Abstract. The zenith of Anasazi Pueblo Indian occupation in the northern Colorado Plateau region of the southwestern U.S.A. coincides with the Little Climatic Optimum or Medieval Warm Period (A.D. 900–1300), and its demise coincides with the commencement of the Little Ice Age. Indexes of winter (jet-stream derived) and summer (monsoon derived) precipitation and growing season length were developed for the La Plata Mountains region of southwestern Colorado. The results show that during the height of the Little Climatic Optimum (A.D. 1000–1100) the region was characterized by a relatively long growing season and by a potential dry farming zone or elevational belt (currently located between 2,000 m and 2,300 m elevation) that was twice as wide as present and could support Anasazi upland dry farming down to at least 1,600 m, an elevation that is quite impossible to dry farm today because of insufficient soil moisture. This expanded dry-farm belt is attributable to a more vigorous circulation regime characterized by both greater winter and summer precipitation than that of today. Between A.D. 1100 and 1300 the potential dry-farm belt narrowed and finally disappeared with the onset of a period of markedly colder and drier conditions than currently exist. Finally, when the Little Ice Age terminated in the mid A.D. 1800s and warmer, wetter conditions returned to the region, another group of farmers (modern Anglos) were able to dry farm the area.

1. Introduction

According to the greenhouse theory, during the next decades and centuries global climatic variation will exceed the historical records as the lower atmosphere warms in response to a rise in concentrations of carbon dioxide, methane, and other gases (Houghton et al., 1990). The sharp contrast between the large predicted future change and the small climatic changes of the last century indicates that this latter period may offer an insufficient basis for appreciating the projected future climate and vegetation changes. Examination of larger-than-historic climatic changes that have occurred in the past, in specific locations, may provide a context for evaluating possible future changes (Schneider, 1986). Estimates of regional climate cannot be viewed in isolation but must be viewed as part of a larger continental and global system to understand fully the underlying driving mechanisms.

Anyone visiting the prehistoric ruins in the American Southwest leaves with a sense of respect for the ancient dwellers, the construction of their dwellings, and
the balance they achieved with nature. The latter aspect is particularly interesting because these ancient people relied so heavily on agriculture in an area recognized for its arid climate and, in some regions, relatively high elevation. The earliest populations before the time of Christ were originally hunters and gatherers, but during the last 2,000 yr they have evolved into three culturally distinct traditions upon stimulus from Mexico. These include the Mogollon or Western Pueblo, the more widespread Anasazi Pueblo of the northern Southwest, and the regionally restricted Hohokam culture, which was confined to the Salt and Gila River drainages of southern Arizona. By A.D. 900 (Figure 1), these cultural traditions had developed advanced and flourishing societies, farming corn, beans, and squash, and supplementing their diet by hunting and gathering or raising food, such as turkeys.

By A.D. 1100 the Anasazi (which, in this case, also includes the corn-growing Fremont and Sevier-Fremont groups of present-day Utah) had reached their most northern extension. Around A.D. 1200, long before any Europeans – or even the Navajo or Apache Indians – arrived in the region, the Anasazi began to abandon most of their former northern territory (currently Colorado and Utah). At the same time, the population in the Rio Grande Valley began to expand rapidly, probably from immigration, and it continued to grow until its peak at about A.D. 1300. Other Anasazi groups migrated to parts of Arizona. By A.D. 1300, the area of Utah and Colorado no longer had evidence of Indian farmers growing corn, suggesting the region had been vacated and during the succeeding several centuries the population of the remaining territory was reduced as other Indian groups and Europeans moved into the southwest United States. However, the Anasazi did not disappear; they probably became the Hopi, Zuni, and other modern Pueblo Indians of northern Arizona and New Mexico, some of which still exist today.

The zenith of Anasazi Pueblo Indian occupation coincides with the Little Climatic Optimum (Medieval Warm Period) of Europe (A.D. 900–1300), a time of purported elevated temperatures compared to those of the present (Lamb, 1977). The exact nature of the climate and vegetation manifested in the Four Corners region (where Utah, Colorado, Arizona, and New Mexico meet) during that time has received only cursory quantification. However, the precarious nature of farming in the Four Corners region has led many researchers to hypothesize that any severe climatic deterioration in the past may have affected the Anasazi's ability to grow corn the same way that it could affect efforts today (see Gumerman, 1988, and references therein).

During recent decades, many scientists have maintained, on the basis of tree-ring evidence, that drought forced the Anasazi from the Four Corners region. However, other scientists refer to indications that there had been earlier droughts that were as serious, yet the Anasazi did not leave during those droughts (Fritts et al., 1965). Some researchers (e.g., Berlin et al., 1977; Bray, 1971; Bryson and Julian, 1963; Martin and Byers, 1965; Smiley, 1961; Woodbury, 1961) have suggested that the demise of the Anasazi culture may coincide with the onset of the Little Ice Age, a time of colder temperatures than the present (Grove, 1988). In many parts of the
world, the Little Ice Age has been described as a time of renewed glacial activity, expanding snowfields and, in some regions, reduced summer monsoons. However, the evidence for the timing, severity, and exact nature of that climatic episode in the Four Corners region generally is unknown.

