AN ABSTRACT OF THE THESIS OF

Hassan Alizadeh Rabii for the degree of Doctor of Philosophy in Geography presented on August 10, 1979.

Title: An Investigation of the Utility of Landsat 2 MSS Data to the Fire-Danger Rating Area, and Forest Fuel Analysis Within Crater Lake National Park, Oregon.

Abstract approved: Redacted for privacy

Dr. James F. Lahey

Inventorying and mapping of the amounts of downed forest fuel tonnage/acre within Crater Lake National Park, Landsat multispectral data was utilized in conjunction with National Cartographic Information Center (NCIC) digital topographic information. It is believed that this combination is the first effort of its type. Classification of combined Landsat spectral/NCIC topographic data sets was accomplished through utilization of a Nova 840 computer system at Berkeley Space Sciences Laboratory, Berkeley, California. Interactive classification capability of this computer and its video color display provided identification and mapping criteria for classification of various surface and cover types within the National Park.

Landsat spectral/NCIC topographic data set analysis technique employed in this research included an unsupervised classification program that separates sets of multidimensional data points into clusters of similar groups. Each cluster is represented numerically

by a "center" or means of all features, and a "width" or a set of standard deviations. To develop the cluster set, the program employs an iterative process, and refines clusters in each iteration. As the process continues, clusters with previously defined "too small" standard deviations are combined into a single cluster, while clusters with larger standard deviations are divided into new clusters. This refinement stops when a measure of "goodness" (set by the user), has been achieved. Use of this cluster classification technique resulted in fifty-four detailed surface type classes for the study area. Through stereoscopic interpretation of NASA high altitude U-2 color infrared (IR) photographs, and use of detailed field observation information, these fifty-four original clusters were evaluated and reevaluated and combined into twenty-three "simplified vegetation" classes. Finally, correlating surface cover type characteristics of fifty-seven downed fuel study areas (DFSAs) to these fifty-four original clusters and twenty-three classes, a "downed fuel" map with thirteen fuel type classes was created.

Forest type, forest density and maturity (crown size) proved to be the major "satellite visible" controls over the amounts of downed fuel. Within coniferous forest types of Crater Lake National Park, mature and dense Mountain Hemlock forest yielded the maximum amounts of downed fuel. The least amounts of downed fuel within the Park was inventoried under young, and very poorly stocked

Lodgepole Pine forest.

Throughout this study use of the quantitative MSS/topographic data set, together with qualitative data from color IR photographs, and "ground truth" information provided an excellent tools for the objectives of this research. NASA U-2 color IR photographs have larger scales and better resolutions than Landsat MSS data while, Landsat's primary advantages over NASA U-2 color IR photographs include its repetitive coverage capability of detecting spectral reflectance subtleties from surface and cover types, and most important its computer compatible quantitative data.

"Ground truth" information was utilized to correlate the MSS/topographic data set to color IR aerial photographic data. Ground truthing proved to be an important factor in classification of remotely sensed data, especially in classification of surface and cover types within as complex a physiographic region as Crater Lake National Park, where complexity of rough terrain has created numerous slopes and slope aspects. As a result, spectral intensity data are significantly altered and slope, slope aspect data aid greatly in analysis. To improve such limitations in Landsat MSS data for identification and mapping of surface and cover types within the Park, fifty-seven extensive "ground truth" activities were conducted within Crater Lake National Park.

A limiting factor in this thesis research proved to be the failure

of the Landsat 3, Band 8 terrestrial thermal radiation band, a failure which vitiated the effort to integrate terrestrial fuel moisture measurements to satellite digital data analysis.

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An Investigation of the Utility of Landsat 2 MSS Data to the Fire-Danger Rating Area, and Forest Fuel Analysis Within Crater Lake National Park, Oregon

by

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AN INVESTIGATION OF THE UTILITY OF LANDSAT 2 MSS DATA TO THE FIRE-DANGER RATING AREA, AND FOREST FUEL ANALYSIS WITHIN CRATER LAKE NATIONAL PARK, OREGON

Introduction

The primary objective of this research was to investigate (1) the utility of Landsat 2 multi-spectral scanner (MSS) data in rating an areas' fire-danger and (2) do a forest fire fuel analysis within Crater Lake National Park, Oregon. In this study, Landsat MSS data were utilized in conjunction with: 1) National Aeronautics and Space Administration (NASA) U-2 color infrared photographic data of various scales, 2) National Cartographic Information Center's (NCIC) digital topographic data of the region, and 3) data acquired through field observation with regard to the amounts of downed fuel under dominant forest species within the Park.

The flow of the argument is presented in seven chapters. Chapter one focuses on the problem statement and geographic area description. In Chapter two, physiographic characteristics of the study area are examined with regard to forest fires within the Park. Within Chapter three the specifications of Landsat reconnaissance satellites, and MSS digital computer compatible tapes are studied to aid those not familiar with the limitations of the Landsat MSS system. Details of those limitations with regard to Landsat MSS data classification and problems of pixel integration are discussed in Chapter four. Field data acquisition processes with regard to downed fuel

moisture content measurements, and the strategy employed in the inventory of downed woody material was extensively examined and is categorized in Chapter five of this study. Chapter six is devoted to a Landsat spectral/NCIC digital topographic data set classification and interpretation procedure. Also included in Chapter six are analysis techniques utilized in generating color-coded photographic products of forest species, and downed fuel amounts within Crater Lake National Park. Chapter seven includes the summary and conclusions of this research.

It is believed that findings of this study, and availability of computer generated photographic and digital maps with regard to: 1) characteristics of dominant forest species of the Park, and 2) the amounts of downed fuel available for forest fires, will assist the National Park Service's Fire Control Division in its fire control efforts within fire hazardous sites and in regulating related tourist activities within Crater Lake National Park.

Problem Statement

Except for prescribed fires, all forest fires are devastating phenomena. Every year forest fires burn and devaluate millions of acres of forest lands all over the world. Forest fires are especially critical in midlatitudes where dramatic changes in regional climatic elements from wet to dry season favor forest fire fuel loading and fuel ignition. According to the Oregon State Forestry Department, the forest fire season in Oregon starts in early July and extends until late October. During this time period an average area of 25,000 acres of forest lands are destroyed (Oregon State Forestry Department, 1969). During the 1970 forest fire season, each forest fire destroyed an average of 57 acres within the Pacific States region (USDA, 1971).

An investigation into a forest fire probability index reveals that the following categories are basic parameters in forest fuel fire loading processes:

1. biomass parameters:
    a. understory characteristics; is it brush, dead fuel or their combination, and are these moist or dry,
    b. fuel size and moisture content.
2. physical parameters:

a. atmospheric conditions: especially temperature, humidity, wind direction and wind speed,

b. surface environment such as topography, slope, slope aspect, and soil moisture characteristics (Brown and Davis, 1973).

Although it would seem a simple task to study the foregoing phenomena and thus be able to forecast and even to prevent forest fires, in practice it has proved to be otherwise. In the United States, for example, in spite of its well organized and advanced forest services and technology, limitation of manpower in the Forest Service in comparison with forested land areas of the country has made forest fire prevention, not only a difficult, but an impossible task.

In recent years, United States National Aeronautics and Space Administration (NASA) by its successful launching of Landsat Satellite Series into earth's orbit has opened a new era and horizon for scientific researchers of all disciplines who are involved in aerial surveillance activities in their studies. Landsat satellites, by scanning the globe accumulate first hand data from every region on the earth; an accomplishment which would otherwise be impossible.

As in many other disciplines, foresters and scientists in related fields have benefitted greatly from the advantages provided by Landsat MSS data. Their approach, in this respect has been mainly devoted to forest inventories, damage survey and damage control,

and similar activities. In an attempt to further extend Landsat MSS data application to silvicultural studies, this study has aimed to investigate the potential capability of Landsat MSS data in inventorying downed woody material, surveying forest fuel fire loading characteristics, and ultimately in establishing fire prevention criteria within Crater Lake National Park, Oregon.

Study Area

For the purpose of this research Crater Lake National Park in the southern High Cascades of Oregon was selected. Crater Lake National Park is located between North latitudes of 42°46' and 43°04' and between West longitudes of 121°59'50" and 122°15'56". Figure 1 represents the location of the National Park within western United States.

Why Crater Lake National Park was Selected as a Site for a Forest Fire Fuel Study Area

In selecting Crater Lake National Park as a study area for this research the following considerations were involved:

1. The area represents one of the most unusual physiographic landscapes of the world. For this reason tourism and tourist activities have increased steadily. This trend is expected to continue through the coming years. Hence man-caused forest fires are expected to increase proportionally to increased tourist activities.

2. Large scale NASA U-2 color infrared photographic coverage for the Park was available.

3. A recent Landsat digital cover map (Walsh, 1977), was available, which together with U-2 color infrared photographs provided excellent aids for selection of Fuel Moisture Study Areas

Location Of Crater Lake National Park In Western U.S.

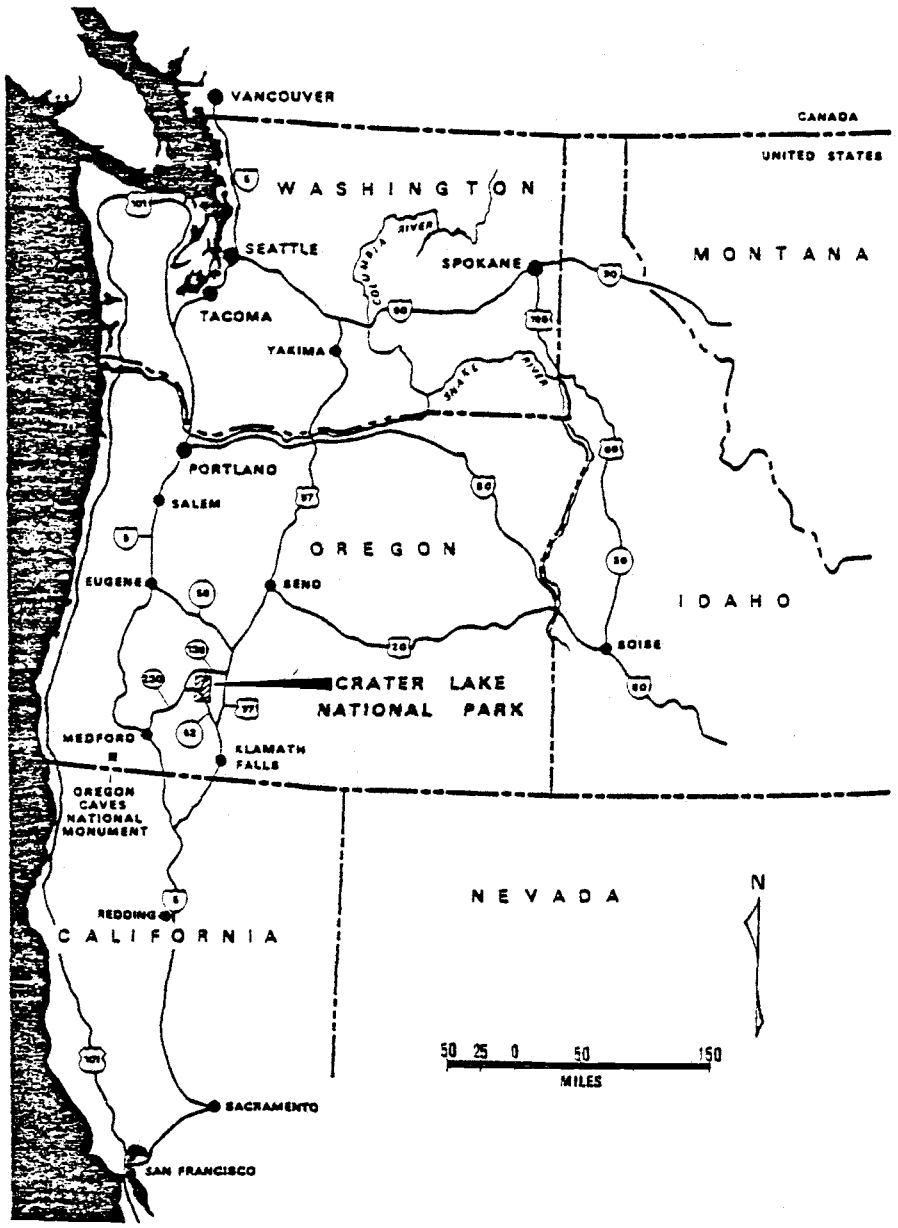


Figure 1. Adapted from NPS (1977).

and Downed Fuel Inventorying Areas.

4. Observing the objectives of the National Park Services Fire Management Plan for Crater Lake National Park, considering its accumulated fire history, the park has already been divided into three fire units (Figure 2). Units 1, 2, and 3 designate respectively wild fire regions within the Park with 1) no fire spread danger to "outside the park" resources, 2) an intermediate area, and 3) an extreme fire zone which is hazardous to the flora and fauna of Crater Lake National Park and its immediate vicinity. The Fire Management Plan of the National Park has provided overall approved directions for the management of natural, wildland, and prescribed fires within Crater Lake National Park. The National Park Service with this Fire Management Plan, aims to preserve the Park as a natural wildland while minimizing wild fire spread hazards from the National Park to its neighbouring national forests (Betts and Dickenson, 1977).

The present study was designed to provide the Park Service with downed fuel characteristics for every dominant forest type as related to topographic phenomena such as elevation, slope, and slope aspect within the Park.

The current chapter has provided the reader with basic information about the purpose, and objectives of this research, and with the location of the study area. In the forthcoming

Fire- Spread-Danger Units Within CLNP

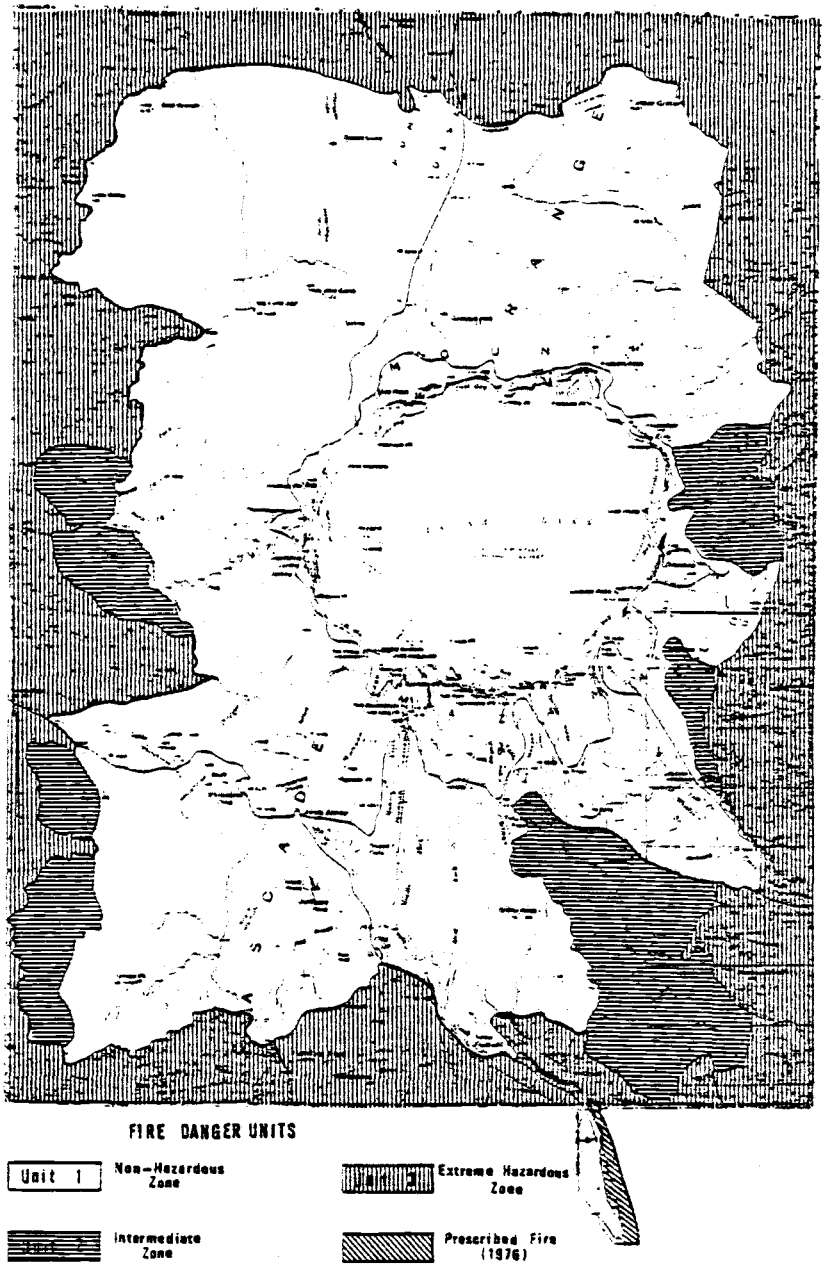


Figure 2. Adapted from Betts and Dickenson (1977).

chapter physical characteristics of Crater Lake National Park will be discussed as background for persons not knowledgeable about the Crater Lake environment and because the physical conditions have important relationships to forest wild fire potential.

CHAPTER 2. PHYSICAL CHARACTERISTICS OF THE PARK WHICH MIGHT INFLUENCE FOREST FIRES WITHIN CRATER LAKE NATIONAL PARK

Physical Setting

The Cascade Mountains, one of the main western highlands of the United States between the Rocky Mountains to the east and Coast Range to the west, extend from Northern Washington State, through Oregon, to Northern California. This Cascade Range itself represents two distinctive structural landscapes. The Western Cascades are a belt of Tertiary lavas and pyroclastic rocks. The High Cascades, on the other hand are younger volcanic cones of Pliocene and recent structural origin. At the time that the recent volcanic eruptions of the Eastern or High Cascades started, Tertiary lavas and pyroclastic rocks of the Western Cascades had already been folded and deeply eroded. During the Pleistocene epoch the High Cascades region rose and numerous mountain peaks developed. Mount Mazama, remnants of which enclose Crater Lake today, was one of these newly developed peaks. This mountain began to grow about two million years ago (Williams, 1942); and became a rival peak to Mount Hood (elevation 11, 253 feet = 3430 m.) before it erupted and became Crater Lake. Similar to the large number of volcanoes of the High Cascades, Mount Mazama's eruptions were explosive in nature. These eruptions took place during the recent epoch of the

Quaternary period. Falling pumice from Mount Mazama's final cataclysmic eruption 6600 years ago (plus or minus 200 years) covered more than 350,000 square miles. The depth of falling pumice and its orientation varied as controlled by the prevailing winds of the time (Figure 3). Of the total of 350,000 square miles only 5,000 square miles were buried under more than 6 inches of falling pumice. Farther away from Mount Mazama's eruption center the size of falling pumice and its depth decreased. Some very fine pumice was carried as far as Alberta, Canada (Williams, 1942, and USGS, 1956). As a result of this extremely explosive eruption, Mount Mazama was destroyed and its peak collapsed into the mountain creating a caldera approximately twenty-four square miles in size. Later, one other, although smaller, orogenetic activity took place at the bottom of the caldera resulting in the present day Wizard Island which continued to erupt until it reached its present dimensions about 1,000 years bp. Today it consists of a symmetrical cinder cone about one half mile in diameter and a summit rising 763 feet above the level of the Lake. Geologic and botanic studies have indicated that Wizard Island erupted at about 1,000 years bp, and ceased volcanic activities not later than 800 years ago (Williams, 1942 and 1953).

The structural setting of Crater Lake National Park consists of Pleistocene cones of Andesite and Pliocene shield volcanoes of basalt. Underlying rocks include the Tertiary lava flows of the Western

Distribution of Pumice Deposits from Mount Mazama

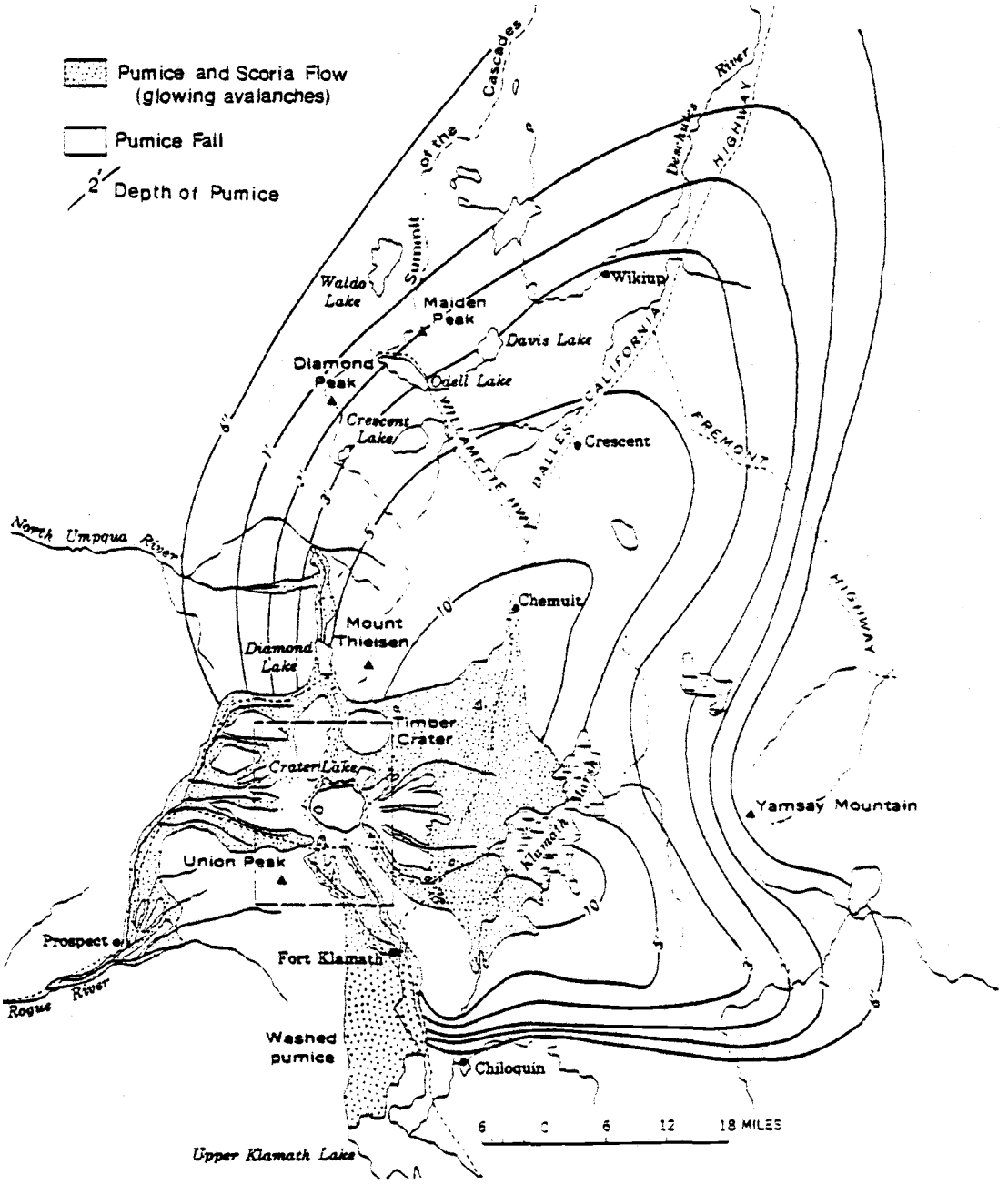


Figure 3. Adapted from U.S.G.S. (1956).

Cascades.

A generalized geologic map of Crater Lake National Park and vicinity (Figure 3-A) represents the resultant physiographic landscape of the region after Mount Mazama's volcanic activities ended. The region is now mainly covered with lava rocks and pumice produced by Mount Mazama's eruptions. There are also remnants of Tertiary lava covered land to the north and to the northwest of the Park. To avoid repetition in geological research study of the region, it is suggested that readers interested in more information on geologic history of the Park refer to a recent summary on this subject by Stephen J. Walsh (1977). Original detailed information on the subject is available through extensive publications by Howel Williams (1942, and 1953).

Crater Lake National Park is about 120 miles inland from the Pacific Ocean. Orogenetic and volcanic activities within the National Park has resulted in a complex topography where abrupt changes in elevation are common especially around the rim areas.
While elevations in the southwest corner of the Park are less than 4,400 feet (about 1341 m.), within a short distance to the northeast on the summit of Mount Scott east of Crater Lake, it reaches to 8,926 feet (2721 m.). With the exception of the caldera rim and a number of scattered volcanic cinder cones around the Park, the elevation ranges between 5,000 and 6,000 feet (1524 m. to 1829 m.), within the

Generalized Geological Map Of CLNP And Vicinity

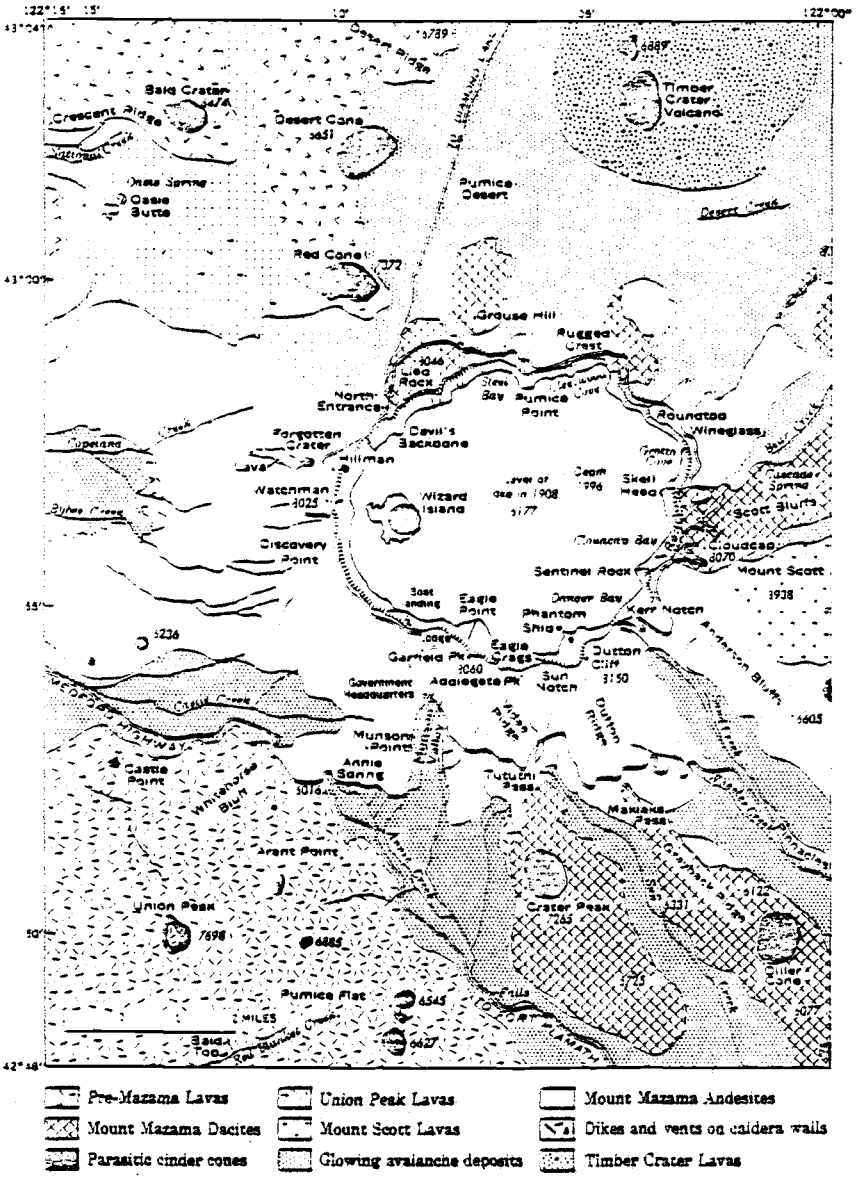


Figure 3A. Adapted from Williams (1942) and USGS (1956).

boundaries of this National Park (USGS, 1956). This unique landscape of the park provides powerful controls over the climate and vegetation of the region.

Figure 4 is a photographic product of computer assisted color enhanced Landsat digital data of Crater Lake National Park and vicinity acquired on September 10, 1974. Computer color enhanced images of Landsat MSS digital data are composites of three basic colors (red, blue, and green), and their different hues. In this figure (Figure 4), nonvegetated areas such as Pumice desert and rim walls as well as bare mountain summits such as Crater Peak, Timber Crater and Union Peak, are shown in bright colors. Forested areas of the National Park are shown in different shades of blue; lighter tones representing lower densities of forest cover types. Deep valleys or canyons are represented by different tones of red depending on cover type density and their reflectance intensities.

Figure 5 is a color enhanced digital contour map of the National Park and vicinity with contour interval of fifty feet. This figure has been produced from topographic digital tapes provided by National Cartographic Information Center (NCIC) in Reston, Virginia and adjusted to the handset pixel grid format.

Comparing figure 4 with figure 5, it is evident that distribution of vegetation within the National Park is a function of topography. According to observations made within the Park during the summer

Color Enhanced Landsat MSS Base Data for Crater Lake National Park and Vicinity.

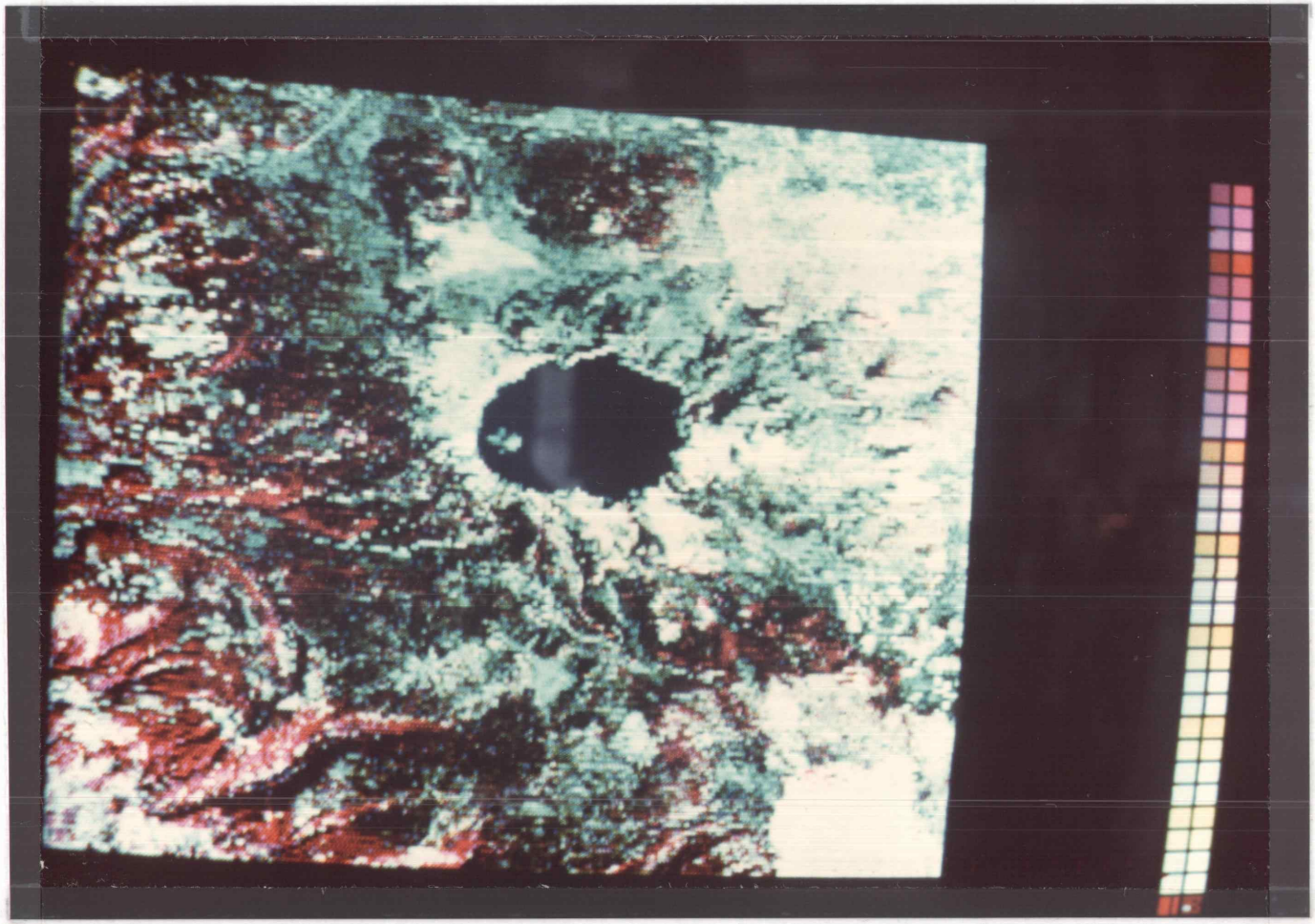


Figure 4

Color-Coded 50 Foot Contour Map of Crater Lake National Park and Vicinity.

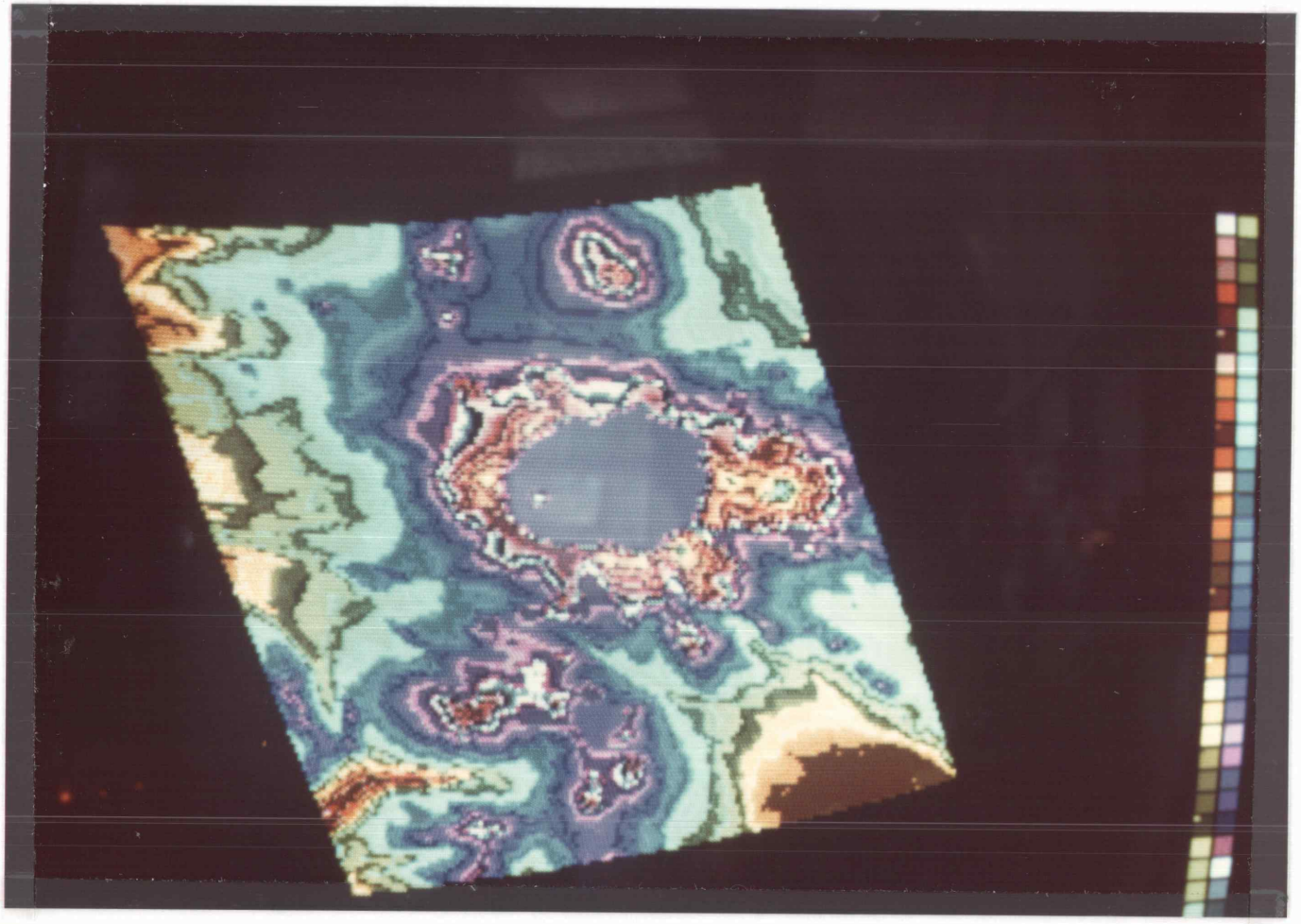


Figure 5

of 1978 lower regions of the Park are forested by Lodgepole Pine (Pinus contorta) and are represented in light blue in Figure 4 and light to medium blue in Figure 5. Areas with higher elevations which have been presented in different tones of red and purple in Figure 5 are forested with Mountain Hemlock (Tsuga mertensiana) and/or Shasta Red Fir (Abies magnifica var. Shastensis). In Figure 4 such areas are shown in darker shades of blue or red. Ground truthing also assures that Whitebark Pine (Pinus albicaulis) with similar reflectance values of that of Lodgepole Pine, replaces it in areas with higher altitudes. Such is the case in Crater Lake rim area.

It is suggested that topographic phenomena in general, and elevation in particular has powerful control(s) over distribution and dominance of cover types within the National Park.

Data accumulated through "ground truthing" during the summer of 1978 within the Park, has indicated that different cover types of the National Park have different downed fuel characteristics. These characteristics will be examined and categorized in Chapter 5.

Climatic Elements

Data Acquisition

Extensive long period climatic records for Crater Lake National Park do not exist. Sternes (1963), has compiled a brief climatic record and climatic analysis for the Park which is based solely on observations made at Crater Lake National Park Headquarters from 1924 through 1961 with a five year gap from 1942 through 1946.

Obviously this station, located at an elevation of 6,475 feet (1974 m.), cannot represent an overall picture of the climate of as complex a terrain surface as Crater Lake National Park, where drastic and abrupt changes in elevation and orientation of deep valleys have created numerous microclimatic regions. None the less, in the absence of any other climatic records for any appreciable period of time for the region, this original work was chosen for analysis. In addition, short term climatic data for the Park were acquired as follows:

a. Snow depth and snow meltout data were made available for seven selected snow depth observation stations within the Park. These data are from field observations made weekly by Dr. James F. Lahey and Mr. William Hamilton from early fall of 1977 through the summer of 1978.

b. Weather reports from observations made at

Crater Lake National Park Headquarters during summer months of July, August and September, 1978. Availability of these data provided day to day weather reports for the period of field observation of downed fuel moisture content within the National Park.

Climatic Analysis

Located within northern hemisphere middle latitudes, a short distance from the North Pacific, and under a basic westerly wind flow, the High Cascades of Oregon are moisture barriers. Although the Park is slightly south of the main track of the numerous winter storms, which originate from the North Pacific, it still is well within the belt of their influence (Sternes, 1963). These locational factors, together with topographic configuration of the Park, control all major climatic phenomena; temperature, precipitation and solar radiation within the National Park. These phenomena are discussed below.

Temperature

In any month of the year freezing temperatures can be observed at all elevations within the Park. Within the National Park, there is steady decline in temperatures as elevation increases. An exception to this ruel, are "pools" of cold air in certain regions at lower elevations the eastern slopes and eastern or southern plateau within the National Park. Sternes (1963) considered three

primary conditions for the occurrance of cold "pools":

a. Impeded air drainage: formation of stagnant cold air due to poor air drainage in all directions such that normal daily mountain-valley breeze does not take place effectively.

b. Invasion of Arctic Air: This air mass forming over continental snow and ice field of the continent moves southward along the east side of the Rocky Mountains. Occasionally, a segment of this air mass breaks through into the Western Rockies and moves toward the eastern slopes of the Cascade Range. Residing there, this Arctic air mass causes lower temperatures for the region.

c. Noneffective Incoming Marine Air: Due to seasonal sea versus land temperature characteristics, during the winter months the marine air mass is warmer and hence lighter than either stagnant air or Arctic air already in the region. As a result, incoming marine air glides over the existing colder, denser air on the ground without having any effect on the temperatures of lower elevations.

Average maximum summer time temperatures within the Park vary from the high 60's at the caldera rim to lower 90's in Munson Valley. Average maximum winter temperatures are in the 50's. Table 1 gives the annual average temperatures and also average temperatures for the months of January and July, for the National Park in comparison with data from surrounding climatic data recording stations

Comparative Climatic Data For Crater Lake Region
(1941 - 1975)

Station	Elevation feet (meters)	Latitude (N)	Longitude (W)	Ave. Temperature F (C)			Ave. Precip. in. (cm)		
				Jan.	July	Annual	Annual	June thru Aug.	Snowfall
Medford	1312 (400)	42 52'	122 52'	36.7 (2.6)	71.9 (22.2)	52.2 (11.2)	20.5 (52.0)	1.4 (3.6)	7.5 (19.1)
Trail 14 NE	1885 (575)	42 47'	122 40'	35.6 (2.0)	65.4 (18.6)	51.3 (10.7)	47.2 (119.9)	2.5 (6.3)	—
Prospect 2 SW	2482 (766)	42 44'	122 31'	35.5 (1.9)	66.7 (19.3)	50.1 (10.1)	42.9 (108.9)	2.4 (6.1)	—
Klamath Falls 2	4098 (1234)	42 12'	121 47'	29.5 (-1.4)	68.1 (20.1)	47.9 (8.8)	14.2 (36.0)	1.7 (4.2)	41.0 (104.1)
Chiloquin	4220 (1286)	42 35'	121 52'	26.4 (-3.1)	59.1 (15.1)	42.8 (6.0)	18.3 (46.6)	1.8 (4.6)	—
Chemlut	4760 (1451)	43 13'	121 47'	25.2 (-3.8)	60.0 (15.6)	41.8 (5.4)	26.4 (67.1)	2.4 (6.0)	160.0 (406.4)
Crater L. Nat. Park Hqs	6475 (1974)	42 54'	122 08'	24.8 (-4.0)	53.3 (11.8)	37.7 (3.2)	69.8 (177.1)	4.0 (10.1)	590.0 (1498.6)

Table 1. Adopted from NPS, Denver Service Center, 1977

(Figure 6).

The climatological data recorded by eight climatic data recording stations located in the vicinity of this National Park reveals the expected decline in temperature as a function of increased elevation.

Precipitation

Variation in elevation, slope and aspect are major factors controlling precipitation within the Park.

Comparative climatic data of the Park region (Table 1), indicate that areas at higher elevations receive more precipitation than the regions at lower altitudes unless unfavorable slope-aspects have created rain shadow areas. Such a condition prevails on the eastern slopes of the National Park where average annual precipitation amounts decline from about 70 inches (178 cm.), at the crest to slightly more than 25 inches (64 cm.), in the eastern lower areas of the National Park (Sternes, 1963, and NPS, 1977). Two major factors are the cause of this phenomenon:

a. Ascending air together with general air flow over the region from the southwest to northwest during storms results in much precipitation before the air passes to the eastern slopes of the Park.

b. Descending air on the eastern slopes causes the air to be

Locations Of Climatic Data Recording Stations In CLNP Region

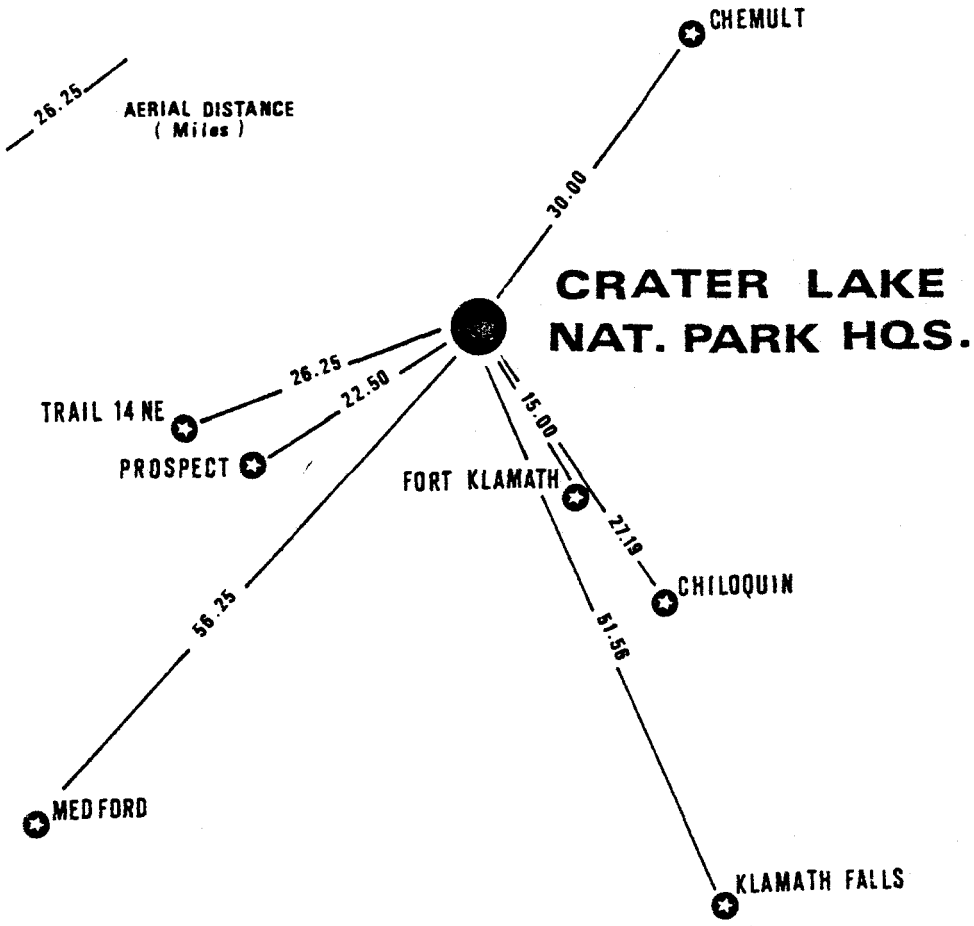


Figure 6

26-year Monthly and Annual Averages of Precipitation
Within Crater Lake National Park, Oregon

Period (year)	Jan. in (cm)	Feb. in (cm)	March in (cm)	April in (cm)	May in (cm)	June in (cm)	July in (cm)	Aug. in (cm)	Sept. in (cm)	Oct. in (cm)	Nov. in (cm)	Dec. in (cm)	Ann. in (cm)
1926 to 1941 & 1946 to 1961	10.35 (26.29)	8.60 (21.84)	8.39 (21.31)	4.33 (11.00)	3.14 (7.98)	2.53 (6.43)	0.66 (1.68)	0.55 (1.40)	2.11 (5.36)	6.39 (16.23)	7.64 (19.38)	11.89 (30.20)	70.30 (178.56)

Table 2. Adopted from Sternes (1963)

compressed to increase its temperature and decrease its relative humidity on these lee slopes.

From mid fall through spring the region receives most of its annual precipitation. During this period land surfaces of the region have much lower temperatures than the adjacent oceanic waters. Furthermore, topography of the region favors orographic precipitation. As the result, incoming, nearly saturated, marine air masses which are considerably warmer than the land over which they are travelling have their temperatures decreased both by air to surface cooling and by the orographic cooling process. This results in great amounts of moisture being released. From late spring through summer and early fall, due to the reversed conditions with regard to sea versus land temperatures, the region receives very small amounts of precipitation (Table 2). During this period of the year interior ground temperatures are considerably higher than those of the ocean beaches. This is true even at the crests of the caldera rim and other higher elevations. As a result, higher inland temperatures cause the incoming air mass to become warmer and hence increase its moisture retaining capacity. Besides, at this time of year there is almost total absence of large scale storms moving into the region; a common situation during winter months. With summertime storms being rare, and with heavy precipitation during winters, the climate of Crater Lake National

Park is characterized by cool dry summers, and cold wet winters (Sternes, 1963). Table 2 gives monthly, and annual averages of precipitation within Crater Lake National Park.

Snowfall

More than 70% of the total precipitation within the Park occurs as snowfall. Duration of snow and snow depth vary significantly with regard to variation in elevation and slope aspect. Typically at higher elevations of the Park, the first measurable snowfall occurs in late September or early October. Annual snowfall at the Park Headquarters varied between 277 and 879 inches (between 704 and 2233 cm. respectively), for the recorded data period from 1924-1961 (Sternes, 1963), with average snowfall for the Park Headquarters station being 590 inches (1498 cm.), (see Table 1, NPS 1977).

Table 3 presents snow depth variation and meltout period for selected sites within Crater Lake National Park and vicinity for the 1977-78 snow season.

According to weekly snow depth observation (Table 3), the Panhandle area with an elevation less than 4,500 feet (1348 m.), received measurable snowfall about a week later than other sites mentioned for the Park in Table 3. Also the maximum accumulated snow depth for this same Panhandle site was much smaller than for other siteswithin the Park for which snow depth observation have been

Variation Of Snow Depth and Snow Meltout Period For Selected Sites Within Crater Lake National Park, Or.

Site #	Location & UTM Coor.	Elevation feet (meters)	1st Measurable Snow On The Ground		Accumulative Snow		Date Snowmelt Completed
			Date Of Obs.	Snow Dep. in. (cm)	Date Of Obs.	Snow Dep. in. (cm)	
1	Panhandle, 576650 E., 4735300 N.	4421 (1348)	11/5/77	4.1 (10.5)	2/17/78	52.1 (132.4)	5/13/78
2	HWY 62 W, 562100 E., 4748650 N.	5550 (1692)	11/5/77	4.3 (10.8)	2/17/78	63.5 (161.3)	5/13/78
3	Annie Sp., 568350 E., 4746700 N.	6012 (1833)	10/29/77	1.8 (4.6)	2/10/78	102.8 (261.1)	7/2/78
4	Crater L. Nat. Park, Hqs., 569859 E., 4749900 N.	6950 (2119)	10/29/77	3.1 (7.9)	2/11/78	116.0 (294.6)	7/2/78
5	Junc. Rim Dr. & N. Rd. 569650 E., 4750850 N.	7000 (2134)	10/29/77	3.2 (8.1)	2/11/78	137.0 (348.0)	7/15/78
6	Junc. N. Rd. & HWY 138 W, 592250 E., 4770750 N.	5775 (1761)	10/29/77	1.8 (4.5)	3/8/78	79.0 (200.7)	7/15/78
7	Junc. HWY 138 & US 97, 592000 E., 4770500 N.	4700 (1433)	11/5/77	2.3 (5.7)	2/17/78	23.8 (60.3)	3/25/78

Table 3. Source: Field observations taken by Dr. James F. Lahey and Mr. William Hamilton.

tabulated in Table 3. Site 5 in Table 3, located at rim area at an elevation of 7,000 feet (2134 m.), had the most accumulated snow within the Park (137 in. = 348 cm.), followed by site 4 at the National Park Headquarters at an elevation of 6,950 feet (2119 m.), (116 in. = 295 cm.). With regard to snow season duration, it is evident that sites 3, 4, and 5 all with elevations over 6,000 feet (1829 m.), had snow on the ground from late October to early July; about two months longer than the other sites, all with elevations of less than 5,800 feet (1770 m.).

Within the Park, snowfall, snow depth and snow duration on the ground is a function of topography, slope aspect, and elevation. Maximum snow depth during the snow season for the National Park Headquarters has been recorded as 155 inches (394 cm.). For the 1978 snow season however, this value was recorded as 116 inches (295 cm.), on February 11, 1978. As is presented in Table 3, snow depth varies significantly within various areas of Crater Lake National Park. In fact, the snow season not only starts earlier but also lasts longer in the areas with higher elevations than those with lower altitudes within the Park. It is reasonable to conclude that the snow season starts from areas with higher elevations and spreads downward onto areas with lower altitudes within the Park. On the other hand snow meltout starts from lower elevations and makes its way up toward areas with higher altitudes within the National Park. To this rule, wind field

and snowfall characteristics of the region (mentioned above in this chapter) should be added. Obviously, the longer snow duration on the ground will result in more moist downed fuel and moist soil which in turn will delay season of potential wild fire spread within those areas of the National Park. On the other hand, areas with lower elevations with favorable slope aspect to solar heat loading dry earlier and thus enhance forest fire danger. As a result, lower areas will have longer forest fire seasons and lower elevations with southern to western slope aspects tend to be more critically prone to forest fires. Due to diurnal insolation intensity characteristics, these areas will have greater solar heat loadings than areas with northern or northeastern slope aspects.

At the present time Dr. Lahey, Mr. Scott Kolar, and Mr. William Hamilton are conducting concurrent snow field studies within Crater Lake National Park. Through these studies, characteristics of two climatically different snow seasons of the National Park, one for the relatively dry snow season of 1976-77, and the other for a so-called normal snow season of 1977-78, will be examined. To avoid duplication, this study will not investigate this topic.

Solar Radiation

Solar energy is the most important controlling factor of the climate in any region on earth. It is also by far the most significant parameter

in forest fire danger. The rate of solar loading has been estimated to be between 1.94 and 2.00 calories per square centimeter per minute at the top of the earth's atmosphere when it is illuminated by the sun's beam normal to that square centimeter. Solar radiation reaching the surface of the earth is called global radiation, which consists of direct and diffuse solar energy, the latter being energy diffused by atmospheric clouds and dust particles. It has been calculated that solar heating of the earth's surface depends on several factors, among those the astronomical parameters and angle of incidence being the most significant (Rosenburg, 1974). These parameters are examined below:

a. Astronomical factors result from the laws of earth-sun geometry which include eccentricity in the earth's orbit around the sun. Eccentricity aphelion and perihelion phases of the earth's orbit around the sun causes the intensity of solar radiation upon the earth's surface to vary from its average value by plus or minus 3.5%. As a result of this, summers in the northern hemisphere are somewhat cooler, and winters a little warmer than their equivalent seasons in the southern hemisphere (Lamb, 1972). The subject will be given further consideration in chapter 6, where, solar insolation intensity will be calculated for various slopes and aspects of the study area with regard to Landsat 2 overpass time of the region on September 10, 1974; the time during which MSS data utilized in this research

had been acquired.

b. The angle of incidence of the solar beam varies with slope angle and slope aspect of the surface exposed to sun's energy. In accordance with Lambert's Cosine law, slope affects the intensity of radiation absorption by the "cosine effect" (Rosenberg, 1974). In other words, the incident angle with larger cosine value assures the larger quantity of solar energy input on the exposed surface. In this respect, slope angle and slope aspect are of significant importance in middle latitudes. In the tropics the sun stays high through the year, while in high latitudes there is a greater proportion of diffused to direct solar beam (because of low sun angle), on one hand and dominance of cloudiness on the other which reduces the significance of "cosine effect". Both factors have significant effects on the heat loading characteristics of Crater Lake National Park because of its location in middle latitudes and also because of its complex and rough topography with many slopes and aspects.

Chapter summary

In this chapter:

1. Physiographic characteristics of the Park that control climatic phenomena within the Park have been discussed,

2. Variations in precipitation amounts on different areas of the Park in conjunction with seasonal temperature variations within the National Park have been discussed,

3. Correlation between topography and vegetation within the National Park has been considered,

4. Snow season variability and its duration with regard to topographic phenomena of the National Park have been examined so that physiographic factors and their control over forest fires can be appreciated,

Due to the usefulness of Landsat MSS data for the objectives of this research, the first section of the forthcoming chapter will be devoted to a statement concerning the systematic characteristics of NASA Landsat satellites, and their observational systems. In the second section of the chapter, computer compatible tapes (CCT) will be described.

CHAPTER 3. LANDSAT RECONNAISSANCE SATELLITES AND MSS DIGITAL COMPUTER COMPATIBLE TAPES

Introductory Statement

The effective utilization of Landsat digital data requires understanding of the Landsat operational system. Therefore, the Landsat satellite series, their observatory systems, and operational characteristics are discussed in this chapter.

NASA Landsat Satellites

NASA initiated the Landsat program by launching Earth Resources Technology Satellite (ERTS) into an earth orbit on July 23, 1972. The foregoing name was later changed to "Landsat 1". Less than three years later, Landsat 2 was launched into an earth orbit on January 21, 1975, and this was followed by Landsat 3 on March 5, 1978. After orbiting the globe for more than 5 years, Landsat 1 ceased operation on January 6, 1978. During this period of time Landsat 1 had returned data for 300,000 images of the earth's surface from space (NASA, 1978).

Landsat Systems

Sun-synchronous earth orbiting Landsat satellites have been designed and developed by the United States National Aeronautics and Space Administration (NASA) to provide repetitive surveillance coverage of the globe, and simultaneously acquire high resolution multispectral data of the earth's surface characteristics. The orbiting direction of Landsat satellites is from N. Northeast to S. Southwest during data acquisition. It takes 103 minutes to complete a revolution. The southward revolution of Landsat is on the illuminated hemisphere of the globe with a nominal 9:30 A.M. descending node (equatorial crossing). Since orbital characteristics of Landsat 3 were not available at this time, Table 4 depicts only parameters for

Landsat 1 and 2.

Due to the oblateness of the earth's surface and perturbational forces acting upon the spacecraft, the altitude of the satellites varies between 880 to 930 kilometers (between 547 to 578 miles). As presented in figure 7, the daily earth coverage swath of the spacecraft shifts 1.43 degrees (159 Km = ~ 99 mi.), westward at the equator. The revolutions progress systematically in a westwardly direction until all the area between orbit N and orbit N+1 in figure 7 is covered. This coverage is termed "one complete cycle". The time required for one complete cycle is exactly 18 days consisting of 251 revolutions or approximately 14 revolutions per day for 18 days (NASA, 1976). During this period of time the orbital parameters of the Landsat spacecraft provide a complete global coverage between 81 degrees north latitude and 81 degrees south latitude.

Landsat satellites ground coverage pattern (Figure 7), has been designed in such a manner that there is 14% sidelap at the equator, which increases to 50% sidelap at 50 degrees north or south. Sidelap percentage reaches as much as 85% at 80 degrees north or south latitudes. Nearness of adjacent Landsat orbits (159 Km at the equator crossings), in comparison with relatively wide area coverage for MSS detector(s) is the cause of sidelapping phenomena in Landsat coverage. This has been illustrated in figures 7, and 8, and also in table 4. The width of scan pattern for MSS detector(s) coverage is

LANDSAT Ground Coverage Pattern

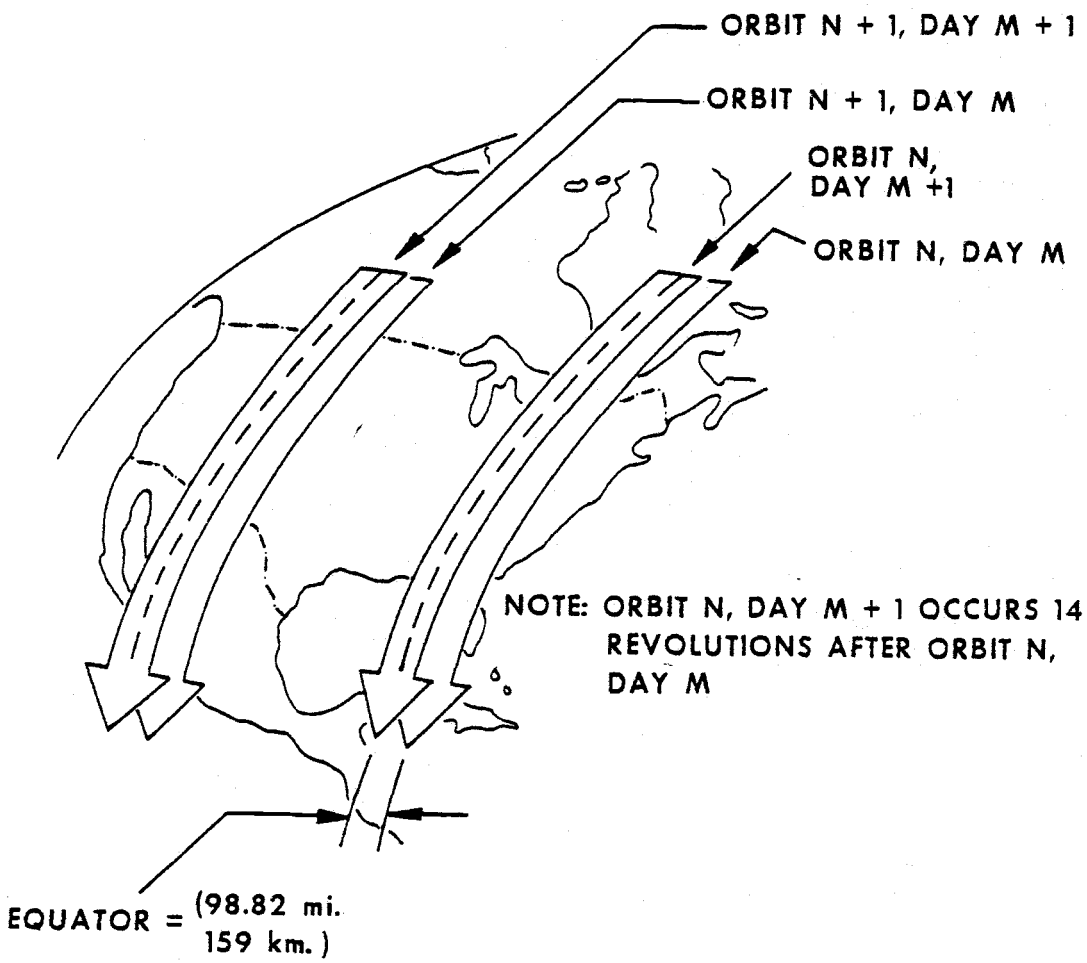


Figure 7. Adapted from NASA (1976).

Ground Scan Pattern for a single MSS Detector

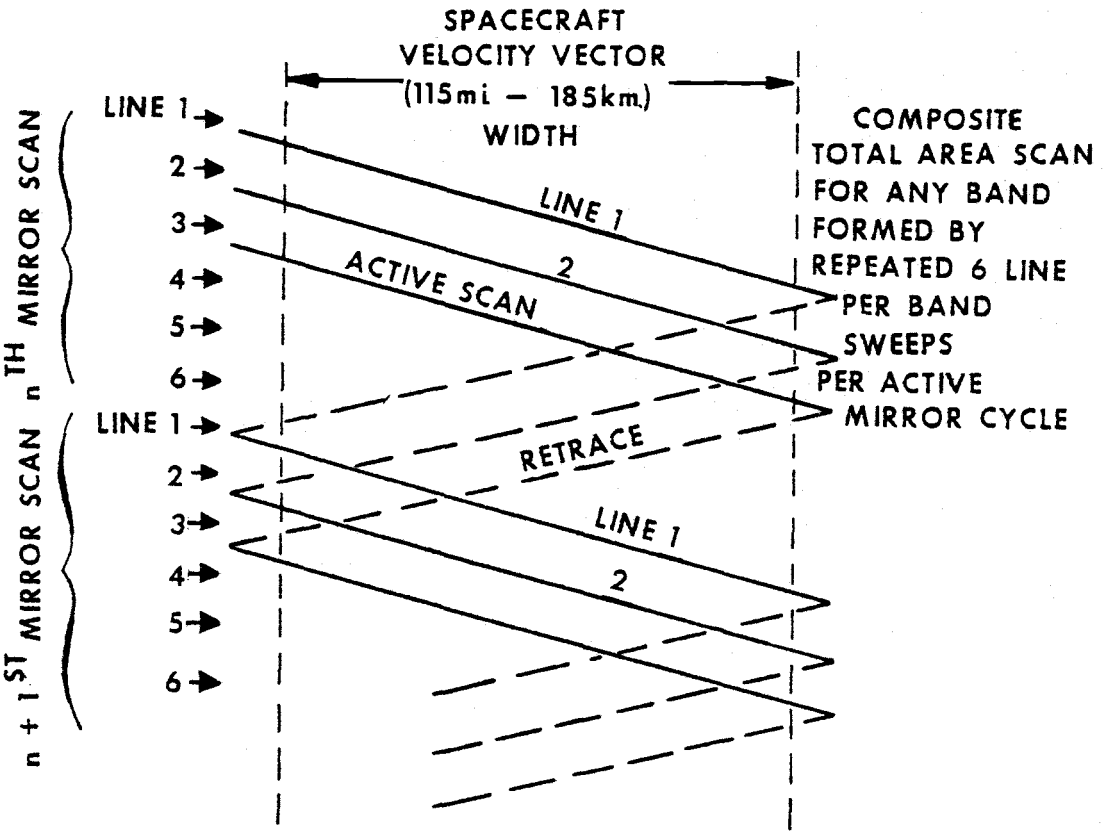


Figure 8. Adapted from NASA (1976).

Landsat 1 and 2 Orbital Parameters
(September 1976)

Parameter	Landsat 1	Landsat 2
Semi-major axis (km)	7285.438	7285.730
Inclination (degrees)	98.906	99.015
Revolution period (minutes)	103.143	103.149
Eccentricity	0.001070	0.001392
Time of descending node (equatorial crossing)	8:50 AM	9:20 AM
Duration of complete cycle	18 days (251 revs.)	18 days (251 revs.)
Distance between adjacent ground tracks at equator(km)	159	159
Nominal altitude (km)	920.00	920.00

Table 4. Adopted from Landsat Data Users Handbook, NASA (1976)

185 Km (approximately 115 mi.), while the distance between the centerlines of two adjacent subsatellite ground coverage-tracks is 159 kilometers (about 99 mi.).

In order to facilitate comparison of the Landsat images from a given area, collected during repetitive coverage cycles, Landsat orbits have been designed in such a manner that Landsat sensor systems survey the same area every 18 days. This procedure also applied to Landsat picture taking sequences, so that, with precise scheduling, the centers of images taken every 18 days correspond to the same area on the ground. This has been possible by referencing all payload operation to the equator (see Figure 9). As seen in Figure 9, when an image of Region A is obtained, it will consist of two consecutive frames, formatted 25 seconds apart from each other, covering all the earth strip which is possible to cover during that orbit. The Landsat orbit has been so calibrated that no more than 37 kilometers of cross-track picture-center variation will occur during the mission life. In-track scheduling on the other hand, assures that no more than 30 kilometers in-track picture-center variation will occur (NASA, 1976).

Every Landsat satellite carries two sensor systems onboard, each with different operational characteristics and surveillance purposes. One sensor system is a Return Beam Vidicon camera (RBV), and the other is a Multispectral Scanner system (MSS).

LANDSAT Tracking Scheme

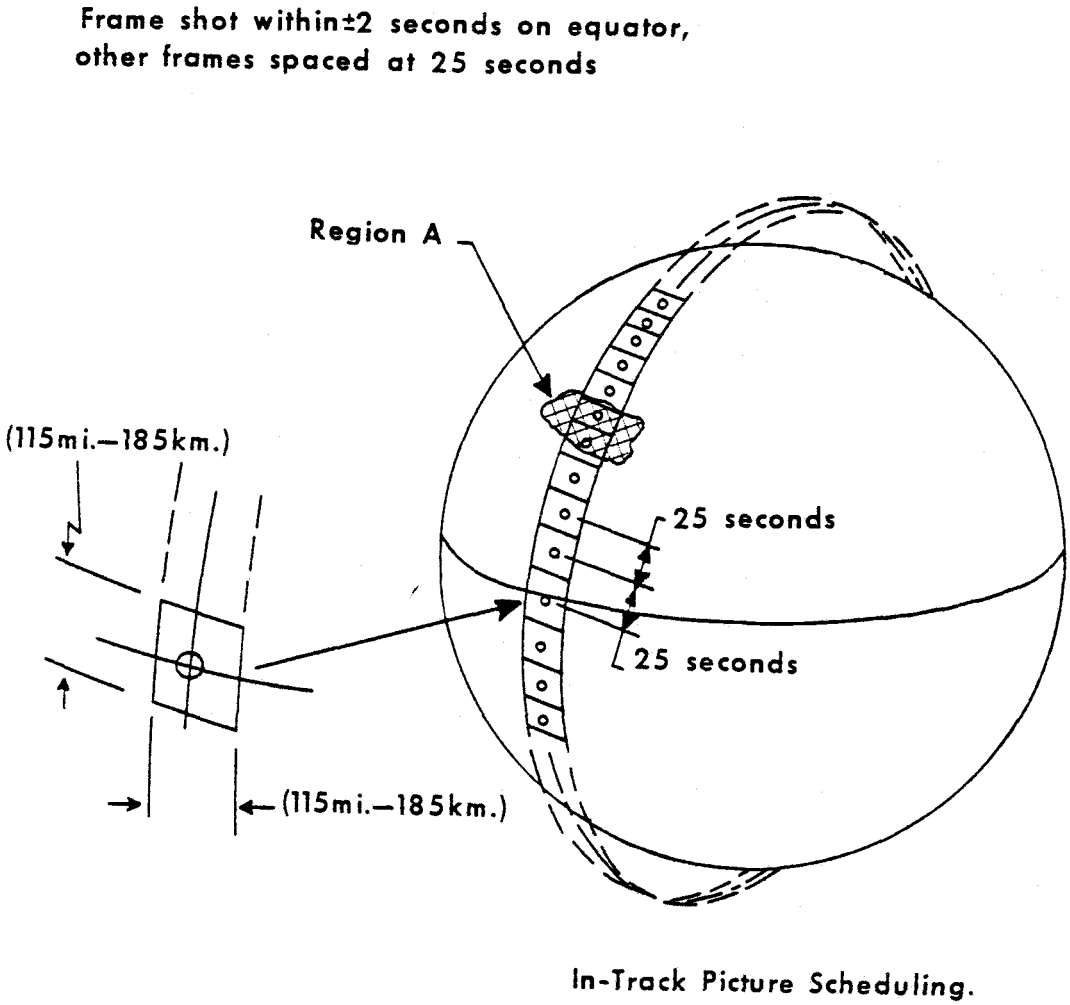


Figure 9. Adapted from NASA (1976).

Because of the importance of the Multispectral Scanner System to this research it is described in the following discussion.

Multispectral Scanner System (MSS)

Mounted onboard each Landsat satellite is a sensor system which produces continuous strip images of the earth's surface within the ranges of visual and near infrared wavelengths of the electromagnetic spectrum. This sensor system known as a Multispectral Scanner (MSS) is capable of detecting the spectral responses from 0.5 to 1.1 micrometers. MSS detection wavelengths coincide with that of reflected solar radiation from the earth's surface extending through the visual and to a portion of the reflected solar infrared spectral region; i.e., from 0.5 to 0.7 and from 0.7 to 1.1 micrometers respectively. By installation of a thermal infrared sensor onboard Landsat 3, MSS detectability in infrared region was further extended from 10.4 to 12.6 micrometers. Unfortunately, this thermal infrared sensor installed on Landsat 3 failed to operate properly since the time the satellite was launched on March 5, 1978; this thermal infrared band finally ceased operation in the late spring of 1978.

Except for the thermal band of Landsat 3, which was planned to operate with two detectors, each of the 4 bands of Landsat MSS satellites operates with 6 detectors. For this reason Landsat 1, and 2 have 24 detectors onboard for MSS bands 4 through 7 (4 x 6) (Figure 10).

The MSS detector system on Landsat satellites has been

Schematic Diagram of the LANDSAT MSS Scanning Arrangement

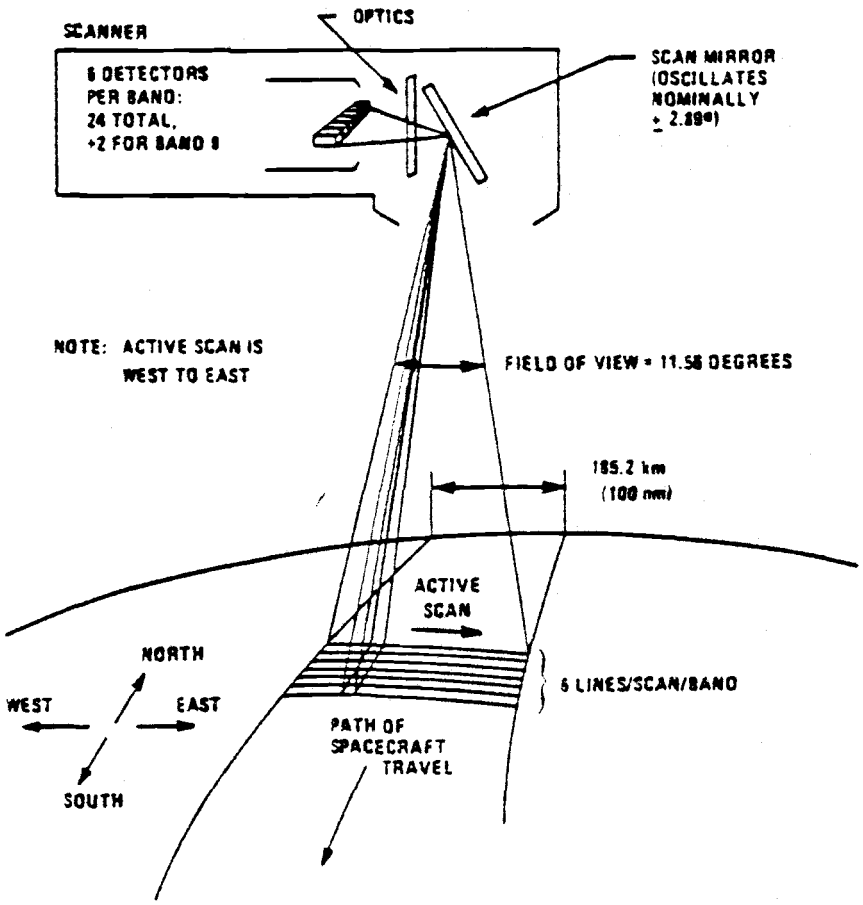


Figure 10. Adapted from Landsat Data Users Handbook, NASA (1976).

designed and calibrated so that their nominal instantaneous field of view (IFOV) or a pixel, of each detector is 79 x 79 meters (259 feet), for MSS bands 4 through 7.

Landsat Ground Scene

A Landsat ground scene composed of Landsat MSS data covers 185 x 185 Km (115 miles square) on the ground, representing reflected radiation values from surface and cover types. The Landsat orbit with its near-polar track produces the along-track spacing between swaths. This along-track motion of the Landsat together with active and retrace mirror scan provides the complete coverage of the Landsat ground scene. The scene includes 2340 parallel scan lines, each of which contains 3000 to 3450 pixels or bytes* (Figure 11). These bytes are arranged in such a manner that they represent differing radiance levels from surface and cover types. The variation in the number of bytes (pixel information) along a scan line is due to the fact that there are variations in spacecraft altitude. At the nominal altitude of the spacecraft at 918.592 Km (about 571 miles), the distance covered by a scan line is 185 Km (115 miles) long (Thomas, 1975). Ignoring mirror scan non-linearities or other perturbations of mirror velocity, a 185 kilometer scan line will produce approximately 3300 video

* A byte is made up of eight binary "bits", which are the smallest units recognizable by the computer systems.

LANDSAT MSS System

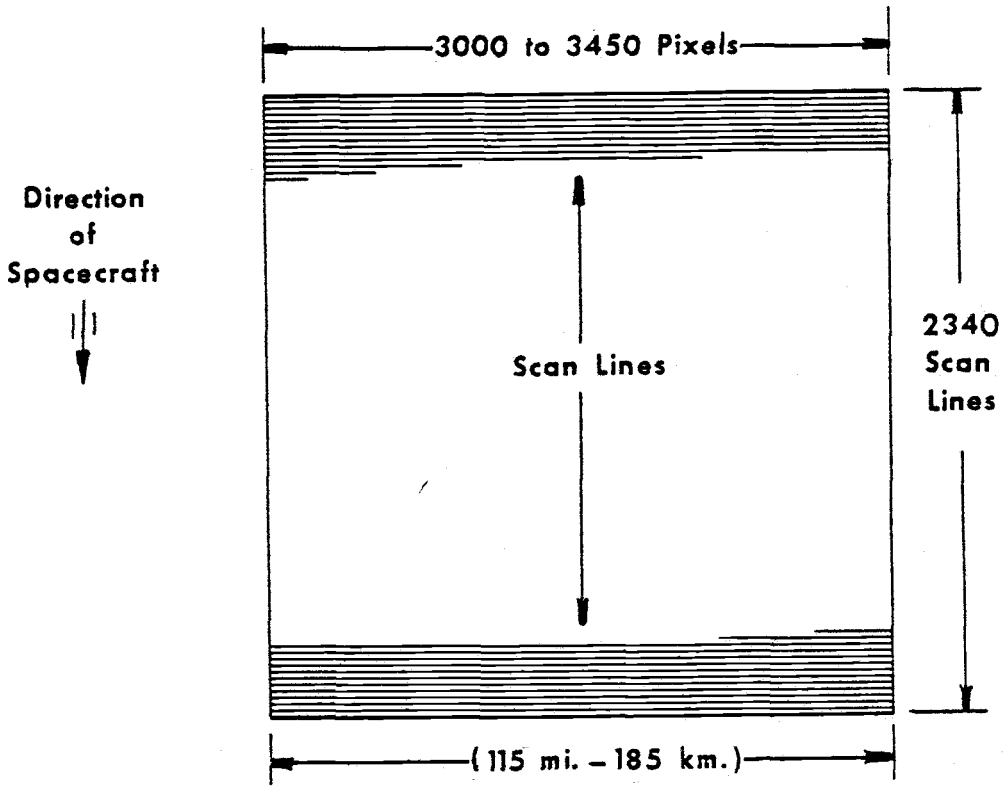


Figure 11. Adapted from Thomas (1975).

images or pixels (185:0.056 = 3304). The reasoning behind this is briefly discussed below:

It was previously noted that the nominal instantaneous field of view (IFOV), for Landsat MSS detectors is 79 x 79 meters. It was also mentioned that, there are 25 detectors or channels (24 detectors plus one sensor for thermal band data) onboard Landsat 1 and 2, these detectors operate sequentially. It should be noted that the time required for a single detector or channel to acquire video image from the scanned ground features is 0.3983 microsecond, and so for 25 channels the required time equals 9.958 microseconds (25 x 0.3983). During this period of time the reflectance characteristics of the sampled ground area (79 x 79 meters) is recorded by the various detectors of the MSS sensors. However, during 9.958 microseconds time span, the 79 x 79 meter video image moves only 55.99 meters of about 56 meters (184 feet) in cross-track direction. For this reason, when the next video image or pixel information is being acquired, it would consist of 23 meters (about 75 feet), repetitive information or previously acquired data and only 56 meters (184 feet) of new information. This 56 x 79 meters area is termed the "effective" IFOV of a detector in the cross-track (scan line) direction (NASA, 1976). Using "effective" IFOV values for pixel size (56 x 79 meters) will eliminate the overlap factor between adjacent pixels. According to some investigators "effective" IFOV has been suggested to be 57 x

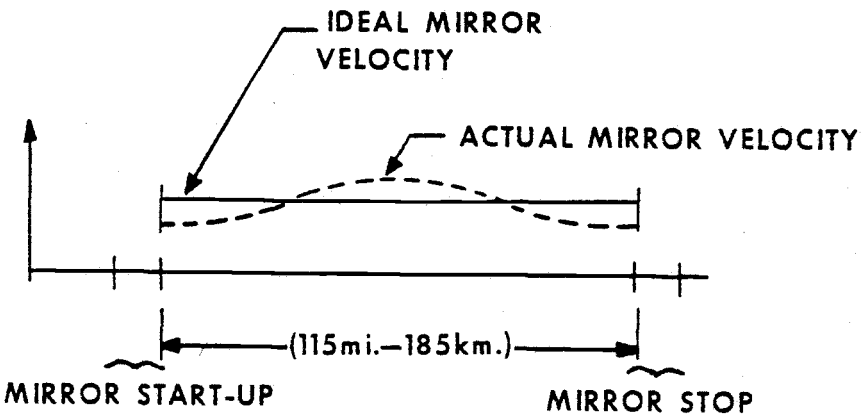
79 meters rather than 56 x 79 meters (Sabins, 1978).

Change in Pixel Integration Caused by Scanning Mirror Velocity

Variations in scanning mirror velocity cause pixel distance center variations from each other. Such variations are due to speeding up and slowing down of the scanning mirror. Thomas (1975) suggests that mirror velocity versus time is not constant but it is very nearly a cosine curve during the active mirror scan (Figure 12). Although it is negligible for most practical purposes, variation in mirror velocity is responsible for the variations in the amount of pixel overlap. For the purpose of illustration, exaggerated integration and variable overlapping of pixels corresponding to a variable mirror velocity are presented in Figure 13. Variable mirror velocity also causes the ground distance covered by a pixel to vary considerably.

The relationship between constant mirror velocity and variable mirror velocity with regard to the distance covered on the ground and the time of the mirror sweep is depicted in Figure 14. The curved line represents actual variable mirror velocity versus the distance covered on the ground. The straight line portrays the same factors for a constant mirror velocity. The difference between two lines indicates necessary corrections to be made on computer compatible tapes so that they reflect accurate distances covered on

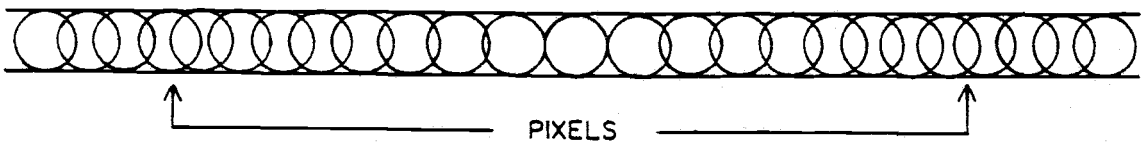
Comparison of the Constant Mirror Velocity and the Variable Mirror Velocity of LANDSAT



NOTE:
NOT DRAWN TO SCALE

Figure 12. Adapted from Thomas (1975).

Integration and Variable Overlapping of Pixels Corresponding to a Variable Mirror Velocity

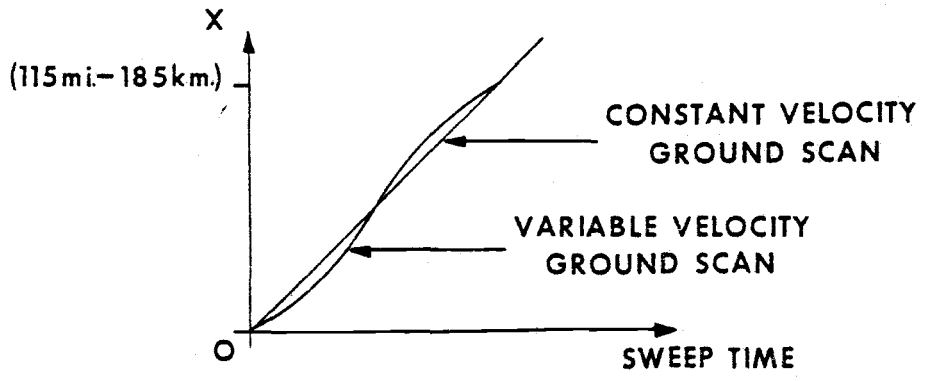


NOTE:

1. Pixels are represented by circles for ease of illustration
2. Not drawn to scale.

Figure 13. Adapted from Thomas (1975).

Comparison of Distance Covered on the Ground for a Constant Mirror Velocity and a Variable Mirror Velocity



NOTE:

1. X = THE EASTERLY SCAN OF THE GROUND
2. NOT DRAWN TO SCALE

Figure 14. Adapted from Thomas (1975).

the ground. Variation in the distance covered on the ground caused by variable mirror velocity along the cross-track direction is not systematic. Studies have indicated that ground registration error due to variable mirror velocity equals zero at mirror sweep start-up, at 92.5 Km (half way of digital scan line), and at mirror stop (at 185 Km). There are two maximum distance errors in every mirror scan, one approximately at 46.25 Km (28.5 miles) after the mirror sweep start-up point, and the other at three quarters of the digital scan line or about 138.75 Km (86.25 miles) from its start-up point. At these two points accumulative ground distance errors reach about 400 meters (about 1312 feet). (See Figure 15.) Thus, for example, it should be understood that the distance represented at the quarter point of a digital scan line does not cover 46.25 Km (28.5 miles) on the ground, but it represents approximately 400 meters (1312 feet) less than that amount or about 45.85 Km (approximately 28.25 miles) as depicted on Figure 15.

As it was mentioned earlier in this chapter, MSS detectors operate sequentially during active mirror scan which is from west to east (Figure 8). During east to west retrace period of the scanning mirror the radiance from the earth scene beneath the spacecraft is

Ground Registration Error Due to Variable Mirror Velocity

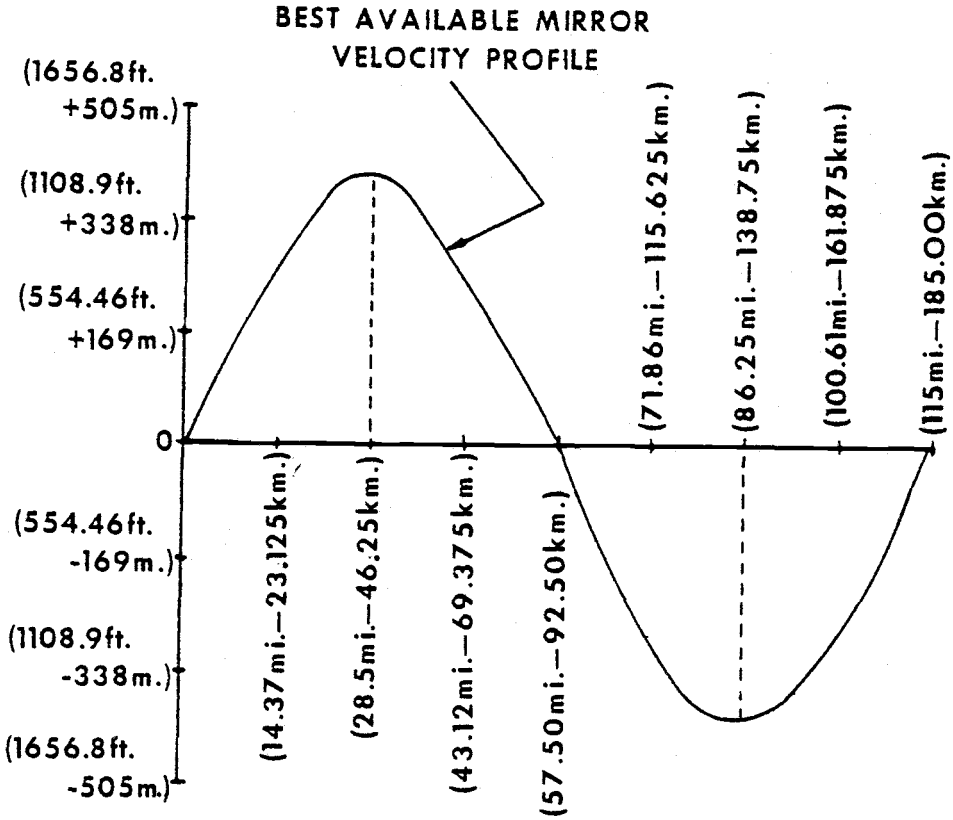


Figure 15. Mirror velocity profile for the active MSS mirror scan. Adapted from Thomas (1975).

blanked out by mechanical shutter. Through every other mirror retrace period, MSS detectors of bands 4 through 7 are exposed to a rotating variable wedge optical filter illuminated by an onboard calibration lamp. The alternate mirror-retrace period was saved for thermal sensors of band 8 detectors to be exposed to temperature references in order to secure calibration of band 8. Calibrated data produced in this manner are utilized to perform radiometric correction to the MSS detector signals (NASA, 1976). MSS data are then telemetered to one of the three prime ground stations* in the United States, where they are reprocessed and recorded on magnetic tapes. Physical characteristics of MSS CCTs are described in the following paragraphs.

Landsat MSS Computer Compatible Tapes

Computer Compatible Tapes (CCT) are standard one-half inch polyester base magnetic tapes. Landsat CCT's are available in different formats; nine-track or seven-track and with 800 or 1600 bpi (bits per inch). For Landsat MSS data to be recorded on CCT's, it is necessary to apply radiometric calibration procedures to them.

Radiometric Calibration

* MSS data receiving stations are located at 1) Goldstone, California, 2) NASA Test and Training Facility (NTTF) at GSFC, Maryland, and 3) Fairbanks, Alaska.

Landsat MSS video data are acquired at a real-time rate and recorded on a multi-track recorder called Ampex FR928. The MSS video data are first entered into a system (DPPS) where data are recorded on a high-density tape (HDT) (NASA, 1976; Hilkenbrink, 1978). Information on HDT then provides input to the digital subsystem (DS). At this point, data are either in a compressed (linear) mode, or in a decompressed (non-linear) tape mode. As a result, values of video data vary from 0 to 63 or from 0 to 127 for compressed and decompressed mode respectively. In the decompressed mode, gains and offsets are used to determine the calibrated values of video data. By having the values for gains and offsets in addition to the values of calibrated video data, the user of CCT's may reverse the process from one type of tape mode to the other. After the final decision is made with regard to the preferred tape mode, data are entered into the DS, are reformatted, calibrated, and finally a computer compatible tape is generated (Thomas, 1975).

Computer Compatible Tape Format

Landsat MSS CCT contains four groups of records:

a) ID record which includes scene and frame ID, data, time passed since launch, sequential bands, and Landsat number (1, 2, or

3.

b) Annotation Data Block; a data block which is normally specified at the time of RBV exposure or at the center of MSS scene (frame). This information is in human readable format, and allows user interpretation.

c) Video Data Record; which includes information from all four MSS bands. In order to obtain a video data record, data from all four spectral bands are combined in a process called interleaving. Through this operation two bytes of data from each spectral band are interleaved to produce an eight-byte "group". This group is the smallest unit in interleaved data, and represents the combined video value for the same two points on the ground. Figure 16 depicts the schematic presentation of the interleaving process of the four bands for video data of Landsat MSS bands.

d) Special Image Annotation Tape Data File (SIAT). This data file consists of seven files including: SIAT logical tape header, Processing Information Data, Spacecraft and Sensor Performance Data, Annotation Block Data file, RBV Computational Data, MSS Computational Data, and Image Location Data (Thomas, 1975).

