U.S. Army Tropic Test Center, Fort Clayton,
" Canal Zone.

Semiannual Report No. 1 and 2

ENVIRONMENTAL DATA BASE FOR REGIONAL STUDIES IN THE HUMID TROPICS

USATECOM Project No. 9-4-0013-01

Report Period: 1 September 1965 through 31 August 1966

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National Oceanic and Atmospheric Administration

Climate Database Modernization Program

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FOREWORD

This summary report, the first of a series to be issued semiannually, covers the progress and status of the Environmental Data Base for Regional Studies in the Humid Tropics. The project is sponsored by the Office, Secretary of Defense, Advanced Research Projects Agency (ARPA), Directorate of Remote Area Conflict, and by the Department of Army, Office of Chief of Research and Development, Army Research Office (ARO).

The study reported herein is being conducted under the guidance and with the direct participation of the Research Division of the U.S. Army Tropic Test Center, Colonel Pedro R. FlorCruz, Commanding Officer. The research program is carried out under the supervision of Dr. Guy N. Parmenter, Chief of the Division. Staff members of the Division have been responsible for the preparation of the individual study papers comprising the body of this report, as noted therein. The assembly and collating of the report has been done by Mr. Edward E. Garrett, Physical Environmental Scientist of the Division.

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SUMMARY

This report reviews principal accomplishments in the Environmental Data Base project during the period September 1965 through August 1966. Objectives and methods are explained and current operational sites are described.

The section on Climate (Part IV) covers types of data collected, location and type of instrumentation, special maintenance problems, and a description of some of the differences between the micrometeorology of the forest site and the open site.

The Soils and Hydrology section (Part V) describes types of data collected and methods used. Data analyses include determination of relationships between moisture content and dry density, moisture content and strength, soil temperature in vertical profile and air temperature, groundwater and rainfall in open and forest sites; and an analysis of seasonal variation in soil strength in open and forest sites.

The Vegetation section (Part VI) includes: (a) A description of the project herbarium. (b) A paper discussing leaf density and horizontal profile of Albrook forest canopy. (c) A paper on forest litter dealing with kind and amount of material, rate of accumulation, and time of fall. (d) A paper on the capability of litter from grass, brush, and forest land to support fire under varying moisture conditions. An inventory of plants at the Albrook forest site is given in an appendix.

The final section (Part VII), Microbiology and Chemistry of the Atmosphere, contains: (a) A paper on the deposition of microorganisms on surfaces which deals with data collection methods and analyses comparing bacterial and fungal deposition. (b) A paper on distribution of airborne microorganisms which discusses data collection methods and presents analyses of bacterial and fungal content of air at different times and elevations. (c) A paper on chemicals in the atmosphere which lists analytical laboratory procedures and presents some preliminary determinations. (d) A paper on microorganisms as sources of atmospheric contamination which presents results of an exploratory use of a gas chromatograph in sensing volatile organics. (e) A paper on condensation nuclei and particulate matter in the air which gives some preliminary observations on detection techniques.

ENVIRONMENTAL DATA BASE FOR REGIONAL STUDIES IN THE HUMID TROPICS

PART I: INTRODUCTION

Background

1. This report, covering the period 1 September 1965 through 31 August 1966, combines the first two Semiannual Technical Reports for the project Environmental Data Base for Regional Studies in the Humid Tropics (USATECOM Proj. No. 9-4-0013-01). It contains a brief review of principal project activities during the year and selected technical findings and data. Additional technical information will be found in the Periodic Data Summaries and Special Reports which are to be issued under the project, starting in the fall of 1966.

2. The project is sponsored jointly by the Advanced Research Projects Agency, Office of the Secretary of Defense, and by the Army Research Office, Office of the Chief of Research and Development, Hqs., Dept. of the Army. Work is carried out by the U.S. Army Tropic Test Center, U.S. Army Test and Evaluation Command, Army Materiel Command, with contracted support of Weather Engineers of Panama, Corp. Additional scientific support was received during the reporting period through co-operative arrangements with the National Center for Atmospheric Research, and with several individual scientists.

3. The project is an intensive, interdisciplinary investigation of the humid tropical environments of the Canal Zone and the Rio Hato military training reservation which is located approximately 80 kilometers (50 miles) southwest of the Canal Zone. These environments include a high rainfall region (over 100 inches/year) on the Caribbean slope of the Isthmus where tropical evergreen broadleaf forests prevail, a less wet region (70-90 inches/year) on the Pacific slope, where tropical semideciduous forests prevail, and the still drier Rio Hato region (about 40 inches/year) where the vegetation is a dry forest-savanna combination. The three environments have a pronounced dry season and are analogous to those found in regions of tropical monsoon and tropical savanna climates (Koeppen AM and AW) in southeast Asia and other parts of the tropics.

Objectives

4. The overall objective of the Data Base project is to increase knowledge of militarily significant factors in humid tropical environments. The project is designed to provide a bank of information and analyses derived from observations of selected physical and biological conditions at representative sites in the three natural environments mentioned above. The specific objective of the U.S. Army Tropic Test Center is to obtain detailed information concerning the environments in which its tests are conducted, information which will be of direct value in the planning and carrying out of tests as well as in the development

of tropical test techniques and methods. The project will establish in representative tropical environments the distribution (both vertically and horizontally), as well as the intensities, frequencies, and diurnal and seasonal variations for a number of natural conditions that affect not only the operability and durability of materiel but also such factors as movement, communication, visibility, and the physical capacity of troops.

Description of Project

Tasks

5. The basic program for the Data Base project provides for investigations in the following fields: (1) Climate, specifically its micro aspects, or the meteorological phenomena manifested between the ground surface and approximately 50 meters; (2) Soils and hydrology, with emphasis on factors related to soil trafficability and ground water; (3) Vegetation, with current emphasis being placed on taxonomy, foliage canopy, and the ground accumulation of forest debris (litter); (4) Microbiology, with emphasis on numbers and kinds of bacteria and fungi and their transportation and deposition; (5) Macrofauna, currently limited to arthropoda; and (6) Atmospheric chemistry, i.e., chemical and physical contaminants of the air.

6. Detailed study plans providing guidance for various aspects of each project task have been prepared in the form of Project Memoranda. Reference to the appropriate memorandum number is provided with each task report.

Observational Approach

7. In order to obtain as much information as possible on the interrelationships between various environmental factors, investigations are carried out simultaneously at selected sites. Manpower limitations and the cost of instrumentation have dictated that the full range of observations be limited to a few main observational sites. Two are in operation; three others are planned. "Main" sites are established where a broad range of environmental elements will be observed over a relatively long period of time. Additional "satellite" sites will be, and have been, established, in the same general area, at places with different physical and biological conditions where data are taken in shorter periods of time or with less frequency.

8. The project plan calls for establishing two main observational sites in each of the two major environmental types found in the Canal Zone. A fifth site is to be located on the Rio Hato military training reservation where the third principal tropical environment is found. The two observational sites in the semideciduous forest environment on the Pacific side of the Canal Zone are now in operation. One is in a dense forest, the other in a large clearing nearby. A similar pair of sites is planned

for the tropical evergreen broadleaf forest environment on the wetter Caribbean side of the Zone. The paired sites are necessary in order to fully characterize conditions in each of the two environments. Both cleared land and forest are extensive throughout the humid tropics and military operations cannot be confined to one or the other, yet each provides significantly different environmental conditions affecting movement, visibility, deterioration of materiel, etc.

9. Some of the observations are made by Tropic Test Center personnel; however, most of the routine observations are made under contract by the Weather Engineers of Panama Corp., following guidance provided in the Project Memoranda. Project scientists on the Tropic Test Center staff monitor all work and provide additional guidance as necessary. Observation frequency varies according to the parameter being observed, ranging from the virtually continuous readings of some meteorological equipment to the one-time observation of some soil factors. The high frequency of some observations requires manning of the main sites on a 24-hour basis.

PART II: OBSERVATION SITES

Site Location

Established Sites

10. Two main observational sites have been established to date. These are located on the Pacific side of the Canal Zone, which is characterized by moderate precipitation (an average annual rainfall of approximately 70 inches) with a pronounced wet and dry season, and semideciduous forest vegetation. The two sites are located in the Albrook Forest and at Chiva Chiva (see Figure II-1). The latter is in an open area of grassland, four kilometers (2-1/2 miles) from the former which is located within a forest with a relatively dense canopy of about 16 to 26 meters height and an understory of shrubs and vines with greatest density at about 2 meters height.

11. Three satellite sites are currently being utilized for observation of soils and meteorological data. These are sites for which significant bodies of data had been gathered before the institution of the Data Base project, and at which instrumentation was already installed. Consequently it was considered desirable to maintain the sites, under reduced observation schedules. Their locations are described in para. 18-20.

Proposed Sites

12. A second pair of main observational sites will be established in the Fort Sherman area on the Atlantic side of the Canal Zone (see Figure II-1). The forest site has been provisionally selected within a forest located on the military reservation. This area is subject to a higher annual rainfall (130 in. average) with a more even distribution, so that the dry season is much less pronounced. The forest has a somewhat higher canopy than that at Albrook and a less developed understory.

13. The fifth main observational site has been planned for location on the Rio Hato Military Reservation about 80 kilometers southwest of the Albrook sites (see Figure II-1). This is within a savanna (grassland) area with an annual rainfall (approximately 40 in) less than that at the Albrook area. Observations of some climatic factors were started at a location near the proposed site in 1965. These include rainfall, temperature, relative humidity, and wind speed and direction.

Site Descriptions

Albrook Forest Site

14. The Albrook Forest site is located in the northeastern portion of the Albrook Air Force Base immediately adjacent to the Fort Clayton Military Reservation. Site elevations range from about 30 to 33 meters above sea level. A walk-up tower, 46 meters high, fabricated from

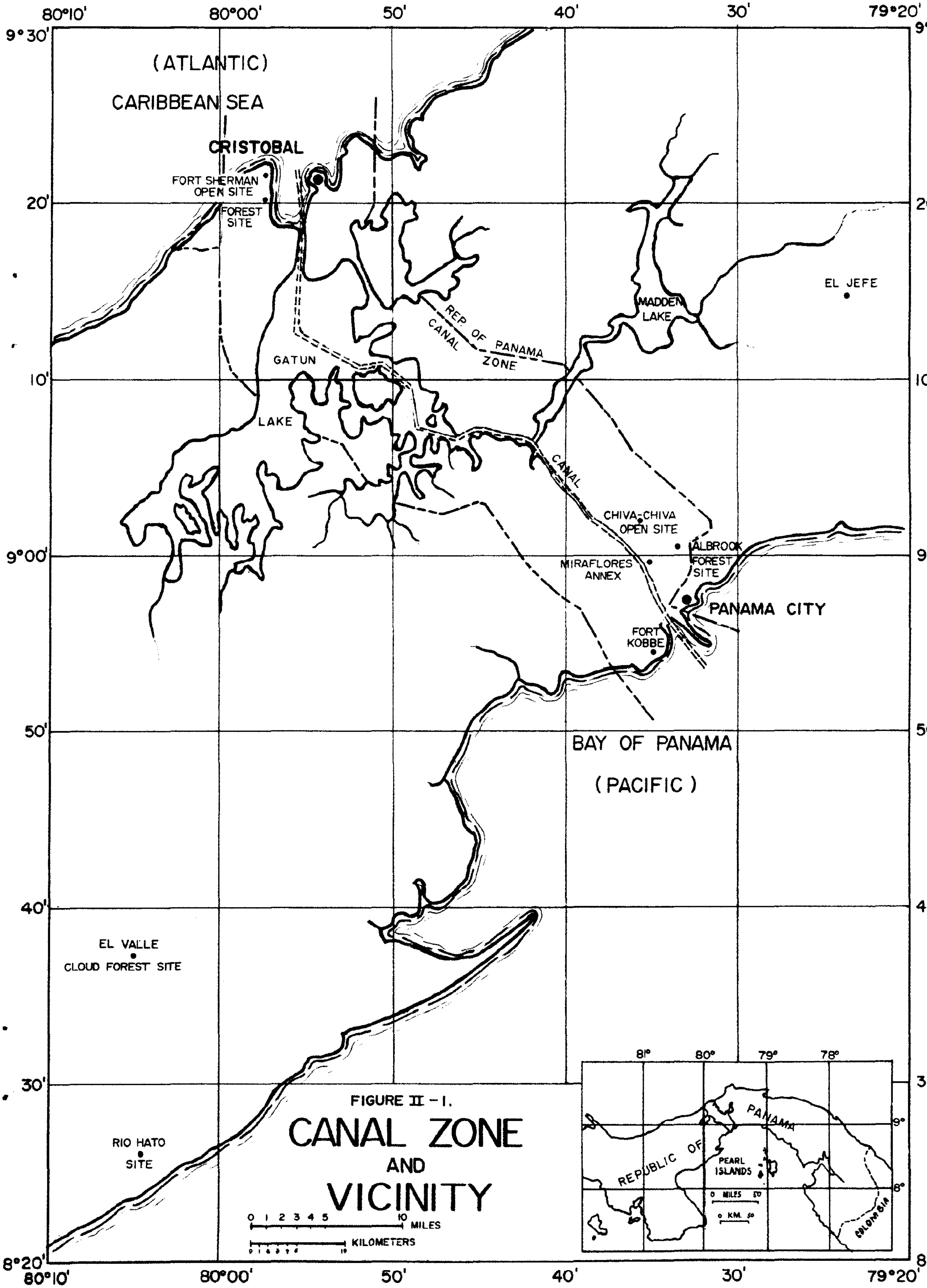


FIGURE II - 1.

CANAL ZONE AND VICINITY

aluminum tubing, is located at the center of the site. Figure II-2 is a diagrammatic sketch of the tower showing the instrumentation array as generally followed at both main sites. Figure II-3 is a photographic view of the below-canopy portion of the tower. The ground slopes very gently to the southeast. The nearly level ground is broken only by a one meter-deep channel of an ephemeral stream across the southeastern corner of the test site. The vegetation consists of many species of trees, shrubs, and vines of varying degrees of deciduousness. The soils are clay oxisols with a light-textured surface rich in organic matter. A gravel road provides access to a paved highway three kilometers distant.

15. Two generators of 30 kw capacity provide the power required to operate the electrical instrumentation (see Figure II-4). They are located at the site entrance within a wire-protected enclosure. A concrete, air-conditioned building for use of the round-the-clock observers, and in which the central components of the data acquisition and recording systems are located, is positioned on the perimeter of the site. (Figure II-4)

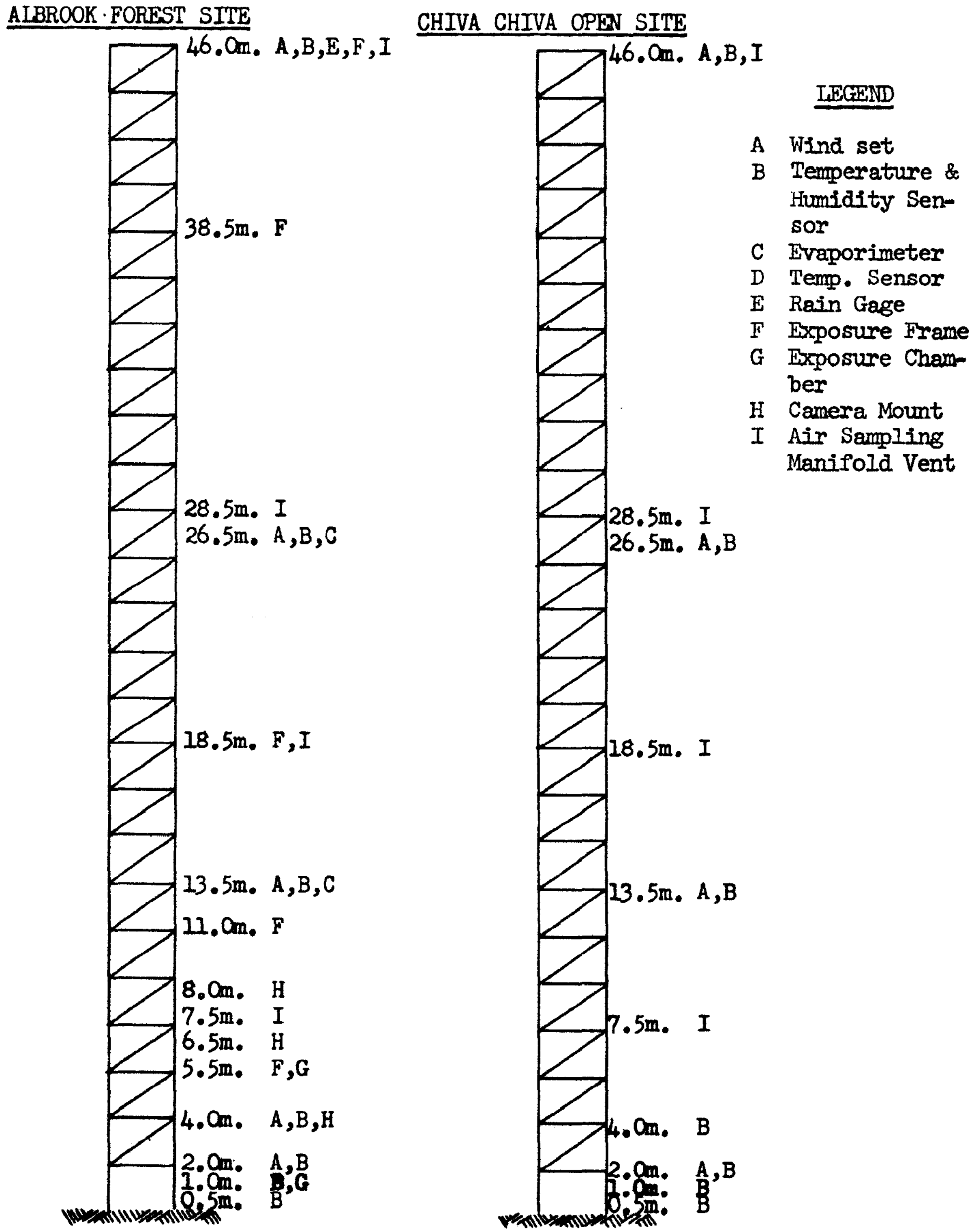
16. Figure II-5 shows the relative locations of the principal installations on the site, including the meteorological, soils, and biological instruments and devices. To minimize disturbance of the existing vegetation and soil surfaces, wooden walk-ways, raised above the ground on concrete blocks (to allow undisturbed passage for small animals), have been installed.

Chiva Chiva Open Site

17. The Chiva Chiva open site is located in the northwestern section of the Fort Clayton Army Reservation approximately four kilometers northwest of the Albrook Forest Site. The location is an open grass-covered area at approximately 30 meters elevation. The topography is nearly level with a slight incline toward the southwest. Clay oxisolic soils, very sticky and plastic, comprise the surface mantle. A tower, identical in structure with that at Albrook forest site, is centrally positioned on the site. This tower carries a somewhat smaller number of instruments than the one at the Albrook Forest site (see Figures II-2 and II-6). Two air-conditioned vans are provided for the observers and the central components of instrumental recording systems. Electricity is supplied to the site by commercial line power. Figure II-7 is a plot of the principal installations at the site. Due to the open nature of the site, vegetation and other biological observations are not as numerous as at the Albrook site. As at Albrook, wooden walk-ways are provided to prevent disturbance of natural conditions.

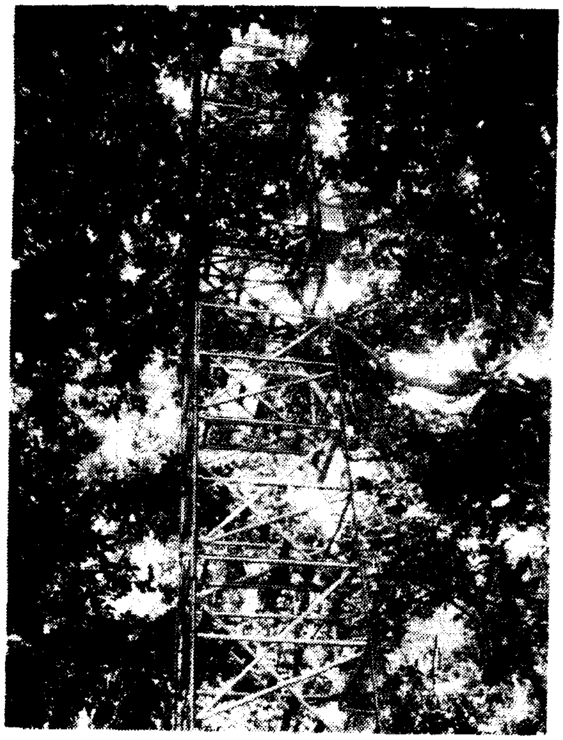
Albrook Satellite Site (Soil)

18. The Albrook soil satellite site is located approximately 600 meters southwest of the Albrook Forest site. The soil is a well drained clay. The physical environment is similar to that of the main site.



20 September 1966

Figure II-2



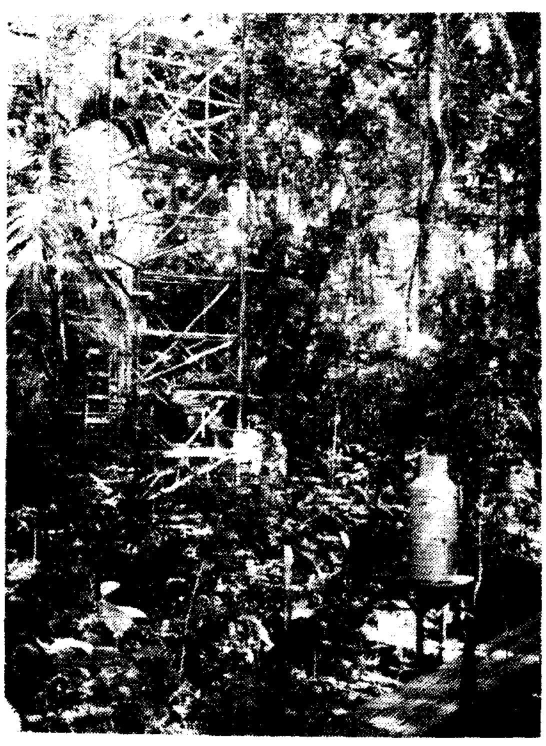
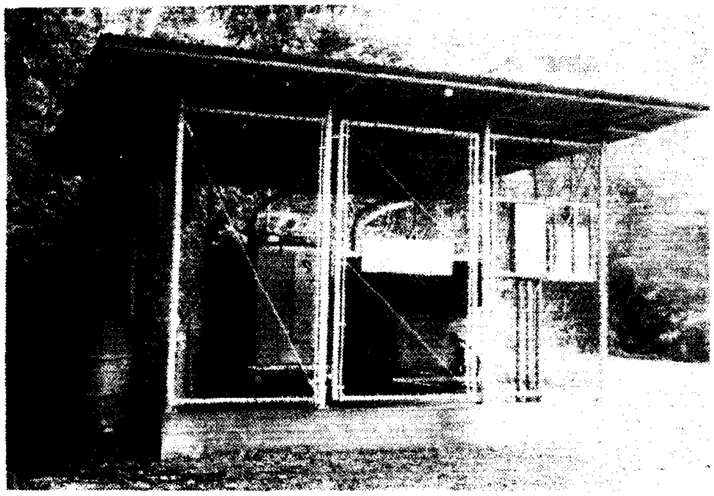


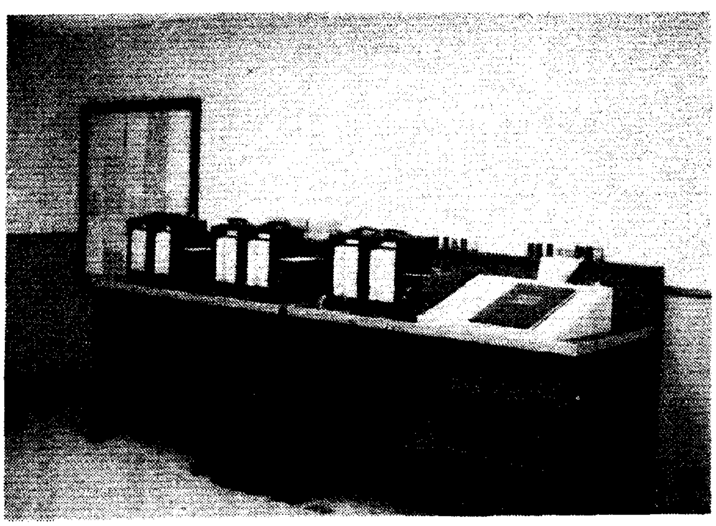
Figure II-3.

Albrook Forest Site,
Observation Tower.



View of generators

Observer's building



Observer's building, wind speed and direction recorders AN/GMQ-12.

Figure II-4. Albrook Forest Site, Installations.

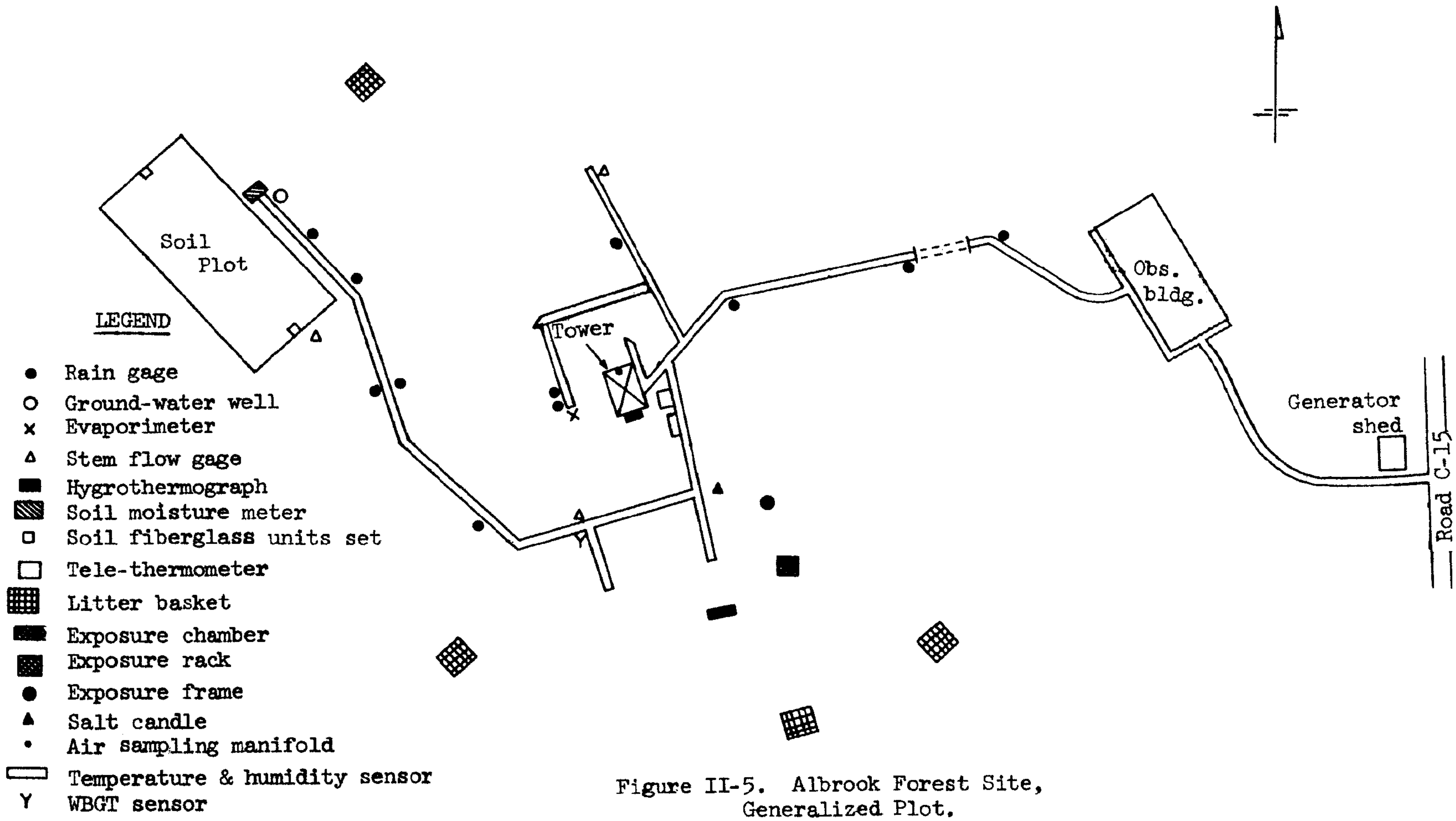
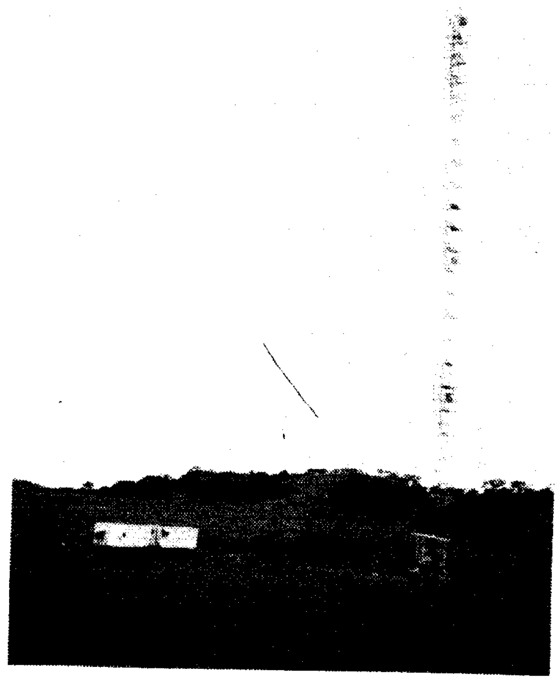


Figure II-5. Albrook Forest Site,
Generalized Plot.

20 September 1966 (Not to scale)



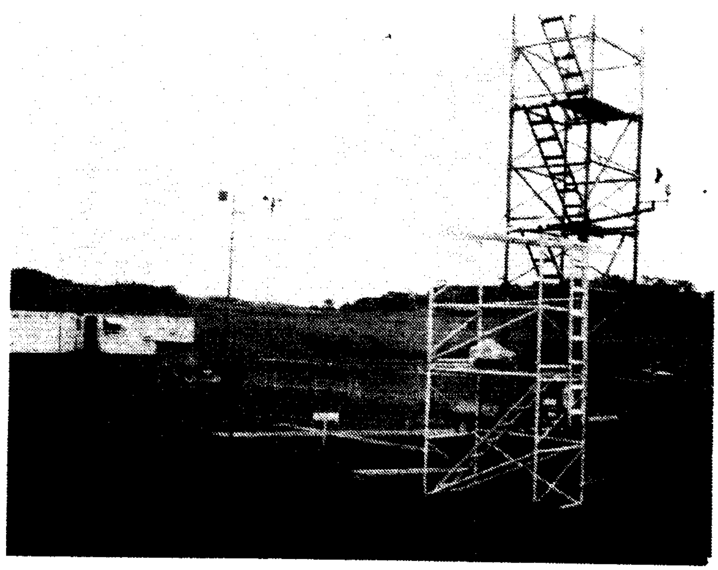


Figure II-6. Chiva Chiva Open Site, Observation Tower and Vans.

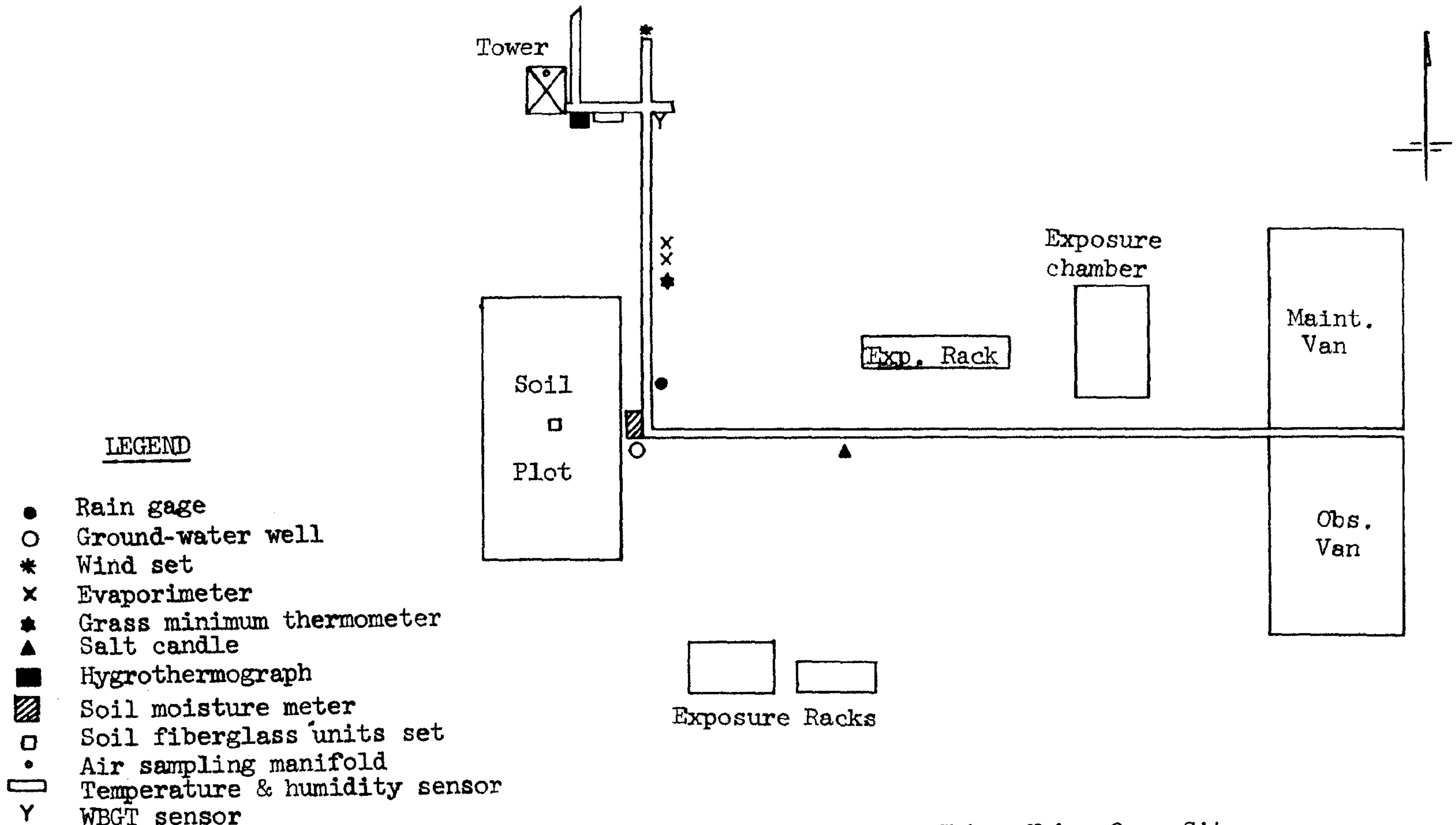


Figure II-7. Chiva Chiva Open Site,
Generalized Plot

20 September 1966 (Not to scale)

A cased ground-water well, with a water-level recorder, a hygrothermograph, and two recording rain gages (one in the open and another under the canopy) comprise the permanently installed equipment at this site.

Fort Kobbe Satellite Site (Soil)

19. The Fort Kobbe soil satellite site (location shown on Figure II-1) is at an elevation of approximately 20 meters. The soil is a dark clay, very sticky and plastic. The topography is nearly flat, with slopes less than 2°. The vegetation is of secondary growth, with trees reaching a maximum height of eight to nine meters. Two rain gages, in the open and under the canopy; a hygrothermograph; and a cased water-well with a level recorder are installed at the site.

Fort Sherman Satellite Site (Soil)

20. This site is located at the Fort Sherman Army Reservation on the Atlantic side of the Canal Zone (see Figure II-1), at an elevation of approximately 80 meters. The generally broken terrain slopes at about 20°. Soils are reddish brown, oxisolic clays, very sticky and plastic. The site is maturely forested, with evergreen broadleaf species of trees predominating. The same meteorological equipment is installed as at the other satellite sites.