Presented here is a specific case study of the Anasazi Pueblo Indians' farmers of the Four Corners region of the southwest United States, focusing on the timing,
nature, and range of climatic and vegetation change coincident with the Anasazi occupation and abandonment of that high plateau region. The research summarized here began in 1972 in conjunction with the Salmon Ruins Archaeological Project (northeast New Mexico) and continued as part of the archaeological mitigation effort (1978–1985) necessitated by the U.S. Bureau of Reclamation’s construction of the McPhee Dam and Reservoir on the Dolores River in southwest Colorado (Breternitz et al., 1986; Petersen and Mehringer, 1976; Petersen et al., 1985; Petersen et al., 1987; Petersen, 1988a).

2. The La Plata Mountains Regional Environment

The La Plata Mountains of southwestern Colorado are a remote and picturesque mountain group that protrudes into the eastern edge of the Colorado Plateau 30 km southwest of the main San Juan Mountain front. Contrasting the adjacent relatively arid plateau, the La Plata Mountains and the intervening rugged hill region between them and the San Juan Mountains are well watered and well timbered. Several peaks in the La Plata exceed 3,660 m. The north side of the La Plata Mountains drains into the Dolores River, and the remaining sides flow into the San Juan River (Figure 2).

Although climatic data are not available for the La Plata Mountains specifically, Bradley and Barry (1973) found that precipitation records from stations throughout southwestern Colorado were highly correlated. Climate records (Table I) illustrate increased precipitation and reduced temperature with elevation. Barry and Bradley (1976) indicate a summer lapse rate for the San Juan National Forest in southwest Colorado of −0.82 °C/100 m and an annual lapse rate of −0.59 °C/100 m, while
Betancourt (1984) reports a slightly lower annual figure for southeastern Utah (-0.45 °C/100 m).

The precipitation distribution through the year in the Four Corners region is bimodal (Figure 3), with pronounced cool and warm season maxima, the latter of which has been recognized as a monsoon (Bryson and Lowry, 1955; Huntington, 1914). The monsoon precipitation in the Four Corners region results primarily from moisture sweeping from the south (Figure 4). South and southeast of the monsoon boundary (and mostly at higher elevations where the growing season is still adequate), the modern dry farmers raise summer crops such as corn, beans, and potatoes. North and west of that monsoon boundary at higher elevation, the soil moisture obtained from winter precipitation is usually adequate to allow dry farmers to raise winter and spring wheat. However, by midsummer soil moisture must be supplemented with irrigation to allow the summer crops to mature.

The climatic differences in the 2,300 m of elevational change between the San Juan River and the highest La Plata Mountain peaks provide several vegetation zones. Figure 5 reconstructs the native vegetation circa 1920, which was just before the extensive use of the tractor. The vegetation reconstruction is based on old photographs, historic descriptions, maps, and fossil pollen evidence (Petersen et al., 1985; Petersen et al., 1987).

The extensive stands of sagebrush (Artemisia tridentata) that occur to the west
Fig. 3. Probability at Cortez, Colorado (1931–1961) that a given day of the year would be wet (≥ 0.25 mm precipitation). Heermann et al. (1971) computed daily average probabilities, then transformed these into weekly averages. Plots are on the midpoint of each 7-day period. Smoothing (dotted line) was done using a 9-level, weighted moving binomial running mean (e.g., $T_0' = [T_{-4} + 2T_{-3} + 4T_{-2} + 6T_{-1} + 8T_{-0} + 6T_{+1} + ...]/34$), and hatching shows the period defined here as the summer monsoon.

of the La Plata Mountains led Newberry (1876, p. 84) to name the divide between the San Juan and Dolores rivers (extending from Mesa Verde west to Comb Ridge, near Blanding, Utah) the 'Sage Plain'. This sagebrush-covered plateau (10,360 km²) ranges between 1,500 and 2,100 m elevation (Gregory and Thorpe, 1938). Much of the area today between 2,010 m and 2,380 m elevation has been cleared of natural vegetation and is under dry-land cultivation. In Figure 5 that zone (or elevational belt) of cultivation represents primarily the higher elevations of the pinyon and juniper, most of the big sagebrush, and the lower elevational limit of the montane scrub mapping units. This relatively narrow agricultural belt is farmable because of the good soils and because it is both wet enough (greater than 35.5 cm of annual precipitation – of which 10 cm fall during the warm season) and warm enough (including a greater-than-110-day frost-free season) to allow routine dry farming of such crops as corn, beans, potatoes, and grains (Petersen et al., 1987; U.S. Department of Agriculture, Soil Conservation Service, 1976).

