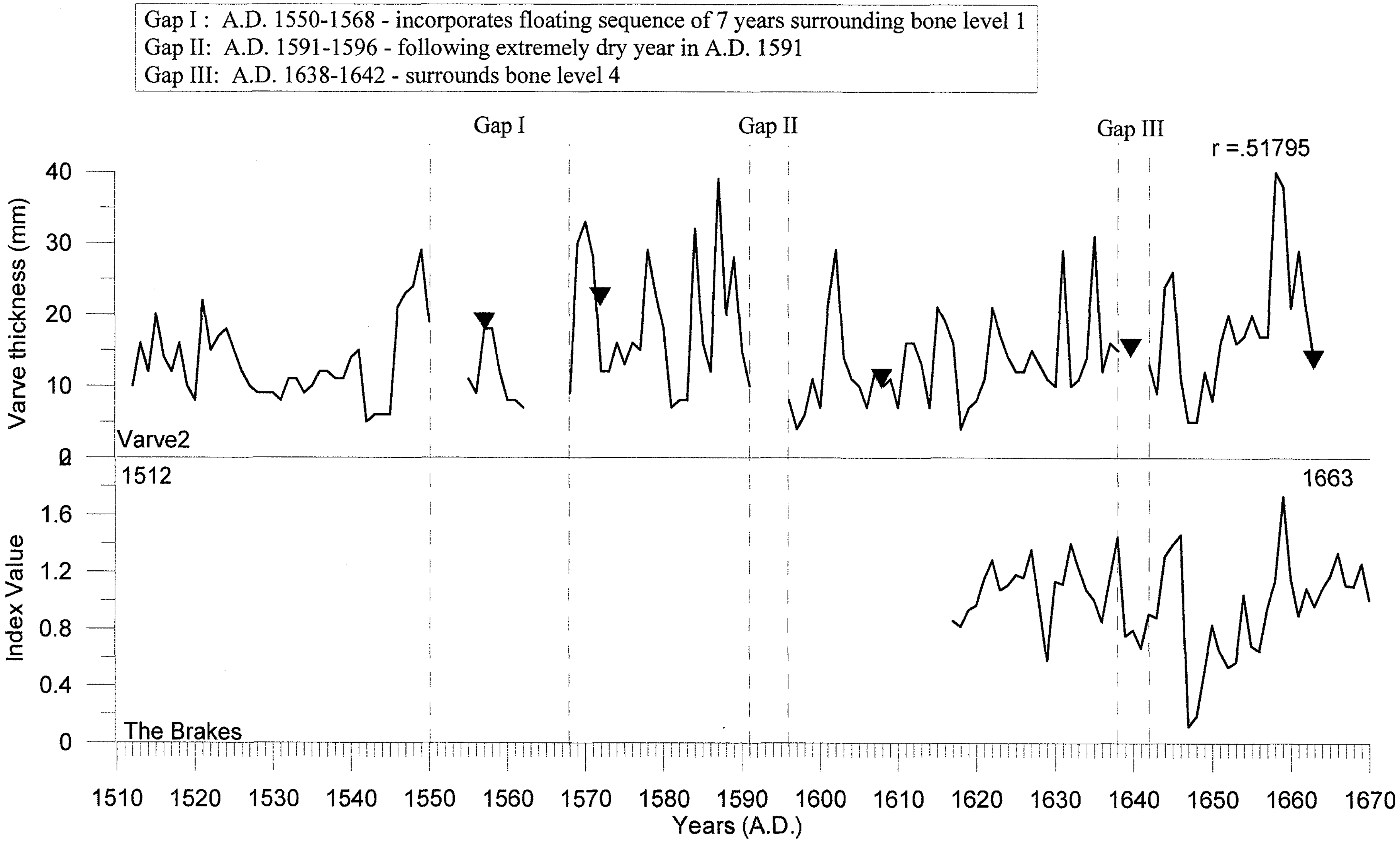


Figure 16 - Line graph comparisons of proposed varve series and The Brakes tree ring series. (r = correlation coefficient for given interval of years, ▼= Bone level)

CHAPTER VIII

DISCUSSION

The Vore Site Varves

The results of the Vore Site varve cross-dating have refined the varve origination dates proposed by Reher and Frison (1980) by approximately 10 years (Table 7).

	Varve origination date	Cultural level I	Cultural level II	Cultural level III	Cultural level IV	Cultural level V
Reher and Frison (1980)	1500-1505	1540-1545	1551-1556	1585-1590	1615-1620	1640-1645
Crago (2003)	1512	1553-1558	1572	1608	1637-1642	1663

Table 7 - Summary table of original and refined Vore site varve origination and cultural level dates (Years A.D.).

The varves were initially determined to have started in the first five years of the 1500's (Reher and Frison 1980:56) and it is suggested here that the origination date of the varve sequence is A.D. 1512. As shown in Table 7, the cultural levels would also be refined by the new dating scheme. The spacing of the first five kill events ranges from 14 to 41 years with a possible 20 or 40 year range (accounting for the range of cultural levels 2 and 4).

Knowing the year or years that an archaeological site was used is a resolution rarely obtained in archaeological investigations. As noted by Thomas (1989: 313), absolute dating techniques, by themselves, do not tell us anything about cultural activities. Arguments of cultural relevance can only be defended if the dated material is associated with human behavioral activities (Thomas 1989:312). The dating of the bison kill events at the Vore site have important implications in regard to ethnic association of individual kills, regional patterns of population movement, and association of ethnic groups within the region to name a few. Furthermore, the intervals between kills suggest that a bison jumping episode could occur only once or twice in a person's lifetime, which has implications for determining reuse of the site by individual ethnic groups. As stated by Reher and Frison (1980:4), "If we are to approach the archaeological study of early Plains Indian culture, the Vore site has to be one of the most significant sites yet discovered."

The results of the cross-dating have also shown that the sedimentary processes that created the laminae, are not easily defined. Strong visual and statistical correlations at the beginning of the varve series (A.D. 1512-1550) show that the annual laminations faithfully recorded the annual change in precipitation until the first kill episode. After that the varve series correlate less well with the numerous tree-ring series, however, some intervals did positively correlate, revealing gaps in the varve series.

The first gap occurs near the first bone varve suggesting that the disturbance of the sinkhole during the first kill episode disturbed the previous laminae, as well as the varve formation for a short time afterwards. Likewise, it seems that the fourth kill episode also disturbed the varves creating a gap of 3 years. The second kill episode, however, did not seem to change varve formation (refer to Figures 15, and 16).

The third kill episode may or may not have changed varve formation, since positive correlations were produced with and without a gap in place of the extra sediment located there. As discussed earlier, the highest correlations for the intervals following bone level 3 are found with the last 22 years of the varve series set at A.D. 1655-1677, which would require 28 total missing years (in three gaps) for the varve sequence. This could only be possible if the sedimentary processes at the site ceased for extended periods of time, since there is not enough sediment deposit to account for that many missing years.

Considering that the bison kill episodes possibly occurred from different sides of the sink hole, it is suggested that the dynamics of each episode and the location of the remaining bone beds could possibly change varve formation in different ways. The varve measurements used in this research were taken in the limited excavation area of the site and the number and placement of bison remains within the site obviously changed from kill episode to kill episode. Site activities directly located in the area where the measurements were taken would significantly change varve formation, whereas activities on the other side of the sinkhole would not. Furthermore, it is possible that with each successive bison kill, the microtopography of the sink bottom could have changed, thereby changing the varve formation processes.

It is also suggested that extreme drought could effectively change the varve formation processes. The second proposed gap in the varve sequence occurs at A.D. 1591 which is one of the driest years evident in the tree-ring series of all of the Black Hills area chronologies used in this study. Considering that the previous and following years were also very dry, it is possible that the varves did not form at all during this time.

Dendroclimatic Analysis of an Elevation Gradient

The northern Black Hills vary in elevation over 3000 feet (910 meters) from the outer base of the Hogback to the Central hills (Figure 17), and as mentioned previously tree-ring properties are known to change with elevation (Fritts et al. 1965; Schweingruber 1988; Splechtna et al. 2000). Fritts et al. (1965) working in northern Arizona, determined that chronologies from the moister, higher elevation sites showed poor correlations with each other, while chronologies from the lower areas correlated well with each other. According to Schweingruber (1988:136),

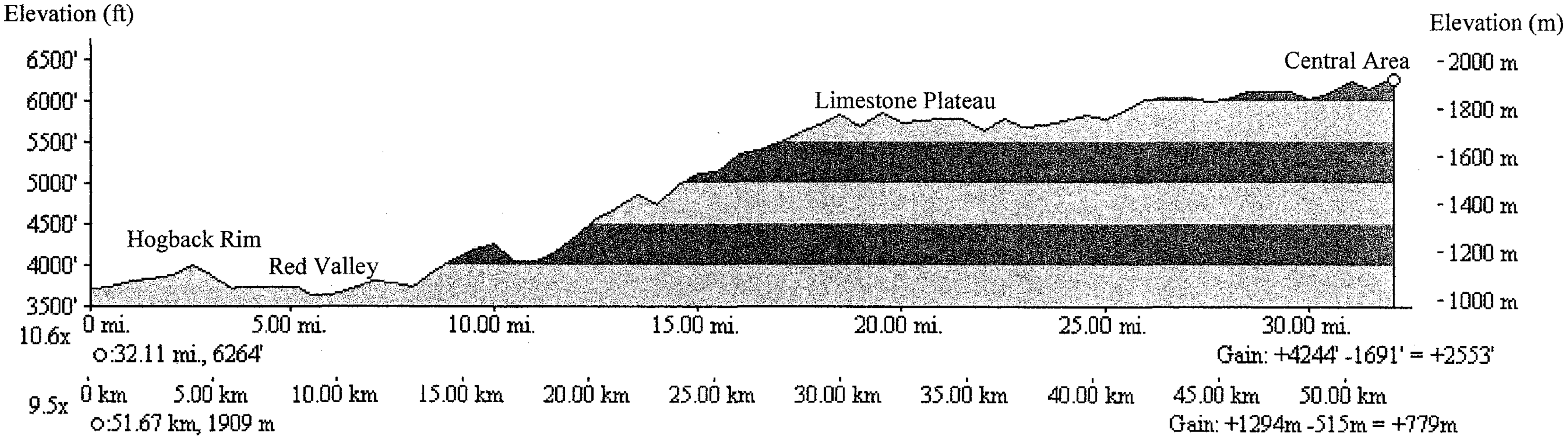


Figure 17 - Elevation Profile of the northern Black Hills.

"chronologies can display less and less similarity with each other as differences in site altitude increases." Although, as mentioned earlier, Schweingruber (1988:138) suggests that the response functions of individual trees of differing elevations are similar in years of extreme climatic conditions.

The results of the current research have shown that the higher elevation tree-ring data has positive correlations with each other and with the lower elevation varve and tree-ring data (Figure 18). As Figure 18 shows, the same periodicity, of peaks and troughs in precipitation, of 20 year average climate is seen in the dendroclimatic data used in this study. Furthermore, the similarities of year to year variations of the individual time series have allowed the positive cross-dating results of the dendrochronology samples used in this study. Therefore, it appears that using paleoclimatic data from differing elevations can be useful in cross-dating applications.

The Little Ice Age Climate in the Black Hills

The paleoclimatic sequence established in this research begins at A.D. 1500, therefore, discussion and analysis of the Little Ice Age will be limited to A.D. 1500 - 1850. Jones and Bradley (1995:659) evaluated current climatic data (from higher resolution sources) to conclude that the Little Ice Age time period was not a monotonously cold interval and was highly variable in temperature and precipitation. These findings appear to be true for the Black Hills region as well, at least in terms of the variability of precipitation patterns. A 20-year average of tree-ring indices for the past 500 years shows that the Little Ice Age climate was highly variable in the region (refer to Figure 18, Tables 8, 9, and 10).