PART III: PROJECT ACCOMPLISHMENTS

General

21. During the year covered by this report, observations were made in all five tasks or fields of study comprising the project (para. 5). The total number of individual items of data observed and recorded in all fields combined exceeded 900,000. Climate observations contributed the most data; the macrofauna investigations contributed the least. Although considerable data were collected, not all work planned for each task was accomplished. Failure to meet all goals can be attributed largely to the following: a. delays in obtaining instruments, equipment, and supplies; b. long-standing staff vacancies; c. the experimental nature of some lines of investigation. Progress was made in overcoming these and lesser problems, but they were still significant at the end of the reporting period.

22. Analysis of data was limited but increased somewhat during the latter part of the year when the length of the observation periods and quantities of data became more adequate and the in-house capability to carry out analyses improved. Two professional papers, based in part on data collected for the project, were presented during the period by Dr. Robert Hutton of the Tropic Test Center staff. The first, "Possible Military Significance of Contaminants Found in Tropical Atmospheres", was presented at the Army Science Conference in June 1966. The second, entitled "Microbiological and Chemical Observations in the Humid Tropics", was presented at the annual meetings of the American Institute of Biological Sciences in August 1966. The second paper was authored jointly with Lt. Reinhold Rasmussen, Walter Reed Army Institute of Research. Information in these papers will be combined in a report to be issued in the Data Base special report series. Other analyses made during the period covered are discussed under the reports of individual task accomplishments.

23. Thus far, only a perfunctory start has been made on the integration of data from the different tasks. Some rainfall and relative humidity data have been considered in studies on the moisture content of forest litter, and wind regimes have been taken into account in investigations of airborne microorganisms and atmospheric contaminants. In the future more attention will be directed toward the synthesis of information from the lines of study involving the different disciplines.

24. The storage of data has been mechanized to a considerable extent for the climate and soils tasks, for which large amounts of data have been transferred to punch cards. Part of the vegetation data is also on punch cards, and forest litter data collected in the future will be recorded by the same means.

Task Accomplishments

25. The reports of individual task accomplishments which follow have been prepared by the individuals indicated. The work reported has been accomplished over time periods approximating the over-all reporting period of 1 September 1965 through 31 August 1966; however, due to exigencies of work scheduling, movements and changes of personnel, and technical considerations of specific tasks, the periods of study covered are variable. Work is reported under the following headings: Climate, Soils and Hydrology, Vegetation, and Microbiology and Air Chemistry. In each case a general description of the work is followed by brief references to methods, instrumentation, and of the specific findings or research still underway.

PART IV. CLIMATE*

Introduction

26. The climate investigations of the Data Base project provide information on microclimatic conditions needed to explain and interpret the microbiological, vegetation, soils, and macrofauna observations also being made under the project. In addition they provide a sound basis for characterizing principal tropical environments of the Canal Zone and determining their degree of analogy with the climates of Southeast Asia and other strategic areas. Although considerable amounts of climatic data have been collected in the Canal Zone by various agencies, these data have application, in almost every instance, in the macro and meso scales rather than the micro scale. For example, a network of rainfall observation stations has been in operation for many years in support of the hydrological investigations relevant to the operations of the Panama Canal; and the Air Weather Service has, for several years, made standard surface weather and upper-air radiosonde observations in support of synoptic, macro, and aeronautical meteorology. The principal exception is the body of data collected by the US Army Meteorological Team (RDT&E Support), Canal Zone, which has made observations in support of testing for many years.

Instrument Location

27. A full range of climatic factors have been studied at each of the two main sites, the Albrook Forest site and the Chiva Chiva open site. Limited data have been taken at the Rio Hato savanna site. The towers erected at the two main sites are similarly oriented. Sensing equipment is mounted at several levels on the towers to provide meteorological measurements through the vertical profile. All tower-mounted instruments are similarly exposed on each tower, thus providing a basis for comparison of the meteorological variations in the horizontal plane, as well as for those produced by the presence of an arboreal canopy and exhibited in the vertical plane. Additional measuring instruments are emplaced in the immediate vicinity near the ground. Tower-mounted instruments consist of temperature, humidity, wind, and evaporation measuring instruments. Instruments placed at ground level consist of precipitation, temperature, evaporation, and wet-bulb globe temperature (WBGT) index (or heat stress index) measuring equipment.

28. Due to the procurement problems encountered in securing integrated wind and psychrometric measuring systems, which may soon be

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* This section has been prepared by Mr. Michael Fradel, Meteorological Technician, US Army Tropic Test Center. The work on which the discussion is based was carried out in general conformance with the 470 Series of the Project Memoranda.

resolved, the instruments currently being used to measure these parameters are of varied types, which will be discussed in the next section. In every case possible, all instruments are matched for each identical exposure at the two sites.

Data Collection

29. The types of meteorological data, with the frequencies of observation, at the two sites during the reporting period are summarized in Table IV-1. Details concerning the instrumentation, etc., are presented below.

30. Dry-bulb temperature measurements, at the forest and the open sites, were made at 10 levels through the vertical plane (surface, 0.5, 1, 2, 4, 8, 13.5, 26.5, 28.5, and 46 meters) at the beginning of the period. Due to instrument failures, with no replacement capability, the levels at Chiva Chiva were reduced to seven beginning October 1965, eliminating the measurements at the 8 and 28.5 meter levels. Measurements of the wet-bulb temperature were made mostly at four levels (0.5, 1, 2, and 4 meters). Except for the soil surface level, relative humidity measurements were made at the same levels as the dry-bulb temperatures. The 1-meter level is represented by the "ground-level" instruments. The instruments used in making these measurements were Bendix hygrothermographs, Foxboro hygrothermographs, Honeywell-Brown hygrothermographs (see Figure IV-1), Bendix psychrons, Yellow-Springs telethermometers, and standard

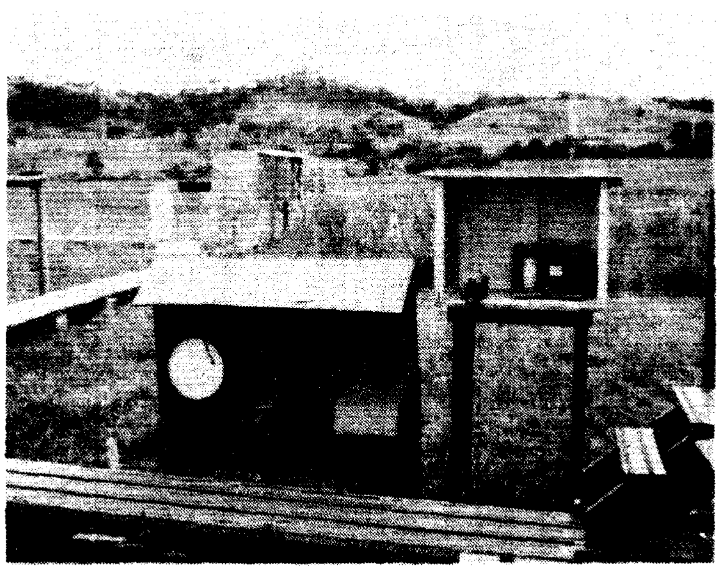

Figure IV-1. Honeywell-Brown Hygrothermograph at Chiva Chiva Site

TABLE IV-1. LOCATION OF SENSORS AND FREQUENCY OF OBSERVATIONS

	Height (meters)										Sites		
Element	sfc	0.5	1	2	4	8	13.5	26.5	28.5	46	Alb	C.C.	Frequency
Temperature:													
Dry Bulb	x	x	x	x	x	x	x	x	x	x	x	x	Hourly*/Continuously
Wet Bulb		x	x	x	x						x	x	Hourly*/Continuously
Grass Min	x											x	Once daily
WBGT			x								x	x	Hourly (0600-1900)
Relative Humidity		x	x	x	x	x	x	x	x	x	x	x	Hourly*/Continuously
Barometric Pressure			x								x	x	Continuously
Evaporation	x							x		x	x	x (sfc only)	Once daily
Precipitation:													
Recording Rain Gage	x									x	x	x (sfc only)	Continuously
Manual Rain Gage	x										x		4 times daily
Stem Flow			x								x		4 times daily
Wind:													
Direction					x					x	x	x	Continuously
Velocity				x	(x)		x	(x)		(x)	x	x	Hourly ( ) Continuously
Clouds	x											x	Hourly
Visibility	x											x	Hourly
Other Phenomena	x										x	x	Upon Occurrence

* The observation is made hourly with a psychrometer when the recorders are removed for maintenance and repair.

sling psychrometers. The available number of any one type of these sensors was insufficient to array either tower with like instruments, however, every attempt has been made to place like sensors at the same levels on each tower.

31. The wet-bulb globe temperature (WBGT) is observed at both the forest and open sites. The WBGT sensor was locally fabricated and consists of a dry-bulb thermometer, a wet-bulb thermometer, and a black-globe thermometer. The three thermometers are suspended from a tri-arm standard one meter above the ground.

32. Lack of instruments has restricted the wind direction measurements to the 46-meter level at the forest site and to the 4 and 46-meter levels at the open site. These measurements began February 1966. Wind-speed measurements were made at the 2, 4, 13.5, 26.5, and 46-meter levels at both the forest and open sites. The instruments used for the wind measurements were Belfort Cup anemometers, Belfort independent wind sets, Taylor wind flow instruments, and B&W GMQ-12 wind measuring sets. Again, as in the case of the psychrometric instruments, like wind-measuring instruments were placed at the same levels on each tower where possible.

33. Rainfall at the open site is measured by a ground-emplaced Belfort weighing and recording type gage. Rainfall on the canopy above the forest site is measured with a tipping-bucket rain gage located on the top of the tower. Rainfall that penetrates the canopy and falls upon the forest floor is measured by a network of 11 rain gages; three are the weighing and recording type and eight are the visually-read type. These are selectively placed at points of varying shelter (from overhead vegetation) so that a representative value of the amount of rain falling upon the forest floor may be obtained. An additional amount of precipitation reaches the ground by flowing down the stems of trees and other plants. An approximation of this measurement is obtained by sealing collecting collars around selected tree trunks, near the bases, from which the stem flow is funneled into visually-read rain gages. Currently, measurements are taken from three trunks, of commonly occurring tree species, at the Albrook site. The measurement is designed to provide a quantitative base for the ultimate determination of total stem flow (see Figure IV-2).

34. Evaporation is measured at three levels at the forest site (surface, 26.5, and 46 meters). Piche evaporimeters are used for this measurement. At the open site, evaporation is measured at the surface level only using both the standard evaporation pan and a Piche evaporimeter. The two instruments are placed side by side so that simultaneous measurements may be compared. The objective is to establish a correlative factor for the Piche evaporimeter using the Standard evaporation pan as the control item (see Figure IV-3).

Observer reading a weighing rain gage.

Observer making a stem-flow measurement.

Figure IV-2. Precipitation Measurement - Albrook Forest Site

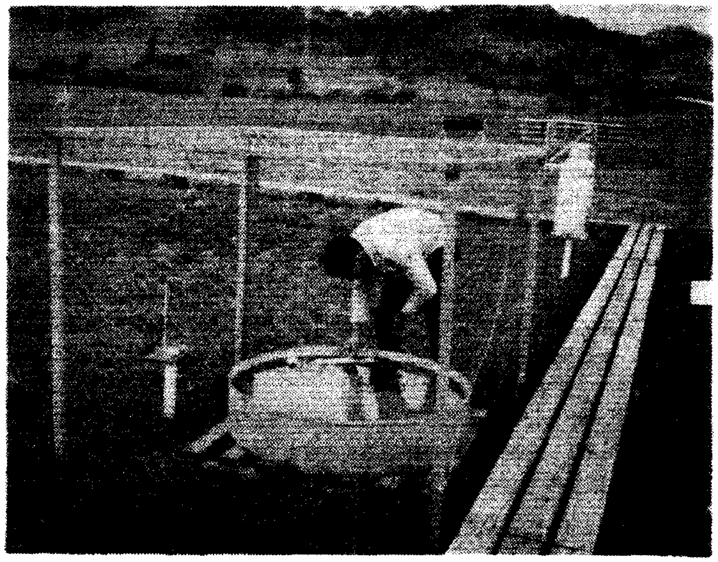

Figure IV-3. Standard Evaporation Pan with a Piche Evaporimeter at the Left.

35. Visual observations of clouds, visibility, and weather phenomena (such as hail, lightning, smoke, etc.) are made at the open site. These observations are made in accordance with WBAN* Circular N.

36. At a temporary site near the proposed Rio Hato savanna site, measurements of temperature, humidity, rainfall, wind speed, and wind direction are being made at the standard instrument shelter height. A Belfort hygrothermograph is used for the temperature and humidity measurements, a Belfort weighing and recording rain gage for rainfall, and a Belfort independent wind set (Anemograph) for the wind measurements. (The wind is measured at the four-meter level).

37. All observations and measurements, except for evaporation, are made on an hourly basis. Evaporation is measured once daily.

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* Weather Bureau, Air Force, and Navy

Data Reduction and Storage

38. All data generated by manual and visual techniques are entered directly on log forms (Figures IV-4 and IV-5). These completed forms plus all chart forms are delivered to a data quality control team, which reads the elements for each full hour from the charts and enters them on the log forms. The data are then reviewed for accuracy and completeness. The completed logs are then transposed to standard punch cards. The cards are verified immediately following the original punch operation, after which they are processed through an IBM 1420 computer for computations of means, extremes, and totals, as appropriate, and produced in a tabular print-out from which the monthly summary is derived (Figure IV-6). The identification code that accompanies this summary is shown in Figure IV-7. Upon completion of all reduction and recording, the original observation records are arranged in chronological order by weeks. These records together with punch cards are stored in the Tropic Test Center Technical Library Annex.

39. The total number of individual meteorological observations recorded and stored during the reporting period, September 1965 through August 1966, are summarized in Table IV-2.

TABLE IV-2. TOTAL NUMBER OF METEOROLOGICAL OBSERVATIONS PERIOD 1 SEPTEMBER 1965 THROUGH 31 AUGUST 1966.

	Albrook	Chiva-Chiva	Rio Hato	Total
Dry Bulb temperature	78,680	61,474	6,538	146,692
Wet Bulb temperature	26,198	29,126	- - -	55,324
Relative humidity	52,398	52,540	6,536	111,474
Wind speed	43,800	43,790	6,596	94,186
Wind direction	8,760	14,568	6,596	29,924
Evaporation	4,952	1,282	- - -	6,234
Rain gage (Recording)	35,040	8,760	366	44,166
Rain gage (Manual)	70,080	- - -	- - -	70,080
Stem flow	26,280	- - -	- - -	26,280
Barometric pressure	8,760	8,760	- - -	17,520
WBGT	20,440	21,640	- - -	42,080
Surface observations	57,208	113,880	- - -	171,088
TOTALS	432,596	355,820	26,632	815,048

Special Maintenance Problems

40. The maintenance and calibration of instruments is one of the greatest problems encountered thus far. As stated above, the instruments, particularly the wind and psychrometric sensors, are of standard makes

LOCATION Chiva Chiva

DATE Sunday OcT 23, 1966

DAILY METEOROLOGICAL OBSERVATIONS

WEPCOR II

TYPE	TIME	VSBY.	WEA. OBSC.	REMARKS	TTL. SKY CVR.	LOW CLOUDS AMOUNT	LOW CLOUDS TYPE DIR.	LOW CLOUDS HEIGHT	MDL. CLOUDS AMOUNT	MDL. CLOUDS TYPE DIR.	MDL. CLOUDS HEIGHT	HIGH CLOUDS AMOUNT	HIGH CLOUDS TYPE DIR.	HIGH CLOUDS HEIGHT	OPAQUE SKY	SFC.	OPEN	DRIP	TOP	HOURLY RAINFALL 1	2	3	4	5	6	7	8	OBSERVERS
R	01	7.5	None		6/10	2/10	8/N	01E	4/10	1-2/u	u				6/10							1-2/u	1-2-3/u					A. Gonzalez
R	02	7.5	None		4/10	2/10	8/N	01E	2/10	1-2/u	u				4/10													A. Gonzalez
R	03	7.5	None		4/10	4/10	6+8/N	01E		-					4/10													A. Gonzalez
R	04	7.6	None		4/10	2/10	6-8/N	01E	2/10	2/u	u				4/10													Oviedo
R	05	7.6	None		8/10	8/10	6-8/N	01E							8/10													Oviedo
R	06	7.5	None		8/10	4/10	6-8-9/N	01E	2/10	1-2-3/u	u	2/10	0-6/u	u	8/10													Oviedo
R	07	7.5	-	G.F. AROUND QUAD D.S PTD	8/10	4/10	6-2-3-4/N	02E	4/10	1-2-4/u	u				8/10													Flores
R	08	7.5	None		8/10	4/10	6-2-3/N	08E	4/10	8/u	u	u	3-4/u	u	7/10													Flores
R	09	7.6	None		8/10	4/10	2-3-4/N	13E	4/10	3-2/u	u				7/10													Flores
R	10	7.5	None		10/10	7/10	2-3-4/N	15E	3/10	2/u	u	u	4/u	u	8/10													Flores
R	11	7.5	None		10/10	7/10	2-4/N	25E	3/10	2-4/u	u				7/10													Flores
R	12	5.0	R	R. HLS.	10/10	8/10	3-4-9/N	25E	4/10	2-4/u	u				9/10													Flores
R	13	2.0	RW	tsTm. L.T.G. QUAD	10/10	10/10	8-9/N	u							10/10													Flores
R	14	2.0	CLDS	ST. CLDS. HLS	10/10	10/10	8-9-6/N	01E							10/10													Flores
R	15	7.5	-	H. TPG HLS + STN	10/10	7/10	2-4-9-3/u	01E	3/10	2-7/u	u				9/10													Sollami
R	16	7.5	-	G.F. W-NW	10/10	9/10	2-4-8/u	02E	1/10	2/u	u				10/10													Sollami
R	17	7.5	-	VSBY TWR OBSCD G.F. ST TPG HLS W-NE	10/10	9/10	2-3-4-8-6/u	02E	1/10	2-7/u	u				10/10													Sollami
R	18	7.5	NFQT -	LTG E VSBY TWR OBSCD CE-W G.F. ST TPG HLS W-NE	10/10	9/10	2-3-8-6-9/u	02E	1/10	2/u	u				10/10													Sollami
R	19	7.5	-	FQT LTG DSNT E S ST TPG ALL HLS	10/10	8/10	3-8-6-9/u	02E	2/10	1/u	u				9/10													Sollami
R	20	7.0	None	CBE CTNUS LTG DSNT SE	10/10	7/10	3-4-8-9/u	04E	3/10	2/u	u				9/10													Sollami
R	21	7.5	-	FQT + QUAD ST TPG HLS N-NE CTNUS LTG SE NB L	10/10	9/10	8-9-6-3/u	01E	1/10	2/u	u				10/10													Sollami
R	22	7.0	ST	NFQT LTG E NR(?) R- ST TPG ALL HLS	10/10	10/10	8-6-3/u	02E							10/10													Sollami
R	23	5.0	ST	ST TPG ALL HLS	10/10	10/10	6-8/u	02E							10/10													E. Oviedo
R	24	7.0	None		10/10	10/10	2-6-8/u	02E	1/10	2/u	u				10/10													E. Oviedo

IMPRESORA, S. A. OFFSET

Figure IV-4. Example of a Completed Log Form, Surface Observations

LOCATION *Chira Chira*

DATE *Sunday Oct 25, 1966*

DAILY METEOROLOGICAL OBSERVATIONS

Observers No. 1 *Gonzalez Oviedo* No. 2 *Flores* No. 3 *Sellami*

WEPCOR-10

Var	Level	0000	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	AVG	Max.	Min.
TEMPERATURE (Dry Bulb)	46.0 m		74.5	74.0	73.5	73.3	73.3	73.0	73.0	73.1	77.1	81.3	82.6	86.1	76.1	72.1	73.1	74.1	77.7	77.6	76.5	76.0	75.5	75.3	75.0	75.0			
	28.5 m																												
	26.5 m		74.4	73.9	73.7	73.4	72.9	72.9	74.7	78.1	82.6	83.6	87.6	83.6	72.1	72.6	74.1	75.6	77.9	77.4	76.4	75.9	75.9	75.6	75.4	75.4			
	13.5 m		73.1	73.1	72.6	72.1	71.6	71.4	75.1	77.5	81.5	82.5	86.5	82.5	71.5	72.0	74.0	75.0	76.8	76.1	75.6	75.1	75.1	74.8	74.6	75.6			
	8.0 m																												
	4.0 m		73.6	73.6	72.6	72.1	71.6	70.6	73.6	77.9	84.4	83.4	88.4	84.4	M	72.4	74.4	76.4	78.6	77.6	77.6	77.1	76.1	76.1	76.2	75.6			
	2.0 m		73.1	73.1	72.6	71.1	71.1	70.1	73.1	78.8	85.1	83.8	89.5	85.3	73.8	73.3	75.3	76.8	79.1	78.1	77.6	77.1	76.1	76.1	76.6	76.1			
	1.0 m		72.7	72.6	72.5	71.6	71.1	70.6	72.6	76.8	82.8	85.8	87.8	88.3	73.3	72.8	74.5	75.8	77.6	76.7	76.1	75.3	74.8	74.6	74.6	74.6			
	0.5 m		73.7	73.7	73.2	72.2	72.2	71.7	73.2	77.1	82.1	84.5	87.4	84.7	76.1	76.1	77.1	79.6	77.9	77.2	76.7	76.2	76.2	75.8	75.7	75.7			
	Grass									70.7																			
	Sfc.		74.0	74.0	73.5	73.0	72.8	72.0	74.0	96.5	92.0	96.5	103.5	90.0	79.0	80.0	82.0	82.8	81.5	80.0	78.2	77.8	77.2	77.0	76.0	75.8			
TEMPERATURE (Wet Bulb)	46.0 m																												
	28.5 m																												
	26.5 m																												
	13.5 m																												
	8.0 m																												
	4.0 m		72.6	72.6	72.1	71.6	70.6	70.1	72.6	74.7	79.2	77.2	77.7	76.7	M	73.2	74.7	76.2	76.6	76.6	76.6	75.6	75.6	75.1	75.1	75.1			
	2.0 m		72.8	72.8	72.3	72.3	70.8	69.8	72.8	75.6	79.4	77.6	78.6	77.6	74.1	73.6	75.6	76.6	77.8	77.3	76.8	75.8	75.8	75.3	75.5	75.3			
	1.0 m																												
	0.5 m		73.2	73.2	72.7	71.7	71.7	70.7	72.2	76.2	78.7	79.2	79.2	78.7	73.7	73.7	75.2	76.7	76.8	76.8	76.0	75.3	75.3	74.8	74.8	74.8			
RELATIVE HUMIDITY	46.0 m		95	95	95	95	95	95	96	97	89	76	63	63	100	100	100	100	95	95	95	95	95	95	95	95			
	28.5 m																												
	26.5 m		94	94	94	94	94	94	94	93	84	74	63	60	99	100	100	100	94	94	94	94	94	94	94	94			
	13.5 m		96	96	96	96	96	96	80	75	70	60	76	80	100	100	100	100	96	96	96	96	96	96	96	96			
	8.0 m																												
	4.0 m		95	95	97	97	96	97	96	86	79	76	62	70	M	100	100	99	91	95	95	93	98	96	95	95			
	2.0 m		98	98	98	98	98	98	98	86	78	76	62	71	100	100	100	99	94	96	96	94	98	96	98	96			
	1.0 m		95	95	95	95	96	95	95	90	94	68	58	92	100	100	100	100	95	95	95	95	95	95	96	95			
	0.5 m		98	98	97	97	97	95	95	92	86	79	70	76	89	100	91	87	96	98	97	96	96	95	96	95			
WIND DIRECTION	46.0 m		325	300	275	305	320	345	calm	315	270	305	120	100	330	160	335	195	calm	265	275	260	350	330	calm	015			
	28.5 m																												
	26.5 m																												
	13.5 m																												
	8.0 m																												
	4.0 m		010	295	245	240	035	010	016	280	265	315	200	135	320	065	320	175	210	285	265	220	020	335	020	025			
	2.0 m																												
	1.0 m																												
WIND SPEED	46.0 m		05	04	03	04	05	02	calm	03	03	10	03	03	09	02	03	03	calm	04	07	03	02	05	calm	06			
	28.5 m																												
	26.5 m		calm	02	02	calm	01	calm	calm	calm	03	06	01	calm	08	calm	01	calm	calm	01	03	01	calm	02	calm	03			
	13.5 m		calm	calm	01	calm	calm	calm	calm	01	03	05	calm	calm	09	calm	calm	calm	calm	calm	01	calm	calm	01	calm	01			
	8.0 m																												
	4.0 m		02	03	03	02	02	02	02	02	01	01	03	02	09	02	03	03	02	02	06	04	02	04	02	04			
	2.0 m		calm	calm	calm	calm	calm	calm	calm	01	01	04	calm	calm	07	calm	calm	calm	calm	calm	01	calm	calm	calm	calm	01			
	1.0 m																												
WBGT Index	Index							70.0	73.6	83.8	89.5	85.3	90.7	82.3	75.2	74.6	77.0	78.5	78.4	77.2	76.2								
	Dry Bulb							70.0	72.0	82.7	89.0	84.3	94.3	83.5	76.0	74.0	76.0	78.0	78.0	77.0	76.0								
	Wet Bulb							70.0	72.0	78.7	81.2	79.0	80.0	78.8	75.0	74.0	76.0	78.0	77.5	77.0	76.0								
	Blk. Bulb							70.0	74.9	104.0	119.0	108.0	126.5	84.0	75.8	77.0	81.0	80.5	81.5	78.0	77.0								
BAROMETRIC PRESSURE	29		800	790	770	775	780	800	840	860	865	860	840	810	795	765	740	730	740	755	770	800	820	810	825	810			
Jungle Vsby.																													

PRECIP	0000	0600	1200	1800	TOTAL
46.0 m					
Surface					
DripCan					
OpnCan					
Total					
Aver.					
STEM FLOW					
Tree 1					
Tree 2					
Tree 3					
Total					
Aver.					
EVAPORATION					
Top Twr.					
Top Can					
Base Can.					
Surface					

TIME RAIN STARTED AND STOPPED

Start					
Stop					

COOLING POWER	0100	0700	1300	1900	TOTAL	AVE

Element	Began	Ended
LTG	0100	0550
L	1150	1200
T	1205	1235
R	1208	1215
L-	1217	1225
RW	1243	1323
TSTM	1240	1430
LTG	1255	1430
L-	1415	1423
L	1430	1500
LTG	1810	2230
T	2030	2240
L	2040	2200
R-	2200	2318
R	2318	2336
R-	2336	2405
LGT	2337	0050

Figure IV-5. Example of Completed Log Form, Tower Observations

IMPRESORA, S. A. 84781

MONTHLY SUMMARY FOR MONTH OF JUNE 1966

CHIVA CHIVA SITE JUNE 1966

LOCATION	ELEMENT	LEVEL	AVERAGE	MAXIMUM	MINIMUM	OBS.
2	01	1	75.8	88.0	66.5	709
2	01	3	77.5	89.0	70.0	712
2	01	4	79.0	93.0	69.0	718
2	01	6	78.6	91.5	68.0	717
2	01	7	79.0	92.0	68.0	717
2	01	9	79.3	90.5	70.0	720
			78.2	93.0	66.5	4293
2	03		80.0	94.0	74.0	720
2	04	6	75.4	81.0	68.0	717
2	04	7	75.6	81.0	68.0	717
2	04	9	76.3	81.5	68.5	720
			75.8	81.5	68.0	2154
2	05	1	90.0	100.0	49.0	717
2	05	3	85.0	100.0	43.0	712
2	05	4	88.0	100.0	54.0	717
2	05	6	87.0	100.0	54.0	717
2	05	7	87.0	100.0	56.0	717
2	05	9	88.0	100.0	59.0	720
			87.0	100.0	43.0	4300
2	07	1	3.0	39.0	0.0	718
2	07	3	2.0	31.0	0.0	718
2	07	4	1.0	20.0	0.0	718
2	07	6	1.0	20.0	0.0	718
2	07	7	1.0	21.0	0.0	718
			2.0	39.0	0.0	3590
2	08	1	80.9	95.4	68.0	419
2	08	2	81.5	94.0	68.0	419
2	08	3	77.8	89.5	68.0	419
2	08	4	91.1	120.5	68.0	419

Figure IV-6.

Example of Monthly Summary Derived from
a Tabular Print-out of Meteorological Data

ENVIRONMENTAL DATA BASE CODES

STATION	CODE
Albrook Forest	1
Chiva-Chiva Open	2
Ft. Sherman Jungle	3
Ft. Sherman Open	4
Rio Hato	5
SOIL SATELLITE SITES	
Albrook	6
Ft. Kobbe	7
Ft. Sherman	8
ELEMENT	
Temp., Dry Bulb	01
Temp., Min. Grass	02
Temp., Surface	03
Temp., Wet Bulb	04
Relative Humidity	05
Wind Direction	06
Wind Speed	07
WBGT Index	08
Barometric Pressure	09
Precipitation	10
Stem Flow	11
Evaporation	12
Clear-Vu Rain gages	13
TOWER LEVEL (meters)	
46.0	1
28.5	2
26.5	3
13.5	4
8.0	5
4.0	6
2.0	7
1.0	8
0.5	9
WBGT INDEX (08)	
Index	
Temp., Dry Bulb	
Temp., Wet Bulb	
Temp., Black Globe	

PRECIPITATION (10)	CODE
Chiva-Chiva Open	Blank
Albrook Forest	
46.0 meter	1
Under full Canopy	2
Under drip Canopy	3
Under open Canopy	4
STEM FLOW (11)	
Large Tree	1
Small Tree	2
Medium Tree	3
EVAPORATION (12)	
Chiva-Chiva Open	
Piche Evaporimeter	Blank
Standard Pan	1
Albrook Forest (Piche)	
46.0 meter	2
26.5 meter	3
13.5 meter	4
Surface	5
CLEAR-VU RAIN GAGES (13)	
# 1	1
# 2	2
# 3	3
# 4	4
# 5	5
# 6	6
# 7	7
# 8	8

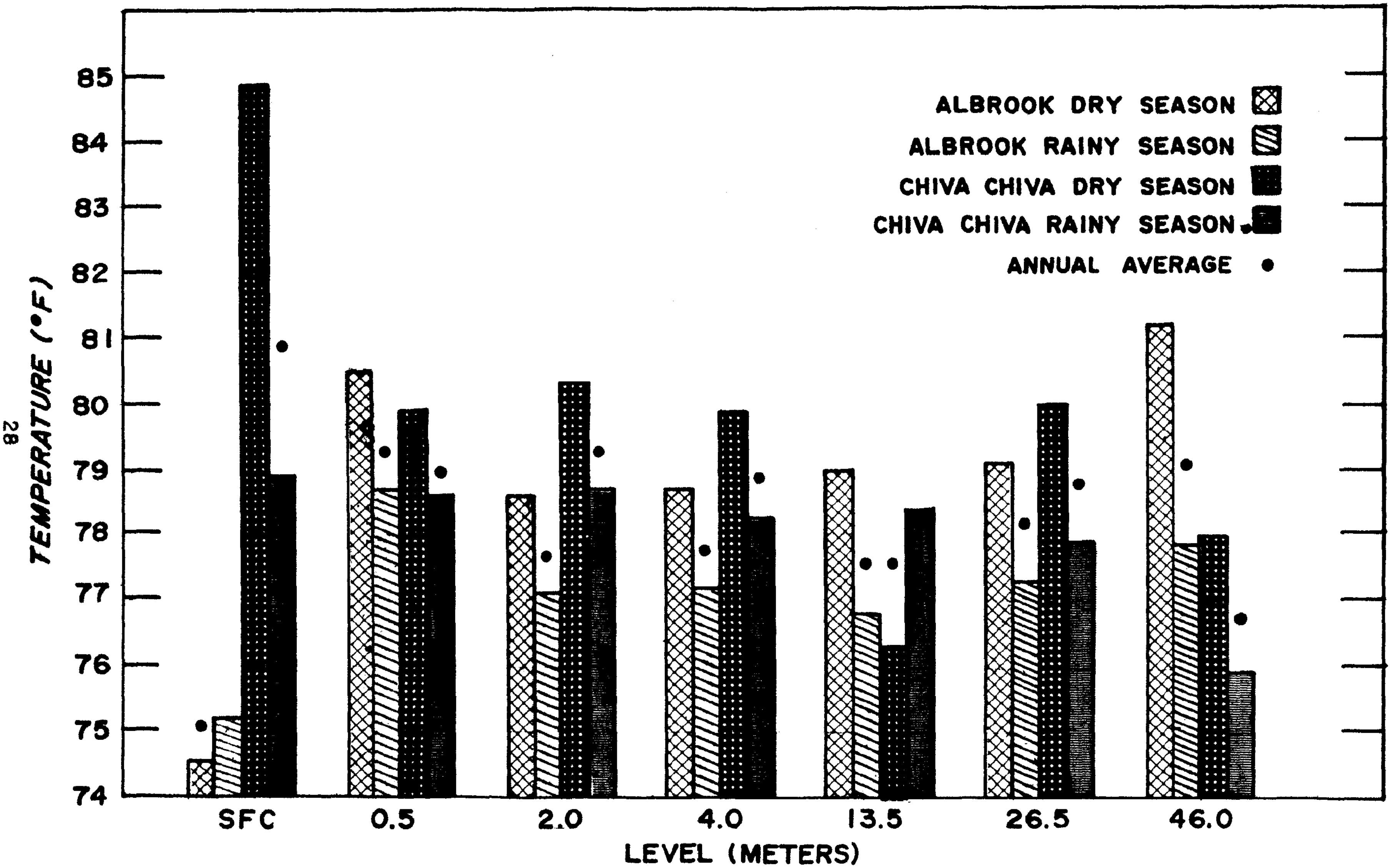
Figure IV-7
Identification Code to Accompany
Monthly Summary.

and as such have not been especially designed for use in the tropics. The effects of the environment on the operation of these instruments, and the deterioration of their component materials, create significant maintenance problems. For example, the extreme susceptibility of the hair elements of humidity sensors to biotic attack and consequent deterioration inhibits their response capability to such degree that weekly replacement may be required. Deterioration of thin sheet metals is so severe that instrument casings frequently fail, necessitating complete replacement. Moving parts may suffer fungal attack to the extent that motion is retarded and the efficiency of the instrument is impaired. The contact surfaces of moving parts may be so affected by corrosion that erratic operation or complete stoppage results, again necessitating replacement. These effects also increase the frequency of required calibration. In some instances where calibrations can normally be performed on location, the instrument must be removed to a controlled environment for correction. These maintenance and calibration problems multiply the number of maintenance personnel required as well as the inventory of spare parts and materials.