When farming within this belt, contemporary farmers often discover the cultural remains of ancient Anasazi, who farmed corn, beans, and squash on the same land hundreds of years earlier. The flanks of the La Plata Mountains in southwestern Colorado are surrounded by vast areas containing evidence of Anasazi occupation, the most famous being preserved in the boundaries of the Mesa Verde National
3. Research Strategy

In this study, the prehistoric elevation and width of the dry farming belt is reconstructed and contrasted with that of the present, based on the premise that...
knowledge of the history of that belt would be useful in unveiling the history of Anasazi settlement and movement. This is because the climatic factors that affect horticulture (i.e., sufficient growing season and moisture for dry farming) are generally the same factors affecting the natural plant community distribution and composition. The index used for hypothesizing the width of the dry-farming belt is the changing width and elevation of the spruce (\textit{Picea engelmannii}) forest zone in the La Plata Mountains. This index was obtained by analyzing pollen records from two different elevations within the spruce zone. The lower-elevation record provided a history of the moisture-dependent lower-elevation spruce boundary while the upper-elevation record provided a history of the temperature-dependent timberline. Because spruce growth responds differently to climate variations at different elevations, the combined radiocarbon-dated pollen records from the two sites yield climate information not obtainable from either site alone. In addition, the changing...
record of pinyon (*Pinus edulis*) pollen, which wafted up from the surrounding lowlands and was deposited at the lower pollen site, is used as a measure of the changing number of pinyon trees on the landscape. A third pollen site that occurs within the potential dry-farm belt was used to verify some of the reconstructions obtained from the pollen records in the spruce forest. Some of the more important findings are summarized here; additional detail is reported elsewhere (Petersen et al., 1985; Petersen et al., 1987; Petersen, 1988a).

4. Results and Discussion

*Location of Pollen Sites and the Spruce Forest Zone.* Twin Lakes and Beef Pasture are located on the west slope of the La Plata Mountains, 45 km east of Cortez, Colorado, near the drainage divide between the Dolores and San Juan rivers (Figure 5). Twin Lakes (3290 m; NE1/4 SE1/4 NE1/4, sec. 18, T37N, R11W, La Plata, Colorado, 7.5 minute quadrangle) is 250 m below timberline in a depression near the headward snout of a landslide (Petersen and Mehringer, 1976). Twin Lakes and the adjacent sedge meadow are surrounded by an open Engelmann spruce and subalpine fir (*Abies lasiocarpa*) forest that has been logged recently.

Beef Pasture (3,060 m; $1/2 SW1/4$, sec. 11, T37N, R12W, Rampart Hills, Colorado, 7.5 minute quadrangle) is an open 75-ha grass and sedge meadow surrounded by a mixed-conifer forest at the lower limit of the dense spruce-fir forest. The surrounding trees are spruce, Douglas-fir (*Pseudotsuga menziesii*), and aspen (*Populus tremuloides*).

The next lower vegetation zone in the La Plata Mountains is the Montane Forest (Figure 5), which has Ponderosa pine (*Pinus ponderosa*) and oak (*Quercus gambelii*). Ponderosa is generally limited to between 2,250 and 2,750 m in elevation.

Confirmation of some aspects of the La Plata Mountain paleoenvironmental reconstruction are provided by a third pollen site, Sagehen Marsh (2,085 m; SW1/4 NE14; sec 36, T38N, R16W, Trible Point, Colorado, 7.5 minute quadrangle), located in the Dolores Project area in a valley that drains into the Dolores River (Petersen et al., 1985; Petersen, 1985). Sagehen Marsh was dammed by an alluvial fan and surrounded by a mosaic of sagebrush, pinyon (*Pinus edulis*), juniper (*Juniperus osteosperma* and *Juniperus scopulorum*), and oak before being submersed in the McPhee Reservoir.

The stippled area in Figure 6 indicates the zone of relatively dense spruce around Twin Lakes in the La Plata Mountains. Results of surface pollen studies and documented historic changes indicate that the large, heavy spruce pollen does not travel very far from the source tree (King, 1967; Maher, 1963; Wright, 1952) and so is a good indicator of the proximity of the trees. The location of the two pollen sites makes them especially sensitive to the changes in the width of the spruce forest. A depression of upper timberline of only 100 m would decrease the area occupied by forest nearly 25 km², doubling the area above timberline. Actually, the pollen record at Twin Lakes does respond to changes in elevation of upper timberline,
especially to timberline receding to lower elevations. Beef Pasture’s location (at the current lower elevational limit of dense spruce forest) makes it particularly sensitive to the elevational changes in that boundary.

