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Final Environmental Research Report

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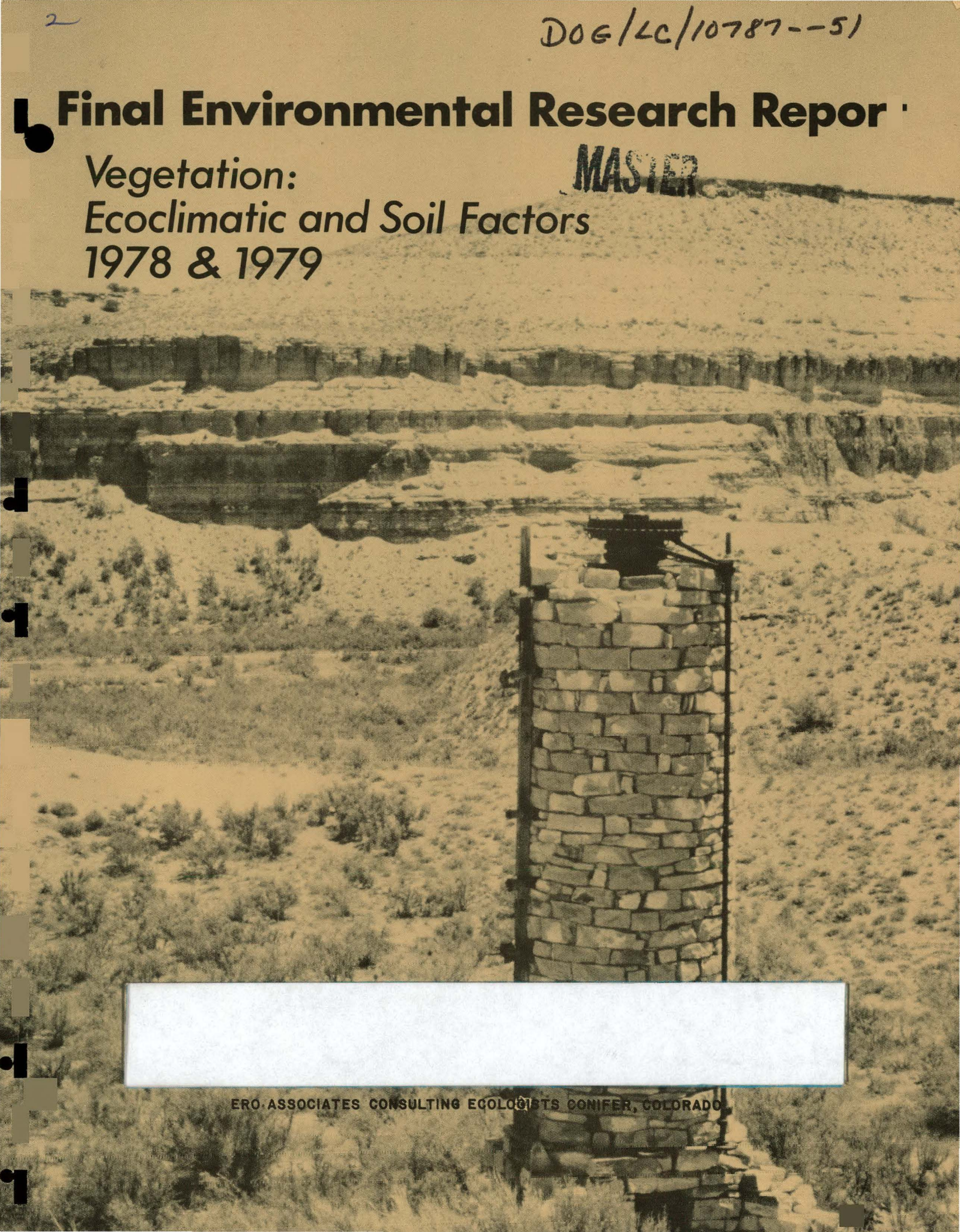
Vegetation: Ecoclimatic and Soil Factors 1978 & 1979



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LOFRECO SITE - GEOKINETICS OIL SHALE PROJECT

UINTAH COUNTY, UTAH

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LOFRECO SITE - GEOKINETICS OIL SHALE PROJECT

UINTAH COUNTY, UTAH

FINAL ENVIRONMENTAL
RESEARCH REPORT:

VEGETATION
ECOCLIMATIC AND SOILS FACTORS
1978-1979

LOFRECO FIELD RESEARCH SITE
GEOKINETICS, INC.
UINTAH COUNTY, UTAH

PREPARED BY
ERO ASSOCIATES, CONSULTING ECOLOGISTS
CONIFER, COLORADO

Erik R. Olgeirson, Ph. D.

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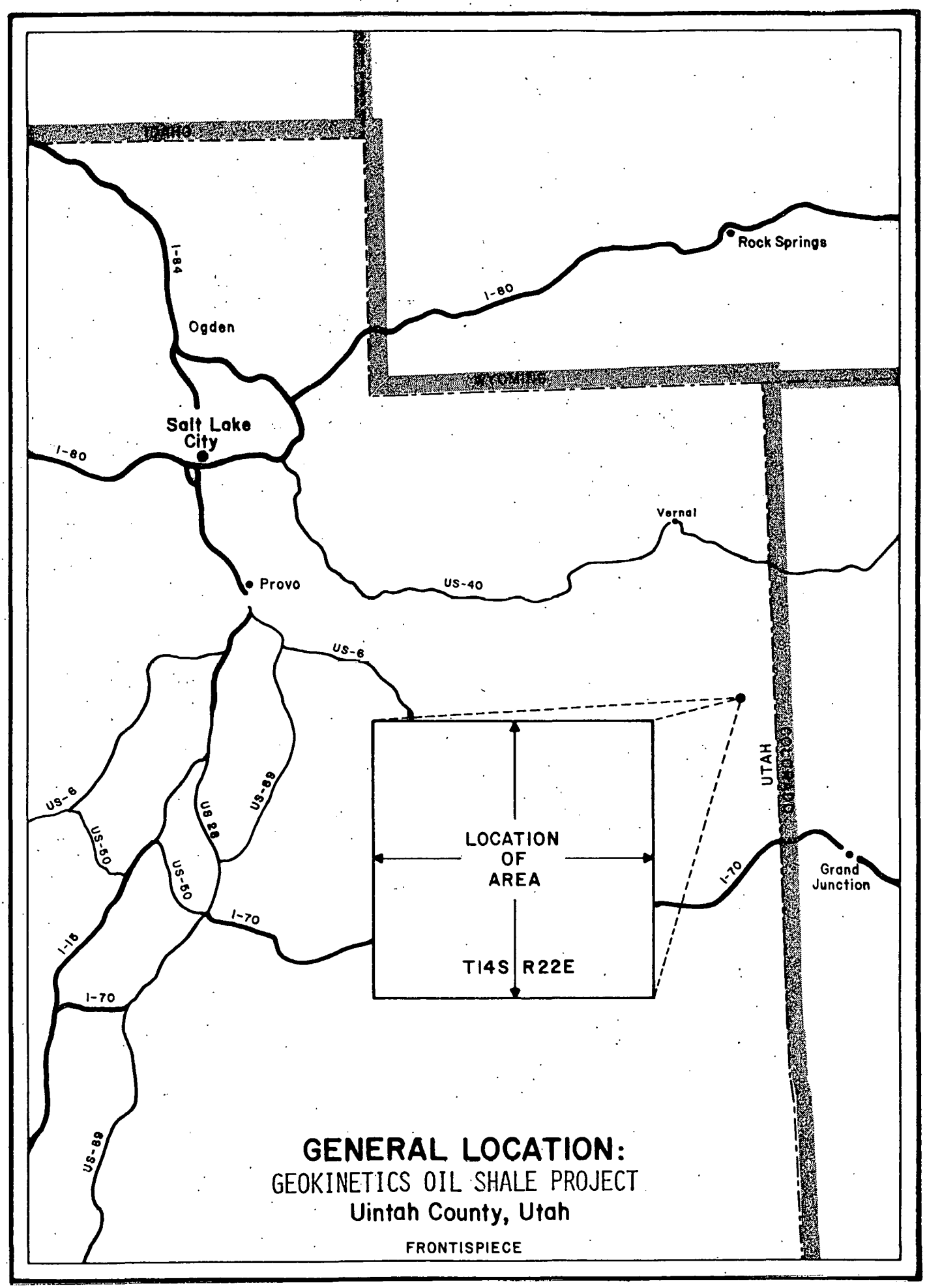
ACKNOWLEDGEMENTS

This environmental report was produced for and financed by Geokinetics, Inc. with partial cooperative funding provided by the United States Department of Energy.

The environmental studies reported in this volume were conducted under the direction of Dr. Erik Olgeirson, ERO Associates. Individuals who contributed to these studies include:

- The management and staff of Geokinetics, Inc. Vernal, Utah and Concord, California, especially Mike Lekus, Hildling Spradlin, Walter Bell, Linda Kinney, Dave Hutchinson, and Ralph Lichtenhann
- The staff of ERO Associates: Steve Dougherty, Carl Mackey, Katie Olgeirson, Marty Pedziwiatr, Marilyn Whitehouse, Craig Sommers, Rod Fosler, Todd Richards, Jane Fosler, Ian Olgeirson, Chris Olgeirson and Woody Neilson
- Larry England, Bureau of Land Management
- Jim Mershon, Western Aquisition, Inc.



GENERAL LOCATION:
GEOKINETICS OIL SHALE PROJECT
Uintah County, Utah

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INTRODUCTION

The Geokinetics Inc., in-situ oil shale retort experimental research site, known as the LOFRECO site, is located in the southern Uintah Basin, Uintah County, Utah. The research site occupies Section 2 of Township 14 South, Range 22 East, approximately 50 miles south of Vernal Utah.

Vegetation studies were begun on the LOFRECO site during the spring of 1978 and continued through the summer of 1979. The principal components of the two year intensive study include collection and analysis of data in the areas of vegetation, ecoclimate, and soils as detailed below:

- Vegetation Studies:
  - Vegetation Mapping
  - Floristics
    - Reconnaissance and collection of vascular plants on the site
    - Rare and endangered species inventory
  - Phytosociological Studies
    - Qualitative and quantitative descriptions of the structural and compositional features of each major vegetation type on the site
  - Primary Productivity Studies
    - Measurement of the above-ground biomass of the herbaceous biomass of the site (shrubby vegetation was also measured in selected areas)
- Ecoclimatological Monitoring Studies
  - Continuous recording measurement of ecoclimatic parameters (temperature and precipitation in the zone influenced by plant growth) in the major vegetation types
- Soil Survey and Analysis Studies
  - Qualitative and quantitative descriptions of the major soil types
  - Quantitative description of the soil characteristics on in-situ retort sites
  - Mapping of major soil series types

This report contains the results of the two-year study, presenting data collected from the three main study topics and interpretive analyses of intra-topical correlations. First year (1978) data, including one-time soil studies, have been previously presented in a series of reports (Olgeirson and Martin 1978, Olgeirson 1979a, 1979b, 1979c). Data collected during the second year of study are presented in this report along with first year information (Appendices A through D and Map Pockets).

The body of the report combines and correlates data from the permanent sampling sites for both of the years studied. Vegetation, soils, and ecoclimate data are considered separately in these discussions. Correlations and interrelationships between the three main topics are discussed in later sections. Conclusions of the studies are given as a summation of the separate and interrelated findings and as a basis for recommended monitoring programs. An attempt has been made to increase readability by restricting the large amount of data to inclusion into textual areas of the report only as summarized figures and tables. Supporting data have all been placed in the appendices.

OBJECTIVES

The objectives of the studies discussed in this report are given below. These primary goals relate operational facets of the in-situ shale oil retort research to the environmental characteritics of the site.

- To produce a descriptive data base that can be applied to an understanding of the carrying capacity of site
- To define dynamic relationships between vegetation and primary factors that influence vegetation, such as soils and ecoclimate
- To use the qualitative and quantitative information obtained in preparing revegetation plans, impact mitigation plans, and long-term monitoring plans
- To employ the qualitative and quantitative data in making distinctions between natural environmental trends and man-induced perturbations

DESCRIPTION OF THE STUDY AREA

The LOFRECO site is located in the Uintah Basin floristic section of the Intermountain West (Cronquist et al. 1972). This area is a cold desert region dominated by open pinyon-juniper woodlands and sagebrush-dominated shrublands. Herbaceous species do not predominate in any of the plant communities of the study site. Cool-season grasses, such as blue grama and western wheatgrass, are an important, but limited, source of forage for domestic cattle. Forbaceous species are infrequent and include a number of ubiquitous species, such as copper globemallow and long-leaf phlox, as well as species known to be restricted to the Uintah Basin including *Townsendia mensana, Parthenium ligulatum, and Eriogonum ephedroides*.

Primary productivity of the area is low in comparison to the Great Plains Province and the adjacent Piceance Basin floristic area. Low rainfall (< 25cm/year)(Bradley 1976) and poor soil quality are the major factors limiting vegetation productivity. Other environmental extremes, particularily temperature, also contribute to the depauperate nature of the vegetation.

Major land uses of the study area include grazing of domestic cattle; wood-cutting; oil and gas exploration; and oil shale exploration. Wildlife utilization of the area is noteably limited (Stoecker 1979).

METHODS

Vegetation Mapping

The final vegetation map for the LOFRECO site (Pocket Figure 1) was produced at a scale of 1" = 200' from aerial photography of the section. The map delineates four major vegetation map units corresponding to those sampled during the two year study. Permanent vegetation sampling plots and eco-climatological monitoring stations are also indicated on the vegetation map.

Soil Mapping

The soil map of the LOFRECO site (Pocket Figure 3) was drawn from aerial photography of the section at a scale of 1" = 200'. This map illustrates the distribution of four major soil mapping units corresponding to the vegetation types sampled.

Floristic Studies

The herbaceous, woody, and succulent flora of the LOFRECO site was studied through systematic ground reconnaissance of the site. This survey was directed toward making collections and identifications of all species occurring in the one-square mile area. A reference collection has been prepared from specimens collected during 1978 and 1979. Species listed as rare, restricted, endangered, and/or threatened in Utah (U.S. Gov't. 1975, Welsh et al. 1975, Welsh 1979) are discussed below and described in Appendix B.

Sampling Site Selection

The location and arrangement of the vegetation, ecoclimate, and soil sampling sites were selected in order to account for the differences potentially resulting from experimental in-situ oil shale retorting activities and those caused by natural trends and cycles. Sampling sites located in each of the major vegetation types (Pocket Figures 1 and 2) are paired so that each vegetation type, its ecoclimate, and its soils, were examined in detail within areas proximal to experimental operations and in other areas remote in terms of these potential perturbations. The sites are termed development and control, respectively.

Phytosociological Studies

Structural and compositional features of the major vegetation types were investigated in permanently located sampling areas. Detailed methods for each vegetation layer occurring in a sampling area (herb layer, shrub layer, and tree layer) are discussed below:

Herb Layer Vegetation

Herbaceous vegetation was sampled using a quadrat method. Twenty, $1m^2$ circular quadrats, permanently located and marked in each vegetation sampling site (Figure 1) were sampled during May of 1978 and 1979. The density and frequency of each herbaceous species occurring in the quadrats were measured. Percent cover by herbaceous plants; litter; soil; rock; mosses and lichens; and woody plants were occularly estimated.

Shrub Layer Vegetation

Shrubs were sampled using a modified line intercept/belt transect (Lindsey 1955). Sampling was conducted during May of 1978 and 1979. Twenty, 4m X 10m permanently located belt transects were used to obtain shrub values. Density and frequency for each species were recorded in the entire 4m X 10m area ($40m^2$); shrub cover was determined along the 10m line intercept (Figure 1).

Tree Layer Vegetation

Trees in woodland stands were sampled during May of 1978, only. The method employed was a point-centered-quarter technique. A total of 48 sampling points were located within the permanent sampling site. Basal area and point-to-point distances were collected for each tree species sampled. The restrictions on sampling included the selection of only live trees, that an individual tree was to be within 13m of the point, and that the diameter-at-breast height of an individual was to be $\geqslant$ 11cm.

Tree cores were taken from 5 individual pinyon pine in order to obtain an approximate age of the woodlands. Cores were prepared, dated, and cross correlated according to standard dendrochronological techniques.

Primary Herbaceous Production Studies

Primary herbaceous productivity sampling grids were established in each of the control and development vegetation study plots (Figure 1). Each sampling grid consists of 100 sampling points identified by ten transects staked and labeled at each end-point. The transects are 27 meters in length. Circular quadrats measuring $0.25m^2$ were located at three meter intervals along the transects.

Herbaceous productivity measurements were made using a double sampling technique. This technique, described in detail below, consists of two segments: 1) an occular estimate and 2) a clip sample. The occular estimate is the larger sample consisting of 100 quadrats. The clip sample consists of 10 quadrats. The clip sample is adjusted in terms of the occular estimate to give a value for the entire plot. (Wilm et al. 1944)

Two samples are taken each growing season. One during approximate peak season and the other at the end of the season. The two samples were compared to show season cycling in the productivity of the herb layer.

Prior to sampling in each grid, ten plots were selected for clipping using a random number generator. The ten quadrats selected were located along the appropriate transects, staked, and labeled. During the entire sampling program no clip quadrat is sampled more than once.

The remaining ninety plots, plus the ten clip plots were estimated occularly during the sampling. Before the occular estimate is started the estimator performs a calibration process consisting of educating himself as to the approximate weight of various fractions to be clipped. This procedure is accomplished by selecting an area outside the sample grid, estimating the various fractions occuring in the 0.25m quadrat, clipping the fractions estimated, and weighing each fraction. This

procedure may be repeated as often as is necessary for the estimator to gain accuracy in occularly determining the weights of samples.

Seven fractions were clipped and estimated during the sampling. These fractions include important life-forms and dominant species, as follows:

- Annual Forbs
- Annual Grasses
- Perennial Forbs
- Perennial Grasses
- Half-Shrubs
- *Agropyron smithii*
- *Bouteloua gracilis*

Clipping was restricted to the standing-live portion of each of these fractions, except in the case of *Bromus tectorum* where all material, including standing-dead, was clipped.

During clipping each fraction was bagged and labeled. Each zip lock bag was marked with the vegetation plot number, clip quadrat number, fraction abbreviation, and sample date.

Occular estimations were begun with the quadrats selected for clipping Occular estimates were made by the same person throughout the sampling to ensure consistency.

Following the sampling period, bagged samples were frozen and transported to laboratory facilities for processing.

In the laboratory, fresh weights of each fraction were determined to the nearest 0.001 gram on a top-loading electronic balance. Each fraction was then dried to a constant weight ($\geqslant$105 C° for 24 hours) and reweighed.

Ecoclimatological Monitoring Studies

Ecoclimatic data were obtained from eight locations on the LOFRECO site. Data stations were established in the eight permanent vegetation sampling sites in 1978. The stations were arranged in pairs: one pair in each of the paired vegetation sampling sites (control and development). The locations of the ecoclimate recording stations are shown on Pocket Figure 1.

Ecoclimatological parameters were recorded at hourly intervals during the growing season (April-May through October-November) of 1978 and 1979. Values measured were recorded on thermal paper tapes, and include the following:

- station number and day of year (DOY)
- time of day (24hour time)
- precipitation (0.001 inches)
- ambient air temperature (°C)
- soil surface temperature (°C)

Recording sensors were placed entirely within the vegetation canopy. Ambient air sensors were placed at a height of 1m in the woodland and lowland sagebrush rabbitbrush sites and at 0.5m in the sagebrush-wheatgrass sites. All soil surface temperatures were placed in the litter/soil surface. Precipitation sensors were placed at a height of 0.75m

The ecoclimatological monitoring stations were manufactured by Western Aquisition, Inc., Grand Valley, Colorado. Electronics and the printing device are housed in a 30 X 30 X 15cm Hoffman-type environmental enclosure mounted on a fixed plate angled 22° and positioned in a south-westerly direction. The stations are powered by a 15 volt gel-cell battery continuously charged by a solar panel mounted in the lid of the environmental enclosure. Temperature sensors are Yellowsprings Instrument Company stainless steel-type. The precipitation collectors are Meterological Research Institute tipping buckets.

Soil Survey and Analysis Studies

Soil mapping units (soil series) were identified using aerial photography and field reconnaissance. Soil mapping units were investigated in the field using standard Soil Conservation Service (SCS) techniques. Soil test pits were dug to a depth approximating the lithological contact of the soil. Each soil was sampled by horizon. Approximately 900gm of soil material was collected from each horizon and bagged in seam-closure type plastic bags for transport to laboratory facilities. See Pocket Figure 3.

The soil mapping units were classified according to SCS nomenclature. Each series was named through information obtained from the Utah State Correlators Office. Soil samples taken from the four native soils were analysed by standard laboratory techniques for the parameters listed in Appendix D.

Soils overlying experimental retorts were sampled along with a control sample. Samples were taken from a depth of approximately 15cm. Sampling was carried out prior to retort blasting and again following retort burning. The control sample was also taken at a depth of 15cm. In order to make comparisons between retort soils and native soils an additional soil sample was taken in the vegetation sampling sites at a depth of from 15 to 46cm. These samples were composite samples consisting of 20 subsamples at each site. The types of analyses performed on retort soils and the native soil composite sample are listed in Appendix D.

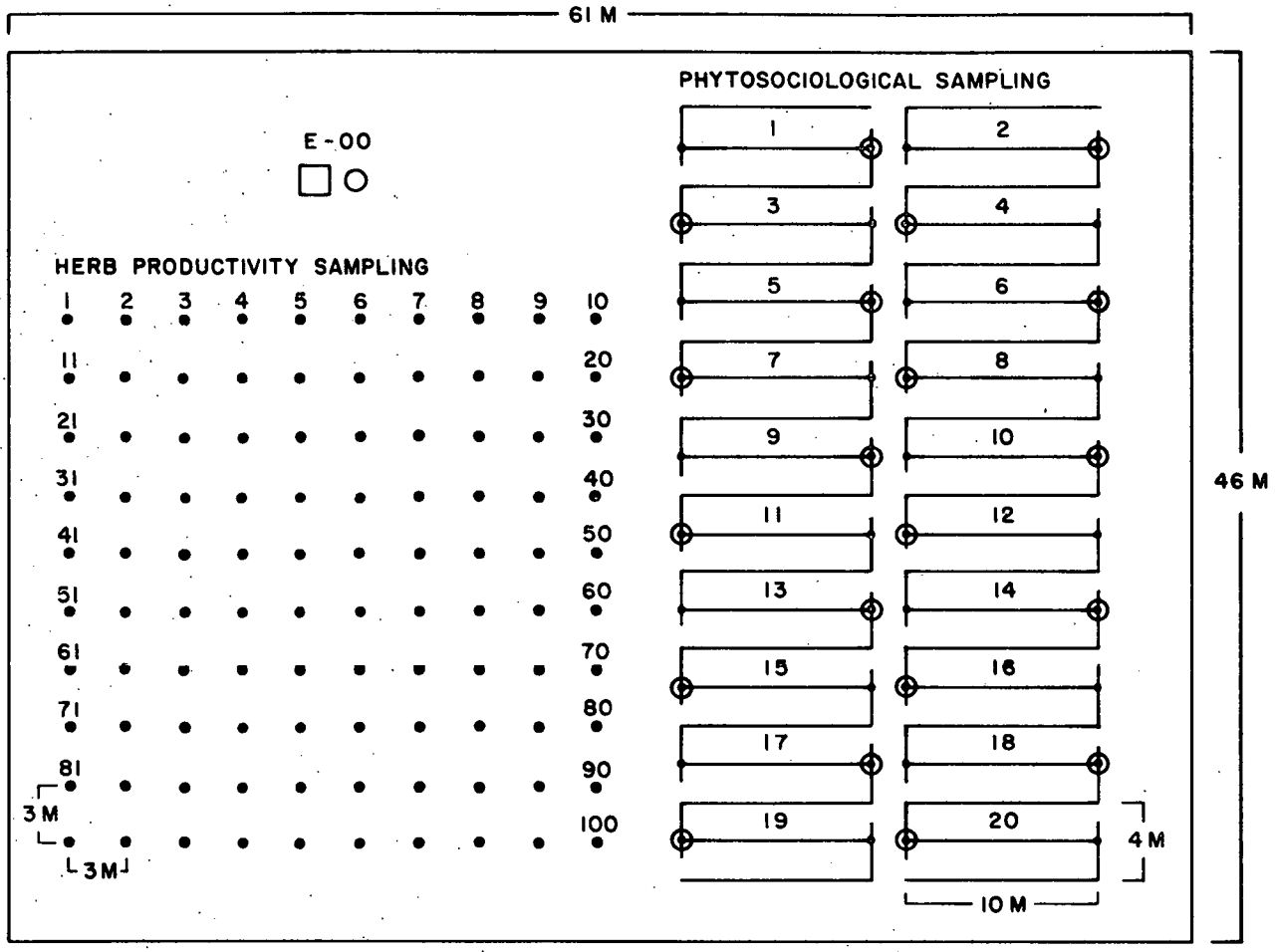
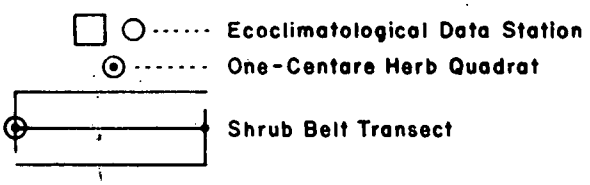


Figure 1

VEGETATION PLOT DESIGN



DATA ANALYSIS AND TREATMENT†

Phytosociological Studies

Vegetation data obtained during 1978 and 1979 sampling was entered into a Wang 2200 MZP mini computer. Data placed in the computer files were subjected to the following types of reduction and analysis:

- summarization of values including frequency, cover, and density (as appropriate) per species and per vegetation sampling site
- calculation of relative frequency, relative cover, and relative density; and importance value (as appropriate) per species and per vegetation sampling site
- one-way analysis of variance to test the differences between the following:
  - values within years for control and development plots including ground cover, herb density, shrub density, shrub cover, tree density, tree cover, and shrub importance value
  - values between years for control or development plots, as above
- coefficient of similarity calculations for the following:
  - values within years for control and development plots including ground cover, herb density, shrub density, shrub cover, tree density, tree cover, and shrub importance value
  - values between years for control or development plots, as above
- sample adequacy for each year for each parameter measured, as above
- linear regression analysis of the following parameters within years for control and development sites:
  - shrub cover-to herb density
  - shrub cover-to-ground cover
  - herb density-to-ground cover

Methods of calculating values in the various tests are detailed in Appendix E.

† In all cases where analyses were performed to test differences between control and development sites or differences among years the null hypothesis, H_o : no difference between parameters tested, was accepted or rejected based on ~0.05 level of confidence.

Primary Productivity Studies

Herbaceous primary productivity data obtained during 1978 and 1979 sampling periods were entered into the computer and manipulated in order to obtain the following analyses:

- double sample regression calculations to adjust estimates to actual clipped dry weight measurements
- summarization of values for each fraction sampled in terms of regression equation values and adjusted dry weight, and calculation of total plot weights
- one-way analysis of variance testing of potential differences between sample means of paired sites (control and development) within 1978 and 1979 and between like sites among 1978 and 1979 values
- linear regression analysis of the following parameters within years for control and development sites:
  - shrub cover-to-production adjusted dry weight
  - herb density-to-production adjusted dry weight
  - ground cover-to-production adjusted dry weight
- determination of sample adequacy for each plot sampled
- multiple range testing to test grouped differences between sampling sites

Ecoclimatological Monitoring Studies

Ecoclimatological data were entered in to computer files and summarized as follows:

- ten-day period means were calculated for air temperature and soil temperature
- ten-day period totals were calculated for precipitation (converted from 0.001 inches to cm)
- ten-day period mean minima and mean maxima were calculated for air temperature and soil temperature
- monthly values for the above were calculated

Summarized ecoclimate data were subjected to the following types of manipulations and statistical analyses:

- one-way analysis of variance to test potential differences between station pairs within years and like stations among years for each of the following:
  - precipitation
  - air temperature means, mean minima, and mean maxima (for 10-day periods)
  - soil surface temperature means, mean minima, and mean maxima (for 10-day periods)
- sample adequacy determinations
- linear regression analysis to determine the levels of correlation between the following parameters:
  - shrub cover-to-mean air temperature
  - shrub cover-to-mean soil surface temperature
  - shrub cover-to-total precipitation
  - herb density-to-mean air temperature
  - herb density-to-mean soil surface temperature
  - herb density-to-total precipitation
  - ground cover-to-mean soil surface temperature
  - production-to-mean air temperature
  - production-to-mean soil surface temperature
  - production-to-total precipitation

Soil Survey and Analysis Studies

Laboratory analyses of native and retort soils have been summarized in terms of each parameter and its level in each soil sample. Native soils sampled during the soil survey have not been subjected to statistical analyses, as this is not a common practice in soil studies. Retort soil parameter values for samples taken before blasting and after burning have been investigated using a paired *t*-test in order to assess significant differences.

VEGETATION STUDIES

Vegetation Mapping

The four vegetation types identified and sampled during the two-year environmental research study on the LOFRECO site are mapped on Pocket Figure 1. Mapped units also include several salient features and habitat units, as shown below, included with topographic and political features:

- South-facing pinyon-juniper woodlands (*Pinus edulis-Juniperus osteosperma*) permanent sampling sites V10 and V11
- North-facing pinyon-juniper woodlands (*Pinus edulis-Juniperus osteosperma*) permanent sampling sites V20 and V21
- Sagebrush-rabbitbrush lowlands (*Artemisia tridentata-Chrysothamnus nauseosus*) permanent sampling sites V30 and V31
- Sagebrush-wheatgrass uplands (*Artemisia tridentata-Agropyron smithii*) permanent sampling sites V40 and V41
- Shaley slopes and Rimrock

Floristics

Herbaceous, woody, and succulent plants occurring on the LOFRECO site are listed in Table 1. Species are listed by scientific and common name by general life form category: herbs (flowering plants and grasses), shrubs (including stem succulents), and trees. Appendix A also contains a list of these plants, the abbreviations used in computer manipulations, and specific life form classifications (Tables A1.1 and A1.2). (Tidestrom 1925, Harrington 1964).

Several herbaceous species listed as rare, restricted, endangered, and/or threatened have been encountered on the LOFRECO site. These species are listed in Table 1 and described in Appendix B. Several of these species have been recommended for delisting (Welsh 1979) and/or are relatively common on the site, as listed below:

- *Parthenium ligulatum*: recommended for delisting (Welsh 1979), common
- *Townsendia mensana*: locally common
- *Eriogonum ephedroides*; locally common

Two of these species, *Parthenium ligulatum* and *Townsendia mensana* were frequently encountered in the phytosociological sampling. This relative abundance suggests that the populations of these plants will not be threatened by the experimental facilities operating on the LOFRECO site. Moreover, the distribution of these species tends to coincide with shaley knolls that lie along the shale outcrop, and, therefore outside of the area potentially to be disturbed by site activities. The remaining species that is considered locally abundant, *Eriogonum ephedroides*, has not been encountered frequently in sampling, but can be termed common. The distribution of this species coincides with that of *Parthenium ligulatum* and *Townsendia mensana*.

Two other species occurring on Federal and State lists of endangered species have been located on the site: *Enceliopsis nutans* and *Penstemon grahamii*. These species have been encountered infrequently; *Penstemon grahamii* has been observed, but not collected. There is not sufficient information on the distribution of either species on the LOFRECO site to provide guidelines for mitigation of potential damage to these species' populations. It is apparent from literature-derived descriptions of *Enceliopsis nutans* (Nelson 1909) that this species occupies habitats similar to the plants discussed above. Information on *Penstemon grahamii* (Welsh 1979) indicates its occurrence in these types of habitats, as well. The plants observed on the LOFRECO site have been on roadsides and other waste areas.