A graph of 10 year averages was also created for the dendroclimatic data used in this research for the period of A.D. 1500-1860, to determine if a shorter climatic trend (than 20 years)

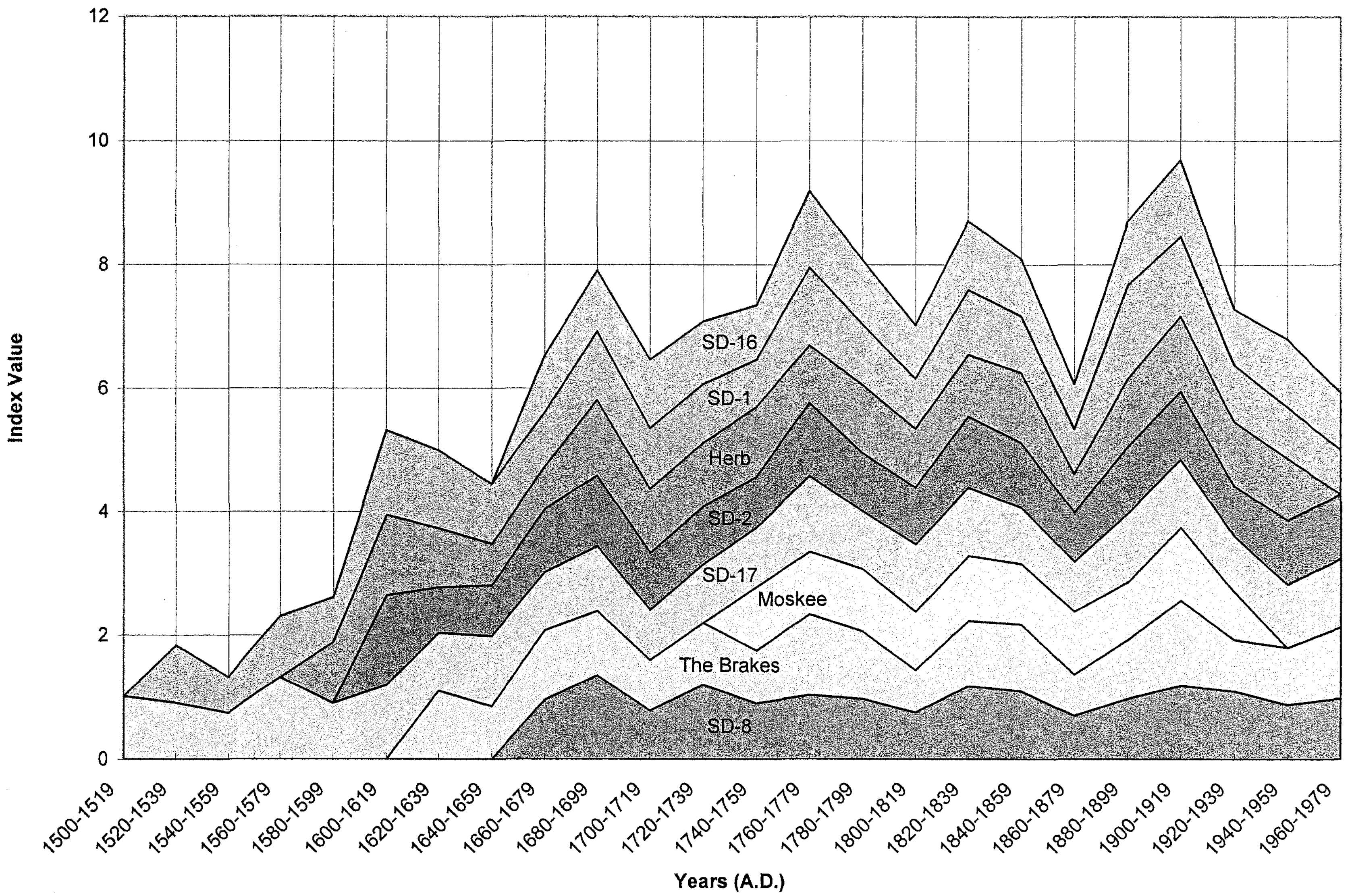


Figure 18 - Stacked graph showing 20-year average climatic trends for dendroclimatic data used in this research.

Years (A.D.)	Northern Black Hills Area							
	SD-8 Average Index Value/ % of modern standard (A.D.)			The Brakes Average Index Value/ % of modern standard (A.D.)			Moskee Average Index Value/ % of modern standard (A.D.)	
		1940-1959	1960-1979		1940-1959	1960-1979		1932-1951*
1500-1519	--------	--------	--------	--------	--------	--------	--------	--------
1520-1539	--------	--------	--------	--------	--------	--------	--------	--------
1540-1559	--------	--------	--------	--------	--------	--------	--------	--------
1560-1579	--------	--------	--------	--------	--------	--------	--------	--------
1580-1599	--------	---------	---------	--------	--------	--------	--------	---------
1600-1619	--------	---------	---------	--------	--------	--------	--------	---------
1620-1639	--------	---------	---------	1.103	119%	97%	--------	---------
1640-1659	--------	---------	---------	.853	92%	75%	--------	---------
1660-1679	.952	108%	97%	1.125	122%	99%	--------	---------
1680-1699	1.353	154%	138%	1.039	112%	92%	--------	---------
1700-1719	.782	89%	80%	.818	89%	72%	--------	---------
1720-1739	1.201	137%	122%	.998	108%	88%	--------	---------
1740-1759	.903	103%	92%	.852	92%	75%	1.027	102%
1760-1779	1.033	117%	105%	1.305	141%	115%	1.016	101%
1780-1799	.975	111%	99%	1.088	118%	96%	1.012	101%
1800-1819	.756	86%	77%	.688	74%	61%	.938	93%
1820-1839	1.180	134%	120%	1.054	114%	93%	1.054	105%
1840-1859	1.097	125%	112%	1.081	117%	95%	.983	98%
1860-1879	.702	80%	72%	.667	72%	59%	1.014	101%
1880-1899	.977	111%	100%	.956	103%	84%	.930	92%
1900-1919	1.189	135%	121%	1.378	149%	121%	1.179	117%
1920-1939	1.093	124%	111%	.836	90%	73%	--------	---------

A.D. 1500-1859 # above average	8	5		8	1		4
A.D. 1500-1859 # below average	2	5		4	11		2

Table 8 - 20 year average tree ring indices compared to 20 year modern standards for the northern Black Hills area dendroclimatic data stations and samples.

* end of chronology

Years (A.D.)	Central Black Hills								
	SD-17 Average Index Value/ % of modern standard (A.D.)			SD-2 Average Index Value/ % of modern standard (A.D.)			Herbert Draw Average Index Value/ % of modern standard (A.D.)		
		1940-1959	1960-1979		1940-1959	1960-1979		1940-1959	1955-1974*
1500-1519	1.018	99%	92%	--------	--------	--------	--------	--------	--------
1520-1539	.910	88%	82%	--------	--------	--------	--------	--------	--------
1540-1559	.748	73%	67%	--------	--------	--------	--------	--------	--------
1560-1579	1.320	129%	119%	--------	--------	--------	--------	--------	--------
1580-1599	.906	88%	81%	---------	---------	---------	.980	98%	105%
1600-1619	1.194	116%	107%	1.453	140%	140%	1.300	129%	139%
1620-1639	.933	91%	84%	.738	71%	71%	.955	95%	102%
1640-1659	1.129	110%	101%	.825	79%	80%	.673	67%	72%
1660-1679	.947	92%	85%	1.022	98%	99%	.677	68%	72%
1680-1699	1.049	102%	94%	1.143	110%	110%	1.227	122%	131%
1700-1719	.811	79%	73%	.924	89%	89%	1.032	103%	110%
1720-1739	.953	93%	86%	.938	90%	91%	1.021	102%	109%
1740-1759	.963	94%	87%	.816	78%	79%	1.134	113%	121%
1760-1779	1.223	119%	110%	1.186	114%	115%	.928	93%	99%
1780-1799	.934	91%	84%	.944	91%	91%	1.103	110%	118%
1800-1819	1.094	107%	98%	.916	88%	88%	.955	95%	102%
1820-1839	1.104	108%	99%	1.153	111%	111%	.995	99%	106%
1840-1859	.906	88%	81%	1.053	101%	102%	1.131	113%	121%
1860-1879	.814	79%	73%	.796	77%	77%	.618	62%	66%
1880-1899	1.118	109%	100%	1.071	103%	103%	1.100	110%	117%
1900-1919	1.097	107%	99%	1.105	106%	107%	1.212	121%	130%
1920-1939	.901	88%	81%	.811	78%	78%	1.037	104%	111%

A.D. 1500-1859 # above average	7	4		5	5		7	11
A.D. 1500-1859 # below average	11	14		8	8		7	3

Table 9 - 20 year average tree ring indices compared to 20 year modern standards for the central Black Hills dendroclimatic data stations and samples.

* end of chronology

Years (A.D.)	Southern Black Hills					
	SD-1 Average Index Value/ % of modern standard (A.D.)			SD-16 Average Index Value/ % of modern standard (A.D.)		
		1940-1959	1960-1979*		1940-1959	1960-1979
1500-1519	--------	--------------	--------------	--------	--------	--------
1520-1539	.929	113%	100%	--------	--------	--------
1540-1559	.581	70%	63%	--------	--------	--------
1560-1579	.988	120%	107%	--------	--------	--------
1580-1599	.730	89%	79%	--------	---------	---------
1600-1619	1.375	167%	149%	--------	---------	---------
1620-1639	1.264	153%	137%	--------	---------	---------
1640-1659	.968	117%	105%	--------	---------	---------
1660-1679	.883	107%	96%	.914	83%	99%
1680-1699	1.108	134%	120%	.994	91%	108%
1700-1719	.985	119%	107%	1.107	101%	120%
1720-1739	.952	115%	103%	1.017	93%	116%
1740-1759	.765	93%	83%	.882	80%	95%
1760-1779	1.262	153%	137%	1.237	113%	134%
1780-1799	.979	119%	106%	1.045	95%	113%
1800-1819	.809	98%	88%	.865	79%	94%
1820-1839	1.051	127%	114%	1.122	111%	121%
1840-1859	.915	111%	99%	.932	85%	101%
1860-1879	.728	88%	79%	.726	66%	79%
1880-1899	1.518	184%	164%	1.036	94%	112%
1900-1919	1.300	158%	141%	1.237	112%	134%
1920-1939	.918	111%	99%	.899	82%	97%

A.D. 1500-1859 # above average	13	11		3	7
A.D. 1500-1859 # below average	4	6		7	3

Table 10 - 20 year average tree ring indices compared to 20 year modern standards for the southern Black Hills dendroclimatic data stations.

* Average modern index value borrowed from SD-16, Pilger Mtn, since SD-1, Pilger Mtn Lookout, chronology ends at 1964 (Average Index values within 1% of each for common intervals)

can be seen (Figure 19). As Figure 19 shows, 20 year and 30 year cycles of peaks and troughs in precipitation can be seen in the tree-ring series. For example, the period from A.D. 1500 -1600 seems to show a 20-year precipitation cycle, whereas the period from A.D. 1690 - 1860 seems to show a 30-year precipitation cycle. It should be noted that although, a 10 or 20-year average may obscure year to year variations, the periodicity of wet and dry periods show a similar climatic pattern for the Black Hills data stations over the last 500 years. Therefore, for purposes of this discussion, 20 year averages will be used.

As Tables 8-10 shows, although some periods of the 1500's, 1600's, 1700's, and 1800's were wetter than a modern average from 1940-1959 or 1960-1979, some of the wettest periods occurred between 1880 and 1920, which is well out of the accepted range of the Little Ice Age. The 1880-1899 interval for the SD-1 chronology is the highest twenty-year average for that tree-ring station for the last 483 years (184 % of normal), with the next interval 1900-1919 being 158% of the 1940-1959 normal. Similarly, the 1880-1899 average for The Brakes was 103% of the 1940-1959 normal, with the 1900-1919 average being the highest twenty-year average for the last 283 years (151% of normal).

A review of Tables 8-10 show that although some periods were well above the average of A.D. 1940-1959, they are nearly average for the period A.D. 1960-1979. This trend can be seen in Table 8 for the Eagle Nest Canyon (SD-8) and The Brakes for the periods A.D. 1660-1679,1760-1769, 1780-1799, 1880-1899. Likewise, in Table 9, Reno Gulch (SD-17) shows the same trend in the periods A.D. 1600-1619, 1640-1659, 1800-1819, 1820-1839, and 1880-1899. Obviously, different trends in the percentages are due to the A.D. 1940-1959 being a somewhat drier period than A.D. 1960-1979, but it raises the question as to what are the normal average

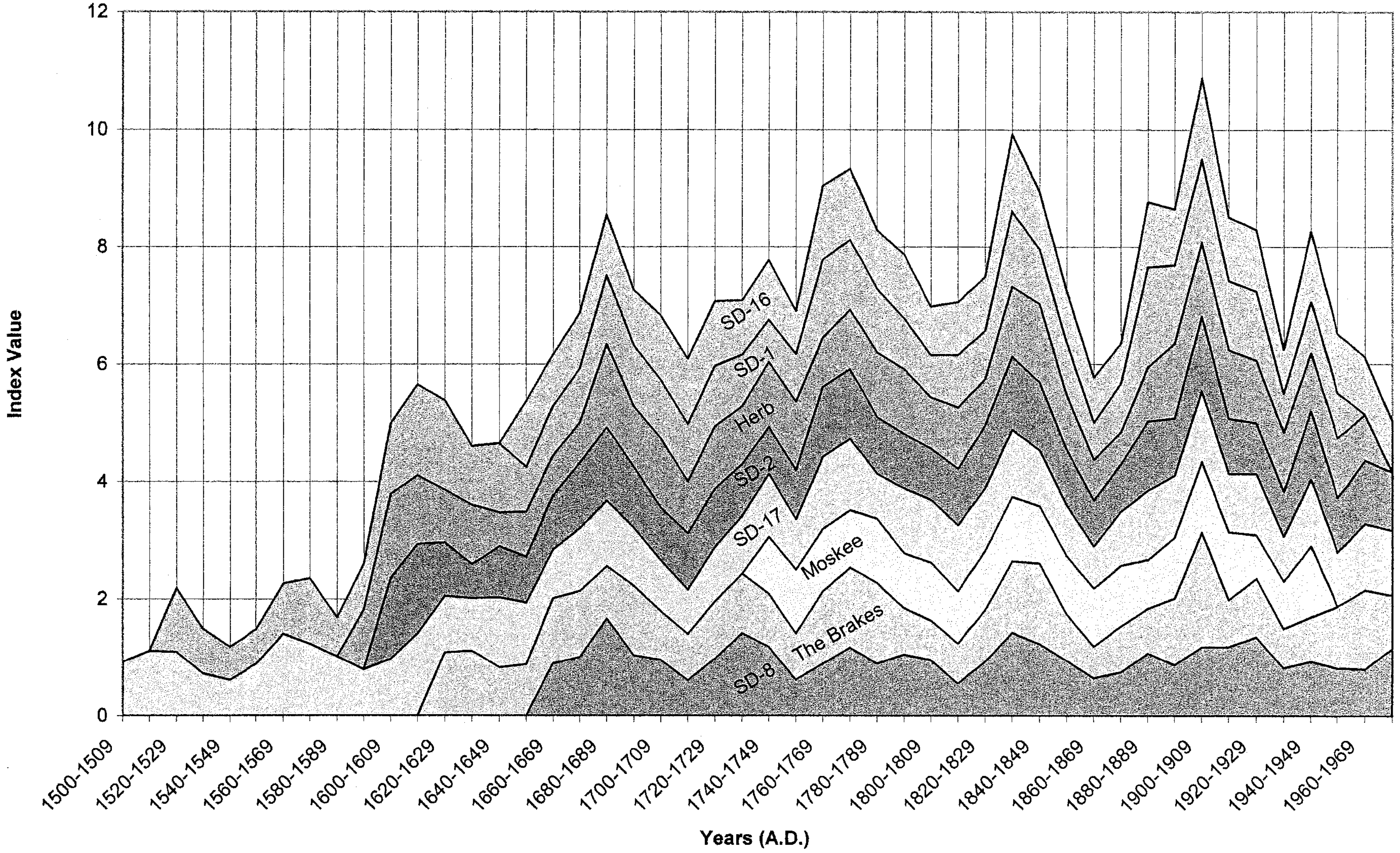


Figure 19 - Stacked graph showing 10-year average climatic trends for dendroclimatic data used in this research.

conditions since the end of the Little Ice Age? As pointed out by Bamforth (1990:362), "the implication of this is that an analyst's choice of 'normal' climatic conditions can have serious effects on his or her conclusions."