**Dating and Pollen Zones.** Age determination of vegetation change in the La Plata Mountains is aided by 17 radiocarbon dates (Figure 7). Because Beef Pasture accumulated almost twice as much sediment over the last 5,600 yr, the depth scales in Figure 7 have been adjusted to allow clear comparison with Twin Lakes. The lines between samples are approximations based on visual judgement. This approach (instead of using a linear regression) was used because of the apparent correspondence in the depositional histories between the two sites. The sediments from both sites are primarily peats that have been shown, in some environments, to have varying rates of deposition depending on the prevailing climate. Slower accumulation rates usually occur during period of shorter, colder, drier summers, while faster rates occur during longer, warmer, wetter summers (Malaurie *et al.*, 1972, p. 116; Nichols, 1975, pp. 60–70; Short and Nichols, 1977, p. 288). Examination of the deposition rate curves for both Twin Lakes and Beef Pasture between 5,000 and 2,500 yr B.P. show marked similarities. For instance, the deposition rate between 3,000 and 2,500 yr B.P. increased at each site, and the comparable age estimates for the zone 3/4 boundary (approximately 3,400 yr B.P.) and the zone 4/5 boundary (approximately 2,700 yr B.P.) are relatively constrained by radiocarbon dates.
A computer clustering program was used to collect adjacent pollen samples into groups that were most similar. The assumption is that a climate change long and severe enough to affect vegetation in the La Plata Mountains would be reflected at a site by the clustering of samples into another group (Petersen, 1988a). The grouped samples were collected into a number of pollen zones, and the zones were numbered from bottom to top (Figure 7). Zone boundaries for each site were drawn to fall precisely on a single pollen sample so that the correlation of zone boundaries between the two pollen sites would be unambiguous. The radiocarbon age of the sample falling on the zone boundary was estimated as shown in Figure 7. Zone boundaries important to this study include those for zones 4/5, 5/6, and 6/7.

To facilitate correlation between dated regional Anasazi archeological sites and the La Plata Mountain pollen sequence the pollen sample ages were converted from the estimated radiocarbon ages derived from Figure 7 to tree-ring calibrated calendar dates. That conversion is discussed in more detail in the following sections. The results are believed to be satisfactory, but the imprecision of radiocarbon dates is clearly a weak link in a study that demands high-resolution dating.

Pollen Ratios and Their Historic Climatic Calibration. The interpretation of vegetation change presented here relies heavily on specific pollen ratios from Twin Lakes and Beef Pastures. At Beef Pasture, near the lower spruce-forest border, the
spruce to pine pollen-ratio curve was selected as the best record of the movement of the lower limit of the spruce forest. Pinyon and ponderosa pine trees are the major contributors to the pine portion of this ratio, and are trees that grow at elevations below the spruce zone. To visually display the relative elevational changes in the lower spruce border (Figure 8) the ratio value is plotted on a negative y-axis that starts at zero and increases downward. Thus, increases in the spruce/pine ratio at Beef Pasture are plotted farther from the origin and represent, relatively, a lowered elevation limit for the lower spruce zone boundary.

Repeat photographs in the La Plata Mountains and surrounding regions document historic thickening (i.e., increase in density) and expansion to lower elevations of the lower spruce forest border over the last 100 yr (Petersen, 1988a). This expansion has occurred despite the impact of logging and/or grazing. This forest expansion probably corresponds to a concomitant increase in effective moisture early this century, primarily in the form of increased winter or spring snow pack the highest in the last 400 yr (Stockton, 1976; Thomas, 1959). Spruce is relatively shallow rooted and cannot tolerate much soil drought, so a decrease in effective moisture would be detrimental to tree survival, while an increase in effective moisture (especially snow) should foster growth (Dix and Richards, 1976; Daubenmire,
At Twin Lakes, the proportion of conifer pollen (spruce + fir + pine) to pollen from nonarboreal plants (NAP) is selected to represent the relative fluctuations of the timberline (Figure 8) as it has been done in Europe (e.g., Patzelt, 1974). This ratio, rather than that used at Beef Pasture, was chosen because the Twin Lakes area recently was logged, thus artificially removing some spruce trees and probably affecting the modern Twin Lakes spruce-to-pine ratio. The ratio of all conifers to NAP was used to offset the effect of modern logging because less weight is given specifically to spruce in the ratio.

Repeat photographs document that the tree-line in the La Plata Mountains has risen about 50 m in the last 100 yr, and there has been a concomitant change in tree-growth form at the tree-line where krummholz form has changed to non-krummholz growth form. Rings from trees at timberline have changed from narrow to wide, coinciding with the extension of the growing season at the lower elevation during part of the same time period (Petersen, 1988a). Because the major limiting climatic factor for tree growth near timberline is summer temperature (Daubenmire, 1954; Tranquillini, 1979; Wardle, 1974), these changes indicate an increase in summer temperature from last century to this century.

The present pollen ratios at the modern surface of Twin Lakes and Beef Pasture (Figure 8) may be too high. Thousands of hectares of sagebrush and pinyon were cleared by modern farmers in the region after 1920 (Petersen et al., 1987). Because these plants are wind pollinated, their pollen is widely distributed beyond the source plants. Extensive removal (such as the clearance by farmers) of these pollen sources would tend to decrease their proportion in the pollen rain deposited in the spruce forest and probably would enhance the relative proportion of spruce pollen deposited. The historic expansion at both the upper and lower limit of the spruce forest in the La Plata Mountains is documented, but the magnitude of that expansion as reflected in the modern surface pollen ratios at Twin Lakes and Beef Pasture (Figure 8) probably is exaggerated because of the bias introduced by the lowland clearing. The unbiased ratio should be below that of the modern but higher than the mean lines shown in Figure 8. At Beef Pasture, the ratio values of \( \geq 0.60 \) are considered representative of conditions similar to those that have occurred historically, and values lower than these are considered drier.