Systematic monitoring studies designed to locate and map the distribution of all the species discussed in this section have been initiated. When this study has been completed its results will be presented to the Federal agency having jurisdiction over this general region, assumedly the Bureau of Land Management.

Phytosociological Studies

The results of the structural and compositional measurements made in the four major vegetation types are presented in this section. Each of the vegetation types is discussed in terms of general distribution, dominant species, salient physical characteristics, successional attributes, and land use.

Pinyon-Juniper Woodlands

General Location and Distribution

Open woodlands dominated by pinyon pine (*Pinus edulis*) and Utah juniper (*Juniperus osteosperma*) are a predominant vegetation type in the Intermountain Region. The woodlands occupy ridge crests, gentle knolls, and side slopes at higher elevations (≥1500m) throughout this floristic region (Cronquist et al. 1972). Pinyon-juniper woodlands are evergreen in nature and low in stature. Average height of the woodlands is between 8 and 15m.

Two subtypes of the woodlands occur on the LOFRECO site. Woodland stands on north and south-facing slopes are differentiated as a result of the extreme differences in exposure on these sites. The major structural differences in the two subtypes are tree density and development of the shrub and herb understories. Potential differences in the use of these sites by wildlife are another factor contributing to their differentiation (Pocket Figure 2).

South-Facing Pinyon-Juniper Woodlands

Structure and Composition

South-facing woodlands are sparse and open. There is little or no overlap of branches of individual trees. Mean tree density is 277 individuals per hectare, as compared with 590 individuals per hectare occurring in north-facing woodlands (Appendix A4). Utah juniper is the predominant species in the south-facing stands. Cover by trees averages 30% of the area sampled. Utah juniper accounts for a slightly greater proportion of the cover values (relative cover=59%) than pinyon pine (relative cover=43%). Juniper and pinyon densities are similar at 140 and 137 plants per hectare, respectively.

The importance value (relative frequency + relative cover + relative density ≤300%) for Utah juniper is 154% in the south-facing woodland sites sampled. Importance value for pinyon pine is 140% (Figure 2).

The shrub layer of the south-facing woodlands is sparse. The dominant shrub is big sagebrush (*Artemisia tridentata*), which accounts for 15% of the total shrub cover. Total shrub cover for the area sampled averages 7%. Mean density of big sagebrush is 444 individuals per hectare (Appendix A3). Other species occurring in the shrub layer include saltbush (*Atriplex canescens*) and saplings of pinyon pine, Utah juniper, and Rocky Mountain juniper (*Juniperus scopulorum*). Prickly pear cactus (*Opuntia polyacantha*) also occurs, but at low values. Important half-shrubs found in the south-facing woodlands include snakeweed (*Gutierrezia sarothrae*), winter fat (*Ceratoides lanata*), pasture sage (*Artemisia frigida*), and prickly gilia (*Leptodactylon pungens*). These species occur at low levels, accounting for <1% of the total mean cover, collectively (Appendix A3). Total mean density of shrubs and half-shrubs is 3800 plants per hectare in the south-facing woodlands. For comparative purposes these values are 516 plant per hectare for north-facing woodlands, 15,350 plants per hectare for bottomland sagebrush-rabbitbrush stands, and 27,745 plants per hectare for upland sagebrush-wheatgrass stands (Appendix A). Figure 2 illustrates the range of importance values of various shrubs and half-shrubs sampled in the south-facing woodlands. This figure is also a comparison between vegetation types, showing the relative difference in importance of dominant shrubs, such as big sagebrush, between woodland types and sagebrush dominated stands.

The herb layer of the south-facing woodlands is also better developed than that occurring in the north-facing sites, although neither site has well developed herbaceous growth (Appendix A2 and Figure 3). Total cover by herbaceous species averages 5% for the stands sampled during 1978 and 1979. Rock contributes 25% of the total surface cover, while litter and soil have mean values of 33% and 36%, respectively (Figure 4).

The predominant perennial herb occurring in the south-facing woodlands is blue grama grass (*Bouteloua gracilis*). Blue grama evades drought as a result of its rhizomatous habit that creates dense mats. This species requires summer precipitation in order to flower and remains dormant during much of the growing season in the pinyon-juniper woodlands (Cronquist et al. 1977). Western wheatgrass (*Agropyron smithii*)also occurs in the south-facing woodlands, but is not common.

The most common herbaceous species in the woodlands are annuals, such as stickseed (*Lappula redowskii*), musineon (*Musineon divaricatum*), fever few (*Parthenium ligulatum*), tansy mustard (*Descurainnia pinnata*), and pig weed (*Chenopodium rubrum*). Scattered perennial forbs including false yarrow (*Chaenactis douglasii*), milk vetch (*Astragalus calycosa*), dwarf goldenweed (*Haplopappus acaulis*), and fleabane daisy (*Erigeron utahensis*) are also found.

Several species occurring in the south-facing woodlands require additional attention as a result of their importance or potential importance in this type. One shrub species -- mountain mahogany (*Cercocarpus montanus*)-- occurs sporadically in these sites. This important browse species is distributed in relation to critical soil factors (Greenwood and Brotherson 1978) involving shallow slick rock areas that occur along geological fractures that apparently run north-south along the eastern boundary of the LOFRECO site. Moisture stress in the fractured slick rock areas is apparently less than in the adjacent, slightly vesicular soils (Piatt 1976), thus accounting for the successful, but limited germination and occurrence of mountain mahogany along the fracture.

Two herbaceous species play important dynamic roles in the woodlands. Blue grama grass and dwarf goldenweed represent a growth form that accounts for their relative importance and stability in these sites. Both species are perennials that form cushions. The large basal area formed by the cushions encorporates both living and dead plant material developed from the perennial root stocks, and also consists of fine soil material that is trapped as it is

moved over the surface by wind or water. The environment that is formed by the cushions is considerably more stable than that of the open pavement surface that dominates in the south-facing woodlands. The cushions also retain moisture and accumulate organic material. These features all contribute substantially to the perpetuation of blue grama grass and dwarf goldenweed during drougthy years or cycles. Both species apparently become established during favorable years and spread slowly in a vegetative manner during periods when temperature and moisture conditions are marginal, but not extremely limiting.

A remaining feature of the cushions that imparts stability is that the deep tap roots provide a mechanism that avoids disruption of roots during the freeze-thaw cycles that are common to the open pavement surfaces of the woodlands. The cushions essentially "float" on the surface during these times of soil instability and are further protected as a result of the plants ability to remain dormant well into the growing season if adequate moisture is not available for resumption of growth.

The importance of the perennial, caespitose habit in the south-facing woodlands can be observed in most of the herbaceous species that occur on the sites sampled. Other species that display this habit are fever few, easter daisy (*Townsendia mensana*), and double bladderpod (*Physaria floribunda*). Annual species that are common to the woodlands occupy the areas of deeper soils and litter under or near trees. The occurrence of annual species on the open pavement zone is rare.

Primary Productivity

The woodland sites have the lowest herbaceous productivity of the vegetation types occurring on the LOFRECO site. The mean total primary production of the south-facing woodlands is 23Kg/Ha during 1978 and 14Kg/Ha for 1979, both measured during peak season (July) (Figure 5).

Primary production on the south-facing sites is comprised chiefly by blue grama grass and perennial forb species (milk vetch, fleabane daisy, and

dwarf goldenweed). These values average 11Kg/Ha (1978) and 9Kg/Ha (1979) for blue grama grass; and 3Kg/Ha (1978) and 4Kg/Ha (1979) for perennial forbs (Appendix A5). Annual forbs, such as stickseed and pig weed also contribute significantly to the standing crop of the woodlands (<1Kg/Ha, 1978; 6Kg/Ha, 1979)(Appendix A5).

Stability, Diversity, and Land Use

Pinyon-juniper woodlands are a climax vegetation type in the Intermountain Region. These woodlands are self-perpetuating; replacement of the tree layer due to old age and disease is an orderly successional progression. Cores taken from pinyon pines on the LOFRECO site give a range of age of mature trees from 111 to 368 years. Younger individuals and seedlings are also present in all stands in relatively low numbers, but proportional to mature tree densities.

The surface configuration of the south-facing woodlands is a factor that suggests low stability. During the winter the surface pavement is hardened and difficult to mark. During the frost-free months the pavement becomes loose. The loosening of the surface is apparently the result of heaving during freeze-thaw cycles in the early spring and the result of wetting during snow melt. Although the instable, dry (and somewhat vesicular) soils are the major factor responsible for the poorly-developed herb layer in the woodlands, this is an ecological feature perpetuated by natural conditions. No successional trend in the herb layer is implied by this configuration. Instead a cycle is maintained between dry and moist years, so that the plants occupying the herb layer remain in their niches, responding to the moisture cycles by slight increases and decreases in cover and density that ostensibly average out over long periods.

Utilization of the south-facing woodlands by herbivorous species is limited. Forage is severely limited, as is shrub browse. The areas may provide cover for cattle during the winter months and a limited, yet essential amount of forage when snow cover prevails on other less well-exposed sites. The woodlands are also used for wood cutting and recreation. Trails of dirt bikes and all-terrain vehicles are common.

North-Facing Pinyon-Juniper Woodlands

Structure and Composition

Tree density on the north-facing woodland sites is somewhat higher than that of the south-facing sites discussed above, averaging 590 plants per hectare for the sites sampled. Pinyon pine is more predominant in these stands. Relative cover of pinyon is 55%, as opposed to 44% for Utah juniper. This is also reflected in importance value: 178% for pinyon and 120% for Utah juniper (Appendix A4). Total mean percent cover for all trees on the north facing woodlands is 43% (as compared with 30% on the south-facing woodlands). The predominance of pinyon pine in these sites versus the south-facing woodlands is accounted for by the increased effectiveness of winter precipitation in the north-facing woodlands. Pinyon pine is characteristically favored on sites having adequate snow accumulation (Tueller and Clark 1975).

The shrub layer of the north-facing woodlands is poorly-developed. Mean cover for shrubs in the sampled stands is <1% (Appendix A4). Mean shrub density for the north-facing woodlands is 516 plants per hectare, including shrubs and half-shrubs. Big sagebrush is the predominant species in the shrub layer, although a substantial part of the total shrub cover is contributed by saplings of pinyon pine and Utah juniper. Important half-shrubs include snakeweed and pasture sage. Figure 2 illustrates the relative importance of shrubs in the north-facing stands. This figure also compares shrub species present and their importance between all stand types on the LOFRECO site.

The common perennial herbs in the north-facing stands include blue grama grass, thread-leaf sedge (*Carex filifolia*), and Indian ricegrass (*Oryzopsis hymenoides*). The herb layer is sparse, even in comparison with the south-facing woodlands. Mean herbaceous cover is 1%. Rock, litter, and soil account for 19%, 56%, and 19%, respectively (Figure 4 and Appendix A1). Common forbs include leafy sprurge (*Euphorbia robusta*), cryptanthe (*Cryptantha sericea*), fleabane daisy, pigweed, birdsbeak (*Cordylanthus wrightii*), and pepperweed (*Lepidium virginianum*) (Appendix A2). Green needle-and-thread (*Stipa viridula*) also occurs on the north-facing sites. Herb importance values for the north-facing woodlands are compared on Figure 3. This figure

also illustrates the comparative values of herb importance (relative frequency + relative density ≤200%) for all stands sampled.

In some of the more moist areas of the north-facing woodlands isolated individuals of snowberry (*Symphoricarpos oreophilus*) and elder (*Sambucus sp.*) occur in depressions downslope from rock outcrops or along fractures. Mountain mahogany is also found in small, isolated stands along fractures. The existence and distribution of these species once again illustrates the limiting relationship between soil moisture and shrub growth on the LOFRECO site.

Primary Productivity

Primary herbaceous productivity in the north-facing woodland stands sampled is dominated by blue grama grass (4Kg/Ha, 1978; 3Kg/Ha, 1979). Total primary herbaceous production for the north-facing woodland sites sampled is 20Kg/Ha, 1978 and 42Kg/Ha 1979, measured during peak season (July). Annual forbs and perennial grasses (primarily thread-leaf sedge) also contribute to the total herbaceous standing crop of these sites. Figure 5 illustrates the comparison of north-facing woodland stands for 1978 and 1979 sampling periods and also illustrates comparative values for all stands sampled on the LOFRECO site.

Stability, Diversity, and Land Use

The north-facing woodlands, like their south-facing analogue, are a well established climax type. The north-facing woodlands are similar to the south-facing stands in terms of age and orderly cycles or trends. The surface instability of the south-facing woodlands does not occur on the north-facing slopes, however. The sparseness of the herb and shrub layer on north-facing slopes is the combined product of shallow channery soils and interception of sunlight and moisture by the more dense tree canopy.

Utilization of the north-facing woodlands is limited. These areas provide cover for large herbivores and nesting areas for song birds. The sparse herb and shrub layer do not provide significant forage or browse. The woodlands are also used for wood cutting and minor recreation.

Big Sagebrush Shrublands

General Location and Distribution

Vegetation types dominated by big sagebrush occupy extensive areas of the LOFRECO site formed from alluvium and mixed alluvial and colluvial soil materials. Two big sagebrush vegetation types occur on the site:

- sagebrush-rabbitbrush lowlands (*Artemisia tridentata-Chrysothamnus nauseosus*)
- sagebrush-wheatgrass uplands (*Artemisia tridentata-Agropyron smithii*)

The two types are ordered along a gradient that corresponds to the relatively narrow valleys that dissect the LOFRECO site. The gradient follows these drainages from the deeper and more narrow areas (sagebrush-rabbitbrush lowlands) to the broad, sloping upland origins of the valleys (Pocket Figure 2). Although both types are dominated by big sagebrush, the density and stature of the shrub layer is markedly different between the two. The upland type is characterized by a low, dwarfed shrub layer that is approximately one-fourth as dense as the lowland type. The open canopy of the upland sites is more conducive to the development of herbaceous species than is the dense, closed canopy of the lowland type.

Big Sagebrush-Rabbitbrush Lowlands

Structure and Composition

Big sagebrush-dominated lowland sites are characterized by a dense shrub overstory. Big sagebrush accounts for 87% of the shrub cover of this type. and 74% of the shrub density (Appendix A3). Total shrub cover in the lowland stands is 43%. The mean density of shrubs in all sites sampled is 15,350 plants per hectare (Appendix A3).

The shrub overstory of the bottomland sites is essentially double, a secondary level being produced by rabbitbrush (*Chrysothamnus nauseosus*) below the taller big sagebrush. Saltbush is also found in the secondary layer. Half-shrubs common to the bottomland stands include snakeweed, pasture sage, and winter fat.

The herbaceous layer of the sagebrush lowlands is dominated by annual forbs, such as ragweed (*Ambrosia artemisifolia*), stickseed, tansy mustard, tumble mustard (*Sisymbrium elegans*), and lambsquarters (*Chenopodium album*). (Appendix A2). This layer is very sparse, as a result of the high density and cover of the shrub overstory. Total mean herbaceous cover for the stands sampled is 12%. Cover values for litter, soil, and rock are 55%, 24%, and 2%, respectively (Appendix A1)(Figure 4).

Primary Productivity

The sagebrush-rabbitbrush lowlands rank second in primary herbaceous plant productivity for the LOFRECO site having mean values of 133Kg/Ha,1978 and 15 Kg/Ha, 1979 for peak season samples (July). These values are due almost entirely to the growth of annuals. Figure 5 illustrates the differences in primary production between 1978 and 1979 between control and development plots and offers comparisons among lowland sites and all other sites sampled.

Stability, Diversity, and Land Use

Lowland stands dominated by big sagebrush are widespread in the Intermountain Region. Individual stands are characteristically homogeneous and mature in terms of the shrub layer. Structurally all size and age classes of the dominant shrub species are present including seedlings, saplings, and dead, decaying plants. These features suggest an orderly and cyclic replacement operating within the type.

The herbaceous layer, on the other hand, is poorly-developed and cycles in composition on a year-to-year basis. The annual forb dominance of this layer is the probable result of overgrazing of these sites (Vale 1975). This condition is perpetuated by the dense, closed shrub canopy. The canopy limits the amount of light that reaches the surface and intercepts a substantial amount of the rainfall (West and Gifford 1976). In addition, the density of shrubs sets up severe competition for the limited soil nutrient resources of these sites. Litter fall from sagebrush increases the toxigen concentration of the soil and further limits the growth of herbaceous species, particularily in terms of germinating perennials (Halligan 1976).

The lowland sites are utilized by cattle and deer as a source of browse. Lagomorphs inhabit the areas. Rabbit runs and burrows are relatively common. The lowlands offer a limited and seasonal source of forage for large herbivores. Observations of cattle presence shows that little use is made of these areas after the spring season.

Sagebrush-Wheatgrass Uplands

Structure and Composition

The big sagebrush that dominate the upland sites are an ecotypic variation of the species (Cronquist et al. 1972). The dwarf sagebrush plants that inhabit the uplands differ markedly in stature and density (Pocket Figure 2 and Appendix A3). Sagebrush density in the upland sites is 27% of the total shrub density of 27,745 plants per hectare. Sagebrush cover values average 50% of the total shrub cover for the sites sampled. Actual sagebrush cover values are 8% of the total area sampled (Appendix A3). Figure 2 shows the importance values of all shrub species in the upland sites. The average height of sagebrush plants in the upland sites is 0.5m, as compared with 2m in the lowland sites sampled.

Saltbush is also present at high frequencies within the upland sagebrush type. Half-shrubs form a secondary shrub layer including species, such as winter fat, pasture sage, snakeweed, prickly pear, and nipple cactus (*Coryphantha vivipara*).

The herb layer of the upland sagebrush type is the most well-developed of any on the LOFRECO site. The dominants in the herb layer are perennial grasses including blue grama grass, western wheatgrass, Sandberg's bluegrass (*Poa sandbergii*), and Indian ricegrass. Blue grama grass and western wheatgrass comprise 57% of the total herb density of the uplands (Appendix A2). Total mean cover by herbaceous species is 28% of the area sampled. Other common herbaceous species occurring in these sites are copper globemallow (*Sphaeralcea coccinea*), long-leaf phlox (*Phlox longifolia*), fleabane daisy, larkspur (*Delphinium nelsonii*), and sandwort (*Arenaria eastwoodiae*). Annual forbs and grasses are also common including stickseed, tansy mustard, lamb's-quarters, and cheat grass (*Bromus tectorum*). Cover by soil, litter, and

rock are 52%, 31%, and <1%, respectively. (Appendix A1 and Figure 4).

Primary Productivity

The relatively high development of the herbaceous layer in the upland sagebrush-wheatgrass sites is reflected in the primary herbaceous production of this vegetation type. The uplands have the highest productivity of the LOFRECO site with values of 311Kg/Ha, 1978 and 564Kg/Ha, 1979 for peak season sampling (July). Blue grama grass accounts for 7% of this amount, western wheatgrass comprises 33% of the total herbaceous productivity, while annuals equal 13% of the total amount measured. Half-shrubs account for 28% of this amount. Shrub production (new growth) was measured on these sites during 1979, only. Sagebrush production was 267Kg/Ha, while saltbush was 547Kg/Ha.

Stability, Diversity, and Land Use

The sagebrush-wheatgrass uplands are the most diverse vegetation type on the LOFRECO site. This feature is true of both the shrub and herb layers. Herbaceous plant diversity is the most outstanding feature, however (Appendix A2).

The structure of the shrub layer indicates a high level of maturity and orderly replacement of individuals. This layer is apparently essentially stable, although the grazing pressure on these sites may prevent true climax from occurring. The herb layer also appears to exhibit this feature of essential balance, although it is also retarded in terms of climax by grazing and surface compaction associated with domestic cattle. The essential functional organization of the upland sites is that of shrub islands that alternate with open intershrub areas. The shrub islands are co-occupied by the plants that form them and herbaceous species that root in the zone of litter and soil accumulation at the bases of the shrubs. These environments are the most favorable and stable micro-niches within the upland stands. The intershrub spaces are occupied by a sparse cover of perennial grasses, half-shrubs, and annual forbs. As a result of soil compaction caused by animal traffic and diurnal temperature changes and the effects of soil and wind erosion these areas are in a perpetual state of disturbance. The

character of the herb layer within the upland type is subject to yearly variations based on temperature and moisture. The resulting cycles are characterized by fluctuations in the annual forb population density and productivity of the perennial grasses and half-shrubs. This variation is reflected in the values obtained during 1978 and 1979 sampling periods as illustrated on Figure 2 through 5.

The upland sagebrush sites are utilized by large herbivores, particularily domestic cattle, as a source of limited, but important forage. Few signs of browse are encountered in these sites, either by cattle or mule deer. Mans' use of the upland areas is apparent in various ways. Numerous roadways and tracks are in evidence. The uplands are also used for locating corrals, trailer courts, and drill pads.

TABLE 1

LIST OF VASCULAR PLANTS

OCCURRING ON THE LOFRECO SITE

Scientific Name	Common Name
Trees:	
Juniperus osteosperma	Utah juniper
Juniperus scopulorum	Rocky Mountain juniper
Pinus edulis	pinyon pine
Shrubs, Half-Shrubs, and Stem Succulents:	
Artemisia cana	silver sagebrush
Artemisia frigida	pasture sage
Artemisia tridentata	big sagebrush
Atriplex canescens	saltbush
Ceratoides lanata=Eurotia lanata	winter fat
Cercocarpus montanus	mountain mahogany
Chrysothamnus depressus	dwarf rabbitbrush
Chrysothamnus greenei	Greene's rabbitbrush
Chrysothamnus greenei greenei	Greene's rabbitbrush
Chrysothamnus nauseosus	rubber rabbitbrush
Chrysothamnus viscidiflorus elegans	small rabbitbrush
Chrysothamnus viscidiflorus	stick-leaf rabbitbrush
Coryphantha vivipara=Mammalaria vivipara	nipple cactus
Ephedra viridis	green ephedra
Gutierrezia sarothrae=Xanthocephalum sarothrae	snakeweed
Leptodactylon pungens	prickly gilia
Opuntia polyacantha	prickly pear cactus
Purshia tridentata	antelope bitterbrush
Sambucus sp.	elder
Symphoricarpos oreophilus	snowberry
Tetradymia canescens	horsebrush
Tetradymia spinosa	spiny horsebrush
Yucca biglovei	yucca
Herbs:	
Agropyron cristatum	crested wheatgrass
Agropyron smithii	western wheatgrass
Agropyron spicatum	bluebunch wheatgrass
Allium geyeri	wild onion
Ambrosia artemisifolia	ragweed
Antennarua parvifolia	pussytoes
Arabis divaricarpa	rockcress

TABLE 1 (CONTINUED)

Scientific Name	Common Name
Herbs:	
Arenaria compacta	dwarf sandwort
Arenaria eastwoodiae	sandwort
Aster arenosus=Leucelene ericoides	aster
Aster fremontii	Fremont's aster
Astragalus calycosa	milkvetch
Astragalus kentrophyta	skeleton milkvetch
Bouteloua gracilis	blue grama grass
Bromus tectorum	cheat grass
Calochortus gunnisonii	sego lily
Carex filifolia	thread-leaf sedge
Casteilleja chromosa	Indian paintbrush
Chaenactis douglasii	false yarrow
Chenopodium album	lamb'sqaurters
Chenopodium rubrum	pig weed
Cordylanthus wrightii	birdsbeak
Crepis accuminata	hawksbeard
Cryptantha flavoculata	cryptanthe
Cryptantha sericea	cryptanthe
Dephinium nelsonii	larkspur
Descurainnia pinnata	tansy mustard
Draba brachycarpa	whitlowgrass
Enoeliopsis nutans (rare, restricted)	sunray
Erigeron utahensis	Utah fleabane daisy
Eriogonum caespitosum	prostrate knotweed
Eriogonum ephedroides (threatened)	ephedra buckwheat
Eriogonum kearnyi	knotweed
Euphorbia robusta	leafy spurge
Erysimum capitatum	wallflower
Haplopappus acaulis	stemless goldenweed
Haplopappus nuttallii	goldenweed
Hilaria jamesia	galleta
Hordeum jubatum	foxtail barley
Hymenoxys acaulis	actinea
Iva xanthifolia	marsh-elder
Lappula redowskii	stickseed
Lepidium virginianum	pepperweed
Linum lewisia	false flax
Lithospermum ruderale	puccoon
Musineon divaricatum	leafy musineon
Oenothera caespitosa	evening primrose
Oenothera strigosa	yellow evening primrose
Oryzopsis hymenoides	Indian ricegrass
Oryzopsis micrantha	little ricegrass
Parthenium ligulatum (endangered)	fever few
Penstemon grahamii (endangered)	Graham's beardtongue
Penstemon strictus	penstemon
Physaria floribunda	double bladderpod
Phlox longifolia	long-leaf phlox

TABLE 1 (CONCLUDED)

Scientific Name	Common Name
Herbs:	
Poa sandbergii	Sandberg's bluegrass
Salsola iberica	Russian thistle
Senecio multilobatus	groundsel
Sisymbrium altissimum	tumble mustard
Sisymbrium elegans	tumble mustard
Sisymbrium linifolium	tumble mustard
Sitanion longifolium	squirreltail grass
Sphaeralcea coccinea	copper globemallow
Stipa viridula	green needle-and-thread
Taraxacum officinale	dandelion
Townsendia mensana (threatened)	easter daisy
Verbascum thapsus	mullein