The tabulation of wet and dry periods (for the period A.D. 1500-1859) at the bottom of Tables 8, 9, and 10 also show rather inconclusive results. The northern Black Hills dendroclimatic data (Table 8) show that the Little Ice Age time period was wetter than the modern standard A.D. 1940-1959, but average to above average than the modern standard A.D. 1960-1979. Conversely, the central and southern Black Hills data (Tables 9 and 10) show that the Little Ice Age time period was mostly drier than either modern standard.

An attempt to determine significantly wetter or drier than average periods for each data station or sample is presented in Table 11. Much like the creation of skeleton plots, the dendroclimatic data was tested against itself to determine significantly wetter (1 or 2 σ above the mean) or drier (1 or 2 σ below the mean) periods. Similar to the indices and percent of the modern standards, the data in Table 11 is ambiguous. Some periods are slightly wetter or drier during the Little Ice Age, as are the periods after the proposed end of the climatic episode and significantly wet periods (+ 2 value) are very limited. The tabulations of the wetter and drier periods, for the Little Ice Age time period, at the bottom of Table 11 are also rather inconclusive in that they are relatively even in number.

Considering the results of the data analysis in this research, conclusions about the Little Ice Age precipitation are debatable. Arguments can be made for there being mostly average conditions across much of the proposed Little Ice Age time period (A.D. 1500-1850) with periodic wet and dry intervals. The same can be said for the time period since the end of the Little

	Northern Black Hills Area						Central Black Hills						Southern Black Hills			
Years (A.D.)	SD-8		The Brakes		Moskee		SD-17		SD-2		Herb		SD-1		SD-16	
1500-1519	--------	-------	--------	-----	--------	-------	1.018	0	--------	---------	--------	-------	---------	-------	--------	-------
1520-1539	--------	-------	--------	-----	--------	-------	0.91	0	--------	-------	--------	-------	0.929	0	--------	-------
1540-1559	--------	-------	--------	-----	--------	-------	0.748	-1	--------	-------	--------	-------	0.581	-1	--------	-------
1560-1579	--------	-------	--------	-----	--------	-------	1.32	2	--------	-------	--------	-------	0.988	0	--------	-------
1580-1599	--------	-------	--------	-----	--------	-------	0.906	0	---------	-------	0.98	0	0.73	-1	--------	-------
1600-1619	--------	-------	--------	-----	--------	-------	1.194	1	1.453	2	1.3	1	1.375	1	--------	-------
1620-1639	--------	-------	1.103	0	--------	-------	0.933	0	0.738	-1	0.955	0	1.264	1	--------	-------
1640-1659	--------	-------	0.853	0	--------	-------	1.129	0	0.825	0	0.673	-1	0.968	0	--------	-------
1660-1679	0.952	0	1.125	0	--------	-------	0.947	0	1.022	0	0.677	-1	0.883	0	0.914	0
1680-1699	1.353	1	1.039	0	--------	-------	1.049	0	1.143	0	1.227	1	1.108	0	0.994	0
1700-1719	0.782	-1	0.818	0	--------	-------	0.811	-1	0.924	0	1.032	0	0.985	0	1.107	0
1720-1739	1.201	1	0.998	0	--------	-------	0.953	0	0.938	0	1.021	0	0.952	0	1.017	0
1740-1759	0.903	0	0.852	0	1.027	0	0.963	0	0.816	-1	1.134	0	0.765	0	0.882	0
1760-1779	1.033	0	1.305	1	1.016	0	1.223	1	1.186	1	0.928	0	1.262	1	1.237	1
1780-1799	0.975	0	1.088	0	1.012	0	0.934	0	0.944	0	1.103	0	0.979	0	1.045	0
1800-1819	0.756	-1	0.688	-1	0.938	0	1.094	0	0.916	0	0.955	0	0.809	0	0.865	-1
1820-1839	1.18	0	1.054	0	1.054	0	1.104	0	1.153	0	0.995	0	1.051	0	1.122	0
1840-1859	1.097	0	1.081	0	0.983	0	0.906	0	1.053	0	1.131	0	0.915	0	0.932	0
1860-1879	0.702	-1	0.667	-1	1.014	0	0.814	-1	0.796	-1	0.618	-2	0.728	-1	0.726	-1
1880-1899	0.977	0	0.956	0	0.93	0	1.118	0	1.071	0	1.1	0	1.518	2	1.036	0
1900-1919	1.189	0	1.378	2	1.179	1	1.097	0	1.105	0	1.212	1	1.3	1	1.237	1
1920-1939	1.093	0	0.836	0	0.772	-2	0.901	0	0.811	-1	1.037	0	0.918	0	0.899	0
1940-1959	0.879	0	0.924	0	--------	--------	1.025	0	1.04	0	1.002	0	0.825	0	1.096	0

A.D. 1500 -1859 # above average	2		1		0		3		2		2		3		1
A.D. 1500 -1859 # below average	2		1		0		2		2		2		2		1

Table 11 – 20 year average tree ring indices tested for significantly wetter or drier periods.

0 = 1 σ ± the mean
1 = >1 σ above the mean
2 = >2 σ above the mean
-1 = <1 σ below the mean
-2 = <2 σ below the mean

Ice Age up to the present. The only conclusive argument is that the Little Ice Age climate in the Black Hills is highly variable, much like it was in other parts of the world.

Climate and Cultural Studies

Sundstrom (1996:1d-2) notes that in the Black Hills, as well as other parts of the Great Plains, "various changes in social organization, settlement pattern, population density, subsistence activities and even ideology have been explained as a human response to environmental conditions." Bryson (1994:115) states, "A characteristic of both paleoclimatology and culture history is that they are multi-causal." Therefore, investigations into paleoclimatic and cultural research must take into account as many variables as possible. For example, the low resolution global climatic models discussed earlier (Kutzbach 1976; Hall 1988), do not draw upon all variables, as they "neglect many of the critical forces determining local climatic conditions" (Bamforth 1990:360). Furthermore, there are also concerns when deriving climatic inferences from cultural evidence or developing cultural inferences from climatic data.

Problems with Inferring Climate Change from Culture Change

According to Caran (1998:111) paleoclimatology or the reconstruction of past climates is based on two testable hypotheses, 1) the evidence has a specific relation to the environment, and 2) the evidence accurately depicts the environment at the time it was preserved. In a study on the paleoenvironmental reconstructions of the southern Great Plains, Caran (1998) addresses the issue of using indirect evidence to reconstruct paleoclimates. Caran (1998:114) classifies direct and indirect evidence with differing degrees of "extrapolation" (First through fourth order). As table 12 shows, climatic inferences would therefore be problematic using any indirect evidence. Caran (1998:114) states that the orders of extrapolation (2-4) become increasingly remote because of the use of indirect evidence.

Extrapolation	Evidence Type	Inferences
First order	Direct	Ice wedges = Cold climate
Second order	Indirect	Prehistoric water well = Limited water = Dry climate
Third order	Indirect	Few bison remains in a site = Low bison population = Sparse grasses = Dry climate
Fourth order	Indirect	Paleoindian projectile points found = Megafauna hunters present =Abundant game = Abundant grasses = Wet climate

Table 12 - Examples of paleoclimatic inferences from direct and indirect evidence. (Adapted from Caran 1998:114)

Problems with Inferring Culture Change from Climatic Change

According to Bamforth (1987:7), "Environmental analysis in anthropology in general has tended to emphasize average conditions and to ignore the patterns of variation in resource availability to which human beings everywhere have had to adapt . . . " Bamforth (1990) suggests that the year to year variation in climatic variables during the Little Ice Age is more important than the average annual precipitation. He also says that "although communal bison hunting may have intensified during the Little Ice Age, as Reher and Frison (1980) suggest, this intensification may reflect more severe overwintering problems rather than greater opportunities for such procurement which resulted from larger bison populations" (Bamforth 1990:364).

Bamforth (1990:362) also critiqued the Wahl and Lawson (1970) study by showing that the time period of A.D. 1850 to 1870 might not be indicative of the Little Ice Age as a whole since it is either at the very end of the climatic episode or not part of it at all. Bamforth (1990:362) demonstrates that if the average annual precipitation for the period A.D. 1850 to 1870 is compared to the 1941-1970 normals (unlike the original study which was compared to 1931-1960 normals), there is no difference in mean annual precipitation. Therefore, as discussed earlier, the modern standard chosen for comparisons can significantly alter the results of a paleoclimatic investigation.

Implications for The Vore Site Model

The Vore site model proposed by Reher and Frison (1980) considers a 10-year precipitation cycle which translated into a 10-year bison population cycle based on effective moisture. Since the precipitation sequence used in the model was derived from the varve sequence, it is presumed that the cycle is somewhat different in the refined dating sequence, although it is still evident that three of the first five kill episodes occurred after a peak in precipitation. Furthermore, the dendroclimatic data used in the current research suggests a possible precipitation cycle of 20 to 30 years for the Black Hills region. This has important implications for the length of the bison population cycle, although at this point these results are preliminary and a more focused investigation into the paleoclimate of the region would need to be conducted to answer any larger questions.

Directions for Future Research

Although positive results have come from the attempt to refine the Vore Site varve dates, much work remains to be done. According to Reher and Frison (1980:13), less than 9% of the Vore Site was tested with the initial excavations, which means that only a portion of the pond that created the varved sediments was exposed. The extent and depth of the laminated sediments across the site is largely unknown at this point and will remain that way until future excavations reveal more information. Furthermore, more dendroclimatic data, temporally comparable with the varves, should be sought from the local area to augment the data presented here. The cross-dating of the varves have shown that the lower levels correlate well with the Black Hills tree-ring data, but decreasingly so through time. The Brakes chronology is the only sequence that correlates well with the last varve interval, perhaps because it is from a closer proximity or a comparable elevation. This possibly suggests a change in the response functions of the varves and The Brakes trees, different from that of the other Black Hills tree-ring stations. Therefore, the individual response functions of the varves would need to be addressed in any future investigation.

As stated by Bamforth (1990:364) "there is clearly more research needed on the nature of the Plains environment during the Little Ice Age." To better understand local paleoenvironments, Bradley and Jones (1995:660) recommend three improvements for the better understanding of climatic history. The first recommendation is a need for improved data coverage with high resolution data from varved sediments and tree-ring chronologies (Bradley and Jones 1995:660). Secondly, the climatic effects of large scale climatic influences (i.e. volcanic eruptions) must be determined (Bradley and Jones 1995:660). The third recommendation is to improve the calibration and interpretation of the paleoclimatic data (Bradley and Jones 1995:660).

The improved interpretations of the climatic data is equally important for archaeological investigations. In this discussion, it has been seen that the differing interpretations of human adaptation can account for the observed evidence in the archaeological record or historic documents. The interpretations presented by Reher (1978), Reher and Frison (1980), Driver (1983), Osborn (1983), and Kennett and Kennett (2000), emphasize the influence of climatic conditions on the cultural adaptations of aboriginal groups. Conversely, the interpretations offered by Koerper et al. (1985), Lensink (1993), Fawcett (1987), and Martin and Szuter (1997) show that other factors besides climate are influencing prehistoric cultures.

It is suggested here that in order to better understand paleoclimate and its effect on prehistoric culture, the individual characteristics of culture and environment must be addressed, as well as their relationship with each other. It has been seen from previous investigations, as well as the results of this research that these questions should be investigated through higher resolution data and improved interpretations of that data. As Bamforth states (1990:364):

> "As is true for all studies of human/environment interactions, analyses of the cultural ecology of the recent occupants of the Plains require accurate, specific information both on what humans did in the past and on the conditions in which they did it, and we must examine the available environmental data as critically as we do the anthropological data on which our research focuses."