Considering the scope of this study, it is believed that the foregoing brief discussion on the subject of CCT's has made basic information available for the reader. It is suggested that for more information, interested readers refer to a detailed publication on the

Interleaving of LANDSAT Data

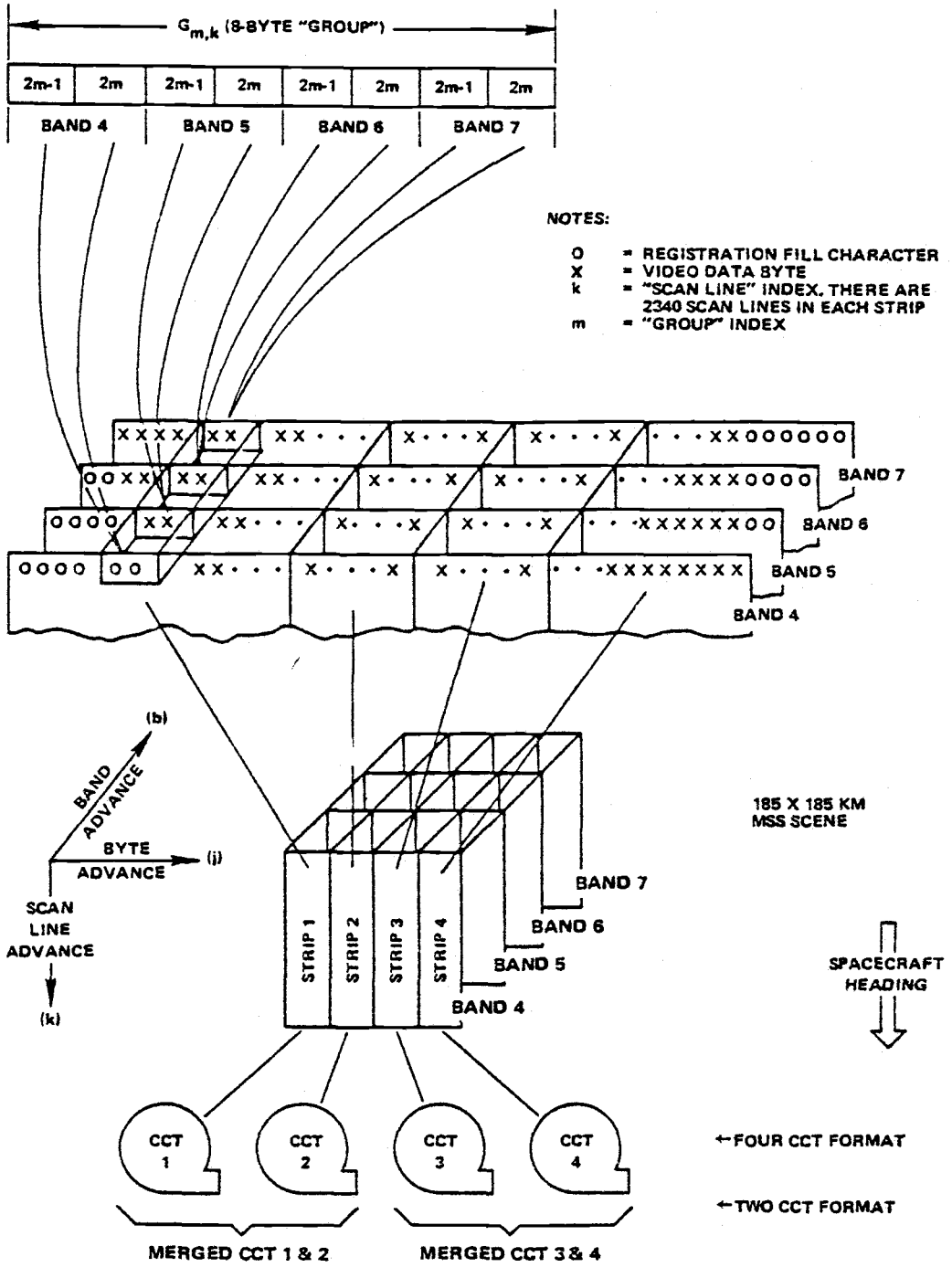


Figure 16. Adapted from Thomas (1975).

subject by Valerie L. Thomas (1975), and Landsat Data Users Handbook, by NASA (1976).

Chapter Summary

In the first section of this chapter, reconnaissance and operational characteristics of NASA Landsat satellites have been described. Physical characteristics of Landsat MSS computer compatible tapes and their generating procedure have been briefly examined in the second section of the chapter.

At this point it is necessary to consider some of the major problems which users encounter in Landsat MSS data classification procedures. Therefore, the forthcoming chapter is devoted to MSS digital data classification limitations and pixel problems.

CHAPTER 4. LANDSAT CLASSIFICATION LIMITATIONS AND PIXEL PROBLEMS

Electromagnetic Radiation

Electromagnetic radiation is the source of energy essential for generation of remotely sensed data. The wavelengths of the electromagnetic spectrum range from long (more than 100 Km) with very low frequency waves to very short (less than 0.01 Angstrom) with extremely high frequency waves. Only a small portion of the electromagnetic spectrum is within visible range (from 0.4 to 0.7 micrometers) where solar radiation is perceived as visible light waves. The sun, the main source of radiant energy, radiates electromagnetic energy at all wavelengths of the electromagnetic spectrum. This energy travels at the speed of light (300,000 Km/sec). When radiant energy from the sun strikes an object, one or more of the following interactions may result. The radiant energy may be reflected, absorbed, transmitted, or re-emitted.

In remote sensing of the environment by Landsat satellites 1 and 2 only reflected energy is involved. The amount of reflected energy from any given object depends upon the reflectivity of that object.

Spectral Reflectance

Different surface and cover types have varying spectral reflectivity.

In forested regions, five basic criteria affect reflectivity: 1) surface cover type, 2) tree crown size, 3) tree crown density, 4) slope angle, 5) slope aspect. Variations in spectral reflectances of various surface cover types occur not only in accordance with their physical or reflective characteristics, but those variations also are due to the angle of incident energy, wavelength of reflectance, angle of viewing (in the case of Landsat remote sensing, and location of the satellite). Studies by Coulson et al. (1969), have indicated that there is a strong control on the factors mentioned above by the intensity and degree of polarization of the reflected radiation. As a general rule, brighter surface cover types reflect higher percentages of incident energy. As an example, among minerals, quartz, a very bright mineral, reflects 93% of the incident energy on the average, while biotite, being the darkest mineral reflects only 7% of the incident energy (Table 5; Janza, 1975). Table 5 depicts reflectance characteristics of selected minerals and desert vegetation. Reflectance values of minerals in Table 5 is given in visible range of electromagnetic spectrum. Minerals presented in Table 5 show pronounced differences in reflectivity within different regions of the visible spectrum. Although, during short seasonal periods (a week or two) reflectance characteristics of surface materials do not vary and therefore Landsat data acquired within short periods of time should be acceptable, the Landsat data user should consider the stability of important target

Reflectance Of Selected Minerals And
Desert Vegetations

	Reflectance %		
	Spectral Regions		
	Wavelength		
Substance	0.43 -0.49	0.51 - 0.59	0.61 - 0.69
MicroCline	61.4	71.7	80.7
Garnet	11.0	18.3	30.3
Epidote	18.6	34.7	36.5
Meadow Chesnut Soil*	8.5	11.7	13.6
Crested Wheat Grass*	3.9	5.8	7.5
Biotite	7.4	7.4	7.4
Meadow Chesnut Soil**	12.4	15.8	19.0
Salt-tolerating Couch Grass**	7.0	10.0	12.4
Quartz	92.9	93.0	93.5

* Over fresh ground water

** Over saline ground water

Table 5. Adopted from Janza (1975)

aspects such as plant phenology, soil moisture, and water turbidity (Dana, 1975).

Variations in reflectivity of surface cover within spectral bands such as those shown in Table 5, aid remote sensing specialists in the interpretation surface cover types from Landsat MSS data. In other words, the Landsat MSS system separates the detected portion of electromagnetic spectrum into a number of different bands so that a unique signature may be obtained for different surface and cover types. Nevertheless, reflectivity values of some earth materials in different spectral ranges have the same or very close values (see Table 5 for quartz and biotite).

Within the range of the electromagnetic spectrum detectable by MSS scanning systems at the present time, three kinds of vegetational information can be obtained from MSS data: 1) variation in pigmentation, which can be detected in visible bands 4 through 7, 2) structural differences in spongy mesophyll of vegetation which are indirectly detectable in near-infrared regions (0.8 - 1.0 micrometers), and 3) moisture stress which is best observed in far solar reflected infrared regions between 1.6 and 2.6 microns (Stanley, 1974).

Atmospheric Attenuation of Solar Radiation

In general, atmospheric effects upon solar radiation include fixed and variable attenuation factors. The fixed effects are due to

molecular absorption, while variable effects are caused by local weather conditions. Due to vertical components of the atmospheric gaseous envelope, attenuation is greatest at low-elevation solar angle, where solar radiation has to traverse longer and denser path in the atmosphere before it reaches the earth's surface. Oppositely, at high-elevation solar angles, radiation is less attenuated due to shorter traverse through denser atmosphere (Beckman, 1975).

With regard to atmospheric effect, the electromagnetic spectrum can be divided into three spectral bands.

1. Visible and near visible band with wavelengths from 0.29-0.75 micrometer. This band is influenced very strongly by scattering processes of the atmosphere.

2. Near-infrared band which extends from 0.75-22 micrometers. Scattering and absorption processes are still significant in this band.

3. Microwave infrared band: this band extends from 0.1 cm. to 30 meter wavelengths. Scattering or absorption processes are absent in this band (Fraser, 1969). This is due to the fact that in microwave region cloud particles and water droplets are very small in comparison to dimensional wavelength (Janza, 1975).

Landsat MSS data are acquired within the 0.5-1.1 micrometer range of electromagnetic spectrum. This wavelength range includes part of visible spectrum (0.5-0.7 micrometer) and a portion of near-infrared region (0.7-1.1 micrometers). As a result all of the spectral range detectable by Landsat MSS system is affected by scattering and absorption processes of the atmosphere.

Atmospheric Scattering and Absorption

Atmospheric effects on radiated and reflected energy are the results of various complex interactions. They consist of scatter and absorption processes of electromagnetic radiation by atmospheric particles. These particles vary in size and type from gas molecules, to aerosols and vapor, up to water droplets (Lillesand and Stevense, 1974).

Scattering has serious effects on the quality of Landsat MSS data. By scattering incoming radiant energy in unpredictable directions, atmospheric particles reduce the intensity of solar radiation reaching earth's surface and cover types. Reflected energy from the earth's surface and cover types on its way to Landsat sensors, encounters various atmospheric gasses or water molecules. As a result atmospheric scattering affects present a serious problem with regard to the accuracy of remotely sensed MSS data.

Atmospheric dust particles and water molecules scatter solar

radiation through four types of scatter: Rayleigh Scatter, Mie Scatter, Non-Selective Scatter and Raman Scatter, although the latter is less important than the others.

As well as being scattered, solar radiation is absorbed by the atmosphere. Radiant energy in a specific wavelength absorbed by atmospheric particles or water molecules, is re-emitted in longer wavelengths (Nunnally, 1973). As a result, the amount of energy reaching the earth's surface in that particular wavelength is somewhat smaller than the actual amount of radiant energy in that specific wavelength. This in turn will result in smaller values of reflected energy from earth's surface cover detected by Landsat MSS bands. Summarizing: atmospheric interaction and attenuation processes affect the values of Landsat MSS data in two ways: by alteration of incoming solar radiation and by reducing the amount of outgoing reflected energy from various earth's surface and cover types.

Furthermore, atmospheric attenuation processes result in reflected energy from atmospheric particles. If such reflected energy is in the same wavelength as MSS detector, and within appropriate direction with respect to the Landsat sensor, it will be in addition to the amount of reflected energy from the cover type below. Such reflection detected by Landsat MSS system will present the cover type as much brighter than its actual reflectance characteristics and

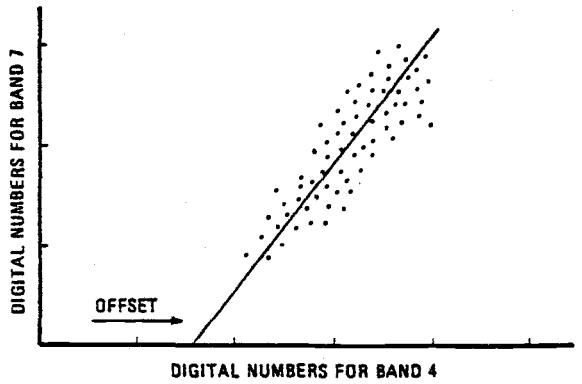
can result in misinterpretation and misclassification of Landsat data.

As it was mentioned earlier, atmospheric scattering and absorption processes occur only in shorter wavelengths. Therefore, Landsat MSS data acquired in band 7 (0.8-1.1 micrometer) is relatively free of atmospheric attenuation (Fraser, 1969 and Sabins, 1978).

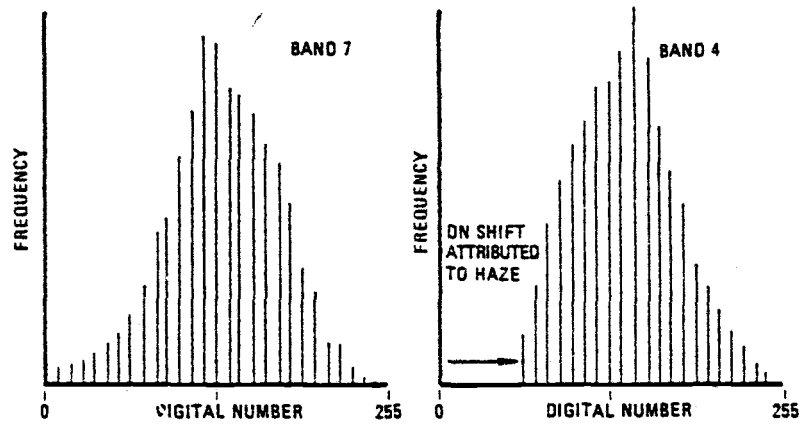
Atmospheric Correction

Atmospheric scattering effect is detected and corrected in two ways: one is a process in which an area within Landsat image which has shadowed area caused by irregular topography is selected, and its band 4 digital values for each pixel is plotted against digital values of band 7 for the same pixels. Using a least square technique a straight line is fitted through the plot (Figure 17-A). If there was no scattering (haze) effect in band 4, the fitted line would pass through origin, and the line would be offset in the band 4 axis. If haze effect was present, its amount would have an additive effect on scene brightness and hence the line would be even more offset. By determining this additive effect, its value is subtracted from digital values of band 4 throughout the Landsat scene. The same technique is also applied to bands 5 and 6. The second correction technique is accomplished by passing the MSS data through computer and generating histograms for digital values of bands 7 and 4. As presented in the Figure 17-B, that histogram of band 4 lacks zero

Atmospheric Correction Methods On LANDSAT MSS Bands



A. PLOT OF BAND 7 VERSUS BAND 4 FOR AN AREA WITHIN THE IMAGE THAT HAS SHADOWS. OFFSET OF THE LINE OF LEAST-SQUARES FIT ALONG THE BAND 4 AXIS IS ATTRIBUTED TO ATMOSPHERIC SCATTERING IN THAT BAND.



B. HISTOGRAMS FOR BANDS 7 AND 4. THE LACK OF LOW DN'S ON BAND 4 IS CAUSED BY ILLUMINATION FROM LIGHT SCATTERED BY THE ATMOSPHERE (HAZE).

Figure 17. Adapted from Sabins (1978).

values. This histogram also shows that because of additive atmospheric (haze) scattering effect its peak is offset toward higher digital values. The other feature of the band 4 histogram in Figure 17-B is its abrupt increase in pixel frequency on the left side of the histogram. Sabins (1978) suggests that this abrupt change is caused by illumination from light scattered by atmospheric particles. To correct MSS data in band 4 this abrupt-increase value is subtracted from the entire data sample of band 4. The same technique is then applied to MSS data in bands 5 and 6. A problem may arise with this correction technique. If the Landsat scene lacks steep terrain no pixels in band 7 could exist with zero values (Sabins, 1978).

Pixel Problems

The Landsat photoelectric MSS detector system has been designed in such a manner that in any one instant it surveys very small area on the ground. This photoelectric sensor system then rotates and surveys another small area (79 x 79 meters or a pixel area) at each successive instant on the ground (Grabau, 1976). This is illustrated in Figure 18. The component of a Landsat scene was briefly described in chapter 3. It was also mentioned that a scan line is a composition of 3000-3450 successive pixels, and that a Landsat scene constitutes 2340 scan lines.

Commonly, an area scanned by a Landsat spacecraft comprises a mixture of various surface and cover types or classes (Figure 18). Many of these classes are sometimes too small compared to the resolution of Landsat MSS system (pixel). Furthermore, in case of larger homogenous surface cover types, areas such as large water bodies, dense forest, ... the natural region is not likely to be divisible into a number of 79 x 79 meters (1.118 acres) pixel areas. As has been depicted in Figure 18, although the cover types are larger than individual pixels, there are still boundary pixels (pixels designated A, B, and C in the upper right corner diagram in Figure 18) which do not represent reflectance characteristics of any one surface cover type in the scanned area. For this reason some pixel signatures acquired by Landsat MSS system represent surface

Concept of an Airborn Scanner

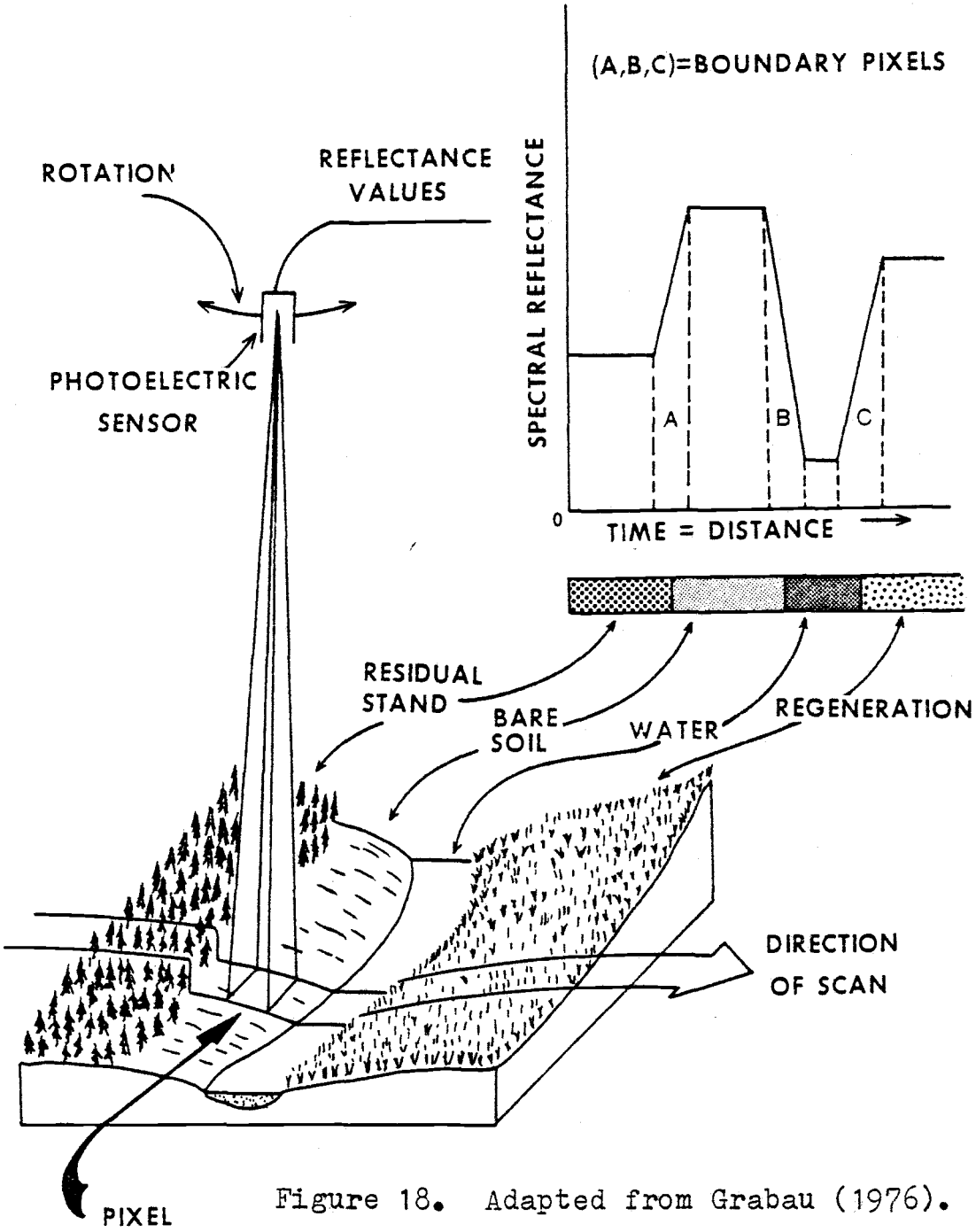


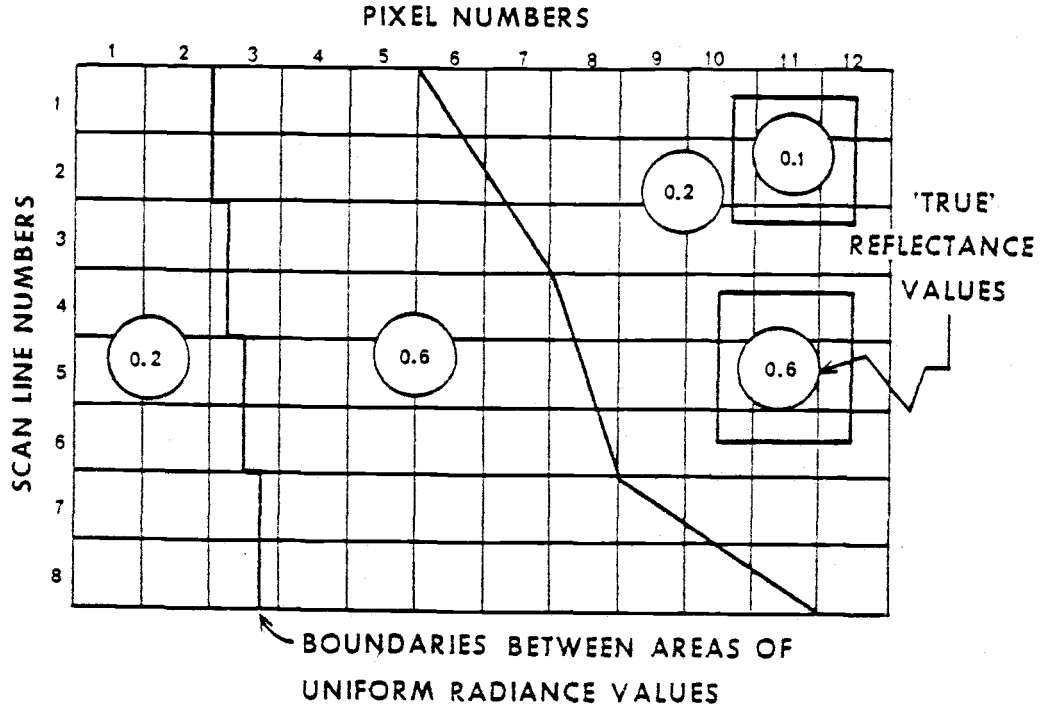
Figure 18. Adapted from Grabau (1976).

characteristics of two or more non-homogeneous contiguous elements. Even within a single surface or cover type or class there may be spectral differences arising from pixel size variations (described in chapter 3).

Attempts have been made to compile ground control maps with regard to mixture pixel spectral reflectances by on-site measurements of boundary pixel reflectance values from differing contiguous cover type boundaries. These studies aimed to provide a key map in order to classify Landsat MSS data in accordance with on-site (ground truth) data. The findings of these studies also suggest that mixture (or boundary) pixels' spectral reflectances do not represent any characteristics of the component classes of the terrain surveyed on-site or scanned by the Landsat scanner (Smedes et al., 1975). Such studies also indicated that using on-site reflectance measurement information of boundary pixels will increase the quality of information extracted through conventional data analysis. However, due to the difficulties in estimating mixture proportions of boundary pixels from "ground truth" data, such studies fail to analyze the accuracy of this method quantitatively.

One of the most serious problems in MSS data interpretation is due to the characteristics of pixel arrays. Pixel array characteristics alter the apparent nature, position, and shape of the boundaries of different surface cover types. Figure 19 illustrates this phenomenon. Each square in this figure represents a pixel area. The top section of

Loss of Boundary Resolution and Position



PIXELS

SCAN LINE NUMBERS

	1	2	3	4	5	6	7	8	9	10	11	12
1	0.2	0.2	0.6	0.6	0.6	0.33	0.2	0.2	0.2	0.19	0.18	0.19
2	0.2	0.2	0.6	0.6	0.6	0.57	0.23	0.2	0.2	0.18	0.10	0.18
3	0.2	0.2	0.5	0.6	0.6	0.6	0.47	0.2	0.2	0.19	0.18	0.19
4	0.2	0.2	0.5	0.6	0.6	0.6	0.6	0.27	0.2	0.30	0.40	0.30
5	0.2	0.2	0.4	0.6	0.6	0.6	0.6	0.4	0.2	0.4	0.6	0.4
6	0.2	0.2	0.4	0.6	0.6	0.6	0.6	0.53	0.2	0.35	0.45	0.35
7	0.2	0.2	0.35	0.6	0.6	0.6	0.6	0.6	0.47	0.23	0.2	0.2
8	0.2	0.2	0.3	0.6	0.6	0.6	0.3	0.6	0.6	0.57	0.33	0.2

Figure 19. Adapted from Grabau (1976).

Figure 19 shows areas of example uniform reflective values, and the bottom figure represents reflective values of the same areas as calculated for every pixel. Close attention to Figure 19 reveals that values of the pixels located at the boundaries of two non-homogeneous classes do not represent any of the component cover types. Furthermore, it is indicated that the boundaries between two large classes have not been delineated sharply but the transitions have been gradational. As a result the boundaries have lost their original locations, so that it would be impossible to locate their original locations from digital values represented in the bottom section of Figure 19. In this regard one other study has been conducted by Smedes, et al. (1975). Figure 20 illustrates spectral reflectance values of two different surface cover types. Extracted from Landsat digital data, "A" represents grassland class, "B" represents reflectance curve for a dense forest type, and "C" is a 50-50 mixture of two classes. Curve "C" in Figure 20 illustrates the mathematical means of spectral reflectance values of two classes "A", and "B". However, spectral response for mixture (boundary), class "C" is quite uncharacteristic of either two classes "A" or "B". Nevertheless, its curve falls between its two component curves.

Shape and size changes of surface and cover types are still other important phenomena in misclassification of Landsat MSS data, as illustrated in Figure 21. For convenience, two relatively large

Spectral Reflectance of Two Pixel Component Surface Cover Types

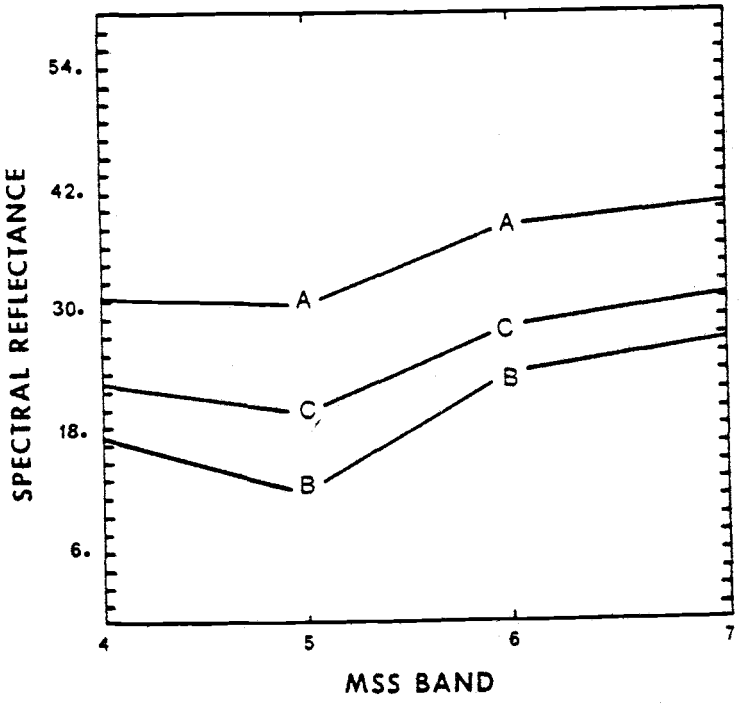
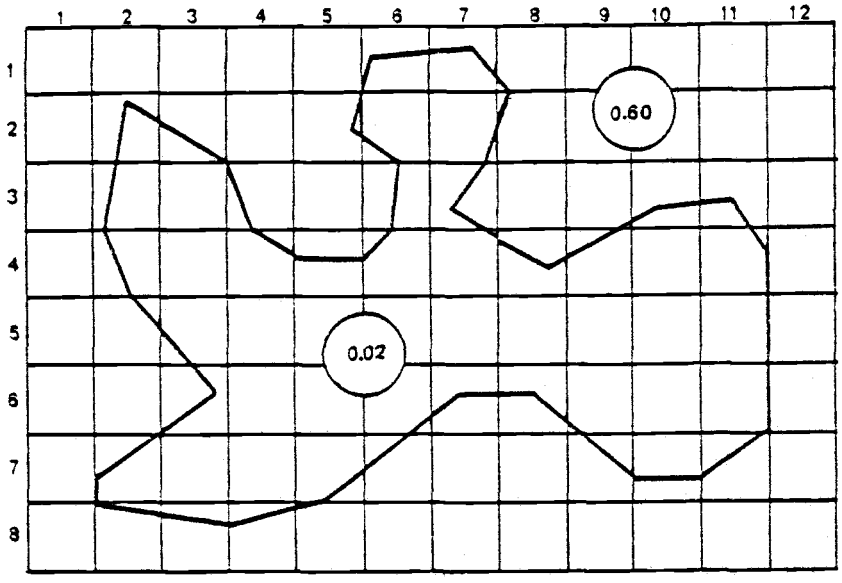


Figure 20: "C" is the mixture of surface cover types "A" and "B." By obtaining the reflectance of "A" and/or "B," "C" is not necessarily obtained. Adapted from Smedes, et al. (1975)

Shape and Size Changes of Surface Cover Types



'TRUE' AREA = 38.5 UNITS (1 PIXEL = 1 UNIT OF AREA)

a. MAP OF SURFACE COVER TYPE

	1	2	3	4	5	6	7	8	9	10	11	12
1	0.60	0.60	0.60	0.60	0.60	0.26	0.26	0.59	0.60	0.60	0.60	0.60
2	0.60	0.34	0.43	0.60	0.57	0.06	0.04	0.57	0.60	0.60	0.60	0.60
3	0.60	0.18	0.02	0.50	0.60	0.31	0.30	0.60	0.59	0.43	0.47	0.60
4	0.60	0.24	0.02	0.05	0.25	0.07	0.04	0.27	0.11	0.02	0.13	0.60
5	0.60	0.53	0.09	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.08	0.60
6	0.60	0.60	0.29	0.02	0.02	0.05	0.33	0.31	0.03	0.02	0.03	0.60
7	0.60	0.21	0.02	0.02	0.50	0.60	0.60	0.60	0.46	0.22	0.43	0.60
8	0.60	0.56	0.47	0.48	0.59	0.60	0.60	0.60	0.60	0.60	0.60	0.60

= CLASSIFIED SURFACE COVER TYPE = 28 UNITS (RADIANCE ≤ 0.15) b. PIXEL CHARACTERIZATION OF SURFACE COVER TYPE USING REFLECTANCE VALUE CUTOFF VALUE OF 0.15 ('TIGHT STATISTICS')

Figure 21. Adapted from Grabau (1976).

homogeneous areas of water and land have been chosen in this figure. With spectral reflectance values of 0.02 for water, and 0.6 for the land, an attempt has been made to separate those two cover types. By setting density slicing or reflectance cutoff value at 0.15, we assume every pixel with reflectance value of 0.15 or less will be classified as water, and that all pixels higher than 0.15 should be classified as land area. Although it seems reasonable that such an arrangement will result in accurate separation of those two cover type classes, in practice the outcome is not so promising. Figure 21-B shows the reflectance values of two classes of water and land arrayed in the same manner as in Figure 21-A. As it has been presented in Figure 21-B, the lake area includes only 28 units (pixels) versus its original (true) 38.5 units (pixels) land coverage as shown in Figure 21-A. As a result, such a classification procedure not only has reduced the size of the lake substantially (from 38.5 to 28 or more than a quarter), but it has also changed the shape of the lake. By increasing the cutoff or threshold value of water cover type to 0.30 in this example, it is possible to increase water cover type class depicted in Figure 21-B by 10 units (pixels) or almost equal to its true size in Figure 21-A. However, the shape change of the lake will remain a problem regardless of what cutoff value is applied. Furthermore, if there were another class with spectral reflectance value of 0.25 in the same area, a raise in threshold or cutoff value from

0.15 to 0.30 would be practically impossible since it would have classified this third class also as water area (Grabau, 1967). This in turn raises the problem called "over estimation" in MSS data classification. In our example it would have indicated "over estimation" of the lake area. Ground control (or "ground truth") is a tool which assists in the improvement of such classification.

Finally, it should be noted that interpretation of Landsat imagery made up with arrays of pixels and scan lines has to be conducted with special care, patience, and full understanding of the mechanisms of the processes involved in generation of those imageries so that misinterpretation and spurious classification is avoided.

Chapter Summary

This chapter included three related topics, which were treated in the following manner:

1. Characteristics of electromagnetic radiation was discussed in the first section of the chapter. Under this topic spectral reflectance peculiarities of several natural phenomena were studied.

2. Discussion of atmospheric effects on Landsat MSS data was included in the second section of the chapter.

3. Major pixel problems were briefly studied in the last section of the chapter. It was concluded that misclassifications in Landsat MSS data occur unless mechanisms and physical characteristics of the generation processes of Landsat imageries are fully understood.

The forthcoming chapter (Chapter 5), will discuss "Data Acquisition Techniques." The chapter will include field data acquisition strategy as related to fuel moisture content, and downed fuel inventory within Crater Lake National Park.

CHAPTER 5. DIGITAL DATA ACQUISITION AND FIELD OBSERVATION STRATEGY

This chapter focuses on the processes involved in the acquisition of various data which were utilized in this study. Acquired data included both: 1) digitized computer compatable tapes, and 2) conventional data acquired during field observation within Crater Lake National Park.

Landsat MSS Data Acquisition

As discussed in Chapter 3, onboard Landsat spacecraft are multi-spectral scanner (MSS) systems, which sense spectral reflectance characteristics of the scanned area on the earth's surface as video data. Video data then, after necessary processes in Landsat data receiving stations, are recorded on CCT's as digital data. Such data have been utilized in this study as a primary tool in classification and analysis of surface cover types within Crater Lake National Park.

Landsat MSS data employed in this study were acquired by Landsat 2 during the Crater Lake National Park over-pass on September 10, 1974. These CCT's along with three other MSS digital tapes acquired through different seasons of the years 1973 and 1974 are owned by Dr. James F. Lahey of Dept. of Geography at Oregon State University. In the choice of selecting the September 10, 1974

CCT, aside from the fact that it has curtailed data acquisition cost, the following criteria have been considered:

1) This tape series were free of bad scan lines.

2) Data were acquired during high-elevation solar angle over the study area located at 42° N. latitude.

3) According to weather reports, September 10, 1974 was a cloud-free day over the Crater Lake National Park region. This cloud-free condition, together with high-elevation solar angle had reduced atmospheric attenuation effects on the acquired data.

4) During this time of the year (September 10, 1974), the ground is practically free of snow within this National Park. This condition facilitates the interpretation processes of reflectance characteristics of surface cover types within the Park and hence increases the accuracy of cover type classification.

Digital Terrain Data

Topographic elements of a surface have powerful control over vegetation. Field observation within Crater Lake National Park indicated that variation in dominant forest types within the Park is a function of elevation (Chapter 2). For this reason, it was believed that accurate information on topographic characteristics of the study area would improve the quality of classification of digital Landsat MSS data of surface or cover types within this National Park.

Digital Terrain Data Acquisition

NCIC digital terrain data for this study were obtained from National Cartographic Information Center (NCIC), in Reston, VA. NCIC terrain data are recorded on multifile 9-track, 1600 bpi (bits per inch) tapes. These tapes are computer compatible magnetic tapes. Each tape covers about one half of a 1:250,000 scale USGS topographic map and Crater Lake National Park occupies portions of four such topographic maps. For this reason NCIC terrain data tapes utilized in this research cover four contiguous one half portions of 1/250,000 scale USGS topographic maps for the following geographic regions:

a. East one half portion of Roseburg quadrangle

b. West one half portion of Crescent quadrangle

c. West one half portion of Klamath Falls quadrangle

d. East one half portion of Medford quadrangle

NCIC terrain data contains digital information on elevation at about 208-foot horizontal intervals.

NCIC digital terrain files are arranged in a horizontal grid system for a given area with successive grid points, as mentioned above, 208 feet (63 meters) apart, south to north (Y coordinate) and west to east (X coordinate). The values are given for the Southwest corners of the grid mesh rather than for the areas covered by 208 feet square. From these data the digital topographic maps, the digital slope and aspect maps were created.

Color Infrared Aerial Photography

Infrared photography is acquired within two different bands of electromagnetic spectrum. Near infrared or shorter infrared band which expands from 0.51-0.9 micrometers. Near infrared photography can be imaged directly on photographic film. For this reason, the shorter or near infrared region of electromagnetic spectrum sometimes is called "photographic infrared".

Color infrared aerial photography has shown to be advantageous over conventional color photography from two major points of view. The first is due to lesser atmospheric scattering characteristics, which is relatively high in visible spectral band and low in infrared wavelength of electromagnetic spectrum (also see Chapter 4). The second factor is that variable vegetation spectral reflectances, uniformly low in the visible portion of electromagnetic spectrum, sometimes sharply increases and is more variable from one vegetation species to another in the near infrared and infrared bandwidths of electromagnetic spectrum. Atmospheric scattering intensity and vegetation reflectance characteristics with regard to different spectral wavelengths have been presented by Figures 22-A and 22-B respectively. Normal color film is sensitive to blue, green and red portion of electromagnetic spectrum, while color infrared film is sensitive also to near infrared (0.7 to 0.9 micrometers) spectrum of electromagnetic radiation. As a result, by using a yellow filter

Atmospheric Attenuation In Normal And Color IR Photography

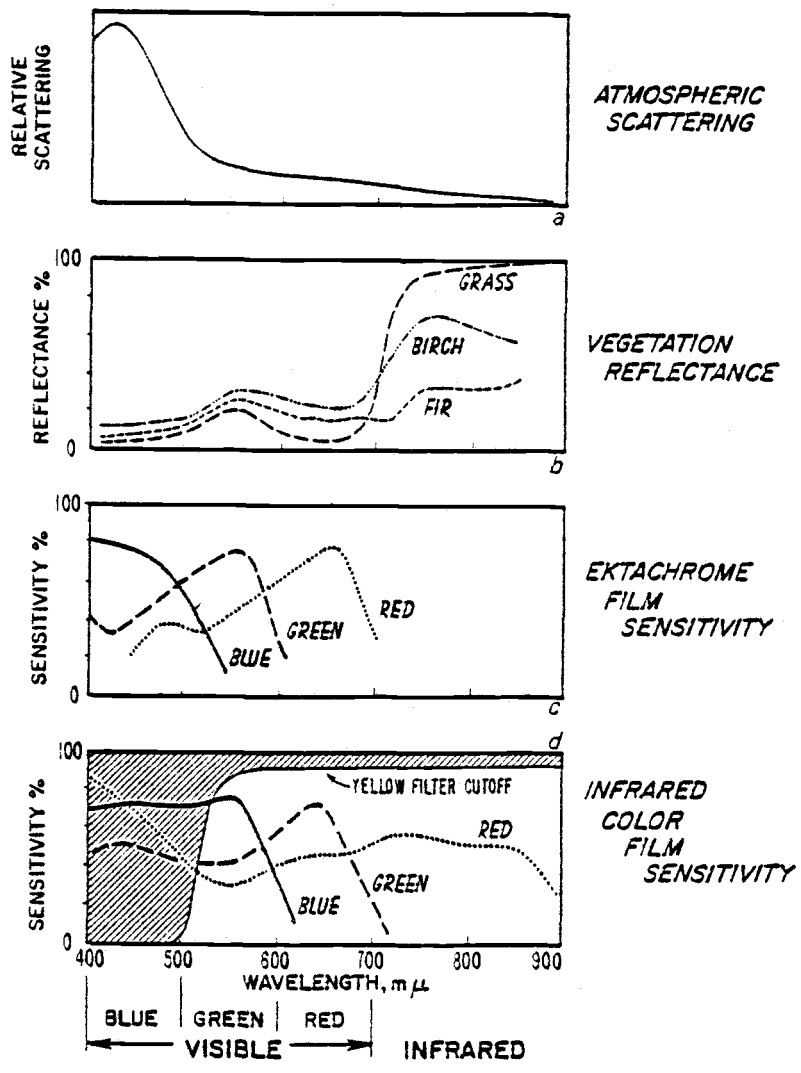


Figure 22. Adapted from Sabins (1973b).

(minus blue), color infrared film can eliminate reflected blue energy together with most of atmospheric scattering and hence enhance vegetation differences (Sabins, 1973b). Principal advantages of the sensitivity of color infrared film over the sensitivity of Ektachrome (normal color) film, have been depicted on Figures 22-C and 22-D.

Color infrared film, when used with a yellow filter, will cause any object that reflects infrared energy to appear red on final photographic reproduction, and objects that reflect red and green energy will appear green and blue respectively. For this reason color infrared film or photographs sometimes are also called "false color" film or "false color" infrared images (Estes, 1975).

Acquisition of Color Infrared Photography

Color infrared photographs utilized in this research were obtained from NASA/Ames Research Center, Moffett Field, California. These images were taken by a NASA U-2 High altitude aircraft from approximately 65,000 feet over Crater Lake National Park on July 3, 1974 and on August 10, 1976. These photographs were acquired within wavelengths of 0.51-0.90 micrometers (NASA/Ames, 1977). Our color IR photographs were in four different scales as follows:

a) 1:122,000 (1 inch = 1.93 miles and 1 cm = 1.22 km)

b) 1:30,500 (1 inch = 0.48 mile and 1 cm = 0.304 km)

c) 1:30,000 (1 inch = 0.47 mile and 1 cm = 0.299 km)

d) 1:7,400 (1 inch = 600 feet and 1 cm = 72.09 m), these photographs were enlargements of the 1:30,500 scale photographs.

Color IR aerial photographs with a scale of 1:30,500 furnish partial coverage of the Park. These photographs combined with enlargements of 1:122,000 scale photographs to 1:30,000 scale provide complete coverage of Crater Lake National Park for the years of 1974 and 1976. Enlargements of the 1:122,000 scale photographs to 1:30,500 scale was done by the EROS Data Center at Sioux Falls, South Dakota.

In locating either fuel moisture study sites (FMIS's) or downed fuel inventorying areas (DFSA's) within the Park, all four different scales of U-2 color infrared photographs along with a U.S. Geological Survey's 1:62,500 scale topographic map of the Park were jointly manipulated.

Field Data Acquisition Techniques

Field data acquisition for this study included two concurrent sets of field observations. One set of field observations was conducted to make an estimation of downed fuel moisture content during the summer months within Crater Lake National Park. The other set of field observations gave an evaluation of the biomass of downed fuel available for wild fires under the forested areas within Crater Lake National Park.

Downed Fuels Available for Wildfires and Environmental Moistures Associated with These Downed Fuels

Solar insolation is an important factor with regard to wild-fire generation within forested regions of the world. Insolation on surfaces exposed at right angle to the sun's radiation is about 5 BTU's per square foot per minute (British Columbia Forest Service, 1955). Some of this energy, of course, is returned from the exposed surface as reflected or emitted energy, while the rest of it is absorbed and conducted from the exposed surface. A portion of this energy warms up the immediate lower layer of the atmosphere. In forested regions some of the absorbed energy is used to dry out the top layers of the woody materials while the rest remains available to heat the forest vegetation. Since increased temperatures near the surface reduce relative humidity, dead fuel present in that environment

will undergo a similar situation, i. e., it will tend to loose its moisture contents until it approaches a value called "Equilibrium Moisture Content". This depends on the average relative humidity and temperature to which fuel has been exposed over the past several hours (Schroeder and Buck, 1970).

Moisture characteristics of different forest fuels vary significantly and such variations are dependent not only on fuel structural differences but also on the size of the fuel. As a general rule, forest fuels with larger diameters have longer timelags to reach equilibrium state with environmental moisture. (Fosberg, 1971).

Canopy characteristics, their varying densities, the fraction of the sky covered by the cloud, the slope and aspect, wind direction and its speed, elevation and time of the year and the day all are variables which play important roles in modulating insolation effectiveness and thus the fuel-moisture component of the environment. With regard to environmental moisture estimate, all factors mentioned had to be considered and evaluated prior to field observation.

Selection of Field Observation Areas for Downed and Dead Fuel Moisture Measurement, and Downed Fuel Inventorying Within Crater Lake National Park

Sample Site Selection Strategy

In July 1978, at the time this project was initiated, the primary

purpose was to utilize Landsat 3 MSS data for analysis of summer months moisture pattern over Crater Lake National Park. Landsat 3, along with its conventional MSS bands of 4, 5, 6, and 7 which operated in the reflected solar spectral region from 0.5 to 1.1 micrometers wavelength, carried a thermal infrared band, Band 8, onboard, which was to be capable of detecting environmental heating and cooling and hence moisture characteristics in scanned areas. Band 8 of Landsat 3 should have operated in the emitted infrared spectral region from 10.4 to 12.6 micrometers wavelength, which coincides with the atmospheric window. Its Band 8 ground resolution was approximately one-third that of the conventional four bands or about 9 acres (Design Specification of Landsat 3, Attachment A-NASA 1976). Therefore, for ground truthing of moisture patterns in our study area, with ground resolution as that of Landsat 3 Band 8, and also considering boundary pixel problems (discussed in Chapter 4), study sites, each with approximately 40 acres of homogeneous Landsat ground coverage, were needed. In an attempt to select for study, sample sites for moisture pattern analysis within dominant forest cover types Crater Lake National Park, alphanumerical values from a digital cover-type map of the Park were utilized (Stephen J. Walsh, 1977). The scale of these maps were approximately equal to that of the U.S. Geological Survey's topographic map for the same area (1/62,500). Also utilized were the 1.1 acre 59 class map of Walsh.

Overlaying transparencies of the foregoing 1:62,500 alphanumerical cover-type map on a USGS topographic map of Crater Lake National Park, intensive study sites were selected with needed 40 acre dimensions. At least six symbols arranged in three arrays and two columns were needed. Such an arrangement, overcoming boundary pixel problems, would yield at least one pure pixel sampled from environmental moisture in the scanned area. Through utilization of large scale U-2 aerial color infrared photographs of the Park, together with the alphanumerical map of the cover-type of the study area twenty-four "acceptable" moisture study areas were delineated within the National Park. Acceptable meant that areas be: 1) individually large enough to be sensed by Landsat 3 thermal band (36-40 acres), 2) to be accessable so that all could be checked in a short period of time during satellite over-pass, 3) well scattered over the Park in order to represent an adequate sampling from different slopes and aspects, and 4) representative of at least one sampling site from every dominant species of different densities within the Park. Each one of the four factors mentioned above, proposed difficulties, and except in few cases it was difficult to fulfill the requirements of all proposed parameters. With information obtained from the alphanumerical map of the park, selected moisture study areas were transferred on a USGS topographical map of Crater Lake National Park. In the field this map was

utilized along with color infrared aerial photographs to locate study sites and establish Fuel-Moisture Indicator Sticks (FMIS). This phase of the research (locating and establishing FMISs within the Park), took place during the period of late June through July 1978. During this period of time we established twenty-four 10-hour time-lag moisture indicator sticks on various locations of the Park (Figure 23). The time-lag principal has been shown to be very useful tool with regard to forest fire danger rating. Time-lag differences for various forest cover types may occur due to structural differences of fuel species or because of surface weathering, rot, exposure and other prevailing physical conditions (Lancaster, 1970).

According to NASA officials, Landsat 3 had been scheduled to pass over the Crater Lake National Park region at about 9:45 A.M. (PST) on July 15, 1978 and at the same local time every subsequent 18th day (August 2nd, August 20th, ...). Moisture data from sample sites were to be collected starting August 2nd 1978, and on every subsequent satellite over-pass of the area during the summer months.

As for the selection of downed fuel inventorying areas within the Park, a similar process as that followed for the fuel moisture detection sites was applied. However, in some restricted cases, the sites were located by on-site selection within the Park with regard to forest cover type homogeneity, and other characteristics.

Locations Of FMISs Within Crater Lake National Park

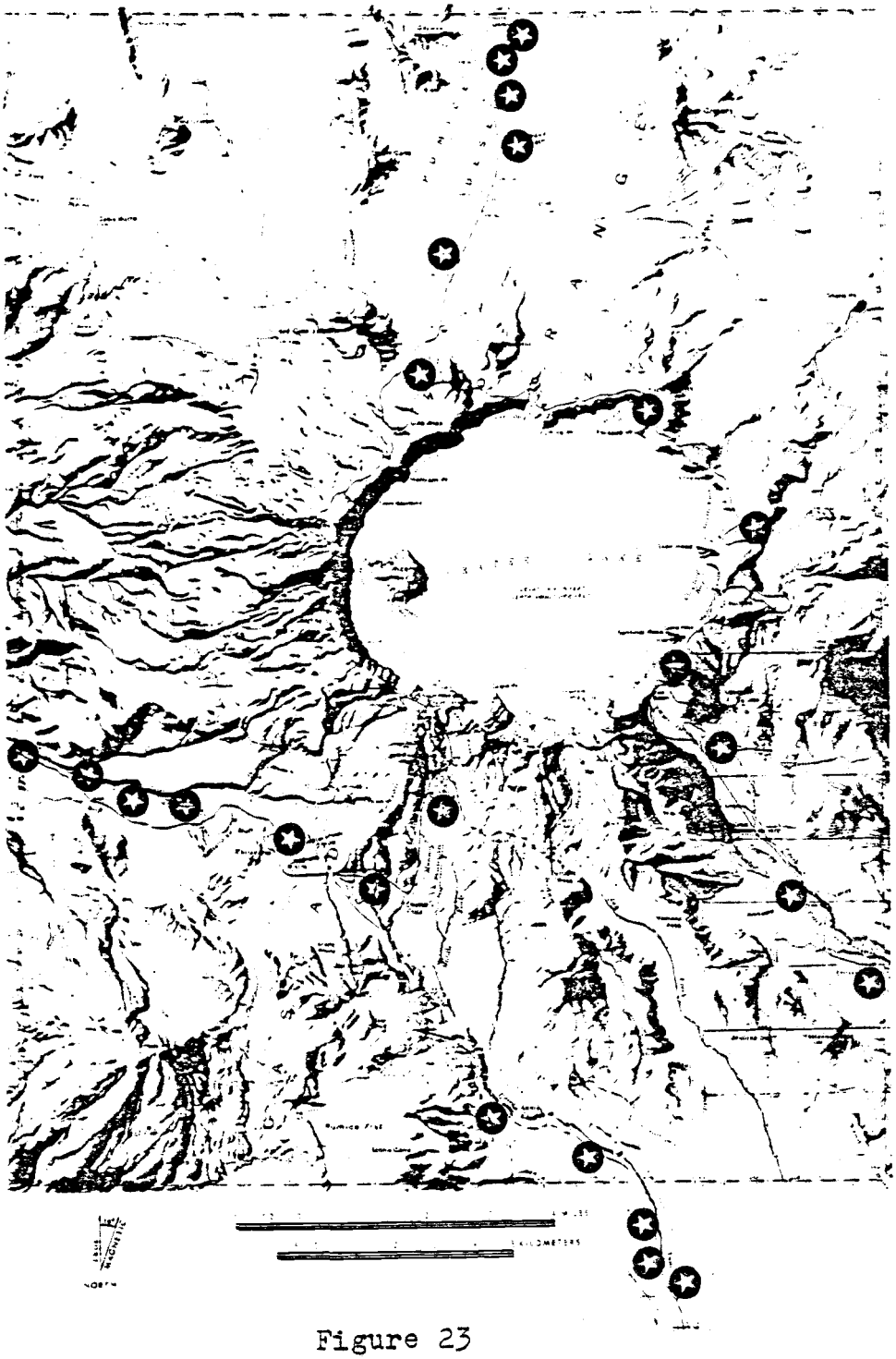


Figure 23

Dead and Downed Fuel Moisture Content Measurement

A practical way of estimating downed fuel moisture content among foresters is through determination of moisture content in Fuel-Moisture Indicator Sticks (FMIS). A set of FMIS consists of four one half an inch ponderosa pine sapwood dowels, each about 20 inches long, spaced 1/4 of an inch apart on two 3/16 inch dowels. The sets are carefully adjusted so that each weighs 100 grams when oven dry (Schroeder and Buck, 1970). In the field, the set is exposed approximately 10 inches above the litter layer or above the soil surface, on two wire brackets pointing toward true north (Figure 24-A). At the time of observation they are weighed by special scale and their moisture content obtained. In our fuel-moisture data acquisition case we used a Chisholm scale which is compact, with easy handling and operating advantages compared to other similar scales. It is a one piece scale with self supporting joints, therefore, unlike other scale types, there is less risk of losing small parts during field observation. Figure 24-B represents FMIS moisture measurements by a Chisholm scale.

It was late July when it was learned that NASA space scientists had encountered problems with the thermal band (Band 8) of Landsat 3. This unofficial knowledge of Landsat 3 thermal band failure was received through a long distance telephone conversation between Dr. James F. Lahey, and Stanley Freden of Goddard Space Flight



Figure 24-A. Fuel Moisture Indicator Stick in the Field.

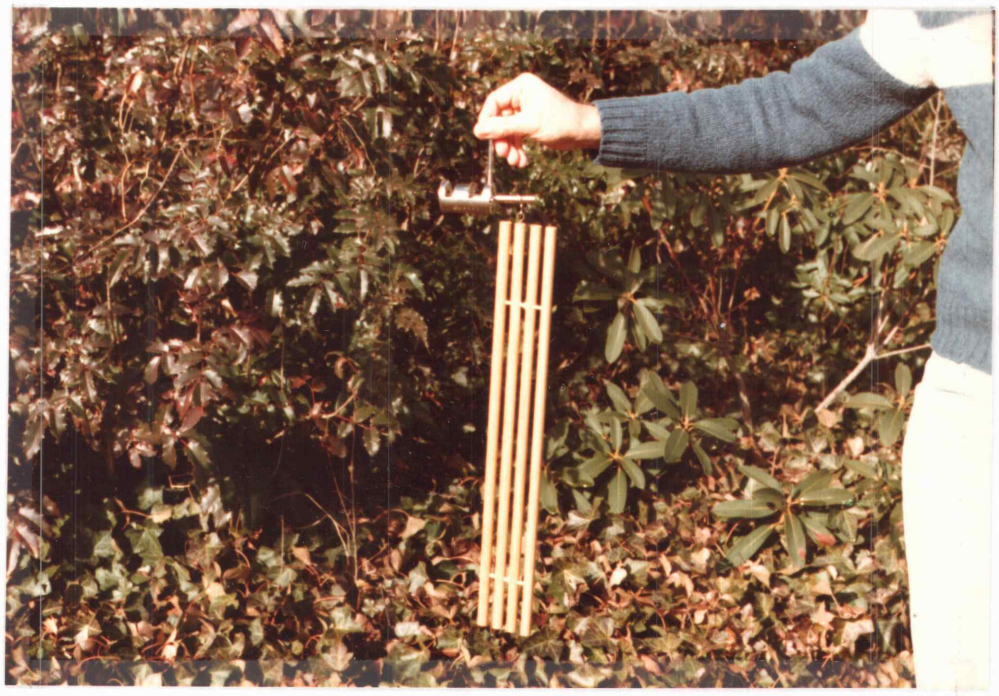


Figure 24-B. Moisture Measurement of FMIS with Chisholm Scale.

Center.

Disappointed with the fact of Landsat 3 malfunction on one hand but having all Fuel-Moisture Indicator Sticks installed over the Park on the other, it was decided nonetheless, to collect ground data. It is believed that such data availability for the first time will provide a source of a general fuel moisture pattern for scattered areas of Crater Lake National Park during this unusually wet summer season of 1978.

As it was mentioned earlier, considering all possibilities, the 24 fuel moisture study sites were selected so that they would represent moisture pattern characteristics of the Park. The locations of FMIS sites were shown earlier in Figure 23. They were located along highways of the National Park as follows:

a. North Entrance - 6 stations,

b. West Entrance (highway 62) - 5 stations,

c. Rim Drive - 3 stations,

d. Pinnacles Road - 3 stations,

e. South Entrance (highway 62 to Park Headquarters) - 7 stations.

The following tabulations (Tables 6 through 9), are the summary descriptions of FMIS sites and their moisture data acquired during summer of 1978 within the Park. Raw data from FMIS presented in the tables have been computed with regard to the period of their

exposure on the field. This computation was made possible by using an appropriate National Fire Danger Rating System (NFDR), nomogram illustrated in Figure 25 (Deeming, Burgan, and Cohen, 1978). As depicted in Figure 25, for example, if a one-month old FMIS indicates 9.5% moisture content, in actuality the moisture content should read 11.5%.

Fuel Moisture Data Analysis

Aside from solar insolation forest fire danger and fire spread depend to a large extent on fuel moisture. Fuel moisture in turn is a function of environmental moisture. In this study, evaluation of environmental moisture was accomplished by 10-hour time-lag FMISs. 10-hour time-lag moisture patterns of the National Park during the summer of 1978 have been graphically represented for locations within the Park as follows:

a. FMISs stationed at North Entrance Road on Figure 26,

b. FMISs stationed at Rim Drive and Pinnacles Road on Figure 27,

c. FMISs stationed at West Entrance Road on Figure 28,

d. FMISs stationed at South Entrance Road on Figure 29.

Figure 30 depicts comparative means of the variations in moisture patterns of the four different localities mentioned above. It should

NFDR 10-Hour Timelag Fuel Moisture Nomogram

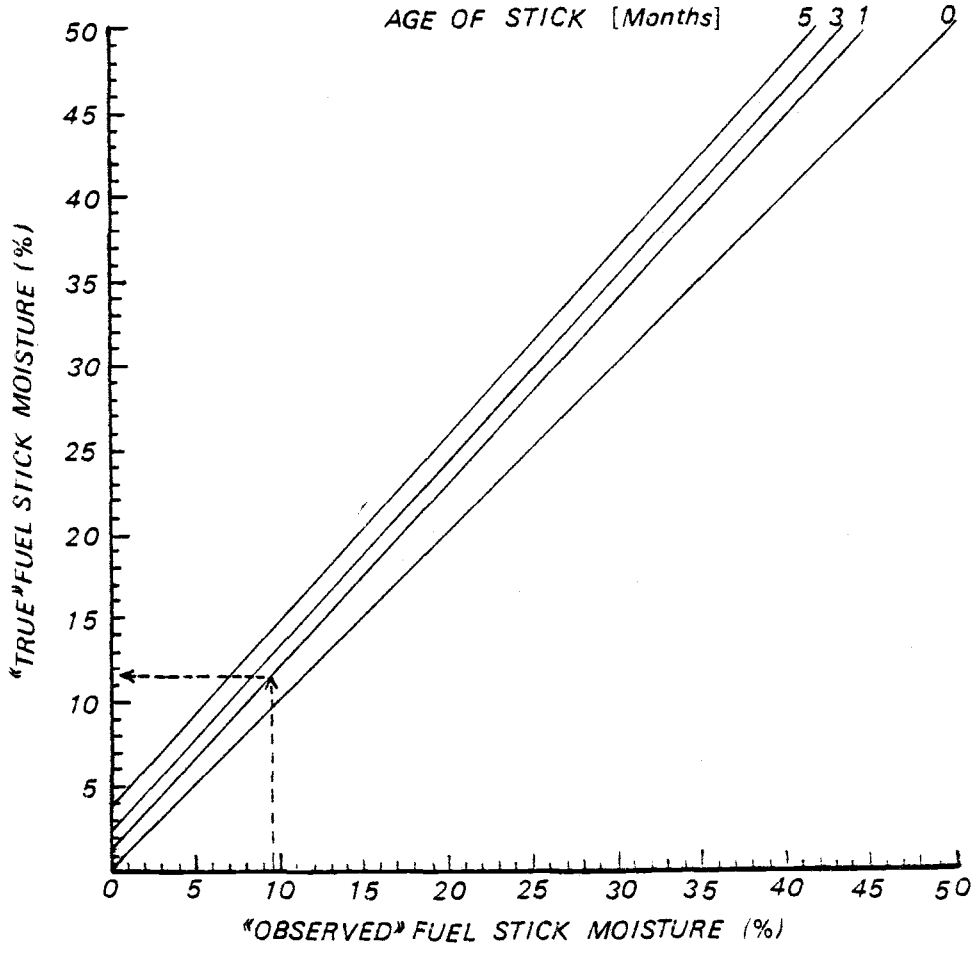


Figure 25. Adapted from Deeming, Burgan, and Cohen (1978).

CLNP 10-Hour Timelag FMIS Moisture Content (North)

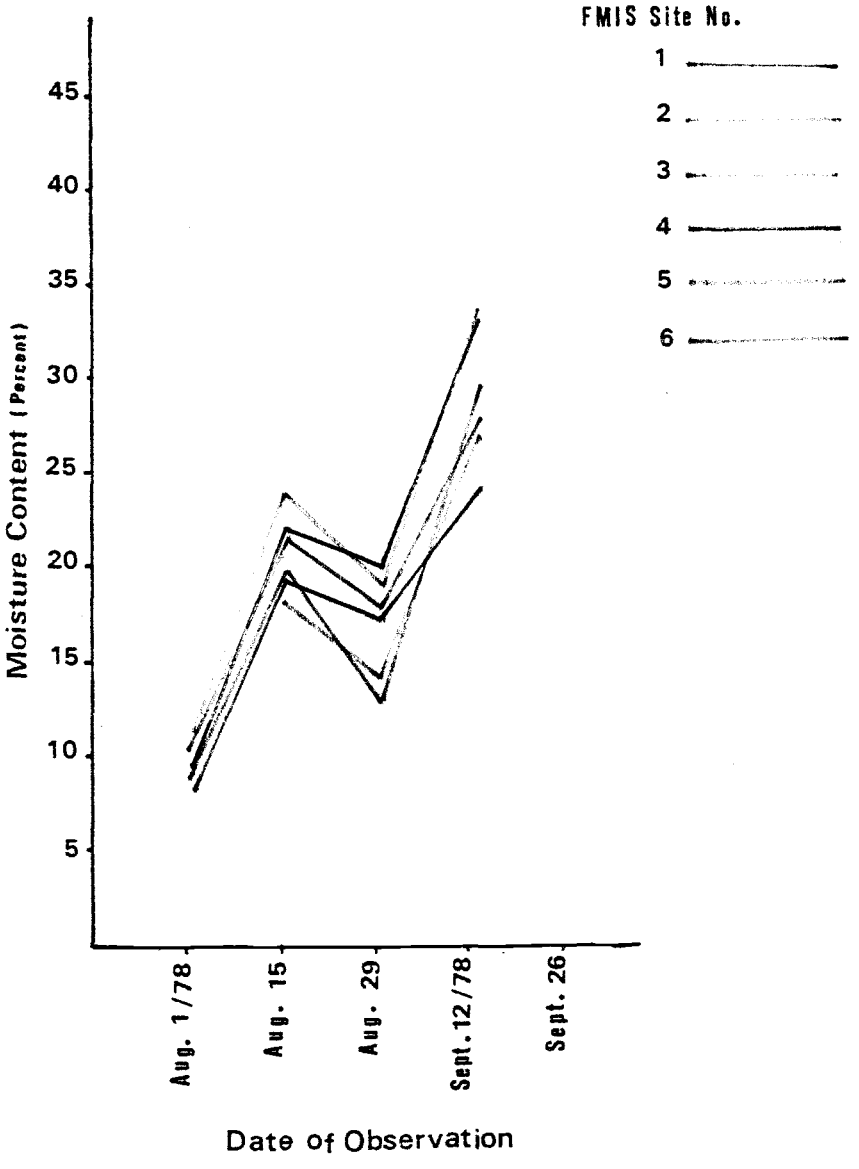


Figure 26

CLNP 10-Hour Timelag FMIS Moisture Content (Rim Dr. & Pinnacles Rd.)

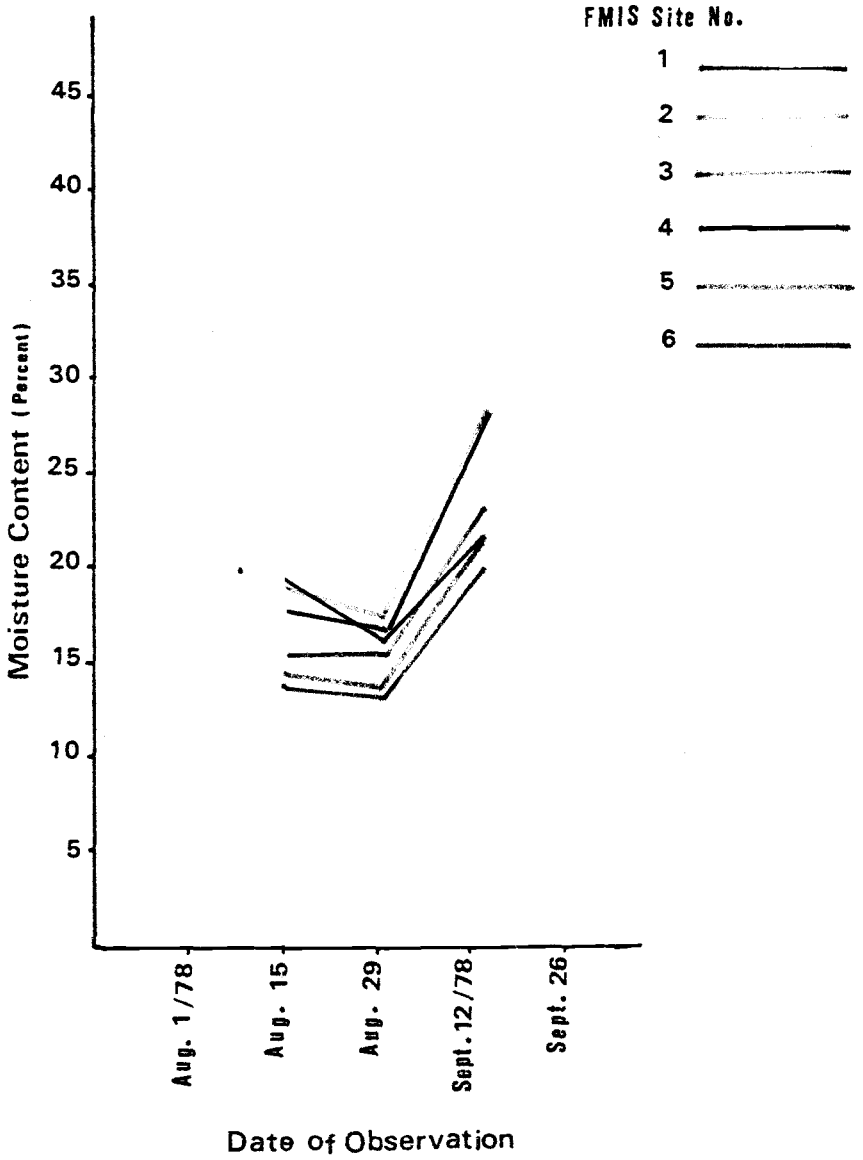


Figure 27

CLNP 10-Hour Timelag FMIS Moisture Content (West)

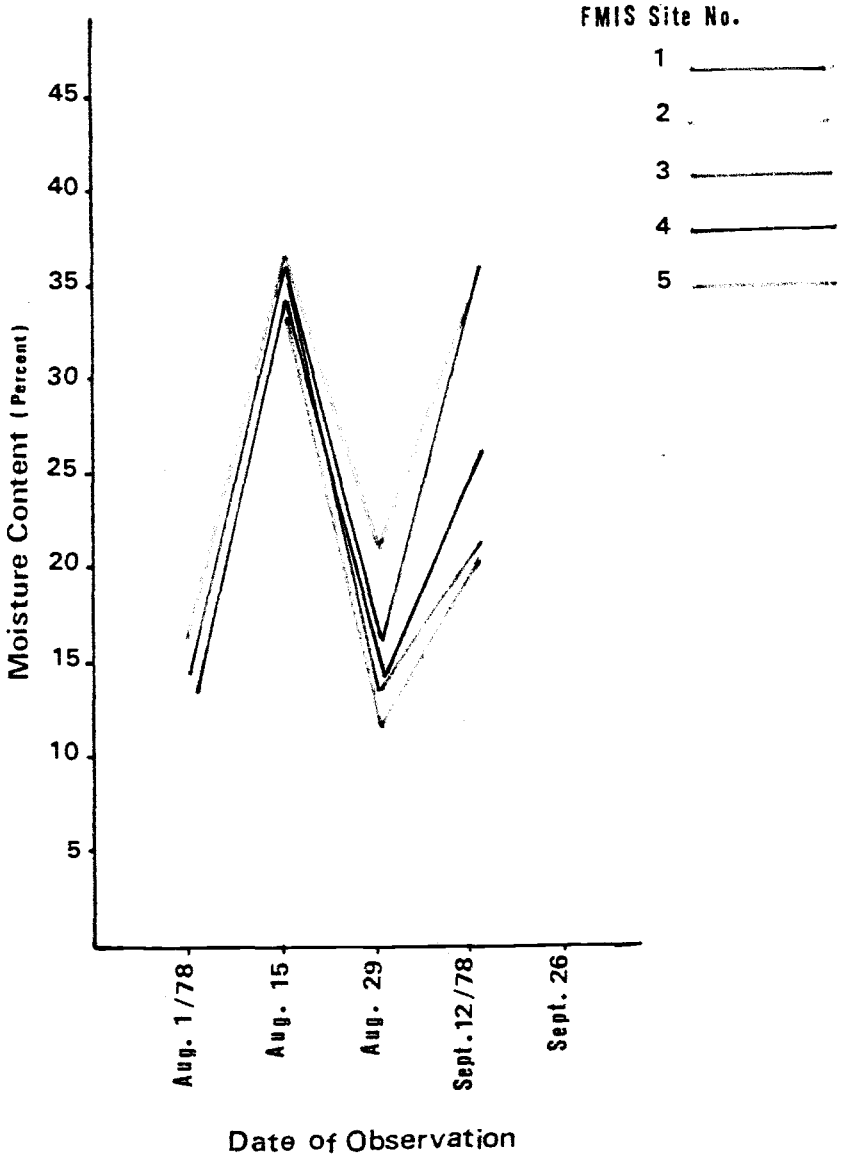


Figure 28

CLNP 10-Hour Timelag FMIS Moisture Content (South)

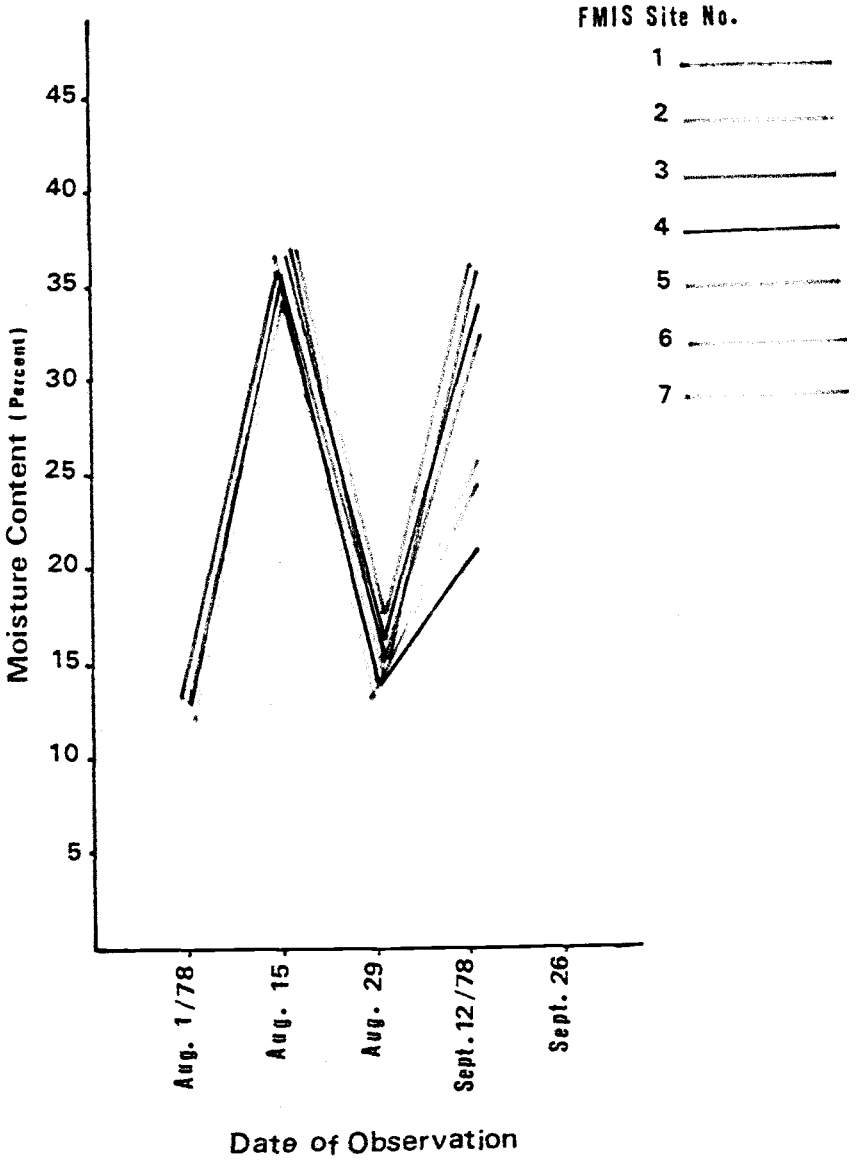


Figure 29

CLNP 10-Hour Timelag FMIS Moisture Content (Means)

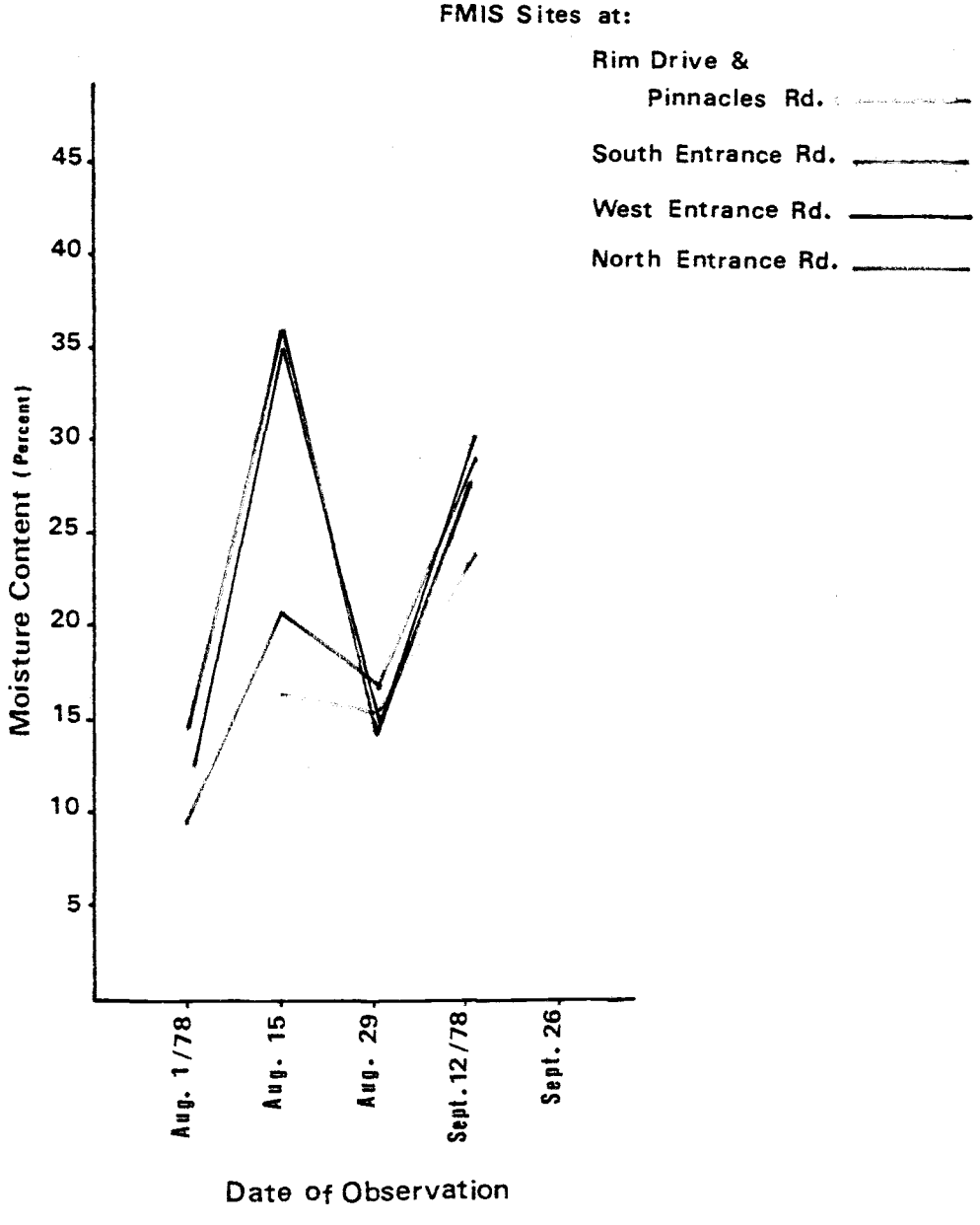


Figure 30

be noted that due to road conditions and difficulties in obtaining enough FMISs at one time, it was not possible to establish fuel sticks on Rim Drive and Pinnacles Road sooner than August 9, 1978. For this reason first period readings of these sites were made on August 15, 1978.

An analysis of Figures 26 to 30 and Tables 6 through 9 reveal two readings of high FMIS moisture contents, and two readings of low FMIS moisture patterns. High moisture content readings were made on August 15, and September 12, 1978, and two low FMIS moisture readings were made on August 1, and August 29, 1978. It should be noted that special considerations had been made to make successive moisture measurements of each FMIS approximately at the same time of the day throughout the observation period; and for the most part the procedure was successful. Basic fluctuations in moisture pattern over the Park seem to be a function of precipitation. According to daily weather reports recorded at Crater Lake National Park Headquarters, local weather conditions have had effective control over FMIS moisture patterns within the Park. There is a close relationship between temperature and precipitation, which in turn control FMISs moisture patterns. Weather conditions of two days prior to and on the days during which fuel moisture observations were made within the National Park have been represented in Table 10.

Fuel Moisture Indicator Sticks (FMIS) stationed at North Entrance Road, Crater Lake National Park, Oregon

Site #	UTM Coordinates and Location descriptions of FMIS Sites	Date of Setting	Covertype	FMISs moisture content(percent), by date & time of the day			
				8/1/1978	8/15/1978	8/29/1978	9/12/1978*
1	572130 E.,4767858 N. (0.5 mile from Park boundary; 443 paces at 90 degrees North)	6/23/78	Lodgepole Pine very poorly stocked	15:30 9.00%	10:30 21.50%	9:00 19.50%	11:30 32.00%
2	571788 E., 4767346 N. (0.7 mile from Park boundary; 180 paces at 90 degrees North)	6/23/78	Lodgepole Pine densely stocked	15:10 11.00%	10:15 23.00%	9:15 18.50%	11:45 32.50%
3	572004 E.,4766138 N. (1.4 miles from Park boundary; 138 paces at 87 degrees North.)	6/23/78	Lodgepole Pine poorly stocked	14:55 10.00%	10:00 21.00%	9:40 17.50%	12:05 27.00%
4	572047 E.,4764412 N. (2.2 miles from Park boundary; 240 paces at 87 degrees North.)	6/23/78	Pumice Desert	14:40 8.00%	9:45 19.00%	9:55 17.00%	12:12 23.50%
5	570756 E.,4762185 N. (3.5 miles from Park boundary; 85 paces at 230 degrees North.)	8/1/78**	Lodgepole Pine poorly stocked	———	10:45 18.00%	10:15 14.00%	12:25 26.50%
6	570000 E.,4759492 N. (5.5 miles from Park boundary; 382 paces at 110 degrees North.)	6/23/78	Grass with sparse Mountain Hemlock	14:15 8.50%	11:00 19.00%	10:35 13.00%	12:35 29.00%

*Readings on September 12, 1978 were made after an intense cyclonic storm over the region which brought snow-fall to higher elevations of the Park, and caused freezing temperatures above 6000 feet.

**Because of late setting of FMIS at site 5, first period reading was not registered for the site on August 1st,1978.

Table 6

Fuel Moisture Indicator Sticks (FMIS) stationed at West Entrance Road, Crater Lake National Park, Oregon

Site #	UTM Coordinates and Location description of FMIS Sites	Date of Setting	Covertype	FMISs moisture content(percent), by date and time of the day			
				8/1/1978	8/15/1978*	8/29/1978	9/12/1978
1	560319 E.,4749433 N. (Just at West Boundary of the Park from the calvert; 70 paces at 220 degrees North.)	6/23/78	Shasta Red Fir and Mountain Hemlock, densely stocked	9:15 14.00%	16:25 35.+%	17:10 16.00%	16:40 ** 35.+%
2	561721 E.,4748898 N. (1.0 mile from Park boundary; 90 paces at 85 degrees N.)	6/23/78	Mountain Hemlock & Shasta Red Fir Very densely stocked	9:30 15.50%	16:38 35.+%	16:55 20.50%	16:35 ** 35.+%
3	562295 E.,4748496 N. (1.6 miles from Park boundary; 40 paces at 15 degrees N.)	8/9/78	Mountain Hemlock & Lodgepole Pine densely stocked	——@	14:50 35.+%	16:45 13.00%	16:25 21.00%
4	564201 E.,4748189 N. (2.6 miles from Park boundary;78 paces at 335 degrees N.)	6/23/78	Lodgepole Pine densely, stocked	10:30 13.50%	15:10 35.+%	16:35 13.50%	16:20 25.50%
5	566574 E.,4747910 N. (4.5 miles from Park boundary; 160 paces at 65 degrees N.)	8/9/78	Mountain Hemlock with medium density	——@	15:25 35.+%	16:20 11.50%	16:10 20.00%

*Readings have been made under rainy condition. Due to maximum scaling capacity of Chisholm Scale of 30.00%, and taking the age factor of FMISs under consideration, we were able to make moisture content measurements up to 35.00% on August 15, 1978.

**Readings have been made after an intense snow storm over the region. High moisture contents of FMIS sites 1and 2 is due the fact that those sites were located under closed forest types.

@First period readings were not made for these sites due to their late setting date.

Table 7

Fuel Moisture Indicator Sticks (FMIS) stationed at Rim Drive and Pinnacles Road, Crater Lake National Park, Oregon

Site #	UTM Coordinates and Location descriptions of FMIS Sites	Date of Setting	Covertype	FMISs moisture content (percent), by date & time of the day			
				8/1/1978*	8/15/1978	8/29/1978	9/12/1978
1	575528 E.,4758941 N. (5.4 miles from junction of Rim Drive and North Entrance Road; 125 paces at 260 degrees North.)	8/9/78	Shasta Red Fir and White-bark Pine; medium density	------	11:20 19.00%	11:10 16.00%	17:20 21.00%
2	578441 E.,4754864 N. (7.7 miles from Rim Drive junction with North Entrance Road 110 paces at 60 degrees North.)	8/9/78	Mountain Hemlock; medium density	------	11:30 18.50%	11:25 17.00%	17:30 27.50%
3	576500 E.,4751382 N. (13.9 miles from Rim Drive and N. Entrance Road junction; 62 paces at 60 degrees North.)	8/9/78	Shasta Red Fir; medium density	------	11:55 15.00%	11:45 15.00%	17:45 22.50%
4	577701 E.,4749480 N. (1.9 miles from Pinnacles Road Junction with Rim Drive; 74 paces at 30 degrees North.)	8/9/78	Mountain Hemlock and Shasta Red Fir; medium density	------	12:05 17.50%	12:00 16.50%	17:50 27.50%
5	579705 E.,4746244 N. (4.2 miles from Pinnacles Road Junction with Rim Drive; 74 paces at 30 degrees North.)	8/9/78	Lodgepole Pine ; low densely stocked	------	12:20 14.00%	12:10 13.50%	18:05 21.00%
6	581295 E.,4744331 N. (5.7 miles from Pinnacles Road junction with Rim Drive; 60 paces at 195 degrees North.)	8/9/78	Lodgepole Pine; densely stocked	------	12:30 14.00%	12:25 13.00%	18:10 19.50%

*Since all of the Fuel Moisture Indicator Sticks at Rim Drive and Pinnacles Road were set on August 9th, 1978, field data for August 1st,1978 are missing in this table.

Table 8

Fuel Moisture Indicator Sticks (FMIS) stationed at South Entrance Road, Crater Lake National Park, Oregon

Site #	UTM Coordinates and Location description of FMIS Sites	Date of Setting	Covertype	FIMSs moisture content(percent), by date and time of the day			
				8/1/1978	8/15/1978*	8/29/1978	9/12/1978
1	576449 E.,4736370 N. (HWY 62 South at Ponderosa Pine Picnic area; 41 paces at 010 degrees N.)	6/24/78	White Fir & Ponderosa Pine with medium density	11:35 12.50%	16:15 34+%	15:50 13.50%	15:50 20.50%
2	576102 E.,4736894 N. (0.4 mile from #1; 78 paces at 255 degrees North.)	6/24/78	Ponderosa Pine and White Fir densely stocked	11:45 12.00%	16:05 34+%	15:40 13.50%	16:00 25.00%
3	575953 E.,4737552 N. (0.7 mile from # 1; 84 paces at 245 degrees North.)	6/24/78	Ponderosa Pine and White Fir with medium density	12:05 12.50%	15:50 34+%	15:20 13.50%	15:30 35+%*
4	574173 E.,4739689 N. (2.5 miles from # 1 67 paces at 190 degrees North.)	8/9/78	Ponderosa Pine and White Fir densely stocked	——**	15:40 34+%	15:05 16.00%	15:20 33.00%
5	572303 E.,4740445 N. (5.0 miles from junction of HWY 62 S. with Park Entrance 58 paces at 185 N.)	8/9/78	Shasta Red Fir and WhitebarkP. densely stocked	——	15:30 34+%	14:50 13.50%	15:12 24.50%
6	568744 E.,4746551 N. (1.9 miles from # 7; 104 paces at 170 degrees North.)	8/9/78	Mountain Hemlock & Shasta Red Fir	——	15:20 34+%	14:30 15.50%	15:00 32.00%
7	570283 E.,4748256 N. (0.8 mile from Park Head Quarters on South Entrance Road 96 paces at 70 degrees North.)	8/9/78	Mountain Hemlock with medium density	——	15:10 34+%	14:15 16.75%	14:40 35+%

*Readings have been made under rainy condition. Due to maximum scaling capacity of Chisholm Scale of 30.00%, and taking the age factor of FMISs under consideration, we were able to make moisture content measurments up to 34.00% on August 15th, and up to 35.00% on September 12th, 1978.

**Due to late setting of FMISs at sites 4-7, first period readings were not registered on August 1st, 1978.

Table 9

Weather Conditions on Two Days Prior and on the Days FMISs' Moisture Measurements Were Made within Crater Lake National Park@

Day of Month	Temperature F (C) Max.	Min.	Rainfall in. (cm)	General Weather Condition
July 30, 1978	74 (23.3)	47 (8.3)	0.0	Clear and calm
July 31, 1978	75 (23.9)	44 (6.7)	0.0	Clear and calm
Aug. 1, 1978*	74 (23.3)	43 (6.1)	0.0	Clear and calm
Aug. 13, 1978	49 (9.4)	35 (1.7)	0.23 (0.58)	Rainy and overcast
Aug. 14, 1978	48 (8.9)	31 (-0.6)	Trace	Clear and calm
Aug. 15, 1978*	62 (16.7)	33 (0.6)	0.0	Clear and calm
Aug. 27, 1978	56 (13.3)	34 (1.1)	0.0	Clear and calm
Aug. 28, 1978	62 (16.7)	36 (2.2)	0.0	Clear and calm
Aug. 29, 1978*	68 (20.0)	42 (5.6)	0.0	Clear and windy
Sept.10, 1978	43 (6.1)	32 (0.0)	1.75 (4.45)	Low clouds and snowing
Sept.11, 1978	37 (2.7)	31 (-0.6)	1.25** 3.18	Cloudy and light snowing
Sept.12, 1978*	44 (6.7)	29 (-1.7)	0.0	Clear and calm

@ Source: Weather reports on file at Crater Lake National Park Headquarters

* Days on which FMISs' moisture readings have been made

** Other than 1.25 inches of rainfall, 1.0 inch of snow accumulation on the ground has been recorded on this day

Table 10

Low FMISs moisture patterns of August 1, and August 29, 1978 are associated with relatively high air temperatures (mid 70's) and lack of precipitation. During these periods (July 30 to August 1, and August 27 to 29) weather was clear and calm. Sunny, and calm days of these periods caused higher air temperatures, which in turn resulted in lower environmental moisture as indicated by fuel sticks. On the other hand high FMISs moisture contents on August 13 to 15, and September 10 to 12 are connected with rainfall or snowfall together with lower air temperatures. During these periods, over-cast skies and precipitation resulted in cooler and in some places subfreezing temperatures and high environmental moisture (Figures 26-30).

Further analysis of moisture related data indicate that Southern and Western regions of the National Park received more precipitation during August 13 to 14 than other areas. The higher values recorded for the fuel moisture sticks in the southern and western regions of the Park indicate this difference. Northwesterly direction of September 12, 1978 storm over the National Park region may have caused variations in the moisture patterns of FMISs as presented in Figures 26 through 30.

Altogether, the summer of 1978 was an unusually wet season

within the Crater Lake National Park region. Average temperatures and average precipitation amounts for the months of July, August and September are given in Table 11. Data in Table 11 indicate that average maximum temperatures of July, August and September of 1978 were much lower than the average maximum temperatures of long term (1924-61) recorded climatic data for the same months at Park Headquarters. Similarly, precipitation amounts during the summer season of 1978 exceeded average precipitation amounts for long term recorded data from 1924 to 1961. Although the National Park did not receive snow during July and August of 1978, the amount of snowfall during September of 1978 was abnormally high. As a result of unusually lower temperatures and relatively high amounts of precipitation within the Park, the fire season of 1978 was abnormally short.

Downed Fuel Inventorying within Crater Lake National Park

Solar insolation intensity and environmental moisture patterns are two major parameters in the ignition of wild fires within the forested areas. The third major factor in this regard is the availability of fire fuels. For this reason, dry, downed woody materials on the forest floor play a most effective role on forest fire ignition.

Comparative Long Term and 1978 Summer Months'
Temperature and Precipitation within Crater Lake National Park

Months	Ave. Temperature F (C)				Ave. Rainfall in.(cm)		Ave. Snowfall in.(cm)	
	1978		1924-1961		1978	1924-1961	1978	1924-1961
	Max.	Min.	Max.	Min.				
July	67 (19.4)	41 (5.0)	70 (21.1)	42 (5.6)	0.81 (2.1)	0.66 (1.7)	0.0	T
August	63 (17.2)	41 (5.0)	70 (21.1)	41 (5.0)	1.82 (4.7)	0.55 (1.4)	0.0	0.2 (0.5)
September	53 (11.7)	33 (0.6)	62 (16.7)	37 (2.8)	5.5 (14.0)	2.10 (5.4)	5.4 (13.7)	2.8 (7.1)
Seasonal Ave.	61 (16.1)	38 (3.5)	67.3 (19.6)	40 (4.4)	2.71 (6.9)	1.10 (2.80)	1.8 (4.6)	1.0 (2.4)

Table 11. Adopted from Sternes(1963), and 1978 weather records on file at the National Park Headquarters.

Foresters suggest different methods for estimating downed fuel volume. Howard and Ward (1972) have developed methods for downed fuel inventory which include mostly larger woody material. This methodology is not so appropriate for sampling small branch wood and twigs. Van Wagner (1968) suggests a method which involves gathering and weighing smaller woody materials from the forest floor and measuring diameters of larger woody pieces intersected with the sample line. One other technique widely employed for downed fuel inventory has been developed by Brown (1971). The method is called "Planar Intersect Technique". Later this method has been updated twice, first by Brown (1974) and then by Brown and Roussopoulos (1974).