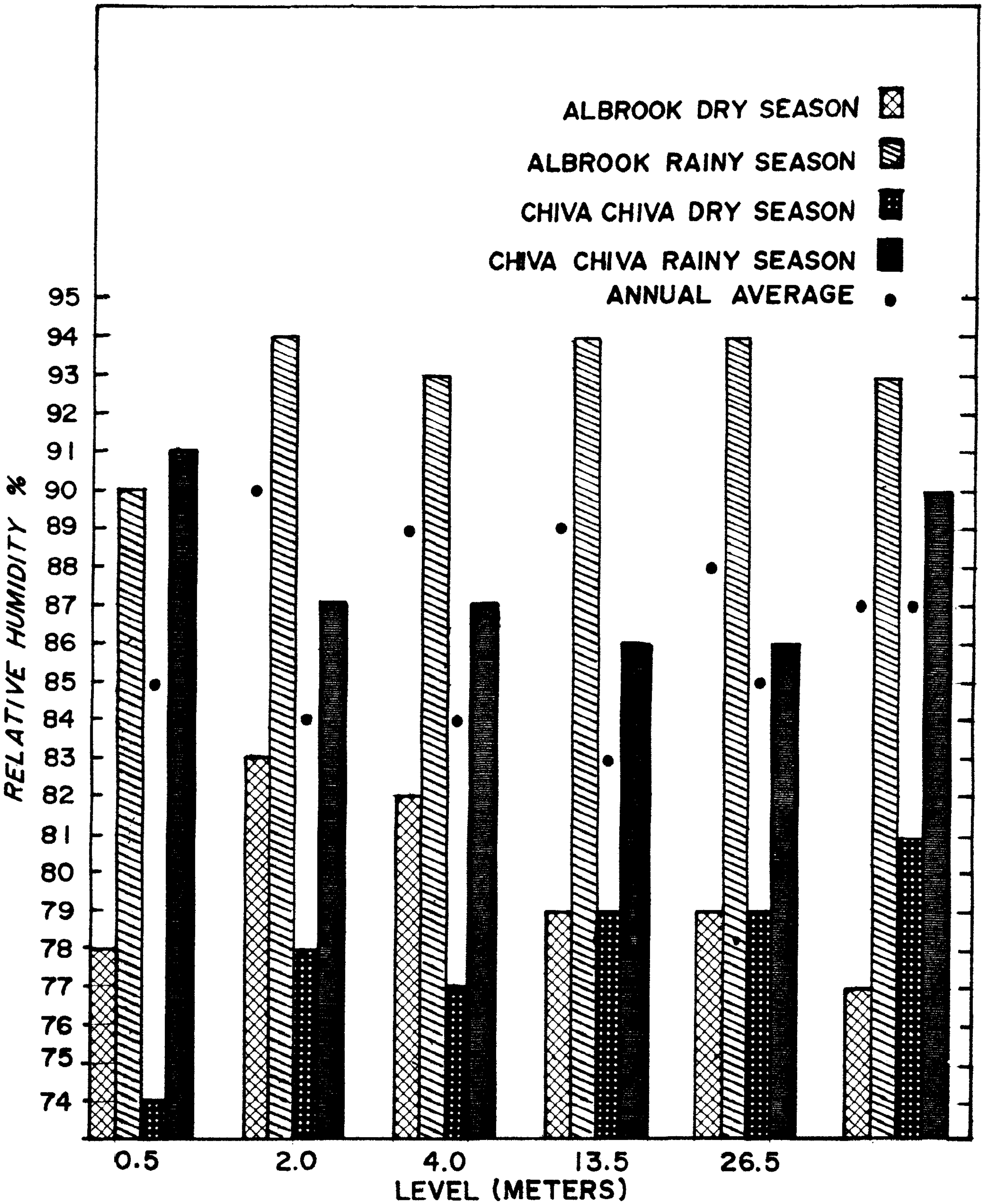
Data Analysis

41. The dense canopy of the tropical forest effects the meteorological factors immediately above it, as well as significantly modifying those within and below it, through impeding air movement, evaporation, insolation, and precipitation. Figures IV-8, IV-9, and IV-10 illustrate some of the effects caused by the canopy on such elements as temperature, humidity, and precipitation, particularly in the vertical plane. The data obtained at the open observation site assist in delineating these effects. Figures IV-8 and IV-9 clearly show the consistency of higher humidities and lower temperatures below the canopy (the canopy top is at the 26.5 meter level). Figure IV-10 shows the results of the measurements of rainfall penetrating the forest canopy as compared to the actual rainfall occurring above the canopy and at the open sites. It is interesting to note that, although the 11 rain gages below the canopy were selectively emplaced, the amount of rainfall recorded there is greater than that in the open. This apparent contradiction is probaly explained by the low number of sampling points under the canopy, where the distribution of precipitation is disturbed and irregular. An increased number of rain gages will be installed as soon as the instruments can be procured. Figure IV-11 shows the monthly rainfall measured in the open at both the forest and open sites. It also shows the differences in the amounts that occur over short distances.

42. Table IV-3 shows the number of occurrences of a diurnal temperature fluctuation (the range of maximum to minimum) of less than 5 F at the 0.5 and 2-meter levels in the forest environment. With an annual average temperature range of 15.1 F at the 0.5-meter level and 17.4 F at the 2-meter level, the percentage of occurrence of less than 5 F is 8 percent and 3 percent respectively. The average annual ranges for the same

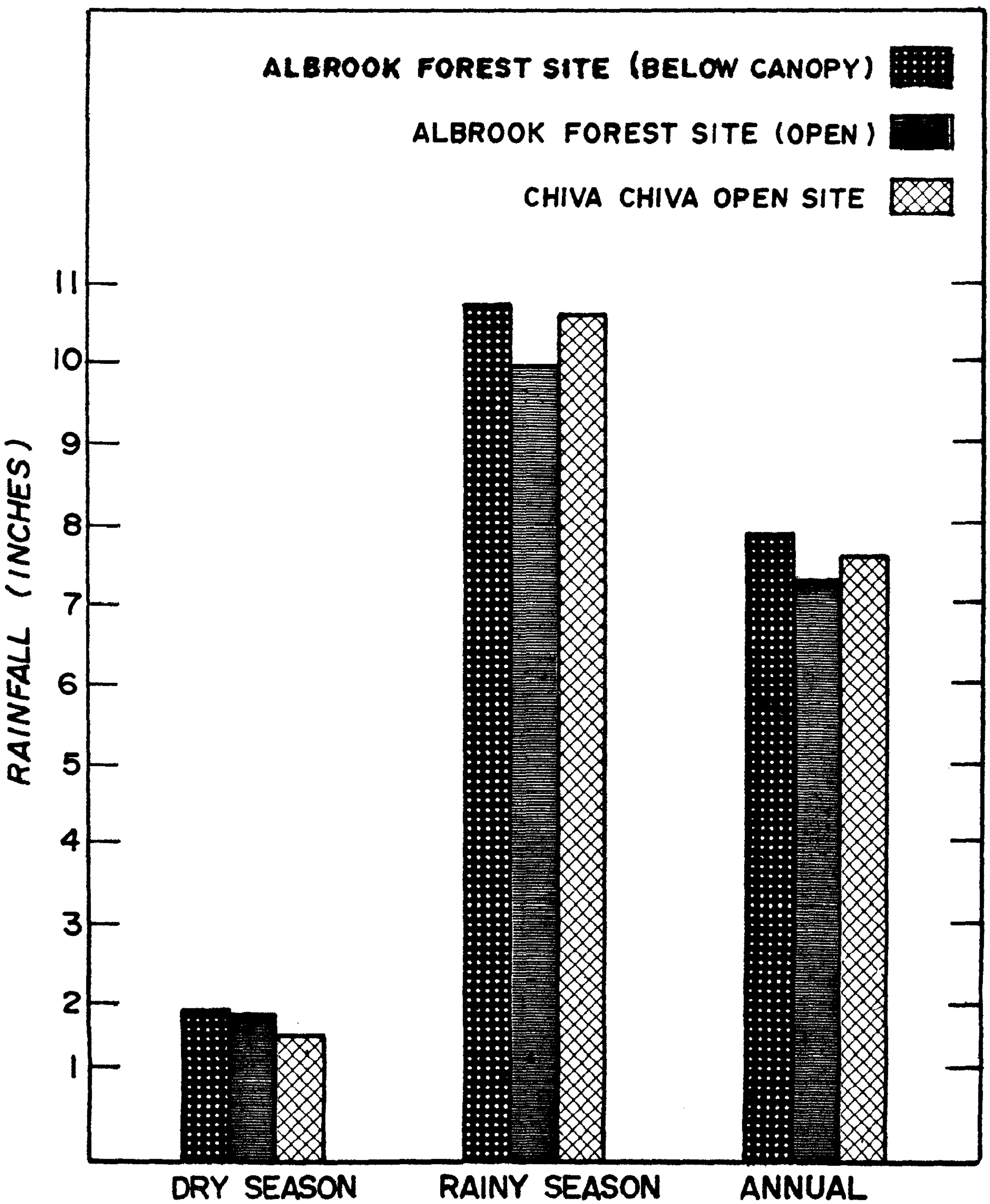


SEASONAL VARIATION OF AVERAGE TEMPERATURE
FIGURE IV-8



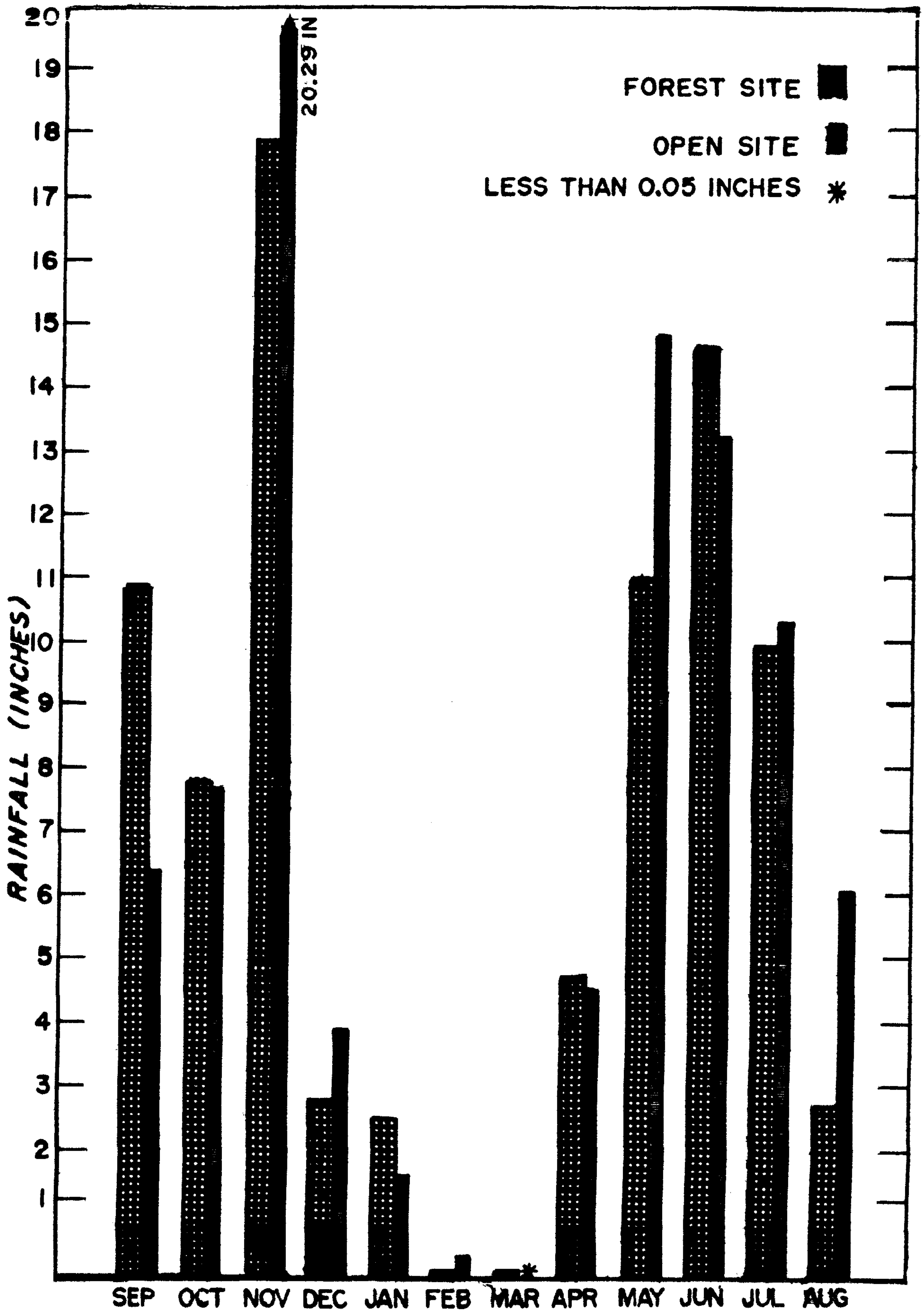
SEASONAL VARIATION OF AVERAGE RELATIVE HUMIDITY

FIGURE IV-9



SEASONAL VARIATION OF AVERAGE RAINFALL

FIGURE IV-10



MONTHLY RAINFALL FOR ONE YEAR AT THE
ALBROOK AND CHIVA CHIVA SITES
FIGURE IV-11

Table IV-3. OCCURRENCE OF DAYS WITH LOW FLUCTUATION OF TEMPERATURE ($\prec$ 5 F) AT NEAR-GROUND LEVELS (0.5 & 2 m), ALBROOK FOREST SITE

Day	Temp. Fluctuation 0.5 m	Temp. Fluctuation 2 m	Avg. Temp.	Avg. Rel. Hum.	Rainfall (inches)
14 Sep 65	3.7	5.9	77.4	94	None
22 Sep	4.5	6.7	77.4	95	1.98
25 Sep	2.5	4.8	77.9	96	0.45
26 Sep	3.2	3.7	76.5	95	1.97
29 Sep	4.4	6.5	76.9	95	0.11
8 Oct	4.5	7.5	77.2	94	1.09
9 Oct	2.0	2.5	76.5	93	0.74
13 Oct	4.0	7.5	77.5	95	0.14
16 Oct	3.5	4.8	78.1	94	0.03
18 Oct	3.0	4.5	76.6	94	0.07
19 Oct	3.5	4.9	77.2	95	0.68
3 Nov	3.7	5.7	77.1	94	0.08
4 Nov	4.8	7.5	76.8	93	None
5 Nov	4.5	6.5	78.3	94	0.08
6 Nov	4.0	5.7	77.1	90	0.03
16 Nov	3.7	5.0	78.3	97	0.05
19 Nov	8.2	4.8	77.4	92	0.06
24 Nov	4.7	3.8	76.0	99	2.02
27 Nov	1.7	3.5	75.7	96	2.65
28 Nov	4.0	6.9	76.2	97	3.80
19 Dec	4.6	7.8	79.0	92	None
23 Apr 66	3.5	4.7	76.6	94	1.42
7 May	4.5	5.3	78.6	94	0.01
13 May	4.5	6.0	77.5	91	0.02
18 May	4.8	7.5	78.9	94	0.08
2 Jun	5.0	3.6	75.6	96	0.06
3 Jun	7.0	4.5	76.8	97	0.16
12 Jun	3.5	6.0	77.0	95	0.40
24 Jun	4.5	5.0	78.8	94	None
25 Jun	4.5	5.8	77.3	95	0.45
6 Jul	4.0	4.2	78.1	93	None
31 Jul	4.5	6.0	77.4	94	None

No occurrence in January, February, March, and August levels in the open environment are 23.4 F and 24.7 F respectively. This particular analysis is an example of Data Base information that was used in support of a specific test project.

43. Table IV-4 shows the average wind speeds at the indicated levels for the forest and the open sites. The number of levels at the forest site is limited because wind instruments with the sensitivity necessary to measure the very light winds below the canopy were not available. This condition will be alleviated upon receipt and installation of a new data acquisition system. The indicated variations of wind speed lie within the expectable trend; however the magnitude of the differences shown appears large. Further data are needed to verify and amplify the results here presented. Figure IV-12 shows the percentage distribution (relative to rainy and dry season) of wind direction occurrence at the 46-meter level at the forest site and the 4 and 46-meter level at the open site. The predominance of the north and northwesterly components of the wind at these two sites is graphically shown. To be noted also is the over-all high frequency of calms, as well as their relatively lower frequency during the dry season at the open site.

44. The conclusions presented here are based solely on the data for one year and must be considered only as preliminary indications. Much more data must be collected to make possible any definitive characterization of the micrometeorological regimes of the Canal Zone.

TABLE IV-4. AVERAGE WIND SPEED (MPH), ALBROOK FOREST SITE, 1965.

Height (meters)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
46.0	2	3	3	2	1	1	1	2	2	2	1	2
26.5	1	2	2	2	1	1	1	1	C	C	C	C
						Chiva Chiva Open Site						
46.0	10	15	13	8	2	3	2	6	6	4	NI	8
26.5	7	10	10	6	2	2	2	4	2	2	2	4
13.5	5	8	8	6	2	1	1	4	2	2	2	4
4.0	3	5	5	3	1	1	1	3	2	2	2	3
2.0	3	5	5	3	1	1	1	1	1	1	1	3

C= Calm NI= No Instrument

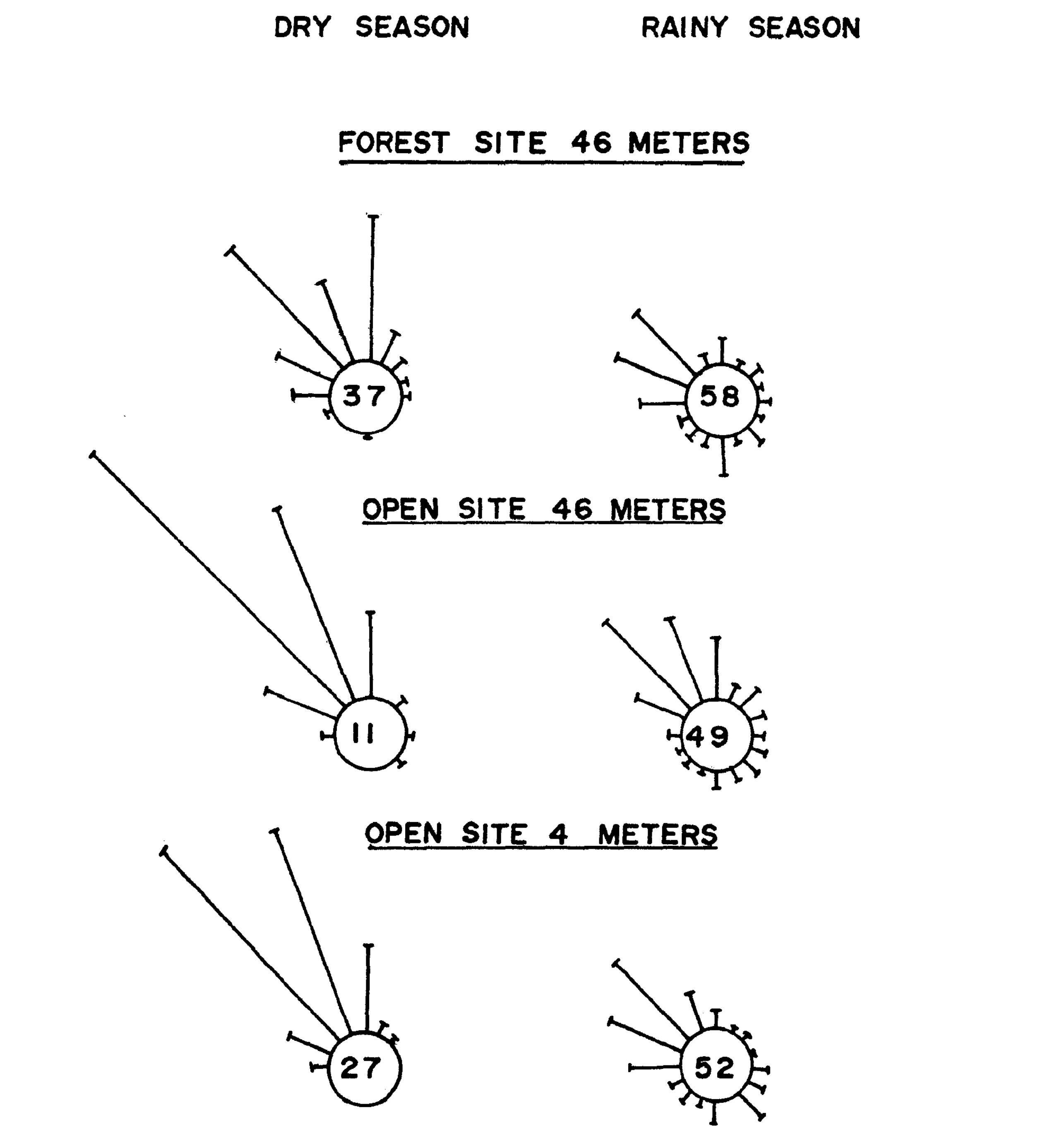


FIGURE IV - 12 PERCENTAGE FREQUENCY WIND DIRECTION

SCALE: ⟋ = 10%

% FREQUENCY OF CALMS = VALUE IN CIRCLE

PART V. SOILS AND HYDROLOGY*

Introduction

45. The soils and hydrology task of the Data Base project encompasses four integrated data-gathering phases connected with studies of soil trafficability. These phases are: (1) soil-strength measurements, (2) soil sample measurements, (3) soil temperature and moisture measurements, and (4) groundwater level measurements.

46. A general test plan was prepared in mid-1964 outlining the equipment to be used, instructions for site layout, and procedures and techniques to be followed for collecting the soil information. The plan followed the system of soil testing as developed by US Army Engineer Waterways Experiment Station (WES)**.

47. After the Albrook Forest and the Chiva Chiva sites were selected a soil plot was laid out at each according to the scheme shown in Figure V-1. The plot was a rectangle (45 x 25 ft) with the longer dimension parallel to the slope of the ground. It was divided along the main axis into three 15-foot blocks, with each block in turn subdivided into 60 sampling plots two and one-half feet on each side. A weekly testing schedule was prepared for randomized sampling of each plot. Sampling at the two sites began in February 1965 and has continued to date without interruption.

48. In addition to the main sites, sampling also has been conducted at three satellite sites which are located near the Albrook Forest site, at Fort Kobbe, and at Fort Sherman. Sampling at these sites was conducted by WES during its 1962-63 environmental observations in the Canal Zone as a part of the Military Evaluation of Geographic Area (MEGA) project. Each of the sites was equipped with automatic rain gages, hygrothermographs, and groundwater wells during the WES program, and similar instruments were installed when the sites were reactivated for the Data Base project. Sampling at two-week intervals began in March 1965 and has continued without interruption to the time of this report.

Data Collection

49. The first year of operation has been almost entirely devoted to the collection and reduction of field data. Sufficient amounts of information have been accumulated from each site to begin the characterization of the soils at these places. Table V-1 summarizes the types of data currently collected and their scheduling at the various sites.

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* This section has been prepared by Mr. Ricardo Ah Chu, Soils Scientist, USA Tropic Test Center. Soils work was carried out in general conformance with the 480 Series of the Project Memoranda.

** "Plan of Tests: Tropical Soil Studies in Panama and Puerto Rico", Waterways Experiment Station, Vicksburg, Miss., January 1962.

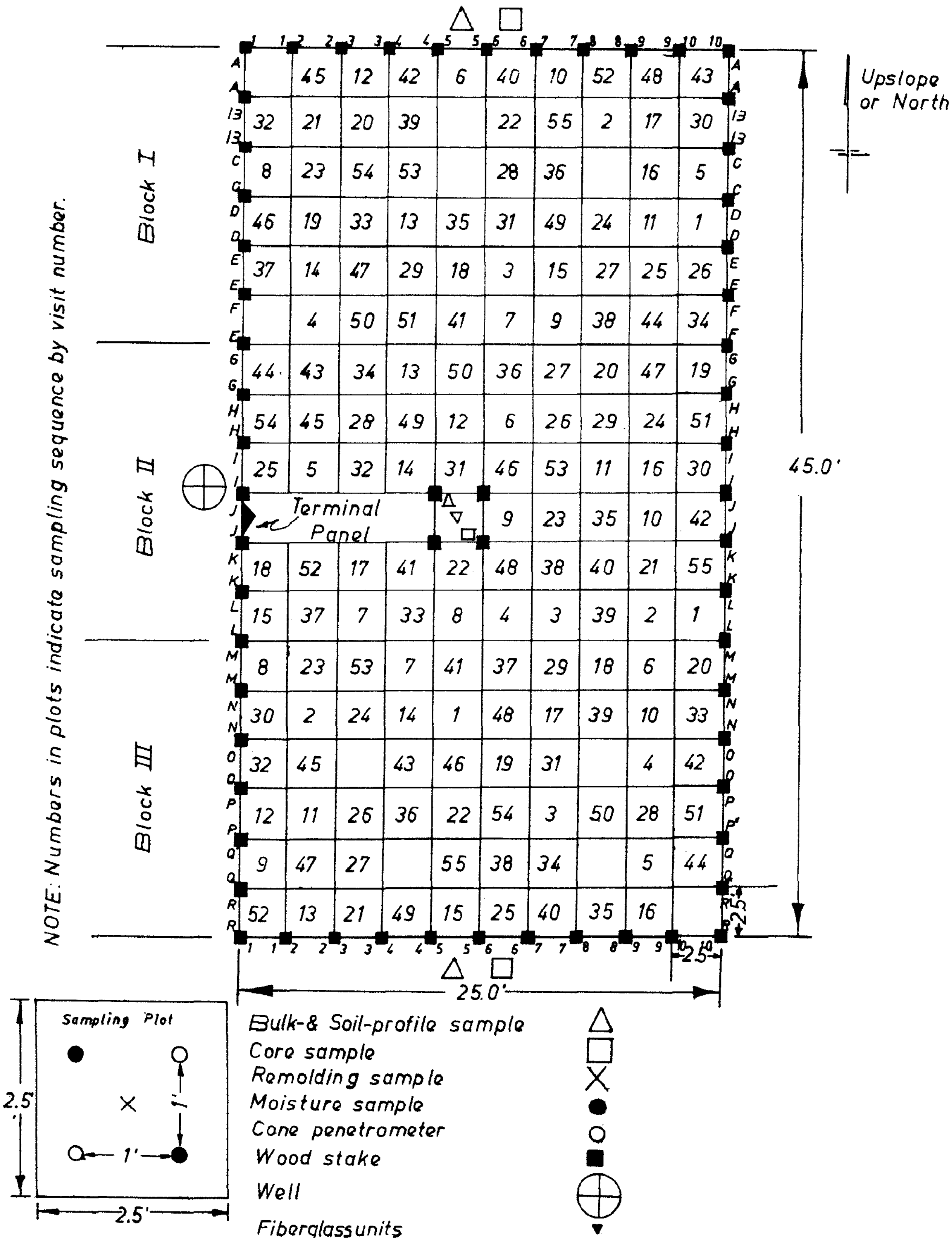

Figure V-1. Soil Test Plot

TABLE V-1. SOIL DATA COLLECTION

Sites	Type of Data and Frequency								
	Strength		Soil Sampling			Soil temperature & Moisture		Grounwater Level	
	Cone Index	Remolding Index	Moisture Content & Density	Bulk density & Moisture Tension	Chemical & Physical Analysis*	Electrical Resistance	Telethermometers	Manual	Automatic
Albrook (Forest)	6/week 0-18"	3/week 6-12"	6/week 0-18"	One time 0-18"	One time 0-18", plus genetic layers	Hourly (2 tiers) 4-100 cm (8 depths)		4/day	None
Chiva Chiva (Open)	6/week 0-18"	3/week 6-12"	6/week 0-18"	"	"	Hourly (1 tier) 4-100 cm (8 depths)	24/day (1 tier)	4/day	None
Satellite**	2/bi-weekly 0-18"	2/bi-weekly 6-12"	2/bi-weekly 0-12"	"	"	None	None	None	Continuous

*Physical Analyses'
Atterberg limits
Specific gravity
Water tension at 3 and 15 atmospheres
Grain size distribution

*Chemical Analyses
Nitrogen
Phosphorous
Potassium
Calcium
Minor elements
Base exchange capacity
Organic matter content

**Satellite Sites
Fort Kobbe
Albrook Forest
Fort Sherman

Soil Strength Measurements

50. Two basic field measurements are made: cone index and remolding index. A third parameter, rating cone index, is computed from the two basic indices. The basic indices are measured with the cone penetrometer which is a field instrument developed at WES and consisting of a 30 degree cone of 0.5 square inch basal area attached to the lower end of a staff, with a proving ring, micrometer dial, and a handle at the upper end. The force required to move the cone slowly through a specified plane, on the surface of, or within the soil is measured on the dial inside the proving ring. This dial reading, the cone index, is an indicator of the shearing resistance of the soil in that plane. Though it closely approximates pounds per square inch, it is considered as a dimensionless number.

51. Cone index. Six sets of measurements taken at the surface and at three-inch increments to a depth of 18 inches are made once each week at each of the main environmental sites. Measurements at the satellite sites are made in sets of two, once every two weeks.

52. Remolding index.* Three remolding tests are performed on a sample obtained from the 6-to 12-inch layer at each main environmental site weekly. In the satellite sites two tests are performed bi-weekly. A standard, manually operated trafficability sampler is used to collect the required sample when possible. A modified sampler, forced into the ground with a heavy hammer, is used when soil conditions prohibit the use of the standard device.

Soil Sample Measurements

53. This phase involves the collection of different types of soil samples for laboratory determination of moisture content, density, and various physical and chemical properties.

54. Moisture content and density. Moisture and density samples are collected each week concurrently with the strength measurements at each main environmental site. Six levels are sampled, at three-inch increments, to a total depth of 18 inches. Six replicate samples from each level are collected in sets of two from a randomized sampling plot for each of the three blocks composing the test plot (see Figure V-1).

55. At the satellite sites moisture and density samples are collected once every two weeks concurrently with the strength measurements. Four levels are sampled, at three-inch increments, to a total depth of 12-inches. Four replicate samples from each level are collected in sets of two from two points picked at random within a 20-meter diameter circular plot.

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* The remolding index is a ratio which expresses the change of soil strength occurring under repetitive mechanical stress.

56. All samples are collected with the standard trafficability sampler when feasible. When the soil is too firm for the proper employment of the sampler, a soil àuger or an Oakfield punch is used to obtain samples for moisture-content determination only. All density samples are collected with the standard trafficability sampler.

57. Soil moisture content is determined by differential weighing of soil samples before and after oven-drying. The procedure is termed "gravimetric", a specialized use of the term, justified by precedent in soil literature. Dry density is computed only for core samples obtained with the trafficability sampler on a dry weight basis.

58. Bulk density and moisture tension. Soil cores, taken with a San Dimas or drive type sampler, are to be obtained once at each test site for laboratory determination of bulk density and water tension at 0 and 0.06 atmospheres. Samples will be taken at three-inch increments to a depth of 18 inches.

59. Chemical and physical analyses. Bulk soil samples of each three-inch incremental layer as well as each of the genetic layers of the natural soil profile are to be obtained once at each test site for physical and chemical analyses. The physical analyses to be determined are Atterberg limits, specific gravity, water tension at 3 and 15 atmospheres, and a grain-size distriuution. The chemical analyses will include determination of organic matter content, nitrogen, phosphorous, and potassium levels; calcium, and minor elements, as well as the base exchange capacity.

Soil Temperature and Moisture Measurements

60. Soil moisture and soil temperature measurements are made with the fiber glass units and the soil moisture meter developed by the California Forest and Range Experiment Station and manufactured by Soiltest Incorporated. These devices indicate soil moisture and temperature indirectly by the measurements of the changes in the electrical resistance of the fiber glass units which are buried in the ground. Measurements are taken at each main environmental site from eight different depths, indicated in centimeters: 4, 11, 19, 27, 34, 42, 50, and 100. The resistance obtained from each unit is in turn correlated with actual moisture content of the soil derived from gravimetric measurements from which calibration curves are constructed. Readings at each observation site are obtained four times daily at 0000, 0600, 1200, and 1800 hours. Three tiers of fiber glass units are being operated: one at Chiva Chiva and two at the Albrook Forest site. No measurements are made at the satellite sites.

61. Because of the unsatisfactory performance of the thermal element in the fiber glass units during part of this reporting period, telethermometer probes have been installed at the Chiva Chiva site at the same levels as the fiber glass units to measure soil temperature. Telethermometer probes will also be installed at the Albrook Forest Site.

Groundwater Level Measurements

62. Collection of groundwater level information is performed by manual and automatic means. At the two main environmental sites, manual procedures for measuring the groundwater level fluctuations are employed. A galvanized perforated casing, 48 inches deep, and three inches in diameter, is used as a measuring well into which a graduated wooden rod is inserted at the time of observation. Measurements are taken four times daily at 0000, 0600, 1200, and 1800 hours.

63. Prior to the installation of automatic water-level recorders, measurements of groundwater at the satellite sites were performed manually once a week using a steel tape to measure the distance between the ground surface and the upper level of the groundwater. The recorders were installed in late November 1965 and have functioned satisfactorily to date.

Analysis of Data

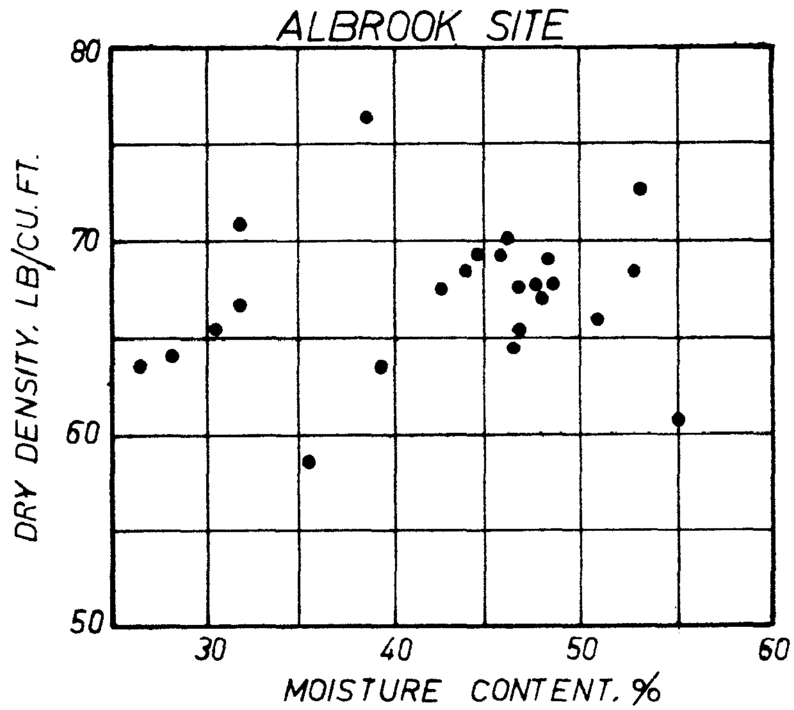
64. Limited analyses of data were made during the period covered by this report. Expansions of these analyses are planned and will be reported in future semiannual reports as well as special reports. Some of the data used were collected before the start of the reporting period. Some relations have been plotted for these data and a tentative comparison made between WES (1963) and TTC (1965) moisture content and soil strength data. The WES data were collected from a soil plot located in the vicinity of the Albrook main observation site.

Moisture Content vs. Dry Density Relations

65. Moisture content and dry density data for the 0 to 6, 6 to 12, and 12 to 18-inch depths have been plotted for the Albrook and Chiva Chiva main observation sites (Figures V-2, V-3, and V-4). The relation for each separate six-inch layer at both main observation sites is not well defined as the data are scattered and do not follow a uniform trend. Density appears to be practically unaffected by changes in moisture content within the range studied. However, if the three separate density-moisture curves are combined into a 0 - 18-inch layer composite curve as shown in Figure V-5, the expected linear relationship between both parameters becomes more apparent. Moreover, the soils at the Albrook main observation site appear to exhibit a separate dry and a wet season density-moisture relationship; there is a definite difference in the trend of the data plotted between 25 and 35 percent soil moisture content from those plotted beyond the 35 percent moisture content. As the profile is penetrated there is a tendency for the dry density to rise. This may be due mainly to the compaction exerted by the weight of the overlying layers and the lower degree of aggregation of the soils at these lower depths.