Summary and Conclusions

A primary goal of this research was to acquire new dendroclimatic data to combine with existing data to refine the dates of the Vore Site varve sequence. Based on the statistical correlations of the varve series with available published tree-ring indices and acquired tree-ring samples, the varve series appears to be discontinuous through time with at least three gaps in the sequence. The gaps have occurred near the levels of bison kill episodes or in one instance, a period of severe drought. Accounting for the gaps in the varve series yields a date for the entire varve sequence of A.D. 1512-1663, rather than the A.D. 1500-1505 start date proposed by Reher and Frison (1980). The refined dating sequence would date the first five bison kill events at the Vore Site to: A.D. 1553-1558; A.D. 1572; A.D. 1608; A.D. 1637-1642; and A.D. 1663.

A second goal was to reconstruct a basic paleoclimatic precipitation record for the northern Black Hills in consideration of using climatic data from differing elevations. This was accomplished to a limited extent in that eight trees were sampled in The Brakes area and have yielded a paleoclimate record dating from A.D. 1617-2001. The Herbert Draw sample was cross-dated to A.D. 1582-1974 and provided supplemental data as a higher elevation tree-ring chronology. A sample from the Moskee, Wyoming area has been found to be somewhat problematic in terms of cross-dating, perhaps because of low sensitivity, but may provide some paleoclimatic information within its chronology of A.D. 1735-1951. It was determined that the elevational gradient of the Black Hills was not a significant factor in the cross-dating analysis of the data sets used in this research.

A final goal of this thesis was to use the current research and previous studies to critically evaluate the reality of the Little Ice Age climatic episode and its effect on prehistoric cultures. Analysis of dendroclimatic data for the Black Hills region covering the last 500 years has given relatively inconclusive results in regards to the proposed increase of precipitation during the period. The dendroclimatic data used in this research suggests a possible 20 or 30-year precipitation cycle in the Black Hills region throughout the Little Ice Age (A.D. 1500-1850). This is significantly different from the 10-year precipitation cycle proposed by Reher and Frison (1980) in the original analysis of the Vore site varves. However, the refined cultural level dates still show that three out of five of the bison kill events incorporated in the varve sequence, occur after peaks in precipitation, as proposed in the Vore model.

Certainly, climatic changes have influenced prehistoric cultures over the last 500 years, and it is suggested that archaeological inquiries must take into account climatic, as well as cultural variables when investigating the Little Ice Age time period in the Black Hills. Furthermore, it will only be through acquiring higher resolution data, such as dendroclimatic evidence, that we may better reconstruct the paleoclimatic record for the region. In turn, this clearer view of the paleoclimatic record, coupled with improvements in interpretations, has important implications for our understanding of the aboriginal adaptations to the climatic changes of the Great Plains and Black Hills region during the Little Ice Age.

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APPENDIX I

Vore Site Varve Measurements

Varves	Width 3	Complete 3
Bone Varves		27
1	7	
2	6	13
3	7	
4	16	20
5	4	
6	23	29
7	6	
8	14	21
9	7	
10	30	38
11	8	
12	30	40
13	10	
14	12	17
15	5	
16	12	17
17	5	
18	11	20
19	9	
20	10	17
21	7	
22	9	16
23	7	
24	16	20
25	4	
26	10	16
27	6	
28	5	8
29	3	
30	8	12
31	4	
32	3	5
33	2	
34	3	5
35	2	
36	8	11
37	3	
38	15	26
39	11	
40	20	24
41	4	
42	4	9
43	5	
44	4	13
45	9	
46	6	15
47	9	
Bone Varves		18
48	12	16
49	4	

#	3	C.W.
50	9	12
51	3	
52	21	31
53	10	
54	5	14
55	9	
56	5	11
57	6	
58	4	10
59	6	
60	5	29
61	24	
62	6	10
63	4	
64	6	11
65	5	
66	4	13
67	9	
68	9	15
69	6	
70	9	12
71	3	
72	6	12
73	6	
74	7	14
75	7	
76	7	17
77	10	
78	7	21
79	14	
80	6	11
81	5	
82	3	8
83	5	
84	4	7
85	3	
86	2	4
87	2	
88	6	16
89	10	
90	7	19
91	12	
92	8	21
93	13	
94	4	7
95	3	
96	3	13
97	10	
98	7	16
99	9	

#	3	C.W.
100	7	16
101	9	
102	3	7
103	4	
104	8	11
	3	
II		
Bone Varves		14
106	6	10
107	4	
108	7	12
109	5	
110	5	7
111	2	
112	6	10
113	4	
114	8	11
115	3	
116	3	14
117	11	
118	14	29
119	15	
120	6	21
121	15	
122	3	7
123	4	
124	4	11
125	7	
126	4	6
127	2	
128	2	4
129	2	
130	5	8
131	3	
132	5	10
133	5	
134	8	15
135	7	
136	8	28
137	20	
138	10	20
139	10	
140	11	39
141	28	
142	6	12
143	6	
144	11	16
145	5	
146	6	22
147	26	
148	4	8
149	4	

#	3	C.W.
150	3	8
151	5	
152	3	7
153	4	
154	8	18
155	10	
156	12	23
157	11	
158	17	29
159	22	
160	4	15
161	11	
162	6	16
163	10	
164	5	13
165	8	
166	4	16
167	12	
168	3	12
169	9	
170	3	12
171	9	
Bone Varves		23
172	12	28
173	16	
174	18	33
175	15	
176	15	30
177	15	
178	5	9
179	4	
180	4	7
181	3	
182	4	8
183	4	
184	5	8
185	3	
186	5	12
187	7	
188	8	18
189	10	
190	7	18
	11	
I		
Bone Varves		17
192	5	9
193	4	
194	6	11
195	5	
196	8	19
197	11	

#	3	C.W.
198	17	29
199	12	
200	12	24
201	12	
202	12	23
203	11	
204	13	21
205	8	
206	3	6
207	3	
208	4	6
209	2	
210	3	6
211	3	
212	2	5
213	3	
214	8	15
215	7	
216	8	14
217	6	
218	5	11
219	6	
220	5	11
221	6	
222	5	12
223	7	
224	9	12
225	3	
226	5	10
227	5	
228	4	9
229	5	
230	5	11
231	6	
232	5	11
233	6	
234	4	8
235	4	
236	5	9
237	4	
238	5	9
239	3	
240	3	9
241	6	
242	5	10
243	4	
244	4	12
245	8	
246	8	15
247	7	

#	3	C.W.
248	9	18
249	9	
250	8	17
251	9	
252	8	15
253	7	
254	4	22
255	18	
256	3	8
257	5	
258	3	10
259	7	
260	9	16
261	7	
262	7	12
263	5	
264	7	14
265	7	
266	12	20
267	8	
268	6	12
269	6	
270	8	16
271	8	
272	5	

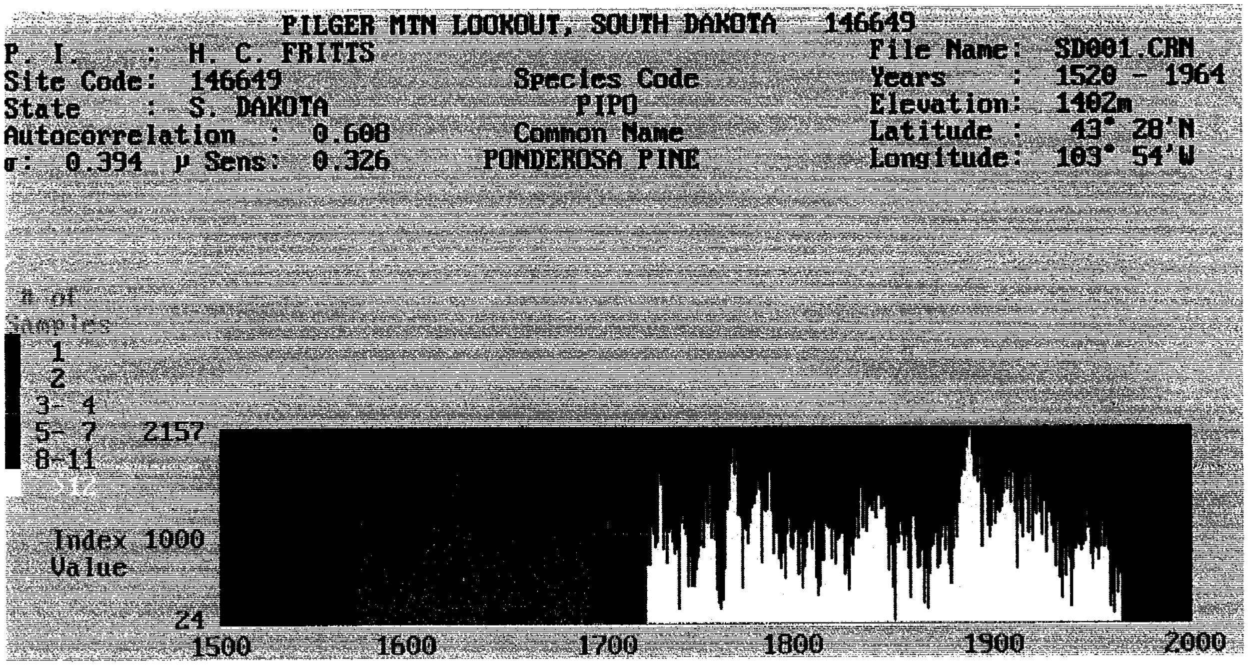
VORE VARVES

Reher (1972)

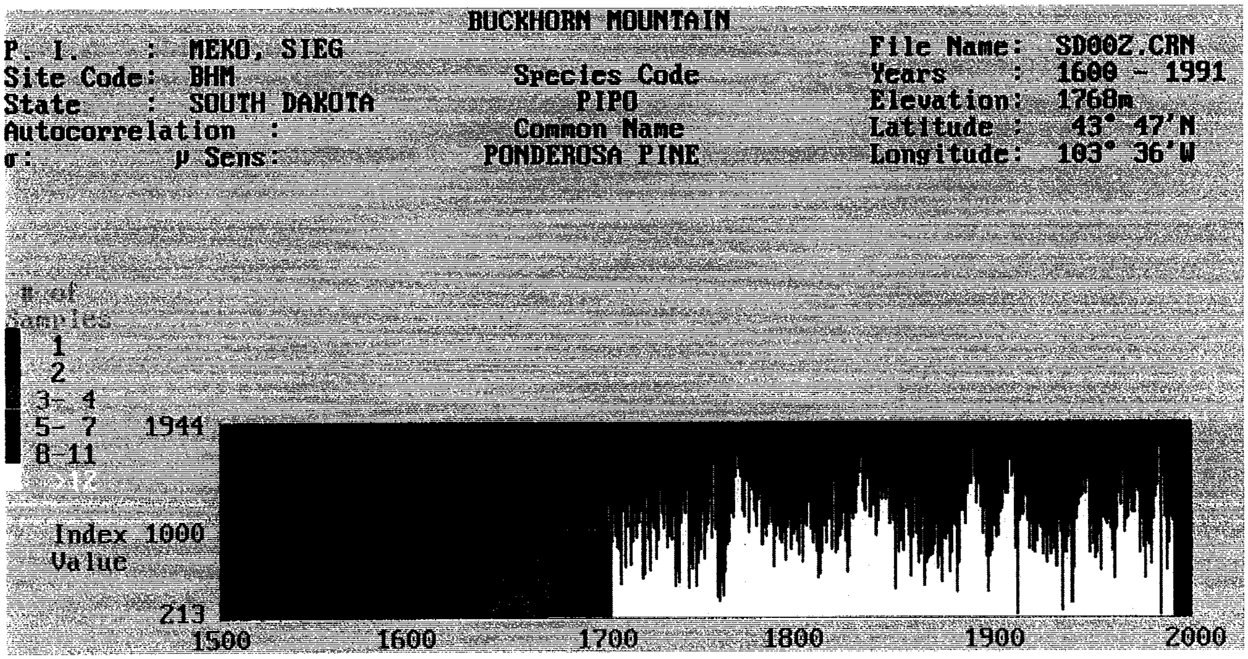
I = 11 mm. of silty deposit - not included in measurements.
II = 17 mm. of silty deposit - not included in measurements.