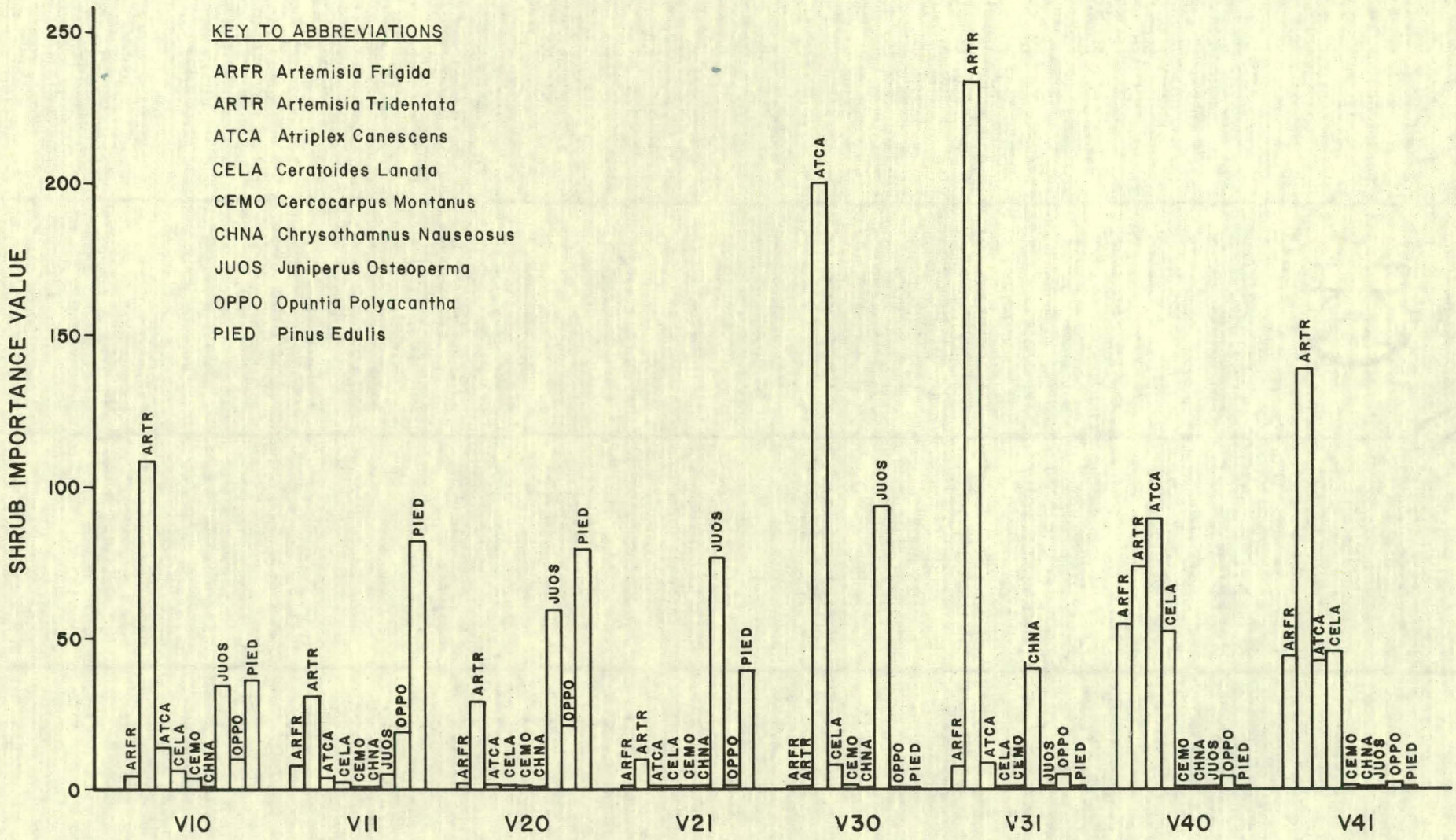


Figure 2

COMPARISON OF IMPORTANCE VALUES
FOR IMPORTANT SHRUB AND TREE SPECIES
LOFRECO FIELD RESEARCH SITE

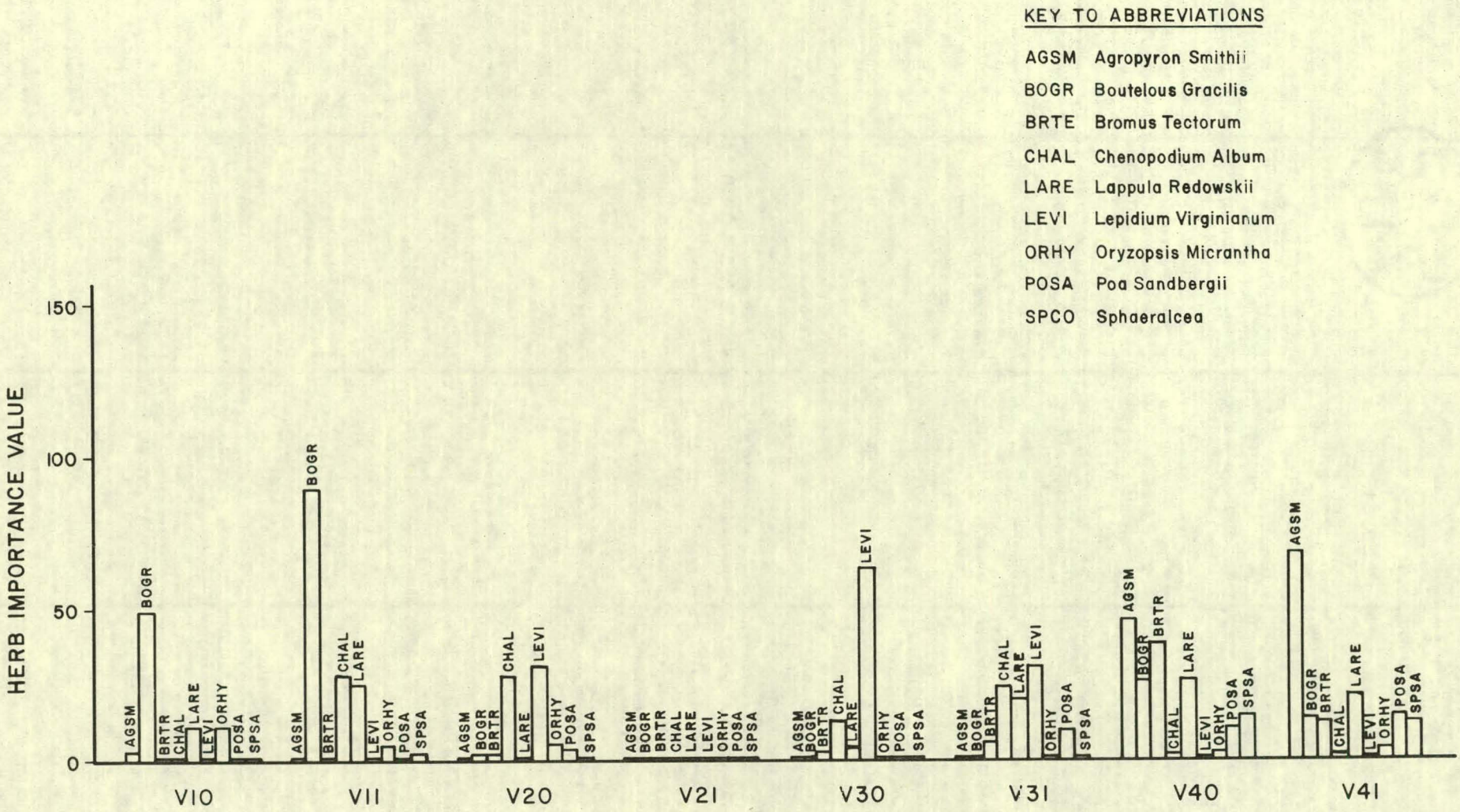


Figure 3

COMPARISON OF IMPORTANCE VALUES
FOR IMPORTANT HERB SPECIES
LOFRECO FIELD RESEARCH SITE

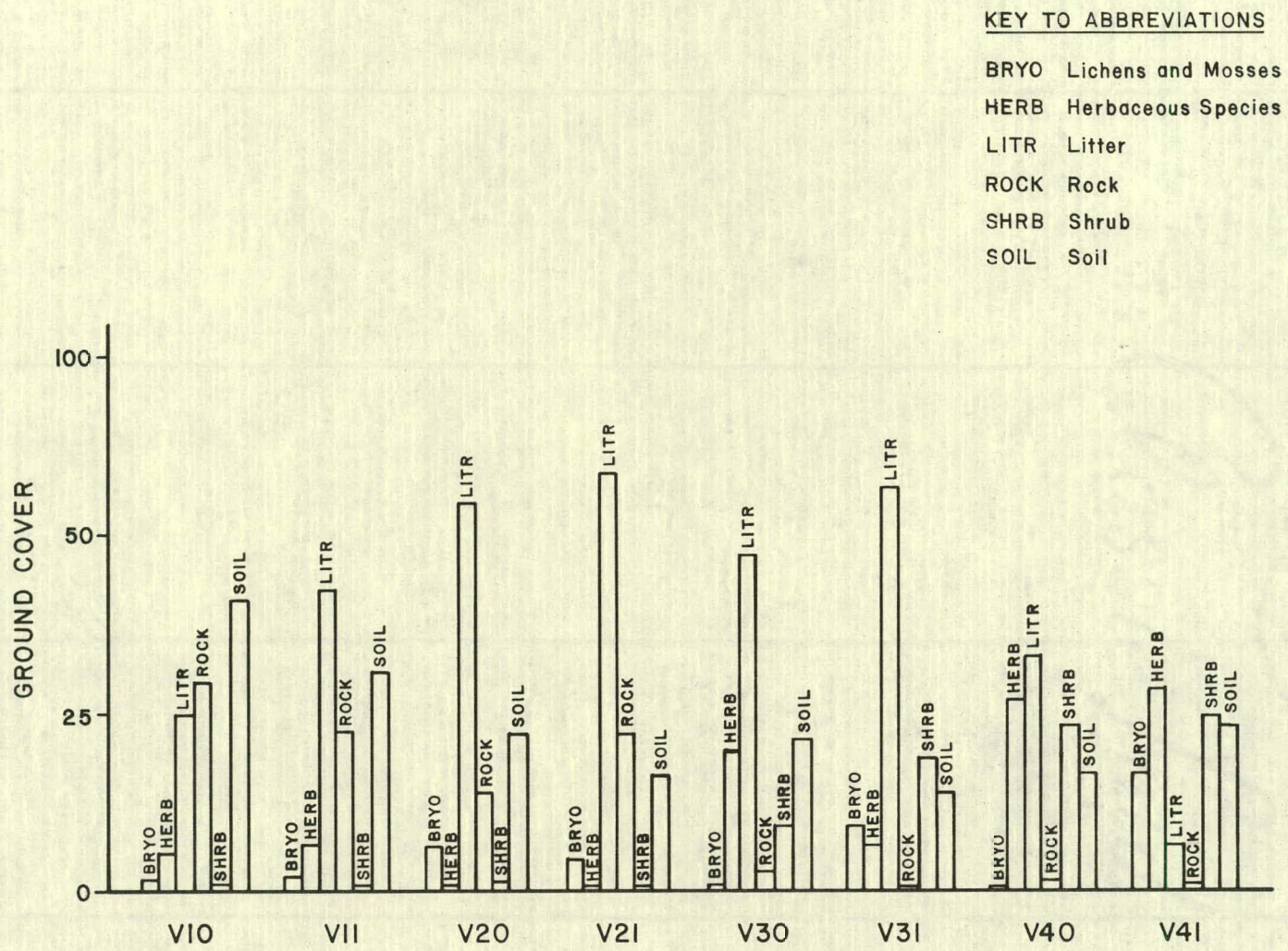


Figure 4

COMPARISON OF GROUND COVER VALUES
FOR THE FOUR MAJOR VEGETATION TYPES
LOFRECO FIELD RESEARCH SITE

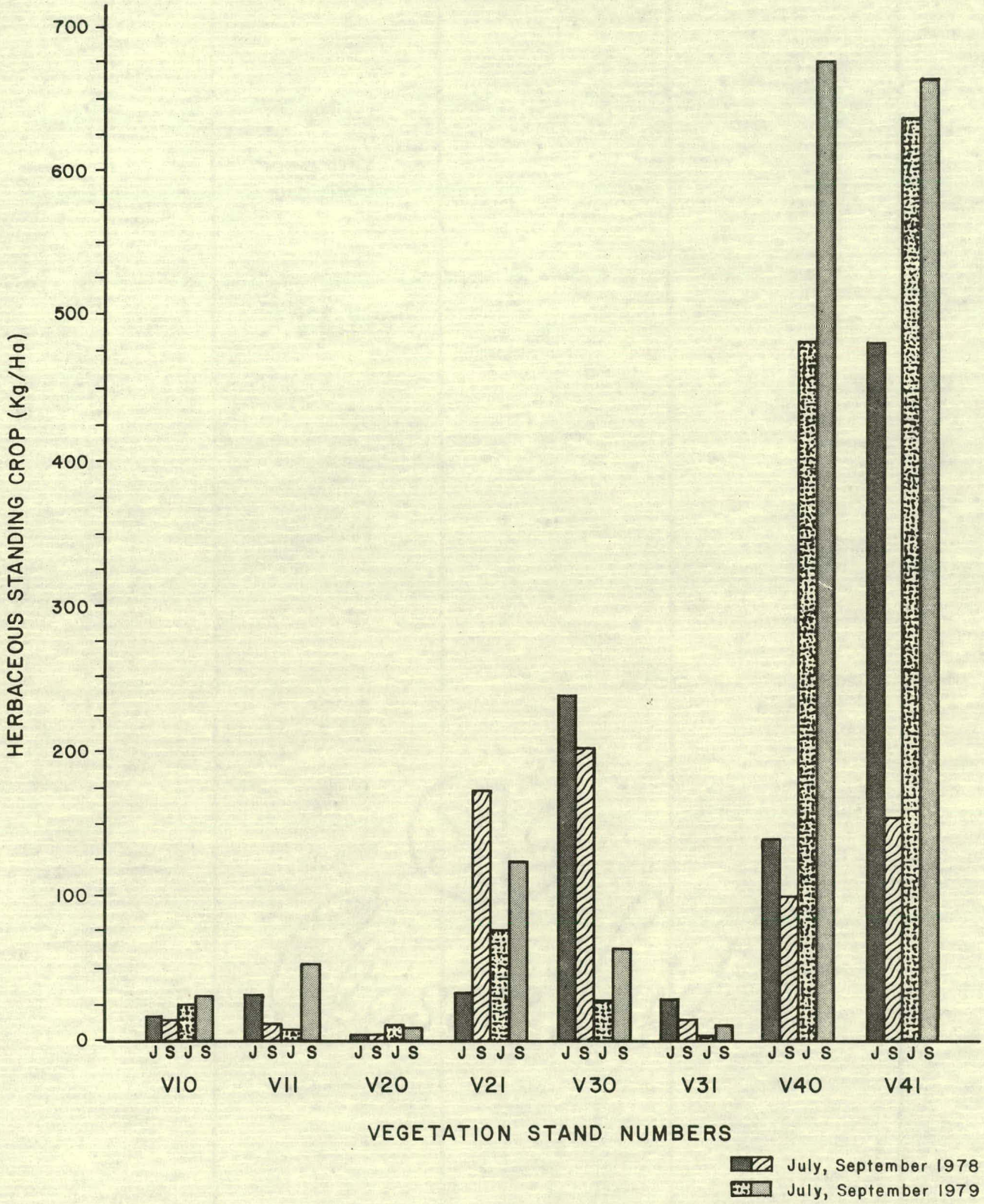


Figure 5

MEAN PRIMARY HERBACEOUS PRODUCTIVITY
PER STAND
LOFRECO SITE—1978 & 1979

ECOCLIMATOLOGICAL MONITORING STUDIES

Ecoclimate data obtained during the 1978 and 1979 growing seasons are presented in Appendix C. General descriptions of the ecolimate of each vegetation type occuring on the study area are given in terms of temperature and moisture characterisitcs. Comparisons between station pairs and between selected non-station pairs are also presented.

General Characteristics

Ecoclimate is essentially controlled by the structural features residing in vegetation and soils. The most distinct controlling feature relating vegetation to ecoclimate is canopy cover. The vegetation canopy influences temperatures in both soils and air. The extent of the canopy also affects the amount of rainfall reaching the surface. Soil characteristics, particularily texture, affect available moisture. The sum of these effects are controls on light, evaporation, and soil moisture.

The influences created by vegetation and soils act within a zone known as the boundary layer. This is the zone between the uppermost extent of the vegetation canopy and the lower-most extent of soil. Within the boundary layer plant densities, vertical layering of vegetation growing at different heights, and life-form categories of plants are directly influenced by the ecoclimate.

The interaction between parameters in the ecoclimate are of high significance. Although vegetation structure contributes significantly to ecoclimate conditions, soil characteristics are important determinants to the types of plants that are capable of growing and reproducing in an area The regional and local climatic conditions of a site contribute the basic ingredients that are acted upon by vegetation and soils. All of these contributions make up the ecoclimatic conditions that are unique to vegetation types and their associated soils.

On the LOFRECO site ecoclimates can be defined generally as partitions of the following controlling factors in order of their importance and

site-specific influence.

- a regional arid climate characterized by low precipitation (occurring principally as snow) and by high insolation;
- distributions of two distinct soil regimes that influence the distribution and character of the vegetation, as a result of poor soil development and water availability on the one hand, and significant levels of toxic soil chemicals, on the other;
- ensuing vegetational distributions that interact with climate and soils to produce distinct ecoclimates on the site.

In order to isolate the importance of the factors listed above on the ecoclimates on the LOFRECO site we can further partition the parameters as follows:

- insolation appears to be the most significant single factor acting as a driving variable of the regional climate;
- precipitation is an important factor also, but demonstrates some substantial local variations over the site;
- soil type influences the availability of soil moisture, but is more directly important to vegetation distributions in terms of alluvial soils and residual soil categories and their associated soil chemistry regimes; and
- vegetation canopy influences buffer the above effects: insolation is variously controlled by canopy types, as is precipitation and soil moisture.

The overall effect is an interface between temperature and moisture controlled by insolation at the ground surface and differentiated by canopy cover.

The discussion of each of the vegetation types in terms of ecoclimate illustrates the system of controlls and their partitions in the manner in which ecoclimates are differentiated.

Temperature

Temperatures recorded at the soil surface show a general pattern of warming beginning in April and ending in late October. Mean temperatures are greatest in July in all sites (Figures 6 through 9).

Ambient air temperatures recorded at the maximum height of the canopy follow the same season pattern of soil surface temperatures, but attain higher values. There is some lag between soil temperatures and air temperatures. This is expected since soils warm more slowly and generally retain their heat for a longer period.

The average maximum soil surface temperatures reached during the growing season are 47°C and 48°C (in the south-facing pinyon-juniper woodland stands) for 1978 and 1979 respectively; 43°C in the north-facing woodlands (1978 only); 50°C and 49°C, in sagebrush-rabbitbrush lowlands; and 44°C and 48°C in the sagebrush-wheatgrass uplands (Appendix C).

Minimum soil temperatures for the vegetation types are 12°C and 10°C (1978, 1979); 13°C; 10°C and 7°C; and 14°C and 11°C, respectively.

Air temperature maximums are 33°C and 43°C (1978, 1979);32°C, 34°C and 46°C; and 35°C and 37°C, respectively. Air temperature minimums are 12°C and 8°C (1978, 1979); 9°C; 8°C and 5°C; and 10°C and 8°C, respectively (Appendix C).

Figure 10 illustrates the growing season pattern of air and soil temperature maximums and minimums. This figure shows that maximum soil temperatures are reached in sagebrush-rabbitbrush lowlands. All other sites are similar in terms of this parameter. Maximum air temperatures vary little between sites. The most noteable factor in both soil and air temperature maximums are apparent in the warming and cooling trends. The sagebrush-grass uplands warm earlier in the season than other sites; are sustained throughout the season, but do not have excessive values; and remain warm later in the season than other sites. This trend is controlled by the canopy cover through its effects on vertical mixing

of air within the canopy, and is further contributed to by vegetation cover in the herbaceous layer.

The low stature of the shrub layer in the upland sites favors surface heating as soon as the seasonal climatic warming trend begins in the spring. The fine-textured soils and relatively high herbaceous cover add to the heat storage capacity in the upland sites, as well. Since these sites tend to recieve more effective precipitation, both as snow and rain (also a result of the open canopy), the additional water retained in soils tends to dampen diurnal changes in soil surface temperatures. Vertical mixing of air within the boundary layer is also greatest in the upland sites. Well-developed mixing between soil and air allows the surface to cool along a steady gradient, thereby reducing overheating of the soil. The low stature of the vegetation also favors good lateral mixing; warm air at the top of the canopy and within the canopy is constantly circulated so that soil is not reheated.

Sagebrush-rabbitbrush lowlands, on the other hand, represent the opposite end of the scale of shrub canopy-induced effects on the ecoclimatic heat budget. The lowland sites have the most dense canopies of all vegetation types on the LOFRECO site. The relatively closed canopy of these sites retards heating of air within the canopy and of the soil surface during the beginning of the growing season. Temperatures eventually attained are chiefly the result of downward convection of heat accumulated at the surface of the canopy. Lateral air currents also bring in air warmed at other sites. Peaks in air and soil temperatures are created by warm air trapped in the canopy; a result of poor vertical mixing and retarded lateral air movement. Both of these effects are results of high canopy cover and shrub density. Relatively rapid and early cooling are the combined result of canopy cover and cold air drainage. Cool air drains downward from up valley positions and valley sides to initiate cooling trends that are perpetuated by the canopy interception of insolation during the daytime hours.

Pinyon-juniper sites are on mid-scale relative to canopy effects on air and soil temperatures. Several important differences between the woodlands and the lowland sites occur. First, the canopy of the woodland sites is more open and higher than the lowland canopy. More vertical and lateral mixing occurs in the woodlands. Slow warming and early cooling in the woodlands is controlled by soil type, rather than strictly by insolation blocking. The coarse, light-colored soils have little heat storage, as well as relatively high reflectivity, as compared with other sites. The woodland soils are more rapidly cooled by the heat exchange occurring within the boundary layer.

South-facing woodland sites warm more rapidly than north-facing sites as a result of their predominant southerly exposure. For this reason the south-facing sites also reach higher maximum temperatures during the growing season. There is a greater degree of diurnal variation on the south-facing slopes, as well. Greater tree densities on the north-facing slopes dampen extreme heating and cooling trends, much like the lowlands, but to a lesser extent, because of the increased canopy cover.

The influences of canopy cover and soil type also represent feedback mechanisms, as previously discussed. The greatest significance of feedback are its effects on vegetation.

The soil characteristics that influence the nature of the shrub and herb layer of the upland sites participate directly in their perpetuation. The relatively mild soil environment characterized by fine textured, relatively deep, and non-toxic soil nutrient regimes provide a medium that will support open shrub communities co-dominated by herbaceous plants. The relatively mild ecoclimatic conditions afforded by the plant structure and composition provide the longest growing season of the vegetation types occurring on the site. The least over-all environmental stresses due to limiting factors of high temperatures; extreme dirunal temperature change; and low effective precipitation and soil moisture availability

occur in these upland sites.

In the lowland sites the more adverse soil characterisitcs have influenced the development of dense shrub stands. Sagebrush has attained greater densities and stature in the lowland sites. The high sagebrush densities are, in part, a result of decreased competition with herbaceous plants that are unable to tolerate the limiting soil environent. The dense canopy perpetuates many of these effects, as well as producing the limiting factors of higher soil moisture stress through high water demand, lowered effecive surface precipitation, and reduced surface light.

Sites dominated by woodlands favor the tree species found, due to shallow, coarse-textured and well drained residual soils. The woodlands are perpetuated on these sites because of lowered competition with herbaceous plants and shrubs. Germination and spread of shrubs and herbs is decreased under the environmental stress conditions of low available soil moisture and poor soil nutrient status. Soil moisture conditions are the combined result of well drained soils, high insolation, and high surface evaporation. The pinyons and junipers that dominate the woodlands effectively avoid the stresses associated with these conditions because they rely on snow melt, water held in rock strata, and because of morpohological adaptations that lower internal temeratures and water loss from tissues.

Precipitation

Rainfall recorded during the 1978 and 1979 growing seasons are summarized in Figure 11 and Table 2. Total rainfall for the period of record was 9.5cm during 1978 and 6.6cm during 1979. Precipitation was greatest in all during the months of May and June. November was the lowest precipitation month of record.

Winter precipitation contributes significantly to the growth of trees and shrubs in the intermountain region. Late spring and early summer rains are of great importance to the resumption of herbaceous growth.

Average precipitation values obtained from Bradley (1976) for this region is 24.2cm per year (3.8cm in spring, 5.1cm in summer, 5.1cm in fall, and 10.2cm in winter). The precipitation values obtained on the LOFRECO site during the summer season in 1978 are significantly lower at between 2.5cm and 4.5cm, and in 1979 at between 0.5cm and 6.6cm.

The differences in precipitation values recorded at the eight eco-log sites (Figure11) reveals no definite pattern. Instead, there are evidences of local effects on precipitation, such as random movements of thunder storms across the site, variable wind directions associated with different storm events, and local differences in topography.

The only apparent trends are related to canopy and topography. The high values recorded at south-facing pinyon-juniper stands and upland sagebrush apparently relate to the interception of wind-borne precipitation by the canopy (Tueller and Clark 1975, West and Gifford 1976). The higher elevation of the south-facing sites also influences this phenomenon in comparison with the north-facing sites and lowland sites. Lowland sites are expected to show lower values also as a result of direct interception of rainfall by sagebrush leaves. The upland sites are subject to loss of recorded values due to wind blow over. These effects are somewhat over-ridden by the lack of foliar interception.

South-facing pinyon-juniper woodlands received the greatest amount of rainfall during the 1978 growing season (9.5cm). Sagebrush uplands rank second in this order (8.0cm), followed by lowland sites(6.8cm) and north facing pinyon-juniper woodlands (5.4cm). During 1979 the south-facing woodland stations received less rainfalll than the upland sagebrush stands: 3.5cm and 5.9cm, respectively. Lowland sagebrush stations recorded an average of 4cm of precipitation. No recordings were made in north-facing woodlands. Although the variation in recorded precipitation makes it difficult to distinguish between local storm movement patterns and ecoclimatic effects, it is still possible to make statements regarding effective precipitation. Canopy cover is responsible for some of the low values recorded in the lowlands and north-facing woodlands. The intercepted

moisture remains of importance to the vegetation of these sites, but is used by shrubs and trees to the significant exclusion of the herb layer. In upland sites the loss of recorded rainfall due to wind can be estimated at as much as 20 percent, so that as much from 5cm to 10cm have been actually received. This moisture is also more effectively used by the herb layer, due to the sparse nature of the shrub layer. High values in the south-facing woodlands suggest less foliar interception, and, therefore direct use by trees. Rainfall received at the surface of the south-facing sites is highly subject to rapid loss by infiltration and evaporation. The latter feature is discussed below.

Available Moisture

In ecoclimatic terms, precipitation values are used to estimate the moisture input to the soil vegetation system that precominates in interacting with ecoclimatic controls. The understanding of how this moisture is made available and used within the ecoclimate requires refinements of the moisture regime that precipitation contributes to.

Three basic properties are involved in defining the moisture budget of a given ecoclimate: 1) precipitation, 2) soil matric tension, and 3) surface evaporation potential. Precipitation has been previously discussed. Soil matric tension refers to the manner in which an individual soil holds moisture. The moisture in a soil that is available to absorption by plants is the difference between the ability of soil to maintain internal tensions that hold water (matric tension or suction) and the ability of plants to develop counter tensions in their root tissues. Soil water is traditionally assumed to be available to plants at soil tensions between -15 Bar (permanent wilting coefficient) and -0.33 Bar (field capacity) (Brady 1974). Theoretically, plants are unable to absorb water held in soils at tensions greater than -15 Bar. Studies of water potential conducted on arid environment vegetation have shown that many of these plants can develop internal tissue pressures that are sufficient to absorb water held at pressures in the soil far in excess of -15 Bar. For examples Dina, et al (1973) report seasonal minimum water potentials for big sagebrush at -70 Bar. Branson et al. (1976) report

maximum seasonal values of -177 Bar for saltbush; corresponding to soil tensions are shown at -85 Bar. Branson also reported maximum tensions for big sagebrush at -60 Bar, rabbitbrush at -40 Bar, and winter fat at -90 Bar. This information indicates that the major shrub species on the LOFRECO site are well-adapted to the soil moisture stresses reported below.

Figures 12 and 15 are soil desorption curves constructed from soil analyses for the four major vegetation types on the LOFRECO site. The desorption, or soil moisture, curves are plotted from laboratory data against a logarithmic scale using curve-fitting. The curves represent an approximation of the behavior of soils under drying conditions. Using the precipitation records it is possible to estimate soil moisture tensions during the growing season. Estimates obtained in this manner from the 1978 data† show that the greatest soil moisture stresses occur in the south-facing sites and are followed by north-facing woodlands in this respect. Lowland sagebrush sites show considerably lesser moisture stresses; upland sites have the least soil moisture stress.

Calculated values for available soil moisture revise this order somewhat (Table 3). Using the data tabulated on Table 3 the available water capacity was calculated for each soil that represents a distinct ecoclimate on the site. Values were determined using the data gathered from the soil moisture control section of each soil type. The soil moisture control section is roughly defined by soil texture: the finer the texture of predominant particles, the more shallow the moisture control zone. The control section is used as a guideline for determining soil porosity , as well as for determining the ability of a soil to develop high internal tension, and therefore retain water as unavailable to plants. Available water tends to increase as soil texture becomes finer. Sandy soils are generally lowest in available moisture; clays greatest (Brady 1974). The flow of water through soils (saturated and unsaturated) is also influenced by texture. More unsaturated flow occurs in fine textured soils, while more saturated flow occurs in coarse soils. This feature relates not only to

† 1978 and 1979 precipitation differences are considered insignificant to these calculations

moisture availability, but also to evaporative losses. Coarse soils tend to have higher condactivities and supply more moisture to plants and to evaporation. Evaporative losses can extend to depths of up to 60cm. This type of loss is generally equal to 75% of the annual rainfall of a semi arid region, such as the LOFRECO site.

The available water capacity values (AWC) given in Table 4 must be adjusted for soil evaporative losses in order to be adequate indicators of moisture. Adjusting these values by using a ration of potential evaporation to AWC gives a better indication of soil water status. For the lowland sagebrush sites this ration equals 30% (Table 4)(5.7ml Potential Evaporation, PE, per day divided by an AWC of 18.2cm H 0, times 100). In other words, 30% of the available water capacity in the soil (in this case calculated to a depth of 112cm) is potentially lost to evaporation. The precipitation values for the lowland sites were recorded at a total of 6.8 cm for the 1978 summer season. Evaporative losses of this precipitation are equal to 2cm of moisture. Similar values are obtained for 1979 values. In the sagebrush upland sites the ratio is equal to 70%, or 5.6cm. In woodland sites 70% or 3.8cm of moisture are potentially lost to evaporation for north-facing woodland sites, and up to 110% of the soil moisture can be lost to evaporation from the south-facing woodlands. Potential evaporation values used were taken from Olgeirson (1977). It is important to note that these values were obtained from open soil surfaces and are significantly reduced by vegetation cover. The real value of the determination of potential evaporative losses relates to the moisture stresses that can develop in the different ecoclimates of the site. This information can be applied to the causative relationship between plant growth and ecoclimate, and be used in treating surfaces during revegetation.