Moisture Content vs Strength Relations

66. Cone index, remolding index, and rating cone index are the



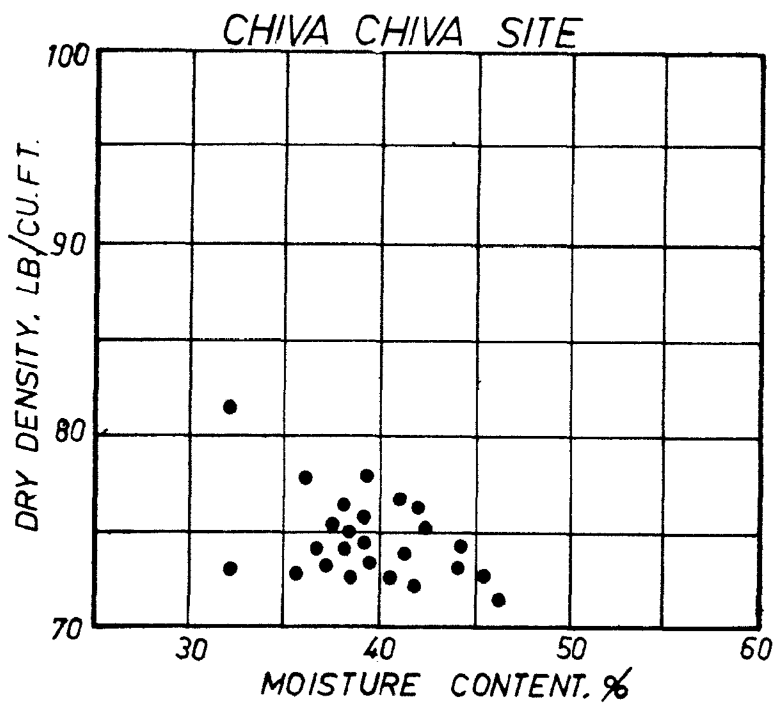
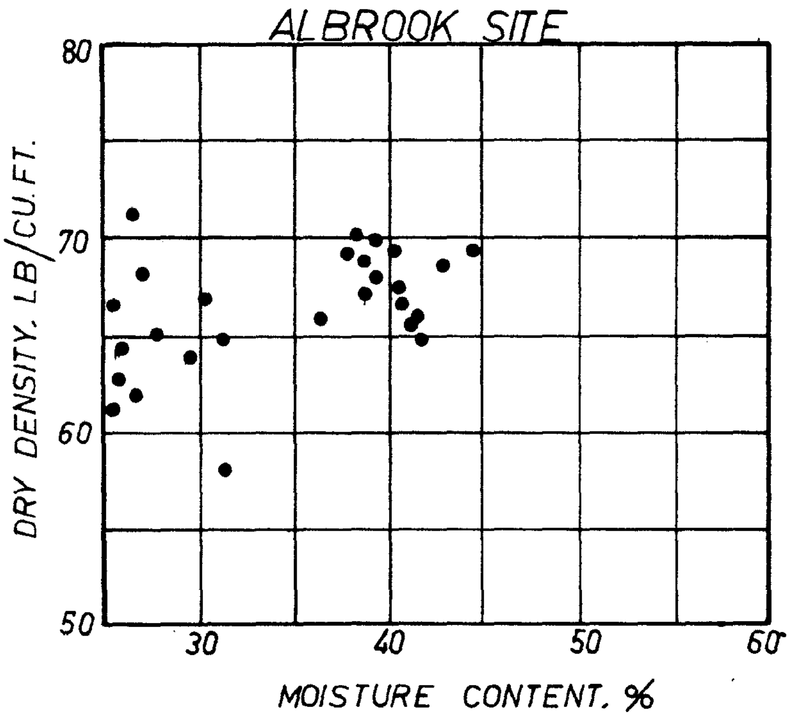


FIGURE V-2. MOISTURE CONTENT VS. DRY DENSITY 0-6-IN. LAYER.



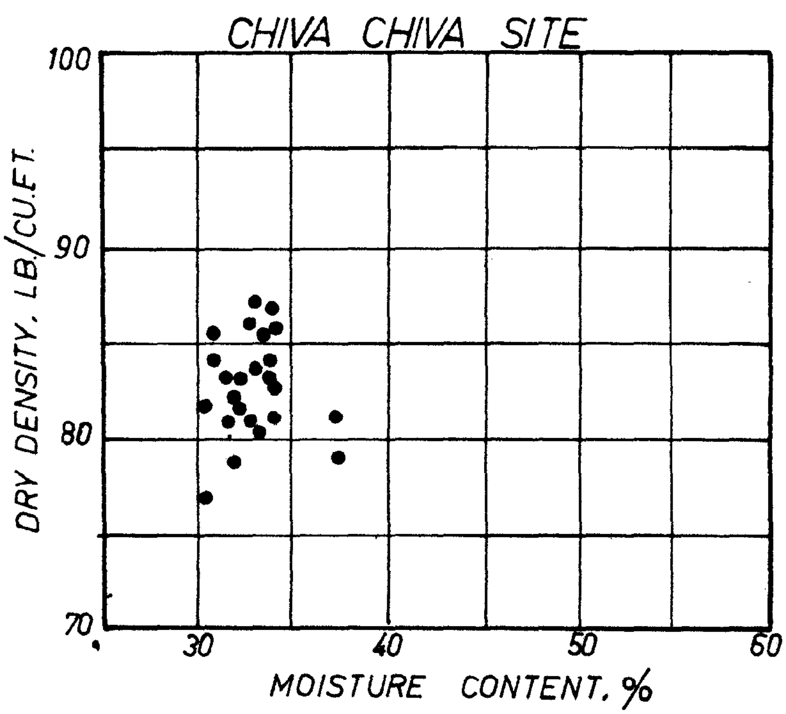
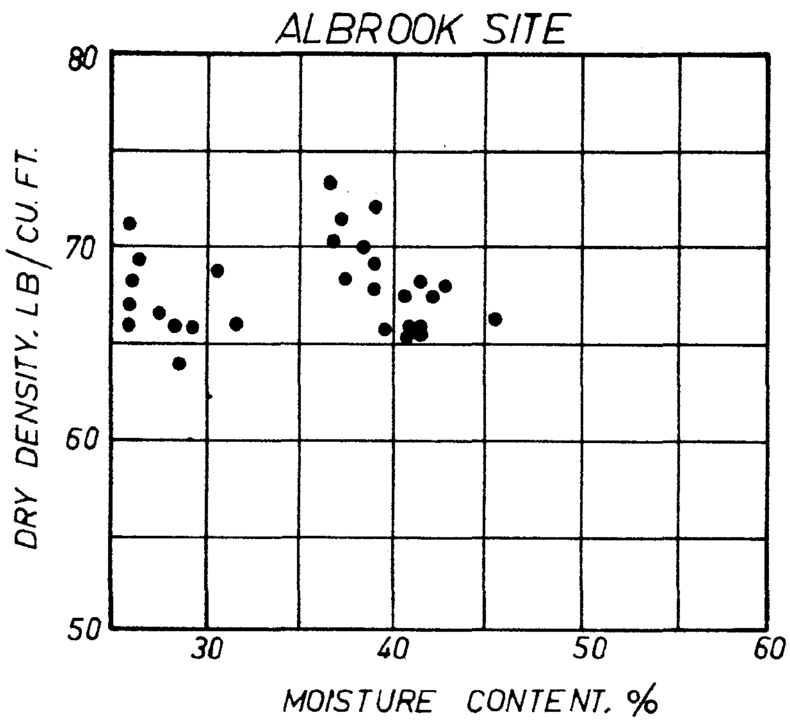


FIGURE V-3. MOISTURE CONTENT VS. DRY DENSITY 6-12-IN. LAYER.



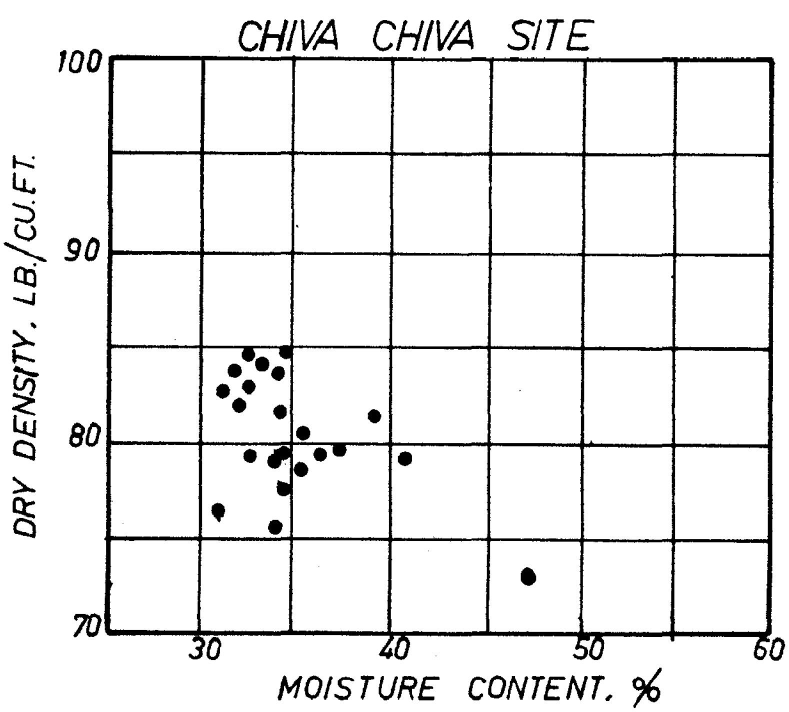
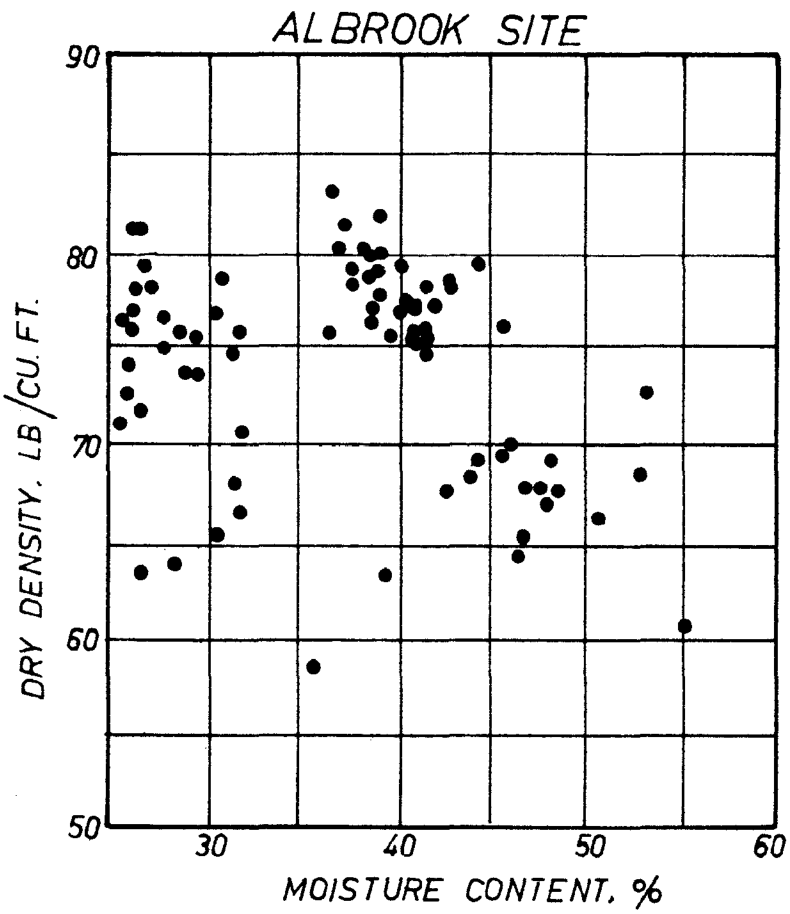


FIGURE V-4. MOISTURE CONTENT VS. DRY DENSITY 12-18-IN. LAYER.



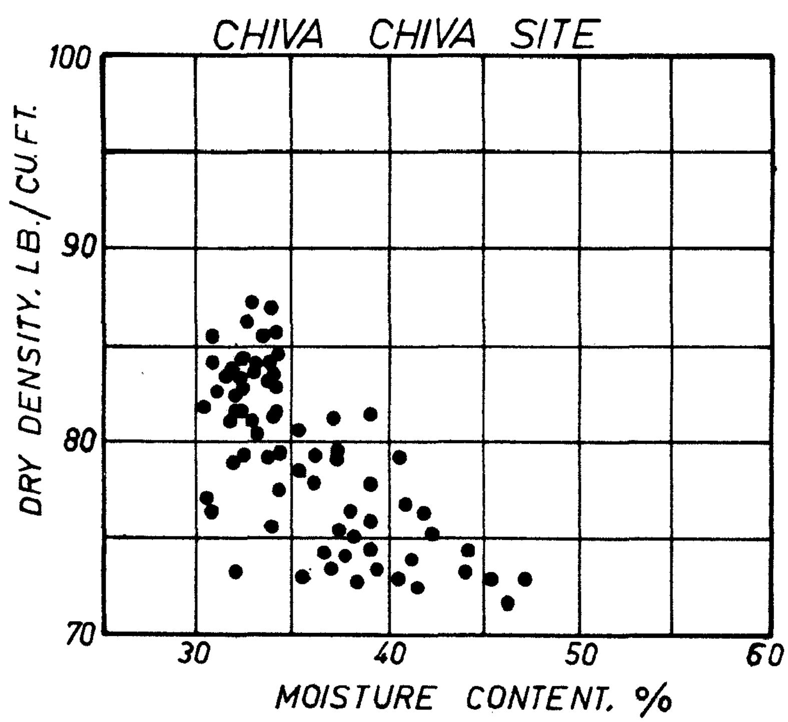


FIGURE V-5. MOISTURE CONTENT VS. DRY DENSITY COMPOSITE FOR THE 0-18-IN. LAYER.

measurements used to express soil strength. Only two measurements, cone index and remolding index, have been plotted against moisture content for each main observation site.

67. Moisture content vs. cone index. Figures V-6 and V-7 summarize some of the relations between moisture content and cone index. In general, there is a decrease in strength with increase in moisture content. In addition, the data obtained at high moisture content tends to follow a more consistent distribution than those obtained at the low moisture range. The 6 to 12-inch layer seems to be more sensitive to changes in moisture content, as suggested by the steepness of the curve, than the surface to 6-inch layer.

68. Moisture content vs. remolding index. The moisture content is plotted against the remolding index data in Figure V-8. A large amount of spread is observed in the Albrook data, particularly at the lower moisture range. Remolding indices do not vary consistently with changes in moisture content. At a given moisture content, remolding indices may go from very low to very high. At the Chiva Chiva site also the data do not show a definite relationship, but a general trend of a decrease in strength with increasing moisture content is observed.

TTC-WES Data Correlation.

69. Summary curves developed from moisture content and cone index data obtained by WES in the Canal Zone in 1962-63 for the MEGA project, and TTC in 1965 for the Data Base project are shown in Figures V-9, V-10, and V-11. The correlation coefficients determined for each set of data are as follows:

Cone Index	Correlation Coefficient	Moisture Content	Correlation Coefficient
0 - 6 in.	0.80	0 - 6 in.	0.90
6 - 12 in.	0.78	6 - 12 in.	0.84
12 - 18 in.	0.89	12 - 18 in.	0.85

These coefficients show good agreement between the methods. Moisture-strength relations exhibited by both sets of data are very similar and tend to follow the same general trend.

Soil Temperature Data.

70. The limited readings so far collected from telethermometer sensors at the Chiva Chiva site indicate that the trend of daily temperature fluctuation is about constant from day to day for each of the layers measured. The surface to 11-cm depth is the most susceptible to temperature fluctuation during the day. Average low temperature readings of 79F for the 4-cm depth and 80F for the 11-cm depth are reached at about 0700 and 0800 respectively; average high readings of 85F and 83F are reached

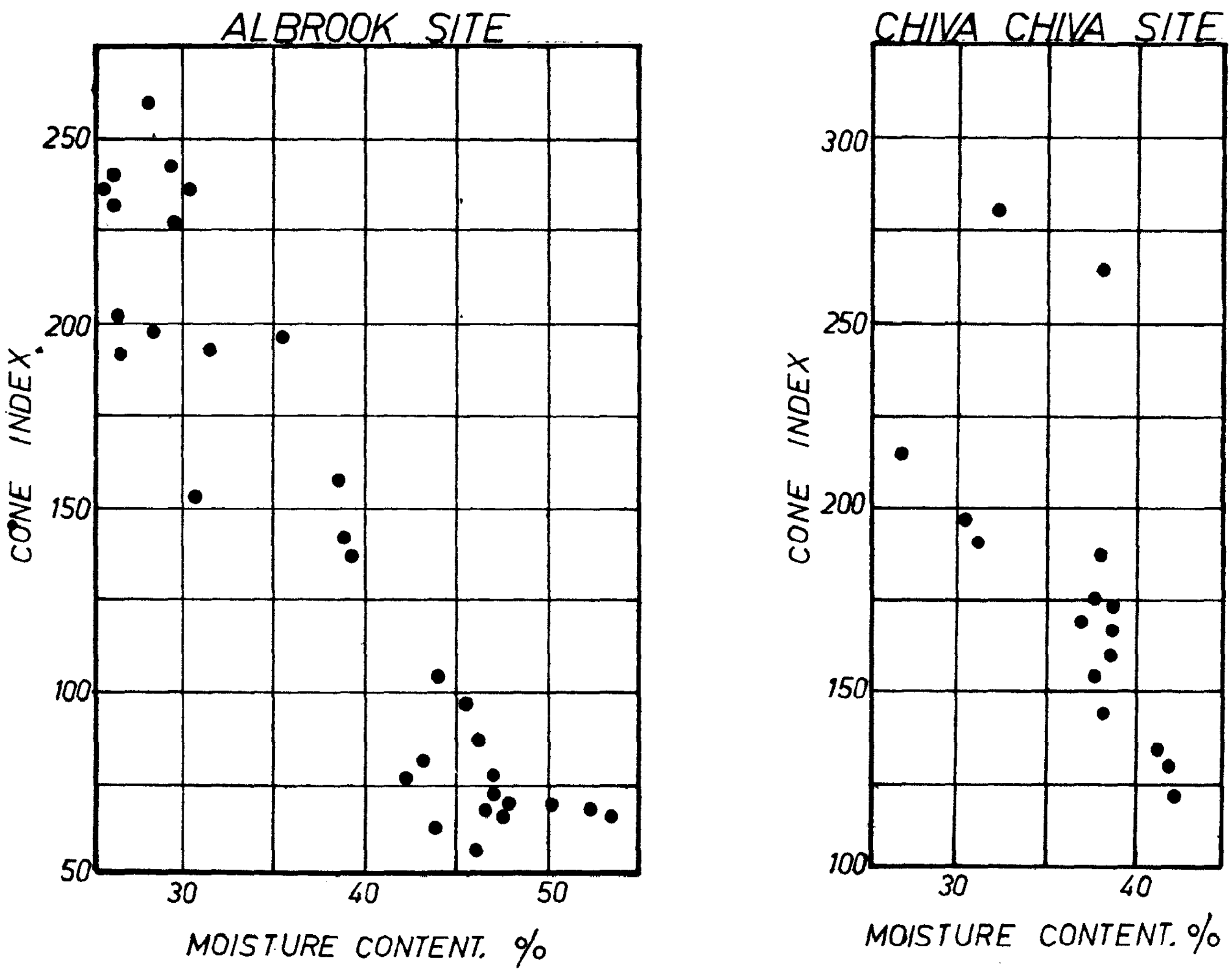


FIGURE V-6. MOISTURE CONTENT VS. CONE INDEX
0-6-IN. LAYER.

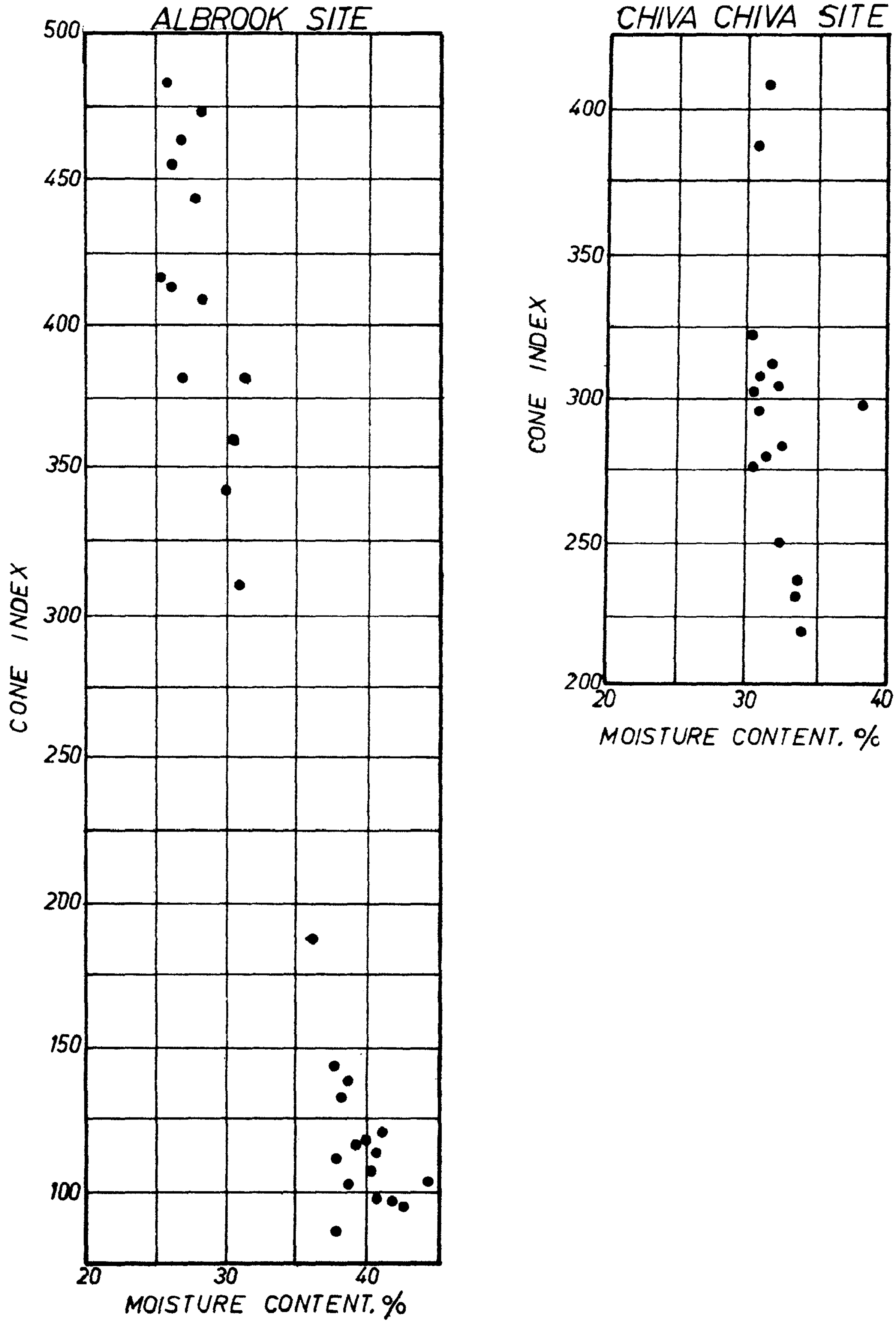


FIGURE V-7. MOISTURE CONTENT VS. CONE INDEX
6-12-IN. LAYER.

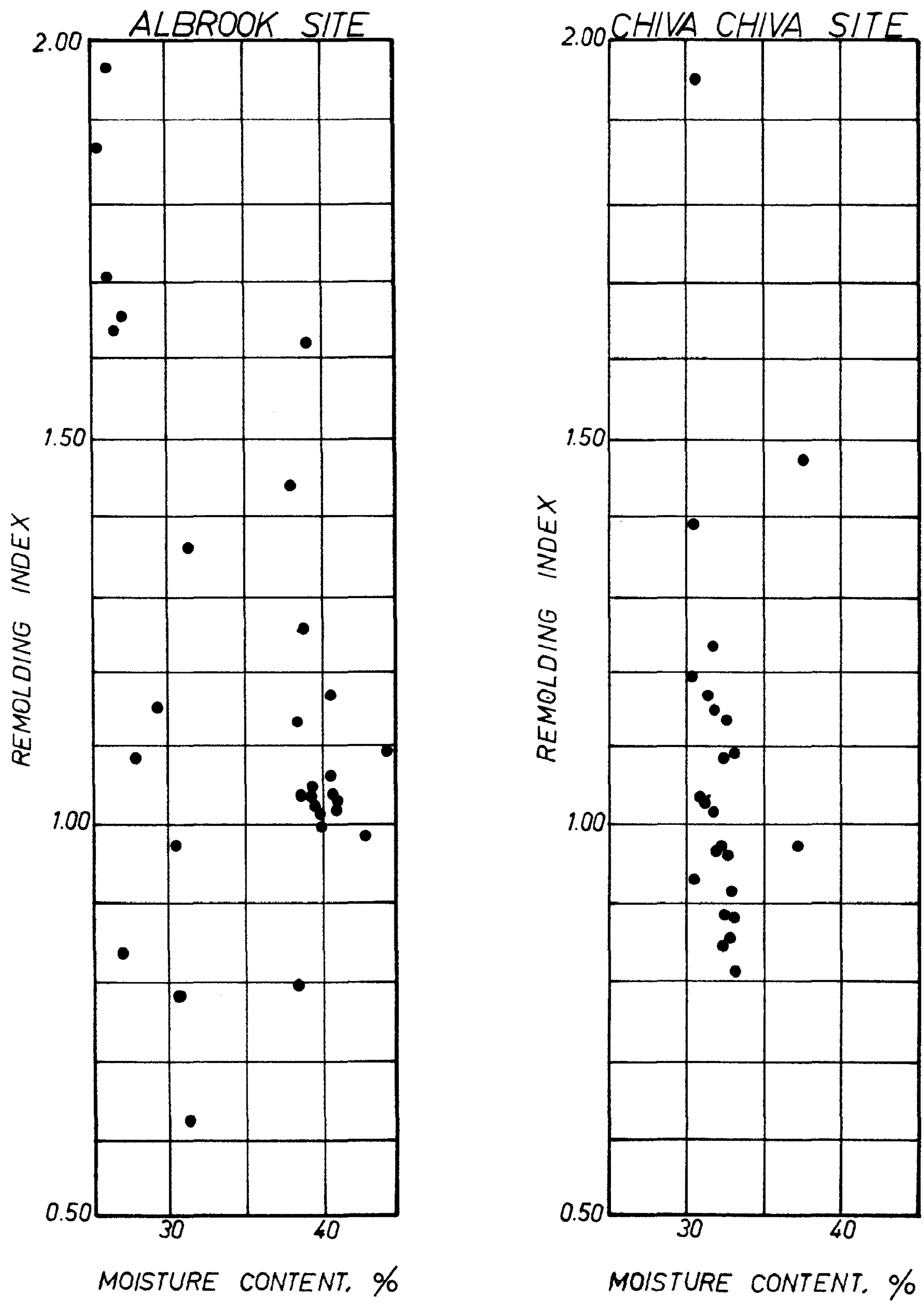


FIGURE V-8. MOISTURE CONTENT VS. REMOLDING INDEX
6-12-IN. LAYER.

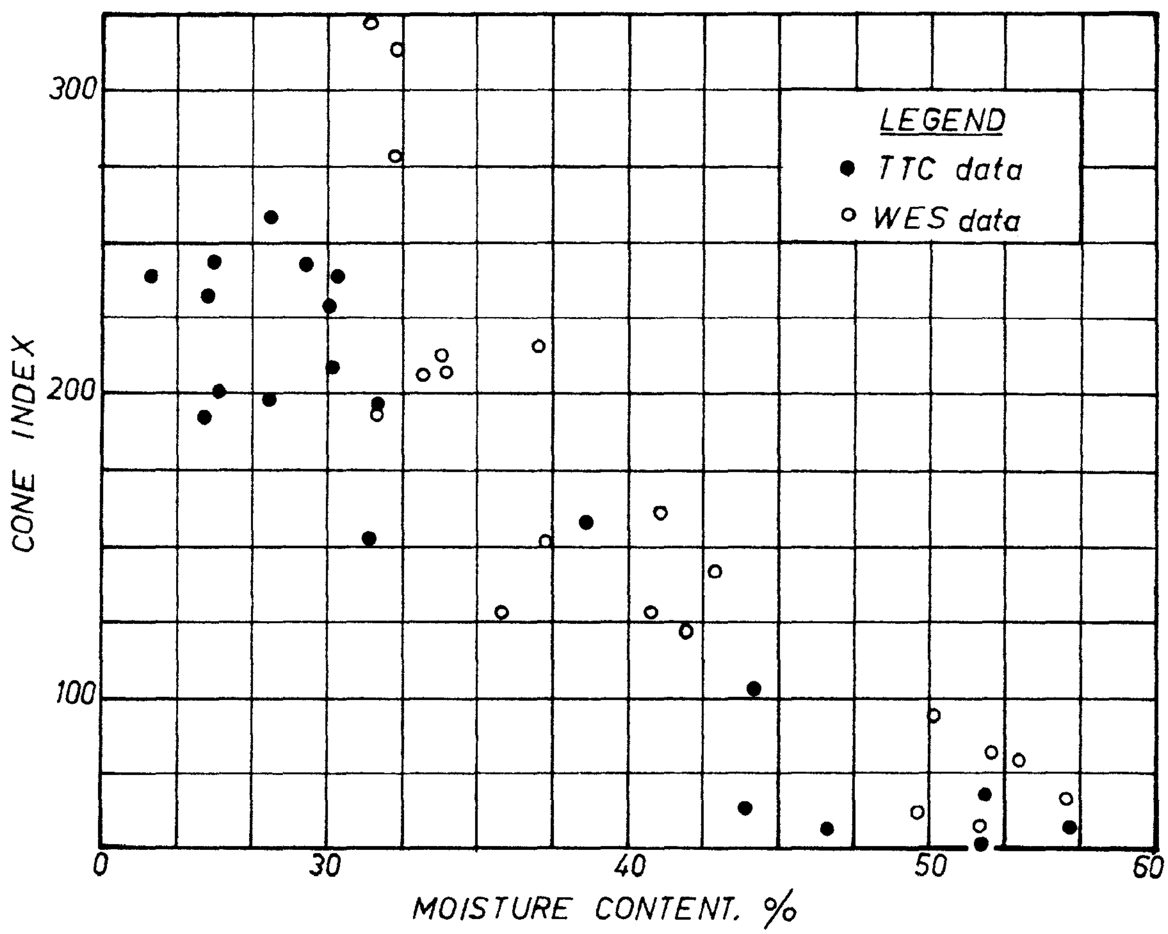


FIGURE V-9. COMPARISON OF TTC AND WES DATA
0-6- IN. LAYER.

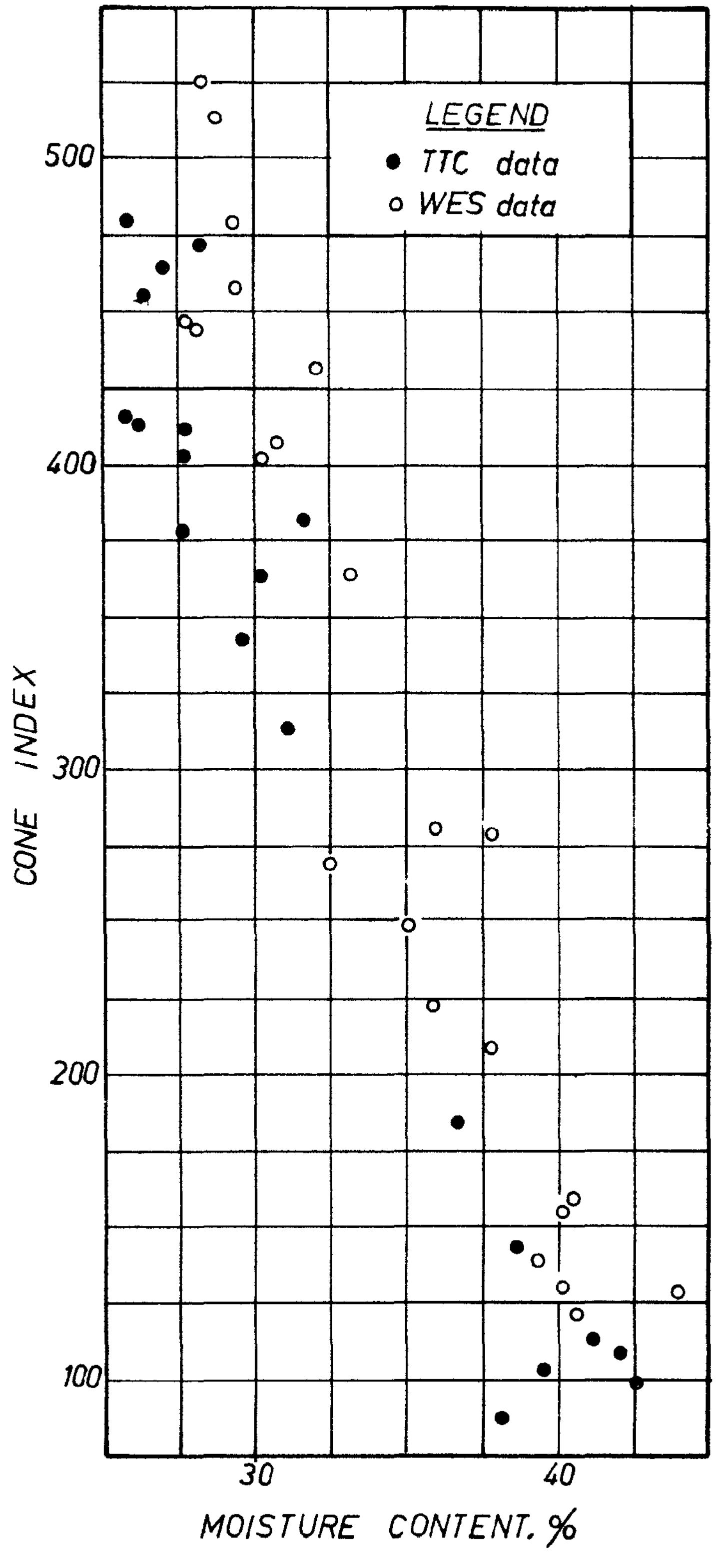


FIGURE V-10. COMPARISON OF TTC AND WES DATA 6-12- IN. LAYER.

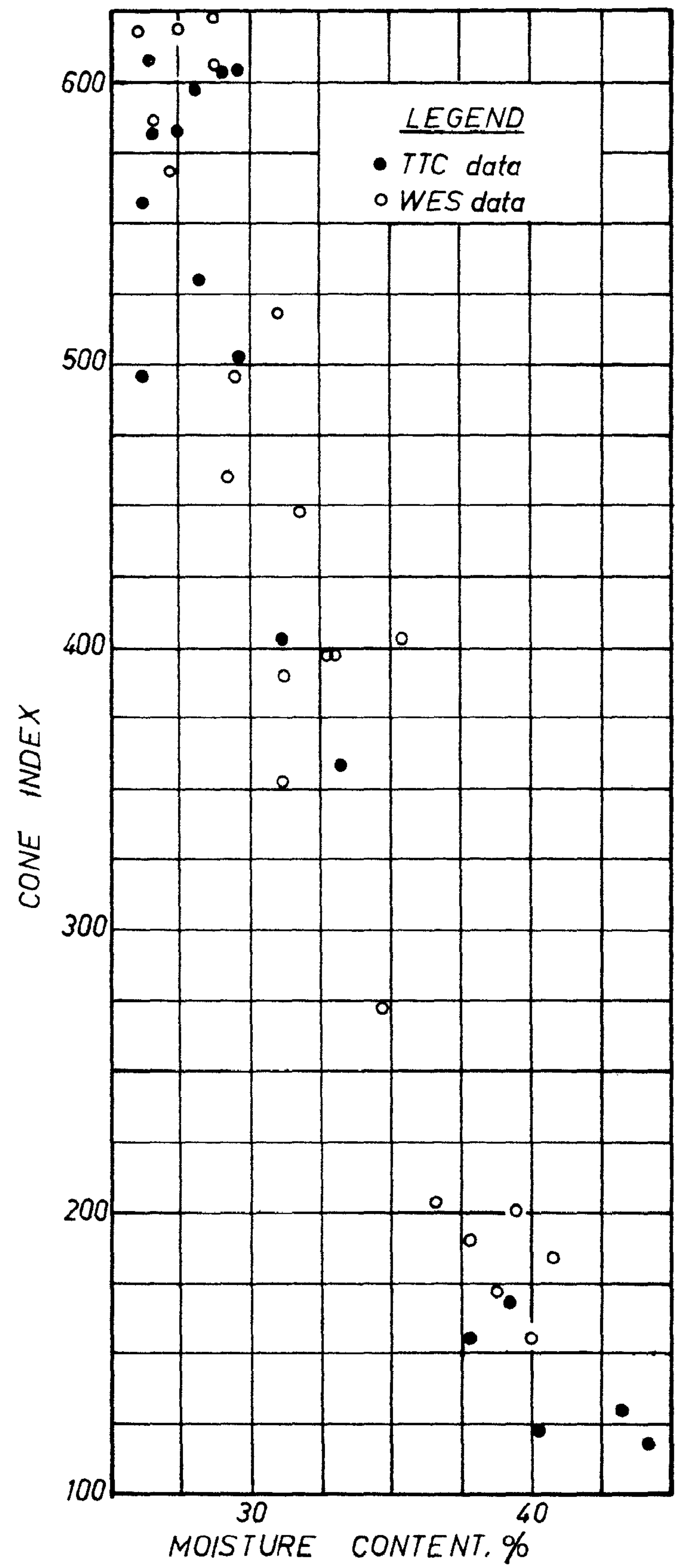


FIGURE V-11. COMPARISON OF TTC AND WES DATA 12-18- IN. LAYER.

at approximately 1500 for the 4-cm depth and at about 1800 for the 11-cm depth. Although there is a slightly higher temperature during part of the day at the 19-cm layer, the temperatures for the rest of the deeper layers are about equalized and remain nearly constant throughout the 24-hour period (see Figure V-12). In general, the soil warms up during the sunny portion of the day and cools off at night. From about 1000 to 2000 heat moves from the surface of the ground downward. During the night and early morning the reverse process occurs. However, from approximately 1600 to 2000 the temperature of the soil is higher than that of the atmosphere. Consequently, there is a flow of heat not only downward from the surface to the underlying soil layers, but also outward into the air. The time lag in the temperature rise between the air and the temperature at the 4-cm depth is about two hours; that between the surface and the underlying soil layers is approximately three hours.