In this research for an inventory methodology of downed woody material within Crater Lake National Park, the Planar Intersect Technique was utilized. Complete, and step by step guidelines of this method are published in "Handbook For Inventorying Downed Woody Material" by James K. Brown (1974) of the Intermountain Forest and Range Experiment Station, Ogden, Utah. It is believed that this method is well suited for downed fuel inventory purposes of this study because:

1) the method has been designed and developed for inventorying downed woody materials (natural or by logging) within fir and pine forests of the Western United States, where Crater

Lake National Park is located,

2) the time required for inventorying downed woody material by this technique is relatively shorter in comparison to other similar techniques. Considering the time and space restrictions involved in this study (due to short summer season of the study area, and the size of Crater Lake National Park), application of the planar intersect technique seemed to be advantageous,

3) the Planar Intersect Method calculates not only estimates of the volume of downed fuel but it also provides the user with estimates of area so that amounts of downed fuel per unit of forest land (Tons/Acre) can be obtained,

4) the Planar Intersect Method has been developed for downed fuel inventorying of large forest lands. It is a time saving technique and requires only a two-man crew to carry out the sampling procedure.

The technique involves tallying intersections of woody material pieces with vertical sampling planes of fuel pieces which have diameters of less than three inches, otherwise measuring diameters of downed fuel. Downed woody materials in size class of less than three inches in diameter are further classified into three subclasses of 0-0.25 inch, 0.25-1 inch, and 1-3 inches. Depending on forest density, the sampling plane in this method for naturally fallen

materials is 6 feet for size class 0-1 inch, 10-12 feet for size class 1-3 inches, and 35-50 feet for the size class of more than 3 inches in diameter. To eliminate bias in sample point selection, the method suggests that plots be selected along transects that lace regularly across the sample area.

During field observation, other related data are also accumulated. Such information included making measurements of the depths of dead fuel and duff layer within sampling plots. Measurements of dead fuel depth and duff layer were recorded to the nearest 1.0 inch and 0.1 of an inch, respectively.

Observing the guidelines given in the Brown's handbook, an attempt has been made to achieve adequate sampling precision. The procedure involves altering the number of sample plots and lengths of sample planes. This alteration is in accordance with forest density and downed fuel intensity within the sampling area. Studies by Brown (1974) indicate that, by adequate precision in sampling procedure, percentage error in downed fuel inventory will be reduced to 15-20 percent. Such percentage errors are considered to be adequate levels of precision in assessing most fuel problems (Brown, 1974).

Sample site selection strategy discussed earlier in this chapter was applied and fifty-seven sampling sites were located within

Crater Lake National Park. These sites were named Downed Fuel Study Areas (DFSA). Attempts were made to select DFSAs to be representative of the vegetation cover types and densities within the National Park. Further consideration was given so that DFSAs would be well distributed over the Park. In some cases, restricting factors arising from rough topography or remoteness of the terrain, created obstacles in the selection of certain DFSAs In selecting DFSAs considerations were observed with regard to firespread danger units established by the Park Management. Considering this fact, 19 DFSAs were selected within Unit III of the Fire Management Plan, the most hazardous fire management unit within the National Park (Figure 2). Locations of DFSAs is shown in Figure 31. During summer months of 1978 downed fuel characteristics of selected DFSAs were studied, and adequate data and information were collected from every downed fuel study area. Additional information was collected in each sampling plot with regard to forest density, tree crown size, and forest floor characteristics. Figure 31-A represents data collection form utilized in downed fuel inventorying procedures. By the end of the 1978 summer season, the downed fuel inventorying project of all 57 DFSAs had been accomplished within the National Park.

Downed Fuel Data Calculation

Locations Of DFSAs Within Crater Lake National Park



Figure 31

Downed Fuel Inventory (Field Form)

FOREST		SUBCOMPARTMENT		ASPECT	
BLOCK		STAND		COVER TYPE	
COMPARTMENT		ELEVATION		HABITAT TYPE	

SIZE CLASS (In.) :	0 - 1	1 - 3	3+
LENGTH OF SAMPLING PLANE (Ft.) :			

		NO. OF INTERSECTS			DUFF DEPTH		3+ DIAMETER						FUEL DEPTH		
Plot No.	Slope	0 - .25"	.25 - 1"	1 - 3"	First	Second	Sound	Sound	Sound	Rotten	Rotten	Rotten	First	Second	Third

GROUND FUEL COMPOSITION		If heavy slash, code 1 :
Species	Percent	
1.		
2.		
3.		

Figure 31A. Adapted from Brown (1974).

Computation of downed fuel inventories data are either possible by computer assisted programs (Johnston, 1975), or by desk calculator. Due to the complexity involved in the preparation of field data for computer assisted computation, the computer program seems to be appropriate only if very large quantities of field data are to be calculated. Considering such complexities, it was decided to apply conventional desk calculation methods to acquired field data.

To compute amounts of downed fuel (Tons/Acre), two slightly different formulas with regard to different fuel size classes were utilized. The formulas follow:

a) For downed fuel classes of 0 to 3 inches in diameter:

$$\text{Tons/Acre} = \frac{11.64 \times n \times d^2 \times s \times a \times c}{N1}$$

b) For downed fuel classes with more than 3 inches in diameter:

$$\text{Tons/Acre} = \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{N1}$$

where:

11.64 = computation constant,

n = total number of intersections over all sample points,

d^2 = squared average of diameters for each size class,

s = specific gravity of the woody material,

a = nonhorizontal angle correction factor,

Σd^2 = the sum of squared diameters for fuel classes of 3 inches or larger in diameter. It is calculated separately for rotten and sound fuel classes,

c = average slope correction factor,

N1 = total length of sampling line for each size class

(Brown, 1974).

The foregoing formulas were applied to field data collected during the 1978 summer season within the Park, and amounts of downed fuel per unit of area (Tons/Acre), were calculated. Summary calculation of downed woody material for all DFSAs have been tabulated in Tables 12-68 in the following pages. This tables form has been adopted from Brown (1974).

For computer assisted calculation of downed fuel data, the area within the Park was divided into 15 blocks, each block into 4 compartments, each compartment into 4 subcompartments, and each subcompartment into 4 stands. Then each of the DFSAs were identified by their locations within these divisions i.e., they were given a code number in accordance with their locations. Although, later it was decided not to utilize the computer for calculations of downed fuel data, the code numbers were still left on computation summary tables.

Varieties of coniferous forest species exist within the National Park; through ground truthing the following dominant forest types of the Park were identified:

a. Mountain Hemlock (Tsuga mertensiana) - abbreviated as M.H. on some of the computation summary tables,

b. Shasta Red Fir (Abies magnifica var. Shastensis) -

abbreviated as S. R. F. on some of the computation summary tables,

c. Lodgepole Pine (Pinus contorta) - abbreviated as L. P. P. on some of the computation summary tables,

d. Ponderosa Pine (Pinus ponderosa) - abbreviated as P. P. on some of the computation summary tables,

e. White Fir (Abies concolor) - abbreviated as W. F. on some of the computation summary tables,

f. Western White Pine (Pinus monticola) - abbreviated as W. W. P. on some of the computation summary tables,

g. Grasslands with sparse forest.

At "ground truthing sites" (DFSAs), purity of forest types varied significantly from pure stands (100%) of a single species to less than 5% mixed with other species.

Estimates of cover type percentages have been made through on-site observations procedures within the DFSAs, while forested area percentage and average crown diameter criteria have been calculated mathematically through stereoscopic analysis and interpretation of 1:30,000 and 1:7400 scale U-2 aerial color infrared photographs of the study areas using equipment provided by the Environmental Remote Sensing Applications Laboratory (ERSAL), located on Oregon State University campus.

Downed fuel characteristics varied greatly for the different species with regard to various parameters such as forest density and

maturity, elevation, slope and slope aspect. Table 69 summarizes some of these characteristics and depicts variations of downed fuel amounts for the dominant forest cover types within the Park. The smallest downed fuel amount (0.35 Tons/Acre), was inventoried under very poorly stocked (11.20% canopy coverage), Lodgepole Pine forest, and largest amount of downed fuel was 91.67 Tons/Acre inventoried under very dense (97.77% canopy coverage), Mountain Hemlock forest (Table 69).

Applied fuel models for each of the DFSAs in "downed fuel summary tables" are selected in accordance with forest fire fuel loading characteristics classified by Deeming, Burgan, and Cohen (1978), in "The National Fire-Danger Rating System 1978" publication. These fuel models and their narative descriptions have been included in Appendix I of this study. We were aided in these classifications by Burgan and Cohen during our visit to Intermountain Forest and Range Experiment Station in Missoula, Montana*.

*Their cooperation and kindness in this regard is greatly appreciated.

Downed Woody Material Computation Summary

Study site # 1

FOREST: 01 COMPARTMENT: 02 STAND: 3

BLOCK #: 12 SUBCOMPARTMENT: 3

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times Id^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre
0 - .25	11.64	142	0.020	.48	1.13	1.00	24	0.75 I
.25 - 1	11.64	20	0.344	.48	1.13	1.00	24	1.81 II
1 - 3	11.64	2	2.87	.40	1.13	1.00	48	0.63 III
		Id^2 for 3+						
3+ Sound	11.64	693		.40	1.00	1.00	200	16.13 IV
3+ Rotten	11.64	209		.30	1.00	1.00	200	3.65 V
				3+ Sound & Rotten = IV + V =				~~19.78~~ VI
				Total = I + II + III + VI =				22.97 VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	73	10	7.30 in.
Rotten :	23	3	7.67 in.

Sum of duff depths: : 12.90 in. Sum of fuel depths : 52 in.

Number observations : 8 Number observations : 12

Average duff depths : 1.61 in. Average fuel depths : 4.33 in.

Sample site description:

Covertype;Lodgepole Pine (99%)
forested area; 43.87%
average crown diameter; 17.10 feet
further information; Forest floor is covered with 1-2 inches of needles.

Applied Fuel Model: F

Table 12

Downed Woody Material Computation Summary

Study site # 2

FOREST: 1 COMPARTMENT: 2 STAND: 2

BLOCK: 12 SUBCOMPARTMENT: 1

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	80	0.0201	.48	1.13	1.00	24	0.42	I
.25 - 1	11.64	26	0.344	.48	1.13	1.00	24	2.35	II
1 - 3	11.64	4	2.87	.40	1.13	1.00	48	1.26	III
		Σd^2 for 3+							
3+ Sound	11.64	530		.40	1.00	1.00	200	12.34	IV
3+ Rotten	11.64	310		.30	1.00	1.00	200	5.41	V
				3+ Sound & Rotten = IV + V =				17.75	VI
				Total = I + II + III + VI =				21.78	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	82	15	5.47 in.
Rotten :	34	5	6.80 in.

Sum of duff depths: : 18.70 in. Sum of fuel depths : 49 in.

Number observations : 8 Number observations : 12

Average duff depths : 2.34 in. Average fuel depths : 4.08 in.

Sample site description:

Covertype; Lodgepole Pine (99%)
forested area; 21.91%
average crown diameter; 15.05 feet
further information; Forest floor is covered with annual grass (80%).

Applied Fuel Model: C

Table 13

Downed Woody Material Computation Summary

Study site # 3

FOREST: 1 COMPARTMENT: 4 STAND: 3

BLOCK : 9 SUBCOMPARTMENT : 2

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	186	0.0156	.48	1.13	1.00	24	0.76	I
.25 - 1	11.64	26	0.295	.48	1.13	1.00	24	2.02	II
1 - 3	11.64	4	2.77	.40	1.13	1.00	48	1.21	III
		Σd^2 for 3+							
3+ Sound	11.64	138		.40	1.00	1.00	200	3.21	IV
3+ Rotten	11.64	1691		.30	1.00	1.00	200	29.52	V
							3+ Sound & Rotten = IV + V =	32.73	VI
							Total = I + II + III + VI =	36.72	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	54	10	5.40 in.
Rotten :	89	6	14.83 in.

Sum of duff depths: : 11.50 in. Sum of fuel depths : 35 in.

Number observations : 8 Number observations : 12

Average duff depths : 1.44 in. Average fuel depths : 2.92 in.

Sample site description:

Covertype; M.H.(70%), S.R.F. (20%), and L.P. (10%)
forested area; 62.71%
average crown diameter; 42.87 feet
further information; Most of downed woody material in large diameters(more than 6 in.) are in rotten class

Applied Fuel Model: H

Table 14

Downed Woody Material Computation Summary

Study site # 4

FOREST: 1 COMPARTMENT: 4 STAND: 1

BLOCK: 9 SUBCOMPARTMENT: 2

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	234	0.0151	.48	1.13	1.00	24	0.93	I
.25 - 1	11.64	31	0.289	.48	1.13	1.00	24	2.36	II
1 - 3	11.64	14	2.76	.40	1.13	1.00	48	4.24	III
		Σd^2 for 3+							
3+ Sound	11.64	504		.40	1.00	1.00	200	11.73	IV
3+ Rotten	11.64	632		.30	1.00	1.00	200	11.03	V
							3+ Sound & Rotten = IV + V =	22.76	VI
							Total = I + II + III + VI =	30.29	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	92	20	4.60 in.
Rotten :	43	3	13.33 in.

Sum of duff depths: ~~11.20~~ in. Sum of fuel depths : 48 in.

Number observations : 8 Number observations : 12

Average duff depths : 1.40 in. Average fuel depths : 4 in.

Sample site description:

Covertype; Shsta Red Fir (80%), Mountain Hemlock (20%)
forested area; 80.19%
average crown diameter; 43.17 feet
further information; 30% grass cover on forest floor

Applied Fuel Model: H

Table 15

Downed Woody Material Computation Summary

Study site # 5

FOREST: 1 COMPARTMENT: 3 STAND: 1

BLOCK: 8 SUBCOMPARTMENT: 4

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/acre
0 - .25	11.64	60	0.0151	.48	1.13	1.00	24	0.24 I
.25 - 1	11.64	18	0.289	.48	1.13	1.00	24	1.37 II
1 - 3	11.64	9	2.76	.40	1.13	1.00	48	2.72 III
		Σd^2 for 3+						
3+ Sound	11.64	1898		.40	1.00	1.00	200	44.19 IV
3+ Rotten	11.64	234		.30	1.00	1.00	200	4.09 V
						3+ Sound & Rotten = IV + V =		48.28 VI
						Total = I + II + III + VI =		52.6 VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	82	6	13.67 in.
Rotten :	18	2	9.00 in.

Sum of duff depths: : 4.3 in. Sum of fuel depths : 25 in.

Number observations : 8 Number observations : 12

Average duff depths : 0.54 in. Average fuel depths : 2.08 in.

Sample site description:

Covertype; Mountain Hemlock (70%), Shasta Red Fir (30%)
forested area; 86.24%
average crown diameter; 42.48 feet
further information; Forest has over mature trees (about 15% of the covertype).

Applied Fuel Model: G

Table 16

Downed Woody Material Computation Summary

Study site # 6

FOREST: 1 COMPARTMENT: 4 STAND: 4

BLOCK #: 9 SUBCOMPARTMENT: 1

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	115	0.0151	.48	1.13	1.02	24	0.47	I
.25 - 1	11.64	25	0.289	.48	1.13	1.02	24	1.94	II
1 - 3	11.64	15	2.76	.40	1.13	1.02	48	4.63	III
		Σd^2 for 3+							
3+ Sound	11.64	1776		.40	1.00	1.02	200	42.17	IV
3+ Rotten	11.64	196		.30	1.00	1.02	200	3.49	V
				3+ Sound & Rotten = IV + V =				45.66	VI
				Total = I + II + III + VI =				52.70	II

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	114	11	10.36 in.
Rotten :	14	1	14 in.

Sum of duff depths: : 5.1 in. Sum of fuel depths : 27 in.

Number observations : 8 Number observations : 12

Average duff depths : 0.64 in. Average fuel depths : 2.25 in.

Sample site description:

Covertype; Mountain Hemlock (99%)
forested area; 85.18%
average crown diameter; 38.33 feet
further information; Needle coverage of about 1 inch on the forest floor

Applied Fuel Model: G

Table 17

Downed Woody Material Computation Summary

Study site # 7

FOREST: 1 COMPARTMENT: 1 STAND: 1

PLOCK : 9 SUBCOMPARTMENT : 3

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{NI}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{NI}$

Size class	Constant	n	d^2	s	a	c	NI	Tons/ acre	
0 - .25	11.64	331	0.0151	.48	1.13	1.01	24	1.18	I
.25 - 1	11.64	59	0.289	.48	1.13	1.01	24	4.53	II
1 - 3	11.64	11	2.76	.40	1.13	1.01	48	3.36	III
		Σd^2 for 3+							
3+ Sound	11.64	294		.40	1.00	1.01	160	8.64	IV
3+ Rotten	11.64	549		.30	1.00	1.01	160	12.10	V
						3+ Sound & Rotten = IV + V =		20.74	VI
						Total = I + II + III + VI =		29.81	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	48	9	5.33 in.
Rotten :	39	3	13 in.

Sum of duff depths: : 8.8 in. Sum of fuel depths : 46 in.

Number observations : 8 Number observations : 12

Average duff depths : 1.1 in. Average fuel depths : 3.83 in.

Sample site description:

Covertype; Shata Red Fir (60%), Mountain Hemlock (40%)
forested area; 58.39%
average crown diameter; 34.72 feet
further information;

Applied Fuel Model: H

Table 18

Downed Woody Material Computation Summary

Study site # 8

FOREST: 1 COMPARTMENT: 1 STAND: 3

BLOCK: 9 SUBCOMPARTMENT: 3

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	26	0.0157	.48	1.13	1.00	24	0.11	I
.25 - 1	11.64	4	0.295	.48	1.13	1.00	24	0.31	II
1 - 3	11.64	00	2.77	.40	1.13	1.00	48	0.00	III
		Σd^2 for 3+							
3+ Sound	11.64	75		.40	1.00	1.00	200	1.75	IV
3+ Rotten	11.64	234		.30	1.00	1.00	200	4.09	V
				3+ Sound & Rotten = IV + V =				5.84	VI
				Total = I + II + III + VI =				6.26	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	19	5	3.80 in.
Rotten :	34	5	6.80 in.

Sum of duff depths: : 0.6 in. Sum of fuel depths : 8 in.

Number observations : 8 Number observations : 12

Average duff depths : 0.08 in. Average fuel depths : 0.67 in.

Sample site description:

Covertype; Grassland(70%), White Pine(10%), L.P.P.(10%)
forested area; 13.01%
average crown diameter; 22.20 feet
further information; Stands have occupied about 25-30% of the area

Applied Fuel Model: A

Table 19

Downed Woody Material Computation Summary

Study site # 9

FOREST: 1 COMPARTMENT: 3 STAND: 4

BLOCK : 6 SUBCOMPARTMENT : 4

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	48	0.0161	.48	1.13	1.00	30	0.16	I
.25 - 1	11.64	5	0.300	.48	1.13	1.00	30	0.32	II
1 - 3	11.64	2	2.78	.40	1.13	1.00	60	0.49	III
		Σd^2 for 3+							
3+ Sound	11.64	304		.40	1.00	1.00	200	7.08	IV
3+ Rotten	11.64	1047		.30	1.00	1.00	200	18.28	V
					3+ Sound & Rotten = IV + V =			25.36	VI
					Total = I + II + III + VI =			26.33	II

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	48	8	6.0 in.
Rotten :	121	17	7.12in.

Sum of duff depths: : 4.9 in. Sum of fuel depths : 24 in.

Number observations : 10 Number observations : 15

Average duff depths : 0.49 in. Average fuel depths : 1.60 in.

Sample site description:

Covertype; Mountain Hemlock(70%), L.P.P(20%), Western W.P.(10%)

forested area; 78.42%

average crown diameter; 28.50 feet

further information; Needle thickness about 1 inch on the forest floor

Applied Fuel Model: H

Table 20

Downed Woody Material Computation Summary

Study site # 10

FOREST: 1 COMPARTMENT: 3 STAND: 4

BLOCK: 6 SUBCOMPARTMENT: 1

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	160	0.0151	.48	1.13	1.00	24	0.64	I
.25 - 1	11.64	21	0.289	.48	1.13	1.00	24	1.60	II
1 - 3	11.64	3	2.76	.40	1.13	1.00	48	0.91	III
		Σd^2 for 3+							
3+ Sound	11.64	975		.40	1.00	1.00	200	22.70	IV
3+ Rotten	11.64	436		.30	1.00	1.00	200	7.61	V
						3+ Sound & Rotten = IV + V =		30.31	VI
						Total = I + II + III + VI =		33.48	II

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	79	7	11.29 in.
Rotten :	54	8	6.75 in.

Sum of duff depths: : 10.20 in. Sum of fuel depths : 40 in.

Number observations : 8 Number observations : 12

Average duff depths : 1.28 in. Average fuel depths : 3.33 in.

Sample site description:

Covertype; M.H. (60%), Shasta Red Fir (35%), Western W.P. (5%)

forested area; 80.02%

average crown diameter; 29.56 feet

further information; Open forest

Applied Fuel Model: H

Table 21

Downed Woody Material Computation Summary

Study site # 11

FOREST: 1 COMPARTMENT: 1 STAND: 4

BLOCK: 6 SUBCOMPARTMENT: 3

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	307	0.0151	.48	1.13	1.00	24	1.22	I
.25 - 1	11.64	19	0.289	.48	1.13	1.00	24	1.44	II
1 - 3	11.64	10	2.76	.40	1.13	1.00	48	3.03	III
		Σd^2 for 3+							
3+ Sound	11.64	2312		.40	1.00	1.00	200	53.82	IV
3+ Rotten	11.64	1842		.30	1.00	1.00	200	32.16	V
							3+ Sound & Rotten = IV + V =	85.98	VI
							Total = I + II + III + VI =	91.67	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	174	18	9.76 in.
Rotten :	92	6	15.33 in.

Sum of duff depths: : 18.10 in. Sum of fuel depths : 50 in.

Number observations : 8 Number observations : 12

Average duff depths : 2.26 in. Average fuel depths : 4.17 in.

Sample site description:

Covertype; Mountain Hemlock(95%), Shasta Red Fir (5%)
forested area; 97.77%
average crown diameter; 36.60 feet
further information; Open forest with heavy downed woody material accumulation

Applied Fuel Model: G

Table 22

Downed Woody Material Computation Summary

Study site # 12

FOREST: 1 COMPARTMENT: 1 STAND: 2

BLOCK: 6 SUBCOMPARTMENT: 4

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre
0 - .25	11.64	43	0.0161	.48	1.13	1.00	30	0.15 I
.25 - 1	11.64	18	0.300	.48	1.13	1.00	30	1.14 II
1 - 3	11.64	3	2.78	.40	1.13	1.00	60	0.73 III
		Σd^2 for 3+						
3+ Sound	11.64	553		.40	1.00	1.00	250	10.30 IV
3+ Rotten	11.64	1014		.30	1.00	1.00	250	14.16 V
				3+ Sound & Rotten = IV + V =				24.46 VI
				Total = I + II + III + VI =				26.48 VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	45	5	9.0 in.
Rotten :	100	12	8.33 in.

Sum of duff depths: : 23.80 in. Sum of fuel depths : 28 in.

Number observations : 10 Number observations : 15

Average duff depths : 2.38 in. Average fuel depths : 1.87 in.

Sample site description:

Covertype; S.R.F.(50%), M.H.(40%), L.P.P.(20%)
forested area; 39.74%
average crown diameter; 34.38 feet
further information; Mixed forest, and 50% of the forest floor covered with annual grass

Applied Fuel Model: H

Table 23

Downed Woody Material Computation Summary

Study site # 13

FOREST: 1 COMPARTMENT: 2 STAND: 2

BLOCK: 5 SUBCOMPARTMENT: 4

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre
0 - .25	11.64	65	0.0151	.48	1.13	1.00	24	0.26 I
.25 - 1	11.64	5	0.289	.48	1.13	1.00	24	0.38 II
1 - 3	11.64	7	2.76	.40	1.13	1.00	48	2.12 III
		Σd^2 for 3+						
3+ Sound	11.64	1454		.40	1.00	1.00	200	33.85 IV
3+ Rotten	11.64	863		.30	1.00	1.00	200	15.07 V
						3+ Sound & Rotten = IV + V =		48.92 VI
						Total = I + II + III + VI =		51.68 VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	116	15	7.73 in.
Rotten :	53	4	13.25 in.

Sum of duff depths: 1.97 in. Sum of fuel depths : 12 in.

Number observations : 8 Number observations : 12

Average duff depths : 0.25 in. Average fuel depths : 1.00 in.

Sample site description:

Covertype; Mountain Hemlock (99%)
forested area; 66.97%
average crown diameter; 27.82 feet
further information; Scattered Mountain Hemlock regeneration; forest floor covered with annual grass

Applied Fuel Model: G

Table 24

Downed Woody Material Computation Summary

Study site # 14

FOREST: 1 COMPARTMENT: 2 STAND: 1

BLOCK: 5 SUBCOMPARTMENT: 3

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	163	0.0156	.48	1.13	1.00	24	0.67	I
.25 - 1	11.64	11	0.295	.48	1.13	1.00	24	0.85	II
1 - 3	11.64	2	2.77	.40	1.13	1.00	48	0.61	III
		Σd^2 for 3+							
3+ Sound	11.64	592		.40	1.00	1.00	200	13.78	IV
3+ Rotten	11.64	526		.30	1.00	1.00	200	9.18	V
				3+ Sound & Rotten = IV + V =				22.96	VI
				Total = I + II + III + VI =				25.09	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	60	8	7.50in.
Rotten :	38	3	12.67in.

Sum of duff depths: : 3.2 in.

Number observations : 8

Average duff depths : .40 in.

Sum of fuel depths : 16 in.

Number observations : 12

Average fuel depths : 1.33 in.

Sample site description:

Covertype; M.H.(85%), L.P.P.(10%), S.R.F.(5%)
forested area; 70.30%
average crown diameter; 28.18 feet
further information; Healthy forest with some patchy openings covered with grass

Applied Fuel Model: H

Table 25

Downed Woody Material Computation Summary

Study site # 15

FOREST: 1 COMPARTMENT: 1 STAND: 4

PLOCK : 5 SUBCOMPARTMENT : 3

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	86	0.0151	.48	1.13	1.00	24	0.34	I
.25 - 1	11.64	14	0.289	.48	1.13	1.00	24	1.06	II
1 - 3	11.64	7	2.76	.40	1.13	1.00	48	2.12	III
		Σd^2 for 3+							
3+ Sound	11.64	105		.40	1.00	1.00	200	5.18	IV
3+ Rotten	11.64	806		.30	1.00	1.00	200	14.07	V
						3+ Sound & Rotten = IV + V =		19.25	VI
						Total = I + II + III + VI =		22.77	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	27	7	3.86 in.
Rotten :	68	7	9.71 in.

Sum of duff depths: : 2.5 in. Sum of fuel depths : 10 in.

Number observations : 8 Number observations : 12

Average duff depths : 0.31 in. Average fuel depths : 0.83 in.

Sample site description:

Covertype; Mountain Hemlock (99%)
forested area; 71.92%
average crown diameter; 36.81 feet
further information; Healthy forest with some openings; understory regeneration of M.H.(about 8 ft. tall)

Applied Fuel Model: H

Table 26

Downed Woody Material Computation Summary

Study site # 16

FOREST: 1 COMPARTMENT: 1 STAND: 1

BLOCK #: 6 SUBCOMPARTMENT: 4

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	217	0.015	.48	1.13	1.00	24	0.86	I
.25 - 1	11.64	22	0.289	.48	1.13	1.00	24	1.67	II
1 - 3	11.64	5	2.76	.40	1.13	1.00	48	1.51	III
		Σd^2 for 3+							
3+ Sound	11.64	190		.40	1.00	1.00	200	4.42	IV
3+ Rotten	11.64	81		.30	1.00	1.00	200	1.41	V
						3+ Sound & Rotten = IV + V =		5.83	VI
						Total = I + II + III + VI =		9.87	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	36	7	5.14 in.
Rotten :	15	3	5.00 in.

Sum of duff depths: : 8.5 in. Sum of fuel depths : 19 in.

Number observations : 8 Number observations : 12

Average duff depths : 1.05 in. Average fuel depths : 1.58 in.

Sample site description:

Covertype; Mountain Hemlock (99%)
forested area; 17.53%
average crown diameter; 39.28 feet
further information; Scattered understory of Whitebark Pine (about 8 ft. tall)

Applied Fuel Model: H

Table 27

Downed Woody Material Computation Summary

Study site # 17

FOREST: 1 COMPARTMENT: 4 STAND: 2

BLOCK: 8 SUBCOMPARTMENT: 1

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	368	0.0151	.48	1.13	1.00	30	1.17	I
.25 - 1	11.64	19	0.289	.48	1.13	1.00	30	1.17	II
1 - 3	11.64	7	2.76	.40	1.13	1.00	60	1.69	III
		Σd^2 for 3+							
3+ Sound	11.64	~~1477~~		~~.40~~	~~1.00~~	~~1.00~~	~~250~~	~~27.51~~	IV
3+ Rotten	11.64	1021		.30	1.00	1.00	250	14.26	V
				3+ Sound & Rotten = IV + V =				41.77	VI
				Total = I + II + III + VI =				45.79	II

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	89	9	9.89 in.
Rotten :	87	10	8.70 in.

Sum of duff depths: : 9.2 in. Sum of fuel depths : 31 in.

Number observations : 10 Number observations : 15

Average duff depths : 0.92 in. Average fuel depths : 2.07 in.

Sample site description:

Covertype; Mountain Hemlock (99%)
forested area; 62.48%
average crown diameter; 41.55 feet
further information; Open forest; litter thickness does not exceed one inch

Applied Fuel Model: G

Table 28

Downed Woody Material Computation Summary

Study site # 18

FOREST: 1 COMPARTMENT: 2 STAND: 1

PLOCK #: 10 SUBCOMPARTMENT: 3

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	241	0.0151	.48	1.13	1.00	30	0.77	I
.25 - 1	11.64	10	0.289	.48	1.13	1.00	30	0.61	II
1 - 3	11.64	15	2.76	.40	1.13	1.00	60	3.63	III
			Σd^2 for 3+						
3+ Sound	11.64	609		.40	1.00	1.00	250	11.34	IV
3+ Rotten	11.64	4896		.30	1.00	1.00	250	68.39	V
							3+ Sound & Rotten = IV + V =	79.73	VI
							Total = I + II + III + VI =	84.74	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	69	11	6.27 in.
Rotten :	176	9	19.56 in.

Sum of duff depths: 12.1 in. Sum of fuel depths : 37 in.

Number observations : 10 Number observations : 15

Average duff depths : 1.21 in. Average fuel depths : 2.47 in.

Sample site description:

Covertype; Mountain Hemlock (99%)
forested area; 70.98%
average crown diameter; 37.20 feet
further information; Healthy forest with heavy downed woody material. Needle thickness about one inch.

Applied Fuel Model: G

Table 29

Downed Woody Material Computation Summary

Study site # 19

FOREST: 1 COMPARTMENT: 2 STAND: 4

BLOCK: 10 SUBCOMPARTMENT: 2

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	143	0.0159	.48	1.13	1.00	24	0.60	I
.25 - 1	11.64	19	0.297	.48	1.13	1.00	24	1.48	II
1 - 3	11.64	10	2.78	.40	1.13	1.00	48	3.05	III
		Σd^2 for 3+							
3+ Sound	11.64	543		.40	1.00	1.00	200	12.64	IV
3+ Rotten	11.64	1653		.30	1.00	1.00	200	28.86	V
				3+ Sound & Rotten = IV + V =				41.50	VI
				Total = I + II + III + VI =				46.63	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	69	11	6.27 in.
Rotten :	83	7	11.86 in.

Sum of duff depths: : 24.60 in. Sum of fuel depths : 23 in.

Number observations : 8 Number observations : 12

Average duff depths : 3.08 in. Average fuel depths : 1.92 in.

Sample site description:

Covertype; Mountain Hemlock(85%), Lodgepole Pine(15%)

forested area; 64.16%

average crown diameter; 28.88 feet

further information; Healthy forest ; needle thickness about one inch.

Applied Fuel Model: G

Table 30

Downed Woody Material Computation Summary

Study site # 20

FOREST: 1 COMPARTMENT: 3 STAND: 3

BLOCK: 10 SUBCOMPARTMENT: 3

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	78	0.0166	.48	1.13	1.00	30	0.27	I
.25 - 1	11.64	11	0.306	.48	1.13	1.00	30	0.71	II
1 - 3	11.64	7	2.79	.40	1.13	1.00	60	1.71	III
			Σd^2 for 3+						
3+ Sound	11.64	132		.40	1.00	1.00	250	2.46	IV
3+ Rotten	11.64	1654		.30	1.00	1.00	250	23.10	V
					3+ Sound & Rotten = IV + V =			25.56	VI
					Total = I + II + III + VI =			28.25	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	26	6	4.33 in.
Rotten :	104	7	14.86 in.

Sum of duff depths: : 14.40 in. Sum of fuel depths : 20 in.

Number observations : 10 Number observations : 15

Average duff depths : 1.44 in. Average fuel depths : 1.33 in.

Sample site description:

Covertype; Mountain Hemlock(70%), Lodgepole Pine(30%)
forested area; 53.27%
average crown diameter; 24.95 feet
further information; Healthy forest; downed woody material seem to be in rotten class if have larger diameters.(>10 in.)

Applied Fuel Model: H

Table 31

Downed Woody Material Computation Summary

Study site # 21

FOREST: 1 COMPARTMENT: 4 STAND: 2

BLOCK #: 11 SUBCOMPARTMENT: 4

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	137	0.0201	.48	1.13	1.00	30	0.58	I
.25 - 1	11.64	14	0.344	.48	1.13	1.00	30	1.01	II
1 - 3	11.64	1	2.87	.40	1.13	1.00	60	0.25	III
		Σd^2 for 3+							
3+ Sound	11.64	611		.40	1.00	1.00	250	11.38	IV
3+ Rotten	11.64	294		.30	1.00	1.00	250	4.11	V
						3+ Sound & Rotten = IV + V =		15.49	VI
						Total = I + II + III + VI =		17.33	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	51	6	8.50 in.
Rotten :	38	6	6.33 in.

Sum of duff depths: : 3.00 in.

Number observations : 10

Average duff depths : 0.3 in.

Sum of fuel depths : 27 in.

Number observations : 15

Average fuel depths : 1.80 in.

Sample site description:

Covertype; Lodgepole Pine (99%)
forested area; 25.80%
average crown diameter; 14.73 feet
further information; Young forest with some patchy openings covered with grass

Applied Fuel Model: U

Table 32

Downed Woody Material Computation Summary

Study site # 22

FOREST: 1 COMPARTMENT: 4 STAND: 4

BLOCK: 11 SUBCOMPARTMENT: 2

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	118	0.0189	.48	1.13	1.00	30	0.47	I
.25 - 1	11.64	12	0.330	.48	1.13	1.00	30	0.83	II
1 - 3	11.64	8	2.84	.40	1.13	1.00	60	1.99	III
		Σd^2 for 3+							
3+ Sound	11.64	294		.40	1.00	1.00	250	5.48	IV
3+ Rotten	11.64	167		.30	1.00	1.00	250	2.33	V
							3+ Sound & Rotten = IV + V =	7.81	VI
							Total = I + II + III + VI =	11.10	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	56	12	4.67 in.
Rotten :	33	7	4.71 in.

Sum of duff depths: : 7.30 in. Sum of fuel depths : 22 in.

Number observations : 10 Number observations : 15

Average duff depths : 0.73 in. Average fuel depths : 1.47 in.

Sample site description:

Covertype; Lodgepole Pine (75%), Mountain Hemlock (25%)
forested area; 18.26%
average crown diameter; 12.50 feet
further information; Some patchy areas with annual grass in the openings of the forest

Applied Fuel Model: U

Table 33

Downed Woody Material Computation Summary

Study site # 23

FOREST: 1 COMPARTMENT: 2 STAND: 2

BLOCK: 10 SUBCOMPARTMENT: 2

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	156	0.0194	.48	1.13	1.00	24	0.80	I
.25 - 1	11.64	16	0.336	.48	1.13	1.00	24	1.41	II
1 - 3	11.64	6	2.85	.40	1.13	1.00	48	1.87	III
		Σd^2 for 3+							
3+ Sound	11.64	97		.40	1.00	1.00	200	2.26	IV
3+ Rotten	11.64	394		.30	1.00	1.00	200	6.88	V
				3+ Sound & Rotten = IV + V =				9.14	VI
				Total = I + II + III + VI =				13.22	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	19	4	4.75 in.
Rotten :	44	6	7.33 in.

Sum of duff depths: : 4.2 in. Sum of fuel depths : 10 in.

Number observations : 8 Number observations : 15

Average duff depths : 0.53 in. Average fuel depths : 0.67 in.

Sample site description:

Covertype; Lodgepole Pine (85%), and Mountain Hemlock (15%)
forested area; 57.17%
average crown diameter; 28.97 feet
further information; Understory of Mountain Hemlock with 5-8 feet tall

Applied Fuel Model: U

Table 34

Downed Woody Material Computation Summary

Study area # 24

FOREST: 1 COMPARTMENT: 3 STAND: 2

BLOCK: 7 SUBCOMPARTMENT: 3

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	119	0.0161	.48	1.13	1.00	24	0.50	I
.25 - 1	11.64	19	0.300	.48	1.13	1.00	24	1.50	II
1 - 3	11.64	5	2.78	.40	1.13	1.00	48	1.52	III
		Σd^2 for 3+							
3+ Sound	11.64	175		.40	1.00	1.00	200	4.07	IV
3+ Rotten	11.64	77		.30	1.00	1.00	200	1.34	V
					3+ Sound & Rotten = IV + V =			5.41	VI
					Total = I + II + III + VI =			8.93	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	31	6	5.17 in.
Rotten :	17	4	4.25 in.

Sum of duff depths: : 6.00 in. Sum of fuel depths : 21 in.

Number observations : 8 Number observations : 12

Average duff depths : 0.75 in. Average fuel depths : 1.75 in.

Sample site description:

Covertype; M.H.(50%),S.R.F.(30%), and L.P.P.(20%)
forested area; 71.10%
average crown diameter; 28.22 feet
further information; Healthy forest

Applied Fuel Model: H

Table 35

Downed Woody Material Computation Summary

Study area # 25

FOREST: 1 COMPARTMENT: 3 STAND: 2

BLOCK : 7 SUBCOMPARTMENT : 4

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	182	0.0161	.48	1.13	1.00	24	0.77	I
.25 - 1	11.64	19	0.300	.48	1.13	1.00	24	1.50	II
1 - 3	11.64	5	2.78	.40	1.13	1.00	48	1.52	III
		Σd^2 for 3+							
3+ Sound	11.64	123		.40	1.00	1.00	160	3.58	IV
3+ Rotten	11.64	25		.30	1.00	1.00	160	0.55	V
				3+ Sound & Rotten = IV + V =				4.13	VI
				Total = I + II + III + VI =				7.92	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	23	5	4.60 in.
Rotten :	5	1	5.00 in.

Sum of duff depths: : 32.40 in. Sum of fuel depths : 12 in.

Number observations : 8 Number observations : 12

Average duff depths : 4.05 in. Average fuel depths : 1.00 in.

Sample site description:

Covertype; M.H. (40%), S.R.F. (40%), and L.P.P. (20%)
forested area; 78.44%
average crown diameter; 22.47 feet
further information; Very young forest, average heights of M.H. and S.R.F. species about 50-60 feet

Applied Fuel Model: H

Table 36

Downed Woody Material Computation Summary

Study area # 26

FOREST: 1 COMPARTMENT: 3 STAND: 1

BLOCK #: 7 SUBCOMPARTMENT: 4

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	211	0.0196	.48	1.13	1.00	24	1.09	I
.25 - 1	11.64	27	0.339	.48	1.13	1.00	24	2.41	II
1 - 3	11.64	3	2.86	.40	1.13	1.00	48	0.94	III
		Σd^2 for 3+							
3+ Sound	11.64	125		.40	1.00	1.00	160	3.64	IV
3+ Rotten	11.64	674		.30	1.00	1.00	160	14.71	V
						3+ Sound & Rotten = IV + V =		18.35	VI
						Total = I + II + III + VI =		22.79	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	25	6	4.17 in.
Rotten :	44	3	14.67 in.

Sum of duff depths: : 33.30 in. Sum of fuel depths : 38 in.

Number observations : 8 Number observations : 12

Average duff depths : 4.16 in. Average fuel depths : 3.17 in.

Sample site description:

Covertype; Lodgepole Pine (90%), Mountain Hemlock (10%)
forested area; 86.88%
average crown diameter; 22.48 feet
further information; Understory regeneration of both species 4-7 feet in hieght

Applied Fuel Model: U

Table 37

Downed Woody Material Computation Summary

Study area # 27

FOREST: 1 COMPARTMENT: 4 STAND: 1

BLOCK #: 7 SUBCOMPARTMENT: 3

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	142	0.0191	.48	1.13	1.00	30	0.57	I
.25 - 1	11.64	30	0.333	.48	1.13	1.00	30	2.10	II
1 - 3	11.64	23	2.85	.40	1.13	1.00	50	6.90	III
		Σd^2 for 3+							
3+ Sound	11.64	863		.40	1.00	1.00	175	22.96	IV
3+ Rotten	11.64	82		.30	1.00	1.00	175	1.64	V
						3+ Sound & Rotten = IV + V =		24.60	VI
						Total = I + II + III + VI =		34.17	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	193	46	4.20 in.
Rotten :	22	6	3.67 in.

Sum of duff depths: : 12.2 in. Sum of fuel depths : 36 in.

Number observations : 10 Number observations : 15

Average duff depths : 1.22 in. Average fuel depths : 2.40 in.

Sample site description:

Covertype; Lodgepole Pine (80%), and Mountain Hemlock (20%)
forested area; 65.48%
average crown diameter; 18.05 feet
further information; Downed woody material most in sound class category

Applied Fuel Model: G

Table 38

Downed Woody Material Computation Summary

Study site # 28

FOREST: 1 COMPARTMENT: 4 STAND: 4

BLOCK : 7 SUBCOMPARTMENT : 2

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	248	0.0151	.48	1.13	1.00	24	0.99	I
.25 - 1	11.64	34	0.289	.48	1.13	1.00	24	2.58	II
1 - 3	11.64	10	2.76	.40	1.13	1.00	40	3.63	III
		Σd^2 for 3+							
3+ Sound	11.64	434		.40	1.00	1.00	140	14.43	IV
3+ Rotten	11.64	1184		.30	1.00	1.00	140	29.53	V
				3+ Sound & Rotten = IV + V =				43.96	VI
				Total = I + II + III + VI =				51.16	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	48	8	6.0 in.
Rotten :	90	10	9.0 in.

Sum of duff depths: : 48.10 in. Sum of fuel depths : 57 in.

Number observations : 8 Number observations : 12

Average duff depths : 6.01 in. Average fuel depths : 4.75 in.

Sample site description:

Covertype; Shasta Red Fir(70%), and Mountain Hemlock(30%)
forested area; 84.10%
average crown diameter; 37.68 feet
further information; Understory of both species with 20-30 feet height

Applied Fuel Model: 0

Table 39

Downed Woody Material Computation Summary

Study site # 29

FOREST: 1 COMPARTMENT: 4 STAND: 4

BLOCK : 7 SUBCOMPARTMENT : 1

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	348	0.0151	.48	1.13	1.01	24	1.40	I
.25 - 1	11.64	25	0.289	.48	1.13	1.01	24	1.92	II
1 - 3	11.64	7	2.76	.40	1.13	1.01	48	2.14	III
		Σd^2 for 3+							
3+ Sound	11.64	241		.40	1.00	1.01	160	2.08	IV
3+ Rotten	11.64	246		.30	1.00	1.01	160	5.42	V
				3+ Sound & Rotten = IV + V =				12.50	VI
				Total = I + II + III + VI =				17.96	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	41	8	5.13 in.
Rotten :	31	4	7.75 in.

Sum of duff depths: : 3.6 in. Sum of fuel depths : 44 in.

Number observations : 8 Number observations : 12

Average duff depths : 0.45 in. Average fuel depths : 3.67 in.

Sample site description:

Covertype; S.R.F.(85%),M.H.(10%), and W.White Pine (5%)
forested area; 86.59%
average crown diameter; 26.91 feet
further information; Most of the stands are very young

Applied Fuel Model: H

Table 40

Downed Woody Material Computation Summary

Study site # 30

FOREST: 1 COMPARTMENT: 3 STAND: 4

BLOCK: 2 SUBCOMPARTMENT: 2

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	14	0.0201	.48	1.13	1.00	30	0.06	I
.25 - 1	11.64	4	0.344	.48	1.13	1.00	30	0.29	II
1 - 3	11.64	00	2.86	.40	1.13	1.00	60	0.00	III
		Σd^2 for 3+							
3+ Sound	11.64	0.00		.40	1.00	1.00	250	0.00	IV
3+ Rotten	11.64	0.00		.30	1.00	1.00	250	0.00	V
							3+ Sound & Rotten = IV + V =	0.00	VI
							Total = I + II + III + VI =	0.35	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	0.00	00	0.00 in.
Rotten :	0.00	00	0.00 in.

Sum of duff depths: : 1.00 in. Sum of fuel depths : 4.00 in.

Number observations : 10 Number observations : 15

Average duff depths : 0.10 in. Average fuel depths : 0.27 in.

Sample site description:

Covertype; Lodgepole Pine (99%)
forested area; 11.21%
crown diameter; 11.80 feet average
further information; Sparsely forested area with out lands understory vegetation- transition of Pumice Desert to forest

Applied Fuel Model: No applicable NFDR Fuel Model was thought.

Table 41

Downed Woody Material Computation Summary

Study site # 31

FOREST: 1 COMPARTMENT: 3 STAND: 2

BLOCK : 2 SUBCOMPARTMENT : 2

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	50	0.0194	.48	1.13	1.00	30	0.20	I
.25 - 1	11.64	6	0.336	.48	1.13	1.00	30	0.42	II
1 - 3	11.64	3	2.85	.40	1.13	1.00	60	0.75	III
		Σd^2 for 3+							
3+ Sound	11.64	61		.40	1.00	1.00	250	1.14	IV
3+ Rotten	11.64	923		.30	1.00	1.00	250	12.89	V
							3+ Sound & Rotten = IV + V =	14.03	VI
							Total = I + II + III + VI =	15.40	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	13	3	4.33 in.
Rotten :	93	11	8.45 in.

Sum of duff depths: : 8.8 in. Sum of fuel depths : 22 in.

Number observations : 10 Number observations : 15

Average duff depths : 0.88 in. Average fuel depths : 1.47 in.

Sample site description:

Covertype; L.P.P.(85%), S.R.F.(10%), and White Fir (5%)
forested area; 30.11%
crown diameter; 16.20 feet average
further information; Sampling site reveals previous forest fire signes.

Applied Fuel Model: H

Table 42

Downed Woody Material Computation Summary

Study site # 32

FOREST: 1 COMPARTMENT: 1 STAND: 2

BLOCK: 3 SUBCOMPARTMENT: 4

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre
0 - .25	11.64	162	0.0151	.48	1.13	1.00	30	0.51 I
.25 - 1	11.64	7	.289	.48	1.13	1.00	30	0.43 II
1 - 3	11.64	9	2.76	.40	1.13	1.00	60	2.18 III
			Σd^2 for 3+					
3+ Sound	11.64	1288		.40	1.00	1.00	250	23.99 IV
3+ Rotten	11.64	1633		.30	1.00	1.00	250	22.81 V
						3+ Sound & Rotten = IV + V =		46.80 VI
						Total = I + II + III + VI =		49.98 II

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	128	17	7.53 in.
Rotten :	67	4	16.74 in.

Sum of duff depths: : 10.70 in. Sum of fuel depths : 52 in.

Number observations : 10 Number observations : 15

Average duff depths : 1.07 in. Average fuel depths : 3.47 in.

Sample site description:

Covertype; Mountain Hemlock (99%)
forested area; 88.49%
crown diameter; 43.88 feet average
further information; Open forest with heavy accumulation of downed woody material

Applied Fuel Model: G

Table 43

Downed Woody Material Computation Summary

Study site # 33

FOREST: 1 COMPARTMENT: 1 STAND: 1

BLOCK : 3 SUBCOMPARTMENT : 4

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	120	0.0186	.48	1.13	1.00	30	0.47	I
.25 - 1	11.64	16	0.328	.48	1.13	1.00	30	1.10	II
1 - 3	11.64	5	2.84	.40	1.13	1.00	60	1.25	III
		Σd^2 for 3+							
3+ Sound	11.64	222		.40	1.00	1.00	250	4.13	IV
3+ Rotten	11.64	665		.30	1.00	1.00	250	9.29	V
							3+ Sound & Rotten = IV + V =	13.42	VI
							Total = I + II + III + VI =	16.24	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	28	4	7.00 in.
Rotten :	87	12	7.25 in.

Sum of duff depths: : 9.70 in. Sum of fuel depths : 20 in.

Number observations : 10 Number observations : 15

Average duff depths : 0.97 in. Average fuel depths : 1.33 in.

Sample site description:

Covertype; L.P.P.(70%), M.H.(25%), and S.R.F.(5%)
forested area; 40.69%
crown diameter; 20.81 feet average
further information; Healthy forest

Applied Fuel Model: H

Table 44

Downed Woody Material Computation Summary

Study site # 34

FOREST: 1 COMPARTMENT: 4 STAND: 2

BLOCK #: 8 SUBCOMPARTMENT: 3

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	238	0.0151	.48	1.13	1.00	24	0.95	I
.25 - 1	11.64	19	0.289	.48	1.13	1.00	24	1.44	II
1 - 3	11.64	8	2.76	.40	1.13	1.00	48	2.42	III
		Σd^2 for 3+							
3+ Sound	11.64	667		.40	1.00	1.00	200	15.53	IV
3+ Rotten	11.64	482		.30	1.00	1.00	200	8.42	V
						3+ Sound & Rotten = IV + V =		23.95	VI
						Total = I + II + III + VI =		28.76	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	63	8	7.88 in.
Rotten :	42	5	8.40 in.

Sum of duff depths: : 7.7 in. Sum of fuel depths : 105 in.

Number observations : 8 Number observations : 12

Average duff depths : 0.96 in. Average fuel depths : 8.75 in.

Sample site description:

Covertype; Mountain Hemlock (80%), and Shasta Red Fir(20%)
forested area; 72.40%
crown diameter; 29.86 feet average
further information; Grass covertype has occupied 50% of the area in study site

Applied Fuel Model: C

Table 45

Downed Woody Material Computation Summary

Study site # 35

FOREST: 1 COMPARTMENT: 1 STAND: 2

BLOCK: 11 SUBCOMPARTMENT: 1

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	194	0.0151	.48	1.13	1.00	24	0.27	I
.25 - 1	11.64	19	0.289	.48	1.13	1.00	24	1.44	II
1 - 3	11.64	7	2.76	.40	1.13	1.00	48	2.12	III
		Σd^2 for 3+							
3+ Sound	11.64	391		.40	1.00	1.00	200	9.10	IV
3+ Rotten	11.64	131		.30	1.00	1.00	200	2.29	V
				3+ Sound & Rotten = IV + V =				11.39	VI
				Total = I + II + III + VI =				15.72	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	41	5	8.20 in.
Rotten :	19	3	6.33 in.

Sum of duff depths: : 19 in. Sum of fuel depths : 26 in.

Number observations : 8 Number observations : 12

Average duff depths : 2.38 in. Average fuel depths : 2.17 in.

Sample site description:

Covertype; Mountain Hemlock (60%), and Shasta Red Fir (40%)

forested area; 52.20%

crown diameter; 31.47 feet average

further information; Needle coverage 1-2 inches on the forest floor

Applied Fuel Model: H

Table 46

Downed Woody Material Computation Summary

Study site # 36

FOREST: 1 COMPARTMENT: 3 STAND: 3

BLOCK: 11 SUBCOMPARTMENT: 4

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	157	0.0159	.48	1.13	1.00	42	0.38	I
.25 - 1	11.64	18	0.297	.48	1.13	1.00	42	0.80	II
1 - 3	11.64	5	2.78	.40	1.13	1.00	84	0.87	III
		Σd^2 for 3+							
3+ Sound	11.64	542		.40	1.00	1.00	280	9.01	IV
3+ Rotten	11.64	175		.30	1.00	1.00	280	2.18	V
							3+ Sound & Rotten = IV + V =	11.19	VI
							Total = I + II + III + VI =	13.24	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	58	9	6.44 in.
Rotten :	29	5	5.80 in.

Sum of duff depths: : 22.40 in. Sum of fuel depths : 44 in.

Number observations : 14 Number observations : 21

Average duff depths : 1.60 in. Average fuel depths : 2.10 in.

Sample site description:

Covertype; Shasta Red Fir (60%), M.H.(25%), and L.P.P. (15%)

forested area; 73.84%

crown diameter; 27.81 feet average

further information; Scattered grass on forest floor

Applied Fuel Model: H

Table 47

Downed Woody Material Computation Summary

Study site # 37

FOREST: 1 COMPARTMENT: 3 STAND: 3

BLOCK: 11 SUBCOMPARTMENT: 3

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	82	0.0227	.48	1.13	1.00	24	0.49	I
.25 - 1	11.64	22	0.269	.48	1.13	1.00	24	1.56	II
1 - 3	11.64	7	2.90	.40	1.13	1.00	48	2.23	III
		Σd^2 for 3+							
3+ Sound	11.64	25		.40	1.00	1.00	200	0.58	IV
3+ Rotten	11.64	1696		.30	1.00	1.00	200	29.61	V
							3+ Sound & Rotten = IV + V =	30.19	VI
							Total = I + II + III + VI =	34.47	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	5	1	5.0 in.
Rotten :	64	3	21.33 in.

Sum of duff depths: : 17.40 in. Sum of fuel depths : 42 in.

Number observations : 8 Number observations : 12

Average duff depths : 2.18 in. Average fuel depths : 3.50 in.

Sample site description:

Covertype; White Fir (40%), Ponderosa P.(40%), and SRF (20%)
forested area; 83.59%
crown diameter; 24.46 feet average
further information; Open forest with scattered downed woody material (most in rotten size class)

Applied Fuel Model: C

Table 48

Downed Woody Material Computation Summary

Study site # 38

FOREST: 1 COMPARTMENT: 1 STAND: 2

PLOCK : 15 SUBCOMPARTMENT : 4

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	105	0.0161	.48	1.13	1.00	30	0.36	I
.25 - 1	11.64	32	0.286	.48	1.13	1.00	30	1.93	II
1 - 3	11.64	7	2.78	.40	1.13	1.00	60	1.71	III
		Σd^2 for 3+							
3+ Sound	11.64	367		.40	1.00	1.00	250	6.84	IV
3+ Rotten	11.64	566		.30	1.00	1.00	250	7.91	V
							3+ Sound & Rotten = IV + V =	14.75	VI
							Total = I + II + III + VI =	18.75	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	83	21	3.95 in.
Rotten :	36	4	9.00 in.

Sum of duff depths: : 10.50 in. Sum of fuel depths : 47 in.

Number observations : 10 Number observations : 15

Average duff depths : 1.05 in. Average fuel depths : 3.13 in.

Sample site description:

Covertype; White Fir(80%), S.R.F.(15%), and Ponderosa P. (5%)

forested area; 36.36%

crown diameter; 22.83 feet average

further information; Healthy forest - downed woody material most in 3-5 in. size class.

Applied Fuel Model: H

Table 49

Downed Woody Material Computation Summary

Study site # 39

FOREST: 1 COMPARTMENT: 1 STAND: 3

BLOCK: 15 SUBCOMPARTMENT: 4

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	62	0.0227	.48	1.13	1.00	30	0.30	I
.25 - 1	11.64	11	0.269	.48	1.13	1.00	30	0.62	II
1 - 3	11.64	10	2.90	.40	1.13	1.00	60	2.54	III
		Σd^2 for 3+							
3+ Sound	11.64	789		.40	1.00	1.00	250	14.69	IV
3+ Rotten	11.64	3012		.30	1.00	1.00	250	42.07	V
							3+ Sound & Rotten = IV + V =	56.76	VI
							Total = I + II + III + VI =	60.22	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	73	13	5.62 in.
Rotten :	110	7	15.71 in.

Sum of duff depths: : 18.20 in. Sum of fuel depths : 59 in.

Number observations : 10 Number observations : 15

Average duff depths : 1.82 in. Average fuel depths : 3.93 in.

Sample site description:

Covertype; White Fir (60%), and Ponderosa Pine (40%)
forested area; 64.95%
crown diameter; 33.17 feet average
further information; understory of white fir most 10 ft. tall.

Applied Fuel Model: G

Table 50

Downed Woody Material Computation Summary

Study site # 40

FOREST: 1 COMPARTMENT: 1 STAND: 4

PLOCK: 15 SUBCOMPARTMENT: 3

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	37	0.0199	.48	1.13	1.00	24	0.46	I
.25 - 1	11.64	25	.276	.48	1.13	1.00	24	1.82	II
1 - 3	11.64	5	2.85	.40	1.13	1.00	48	1.56	III
		Σd^2 for 3+							
3+ Sound	11.64	982		.40	1.00	1.00	200	22.86	IV
3+ Rotten	11.64	169		.30	1.00	1.00	200	2.95	V
				3+ Sound & Rotten = IV + V =				25.81	VI
				Total = I + II + III + VI =				29.65	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	74	9	8.22 in.
Rotten :	17	2	8.50 in.

Sum of duff depths: : 3.90 in. Sum of fuel depths : 28 in.

Number observations : 8 Number observations : 12

Average duff depths : 0.49 in. Average fuel depths : 2.33 in.

Sample site description:

Covertype; White Fir(60%), Ponderosa P.(25%), M.H.(15%)
forested area; 77.33%
crown diameter; 31.39 feet average
further information; Forest floor is covered with Ponderosa Pine needles or Manzanita brush
Applied Fuel Model: U

Table 51

Downed Woody Material Computation Summary

Study site # 41

FOREST: 1 COMPARTMENT: 2 STAND: 2

BLOCK : 6 SUBCOMPARTMENT : 2

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	19	0.0342	.48	1.13	1.00	30	0.14	I
.25 - 1	11.64	8	0.238	.48	1.13	1.00	30	0.40	II
1 - 3	11.64	4	3.12	.40	1.13	1.00	60	1.09	III
		Σd^2 for 3+							
3+ Sound	11.64	410		.40	1.00	1.00	250	7.64	IV
3+ Rotten	11.64	606		.30	1.00	1.00	250	8.46	V
							3+ Sound & Rotten = IV + V =	16.10	VI
							Total = I + II + III + VI =	17.73	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	38	5	7.60 in.
Rotten :	52	7	7.43 in.

Sum of duff depths: : 3.80 in. Sum of fuel depths : 15 in.

Number observations : 10 Number observations : 15

Average duff depths : 0.38 in. Average fuel depths : 1.00 in.

Sample site description:

Covertype; Ponderosa Pine (99%)
forested area; 60.93%
crown diameter; 47.41 feet average
further information; Healthy open forest

Applied Fuel Model: C

Table 52

Downed Woody Material Computation Summary

Study site # 42

FOREST: 1 COMPARTMENT: 2 STAND: 2

BLOCK: 3 SUBCOMPARTMENT: 3

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	80	0.0335	.48	1.13	1.00	30	0.56	I
.25 - 1	11.64	19	0.243	.48	1.13	1.00	30	0.97	II
1 - 3	11.64	11	3.11	.40	1.13	1.00	60	3.00	III
		Σd^2 for 3+							
3+ Sound	11.64	318		.40	1.00	1.00	250	5.92	IV
3+ Rotten	11.64	16		.30	1.00	1.00	250	0.22	V
				3+ Sound & Rotten = IV + V =				6.14	VI
				Total = I + II + III + VI =				10.67	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	36	6	6.00 in.
Rotten :	4	1	4.00 in.

Sum of duff depths: : 9.60 in. Sum of fuel depths : 35 in.

Number observations : 10 Number observations : 15

Average duff depths : 0.96 in. Average fuel depths : 2.33 in.

Sample site description:

Covertype; Ponderosa Pine(95%), Lodgepole Pine(5%)
forested area; 77.21%
crown diameter; 47.09 feet average
further information; Heavy accumulation of litter on forest floor.

Applied Fuel Model: C

Table 53

Downed Woody Material Computation Summary

Study site # 43

FOREST: 1 COMPARTMENT: 3 STAND: 2

PLOCK #: 3 SUBCOMPARTMENT #: 3

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	61	0.0208	.48	1.13	1.00	30	0.27	I
.25 - 1	11.64	6	0.339	.48	1.13	1.00	30	0.43	II
1 - 3	11.64	0	2.88	.40	1.13	1.00	60	0.00	III
		Σd^2 for 3+							
3+ Sound	11.64	25		.40	1.00	1.00	250	0.47	IV
3+ Rotten	11.64	221		.30	1.00	1.00	250	3.09	V
						3+ Sound & Rotten = IV + V =		3.56	VI
						Total = I + II + III + VI =		4.26	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	7	2	3.50 in.
Rotten :	21	2	10.50 in.

Sum of duff depths: : 9.20 in. Sum of fuel depths : 16 in.

Number observations : 10 Number observations : 12

Average duff depths : 0.92 in. Average fuel depths : 1.33 in.

Sample site description:

Covertype; Lodgepole Pine(95%),and Ponderosa Pine(5%)

forested area; 39.24%

crown diameter; 18.43 feet average

further information; Bitter brush in the openings

Applied Fuel Model: U

Table 54

Downed Woody Material Computation Summary

Study site # 44

FOREST: 1 COMPARTMENT: 3 STAND: 4

BLOCK: 2 SUBCOMPARTMENT: 4

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $\frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $\frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	126	0.0169	.48	1.13	1.00	30	0.45	I
.25 - 1	11.64	14	0.308	.48	1.13	1.00	30	0.91	II
1 - 3	11.64	3	2.80	.40	1.13	1.00	60	0.74	III
		Σd^2 for 3+							
3+ Sound	11.64	335		.40	1.00	1.00	300	5.20	IV
3+ Rotten	11.64	1831		.30	1.00	1.00	300	21.31	V
							3+ Sound & Rotten = IV + V =	26.51	VI
							Total = I + II + III + VI =	28.61	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	39	5	7.80 in.
Rotten :	147	14	10.50 in.

Sum of duff depths: : 7.10 in. Sum of fuel depths : 47 in.

Number observations : 10 Number observations : 15

Average duff depths : 0.71 in. Average fuel depths : 3.13 in.

Sample site description:

Covertype; M.H.(60%),L.P.P.(35%),and Western W.P.(5%)
forested area; 75.88%
crown diameter; 36.93 feet average
further information; Downed woody material most in rotten size class

Applied Fuel Model: H

Table 55

Downed Woody Material Computation Summary

Study site # 45

FOREST: 1 COMPARTMENT: 4 STAND: 2

BLOCK: 2 SUBCOMPARTMENT: 3

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	120	0.0194	.48	1.13	1.00	36	0.41	I
.25 - 1	11.64	7	0.336	.48	1.13	1.00	36	0.41	II
1 - 3	11.64	5	2.85	.40	1.13	1.00	72	1.04	III
			Σd^2 for 3+						
3+ Sound	11.64	414		.40	1.00	1.00	300	6.43	IV
3+ Rotten	11.64	891		.30	1.00	1.00	300	10.37	V
						3+ Sound & Rotten = IV + V =		16.80	VI
						Total = I + II + III + VI =		18.66	VII

	Sum of 3+-inch diameters	Number/ of pieces	Average diameter
Sound :	46	6	7.67 in.
Rotten :	87	10	8.70 in.

Sum of duff depths: : 26.70 in.

Number observations : 12

Average duff depths : 2.23 in.

Sum of fuel depths : 64 in.

Number observations : 18

Average fuel depths : 3.56 in.

Sample site description:

Covertype; Lodgepole Pine(85%), and Mountain Hemlock (15%)
forested area; 35.49%
crown diameter; 18.62 feet average
further information; open forest; no ground vegetation

Applied Fuel Model: H

Table 56

Downed Woody Material Computation Summary

Study site # 46

FOREST: 1 COMPARTMENT: 2 STAND: 2

BLOCK : 2 SUBCOMPARTMENT : 4

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	127	0.0201	.48	1.13	1.00	42	0.53	I
.25 - 1	11.64	22	0.344	.48	1.13	1.00	42	1.14	II
1 - 3	11.64	9	2.87	.40	1.13	1.00	70	1.94	III
		Σd^2 for 3+							
3+ Sound	11.64	252		.40	1.00	1.00	280	4.19	IV
3+ Rotten	11.64	1316		.30	1.00	1.00	280	16.41	V
							3+ Sound & Rotten = IV + V =	20.60	VI
							Total = I + II + III + VI =	24.21	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	49	10	4.90 in.
Rotten :	92	7	13.14 in.

Sum of duff depths: : 6.60 in. Sum of fuel depths : 72 in.

Number observations : 14 Number observations : 21

Average duff depths : 0.47 in. Average fuel depths : 3.43 in.

Sample site description:

Covertype; Lodgepole Pine(99%)
forested area; 31.37%
crown diameter; 15.97 feet average
further information; Ground vegetation about 6 inches tall.

Applied Fuel Model: H

Table 57

Downed Woody Material Computation Summary

Study site # 47

FOREST: 1 COMPARTMENT: 2 STAND: 1

BLOCK #: 2 SUBCOMPARTMENT: 2

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	142	0.0201	.48	1.13	1.01	36	0.52	I
.25 - 1	11.64	16	0.344	.48	1.13	1.01	36	0.97	II
1 - 3	11.64	8	2.87	.40	1.13	1.01	72	1.69	III
		Σd^2 for 3+							
3+ Sound	11.64	173		.40	1.00	1.01	300	2.71	IV
3+ Rotten	11.64	1083		.30	1.00	1.01	300	12.73	V
				3+ Sound & Rotten = IV + V =				15.44	VI
				Total = I + II + III + VI =				18.62	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	21	3	7.0 in.
Rotten :	97	10	9.70 in.

Sum of duff depths: : 4.80 in. Sum of fuel depths : 25 in.

Number observations : 12 Number observations : 18

Average duff depths : 0.40 in. Average fuel depths : 1.39 in.

Sample site description:

Covertype; Lodgepole Pine (99%)
forested area; 21.24% average
crown diameter; 17.72 feet
further information; Open forest; large downed woody material in rotten size class exceeds that of sound class

Applied Fuel Model: H

Table 58

Downed Woody Material Computation Summary

Study site # 48

FOREST: 1 COMPARTMENT: 2 STAND: 3

BLOCK: 2 SUBCOMPARTMENT: 1

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	27	0.0201	.48	1.13	1.00	24	0.41	I
.25 - 1	11.64	13	0.344	.48	1.13	1.00	24	1.18	II
1 - 3	11.64	3	2.87	.40	1.13	1.00	48	0.94	III
		Σd^2 for 3+							
3+ Sound	11.64	372		.40	1.00	1.00	160	10.83	IV
3+ Rotten	11.64	1188		.30	1.00	1.00	160	25.93	V
							3+ Sound & Rotten = IV + V =	36.76	VI
							Total = I + II + III + VI =	39.29	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	50	8	6.25 in.
Rotten :	108	11	9.82 in.

Sum of duff depths: : 6.80 in.

Number observations : 8

Average duff depths : 0.85 in.

Sum of fuel depths : 18 in.

Number observations : 12

Average fuel depths : 1.50 in.

Sample site description:

Covertype; Lodgepole Pine (99%)
forested area; 65.25%
crown diameter; 20.40 feet average
further information; Understory of Logepole Pine regeneration.

Applied Fuel Model: G

Table 59

Downed Woody Material Computation Summary

Study site # 49

FOREST: 1 COMPARTMENT: 2 STAND: 4

BLOCK: 11 SUBCOMPARTMENT: 2

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	265	0.0151	.48	1.13	1.00	30	0.84	I
.25 - 1	11.64	24	0.289	.48	1.13	1.00	30	1.46	II
1 - 3	11.64	6	2.76	.40	1.13	1.00	60	1.45	III
		Σd^2 for 3+							
3+ Sound	11.64	331		.40	1.00	1.00	250	6.16	IV
3+ Rotten	11.64	747		.30	1.00	1.00	250	10.43	V
				3+ Sound & Rotten = IV + V =				16.59	VI
				Total = I + II + III + VI =				20.34	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	31	4	7.75 in.
Rotten :	65	8	8.13 in.

Sum of duff depths: : 15.60 in. Sum of fuel depths : 29 in.

Number observations : 10 Number observations : 15

Average duff depths : 1.56 in. Average fuel depths : 1.93 in.

Sample site description:

Covertype; M.H.(55%), S.R.F.(40%),and Grass(5%)
forested area; 83.64%
crown diameter; 26.81 feet average
further information; Patchy grassy areas; open forest

Applied Fuel Model: H

Table 60

Downed Woody Material Computation Summary

Study site # 50

FOREST: 1 COMPARTMENT: 2 STAND: 1

BLOCK: 11 SUBCOMPARTMENT: 3

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	65	0.0151	.48	1.13	1.06	24	0.27	I
.25 - 1	11.64	10	0.289	.48	1.13	1.06	24	0.81	II
1 - 3	11.64	4	2.76	.40	1.13	1.06	48	1.28	III
		Σd^2 for 3+							
3+ Sound	11.64	209		.40	1.13	1.06	200	5.16	IV
3+ Rotten	11.64	41		.30	1.13	1.06	200	0.76	V
							3+ Sound & Rotten = IV + V =	5.92	VI
							Total = I + II + III + VI =	8.28	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	23	3	7.67 in.
Rotten :	9	2	4.50 in.

Sum of duff depths: : 1.70 in. Sum of fuel depths : 13 in.

Number observations : 8 Number observations : 12

Average duff depths : 0.21 in. Average fuel depths : 1.08 in.

Sample site description:

Covertype; S.R.F.(50%), White Bark P.(40%),and M.H.(10%)
forested area; 29.03%
crown diameter; 21.75 feet average
further information; Sparse grassy areas over 70% of the forest floor

Applied Fuel Model: A

Table 61

Downed Woody Material Computation Summary

Study site # 51

FOREST: 1 COMPARTMENT: 2 STAND: 3

BLOCK : 11 SUBCOMPARTMENT : 3

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	148	0.0151	.48	1.13	1.01	30	0.48	I
.25 - 1	11.64	38	0.289	.48	1.13	1.01	30	2.33	II
1 - 3	11.64	16	2.76	.40	1.13	1.01	60	3.91	III
		Σd^2 for 3+							
3+ Sound	11.64	285		.40	1.13	1.01	300	4.47	IV
3+ Rotten	11.64	1359		.30	1.13	1.01	300	15.98	V
							3+ Sound & Rotten = IV + V =	20.45	VI
							Total = I + II + III + VI =	27.17	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	43	9	7.48 in.
Rotten :	79	7	11.29 in.

Sum of duff depths: : 22.00 in. Sum of fuel depths : 71 in.

Number observations : 10 Number observations : 15

Average duff depths : 2.20 in. Average fuel depths : 4.73 in.

Sample site description:

Covertype; Shasta Red Fir (99%)
forested area; 89.83%
crown diameter; 26.81 feet average
further information; ---

Applied Fuel Model: H

Table 62

Downed Woody Material Computation Summary

Study site # 52

FOREST: 1 COMPARTMENT: 2 STAND: 3

BLOCK #: 7 SUBCOMPARTMENT: 1

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	125	0.0189	.48	1.13	1.00	30	0.50	I
.25 - 1	11.64	17	0.330	.48	1.13	1.00	30	1.18	II
1 - 3	11.64	6	2.84	.40	1.13	1.00	60	1.49	III
		Σd^2 for 3+							
3+ Sound	11.64	142		.40	1.00	1.00	250	2.64	IV
3+ Rotten	11.64	16		.30	1.00	1.00	250	0.22	V
				3+ Sound & Rotten = IV + V =				2.86	VI
				Total = I + II + III + VI =				6.03	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	20	3	6.67 in.
Rotten :	4	1	4 in.

Sum of duff depths: : 3.7 in. Sum of fuel depths : 22 in.

Number observations : 10 Number observations : 15

Average duff depths : 0.37 in. Average fuel depths : 1.47 in.

Sample site description:

Covertype; Lodgepole Pine (75%),and Mountain Hemlock(25%)
forested area; 37.16%
crown diameter; 17.61 feet average
further information; Open forest; understory most are mountain hemlock species

Applied Fuel Model: H

Table 63

Downed Woody Material Computation Summary

Study site # 53

FOREST: 1 COMPARTMENT: 2 STAND: 2

BLOCK : 7 SUBCOMPARTMENT : 2

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	131	0.0151	.48	1.13	1.00	30	0.42	I
.25 - 1	11.64	17	0.289	.48	1.13	1.00	30	1.03	II
1 - 3	11.64	11	2.76	.40	1.13	1.00	60	2.66	III
		Σd^2 for 3+							
3+ Sound	11.64	676		.40	1.00	1.00	250	12.59	IV
3+ Rotten	11.64	1412		.30	1.00	1.00	250	19.72	V
						3+ Sound & Rotten = IV + V =		32.31	VI
						Total = I + II + III + VI =		36.44	II

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	58	8	7.25 in.
Rotten :	96	8	12.00 in.

Sum of duff depths: : 13.10 in. Sum of fuel depths : 39 in.

Number observations : 10 Number observations : 15

Average duff depths : 1.31 in. Average fuel depths : 2.60 in.

Sample site description:

Covertype; Mountain Hemlock (99%)
forested area; 42.68%
crown diameter; 26.74 feet average
further information; Open forest; some scattered lare downed woody material on the forest floor; ground covered with annual grass>75%

Applied Fuel Model: C

Table 64

Downed Woody Material Computation Summary

Study site # 54

FOREST: 1 COMPARTMENT: 1 STAND: 1

BLOCK : 5 SUBCOMPARTMENT : 2

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	71	0.0199	.48	1.13	1.00	30	0.30	I
.25 - 1	11.64	6	0.341	.48	1.13	1.00	30	0.43	II
1 - 3	11.64	1	2.86	.40	1.13	1.00	60	0.25	III
		Σd^2 for 3+							
3+ Sound	11.64	9		.40	1.00	1.00	250	0.17	IV
3+ Rotten	11.64	116		.30	1.00	1.00	250	1.62	V
						3+ Sound & Rotten = IV + V =		1.79	VI
						Total = I + II + III + VI =		2.77	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	3	1	3.0 in.
Rotten :	14	2	7.0 in.

Sum of duff depths: : 6.60 in. Sum of fuel depths : 9 in.

Number observations : 10 Number observations : 15

Average duff depths : 0.66 in. Average fuel depths : 0.60 in.

Sample site description:

Covertype; Lodgepole Pine (95%), and Mountain Hemlock(5%)
forested area; 18.12%
crown diameter; 14.15 feet average
further information; Patchy annual grass in the openings

Applied Fuel Model: U

Table 65

Downed Woody Material Computation Summary

Study site # 55

FOREST: 1 COMPARTMENT: 4 STAND: 4

BLOCK: 2 SUBCOMPARTMENT: 4

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	69	0.0191	.48	1.13	1.00	30	0.28	I
.25 - 1	11.64	8	0.333	.48	1.13	1.00	30	0.56	II
1 - 3	11.64	1	2.85	.40	1.13	1.00	60	0.25	III
		Σd^2 for 3+							
3+ Sound	11.64	314		.40	1.00	1.00	250	5.85	IV
3+ Rotten	11.64	1708		.30	1.00	1.00	250	23.86	V
						3+ Sound & Rotten = IV + V =		29.71	VI
						Total = I + II + III + VI =		30.80	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	34	4	8.50 in.
Rotten :	132	12	11.00 in.

Sum of duff depths: : 12.00 in. Sum of fuel depths : 9 in.

Number observations : 10 Number observations : 15

Average duff depths : 1.20 in. Average fuel depths : 0.60 in.

Sample site description:

Covertype; Lodgepole Pine (80%), and Mountain Hemlock(20%)
forested area; 58.20%
crown diameter; 20.34 feet average
further information; Young regeneration of both species ; grass in the openings

Applied Fuel Model: H

Table 66

Downed Woody Material Computation Summary

Study site # 56

FOREST: 1 COMPARTMENT: 3 STAND: 4

BLOCK: 1 SUBCOMPARTMENT: 3

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre
0 - .25	11.64	360	0.0154	.48	1.13	1.00	30	1.17 I
.25 - 1	11.64	20	0.292	.48	1.13	1.00	30	1.23 II
1 - 3	11.64	10	2.77	.40	1.13	1.00	60	2.43 III
		Σd^2 for 3+						
3+ Sound	11.64	1049		.40	1.00	1.00	250	19.54 IV
3+ Rotten	11.64	1551		.30	1.00	1.00	250	21.66 V
				3+ Sound & Rotten = IV + V =				41.20 VI
				Total = I + II + III + VI =				46.03 VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	95	11	8.64 in.
Rotten :	105	8	13.13 in.

Sum of duff depths: : 12.0 in. Sum of fuel depths : 31 in.

Number observations : 10 Number observations : 15

Average duff depths : 1.20 in. Average fuel depths : 2.07 in.

Sample site description:

Covertype; M.H.(90%), L.P.P.(5%), and S.R.F.(5%)
forested area; 94.22%
crown diameter; 31.90 feet average
further information; Clusteres of downed woody material and continuous

Applied Fuel Model: G

Table 67

Downed Woody Material Computation Summary

Study site # 57

FOREST: 1 COMPARTMENT: 1 STAND: 2

BLOCK : 1 SUBCOMPARTMENT : 2

Formulas to compute tons/acre:

(A) 0- to 3-inch material: $= \frac{11.64 \times n \times d^2 \times s \times a \times c}{Nt}$

(B) 3+-inch material : $= \frac{11.64 \times \Sigma d^2 \times s \times a \times c}{Nt}$

Size class	Constant	n	d^2	s	a	c	Nt	Tons/ acre	
0 - .25	11.64	200	0.0151	.48	1.13	1.00	30	0.64	I
.25 - 1	11.64	32	0.289	.48	1.13	1.00	30	2.25	II
1 - 3	11.64	14	2.76	.40	1.13	1.00	60	3.39	III
		Σd^2 for 3+							
3+ Sound	11.64	881		.40	1.00	1.00	250	16.41	IV
3+ Rotten	11.64	544		.30	1.00	1.00	250	7.60	V
							3+ Sound & Rotten = IV + V =	24.01	VI
							Total = I + II + III + VI =	30.29	VII

	Sum of 3+-inch diameters	Number of pieces	Average diameter
Sound :	91	11	8.27 in.
Rotten :	48	5	9.60 in.

Sum of duff depths: : 11.00 in.

Number observations : 10

Average duff depths : 1.10 in.

Sum of fuel depths : 31 in.

Number observations : 15

Average fuel depths : 2.07 in.

Sample site description:

Covertype; M.H.(85%), S.R.F.(15%), and W.W.P.(5%)
forested area; 63.23%
crown diameter; 42.47 feet average
further information; Forest floor covered with annual grass of 4-6 inches tall

Applied Fuel Model: H

Table 68

Downed Fuel Variation Within Dominant Species of Crater Lake National Park

Cover Type	No. of Sites Studied	% canopy area forested		Crown Size (ft.)		Downed Fuel (Tons/Acre)		
		Min.	Max.	Min.	Max.	Min.	Max.	Av. (all sites)
Mountain Hemlock	21	17.33	97.77	24.95	42.48	9.87	91.67	40.21
White Fir w/ Ponderosa P.	3	36.36	77.33	22.83	33.17	18.75	60.22	36.21
Shasta Red Fir	6	58.40	89.80	26.80	43.20	13.24	51.16	28.27
Lodgepole P.	18	11.20	88.90	11.80	29.00	0.35	39.29	17.73
Ponderosa P.	2	60.90	77.20	47.10	47.40	10.67	17.73	14.20
Grassland w/ sparse forest	1	13.00	13.00	22.20	22.20	6.26	6.26	6.26
Mixed forest* (all above)	6	29.00	83.60	21.80	34.40	7.92	34.47	34.40

*Forests where dominant species comprises less than 55% of the stand.

Table 69

Chapter Summary

In this chapter data acquisition processes utilized in this study have been discussed. Data accumulation was in several categories as follows.

1) Digitized Landsat MSS data recorded on CCTs were secured. These tapes were acquired by Landsat 2 on September 10, 1974 over Crater Lake National Park.

2) Digital Terrain Tapes from National Cartographic Information Center (NCIC), in Reston, VA were purchased. These tapes were also on CCT format. These NCIC tapes contain data on elevation which were converted into a digital topographic map, and digital slope and aspect maps of the National Park region.

3) Color infrared photography was utilized. This brief discussion included descriptions of major characteristics of color infrared photography versus normal color photography. The readers were also provided with further information on different scales of color infrared photography utilized in this study.

4) Field data acquisition techniques comprised the major section of this chapter. Sample site selection strategy involved in locating sampling sites within the Park with regard to fuel moisture detection, and inventorying downed woody material was discussed. Fuel moisture pattern analysis of the Park was also included in this section of the chapter.

5) In the final section of this Chapter 5, a downed fuel inventory and fuel data calculation procedure were discussed. Finally a computational summary and results of field data on downed fuel were tabulated in appropriate tables.

At this point, with availability of data from "ground truthed" areas, computer assisted analysis of Landsat MSS data could be applied to Crater Lake National Park's surface cover types. Through this analysis, surface cover types of the Park are to be classified. Further analysis of Landsat MSS data included classification of downed fuel amounts under dominant forest types within the National Park. Color coded photographic products from the results of these classifications cover the final section of the ensuing chapter.

CHAPTER 6. COMPUTER ASSISTED ANALYSIS OF FIELD DATA AND LANDSAT MSS/TOPOGRAPHIC DATA SETS

Data acquisition processes were discussed in Chapter 5, and it was noted that we obtained various related data sets with regard to the objectives of this study through two basic approaches. A set of data were acquired through field observation, within Crater Lake National Park, while another data set was digitized data on Computer Compatable Tapes (CCT) obtained from appropriate agencies. In this chapter the collected data are analyzed. The process proceeded through utilization of computer systems in two major stages. Preliminary data analysis was carried out on the Oregon State University computer facilities, in preparation for final analysis at the Berkeley Spaces Sciences Laboratory, Berkeley, California. Due to complexities involved in the analysis of a Landsat MSS/topographic data set, analysis at O.S.U. computer facilities was not entirely feasible. Therefore, decision was made to primarily utilize the interactive computer system of Berkeley Space Sciences Laboratory.

Preliminary Analysis of Data at Oregon State University

Throughout the field observations it had been noticed that variations in the amount of downed fuel within DFSAs occur in accordance with forest species, forest density and crown maturity. Dense and mature forests had larger amounts of downed fuel than

less dense forest with younger forest canopies. Within a given species, density and maturity were found to be the most dominant parameter with regard to variation of the amounts of downed fuel. Between species, however, with similar maturities and densities, downed fuel amounts varied. For example inventoried field data had revealed that everything else being equal, Mountain Hemlock or Mountain Hemlock/Shasta Red Fir forests in general tend to have larger amounts of downed fuel than Lodgepole Pine forests (see also table 69).

The primary objective of data analysis at Oregon State University computer facilities was to indicate the feasibility of the foregoing argument by Landsat 2 MSS data analysis. To start with, it was decided to generate a gray scale from Landsat MSS data for the study area. Gray scale is a black and white image of a scene which indicates brightness variations of scanned area in a calibrated fashion. On a gray scale lighter tones indicate higher reflectances from the scanned cover types, while darker tones represent lower reflected values of the scanned areas sensed by MSS system. Such an image provides the interpreter with MSS data with a general view of the area to be studied.

For the purpose of this study a gray scale from the major portion of MSS data of the study area for September 10, 1974 was generated. To curtail the cost of the study, gray scale generation

of MSS data for whole areas of the National Park was omitted. As a result, the generated gray scale image covered the entire Park and vicinity except for a small region in the northwest corner of the Park. Locating twenty ground control points (GCPs) on the 1/62,500 USGS topographic map of the Park and vicinity with corresponding points on the gray scale image of the National Park, the map was registered on to gray scale image. Ground control point locations utilized in this study have been depicted on Figure 32. Locations, column numbers, and scan-lines of twenty ground control points with corresponding Universal Transverse Mercator (UTM), Easting and Northing coordinates have been presented in Table 70. Through multi-variate regression analysis, locational registration errors of not more than one half a pixel area occurred for any control pixel. Regression analysis procedure and its results have been presented in table 70-A.

Having the topographic map of the Park registered on to gray scale image of the study area, we were able to locate downed fuel study areas (DFSAs) on gray scale image. This phase was accomplished by a computer assisted program in which the UTM coordinates of DFASs were given to the computer and pixel or column and scan-line numbers of those areas were obtained. These numbers then were matched with the symbols of 59 surface cover type classification of the Park (Walsh, 1978), and their corresponding explanations. Characteristics of DFSAs obtained thus, then were compared with

Ground Control Point Locations

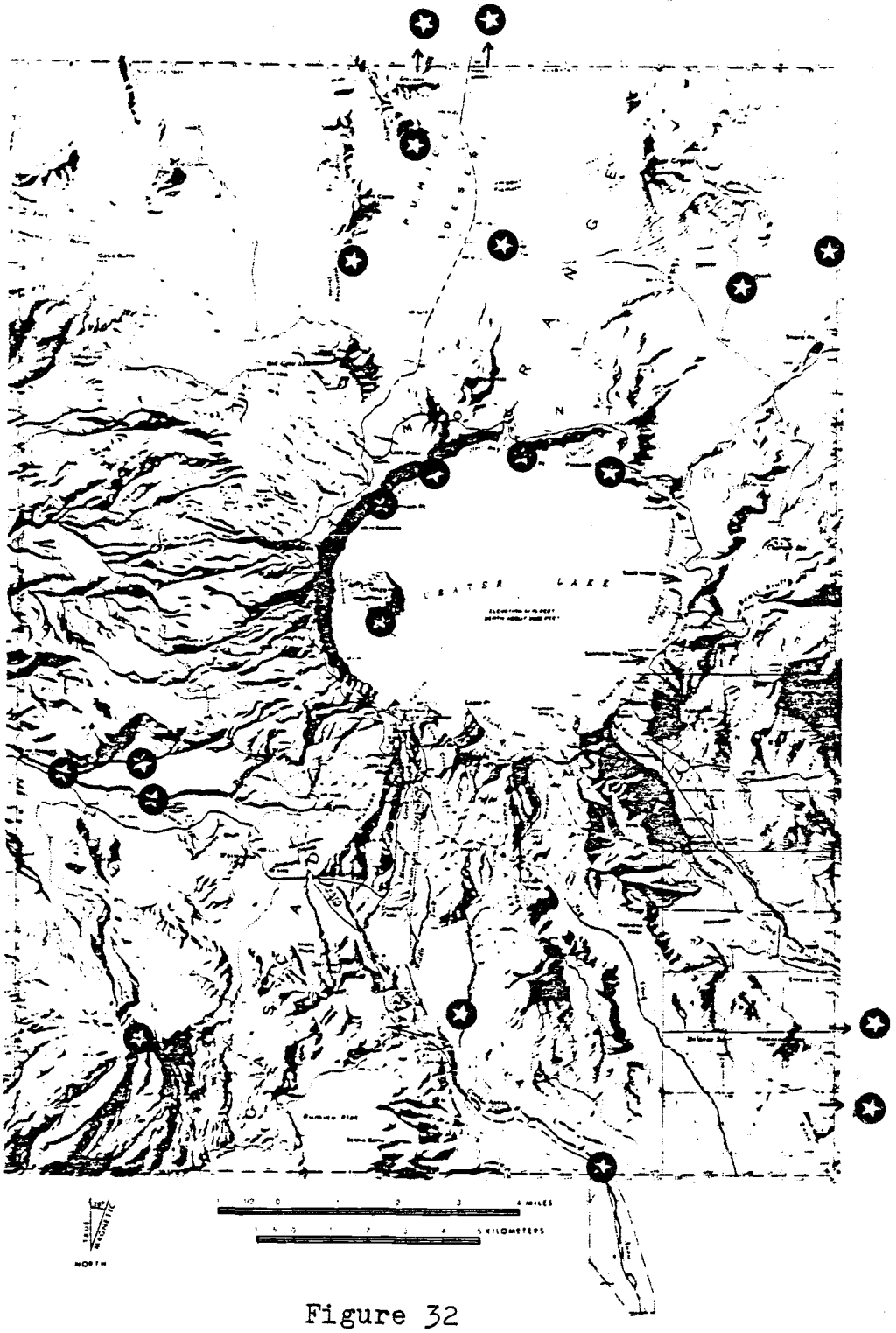


Figure 32

UTM Coordinates and Locations of
Ground Control Points

1	127	1062	572008	4770843	HWY 138 East
2	103	1050	570913	4772095	HWY 138 West
3	122	1124	570449	4766192	Pumice Desert(north)
4	107	1165	568780	4763213	Pumice Desert(southwest)
5	176	1147	573000	4763772	Pumice Desert(southeast)
6	290	1141	579488	4762898	Northeast Park
7	152	1243	569655	4756669	Crater Lake Rim(Marriam Pt.)
8	173	1226	571157	4757724	Crater Lake Rim(Llao Pt.)
9	209	1216	573402	4758071	Crater Lake Rim(Pumice Pt.)
10	244	1212	575441	4757984	Crater Lake Rim(Pilisade Pt.)
11	168	1281	569776	4753575	Wizard Island
12	44	1356	561299	4749268	Castle Creek
13	73	1346	563118	4749654	Castle Creek(North Fork)
14	90	1360	563787	4748425	Castle Creek(Main)
15	431	1373	582466	4743370	Union Peak
16	116	1437	563575	4742188	southeast clear cuts
17	462	1373	584228	4743031	southeast clear cuts
18	342	1445	576074	4738898	Pan-handle
19	325	1131	581614	4763224	Northeast Park(edge)
20	256	1406	572079	4742898	East Fork of Annie Creek

Table 70

Computer Printout of Map to Gray
Scale Registration

```
$READ,*HASSAN,7-10

$SET 1=(7-244.)*0.1

$SET 2=(8-1212.)*0.125

$SET 3=(9-575441.)*0.00164

$SET 4=(10-4757984.)*0.00164

$REGRESS,1,2-4

Y( 1)    =-4.3500E+00

:ADD ,3,4


Y( 1)    = 1.8103E-02          +1.0350E+00 X( 3)
          -2.7959E-01 X( 4)

:RESIDUAL
 OBS.          VALUE
(     1)=    5.40138572E-03
(     2)=    3.81553557E-02
(     3)=    1.90365971E-02
(     4)=   -1.39453525E-02
(     5)=   -2.07218265E-02
(     6)=   -3.43159375E-02
(     7)=    1.75984344E-04
(     8)=    3.44090855E-02
(     9)=   -1.71793664E-02
(    10)=   -1.81033710E-02
(    11)=   -2.39122575E-02
(    12)=   -9.81642026E-03
(    13)=   -2.04227846E-02
(    14)=   -1.95311941E-02
(    15)=    5.65475780E-02
(    16)=    8.04511649E-02
(    17)=    1.02575631E-02
(    18)=   -4.41273029E-02
(    19)=    6.45894744E-03
(    20)=   -2.88178537E-02
```

Table 70a -- Pixel

```
:DEP,2

Y( 2)    =-2.8810E-02          -1.9876E-01 X( 3)
          -9.3778E-01 X( 4)

:RESIDUAL
 OBS.          VALUE
(     1)=    -6.36282950E-02
(     2)=     4.96179238E-03
(     3)=     2.51453379E-02
(     4)=     2.45288918E-02
(     5)=     9.82769486E-03
(     6)=     3.05250762E-02
(     7)=    -4.64921707E-03
(     8)=    -1.75010010E-02
(     9)=    -2.03388935E-03
(    10)=     2.88101494E-02
(    11)=     2.63497971E-02
(    12)=     1.41424038E-02
(    13)=    -4.92719896E-02
(    14)=     2.86490857E-02
(    15)=    -3.19952886E-02
(    16)=    -7.70179369E-03
(    17)=     2.09904411E-02
(    18)=     6.67508505E-03
(    19)=    -2.50949918E-02
(    20)=    -1.87292942E-02

:END
```

Table 70a(continued)--Scan line

```
$REGRESS,3,1-2,4

Y( 3)    =-5.4539E+00

:ADD,1,2


Y( 3)    =-2.4447E-02          +9.1384E-01 X( 1)
           -2.7246E-01 X( 2)

:RESIDUAL
 OBS.          VALUE
(     1)=    -2.22545684E-02
(     2)=    -3.35137853E-02
(     3)=    -1.05572629E-02
(     4)=     1.93863362E-02
(     5)=     2.16378828E-02
(     6)=     3.97967201E-02
(     7)=    -1.46286306E-03
(     8)=    -3.62241777E-02
(     9)=     1.51680068E-02
(    10)=     2.44467056E-02
(    11)=     2.89939679E-02
(    12)=     1.26534835E-02
(    13)=     5.09630935E-03
(    14)=     2.55202134E-02
(    15)=    -6.02511873E-02
(    16)=    -7.57628377E-02
(    17)=    -3.48688709E-03
(    18)=     4.21840491E-02
(    19)=    -1.25867182E-02
(    20)=     2.12166149E-02
```

Table 70a(continued)--UTM Easting

```
:DEP,4

Y( 4)    =-2.5574E-02          -1.9369E-01 X( 1)
          -1.0086E+00 X( 2)

:RESIDUAL
 OBS.          VALUE
(     1)=    -6.30646353E-02
(     2)=     1.24608492E-02
(     3)=     2.90887551E-02
(     4)=     2.20607207E-02
(     5)=     5.93715347E-03
(     6)=     2.41977423E-02
(     7)=    -4.65731876E-03
(     8)=    -1.09795363E-02
(     9)=    -5.36258943E-03
(    10)=     2.55742182E-02
(    11)=     2.19301477E-02
(    12)=     1.23015032E-02
(    13)=    -5.37047642E-02
(    14)=     2.50561680E-02
(    15)=    -2.13318234E-02
(    16)=     7.73173338E-03
(    17)=     2.31481227E-02
(    18)=    -1.86884543E-03
(    19)=    -2.39943413E-02
(    20)=    -2.45232643E-02

:END
```

Table 70a(continued)--UTM Northing

color infrared aerial photographs, and field observation information. If agreement existed between field observation information and color IR photographs on one hand and corresponding gray scale image, and classified definitions of 59 classes of the surface cover types on the other, then we made certain that, the selected DFSA on the Landsat data had been located correctly; otherwise further adjustments were necessary until satisfactory results were obtained. This procedure enabled us to locate 56 out of 57 DFSAs within the Park on Landsat MSS data. DFSA number 57 was located in Boundary Springs region in the northwest corner of the Park, and as it was noted earlier generated gray scale image did not cover that portion of the Park.