**Correlation and Dating of Twin Lakes and Beef Pasture Records.** The age assignment given to each of the pollen samples in Figure 8 depends on many critical assumptions. One of these is that pollen zone boundaries can be correlated between the two sites. Zone 4/5 boundary (at the left edge of Figure 8) was assigned using radiocarbon dating, the results of the pollen sample clustering computer program, and the pollen ratio signature just to the right that indicates a relatively short period of time, characterized by a very narrow spruce forest. Because the recovery of the forest seems to be as rapid as the onset, the trees located near the climatically stressed upper and lower margin of the spruce forest zone simply may have cur-
TABLE II: Radiocarbon Dates Presented in this Study

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<td>A.D. 643 (661) 682</td>
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* Damon et al. (1974).
** Stuiver and Reimer (1986).
*** Klein et al. (1982).

tailed pollen production temporarily, recovering when conditions improved (Hevly, 1981; Nichols, 1975, pp. 28–29) rather than reflecting only the loss of trees, which were later replaced by seedlings that grew to mature pollen producing trees. Another such narrow forest episode, along with the computer pollen clustering results, was used to correlate the samples on the zone 5/6 boundary. Finally, the correlation for zone 6/7 boundary was accomplished by aligning the samples showing the broadest spruce forest zone down core from the present.

None of these three anchor points have radiocarbon dates that coincide directly with them, but each has a date closely associated with it. Initially, the tables of Damon et al. (1974) were used to convert the radiocarbon age of the radiocarbon sample to a tree-ring corrected calendar age. Because the bracketing range of the standard deviation on the radiocarbon dates (Table II) is in excess of 100 yr, the calendar dates for the zone boundaries were not assigned in increments of less than a half century. The radiocarbon dates from both Twin Lakes and Beef Pasture were used to constrain the earliest narrow spruce zone episode shown on the extreme left of Figure 8; it was assigned an age of 800 B.C. The zone 4/5 boundary that falls on the left edge of the figure was assigned a calendar age of 900 B.C.; A.D. 550 was assigned to the zone 5/6 boundary; and A.D. 1100 was assigned to the widest spruce forest of zone 6 at the zone 6/7 boundary.
Once the calendar ages were assigned to the zone boundaries, the deposition curve based on those in Figure 7 was used to assign appropriate calendar ages to every sample using their intersection with the deposition rate curve (i.e., the rate of deposition was not assumed to be constant between zone boundaries). These ages then were used to plot the pollen ratios and pinyon values in Figure 8. When Stuiver and Reimer (1986) became available, the conversions to tree-ring corrected calendar dates (Table II) were compared; the data comparison indicated that the zone 6 boundaries could be shifted slightly. However, based on the results of tree-ring correlation (which is discussed in the following sections), the original dates were retained.

**Correlation and Relative Calibration of the La Plata Mountain Pollen Ratio Record with Tree-Ring Indices.** In this study, long tree-ring records from high-elevation trees near timberline were sought as a climate proxy to be compared with that of the La Plata Mountain pollen records. A model of the relationship between tree growth and climate has been devised by Fritts (1976) that shows that stored food reserves are the link between the previous year’s climate and current year’s growth. That is, the food reserves (and its manifestation in a resultant tree-ring width) are constrained in trees growing at low elevations by moisture, whereas at high elevation, reserves are constrained primarily by summer temperature. In the latter case, the summer must be long enough or warm enough to allow production of adequate food reserves to be used for respiration and needle replacement requirements. In addition, the reserves must be sufficient for ring production the following year; the larger surplus values correlate to wider rings, so the warmer summers lead to wider rings.

LaMarche and Stockton (1974) obtained ring width records for high-elevation bristlecone pine (*Pinus aristata*) from Almagre Mountain (near Pikes Peak, Colorado). The Almagre record was selected for this study because it was the longest regional record that could be used to reconstruct summer warmth. The published yearly indices (Drew, 1974) were used to obtain the average for each successive 20-yr mean, which was plotted in Figure 8 on the 11th year. Changes in these tree-ring indices reflect long-term changes in summer temperature. A decrease in the indices indicates a lower relative summer temperature (or, for the purposes of this report, probably a shorter growing season; see Petersen (1988a) for a more complete discussion). Points of correlation between the Almagre and Twin Lakes records are shown by arrows in Figure 8.

In addition to the record from Almagre Mountain, many high-elevation bristlecone pine records for the western United States show very narrow rings for the mid-1800s (LaMarche and Stockton, 1974), coinciding with an intense cold period documented by deposition of Little Ice Age glacial moraine in the mountains of the western United States (Porter, 1986). Tree rings of timberline spruce trees in the La Plata Mountains also show very narrow rings for the mid-1800s (Petersen, 1988a). Scuderi (1990) reports narrow tree rings recorded for high-elevation fox...
tail pine (*Pinus balfouriana*) in the Sierra Nevadas of California for the mid-1800s, which he correlates to similarly aged lichen-dated glacial moraines.