Groundwater Level Data

71. Figures V-13 and V-14 are graphic representations of the daily rainfall and fluctuation of groundwater level for the Albrook Forest and the Chiva Chiva open sites respectively. The two variables are superimposed for case of comparison. There is an indication that the initial moisture of the soil as well as the depth of the groundwater level before a storm determine to some extent the maximum rise of the groundwater level after the storm. The first several storms of the rainy season during April and May are completely used to saturate the column of dry soil to the depth of the receded groundwater level. Approximately eight to ten inches of rainfall must be accumulated to cause a detectable rise of the groundwater in the 48-inch-deep measuring well. The infiltration capacity of the soils, on the other hand, is gradually exceeded at the various soil depths with increasing rainfall intensities, generally, as the rainy season progresses. Once the infiltration capacity of the soils is exceeded, surface run-off of rainfall water occurs. The infiltration capacity was more frequently exceeded on the soils of the Chiva Chiva open site. The tendency for a slightly overall higher level of the groundwater at the open site may be the result, at least in part, from the lower rate of transpiration due to the absence of deep rooted vegetation.

72. Table V-2 presents a tabulation of rainfall, groundwater level, and soil moisture values for one month, as an example of data reduction for which regression and correlation analyses are planned. Regressions will be computed for rainfall and groundwater against soil moisture content to determine the quantitative effect of each of these parameters on soil moisture for each three-inch layer. Correlation will be established between rainfall and soil moisture, groundwater level and soil moisture, and rainfall and groundwater level.

Frequency of Soil Moisture and Strength Values

73. Figure V-15 presents the frequency of occurrence of soil moisture ranges determined for the main environmental sites at three depths during a

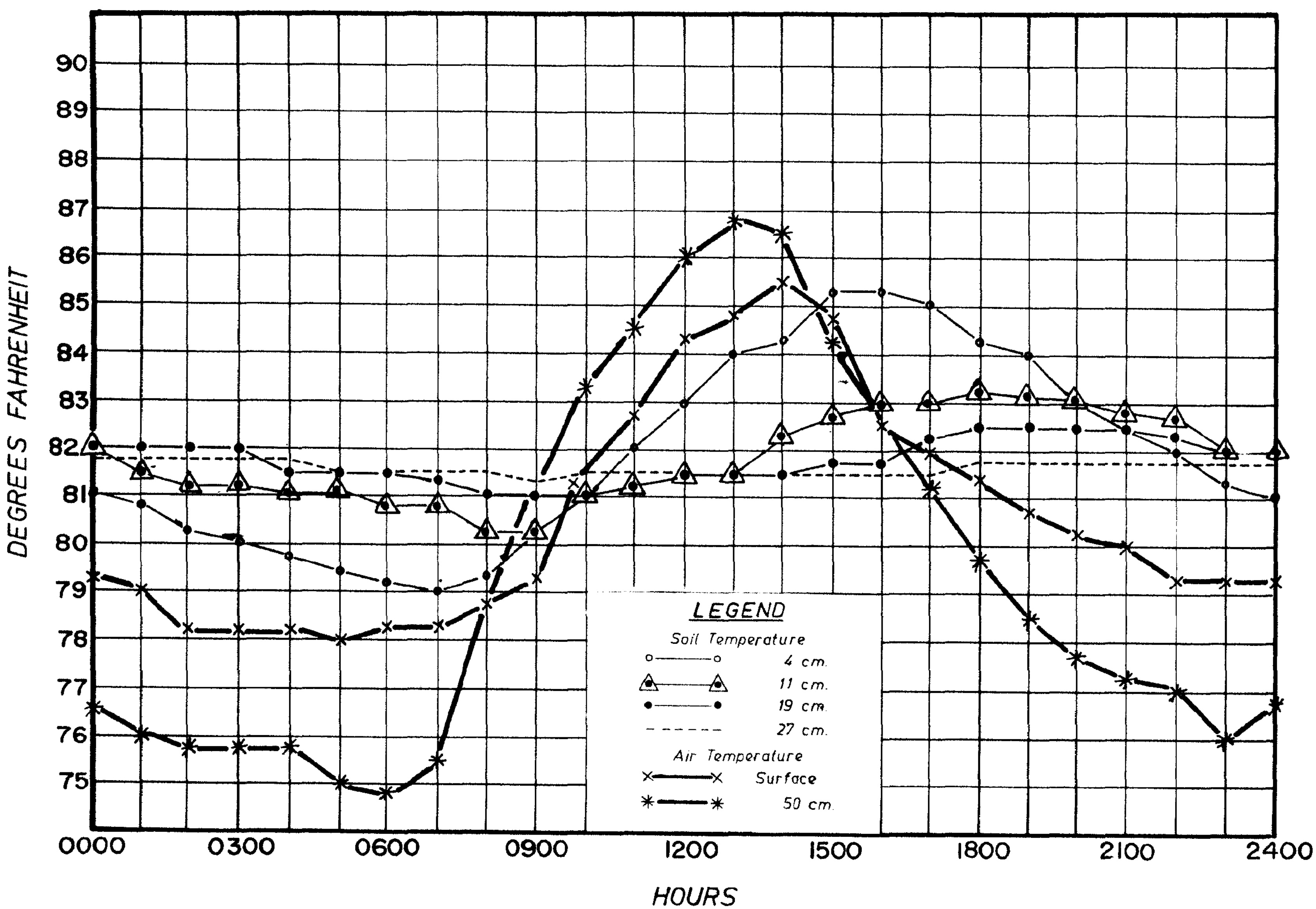


FIGURE V- 12 MEAN SOIL AND AIR TEMPERATURES AT THE CHIVA CHIVA SITE, JULY 1966

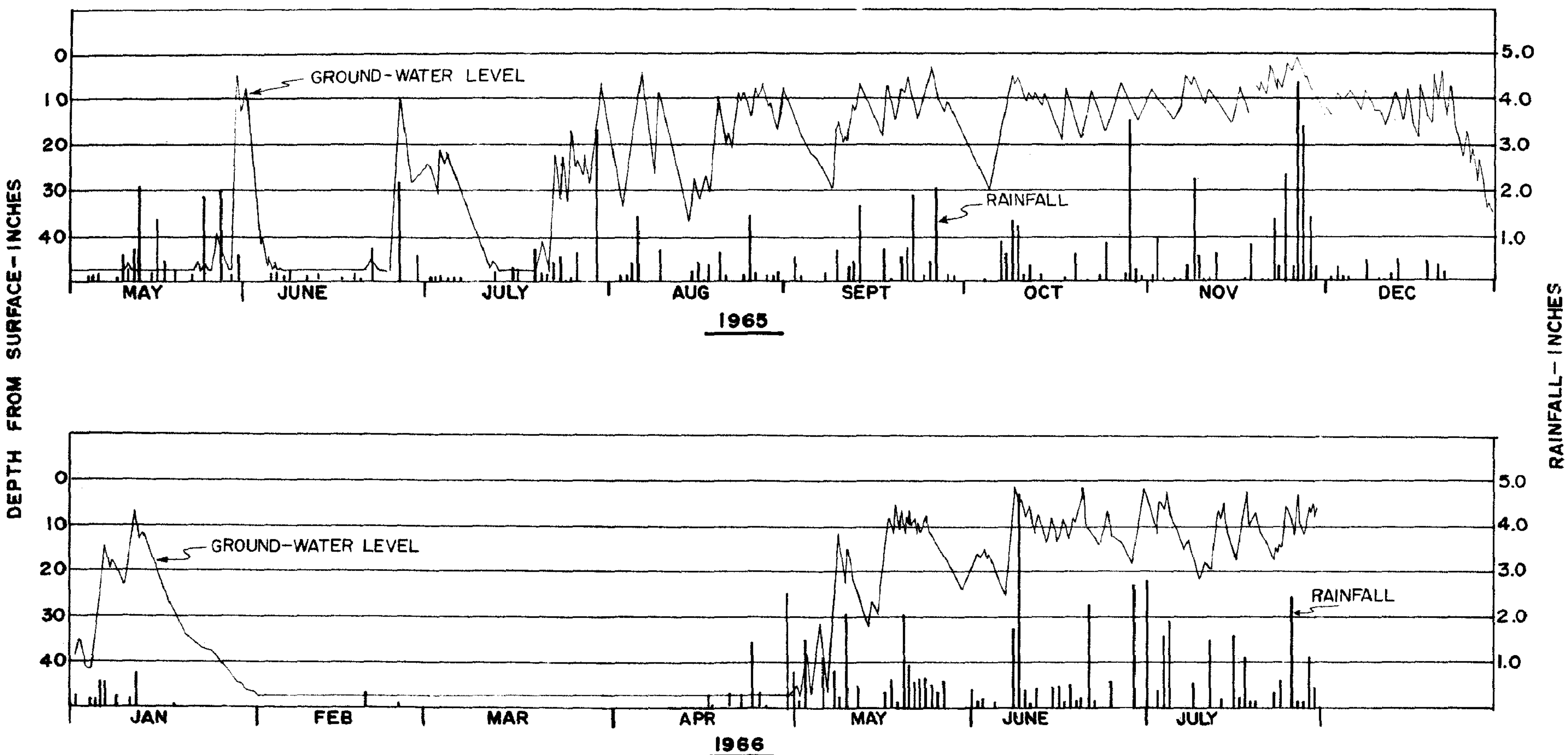


FIGURE V-13. GROUNDWATER LEVEL AND RAINFALL RELATION AT THE ALBROOK FOREST SITE.

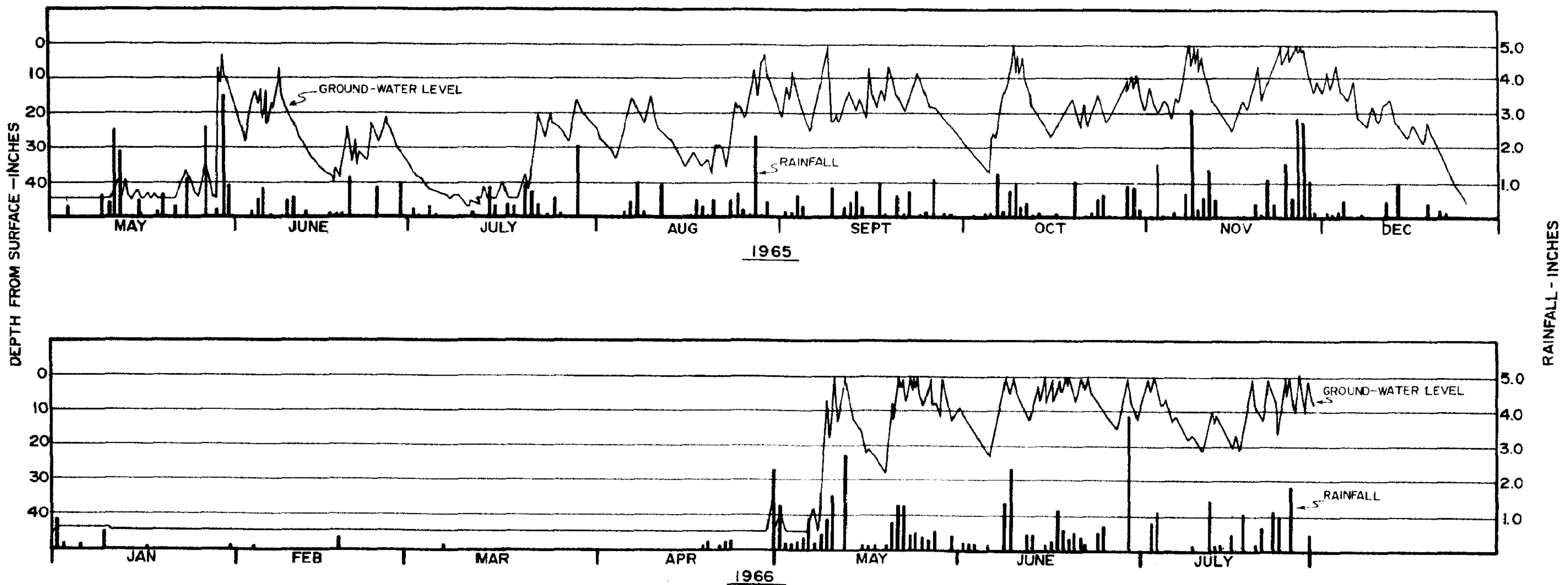


FIGURE V-14. GROUNDWATER LEVEL AND RAINFALL RELATION AT THE CHIVA CHIVA SITE.

TABLE V-2. SOIL MOISTURE, RAINFALL, AND GROUNDWATER RECORD, ALBROOK FOREST SITE, JANUARY 1966.

	Soil Moisture (% wt.) Depth (in)						Rainfall	Groundwater level (in
Day	0-3	3-6	6-9	9-12	12-15	15-18	(in)	from ground surface.)
1	51	44	40	40	42	50	0.25	37
2	52	44	40	40	42	49	0.00	37
3	52	44	40	40	42	48	0.16	39
4	53	44	40	40	42	46	0.16	41
5	57	44	40	40	42	44	0.57	39
6	58	45	41	43	47	51	0.53	27
7	60	45	42	45	48	54	0.00	15
8	58	45	43	44	48	52	0.21	18
9	59	45	42	45	49	55	0.00	19
10	58	45	43	45	49	53	0.14	23
11	58	45	42	45	48	55	0.78	22
12	59	45	43	45	49	55	0.00	10
13	58	45	42	45	49	52	0.00	11
14	57	45	41	45	48	55	0.00	16
15	56	45	40	45	47	55	0.00	20
16	55	45	40	45	46	55	0.00	24
17	53	45	40	44	46	54	0.03	28
18	53	45	40	43	45	54	0.00	30
19	52	45	40	42	45	53	0.00	32
20	51	44	40	41	44	52	0.00	34
21	50	44	40	41	43	50	0.00	38
22	50	42	39	41	42	47	0.00	38
23	49	41	38	40	40	44	0.00	41
24	M	40	37	39	40	42	0.00	42
25	M	39	36	39	38	40	0.00	44
26	M	38	35	38	38	38	0.00	44
27	46	37	34	37	36	34	0.00	46
28	47	35	33	36	35	35	0.00	45
29	48	34	30	36	34	34	0.00	46
30	48	34	30	35	34	34	0.00	48
31	48	39	34	31	37	38	0.00	48

M= missing

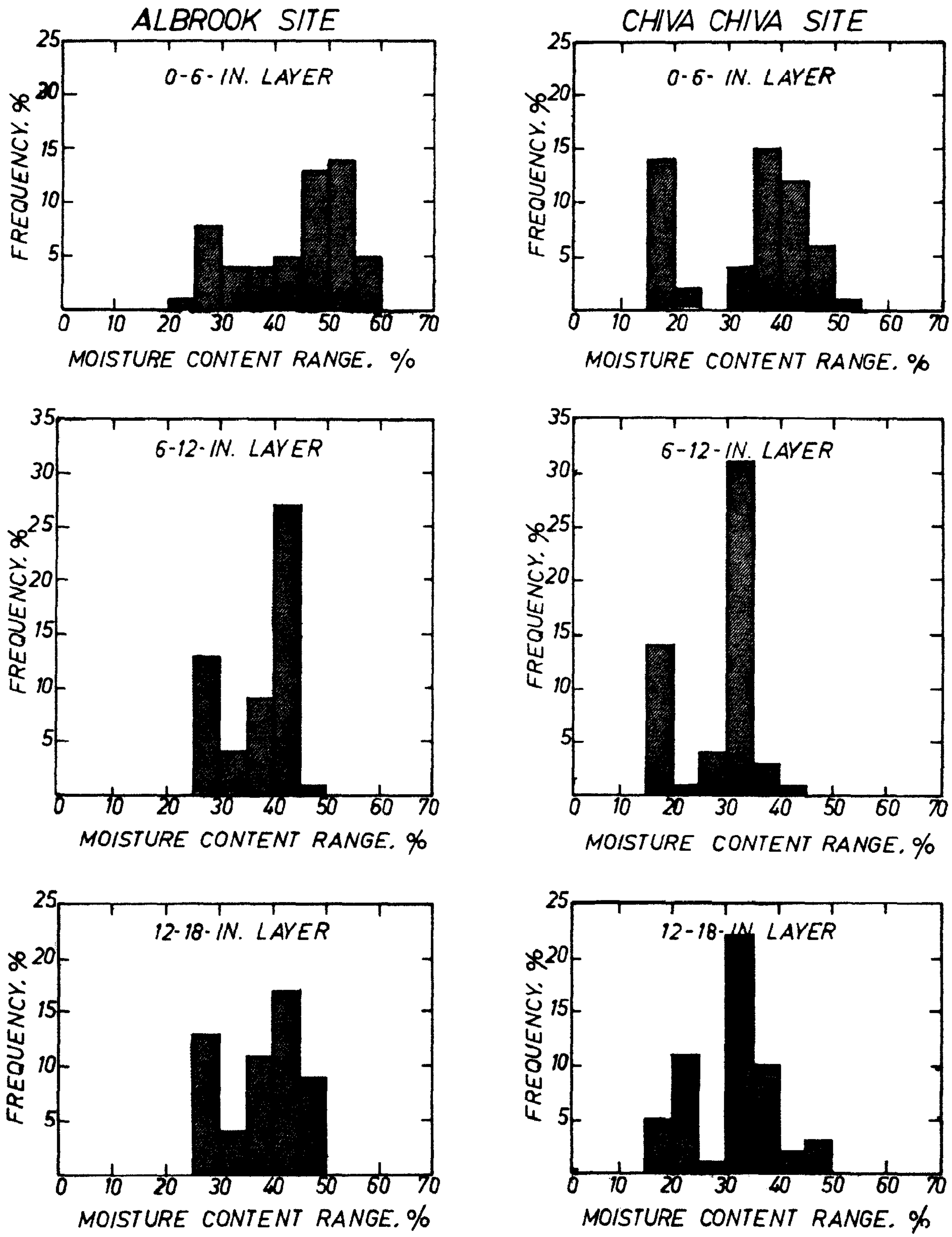


FIGURE. V-15. FREQUENCY OCCURRENCE OF MOISTURE CONTENT PER SIX-IN. LAYER. FEBRUARY 1965 – JANUARY 1966

12-month period beginning in February 1965. The moisture contents were computed from weekly gravimetric samples. The low ranges, 20-30 percent at Albrook and 15-25 percent at Chiva Chiva, correspond to the dry season (February, March, and April). In general, the mode of the range of moisture content for each layer is only about ten percent higher at the forested site. The slightly higher capacity for moisture retention of the forested soils can be attributed, at least in part, to the integrated effects of the vegetation on air temperature, evaporation, and relative humidity.

74. Frequency occurrence of cone index. The frequency occurrence of cone index ranges for the Albrook and Chiva Chiva sites during the same one year period is plotted in Figure V-16. The cone indices during the rainy season show more variation at the Chiva Chiva open site, varying from approximately 100 to 200 for the surface to 6-inch layer, 200 to 300 for the following 6-12 inch layer, and 300 to 400 for the lowermost layer. Soil strength increases with depth. Readings during the dry season, however, remain about constant, usually above the capacity of the measuring instrument.

75. A reverse situation occurs at the forested site. Greater variation is obtained during the dry season, with depth exerting a significant influence on soil strength. Wet season readings, on the other hand, are relatively uniform throughout the soil profile, except for the top six inch layer which tends to exhibit slightly weaker strength readings than the other layers.

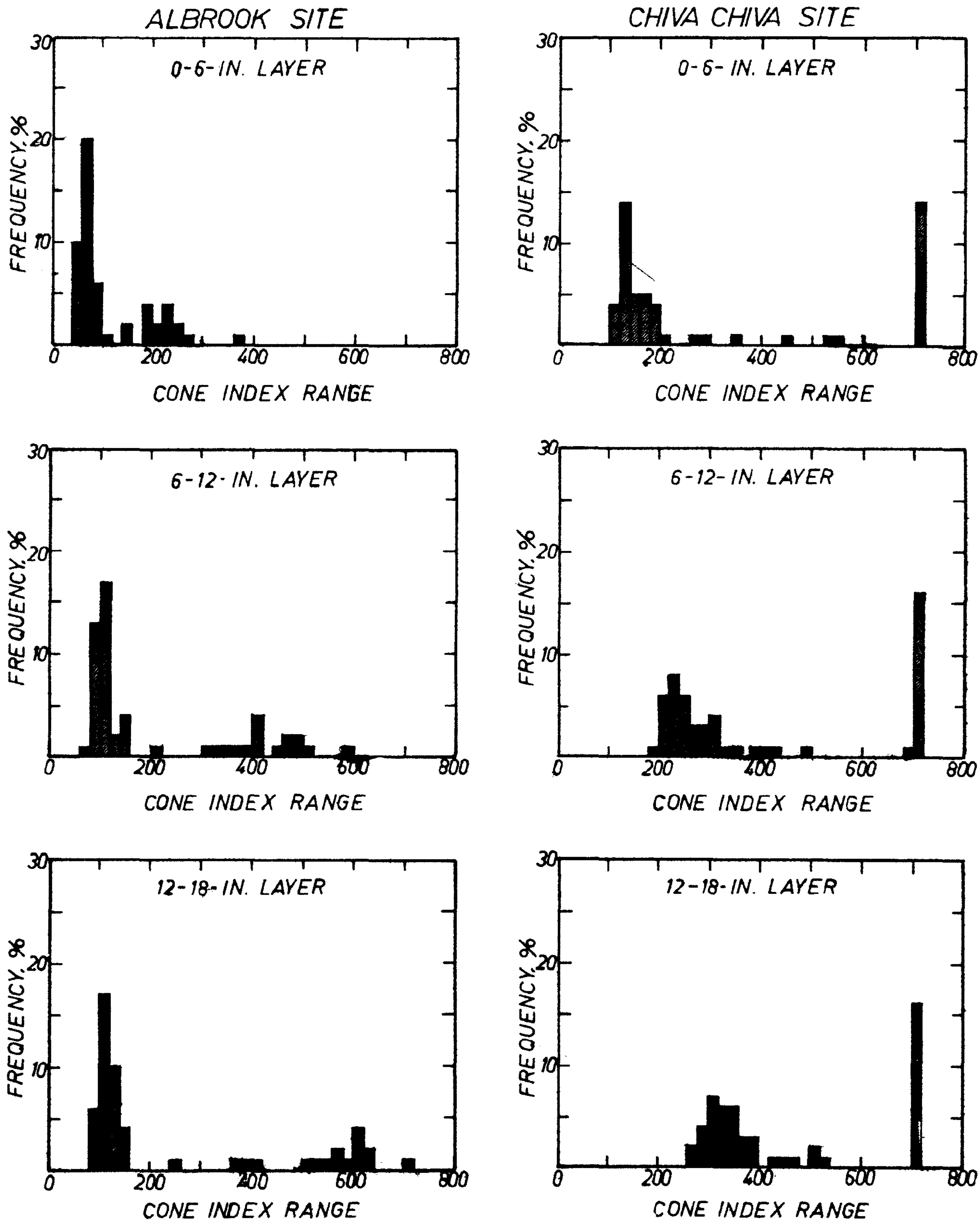


FIGURE V-16. FREQUENCY OCCURRENCE OF CONE INDEX PER SIX-IN. LAYER. FEBRUARY 1965–JANUARY 1966.

PART VI. VEGETATION

76. Appreciable progress was made on the vegetation task during the reporting period. Vegetation at the Albrook site was inventoried and the vegetation inventory volume (see Appendix) was revised and expanded. The inventory volume shows the location of all trees, shrubs, and vines with stem diameter of more than 2-1/2 cm in an area 60 meters square approximately centered on the observation tower. Plant names are given, and both upper and lower canopy coverage is shown.

77. A herbarium was established as an aid to the identification of plants from the Data Base sites and adjoining areas. The herbarium is necessary for identification of plants in the microbiology and atmospheric chemistry studies, and will facilitate the preparation of vegetation descriptions. Plants were collected from the established and the proposed Data Base sites as well as neighboring parts of Panama. The herbarium specimens are filed in insect-proof cabinets in an airconditioned room. The size and nature of the collection is described later in this section.

78. A third activity started during the period was a survey of forest canopy density and height in the vicinity of the Albrook site. Further investigation of the canopy as well as its effects on illumination and visibility are planned.

79. A fourth line of observations related to vegetation, as well as to the microbiology and atmospheric chemistry investigations, is that of the forest litter studies which were initiated on a small scale during the period. These studies are on the composition of forest litter, rate of accumulation, seasonal variation of accumulation, moisture content, and microbial content. Study of litter decomposition and its role as a source of atmospheric contaminants also was started during the past year. Expanded programs, based on experience gained in the first year, were started at the close of the period.

Plant Collection and Taxonomic Identification*

Introduction

80. During the year ending in July 1966 almost 6,000 numbers of plants (each "number" consisting of three specimens) were collected, processed, and stored in the Tropic Test Center Data Base Herbarium. Collections were made at the active and proposed Data Base sites as well as at neighboring areas in the Canal Zone and Republic of Panama. Nearly half of the collected plants have been identified.

81. The Data Base herbarium is the second largest single collection of plants from Panama, and is the largest herbarium located in Panama. It includes approximately 75 percent of the species represented in the vicinity of Albrook Forest site, 50 percent of the species near Rio Hato and El Jefe and about 25 percent of those found in the Fort Sherman area. Many new species have been found.

Data Collection: Methods and Results

82. A total of 5,964 numbers of plants have been collected, pressed, dried, and labeled. At least one plant from each number has been sent to the Missouri Botanical Garden,St. Louis, Missouri where Drs. John Dwyer, James Duke and others have helped in identification. Many specimens of plants, especially Gramineae, Cyperaceae, Melastomaceae and Piperaceae, have been sent to the herbarium in Florida State University where Drs. Robert K. Godfrey and Sidney McDaniels have made many identifications. In addition, Mr. J. S. McCorkle, US Agency for International Development, Panama has collected 249 numbers (mostly grasses) in return for identifications. Dr. John Dwyer donated approximately 100 named specimens to the herbarium. Dr. F. S. Fosberg, Smithsonian Institution, donated 40 specimens.

83. Approximately 1,000 plants have been identified, at least to genus, mounted on white herbarium paper, and filed by families. Of these, 103 families, 461 genera, and 850 species of vascular plants are represented, including 19 genera and 37 species of ferns. In addition to these mounted specimens, approximately 1,500 numbers have been identified, labeled, and now await mounting. Seeds from about 200 known species of plants have been collected and planted. About 150 of these germinated, and most of the seedlings have been pressed and dried and form the only such known collection from Panama.

84. Table VI-1 lists all families, genera, and species represented by the mounted specimens.

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* This section has been prepared by Dr. Edwin Tyson, Biologist, US Army Tropic Test Center. Work on which this study is based was carried out in general conformance with Project Memorandum 500-1.3, 13 Sept. 1965.

TABLE VI-1. PLANT FAMILIES MOUNTED IN THE TROPIC TEST CENTER DATA BASE HERBARIUM

	Family	Common Name	No. Genera	No. Species
1.	Typhaceae	Cattail	1	1
2.	Graminaceae	Grass	41	93
3.	Cyperaceae	Sedge	11	38
4.	Phoenicaceae	Palms	2	2
5.	Cyclanthaceae	Cyclanthus	1	1
6.	Araceae	Arum	5	7
7.	Commelinaceae	Dogflower	4	4
8.	Liliaceae	Lily	1	1
9.	Smilacaceae	Sasparilla	1	2
10.	Haemodoraceae	Bloodwort	1	1
11.	Amaryllidaceae	Amaryllis	1	1
12.	Dioscoreaceae	Yam	1	5
13.	Musaceae	Banana	1	2
14.	Zingiberaceae	Ginger	2	8
15.	Cannaceae	Canna	1	1
16.	Marantaceae	Maranta	7	11
17.	Orchidaceae	Orchid	2	2
18.	Piperaceae	Pepper	3	19
19.	Lacistemaceae	Lacistema	1	1
20.	Ulmaceae	Elm	1	1
21.	Moraceae	Mulberry	5	5
22.	Urticaceae	Nettle	5	6
23.	Loranthaceae	Mistletoe	4	7
24.	Olacaceae	Olax	1	1
25.	Polygonaceae	Buckwheat	3	6
26.	Amaranthaceae	Pigweed	6	7
27.	Nyctaginaceae	Four-o'clock	2	2
28.	Phytolaccaceae	Pokeberry	2	2
29.	Aizoaceae	Carpetweed	1	1
30.	Partulacaceae	Purslane	1	1
31.	Menispermaceae	Moonseed	1	2
32.	Annonaceae	Custard-Apple	4	6
33.	Myristicacea	Nutmeg	1	1
34.	Monimiaceae	Monimia	1	3
35.	Lauraceae	Laurel	2	2
36.	Capparidaceae	Caper	3	4
37.	Amygdalaceae	Almond	2	3
38.	Connaraceae	Connarus	3	4
39.	Mimosaceae	Mimosa	9	23
40.	Caesalpiniaceae	Senna	7	20
41.	Fabaceae	Bean	30	61
42.	Oxalidaceae	Oxalis	1	1

TABLE VI-1. (Cont'd)

	Family	Common Name	No. Genera	No. Species
43.	Zygophyllaceae	Caltrop	1	1
44.	Rutaceae	Rue	1	1
45.	Simaroubaceae	Simaruba	1	1
46.	Burseraceae	Torchwood	2	2
47.	Meliaceae	Chinaberry	2	3
48.	Malpighiaceae	Malpighia	2	3
49.	Polygalaceae	Polygala	1	2
50.	Euphorbiaceae	Spurge	13	28
51.	Anacardiaceae	Cashew	4	5
52.	Celastraceae	Bittersweet	1	1
53.	Hippocrateaceae	Hippocratea	2	2
54.	Sapindaceae	Soapberry	6	12
55.	Rhamnaceae	Buckthorn	2	2
56.	Vitaceae	Grape	2	5
57.	Elaeocarpaceae	Elaceocarpus	2	2
58.	Tiliaceae	Linden	5	7
59.	Maluaceae	Mallow	7	14
60.	Bombacaceae	Cottontree	1	1
61.	Sterculiaceae	Cocoa	7	8
62.	Dilleniaceae	Dillenia	6	9
63.	Ochnaceae	Ochna	2	5
64.	Theaceae	Tea	1	1
65.	Hypericaceae	St. Johnswart	1	3
66.	Clusiaceae	Clusias	3	3
67.	Bixaceae	Anatto	1	1
68.	Cochlospermaceae	Poroporo	1	1
69.	Flacourtiaceae	Flacourtia	4	7
70.	Passifloraecae	Passion Flower	1	3
71.	Caricaceae	Papaya	1	1
72.	Loasaceae	Loasa	1	1
73.	Begoniaceae	Begonia	1	1
74.	Cactaceae	Cactus	1	1
75.	Lythraceae	Loosestrife	2	4
76.	Lecythidaceae	Brazil nut	1	1
77.	Rhizophoraceae	Mangrove	1	1
78.	Combretaceae	Combretum	4	6
79.	Myrtaceae	Myrtle	3	5
80.	Melastomaceae	Melastome	16	51
81.	Onagraceae	Evening primrose	2	5
82.	Araliaceae	Ginseng	1	1
83.	Apiaceae	Parsley	1	1
84.	Myrsinaceae	Myrsine	2	4
85.	Sapotaceae	Sapodilla	1	1
86.	Loganiaceae	Logania	2	2
87.	Gentianaceae	Gentian	5	9

TABLE VI-1. (Cont'd)

	Family	Common Name	No. Genera	No. Species
88.	Apocynaceae	Dogbane	6	7
89.	Asclepiadaceae	Milkweed	3	4
90.	Convolvulaceae	Morning-glory	3	8
91.	Boraginaceae	Borage	2	11
92.	Verbenaceae	Verbena	9	12
93.	Menthaceae	Mint	2	7
94.	Solanaceae	Potato	7	19
95.	Scrophulariaceae	Figwart	6	8
96.	Bignoniaceae	Bignonia	9	10
97.	Gesneriaceae	Gesneria	4	5
98.	Acanthaceae	Acanthus	5	5
99.	Rubiaceae	Madder	35	76
100.	Cucurbitaceae	Gourd	4	4
101.	Lobeliaceae	Lobelia	2	4
102.	Compositae	Sunflower	34	45
103.	Order Filicales	Ferns	19	37
		TOTALS	461	850

Forest Canopy Observations*

Introduction

85. Included in the vegetation studies of the Data Base project are investigations of certain forest canopy characteristics. Forest canopy may be defined as the approximately continuous horizontal mass of crown branches and foliage formed by the juxtaposition of trees or shrubs of like height. The canopy may exhibit stratification, or occurrence at different levels over one locality, which stratification may have seasonal as well as areal variance. Other characteristics of the canopy may change markedly with seasonal changes in foliage.

86. Investigations in process, or planned, include determination of heights of canopy levels, canopy densities, and the extent to which branches and foliage affect light levels in the forest. This discussion deals briefly with two parameters of the forest canopy: leaf density at various elevations at the Albrook tower; and the height of the canopy in the vicinity of the Albrook site. A number of additional observations will be necessary to characterize the canopy of this forest.

Data Collection: Methods and Results

87. For determination of leaf density, measurements were taken from the tower at the Albrook Forest site in a northwesterly arc through places where understory vegetation was least disturbed. A pole was extended out approximately six meters from the tower from which a plumb line was dropped to the ground surface. One observer climbed the tower, counting and recording leaves touched by the line, while another remained on top of the tower and kept the line moving slowly up and down causing leaves to vibrate, thus facilitating observation of leaf contacts. Leaves were counted along a total of 30 such plumb lines. The number of leaves touched per line ranged from one to ten with an average of 4.26. (Confidence limits at the 95% level of confidence are $\pm$ 0.95.) Figure VI-1 shows graphically the elevations at which leaves were located.

88. These measurements were taken from the Albrook tower and may not be representative of the forest as a whole unit. However, the results point out the relatively few foliage layers which may obstruct vertical visibility. Further, as is to be expected, since the Albrook forest is not mature but is of secondary growth rather than primary, the site shows no evidence of the three-layering effect of the canopy often described for primary rainforest. It does indicate a dense layering of foliage below two meters and another at from 18-23 m, while a lesser density of leaves is indicated between 6 and 15m. These conditions can readily be detected visually by an observer on the tower.