At this point there was information on all pixels within every DFSA, and sampling sites covered an area much more than a pixel size on the ground. To be sure that extracted Landsat MSS values would be accurate representatives of areas within DFSAs, eight surrounding pixels of the one already selected pixel were also included and their spectral values for MSS bands 4, 5, 6, and 7 were extracted from Landsat MSS data tape of September 10, 1974.

In preparation for an investigation of the possibility of correlation between forest cover type characteristics, and amounts of downed fuel by means of Landsat 2 MSS data, twenty-nine parameters

were established. These parameters with their relevant data are tabulated in table 71. Explanation of parameters in the table from left to right other than study site numbers (first column), are as follows:

Columns 1 through 8 describe the percentages of forest cover types within DFSAs. As was mentioned in Chapter 5, these estimates were made through on-site observations based on the assumption that a correlation exists between proportions of live forest stand and downed fuel composition laying on the ground under those forest types. The abbreviations from left to right correspond to Lodgepole Pine, Shasta Red Fir, Mountain Hemlock, Ponderosa Pine, Western White Pine, White Fir, Whitebark Pine and Grass. Columns 9, and 10 show forest density and crown diameter to the nearest one tenth of a percent and to the nearest foot respectively. These parameters were calculated through photographic interpretation of color infrared imagery. Column 11 indicates the amounts of downed fuel in tons per acre calculated from field data. Calculation procedures of these data tabulated in columns 9, 10, and 11 of table 71 were explained in data acquisition section of this study (Chapter 5). Columns 12 and 13 describe aspect and slope of each DFSA in whole degrees and to one tenth of a degree respectively. Column 14 shows elevation of study areas in feet. Column 15 is the amount of solar insolation in gram calories per square centimeter (Langleys) per minute to the

Table 71_ Parameters Established for 56 DFSAs and 47 Non-forested Areas Within Crater Lake National Park

Col.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Site #	LPP %	SRF %	MH %	PP %	WWP %	WF %	WbP %	Grass %	Density % (to 0.1)	Crown r2(ft)	Fuel (t/a) to 0.01	Aspect (in degrees)	Slope (0.1 of degrees)	Elevation (feet)	Insolation	Band 4 $\bar{x}$	Band 5 $\bar{x}$	Band 6 $\bar{x}$	Band 7 $\bar{x}$	4/5 ratio	4/6 ratio	4/7 ratio	5/6 ratio	5/7 ratio	6/7 ratio	W or Sh or Mack Brush w/D Leaw Trees			

Table 71(continued)

Col.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Site #	LPP %	SRF %	MH %	PP %	WWP %	WF %	WbP %	Grass %	Density % (to 0.1)	Crown r-2(ft)	Fuel (1/a) to 0.01	Aspect (in degrees)	Slope (0.1 of degrees)	Elevation (feet)	Insolation	Band 4 $\bar{x}$	Band 5 $\bar{x}$	Band 6 $\bar{x}$	Band 7 $\bar{x}$	4/5 ratio	4/6 ratio	4/7 ratio	5/6 ratio	5/7 ratio	6/7 ratio	W of SL of Track	Finish Well	Easy Track	
058																186	136	130	140	256	143	206	110	073	044	063	119	000	111
059																138	305	000	233	310	027	759	044	133	321	550	023	331	000
060																265	027	588	263	381	275	095	099	208	104	219	211	011	000
061																232	252	025	242	251	250	096	095	186	100	194	194	000	111
062																212	521	212	521	210	000	000	100	213	100	213	213	000	111
063																230	023	752	300	182	500	975	034	201	260	851	530	011	555
064																250	026	676	260	012	500	094	096	020	010	321	320	800	000
065																143	305	330	300	001	000	269	473	114	331	178	533	800	000
066																222	022	380	260	001	520	097	085	014	608	815	014	100	000
067																165	011	172	550	017	671	148	065	093	044	063	144	000	111
068																182	515	132	568	177	581	210	710	103	058	085	146	000	111
069																196	018	802	340	113	201	044	084	014	808	014	214	770	000
070																171	311	632	443	166	634	147	071	010	304	807	014	500	001
071																243	326	332	833	170	080	092	080	014	309	315	516	700	000
072																190	016	332	433	160	041	160	780	011	906	710	215	200	000
073																242	025	202	380	114	009	096	102	021	212	106	221	209	000
074																276	029	403	340	018	800	094	083	014	708	815	617	800	000
075																203	320	002	700	166	701	020	750	012	207	412	016	200	000
076																216	020	402	860	210	001	060	750	010	307	109	137	000	111
077																306	732	173	050	155	000	955	101	019	810	528	081	970	000
078																356	338	336	332	250	092	093	015	911	173	277	020	000	111
079																255	025	753	600	257	509	907	100	999	072	100	400	000	111
080																234	324	142	743	170	000	980	050	135	088	142	161	000	000
081																207	118	432	200	012	571	120	940	016	550	844	147	750	000
082																203	316	869	323	326	331	200	630	077	052	064	123	000	111
083																277	528	258	280	013	250	980	930	209	101	213	211	000	111
084																265	028	632	988	172	509	930	890	154	096	166	173	000	111
085																197	816	446	244	221	116	200	700	008	905	807	412	900	000
086																270	028	803	300	206	009	940	860	201	310	871	401	600	000
087																233	322	332	533	135	001	040	902	017	308	816	516	800	000
088																312	933	573	171	171	409	309	901	331	061	961	851	000	111
089																180	012	252	850	215	014	790	630	084	043	057	133	000	000
090																225	020	501	917	076	711	011	170	293	107	267	250	000	111
091																131	705	000	267	010	002	634	993	131	713	750	026	701	000
092																277	527	503	225	205	010	186	601	350	851	134	157	000	111
093																322	535	003	475	195	009	209	301	165	011	179	178	001	000
094																194	015	003	320	282	012	305	601	006	904	505	311	800	000
095																175	014	752	675	190	001	190	050	092	055	076	141	000	000
096																240	025	003	200	205	009	960	750	117	073	122	154	000	111
097																253	327	332	717	131	701	930	930	192	101	208	206	000	111
098																166	011	801	060	034	014	214	580	049	411	134	731	200	000
099																194	416	001	500	045	601	221	300	042	610	735	132	900	000
100																282	530	503	500	212	509	308	101	330	087	144	165	800	000
101																270	027	252	925	170	000	990	920	159	093	161	017	200	000
102																320	034	503	150	162	500	931	020	197	110	212	194	000	000
103																192	015	403	020	252	012	506	400	076	051	061	120	000	111
104																214	022	602	560	136	009	950	840	157	088	166	188	800	000

Table 71

nearest two decimals. Complete calculation description of this parameter will follow immediately after the current discussion. Columns 16 through 19 are means of Landsat MSS data for all pixels within each of DFSAs. As was mentioned earlier in this chapter, more than one pixel area was selected for each DFSA. Depending on site characteristics the number of pixels selected for every sampling site varied from 4 to 10 pixels; although generally there were 9 pixels selected for each DFSA. Columns 20 through 25 in Table 71 represent ratios of the means of spectral MSS bands to each other as indicated in respective columns. Columns 26 through 29 indicate surface cover types from left to right as water or shadow, pumice or bare rock, brush with pumice, and few trees within bare rock or pumice lands respectively. It should be noted that values of zero and of one in these columns stand for zero percent and for 100% of specified cover type respectively. Sites 1-56 are DFSAs, and skipping site 57 (reason mentioned earlier), sites 58-104 are areas which are not forested. For this reason, the latter sites are means of MSS band values and their ratios have been so assigned.

Parameter 15: Variations of Solar Insolation Intensity on Varying Slopes and Slope Aspects of the Park

Variation in incident solar energy on the earth's surface is one of the most important parameters effecting the intensity of reflected energy detected by the Landsat MSS system. Especially

the amount of energy incident on two similar surface or cover types but with different slopes or slope aspects will vary considerably. This in turn results in variation of the amount and intensity of reflected energy from those similar surface cover types and can result in incorrect data. Considering the mountainous landscape of the study area it was known that inclusion of slope and slope aspect correction in the analysis of Landsat MSS data of the National Park should have a positive effect in the accuracy of digital analysis.

An extensive literature exists with regard to computation of the amounts of incident solar radiation on horizontal surface or surfaces with different slopes and slope aspects with respect to sun's radiation notably: Swift (1976) has provided an algorithm for the calculation of daily solar radiation on mountain slopes. The only inputs necessary for the calculations with this program are degrees of latitude, slope and aspect, and the day of the year. Another program and calculation has been published by Buffo, Fritschem, and Murphy (1972), a program which computes hourly, daily, and yearly amounts of incident solar energy on the earth's surface; again for various latitudes, slopes and slope aspects.

For computation of solar radiation intensity in this study the following formula was utilized because it has the capability of calculating instantaneous incident solar energy on the earth's surface.

Only a formula with such characteristics would enable us to compute the amount of incident solar energy for the time of Landsat overpass over the study area. The relevant formula for calculating cosine i (energy incident on the surface), as developed by Brooks (1959), follows:

$$\begin{aligned}\text{Cos(I)} = {} & \text{Cos(P) Sin(L) Sin(B)} + \\ & \text{Cos(L) Cos(B) Cos(D) Cos(H)} + \\ & \text{Sin(P) Sin(B) Cos(D) Sin(H)} + \\ & \text{Sin(L) Cos(B)} - \\ & \text{Cos(P) Cos(L) Sin(B) Sin(D)}\end{aligned}$$

Where:

I is the incident solar energy
P is the angle from East-West that the surface is oriented
L is the north latitude of the station
B is the angle of the slope (southward facing slopes are positive)
D is the declination of the sun
H is the hour angle of the sun. This is equal to 15 times the number of the hours from solar noon (positive in the afternoon, negative in the morning hours).

As a test case, by utilizing the foregoing formula, cosine i, was computed for 57 DFSAs within the Park (Table 72). This table presents incident solar radiation variations for 57 sample sites within the Park for 9:32 AM, September 10, 1974. The time and date coincided with that of the Landsat 2 overpass of Crater Lake National Park region whose MSS recorded data had been utilized in the digital analysis of this study. Incoming solar energy is depleted by atmospheric attenuation processes, with only about 70% of the radiant solar

Table 72— Solar Radiation Amounts Within DFSAs at the Time of Landsat 2 Overpass

Site #	Elevation feet (meters)	East-West angle (P)	Latitude (L)	Slope angle (B)	Slope aspect, degrees from North	Declination of sun (D)	Hour angle of the sun (H)	Cos i	Ave. solar insulation Ly/min	With eccentricity Ly/min
1	5525 (1684)	30°	42° 51'	3° 9'	030°	4° 53' 4"	15 (-2:18.15)	0.67	0.93	0.90
2	5800 (1768)	—	42° 52'	— —	—	" " "	" " "	0.66	0.92	0.89
3	6200 (1890)	-90°	42° 54'	4° —	090°	" " "	" " "	0.70	0.98	0.95
4	6450 (1966)	-90°	42° 54'	2° 52'	090°	" " "	" " "	0.69	0.96	0.93
5	6750 (2057)	—	42° 53'	— —	—	" " "	" " "	0.66	0.92	0.89
6	7500 (2286)	+30°	42° 54'	2° 52'	030°	" " "	" " "	0.67	0.93	0.90
7	7150 (2179)	-65°	42° 55'	3° 27'	115°	" " "	" " "	0.70	0.98	0.95
8	7100 (2164)	—	42° 55'	9° 04'	180°	" " "	" " "	0.73	1.02	0.99
9	7050 (2149)	+60°	42° 57'	-4° 25'	060°	" " "	" " "	0.68	0.95	0.92
10	6825 (2080)	+30°	42° 58'	-4° 25'	030°	" " "	" " "	0.65	0.90	0.87
11	6400 (1951)	+60°	42° 58'	-9° 39'	060°	" " "	" " "	0.69	0.97	0.94
12	6950 (2118)	-60°	42° 59'	7° 06'	120°	" " "	" " "	0.74	1.04	1.00
13	6900 (2103)	—	42° 59'	-12° 41'	360°	" " "	" " "	0.53	0.75	0.72
14	6800 (2073)	—	42° 59'	-5° 43'	360°	" " "	" " "	0.61	0.85	0.82
15	7300 (2225)	+90°	42° 59'	10° 34'	270°	" " "	" " "	0.54	0.76	0.73

Table 72(continued)

Site #	Elevation feet (meters)	East-West angle (P)	Latitude (L)	Slope angle (B)	Slope aspect, degrees from North	Declination of sun (D)	Hour angle of the sun (H)	Cos i	Ave. solar insulation Ly/min	With eccentricity Ly/min
16	6750 (2057)	+90°	42° 59'	6° 40'	270°	4° 53' 4"	15(-2:18.15)	0.59	0.82	0.79
17	6350 (1935)	+55°	42° 54'	13° 19'	235°	" " "	" " "	0.60	0.84	0.81
18	6250 (1905)	+60°	42° 51'	-3° 59'	060°	" " "	" " "	0.68	0.95	0.92
19	6250 (1905)	-50°	42° 52'	-9° 50'	310°	" " "	" " "	0.52	0.73	0.70
20	6300 (1920)	-40°	42° 49'	1° 29'	140°	" " "	" " "	0.68	0.95	0.92
21	6100 (1859)	+50°	42° 49'	2° 07'	230°	" " "	" " "	0.66	0.92	0.89
22	5900 (1798)	—	42° 50'	5° 43'	180°	" " "	" " "	0.71	0.99	0.96
23	6150 (1875)	—	42° 52'	— —	—	" " "	" " "	0.66	0.92	0.89
24	6100 (1859)	+90°	42° 53'	1° 43'	270°	" " "	" " "	0.64	0.90	0.87
25	5750 (1753)	-50°	43° 53'	-5° 52'	310°	" " "	" " "	0.58	0.81	0.78
26	5700 (1737)	—	43° 53'	— —	—	" " "	" " "	0.66	0.92	0.89
27	5670 (1728)	+90°	42° 53'	3° 11'	270°	" " "	" " "	0.63	0.88	0.85
28	5500 (1676)	+45°	42° 53'	4° 39'	225°	" " "	" " "	0.65	0.91	0.88
29	5200 (1585)	+30°	42° 54'	3° 38'	150°	" " "	" " "	0.67	0.94	0.91
30	6000 (1829)	—	43° 01'	— —	—	" " "	" " "	0.66	0.92	0.89

Table 72(continued)

Site #	Elevation feet (meters)	East-West angle (P)	Latitude (L)	Slope angle (B)	Slope aspect, degrees from North	Declination of sun (D)	Hour angle of the sun (H)	Cos i	Ave. solar insulation Ly/min	With eccentricity Ly/min
31	6100 (1859)	—	43° 02'	1° 04'	180°	4 53' 4"	15(-2:18.15)	0.67	0.93	0.90
32	6500 (1981)	+90°	43° 03'	6° 50'	270°	" " "	" " "	0.59	0.82	0.79
33	6250 (1905)	+90°	43° 03'	7° 30'	270°	" " "	" " "	0.58	0.81	0.78
34	6250 (1905)	-90°	42° 53'	3° 35'	090°	" " "	" " "	0.69	0.97	0.94
35	6000 (1829)	—	42° 52'	14° 02'	180°	" " "	" " "	0.76	1.06	1.02
36	5400 (1646)	-30°	42° 49'	1° 12'	150°	" " "	" " "	0.67	0.94	0.91
37	5100 (1554)	-90°	42° 48'	2° 43'	090°	" " "	" " "	0.69	0.96	0.93
38	4700 (1433)	-30°	42° 47'	1° 25'	150°	" " "	" " "	0.68	0.95	0.92
39	4600 (1402)	-90°	42° 47'	1° 32'	090°	" " "	" " "	0.68	0.95	0.92
40	4500 (1372)	-60°	42° 47'	2° —	120°	" " "	" " "	0.69	0.96	0.93
41	5750 (1753)	—	43° —	— —	—	" " "	" " "	0.66	0.92	0.89
42	5200 (1585)	-90°	43° 03'	— 46'	090°	" " "	" " "	0.67	0.93	0.90
43	5225 (1593)	—	43° 01'	— —	—	" " "	" " "	0.66	0.92	0.89
44	6300 (1920)	—	43° —	-4° 57'	360°	" " "	" " "	0.61	0.86	0.83
45	6200 (1890)	+60°	43° 01'	-1° 52'	060°	" " "	" " "	0.67	0.93	0.90

Table 72(continued)

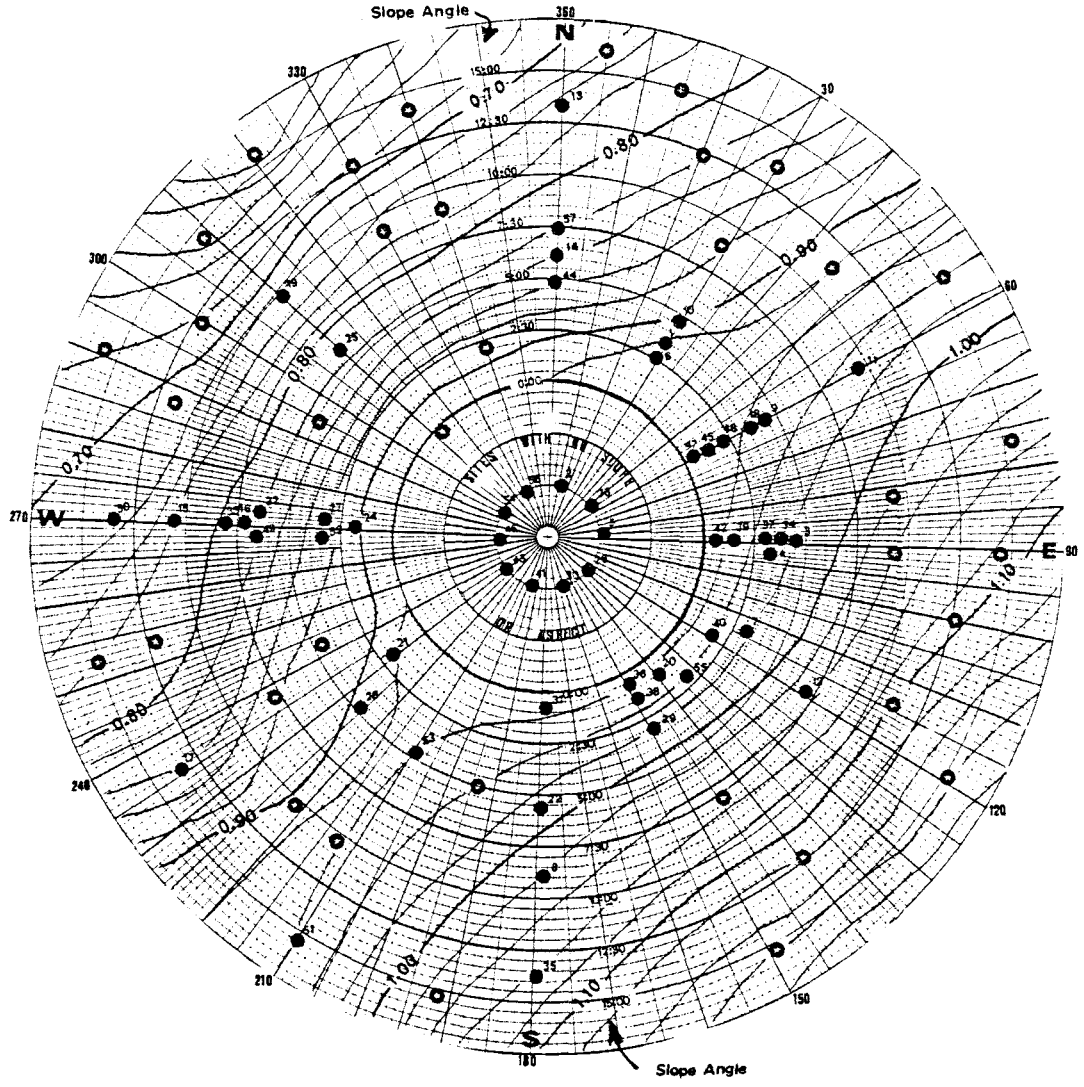
Site #	Elevation feet (meters)	East-West angle (P)	Latitude (L)	Slope angle (B)	Slope aspect, degrees from North	Declination of sun (D)	Hour angle of the sun (H)	Cos i	Ave. solar insulation Ly/min	With eccentricity Ly/min
46	6020 (1835)	—	43° 03'	— —	—	4° 53' 4"	15(-2:18.15)	0.66	0.92	0.89
47	5950 (1814)	+60°	43° 03'	— -36'	060°	" " "	" " "	0.66	0.92	0.89
48	6000 (1829)	+60°	43° 04'	-1° 53'	060°	" " "	" " "	0.67	0.93	0.90
49	6500 (1981)	+90°	42° 52'	6° 19'	270°	" " "	" " "	0.59	0.83	0.80
50	7000 (2134)	+90°	42° 51'	13° 29'	270°	" " "	" " "	0.51	0.71	0.69
51	6500 (1981)	+30°	42° 51'	15° 31'	210°	" " "	" " "	0.67	0.94	0.91
52	6300 (1920)	+90°	42° 55'	3° 23'	270°	" " "	" " "	0.62	0.87	0.84
53	6650 (2027)	+30°	42° 56'	4° 43'	210°	" " "	" " "	0.67	0.94	0.91
54	6450 (1966)	—	43° —	— —	—	" " "	" " "	0.66	0.92	0.89
55	6200 (1890)	-45°	43° 01'	2° 09'	135°	" " "	" " "	0.69	0.96	0.93
56	6100 (1859)	—	43° —	— —	—	" " "	" " "	0.66	0.92	0.89
57	5400 (1646)	—	43° 04'	-7° 22'	360°	" " "	" " "	0.59	0.82	0.79

Table 72

energy available at the top of the atmosphere reaching the earth's surface. This factor was considered in preparation of Table 72 as averages of solar insolation intensity (Langleys per minute) were calculated for various DFSAs. Furthermore, since Landsat 2 MSS data, which were utilized in this study, had been acquired during summer season (September 10), of the Northern hemisphere, amounts of solar insolation intensity are 3.5% smaller than the average (Lamb, 1972). This is due to variations in Sun-Earth distance (eccentricity), during a solar year. This effect along with all topographic characteristics of DFSAs have been depicted in the foregoing table.

For a better understanding of solar radiation intensity fluctuations on varying slopes and slope aspects of Crater Lake National Park, Figure 33 was developed. Insolines on this figure present areas of equal incident solar energy for 9:32 AM, September 10, 1974. For this purpose, cosine i for 36 synthetic sites in addition to 57 downed fuel study areas were calculated and averages of radiant energy were plotted on a polar projection graph; so that insolines course over variably sloped areas of the Park for Landsat overpass time. Values are gram calories per square centimeter per minute (Langleys per minute), corresponding to the amount of impinging solar radiation at the top of the crown canopy for forested areas and over the exposed land areas. Although amounts of reflected energy from the surface cover types, which are recorded by Landsat MSS detector system, could be determined by

Variations of Solar Radiant Loading on Various Slopes & Aspects -09:32 Sept. 10, 1974



Contour Interval: 0.02 Langley
Time: 09:32 a.m.
Date: Sept. 10, 1974
39 Downed Fuel Study Area (DFSA)
Synthetic Site

Figure 33

this procedure and thus solar insolation and heat loading parameters could be defined; with regard to fire fuel loading study the situation is somewhat different. Intensity of reflected solar energy from the openings of the forest types, and estimation of solar heating characteristics within the stands depend not only on incident energy but other factors such as diffused solar energy from under the crowns and sunflecks as well. Although, under crowns, insolation intensity is usually much lower than that of the top of the crowns, Muller (1971), has indicated that in lower and middle latitudes variation in stand characteristics may cause significant variation in under crown insolation intensity. As a result, in some occasions, because of downward scattering effects of the crowns, insolation intensity under the forest canopy becomes slightly higher than solar radiation intensity in the atmosphere.

Now that the readers have become familiar with all 29 parameters involved in a preliminary analysis of this study, grouping of data with regard to their similarity is relevant.

Dissimilarity Clustering

The numerical classification technique utilized in this study was developed by James A. Keniston (1978) while associated with the Oregon State University Marine Science Center. Program "CLUSTER", as it is called, uses agglomerative clustering to classify a set of entities based on comparison of their attributes. Although this program was developed primarily for use in ecological investigations, it is applicable to any field in which numerical classification is desired (Keniston, 1978). A matrix of data cited earlier in Table 71 was used as input to the CLUSTER program. To eliminate quantitative weighting factor of data in clustering procedure, data were statistically normalized prior to generation of CLUSTER classification. Then program CLUSTER was generated, and its result was plotted by Gerber plotter and is represented in Figure 34. It should be noted that this classification is based on a dissimilarity factor of the data through which similar data are classified and grouped and classified. Similar groups in Figure 34 have been designated by alphabetical letters on the X axis of the figure.

Attempting to classify downed fuel characteristics for "Fire-Danger Rating Area" purposes, this study is primarily concerned with forested areas of the Park. Separation of forested and non-forested cover types of the Park by utilization of Landsat MSS data

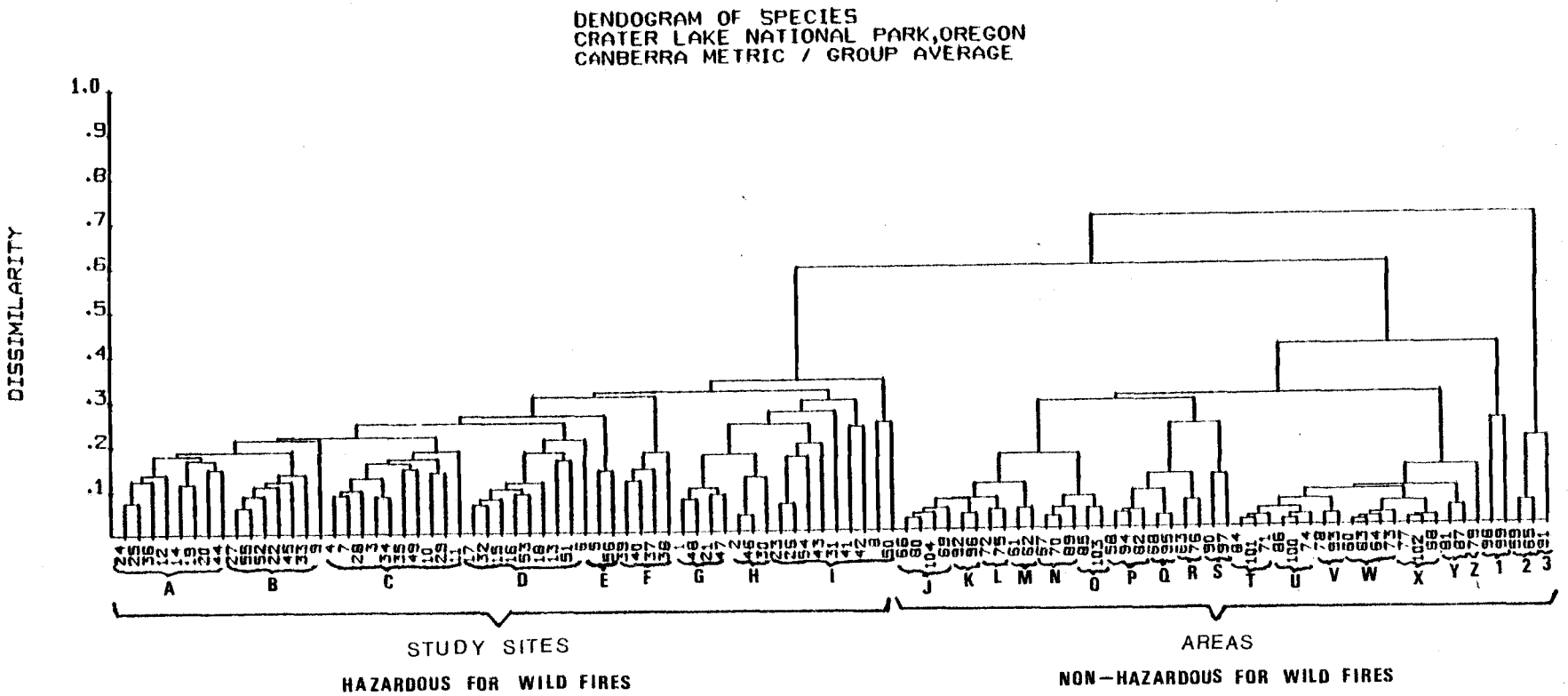

DENDOGRAM OF SPECIES
CRATER LAKE NATIONAL PARK,OREGON
CANBERRA METRIC / GROUP AVERAGE
DISSIMILARITY
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
Y
Z
1
2
3
STUDY SITES
HAZARDOUS FOR WILD FIRES
AREAS
NON-HAZARDOUS FOR WILD FIRES

Figure 34

has already been accomplished by Walsh (1977). For this reason, the prime intention here was to group (cluster), similar subclasses within each major group (forested or non-forested). Therefore, no statistical classification significance should be attributed to the major break between forested and non-forested because these two groups are comprised of unlike data bases. However, within each of the major subsets - forested or non-forested, there is significance to the differences in subclassifications. Detailed information with regard to cover type and downed fuel characteristics of every subclass within forested clusters A through I shown in Figure 34 are given in Tables 73-81. For convenience of comparison, means, and standard deviations of MSS data for DFSAs classified within clusters A through I, have also been presented along with every cluster in Tables 73A-81A.

Surface cover types of sample sites designated as "Areas Non-Hazardous For Wild Fires" on Figure 34 were studied through joint utilization of U-2 color infrared aerial photographs, 59 classes of surface cover type classification (Walsh, 1978), the USGS topographic map of Crater Lake National Park, and Landsat MSS data. Due to the fact that those sites were non-forested areas, on-site observations within those areas for downed fuel study purposes were not carried out. General surface cover types of non-forested areas for clusters J through 3 within the National Park have been identified as follows:

Field Observation Information for DFSAs
Within Cluster A

DFSA* #	Composition of Cover Type	Forested Area (%)	Crown Size (feet)	Downed Fuel (t/a)
24	Mountain Hemlock (50%), Shasta Red Fir (30%), Lodgepole Pine (20%)	71.1	28.2	8.93
25	Mountain Hemlock (40%), Shasta Red Fir (40%), Lodgepole Pine (20%)	78.4	22.4	7.92
36	Shasta Red Fir (60%), Mountain Hemlock (25%), Lodgepole Pine (15%)	73.8	27.8	13.24
12	Shasta Red Fir (50%), Mountain Hemlock (30%), Lodgepole Pine (20%)	39.7	34.4	26.48
14	Mountain Hemlock (85%), Lodgepole Pine (10%), Shasta Red Fir (5%)	70.3	28.2	28.18
19	Mountain Hemlock (85%), Lodgepole Pine (15%)	64.2	28.9	46.63
20	Mountain Hemlock (70%), Lodgepole Pine (30%)	53.3	25.0	28.25
44	Mountain Hemlock (60%), Lodgepole Pine (35%), Whitebark Pine (5%)	75.9	36.9	28.61

*Downed Fuel Study Area

Table 73

Means and Standard Deviations of Landsat
MSS Data For Ground Truthing Sites
Within Cluster A

MSS Bands	4	5	6	7	Distances
DFSA* # 24					
Means	16.56	11.56	18.89	9.00	3.56
ST DEV	1.01	1.59	.60	.71	4.74
Number of samples(pixels)		9			
DFSA # 25					
Means	16.22	11.67	17.78	9.67	3.56
ST DEV	.97	1.73	1.48	.71	2.70
Number of samples(pixels)		9			
DFSA # 36					
Means	16.33	12.89	20.44	11.89	3.56
ST DEV	.50	1.17	1.13	.93	2.40
Number of samples(pixels)		9			
DFSA # 12					
Means	15.83	10.17	18.33	9.33	3.33
ST DEV	1.60	3.13	3.08	2.42	5.50
Number of samples(pixels)		6			
DFSA # 14					
Means	15.00	9.63	17.88	9.00	2.63
ST DEV	.53	1.06	1.73	1.07	2.20
Number of samples(pixels)		8			

*Downed Fuel Study Area

Cluster A (continued)

MSS Bands	4	5	6	7	Distances
DFSA # 19					
Means	15.33	9.11	16.56	8.56	3.56
ST DEV	.50	1.17	1.67	.53	1.28
Number of samples(pixels)		9			
DFSA # 20					
Means	16.71	11.86	19.57	11.00	3.43
ST DEV	2.14	1.86	1.51	1.00	1.95
Number of samples(pixels)		7			
DFSA # 44					
Means	16.56	12.44	18.33	10.22	3.56
ST DEV	1.13	1.01	.71	.83	2.08
Number of samples(pixels)		9			

Table 73a

Field Observation Information for DFSAs
Within Cluster B

DFSA* #	Composition of Cover Type	Forested Area (%)	Crown Size (feet)	Downed Fuel (t/a)
27	Lodgepole Pine (80%), Mountain Hemlock (20%)	65.5	18.1	34.17
55	Lodgepole Pine (80%), Mountain Hemlock (20%)	58.2	20.3	30.80
52	Lodgepole Pine (75%), Mountain Hemlock (25%)	37.2	17.6	6.03
22	Lodgepole Pine (75%), Mountain Hemlock (25%)	18.3	12.5	11.10
45	Lodgepole Pine (85%), Mountain Hemlock (15%)	35.5	18.6	18.66
33	Lodgepole Pine (70%), Mountain Hemlock (25%), Shasta Red Fir (5%)	40.7	20.8	16.24
9	Mountain Hemlock (70%), Lodgepole Pine (25%), Whitebark Pine (5%)	78.4	28.5	26.33

*Downed Fuel Study Area

Table 74

Means and Standard Deviations of Landsat MSS Data For Ground Truthing Sites Within Cluster B

MSS Bands	4	5	6	7	Distances
DFSA*# 27					
Means	16.56	10.78	18.00	9.67	3.56
ST DEV	1.01	1.56	.71	.87	2.13
Number of samples(pixels)		9			
DFSA # 55					
Means	16.33	12.56	18.33	10.22	3.56
ST DEV	.71	1.42	.71	.83	1.79
Number of samples(pixels)		9			
DFSA # 52					
Means	16.25	11.00	18.50	10.00	3.00
ST DEV	.50	.82	1.73	1.15	1.19
Number of samples(pixels)		4			
DFSA # 22					
Means	16.10	11.90	17.70	9.30	3.60
ST DEV	.99	2.51	1.49	1.77	3.71
Number of samples(pixels)		10			
DFSA # 45					
Means	17.67	14.67	18.89	9.89	3.56
ST DEV	.71	.50	1.05	.60	2.65
Number of samples(pixels)		9			

*Downed Fuel Study Area

Cluster B (continued)

MSS Bands	4	5	6	7	Distances
DFSA # 33					
Means	16.22	11.33	18.22	9.56	3.56
ST DEV	.67	1.22	.67	1.01	1.83
Number of samples(pixels)		9			
DFSA # 9					
Means	15.67	10.22	18.78	11.78	3.56
ST DEV	.50	.97	.67	.83	1.91
Number of samples(pixels)		9			

Table 74a

Field Observation Information for DFSAs
Within Cluster C

DFSA* #	Composition of Cover Type	Forested Area (%)	Crown Size (feet)	Downed Fuel (t/a)
4	Shasta Red Fir (80%), Mountain Hemlock (20%)	80.2	43.2	30.29
7	Shasta Red Fir (60%), Mountain Hemlock (40%)	58.4	34.7	29.81
28	Shasta Red Fir (70%), Mountain Hemlock (30%)	84.1	37.7	51.16
3	Mountain Hemlock (70%), Shasta Red Fir (20%), Lodgepole Pine (10%)	62.7	42.9	36.75
34	Mountain Hemlock (80%), Shasta Red Fir (20%)	72.4	29.9	28.76
35	Mountain Hemlock (60%), Shasta Red Fir (40%)	52.2	31.47	15.72
49	Mountain Hemlock (55%), Shasta Red Fir (40%), Grass (5%)	83.6	26.8	20.34
10	Mountain Hemlock (60%), Shasta Red Fir (35%), Whitebark Pine (5%)	80.0	29.6	33.46
29	Shasta Red Fir (85%), Mountain Hemlock (10%), Whitebark Pine (5%)	86.6	26.9	17.96
11	Mountain Hemlock (95%), Shasta Red Fir (5%)	97.8	36.6	91.67

*Downed Fuel Study Area

Table 75

Means and Standard Deviations of Landsat
MSS Data For Ground Truthing Sites
Within Cluster C

MSS Bands	4	5	6	7	Distances
DFSA* # 4					
Means	15.00	9.11	18.22	11.00	3.56
ST DEV	.50	.78	1.20	.87	3.31
Number of samples(pixels)		9			
DFSA # 7					
Means	16.44	12.00	20.22	13.11	3.56
ST DEV	1.67	2.35	1.72	1.69	1.75
Number of samples(pixels)		9			
DFSA # 28					
Means	15.67	9.44	17.44	10.11	3.56
ST DEV	.71	1.01	1.51	.60	2.27
Number of samples(pixels)		9			
DFSA # 3					
Means	15.29	10.00	19.00	10.43	3.43
ST DEV	.76	1.29	1.41	1.13	3.36
Number of samples(pixels)		7			
DFSA # 34					
Means	15.56	9.89	18.89	11.11	3.56
ST DEV	.73	1.05	1.96	2.37	2.58
Number of samples(pixels)		9			

*Downed Fuel Study Area

Cluster C (continued)

MSS Bands	4	5	6	7	Distances
DFSA # 35					
Means	16.11	12.33	19.00	10.67	3.56
ST DEV	1.05	1.94	.71	1.22	2.45
Number of samples(pixels)		9			
DFSA # 49					
Means	15.00	9.11	18.11	9.33	3.56
ST DEV	.50	.78	1.05	1.00	3.76
Number of samples(pixels)		9			
DFSA # 10					
Means	14.88	10.50	17.63	9.88	3.50
ST DEV	.35	1.20	.92	.64	2.18
Number of samples(pixels)		8			
DFSA # 29					
Means	15.22	9.89	18.22	10.56	3.56
ST DEV	.44	1.05	1.39	.73	3.13
Number of samples(pixels)		9			
DFSA # 11					
Means	15.14	10.00	17.86	9.14	3.43
ST DEV	.38	1.83	1.07	.90	2.57
Number of samples(pixels)		7			

Table 75a

Field Observation Information for DFSAs
Within Cluster D

DFSA* #	Composition of Cover Type	Forested Area (%)	Crown Size (feet)	Downed Fuel (t/a)
17	Mountain Hemlock (99%), or pure single species	62.5	41.6	45.79
32	Mountain Hemlock (99%), or pure single species	88.5	43.9	49.92
15	Mountain Hemlock (99%), or pure single species	71.9	36.8	22.77
16	Mountain Hemlock (99%), or pure single species	17.5	39.4	9.87
53	Mountain Hemlock (99%), or pure single species	42.7	26.7	36.42
18	Mountain Hemlock (99%), or pure single species	71.0	37.2	84.74
13	Mountain Hemlock (99%), or pure single species	67.0	27.8	51.68
51	Shasta Red Fir (99%), or pure single species	89.8	26.8	27.17
6	Mountain Hemlock (99%), or pure single species	85.2	38.3	52.70

*Downed Fuel Study Area

Table 76

Means and Standard Deviations of Landsat MSS Data For Ground Truthing Sites Within Cluster D

MSS Bands	4	5	6	7	Distances
DFSA*# 17					
Means	15.11	8.56	17.11	8.89	3.56
ST DEV	.33	.53	.78	.60	2.02
Number of samples(pixels)		9			
DFSA # 32					
Means	15.00	9.22	17.11	8.67	2.67
ST DEV	.25	.67	.60	.50	1.98
Number of samples(pixels)		9			
DFSA # 15					
Means	15.17	10.83	16.67	8.67	3.33
ST DEV	.41	1.17	1.86	1.21	2.04
Number of samples(pixels)		6			
DFSA # 16					
Means	15.13	9.88	18.38	9.88	3.50
ST DEV	.64	1.13	.74	.83	2.27
Number of samples(pixels)		8			
DFSA # 53					
Means	15.40	10.00	18.50	10.40	3.60
ST DEV	.52	.82	1.08	1.17	2.69
Number of samples(pixels)		10			

*Downed Fuel Study Area

Cluster D (continued)

MSS Bands	4	5	6	7	Distances
DFSA # 18					
Means	14.78	8.78	16.33	8.67	3.56
ST DEV	.44	.83	1.12	.50	1.39
Number of samples(pixels)		9			
DFSA # 13					
Means	15.38	9.50	16.88	8.75	3.50
ST DEV	.52	.53	1.36	.89	1.16
Number of samples(pixels)		8			
DFSA # 51					
Means	15.13	9.88	18.13	9.50	3.50
ST DEV	.35	1.25	.99	.53	2.37
Number of samples(pixels)		8			
DFSA # 6					
Means	19.60	19.60	25.00	16.00	3.20
ST DEV	1.34	3.05	1.41	.71	1.77
Number of samples(pixels)		5			

Table 76a

Field Observation Information for DFSAs
Within Cluster E

DFSA* #	Composition of Cover Type	Forested Area (%)	Crown Size (feet)	Downed Fuel (t/a)
5	Mountain Hemlock (70%), Shasta Red Fir (30%)	86.2	42.5	56.61
56	Mountain Hemlock (90%), Shasta Red Fir (5%), Lodgepole Pine (5%)	94.2	31.9	46.03

*Downed Fuel Study Area

Table 77

Means and Standard Deviations of Landsat
MSS Data For Ground Truthing Sites
Within Cluster E

MSS Bands	4	5	6	7	Distances
DFSA*# 5					
Means	15.11	10.33	17.78	10.44	3.56
ST DEV	.33	.87	1.72	1.01	3.67
Number of samples(pixels)		9			
DFSA # 56					
Means	15.56	11.00	17.22	9.56	3.56
ST DEV	.73	1.12	1.56	1.01	1.92
Number of samples(pixels)		9			

*Downed Fuel Study Area

Table 77a

Field Observation Information for DFSAs
Within Cluster F

DFSA* #	Composition of Cover Type	Forested Area (%)	Crown Size (feet)	Downed Fuel (t/a)
39	White Fir (60%), Ponderosa Pine (40%)	64.9	33.2	60.22
40	White Fir (60%), Ponderosa Pine (25%), Mountain Hemlock (15%)	77.5	31.4	29.65
37	White Fir (40%), Ponderosa Pine (40%), Shasta Red Fir (20%)	83.6	24.5	34.47
38	White Fir (80%), Shasta Red Fir (15%), Ponderosa Pine (5%)	36.4	22.8	18.75

*Downed Fuel Study Area

Table 78

Means and Standard Deviations of Landsat
MSS Data For Ground Truthing Sites
Within Cluster F

MSS Bands	4	5	6	7	Distances
DFSA*# 39					
Means	16.38	10.38	19.88	11.88	3.50
ST DEV	.52	.52	.83	1.36	1.81
Number of samples(pixels)		8			
DFSA # 40					
Means	17.00	11.78	20.67	11.67	3.56
ST DEV	.87	.97	.87	.50	2.44
Number of samples(pixels)		9			
DFSA # 37					
Means	15.11	9.33	19.22	11.00	3.56
ST DEV	.33	.50	.67	1.00	3.37
Number of samples(pixels)		9			
DFSA # 38					
Means	16.22	9.67	21.33	12.44	3.56
ST DEV	.67	.71	1.32	.88	2.46
Number of samples(pixels)		9			

*Downed Fuel Study Area

Table 78a

Field Observation Information for DFSAs
Within Cluster G

DFSA* #	Composition of Cover Type	Forested Area (%)	Crown Size (feet)	Downed Fuel (t/a)
1	Lodgepole Pine (99%), or pure single species	43.9	17.1	22.97
48	Lodgepole Pine (99%), or pure single species	65.3	20.4	39.29
21	Lodgepole Pine (99%), or pure single species	25.8	14.7	17.33
47	Lodgepole Pine (99%), or pure single species	21.2	17.7	18.62

*Downed Fuel Study Area

Table 79

Means and Standard Deviations of Landsat MSS Data For Ground Truthing Sites Within Cluster G

MSS Bands	4	5	6	7	Distances
DFSA*# 1					
Means	16.00	12.00	18.00	9.00	3.43
ST DEV	.82	.58	.58	.58	2.96
Number of samples(pixels)		7			
DFSA # 48					
Means	16.20	12.20	17.80	10.00	2.70
ST DEV	.42	1.03	.92	.21	2.56
Number of samples(pixels)		10			
DFSA # 21					
Means	16.22	13.44	17.89	10.11	3.56
ST DEV	.67	.88	1.45	.78	3.53
Number of samples(pixels)		9			
DFSA # 47					
Means	17.14	14.71	18.57	10.57	3.43
ST DEV	.69	.49	.79	.98	2.19
Number of samples(pixels)		7			

*Downed Fuel Study Area

Table 79a

Field Observation Information for DFSAs
Within Cluster H

DFSA* #	Composition of Cover Type	Forested Area (%)	Crown Size (feet)	Downed Fuel (t/a)
2	Lodgepole Pine (99%), or pure single species	21.9	15.0	21.78
46	Lodgepole Pine (99%), or pure single species	31.4	16.0	24.21
30	Lodgepole Pine (99%), or pure single species	11.21	11.8	0.35

*Downed Fuel Study Area

Table 80

Means and Standard Deviations of Landsat
MSS Data For Ground Truthing Sites
Within Cluster H

MSS Bands	4	5	6	7	Distances
DFSA* # 2					
Means	16.78	13.00	19.11	9.78	3.56
ST DEV	.67	.87	1.05	.67	2.26
Number of samples(pixels)		9			
DFSA # 46					
Means	18.11	14.89	20.56	10.89	3.56
ST DEV	1.45	1.36	1.33	.78	2.88
Number of samples(pixels)		9			
DFSA # 30					
Means	18.78	16.89	19.67	10.00	3.56
ST DEV	.67	1.54	.71	.71	3.72
Number of samples(pixels)		9			

*Downed Fuel Study Area

Table 80a

Field Observation Information for DFSAs
Within Cluster I

DFSA* #	Composition of Cover Type	Forested Area (%)	Crown Size (feet)	Downed Fuel (t/a)
23	Lodgepole Pine (85%), Mountain Hemlock (15%)	57.2	29.0	13.22
26	Lodgepole Pine (90%), Mountain Hemlock (10%)	86.9	22.5	22.79
54	Lodgepole Pine (95%), Mountain Hemlock (5%)	18.1	15.2	2.77
43	Lodgepole Pine (95%), Ponderosa Pine (5%)	39.2	18.4	4.26
31	Lodgepole Pine (85%), Shasta Red Fir (10%), White Fir (5%)	30.1	16.2	15.40
41	Ponderosa Pine (99%), or pure single species	60.9	47.4	17.73
42	Ponderosa Pine (95%), Lodgepole Pine (5%)	77.2	47.1	10.67
8	Grass (70%), Whitebark Pine (10%), Lodgepole Pine (10%), Mountain Hemlock (10%)	13.0	22.2	6.26
50	Shasta Red Fir (50%), Whitebark Pine (40%), Mountain Hemlock (10%)	29.0	21.8	8.93

*Downed Fuel Study Area

Table 81

Means and Standard Deviations of Landsat
MSS Data For Ground Truthing Sites
Within Cluster I

MSS Bands	4	5	6	7	Distances
DFSA*# 23					
Means	16.56	11.78	18.00	9.56	3.56
ST DEV	.53	1.20	.71	1.24	2.77
Number of samples(pixels)		9			
DFSA # 26					
Means	15.33	11.22	17.56	9.11	3.56
ST DEV	.50	.44	.53	.33	2.72
Number of samples(pixels)		9			
DFSA # 54					
Means	18.00	16.00	20.38	9.88	3.50
ST DEV	.76	1.20	1.19	.83	1.61
Number of samples(pixels)		8			
DFSA # 43					
Means	17.50	14.38	19.50	10.75	3.50
ST DEV	1.31	1.85	1.51	.71	2.44
Number of samples(pixels)		8			
DFSA # 31					
Means	15.78	12.56	17.56	9.67	3.56
ST DEV	.44	1.13	.73	.50	2.23
Number of samples(pixels)		9			

*Downed Fuel Study Area

Cluster I (continued)

MSS Bands	4	5	6	7	Distances
DFSA # 41					
Means	17.67	14.50	21.17	12.00	3.33
ST DEV	1.03	.84	.98	1.26	4.02
Number of samples(pixels)		6			
DFSA # 42					
Means	17.00	13.22	20.44	12.00	3.56
ST DEV	.50	1.09	.53	.71	2.17
Number of samples(pixels)		9			
DFSA # 8					
Means	20.89	19.89	26.33	16.56	3.56
ST DEV	1.17	2.15	1.87	1.94	2.58
Number of samples(pixels)		9			
DFSA # 50					
Means	18.22	14.67	22.89	13.67	3.56
ST DEV	1.20	1.94	2.03	2.45	2.60
Number of samples(pixels)		9			

Table 81a

Cluster J: Pumice or bare rock with few trees

Cluster K: Pumice and bare rock

Clusters L, M, N, O: Bare rock with few trees

Clusters P, Q, R, S: Bare rock/pumice

Clusters T, U, V, W, X, Y, Z: Pumice

Cluster 1: Few sparse trees on pumice lands

Cluster 2: Shadow or water

Cluster 3: Pumice/lava

MSS data for non-forested areas have been presented in Table 71.

Points of interest from the CLUSTER classification of Landsat MSS, NCIC topographic, and field observation data sets may be summarized as follows:

a. Pure stands of forest species have been classified with great accuracy.

b. All combinations of cover types are clustered with regard to dominant species.

c. Separation of Mountain Hemlock and Shasta Red Fir with CLUSTER classification seems impractical.

d. Other than species type and forest density, the crown size and hence forest maturity seems to have a major control over the amount of downed fuel. Larger crown sizes are indicative of a mature forest and hence larger amounts of downed fuel. However,

there seem to be exceptions to this rule throughout the field observations, which we believe they may be either due to errors in photographic interpretation of crown sizes or errors in locating of those DFSAs on color IR aerial photographs or perhaps due to prior forest fires.

e. As a general rule Lodgepole Pine forests have a higher spectral value and smaller amounts of downed fuel in comparison to other dominant species within the Park.

Final Analysis of Data at Berkeley Space Sciences Laboratory, Berkeley, California

This stage of analysis took place during late April, 1979. The primary objective was to classify Landsat MSS data in conjunction with digital terrain data with the assumption that such procedure would result in more realistic surface cover type classification than classification of MSS data alone. The assumption in this regard was based on field observation information which indicated that topographic elements of an area exert a powerful control over vegetation types and vegetation habitats within the region (Chapter 2). The final goal was to produce color coded photographic maps of digital surface cover types and downed fuel characteristics within the National Park. Since it was not feasible to carry out this procedure at the O.S.U. computer facilities, arrangements were made with Berkeley Space Sciences Laboratory to utilize their computer facilities for a MSS/topographic data set analysis.

Hardware Specification

The computer system utilized in the final analysis of this MSS/topographic data set at the Berkeley Space Sciences Laboratory included a Nova 840, and a standard Nova linked together by a data transmission line. Both computers were built by Data General Corporation. The Nova 840 has a 64K memory location, a word size

of 16 bits, 4 accumulators, an 800 nanosecond memory cycle time, and is capable of running two (foreground/background) programs simultaneously (University of California, 1974). Other hardware systems utilized in this phase of the study included an Interactive Color Display, and Digital Disc Memories.

Landsat MSS/topographic Data Set

Considering time and accomodation cost at Berkeley, California, decisions were made with regard to accomplishment of necessary preparation of data analysis prior to our trip to Berkeley. In cooperation with Mr. Gregory Smith of Space Sciences Laboratory, a spectral/topographic data set was produced for Crater Lake National Park and vicinity. The procedure included the adjustment of NCIC digital terrain data units to Landsat MSS 1.1 acre pixels. Original digitized NCIC terrain data tapes contain information on topographic elevations. Slopes and aspects were computed from these elevations (see Chapter 5 for details). Problems had to be overcome with regard to non-continuous contours on the adjoining four separate terrain data blocks, which, unfortunately joined over Crater Lake National Park. The separate data blocks pertained to four 1:250,000 scale USGS topographic quadrangles of the region, portions of each occupied by Crater Lake National Park (Chapter 5). When these were

conected at the splice lines one continguous data block was produced.

Digital data of terrain were oriented in a north-south direction which means that they were arrayed approximately 90 degrees from the orientation of the MSS pixel data. For this reason, to match terrain data cells with the Landsat 1.1 acre pixel areas of the study area a regression relationship was established between Landsat MSS, and Digital Terrain Tape (DTT) Coordinate system. This regression relationship provided the necessary means for data rotation.

In order to register Landsat MSS data with topographic information (slope, aspect, and elevation), eight readily definable points (mountain peaks), were relocated on both Landsat and terrain digital data, and the two sets of digital data information were registered with each other. The procedure provided seven sets digital values for each 1.1 acre pixel area within the National Park; four spectral Landsat bands (4-7), and three digital topographic bands for elevation, slope and slope aspect.

Analysis Procedure of Landsat Spectral/Topographic Data Sets

In the computer assisted classification of Landsat spectral/NCIC topographic data sets at Berkeley Space Sciences Laboratory, the Program Cluster was utilized. This program is an unsupervised

classification tool that separates a set of multi-dimensional data points into clusters of "similar" groups. Each cluster is represented numerically by a "center" mean of all features, and a "width" or the set of standard deviations of all features. Program cluster employs an iterative process to develop the cluster sets, and refines clusters in each iteration (Ritter, and Kaugars, 1978). Through this refinement procedure clusters with large standard deviations are divided into two new clusters, while separate clusters with similar, small standard deviations are combined into a single group or cluster. The refinement continues until clusters reached to a specific refinement stage called measure of "goodness". Limits of "goodness" is set by user by means of various parameters in the program.

Considering the large quantity of data involved in the computation, prior to analysis, data were transferred from digital tapes to a small 4.25 megabit fixed head disk. This disk is used for storage of crucial system programs, and data involved in high-speed computation (University of California, 1974).

When all necessary preparations involved in classification were completed and program cluster was generated, its results were displayed on a 19-inch interactive color monitor. Portions of displayed images were "zoomed" to magnify points of interest. Needed information for comparison and location purposes were extracted from the color monitor by selecting point coordinates with a light pen. These

screened and enhanced sets of information were then studied in conjunction with U-2 color infrared aerial photographs of the National Park. After a satisfactory measure of "goodness" was believed to have been achieved in cluster classification, the results were stored in the computer. Cluster classification provided us with fifty-four classes of surface cover types within the National Park. This result, along with base data criteria, i.e. Landsat/topographic data set parameters were displayed one at a time, on the color monitor screen and were examined as to their cover type character. At the same time color slides were made directly from the 19-inch color monitor screen. Photographic reproductions with regard to enhanced Landsat MSS base data, a fifty foot contour map of Crater Lake National Park and vicinity presented in Chapter 2, and digital depictions of slope and slope aspect of the Park and vicinity in this chapter were reproduced from the slides.

A computer compatible tape was then generated from the stored classification results and the tape was printed out and analysed at Oregon State University.

Analysis Results

By assigning fifty-four symbols for the computer determined fifty-four classes of cluster analysis accomplished at Berkeley,

California, a printout was generated from the tape at Oregon State University computer center.

At this point we had the following tools to study the cluster classification result:

a. A computer line print product represented by fifty-four symbols for the fifty-four original cluster classes of surface cover types within the National Park and vicinity (Appendix II).

b. Tabulations of fifty-four clusters (classes), with regard to their mean spectral values for each of four Landsat MSS band, plus three sets of digital terrain information pertaining to mean elevation, slope and slope aspect of each cluster.

c. Standard deviations of criteria in "b" above.

d. Information with regard to a number of points (pixels), for each cluster within fifty-four classes. Numerical information with regard to categories, b, c, and d are presented in Tables 82-84.

e. Varying scale U-2 color IR photographs for the study areas explained in Chapter 5.

f. Information acquired through field observation which have been described in Chapter 5.

Based on digital terrain information noted in "b" above, Figures 35 and 36 are color photographic representations of slope and slope aspect respectively for Crater Lake National Park

Number of Pixels in Each 54 Original Cluster Classes

CLUSTER	POINTS IN CLUSTER
1	259.
2	460.
3	5171.
4	2339.
5	2147.
6	438.
7	2364.
8	2676.
9	449.
10	1802.
11	5356.
12	858.
13	5048.
14	1995.
15	4123.
16	7993.
17	730.
18	959.
19	23630.
20	4960.
21	2586.
22	2014.
23	26465.
24	7178.
25	1456.
26	1895.
27	730.
28	10494.
29	5416.
30	3496.
31	454.
32	46340.
33	3911.
34	1262.
35	342.
36	4501.
37	1653.
38	1463.
39	3190.
40	15518.
41	1025.
42	7517.
43	1344.
44	9757.
45	1079.
46	1543.
47	32746.
48	1681.
49	1985.
50	1887.
51	12317.
52	27476.
53	45828.
54	19989.
TOTAL	379797.

Table 82

Means of MSS/Topographic Data Set for 54 Original Cluster Classes

CLUSTER	Band 4 CH(1)	Band 5 CH(2)	Band 6 CH(3)	Band 7 CH(4)	Elevation CH(5)	Slope CH(6)	Aspect CH(7)
1	32.06	33.09	35.07	14.96	7051.50	38.20	34.02
2	37.02	40.08	43.38	19.03	7545.72	27.06	38.67
3	15.44	9.67	18.08	9.83	6145.71	9.09	66.01
4	14.75	8.80	17.08	9.23	6473.41	13.41	8.78
5	18.53	15.03	23.73	12.77	6540.09	17.15	47.76
6	16.35	9.96	24.77	14.78	4918.72	42.55	57.76
7	14.57	11.90	21.10	11.70	6775.98	9.94	14.25
8	15.66	9.22	20.05	11.40	5012.42	19.83	47.07
9	16.74	11.76	15.46	7.21	6738.81	39.78	35.44
10	30.23	31.53	32.75	13.99	6628.70	6.10	43.38
11	14.86	8.81	16.75	9.18	5832.45	15.66	50.43
12	13.50	5.42	4.08	.92	6604.51	38.34	32.24
13	12.83	13.14	22.14	12.14	6421.31	6.46	47.60
14	19.72	15.59	32.52	19.05	5754.52	7.45	34.94
15	15.95	9.97	18.99	10.48	5748.09	13.13	12.91
16	13.65	9.11	21.94	12.80	5035.08	5.12	34.83
17	23.69	22.35	26.84	12.76	6874.90	17.17	55.45
18	26.82	27.23	34.33	17.05	6994.90	20.18	37.04
19	14.82	10.39	18.38	9.98	5736.27	2.75	56.92
20	14.82	8.96	17.33	9.40	6331.51	3.16	6.23
21	20.40	17.64	25.45	13.21	6245.31	5.39	55.33
22	17.29	11.95	26.63	15.81	5776.53	13.00	38.13
23	17.19	12.66	18.92	9.99	4839.28	.83	2.50
24	15.54	9.73	19.00	10.48	6085.27	8.23	41.92
25	15.90	10.59	19.59	10.71	6819.24	22.05	38.49
26	24.86	24.69	29.24	13.70	6479.83	4.35	55.51
27	37.49	40.30	42.44	18.01	7214.17	8.09	32.83
28	13.10	4.21	2.71	.32	6128.29	.12	.61
29	18.83	15.22	22.14	11.74	6109.28	4.43	14.93
30	18.01	13.11	26.89	15.42	4680.48	3.55	42.17
31	20.72	17.76	27.30	14.50	6482.58	39.07	38.32
32	16.22	10.12	22.43	12.89	3926.83	.22	.61
33	14.33	8.00	16.21	8.55	5546.02	9.03	13.94
34	18.56	14.75	25.12	13.85	6633.10	19.11	15.44
35	16.38	9.90	27.88	16.85	5063.56	38.14	15.06
36	18.84	11.70	20.44	11.37	6050.39	8.86	22.17
37	15.58	9.15	20.79	11.92	5443.93	21.53	7.60
38	15.24	9.04	18.25	10.09	5435.24	35.07	40.25
39	28.77	29.72	32.00	14.66	4670.34	.50	1.98
4	14.53	8.07	16.84	9.24	5579.94	4.47	53.69
41	13.27	5.08	3.96	.38	6372.37	13.64	36.21
42	17.04	11.90	22.30	12.56	5501.13	4.69	49.64
43	17.96	13.04	27.20	16.06	5612.48	3.83	17.56
44	16.00	10.44	18.91	10.40	5826.76	3.91	21.15
45	22.77	21.10	28.42	14.60	6627.52	15.98	19.96
46	25.35	25.45	33.72	17.02	6711.67	7.03	35.18
47	15.04	8.86	16.88	9.06	4232.18	.26	.78
48	20.03	17.24	25.42	13.51	6629.25	4.99	12.68
49	15.15	9.38	27.42	16.69	4594.25	14.13	41.25
5	14.23	10.35	19.02	10.34	5990.63	23.08	35.49
51	23.57	22.46	23.72	11.69	3727.15	.37	1.52
52	19.36	15.64	23.27	12.38	3916.56	.46	2.61
53	18.98	13.92	31.58	18.68	3571.48	.07	.29
54	15.66	9.27	19.52	10.95	3717.92	.37	3.04

Table 83

Standard Deviations of MSS/Topographic Data Set for 54 Original Cluster Classes

CLUSTER	Band 4 CH(1)	Band 5 CH(2)	Band 6 CH(3)	Band 7 CH(4)	Elevation CH(5)	Slope CH(6)	Aspect CH(7)
1	13.78	14.81	12.80	8.60	502.19	10.03	21.83
2	3.80	6.65	5.65	3.08	460.27	8.37	19.33
3	1.02	1.58	1.94	1.37	557.85	2.85	4.54
4	.90	1.33	1.79	1.14	419.54	4.55	7.05
5	1.17	1.75	2.43	1.78	661.71	4.79	11.10
6	1.07	2.00	3.03	2.18	876.49	21.32	14.42
7	.87	1.62	1.76	1.23	298.21	3.30	9.21
8	.97	1.51	2.07	1.43	416.04	4.25	10.57
9	1.87	2.63	3.42	2.49	409.93	9.16	24.89
10	1.82	2.22	2.86	2.03	727.65	4.70	14.51
11	.99	1.35	2.33	1.53	604.05	3.61	11.02
12	1.19	1.64	2.39	1.35	322.71	9.75	20.74
13	.87	1.47	1.74	1.23	298.91	3.10	11.49
14	1.62	2.85	3.96	2.70	783.71	4.98	15.74
15	.80	1.57	1.57	1.21	480.69	2.64	10.47
16	.85	1.34	1.83	1.23	443.61	2.74	14.01
17	1.95	2.31	3.08	2.55	839.34	6.95	10.99
18	2.07	2.87	3.55	2.48	800.47	6.30	15.75
19	.83	1.55	1.47	1.07	437.57	1.59	10.30
20	.83	1.21	1.62	1.08	271.31	2.18	6.71
21	1.27	2.02	2.46	1.81	704.87	3.13	10.92
22	1.11	2.12	2.94	2.20	549.86	4.46	13.98
23	.85	1.31	1.47	1.06	1263.32	1.62	5.85
24	.85	1.36	1.47	1.06	538.43	2.48	5.95
25	.97	1.64	2.20	1.57	324.99	3.99	18.44
26	1.78	2.43	2.42	2.13	709.17	2.71	9.81
27	5.40	6.07	4.88	2.60	828.11	5.07	22.91
28	.82	.91	1.28	.91	240.62	.90	4.63
29	1.00	1.45	1.67	1.18	358.55	3.13	11.77
30	1.38	2.45	2.51	1.85	420.05	2.35	9.31
31	1.85	2.87	4.61	3.59	926.13	11.36	13.76
32	.98	1.84	2.05	1.55	784.58	.88	3.04
33	.82	1.10	2.08	1.29	423.45	3.79	10.67
34	1.16	1.69	2.95	2.07	637.19	4.23	9.45
35	1.12	1.98	4.15	2.93	735.82	8.19	12.37
36	.78	1.39	1.62	1.19	366.12	2.42	9.77
37	1.11	1.74	2.63	1.88	663.47	4.17	8.47
38	1.13	1.68	2.43	1.58	679.04	9.53	16.44
39	1.74	2.66	2.74	2.34	1358.32	1.97	6.04
40	.79	.90	2.04	1.35	508.52	2.26	10.14
41	1.12	1.46	2.45	1.36	380.23	6.07	17.66
42	.88	1.64	1.87	1.37	477.31	2.84	11.32
43	1.30	2.25	2.31	1.56	483.31	2.72	13.49
44	.78	1.46	1.35	1.02	339.95	1.66	8.61
45	1.50	1.99	3.33	2.38	851.62	5.73	13.51
46	1.80	2.66	3.17	2.27	889.91	3.28	13.67
47	.99	1.62	1.78	1.13	1008.28	.86	3.49
48	1.21	1.82	1.77	1.47	535.11	3.74	10.96
49	.95	1.58	3.55	2.48	488.35	5.36	16.35
50	1.09	1.74	2.27	1.67	352.74	3.41	16.13
51	1.43	2.01	3.57	2.60	945.79	1.34	5.32
52	1.34	1.91	1.51	1.15	727.30	1.27	6.68
53	1.94	3.08	5.08	4.49	285.28	.64	2.57
54	.85	1.48	1.23	.94	449.59	1.13	8.88

Table 84

Color-Coded digitized Slope Map of Crater Lake National Park and Vicinity.

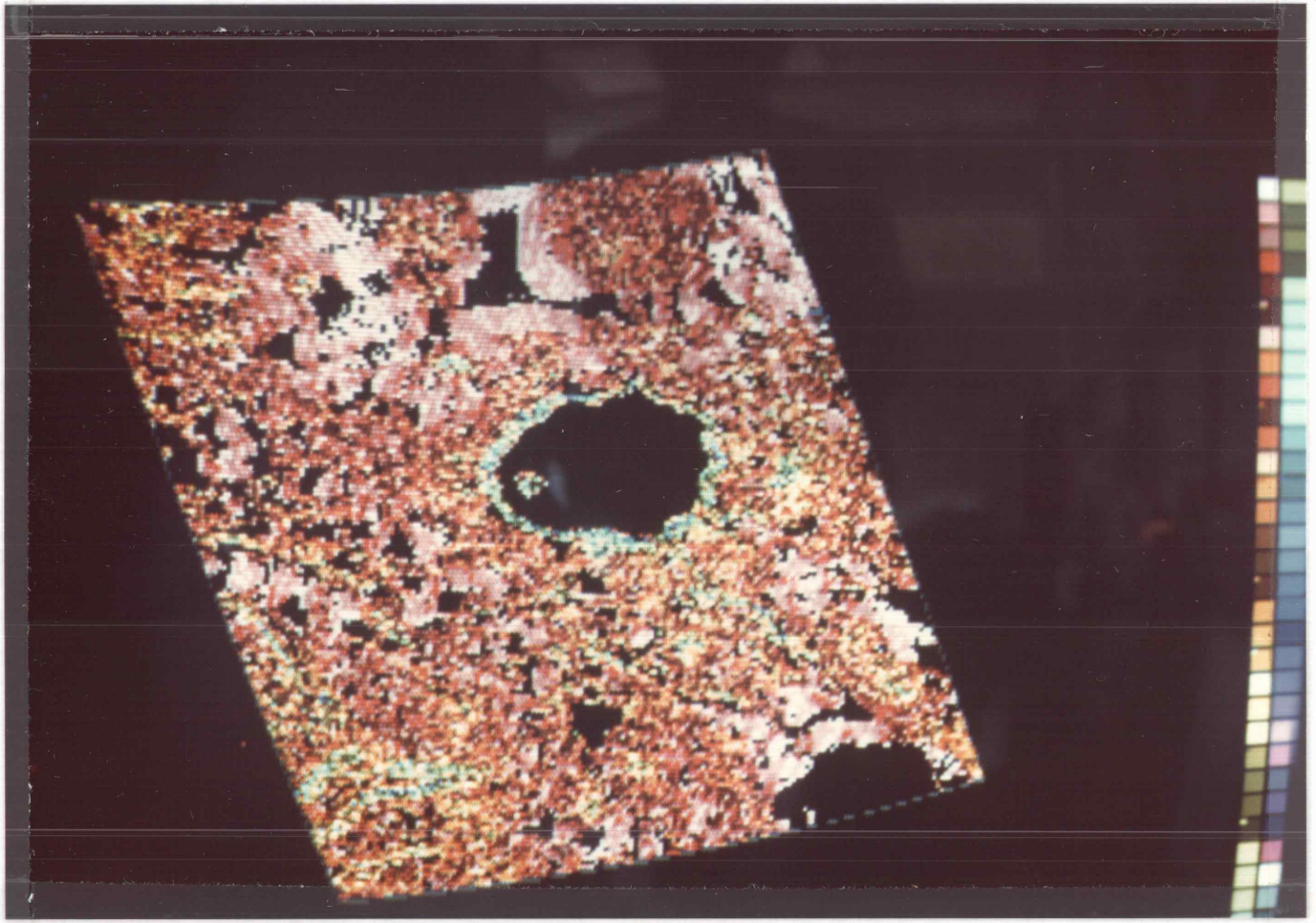


Figure 35

Color-Coded Digitized Slope Aspect Map of Crater Lake National Park and Vicinity.

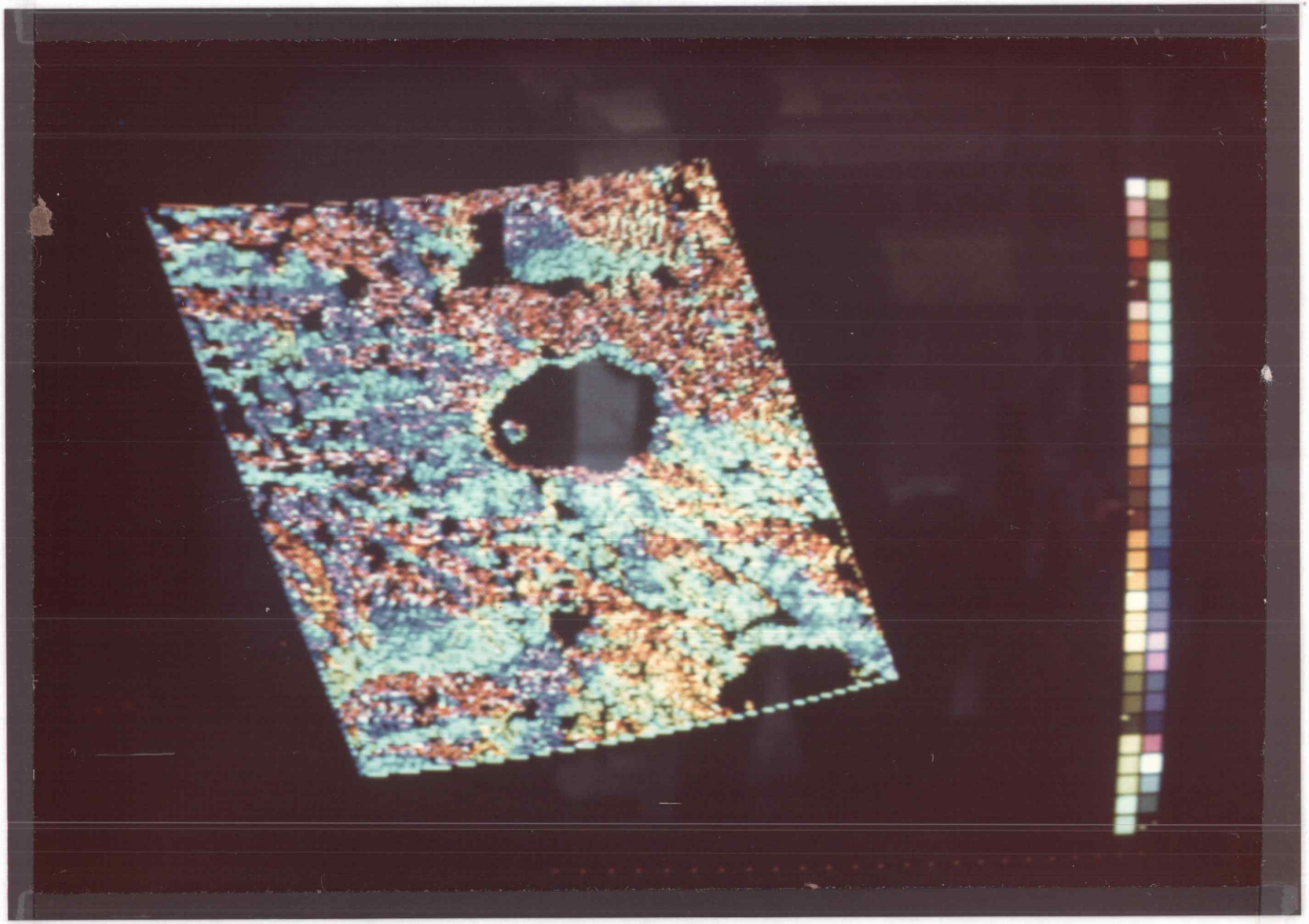


Figure 36

and vicinity. In Figure 35, surfaces with no slope such as surface of the Lake or sections of Pumice desert are shown in dark blue. Steeper slopes of inner rim walls and mountain peaks are shown in shades of bluish green. Shades of red have been assigned to the gentler sloped surfaces of the study area. Color codes of varying slope aspects in Figure 36 may be understood from the coloration of the inner rim walls of the Lake, matching those colors with similar slope aspects of other areas within the Park. It should be noted that slopes and slope aspects of the National Park in Figures 35 and 36 have been classified in one and five degrees increments respectively for calculation purposes while coloration variations are much less refined. Slope aspect was initiated from true north in a clockwise direction (see Table 83).

In the analysis of cluster classification results, all criteria mentioned in "a" through "f" above, were jointly analyzed, and cluster decisions were made with regard to surface cover types (Figure 37). Explanations with regard to cluster (class) symbols in Appendix II and color codes of Figure 37 follow the current discussion. The Fifty-Four Cluster Classes were first divided into forested and non-forested areas. Non-forested areas were combined into one single class and remaining cluster classes were classified according to their similarities ignoring their slope and slope aspect differences. As a result twenty-three surface cover type classes were designated

as Simplified Vegetation Classes, and Figure 38 was developed for these new classes. These simplified vegetation classes are presented in Appendix III.

The twenty-three and fifty-four cluster classifications were then correlated to the fifty-seven Downed Fuel Study Areas (DFSAs) by organizing their similarities from three major points of view:

a. Comparison of their spectral values i. e. weighting their spectral values (Tables 73A-81A) with those of twenty-three, and fifty-four cluster classes.

b. Matching DFSAs topographic information such as elevation, slope and slope aspect from Table 72, presented earlier in this chapter, with similar criteria in the twenty-three and fifty-four cluster classes.

c. Comparison of forest characteristics of DFSAs such as density, and maturity with the twenty-three and fifty-four cluster classes of surface cover types.

In all comparisons mentioned above, NASA U-2 color IR photographs were employed as an intermediate tool in locating specific locations of DFSAs, and registering them on computer print-outs of the fifty-four cluster classes.

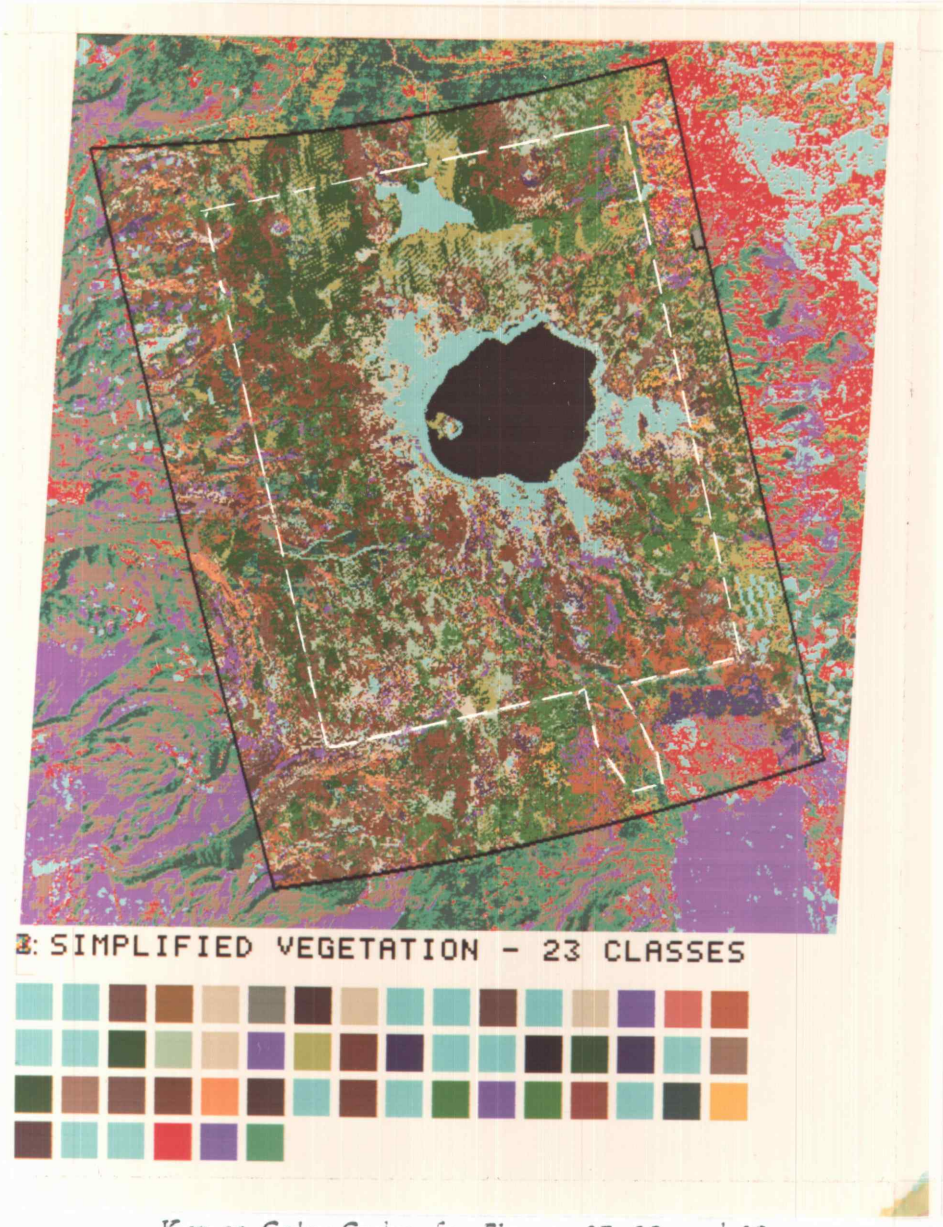
As a result several cluster classes were combined and Figure 39 was generated with 13 generalized Downed Fuel Classes.



Key to Color-Codes, for Figures 37, 38, and 39

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
49	50	51	52	53	54										

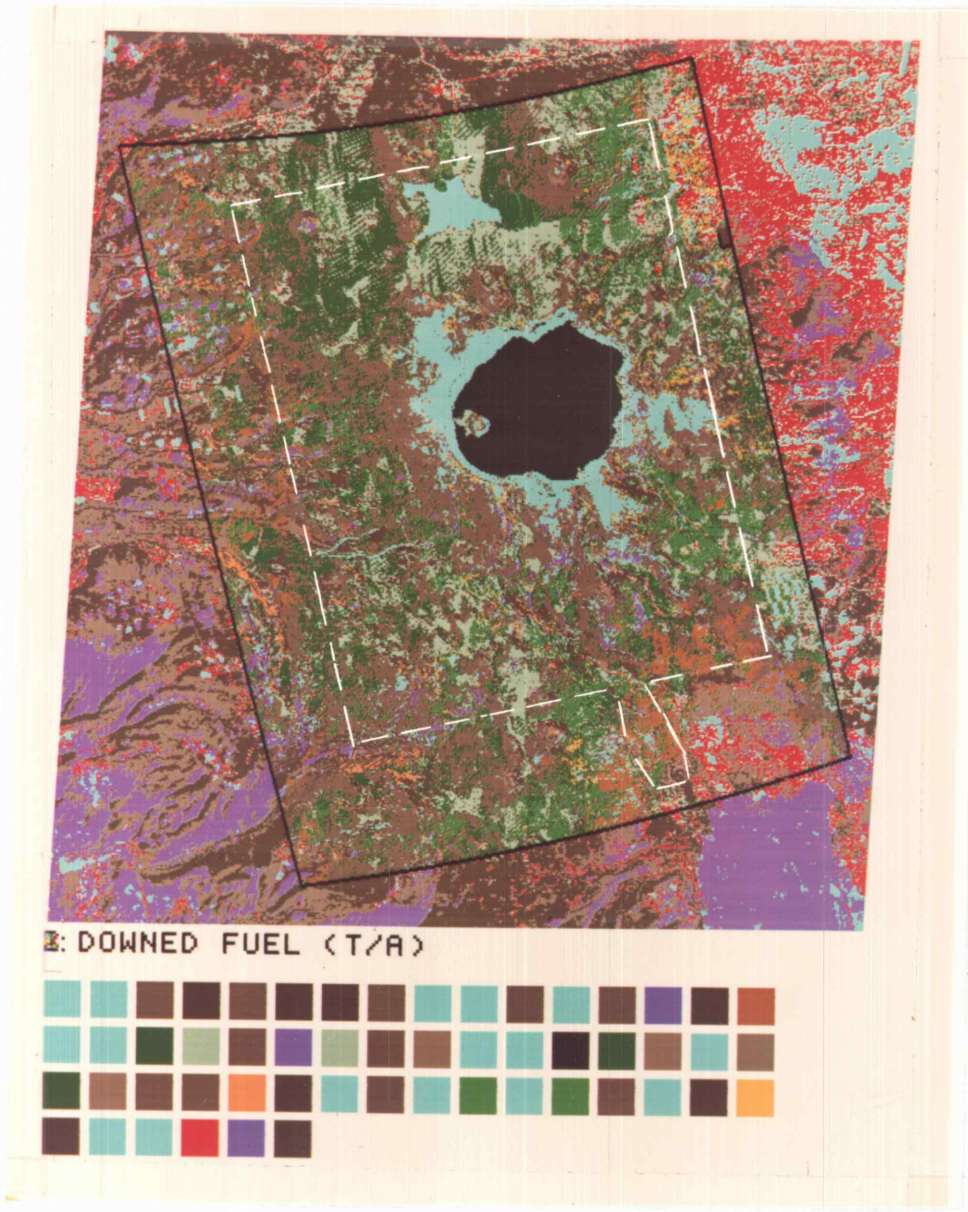
Figure 37
(see text for explanation)



Key to Color-Codes, for Figures 37, 38, and 39

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
49	50	51	52	53	54										

Figure 38
(see text for explanation)



Key to Color-Codes, for Figures 37, 38, and 39

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
49	50	51	52	53	54										

Figure 39
(see text for explanation)

It should be noted that the downed fuel classification results are to be considered provisional and will be randomly field tested in the near future. A computer print-out of downed fuel classification is given in Appendix IV.

Before initiating the section on description of symbols utilized in these three stages of classification, it is appropriate to discuss briefly, the color reproductions presented in Figures 37, 38, and 39. Color arrangements of these photographs are in accordance with the new IGOR colors whose color arrays and hue planes are represented in Figure 40. The colors arranged in an 8 x 32 array. In this manner, 248 color choices have been made available to the IGOR users.

In the processes leading to the development of the color scheme seen in Figure 37 and its Key, Table 85, (original cluster classification), an attempt has been made to choose colors from IGOR color arrays, which hues are conveniently recognizable by the unaided eye. In Figure 38 sets of several groupings of the original cluster classes have been assigned a single color. In order to follow the rearrangement of color codes with descriptions of classes, see Figure 41, and the

Table 85. Key to Figure 37 and Appendix II

Color-code and class #	Class Symbol	Surface cover types of the 54 cluster classes
1	B	Cliff, very steep, S.S.E. slopes.
2	C	Bare rock and/or pumice.
3	D	Mountain Hemlock, medium densely stocked.
4	E	Mountain Hemlock and Shasta Red Fir, densely stocked.
5	F	Young Mountain Hemlock, medium densely stocked, on northeastern slopes.
6	G	Young to mature Mountain Hemlock forest, medium densely stocked.
7	H	Mountain Hemlock, densely stocked.
8	I	Medium densely stocked young Mountain Hemlock forest on southwestern slopes.
9	J	Caldera rim areas with light grass cover.
10	K	Pumice lands on varying slopes.
11	L	Mature Mountain Hemlock forest, medium densely stocked.
12	M	Inner caldera rim walls.
13	N	Medium densely stocked young Mountain Hemlock forest on southwestern slopes(gentler slopes than class 8).
14	O	Brush with few trees.
15	P	Mountain Hemlock predominant, with some Lodgepole Pine, densely stocked forest.
16	Q	White Fir and Ponderosa Pine with some Shasta Red Fir, dense forest.

Table 85(continued)

Color-code and class #	Class Symbol	Surface cover type of the 54 cluster classes
17	R	Pumice lands on western slopes.
18	S	Pumice lands with grass cover type.
19	T	Lodgepole Pine forest, densely stocked.
20	U	Lodgepole Pine and Mountain Hemlock, poorly stocked forest(if at rim areas Lodgepole Pine is replaced with Whitebark Pine), medium densely stocked forest.
21	V	Very young generation of Mountain Hemlock and/or Shasta Red Fir, densely stocked forest.
22	W	Brush on well drained pumice lands.
23	X	Lodgepole Pine poorly stocked(if at caldera rim areas, it is shadowed pumice or lava).
24	Y	Shasta Red Fir and/or Mountain Hemlock with approximately 15% Lodgepole Pine stands, medium density forest.
25	Z	Very poorly stocked Mountain Hemlock forest on very steep slopes.
26	0(zero)	Pumice with grass.
27	1	Pumice.
28	2	Water(outside the Lake at caldera rim areas it is dark, shadowed lava or rock outcrop).
29	3	Densely stocked Lodgepole Pine with some Ponderosa Pine or Mountain Hemlock.
30	4	Very poorly stocked Mountain Hemlock on less steeper slopes than class 25

Table 85(continued)

Color-code and class #	Class Symbol	Surface cover types of the 54 cluster classes
31	5	Cliffs, very steep, S, S.W. slopes.
32	6	Mountain Hemlock and/or Shasta Red Fir, clustered canopies on flat surfaces.
33	7	Dense Lodgepole Pine forest with some Mountain Hemlock.
34	8	Mountain Hemlock and/or Shasta Red Fir, clustered canopies, on steep slopes.
35	9	Medium densely stocked Mountain Hemlock forest on very steep slopes.
36	+	Predominantly Shasta Red Fir and/or Mountain Hemlock forest with some brush or Lodgepole Pine, medium density forest.
37	-	Medium density White Fir forest with some Mountain Hemlock stands.
38	*	Mountain Hemlock forest, dense, on western steep slopes.
39	/	Pumice on flat lands.
40	(	Shasta Red Fir and/or Mountain Hemlock predominant, some Lodgepole Pine, medium densely stocked.
41	)	Caldera rim walls(steep slope).
42	$	Densely stocked young Lodgepole Pine forest.
43	=	Dense brush with scattered White Fir.
44	Blk	Lodgepole Pine medium dense forest, with Ponderosa emphasized on northeastern section of the Park.

Table 85(continued)

Color-code and class #	Class Symbol	Surface cover types of the 54 cluster classes
45	,	Medium density Mountain Hemlock forest on less steep slopes than class 9.
46	.	Pumice with thin grass cover type.
47	≡	Mountain Hemlock and/or Shasta Red Fir, medium to densely stocked forest.
48	[	Very low density Lodgepole Pine forest(if at rim areas, it is replaced with Whitebark Pine).
49	]	Dense Mountain Hemlock forest with some Shasta Red Fir.
50	%	Pumice, lava or bare rock with thin grass cover.
51	≠	Pumice lands, nearly flat.
52	⊢	Low to medium densely stocked Ponderosa Pine forest.
53	v	Dense brush.
54	Λ	Mountain Hemlock and/or Shasta Red Fir, densely stocked forest.