APPENDIX II

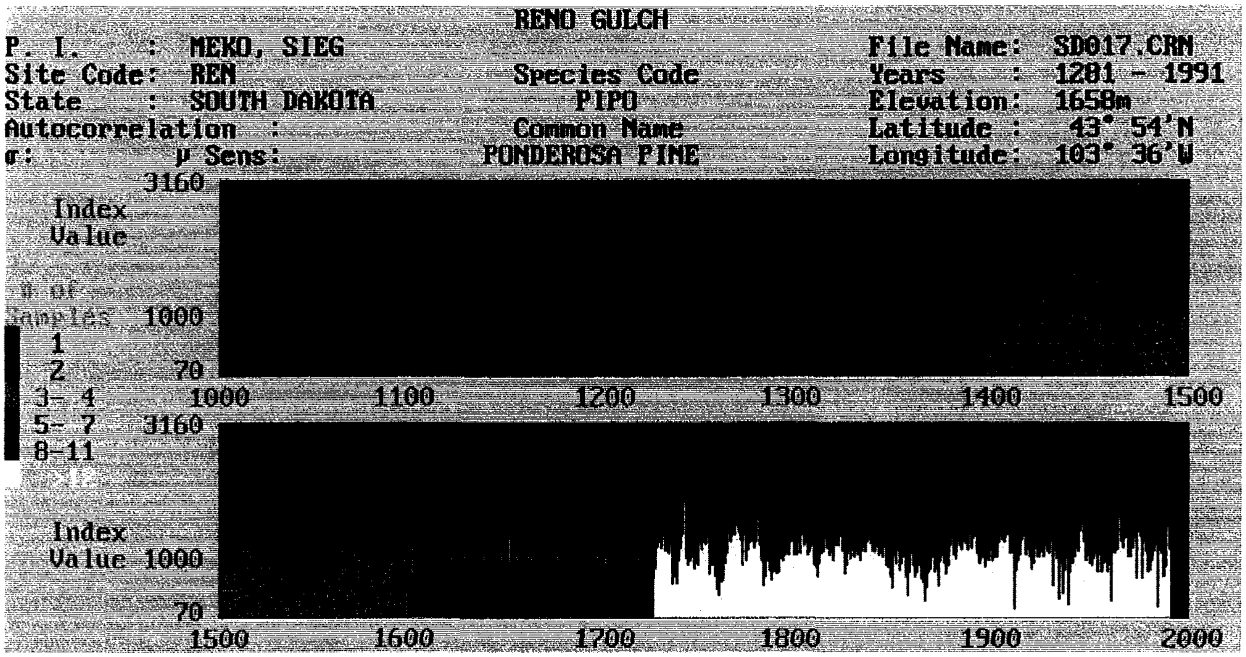
ITRDB Tree Ring Station Information



```
                     PILGER MTN LOOKOUT, SOUTH DAKOTA   146649
P. I.     :  H. C. FRITTS                                   File Name:  SD001.CRN
Site Code:  146649                 Species Code             Years    :  1520 - 1964
State     :  S. DAKOTA                 PIPO                 Elevation:  1402m
Autocorrelation  :  0.608          Common Name              Latitude :   43° 28'N
σ:  0.394  μ Sens:  0.326          PONDEROSA PINE           Longitude:  103° 54'W
```



```
                               BUCKHORN MOUNTAIN
P. I.     :  MEKO, SIEG                                     File Name:  SD002.CRN
Site Code:  BHM                    Species Code             Years    :  1600 - 1991
State     :  SOUTH DAKOTA              PIPO                 Elevation:  1768m
Autocorrelation  :                 Common Name              Latitude :   43° 47'N
σ:          μ Sens:                PONDEROSA PINE           Longitude:  103° 36'W
```

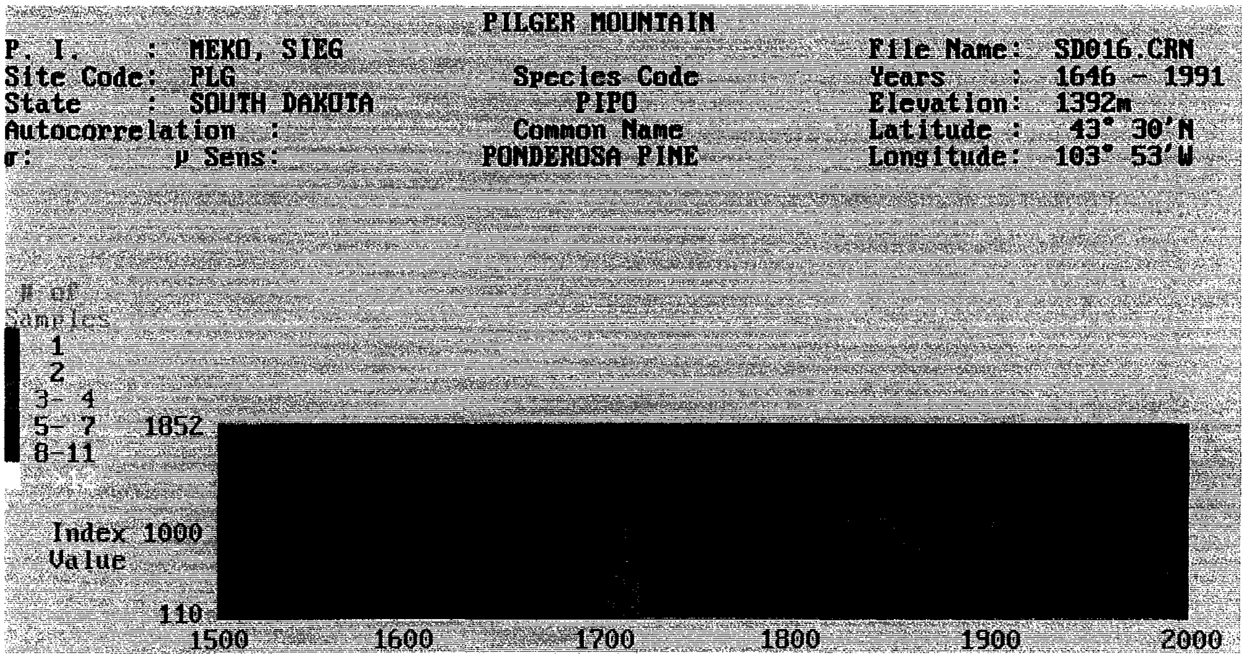


RENO GULCH

P. I. : MEKO, SIEG
Site Code: REN
State : SOUTH DAKOTA
Autocorrelation :
σ: μ Sens:

Species Code
PIPO
Common Name
PONDEROSA PINE

File Name: SD017.CRN
Years : 1281 - 1991
Elevation: 1658m
Latitude : 43° 54'N
Longitude: 103° 36'W

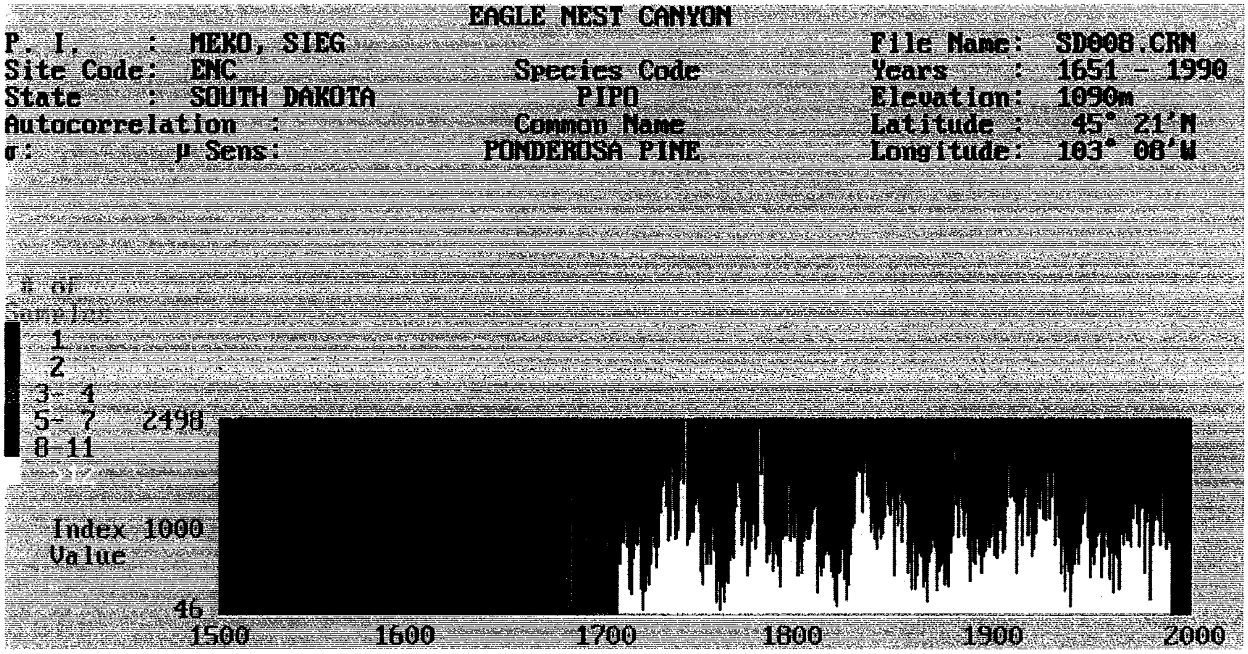


PILGER MOUNTAIN

P. I. : MEKO, SIEG
Site Code: PLG
State : SOUTH DAKOTA
Autocorrelation :
σ: μ Sens:

Species Code
PIPO
Common Name
PONDEROSA PINE

File Name: SD016.CRN
Years : 1646 - 1991
Elevation: 1392m
Latitude : 43° 30'N
Longitude: 103° 53'W



```
                          EAGLE NEST CANYON
P. I.     :  MEKO, SIEG                                File Name:  SD008.CRN
Site Code:  ENC                Species Code            Years    :  1651 - 1990
State    :  SOUTH DAKOTA           PIPO                Elevation:  1090m
Autocorrelation  :             Common Name             Latitude :   45° 21'N
σ:         µ Sens:            PONDEROSA PINE           Longitude:  103° 08'W
```

APPENDIX III

Dendrochronology Field Form

UNIVERSITY OF WYOMING DENDROCHRONOLOGY LAB
Field Specimen Recording Form

Project:______________________________

Tree Specimen Number:__________ **Date:**__________ **Recorder:**__________

Species:______________________________

Location: County__________ State__________ Quad. Name:______________

T__________ R__________ ________of Section #:__________

UTM: E__________________m N____________________m

Type of Specimen:

Slab________ V-Cut________ Incr. Core________ Dry Core________ Other________

Specimen Direction:______________ (proximal end of core to distal end)

Compass:______________ Relation to Slope:______________

Specimen Ht. Above Ground:____________

Tree Size: Tree Ht.________ Diam.________ Ht. Diam above ground:__________

Basal circumference__________ Core location circumference:__________

Conditions of Tree Growth:

Topography:______________________________

____

____

Elevation:________ On Slope:________ Slope Face:____________

Root Water:______________________________

Relation to Drainage Line:______________________________

Soil:______________________________

Nature:______________________________

Depth:______________________________

Porosity, Drn.:______________________________

Depth to Bedrock:____________ Type:______________

Surroundings:

Other Trees:______________________________

____

Other vegetation:______________________________

____

FIELD NOTES

Crew:____

Photo List:____

____

General Comments:____

____

____

____

Sketch Map of Specimen Locations:

Attach xerox of USGS 7.5 min. Quad. showing project and specimen location as appropriate