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* This section has been prepared by Dr. Edwin Tyson, Biologist, US Army Tropic Test Center. Work was carried out in general conformance with Project Memorandum 505-7, 22 September 1965.

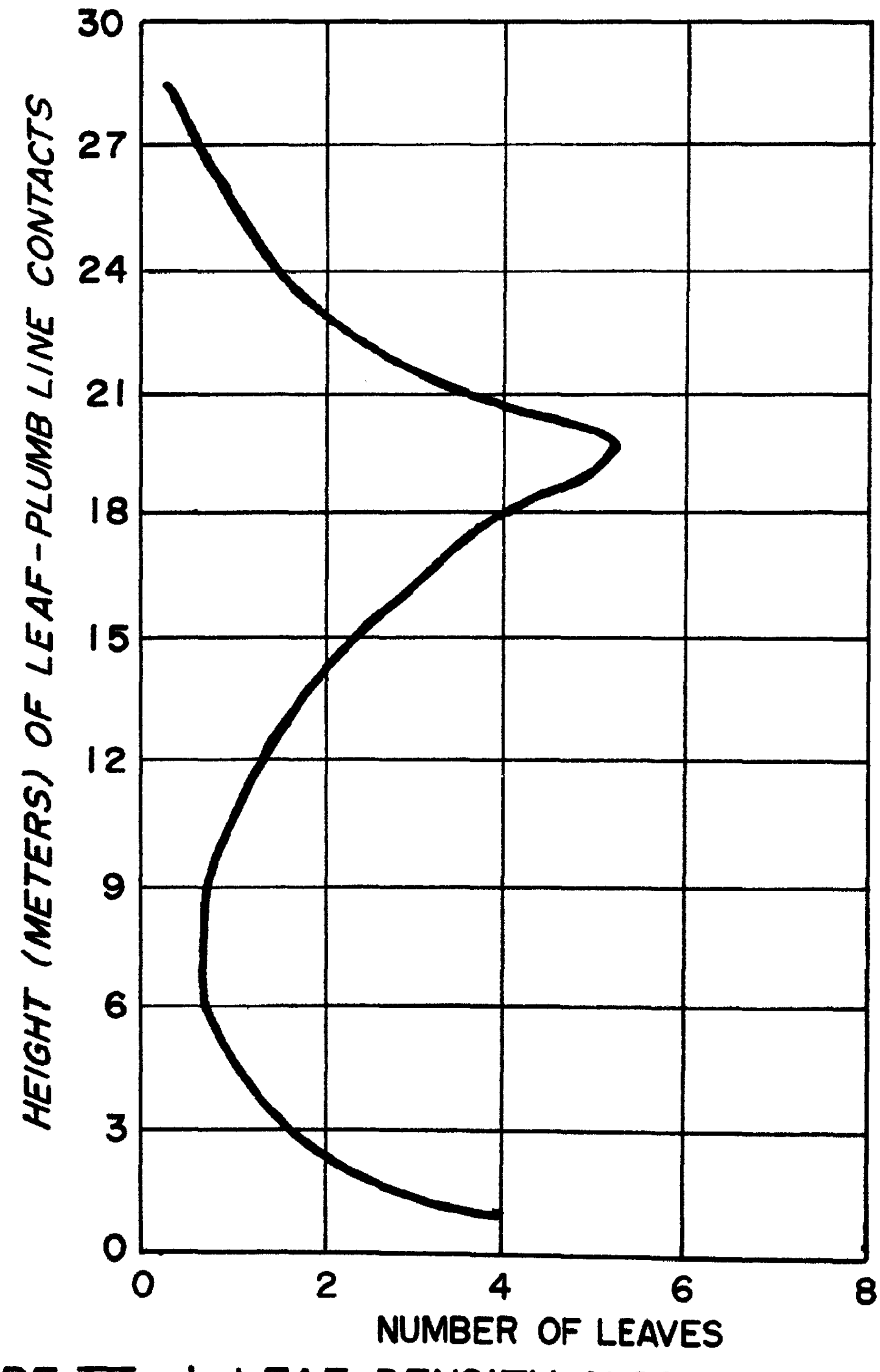


FIGURE VI-1. LEAF DENSITY, ALBROOK FOREST SITE

89. The average of 4.26 leaves touching the plumb line is somewhat lower than the average of between 5 and 6 found by investigators at the Puerto Rico Nuclear Center. It is not certain if this is an indication of the greater rainfall on the Puerto Rican site, sample error, or disturbance of the vegetation at the time the Albrook tower was constructed.

90. An investigation of canopy height was also carried out in the Albrook Forest not far from the Data Base site. As mentioned above a forest canopy is considered made up of tree crowns of approximately even height in a more or less continuous layer. However, in many forests the tree crowns that form the continuous layer are not of identical height. Thus it is perhaps better to think in terms of an undulating canopy with highs and lows produced by trees of varying height.

91. Measurements were made at five-meter intervals, along a transect of 250 meters, of the highest point of the crown mass of existent vegetation at each precise interval, without regard to the origin of that vegetation. Thus, consecutive measurements might be taken of the crown of a single tree, or, conversely, individual or consecutive measurements might be made of shrubs or graminaceous vegetation occurring under "holes" in the arboreal canopy. Heights of the upper canopy levels were determined by the use of a Haga altimeter and, though not precise, are considered to be sufficiently accurate. Identification was made of each tree or plant, and its stem diameter, measured at breast height (DBH), was determined and recorded.

92. From the data so obtained the graph shown in Figure VI-2 was constructed. This simple technique results in the forest canopy being represented graphically in a manner that permits comparison with other forests for which a similar graph has been constructed, and that provides a diagnostic signature of the canopy physiognomy.

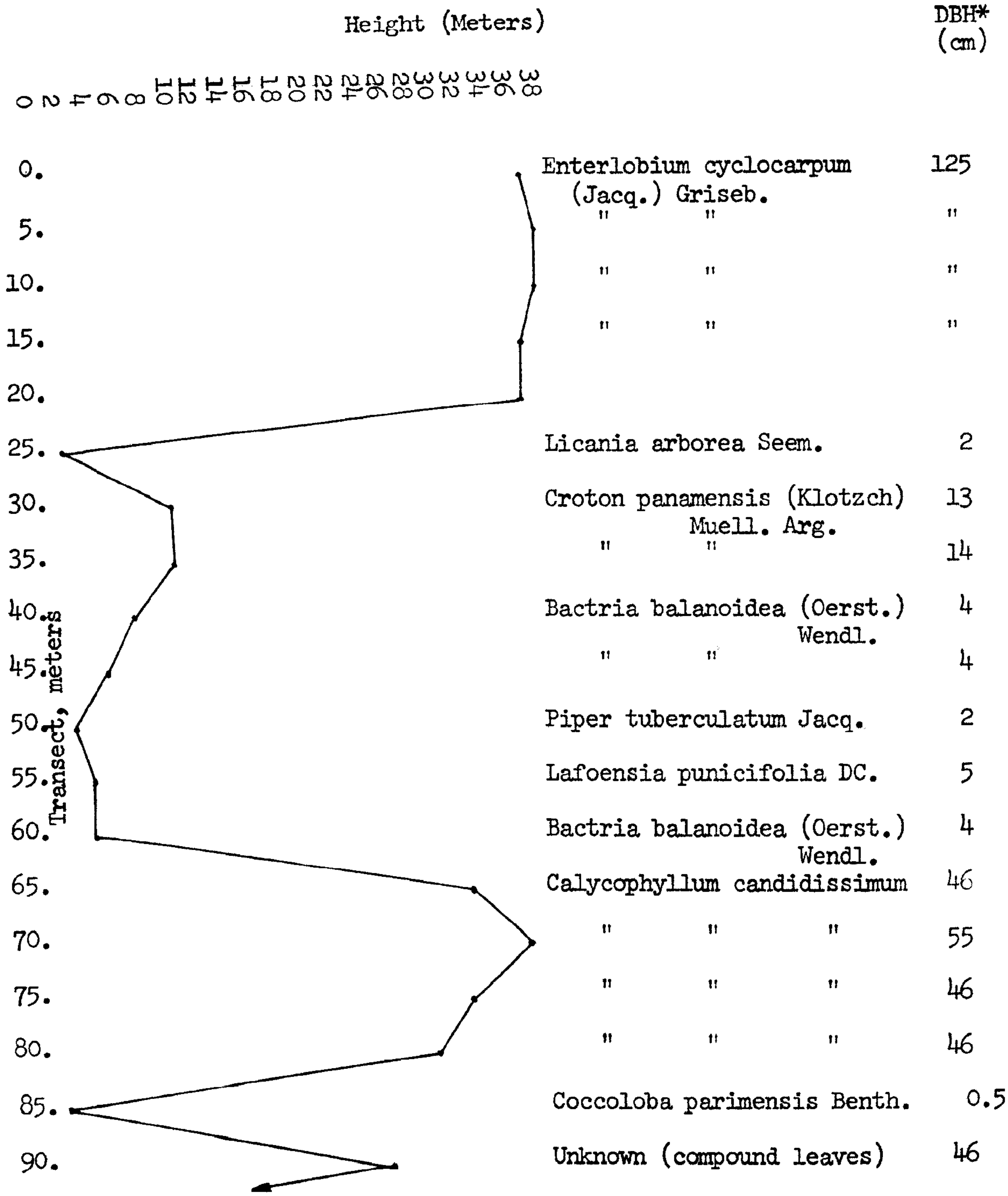
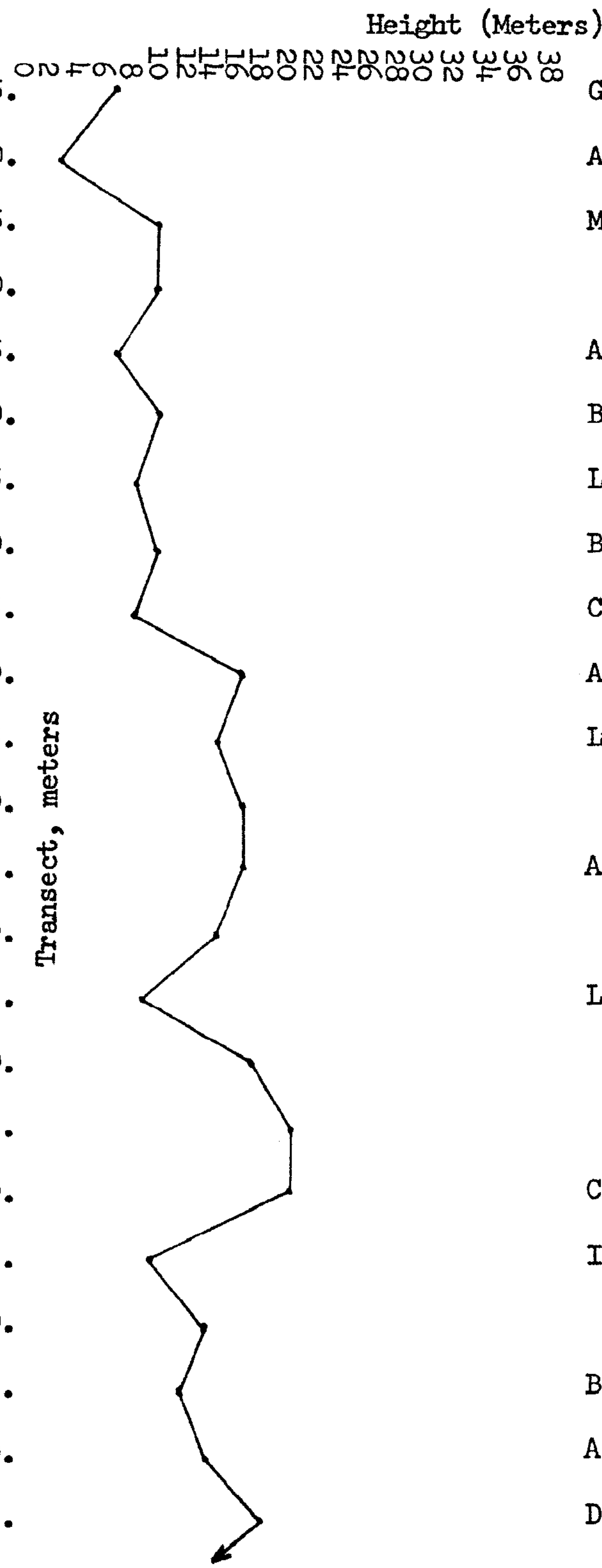


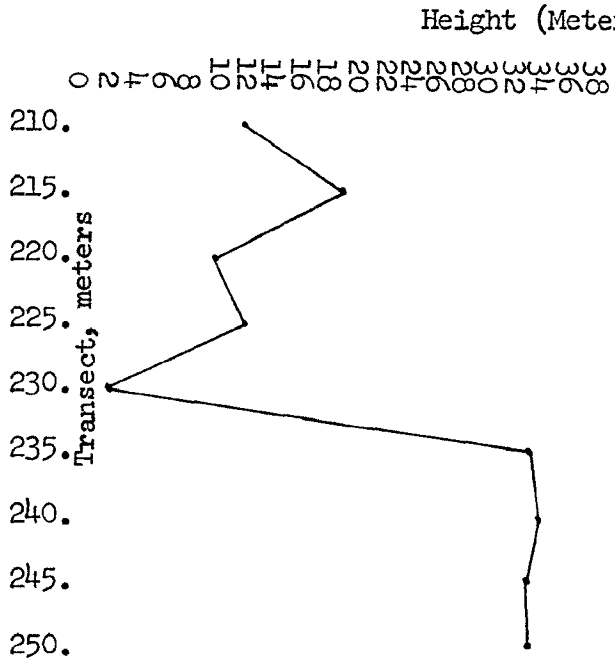
Figure VI-2. Canopy Profile, Albrook Forest in Vicinity of Data Base Site.

* DBH = Stem diameter at breast height.



Transect (m)	Species	Height
95.	Gouania polygama (Jacq.) Urban.	0.5
100.	Anacardium excelsum (Bert.& Balb.) Skeels	2
105.	Miconia argentea (Swartz)DC.	18
110.	" "	18
115.	Anacardium excelsum (Bert.& Balb.) Skeels	18
120.	Belotia Panamensis Pittier	12
125.	Luehea speciosa Willd.	18
130.	Belotia panamensis Pittier	14
135.	Cordia alliodora (Ruiz & Pav.) Roem. & Schult.	13
140.	Anacardium excelsum (Bert. & Balb.) Skeels	32
145.	Luehea seemannii Triana & Planch	24
150.	" "	38
155.	Anacardium excelsum (Bert.& Balb.) Skeels	38
160.	" "	38
165.	Luehea seemannii Triana & Planch.	53
170.	" "	53
175.	" "	53
180.	Cecropia obtusifolia Bertol.	18
185.	Inga spuria Humb. & Bonpl.	25
190.	" "	25
195.	Belotia panamensis Pittier	31
200.	Anona purpurea Mock.& Sesse.	13
205.	Didymopanax morototoni (Aubl.) Decaisne & Planch.	23

Figure VI-2. (Cont'd)



Transect	Species	
210.	Miconia argentea (Swartz)DC	18
215.	Calycophyllum candissimum (Vahl) DC.	23
220.	Guazuma ulmifolia Lem.	33
225.	" "	33
230.	Heliconia latispatha Benth.	4
235.	Ficus sp	101
240.	" "	101
245.	" "	101
250.	" "	101

Figure VI-2. (Cont'd)

Forest Litter*

Introduction

93. The purpose of this study is to provide information concerning the composition and the quantity of litter fall within a humid tropic forest. Litter is defined as the ground accumulation under a forest canopy of leaves, seeds, fruit, insect and animal forms, and debris such as animal and bird droppings, sap, and other particulate material. Forest litter observations were made at the Albrook site and vicinity during the year covered by this report. Rates of litter fall, amount of litter on the ground, composition, moisture content, insect infestation, and other characteristics of the litter were investigated.

94. The type, amount, and time of fall of litter in the forest influences ground cover, microbial and insect activity, chemical and particulate matter in the atmosphere, and the conduct of exposure tests in materials deterioration studies. Observation of contamination, infestation, and damage to fallen leaves and flowers reveals intesity of activity of macro and microfauna. The duration of leaf, flower, and fruit fall can provide a supplementary observation of phenological events usually measured visually and photographically.

95. Litter samples were collected both in litter pans and directly from the ground. That which fell into the pans provided a basis for measuring rates of litter accumulation; while collections of accumulated litter deposits from the ground provided a measure of the amount of litter on the forest floor throughout the sampling period. Weights of the pan litter samples and their components (leaves, seeds, fruits, insect and animal forms, and various other kinds of debris) were determined. The ground litter was processed to determine weights, moisture content, and microbial content, and arthropods.

96. The litter investigation carried out during the year were largely of developmental nature. They were carried out under varying conditions by several observers, and the number of samples taken proved to be too small for definitive conclusions. Results therefore, can be viewed only as indicative of conditions. An expanded litter investigation involving a far larger number of samples and more intensive analyses was started at the conclusion of the reporting period.

97. Background for these observations and a discussion of the importance of litter as an element of the forest environment is discussed more fully by Bray**.

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* This section has been prepared by Dr. Robert Hutton, Microbiologist, and by Dr. Edwin Tyson, Biologist, US Army Tropic Test Center. Work on which the discussion is based was performed in general conformance with Project Memoranda 505.1, 1 June 1965 and 505-3.1, 24 Sept. 1965.

** Advances in Ecological Research, 2, page 101, 1964.

Pan Litter

98. Data Collection Methods. Litter was collected weekly from five collection pans located within a 25-meter radius of the Albrook Forest site tower. The pans are shallow square trays, one meter on a side, constructed of 16-mesh metal screen. An attempt was made to locate the pans under varying densities of the canopy in order that the five pans would yield a representation of the total accumulation. The pan location with respect to the canopy is indicated on the canopy coverage diagrams in the Vegetation Inventory included as an appendix to this report.

99. The weight of litter from each pan was determined, after which the litter was dried at 100°C to constant weight. The leaves, seeds, fruit, and debris were noted by weight or number, as appropriate. Samples were preserved for future reference and/or chemical analysis (e.g., total nitrogen or ash content).

100. Results. The total wet weight, in grams, of the litter and of the leaves alone is shown in the following tabulation:

	Pan					
	1	2	3	4	5	Mean
Total litter in Pan	2,066	2,599	2,602	1,353	2,451	2,214
Leaves	1,362	1,591	1,490	762	1,291	1,299

It is seen that the accumulation in the pans varies by a factor of up to 2:1. The results obtained must be interpreted with this in mind. An average of all the pans represents the observational area only if the attempt to empirically choose collection points was valid. Shortly after the reporting period closed the number of pans was increased to 30 to assure that the total collection in the future will be truly representative of the area under study.

101. Table VI-2 presents the dry weight of the combined litter collection, from all pans, by month, with a break-out of leaves, fruit and seed, and the remaining components. A definite correlation is shown between high litter weights and the dry season (mid-December through April) with a carry-over into the beginning of the rainy season.

102. Table VI-3 shows total number of seeds and fruit collected monthly, by pan. Interpretation of results should be subject to the same precaution on the distribution and number of pans as above.

103. Seventy different kinds of fruits and seeds were separated from the litter collected during the twelve-month period shown on Table VI-3. Only a few of these were identified as the plant of origin. Since some of the fruits broke open and scattered their seeds before the litter was examined, it is probable that less than 70 kinds of plants were involved.

TABLE VI-2. DRY WEIGHT OF PAN LITTER (grams)

Date	Leaves	Fruit & Seed	Balance of Litter	Total
August 1965	169	16	49	234
September	150	5	30	185
October	170	5	19	194
November	54	3	33	234
December	61	2	27	256
January 1966	738	12	144	894
February	624	31	204	859
March	382	44	280	706
April	352	42	103	497
May	283	38	111	432
June	303	21	114	438
July	202	15	68	303
	2,768	230	1,038	4,338

Note: Arithmetical inconsistencies appearing above may arise from proliferation of seeds due to maturation of fruits and pods after collection and preliminary count. Consequently this table should be interpreted as presenting quantitative evaluations rather than as a precise balance sheet.

TABLE VI-3. NUMBER OF FRUITS AND SEEDS FOUND MONTHLY, BY PAN.

	Pan Number					
	1	2	3	4	5	Total
August - 65	28	88	28	7	64	215
September	0	61	123	26	1	211
October	36	13	12	17	38	116
November	8	44	10	11	3	76
December	8	73	58	8	9	156
January - 66	368	1,079	73	118	16	1,654
February	1,438	10,640	1,830	879	472	15,259
March	329	725	260	1,165	637	3,116
April	522	924	176	541	527	2,690
May	1,286	2,758	653	466	699	5,862
June	987	1,262	415	128	305	3,097
July	407	474	273	56	200	1,410
TOTALS	5,417	18,141	3,911	3,422	2,971	33,862

Drawings were made of each kind of seed and fruit for use in later identification, and the number collected of each was recorded by month.

Ground Litter

104. Data collection methods. Ten samples of 200 cm^2 of litter were collected from the forest floor every two weeks from randomly selected locations in the immediate vicinity of the Albrook Forest site. The samples were sealed in plastic bags to prevent moisture loss before being transported to the laboratory. At the same time a sample of litter was collected in a sterile vial from each of the sites for determination of microbial content.

105. Analytical methods. Analysis for microbiological content is carried out by means of the following procedure. A 3-gram sample is weighed and blended for one minute in 300 ml of water. Serial dilutions are made. A one-ml aliquet of each dilution to be plated is added to a tube of melted nutrient agar and carrot agar. The inoculated melted agar is then poured into petri plates, cooled, and incubated for five days at 85F. The number of bacterial colonies which appear on the nutrient agar plates are counted, and the numbers, per gram of original sample used, are recorded, as are the number of fungal colonies which appear in the carrot agar plates.

106. Arthropod and ash analysis involves the following steps. Each sample is weighed in the plastic bag in order not to lose moisture, after which the samples are placed in a standard Berlese funnel for 48 hours. The arthropods are separated from trash which falls through the funnel, counted, and stored for further studies by an entomologist. The samples are then placed in a drying oven at 50C for 24 hours, after which they are again weighed to enable calculation of the moisture content. The samples are finally placed in the muffle oven at 450C for 24 hours, cooled, and the weight of the remaining ash is determined. Ash samples are saved for radiation studies.

107. Studies on the taxonomy of microorganisms are being conducted by the Tropic Test Center microbiological laboratory. The results of these studies are not ready for release and report at this date.

108. The wet and dry weights of the litter, moisture-content percentage, and the weight of the ash collected bi-weekly for a period spanning the rainy-dry-rainy progression of 1965 and 1966 are presented in Table VI-4. Examination of the weights indicates a general decrease of litter from the latter part of the wet season (November) through the first half of the dry season, after which the amount increases into the early part of the wet season (first rain began in April). The final samplings indicate a decrease as the wet season progresses. The moisture content follows the wet and dry season closely, running above 60 percent in the wet months and dropping below 30 percent in the dry season.

TABLE VI-4. WEIGHT AND MOISTURE CONTENT OF GROUND LITTER FROM ALBROOK FOREST SITE.

Date	Wet Weight	Dry Weight	% Moisture	Weight of Ash
26 Nov 1965	592	171	75	45
10 Dec	471	139	70	34
23 Dec	336	116	65	47
7 Jan 1966	308	120	61	41
20 Jan	215	127	41	23
4 Feb	254	191	25	35
18 Feb	204	147	28	21
4 Mar	230	165	28	23
21 Mar	230	184	20	32
1 Apr	233	132	43	35
15 Apr	236	180	23	26
29 Apr	384	194	49	34
13 May	811	275	66	64
27 May	613	221	64	74
10 Jun	727	268	63	87
24 Jun	341	139	59	34
9 Jul	452	182	60	74
22 Jul	456	168	63	61

Note: Weight in grams of total litter collected from 10 random samples of 200 cm^2 each.

Moisture Content of Forest, Brush, and Grassland Litter in Relation to Fire*

Introduction

109. Quantitative data are not available on the minimum moisture content of litter which would be necessary for the suppression of fire in forest, brush, or grasslands in Panama. This report attempts to identify: (1) the hours of the day during which fire may maintain itself unaided; (2) the moisture content of the litter during times of fire.

110. All tropical areas of the world in which marked dry seasons occur are subject to fire. In most such areas, much fire-resistant vegetation is present due to annual burning as, for example, in grasslands. It has been said that all native grasslands, such as savannas, are fire-maintained. Many forested areas are dominated by fire-resistant trees which are maintained by the annual fires that limit the development of other forest species. If fire is kept out of these fire-maintained forests, the less resistant species will rapidly regain dominance. Further, the newly formed forest rapidly creates an area that tends to exclude fire, first, by developing a more dense canopy which limits evaporation by filtering sunlight and wind; second, by shading out the grasses which furnish the best fuel for fires. Thirdly, the trees tend to be less deciduous; consequently fewer leaves fall at the beginning of the dry season, thus limiting formation of fire-supporting litter.

111. Information on the capability of natural vegetation to resist or support fire is useful to the military services in establishing storage areas, building roads, and in the maintenance of installations and grounds. In military field operations, commanders can estimate the time when enemy areas can be burned or, conversely, when their own areas may be burned by the enemy. Foresters may utilize fire in order to maintain particularly desirable species, such as teak. Forage agriculturists often maintain grasslands with fire.

Location of Study Sites

112. All work areas were in the general vicinity of the Albrook forest, an area where the natural vegetation is semideciduous forest. Grasslands, brushlands, and areas of forest were used as study sites. Site selection was arbitrary.

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* This section has been prepared by Dr. Edwin Tyson, Biologist, US Army Tropic Test Center. The work on which this report is based was carried out in general conformance with Project Memoranda 505-3.1 and 505-5, September 1965.

113. Grassland. An area was selected on a roadbank that was known to have burned each year from 1961 through 1965 during the dry seasons. The most common grasses were Panicum maximum and Seccharum sp., each clumped in single-species clusters, often of several meters in diameter. The only shrub present was Hamilia sp. The small legume vine, Schrankia sp., occurred also.

114. Brushland. This area was adjacent to the grassland but in an area where larger vegetation was sufficiently dense to limit the growth of grass. The common trees were fire-maintained species such as Byrosonima crassifolia, Spondias mombin, Apeiba tibourbon, Vismia ferruginea, Cochlospermum vitifolium and many other less conspicuous species. Trees were no more than 12 meters tall and formed almost a complete canopy. The underbrush was rather dense, and during the wet season it forms almost a complete understory canopy. Many species lost their leaves at some time during the dry season, but not necessarily at its onset.

115. Forest land. This study area adjoined the Albrook forest tower site to the east, and included trees up to 30 m or more in height. Some of the more common tree species were Ficus sp., Anacardium excelsum, Lafoensia punicifolia, Luehea seemanii, and Spondias mombin, the latter a fire-maintained species that persists in the forest, evidence of the immaturity of the area. This forest area may best be described as an advanced secondary forest. There is no evidence of the three canopies reported to occur in primary forests*; the canopy may best be described as having the appearance when viewed from above, of a series of mounds and depressions.

Method of Investigation

116. The date for beginning this project was based on previous weather information. It was thought best to begin about one month before the first rain of about one-half inch was to be expected. By so doing it was believed that maximum information could be gained in a minimum of time. Sampling began on 5 April 1966 and followed at weekly intervals thereafter for three weeks.

117. The hours in which to take samples were determined by the results of one day of previous work in which samples were taken each hour from 0600 through 2100. It was found that dew began to evaporate after 0700 and that grass was too wet to burn by 1900. Therefore these hours were arbitrarily established as the beginning and ending hours for daily sampling, with additional samples being taken at 1000, 1300, and 1600, or at three hour intervals, and at ± 20 minutes from the hour.

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* Richards, P. W. 1952. The Tropical Rain Forest. Cambridge University Press, England

118. Ten samples of non-living litter were collected on each of the three sites, five times daily, for three days.

119. Litter samples were picked up from the ground surface, care being taken to collect each sample from an undisturbed place. Samples were taken by hand, and each included litter from the top of the accumulation to the ground surface. Litter was placed in 25 X 36 cm cotton cloth bags with draw-string closures. Bags had previously been weighed and numbered to facilitate record keeping. Litter was placed loosely in the bags to facilitate drying.

120. Litter was placed in a cloth bag in the field which was immediately enclosed in a plastic bag to limit evaporation. Plastic bags were transported to the laboratory after 10 cloth bags of litter were collected at each of the three sites. Cloth bags were removed individually from the plastic bags, immediately weighed, in the bags, and placed in a drying oven with a constant temperature of 55 C. Samples remained in the oven at least 36 hours before reweighing. Each sample was weighed in the cloth bag, and, following each weighing, the dry weight of the bag was subtracted from the total.

Results

121. Figure VI-3 summarizes the results, for each study area, of the moisture-content determination of all 10-bag litter samples, showing the mean values.

122. Figure VI-4 shows accumulative rainfall and the relative humidity at the Albrook Forest site from 1 March through the termination of this study on 19 April. Though the precipitation there is not necessarily the same as on the grassland and brushland sites, reasonably close correlation may be presumed. Casual observation indicated that on 7 April somewhat less rain fell at the tower than at the other sites. Note that the first rain of more than 0.5 inches was on 16 April, three days before the last samples were taken. On the final day, 19 April, 0.3 inches fell between 1700 and 1800, wetting all the grassland and brushland litter, so no sample was taken at 1900.

123. Relative humidity during the time of this study was somewhat lower than during the previous month in spite of the increased rainfall. Precipitation consisted of local showers lasting a few minutes only, and they were over before the recording instrument changed sufficiently to show an exact picture.

124. Temperatures were high throughout the study period, with a maximum ranging from 88 to 95 F and a nightly minimum from 71 to 75 F, averaging from 80 to 84 F.

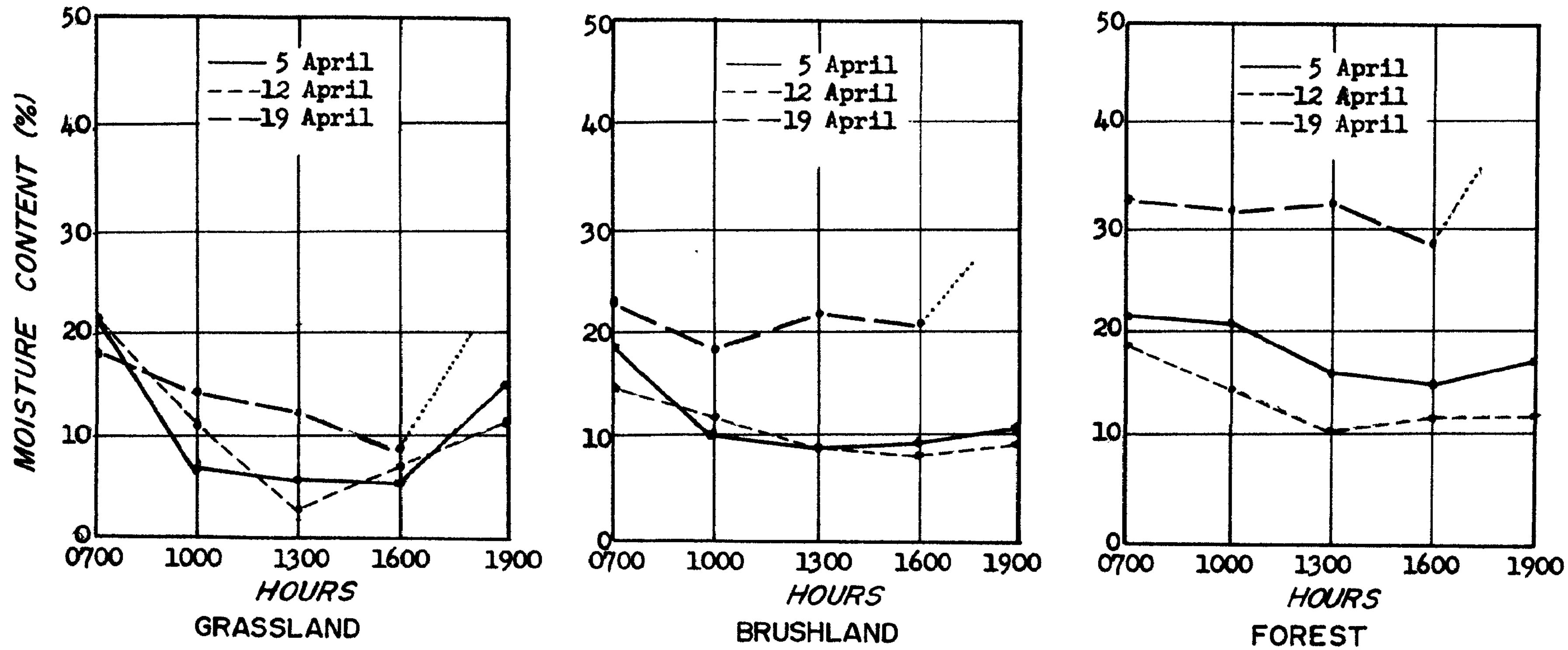

FIGURE VI-3. MEAN MOISTURE CONTENT OF LITTER

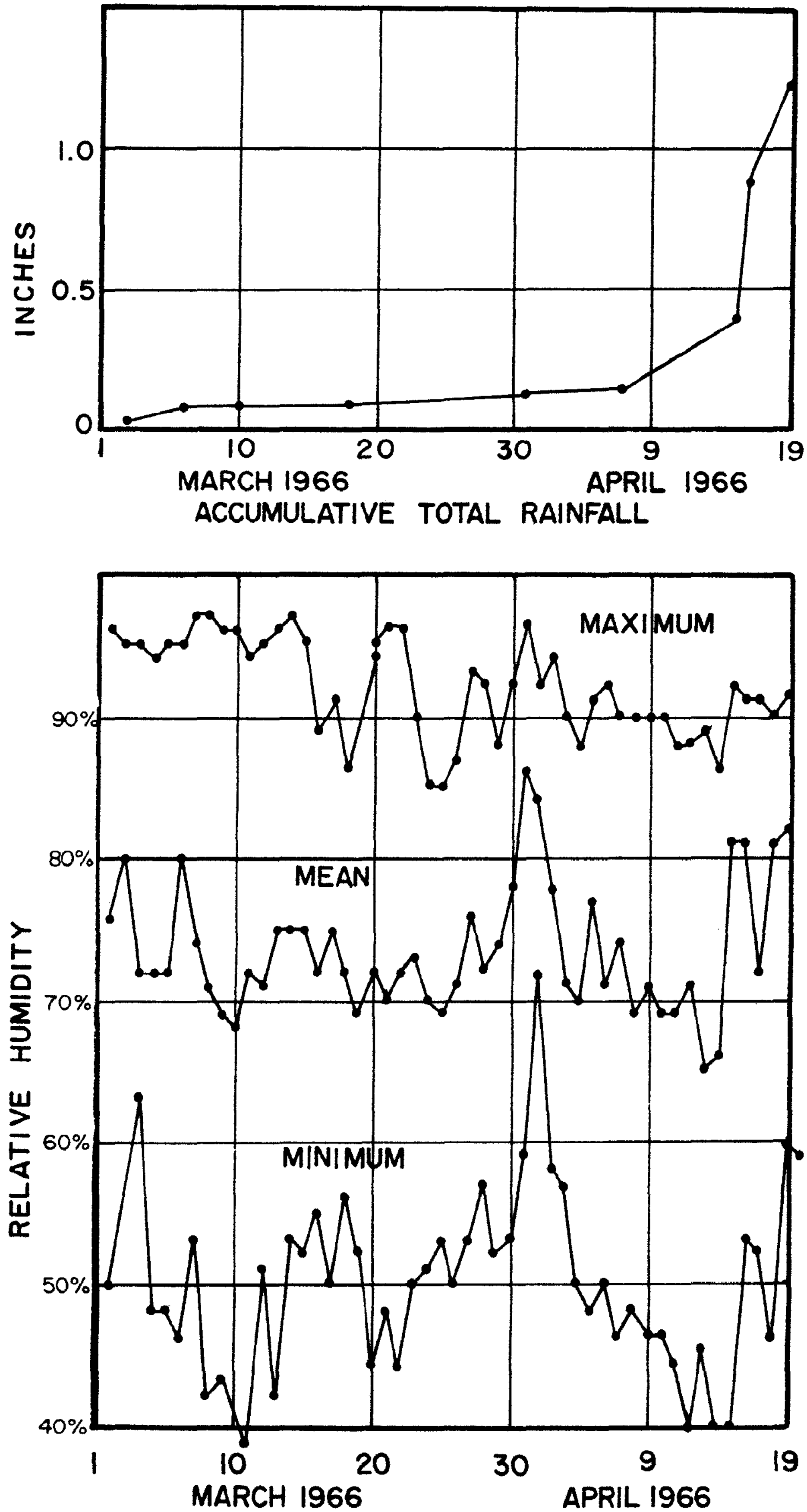

FIGURE VI-4. RAINFALL AND RELATIVE HUMIDITY, ALBROOK FOREST SITE

Discussion

125. Moisture is the most obvious factor affecting the combustibility of litter. For this reason a direct measurement was made of the percentages of moisture content in litter. Further, moisture content of litter will vary daily, or even hourly; therefore observations were made each day, from the time dew begins to evaporate in the morning until it forms in the evening. The most obvious time for the normal moisture content to be at its lowest is toward the end of the dry season immediately before the rains begin when it was hoped to begin this project; since the 1966 wet season began 1-2 weeks earlier than expected, samples were taken only two weeks before the first rainfall of at least one-half inch.