Table 85

New IGOR Color Arrangement (248 Colors)

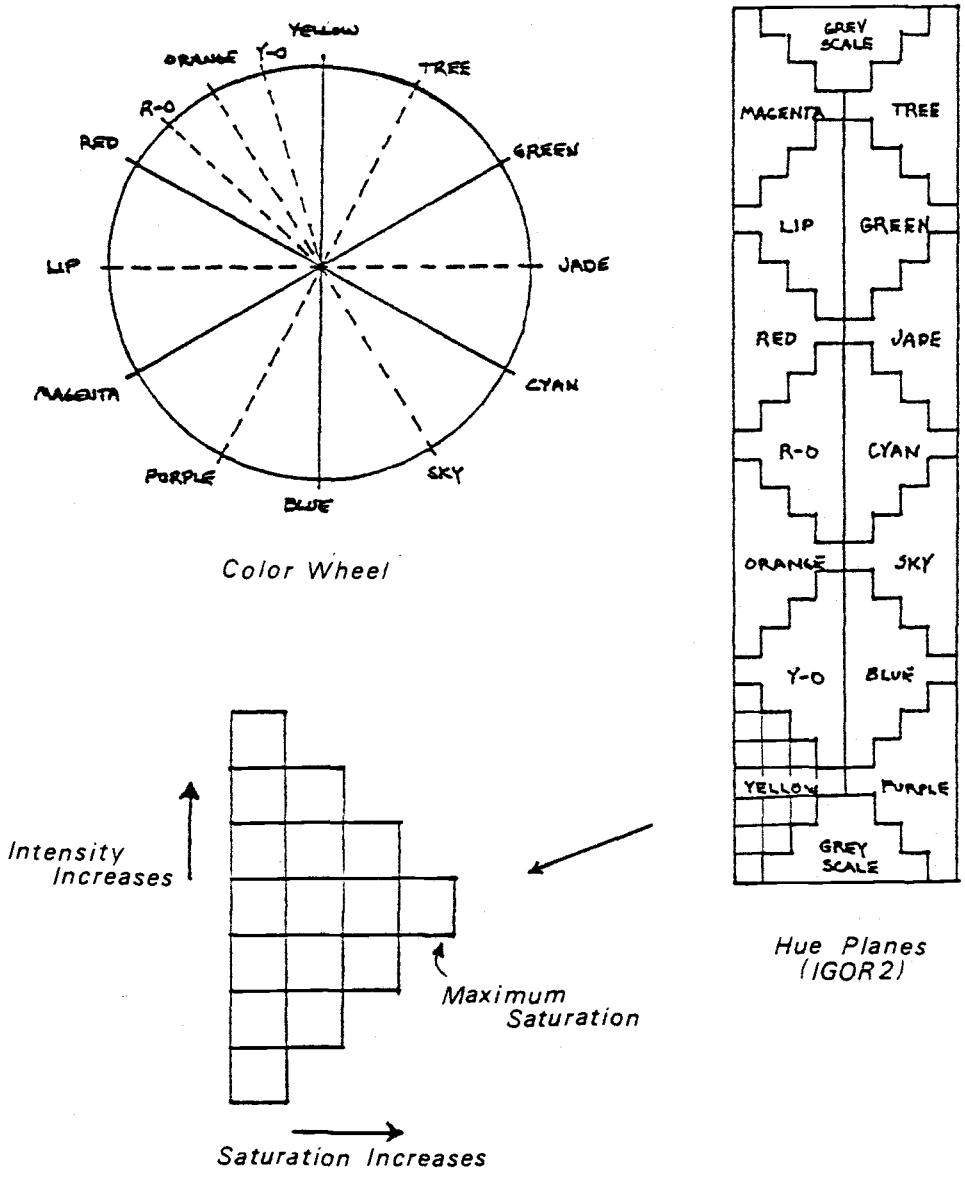


Figure 40. Adapted from IGOR manual (1979).

Key to Color-Codes, for Figures 37, 38, and 39

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
49	50	51	52	53	54										

Figure 41

key, Table 86. On Figure 41 the array of fifty-four original classes have been represented as they appear under Figures 37, 38, and 39. The number within each square indicates the class number in the original cluster classification. Thus, in studying color codes in each figure, the reader seeking the meaning of a specific color should consult Figure 41 for the original fifty-four class number, and then refer to class description in the appropriate table. Descriptions of the original fifty-four cluster classes is given in Table 85. Description of classes combined in the simplified vegetation classification map, and in the downed fuel classification map is given in Table 86 and 86 respectively.

Fuel classes in Table 87 have been grouped from the original fifty-four cluster classes with regard to dominant forest cover types, and their downed fuel characteristics. Cover types and downed fuel amounts for those classes are given in Table 88. For a better understanding of this procedure, numerical cover type characteristics of downed fuel amounts within fuel classes shown in Table 88, are given in Table 89.

It should be noted that areas presented in Figures 37, 38, and 39 represent an area considerably larger than that of Crater Lake National Park. In fact, the figures cover the area for which Landsat MSS spectral/NCIC topographic data sets were

Table 86. Key to Figure 38 and Appendix III

Class #	Class Symbol	Original 54 cluster classes combined*
1	A	Classes 32, and 34.
2	B	Classes 19, 29, and 33.
3	C	Classes 3, 11, and 35.
4	D	Classes 24, 36, and 40.
5	E	Class 37.
6	F	Classes 7, 38, and 49.
7	G	Classes 1, 2, 9, 10, 12, 17, 18, 26, 27, 31, 39, 41, 46, 50, and 51.
8	H	Classes 42, and 44.
9	I	Classes 14, 22, 43, and 53.
10	J	Class 45.
11	K	Class 47.
12	L	Class 48.
13	M	Class 52.
14	N	Class 54.
15	O	Class 4.
16	P	Classes 5, 8, 13, and 21.
17	Q	Class 6.
18	R	Class 15.
19	S	Class 16.
20	T	Class 20.
21	U	Class 23.
22	V	Class 28.
23	W	Classes 25, and 30.

* For description of classes refer to table 85.

Table 87. Key to Figure 39 and Appendix IV

Class #	Class Symbol	Original 54 cluster classes combined*	Color-codes and their (purposes)*
1	A	Class 28.	Black(water)
2	B	Classes 1, 2, 9, 10, 12, 17, 18, 26, 27, 31, 39, 41, 46, 50, and 51.	Light blue (non-hazardous for forest fires)
3	C	Classes 30, 32, and 34.	Light brown (Mountain Hemlock, low density)
4	D	Classes 3, 5, 8, 11, 13, 21, 24, 35, 36, 40, and 45.	Med. brown (Mountain Hemlock, med. dense)
5	E	Classes 4, 6, 7, 15, 38, 47, 49, and 54.	Dark brown (Mountain Hemlock, dense)
6	F	Class 48.	Yellow(Lodgepole Pine very poorly stocked)
7	G	Classes 20, and 23.	Light green (Lodgepole pine, low density)
8	H	Classes 42, and 44.	Med. green (Lodgepole Pine, med. density)
9	I	Classes 19, 29, and 33.	Dark green (Lodgepole Pine, high density)
10	J	Class 37.	Light orange (White Fir, med. dense)

Table 87(continued)

Class #	Class Symbol	Original 54 cluster classes combined	Color-codes and their (purposes)*
11	K	Class 16.	Dark orange (White Fir, high density)
12	L	Class 52.	Red(Ponderosa Pine, med. density)
13	M	Classes 14, 22, 43, and 53.	Purple (brush)

*For complete description of color-codes, and individual classes refer to Figure 41, and Table 85.

Table 87

Fuel Classes and Amounts of Downed Fuel in Each Class

Class Symbol	Cover type (density)	Original 54 cluster classes combined	Downed fuel(t/a)
A	Mountain Hemlock and/ or Shasta Red Fir, (low density)	Classes 25, 30, 32, and 34.	9.06
B	Mountain Hemlock and/ or Shasta Red Fir, (medium density)	Classes 3, 5, 8, 11, 13, 21, 35, 36, 40, and 45.	32.90
C	Mountain Hemlock and/ or Shasta Red Fir, (high density)	Classes 4, 6, 7, 15, 47, 49, and 54.	36.70
D	Lodgepole Pine, (very poorly stocked)	Class 48	0.35
E	Lodgepole Pine, (low density)	Classes 20, and 23.	14.32
F	Lodgepole Pine, (medium density)	Classes 42, and 44.	16.77
G	Lodgepole Pine, (high density)	Classes 19, 29, and 33.	32.08
H	White Fir (medium density)	Class 37.	18.75
I	White Fir (high density)	Class 16.	41.45
J	Ponderosa Pine (medium density)	Class 52.	14.20
K	Brush	Classes 14, 22, 43, and 53.	—
L	Water	Class 28	—
M	Pumice and "Areas Non-Hazardous For Forest Fire"	Classes 1, 2, 9, 10, 12, 17, 18, 26, 27, 31, 39, 41, 46, 50, and 51.	—

Table 88

Numerical Specifications of Fuel Classes

Cover type	Density (%)	Mean % canopy area forested	Mean crown size (feet)	Downed Fuel Means(t/a)	ST Dev.
Mountain Hemlock/Shasta Red Fir (poorly stocked)*	15-30	23.38	30.62	9.06	±1.15
Mountain Hemlock/Shasta Red Fir (medium densely stocked)	30-65	55.89	34.19	31.79	±12.19
Mountain Hemlock/Shasta Red Fir (high densely stocked)	65+	80.28	33.09	36.71	±22.38
Lodgepole Pine (very poorly stocked)	15	11.21	11.80	0.35	—
Lodgepole Pine (poorly stocked)	15-30	21.07	14.83	14.32	±7.53
Lodgepole Pine (medium densely stocked)	32-65	41.43	19.39	16.77	±8.53
Lodgepole Pine (high densely stocked)	65+	72.54	21.31	32.08	±8.45
White Fir (medium densely stocked)*	30-65	36.36	22.83	18.75	—
White Fir (high densely stocked)	65+	75.61	29.67	41.45	±16.44
Ponderosa Pine (medium densely stocked)*	30-65	61.07	47.25	14.20	±4.99

*Omitted density categories did not exist within the Park.

Table 89

available. Park boundaries are represented in dashed lines which have been added manually onto photo negatives.

Finally, it has been concluded that the diagonal stripping effect on the photos, especially in and around Pumice desert are due to multi-variable data analysis. In the other words, analysis of MSS/ topographic data sets with the cluster program should optimally have been subjected to, at least one further iteration.*

*Personal communications with Mr. Gregory Smith, Space Sciences Laboratory, University of California, Berkeley.

Chapter Summary

This chapter has focused on MSS, topographic and field observation data analysis of this study. This procedure took place in two stages. First stage analysis was conducted with Oregon State computer facilities during which field data were clustered with regard to DFSAs MSS spectral/NCIC topographic values. The second, or final stage of analysis was done on the computer facilities at Berkeley Space Sciences Laboratory, Berkeley, California. During this phase of study a complete set of MSS spectral/NCIC topographic data were analyzed. As a result, surface cover types of the study area were clustered into fifty-four classes. With further analysis of the fifty-four original classes a set of simplified vegetation classes was developed. Finally by correlating these findings to downed fuel field observation data a downed fuel map of the Crater Lake National Park was generated. Three color coded photographic products with regard to original fifty-four cluster classes, simplified vegetation classes, and downed fuel amounts were originated, and their specifications were discussed.

Chapter seven is a summary and conclusion of this study.

CHAPTER 7. SUMMARY AND CONCLUSIONS

SUMMARY

This research has focused on utilization of Landsat 2 MSS and NCIC digital topographic data for wild land surface and cover type mapping and downed fuel tonnage/acre classification within Crater Lake National Park, Oregon. In identification and mapping of surface cover types through "ground truth" activities; Landsat reconnaissance and operational specifications, Landsat MSS data limitations and capabilities, and influences of topographic elements of the study area in altering MSS data acquired by Landsat sensor system have been evaluated. Furthermore, as a complimentary research tool, NASA U-2 color infrared photographs have been utilized and their advantages and limitations to that of Landsat MSS data have been considered.

Data Acquisition Techniques

Acquired data in this study included: a) digitized Landsat and NCIC topographic data and b) conventional data acquired through "ground truth" activities.

Landsat MSS and topographic data were both in computer compatible tape (CCT) formats. Landsat MSS data acquired for September 10, 1974 were owned by Dr. James F. Lahey of Dept. of Geography at Oregon State University. This tape series was chosen

from among several other MSS tapes because:

a) Data were free of bad scan lines,

b) Data were acquired during relatively high-elevation solar angle

c) Data were acquired under cloud free conditions, and finally,

d) Due to seasonality, at the time of acquisition of these data, the ground surface within the National Park was free of snow. For this reason the MSS data represented adequate spectral reflectance ranges from the variable surface cover types.

Digitized topographic data were acquired from National Cartographic Information Center (NCIC), Reston, Va. NCIC topographic data tapes contain digital information of elevation at about 208-foot horizontal intervals. By computer assisted programs these data from the digital topographic map were organized into the digital slope and slope aspect maps used for this study.

As complimentary data for this research NASA U-2 color infrared photographs were utilized. These photographs were obtained from NASA/Ames Research Center, Moffett Field, California. The color IR photographs were in four different scales: 1:122,000, 1:30,500, 1:30,000, and 1:7,400. The latter photographs were enlargements of 1:30,500 scale IR photographs mentioned above, and were processed at EROS Data Center Sioux Falls, South Dakota.

"Ground Truth" Activities

Data from field observations were acquired during summer months of 1978. Two sets of observations were taken; 1) estimation of downed fuel moisture contents were made at designated time and space intervals, and 2) another set of observation was made of the amounts of downed fuel available for wild fires under sample forested areas within Crater Lake National Park. For moisture data collection, twenty-four Fuel Moisture Indicator Sticks (FMIS) were established at various sites within Crater Lake National Park. Moisture content measurements were made from these FMISs through the months of August and early September of 1978. With regard to second phase of field observation, fifty-seven sites were selected within the Park and amounts of their downed fuels were inventoried. In the selection of downed fuel study areas (DFSAs), necessary considerations were observed so that each DFSA represented a specific forest species or forest species complex.

For inventorying downed woody material a Planar Intersect Method developed by James K. Brown (1974), was employed. This methodology was preferred over similar procedures because it was the most recognized and suitable downed fuel inventorying tool for forests in the Western high-lands of the United States. Furthermore, the method provides the user with estimates of downed fuel amounts per unit of forested land (Tons/Acre). Finally, it is a

fast and time saving methodology for inventorying downed woody material with 80 percent or more precision, an accuracy which is generally considered adequate by scientists working with forest fire related problems.

Through field observations with regard to inventorying downed woody materials it was learned that although a wide variety of coniferous forest species exist within the National Park, only the following species are dominant: a) Mountain Hemlock (Tsuga mertensiana), b) Shasta Red Fir (Abies magnifica), c) Lodgepole Pine (Pinus contorta), d) Ponderosa Pine (Pinus ponderosa), e) White Fir (Abies concolor), and f) to lesser degree Western White Pine (Pinus monticola). Within "ground truth" or DFSA sites, stands of these tree species varied from pure or 100% of single species to less than 5% mixed with other species. Accumulated field data revealed that amounts of downed woody materials varied significantly within the various DFSAs. The minimum amount of downed fuel within all inventoried DFSA was 0.35 Ton/Acre, inventoried under a very poorly stocked Lodgepole Pine forest. The maximum amount of downed fuel was 91.67 Tons/Acre inventoried under a very high density and mature Mountain Hemlock forest.

In general, surface and surface cover types of non-forested areas within the National Park included: 1) Pumice or bare rock, 2) Water, 3) Pumice lands with a few or sparse trees, and 4) Pumice and/or lava. In accordance with spectral reflectance characteristics of

these non-forested surface cover types as determined by a detailed computer cluster analysis at the EROS Data Center by Walsh (1977), 47 different non-forested sample sites were detected, bringing this study total number of sample sites (forested and non-forested), to 104 within Crater Lake National Park.

Data Analysis Techniques

Based on field observations and Landsat MSS data for 57 DFSAs, twenty-nine parameters were created to depict surface cover type characteristics associated with amounts of downed fuels within the Park. Analysis of these data was accomplished primarily at Oregon State University, and then final analysis of the total MSS/topographic data set for the entire study region was conducted at Berkeley Space Sciences Center at Berkeley, California.

Preliminary Analysis at Oregon State University

The twenty-nine parameters mentioned above were established in accordance with downed fuel amounts, forest type characteristics, topographic elements, and MSS data specifications of all ground truthed areas (DFSAs). In analysis of these data a dissimilarity clustering technique developed by James A. Keniston (1978), from Oregon State University, was utilized. This program uses an agglomerative clustering technique to classify a set of entities based on comparison of their attributes. Utilizing this technique, forested and non-forested surface cover types within Crater Lake National Park were classified into subclasses. As a result pure stands of dominant forest types were classified with precision. Furthermore, dissimilarity cluster analysis created nine subclasses for 57 DFSAs, and twenty subclasses for non-forested sample sites within the

National Park.

Final Analysis at Berkeley Space Sciences Laboratory

The final stage of data analysis was performed at Berkeley Space Sciences Laboratory, Berkeley, California. The computer system utilized at Berkeley was an interactive Nova 840, and a standard Nova linked together by a data transmission line. Complimentary units were a color video display, a memory disk, a magnetic tape driver, and a line printer.

At the Berkeley Space Sciences Laboratory, a Landsat spectral/NCIC topographic data set of the Park region was classified by a clustering algorithm. This is an unsupervised classification program that separates a set of multidimensional data points into clusters of similar groups. Each cluster is represented numerically by a "center" or means of all features, and a "width" or a set of standard deviations. To develop the cluster set, the program cluster employs an iterative process, and refines clusters in each iteration. As the process continues, clusters with too small standard deviations are combined into a single cluster, while clusters with larger standard deviations are divided into two new clusters. The refinement will stop when a measure of "goodness" (set by the user), has been achieved.

As a result of the clustering procedure, surface cover types of the Crater Lake National Park were classified into fifty-four clusters

(classes). Later they were generalized into twenty-three classes, as "simplified vegetation". Correlating characteristics of fifty-seven DFSAs to these fifty-four clusters, and twenty-three classes, a "downed fuel" map was created. Throughout these processes for identification and classification of various surface cover types within the Park, NASA U-2 color infrared photographs were utilized extensively. Finally, from all three classifications, color coded photographic products were reproduced.

CONCLUSIONS

Within mountainous forested areas spectral reflectances of a single surface cover type may be altered due to slope, slope aspect and canopy density, maturity, and crown size. The problem of slope and slope aspect influence in surface cover type mapping and classification may be overcome by application of National Cartographic Information Center's (NCIC), digital terrain information to Landsat MSS data. To the knowledge of the analysts on this project, this is the first attempt of this nature.

For a better result, solar radiation intensity on varying slopes and slope aspects should be calculated for the time of Landsat data acquisition, so that proportionality of reflected solar radiation for different slopes and slope aspects could be defined.

Landsat bands 5 and 7 are best for vegetative cover type differentiation. These bands combined with the other two Landsat bands (4 and 6) provide the basically available digital tools for all surface cover type classifications.

Variations in spectral reflectances of boundary pixels between two different surface cover types is indicated by the spectral reflectances of adjacent cover types, and the proportion of the pixel area divided between those two surface cover types. Practical solutions for this problem have not yet been created.

Interpretation of NASA U-2 high altitude color infrared

photography is a useful technique in these Landsat MSS, NCIC topographic data related classifications. Such color infrared photographs are of special importance in classification of vegetative cover types due to the fact that they are acquired in similar ranges of the near infrared region of electromagnetic spectrum, where atmospheric scattering affect is at a minimum, and for this reason, spectral reflectances of vegetative cover types are enhanced in this portion of the electromagnetic spectrum. NASA U-2 color IR photographs have better resolutions and larger scales than Landsat, but they lack the capability of the Landsat system in gathering repetitive spectral reflectance characteristics of surface cover types. The analysis of these photographs employed relative to Landsat data is a qualitative rather than quantitative.

Ground truthing is a most important factor in Landsat MSS data related studies. The extent of ground truth needed is directly related to the complexity of the terrain, surface cover types characteristics, and details expected in classification.

Spectral reflectances of forest species not only vary due to species type, but they vary also with canopy maturity. Younger tree species show higher reflectances than mature trees of the same species. There also exists a close relationship between cover type maturity and density, and amounts of downed fuel available for forest fires within the forested areas. The magnitudes of downed

fuel vary significantly among different coniferous forest species. Mature Mountain Hemlock forest generally has the maximum amounts of downed fuel, while young and very poorly stocked Lodgepole Pine forest have the smallest amounts of downed fuel within Crater Lake National Park.

Environmental moisture patterns within the National Park during summer season is the function of air temperatures and precipitation amounts over the region. The mountainous topography of Crater Lake National Park creates rain shadows, and numerous microclimatic regions within the Park. For this reason, and for a better understanding of the climate of the Park area a large number of climatic data recording stations and snow data would be useful.

Cluster classifying of Landsat MSS data is an adequate tool for surface cover type separation. This approach gives the best result when it is combined with multi-scale NASA U-2 color infrared photographs, and adequate "ground truth" information. In this respect the clustering techniques may be referred to as "controlled unsupervised" classification. Within mountainous regions, application of Landsat MSS data to surface cover type mapping can be combined with NCIC digital topographic data for the region, to provide a better result with regard to separation of vegetative classes and downed vegetative fuel amounts. For multi-variable spectral/topographic data computation and analysis, interactive computers with video

color display units like the one at the Berkeley Space Sciences Laboratory are necessary.

Finally, in Landsat MSS data related studies, limitations and capabilities of multi-spectral scanner data must be appreciated. Furthermore the complexity of these limitations in mountainous regions must be considered so that misinterpretation, and thus misclassification of surface cover types are avoided. By increased "ground truth" activities and adequate field observations, the problems may be reduced to a minimum.

POSTSCRIPT

The reader has undoubtedly noted that fuel moisture ground truth readings have not been integrated with digital satellite data analyses as have all other surface derived data. This was a portion of the original plan of action, but was eliminated by the unfortunate failure of the Landsat 3, Band 8-the terrestrial heat sensing thermal radiation band.

Perhaps this study will serve as a "structural guidepost" for such a study in the near future.

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APPENDICES

Appendix I

FUEL MODELS*

*Deeming, Burgan, and Cohen. The National Fire-Danger Rating System - 1978, USDA Forest Service, General Technical Report INT-39 Intermountain Forest & Range Experiment Station, Forest Service, U.S. Department of Agriculture, Ogden, Utah.

FUEL MODEL A

This fuel model represents western grasslands vegetated by annual grasses and forbs. Brush or trees may be present but are very sparse, occupying less than one-third of the area. Examples of types where Fuel Model A should be used are cheatgrass and medusahead. Open pinyon-juniper, sagebrush-grass, and desert shrub associations may appropriately be assigned this fuel model if the woody plants meet the density criteria. The quantity and continuity of the ground fuels vary greatly with rainfall from year to year.

FUEL MODEL B

Mature, dense fields of brush 6 feet or more in height are represented by this fuel model. One-fourth or more of the aerial fuel in such stands is dead. Foliage burns readily. Model B fuels are potentially very dangerous, fostering intense, fast-spreading fires. This model is for California mixed chaparral generally 30 years or older. The F model is more appropriate for pure chamise stands. The B model may also be used for the New Jersey pine barrens.

FUEL MODEL C

Open pine stands typify Model C fuels. Perennial grasses and forbs are the primary ground fuel but there is enough needle litter and branchwood present to contribute significantly to the fuel loading. Some brush and shrubs may be present but they are of little consequence. Situations covered by Fuel Model C are open, longleaf, slash, ponderosa, Jeffrey, and sugar pine stands. Some pinyon-juniper stands may qualify.

FUEL MODEL D

This fuel model is specifically for the palmetto-gallberry understory-pine overstory association of the southeast coastal plains. It can also be used for the so-called "low pocosins" where Fuel Model O might be too severe. This model should only be used in the Southeast because of a high moisture of extinction.

FUEL MODEL E

Use this model after leaf fall for hardwood and mixed hardwood-conifer types where the hardwoods dominate. The fuel is primarily hardwood leaf litter. The oak-hickory types are best represented by Fuel Model E, but E is an acceptable choice for northern hardwoods and mixed forests of the Southeast. In high winds, the fire danger may be underrated because rolling and blowing leaves are not accounted for. In the summer after the trees have leafed out, Fuel Model E should be replaced by Fuel Model R.

FUEL MODEL F

Fuel Model F is the only one of the 1972 NFDRS Fuel Models whose application has changed. Model F now represents mature closed chamise stands and oakbrush fields of Arizona, Utah, and Colorado. It also applies to young, closed stands and mature, open stands of California mixed chaparral. Open stands of pinyon-juniper are represented; however, fire activity will be overrated at low windspeeds and where there is sparse ground fuels.

FUEL MODEL G

Fuel Model G is used for dense conifer stands where there is a heavy accumulation of litter and downed woody material. Such stands are typically overmature and may also be suffering insect, disease, wind, or ice damage--natural events that create a very

heavy buildup of dead material on the forest floor. The duff and litter are deep and much of the woody material is more than 3 inches in diameter. The undergrowth is variable, but shrubs are usually restricted to openings. Types meant to be represented by Fuel Model G are hemlock-Sitka spruce, Coast Douglas-fir, and windthrown or bug-killed stands of lodgepole pine and spruce.

FUEL MODEL H

The short-needled conifers (white pines, spruces, larches, and firs) are represented by Fuel Model H. In contrast to Model G fuels, Fuel Model H describes a healthy stand with sparse undergrowth and a thin layer of ground fuels. Fires in H fuels are typically slow spreading and are dangerous only in scattered areas where the downed woody material is concentrated.

FUEL MODEL I

Fuel Model I was designed for clearcut conifer slash where the total loading of materials less than 6 inches in diameter exceeds 25 tons/acre. After settling and the fines (needles and twigs) fall from the branches, Fuel Model I will overrate the fire potential. For lighter loadings of clearcut conifer slash, use Fuel Model J, and for light thinnings and partial cuts where the slash is scattered under a residual overstory, use Fuel Model K.

FUEL MODEL J

This model complements Fuel Model I. It is for clearcuts and heavily thinned conifer stands where the total loading of materials less than 6 inches in diameter is less than 25 tons/acre. Again, as the slash ages, the fire potential will be overrated.

FUEL MODEL K

Slash fuels from light thinnings and partial cuts in conifer stands are represented by Fuel Model K. Typically the slash is scattered about under an open overstory. This model applies to hardwood slash and to southern pine clearcuts where the loading of all fuels is less than 15 tons/acre.

FUEL MODEL L

This fuel model is meant to represent western grasslands vegetated by perennial grasses. The principal species are coarser and the loadings heavier than those in Model A fuels. Otherwise the situations are very similar; shrubs and trees occupy less than one-third of the area. The quantity of fuel in these areas is more stable from year to year. In sagebrush areas Fuel Model T may be more appropriate.

FUEL MODEL N

This fuel model was constructed specifically for the sawgrass prairies of south Florida. It may be useful in other marsh situations where the fuel is coarse and reedlike. This model assumes that one-third of the aerial portion of the plants is dead. Fast-spreading, intense fires can occur even over standing water.

FUEL MODEL O

The O fuel model applies to dense, brushlike fuels of the Southeast. O fuels, except for a deep litter layer, are almost entirely living in contrast to S fuels. The foliage burns readily except during the active growing season. The plants are typically over 6 feet tall and are often found under an open stand of pine. The high

pocosins of the Virginia, North and South Carolina coasts are the ideal of Fuel Model O. If the plants do not meet the 6-foot criteria in those areas, Fuel Model D should be used.

FUEL MODEL P

Closed, thrifty stands of long-needled southern pines are characteristic of P fuels. A 2- to 4-inch layer of lightly compacted needle litter is the primary fuel. Some small diameter branchwood is present but the density of the canopy precludes more than a scattering of shrubs and grass. Fuel Model P. has the high moisture of extinction characteristic of the Southeast. The corresponding model for other long-needled pines is U.

FUEL MODEL Q

Upland Alaskan black spruce is represented by Fuel Model Q. The stands are dense but have frequent openings filled with usually inflammable shrub species. The forest floor is a deep layer of moss and lichens, but there is some needle litter and small-diameter branchwood. The branches are persistent on the trees, and ground fires easily reach into the tree crowns. This fuel model may be useful for jack pine stands in the Lake States. Ground fires are typically slow spreading, but a dangerous crowning potential exists. Users should be alert to such events and note those levels of SC and BI when crowning occurs.

FUEL MODEL R

This fuel model represents the hardwood areas after the canopies leaf out in the spring. It is provided as the off-season substitute for E. It should be used during the summer in all hardwood and mixed conifer-hardwood stands where more than half of the overstory is deciduous.

FUEL MODEL S

Alaskan or alpine tundra on relatively well-drained sites is the S fuel. Grass and low shrubs are often present, but the principal fuel is a deep layer of lichens and moss. Fires in these fuels are not fast spreading or intense, but are difficult to extinguish.

FUEL MODEL T

The bothersome sagebrush-grass types of the Great Basin and the Intermountain West are characteristic of T fuels. The shrubs burn easily and are not dense enough to shade out grass and other herbaceous plants. The shrubs must occupy at least one-third of the site or the A or L fuel models should be used. Fuel Model T might be used for immature scrub oak and desert shrub associations in the West, and the scrub oak-wire grass type in the Southeast.

FUEL MODEL U

Closed stands of western long-needled pines are covered by this model. The ground fuels are primarily litter and small branchwood. Grass and shrubs are precluded by the dense canopy but occur in the occasional natural opening. Fuel Model U should be used for ponderosa, Jeffrey, sugar pine, and red pine stands of the Lake States. Fuel Model P is the corresponding model for southern pine plantations.

Key To Appendix II, 54 Cover Type Classes

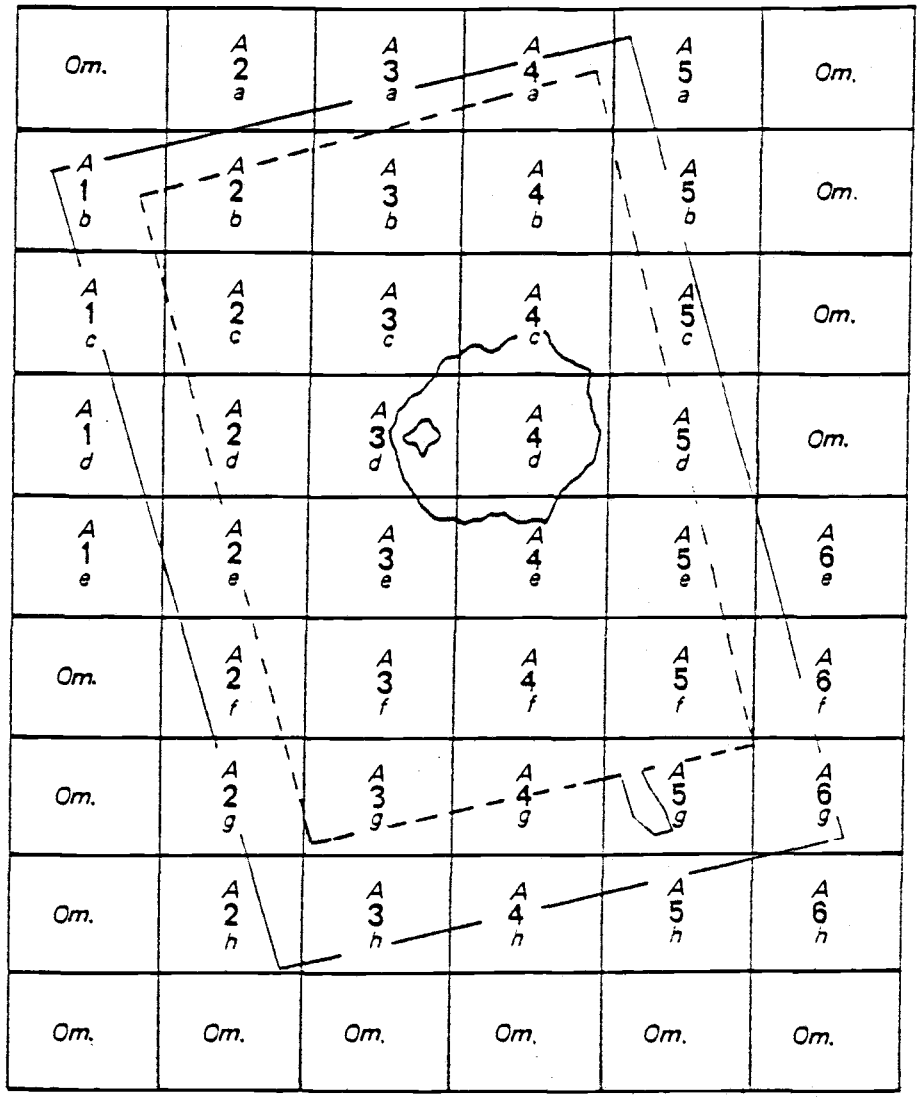


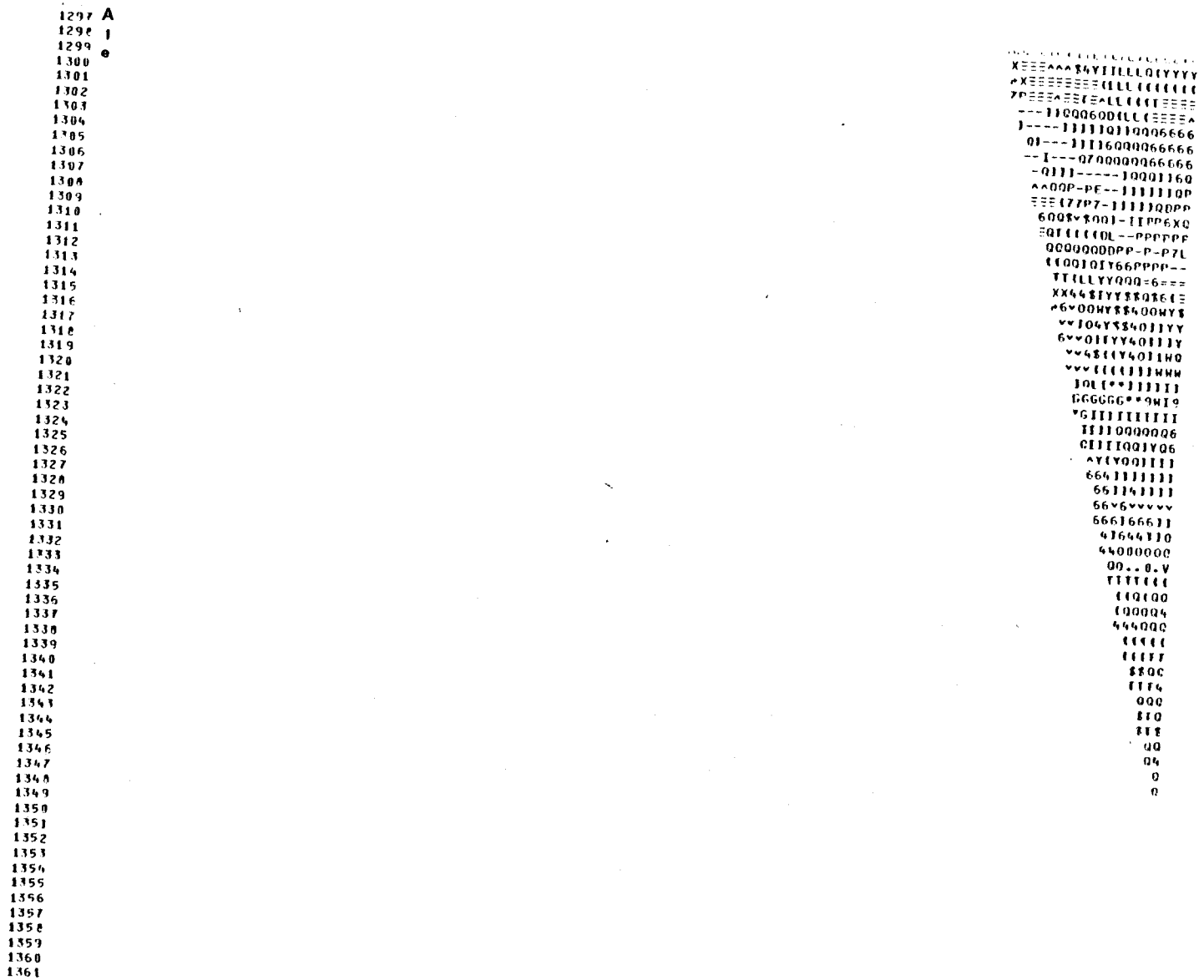
Figure 42. The outline of Crater Lake National Park and vicinity has been inserted in figure above to indicate which portions of Appendix II cover which portion of the Park and vicinity.

--- Park boundary, —— Spectral/Topographic data boundary, Om. Omitted.

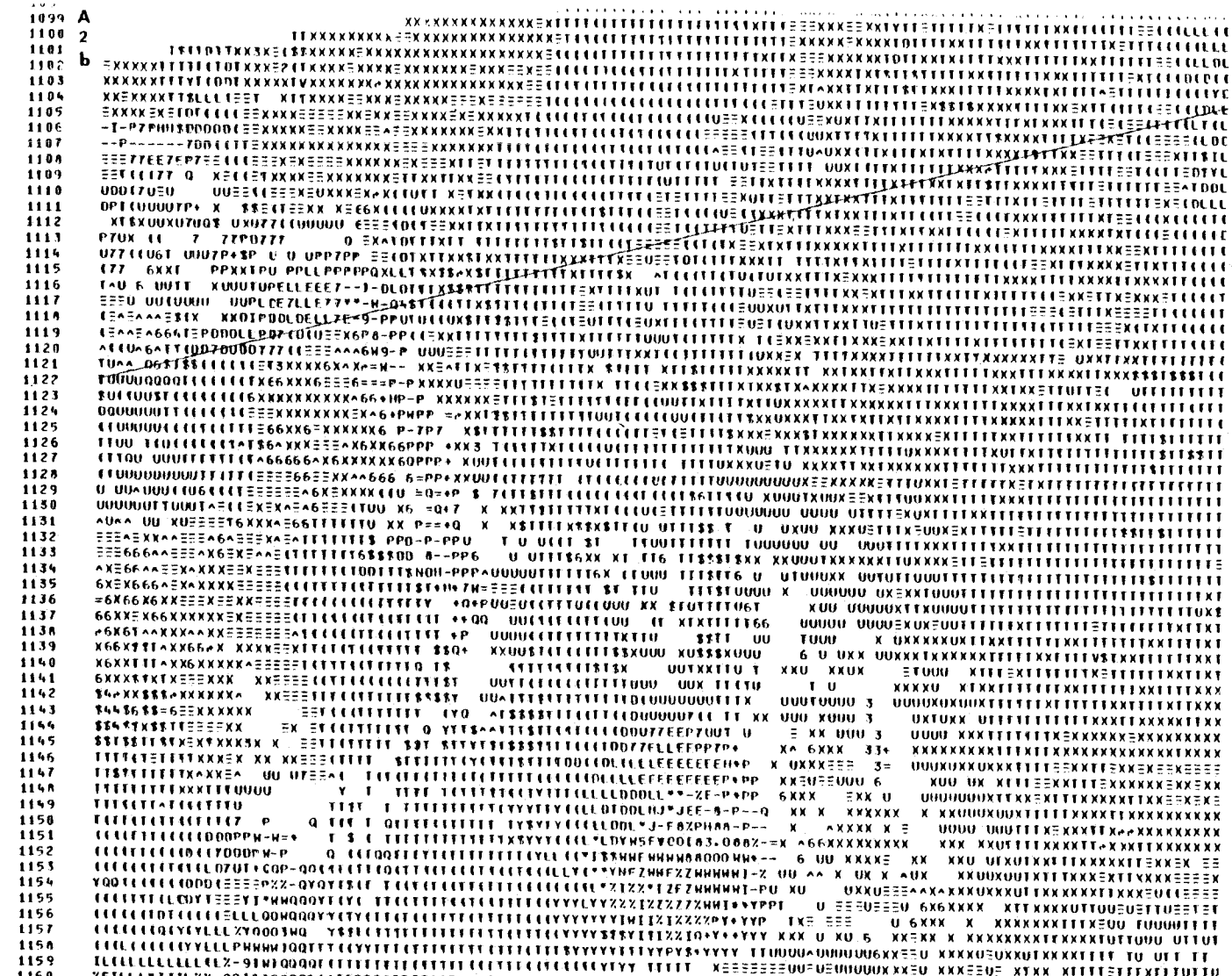


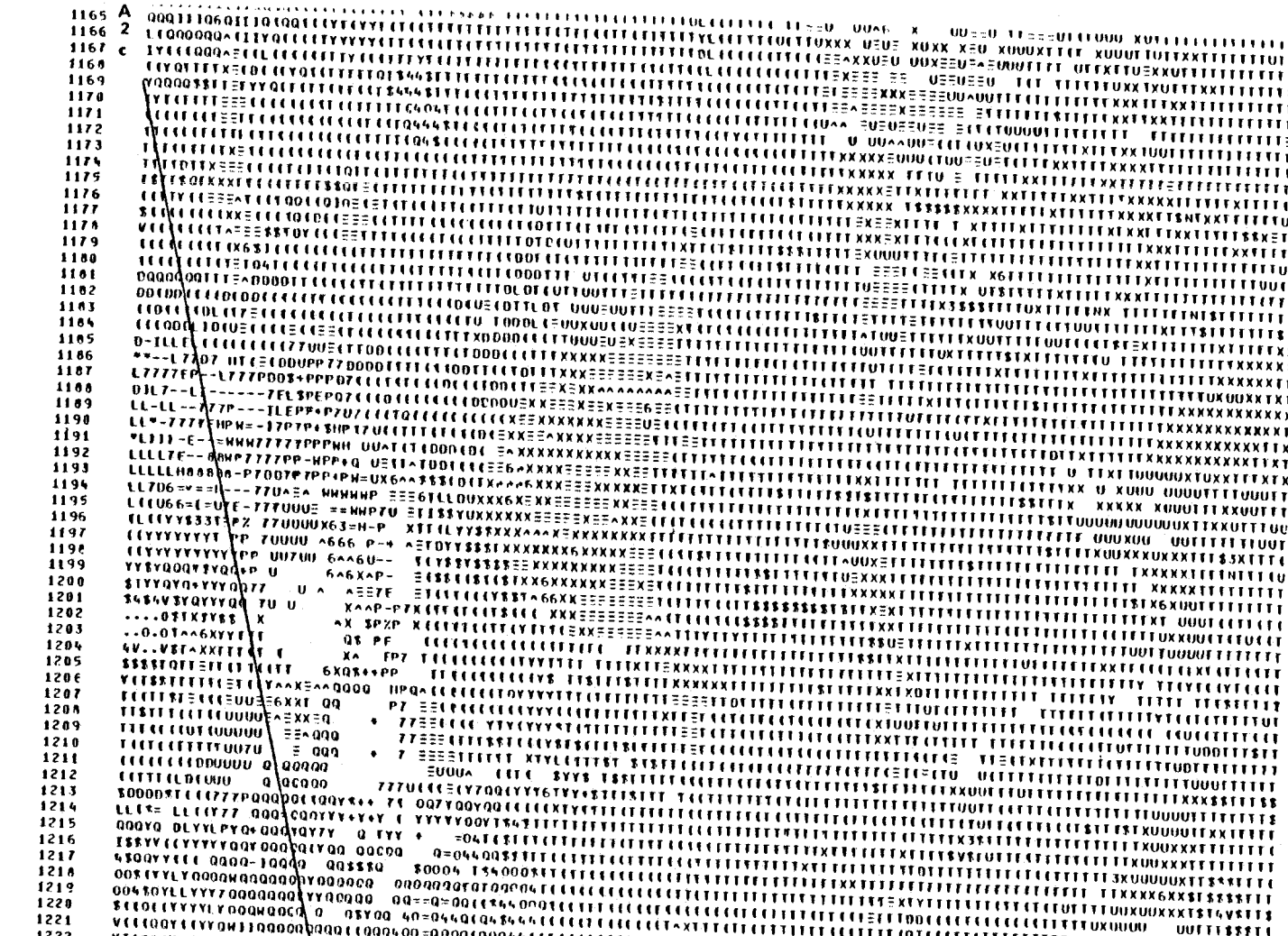


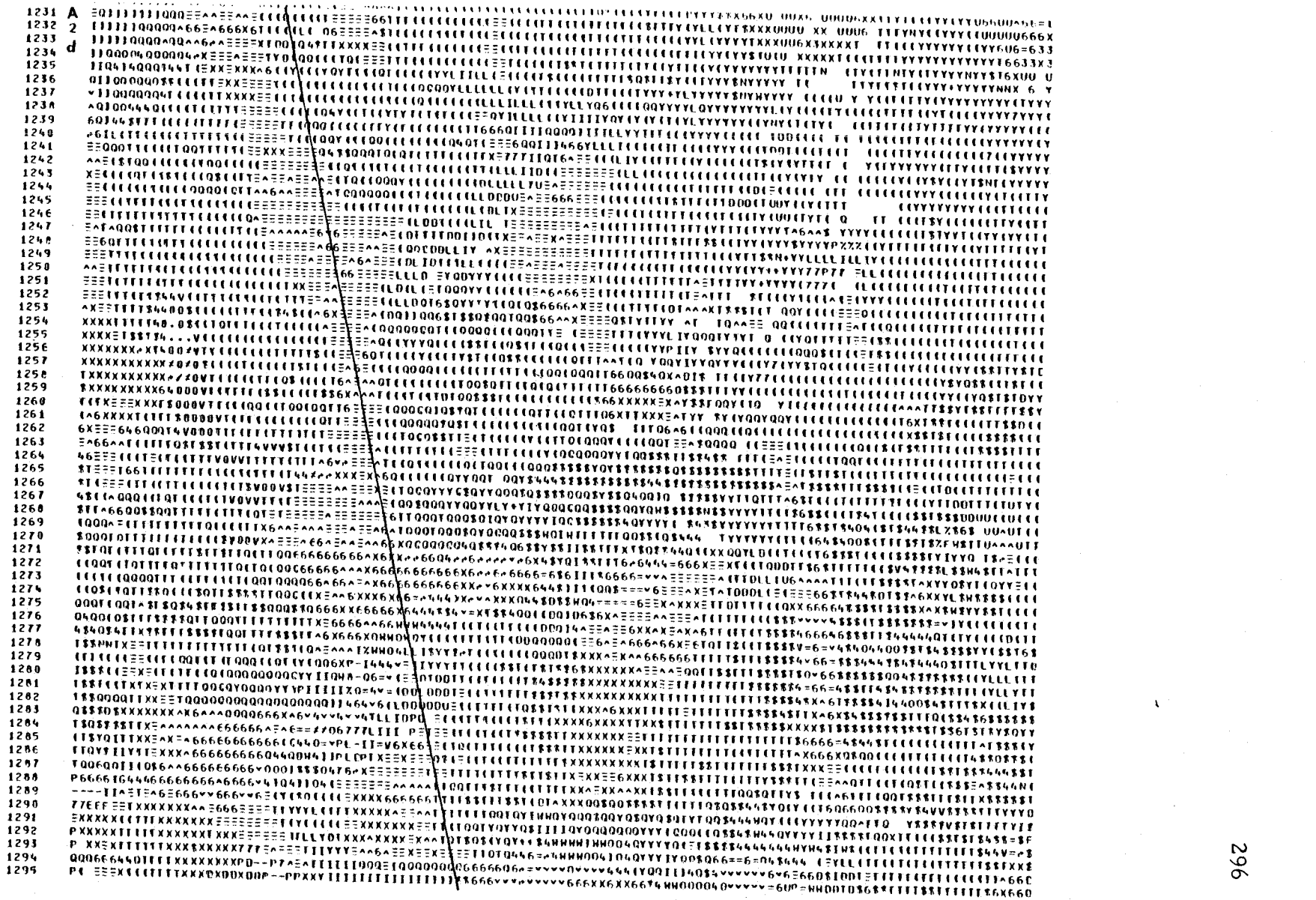


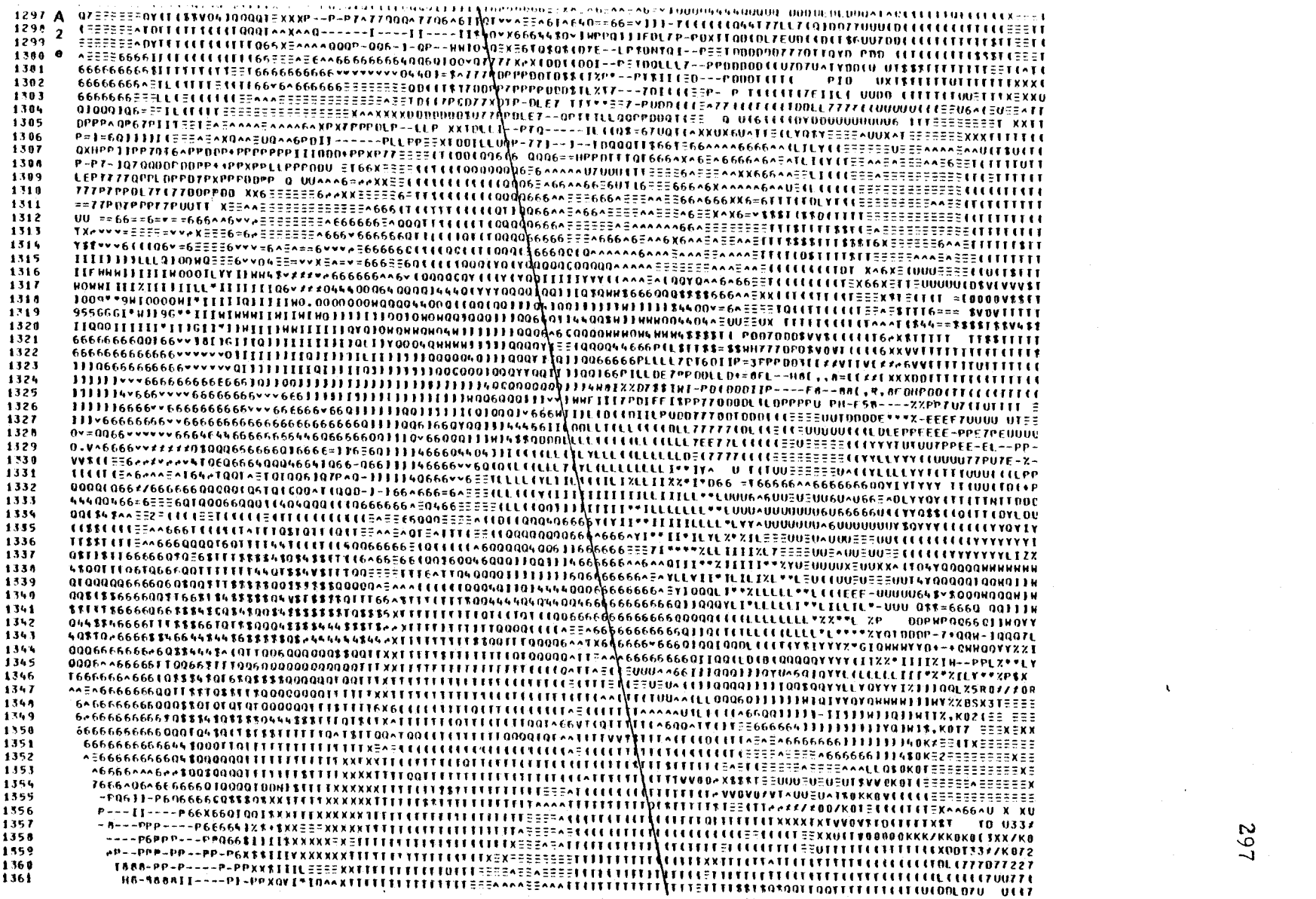


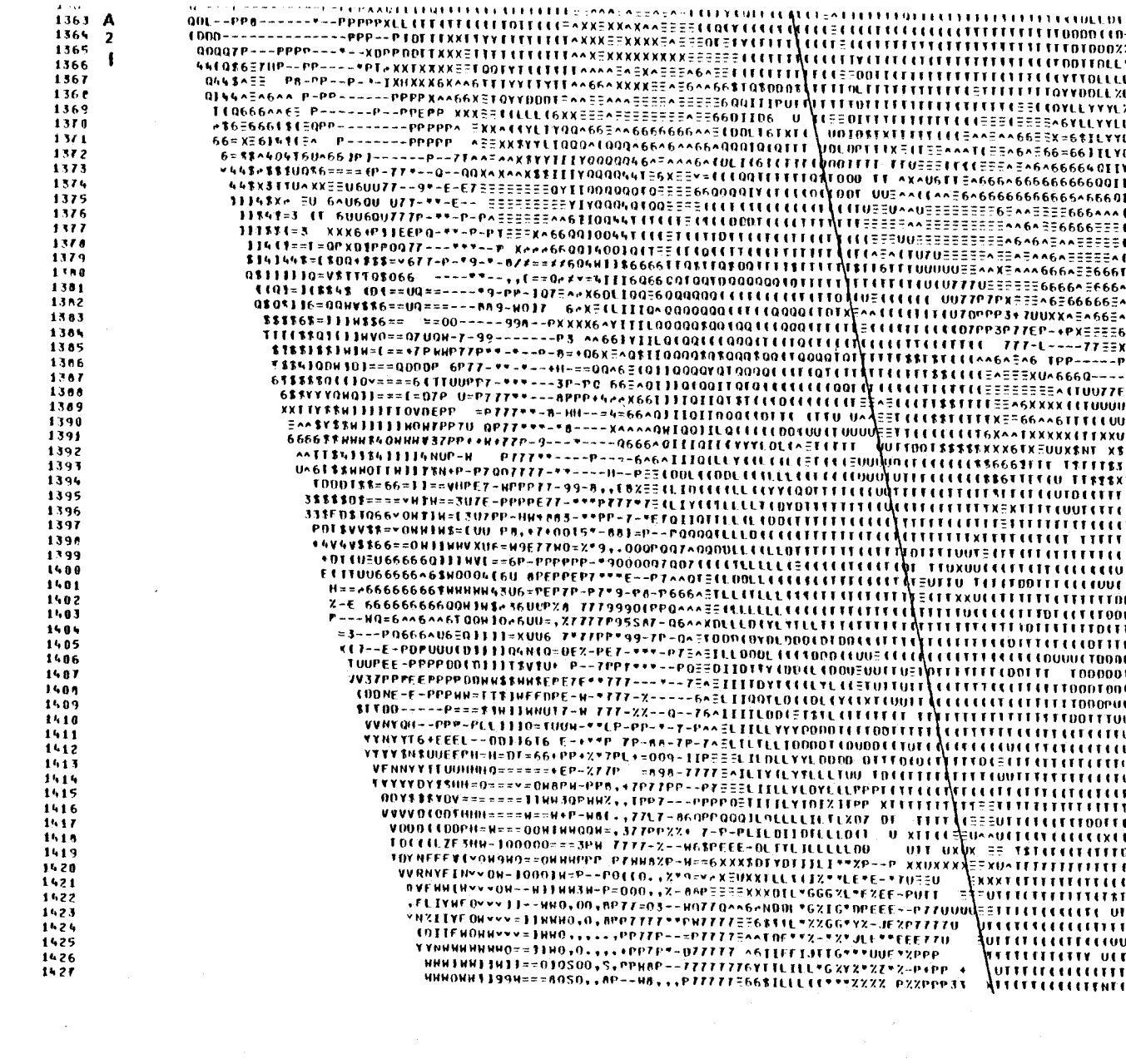

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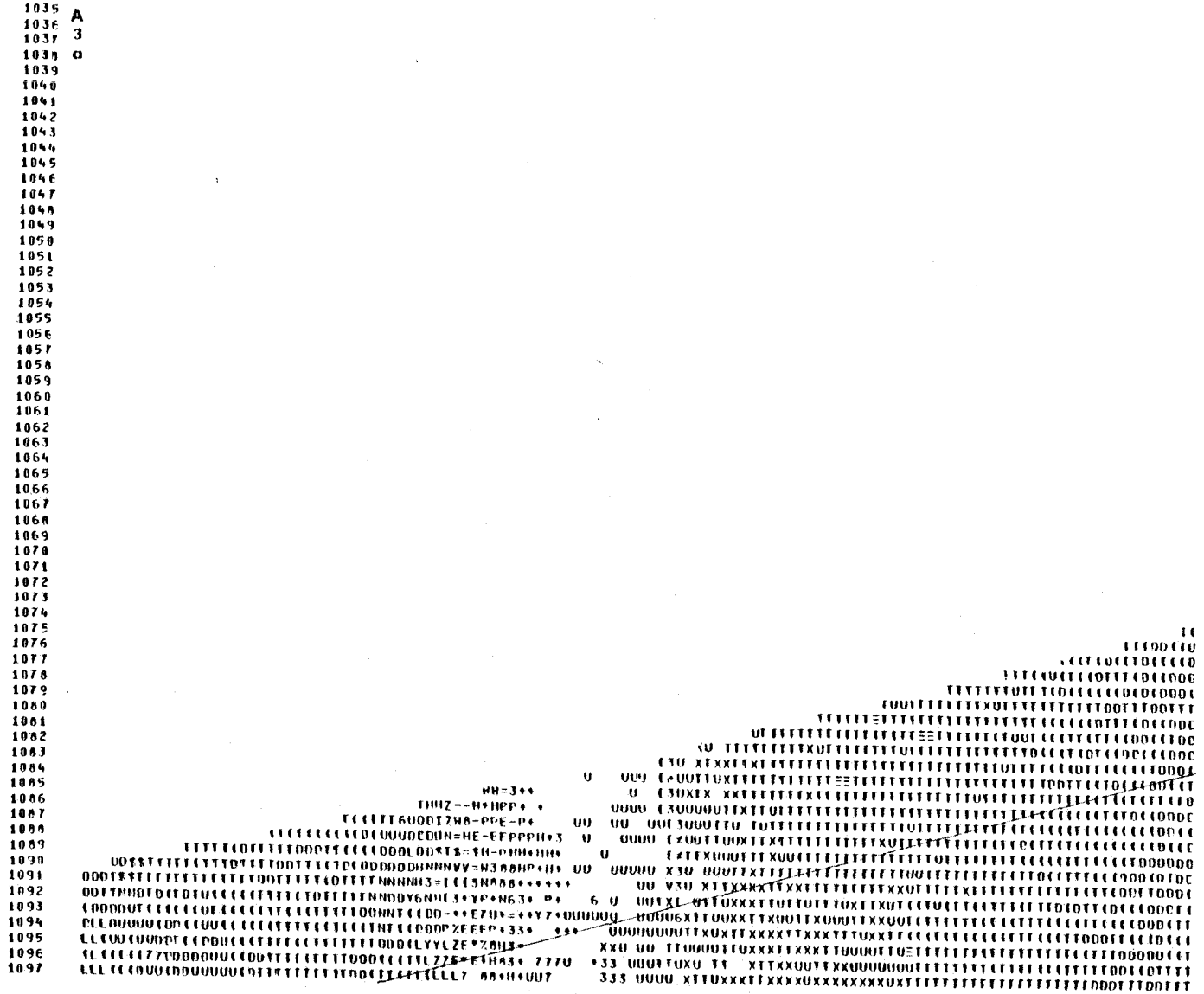