As evident from Figure 8, the spruce forest in the La Platas was relatively narrow in the mid-1800s. According to LaMarche (1974), the tree-ring widths from bristlecone pines (in the White Mountains of eastern California), located near their upper and lower elevational ranges, are indicative of conditions that were relatively cold (based on narrow rings in high-elevation trees) and dry (based on narrow rings in low-elevation trees), compared to current conditions.

As discussed previously, pollen zone 6 begins at Twin Lakes with a very low ratio of conifer/NAP in A.D. 500s. Additional corroborative evidence for a widely spread cold episode during the 6th century is provided by Scuderi (1990), who reports narrow tree rings at that time in high-elevation fox tail pine records (for the Sierra Nevadas), which he correlates with similarly aged lichen-dated glacial moraines.

An Index of Pinyon, a Proxy for the Summer Monsoon. The bottom panel of Figure 8 plots the number of pinyon pollen grains falling on a 1 cm² surface area during 1 yr at Beef Pasture. These figures were calculated using the deposition rate curve based on Figure 7 to estimate the rate (cm/yr) applicable for each sample. This was obtained by calculating the slope of the tangent at the point where the sample depth intersects the deposition curve. This figure (cm/yr) was then multiplied by the pinyon pollen content from each sample (grains/cm³) as estimated by using the *Lycopodium* spore tracers introduced for that purpose. This gave a yearly pinyon pollen influx value of pollen grains per square centimeter per year (grains/cm²/yr).

Changes in pinyon pollen absolute influx values are evident for the past 200 yr; Figure 8 indicates an increase followed by a decrease. This reflects the actual history of pinyon trees on the landscape. Beginning in the last century, pinyon has been expanding its range in the Four Corners region (Erdman, 1970, p. 21; Spencer, 1964, p. 148; Van Pelt, 1978). That trend probably would have continued in the Great Sage Plain, except for the extensive clearing for farming. A 20-fold increase (from 105 to 1,988 grains/cm²/yr) in pinyon pollen accumulation is evident at Beef Pasture for samples dated between A.D. 1750 and 1890. After 1890, pinyon pollen influx decreased steadily at Beef Pasture to 458 grains/cm²/yr (a 4-fold decrease) in a sample dating to 1970. The record at Sagehen Marsh has even tighter chronological control and clearly records the same pattern (Petersen, 1985; Petersen et al., 1987).

Summer rainfall seems critical for pinyon seedling establishment and tree growth. Physiological adaptations such as root characteristics, large seed, needle form and number, cuticle thickness, and small growth form all seem to be special adaptations that take advantage of summer precipitation (Daubenmire, 1943, p. 11; Emerson, 1932; Wells, 1979, p. 318). In addition, there is a coincidence between the geographical distribution of summer rainfall in the west and that of pinyon. Arguments are presented elsewhere (Petersen, 1985; Petersen, 1988a) to substan-
tiate pinyon as a good index for long-term changes in the relative strength of the summer monsoon and Davis (this volume) provides some corroborative evidence for that conclusion. When the monsoon is weak, it arrives later, does not penetrate as far to the northwest (Figure 4), and leaves earlier. When it is strong, just the opposite is true. Figure 8 indicates that during the last 2,800 yr there have been episodes of the monsoon being weaker than the present, and between A.D. 750 and 1150 it was at least as strong as the historic period.

Correlation with Other Records. Schoenwetter (1966) was the first to propose a chronology of fluctuating winter-dominant precipitation during Anasazi occupation of the Four Corner region. He also suggested that the times of low winter precipitation probably were offset by increases of summer precipitation. His independently dated climatic sequence for effective moisture (Schoenwetter, 1966, 1967, 1970; Schoenwetter and Eddy, 1964), and those of Euler et al. (1979) and Dean et al. (1985) closely match the timing and direction of fluctuations presented here. (See Samuels and Betancourt, 1982 for an alternative explanation for the decrease of pinyon after A.D. 1150 in the Chaco Canyon region of northwest New Mexico.)

Another independently dated test of the Beef Pasture reconstruction is provided by the tallying of the pith dates of ponderosa pine (Pinus ponderosa) timbers that were used in construction by the Anasazi in the Dolores Project area. Dates of ponderosa pine seedlings establishment coincide with springs characterized by higher-than-average precipitation, whereas low spring precipitation or snowpack inhibit establishment (Schubert, 1974). Pith dates of archaeological tree-ring samples may not be able to be applied to the year of tree germination because there is no way of telling whether the sample represents the base of the trunk or a much higher (and therefore later) position on the bole. However, I attempted to overcome this by comparing 25-yr groupings of pith dates with the pollen record. (See Petersen, 1988a, for further details.) The cluster of Dolores pith dates before A.D. 900 (when the record ends) matches the periods reconstructed to be at least as wet at the present (a ratio value greater than 0.60 in Figure 8) (Petersen, 1988a). Additionally, the direction of vegetation change indicated by paired pollen samples from well-dated superimposed archaeological floors of differing age in the Dolores Project (Petersen, 1986) is in agreement with that proposed here.