PHOTO FORM

Roll/Photo #:______________________________

View Direction:_____________________________

Tree Specimen No.:__________________________

Comments: (e.g. other tree specimens in background) ______________________

____

APPENDIX IV

Verify 5 Output of Basic Statistics for Dendrochronology Samples

```
                    MEASUREMENT VERIFICATION RESULTS

     ORIGINAL FILE    : c:\windows\desktop\bhtree\tb6\tb6.m
     VERIFICATION FILE: c:\windows\desktop\bhtree\tb6\tb6.m

                            Base Information

     ORIGINAL FILE:                      VERIFICATION FILE:
     Measured by  :          N/A         Measured by  :          N/A
     Measured on  :          N/A         Measured on  :          N/A
     First year   :         1000         First year   :         1000
     Last year    :         1374         Last year    :         1374
     Total years  :          375         Total years  :          375

*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*
            FIRST ANALYSIS: COMPARATIVE STATISTICS, 1000-1374
*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*

     Average width      :  1.051        Average Width      :  1.051
     Median             :  0.920        Median             :  0.920
     Variance           :  0.396        Variance           :  0.396
     Standard deviation :  0.629        Standard deviation :  0.629
     Coef of variation  :  0.598        Coef of variation  :  0.598
     Relative skewness  :  1.350        Relative skewness  :  1.350
     Pearson's Gamma    :  0.626        Pearson's Gamma    :  0.626
     Kurtosis           :  4.820        Kurtosis           :  4.820
     Mean sensitivity   :  0.307        Mean sensitivity   :  0.307
     Autocorrelation    :  0.800        Autocorrelation    :  0.800

*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*
                SECOND ANALYSIS: LINEAR REGRESSION, 1000-1374
*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*

               Dependent variable    (Y): Original file
               Independent variable (X): Verification file
               Slope of regression      :       1.000
               Intercept of regression :       0.000
               Root mean square error  :       0.000
               Coefficient of variation:       0.000
               Correlation coefficient :       1.000
               Coef of determination   :       1.000

*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*
                  THIRD ANALYSIS: VERIFICATION, 1000-1374
*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*

             Sum of differences        :       0.000
             Sum of squared differences:       0.000
             Average difference        :       0.000
             Average squared difference:       0.000

             HARDWOODS                          CONIFERS
      Confidence level: 0.05 ACCEPT   Confidence level: 0.01 ACCEPT
```

```
                     MEASUREMENT VERIFICATION RESULTS

ORIGINAL FILE     : c:\windows\desktop\bhtree\moskee\mosk.m
VERIFICATION FILE: c:\windows\desktop\bhtree\moskee\mosk.m

                            Base Information

ORIGINAL FILE:                     VERIFICATION FILE:
Measured by  :            N/A      Measured by  :            N/A
Measured on  :            N/A      Measured on  :            N/A
First year   :           1000      First year   :           1000
Last year    :           1216      Last year    :           1216
Total years  :            217      Total years  :            217

*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*
          FIRST ANALYSIS: COMPARATIVE STATISTICS, 1000-1216
*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*

Average width      :  1.473        Average Width      :  1.473
Median             :  1.330        Median             :  1.330
Variance           :  0.560        Variance           :  0.560
Standard deviation :  0.748        Standard deviation :  0.748
Coef of variation  :  0.508        Coef of variation  :  0.508
Relative skewness  :  0.522        Relative skewness  :  0.522
Pearson's Gamma    :  0.573        Pearson's Gamma    :  0.573
Kurtosis           :  2.389        Kurtosis           :  2.389
Mean sensitivity   :  0.235        Mean sensitivity   :  0.235
Autocorrelation    :  0.810        Autocorrelation    :  0.810

*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*
              SECOND ANALYSIS: LINEAR REGRESSION, 1000-1216
*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*

             Dependent variable    (Y): Original file
             Independent variable (X): Verification file
             Slope of regression      :        1.000
             Intercept of regression :        0.000
             Root mean square error  :        0.000
             Coefficient of variation:        0.000
             Correlation coefficient :        1.000
             Coef of determination   :        1.000

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                 THIRD ANALYSIS: VERIFICATION, 1000-1216
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           Sum of differences        :        0.000
           Sum of squared differences:        0.000
           Average difference        :        0.000
           Average squared difference:        0.000

           HARDWOODS                        CONIFERS
 Confidence level: 0.05 ACCEPT   Confidence level: 0.01 ACCEPT
```

```
                      MEASUREMENT VERIFICATION RESULTS

     ORIGINAL FILE    : c:\windows\desktop\bhtree\herb\herb.m
     VERIFICATION FILE: c:\windows\desktop\bhtree\herb\herb.m

                             Base Information

     ORIGINAL FILE:                     VERIFICATION FILE:
     Measured by  :          N/A        Measured by  :          N/A
     Measured on  :          N/A        Measured on  :          N/A
     First year   :         1582        First year   :         1582
     Last year    :         1973        Last year    :         1973
     Total years  :          392        Total years  :          392

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           FIRST ANALYSIS: COMPARATIVE STATISTICS, 1582-1973
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     Average width      : 1.584         Average Width      : 1.584
     Median             : 1.300         Median             : 1.300
     Variance           : 1.024         Variance           : 1.024
     Standard deviation : 1.012         Standard deviation : 1.012
     Coef of variation  : 0.639         Coef of variation  : 0.639
     Relative skewness  : 0.891         Relative skewness  : 0.891
     Pearson's Gamma    : 0.843         Pearson's Gamma    : 0.843
     Kurtosis           : 2.829         Kurtosis           : 2.829
     Mean sensitivity   : 0.264         Mean sensitivity   : 0.264
     Autocorrelation    : 0.853         Autocorrelation    : 0.853

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               SECOND ANALYSIS: LINEAR REGRESSION, 1582-1973
*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*

                  Dependent variable   (Y): Original file
                  Independent variable (X): Verification file
                  Slope of regression     :        1.000
                  Intercept of regression :        0.000
                  Root mean square error  :        0.000
                  Coefficient of variation:        0.000
                  Correlation coefficient :        1.000
                  Coef of determination   :        1.000

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                 THIRD ANALYSIS: VERIFICATION, 1582-1973
*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*

                Sum of differences        :        0.000
                Sum of squared differences:        0.000
                Average difference        :        0.000
                Average squared difference:        0.000

                HARDWOODS                       CONIFERS
      Confidence level: 0.05 ACCEPT   Confidence level: 0.01 ACCEPT
```
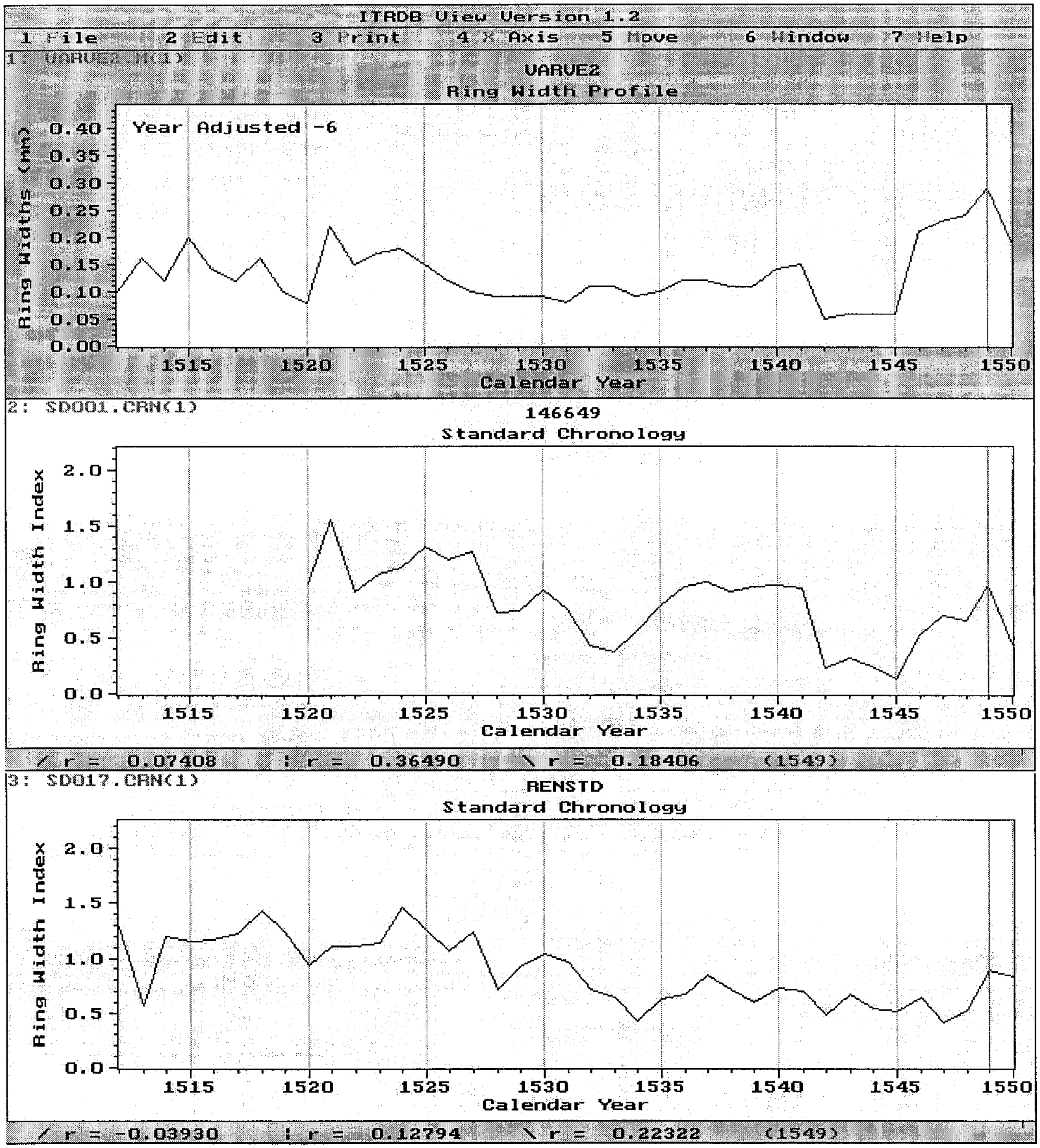

APPENDIX V

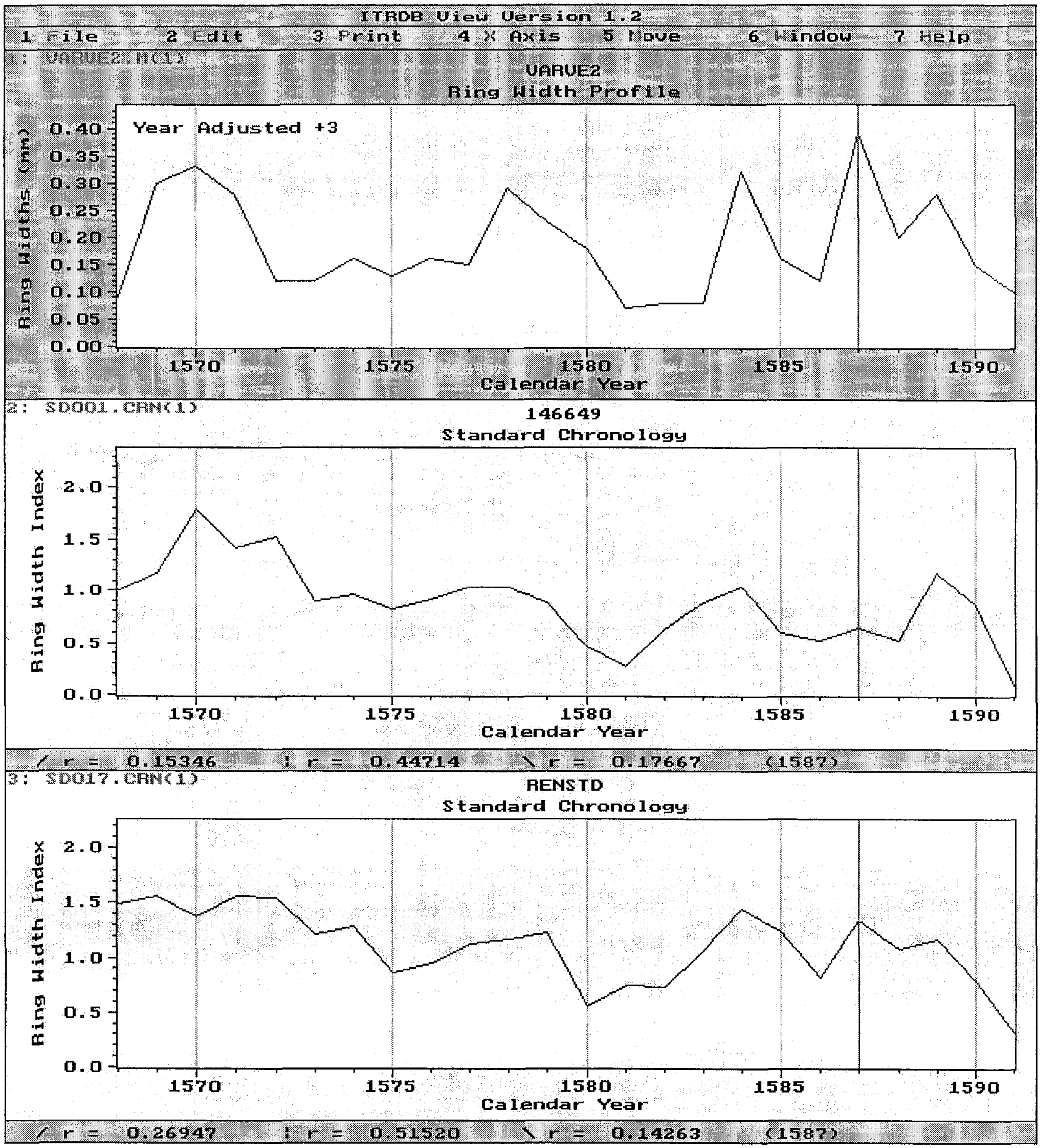
ITRVIEW 2.0 Cross-dating Graphs



```
/ r =  0.07408    ¦ r =  0.36490    \ r =  0.18406     (1549)
```

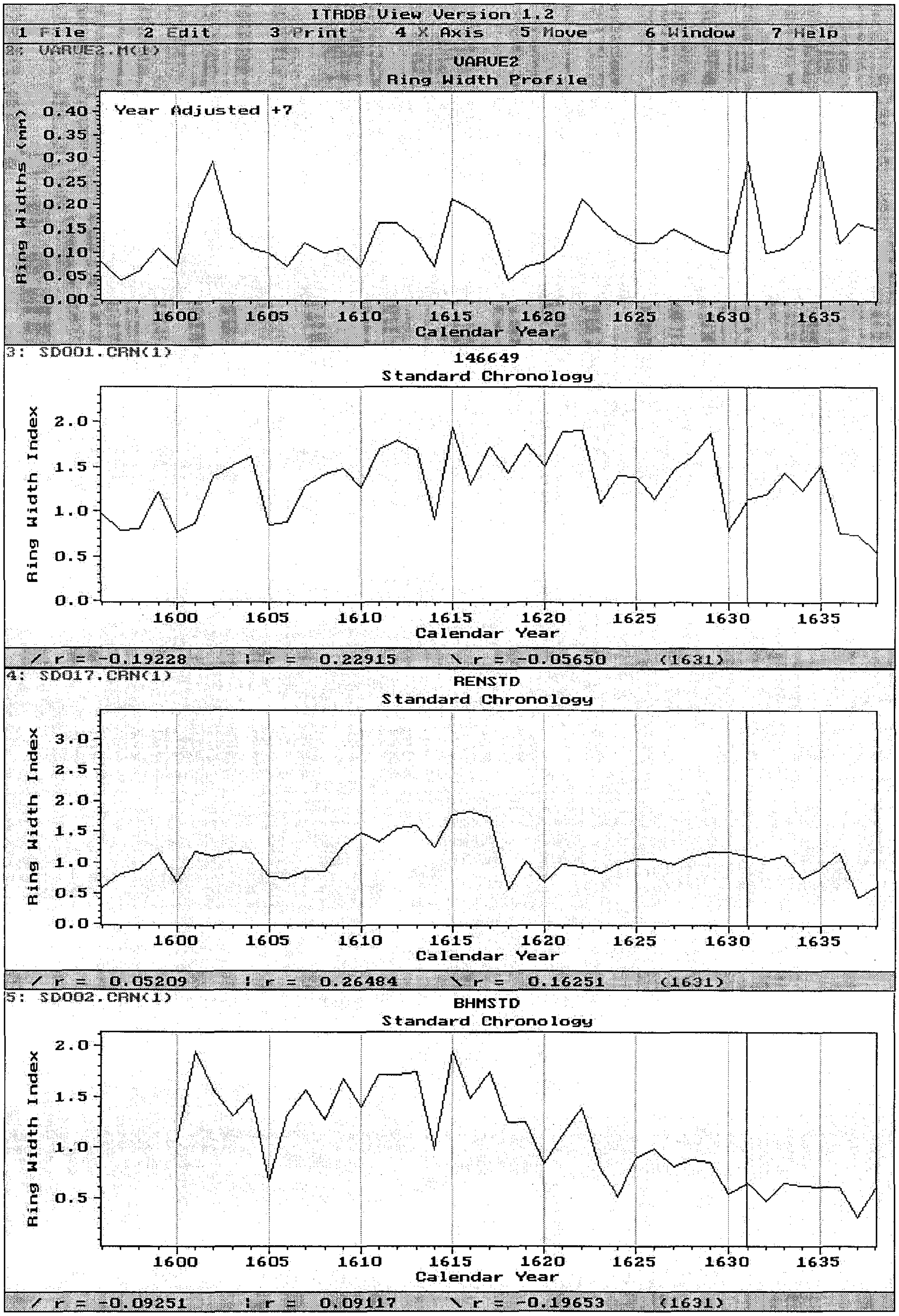
```
/ r = -0.03930    ¦ r =  0.12794    \ r =  0.22322     (1549)
```

Bivariate plot comparisons of varve series and tree ring chronologies, SD-1 and SD-17 (A.D. 1512-1550).



```
/ r =  0.15346    ! r =  0.44714    \ r =  0.17667    (1587)
/ r =  0.26947    ! r =  0.51520    \ r =  0.14263    (1587)
```

Bivariate plot comparisons of varve series and tree ring chronologies, SD-1 and SD-17 (A.D. 1568-1591).