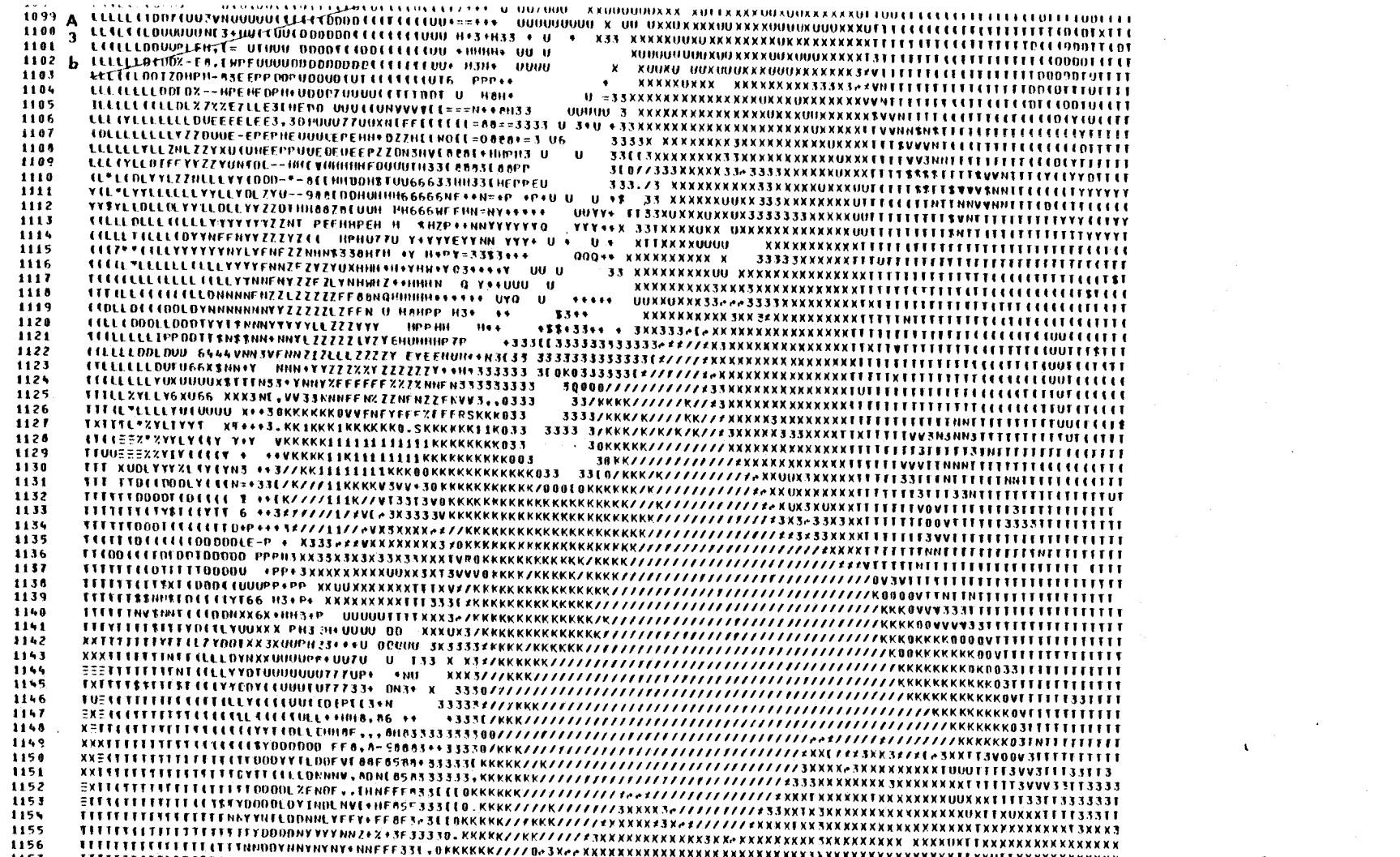


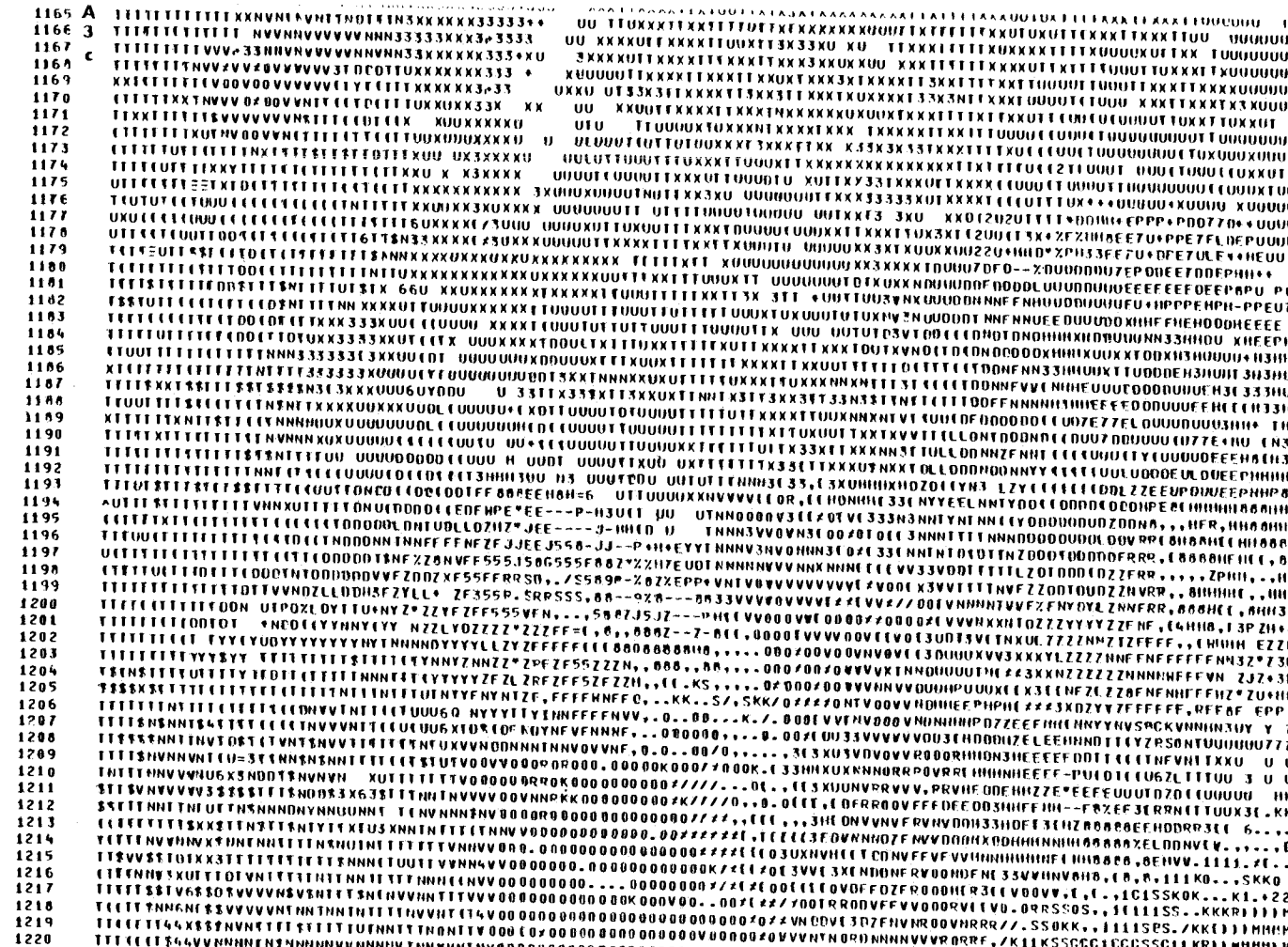


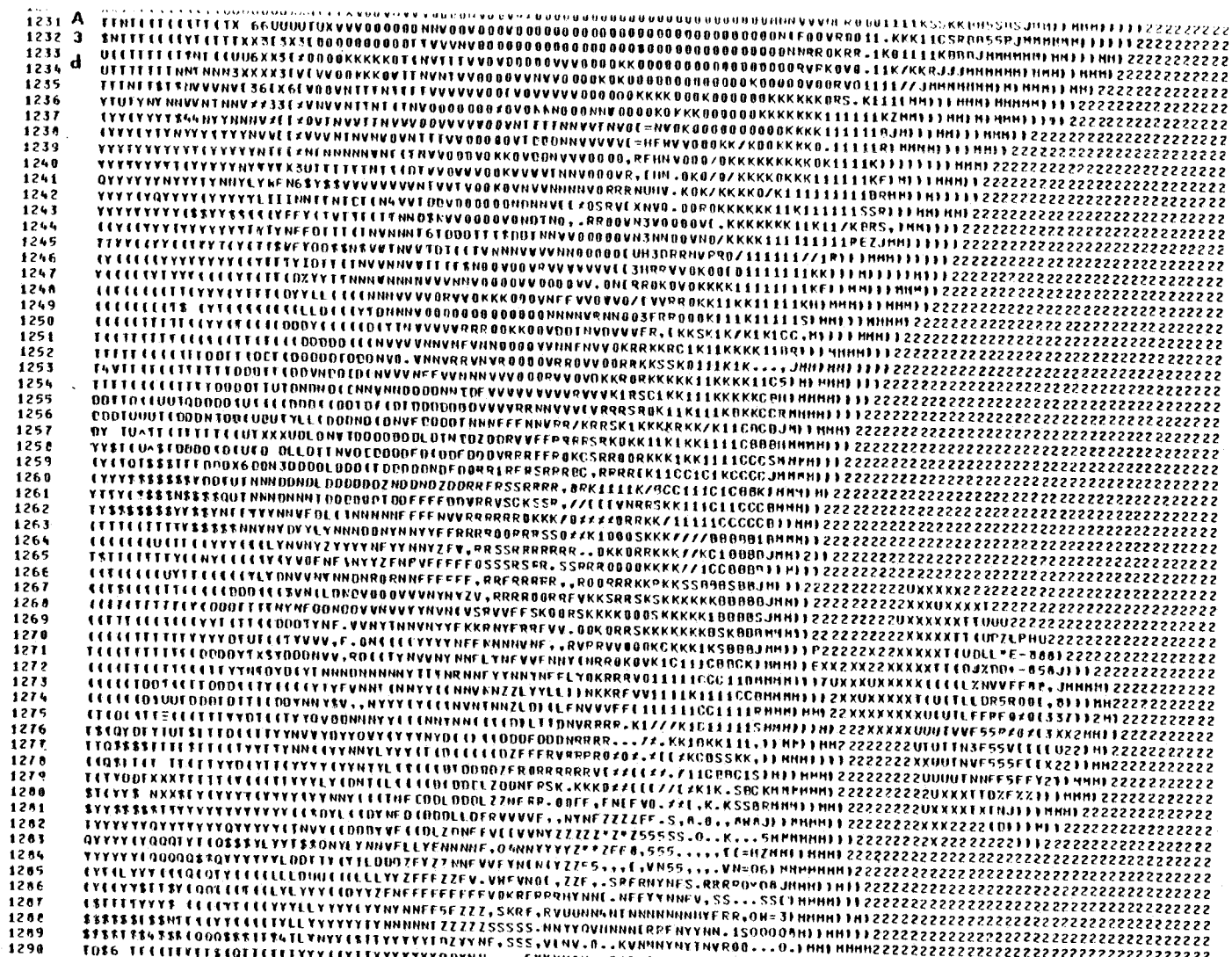


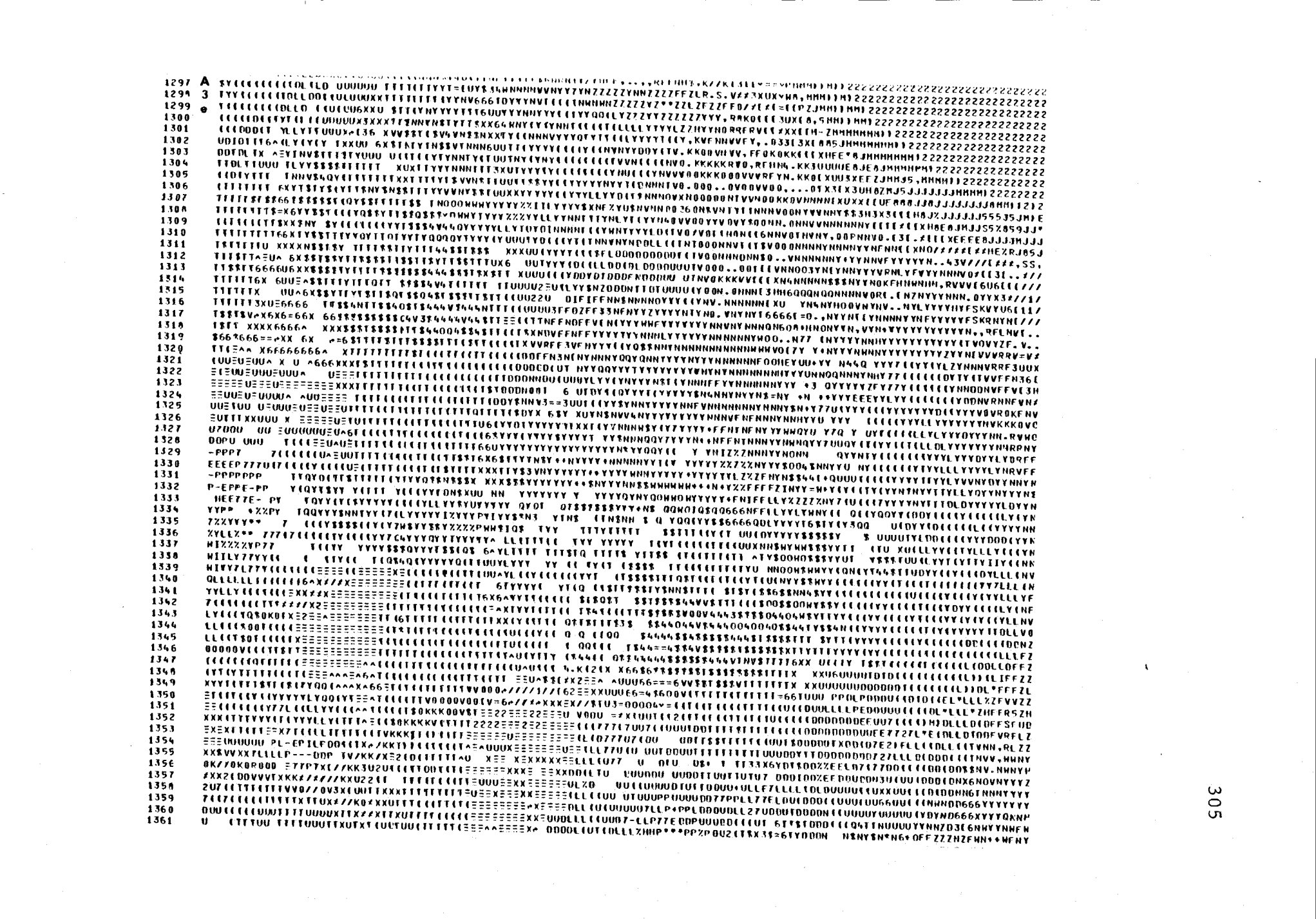


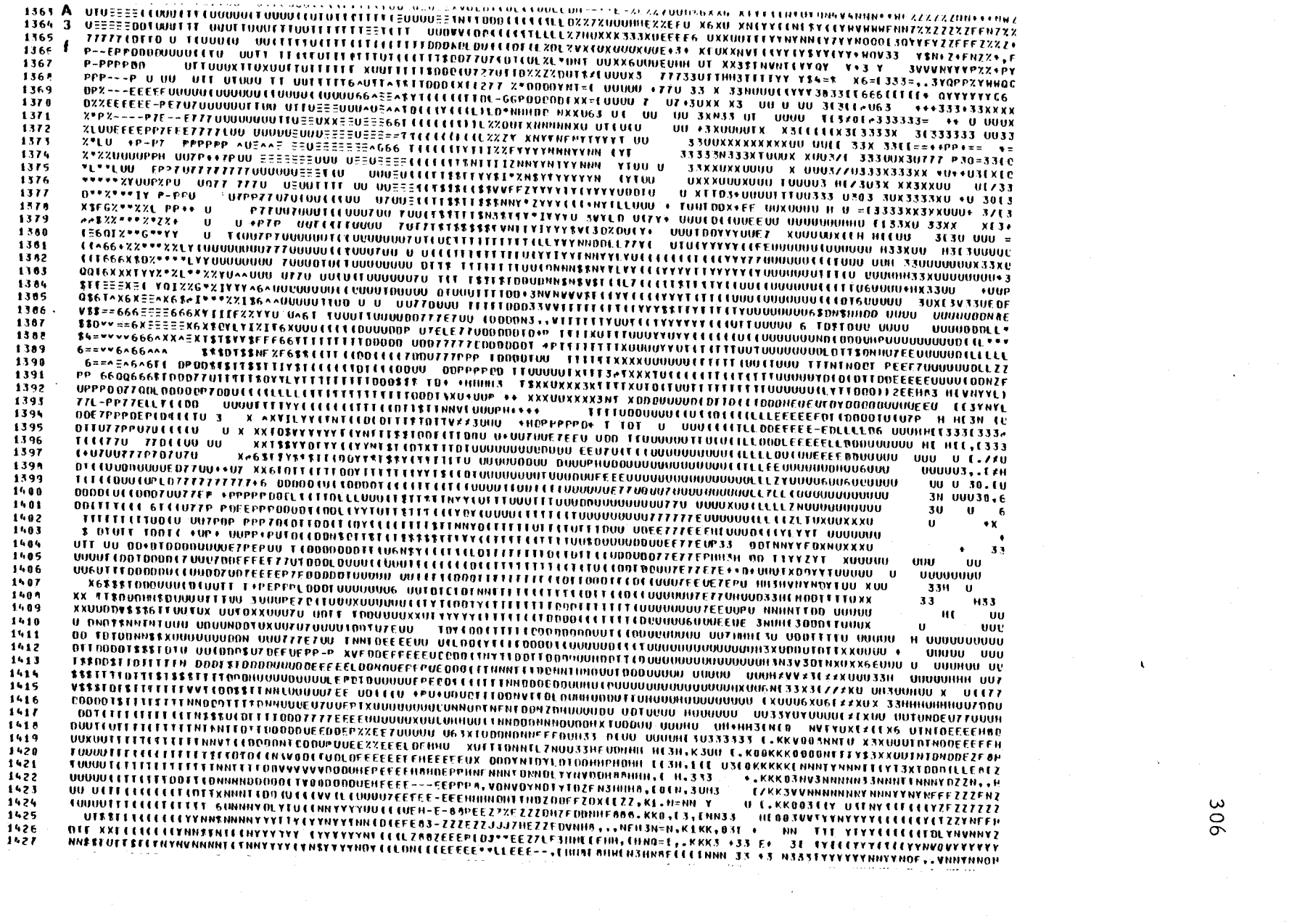








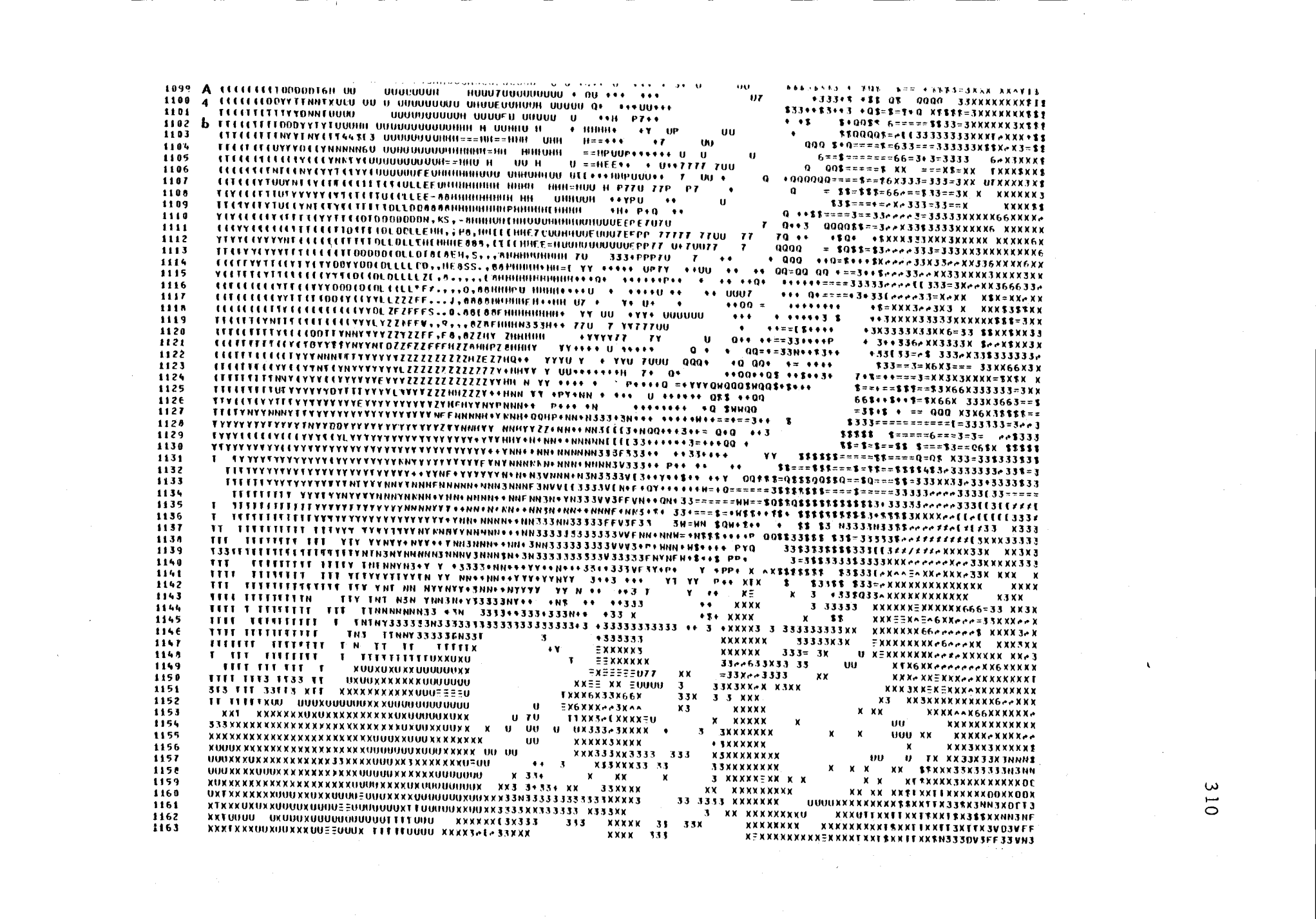


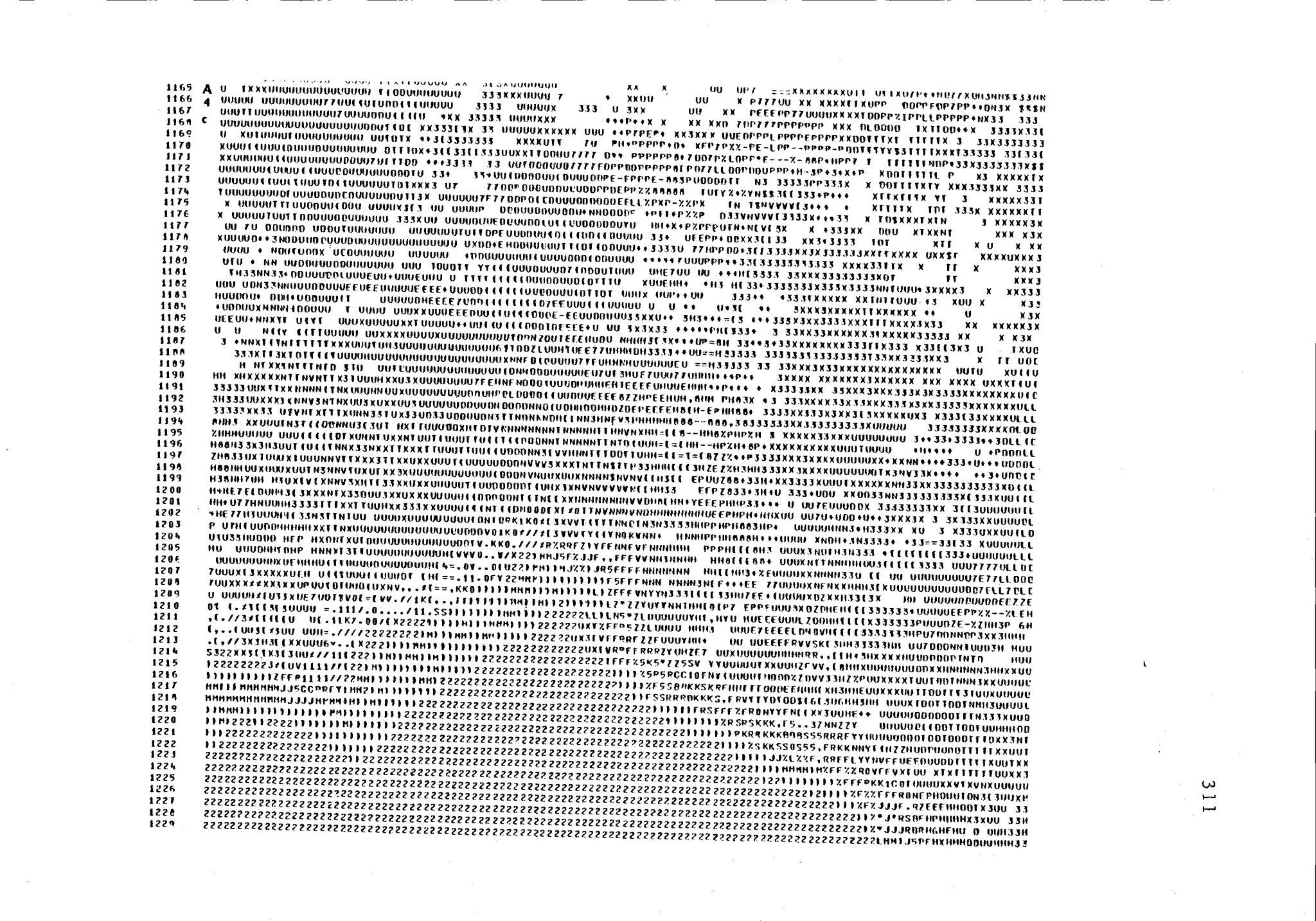


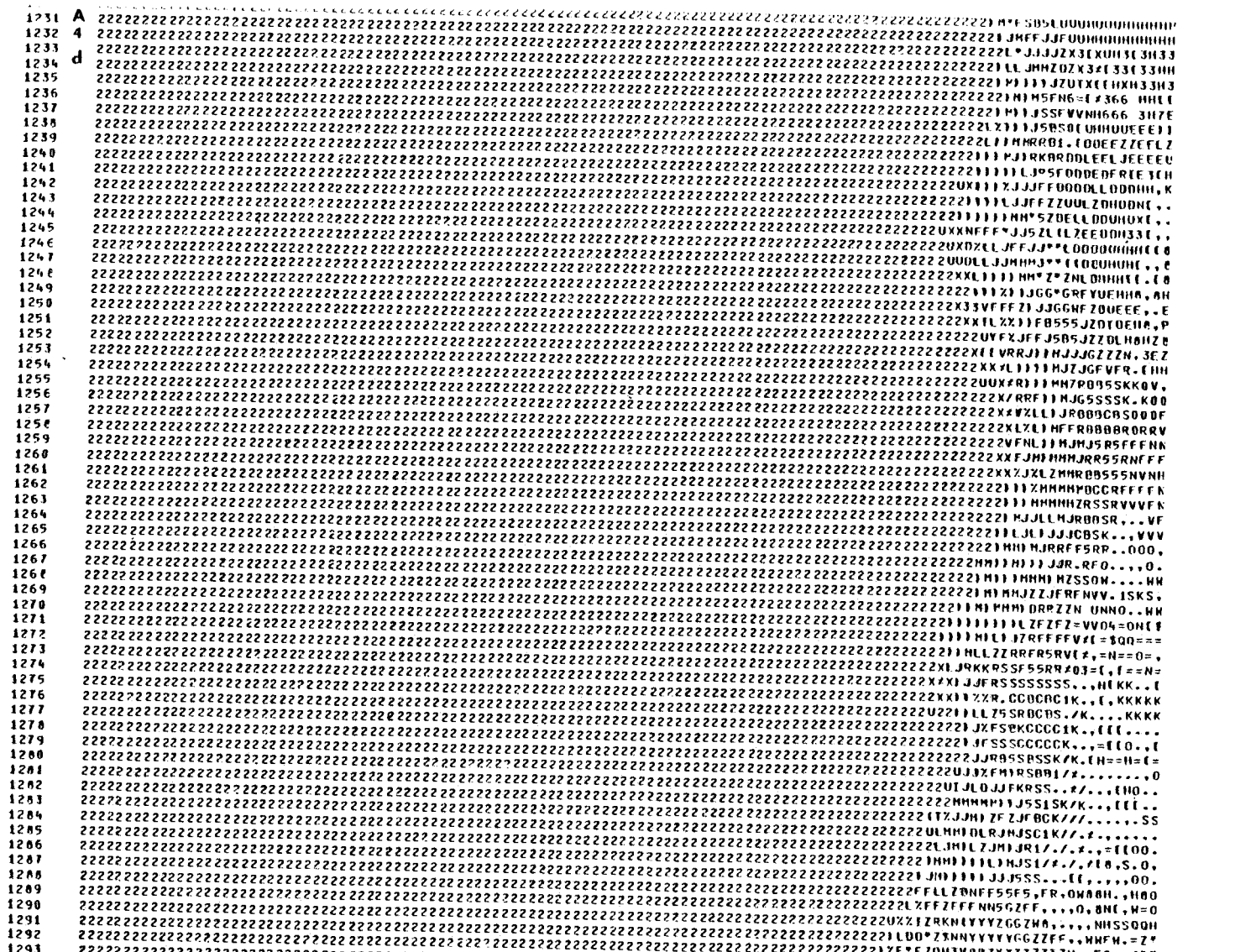


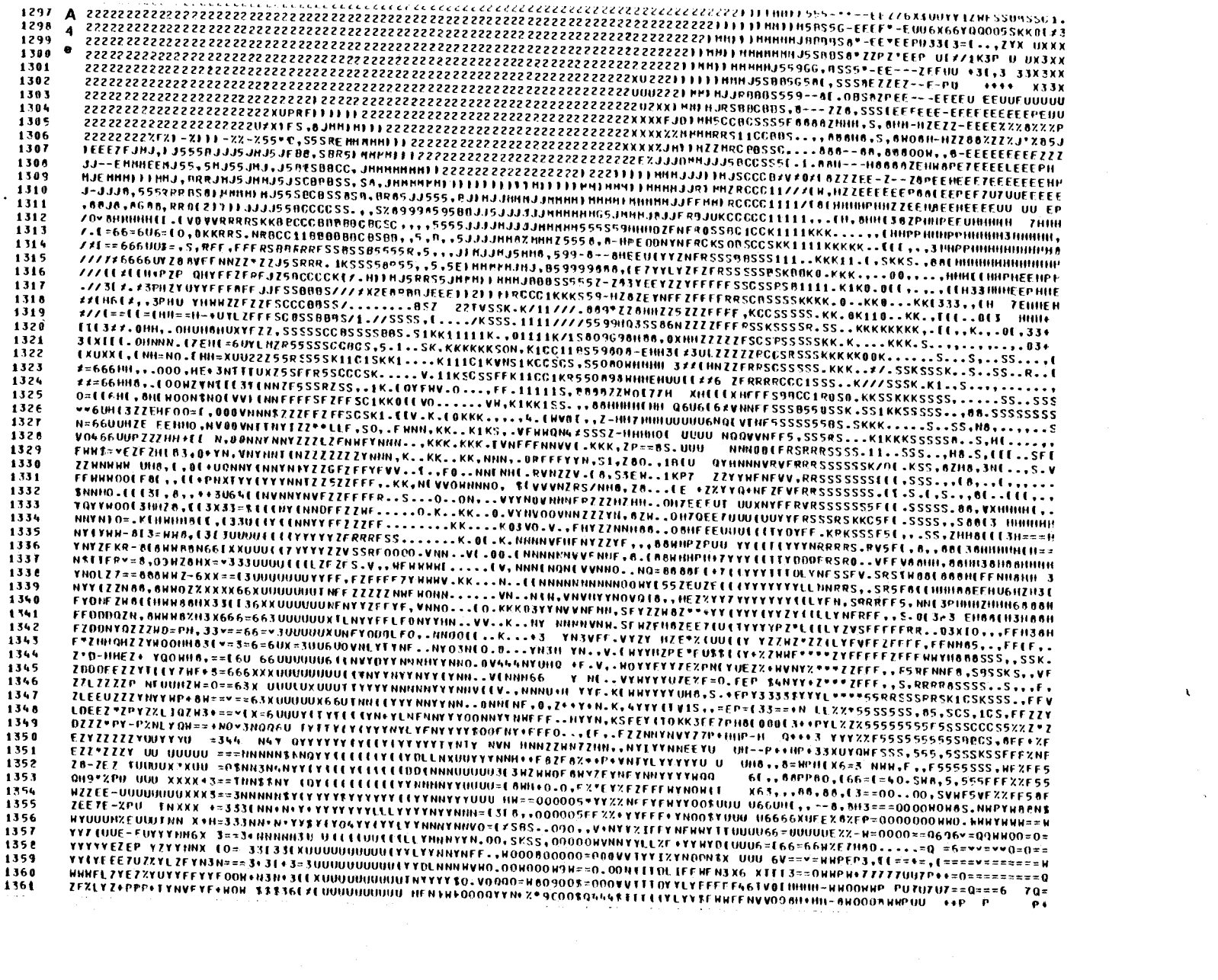




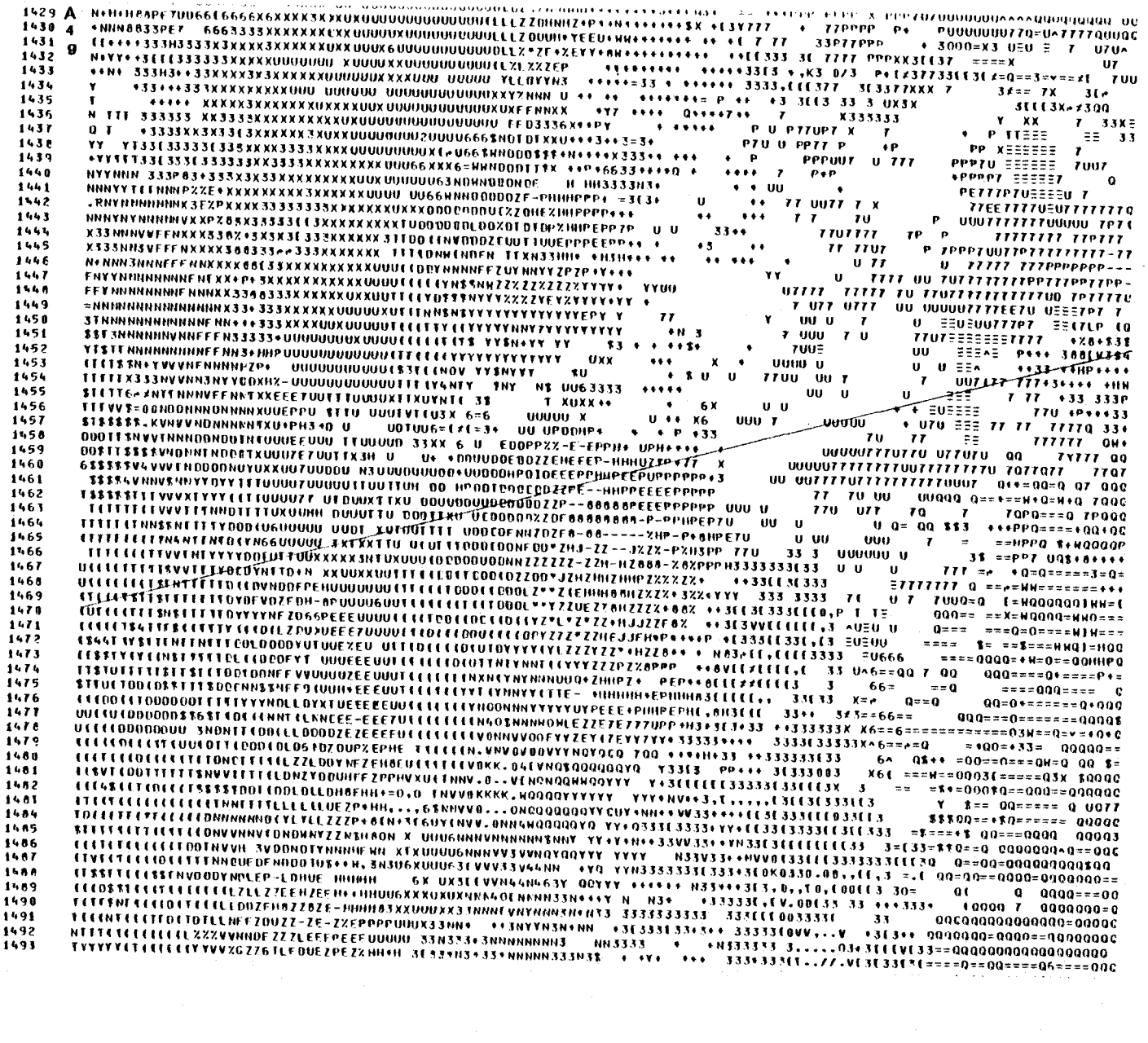




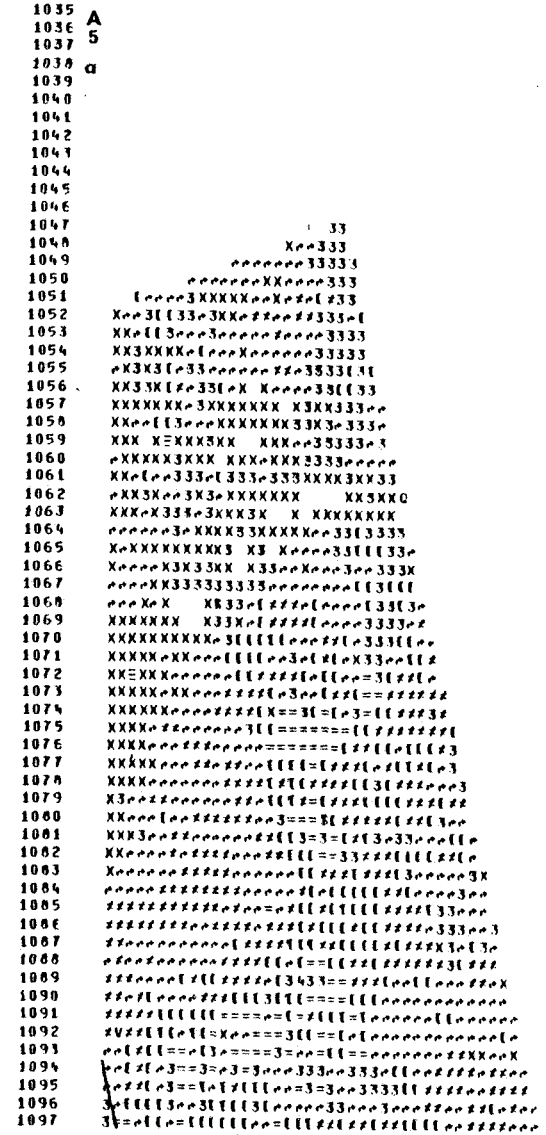


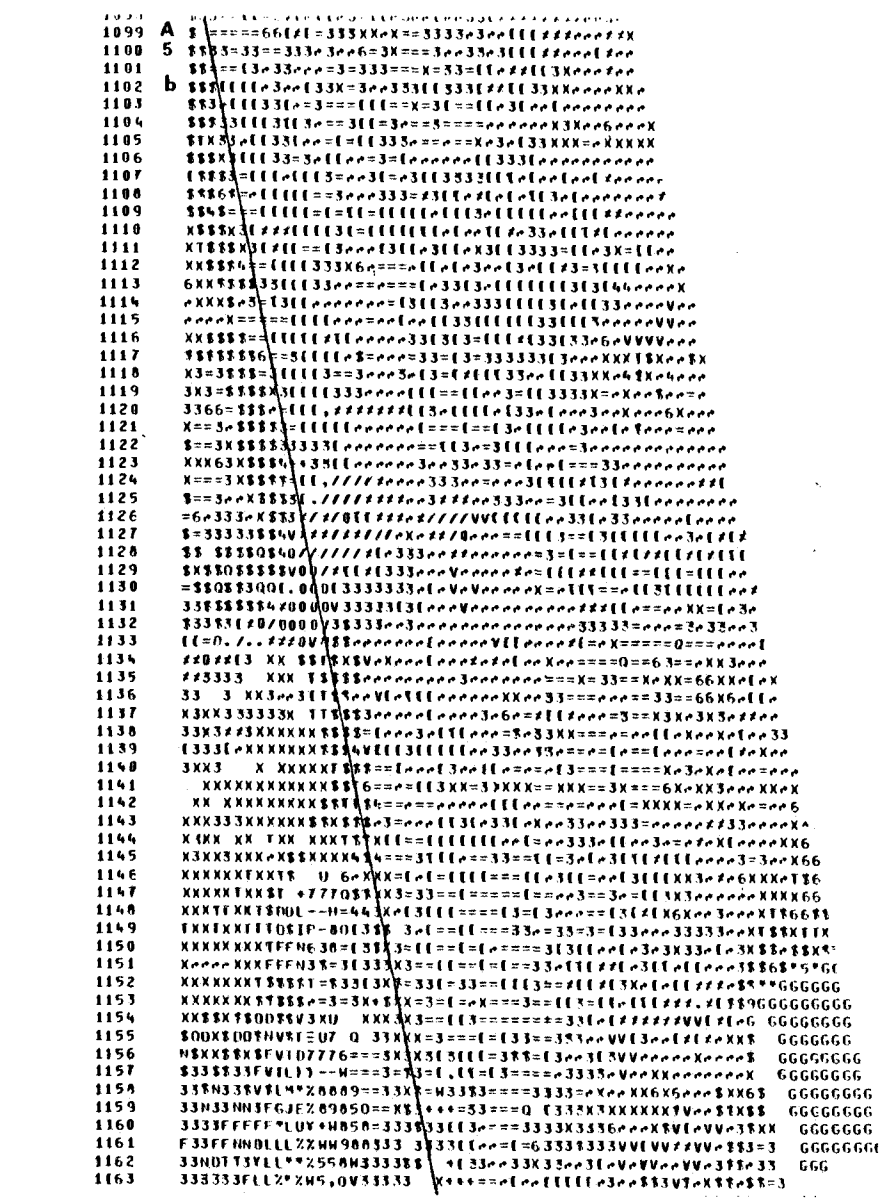


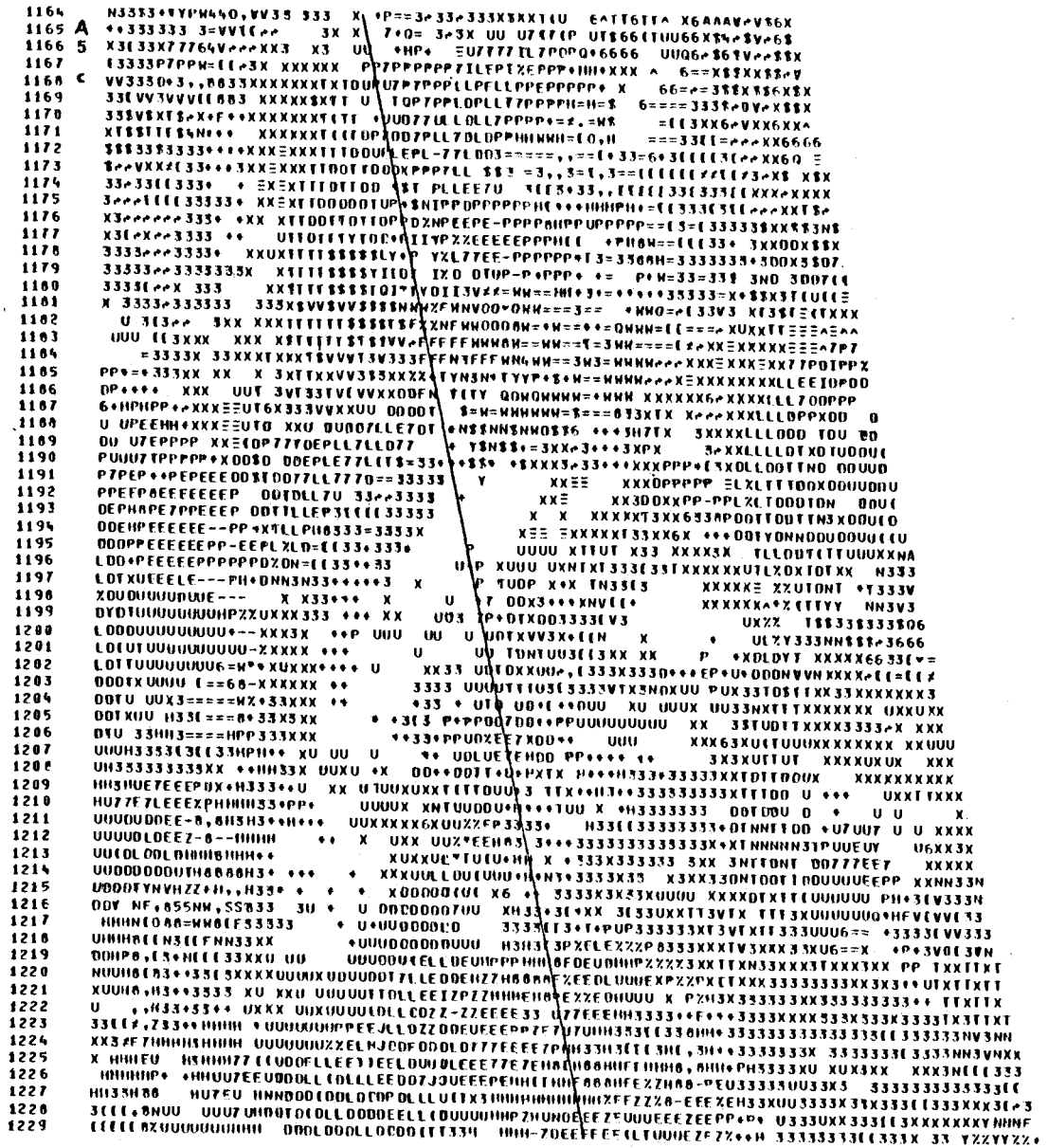


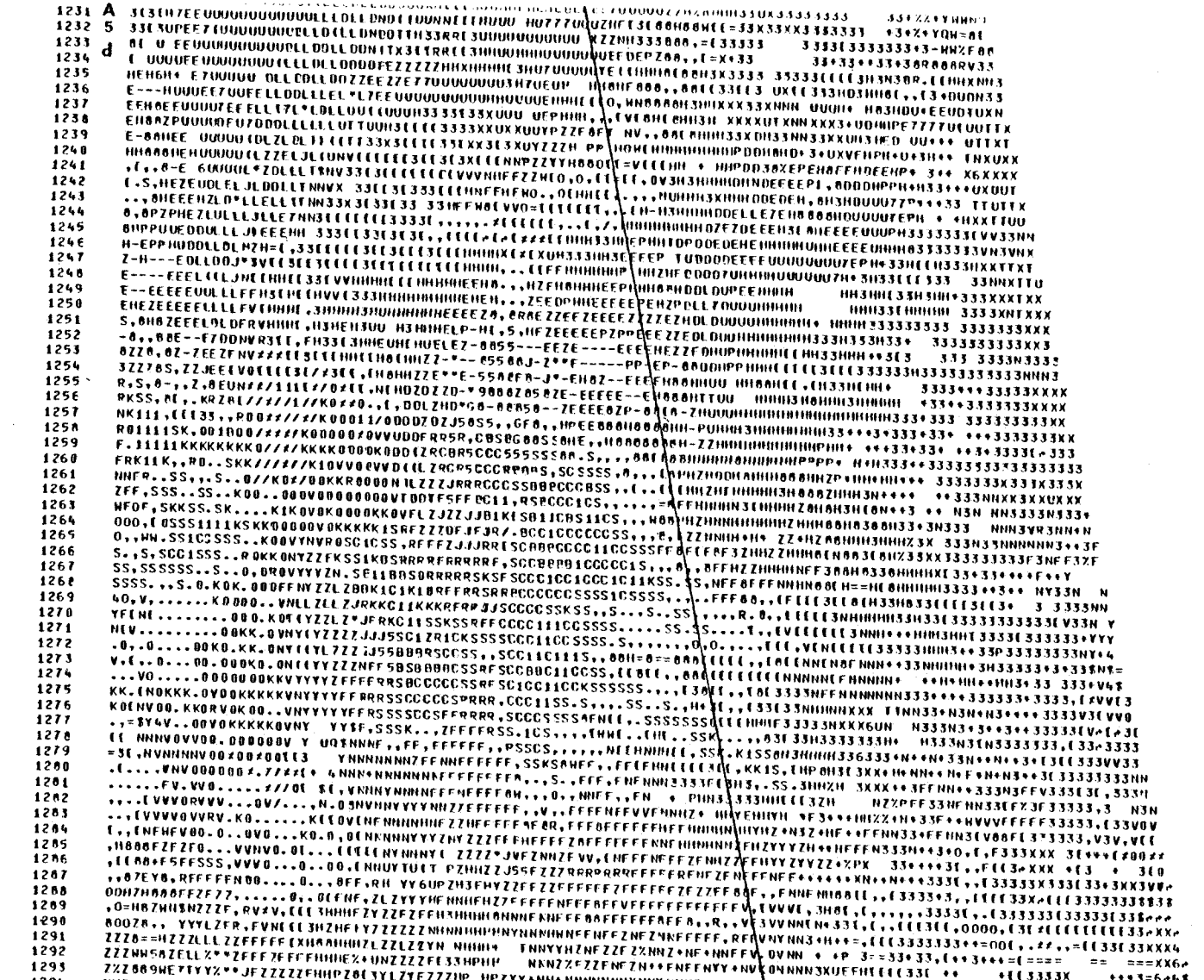


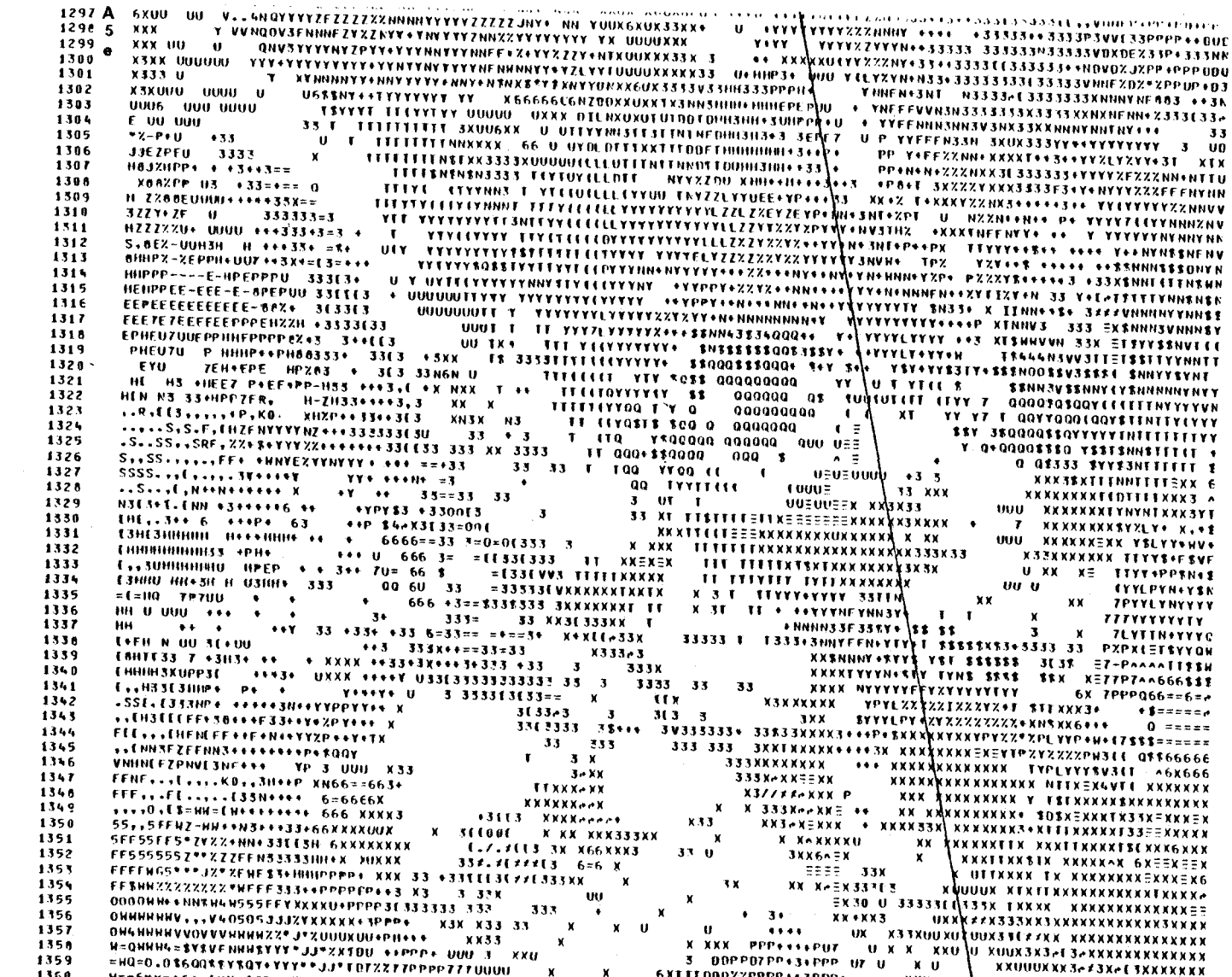








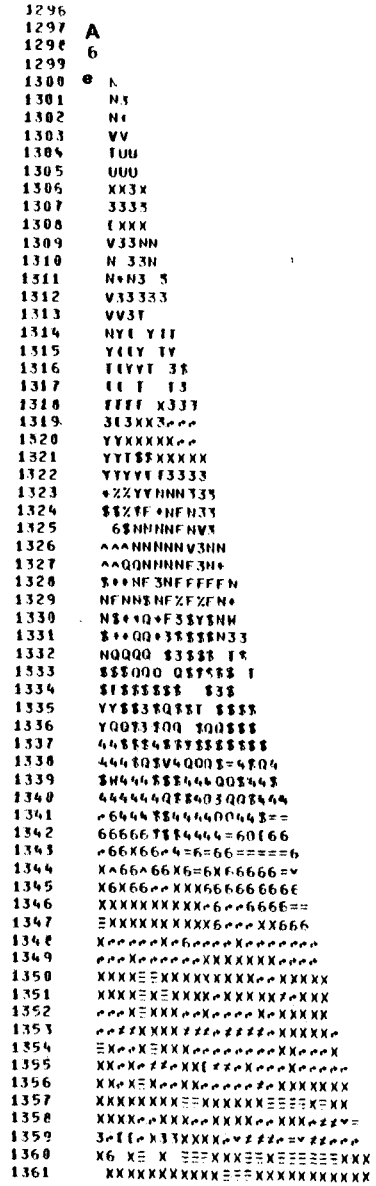


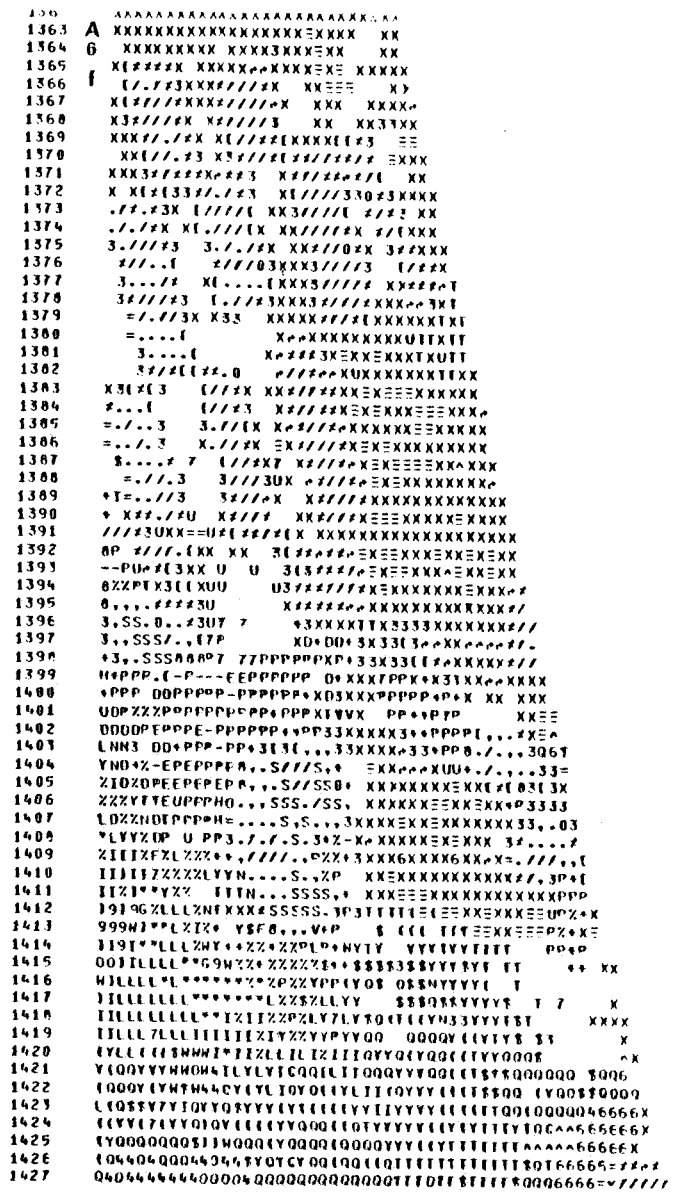


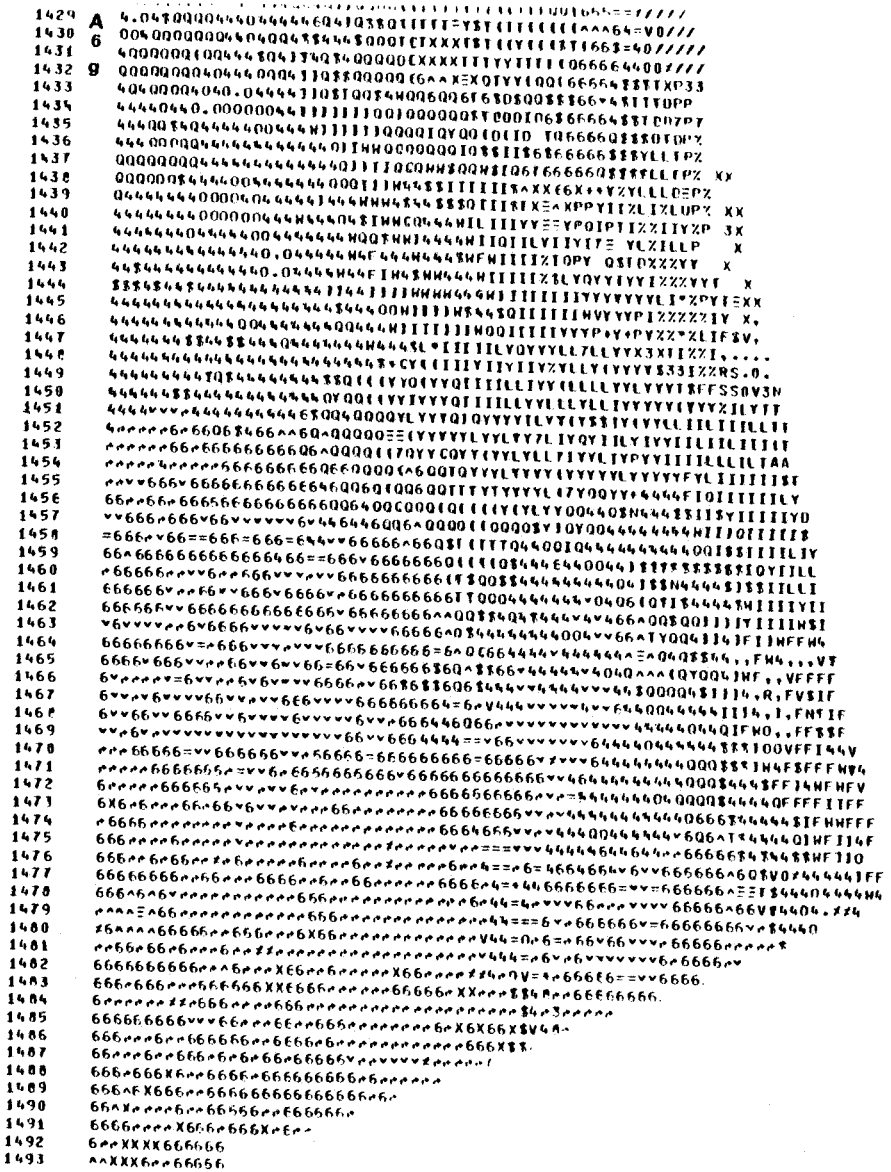












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Key To Appendix III, 23 Cover Type Classes

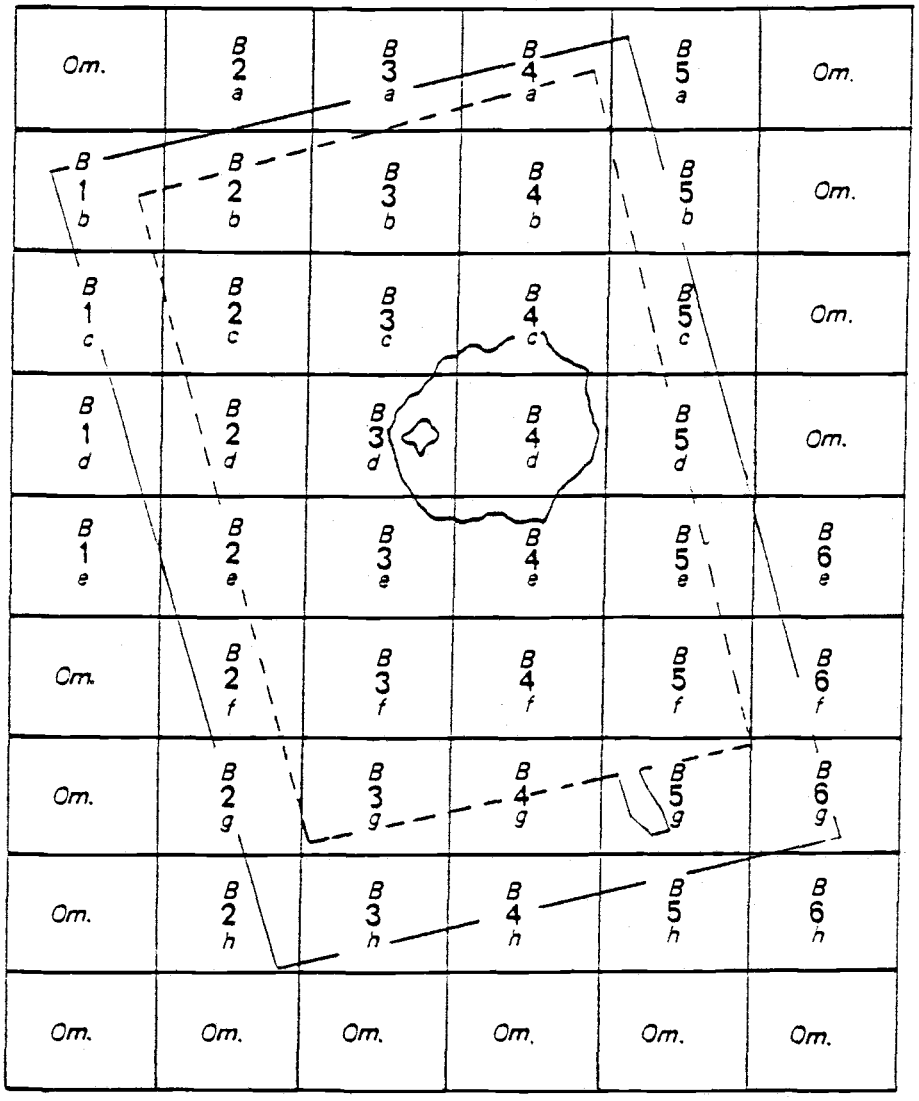
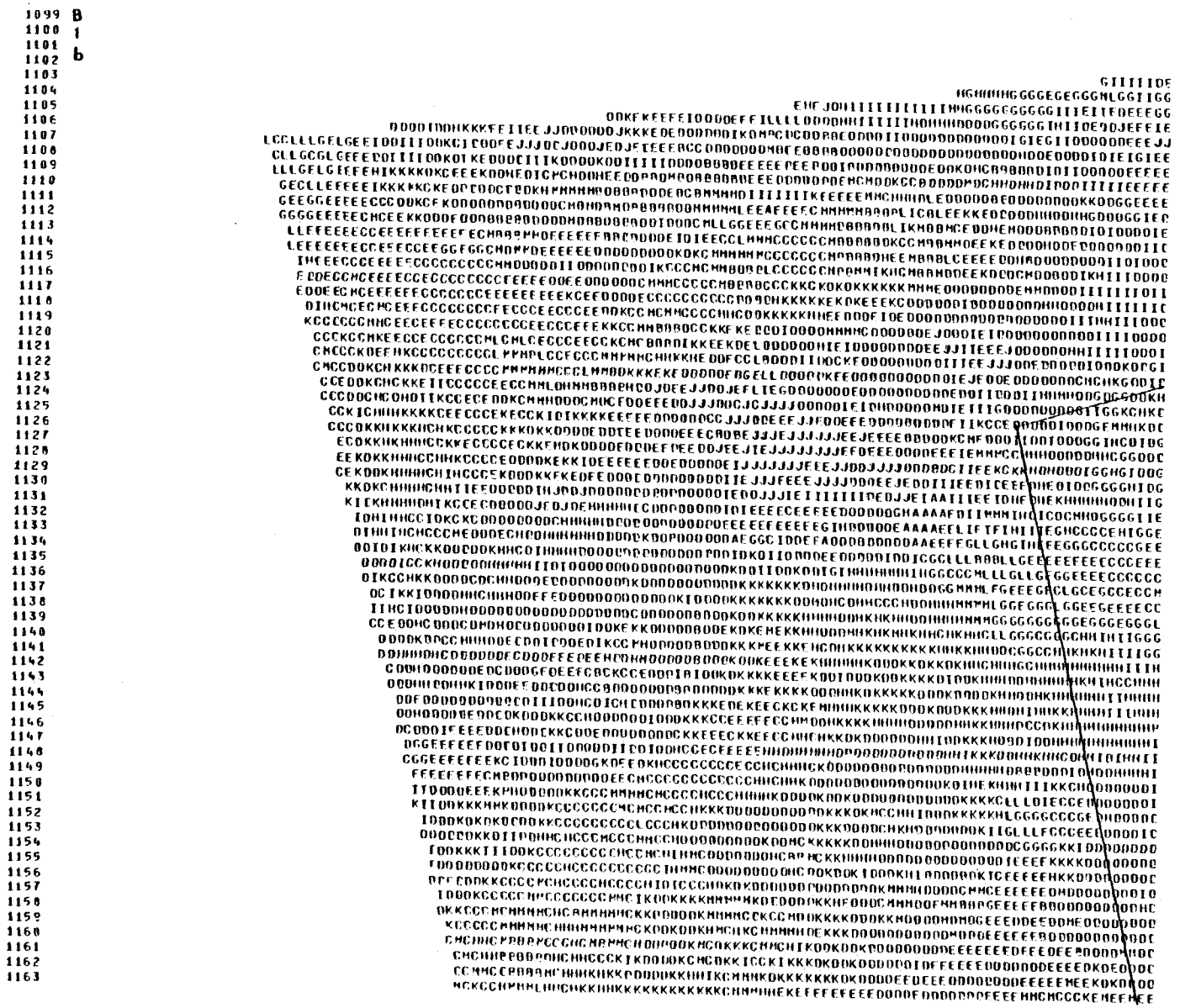
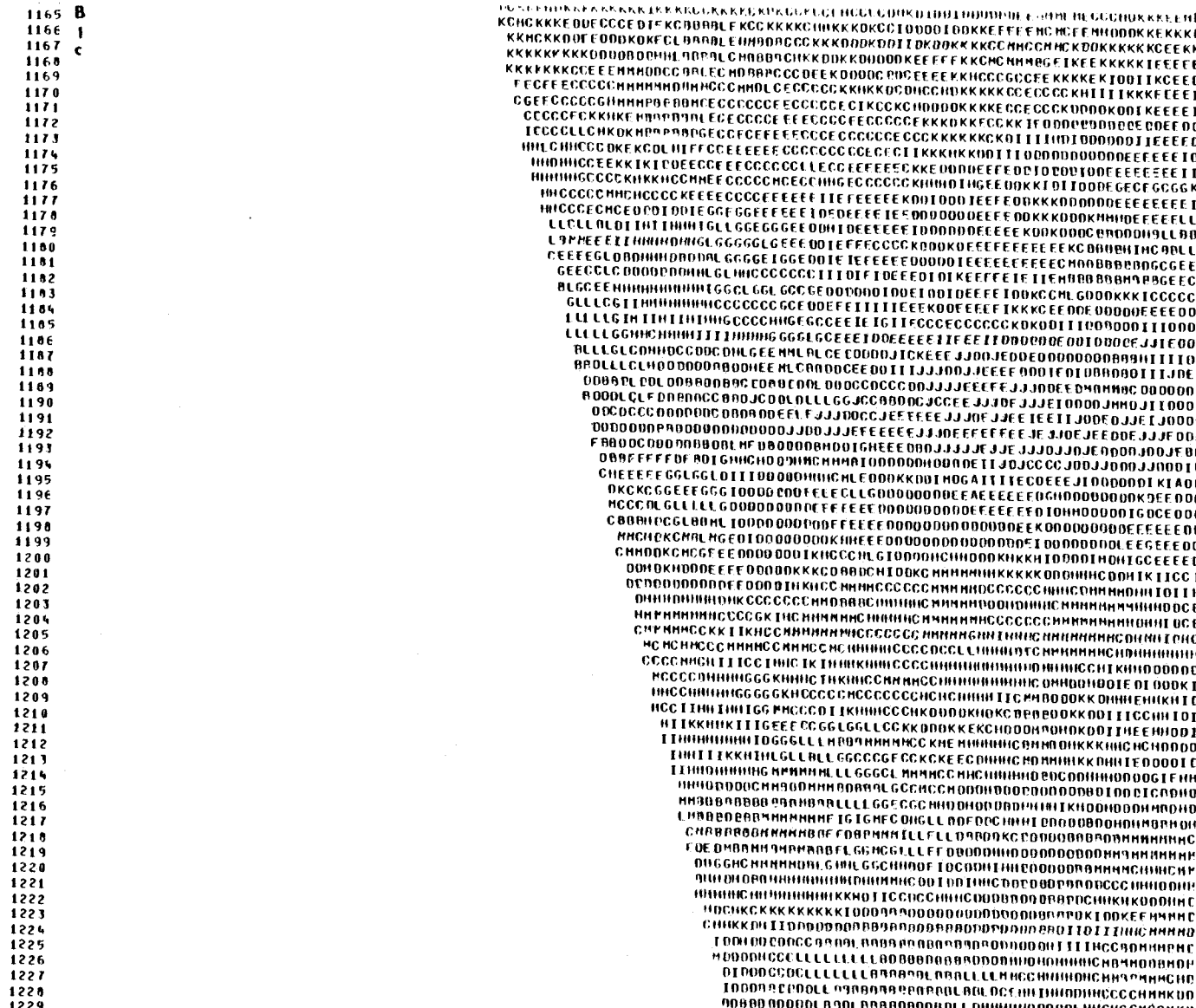
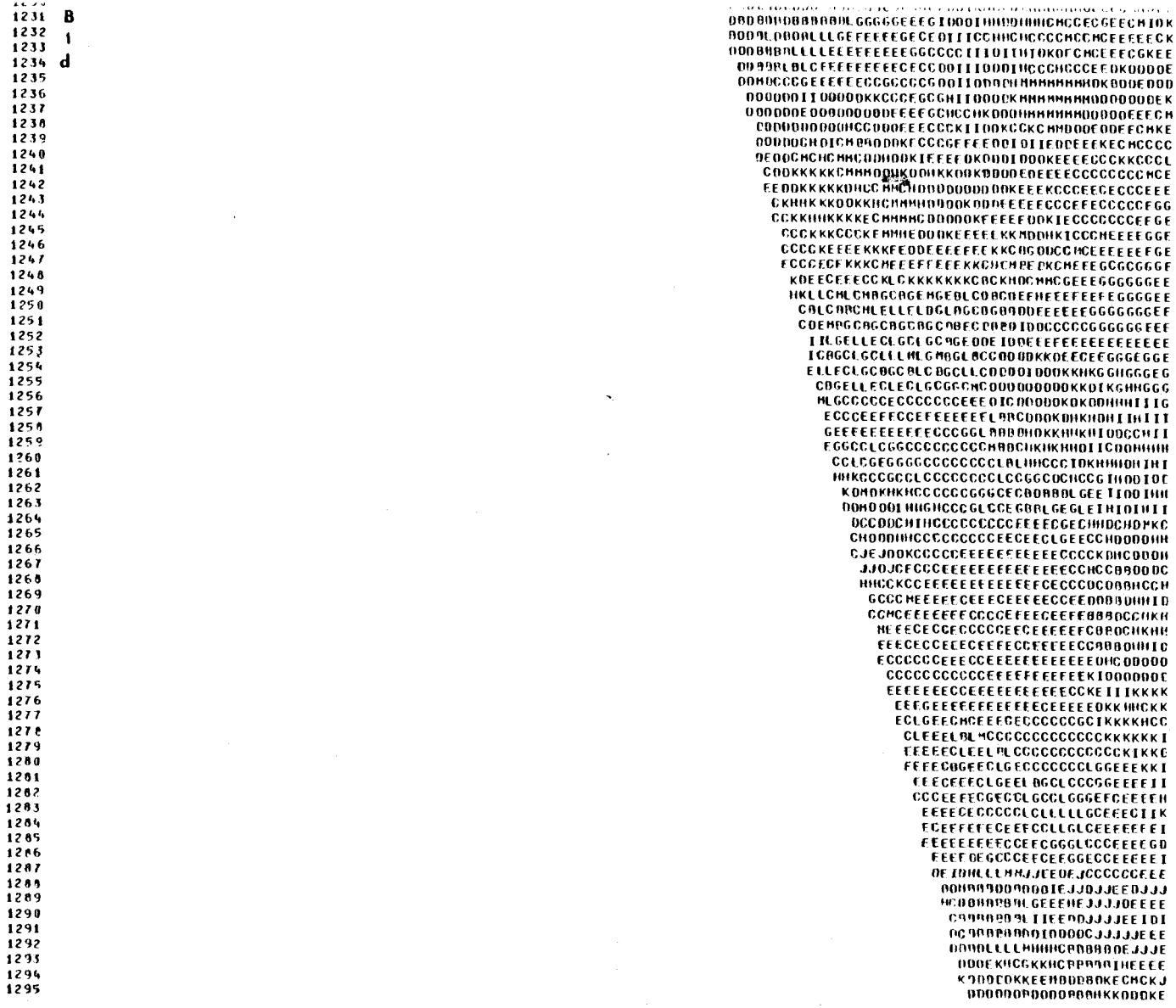


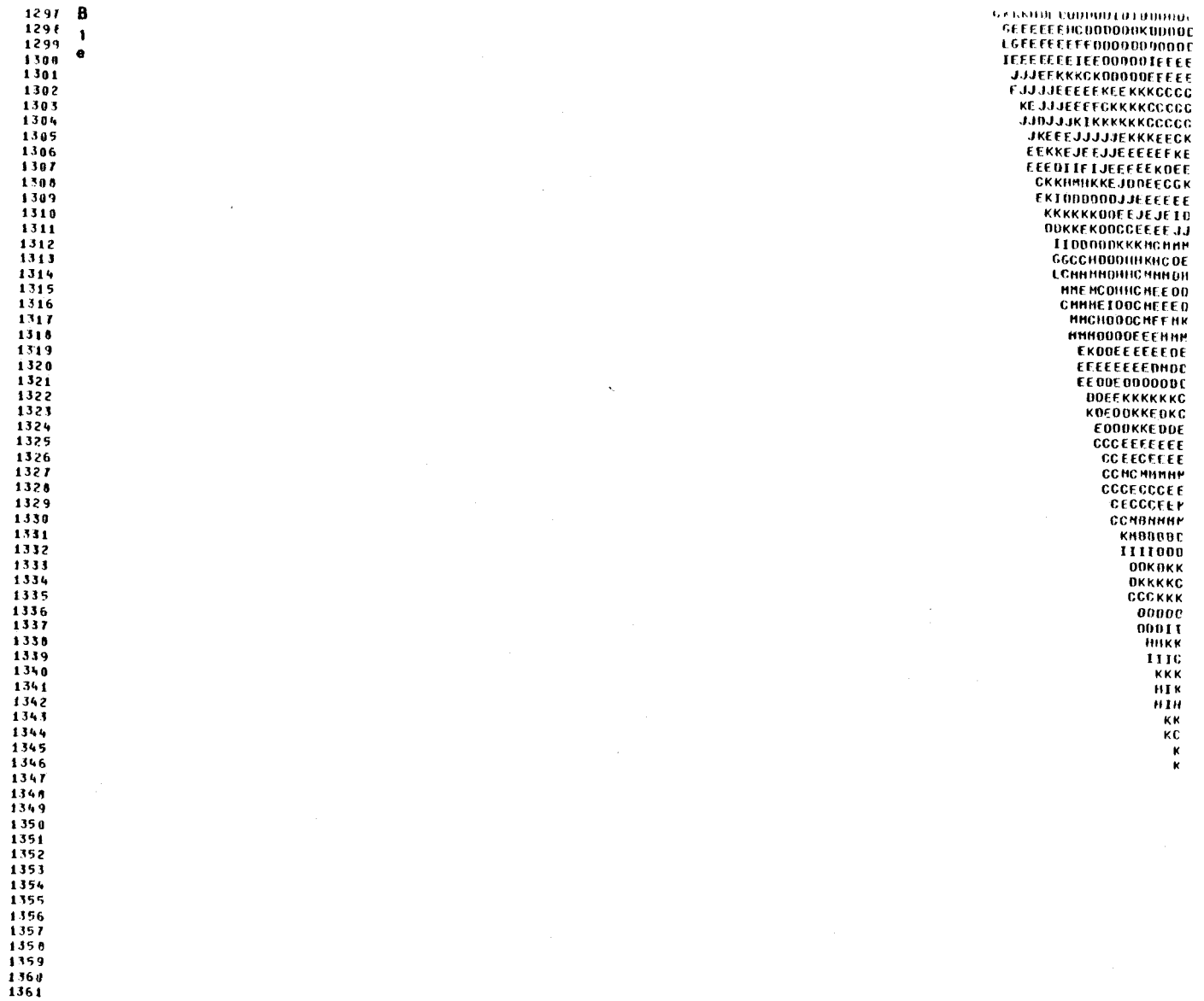
Figure 43. The outline of Crater Lake National Park and vicinity has been inserted in figure above to indicate which portions of Appendix III cover which portion of the Park and vicinity.

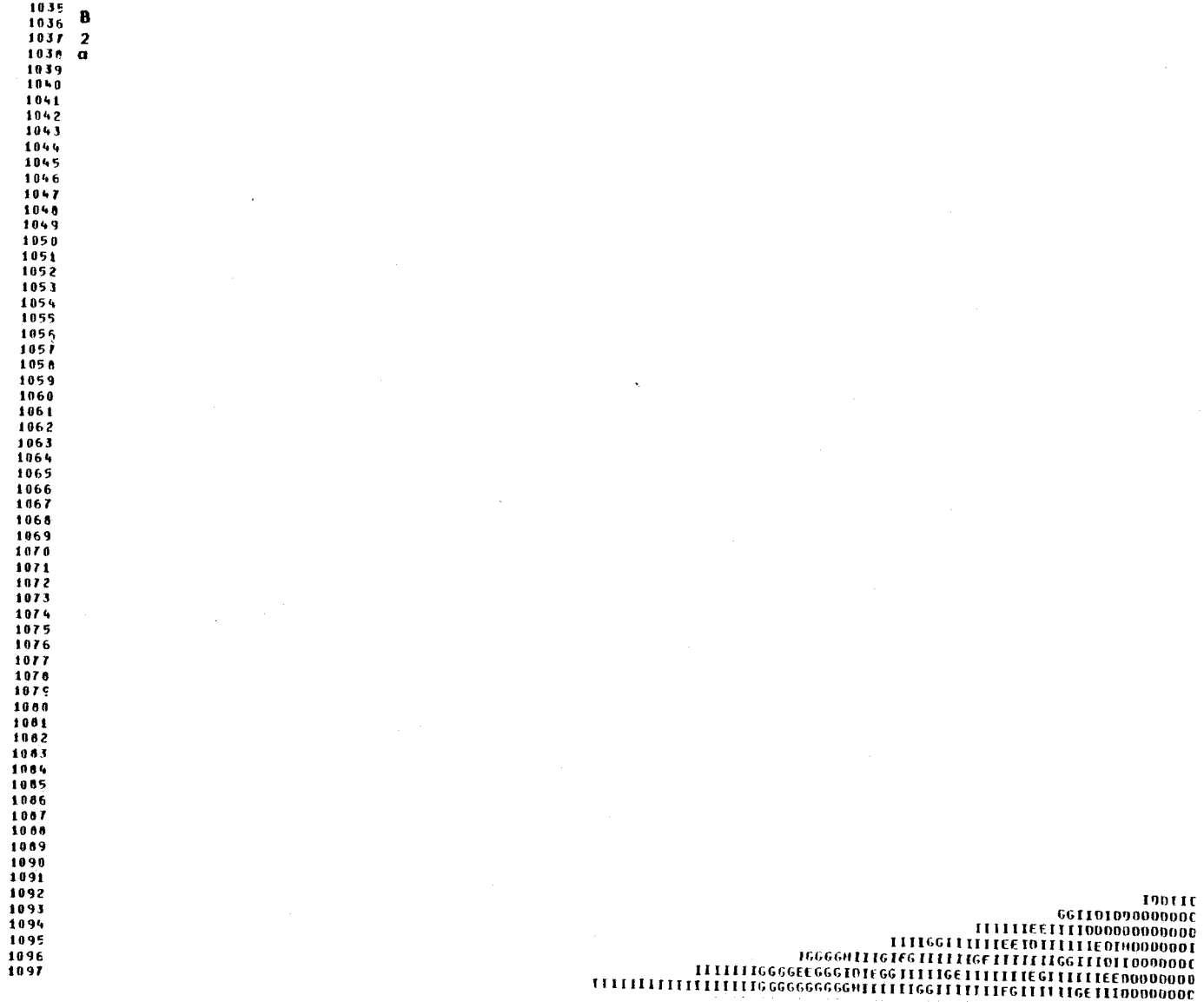
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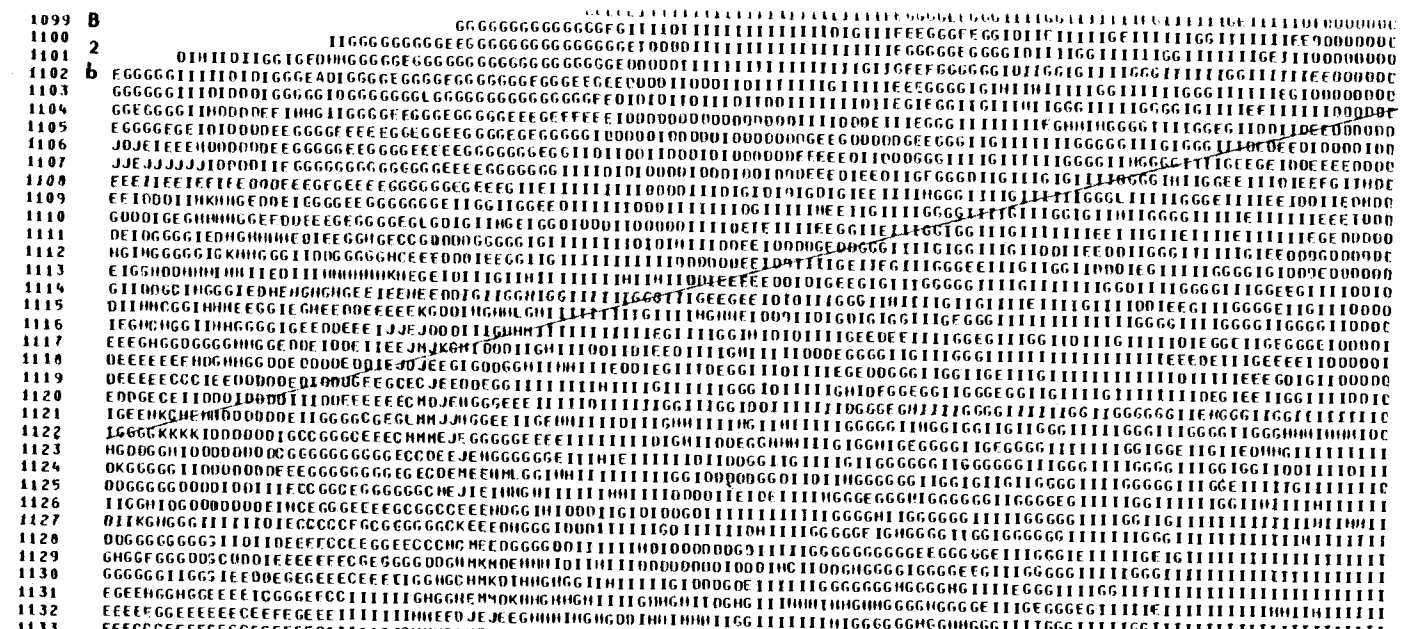


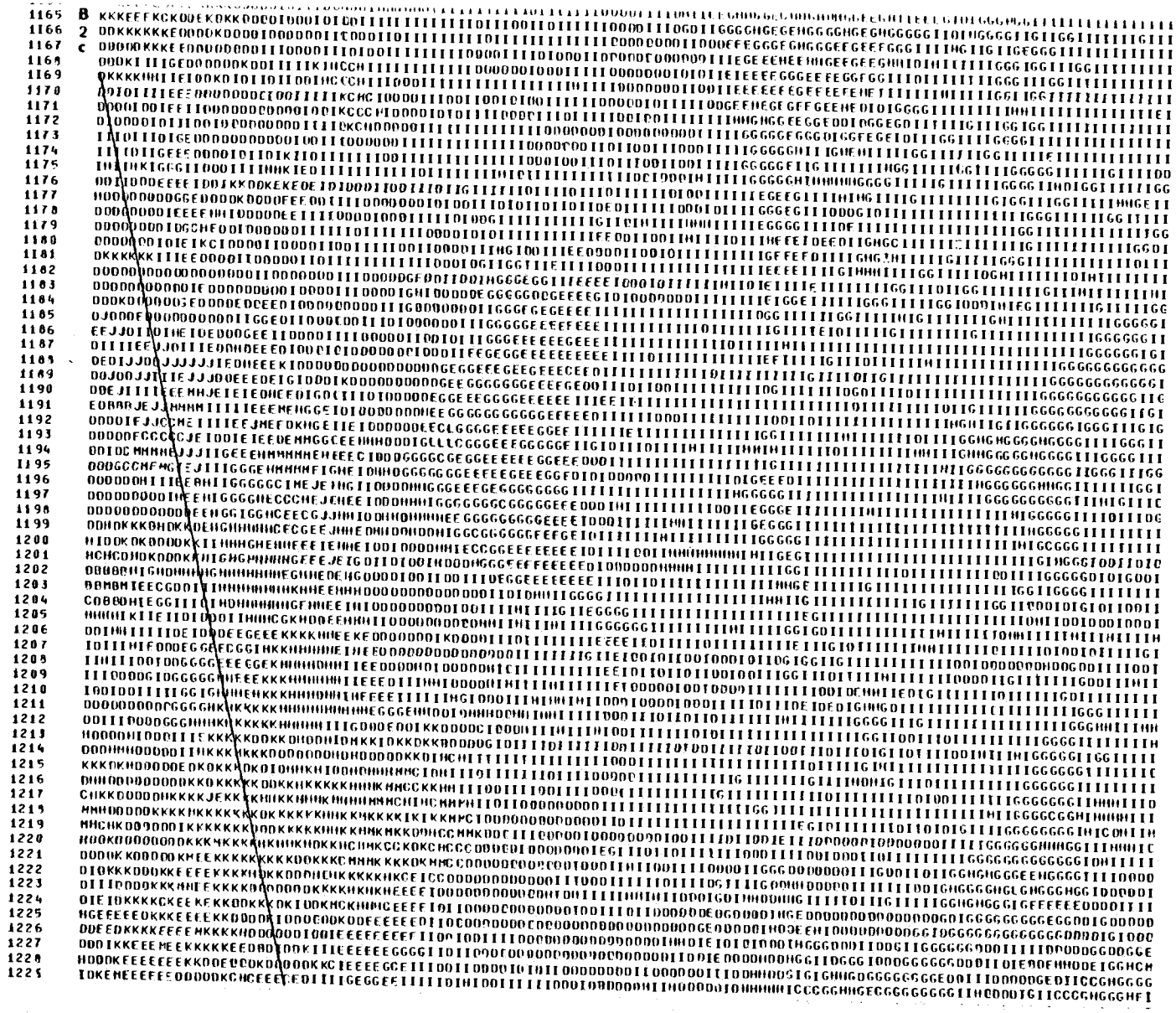


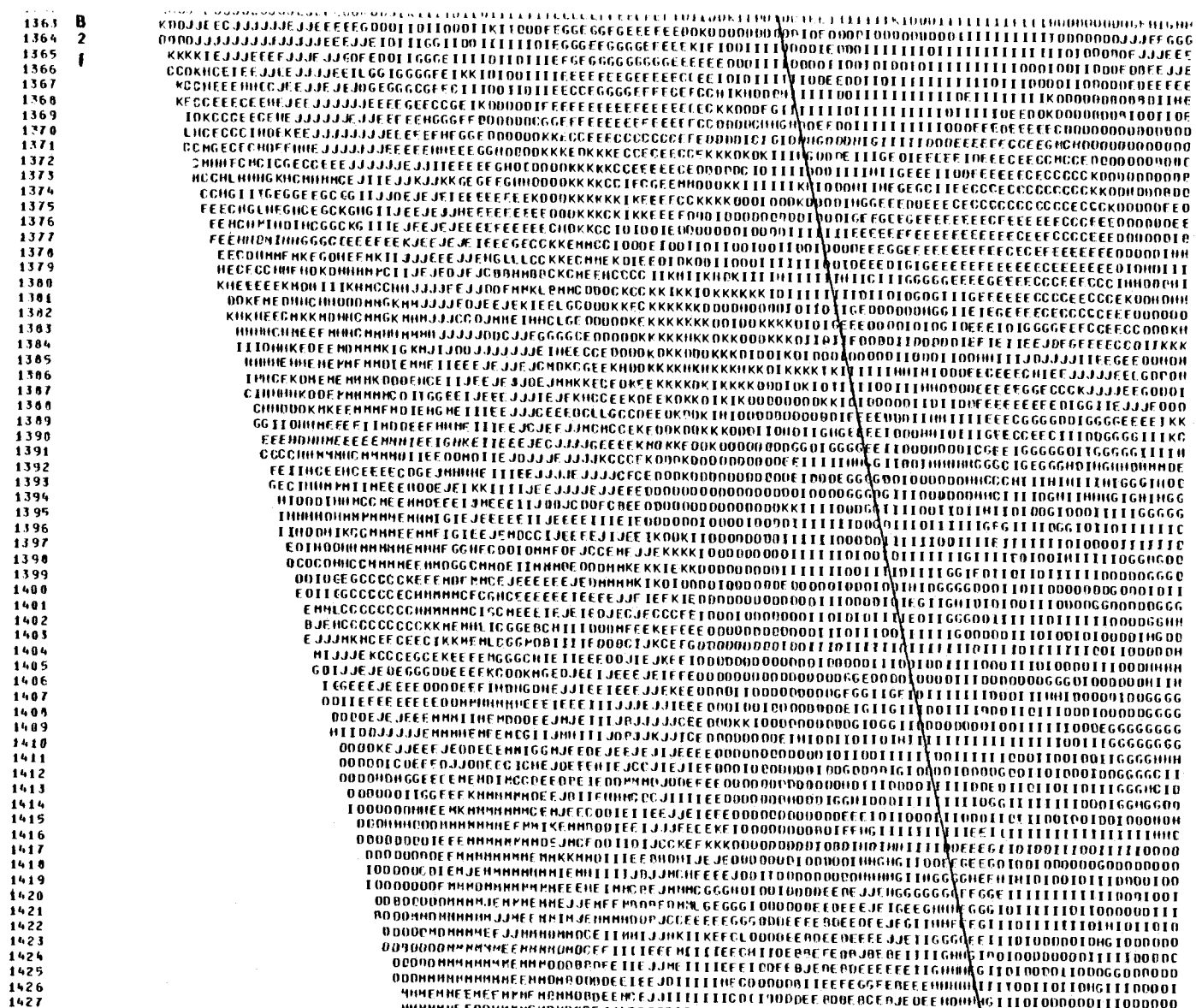

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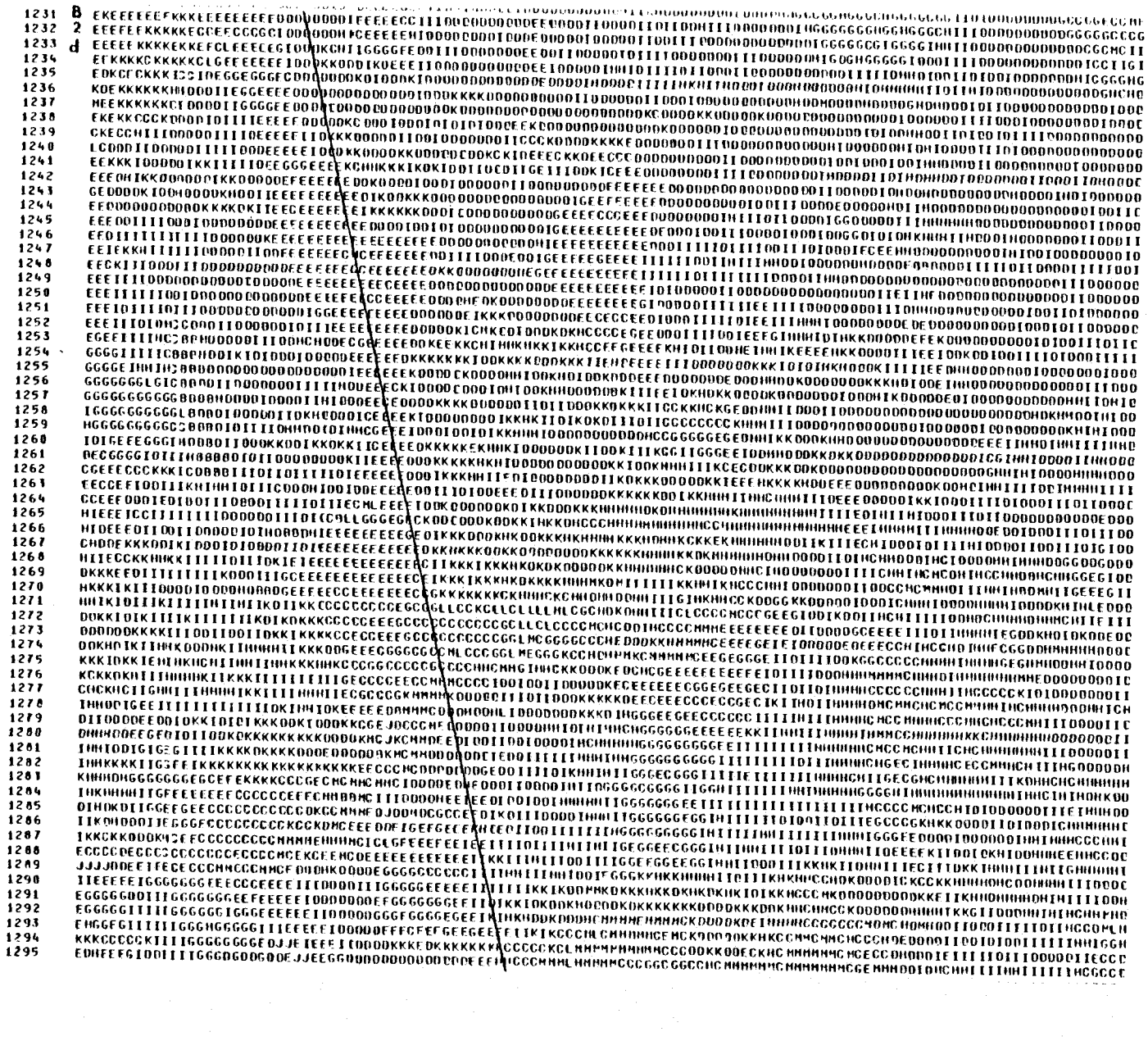

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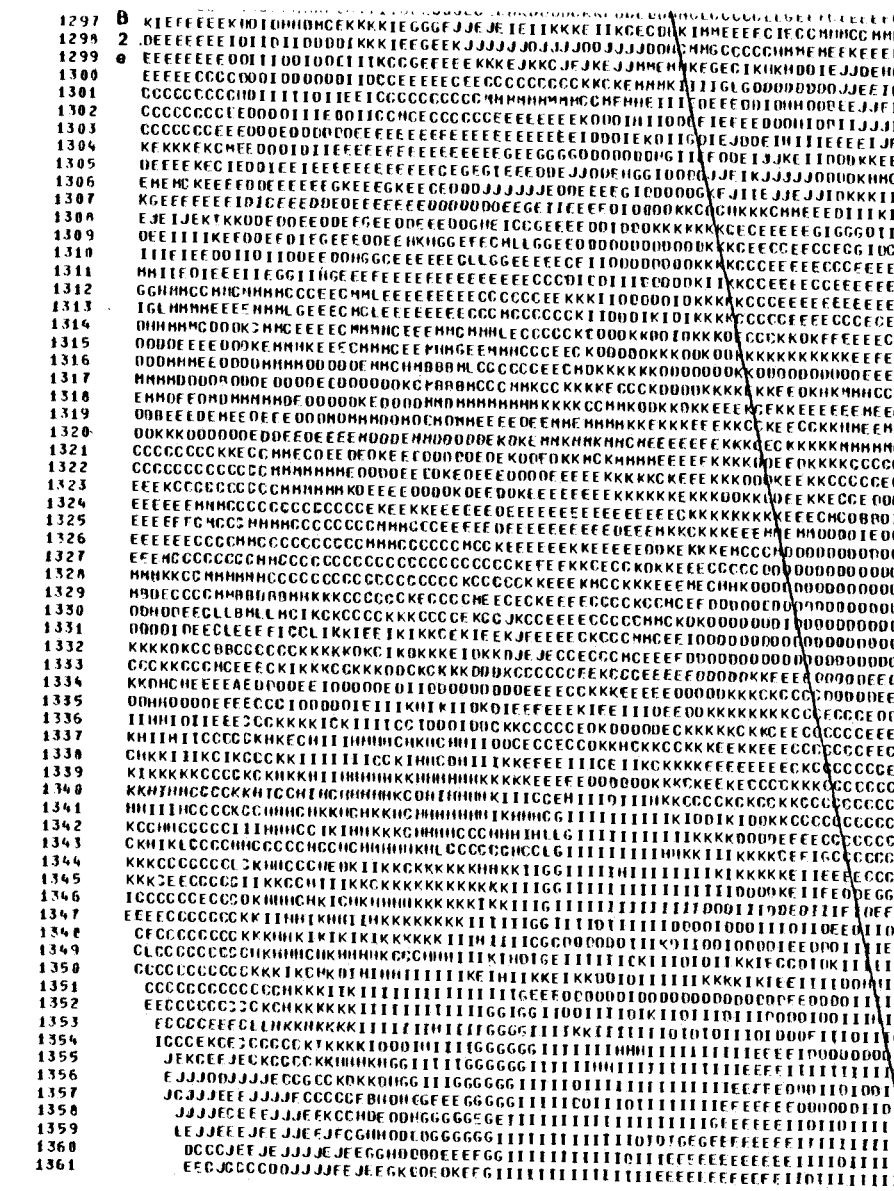

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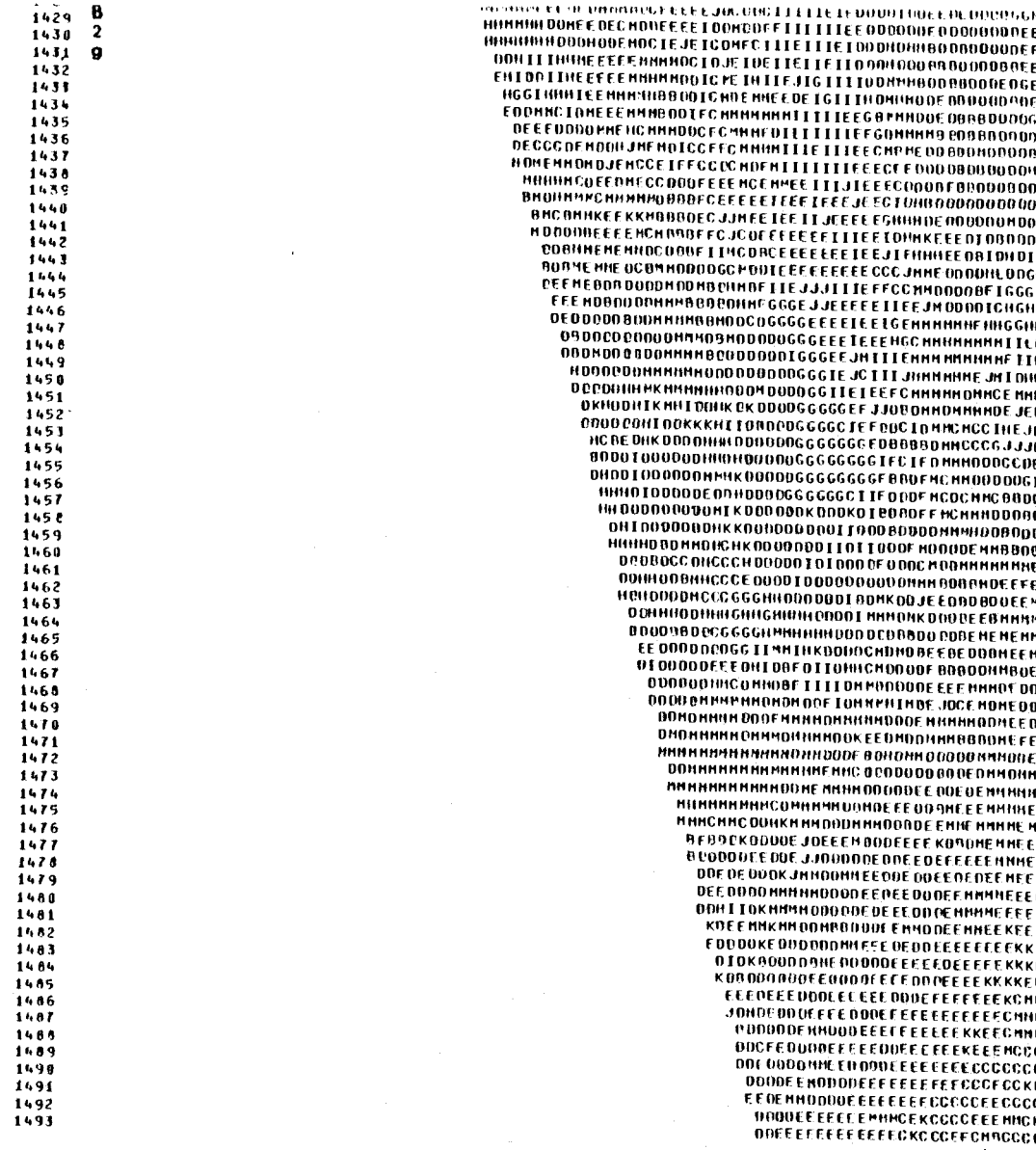