Bird's Eye View of the Changing Width of the Potential Dry-Farming Belt. The Dolores Project Area is situated near the upper modern limits of the dry-farming belt; this belt, defined by both moisture and temperature, exists within narrow altitudinal limits (Figure 9a). Consequently, prehistoric agricultural activity should have been affected by changes in the elevational extent (width) of the agricultural belt as modern dry farming is today. The reconstructions presented in Figures 9 and 10 are based on an interpretation of the climate indices in Figure 8. The combination of Colorado Front Range tree-ring width data with the Twin Lakes conifers/NAP Climatic Change March 1994
Fig. 9. A bird's eye view of the reconstruction of the relative width of the potential dry-farm beld in southwestern Colorado. (A) Modern and A.D. 600–800, (B) A.D. 800–1000 and 1100–1300.
Fig. 10. A bird’s eye view of the reconstruction of the relative width of the potential dry-farm belt in southwestern Colorado. (A) A.D. 1000–1100, (B) A.D. 1300–1850.
pollen ratio is used to locate the upper elevational limit of the dry-farm belt and described in terms of growing season length. The Beef Pasture spruce/pine ratios are used to locate the lower elevational extent of the dry-farming belt (supplemented with archaeological site distribution data as discussed below) and described in terms of jet-stream derived winter precipitation. Finally, pinyon pollen influx is used to evaluate the risk for dry farming within the farm belt and also is used to characterize the strength of the summer monsoon. The pattern shown in Figure 9a is the historic pattern and represents the reconstruction for the period A.D. 600–800.

At the beginning of the A.D. 600–800 period, after the very narrow spruce zone centered about A.D. 550, the Almagre tree-rings show a very rapid increase in width. The region was emerging from the grips of cold weather of the 6th century. At that time the Anasazi began appearing in large numbers in southwest Colorado (Schlanger, 1988). The rapid warming widened the dry-farming belt to about the same size it is today. The pollen samples dating to the mid A.D. 600s from Sagehen Marsh (Table II) in the Dolores Project area are indistinguishable from the pollen samples that date shortly before the 1920 clearing (Petersen, 1984, 1988b; Petersen et al., 1987). During this period populations grew and the Anasazi thrived.

About A.D. 750, long-term winter drought moved into the area and the agricultural zone narrowed by about half of that today (Figure 9b). That winter drought continued for about 200 yr; however, it was offset somewhat by increased summer convective storms that more commonly discharged precious moisture near the elevation of the potential dry-farm belt, rather than at lower elevations (Farmer and Fletcher, 1971; Petersen et al., 1987). The large population increases that occurred in the Dolores Project area at that time cannot be accounted for by births alone, suggesting that the Anasazi survived by moving their fields to higher elevations and exploiting the narrowed (but still productive) farm-belt (Schlanger, 1988). Historic documents show that about half the farm land in the region (and those from mostly lower elevations in the historic farm belt) was abandoned during the severe drought of the 1930s, providing an analog for a narrowed dry-farm belt (Gregory and Thorpe, 1938; Petersen et al., 1987).

There is a period of narrow tree-ring widths in the Almagre record that dates to the 10th century. A further test of the correlation between narrow tree-ring and summer warmth or growing season length is provided by Dolores Project archaeological data. Areas subject to cold air pooling were mapped in the Dolores Project area, and it was found that although these areas had been almost continuously occupied since the 7th century, they were abandoned by Anasazi farmers for a short time in the 10th century when the Almagre tree-ring record suggests cooling. The farm land was again reoccupied in the 11th century when tree-ring width at timberline again became wider (Breternitz et al., 1986; Petersen et al., 1987).

By A.D. 1000, the climate had warmed to a point that the growing season was adequate for farming in the Dolores Project area, and the summer monsoon moisture was supplemented by a large increase in the amount of winter precipitation. This combination greatly expanded the farming belt, dropping its lower limit to about
1,600 m elevation (Figure 10a), which more than doubled the amount of farmland available, compared to that of today (as shown in Figure 9a). During this time period, there was a tremendous explosion in archeological evidence (locally called the PII expansion) for areas currently below the modern extent of the farm belt.

It is generally accepted that Anasazi dwellings would not be located too far from their corn fields. For instance at Hovenweep National Monument (1,600 m), where there are abundant Anasazi ruins, one cannot grow corn today because the 30 cm of annual precipitation at that elevation is not adequate. In fact, modern farmers cannot obtain crop insurance for dry farming for elevations below 1,830 m (some 230 m higher in elevation) and routine dry farming is not practiced below 2,010 m (Petersen et al., 1987). However, Woosley (1977) found in surface pollen transect on suspected Anasazi dry-farming fields at Hovenweep that there was corn and bean pollen still preserved in the soil by the arid climate. Corn pollen is a relatively large pollen grain that usually does not travel more than a few meters from the source plant and even in modern corn fields is only 1 or 2% of the pollen count (Martin, 1963, p. 50). To find it in such upland field locations suggests that conditions for rainfall farming had to have been drastically different from current conditions. Possibly the combination of the high winter snowpack like the early part of pollen zone 6 (Figure 8) but with added component of additional summer precipitation combined to produce the unprecedented broad farm belt. It was as if there was greater vigor in the general circulation regime whereby more oceanic climate (both summer and winter) were pulled deeper inland (see Wallen (1955) for a possible explanation for such an occurrence earlier this century).