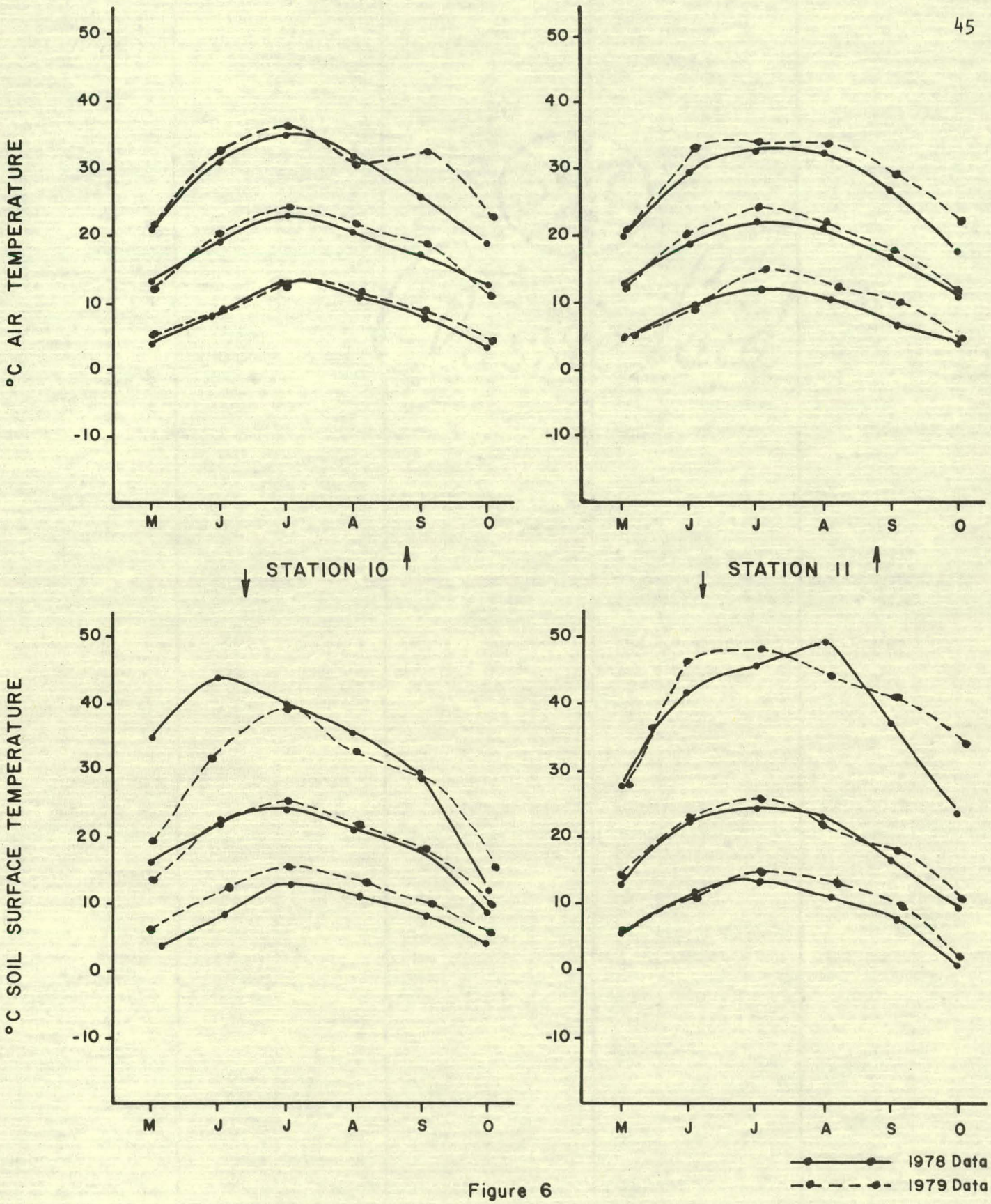


Figure 6

TEMPERATURE SUMMARY - LOFRECO SITE
SOUTH FACING PINYON-JUNIPER WOODLAND
(STATIONS 10 and 11)
1978–1979

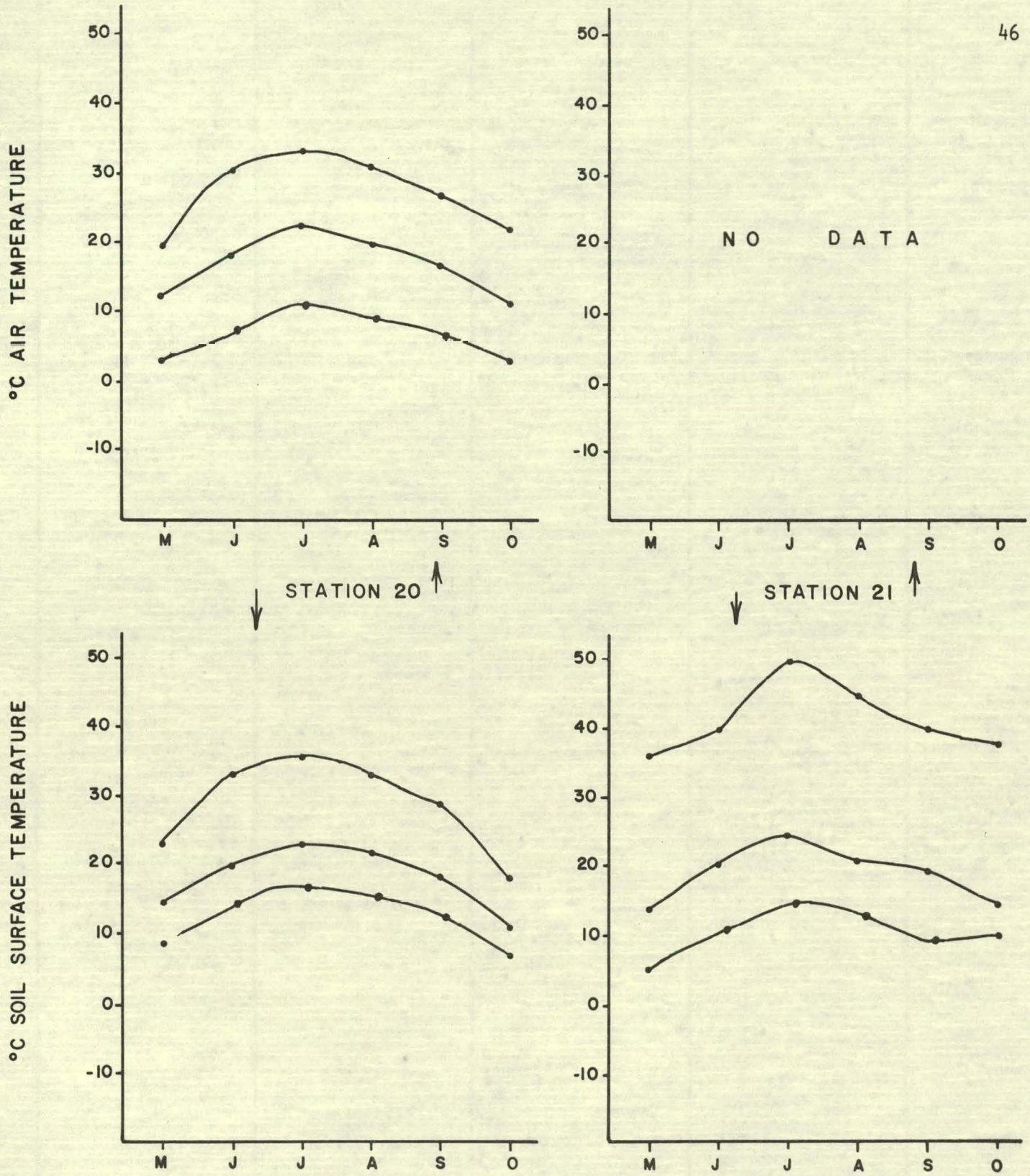


Figure 7

TEMPERATURE SUMMARY - LOFRECO SITE
NORTH FACING PINYON - JUNIPER WOODLAND
(STATIONS 20 and 21)
1978

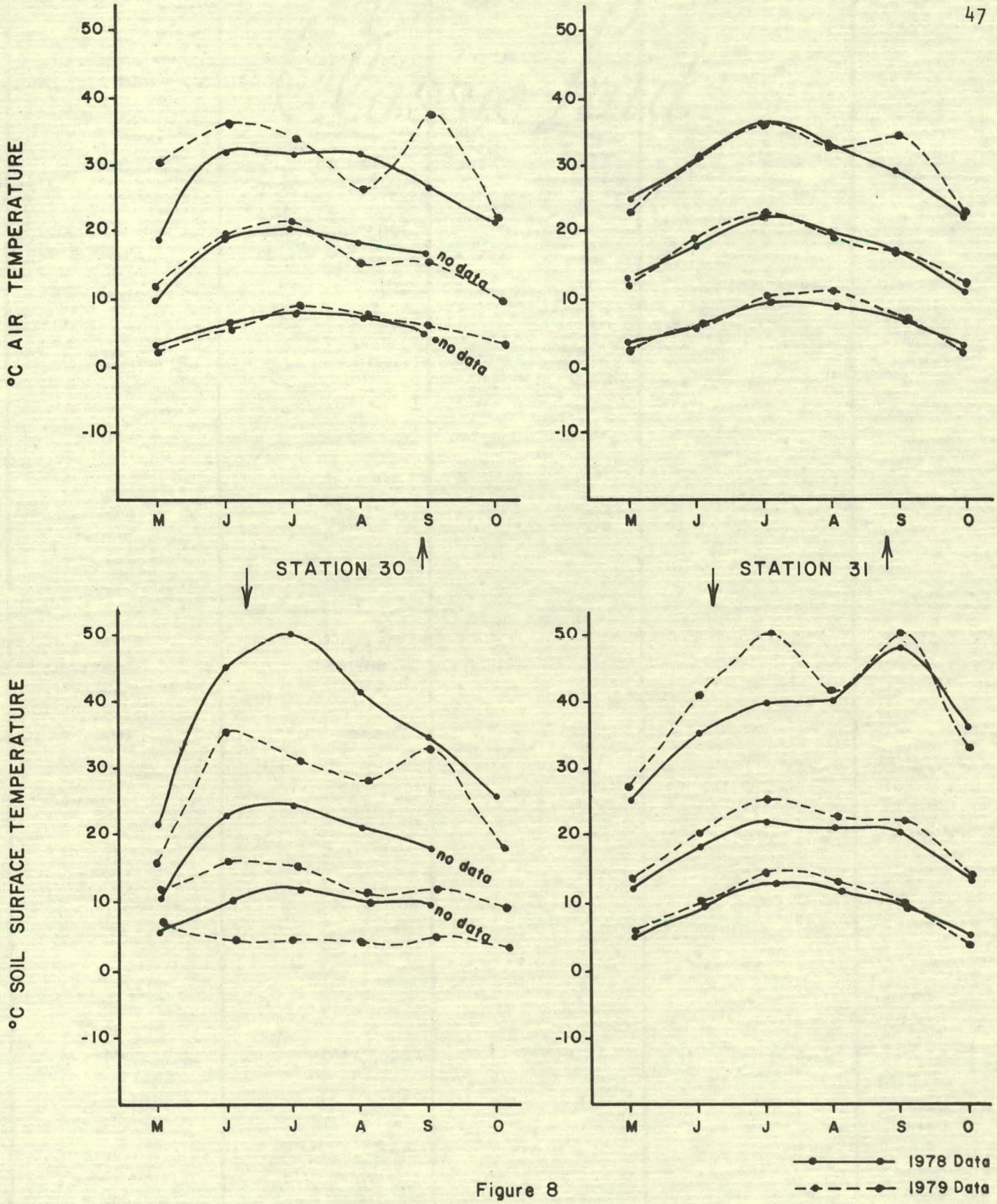


Figure 8

TEMPERATURE SUMMARY - LOFRECO SITE
SAGEBRUSH - SALTBUSH LOWLANDS
(STATIONS 30 and 31)
1978-1979

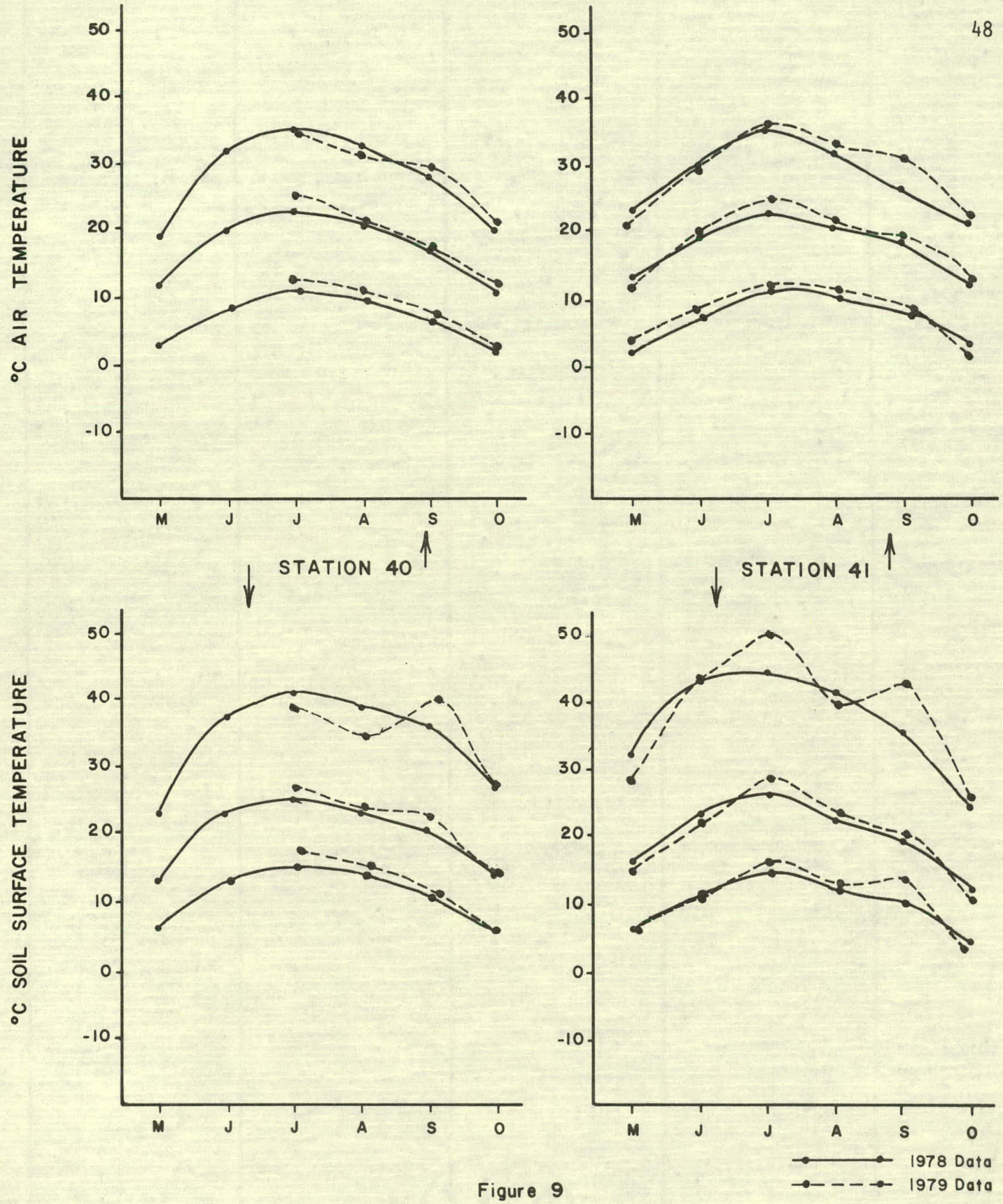


Figure 9

TEMPERATURE SUMMARY - LOFRECO SITE
SAGEBRUSH - GRASS UPLANDS
(STATIONS 40 and 41)
1978-1979

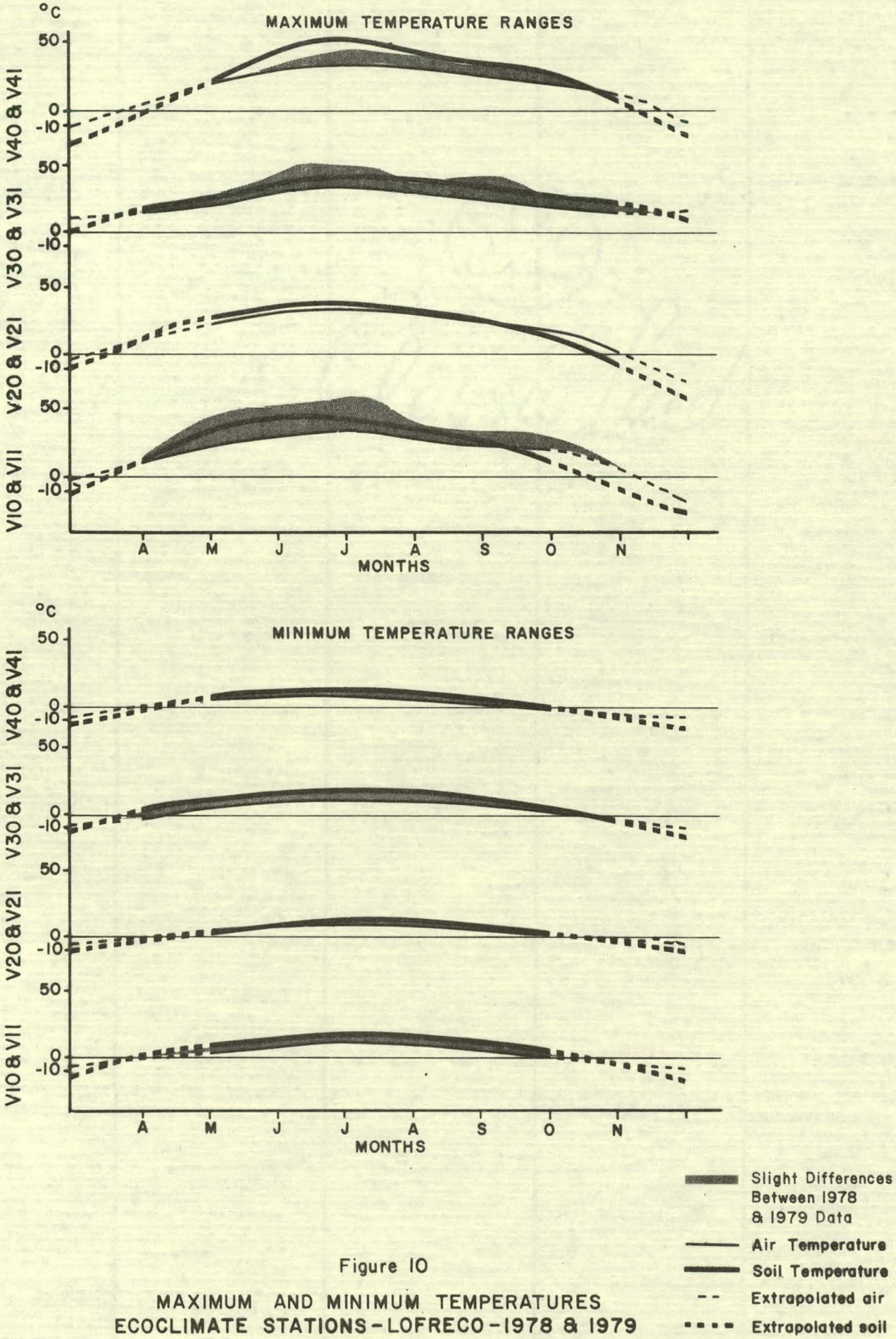


Figure 10

MAXIMUM AND MINIMUM TEMPERATURES
ECOCLIMATE STATIONS - LOFRECO - 1978 & 1979

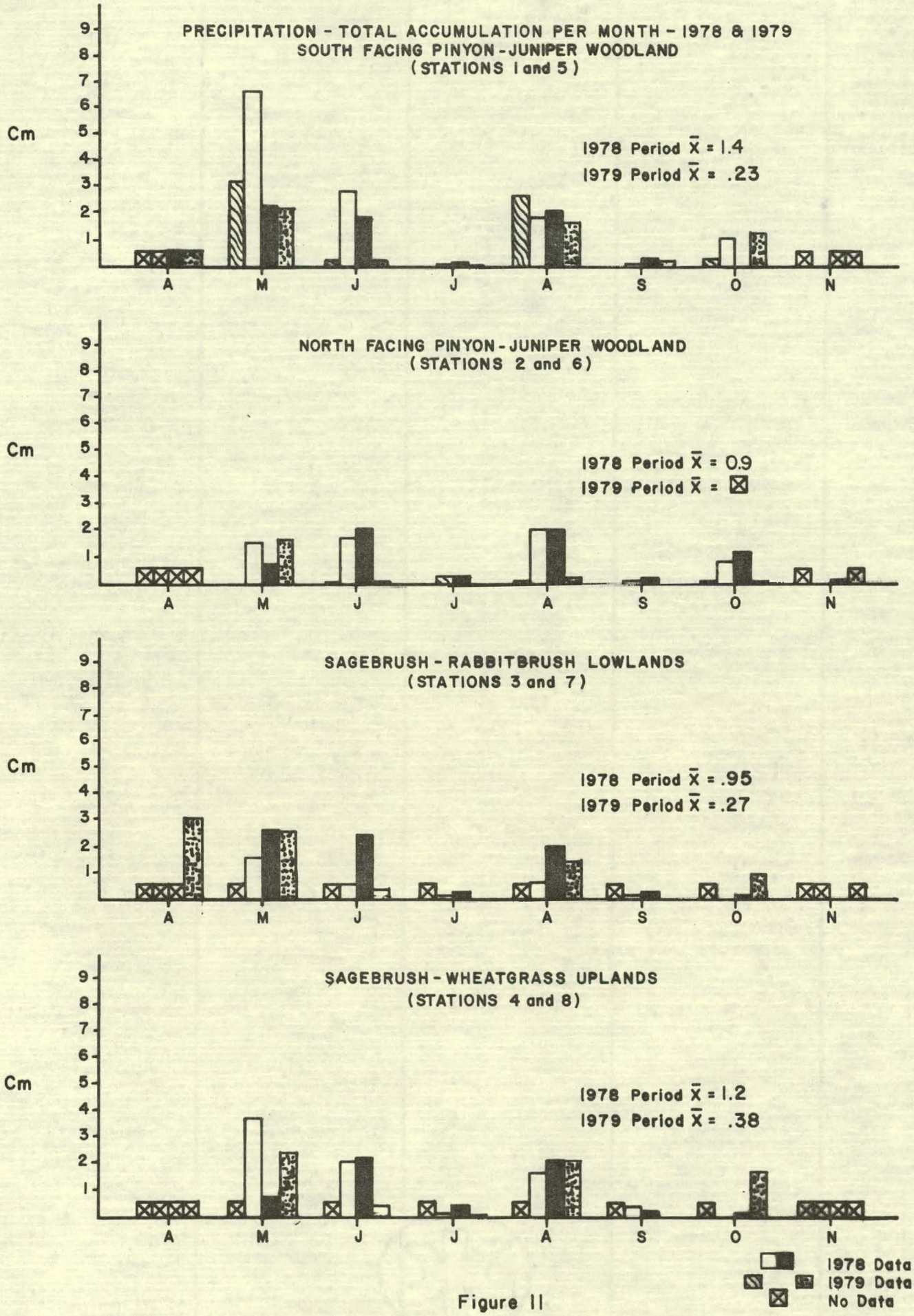


Figure 11

PRECIPITATION SUMMARY FOR THE ECO-LOG STATION PAIRS — LOFRECO — 1978 & 1979

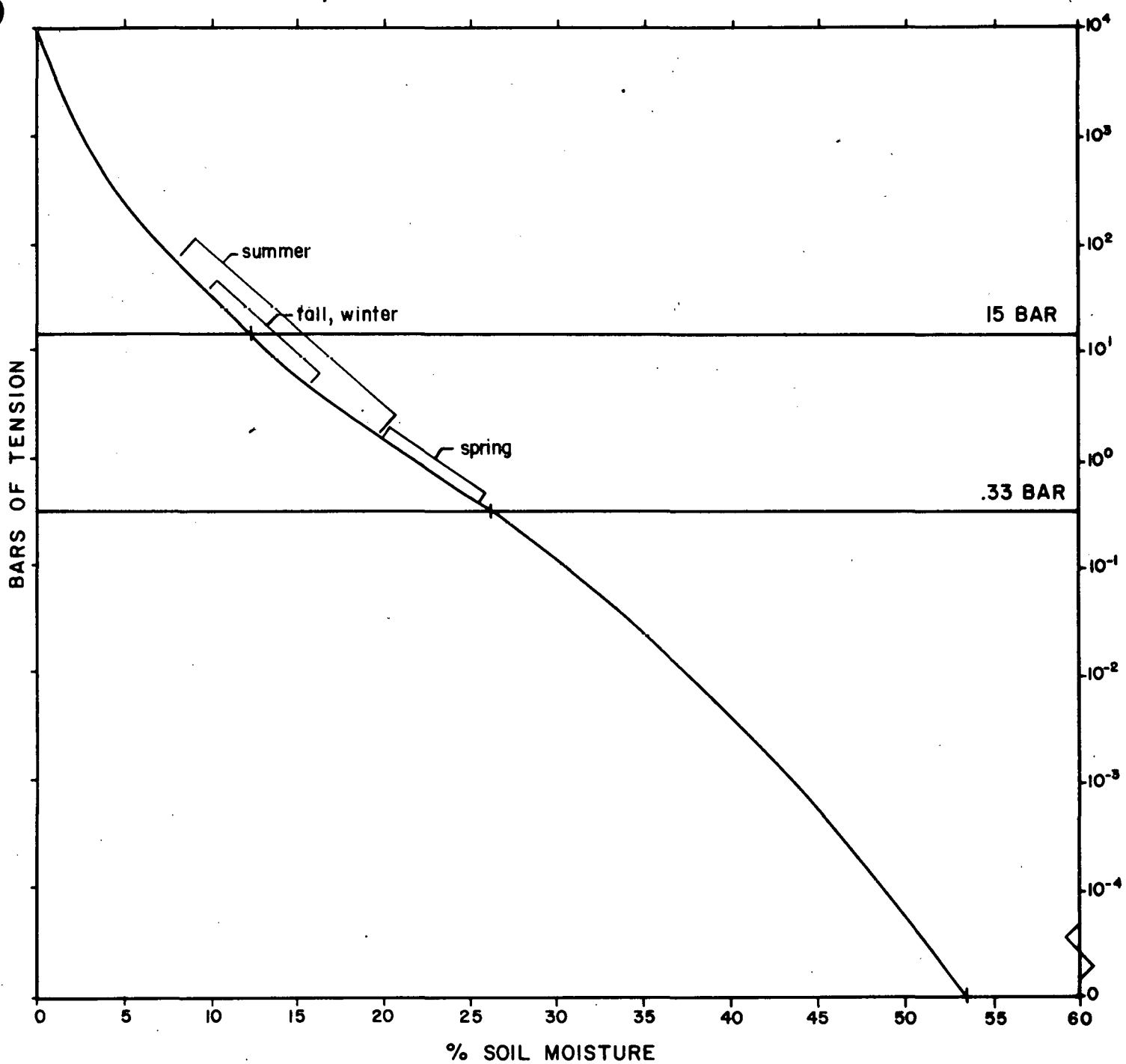


Figure 12

SOIL MOISTURE DESORPTION CURVE
SOUTH FACING PINYON-JUNIPER WOODLANDS
(LR LOAM)

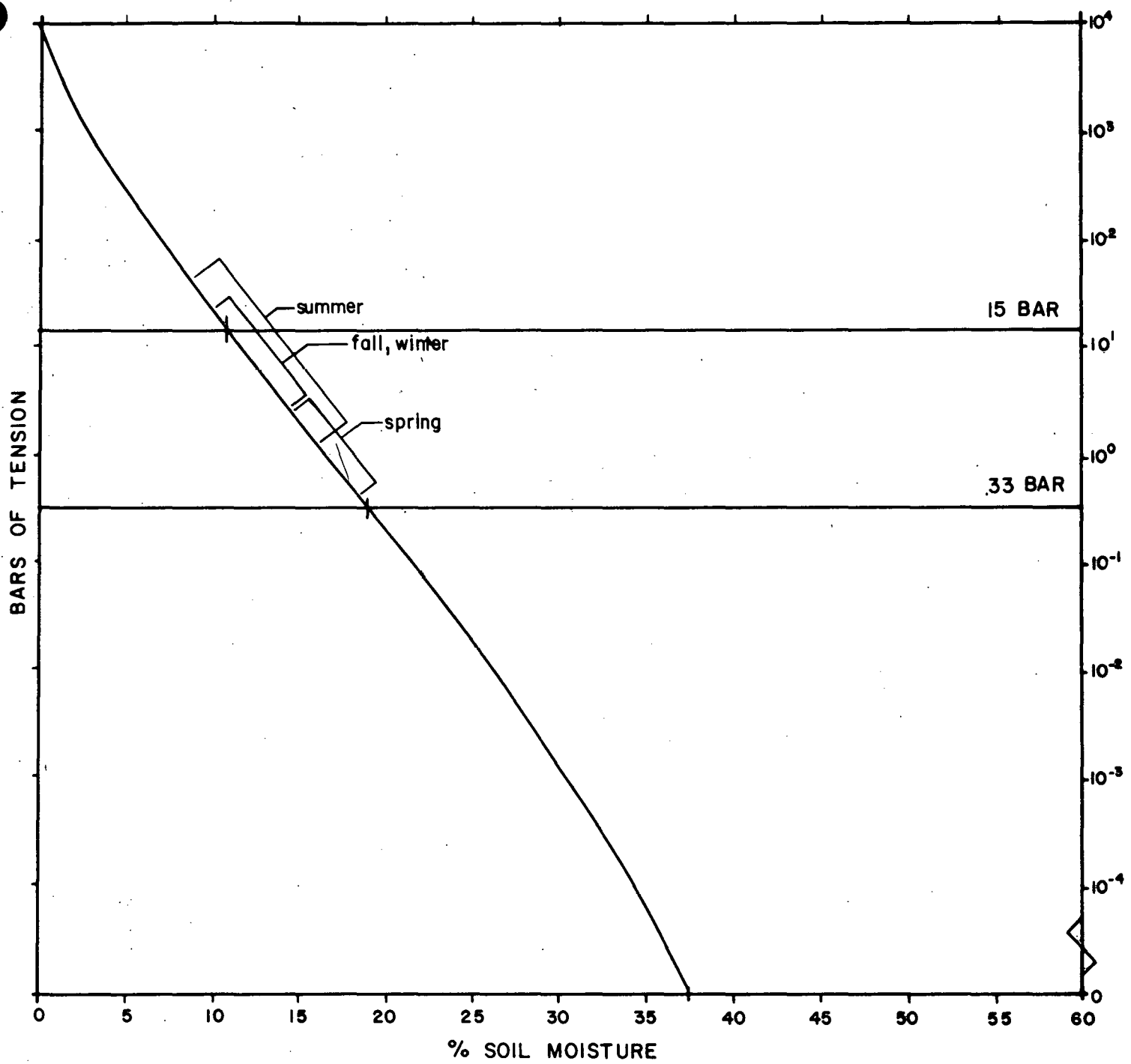


Figure 13

SOIL MOISTURE DESORPTION CURVE
NORTH FACING PINYON-JUNIPER WOODLANDS
(JR LOAM)

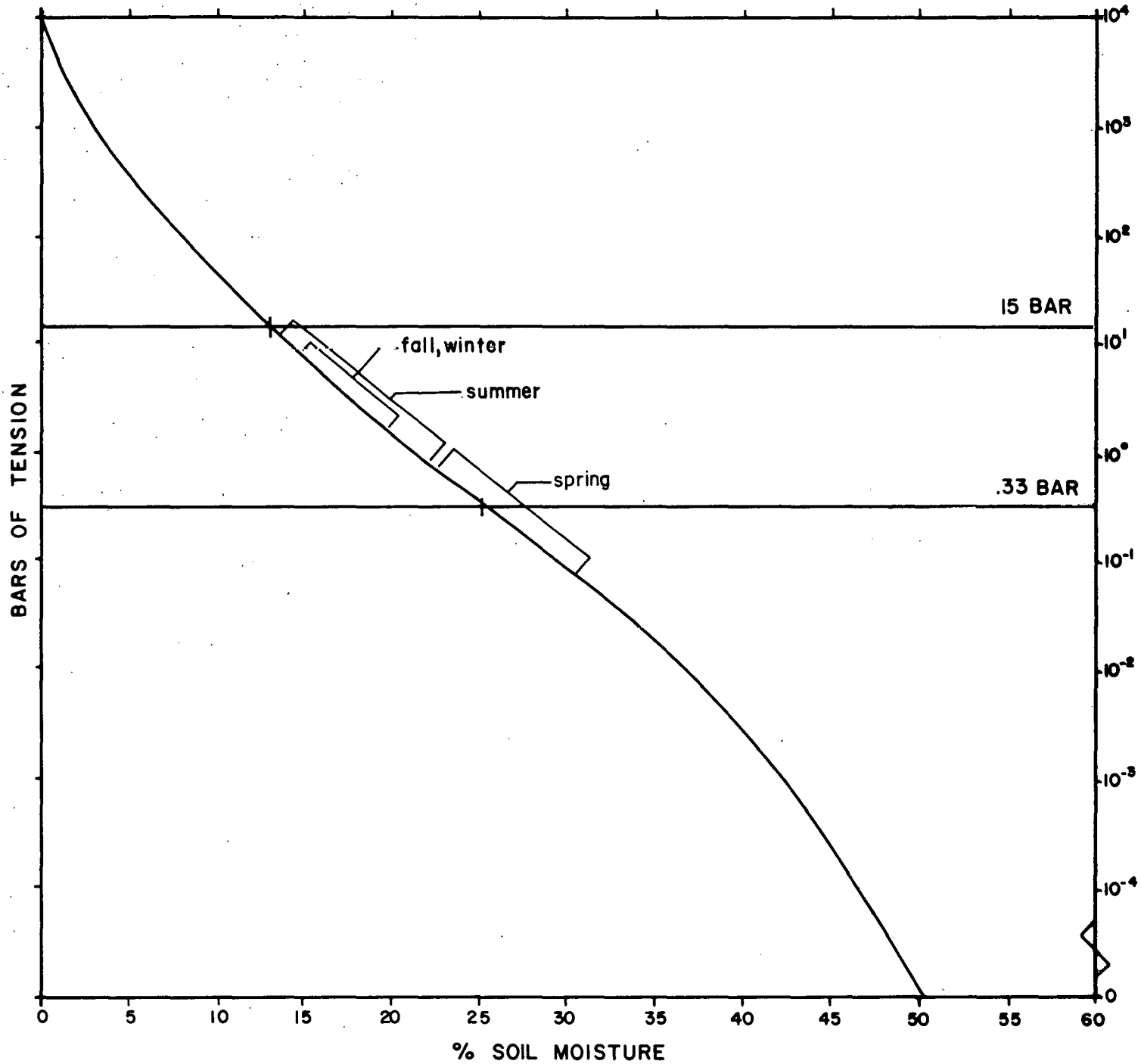


Figure 14

SOIL MOISTURE DESORPTION CURVE
SAGEBRUSH-SALTBUSH LOWLANDS
(HAVRE LOAM)

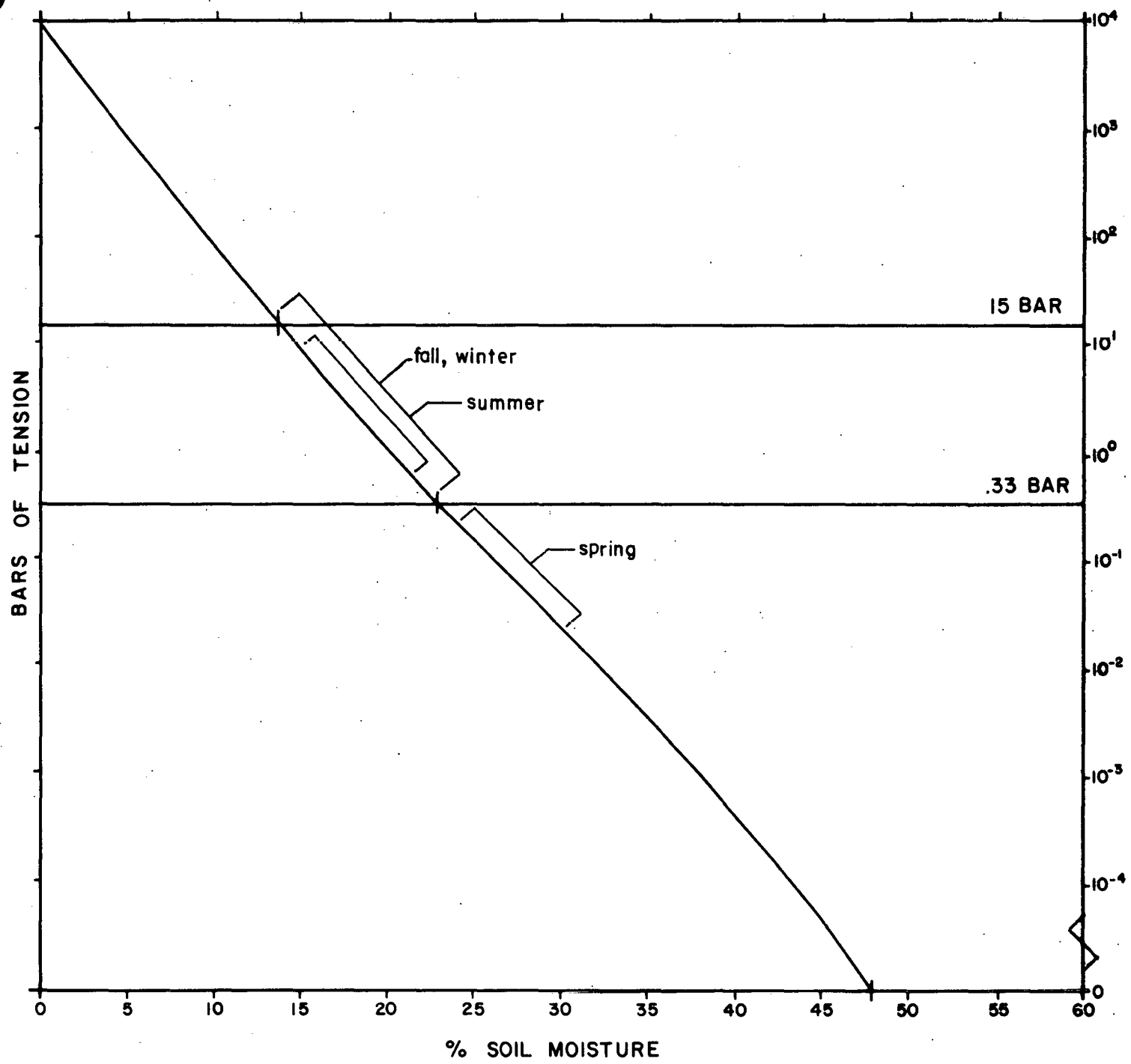


Figure 15

SOIL MOISTURE DESORPTION CURVE
SAGEBRUSH - GRASS UPLANDS
(LUHON LOAM)