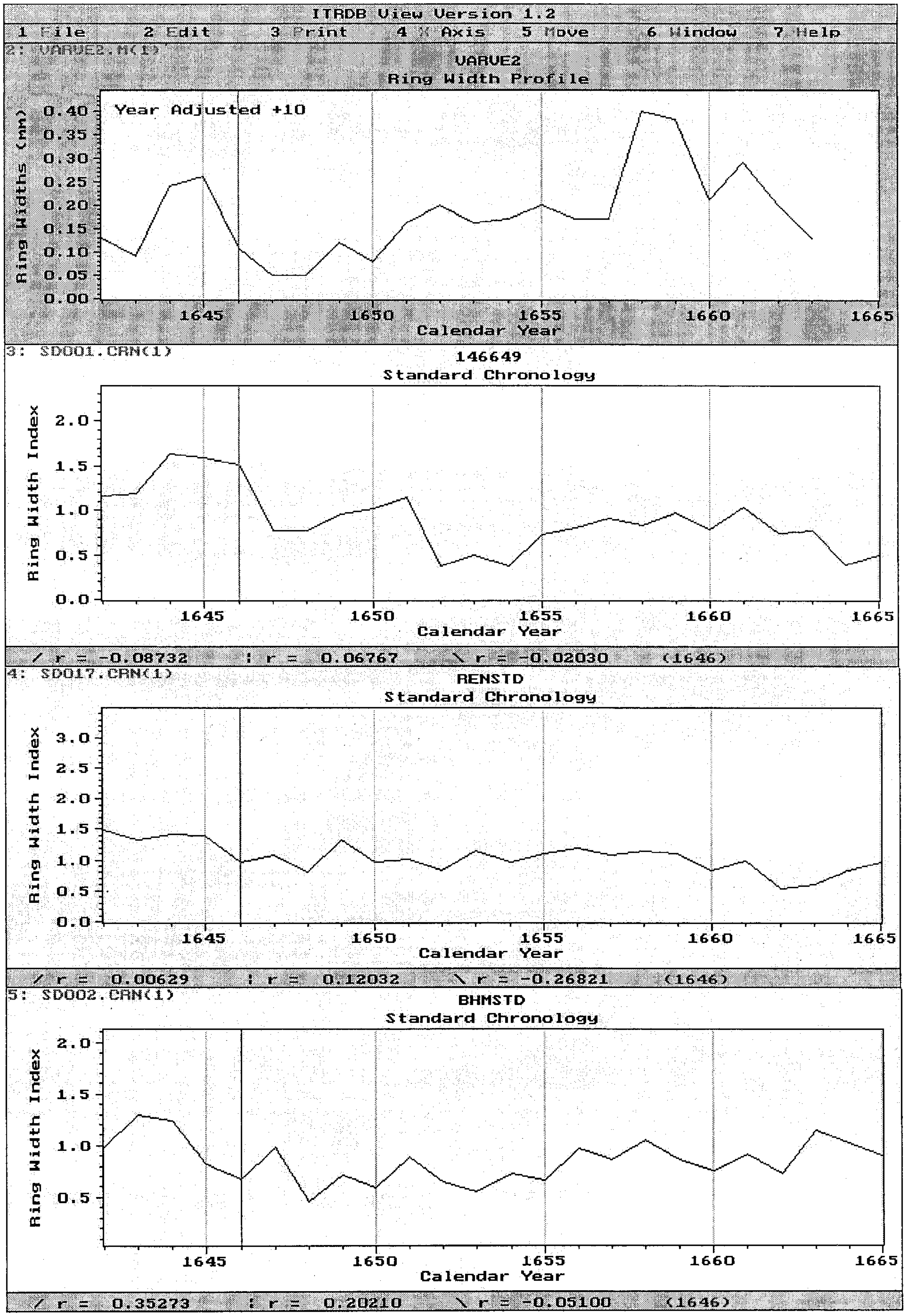


```
/ r = -0.19228     ! r =  0.22915     \ r = -0.05650     (1631)
```

```
/ r =  0.05209     ! r =  0.26484     \ r =  0.16251     (1631)
```

```
/ r = -0.09251     ! r =  0.09117     \ r = -0.19653     (1631)
```

Bivariate plot comparisons of varve series and tree ring chronologies, SD-1, SD-17, and SD-2 (A.D. 1596-1638).

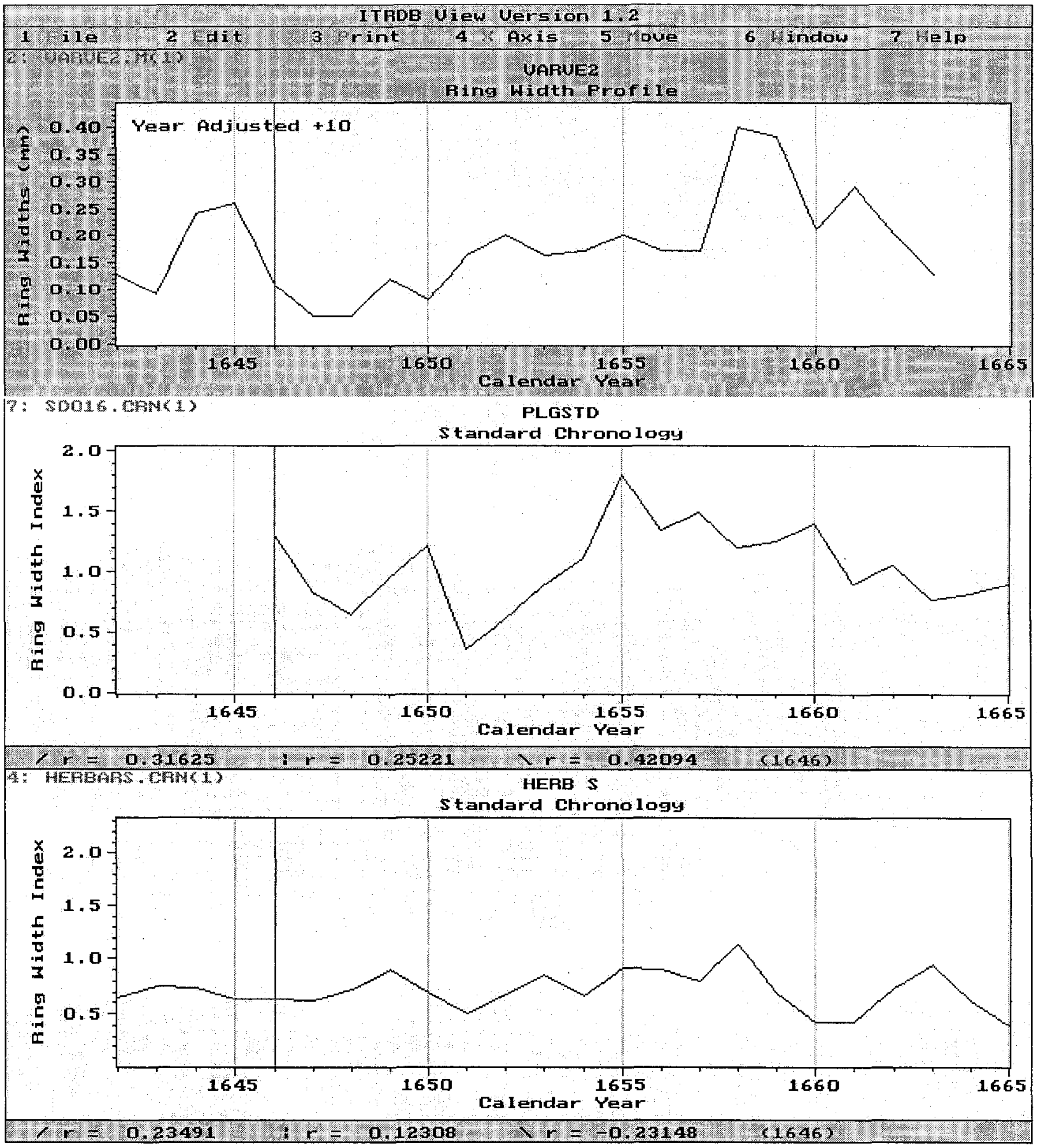


/ r = -0.08732 : r = 0.06767 \ r = -0.02030 (1646)

/ r = 0.00629 : r = 0.12032 \ r = -0.26821 (1646)

/ r = 0.35273 : r = 0.20210 \ r = -0.05100 (1646)

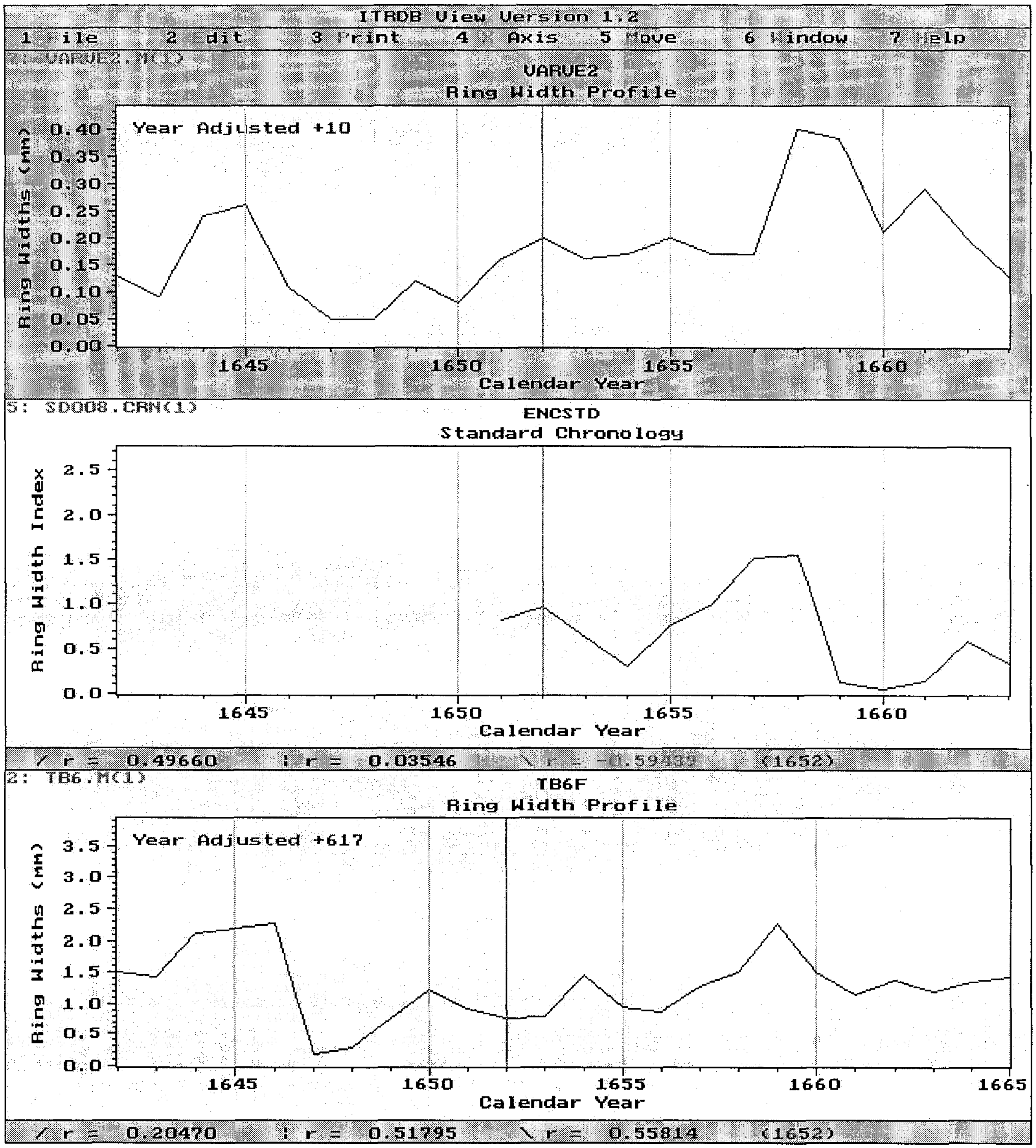
Bivariate plot comparisons of varve series and higher elevation tree ring chronologies, SD-1, SD-17, and SD-2 (A.D. 1642-1663).



```
/ r =  0.31625     : r =  0.25221     \ r =  0.42094     (1646)
```

```
/ r =  0.23491     : r =  0.12308     \ r = -0.23148     (1646)
```