126. Local farmers, as a cultural practice, burn their fields, pastures, and newly-cut forest areas. These were watched closely to try to correlate local burning with moisture content of litter. The assumption was that farmers, whose livelihood depends to some degree on the timing of burning, would know best when to begin fires in their fields. In addition, activities of the Canal Zone fire department were observed, as they burned, or attempted to burn, areas which were considered fire hazards.

127. Perhaps the most obvious factor related to burning, especially over a large area, is the amount of smoke in the air. This was noticeable to the unaided eye. As the mositure content of litter went down in the morning the amount of smoke in the air began to increase. A Gelman paper-tape sampler placed at the 46-meter level on the Chiva Chiva tower was used to measure this change. The sample device is made up of an air pump which pulls a steady steam of air through a piece of paper tape that filters out all large particles in the air such as carbon (smoke), pollen, fungal spores, and perhaps many other items. The sampler was set to change automatically to a new spot on the tape at the end of each hour. Thus a record of particles in the air for a complete day was made on each work day. To quantify data, each tape, or spot on the tape for each our was measured at the end of the hour. Measurement was made by the ability of the spot on the tape to attenuate a beam of light as compared with unused tape. This gave an optical density, which was converted into a coefficient of haze (COH). The darker the spot on the tape, the higher the COH. Figure VI-5 shows the COH for the three work days.

128. The first field observation of fire was a Fire Department control burn on 4 April 1966. At 1700 hours the grass and forest behind the housing area near the Albrook forest was ignited with standard Forest Service oil-burning fire pots. The grass fires burned slowly except on the north side of the hill where wind was behind the fire. By about 1800 hours all the fire had died down except for a few logs and piles of litter which smoldered all night. At about 0900 hours the following morning, 5 April, the whole hill was ablaze, burning more vigorously than on the previous day. From a hilltop near the Albrook tower, at about 1000 hours, smoke could be observed throughout the general area.

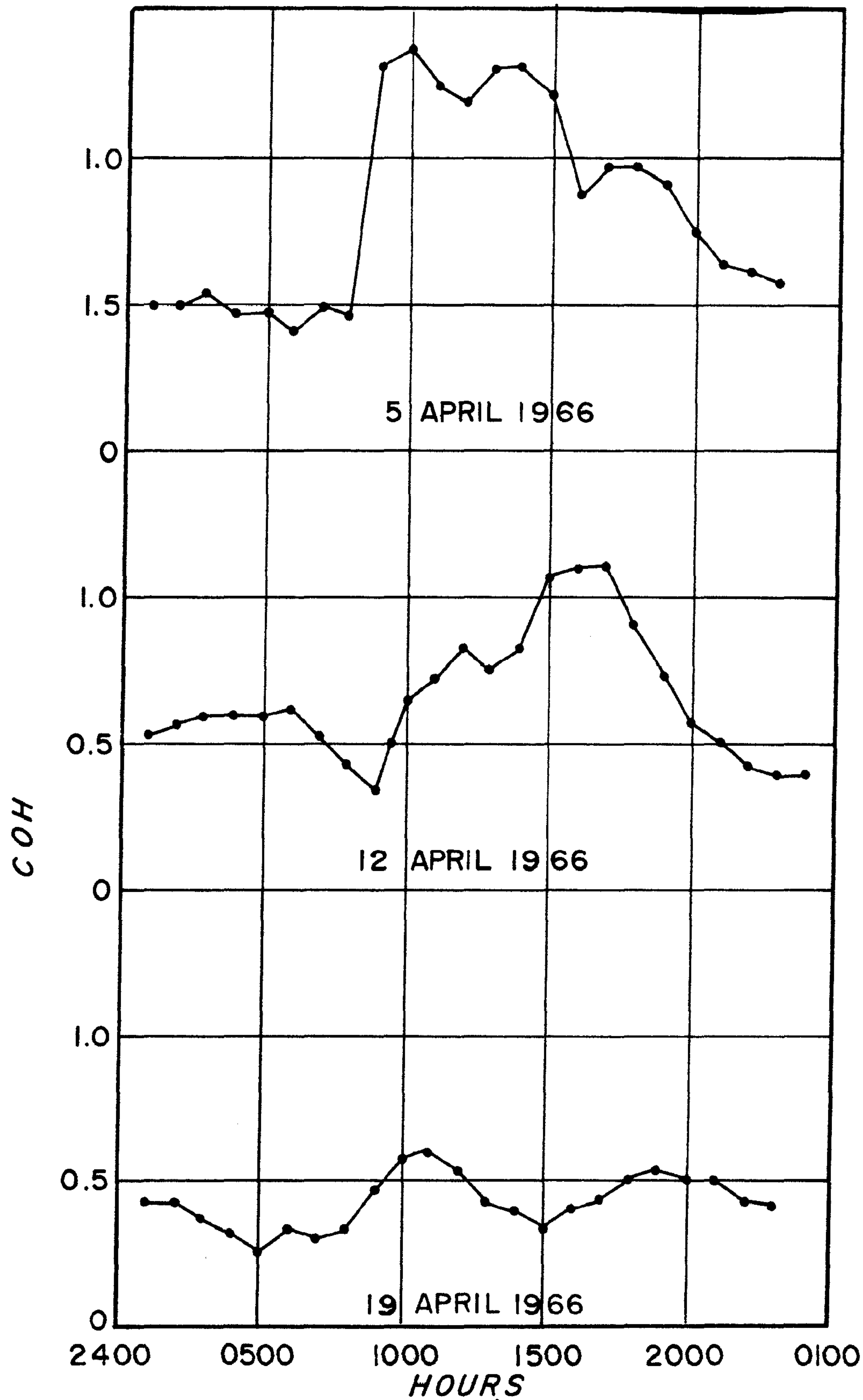

FIGURE VI-5. COEFFICIENT OF HAZE (COH) AT 46-METER LEVEL, CHIVA CHIVA TOWER

129. Referring to the COH, Figure VI-5, it can readily be seen that the number of particles in the air began increasing just before 0900 and remained high until 1500 when they began to taper off. Referring to Figure VI-3, it can be seen that the moisture content of grassland litter fell to 10 percent at approximately 0900, about the same time the carbon particles increased in the air.

130. By 1100 on 5 April the brushland on the hill adjoining the control burn took fire, but the forest did not ignite. Figure VI-3 indicates that moisture content of the brush litter dropped to 10 percent at approximately 1000 and that the forest litter never fell below 15 percent moisture content; however, it did not burn.

131. On 12 April the moisture percent dropped to 10 percent in the grassland at 1000 hours; in the brushland at approximately 1130 and 10 percent was just barely reached in the forest at 1300 hours (Figure VI-3). These data indicate that vegetation was more humid on 12 April except in the forest, and that fire was less likely to occur. Nevertheless, fires were observed in surrounding grasslands by 1030. Figure VI-5 shows further that particles in the air began increasing between 1000 and 1100 hours reaching a COH of 1.10 at 1600 as compared to 1.35 at 1000 hours on 5 April.

132. On 19 April after a 0.55 inch rain, only the grassland litter briefly reached 10 percent moisture and the COH reached 0.6 at 1100. No fires were observed.

Conclusions

133. These data indicate that the moisture content of litter must fall to about 10 percent before combusiton can be maintained. Also grassland becomes dry enough to burn much earlier in the day than forest or brushland. However, a small shower will have more effect on the moisture content of grassland or brushland than on older forests. Furthermore, indications, based on the amount of burn observed in brushlands and forest, are that the dry season of 1966 was not as dry as most previous years.

PART VII. MICROBIOLOGY AND CHEMISTRY OF THE ATMOSPHERE

134. Five lines of investigation in the fields of microbiology and chemistry of the atmosphere were carried out during the period covered by this report. These included investigations of the deposition of microorganisms on surfaces, observations on the distribution of airborne microorganisms, and investigation of the amounts and variabilities of chemicals in the atmosphere, an exploratory study of the roles of microorganisms as sources of atmospheric contaminants in the tropics, and several short term observations of condensation nuclei and particulate matter in the atmosphere.

135. In the case of each investigation work was carried out during only part of the period, and the amount of data collected permits only tentative conclusions. For several investigations most of the period was spent determining which method of data collection was most appropriate. Appreciable time also was spent adapting equipment or finding ways to get it to operate in the tropical environment. These things accomplished, it was possible to start routine observations before the end of the period for all but the investigations of microorganisms as sources of contaminants and the observations of condensation nuclei and particulate matter. Additional work in the former is dependent upon the availability of a gas chromatograph and a skilled operator. The latter depends upon success in keeping equipment operating.

Deposition of Microorganisms on Surfaces*

Introduction

136. Fabric, paper, some plastics, leather, wood and in fact most organic substances and even metals have been reported to suffer from microbial attack. The Prevention of Deterioration Center's annotated bibliographies #63-025 dated 11 July 1963 and #65-027-3 dated 11 May 1965 list publications citing effects of microorganisms on all kinds of materials.

137. Surfaces initially free of microorganisms become heavily contaminated when they are exposed to the tropical atmosphere. The nature and extent of contamination have generally been observed to vary with factors of region, season, and characteristics of the environment.

138. This is a report of sampling to observe numbers of microorganisms falling on unit areas of surfaces exposed in a forest atmosphere. The program of research is designed as a portion of the Data Base project. Observations were made at irregular intervals during the period of July 1965 through April 1966. The sampling plan provided for the observation of the effect of height of exposure within the forest, time of day, and season (dry or rainy). The place of observation for this period of reporting was the Albrook Forest tower and immediate vicinity.

Data Collection Methods

139. During the reporting period, attempts were made to determine the effect of experimental procedure on the results obtained in order to determine what methods were best adapted to the long-term observations called for in the Data Base project. For example, experiments were carried out to determine whether the numbers of microorganisms collected on various kinds of surfaces are related to the composition of the surfaces. Carrot Infusion Agar (weakly nutrient) was compared with Czapek's Agar (abundantly nutrient and selective for fungi) and Bacto Nutrient Agar (selective for bacteria). Numbers of microorganisms collected on these surfaces were compared with the numbers collected on agar containing no nutrient at all, glass, and a chrome plated steel surface. Results obtained from these variations in material did not appear to be worth the effort required to obtain them. For all practical purposes the number of microorganisms falling on unit areas in a given period of time were not affected by the kind of material exposed. As a result of this and other experiments the method of observation described below was adopted.

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* This section has been prepared by Dr. Robert Hutton, Biological Scientist, US Army Tropic Test Center. Work on which the discussion is based was carried out in general conformance with Project Memorandum 510-1, 20 July 1965.

140. Precedent for observing microorganisms falling on exposed surfaces was established by Gregory and Savage*. Savage also exposed plates to collect and enumerate fungi. The procedure used to obtain the results reported below differed from the simple open plate exposure used by Gregory and Savage in the following respects.

(a) Non-nutrient agar surfaces which had been exposed in the field were overlaid with sterile nutrient-containing pads in the laboratory. This procedure enabled not only a saving of time and materials but also allowed us to selectively cultivate bacterial and fungal forms. In the future, as more is learned about the method and as more data are obtained, it should be possible to make observations on the effects of interaction between bacterial and fungal forms as each grows on a surface more or less favorable for growth. Further observations on methods, if such prove to be of interest, will be recorded in a report specifically addressed to that subject.

(b) Exposed surfaces were inside "exposure tubes" which were placed horizontally in both north-south (NS) and east-west (EW) directions. Exposure tubes are five-inch fiber glass cylinders two feet long. Open plates are placed in the sterilized tube in the laboratory and carried to the field where the end caps are removed for the period of exposure. After exposure caps are replaced, and the entire device is returned to the laboratory. Use of exposure tubes was necessary to prevent debris, insects, or rain from falling into the plates during exposure. The NS-EW orientation of the tubes during exposure was to test the effect of wind direction.

Results

141. The test for tube orientation effects has not produced conclusive data, as yet. Variation in the overall average of numbers of microorganisms collected between NS and EW oriented exposure chambers was less than five percent. Data could be analyzed to attempt to correlate day-by-day variation in numbers with wind direction. This was not done and probably should not be attempted until at least one full cycle of rainy-dry season sampling is completed.

142. Table VII-1 is a record of the results of sampling for the report period. The relatively small number of observations in July and August 1965 gives an indication of wet season conditions. The more

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* Gregory, "Spore Content of the Atmosphere Near the Ground", Nature 170, 475 (1952).

Savage, "A Qualitative Study of the Atmospheric Fungi in Southern Arizona", Bacteriological Proceedings, G 13, 15, (1965).

TABLE VII-1. SURFACE DEPOSITION OF MICROORGANISMS* JULY 1965 THROUGH APRIL 1966.

DATE	Level**	0 - 6 Hours Bacteria NS	0 - 6 Hours Bacteria EW	0 - 6 Hours Fungi NS	0 - 6 Hours Fungi EW	6 - 12 Hours Bacteria NS	6 - 12 Hours Bacteria EW	6 - 12 Hours Fungi NS	6 - 12 Hours Fungi EW	12 - 18 Hours Bacteria NS	12 - 18 Hours Bacteria EW	12 - 18 Hours Fungi NS	12 - 18 Hours Fungi EW	18 - 24 Hours Bacteria NS	18 - 24 Hours Bacteria EW	18 - 24 Hours Fungi NS	18 - 24 Hours Fungi EW
19 Jul	Over Canopy					69	21	117	61	68	90	170	175				
	Under Canopy					62	30	80	79	175	75	137	168				
20	Over Canopy					54	46	117	109	60	60	167	177				
	Under Canopy					34	70	177	148	76	60	205	197				
21	Over Canopy													160	73	147	170
	Under Canopy													266	(509)	190	180
2 Aug	Over Canopy					122	134	141	161								
	Under Canopy					68	41	190	208								
4	Over Canopy									46	68	320	258				
	Under Canopy									96	81	293	328				
5	Over Canopy									63	69	215	243				
	Under Canopy									65	48	172	39				
7 Mar	Over Canopy									0	293	242	248				
	Under Canopy									(2929)	615	(3025)	(2402)				
8	Over Canopy									24	43	38	38				
	Under Canopy									333	(1670)	515	(1110)				
9	Over Canopy					39	40	38	48					31	21	78	69
	Under Canopy					49	46	63	80					63	80	44	46

* Number of living organisms deposited on 100 cm^2 of exposed surface in one hour.
** "Over canopy" level at 46 meters, "Under canopy" level at 1.5 meters.
Key: NS, EW= North-South, East-West orientation.

TABLE VII-1. (Cont'd)

Date	Level**	0 - 6 Hours Bacteria NS	EW	Fungi NS	EW	6 - 12 Hours Bacteria NS	EW	Fungi NS	EW	12 - 18 Hours Bacteria NS	EW	Fungi NS	EW	18 - 24 Hours Bacteria NS	EW	Fungi NS	EW
10 Mar	Over Canopy					20	11	39	44					121	42	123	38
	Under Canopy					55	6	73	27					46	219	259	353
14	Over Canopy									22	15	78	70	172	221	290	191
	Under Canopy									46	36	42	99	445	(990)	314	(1759)
15	Over Canopy					30	36	55	62	31	24	115	84				
	Under Canopy					46	65	69	86	72	46	(1600)	124				
16	Over Canopy													16	26	127	161
	Under Canopy													614	(2882)	(3095)	(1991)
17	Over Canopy									29	28	27	52	6	15	3	15
	Under Canopy									76	70	69	136	19	7	4	6
18	Over Canopy													3	(728)	115	(1572)
	Under Canopy									76	81	222	132	7	4	100	225
21	Over Canopy									48	18	141	45	102	24	115	16
	Under Canopy									38	9	258	224	104	47	270	260
22	Over Canopy									19	21	105	82	63	1	167	24
	Under Canopy									16	122	94	278	85	75	246	195
23	Over Canopy									0	70	64	79		42		22
	Under Canopy									42	92	294	255	59	91	388	280
25	Over Canopy																
	Under Canopy									176	31	194	179				
28	Over Canopy									15	18	173	194	34	25	220	111
	Under Canopy									280	28	(2230)	332	16	17	230	155
29	Over Canopy													1	3	(2802)	164
	Under Canopy													15	9	149	142

TABLE VII-1. (Cont'd)

Date	Level**	0 - 6 Hours Bacteria NS	0 - 6 Hours Bacteria EW	0 - 6 Hours Fungi NS	0 - 6 Hours Fungi FW	6 - 12 Hours Bacteria NS	6 - 12 Hours Bacteria EW	6 - 12 Hours Fungi NS	6 - 12 Hours Fungi EW	12 - 18 Hours Bacteria NS	12 - 18 Hours Bacteria EW	12 - 18 Hours Fungi NS	12 - 18 Hours Fungi EW	18 - 24 Hours Bacteria NS	18 - 24 Hours Bacteria EW	18 - 24 Hours Fungi NS	18 - 24 Hours Fungi EW
30 Mar	Over Canopy									17	20	67	115				
	Under Canopy									15	142	115	107				
31	Over Canopy									45	59	146	193	201	(495)	902	345
	Under Canopy									15	0	120	63	440	246	800	(865)
12 Apr	Over Canopy	23	43	262	244					29	18	499	626				
	Under Canopy	17	15	350	370					16	25	280	325				
13	Over Canopy	15	46	26	26					15	36	31	22				
	Under Canopy	28	130	67	73					34	33	48	75				
14	Over Canopy	66	22	33	60					0	0	91	116				
	Under Canopy	22	58	151	98					(6)	0	95	75				
15	Over Canopy	4	7	107	30					(6)	86	30	51				
	Under Canopy	22	10	90	36					70	31	138	120				
18	Over Canopy	21	22	24	31					15	25	21	22				
	Under Canopy	25	48	30	58					0	52	19	61				
19	Over Canopy	52	41	82	64					10	24	21	113				
	Under Canopy	31	37	51	121					37	0	77	45				
21	Over Canopy					10	18	103	51								
	Under Canopy					22	17	80	52								
25	Over Canopy																
	Under Canopy													39	0	55	78

numerous March 1966 observations were made at the height of the dry season, and those in April cover the beginning of the 1966 wet season. These data were processed to yield the material presented in the subsequent tables. The data display a very wide range of values, from zero to more than three thousand, in which the distribution is very irregular. These can be roughly divided into two groups: One with many relatively low values, and a second with a few high values.

143. The extreme variation in value between numbers of fungi and bacteria observed over and under the canopy, point to the need for further observations to determine its cause. Diurnal and day-to-day variation in these numbers resemble those reported by Pathak and Pady*. These workers attribute the hundred to one, or greater, variability in numbers sample to "some disseminating mechanisms characteristic of the species of fungus." Since we obtain variations in numbers not only with fungi but also with bacteria (not known to possess any characteristic mechanisms enabling them to become airborne), it seems more likely that we should look for correlations between the numbers of microorganisms collected on surfaces and some of the microenvironmental factors such as leaf wetness, leaf drying, insect activity, rainfall, dew formation, etc.

144. The bracketed values in Table VII-1 have been omitted in the computations of the succeeding tables. These values, which are 10 to 50 times greater than the others, were omitted from the averages on the assumption that the high numbers were the results of unusual "shower" type increases in microbial populations such as those reported by Pathak and Pady. It is interesting to note that there were no very high numbers observed in the 0-6 and 6-12 hour periods.

145. The numbers in Table VII-2 are averages, by date, of fungi and bacteria falling on 100-cm^2 areas in one hour. This table condenses information given in Table VII-1 and shows more clearly the seasonal aspects. (July and August are wet season months).

146. The values in Table VII-3 are averages, by time of day, and by exposure position relative to the canopy, of the numbers of bacteria and fungi falling on 100-cm^2 areas in one hour. Would-be analysts of the data should bear in mind that averages of numbers of bateria and fungi shown are derived from numbers of samples which varied widely. The lack of symmetry in the sampling protocol was unavoidable during the reporting period but will be corrected in the future.

147. Table VII-4 presents the average numbers of bacteria and fungi falling on 100-cm^2 areas in one hour, comparing daylight and dark hours in the rainy and dry seasons. A close look at these data reveals that daylight-over canopy-rainy season numbers are significantly <u>higher</u> than

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* Numbers and Viability of Certain Airborne Fungus Spores, Mycologia <u>57</u>, 302 (1965).

TABLE VII-2. NUMBERS OF BACTERIA AND FUNGI DEPOSITED ON 100^2 CM SURFACE IN ONE HOUR

	Bacteria		Fungi	
DATE 1965	Times Sampled	Average of all samples	Times Sampled	Average of all samples
19 July 1965	9	66	9	110
20	8	58	8	162
21	4	252	4	179
2 August 1965	4	91	4	175
4	4	73	4	298
5	4	61	4	218
1966				
7 March 1966	3	354	3	633
8	3	133	4	197
9	8	46	8	61
10	10	520	5	191
14	8	135	5	271
15	8	44	7	85
16	4	210	4	144
17	9	28	5	62
18	8	112	7	132
21	8	49	5	266
22	8	50	5	238
23	8	50	4	346
25	2	104	2	187
28	8	52	8	201
29	4	7	4	152
30	4	49	4	101
31	8	188	5	687
12 April 1966	8	23	8	371
13	8	42	8	46
14	4	44	5	142
15	8	30	4	151
18	8	26	8	33
19	7	33	9	64
21	4	17	4	72

daylight-over canopy-dry season numbers for both bateria and fungi. All other indications of differences such as the increase of bacteria under canopy in the rainy season are of questionable statistical significance.

Table VII-3. AVERAGE NUMBERS OF BACTERIA AND FUNGI DEPOSITED IN ONE HOUR ON 100 cm^2 SURFACE
(numbers of samples indicated in parentheses)

	A. TIME OF DAY			
	0 - 6	6 - 12	12 - 18	18 - 24 hours
Bacteria	36 (26)	45 (29)	66 (77)	88 (48)
Fungi	98 (26)	88 (30)	148 (82)	183 (47)

	B. HEIGHT	
	Under Canopy	Over Canopy
Bacteria	73 (92)	45 (87)
Fungi	158 (88)	110 (91)

Table VII-4. AVERAGE OF BACTERIA AND FUNGI BY SEASON AND TIME OF DAY
(numbers of samples indicated in parentheses)

		Daylight		Dark	
Deposition	Season	6 - 18 hours		0-6 hours and 18-24 hours	
		Under Canopy	Over Canopy	Under Canopy	Over Canopy
Bacteria	Rainy	104 (14)	64 (14)	229 (1)	71 (2)
	Dry	43 (39)	24 (37)	69 (35)	50 (34)
Fungi	Rainy	167 (14)	153 (14)	115 (2)	116 (2)
	Dry	128 (41)	121 (41)	194 (32)	107 (34)

Distribution of Airborne Microorganisms*

Introduction

148. Air at the Albrook Forest site and the Chiva Chiva open site was examined for content of living bacteria and fungi. Data collection was started on an experimental basis in November 1965, but a practical sampling system was not settled upon until March 1966. Sampling was at ground level and 15, 21, and 46 meters above the surface. Tree top level in the forest area is about 26 meters. Sampling was carried out to determine the diurnal and seasonal variations as well as the variations occurring at different elevations.

Data Collection Methods

149. In sampling for viable microorganisms individual cells are trapped on some nutrient surface, often a filter. Surfaces are then incubated in the presence of nutrient where the trapped cells grow to colony size. Thus each viable cell is responsible for a colony which can not only be counted but also can be observed for identifying characteristics. For the period of this report identification was limited to separation into two groups, bacteria and fungi. Several variations of sampling technique were tried. The important finding in these early trials was that capture of microorganisms on a dry sterile membrane filter from air drawn directly through the filter gave the highest yield of numbers and the most consistent results. This is in contrast to most reports of results of sampling air in temperate climates. In the latter instance, significant losses in viability occur when sampling is by direct filtration of air. In temperate climates maximum numbers are obtained only when air being sampled is bubbled through liquid, usually nutrient media. In this method microorganisms pass from the air into the liquid and are later captured on filter membranes by liquid filtration. Reduced numbers obtained by direct sampling in temperate regions are attributed to an adverse effect of prolonged contact of trapped microorganisms with the relatively dry air being sampled. Presumably because of higher moisture content, tropical air passing through filters does not cause detectable injury to microorganisms already deposited on the filter.

150. A special filtering device, designed for field use, is shown in Figure VII-1, showing disassembled view and manner of use. Air is drawn through filter in sampling. Reduced pressure is supplied by a piston pump

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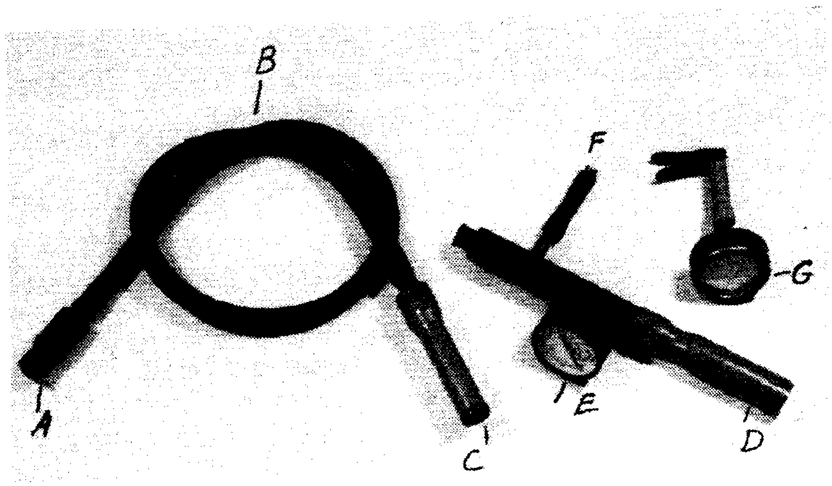
* This section has been prepared by Mr. George Gauger, Microbiologist, and by Dr. Robert Hutton, Biological Scientist, US Army Tropic Test Center. Work on which the discussion is based was carried out in general conformance with Project Memorandum 510-3, 12 July 1965.



Disassembled Sampling Device

(A) Connector to vacuum pipe
(B) Rubber tubing
(C) Male slide connector
(D) Female slide connector
(E) Vacuum gage
(F) Filter holder connector
(G) Filter holder

Field use of air sampler

Figure VII-1. Direct Air Sampling Device capable of maintaining 46 cm negative pressure while drawing 11 liters of air per minute through the filter. Sampled air is drawn through a calibrated orifice to enable calculation of sample size. Reduced pressure from the pump is available at all levels through a permanently installed line extending the length of the towers. Outlet valves, located at six-meter intervals, are closed except during sampling.

Results

151. The sampling system was tested in a four-day sampling period in April 1966, to determine whether it would provide reliable data. The results shown in Table VII-5 were favorable. Variation between samples taken the same day was of the same order of magnitude as the variation between samples taken on different days. From this group of figures we can conclude that, if numbers of either bacteria or fungi differ from a mean of a number of samples by more than 20 percent, the sample being observed may be considered to be from a different population than that which made up the mean.

152. The first routine sampling was done at the Albrook Forest site starting in March 1966. Sampling was at the surface, and at 15, 21, and 46 meters. The 21-m level lies within the canopy, and the 46-m level at approximately 20 m above the top of the foliage. Data collected during a three-week period in March and April is shown in Table VII-6. The mean number of microorganisms at the various levels is graphically shown in Figure VII-2. This dry season period approximately coincides with the period when very high numbers of microorganisms were encountered occasionally on surface deposition plates. Data shown in the table and graph indicate that numbers of both bacteria and fungi decrease with increasing height above ground. Numbers of both bacteria and fungi observed are almost always greater at night than at mid-day. This is the expected tendency since sunlight is injurious to airborne microorganisms. There is no obvious tendency of canopy shielding to reduce the effect of light. Many of the numbers in each column differ from the means by more than 20 percent. If the decision to recognize a difference of this magnitude as evidence of the presence of a different population is accepted, then we may say that airborne microbial populations in and around a forest are highly heterogeneous. This alone is evidence of the need for intense study of not only the microbial populations present, but also of the micrometeorological and other factors which exist to cause the development of heterogeneous populations.

153. Data to enable comparison of a forested area and a cleared area, with sampling at two levels and four intervals in each 24 hour period are contained in Table VII-7. Inspection of the data will reveal that numbers for both bacteria and fungi are higher at the Chiva Chiva (open) site. Numbers of fungi encountered at the open site appear to conform to a pattern of daylight minimums. Such a pattern is not easily discernable for bacteria--nor is there much tendency for daylight reduction of numbers

TABLE VII-5. TEST OF METHOD FOR AIR-SAMPLING OF MICROORGANISMS, ALBROOK FOREST SITE
ALL SAMPLES TAKEN AT THE SURFACE LEVEL AT 1400 HOURS

Date		Number of Microorganisms per 100 litters of Air	
(1966)	Sample No.	Bacteria	Fungi
19 April	1	9	61
	2	7	70
	3	9	58
	4	9	64
20 April	1	5	58
	2	5	67
	3	7	66
	4	7	56
21 April	1	-	-
	2	0	56
	3	9	53
	4	9	60
22 April	1	9	75
	2	-	-
	3	12	64
	4	7	60
Mean		7.4	62.0

95% confidence limits, Bacteria: 7.4 ± 1.5
Fungi: 62.0 ± 3.2

TABLE VII-6. NUMBER OF MICROORGANISMS PER 100 LITTERS OF AIR, ALBROOK FOREST SITE

Date	Surface				15 Meters				21 Meters				46 Meters			
	Bacteria		Fungi		Bacteria		Fungi		Bacteria		Fungi		Bacteria		Fungi	
(1966)	1300	0100	1300	0100	1300	0100	1300	0100	1300	0100	1300	0100	1300	0100	1300	0100
16 March	28	-	101	-	-	-	-	-	2	-	32	-	7	-	42	-
18 March	18	-	115	-	5	-	49	-	5	-	27	-	0	-	23	-
21 March	28	-	69	-	21	-	23	-	-	-	-	-	7	-	23	-
22 March	51	-	108	-	14	-	44	-	16	-	30	-	2	-	9	-
23 March	18	-	127	--	7	-	48	-	2	-	41	-	0	-	21	-
24 March	35	78	83	182	2	9	58	48	5	12	18	41	7	5	7	78
26 March	-	176	-	67	-	71	-	39	-	74	-	64	-	7	-	28
28 March	7	-	94	-	-	-	-	-	2	-	-	-	2	-	39	-
29 March	30	87	117	124	9	-	90	-	5	5	12	25	0	0	14	32
30 March	7	37	94	101	7	12	87	58	0	0	23	23	2	7	37	21
31 March	37	131	122	278	-	55	-	209	30	18	258	81	16	12	41	46
1 April	21	48	131	115	16	44	48	133	16	48	37	78	0	16	41	58
2 April	-	28	-	135	-	9	-	58	-	5	-	46	-	0	-	7
4 April	30	-	160	-	9	-	90	-	5	-	62	-	2	-	28	-
5 April	16	18	51	216	7	2	76	113	7	35	30	182	0	2	55	90
6 April	5	9	101	179	-	7	-	161	-	2	-	74	0	0	23	32
Mean	24	68	105	155	10	26	61	104	8	22	52	68	3	5	28	41

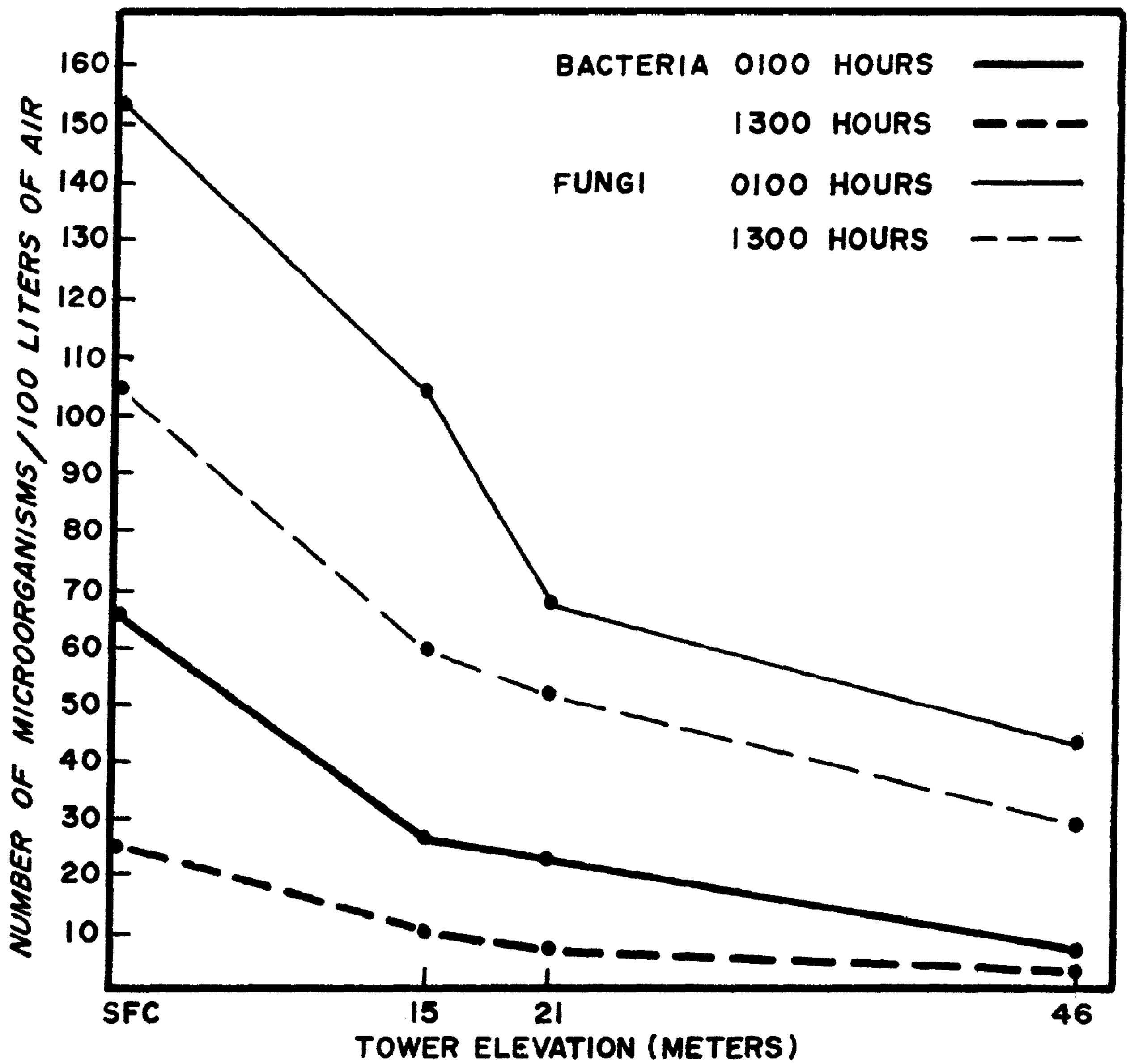


FIGURE VII-2. MEAN NUMBERS OF MICROORGANISMS FOR A 3 WEEK PERIOD IN MARCH AND APRIL 1966, ALBROOK FOREST SITE

Table VII-7. AIRBORNE MICROORGANISMS IN FORESTED AND OPEN AREAS

Average Number of Microorganisms/100 Liters of Air

Site	Elevation	Month	0200 Hrs.		0800 Hrs.		1400 Hrs.		2000 Hrs.	
			Bacteria	Fungi	Bacteria	Fungi	Bacteria	Fungi	Bacteria	Fungi
Chiva Chiva (open)	Surface	June	16.0	56.0	5.2	37.0	6.6	21.4	5.2	20.6
	46 meters	June	12.5	41.5	9.2	31.0	2.8	14.8	1.6	11.0
Albrook (forest)	Surface	June	10.3	43.0	11.0	49.0	10.0	43.0	8.6	31.0
	46 meters	June	10.3	38.7	3.2	27.0	4.0	11.8	4.5	21.4
Chiva Chiva (open)	Surface	July	44.0	67.4	10.0	43.5	4.5	16.0	12.4	31.4
	46 meters	July	11.5	62.8	5.3	38.3	10.0	22.7	4.6	40.0
Albrook (forest)	Surface	July	13.4	52.4	11.0	30.0	8.8	8.8	5.0	40.8
	46 meters	July	14.0	32.6	4.0	15.0	8.2	18.8	5.2	40.0
Chiva Chiva (open)	Surface	Aug	66.2	70.0	13.8	59.2	3.6	8.8	4.0	27.0
	46 meters	Aug	13.0	70.2	12.5	50.8	5.4	17.2	2.8	35.8
Albrook (forest)	Surface	Aug	25.0	52.8	12.0	41.2	10.2	21.0	9.6	56.2
	46 meters	Aug	12.4	37.0	8.2	43.7	7.4	16.6	7.4	49.2
Chiva Chiva (open)	Surface	Sep	56.3	127.7	16.3	49.5	12.8	42.6	32.4	46.2
	46 meters	Sep	12.8	104.4	12.2	45.4	17.0	26.8	9.7	74.3
Albrook (forest)	Surface	Sep	10.5	54.0	5.2	24.6	5.6	32.8	3.2	38.2
	46 meters	Sep	19.0	75.2	11.0	45.0	43.4	52.4	8.0	47.3

of either bacteria or fungi in the forest area. Attempts to examine these data in minute detail and to infer "meaning" from the results are not justified--not because the data are inferior but because, as was pointed out in the discussion of the data for Table VII-6, we are obviously working with mixed populations which should not be lumped together. An adequate examination of cause and effect relationships for airborne microorganisms will require the accumulation of much more data and interpretation of these data in terms of other elements of the environment.