TABLE 2

PRECIPITATION (cm) SUMMARY

1978-1979

LOFRECO SITE

Month	Ecoclimate Data Collection Station							
	E-10	E-11	E-20	E-21	E-30	E-31	E-40	E-41
April	*/*	*/*	*/*	*/*	*/1.78	*/*	*/3.04	*/*
May	6.6/3.12	1.5/.05	1.6/*	3.7/*	2.2/2.13	0.7/1.7	2.5/2.59	0.7/2.36
June	2.8/.28	1.7/.08	0.6/*	2.0/*	1.8/.25	2.0/.10	2.4/.28	2.1/.30
July	0.1/.07	0.2/0.0	0.1/*	0.1/*	0.2/.08	0.2/.03	0.2/.03	0.3/.08
August	1.8/2.66	2.0/.13	0.6/*	1.6/*	2.0/1.67	2.0/.25	2.0/1.4	2.0/2.0
September	0.1/.03	0.1/.05	0.1/*	0.4/*	0.3/.25	0.2/.03	0.2/.03	0.2/.03
October	1.1/.25	0.8/.15	0.0/*	0.0/*	0.0/1.29	1.0/.10	1.0/.91	1.0/1.68
November	0.05/*	0.03/*	*/*	*/*	*/*	0.1/*	0.05/*	*/*
Total	12.6/6.58	6.3/.46	3.0/*	7.8/*	7.2/5.72	6.3/2.21	9.7/5.21	6.3/6.61
Mean	1.8/1.06	0.9/.08	0.5/*	1.3/*	1.0/.96	0.9/.38	1.2/.86	1.1/1.07
Vegetation Type Mean	1.4/.55		.9/ *		.95/ .67		1.2/ .96	

1978/ 1979
*- NO DATA RECORD

Table 3

**AVAILABLE SOIL MOISTURE SUMMARY
FOR THE FOUR SOIL TYPES
CORRESPONDING TO ECOCLIMATE STATIONS
LOFRECO SITE
1978**

STATION @	#	BULK DENSITY	1/3 BAR(-)	-15 BAR (X)	SAMPLE DEPTH(=)	% + AWC	P.E. ⁜ cm/cm
10	11	1.41	26	13	25	4.6	5.1
20	21	1.40	26	14	46	7.7	5.1
30	31	1.48	24	13	112	18.2	5.7
40	41	1.48	24	13	58	9.4	6.3

@ See figures 12 through 15 for explanation

\+ **Percent Available Water Capacity**

⁜ **Potential Evaporation, cm H_2O/cm Soil (after Olgeirson 1977)**

Table 4

POTENTIAL EVAPORATION SUMMARY
(ADJUSTED FOR PERCENT AVAILABLE WATER CAPACITY)
ECOCLIMATE STATIONS 10 - 41
LOFRECO SITE
1978

STATION #		Potential Evaporation cm H_2O / cm soil (÷)	Percent Available Water Capacity (x) 100	(=) Adjusted Potential Evaporation
10	11	5.1	4.6	110
20	21	5.1	7.7	70
30	31	5.7	18.2	30
40	41	6.3	9.4	70

Nomenclature for soils identified on the LOFRECO site is presented in Table 5. The soil series units are mapped on Pocket Figure 2.

Soil series on the LOFRECO site have been classified according to the U.S. Department of Agriculture Soil Classification System. This hierarchial system defines soil at six levels of classification. The broadest category of classification (soil order) is used to compare soil over large areas. The suborder category is used to define soil based on certain critical horizonal properties indicating essential features about soil development. The third level (great group) arranges soils according to characteristics that are indicative of moisture and temperature regimes, as well as the total arrangement of the horizons. The fourth level of the soil classification system is the series which is used to differentiate soil families into groups that display a range of properties more narrow than the soil family group.

Interpretation of Soils with Respect to Soil Moisture

The classification of soils at the level of order, suborder, and great group includes the identification of the soil moisture regime. The soil moisture regime refers to the presence of water held in the soil at the tension of less than 15 bars during various periods of the year in the "soil moisture control section". The soil moisture control section is roughly defined by depth and particle size, so that the depth of the soil moisture control section increases as particle size increases from clay to sand-sized particles. The soil moisture control sections of the soils occuring on the LOFRECO site are given in the Appendix D, Tables D1.8 through D1.12.

The soil moisture regimes of the soils on the LOFRECO site are classified as ustic (the classification of ustic torrifluvents and ustic torriorthents in Table 5 indicates that these soils border on more dry moisture regimes than those that are strictly "ustic"). Ustic

soils have limited moisture regimes, but there is a surplus of moisture (where precipitation exceeds evapotranspiration) in fall and early winter. Leaching can occur during the summer; limiting the growth and establishment of vegetation (Figure 16).

Interpretations of Soil with Respect to Soil Temperature

The soils of the LOFRECO site are classified in the frigid temperature regime. A frigid soil is one having a mean annual temperature lower than 8°C (47°F).

General Description of Soil Taxonomic Units

The soils of the LOFRECO site are classified in three subgroups, as described below:

Orthids

The orthid soils are characterized as having thin, light-colored surface horizons that are low in organic matter and may have a horizon of salt accumulation. As a result of low organic matter and fine particle size, these soils tend to take up water slowly so that much of the precipitation received runs off. In many orthid soils development has been retarded by a combination of factors. As a result, these soils may occur on active erosion surfaces; the degree of erosion hazard and droughtiness may be great on these sites. The Luhon series is an orthid soil further classified as a calciorthid because of significant calcium carbonate accumulations in the profile.

Fluvents

Fluvent soils are subject to flooding, but not perpetually saturated. The parent materials of these soils are alluvial sediments that may contain significant amounts of organic matter. Subhorizons of these soils have very fine sandy loamy texture. Orgnaic matter regularly decrease with depth in this group and depth to bedrock is greater than 25cm (10 inches). The Havre series is a fluvent soil further classified as an ustic torrifluvent because of an

ustic moisture regime that borders on torric (torric, in terms of the study area, indicates an absence of summer precipitation).

Orthents

Orthents are found in areas where little or no soil development has taken place, such as uplands and erosion surfaces. These soils are low in organic content and are subject to frequent erosion disturbance. The JR and LR soils are orthent soils classified as ustic torriorthents as a result of their low moisture regimes, which do, however, support a moderate vegetation cover.

Classification of Soils

The soils of the LOFRECO site are classified as shown on Table 5. Characteristics common to all of these soils are elevation: approximately 2073m, (6800 ft); mean annual precipitation range: from 254 to 330mm (10 to 13 inches) mean annual soil temperature regime: from 6 to 8°C (43 to 47°F) and frost-free period: approximately from 90 to 110 days. The soil sites in the study area are suitable as wildlife habitat and for livestock grazing. The vegetation types associated with the soil described below are given in Table 6.

JR Loam, 5 to 40 Percent Slopes (Profile Pit #2)

- (series not named or correlated in Utah but is being mapped as JR series in the Duchesne soil survey).
- Classification: Loamy, skeletal, mixed, (calcareous) frigid, Ustic Torriorthent (Table 5).

This mapping unit consists of moderately deep, well-drained soils that formed in residuum on colluvium from Green River shale. The JR series is located on north and east-facing ridges. Present native vegetation is dominated by Utah Juniper, pinyon pines, shrubs, and grasses. About 50 percent of the surface is covered by juniper and pinyon duff 5 to 10cm (2 to 4 inches) thick. In a typical profile the surface layer is grayish-brown, strongly calcareous loam about 31cm (12 in) thick. The underlying subsoil layer consists of weathered angular shale

fragments and is about 40 percent of the soil by volume. This layer is about 31cm (12 inches) thick. The lowest subsoil layer consists of about 95 percnet slightly-weathered, angular shale fragments with some silt loam. About 61cm (24 in) thick. Below this lowest subsoil horizon is hard, unweathered and fractured shale.

- Representative Profile:
  - o A11 0-18cm (0-7 in), grayish-brown (10YR 5/2) loam; dark grayish-brown (10YR 4/2) moist; weak, medium granular structure; slightly hard, friable; non-sticky and slightly plastic; strongly calcareous; moderately alkaline; gradual, wavy boundary (3 to 9 in) thick.
  - o A12 18-31cm (7-12 in) light brownish-gray (10YR 6/2)loam; brown (10YR 4/3) moist; weak coarse granular structure; slightly hard, fraible; non-sticky and slightly plastic; strongly calcareous, moderately alkaline; gradual, wavy boundary (4 to 6 in) thick.
  - o C1 31-61cm (12-24 in), very pale brown (10YR 6/4) moist; weak, medium subangular blocky structure; slightly plastic; strongly calcareous, moderately alkaline; gradual, wavy boundary (22 to 26 in) thick.
  - o C2 R 61-122cm (24-48 in) 95 percent weathering fragmental shale.
  - o R 122cm+ (48 in+) unweathered fragment shale.
  - o Pit Location: 533m W(1750 ft) and 762m S(2500 ft) of NE corner of Section 2, T-14 S, R-22 E, Uintah County, Utah. This soil is in the semi-desert, stony-loam, pinyon-juniper summer precipitation range site.

<u>LR Gravelly Loam 5 to 40 Percent Slopes (Profile Pit #4)</u>

- (series not named or correlated in Utah but is being mapped by LR series in the Duchesne Soil Survey).

  Classification: loamy, mixed (calcareous) frigid, shallow, Ustic Torriorthent.

  This soil series consists of shallow, well-drained soils that formed in residuum from Green River shale. The LR series occurs

on south and west-facing slopes and ridges. Present native vegetation is dominated by Utah juniper, (*Juniperus osteosperma*) pinyon pine (*Pinus edulis*) and bunch-grasses. About 2.5cm (1 in) of juniper or pinyon duff occurs under the trees on about 10 percent of the ground surface.

In a typical profile, the surface layer is light brownish-gray, strongly calcareous, gravelly loam. The underlying material is composed chiefly of slightly weathered, hard, angularly-oriented shale fragments.

- Representative Profile:
  - o A1 0-15cm (0-6 in) light brownish-gray (10YR 6/2) gravelly loam brown (10YR 5/3) moist (The gravel consists of about 25 percent angular shale fragments. A gravel pavement of angular shale fragments covers approximately 50 percent of the ground surfaces); very weak, medium, platy structure; slightly plastic; strongly calcareous moderately alkaline; abrupt, wavy boundary 10 to 20cm (4 to 8 in) thick.
  - o CR 15-91cm (6-36 in) 95 percent slightly weathered, hard angularly oriented shale fragments; 5 percent silt loam and roots.
  - o Pit Location: 549m E(1800 ft) and 533m S(1750 ft) of NW corner of Section 2, T-14 S, R-22 E, Uintah County, Utah. This soil is in the semi-desert shallow loam, pinyon-juniper summer precipitation range site.

Luhon Loam, 3 to 8 Percent Slopes (Profile Pit #3)

Classification: Fine loamy, mixed, (calcareous) Borrolic Calciorthid (Table 5).

This mapping unit consists of deep, well-drained soils that formed from mixed alluvium and in residuum from Green River shale. Luhon soils occur on gently sloping to gently rolling fans and valley side slopes. Present

native vegetation is mainly big sagebrush, (*Artemisia tridentata*) four-wing saltbush, (*Atriplex canescens*) winterfat, (*Ceratoides lanata*), western wheatgrass, (*Agropyron smithii*), blue grama grass, (*Bouteloua gracilis*), and blue-bunch wheatgrass (*Agropyron spicatum*).

In a typical profile the surface layer is a pale brown, silty clay loam about 23cm (9 in) thick. The substratum consists of about 18cm (7 in) of very strongly calcareous loam underlain by gravelly loam. (The gravelly loam is about 90 percent soft, weathered shale fragments; about 60 percent of these shale fragments slake when soaked in water.)

- Representative Profile:
  - o A1 0-18cm (0-7 in), pale brown (10YR 6/3) loam brown (10YR 4/3) moist; weak medium subangular-blockly structure; hard friable; non-sticky and slightly plastic; strongly calcareous, moderately alkaline; clear, smooth boundary.
  - o B2 18-41cm (7-16 in), very pale brown (10YR 7/4) silty-clay loam, yellowish-brown (10YR 5/4) moist: moderate, medium angular-blocky structure; very hard, firm; slightly sticky and plastic; very strongly calcareous, strongly alkaline; gradual wavy boundary.
  - o C1ca 41-58cm (16-23 in) light gray (10YR 7/2) loam, pale brown (10YR 6/3) moist; weak medium subangular-blockly structure; slightly hard, very friable; non-sticky and slightly plastic; strongly calcareous, strongly alkaline; gradual wavy boundary.
  - o II C2 58-152cm (23-60 in) light gray (10YR 7/3) gravelly loam, brown (10YR 5/3) moist; (this gravelly loam is about 90 percent soft, weathered shale; about 60 percent shale fragments slake when soaked in water); strongly calcareous and strongly alkaline.
  - o Pit Location: 183m E(600 ft) and 610m S(2000 ft) of NW corner of Section 2, T-14 S, R-22 E Uintah County, Utah.
  - o This soil is in the semi-desert loam, summer precipitation range site.

Havre Silt Loam, 2 to 8 Percent Slope (Profile Pit #1)

- Classification: Fine loamy, mixed (calcareous) frigid, Ustic Torrifluvent (Table 5).

This mapping unit consists of deep, well-drained soils that formed in mixed alluvium. The Havre series occupies nearly level to moderate sloping stream terraces and flood plains. The present native vegetation community is composed chiefly of big sagebrush, rabbitbrush (*Chrysothamnus nauseosus*) and flowering saltbush. In a typical profile, the surface layer is grayish brown, strongly calcareous silt loam, about 20cm (8 in) thick. The surface layer is typically covered by a layer of sage duff about 2.5cm (1 in) thick. The underlying material is light brownish-gray, strongly calcareous loam to a depth of 152cm (60 in) or more.

- Representative Profile:
  - o A0 2.5 to 0cm (1 in) duff consisting of sage leaves and twigs.
  - o A1 0-20cm (0-8 in), grayish-brown (10YR 5/2) silt-loam, brown (10YR 4/3) moist; very weak, coarse platy structure; soft, very friable; non-sticky and non-plastic; strongly calcareous, moderately alkaline; clear, smooth boundary 18-25cm (0-7 in) thick.
  - o C1 20 to 71cm (8-28 in) light brownish-gray (10YR 6/2) loam, brown (10YR 4/3) moist, weak, medium subangular-blocky structure; slightly hard, friable; non-sticky and slightly plastic; strongly calcareous, moderately alkaline; gradual, wavy boundary 41 to 61cm (16 -24 in) thick.
  - o C2 71-152 cm (28-60 in) pale brown (10YR 6/3) heavy loam, brown (10YR 4/3) moist; masive; slightly hard, friable; slightly-sticky and slightly plastic; strongly calcareous, moderately alkaline.
  - o Pit Location: 549m W (1800 ft) 732m S(2400 ft) of NE corner of section 2, T-14 S, R-22 E, Uintah County, Utah. This soil is in the semi-desert loam summer precipitation range site.

Soil Physical and Chemical Analyses

The results of the physical and chemical soils analyses are contained in Appendix, Tables D1.1 - D1.7.

Native Soils

The overall nutrient regime of the soils occuring on the LOFRECO site is low. Nitrate-nitrogen is low to near normal in all native soils (less than 8ppm), although slightly high values are found in the upper horizon of the Havre loam series(Appendix D). It is noteworthy that high nitrogen concentrations can reduce the availability of both potassium and phosphorus to plants, although phosphorus and potassium present in plant tissues counteracts this to an extent. Sodium is normal in the upper horizons of all soils (less than 200ppm) (Appendix D).
The Havre loam subsoils, however, exhibit high concentrations of sodium (Appendix D).Potassium occurs at wide range of concentrations between soil types. The Havre loam series demonstrates normal concentrations of potassium (200-400ppm), while the Luhon loam series has slightly higher values for this soil constituent in the upper horizon (480ppm). JR and LR loams show potassium levels ranging from deficient to normal (150-50ppm or less). Calcium concentrations in all soils are in the normal range (ca.2400ppm). Ammonium-nitrate values have a wide range in the soils sampled. In the LR and JR series this nutrient is found at normal levels (ca. 1ppm). In the Havre and Luhon series, ammonium-nitrate ranges from normal to high (1-4ppm). Sulfate-sulfur is normal to high in all soils taken as whole units (30-120ppm). However, some horizons demonstrate low levels of this constituent (less than 7ppm) (Appendix D).
Lime is relatively high in all soils (greater than 8%), but this does not represent a deliterious level. Magnesium occurs at normal levels in all soils (200-700ppm) except for the lower horizons of the Havre and Luhon series where it reaches high values of approximately 1400 to 2000ppm. The ph of all the soils sampled is high at 8.0 to 8.5. In the Havre and Luhon series ph is excessive in the lowermost horizons (8.7-8.9). Organic matter percent is normal to slightly high (greater

values of nitrate (Havre loam). The disturbance of soils with higher lime concentrations is another important consideration. This is a consideration in the Luhon loam series.

Retort Soils

The values for most soil contituents in retort soils are comparable with those of the native soils discussed above; Figures 18 through 30, illustrate a comparison of some of the more important soil characterists. This is also true of the constituents determined in the special analysis Appendix D. Several points of significance are, however, apparent from the analysis. The first of these is ostensibly the result of activities on the retorts prior to blasting. There is a noted increase in nitrate nitrogen in some of the retort soils (Figure 18). This is the result of spillage of ANFO during the process of loading blast holes. The effects of this spillage are, however, not deliterious. In fact, they appear to have a positive effect on plant growth since ANFO is primarily composed of nitrates. The only potential damage due to ANFO might occur if an excess of this material created a nitrate inhibition of potassium and phosphorus. The second type of significant soil alteration ostensibly caused by retorting is the alteration in soil structure. The analyses show a signigicant change in two soil parameters that relate to structure and to water holding capacity (although the first is of greater significance). The concentration of clay sized particles is decreased after the burning of retorts(Appendix D, Table 19). Bulk density of the soil samples shows a significant increase following burning of the retorts (Figure 20). Although the changes in these two parameters are the apparent result of retorting, they must be considered, instead, to be significant changes caused by the process of creating the retort mounds. The decrease in percent clay content is most probably the result of the loss of these particles during wind erosion. This alteration can be controlled through the use of temporary physical erosion control measures. The increase in bulk density is the apparent result of compaction due to drilling and other traffic. This increase occurs in the soil surface

than 3-4%). The electrical conductivity of all surface soil horizons is acceptable (ca. 0.5-1. 5mmhos/cm). The subsoil of the Havre loam has excessive electrical conductivity values (greater than 6mmhos/cm). The cation exchange capacity of all soil horizons is normal (less than 20 meq/100gm) to slightly low. Trace element concentrations of Manganese. Copper, Zinc, Molybdenum, and Cobalt are in acceptable ranges for all soils. Iron is normal in all soils at approximately 2.5 to 5ppm. Boron is slightly high in all soils (greater than 1ppm), but can not be termed excessive. Selenium concentrations are not problematical (less than 2ppm). Arsenic is slightly high in most soils at greater than 0.5ppm. The range of the sodium absorption ratio is acceptable in all soils (less than 8%). Available water capacity is moderate to low in all soils (compared with a mean adequate level of greater than 0.25cmH_2O/cm soil).

The general reclamation potential of all soils is acceptable. Figure 17 illustrates a comparison of the levels of soil parameters typically evaluated in determining a soil's reclamation potential (Wyoming DEQ 1976). The comparisons made in this figure reveal no special problems likely to be encountered in reclaiming sites based on soil properties. However, it must be noted that the lowermost horizons of the Havre and Luhon loams may present problems in terms of electrical conductivity and sulfate-sulfur.

Although there are no apparent reclamation problems indicated by the comparison of certain soil constituents with standard values, other considerations of soils must be made in terms of reclamation. The low nutrient status of the native soils may require fertilization during the reclamation process. In addition, the relatively high erodability of soils, particularly susecptibility to wind erosion, must be considered during revegetation activities. Finally, the interactions between various soil constituents, such as the effects of nitrates on potassium and phosphorus must be considered during the reclamation of soils that demonstrate high

layer and can be reversed by roughing during the revegetation of the retorts. The last soil alteration requiring discussion is the increase in sulfate-sulfur. Although this parameter does not increase to excessive levels it should be carefully monitored as a potential source of problems in reclamation.

The soil constituents analyzed in samples collected from retorts before blasting and after burning were subjected to a paired t-test in order to assess any significance of change in any parameter. The results of this test are given in Table 7. This table shows that two significant alterations before blasting and after burning occured at the 95% confidence interval. These alterations were in the decrease of percent clay and increase of bulk density. The remaining differences in soil constituents were determined to be of no real significance. It should also be noted that the natural variation in soil characteristics revealed by all of the data presented (Tables D1.1-D1.7) is a further indication of the low level change in the soil constituents of the surface layer on retorts.

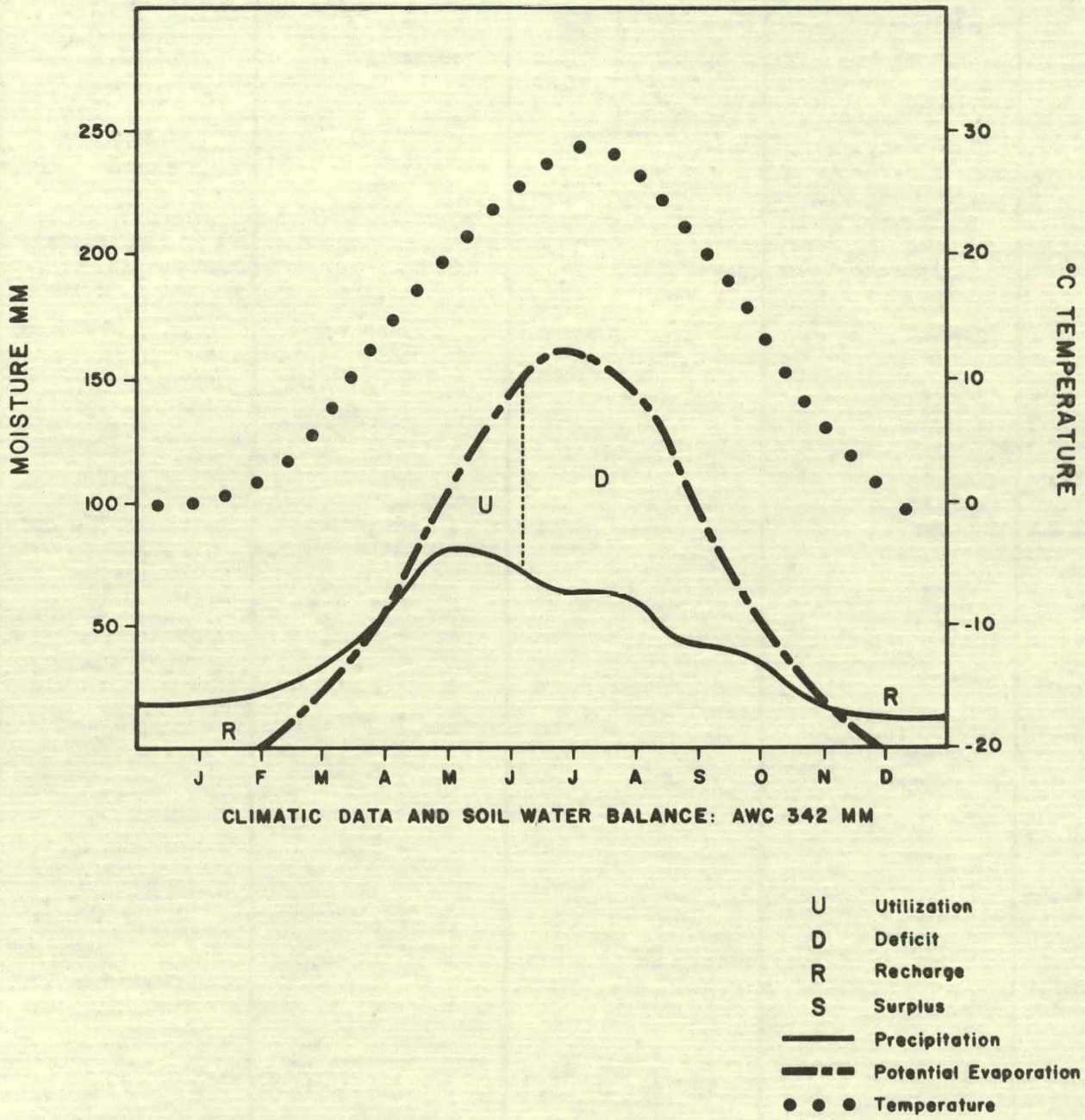
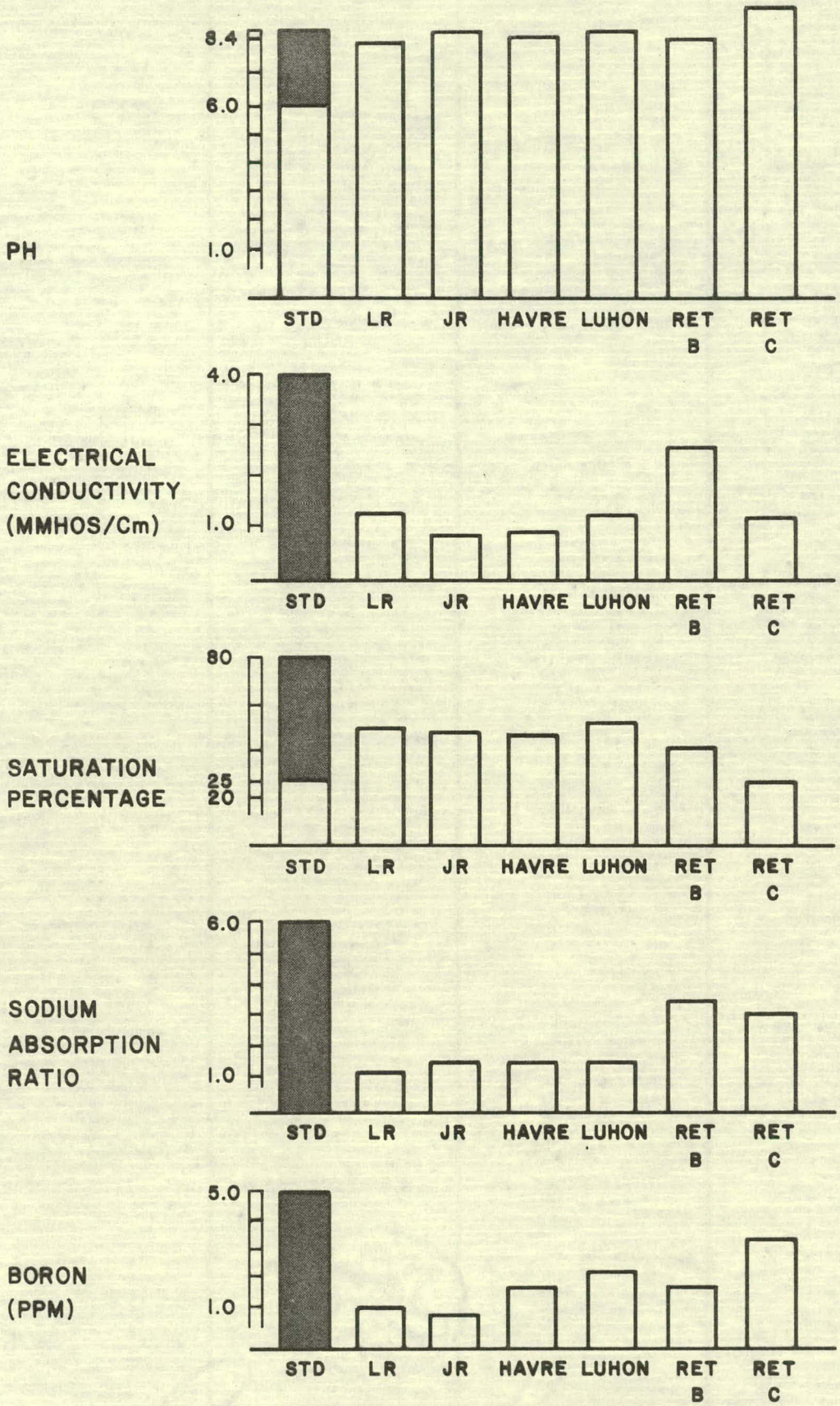


Figure 16

CLIMATIC DATA AND SOIL WATER BALANCE
FOR A SOIL THAT HAS AN USTIC SOIL MOISTURE REGIME,
AFTER U.S.D.A. 1975



Acceptable Range shown by screened pattern.