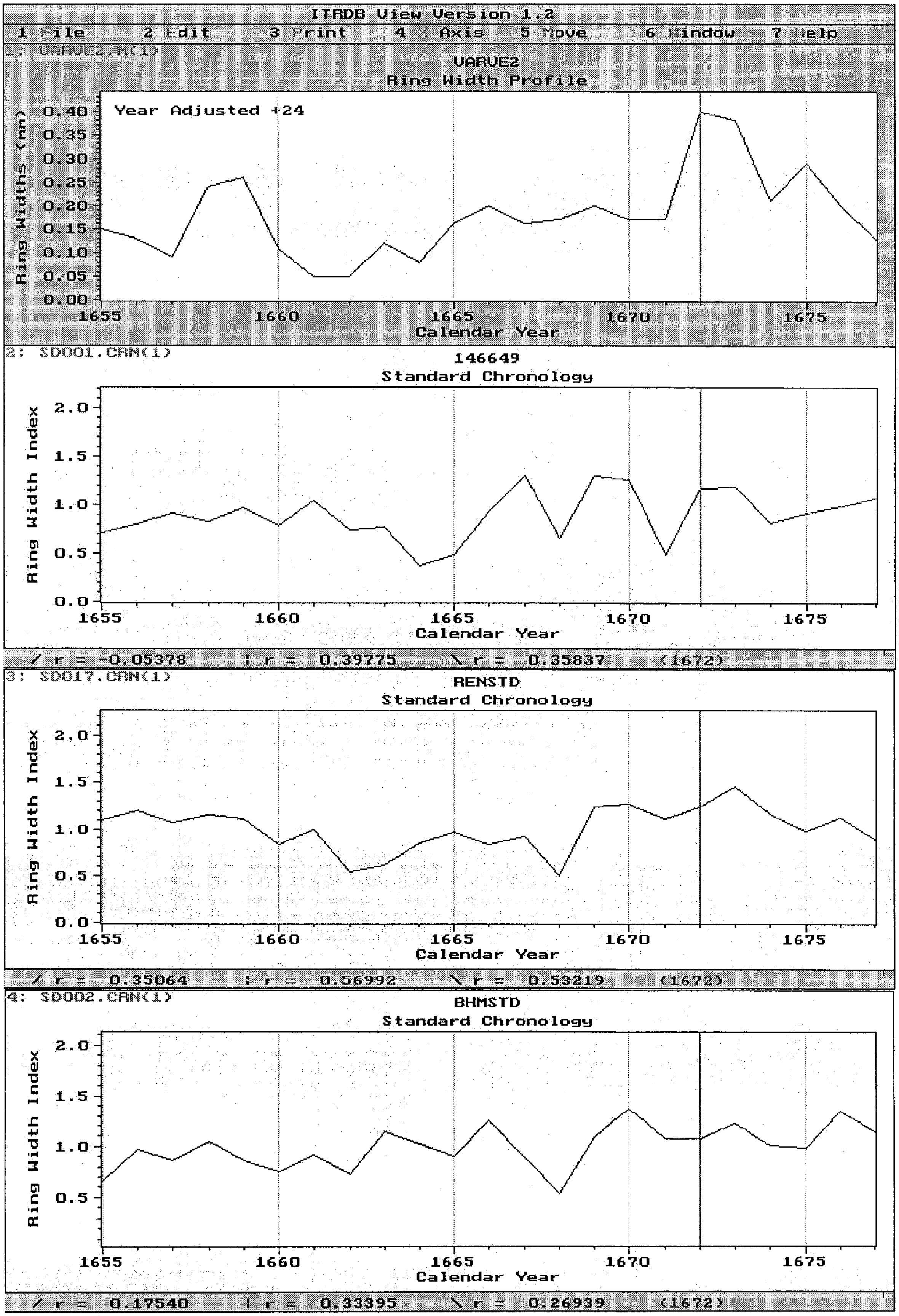
Bivariate plot comparisons of varve series and higher elevation tree ring chronologies, SD-16, and Herbert Draw (A.D. 1642-1663).



```
/ r =  0.49660     : r =  0.03546     \ r = -0.59439     (1652)
```

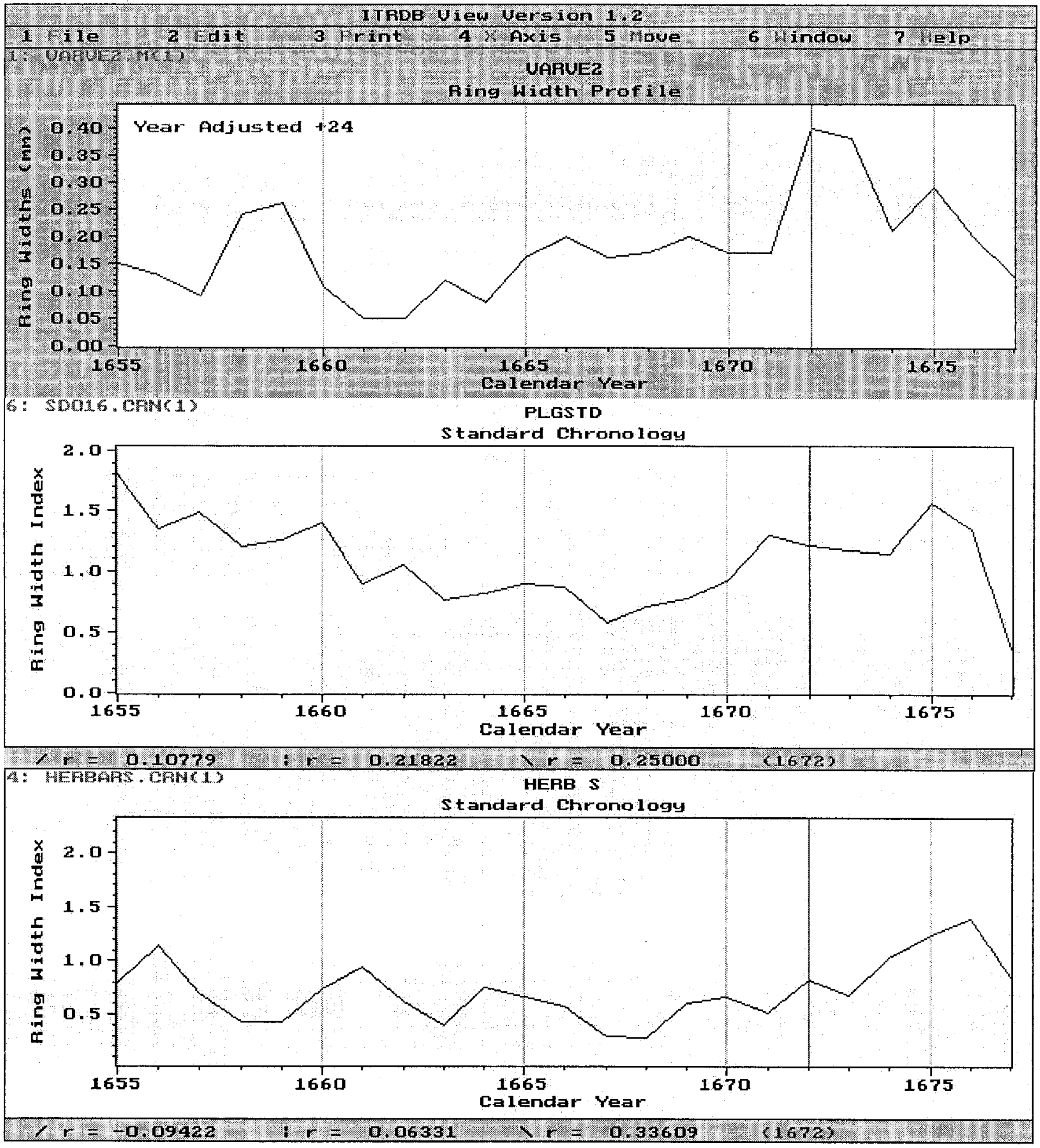
```
/ r =  0.20470     : r =  0.51795     \ r =  0.55814     (1652)
```

Bivariate plot comparisons of varve series and lower elevation tree ring chronologies, SD-8 and TB-6 (A.D. 1642-1663).



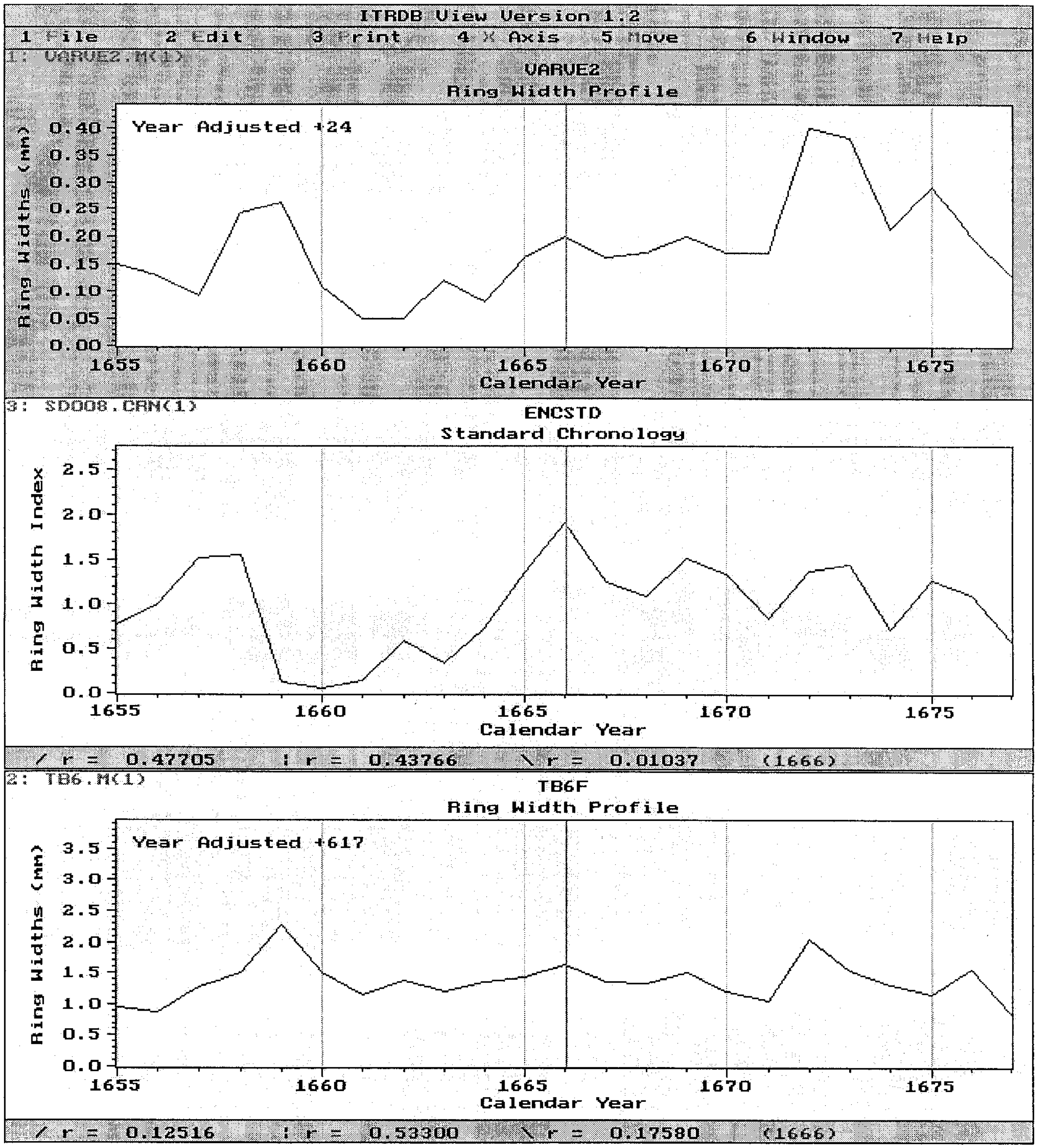
```
/ r = -0.05378   ¦ r =  0.39775   \ r =  0.35837   (1672)
/ r =  0.35064   ¦ r =  0.56992   \ r =  0.53219   (1672)
/ r =  0.17540   ¦ r =  0.33395   \ r =  0.26939   (1672)
```

Bivariate plot comparisons of varve series and higher elevation tree ring chronologies, SD- 1, SD-17, and SD-2 (A.D. 1655-1677).



```
/ r =  0.10779     : r =  0.21822     \ r =  0.25000     (1672)
/ r = -0.09422     : r =  0.06331     \ r =  0.33609     (1672)
```

Bivariate plot comparisons of varve series and higher elevation tree ring chronologies, SD-16, and Herbert Draw (A.D. 1655-1677).



```
/ r =  0.47705    | r =  0.43766    \ r =  0.01037    (1666)
```

```
/ r =  0.12516    | r =  0.53300    \ r =  0.17580    (1666)
```

Bivariate plot comparisons of varve series and lower elevation tree ring chronologies, SD-8 and TB-6 (A.D. 1655-1677).