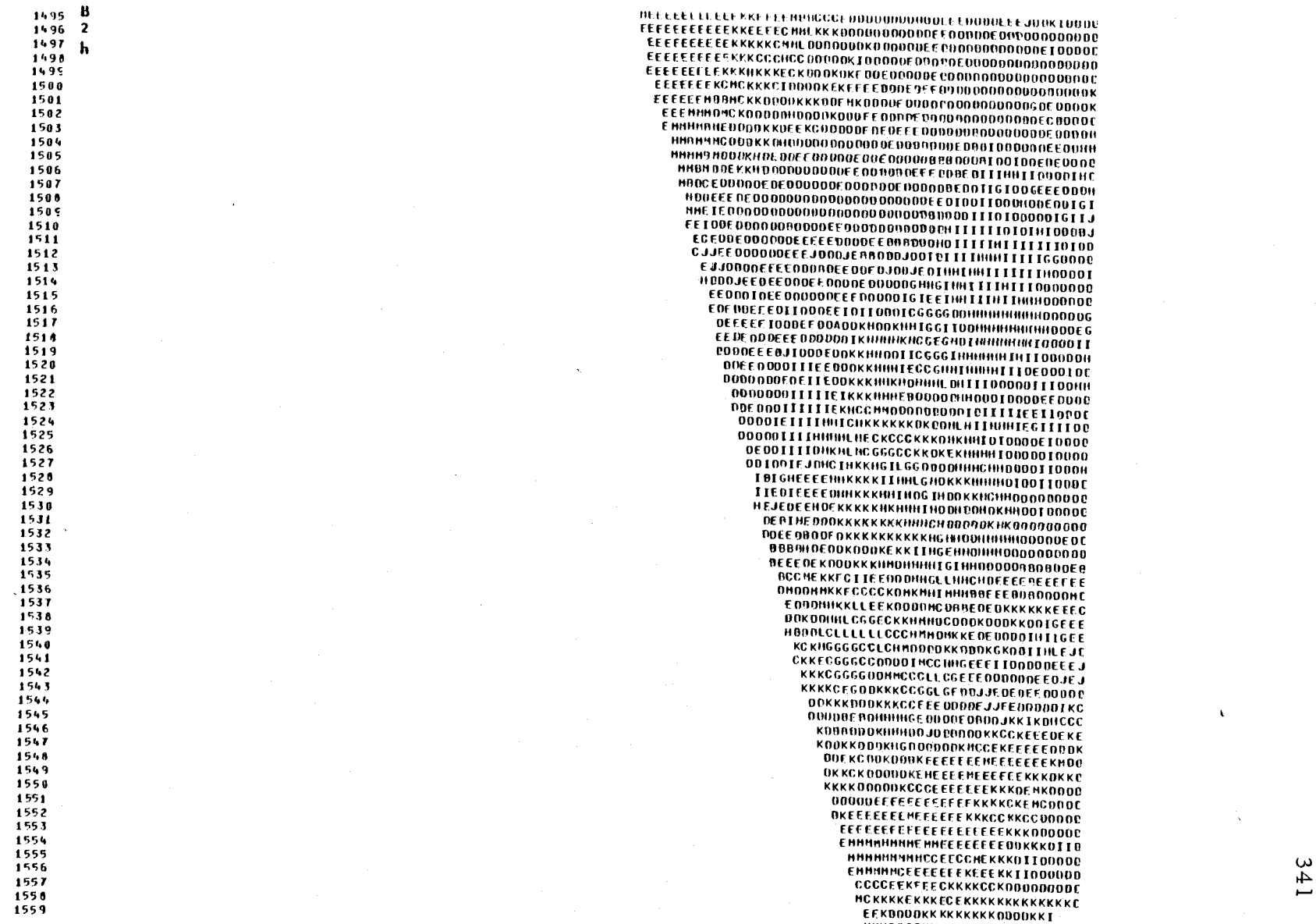


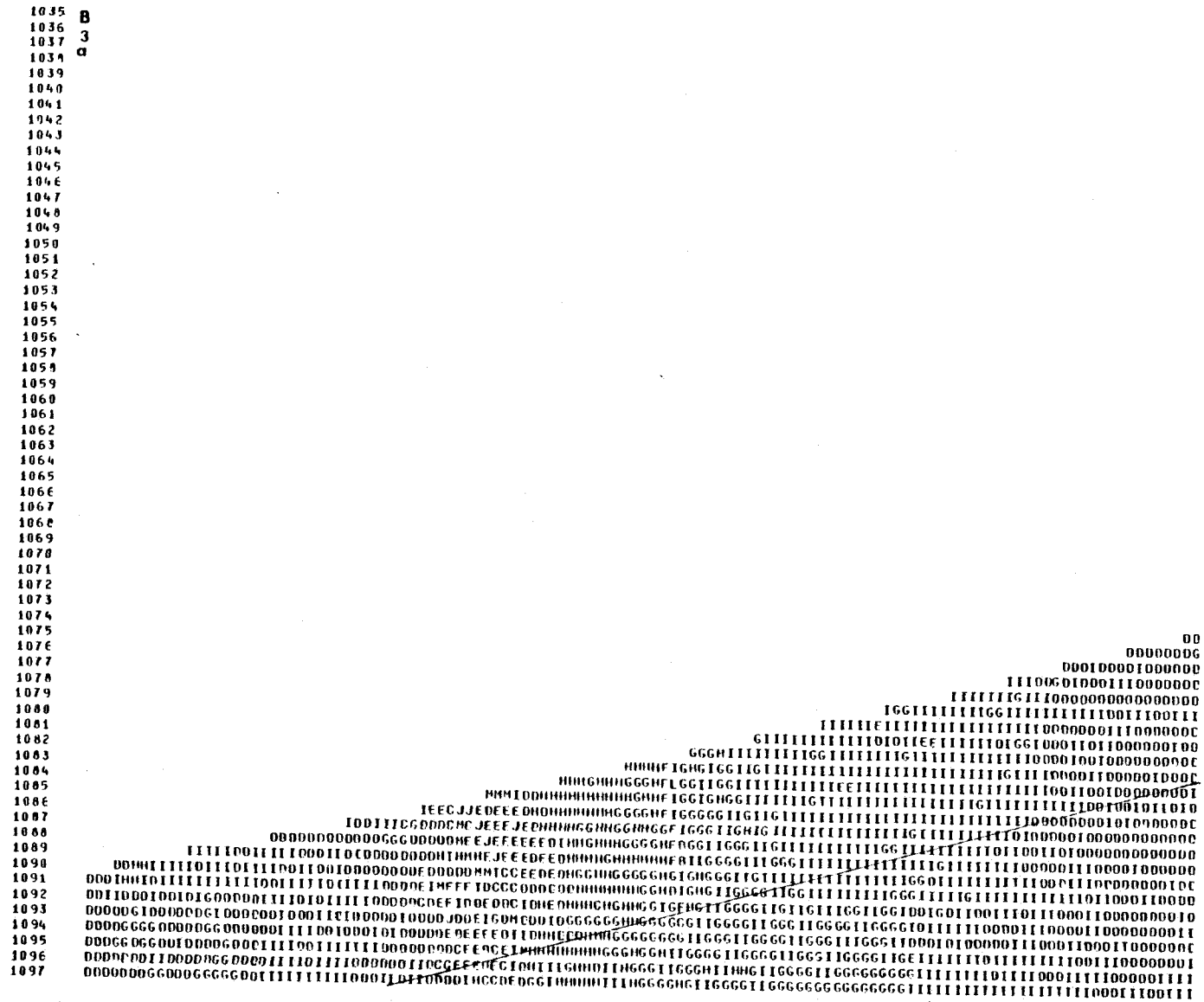


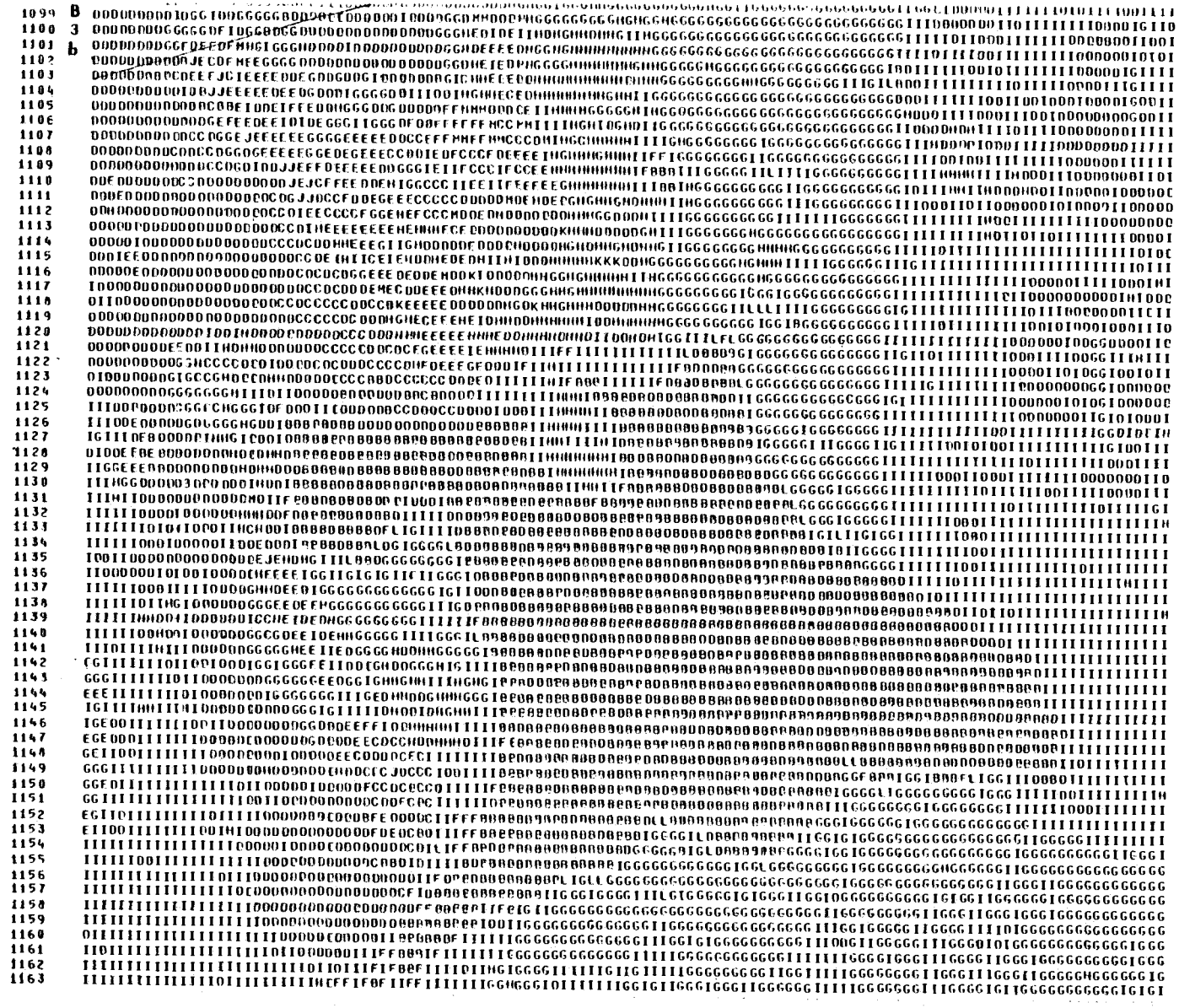


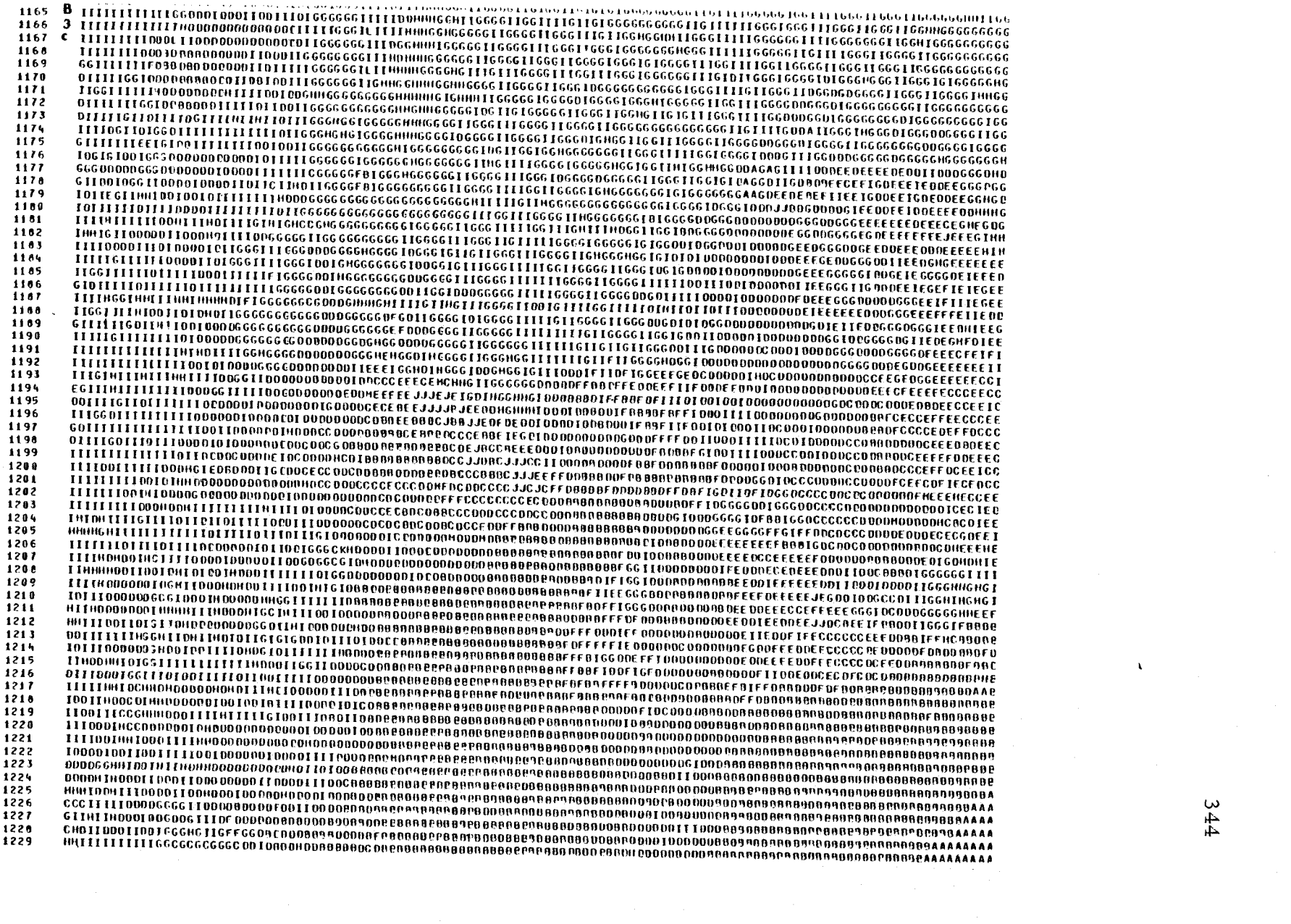


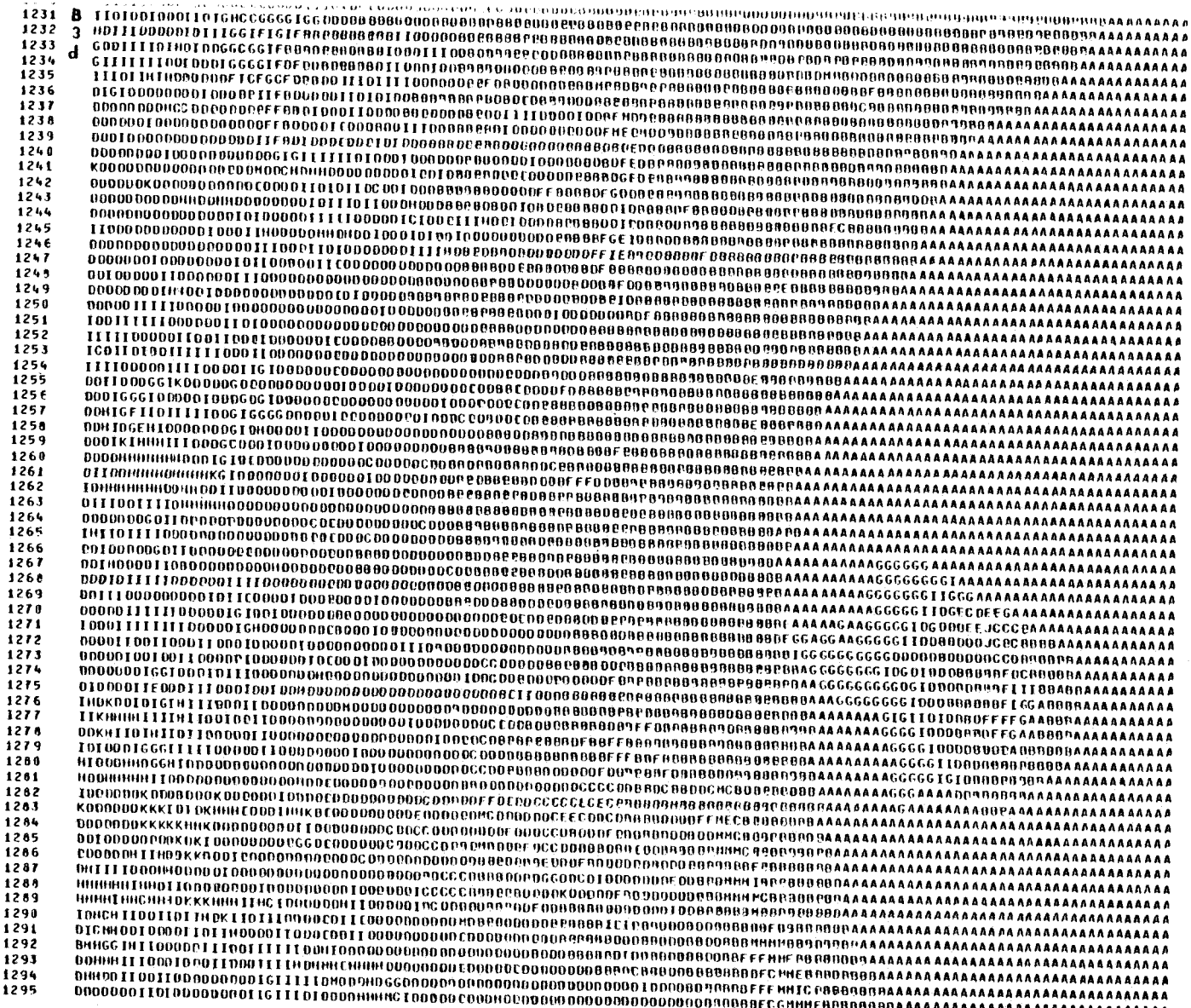


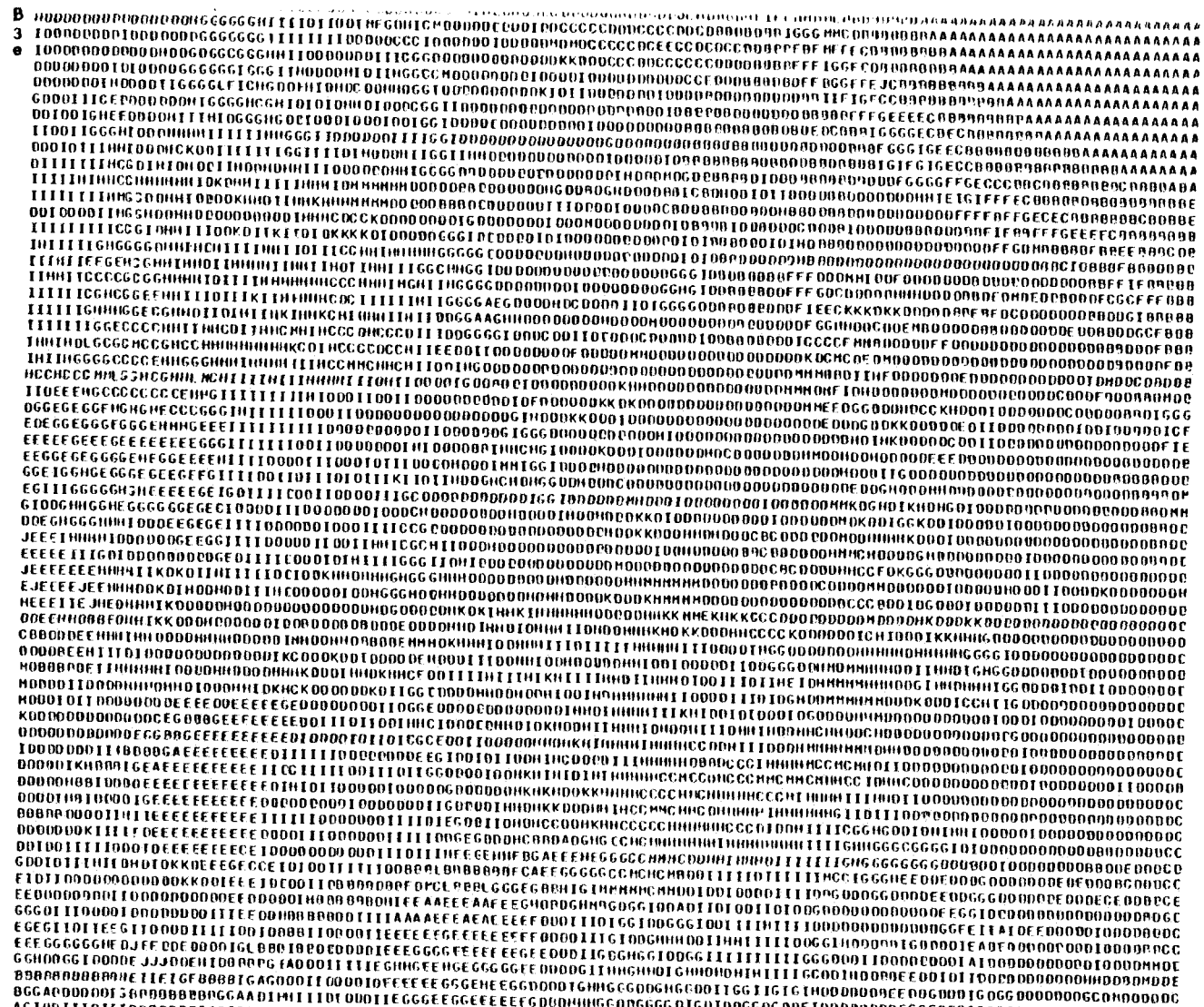


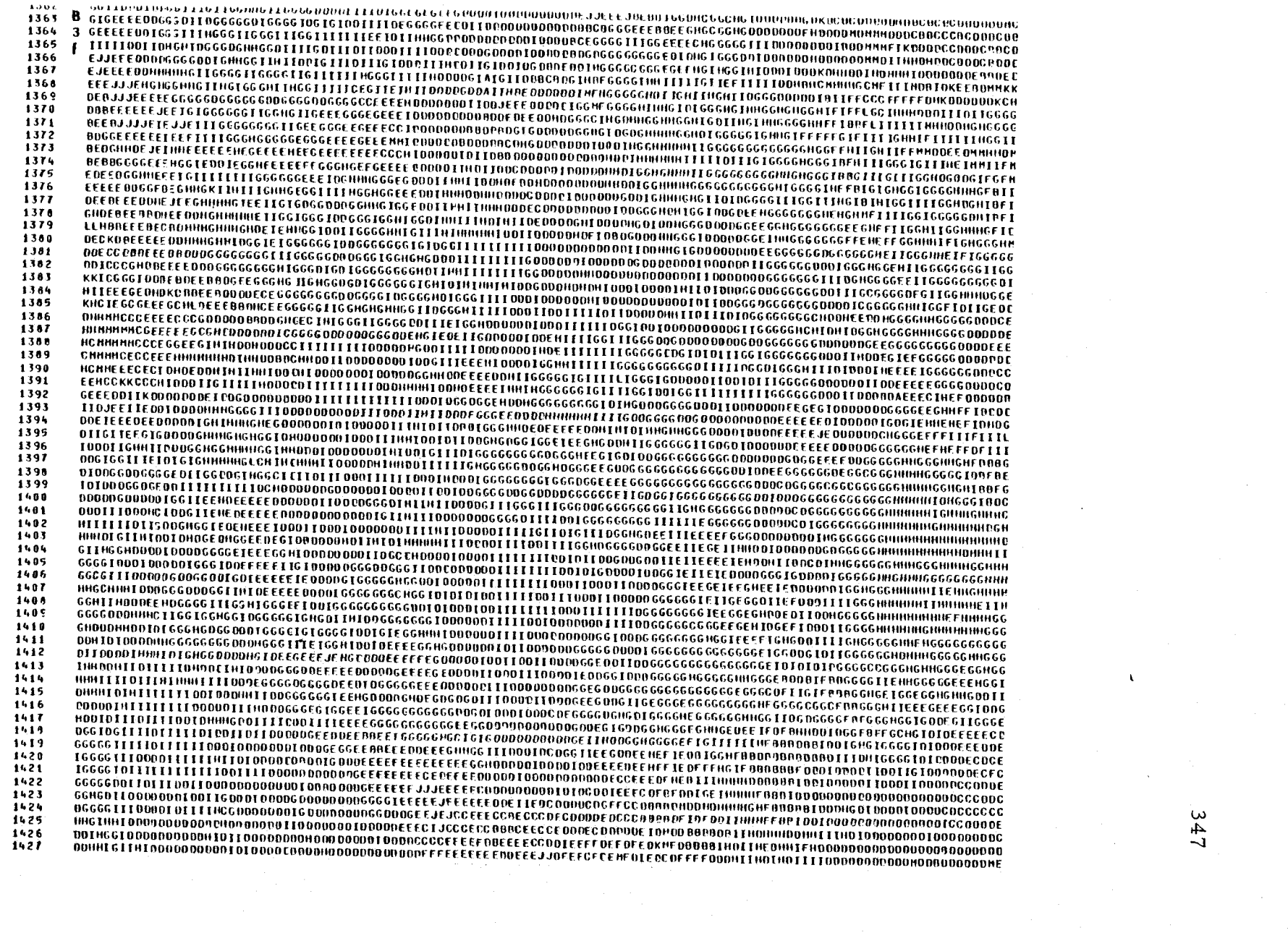


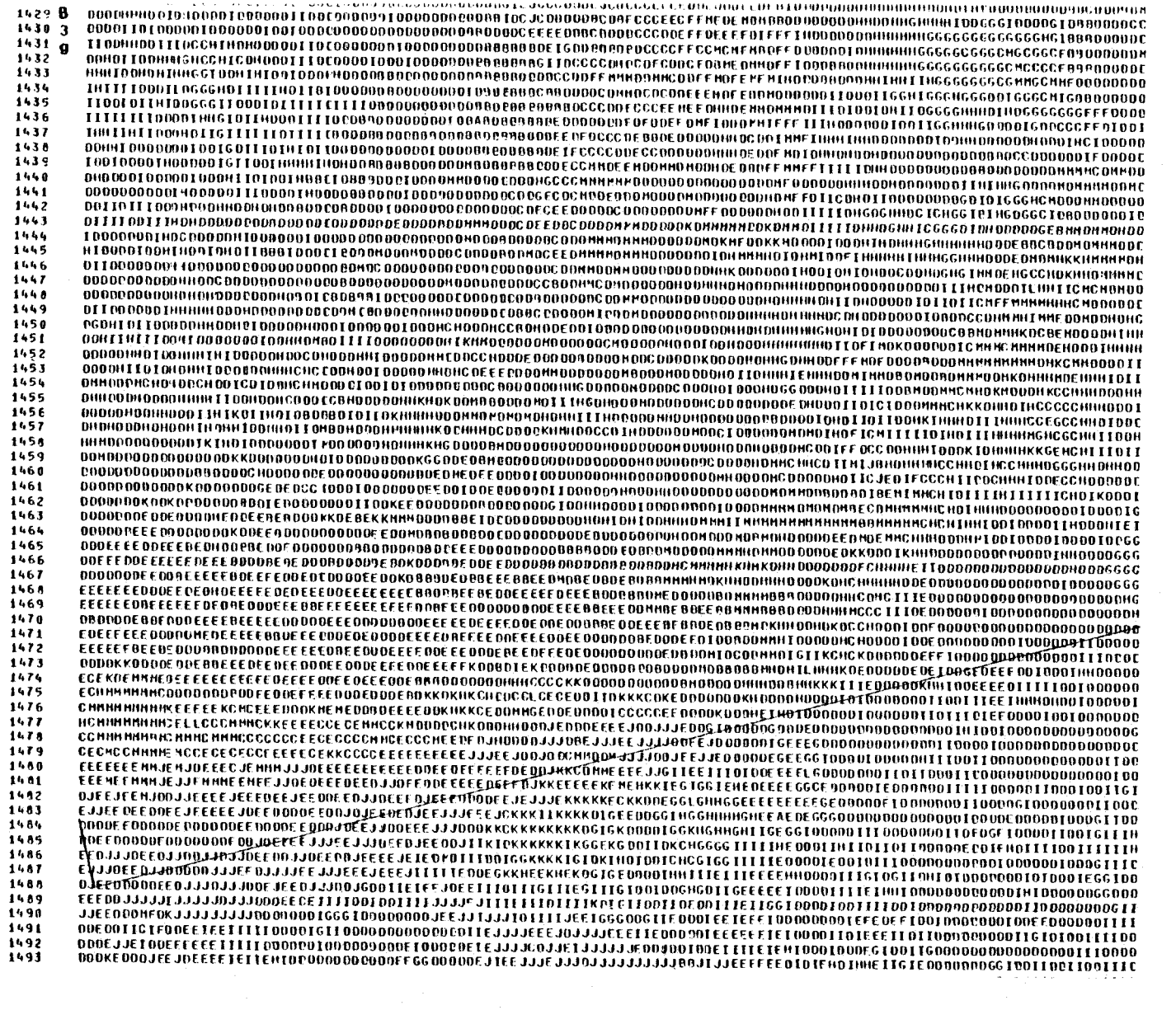




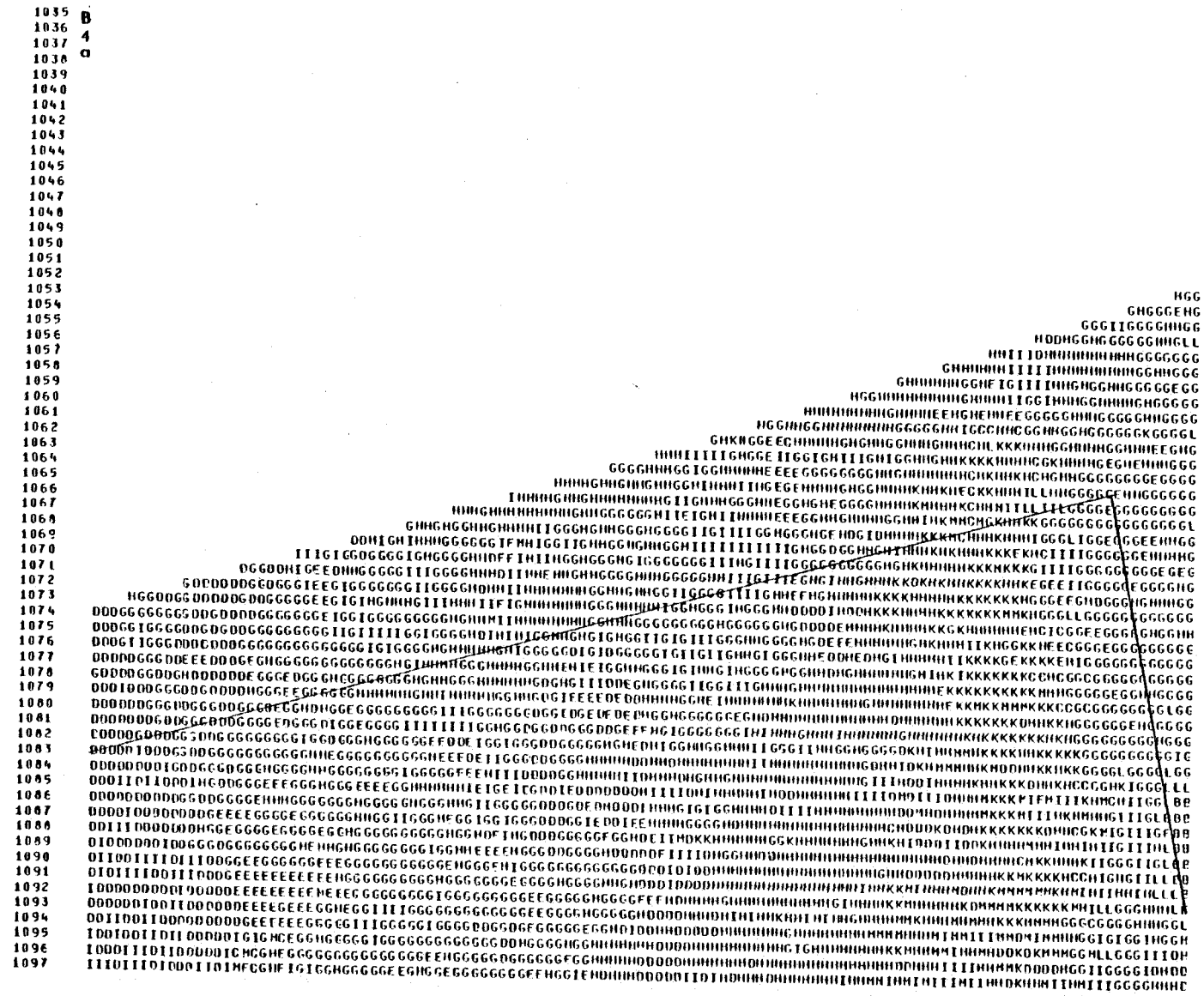


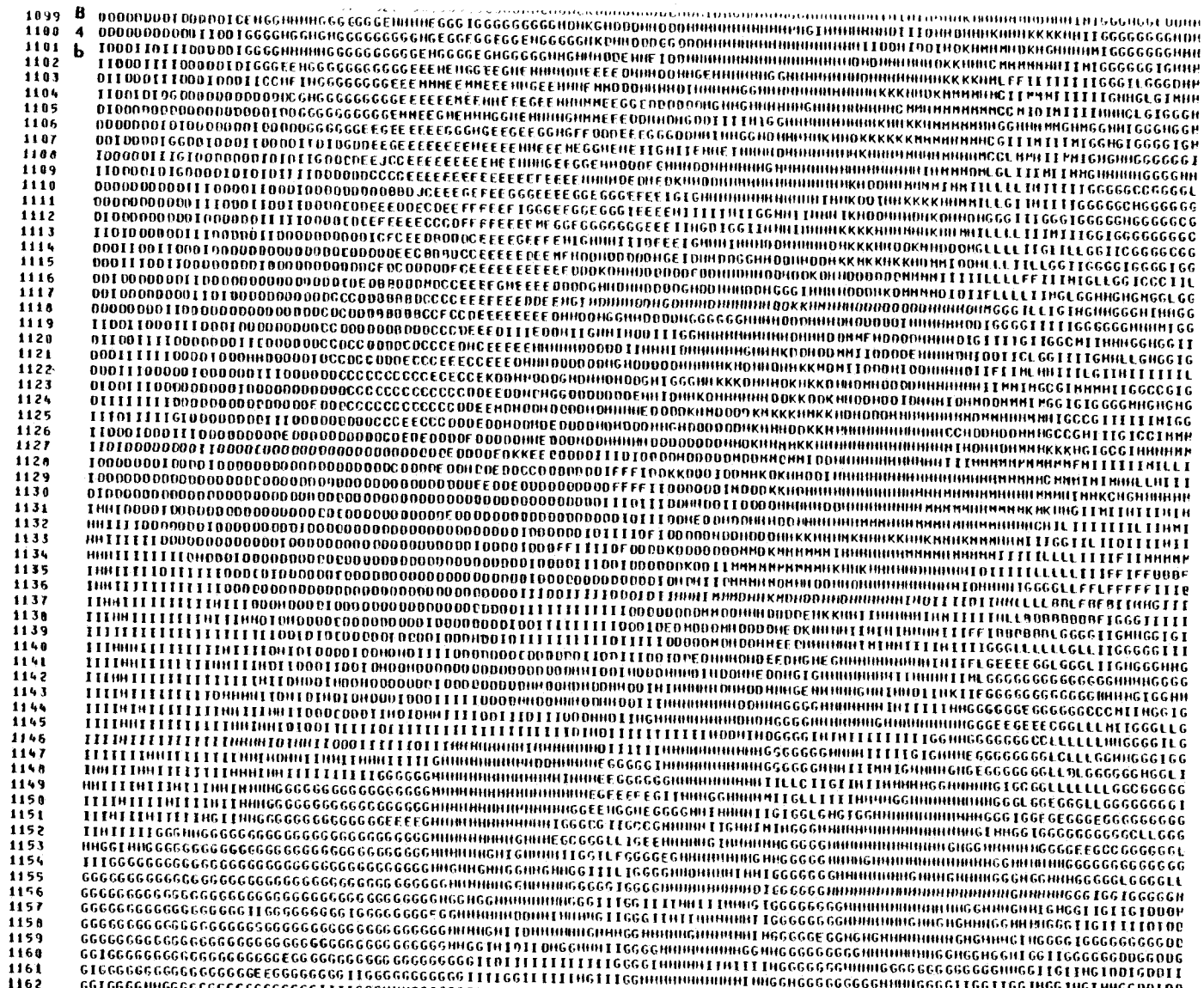


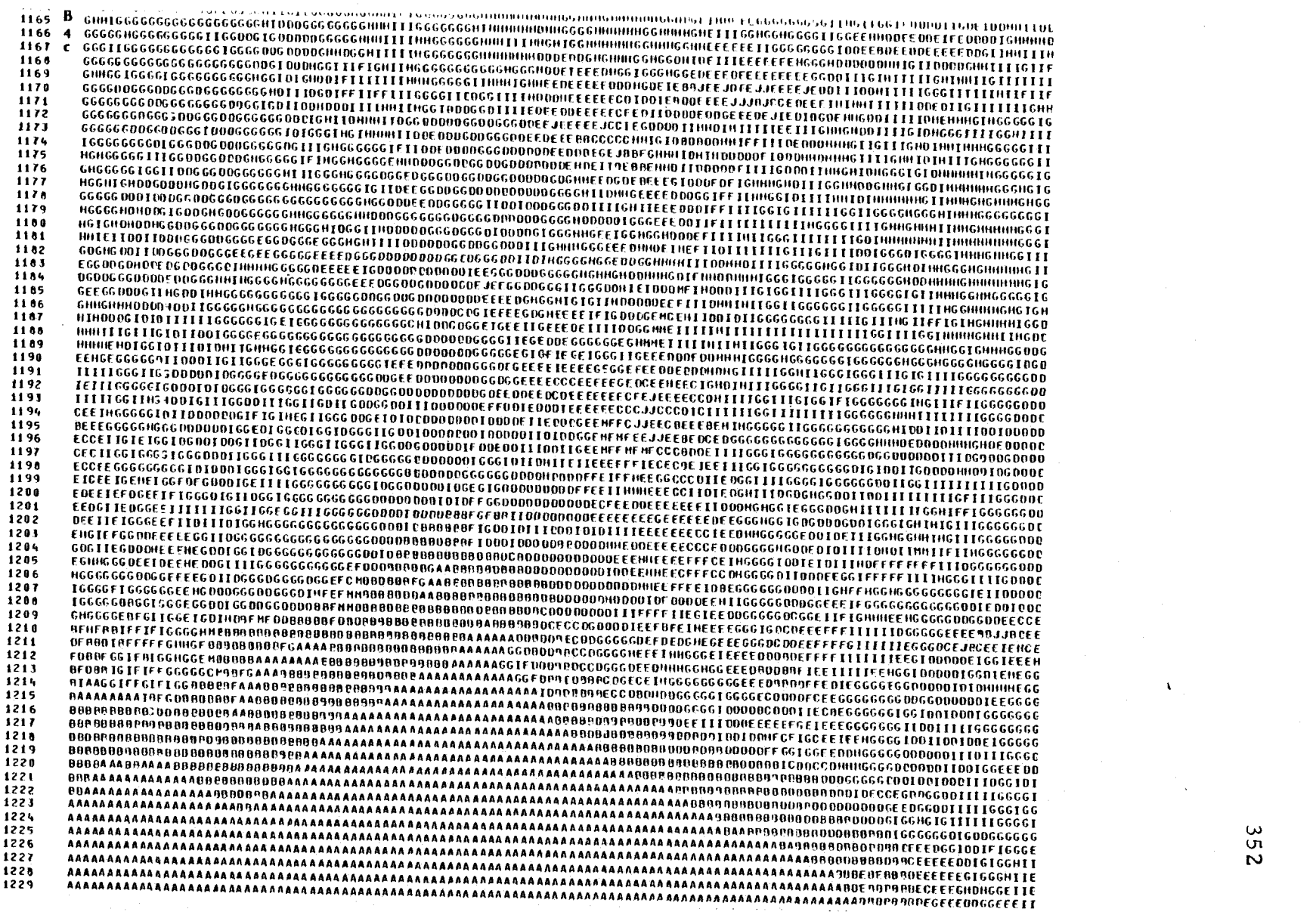


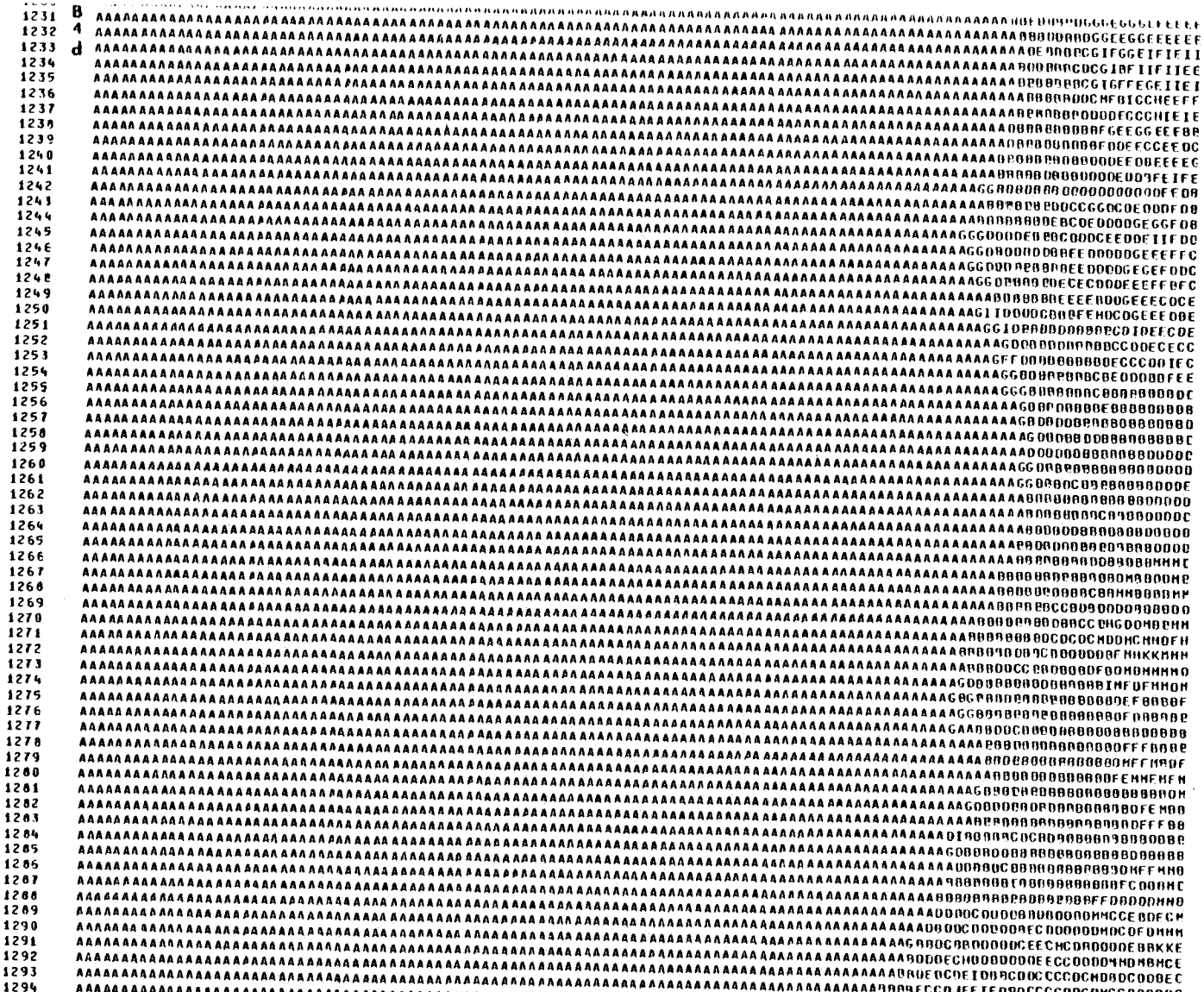


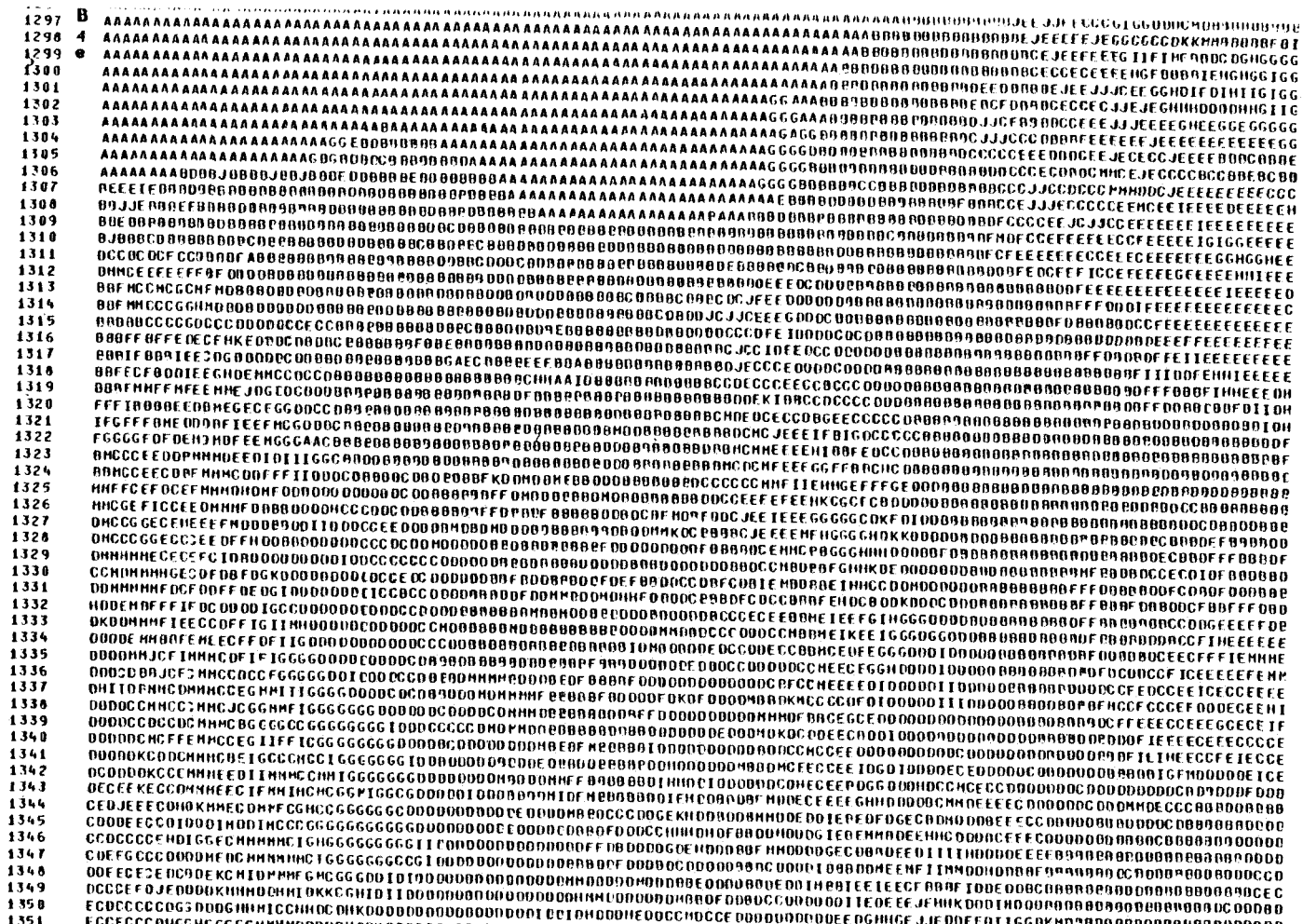


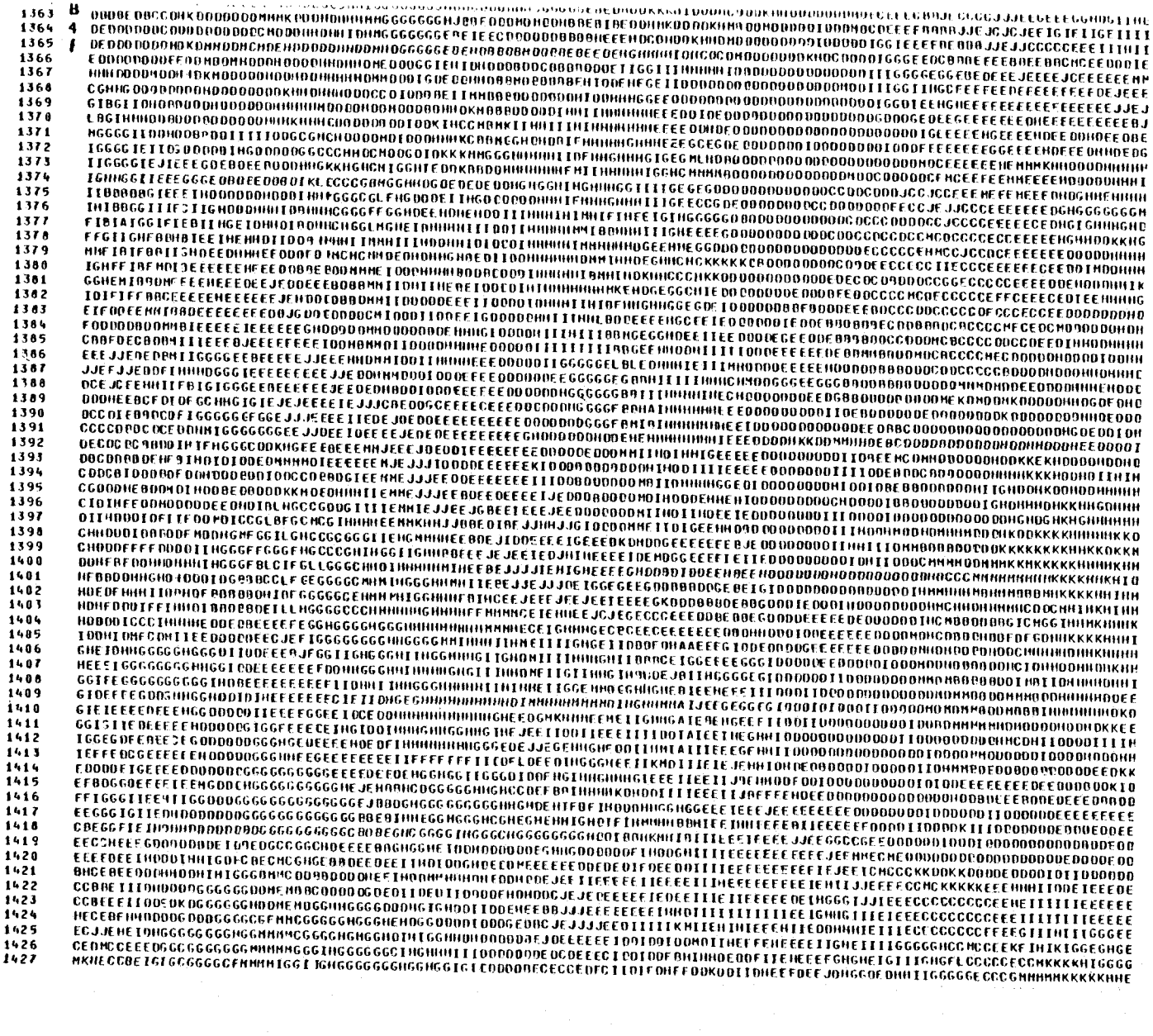


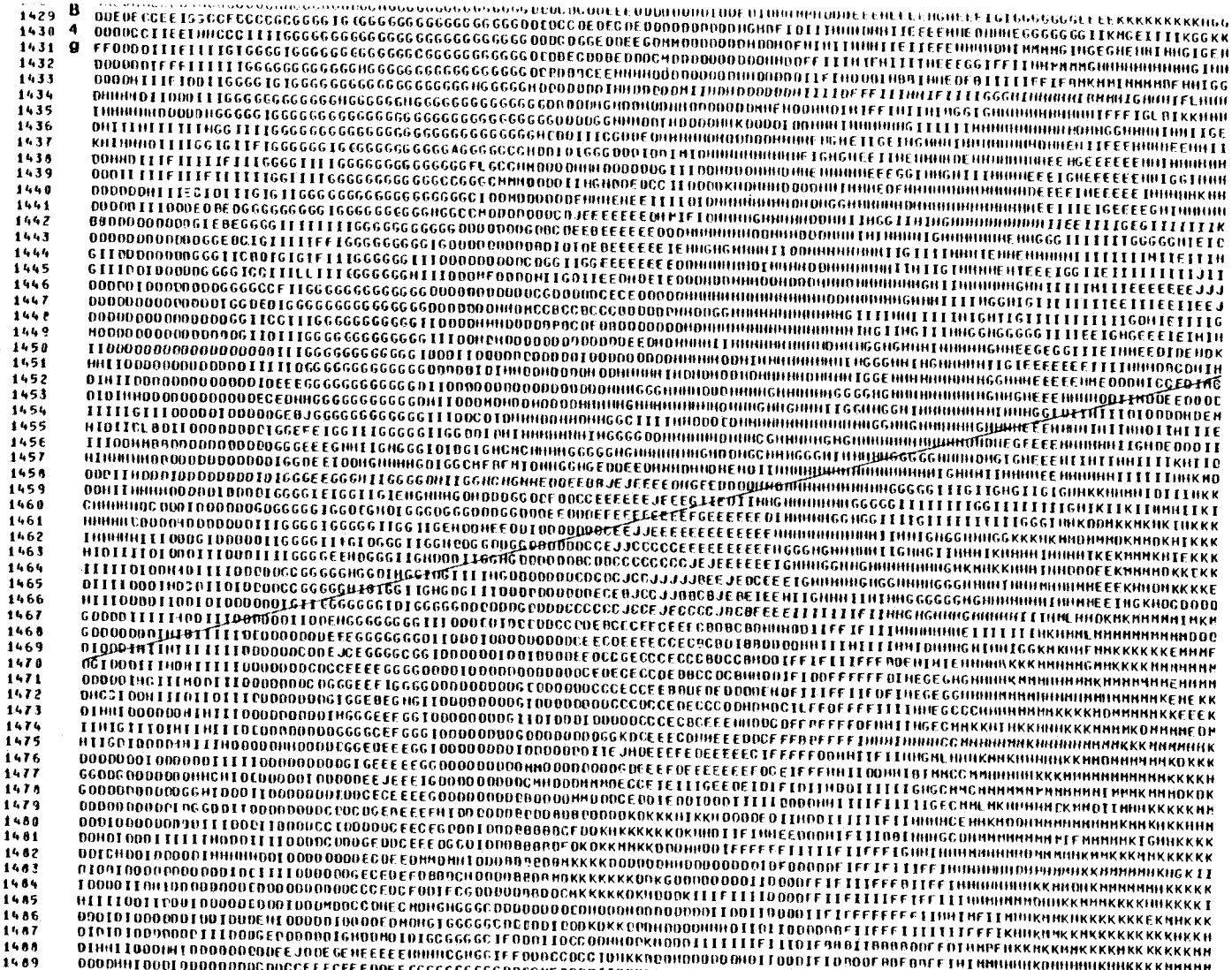




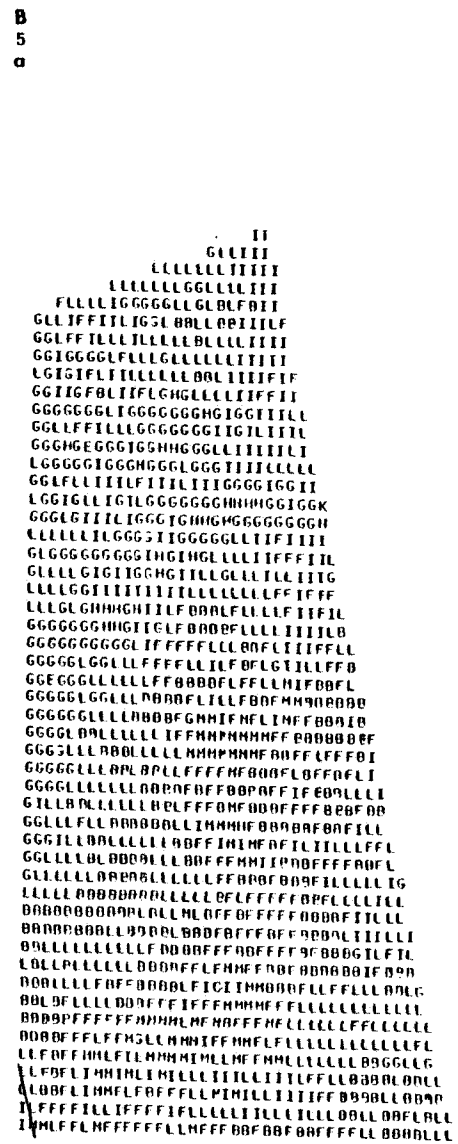


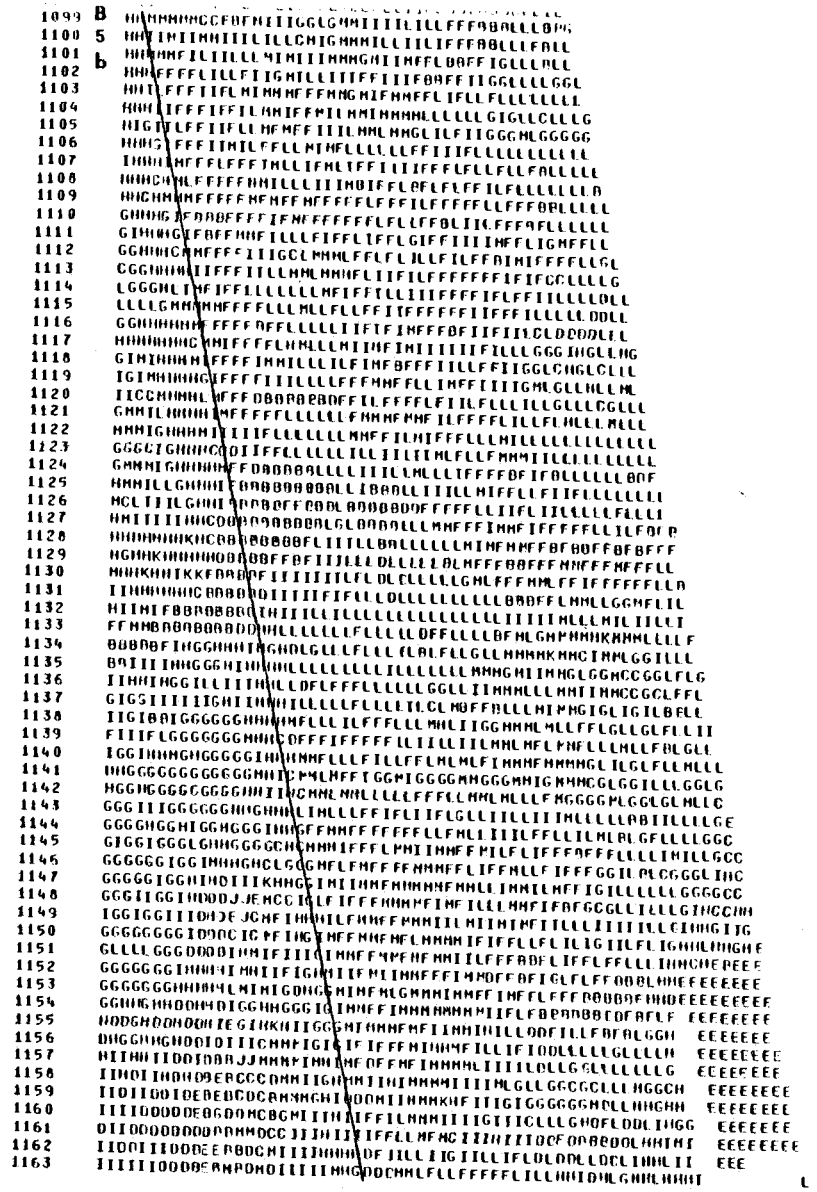


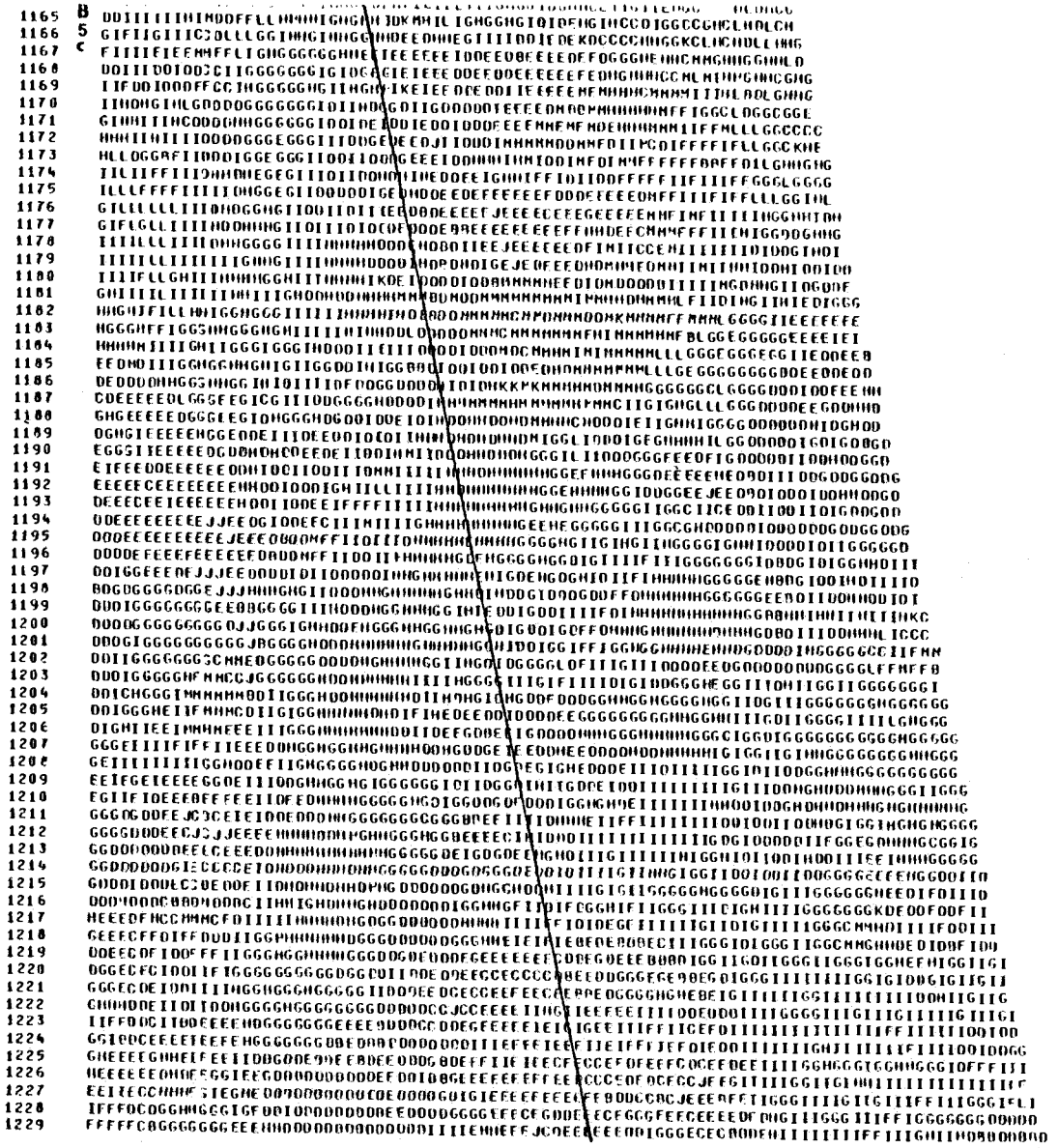


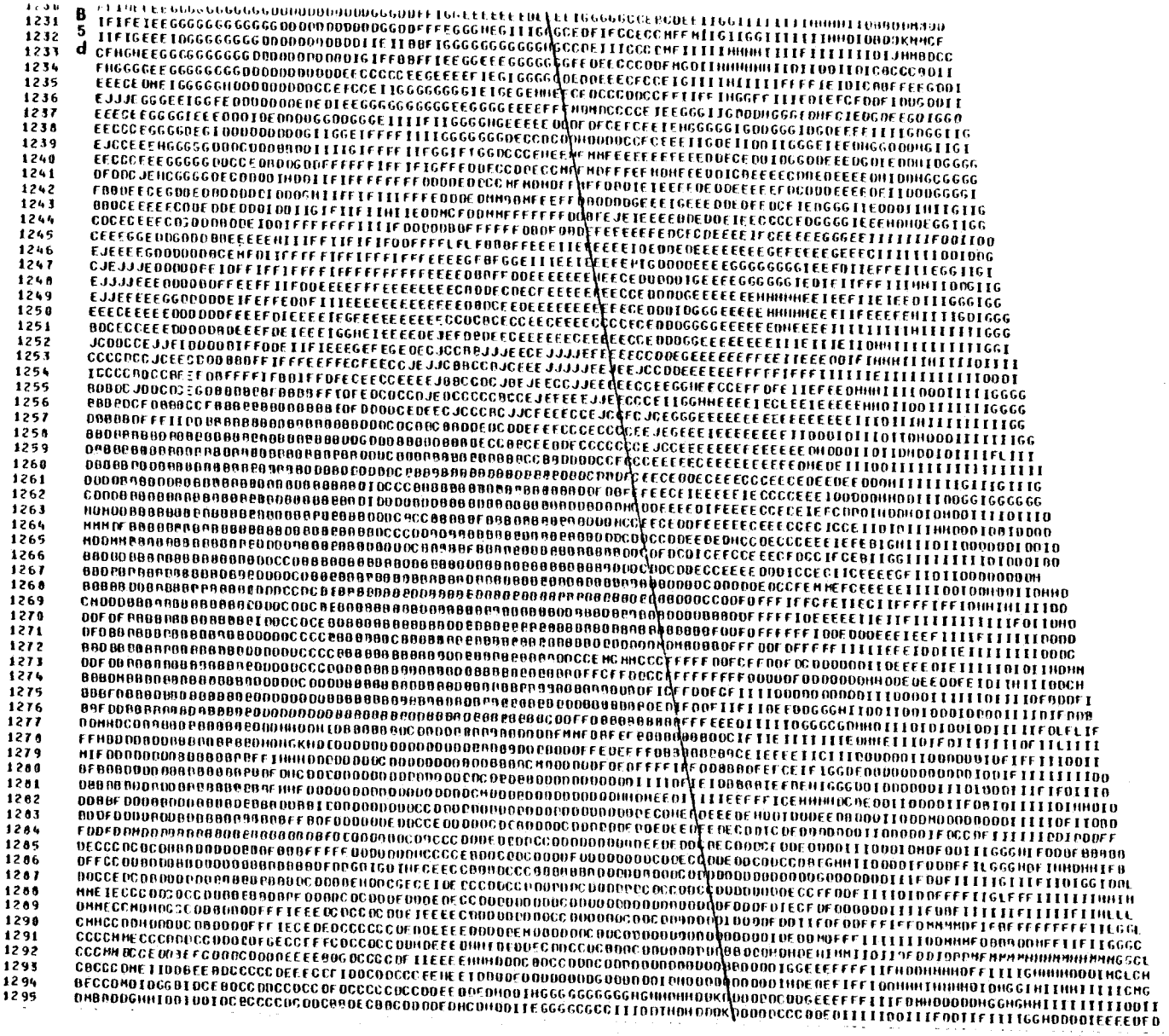


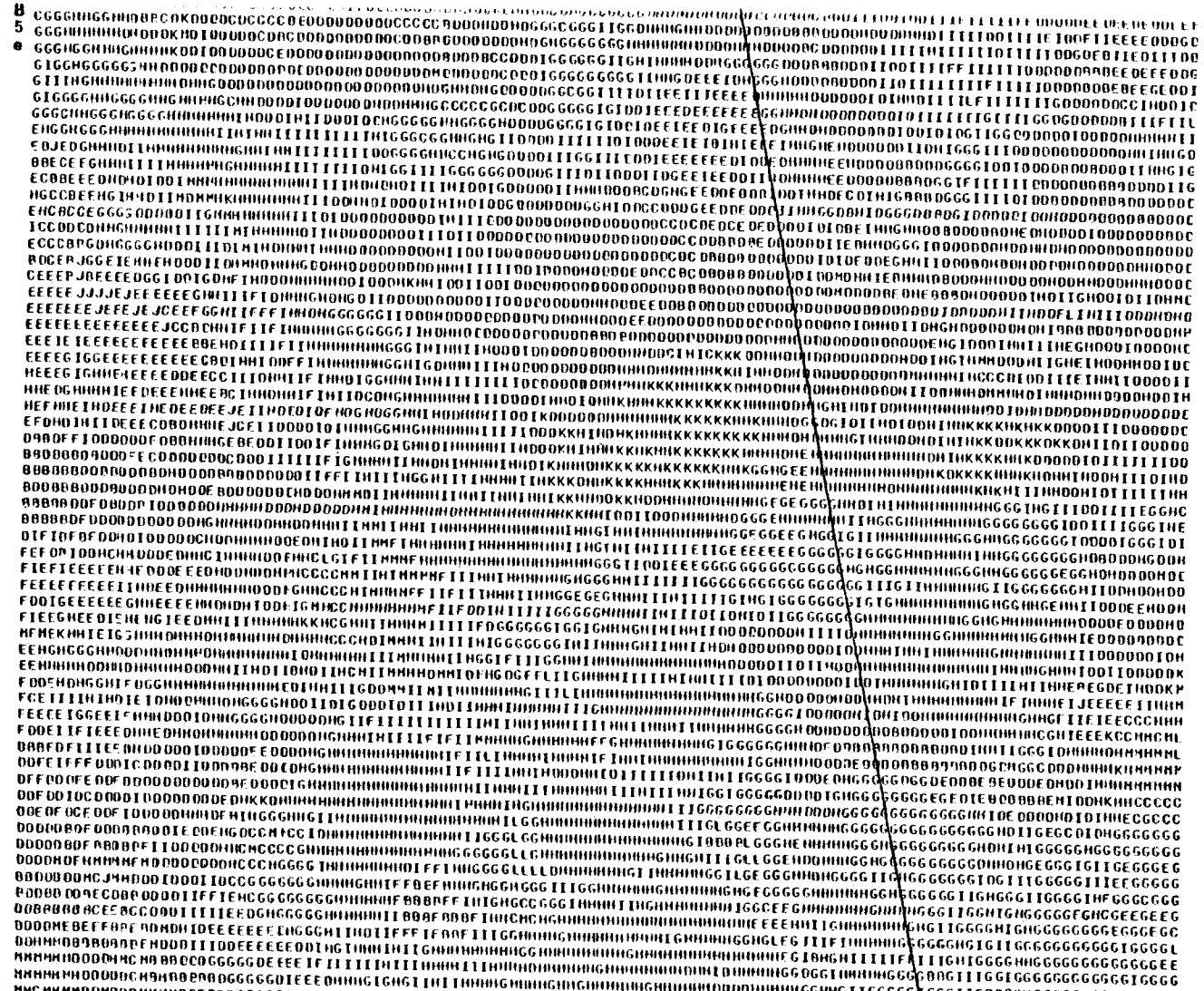


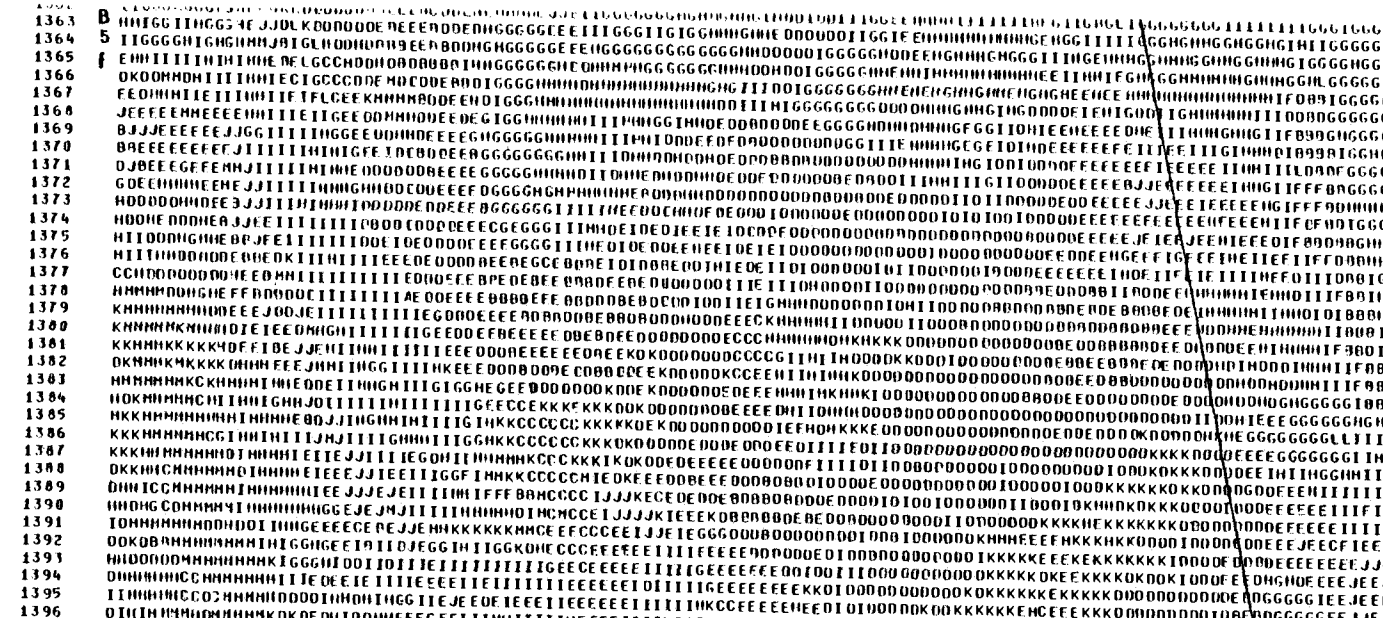


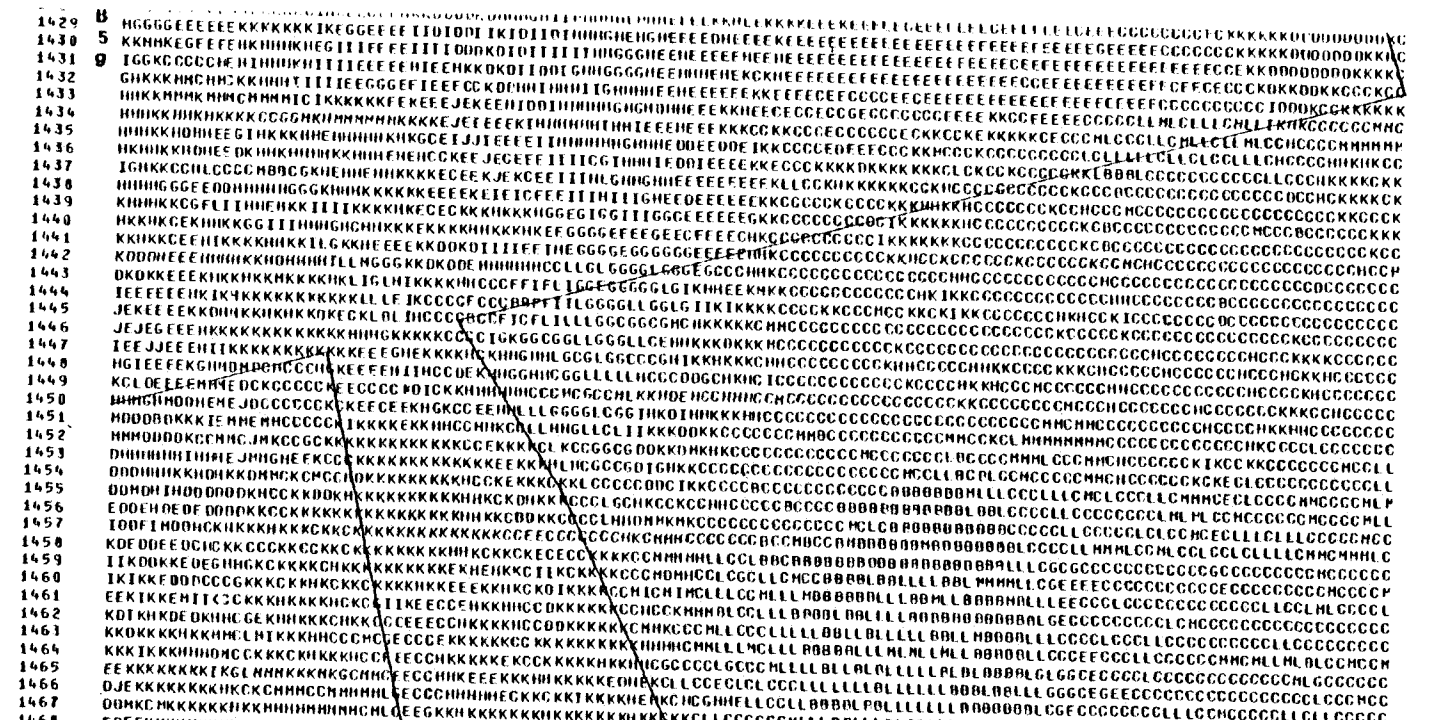




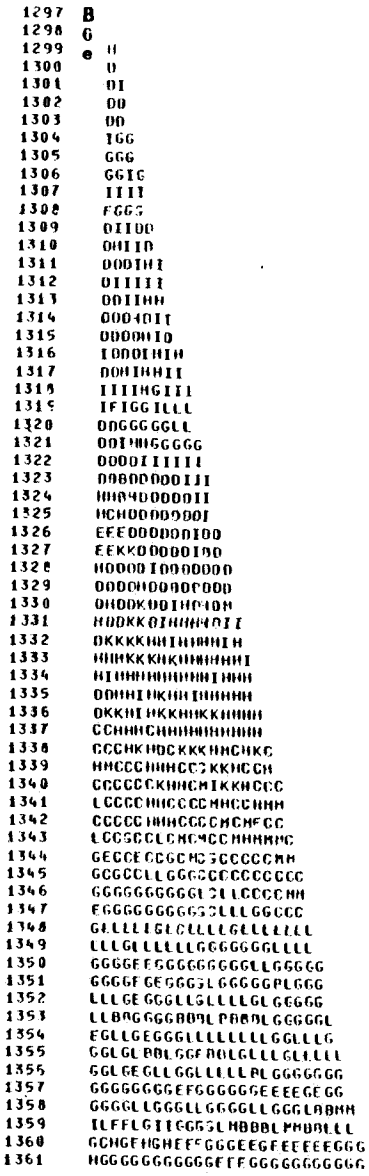


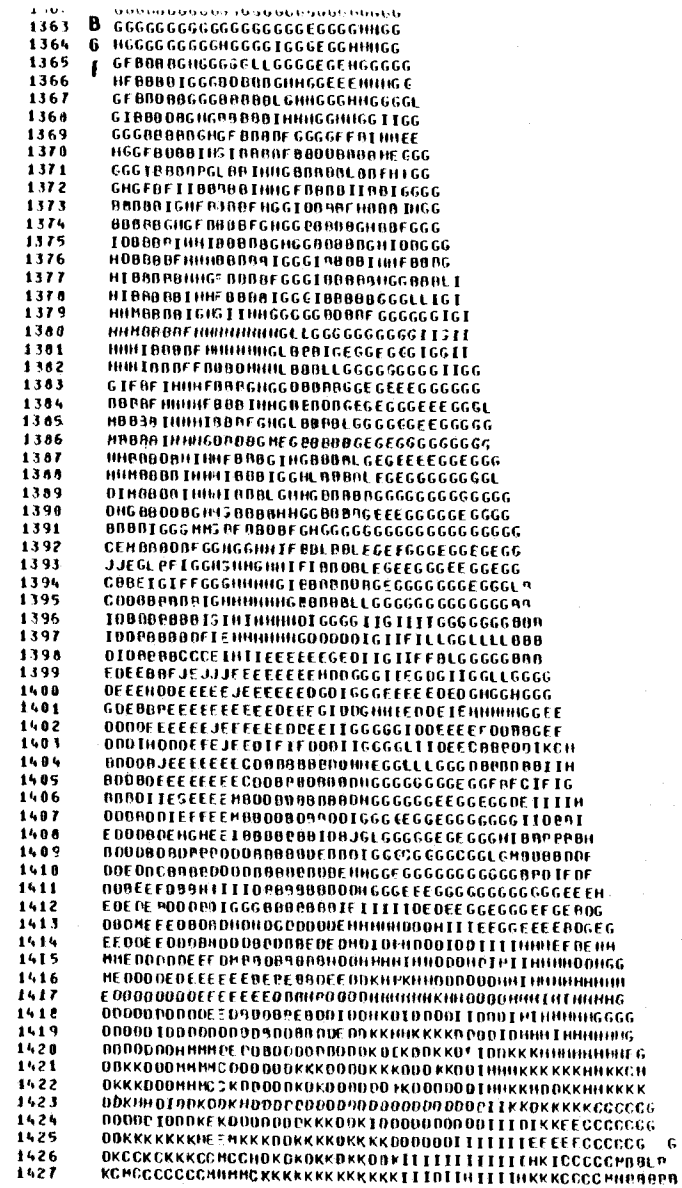


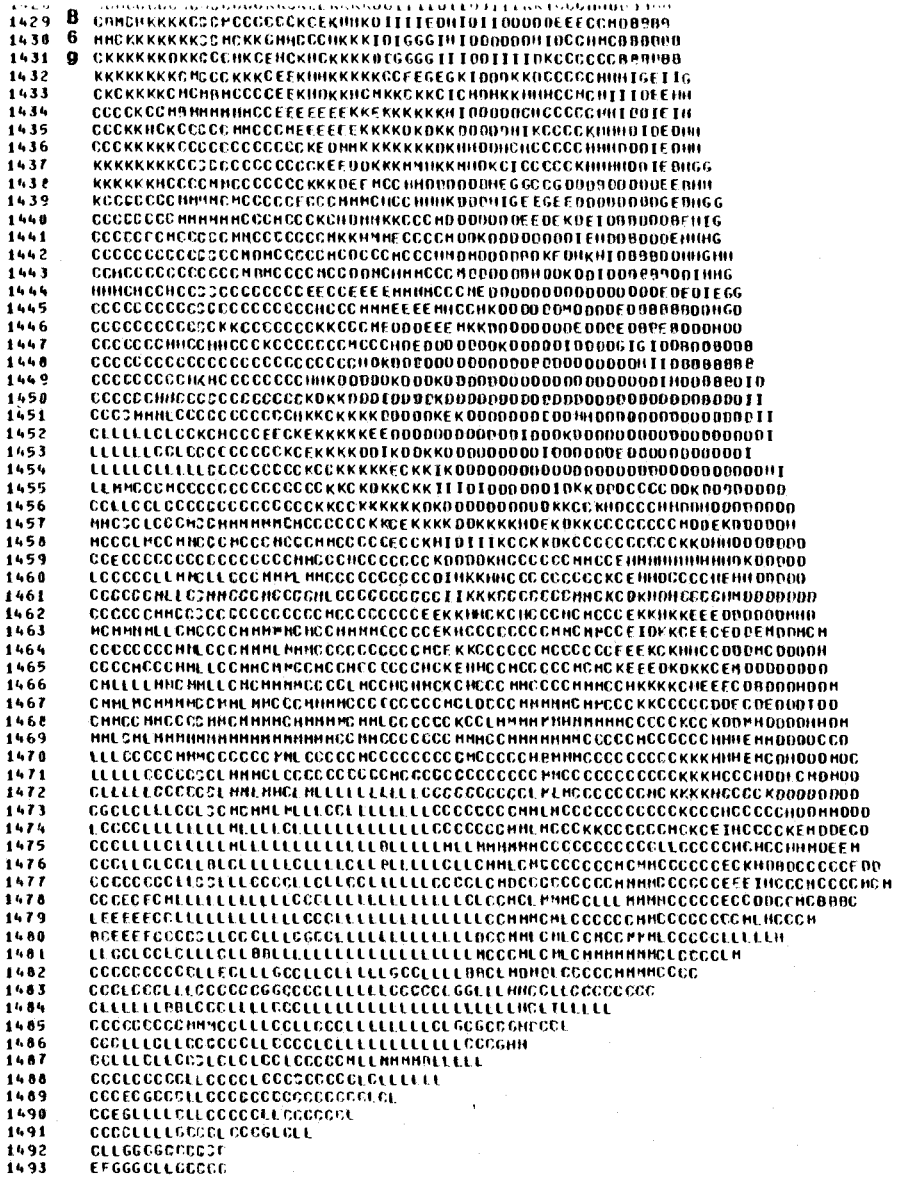












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Key To Appendix IV, 13 Fuel Type Classes

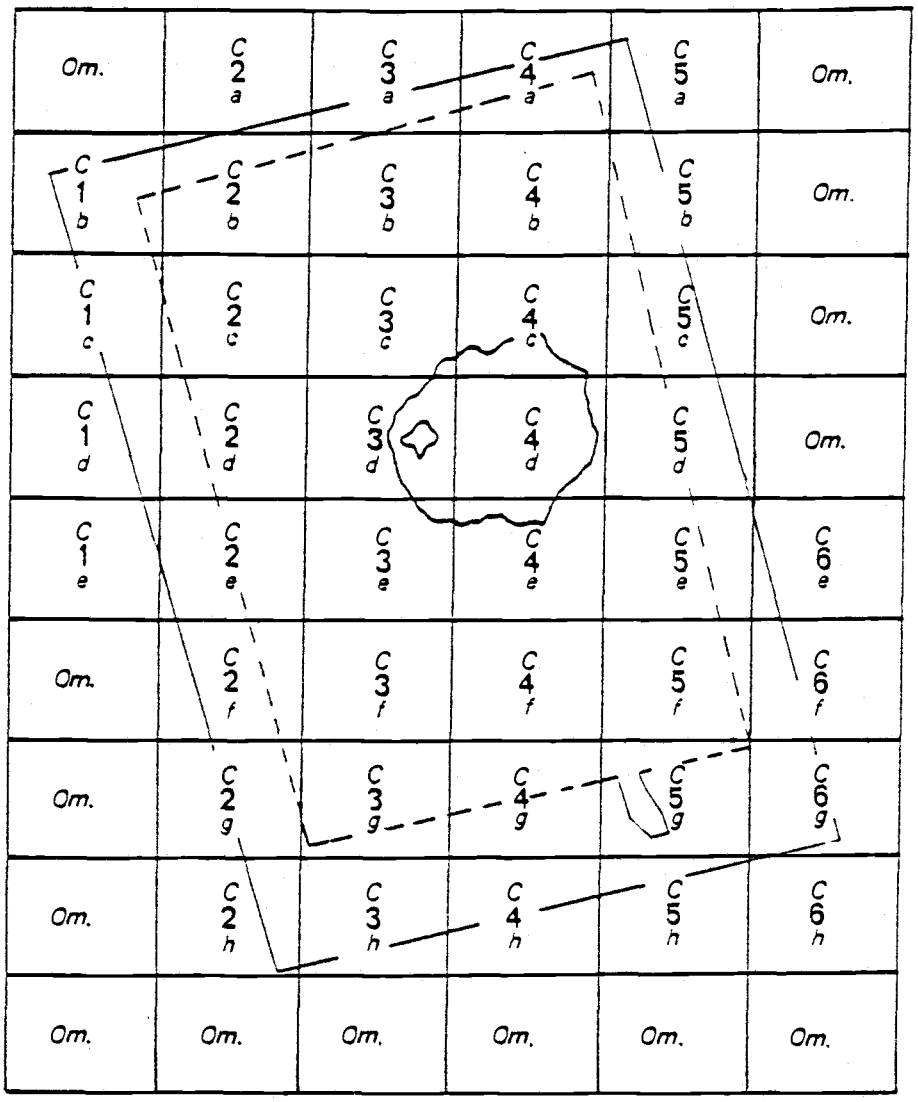
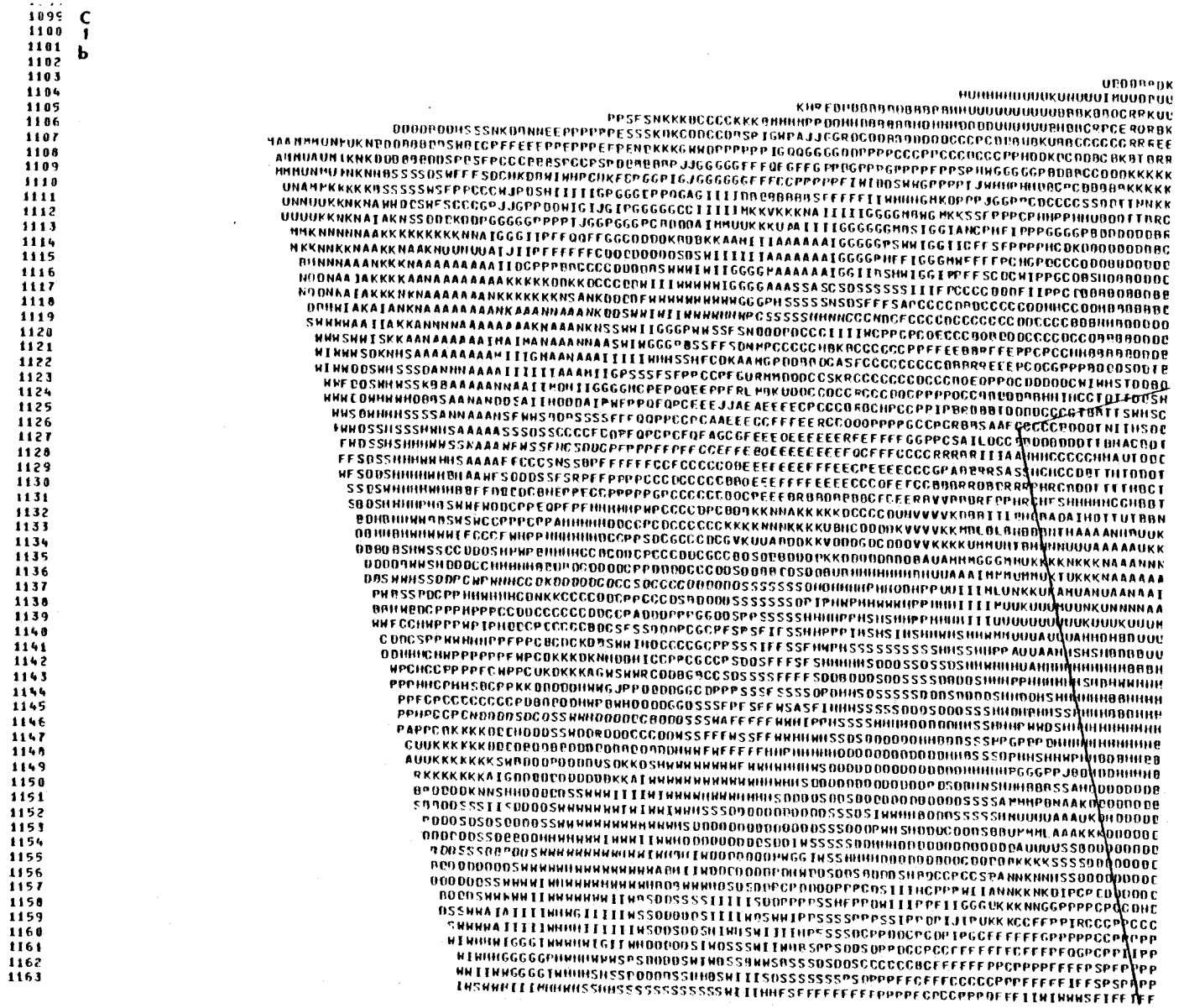
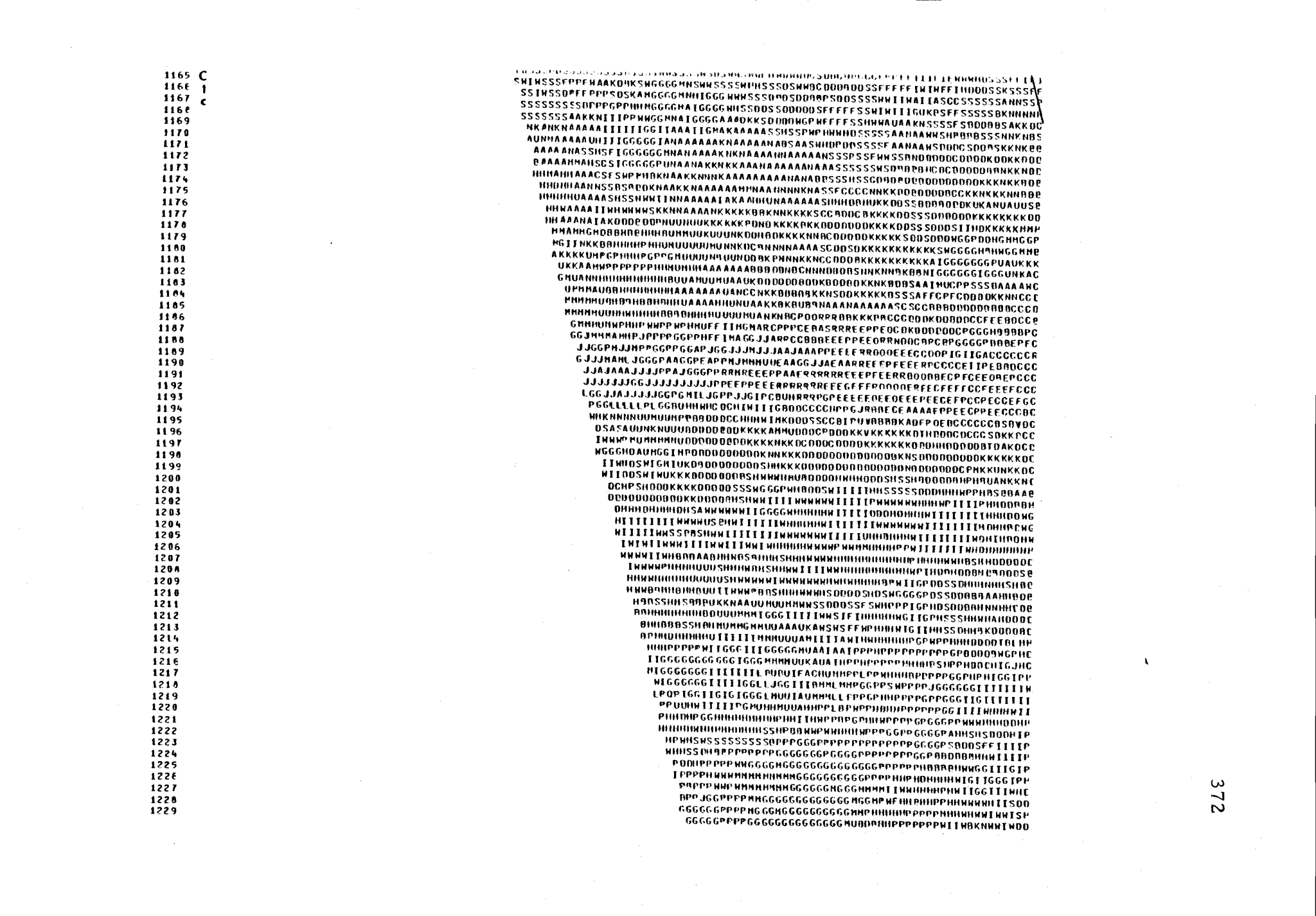


Figure 44. The outline of Crater Lake National Park and vicinity has been inserted in figure above to indicate which portions of Appendix IV cover which portion of the Park and vicinity.

--- Park boundary, —— Spectral / Topographic data boundary, Om. Omitted.



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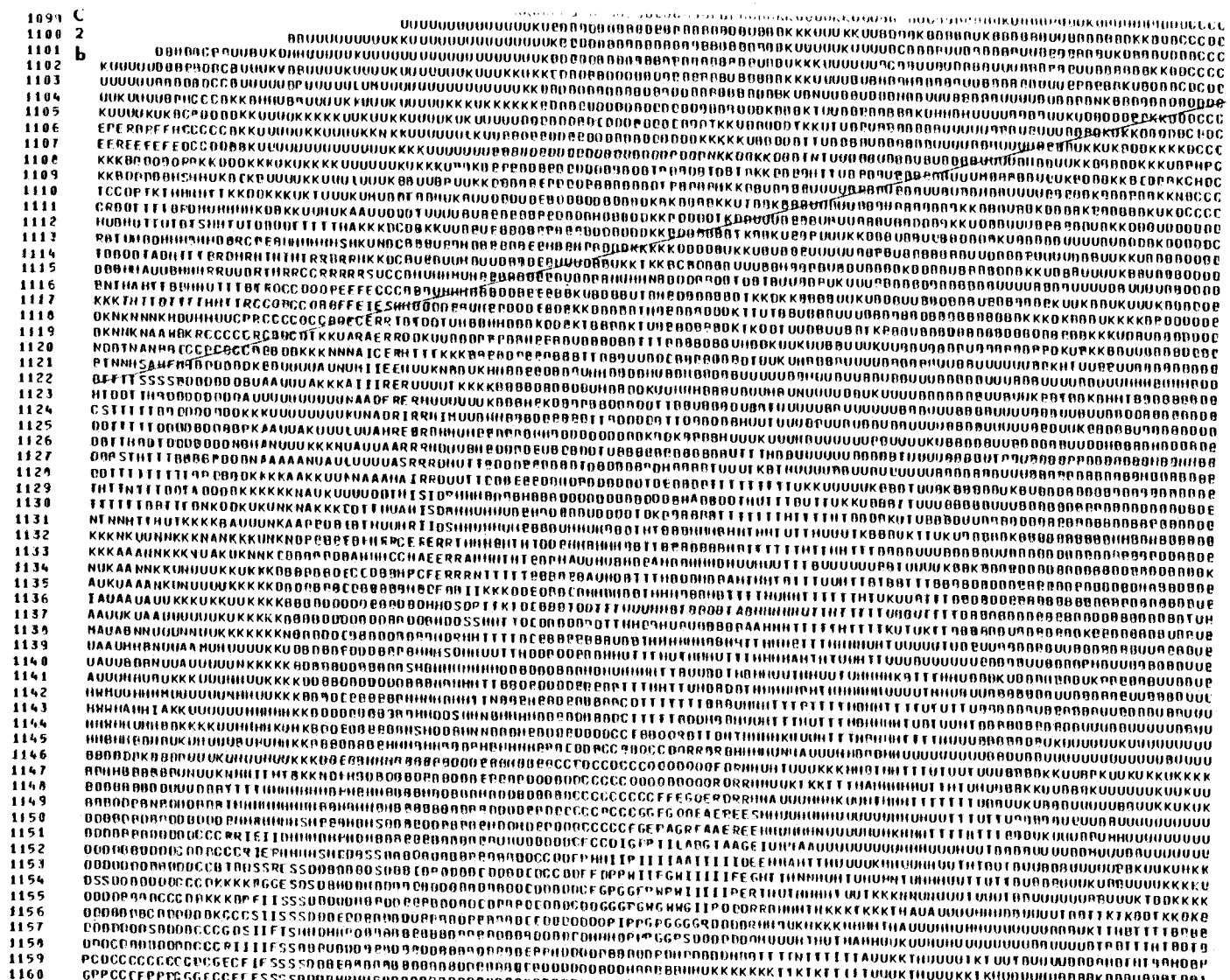

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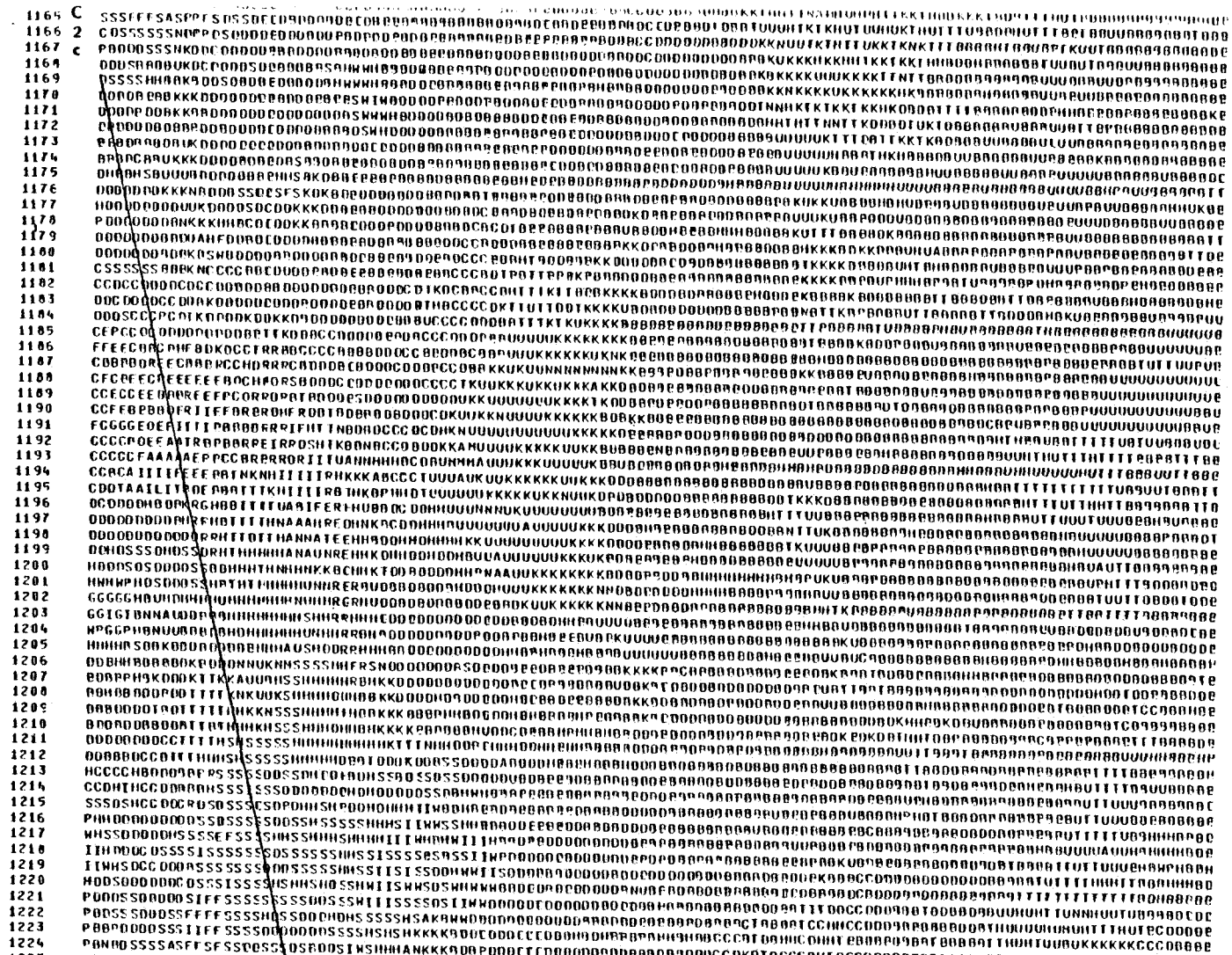
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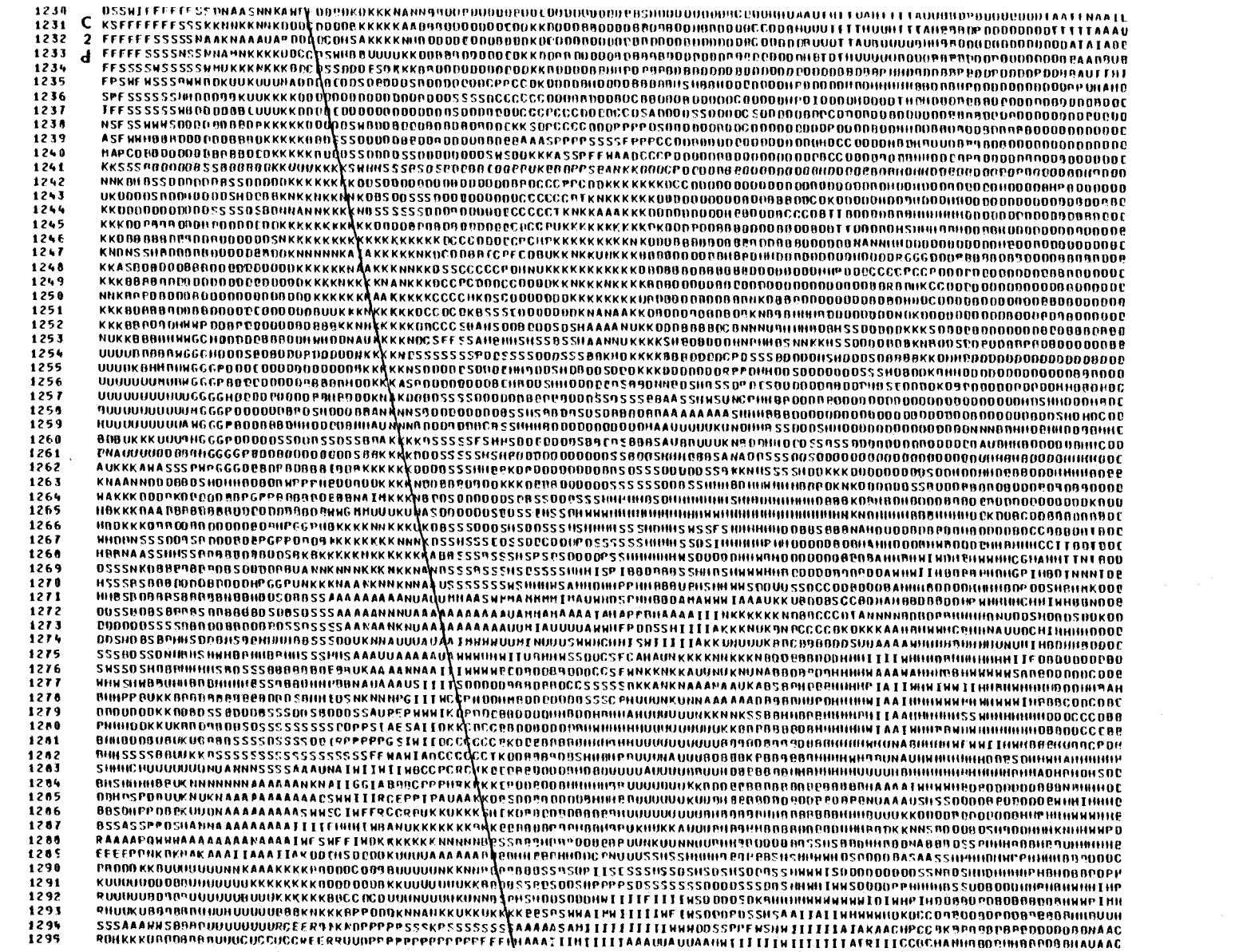
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IIFIWDHHWIFFDD
AIIIFBDDWIFFFD
IIWHDDDWIFFIS
IIIDDDDFFFIII
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PPFFSSSSSSA
SPFPPSSFDSA
NDDDSSFPPF
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AAFFWFFFF
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SIGGGGP
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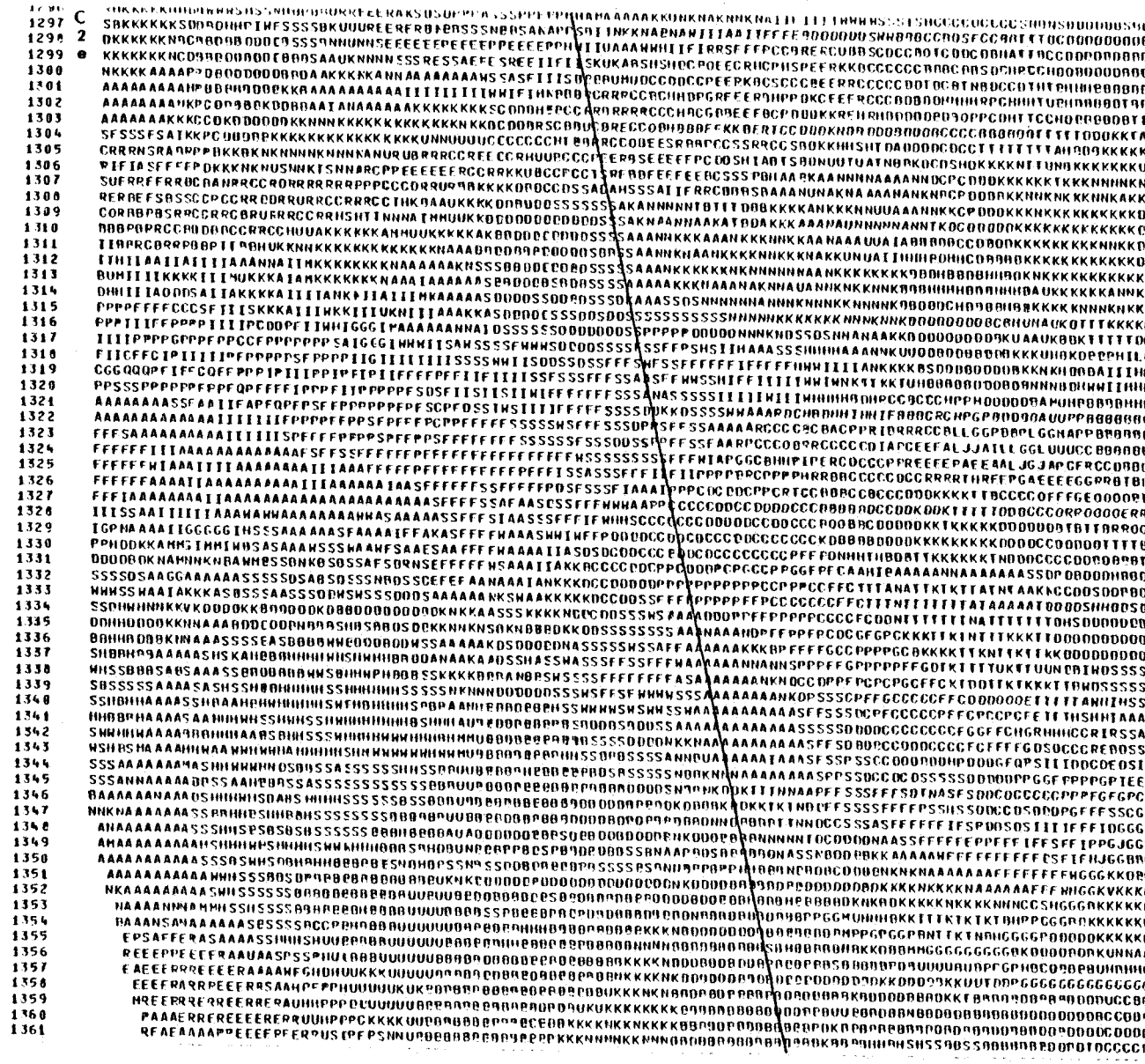
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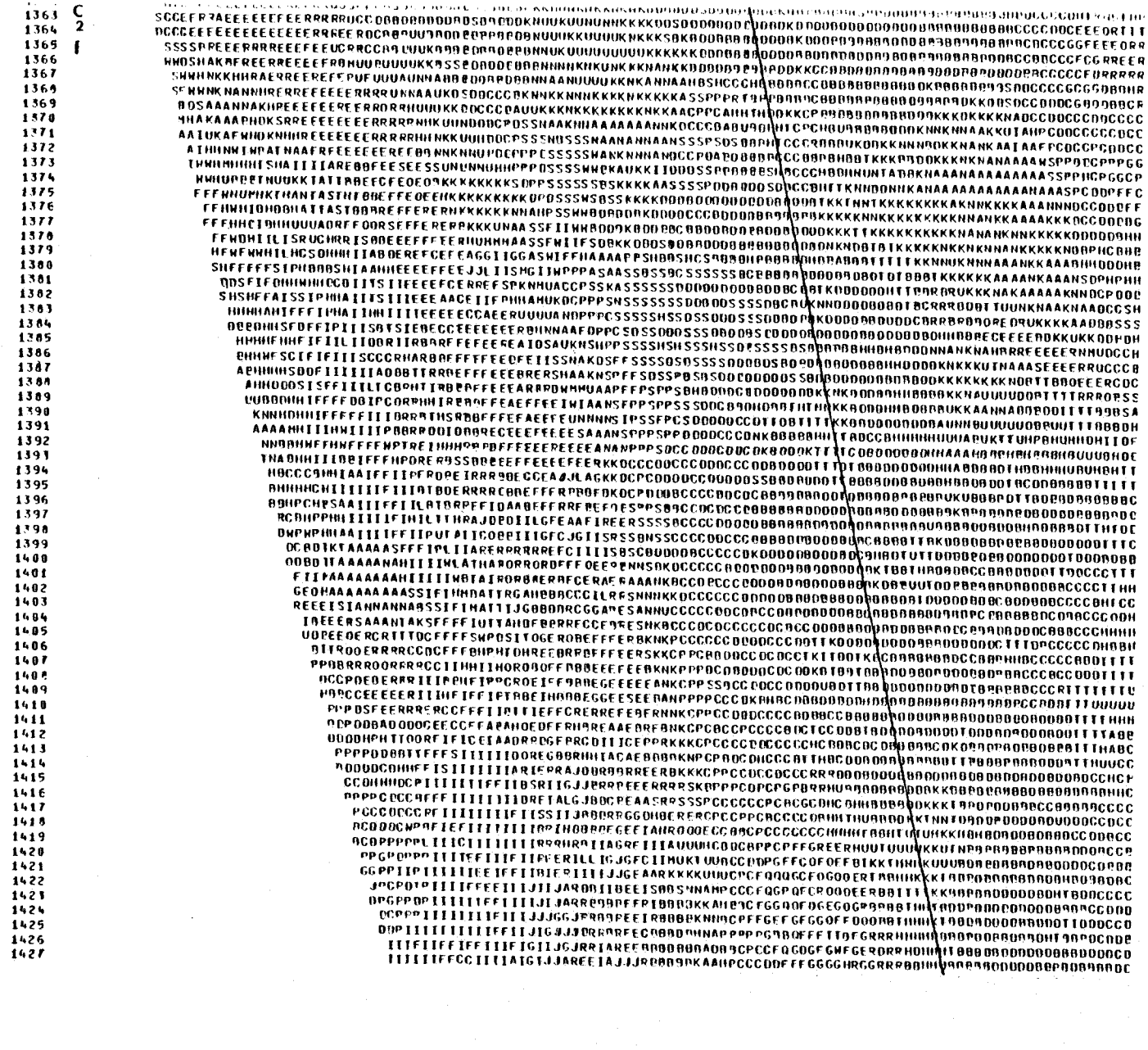