Figure 17

COMPARISON OF SELECTED SOIL RECLAMATION POTENTIAL STANDARDS* WITH SOILS OCCURRING ON THE LOFRECO SITE

*WYOMING DEPARTMENT OF ENVIRONMENTAL QUALITY 197

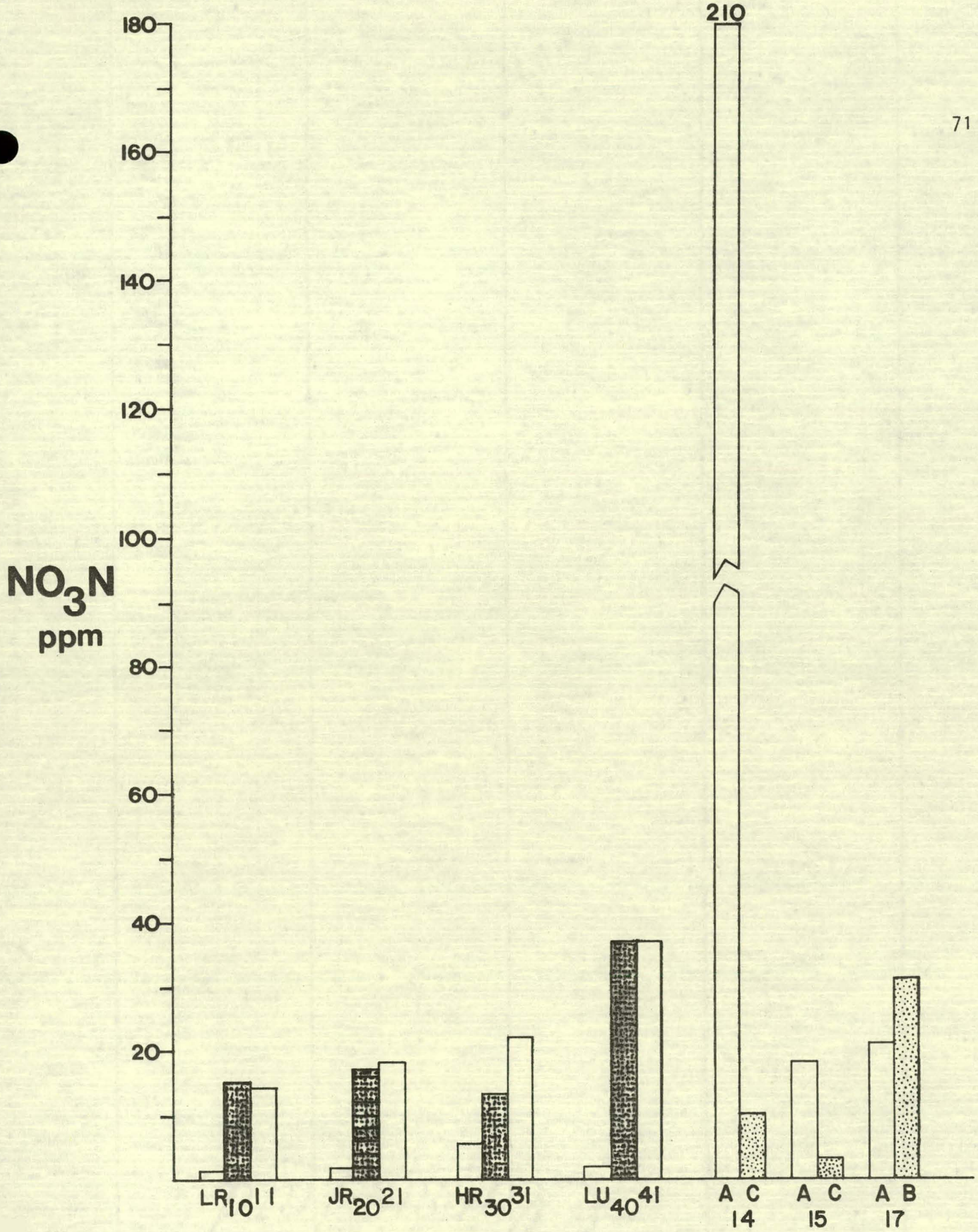


FIGURE 18
COMPARISON OF NATIVE AND RETORT SOILS
NITRATE-NITROGEN

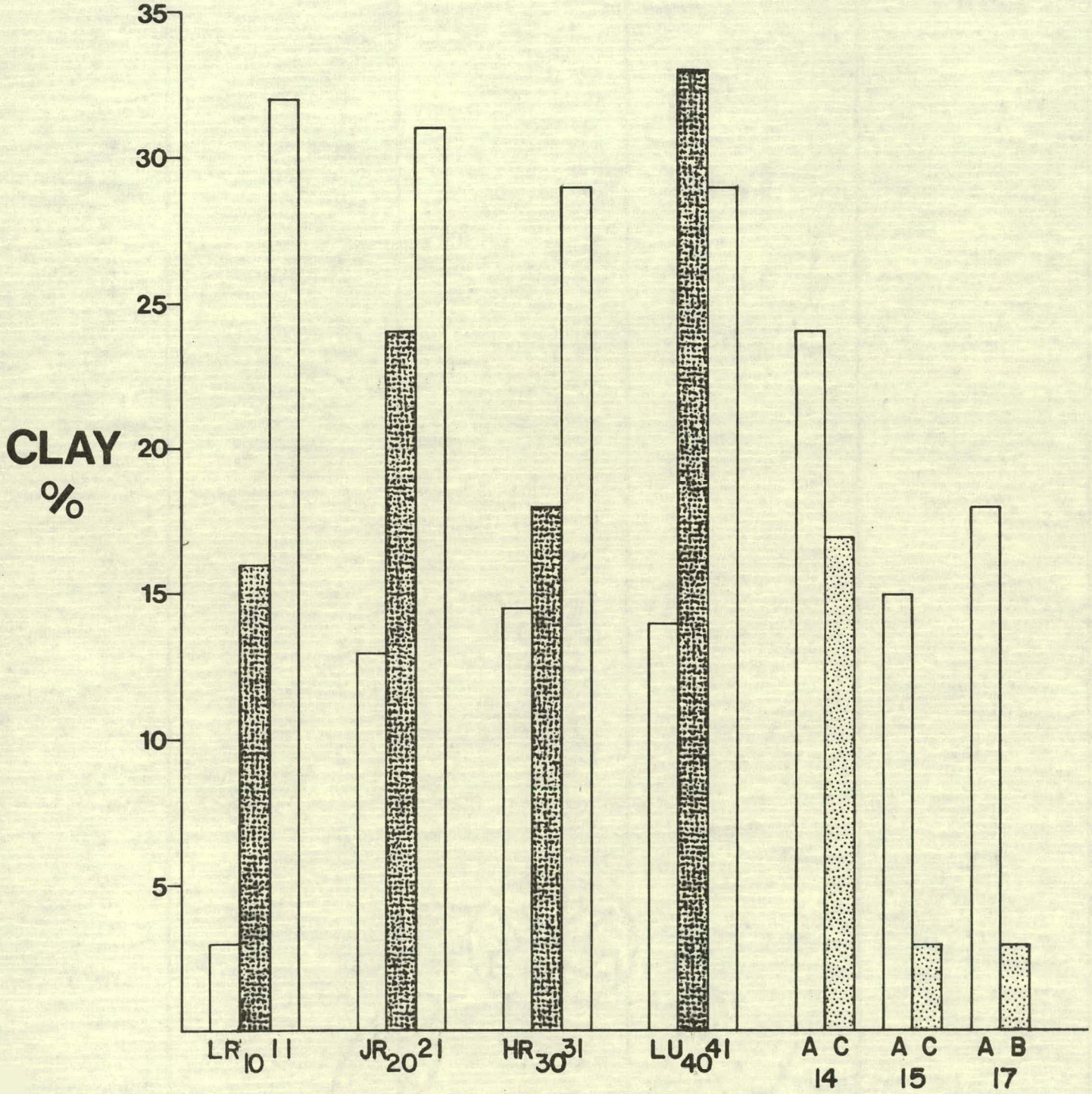


FIGURE 19

COMPARISON OF NATIVE AND RETORT SOILS
% CLAY

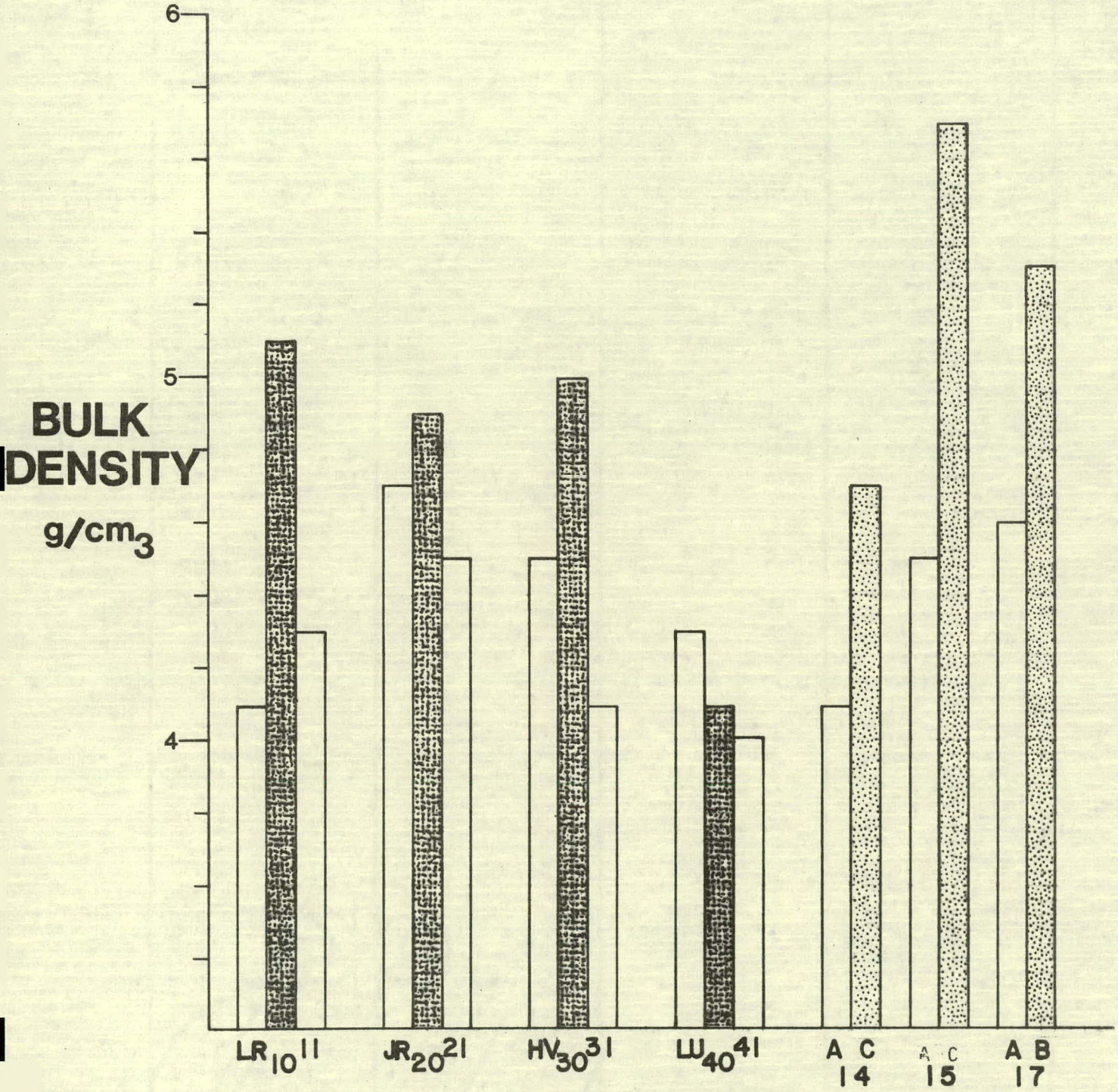


FIGURE 20

COMPARISON OF NATIVE AND RETORT SOILS
BULK DENSITY

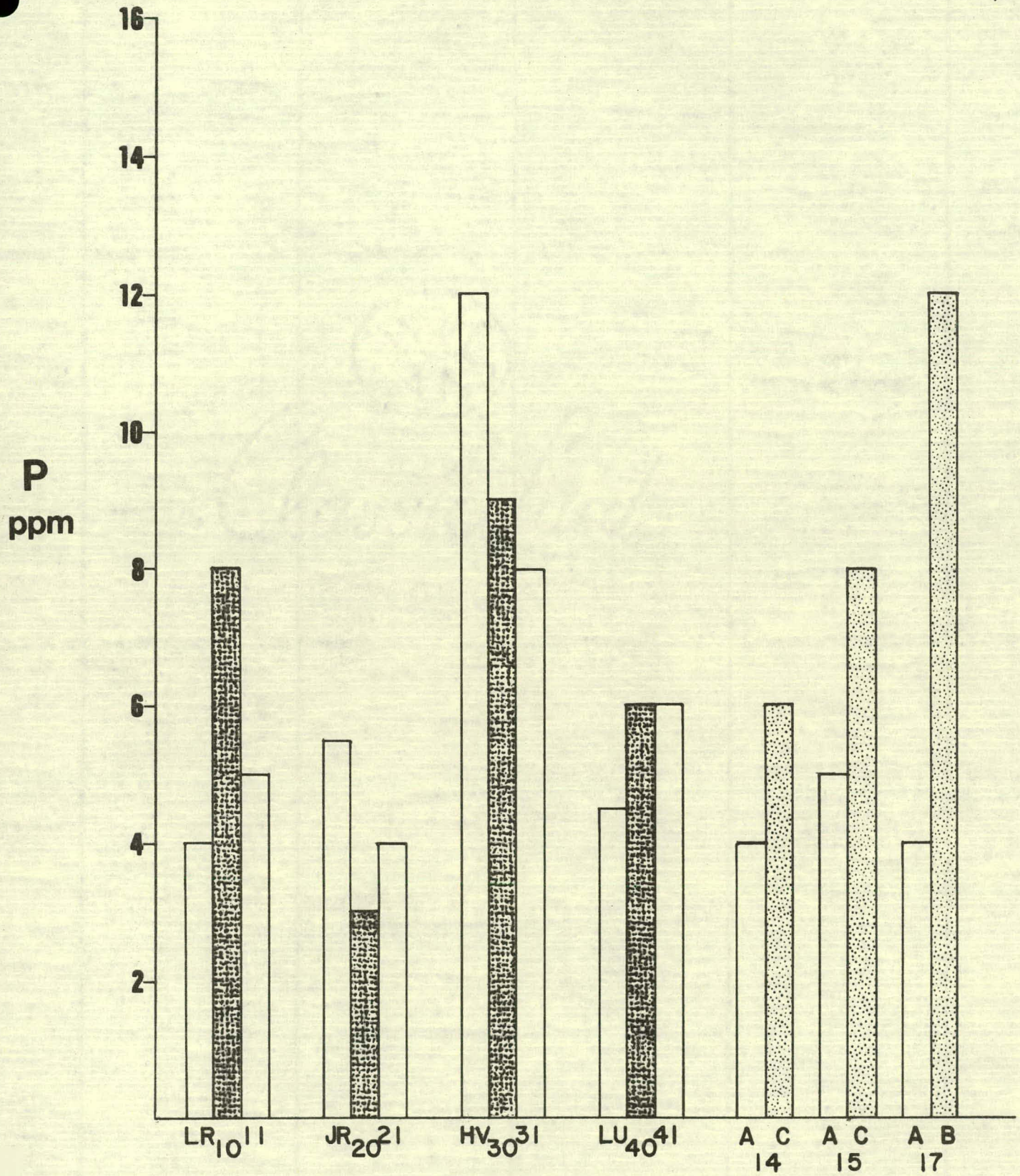


FIGURE 21

COMPARISON OF NATIVE AND RETORT SOILS
PHOSPHORUS

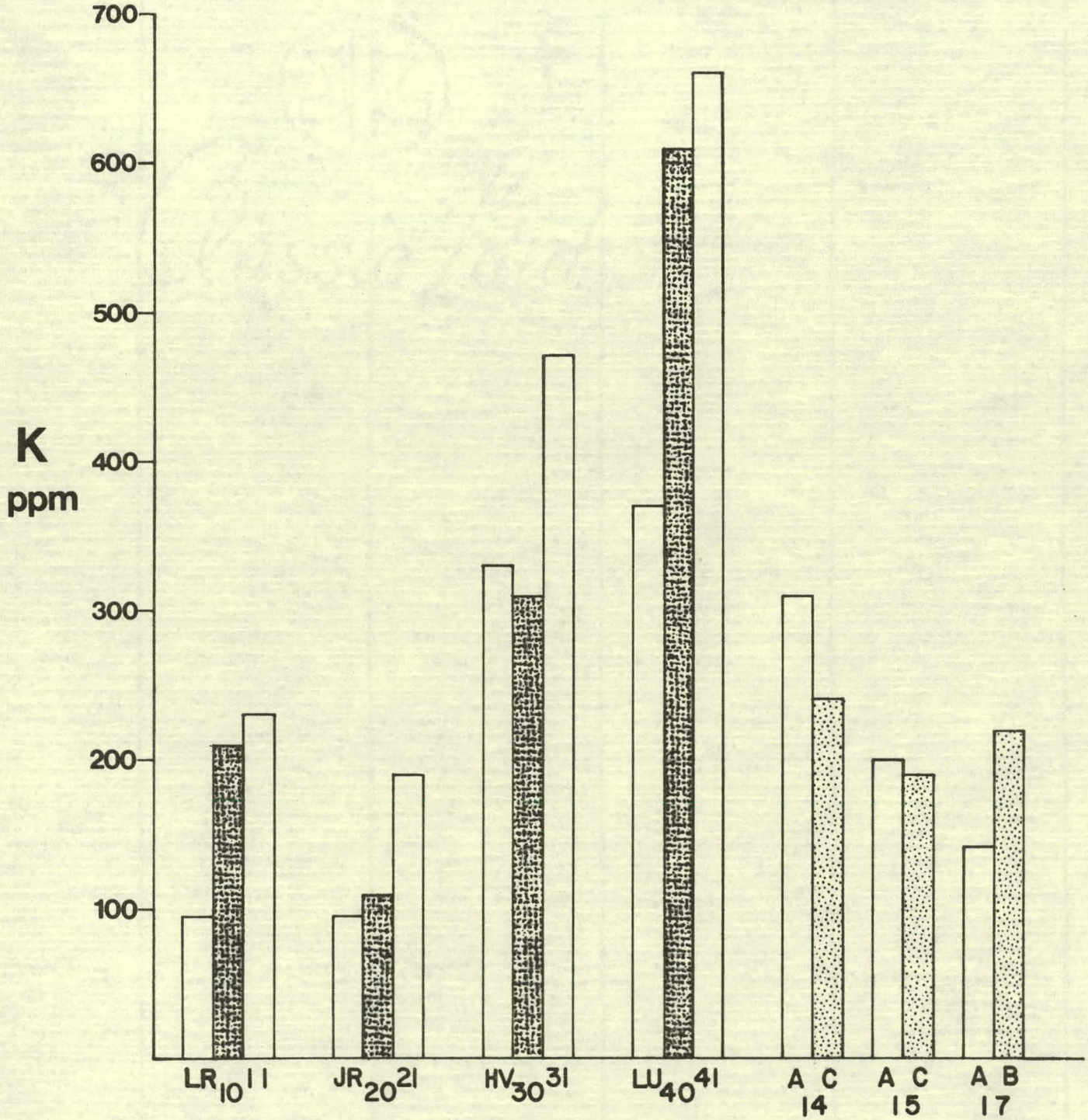


FIGURE 22

COMPARISON OF NATIVE AND RETORT SOILS
POTASSIUM

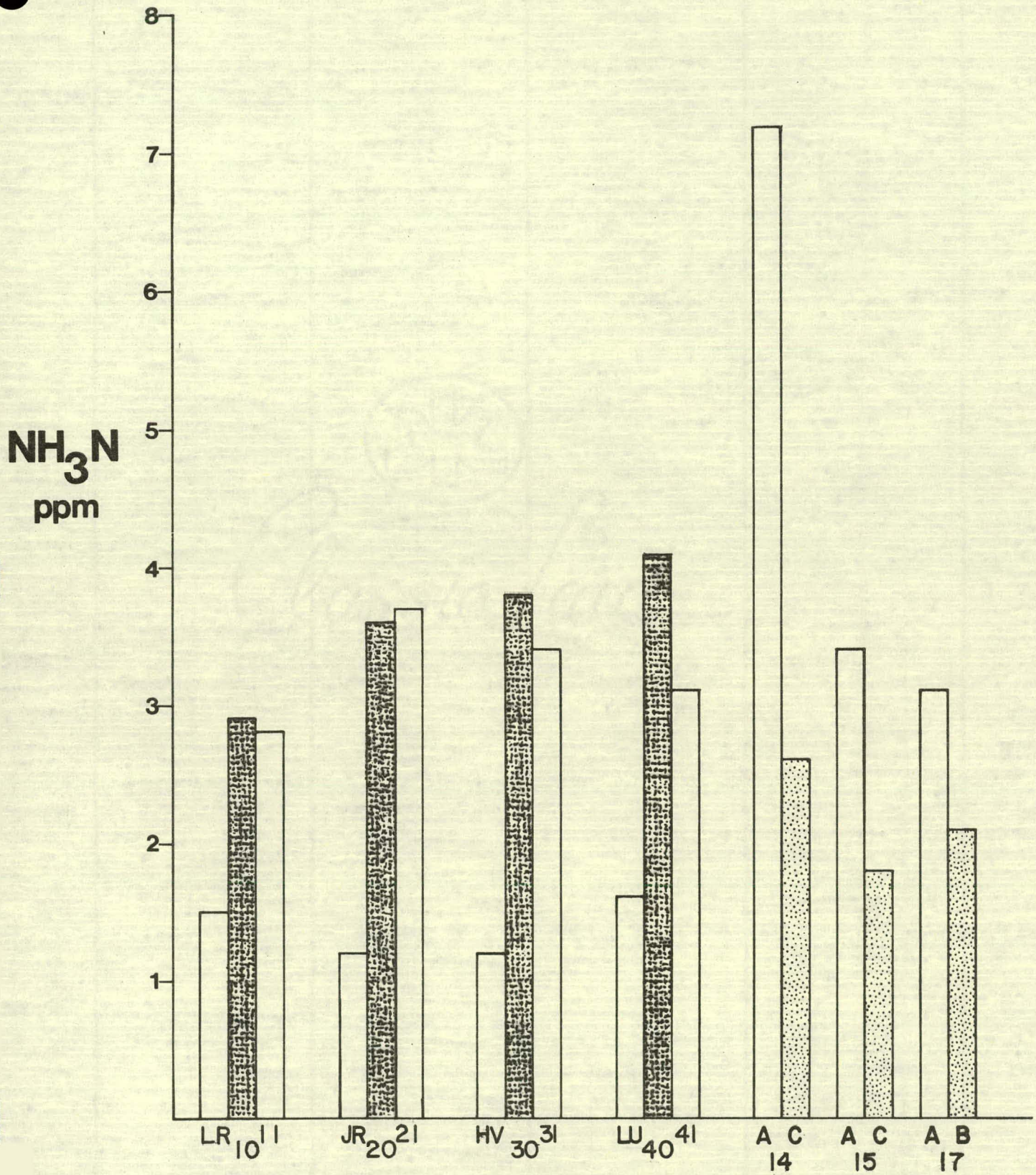


FIGURE 23

COMPARISON OF NATIVE AND RETORT SOILS
AMMONIUM-NITRATE

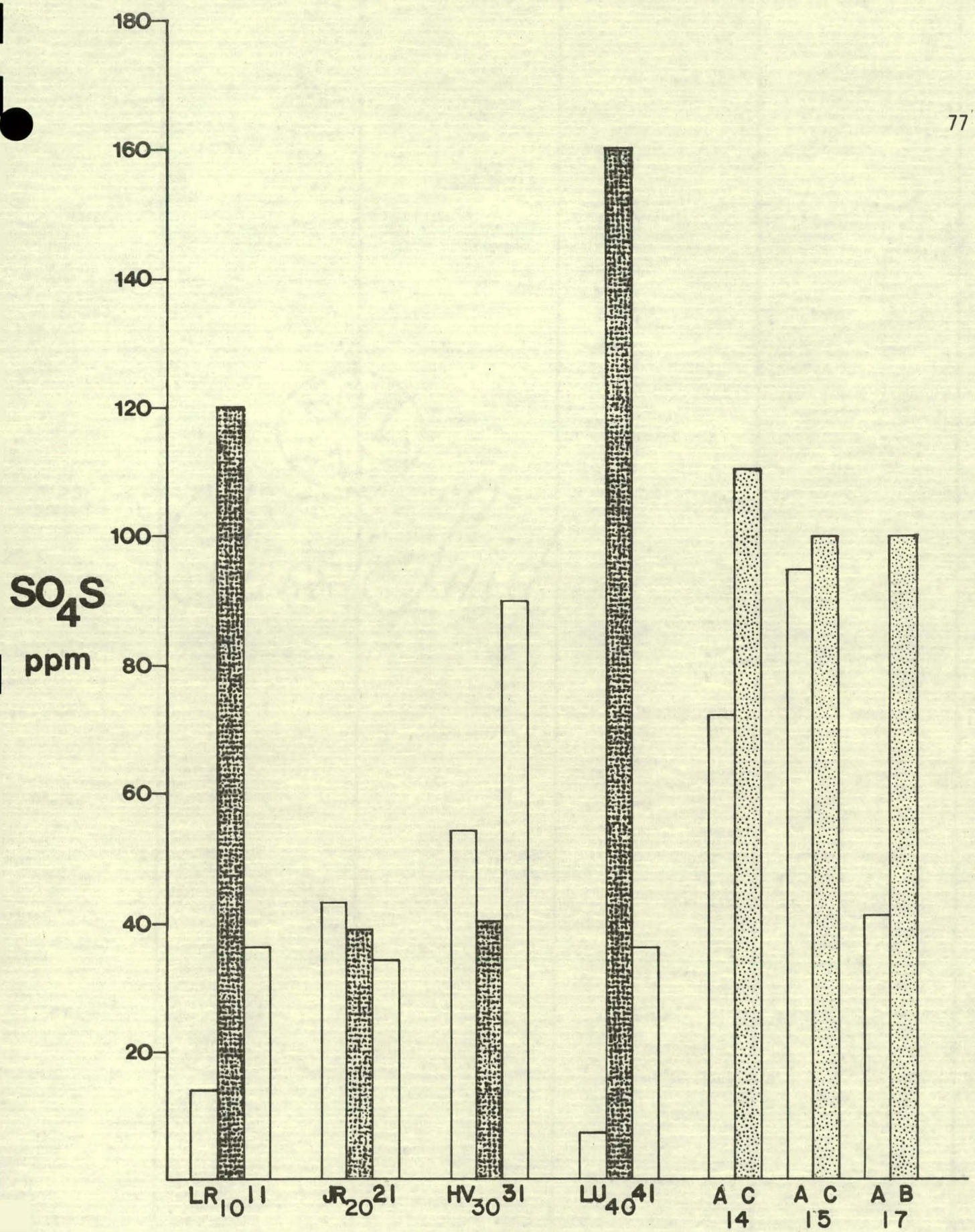


FIGURE 24

COMPARISON OF NATIVE AND RETORT SOILS
SULFATE-SULFUR

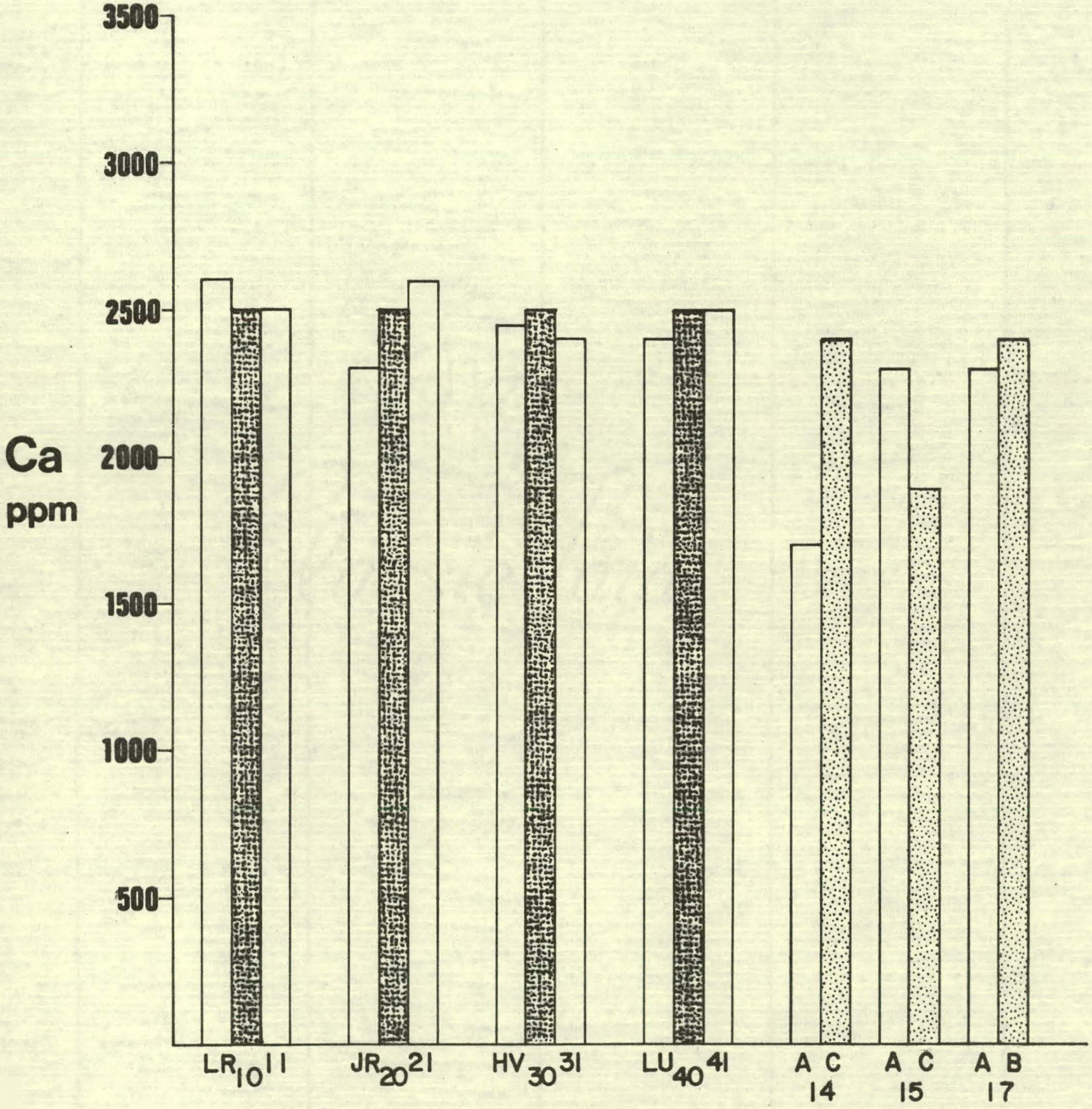


FIGURE 25

COMPARISON OF NATIVE AND RETORT SOILS
CALCIUM

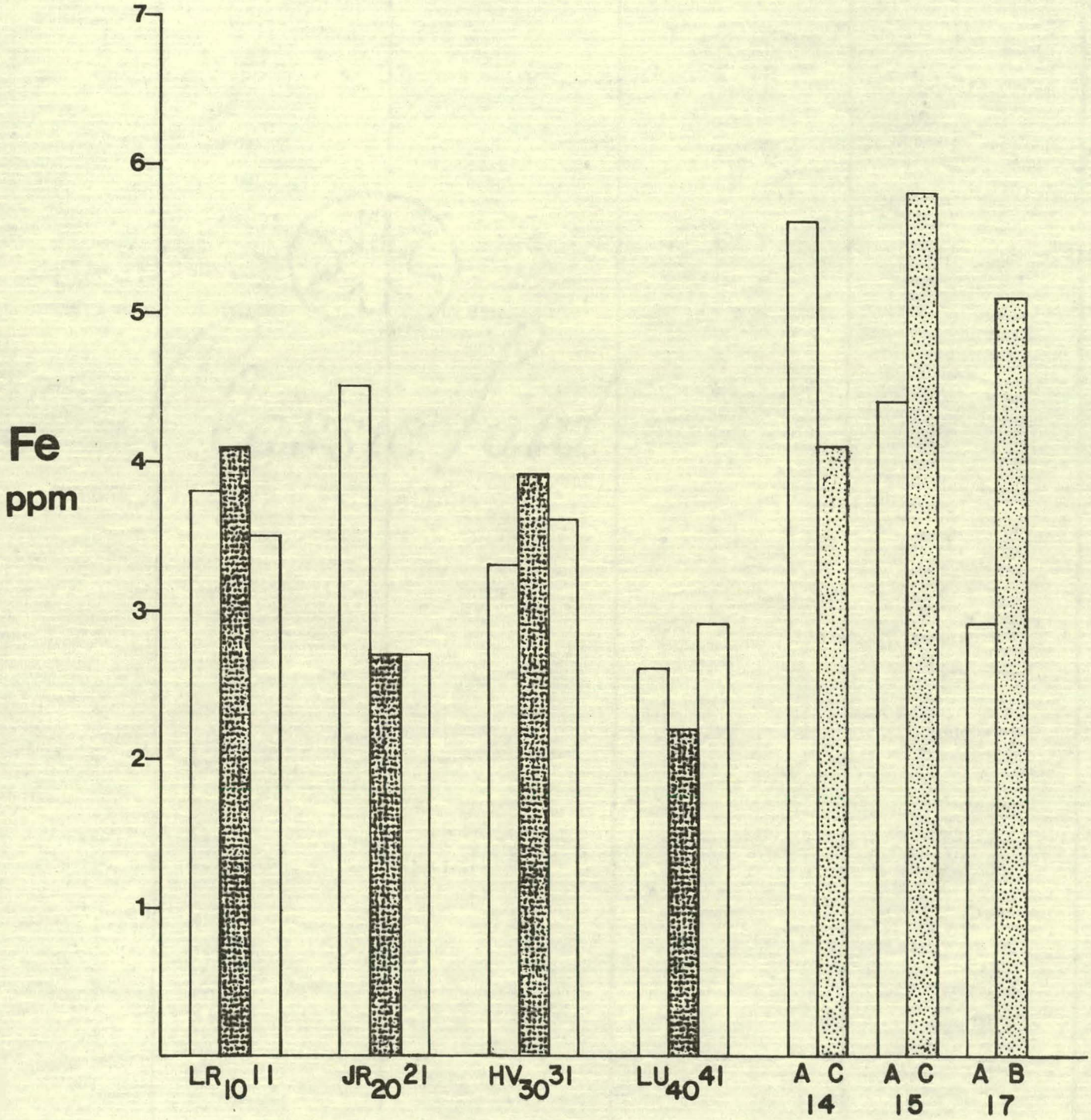


FIGURE 26

COMPARISON OF NATIVE AND RETORT SOILS
IRON

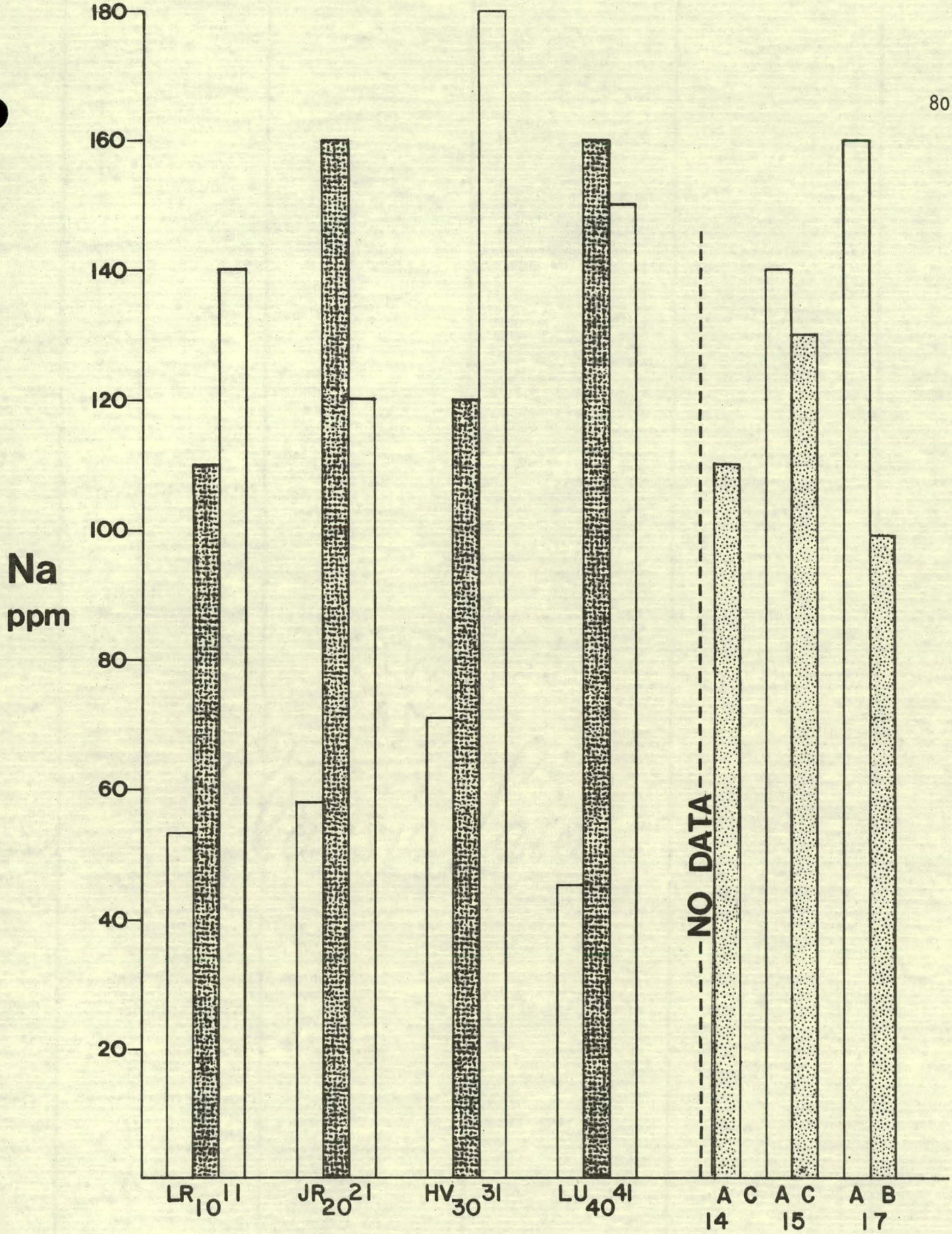


FIGURE 27

COMPARISON OF NATIVE AND RETORT SOILS
SODIUM

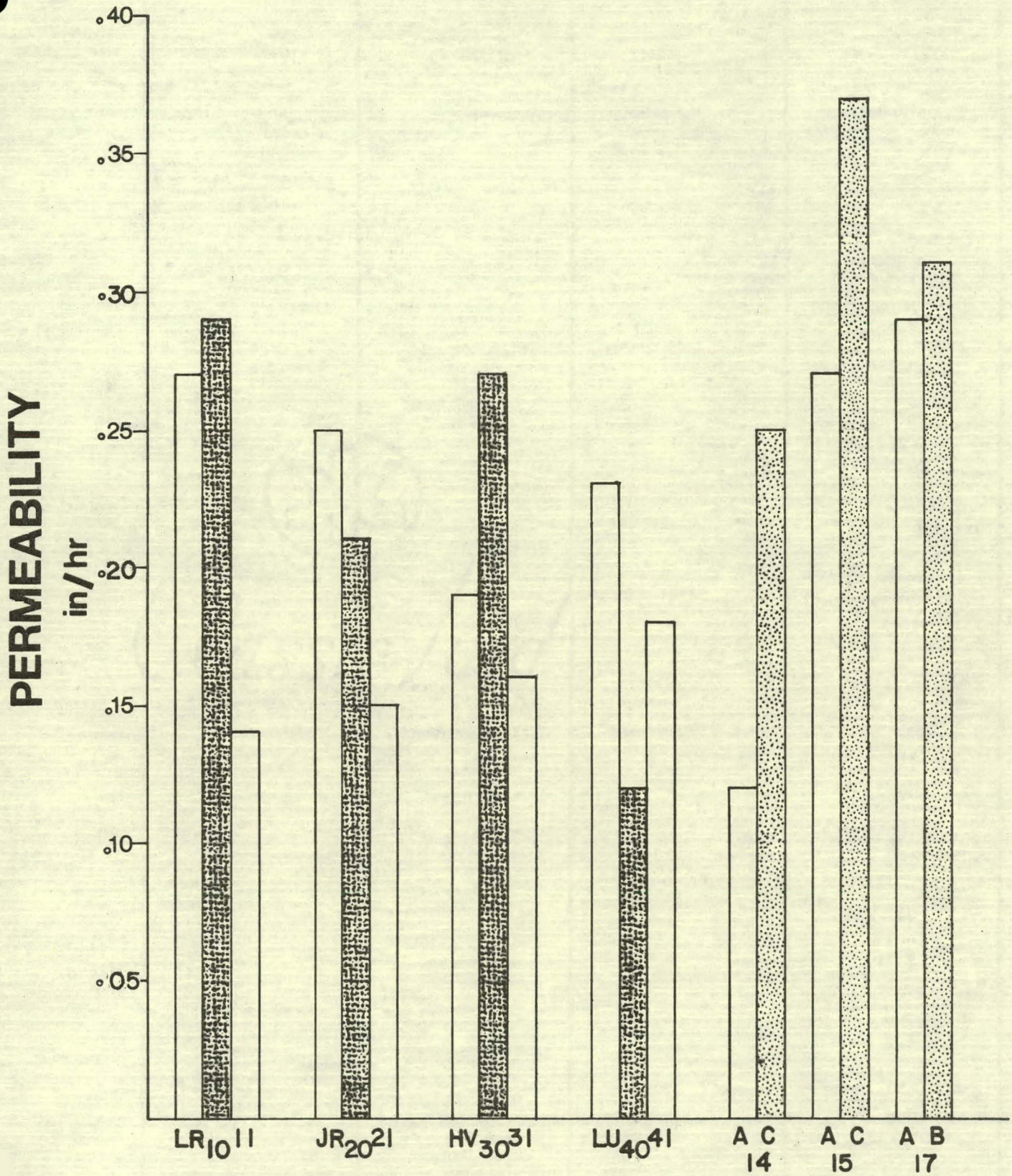


FIGURE 28

COMPARISON OF NATIVE AND RETORT SOILS
PREMEABILITY

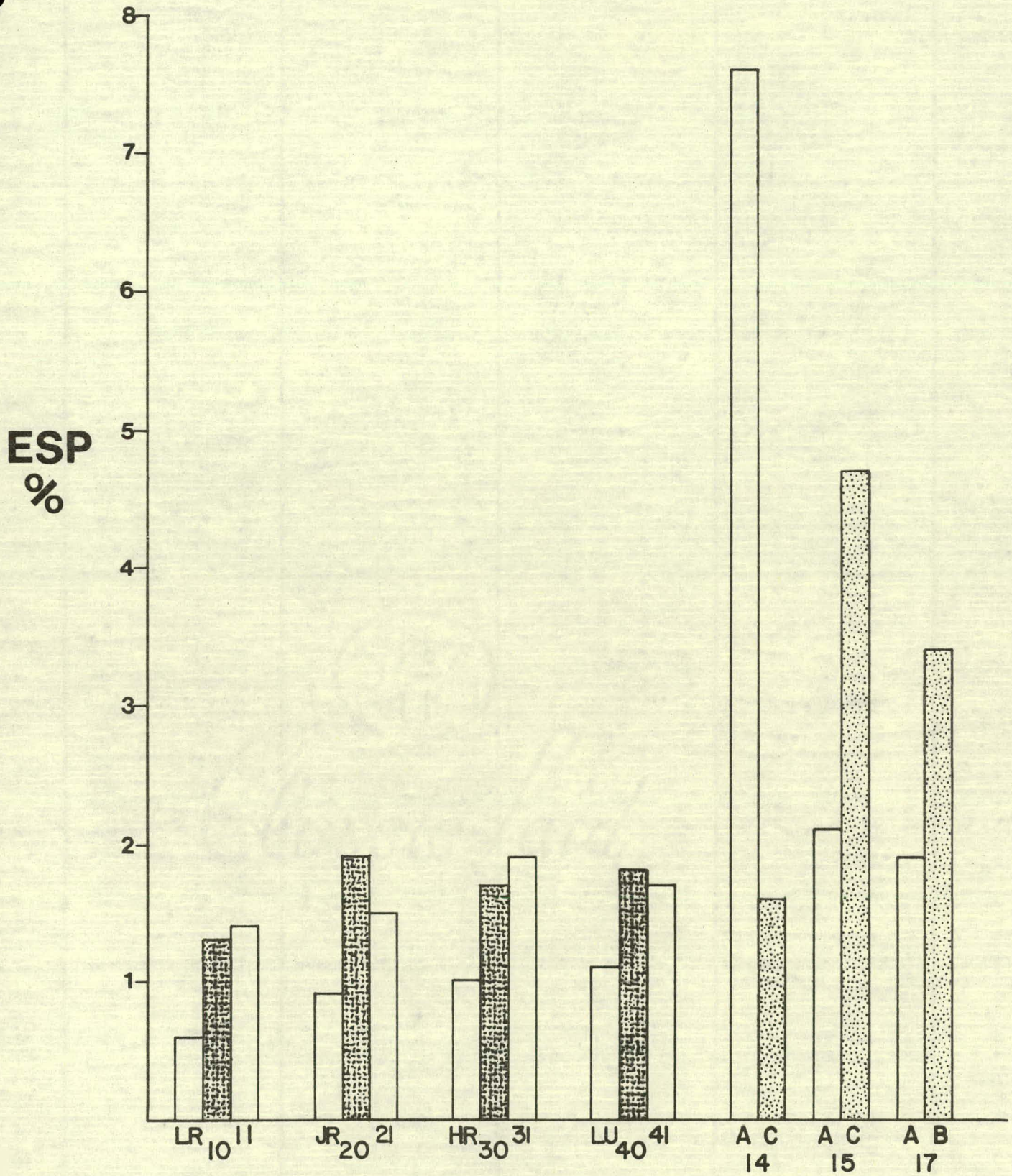


FIGURE 29

COMPARISON OF NATIVE AND RETORT SOILS
EXCHANGEABLE SODIUM PRECENTAGE

TABLE 5

SOILS OF THE LOFRECO SITE

ORDER	SUBORDER	GREAT GROUPS	SUBGROUP	FAMILY	SERIES
Aridisoils	Orthids	Calciorthids	Borollis	Fine-Loamy Mixed (calcareous)	Luhon
Entisoils	Fluvents	Torrifluvents	Ustic	Fine-Loamy Mixed (calcareous) frigid	Havre
	Orthents	Torriorthents	Ustic	Loamy-Shetatal Mixed (calcareous) frigid	JR
				Loamy-Mixed (calcareous) frigid shallow	LR

TABLE 6

TABLE 2 SOIL AND VEGETATION ASSOCIATIONS ON THE LOFRECO SITE

Vegetation Type	LR Gravelly Loam	JR Loam	Havre Silt Loam	Luhon Loam
Pinyon-Juniper Woodland (South-Facing)	X	(X)		
Pinyon-Juniper Woodland (North-Facing)	(X)	X		
Sagebrush-Saltbush Lowland			X	(X)
Sagebrush-Grass Upland	(X)		(X)	X

(X) indicates a lesser degree of positive association, usually occuring because of the transition from one vegetation/soil association to the next (this is particularly true in the transition from sagebrush-grass upland/Luhon loam associations to sagebrush-saltbrush lowland Havre silt loam associations.

TABLE 7

RESULTS OF PAIRED t-TEST
FOR DIFFERENCES BETWEEN SOIL CHARACTERISTICS
BEFORE AND AFTER RETORT BURNING

	t-Statistic		t-Statistic
NO_3-N	1.0318	OM%	-0.0354
P	-2.3349	%Lime	-1.6304
Na	1.3922	pH	1.3093
K	-0.0714	SAR	0.0754
Ca	-0.4193	EC	0.8386
Mg	1.9686	CEC	0.8470
NH_4-N	2.1553	ESP	0.2343
SO_4-S	-2.1633	Sn	-2.3604
Mn	-1.0360	Si	0.3571
Fe	-0.3921	Cl	4.8571 †
Cu	-1.1429	B.D.	-4.4901 †
Zn	-0.6667	Perm.	-2.6186
B	-1.3079	FC1/3	0.9449
Mo	0.0000	FC15	0.9449
Co	not tested ★	Sat%	0.9626
Cl	0.1333	AWC	0.5547
Se	-0.8386	Fl	0.3333
As	-0.9167	Phenols	-1.7812
CN	not tested ★	Li	not tested ★
OC	-0.2223	Hg	not tested <
Org-Met	not tested ★	Br	not tested <
Halides	1.5532	Be	not tested <

† Significant at the 0.05 level (critical t-value = 4.303)

★ all values equal

< insufficient data

SAMPLE ADEQUACY

Tests were performed on the adequacy of phytosociological, production, and ecoclimate samples by calculating the coefficient of variation (CV) of the mean (Appendix E). Tests were performed on 1978 and 1979 data. The results of these tests are presented in Tables 8, 9 , 10, and 11. All adequacy tests were performed within years for each vegetation site sampled. In the tests a coefficient of variation of $\leqslant 20$ is considered sufficient to show an adequate sample size.

The results of sample adequacy determinations show that samples taken for the majority of parameters are adequate. The exceptions are shrub and herb cover, and herb density in vegetation types where the herb and shrub layers are sparse (pinyon-juniper woodlands) and where the herb layer is composed chiefly of annuals (lowland sagebrush). The results also show that to reach sample adequacy in these situations, a significantly larger sample would be required. Sample sizes were not increased in these situations as a result of the imbalance that would occur between economics and an adequate sample size. Moreover, the information from the sample taken is considered to be sufficient for the purposes of describing the vegetation types in question. Tracing trends between years can be accomplished at the levels of sampling that have been carried out. This is reflected by the one-way analysis of variance test results.

SITE SIMILARITIES

The results of various statistical analyses designed to test vegetation, ecoclimate, and soils parameters are presented in Table 12. Three general types of tests were made:

- Coefficients of similarity (a test of overall shared information)
- One-way analysis of variance (a test of the statistical equality of two sample means)
- Linear regression analysis (a test of the correlation of two inter-related parameters)

These test were performed in order to assess the following:

- Similarity between control and development sites
- Potential differences between control or treatment sites during the two years of sampling
- Potential interactions between physical and biological parameters within biological parameters, and within physical parameters that may help to explain the overall system and thus provide information critical to revegetation and monitoring of potential perturbations.

Coefficient of Similarity Tests

The phytosociological parameters measured during sampling were tested within and among years in order to determine the similarity of sites based on shared information. Table 12 shows the results of these tests between control and development sites for both years of study. Table 13 gives the results of similarity test between the same sites during different years. Values >75% indicate reliable similarity; values <25% indicate a reliable degree of dissimilarity.

The test results between control and development sites for each of the years during which sampling was conducted show that the control and development sites are similar in terms of most phytosociological parameters. Several parameters that show low similarity are herb density in the north-facing woodland sites

and lowland sagebrush sites. These results reinforce the data obtained during phytosociological sampling leading to the description of the herb layers within these sites as cyclic. The annual forb populations are randomly distributed within any given year and variable between or among years. Herb cover similarity values tend to follow this same pattern. High similarities obtained for herb cover values in one north-facing woodland stand also reflect the difficulties of sampling the annual populations that occur on these sites: The random possibility of obtaining a more adequate sample is illustrated by the 99% similarity between V20 and V21 in 1979. Shrub density and cover values also show this relationship in several of the test results. (Table 13)

Similarity values for the same sites during different years illustrate a pattern similar to that discussed above within years (Table 13).

Similarity values for primary production within years (Table 12) are generally low, but do not reflect dissimilarity except in cases where annuals comprise the greatest part of the primary productivity, as in the woodlands and lowland sagebrush stands. Upland sagebrush similarity values show a range from high correlation to inconsequential values (≈50%).

Primary production similarity for the same sites between years reveal a pattern much like that among years. These data help to define those stands that will provide the more reliable data during monitoring and further reinforce the difficulty of measuring the randomly distributed annual component of some sites (Table 13).

Coefficient of similarity values were not performed for ecoclimatic data. The stronger one-way analysis of variance testing was deemed more effective in assessing the acceptance or rejectance of the null hypothesis for this large data base.

One-Way Analysis of Variance Tests