During the period from A.D. 1000 to A.D. 1100 the Anasazi cultures reached their zenith. Populations increased dramatically in the Four Corners region and elsewhere (Figure 1) and developed complex social, economic, and political structures, the most famous of which is preserved in Chaco Canyon National Monument in northeastern New Mexico. The monsoon boundary (Figure 2) most likely was located north of its present location.

Interestingly the expansion of the farm belt at its lower elevational limit in the Four Corners region actually led to a decrease in population in the Dolores Project area (Schlanger, 1988), now located at the uppermost margin. This was most likely because the Anasazi farmers now had a greater choice of land and could avoid the cold air drainage that often occurs in the Dolores River valley proper (Petersen et al., 1987).

Soon after A.D. 1100, another winter drought began to move into the region, narrowing the potential dry-farm belt from the bottom (Figure 9b). As before, the Anasazi adjusted, but unlike the drought of the A.D. 800s (Figure 8), summer rain was not as plentiful or dependable, the summer monsoon boundary was most likely located south of its present locations. Summer rains arrived later, left earlier, and were not as predictable. This time the Anasazi compensated by utilizing a number of water control strategies such as check dams, ditches, and reservoirs (e.g., Erdman et al., 1969).
Then severe, dry cold started to move into the region about A.D. 1200, making farming risky at higher elevations (Figure 8). As the summer and winter drought pinched the farming belt from the bottom, cold pinched it from the top. By A.D. 1200 the Anasazi began leaving the area. The most severe impact of the combination was felt late in the A.D. 1200s, where in effect, the farming belt was squeezed to the point that it disappeared (Figure 10b). The Anasazi simply left the higher elevations of the Four Corners region and headed south, seeking more dependable summer monsoons, sufficient winter precipitation (or areas that could be irrigated), and longer growing seasons (Figure 1).

Interestingly, the cold, dry conditions that began in the A.D. 1200s lasted for hundreds of years – without much change – to about the A.D. 1850s. Because weather stations in the region were mostly established after 1895, somewhat after the change to warmer and wetter conditions that have existed during the last 130 years or so, our modern weather records give little hint of the severity of conditions that had occurred. The narrow tree rings in timberline trees in the La Plata Mountains during this time period is suggestive (Petersen, 1988a). Further, an account by a military expedition led by Col. Macomb into the region in 1859 describes relatively cold conditions. Newberry (1876, pp. 76–77, pp. 88–89) observed a broad surface of snow covering the San Miguel Mountains of the San Juans in early August (today it is gone by early July), and from a site near modern day Yellow Jacket they observed that it was too high, too cold, and too dry to grow corn and other crops in the area. This same locality today supports thousands of hectares of successful dry farming of those very same crops (Petersen et al., 1987; Petersen, 1988a).

In the 1870s, some 20 to 30 yr after Macomb’s and Newberry’s expedition, when white settlers began moving into the area (Figure 9a), the mountain peaks were clear of snow in late summer, young pinyon trees were invading the sagebrush, the spruce forest was beginning to expand, and timberline advance to higher elevations and the rings in timberline trees became wider. All these were signs that the farming belt had rebounded and that the new settlers would find ideal dry-farming conditions with abundant summer and winter precipitation and an adequate growing season. The climate had reverted to conditions similar to those during the 700-yr Anasazi occupation, and the modern farms could locate exactly where the Anasazi had farms during their sojourn in the region.

5. Conclusions

In the next century, increases in atmospheric trace gas concentration could warm the global average temperature beyond what it has ranged during the past century. Examination of larger-than-historic climatic changes that have occurred in the past in specific regions provides realistic context for evaluating such potential future changes. This paper has contrasted the climatic manifestation of the Little Climatic Optimum or Medieval Warm Period (A.D. 900–1300) with that of the Little Ice
Warm and Wet Little Climatic Optimum and a Cold and Dry Little Ice Age

Age (A.D. 1300–1850) in the northern Colorado Plateau region of the southwestern U.S.A. The zenith of the Anasazi occupation coincides with the former and their demise coincides with the latter, when conditions became too cold and especially dry (in the summer) to support upland dry farming. During the height of the Little Climatic Optimum the region was characterized by a relatively long growing season and greater winter and summer precipitation than that of today. This resulted in a relatively rapid development of a potential dry-farming belt that was twice as wide as the present and areas that cannot be dry farmed today were routinely farmed by the Anasazi. Such conditions would be beneficial to dry farmers in the Four Corners region if those conditions were repeated in the near future.

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