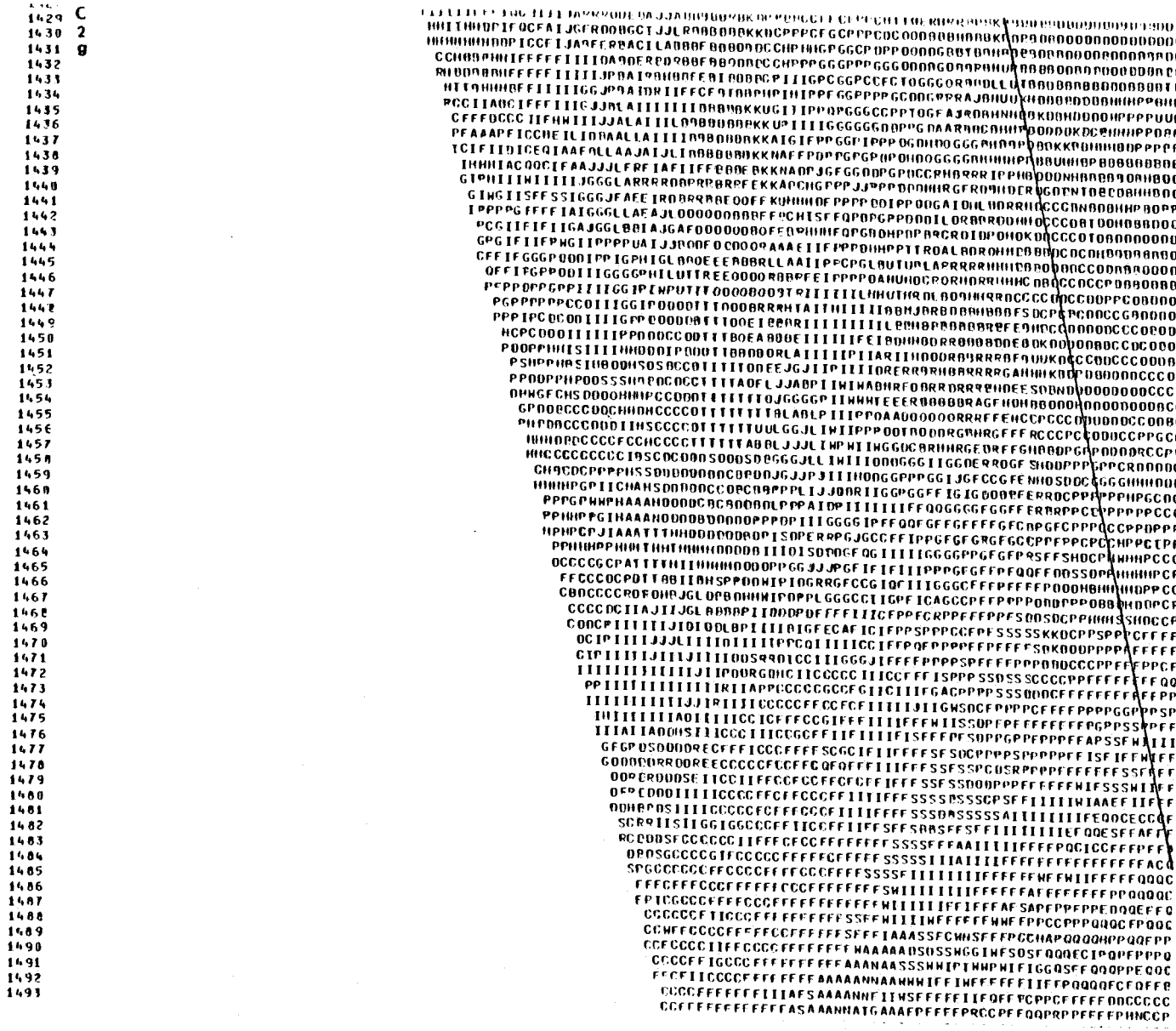




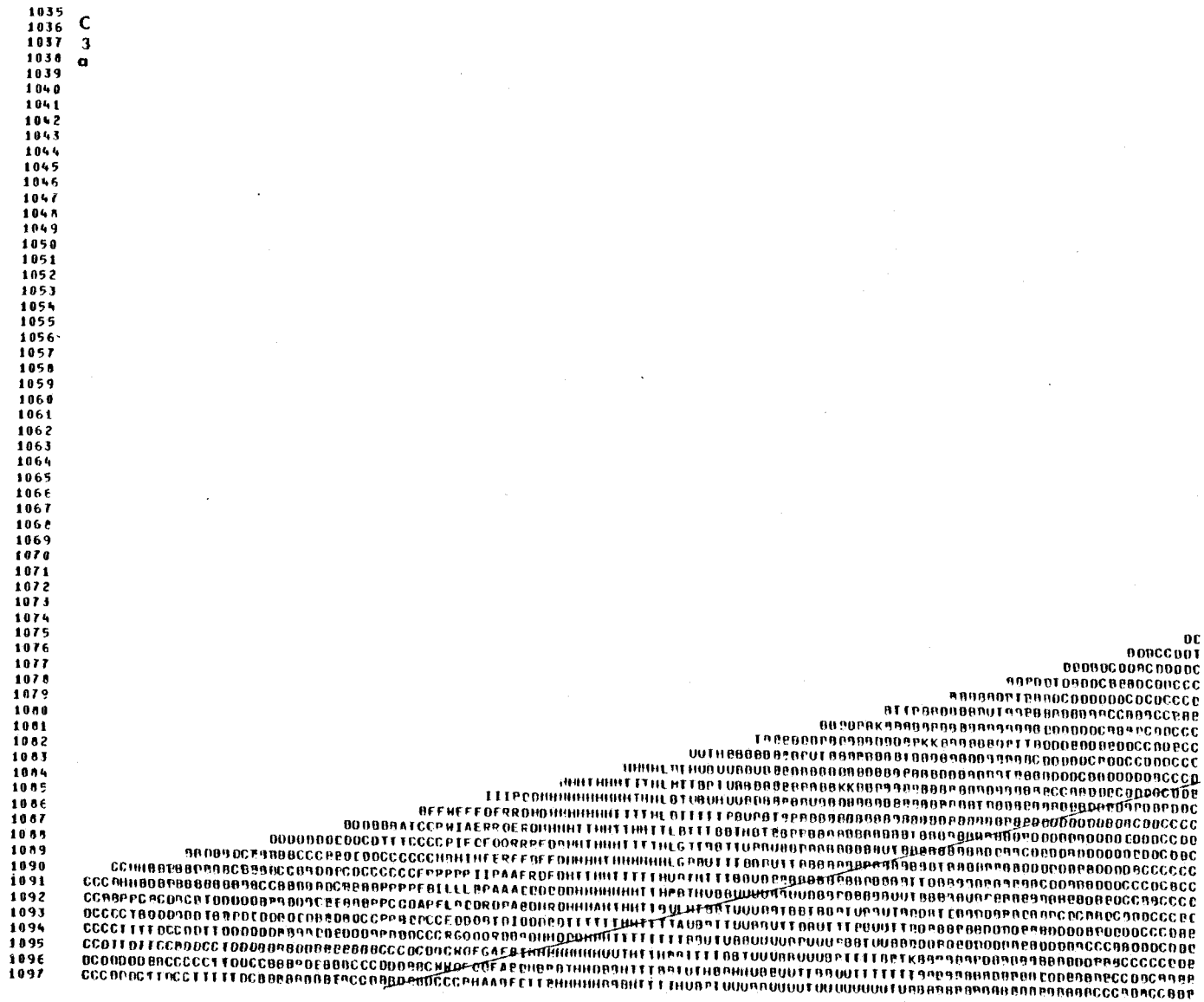


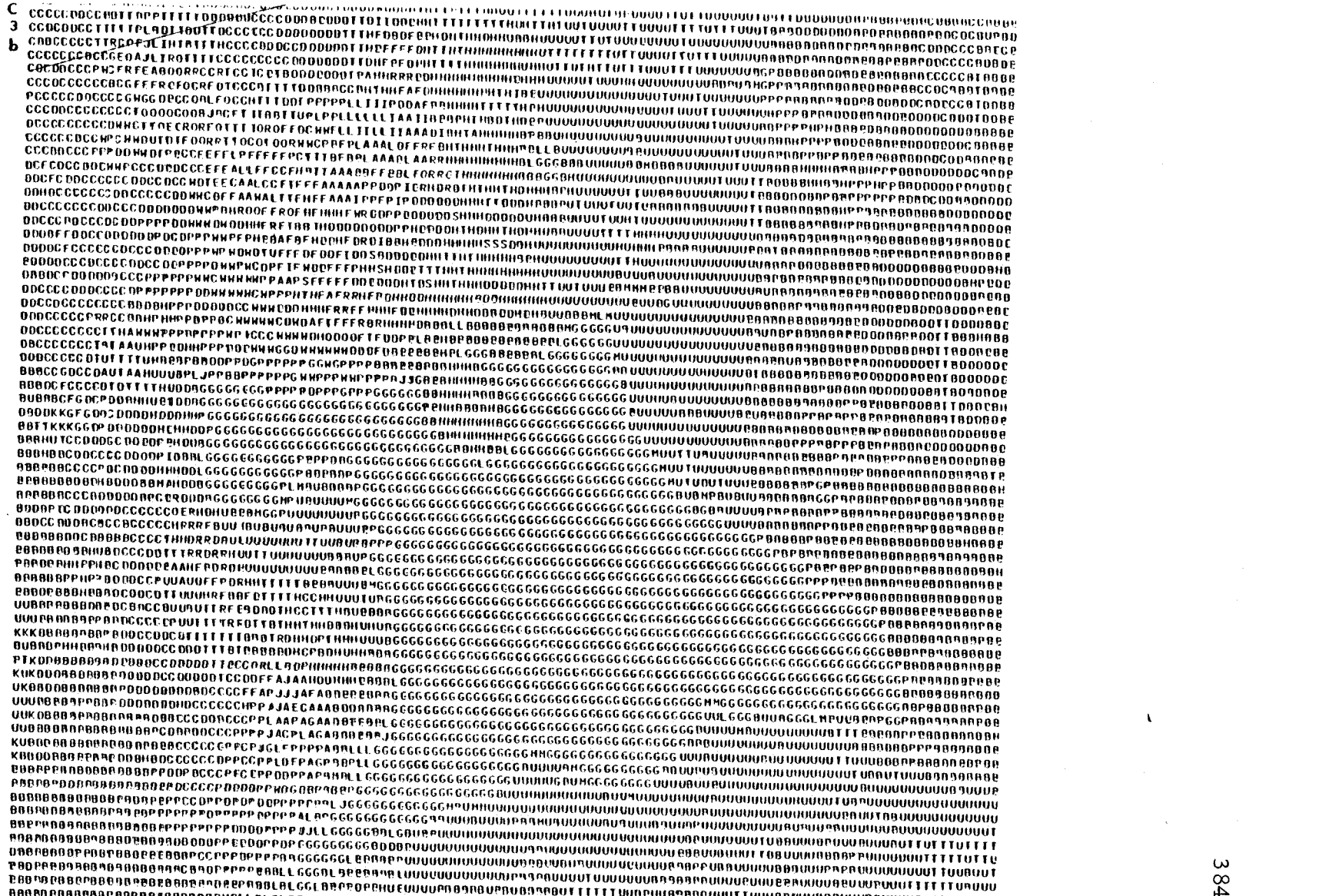


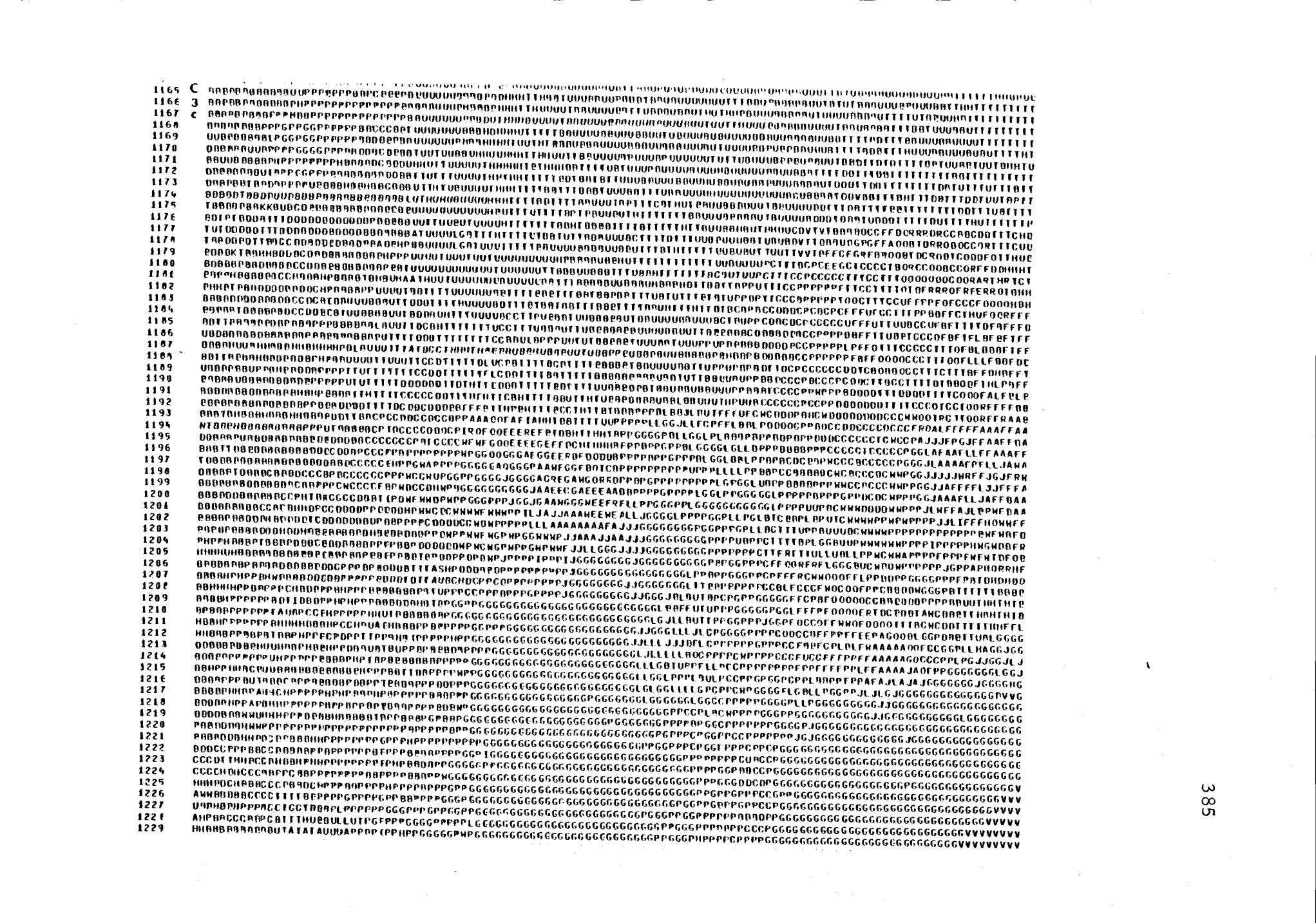


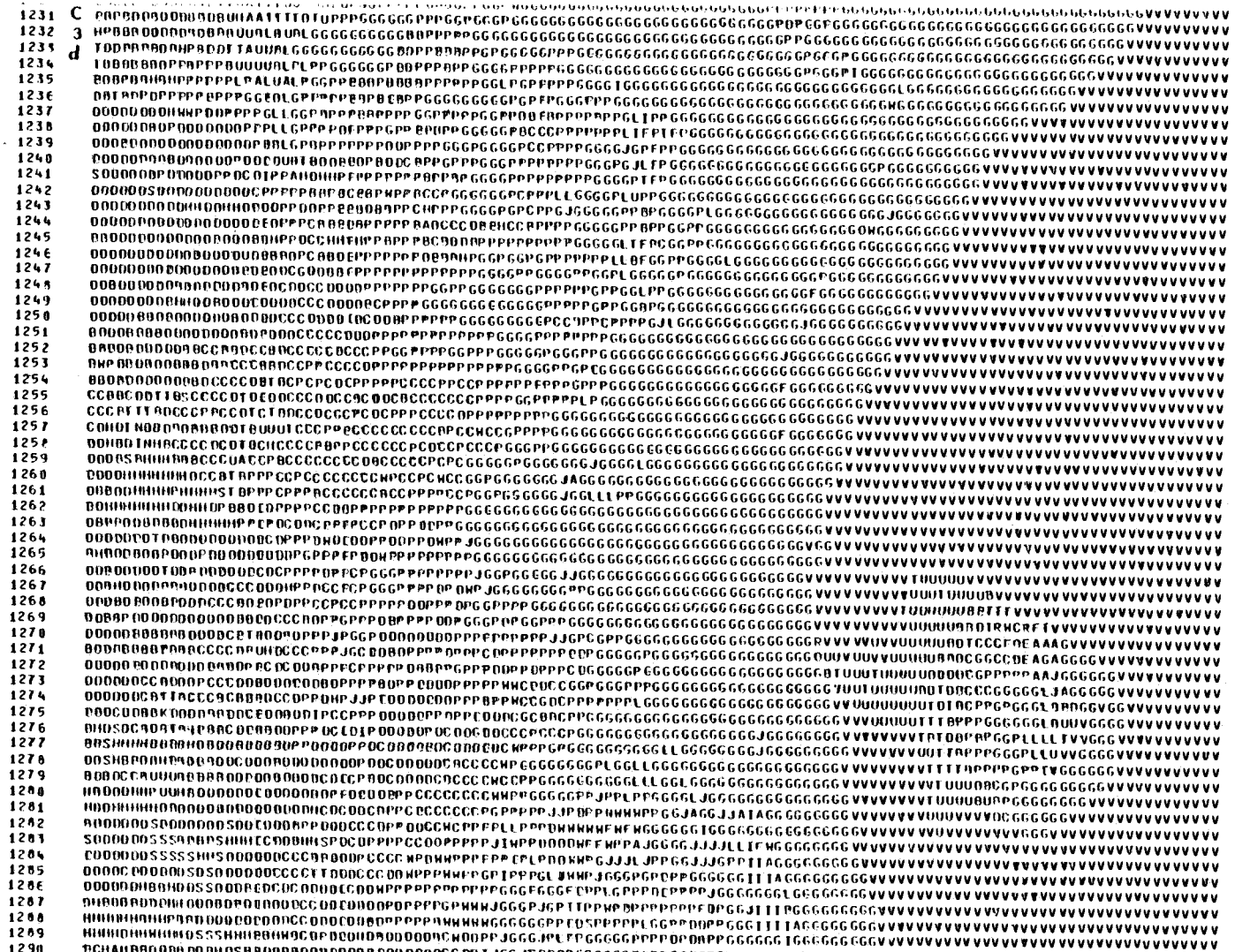


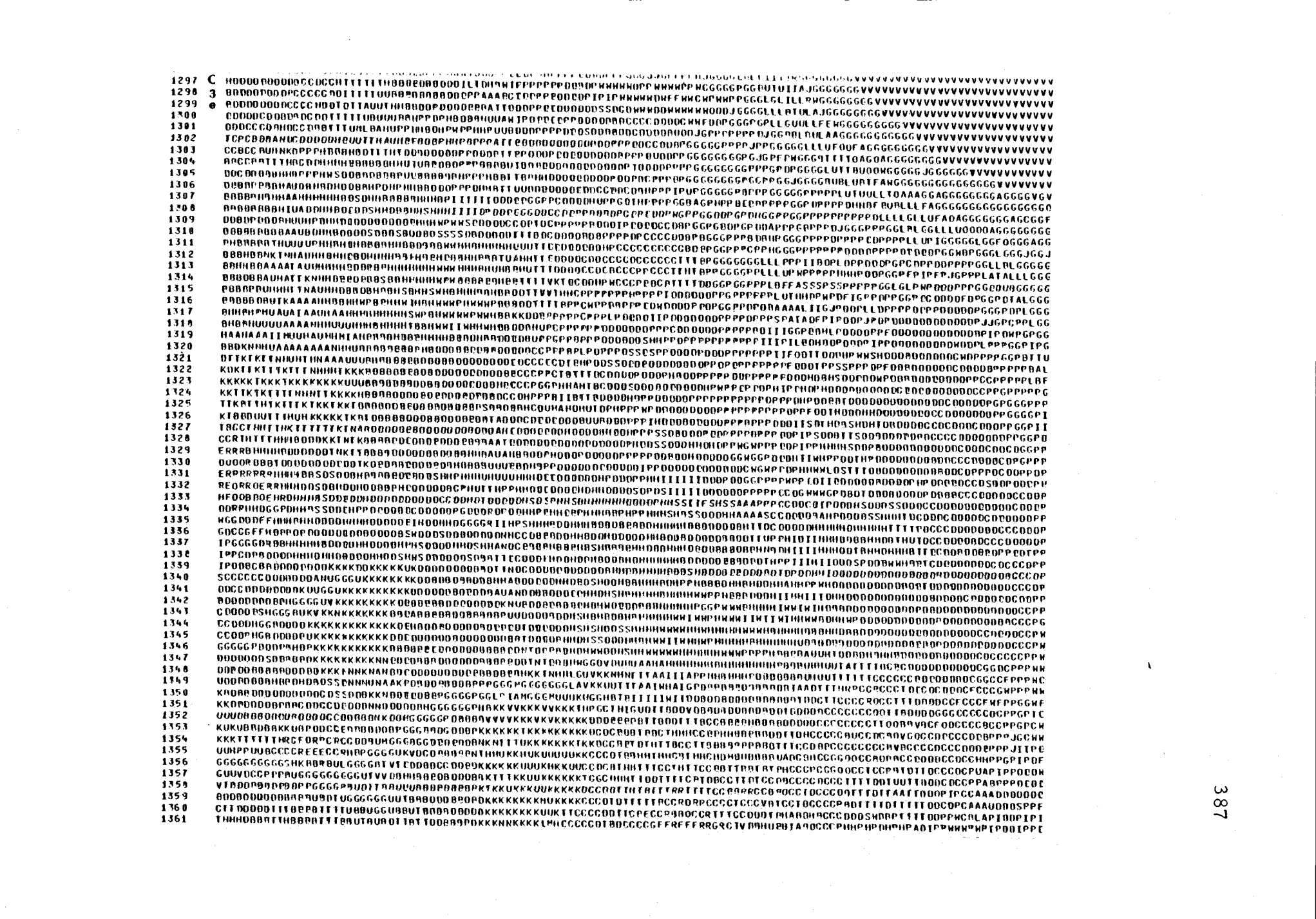


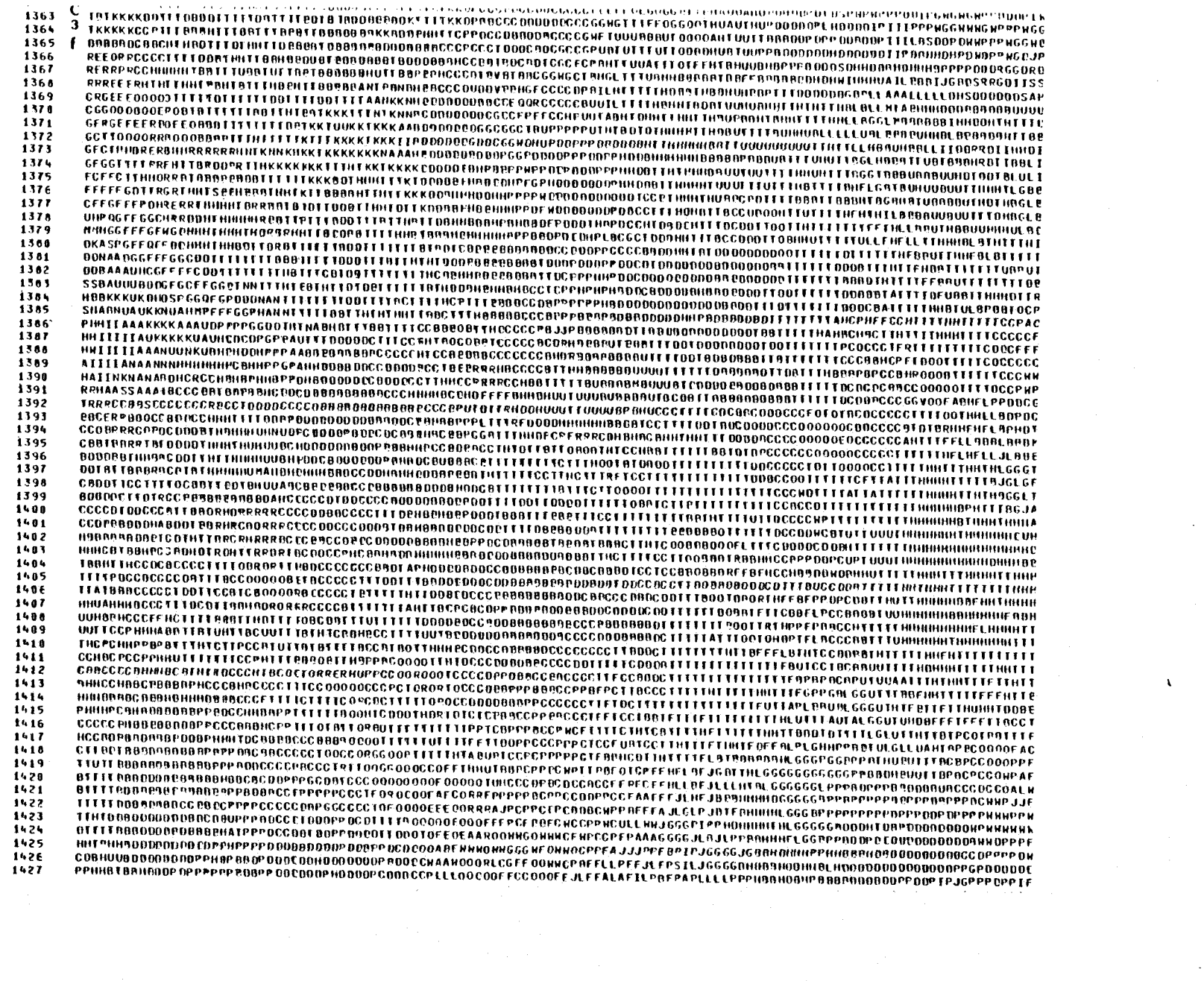


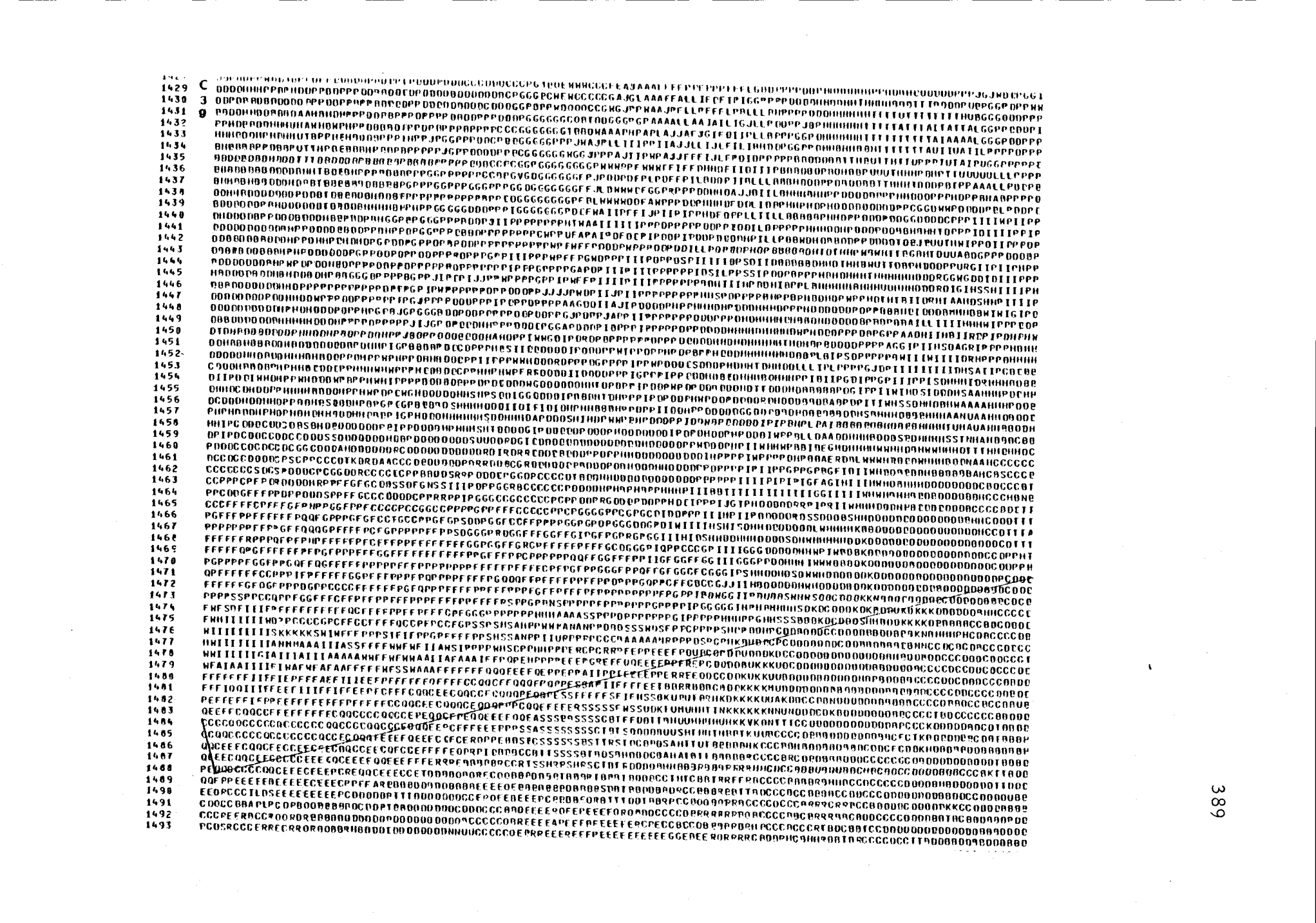


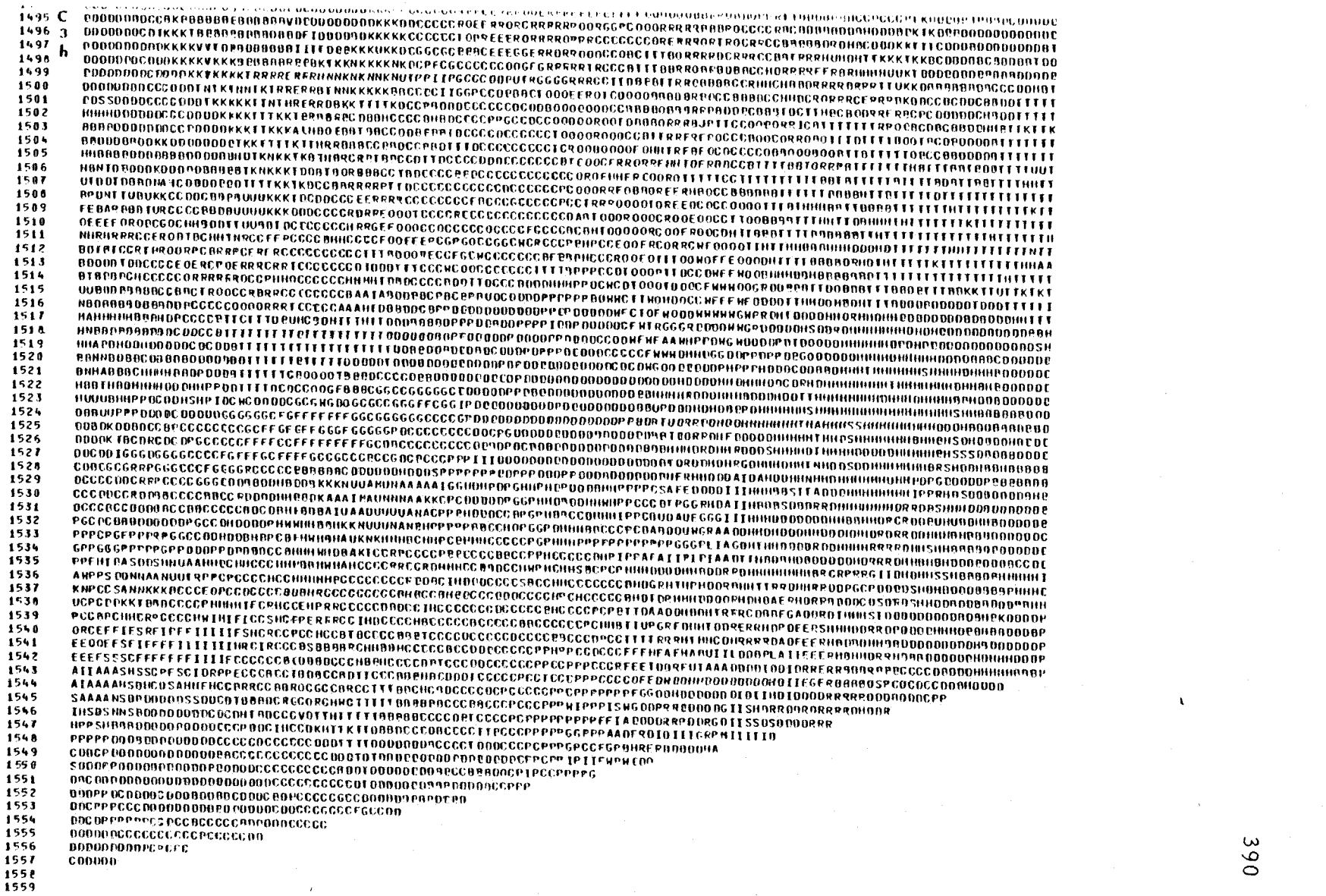


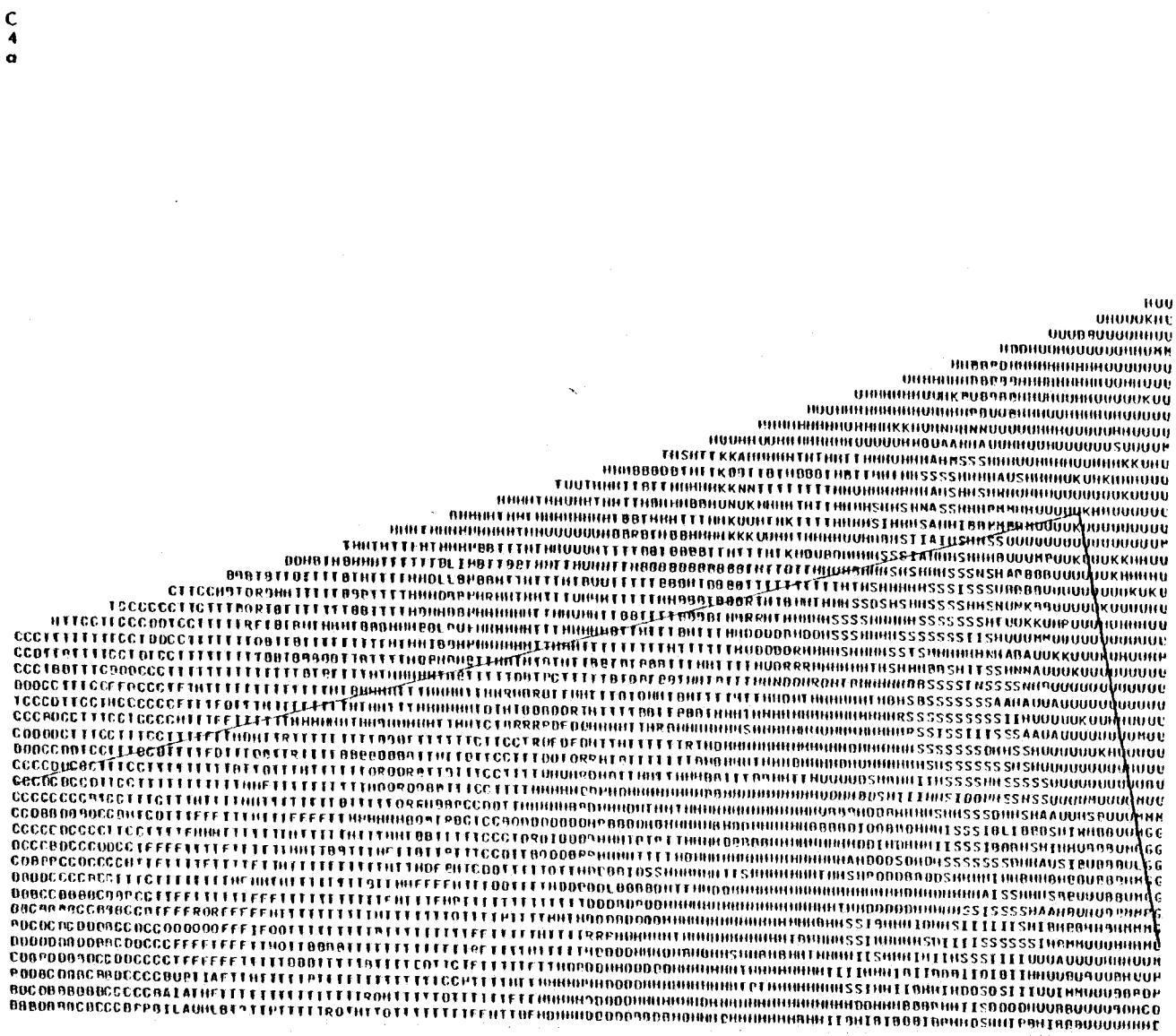


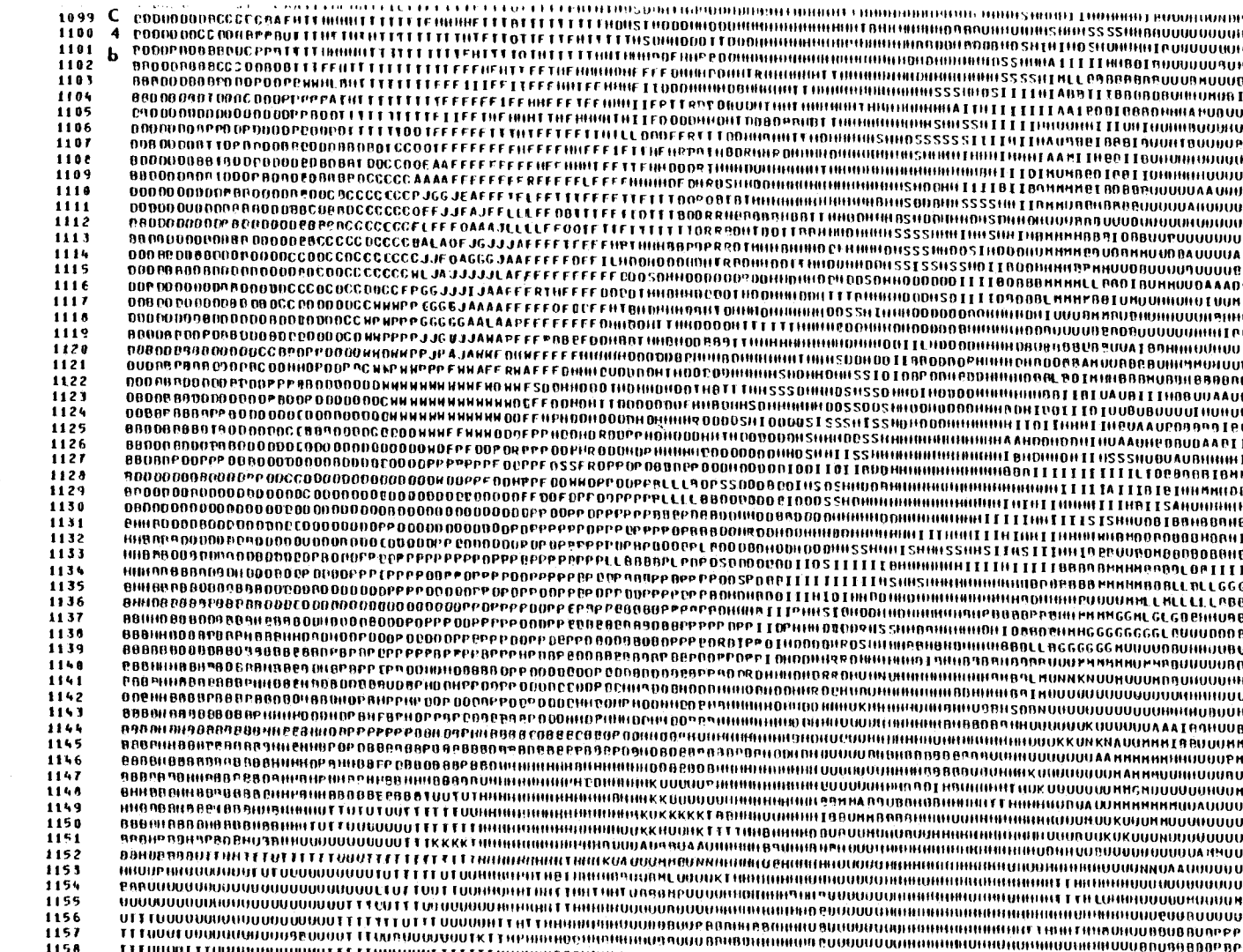


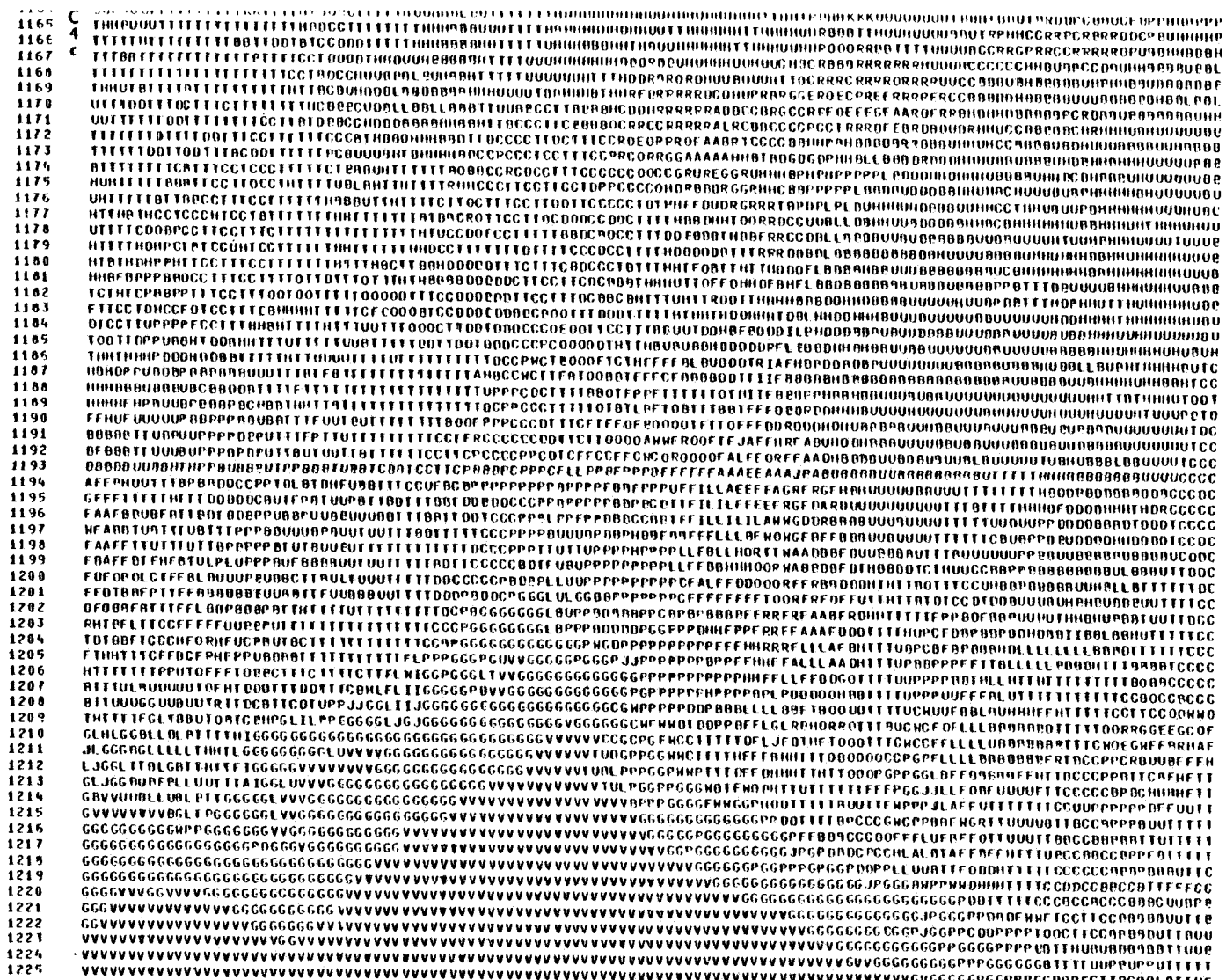


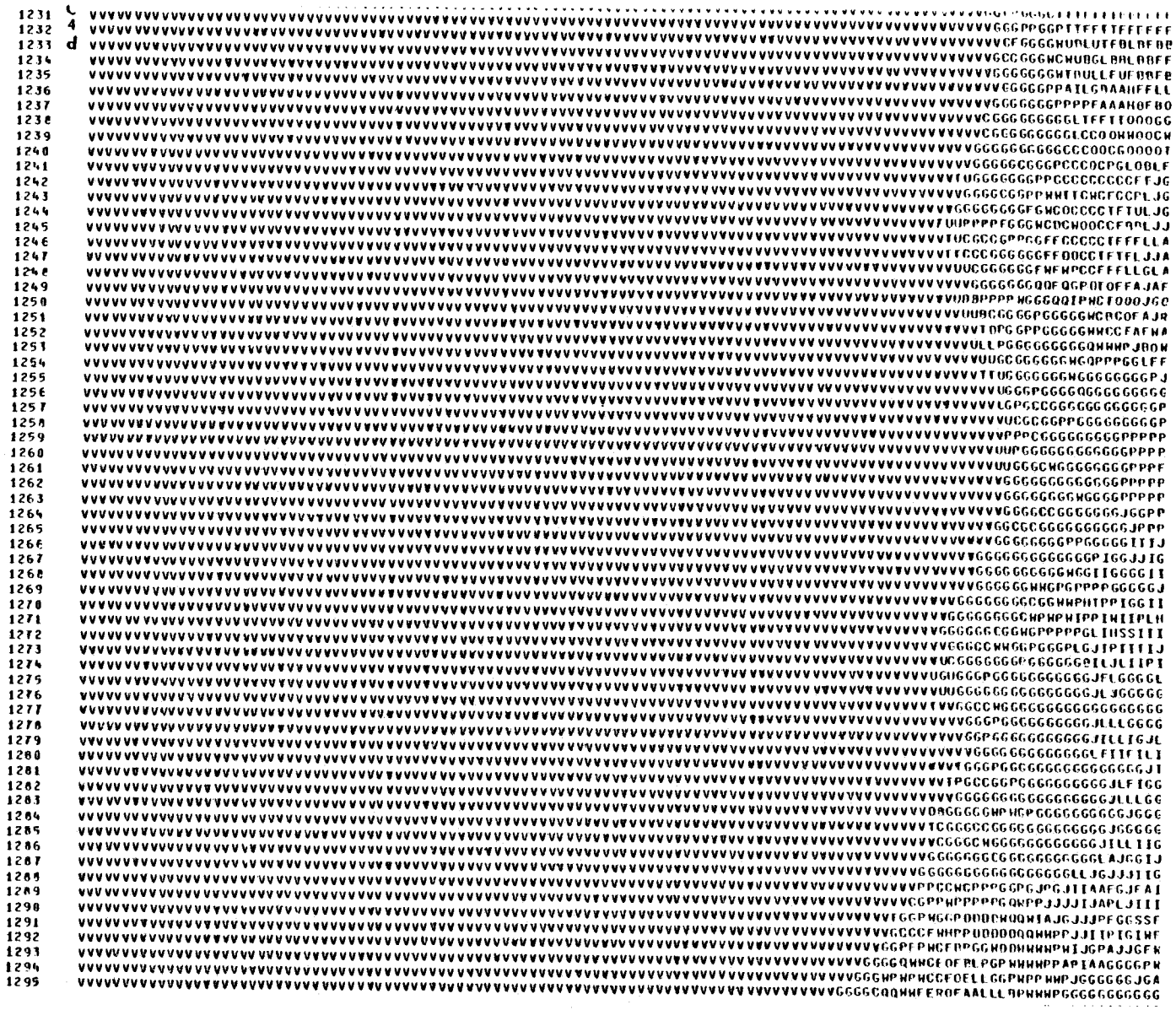




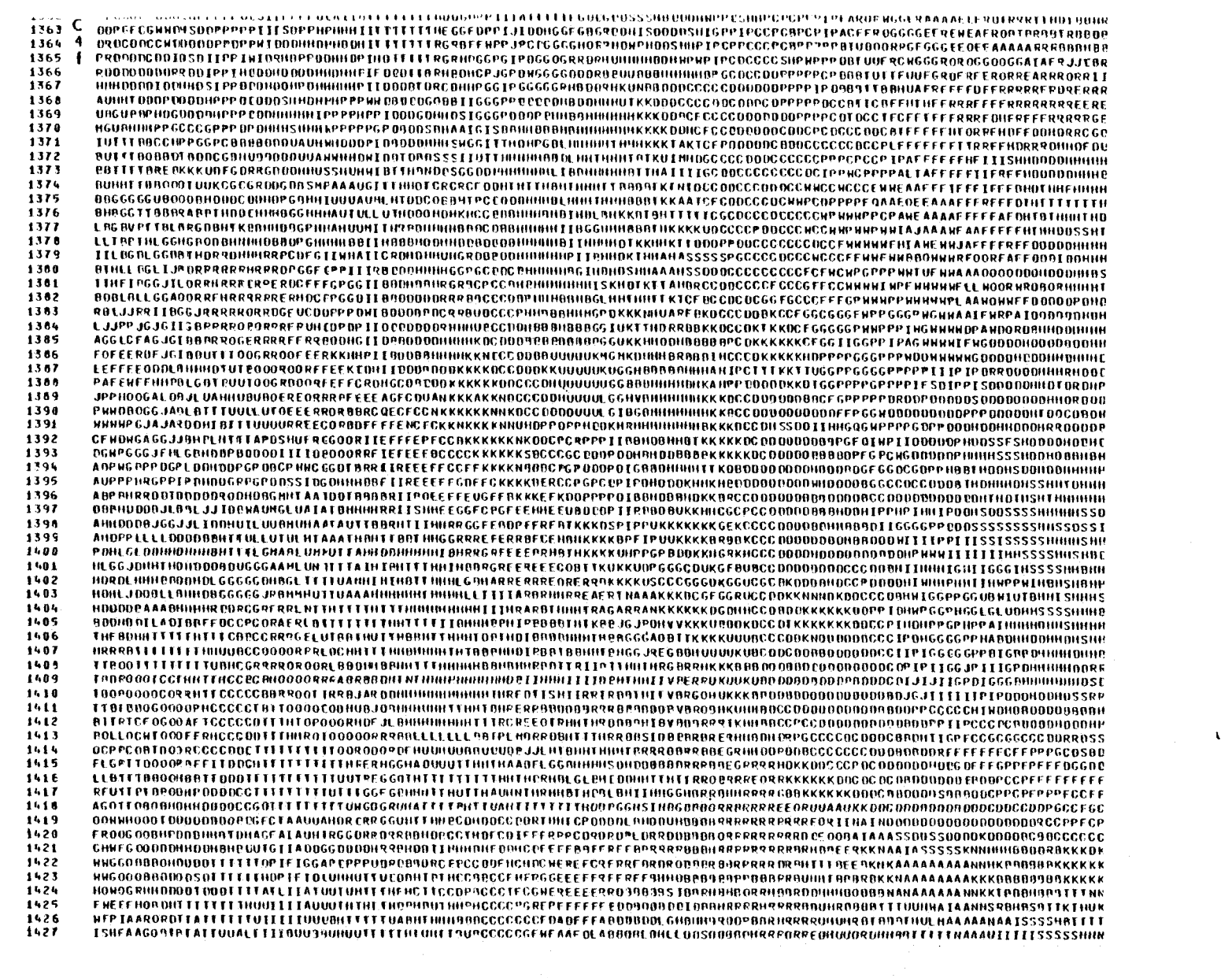






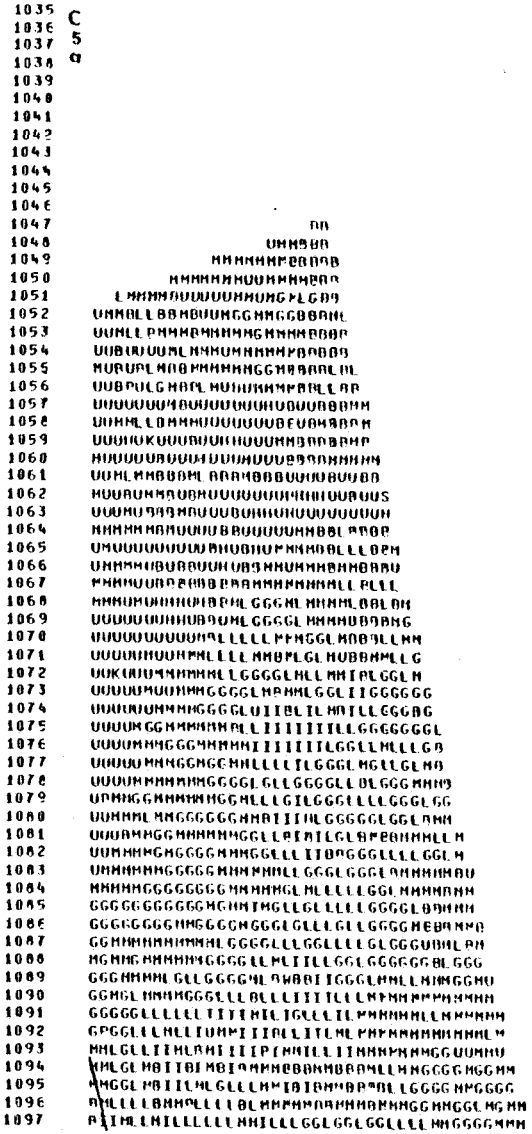


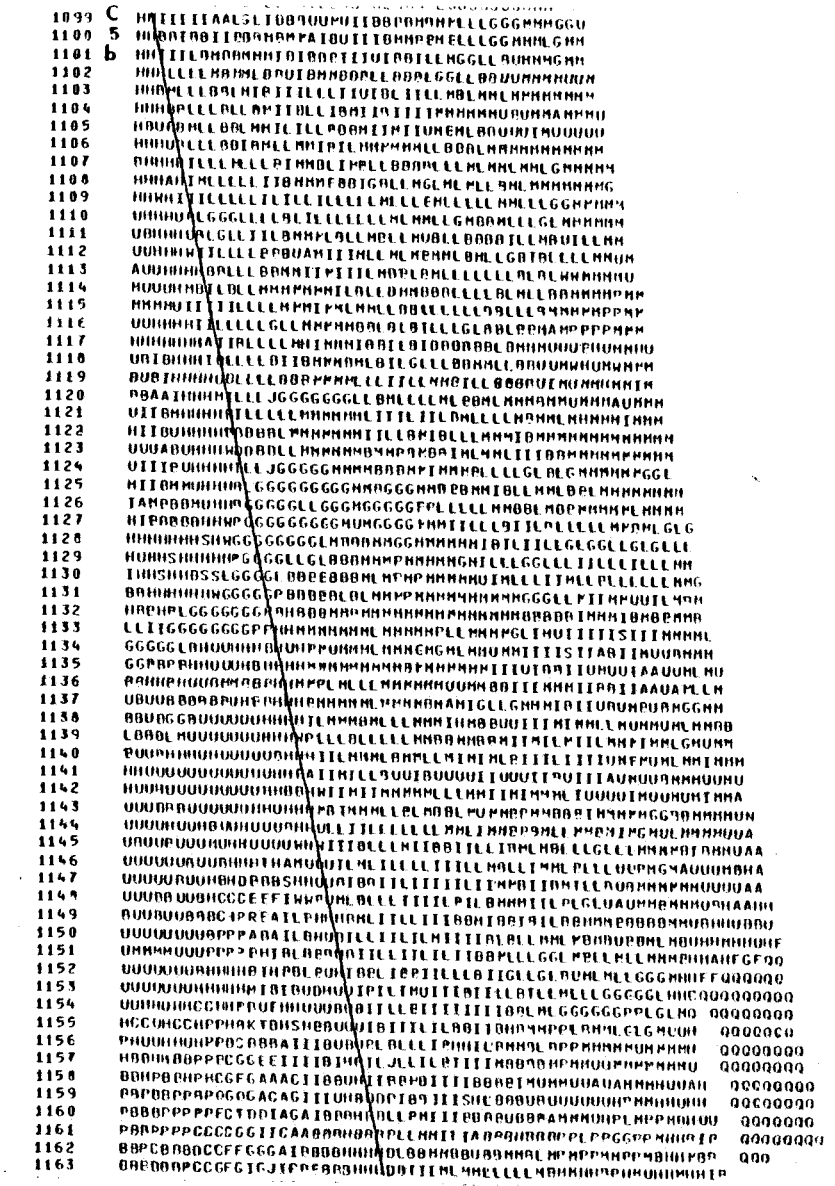


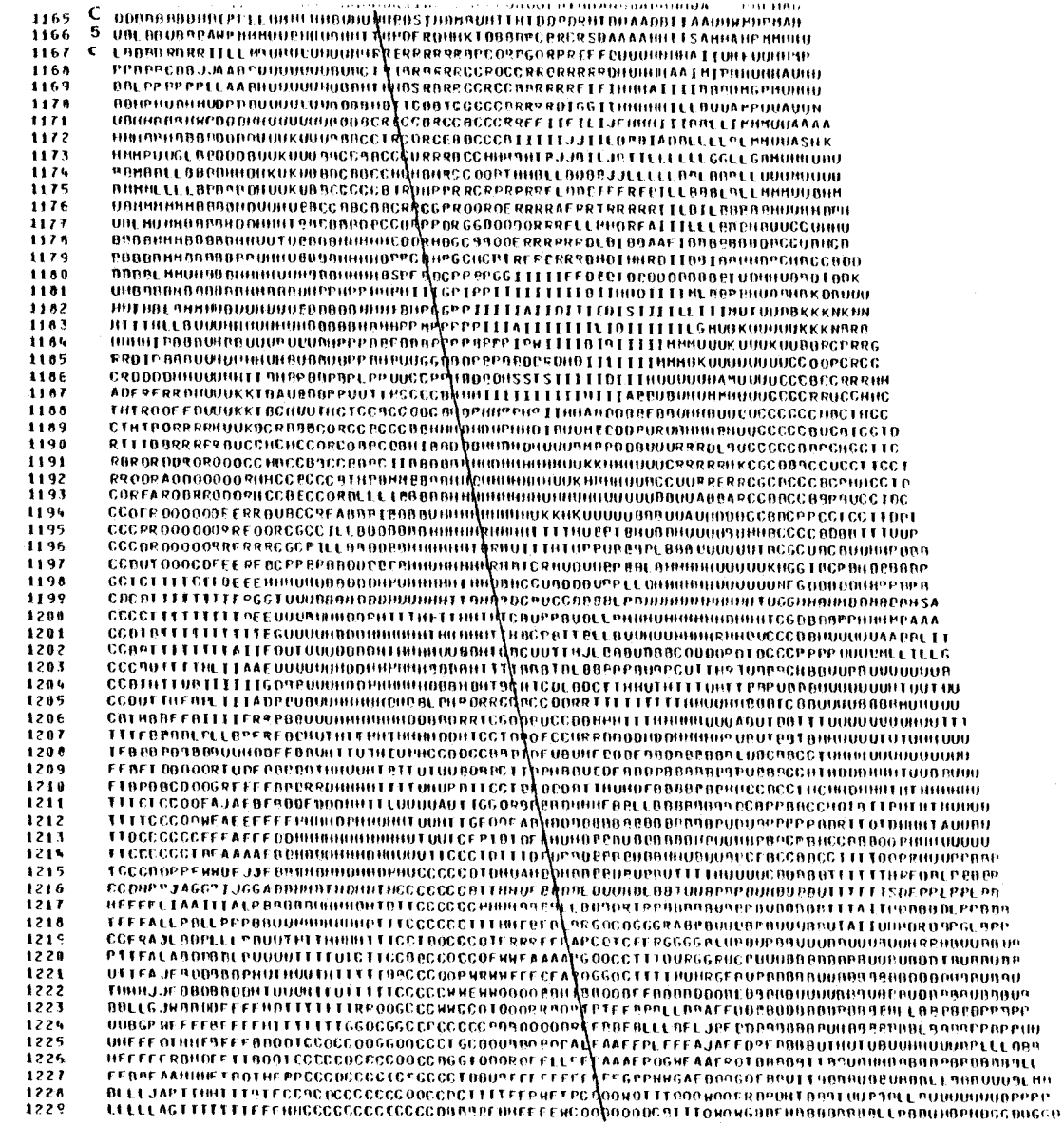


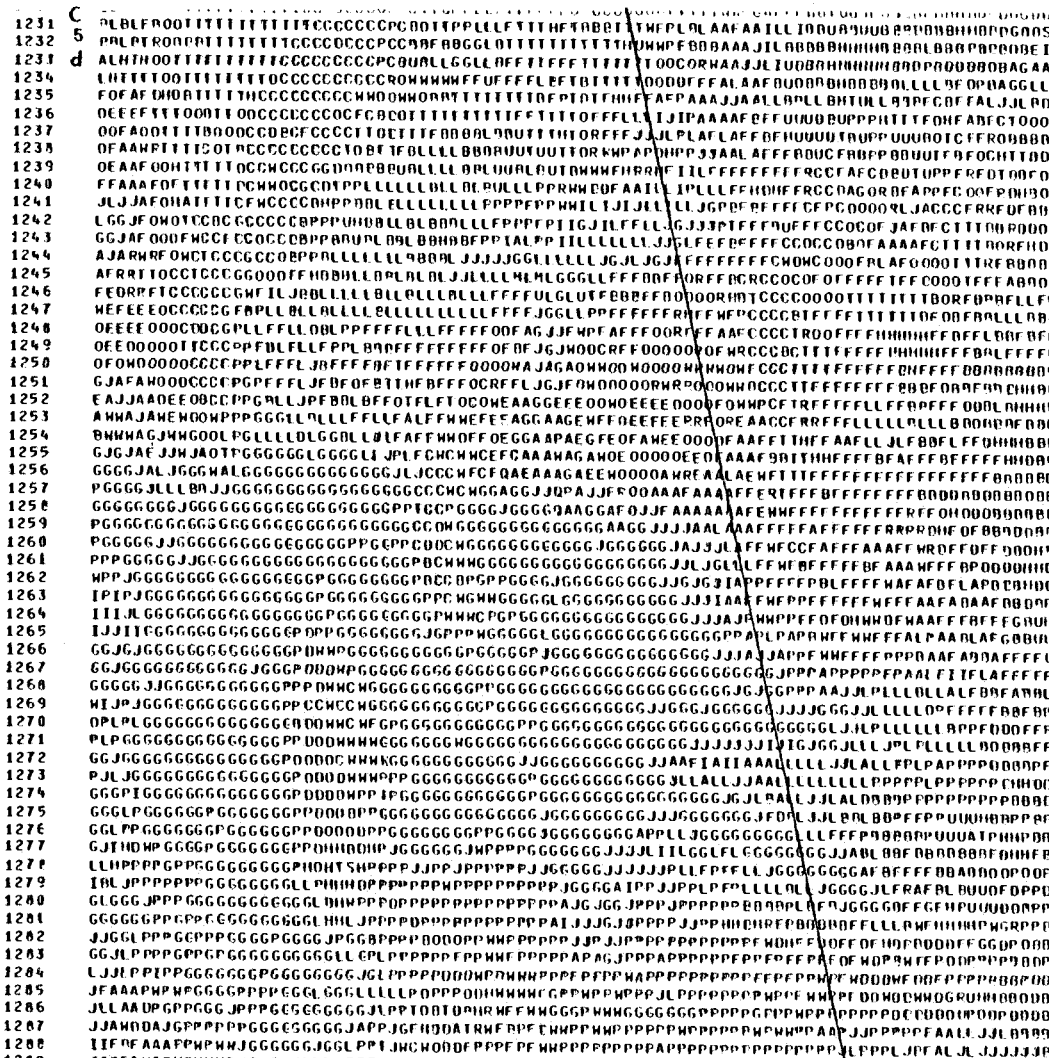


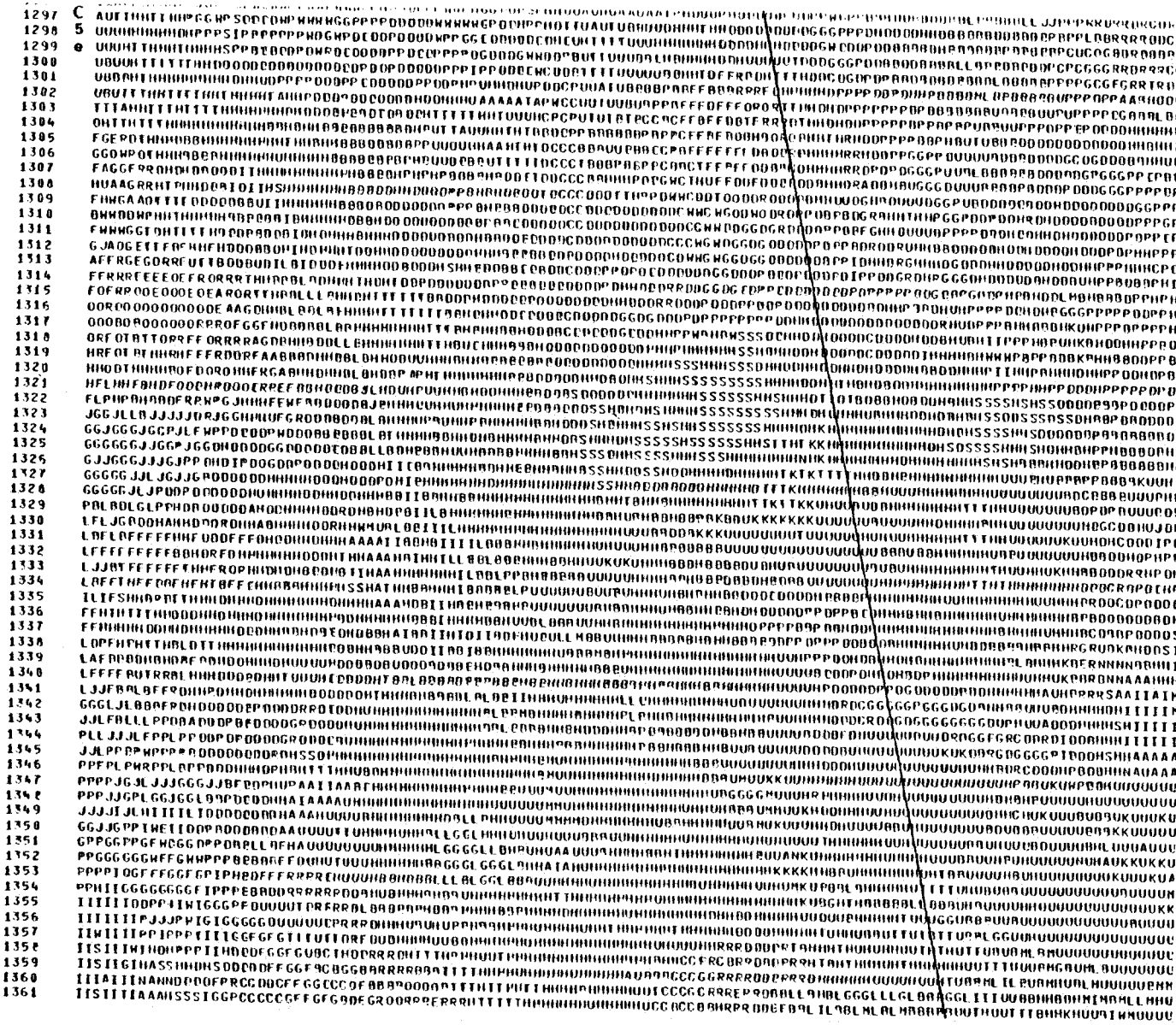


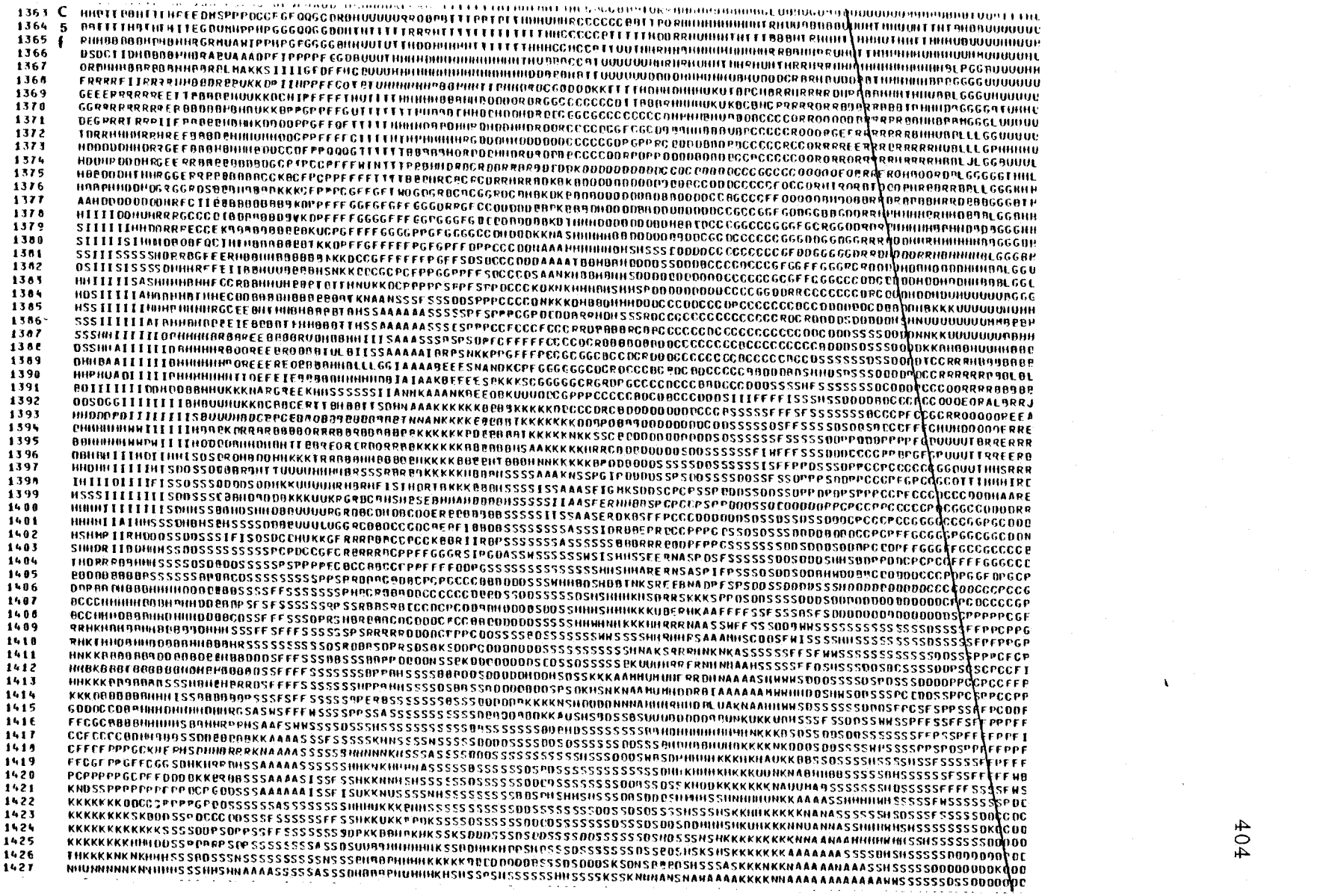


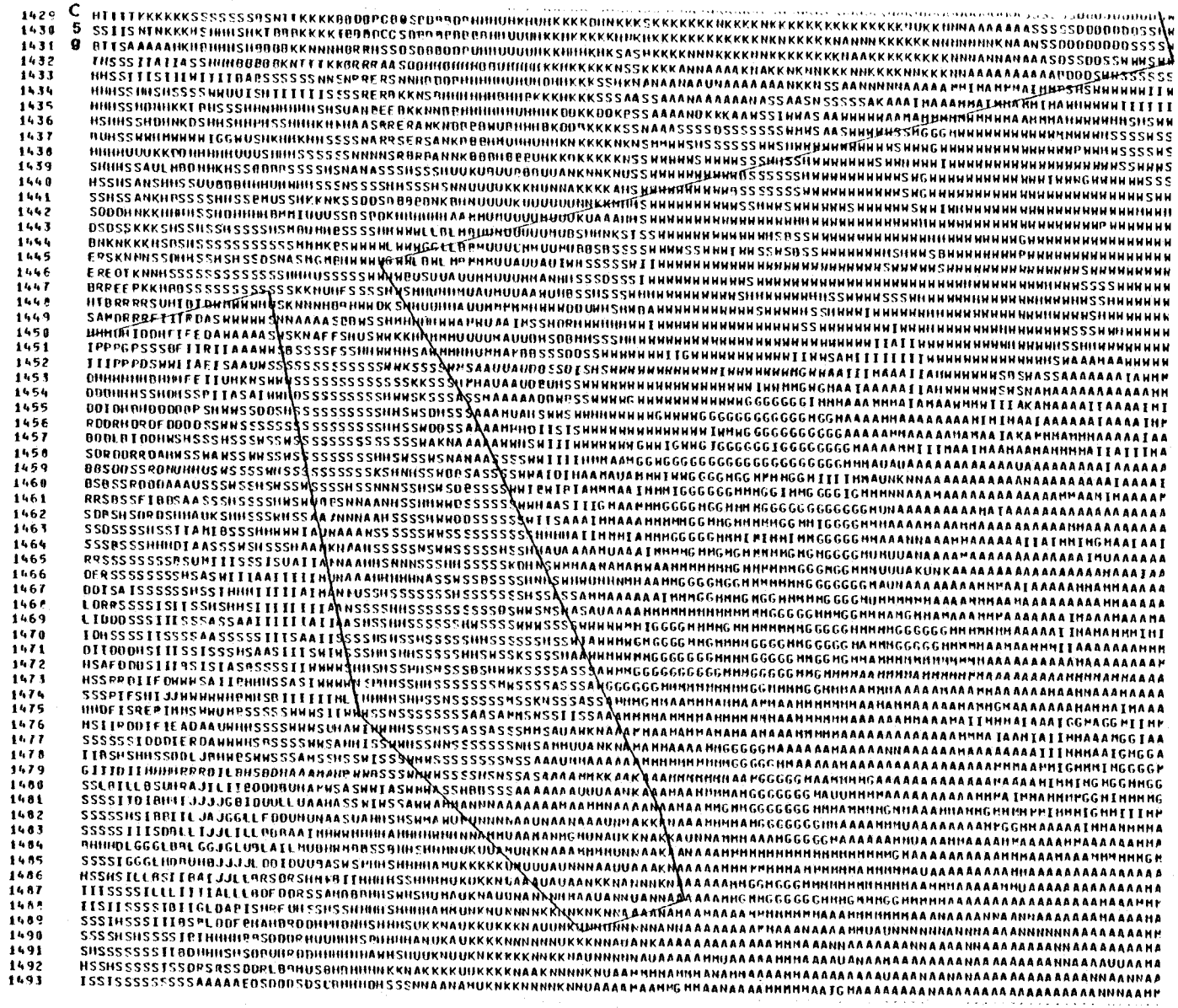


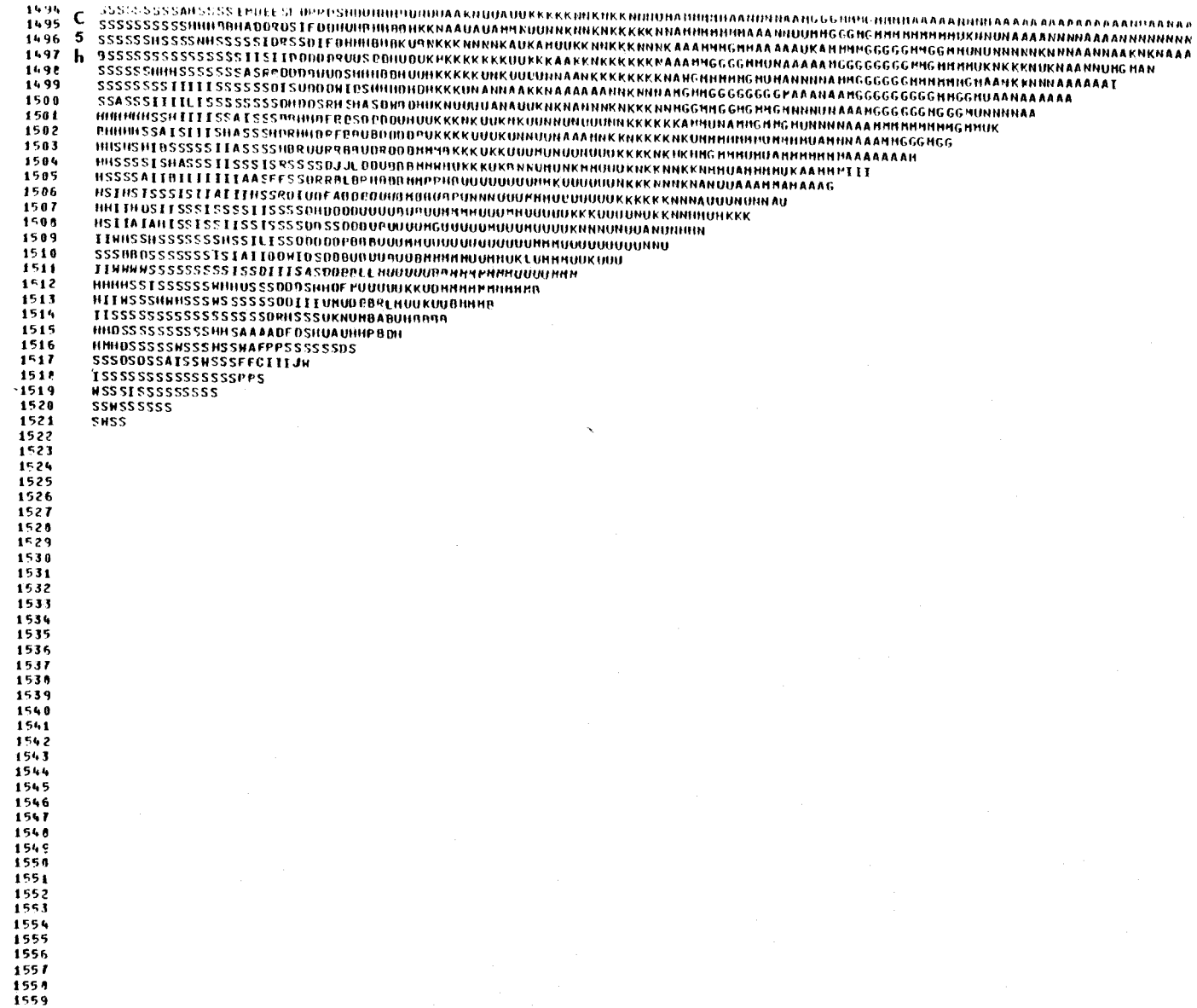


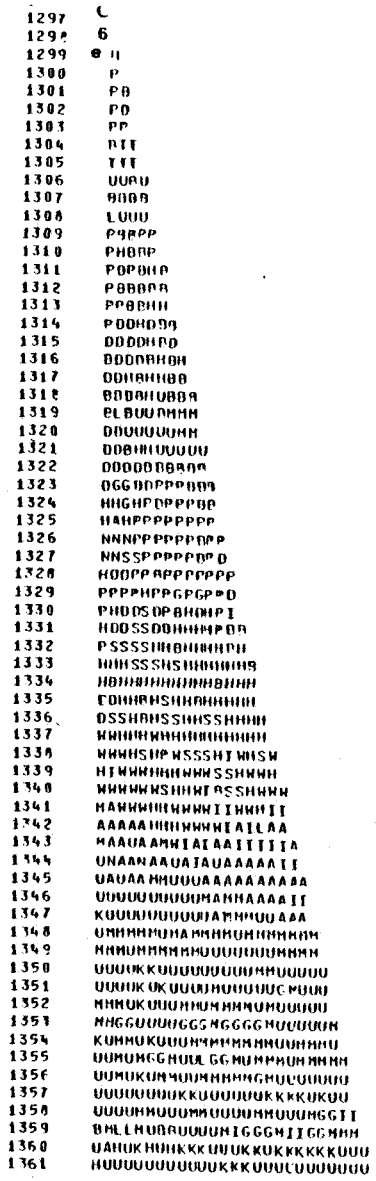


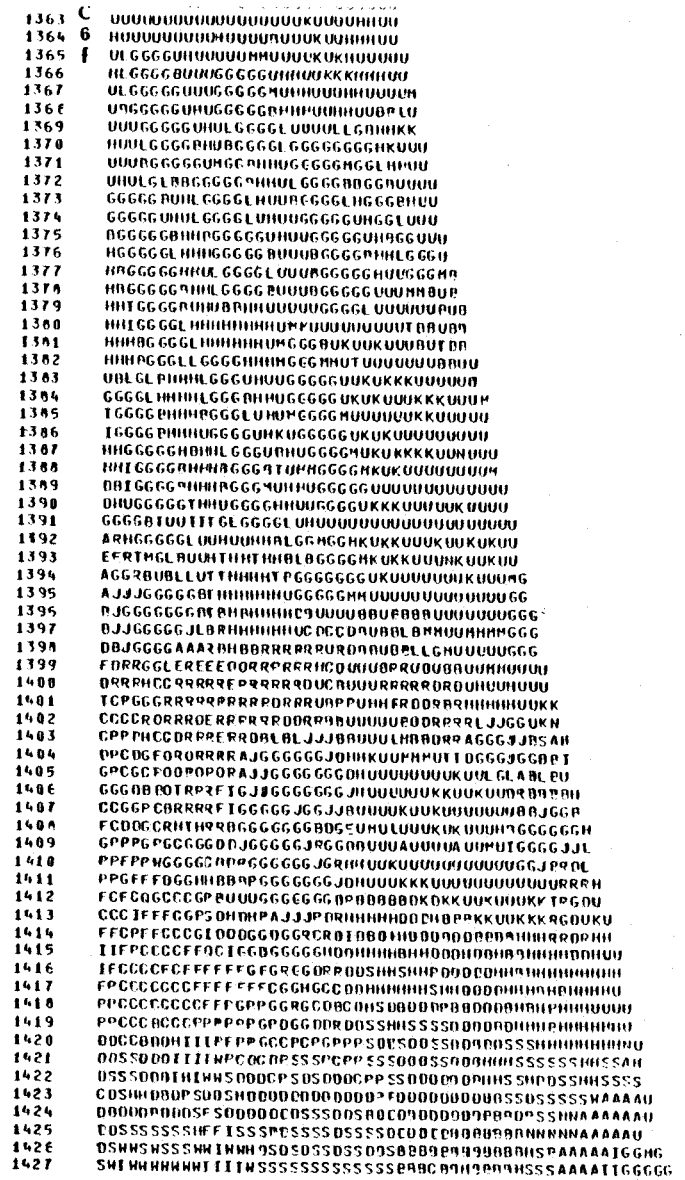


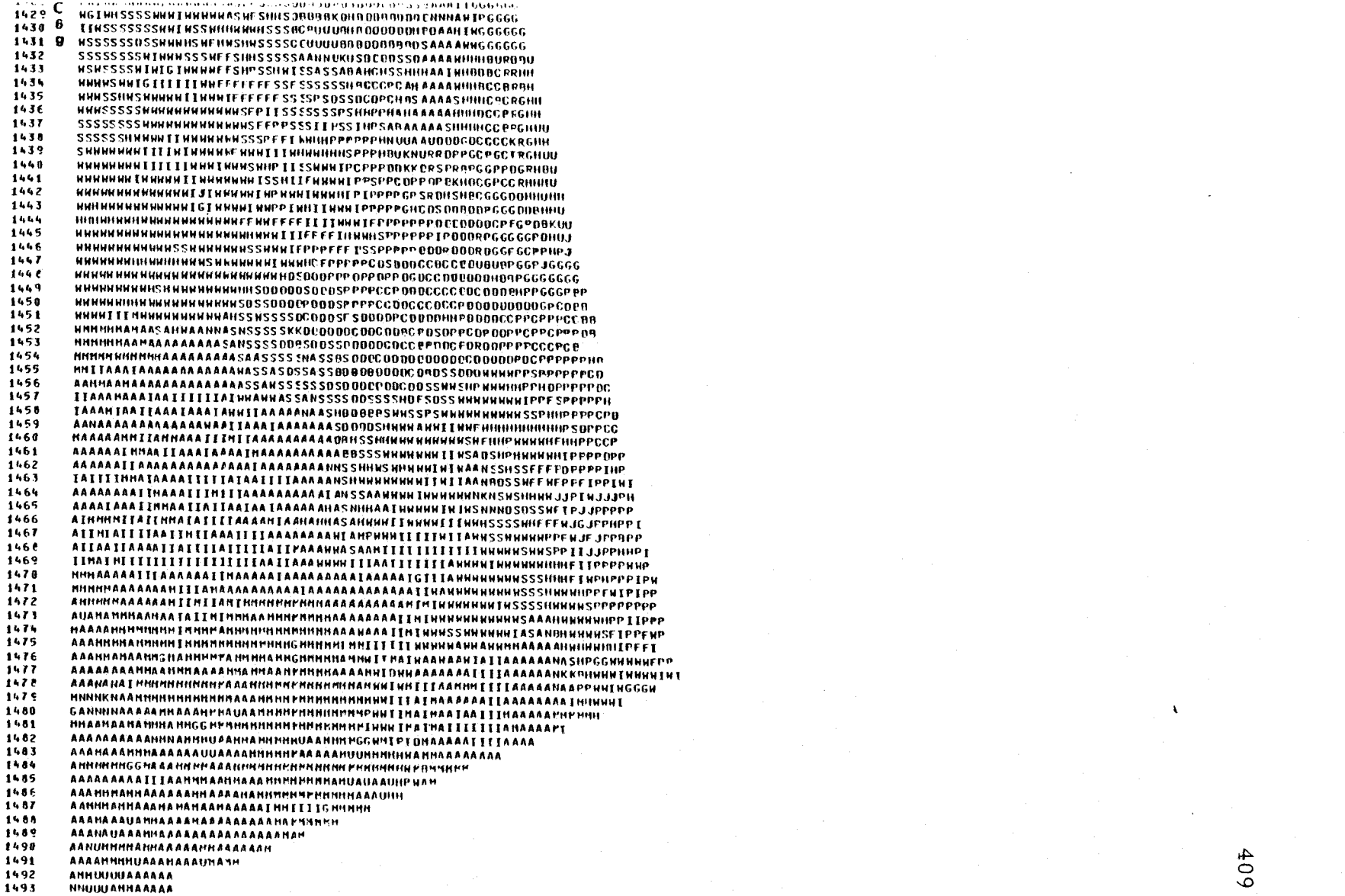












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