Tests on phytosociological values for control and development sites for 1978 and 1979 sampling are presented in Table 14 . The test results indicate that there is no difference between control and development sites based on mean values of all phytosociological measurements made. The only exception is the test performed on herb density values in the sagebrush-rabbitbrush lowlands for 1978 values. It is presumed that this difference is an artifact of sampling. Density counts within the crowded lowland stands are subject to intrinsic error. Sample adequacy for these stands is, however, sufficient, so that the discrepancy does not lie in data variance. The control and development sites for the lowland sage type also lie in different positions along the gradient between lowland and upland sagebrush. It is probable that this factor explains the difference in densities between the two sites. Since no lowland sites on the extreme part of the gradient lie in areas that may be disturbed the development site was placed up-gradient. The differences between sites are documented and can be treated accordingly during monitoring evaluations.

Test on phytosociological data between years for the same sites are summarized in Table 15 . For the most part the null hypothesis has been accepted through these tests, as most sites appear to demonstrate no differences in mean values between years. The null hypothesis is rejected for the tests made on ground cover values in the sagebrush uplands. This is ostensibly the result of greater total herbaceous cover during the 1979 sampling period. This fluctuation is part of the natural cycle discussed above that the herb layer in the sagebrush uplands is subjected to. The 1979 spring period was wetter than that during 1978. As a result a greater growth of perennial grasses and annual grasses was produced. Herb densities in the sagebrush lowlands are also shown to be significantly different between years. The annual forb population of these sites was also increased by spring moisture received in 1979. The apparent differences in shrub density in the sagebrush lowlands can only be explained as an error in sampling between years, since increased numbers of mature shrubs could not have occured between two adjacent years.

Tests performed on primary production values on control and development site data within each sampling year are shown in Figure 14. The test results show that the mean production values determined for all sites are not significantly different and the null hypothesis can be accepted.

Similar results are shown (Figure 15) for tests of the same sites between 1978 and 1979. It can be concluded from these results that differences in precipitation received as spring rains do not have a significant effect on overall herbaceous primary productivity.

Linear Regression Analysis

Correlation analyses of phytosociological parameters are given in Tables 16 through 19. Analyses of shrub cover with herb density, ground, cover, and primary production (Table 16) for each year of sampling. show no significant correlation between any of these pairs of parameters.

Comparison of herb density values with ground cover values for 1978 and 1979 (Table 17) show that these two parameters are not related causally. Similar results were obtained for correlation analyses between herb density and primary production (Table 17).

Linear regression analyses for ground cover and primary production (Table 18) illustrate that ground cover does not significantly influence the standing crop of herbaceous species.

Comparison of production values with selected ecoclimatic means (Table 19) illustrates that the only significant correlations that occur are between mean surface temperature and July primary herbaceous production and between mean surface temperature and herb density.

Table 8
SAMPLE ADEQUACY
SUMMARY FOR 1978 and 1979*
GEOKINETICS, INC.,
LOFRECO INSITU SHALE OIL RETORT
FIELD RESEARCH SITE
UINTAH COUNTY, UTAH

PARAMETER	V10 1978 $\bar{x}\pm SE$	CV †	V10 1979		V11 1978		V11 1979	
GROUND COVER	131.5 ± 5.0	4	150.2 ± 4.1	4	113.1 ± 6.8	6	149.1 ± 6.6	5
HERB DENSITY	9.4 ± 1.5	16	31.1 ± 8.0	26	7.5 ± 2.8	37	28.9 ± 8.9	30
HERB COVER	5.7 ± 1.7	29	1.9 ± 0.4	19	54.5 ± 8.5	16	10.5 ± 3.2	30
SHRUB DENSITY	22.4 ± 4.5	20	17.3 ± 3.6	21	8.4 ± 1.8	22	13.5 ± 2.6	19
SHRUB COVER	0.8 ± 0.3	33	0.3 ± 0.08	40	0.2 ± 0.1	55	0.2 ± 0.09	52
TREE DENSITY	18.1 ± 1.4	8	ND	ND	21.9 ± 1.5	7	ND	ND
TREE COVER	192.3 ± 26.6	14	ND	ND	230.7 ± 25.0	11	ND	ND
PRODUCTION: JULY	2.0 ± 0.14	7	1.7 ± 0.1	7	3.0 ± 0.3	7	1.3 ± 0.1	7
AUGUST	1.3 ± 0.1	6	0.5 ± 0.0	0	1.5 ± 0.1	8	2.0 ± 0	0
AIR TEMPERATURE	15.9 ± 1.4	9	15.6 ± 1.3	9	16.1 ± 1.2	8	16.9 ± 1.0	6
SOIL TEMPERATURE	16.1 ± 1.6	11	16.1 ± 1.5	10	17.1 1.6	9	18.2 ± 1.1	6

* THESE COMPARISONS ARE WITHIN YEARS FOR CONTROL OR DEVELOPMENT STANDS, SUCH AS VIO OR VII (PINYON - JUNIPER, WOODLANDS, SOUTH-FACING) (CONTROL OR DEVELOPMENT SITES).

† CV Coefficient of Variation of the Mean
ND No Data
$\bar{X}\pm SE$ Mean ± Standard Error

Table 9
SAMPLE ADEQUACY
SUMMARY FOR 1978 and 1979*
GEOKINETICS, INC.,
LOFRECO INSITU SHALE OIL RETORT
FIELD RESEARCH SITE
UINTAH COUNTY, UTAH

PARAMETER	V20 1978 $\bar{x}\pm SE$	CV	V20 1978		V21 1979		V21 1979	
GROUND COVER	105.3± 6.3	6	123.2± 5.2	4	111.1± 3.0	3	119.9± 4.0	4
HERB DENSITY	3.1± 1.1	36	10.7± 5.2	49	0.9± 0.4	45	2.7± 0.8	29
HERB COVER	1.4± 0.4	31	61.3± 6.4	11	5.1± 1.6	32	65.3± 7.5	12
SHRUB DENSITY	2.2± 4.5	20	3.3± 0.7	22	0.7± 0.2	26	ND	ND
SHRUB COVER	ND	ND	0.1± 0.04	38	0.03± 0.03	100	ND	ND
TREE DENSITY	11.9± 1.0	9	ND	ND	16.0± 3.1	19	ND	ND
TREE COVER	279.4± 46.9	17	ND	ND	202.3± 24.8	12	ND	ND
PRODUCTION: JULY	2.5± 0.2	9	1.2± 0.1	8	2.3± 0.1	5	1.7± 0.1	6
AUGUST	1.1± 0.2	14	1.5± 0	0	1.2± 0.1	11	9.0± 0	0
AIR TEMPERATURE	15.7± 1.4	9	ND	ND	ND	ND	ND	ND
SOIL TEMPERATURE	17.1± 1.6	9	ND	ND	18.8± 1.1	6	ND	ND

* THESE COMPARISONS ARE WITHIN YEARS FOR CONTROL OR DEVELOPMENT STANDS, SUCH AS VIO OR VII (PINYON-JUNIPER, WOODLANDS, SOUTH-FACING) (CONTROL OR DEVELOPMENT SITES).

CV Coefficient of Variation of the Mean
ND No Data
$\bar{X}\pm SE$ Mean ± Standard Error

Table 10
SAMPLE ADEQUACY
SUMMARY FOR 1978 and 1979*
GEOKINETICS, INC.,
LOFRECO INSITU SHALE OIL RETORT
FIELD RESEARCH SITE
UINTAH COUNTY, UTAH

PARAMETER	V30 1978 $\bar{x}$±SE	V30 1978 CV	V30 1978		V31 1979		V31 1979	
GROUND COVER	121.4± 4.8	4	126.0± 7.5	6	86.2± 3.9	5	140.0± 6.0	4
HERB DENSITY	116.3± 23.8	20	30.3 7.2	24	21.3± 6.5	30	4.5± 1.3	28
HERB COVER	40.8± 6.1	15	8.1± 1.9	24	9.0± 3.7	41	1.3± 0.2	13
SHRUB DENSITY	47.2± 1.7	4	81.0± 7.2	9	53.3± 2.7	5	64.1± 6.9	11
SHRUB COVER	6.8± 0.4	6	7.0± 0.9	12	6.5± 0.4	6	7.5± 0.5	6
TREE DENSITY	ND	ND	ND	ND	ND	ND	ND	ND
TREE COVER	ND	ND	ND	ND	ND	ND	ND	ND
PRODUCTION: JULY	24.0± 2.0	22	2.5± 0.7	28	9.2± 2.0	22	0.8± 0.1	17
AUGUST	5.5± 0.4	7	0.5± 0	0	2.2± 0.3	14	7.0± 0	0
AIR TEMPERATURE	12.9± 2.0	16	16.1± 0.8	5	16.3± 1.2	7	14.8± 1.9	13
SOIL TEMPERATURE	15.1± 2.4	16	12.2± 0.5	4	17.8± 1.2	7	16.1± 2.3	14

* THESE COMPARISONS ARE WITHIN YEARS FOR CONTROL OR DEVELOPMENT STANDS, SUCH AS VIO OR VII (PINYON - JUNIPER, WOODLANDS, SOUTH-FACING) (CONTROL OR DEVELOPMENT SITES).

CV Coefficient of Variation of the Mean
ND No Data
$\bar{X}$±SE Mean ± Standard Error

Table 11
SAMPLE ADEQUACY
SUMMARY FOR 1978 and 1979*
GEOKINETICS, INC.,
LOFRECO INSITU SHALE OIL RETORT
FIELD RESEARCH SITE
UINTAH COUNTY, UTAH

PARAMETERS	V40 1978 $\bar{x}$±SE	V40 1978 CV	V40 1978		V41 1979		V41 1979	
GROUND COVER	47.3± 6.4	14	145.0± 9.7	7	43.6± 5.0	12	137.7± 4.3	3
HERB DENSITY	86.4± 7.5	9	171.3± 15.3	9	65.6± 6.0	9	104.6± 11.6	11
HERB COVER	13.9± 2.1	15	39.8± 3.2	8	11.8± 1.7	14	36.8± 3.5	10
SHRUB DENSITY	159.2± 14.2	9	91.9± 6.8	8	117.1± 6.9	6	75.8± 4.4	6
SHRUB COVER	3.5± 1.6	46	1.5± 0.2	10	1.7± 0.3	16	1.7± 0.3	17
TREE DENSITY	ND	ND	ND	ND	ND	ND	ND	ND
TREE COVER	ND	ND	ND	ND	ND	ND	ND	ND
PRODUCTION: JULY	4.7± 0.2	4	2.9± 0.1	4	3.9± 0.1	4	3.4± 0.1	4
AUGUST	1.9± 0.1	5	1.1± 0.1	7	1.7± 0.1	4	1.2± 0.1	7
AIR TEMPERATURE	15.7± 1.0	9	15.8± 2.0	11	17.4± 1.0	7	15.7± 1.0	9
SOIL TEMPERATURE	18.2± 1.0	8	19.0± 2.0	10	19.5± 1.0	8	18.4± 2.0	9

* THESE COMPARISONS ARE WITHIN YEARS FOR CONTROL OR DEVELOPMENT STANDS, SUCH AS VIO OR VII (PINYON-JUNIPER, WOODLANDS, SOUTH-FACING) (CONTROL OR DEVELOPMENT SITES).

CV Coefficient of Variation of the Mean
ND No Data
$\bar{X}$±SE Mean ± Standard Error

Table 12
COEFFICIENT OF SIMILRAITY
SUMMARY FOR 1978 and 1979*
GEOKINETICS, INC.,
LOFRECO INSITU SHALE OIL RETORT
FIELD RESEARCH SITE
UINTAH COUNTY, UTAH

PARAMETER	V10&11		V20&21		V30&31		V40&41	
	1978	1979	1978	1979	1978	1979	1978	1979
GROUND COVER	93	100	97	99	83	97	96	97
HERB DENSITY	89	96	44	39	31	26	86	76
HERB COVER	89	79	58	99	30	19	92	96
SHRUB DENSITY	54	88	48	ND	94	84	85	90
SHRUB COVER	485	89	48	ND	97	70	64	92
TREE DENSITY	91	ND	84	ND	ND	ND	ND	ND
TREE COVER	90	ND	85	ND	ND	ND	ND	ND
SHRUB IMPORT. VALUE	94	84	77	ND	67	100	100	92
PRODUCTION: JULY	66	55	14	24	22	3	45	86
AUGUST	96	ND	2	ND	14	ND	77	ND

* THESE COMPARISONS ARE WITHIN YEARS, BETWEEN CONTROL AND DEVELOPMENT STAND PAIRS, SUCH AS VIO AND VII (PINYON - JUNIPER WOODLANDS, SOUTH-FACING) (CONTROL AND DEVELOPMENT SITES).

Table 13
COEFFICIENT OF SIMILARITY
SUMMARY FOR 1978 and 1979 *
GEOKINETICS, INC.,
LOFRECO INSITU SHALE OIL RETORT
FIELD RESEARCH SITE
UINTAH COUNTY, UTAH

PARAMETER	V10 1978/79	V11 1978/79	V20 1978/79	V21 1978/79	V30 1978/79	V31 1978/79	V40 1978/79	V41 1978/79
GROUND COVER	93	86	92	96	96	76	47	48
HERB DENSITY	46	41	44	50	41	35	67	77
SHRUB DENSITY	87	76	80	ND	51	59	73	79
SHRUB COVER	43	83	ND	ND	34	58	59	98
TREE DENSITY	ND	ND	ND	ND	ND	ND	ND	ND
TREE COVER	ND	ND	ND	ND	ND	ND	ND	ND
PRODUCTION: JULY	86	40	ND	ND	22	3	45	85
AUGUST	ND	ND	ND	ND	ND	ND	ND	ND
SHRUB IMPORT. VALUE	90	100	100	ND	86	54	100	92

* THESE COMPARISONS ARE AMONG YEARS, BETWEEN CONTROL OR DEVELOPMENT STANDS, SUCH AS V10 (1978) AND V10 (1979) (PINYON - JUNIPER WOODLANDS, SOUTH-FACING) (CONTROL SITES).

Table 14
ONE-WAY ANALYSIS OF VARIANCE
SUMMARY FOR 1978 and 1979*
GEOKINETICS, INC.,
LOFRECO INSITU SHALE OIL RETORT
FIELD RESEARCH SITE
UINTAH COUNTY, UTAH

PARAMETERS	V10&11 1978	V10&11 1979	V20&21 1978	V20&21 1979	V30&31 1978	V30&31 1979	V40&41 1978	V40&41 1979
GROUND COVER	.35	3.42	.08	.33	.59	.03	.95	.35
HERB DENSITY	.12	.46	3.42	2.77	8.42†	4.87	1.88	2.22
SHRUB DENSITY	3.17	.81	4.98	ND	.82	.05	2.59	.02
SHRUB COVER	1.94	.14	1.75	ND	2.85	.34	1.12	1.75
TREE DENSITY	3.32	ND	1.65	ND	ND	ND	ND	ND
TREE COVER .	1.11	ND	2.11	ND	ND	ND	ND	ND
PRODUCTION: JULY	.37	.97	4.66	3.08	.65	1.11	1.96	.33
AUGUST	.004	ND	1.53	ND	.86	ND	.05	ND
$\overline{X}$ AIR TEMPERATURE	.02	.60	12.00†	ND	2.09	16.10†	.83	.01
$\overline{X}$ SOIL TEMPERATURE	.17	1.27	.73	ND	1.03	6.22†	.41	.07
MAX. SOIL TEMPERATURE	2.33	3.59	23.20†	ND	.67	.12	2.08	.72
SHRUB IMPORT. VALUE	.06	.39	2.40	.84	.62	0.00	0.00	.11

* THESE COMPARISONS ARE WITHIN YEARS, BETWEEN CONTROL AND DEVELOPMENT STAND PAIRS, SUCH AS VIO AND VII (PINYON-JUNIPER WOODLANDS, SOUTH-FACING) (CONTROL AND DEVELOPMENT SITES).

† f-value exceeds critical f @ 0.05

Table 15
ONE-WAY ANALYSIS OF VARIANCE
SUMMARY FOR 1978 and 1979*
GEOKINETICS, INC.,
LOFRECO INSITU SHALE OIL RETORT
FIELD RESEARCH SITE
UINTAH COUNTY, UTAH

PARAMETERS	V10 1978/79	V11 1978/79	V20 1978/79	V21 1978/79	V30 1978/79	V31 1978/79	V40 1978/79	V41 1978/79
GROUND COVER	.002	1.637	1.811	.163	.343	2.045	30.780†	27.180†
HERB DENSITY	4.014	3.520	1.990	1.520	7.150†	6.670†	4.040	4.530
SHRUB DENSITY	.169	.988	4.660	ND	8.560†	5.310†	4.760	.431
SHRUB COVER	3.290	.477	6.890	ND	.030	3.980	1.050	1.060
PRODUCTION: JULY	.100	.920	1.110	.840	.760	1.260	4.000	.250
AUGUST	ND	ND	ND	ND	ND	ND	ND	ND
$\overline{X}$ AIR TEMPERATURE	.020	.240	ND	ND	2.870	.350	.000	.820
$\overline{X}$ SOIL TEMPERATURE	.000	.330	ND	ND	1.970	.430	.120	.260
MAX. SOIL TEMPERATURE	.590	1.360	ND	ND	.000	2.400	.000	.010
SHRUB IMPORT. VALUE	.190	.000	.330	.250	.240	1.710	.000	.080

* THESE COMPARISONS ARE AMONG YEARS, BETWEEN CONTROL OR DEVELOPMENT STANDS, SUCH AS V10 (1978) AND V10 (1979) (PINYON - JUNIPER WOODLANDS, SOUTH-FACING) (CONTROL SITES).

† f value exceeds critical f @ 0.05

Table 16
LINEAR REGRESSION ANALYSIS
SUMMARY FOR 1978 and 1979*
GEOKINETICS, INC.,
LOFRECO INSITU SHALE OIL RETORT
FIELD RESEARCH SITE
UINTAH COUNTY, UTAH

SHRUB COVER:

PARAMETERS	1978 V10	1978 V11	1978 V20	1978 V21	1978 V30	1978 V31	1978 V40	1978 V41
GROUND COVER	.07	.24	ND	.45	.14	.12	.02	.24
HERB DENSITY	.06	.15	.12	ND	.12	.03	.21	.05
PRODUCTION: JULY	.06	.00	.00	.09	.19	.10	.01	.00
AUGUST	.05	.01	.00	.06	.19	.09	.02	.03
	1979 V10	1979 V11	1979 V20	1979 V21	1979 V30	1979 V31	1979 V40	1979 V41
GROUND COVER	.006	.049	.104	ND	.392	.588	.017	.045
HERB DENSITY	.002	.750	.040	ND	.213	.014	.099	.075
PRODUCTION: JULY	.36	.03	.31	ND	.54	.11	.03	.02
$\overline{X}$ AIR TEMPERATURE	.28	.09	ND	ND	.49	.19	ND	ND
MAX. SOIL TEMPERATURE	.27	.04	ND	ND	.38	.19	.04	.05

* THESE COMPARISONS ARE WITHIN YEARS, BETWEEN CONTROL AND DEVELOPMENT STAND PAIRS, SUCH AS VIO AND VII (PINYON-JUNIPER WOODLANDS, SOUTH-FACING) (CONTROL AND DEVELOPMENT SITES).

Table 17
LINEAR REGRESSION ANALYSIS
SUMMARY FOR 1978 and 1979*
GEOKINETICS, INC.,
LOFRECO INSITU SHALE OIL RETORT
FIELD RESEARCH SITE
UINTAH COUNTY, UTAH

HERB DENSITY:

PARAMETERS	1978 V10	1978 V11	1978 V20	1978 V21	1978 V30	1978 V31	1978 V40	1978 V41
GROUND COVER	.004	.10	.17	.27	.23	.05	.11	.101
PRODUCTION: JULY	.02	.06	.14	.17	.05	.06	.26	.06
AUGUST	.06	.07	.07	.00	.05	.00	.00	.00
	1979 V10	1979 V11	1979 V20	1979 V21	1979 V30	1979 V31	1979 V40	1979 V41
GROUND COVER	.155	.004	.105	.027	.169	.252	.058	.028
PRODUCTION: JULY	.03	.00	.09	.04	.06	.31	.06	.04
$\overline{X}$ AIR TEMPERATURE	.08	.02	ND	ND	.04	.28	.01	ND
MAX. SOIL TEMPERATURE	.11	.06	ND	ND	.04	.26	.01	.03

* THESE COMPARISONS ARE WITHIN YEARS, BETWEEN CONTROL AND DEVELOPMENT STAND PAIRS, SUCH AS VIO AND VII (PINYON-JUNIPER WOODLANDS, SOUTH-FACING) (CONTROL AND DEVELOPMENT SITES).

Table 18
LINEAR REGRESSIONA ANALYSIS
SUMMARY FOR 1978 and 1979*
GEOKINETICS, INC.,
LOFRECO INSITU SHALE OIL RETORT
FIELD RESEARCH SITE
UINTAH COUNTY, UTAH

GROUND COVER:

PARAMETERS	1978 V10	1978 V11	1978 V20	1978 V21	1978 V30	1978 V31	1978 V40	1978 V41
PRODUCTION: JULY	.09	.19	.01	.04	.04	.05	.10	.05
AUGUST	.04	.12	.17	.06	.08	.09	.10	.12
	1979 V10	1979 V11	1979 V20	1979 V21	1979 V30	1979 V31	1979 V40	1979 V41
PRODUCTION: JULY	.09	.19	.01	.04	.04	.05	.10	.05
MAX. SOIL TEMPERATURE	.02	.11	ND	ND	.01	.01	.05	.02

* THESE COMPARISONS ARE WITHIN YEARS, BETWEEN CONTROL AND DEVELOPMENT STAND PAIRS, SUCH AS VIO AND VII (PINYON-JUNIPER WOODLANDS, SOUTH-FACING) (CONTROL AND DEVELOPMENT SITES).

TABLE 19

LINEAR REGRESSION ANALYSIS

SELECTED VALUES

	JULY PRODUCTION	AUGUST PRODUCTION	HERB DENSITY	GROUND COVER
MEAN AIR TEMPERATURE	.40/-.25†	ND	ND	ND
MEAN SOIL TEMPERATURE	.67/.62	ND	.69/.84	-.16/ND
MEAN MAXIMUM SOIL SURFACE TEMPERATURE	-.36/-.01	ND	ND	ND
MAY, JUNE, JULY PRECIPITATION	.07/-.28	ND	ND	ND
TOTAL GROWING SEASON PRECIPITATION	.00/.38	.07/ND	ND	ND

† 1978/1979 data

SUMMARY AND CONCLUSIONS

The two year intensive baseline study of vegetation, ecoclimate, and soils has shown the presence of four distinct vegetation environments. These plant-soil-ecoclimate units have significance to a general understanding of the natural system on the LOFRECO site and to impact mitigation and reclamation of areas disturbed by the experimental in-situ retorting operations on the site. Significant results of the two year baseline can be partitioned in to the following categories, as will be discussed below:

- The significance of populations of rare and endangered plants species occurring on the LOFRECO site
- The significance of herbaceous productivity to large herbivores, particularily domestic cattle
- The significance of vegetation structural features; and soils and ecoclimatic conditions to mitigating impacts and to the successful reclamation of disturbed areas
- The significance of the baseline data to making future separations between man-induced perturbations and natural trends and/or cycles

Rare and Endangered Species

The bulk of the plant species listed as rare, restricted, endangered, and/or threatened are apparently restricted to special environmental conditions, such as those that prevail on the LOFRECO site. Many of these conditions are listed in the literature (Welsh et al. 1975) as soil related. These same environmental conditions are comon to the Uintah Basin, as well. As a result, the populations occurring on the LOFRECO site do not apparently represent a critical segment of these species' range. In fact, the majority of the rare and endangered species found on the LOFRECO site are locally common in fair abundance. It is also possible that the endemic nature of many of the rare and endangered species in the Unitah Basin may not be trully endemic, but rather epibiotic, indicating that these plants are of young species that have not expanded their range outside the limits of

the basin. On the other hand, the energy resource development currently affecting the southern Uintah Basin may pose a threat to these plants, which are considered a valuable natural resource in themselves.

Three areas of consideration have been given to the rare and endangered species on the LOFRECO site in this report:

- Development of preliminary distribution information showing that the occurrence of most large population segments are on areas outside the development zone on the LOFRECO site
- Location and mapping of individual species is in progress in order to provide the Bureau of Land Management with information useful to this agency in monitoring regional populations of rare and endangered species
- Development of quantitative information significant to documentation of species occurrence and to the understanding of specific habitat affinities of the species found

Herbaceous Productivity Relationships to Large Herbivores

The primary herbaceous productivity of the LOFRECO site is extremely limited. Table 20 represents production on the LOFRECO site in comparison with that of other areas in the region. This table illustrates that the production values discussed in this report are substantially lower that regional values. Sagebrush uplands are similar to other sites during years of greater rainfall (1979 values on Table 20). The lower rainfall received during 1978 had an apparent direct influence on herbaceous standing crop. The increased spring rainfall received during 1979 increased the herbaceous production values to a significant level in terms of available forage (if not is terms of statistical significance). Important in this increased production in the production of blue grama grass, western wheatgrass, and other perennial grasses. Half-shrubs also respond positively to increased moisture, although not as directly as the grasses. The net result of the productivity relationships with precipitation is the cyclic nature of this correlation. Wetter years will produce additional forage, most available

in late spring and early summer. During drier years, the inverse will occur. Total changes in production are, however, not significant between years and not substantial enough to increase animal unit months on any given site. Another important feature of the cyclic nature of the herbaceous productivity is the stable nature of the shrub resource. Sagebrush is utilized by both cattle and big game (more by the former), and may supply an important source of browse during dry years or periods. This factor is significant in considering revegetation plans, and indicates the adviseability of including shrubs (as transplants, particularily) in revegetated areas. Moreover, the shrub islands of the upland sagebrush sites tend to increase snow catchment and increase rainfall interception, thus increasing the effectiveness of any precipitation received by a site.

Importance of Vegetation Structure, Soils and Ecoclimatic Conditions to Reclamation of Disturbed Areas

The major factor interaction between ecoclimate and vegetation is the interrelationship between temperature and moisture, and the shrub or tree canopy. In general, the vegetation canopy tends to mitigate some of the extreme influences of temperature and aid in accumulating precipitation as snow and rain. The canopy also tends to obviate some positive effects of climate, such as incident light and rainfall received at the surface of dense shrub communities. Soil conditions also interact with vegetation, especially in terms of their low nutrient status and textural properties. Through these conditions they limit growth in terms of biomass accumulation and germination as a result of single factor interactions or combinations of factors, such as available soil moisture; the dessicating effects of vesicular and channery soils; and soil toxigens (Thatcher and Hart 1979).

The information obtained on these parameters is given priority in its usefulness to the reclamation of the four vegetation types that may be disturbed during the development of the LOFRECO site. These data reveal that the primary problem areas potentially encountered in any revegetation effort on the LOFRECO site and their potential solutions are as follows:

- The control of surface temperature and associated soil water budgets, by using mulches and roughened surfaces
- Increasing interception, accumulation, and effectiveness of any precipitation received, as in open, rough-surfaced shrub stands
- Maintaining moderate air temperature maximums by favoring vertical mixing of air, as in open shrub communities
- Enhancing maximum biomass accumulation in revegetated sites by mitigating soil hazards, such as erosion and toxicity, and increasing soil nutrient status
- Avoiding germination failure through seed dessication, by not developing vesicular soil conditions on channery soils
- Decrease invasion of annuals by increasing conditions favorable to perennials (especially grasses), such as roughened soils and increased effective soil moisture

The Use of Baseline Data in Distinguishing Man-Induced Perturbations From Natural Trends and Cycles

The comparisons of various baseline data by means of coeffiecient of similarity and analysis of variance tests demonstrate that there are no significant differences between control and development sites or between the same sites among the two baseline years that will interfere with the monitoring of natural cycles and trends during development activities. The level of sensitivity of these tests is sufficiently high to assure detection of natural changes based on the parameters measured and their behavior over the two year period.

The majority of perturbation on the LOFRECO site related to development activities are of a gross nature, such as direct disturbance or removal of the natural vegetation environment. The baseline data provides an adequate basis from which to monitor the success of revegetation in terms of restoring essential vegetation environment conditions.

The effects of potential increased toxigens released in ambient air as a result of any development-related activities can be monitored through

subsequent changes in vegetation type species composition, structure, or productivity. The relationship between vegetation parameters and changes in physical environmental parameters are well-doumented and can be used to distinguish between natural and man-induced effects. Potential effects of increased soil toxicity as the result of retort operations are not anticipated, as shown by the sampling of soil overlying retorts.

The following ecoclimatic parameters will be of importance in distinguishing between perturbations and natural cycles:

- Correlations between spring precipitation and perennial grass production
- Correlations between air and soil surface maximum temperatures and perennial grass and half-shrub production

Baseline study methodology and sampling locations are well-documented and amenable to reproducability during future years. The ranges of values obtained for the parameters studied have been shown to be reliable in making repetive samples that equally characterize the natural system on the LOFRECO site.

TABLE

REGIONAL COMPARISONS

MEAN PRIMARY HERBACEOUS PRODUCTIVITY

LOFRECO SITE

1978-1979

Kg/Ha

VEGETATION TYPE	NORTHWESTERN COLORADO 1975 +	LOWER UINTAH BASIN 1975 '	LOFRECO SITE 1978 ●	LOFRECO SITE 1979 ●
Pinyon-Juniper Woodlands	219★	88	21	23
Sagebrush Uplands	520	510	311	564
Sagebrush Bottomlands	312	NO DATA	132	15

★ measurements taken during June in each of sites are for standing live herbaceous biomass

\+ after C-b Shale Oil Venture, 1977

' after While River Shale Project, 1976

● values given are for July samples

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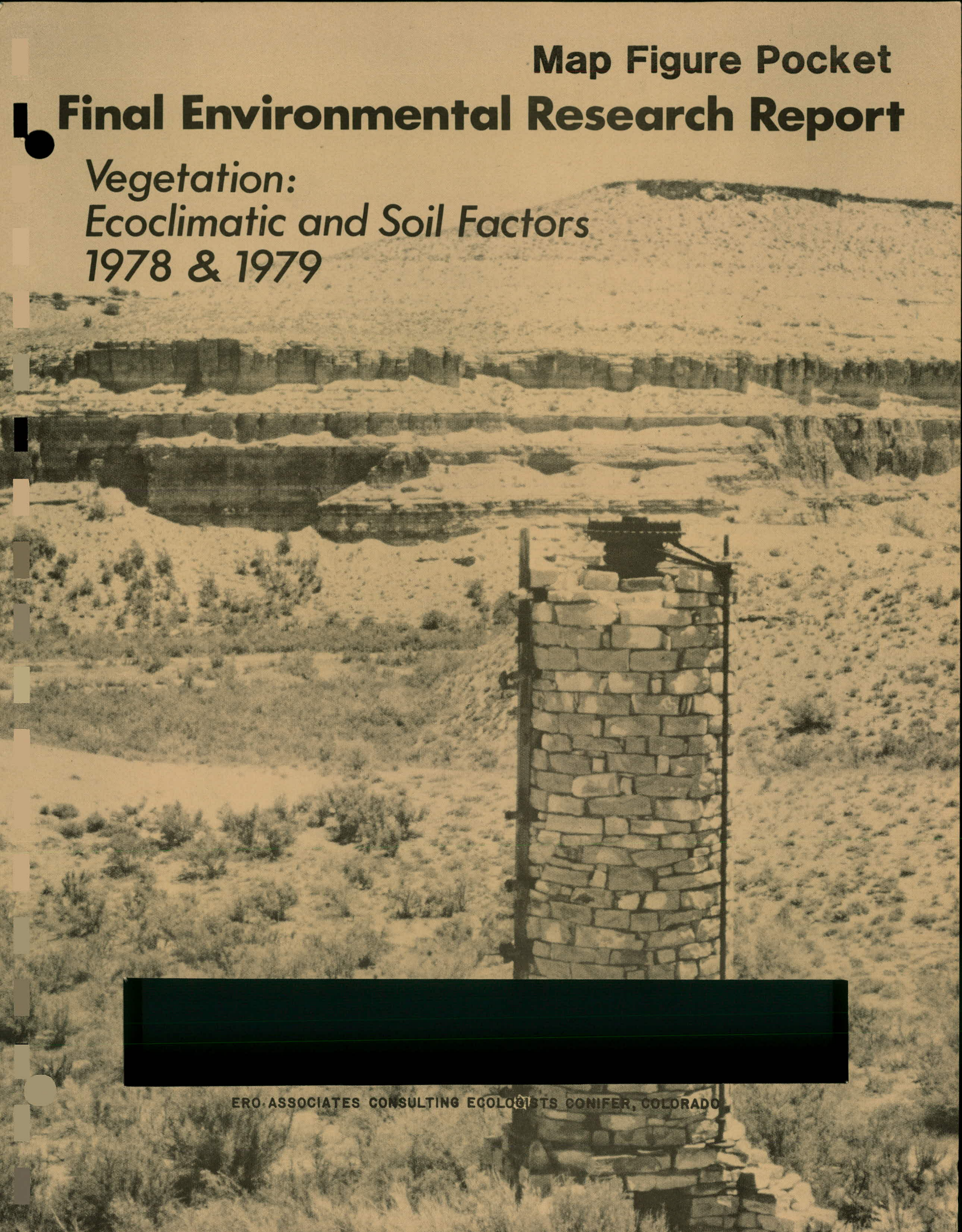
Map Figure Pocket

Final Environmental Research Report

Vegetation: Ecoclimatic and Soil Factors 1978 & 1979



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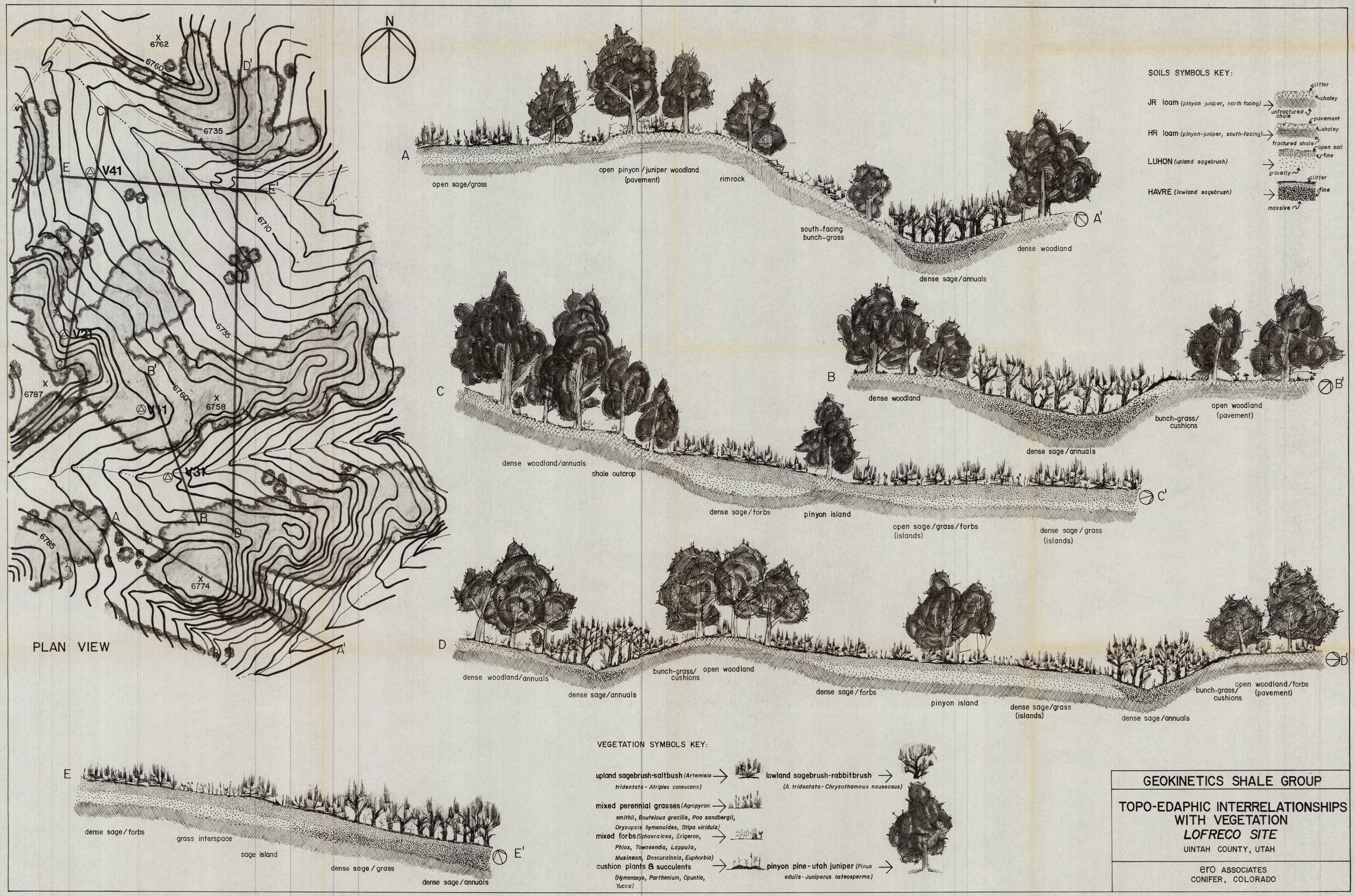
LOFRECO SITE - GEOKINETICS OIL SHALE PROJECT

UINTAH COUNTY, UTAH



GEOKINETICS SHALE GROUP

TOPO-EDAPHIC INTERRELATIONSHIPS WITH VEGETATION
LOFRECO SITE
UINTAH COUNTY, UTAH

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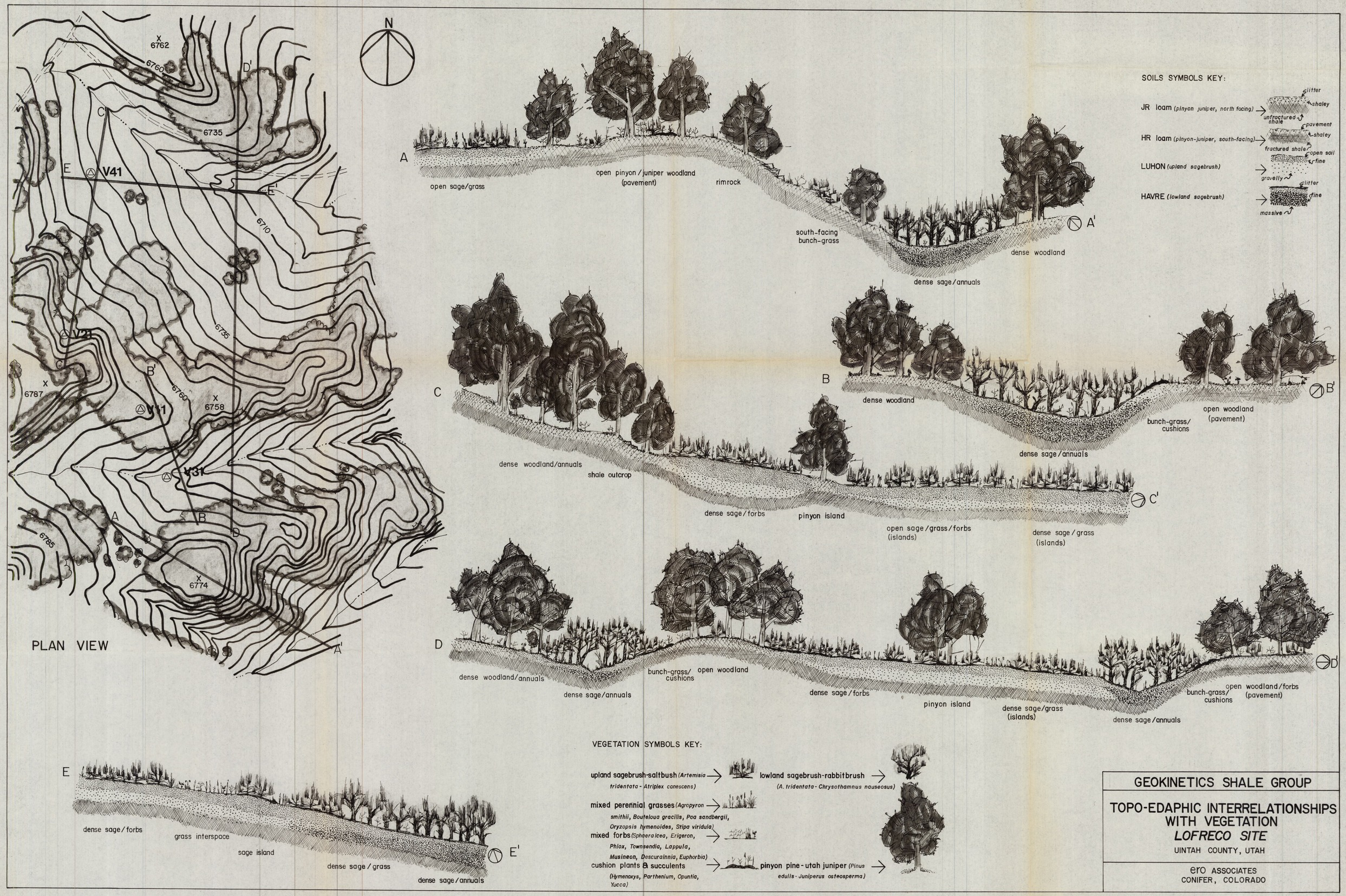
POCKET MAP 2



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TOPO-EDAPHIC INTERRELATIONSHIPS WITH VEGETATION
LOFRECO SITE

UINTAH COUNTY, UTAH

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POCKET MAP 2

LEGEND:

V permanent vegetation sample site

EO ecoclimate sample site

pinyon-juniper woodland (north-facing)
Pinus edulis–Juniperus osteosperma

pinyon-juniper woodland (south-facing)
Pinus edulis–Juniperus osteosperma

shaley slopes and rimrock (south-facing)
cushion plants and succulents

sagebrush-rabbitbrush lowland
Artemisia tridentata–Chrysothamnus nauseosus

sagebrush-western wheatgrass upland
Artemisia tridentata–Agropyron smithii

SCALE: 1" = 200' *CONTOUR INTERVAL: 5'*

GEOKINETICS SHALE GROUP

VEGETATION MAP
LOFRECO SITE

UINTAH COUNTY, UTAH

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REVISED
1980

POCKET MAP 1

LEGEND

- LR GRAVELLY LOAM
- JR LOAM
- HAVRE SILT LOAM
- LUHON LOAM

Scale-1"=200'
Contour Interval-5'

GEOKINETICS OIL SHALE GROUP - LOFRECO SITE

ENVIRONMENTAL RESEARCH PROGRAM

SOIL MAP

SECTION 2, R·22·E, T·14·S, UINTAH COUNTY, UTAH

ERIK R. OLGEIRSON ASSOCIATES
CONIFER, COLORADO
1978

POCKET MAP 3