Chemicals in the Atmosphere*

Introduction

154. This is a report of sampling to determine the level and variability of trace gas contaminants in the tropical atmosphere. The investigation was performed as a component task of the Data Base project. The sampling reported on here was carried out in three periods, each of about two weeks duration. One period was in February 1965, another in November 1965, and the third in February 1966. The November samplings were at the height of the wet season, those in February were in dry seasons. The measurements are the result of cooperative work between the US Army Tropic Center and the National Center for Atmospheric Research (NCAR) Boulder, Colorado. A report substantially parallel to the one appearing here was published in Science, vol 153, 22 July 1966, by J. P. Lodge Jr., and John B. Pate, NCAR.

Location of Observation Sites

155. The orientation of the Canal Zone and the Isthmus of Panama is shown in Figure II-1. The Caribbean is to the north of the Isthmus, and the Bay of Panama, which opens into the Pacific, is to the south. The generalized wind pattern across the Isthmus consists of a dominant wind from the Caribbean Sea. In November it is weak and variable from north to northwest, while in February a rather persistant wind blows from the northeast.

156. The three principal sampling sites shown on Figure II-1 were used. The first site was Fort Sherman, on the Caribbean (northern) side of the Isthmus. This side of the Isthmus is characterized as an evergreen forest environment. All samples from this area were collected a short distance from the shore, and thus represent tropical maritime air typical of the Caribbean. The second sampling site was at the observation tower of the Albrook Forest site on the Pacific (Bay of Panama) side of the Isthmus, an area characterized as a semideciduous tropical forest. The third sampling site was on the north side of the Pearl Islands archipelago in the Bay of Panama. This site is in the path of air which has traversed the Isthmus and then has passed a short distance over the ocean surface. It has not passed directly over the Canal Zone and Panama City but rather over the sparsely populated eastern part of Panama, and thus has been influenced very little by human activity. A few samples were collected at a subsidiary site on Madden Ridge Road, near El Jefe. This site is northeast of Panama City on the continental divide and in the path of Caribbean air which has traversed approximately 50 kilometers of forested land.

* This section has been prepared by Dr. Robert Hutton, Biological Scientist, US Army Tropic Test Center.

Analytical Methods

157. Several techniques were employed for determination of the various atmospheric contaminants. These are described briefly below under the headings of the chemical species.

158. Aliphatic aldehydes. (Hauser and Cummins) (2). Known volume of air bubbled through fritted glass sparger into 3-methyl-2 benzothiozolone hydrozone hydrochloride (MBTH). Color proportional to quantity of aldehyde present develops when sulfamic acid and ferric chloride are added. Colorimetric assay, read at 628 mu.

159. Nitrogen dioxide. (Saltzman) (3). Known volume of air bubbled through fritted glass sparger into N-1-Naphthylethylenediamine Dihydrochloride (NEDA) in a glacial acetic acid-sulfanilic acid mixture. Color proportional to quantity of nitrogen dioxide present. Colorimetric assay, read at 550 mu.

160. Nitric oxide. (Jones et al.) (4). Saltzman method (3) adapted by use of sodium dichromate - sulfuric acid oxidizing filter in the gas train ahead of NEDA reagent. Nitric oxide calculated as total oxides of N (Method 4) minus Nitrogen dioxide (Method 3) equals Nitric oxide.

161. Ammonia. (Tetlow and Wilson) (5). Known volume of air bubbled through dilute sulfuric acid, add acetone, sodium phenate, and sodium hypochlorite to develop color (60 minutes at 25C required). Colorimetric assay, read at 630 mu.

162. Hydrogen sulfide. (Jacobs) (6). Known volume of air bubbled through alkaline cadmium sulfate solution containing gum arabic. Develop color with $FeCl_3$ and add ammonium phosphate to discharge excess ferric iron. Colorimetric assay, read at 670 mu.

163. Sulfur dioxide. (West, Gaeke) (7). Bubble known volume of air through mercuric and sodium chloride absorbing reagent. Add formaldehyde, sulfamic acid, and pararosaniline to develop color. 30 minutes required. Colorimetric assay, read at 560 mu.

164. Sulfuric acid aerosol. (Lodge, Frank) (8). Particles from air collected on silicon monoxide films using fourth stage of cascade impactor. After sampling, grids are subjected to metal shadowing to produce characteristic particle. Particles identified using electron microscope.

Results

165. Although the samples collected thus far have been for the purpose of obtaining preliminary or guide-line data, some reliable estimates of atmospheric levels have been obtained. In a recent monograph on atmospheric chemistry, C. E. Junge (1) summarizes measurements of previous investigators and gives a range of probable atmospheric levels. The levels

cited by Junge are largely uncertain, owing to the paucity of previous measurements, and it is interesting to compare Junge's data with our estimates for various gases and particulates.

166. Aldehydes. Junge cites the few formaldehyde measurements which have been made, and gives a probable ground-level concentration range from 0 to 10 parts per billion (10^9) (ppb). He points out that these measurements were made in Europe and that the formaldehyde may be of anthropogenic origin. Although we did not measure formaldehyde directly, we used Hauser's method (2) to give a measure of total aliphatic aldehydes. Our results showed a mean concentration of 1.1 ppb (range: >0.2 to 2.7 ppb). No statistically significant differences were found between samples collected during the rainy and dry seasons, or between those of maritime character collected on the Pacific and Caribbean sides.

167. Nitrogen dioxide. Junge cites ground-level concentrations of nitrogen dioxide as 0 to 3 ppb. Using a specific method for nitrogen dioxide (3), we found that our results corroborated Junge's data. During the dry season, the maritime air from the Caribbean had a mean concentration of 0.9 ppb (range: > 0.5 to 1.4 ppb). During the rainy season, with mixed sunshine and thunderstorm activity, the mean concentration was 3.6 ppb (range: > 2.6 to 5.00 ppb).

168. Samples from the forest site gave a mean concentration of 1.3 ppb (range: >0.5 to 2.7) below the forest canopy, and 2.2 ppb (range: > 1.9 to 4.0) above the forest. Three samples collected about 40 km out in the Bay of Panama (Pearl Islands) gave a mean concentration of 1.6 ppb (range: 1.5 to 1.7).

169. Nitric oxide. Junge found no measurements of this species. Using a relatively specific method (4), we found concentrations ranging up to 6 ppb. Although the data are too few to draw firm conclusions, they tend to show a somewhat higher concentration of nitric oxide than nitrogen dioxide.

170. Ammonia. The method used to determine ammonia (5) has not been validated for part-per-billion air samples. Thus we will simply note that the data obtained confirm the order of magnitude given by Junge (0 to 20 ppb). However, the lowest concentration found, including those in the Caribbean samples, were higher than 20 ppb.

171. Hydrogen sulfide. One isolated sample on the Caribbean coast gave a 4-ppb concentration. All other samples showed only traces or less than the minimum detectable amount of 1 ppb. Although the method (6) requires additional checking, corroborative evidence indicates that the ground-level range of 2 to 20 ppb given by Junge is too high for the region sampled.

172. Sulfur dioxide. Sulfur dioxide concentrations were measured by the West-Gaeke method (7). The values found ranged from < 1 to 5 ppb, with

no general pattern being clearly evident. This compares with Junge's world wide ground-level concentrations of 0 to 20 ppb.

173. Sulfuric acid aerosol. Despite the apparent availability of free ammonia in the atmosphere, sulfuric acid aerosols were found to be present at all sites, using the specific technique developed by Lodge (8). The Caribbean coast samples showed a minimal number of droplets but appreciable quantities of ammonium sulfate. The Madden Ridge Road samples showed the highest levels of droplets. Our findings are confirmed by samples taken in maritime, continental, and upper tropospheric air masses at other localities.

Discussion

174. We expected to find that the tropic forest was a major source of atmospheric hydrogen sulfide and other reduced chemical species. However, extremely low levels of hydrogen sulfide were found both under the canopy in the forest environment and above the canopy in the ambient atmosphere. We conclude that the tropic land regions are not usually a source of atmospheric hydrogen sulfide. Further, all of the data collected indicate that the atmospheric constituents associated with a tropic forest area are characterized by partially or completely oxidized chemical species. We postulate that reduced species formed by anaerobic processes will only be found, except where localized extreme conditions exist, at a level well below ground surface.

175. Although the values for the ammonia measurements are questionable, they tended to show high values for the Caribbean air, intermediate values for the under-canopy forest samples, and low values above the forest canopy. Electron microscopy showed the Caribbean aerosols to be characterize by the presence of ammonium sulfate and the virtual absence of sulfuric acid. This seems to corroborate previous suggestions that the Atlantic is an ammonia and ammonium sulfate source. On the other hand, samples from all other sites showed sulfuric acid to be present in substantial amounts as a characteristic aerosol.

176. Assuming a typical concentration of 100 sulfuric acid droplets of 0.1 unit diameter per cc, the capacity of the sulfuric aerosol as an ammonia sink was calculated to be 3×10^{-14} g ammonia per cc. A very conservative estimate of ambient ammonia concentrations, from Junge's and other data, shows these levels to be two to three orders of magnitude greater than required to convert all sulfuric to ammonium sulfate. The comparative absence of ammonium sulfate and the characteristics prevalence of sulfuric acid over the land indicates that another sink for ammonia must exist.

177. The apparent enrichment of nitrogen dioxide levels over the land and the rapid decrease to a lower level over the sea indicate that photo-oxidation of ammonia may be the active sink for ammonia. Our data suggest that nitric oxide could be the oxidation product, and that nitrogen

dioxide is a transient product of further oxidative reactions.

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Microorganisms as Sources of Atmospheric Contaminants*

Introduction

178. Microbial activity may contribute measurably to the chemical content of the relatively confined atmosphere in tropical forest environments. To find out more about what is present in atmospheres in which microorganisms are growing profusely, sensitive gas chromatography was carried out in the period 18 May to 13 July 1966. Rasmussen and Went** pioneered in this field.

Methods and Results

179. We were able to show that observable concentrations of volatile organic substances derive from microorganisms growing in association with plants. In one case a royal palm frond heavily overgrown with various fungi was obtained from the forest. The frond had a distinctive odor but appeared to be fully alive and healthy. Organic volatiles associated with the frond were analyzed in three steps. Figure VII-3a shows the volatile organics derived from the atmosphere immediately surrounding the frond Figure VII-3b shows the atmosphere immediately surrounding the frond after it has been washed lightly with water. Figure VII-3c represents the highly reduced signature from the atmosphere surrounding the same frond after it had been washed thoroughly with water. The fungi associated with the plant were easily removed and appeared to be present in an essentially epiphytic association. This experiment suggests that much of the contamination found in the tropic atmosphere may come from the microbial forms which grow profusely on almost all surfaces.

180. In another series of observations we determined that fungi growing together in "community" produce substances which none of the fungi growing in pure culture produced by themselves. Analyses were made of the organic volatiles produced by several of the common airborne microorganisms isolated from leaf surfaces. Organic volatiles from pure cultures of these fungi are detected by the gas chromatograph, as distinct "signatures". Figure VII-4 shows the characteristic signature of four of these cultures. In fact, some of the characteristic elements of the individual signatures are much reduced or absent in the group signature, and new combinations are noted. Except for the fact that these volatiles are very similar to those we can condense from the atmosphere using a liquid-nitrogen-cooled cold trap, we know very little about the contribution of communities of microorganisms to their environment.

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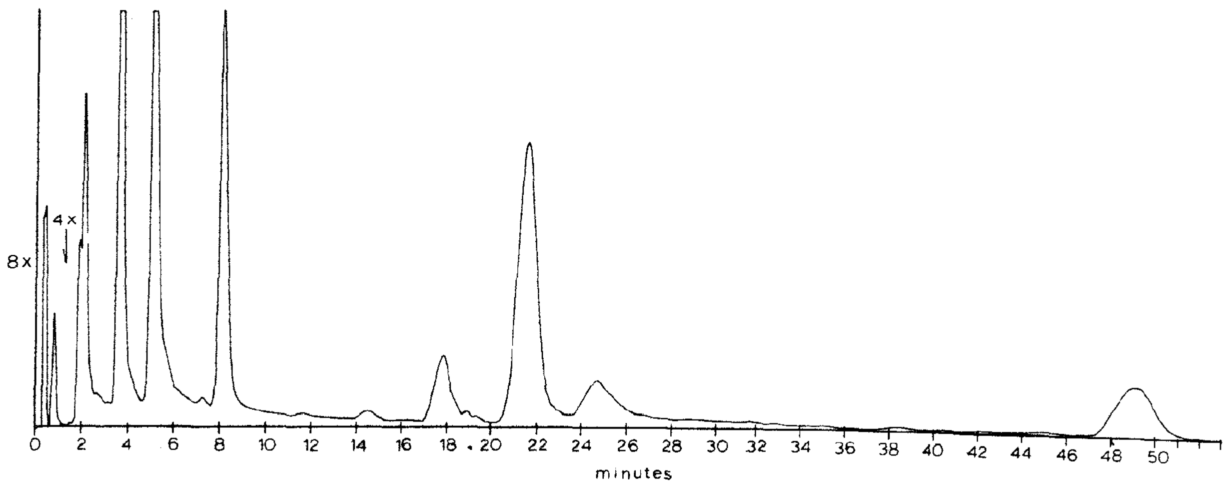
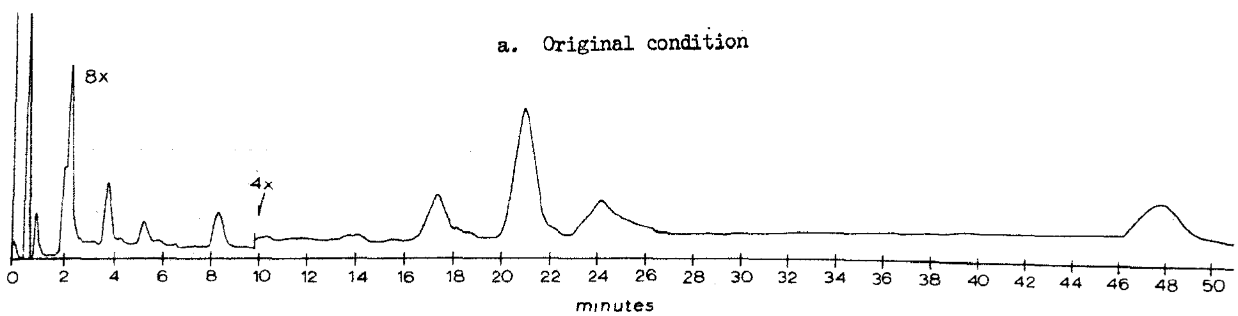
* This section has been prepared by Dr. Robert Hutton, Biological Scientist, US Army Tropic Test Center.

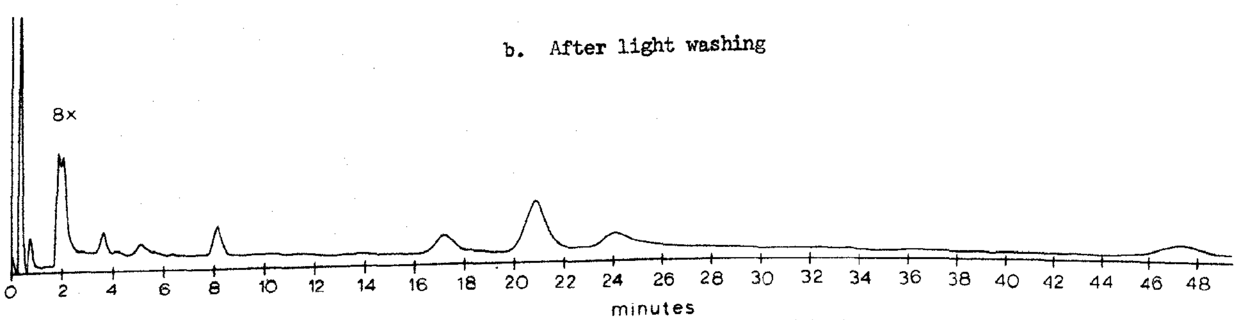
** Volatile Organic Material of Plant Origin in the Atmosphere, Procd. Nat'l Acad. Sci <u>153</u>, 215-220 (1965).



a. Original condition



b. After light washing



c. After thorough washing

Figure VII-3. Gas Chromotograph Tracing of Volatile Organics from Fungi-coated Palm Frond.

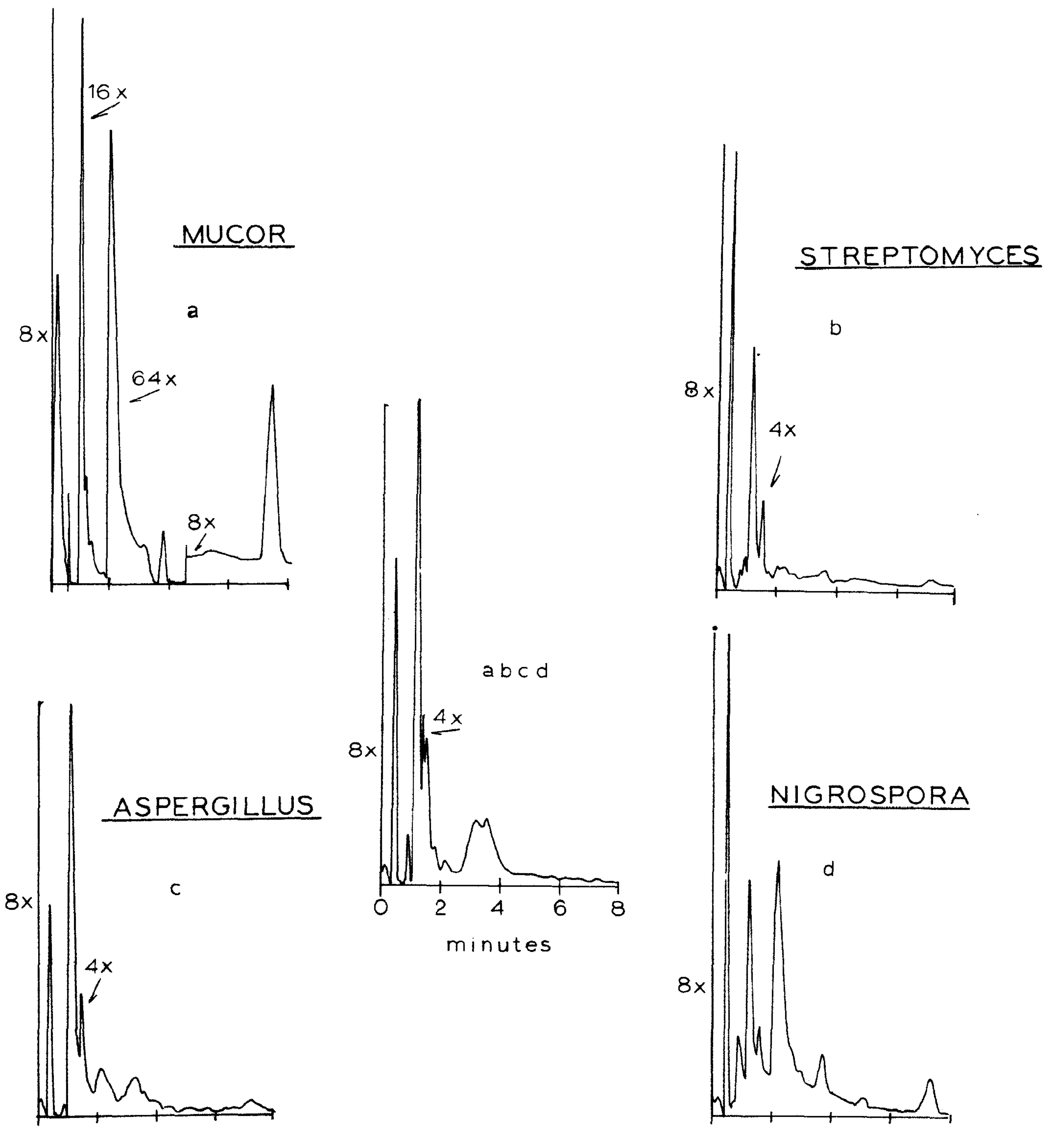


Figure VII-4. Gas Chromatograph Tracing of Volatile Organics from Cultures of Pure and Mixed Microorganisms

181. Further work will be required to determine whether or not communities of microorganisms produce a significant proportion of the contaminants found in the atmosphere, whether these contaminant are products of microorganisms or nutrients for microorganisms growing epiphytically, or both, and finally whether these contaminants are important to other forms of life and are related to the deterioration of materials.

Condensation Nuclei and Particulate Matter*

Introduction

182. During the reporting period, several brief observations of very small particles in the atmosphere were made at several locations in the Canal Zone. A General Electric condensation nuclei detector was used to determine relative concentrations of the submicroscopic liquid and solid airborne particles which form condensation nuclei. A four-stage Casella cascade impactor was used to collect particulate matter. Measurement of both the condensation nuclei and particulate matter is important for complete understanding of the chemical and biological components in the atmosphere. The particulates and nuclei are significant factors in cloud and precipitation formation and for air contamination; and they contribute to the accumulation of surface films on exposed items.

183. The detector, used for measuring the concentrations of nuclei, samples air continuously. Air brought into the machine is humidified to saturation and is subsequently cooled adiabatically to produce supersaturation. Nuclei present in the supersaturated air condense water vapor and become large enough to reflect visible light. The light reflected is proportional to the particles present. This reflected light is sensed by a photomultiplier tube and is electronically converted to energy which operates a meter and a recorder. In the hands of a skilled operator the detector is capable of use with suitable converters to detect volatile gases in the atmosphere. These gases include volatile hydrocarbons, ammonia, oxides of nitrogen, carbon dioxide, sulfur oxides, and hydrogen sulfide. During operation to detect nuclei the machine samples the total particulate matter in the air as well as the nuclei, however, the numbers of these larger particles are usually negligible as compared with condensate nuclei. So far only the simplest type of operation has been attempted. As soon as patterns of distribution of all particles are defined, investigations can be extended to compare numbers of condensate nuclei with numbers of larger particles and, provided the necessary level of operator skill is available, or can be developed, the detector can be used with available converters to determine levels of volatile gases present in the sampled air. Two methods of differentiating between condensate nuclei and microscopic particles are available. In one method the microscopic particles are determined by the difference between detector readings obtained with and without a pre-impinger in the air going to the detector. The pre-impinger removes large particles by impaction against a baffle in a fast moving air stream. Since the nuclei detector samples very small amounts of air which have not been subjected to rapid acceleration in an air stream, the use of a pre-impinger introduces new variables and complicates the observation. The use of a pre-impinger is not apt to be the method of choice. The more direct and more exact method is to determine the number and size of microscopic

* This section has been prepared by Dr. Robert Hutton, Biological Scientist, US Army Tropic Test Center.

particles using a cascade impactor. The latter method, however, is very time consuming and requires a relatively high degree of operator skill.

Methods

184. The equipment used to determine condensation nuclei in the atmosphere was the General Electric Condensation Nuclei Detector. Difficulties encountered in operation were considerable. At first the detector was placed in an airconditioned environment and air was drawn into the machine from outside the enclosure. Condensate from the sampled air quickly upset the steady-state operation of the machine and results were not reliable. Operation of the machine in the ambient atmosphere was impossible because both electronic and optical components failed after short periods of operation. The equipment does operate satisfactorily and results obtained appear to be satisfactory if the entire detector mechanism is kept at a temperature 10 to 20 degrees above ambient and at a relative humidity of 50 to 60 percent. In this (present) operation the vacuum source is separate from the detector proper and is located outside the heated dehumidified enclosure.

185. A four-stage Casella cascade impactor was used to collect particulate matter for microscopic examination. Slides in the first three stages of the impactor (collecting particles at 5, 3, and 2 microns diameter respectively) tend to become wet during sampling, and no satisfactory samples have yet been obtained. Air entering the fourth stage of the impactor is sufficiently dried, however, so that satisfactory electron microscope grids can be prepared. The fourth stage collects the very smallest particles visible under a light microscope (about one micron) and particles visible only under the electron microscope.

Results

186. The results obtained so far using the Condensation Nuclei Detector are presented in Figures VII-5 and VII-6. The data of Figure VII-5 were obtained at the Miraflores Annex area. This is near the Panama Canal and a large power plant. The peaks of the curves no doubt reflect the presence of a high content of particulate and chemical matter attributable to the operation of the power plant and the passage of ships. The data of Figure VII-6 were obtained at the Albrook Forest site under the canopy of the trees. The numbers of condensation nuclei under the canopy were 5 to 50-fold smaller than those found at Miraflores. Periods of high readings occurred consistently before or during periods when rain fell.

187. No examination of the larger elements of the particulate matter has been possible. Representative electron photomicrographs are shown in Figure VII-7 showing collections at the Albrook Forest site and the Rio Hato savanna site respectively. Electron microscopy was done at the National Center for Atmospheric Research (NCAR). Staff members at NCAR were unwilling to comment on the results except to say that most of the particulate matter observed was unfamiliar to them.

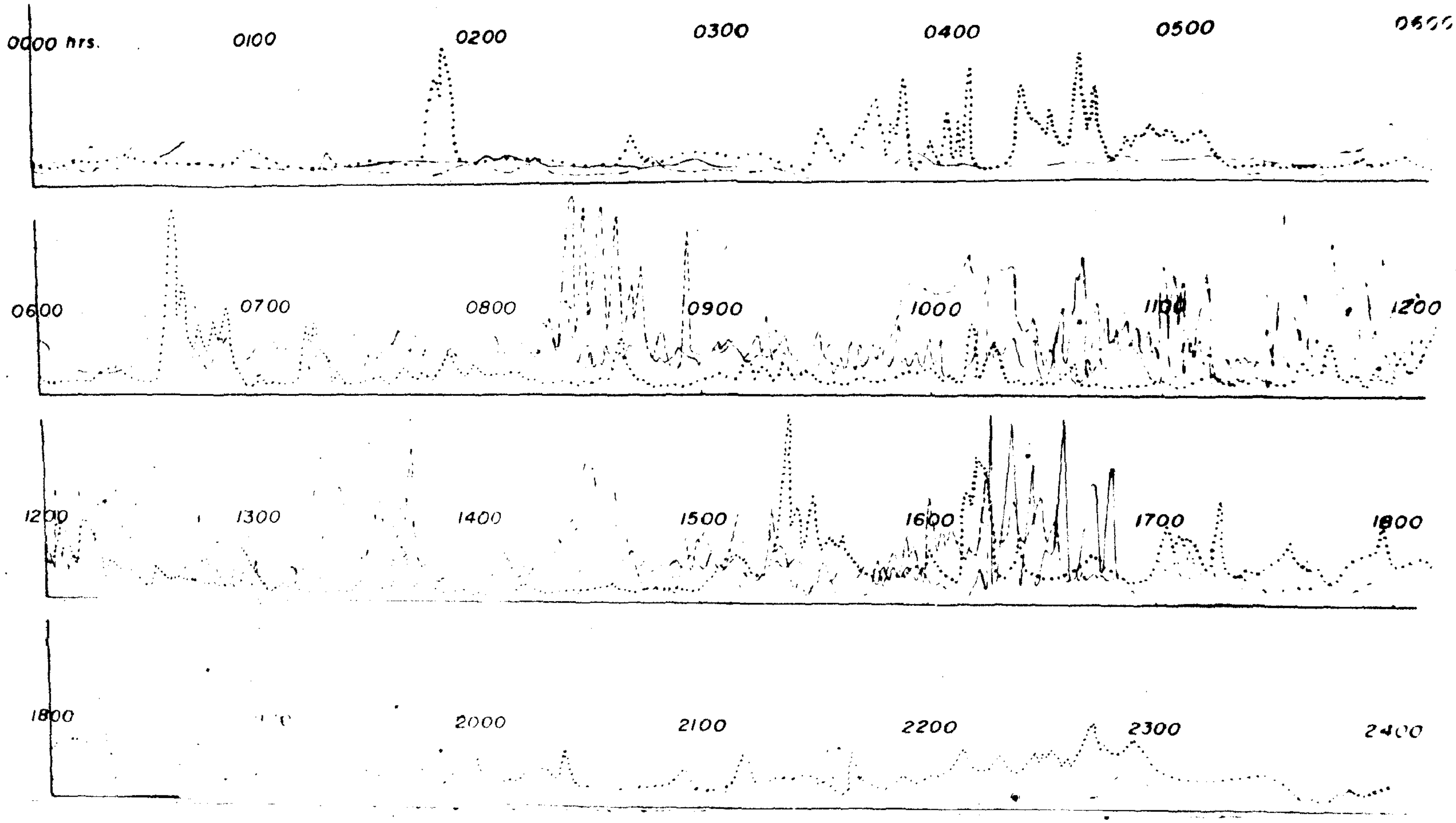


Figure VII-5. Trace of Condensate Nuclei, Miraflores Annex Area.

10^5 Nuclei per cc of ambient air at full scale

18 July 1966 ———
19 July 1966 - - -
20 July 1966 .....

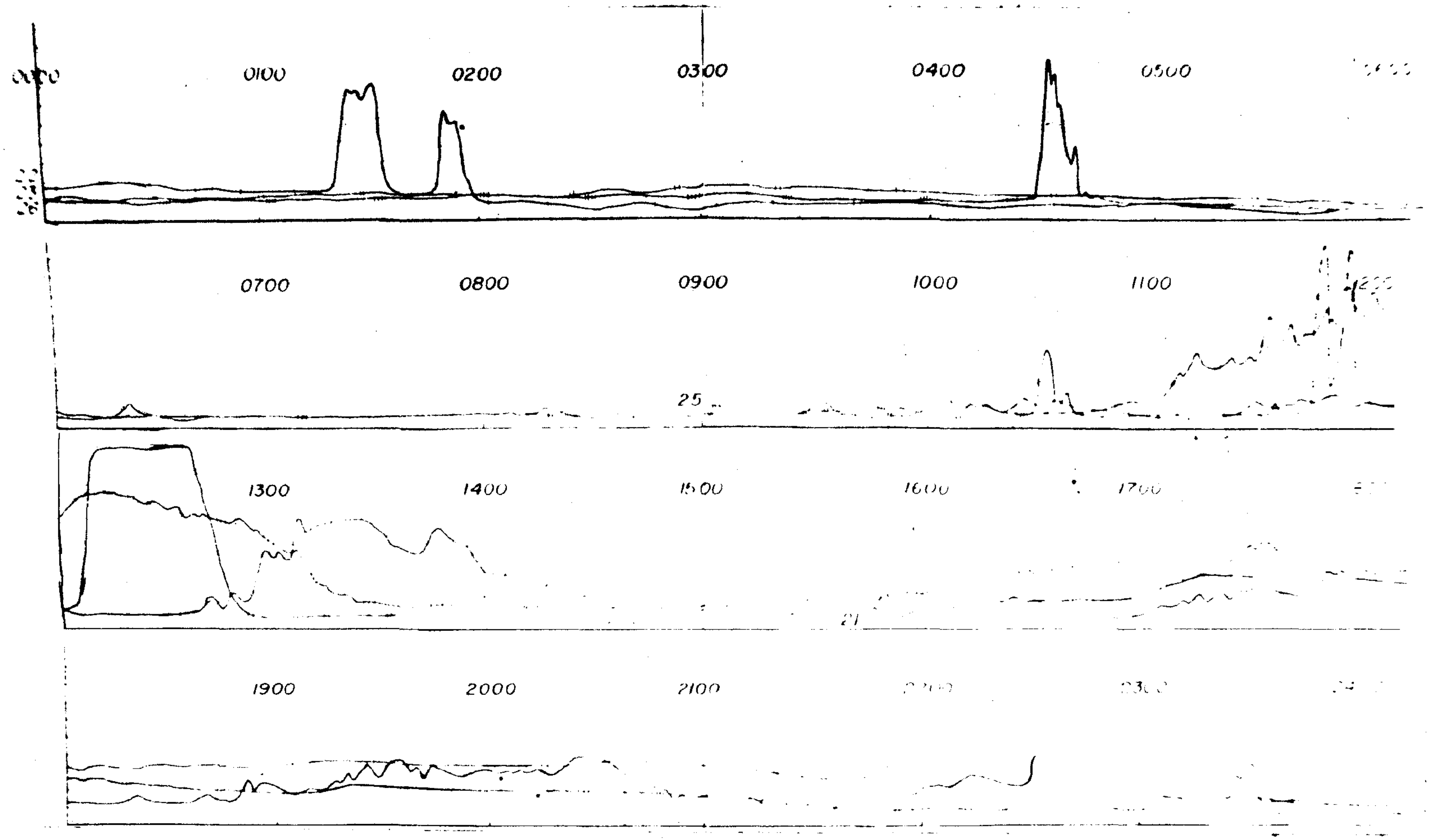


Figure VII-6. Trace of Condensate Nuclei, Albrook Forest Site.

$3x10^4$ nuclei per cc of ambient air at full scale

21 July 1966 ____ 23 July 1966 ____ 26 July 1966 ____
22 July 1966 ____ 25 July 1966 ____

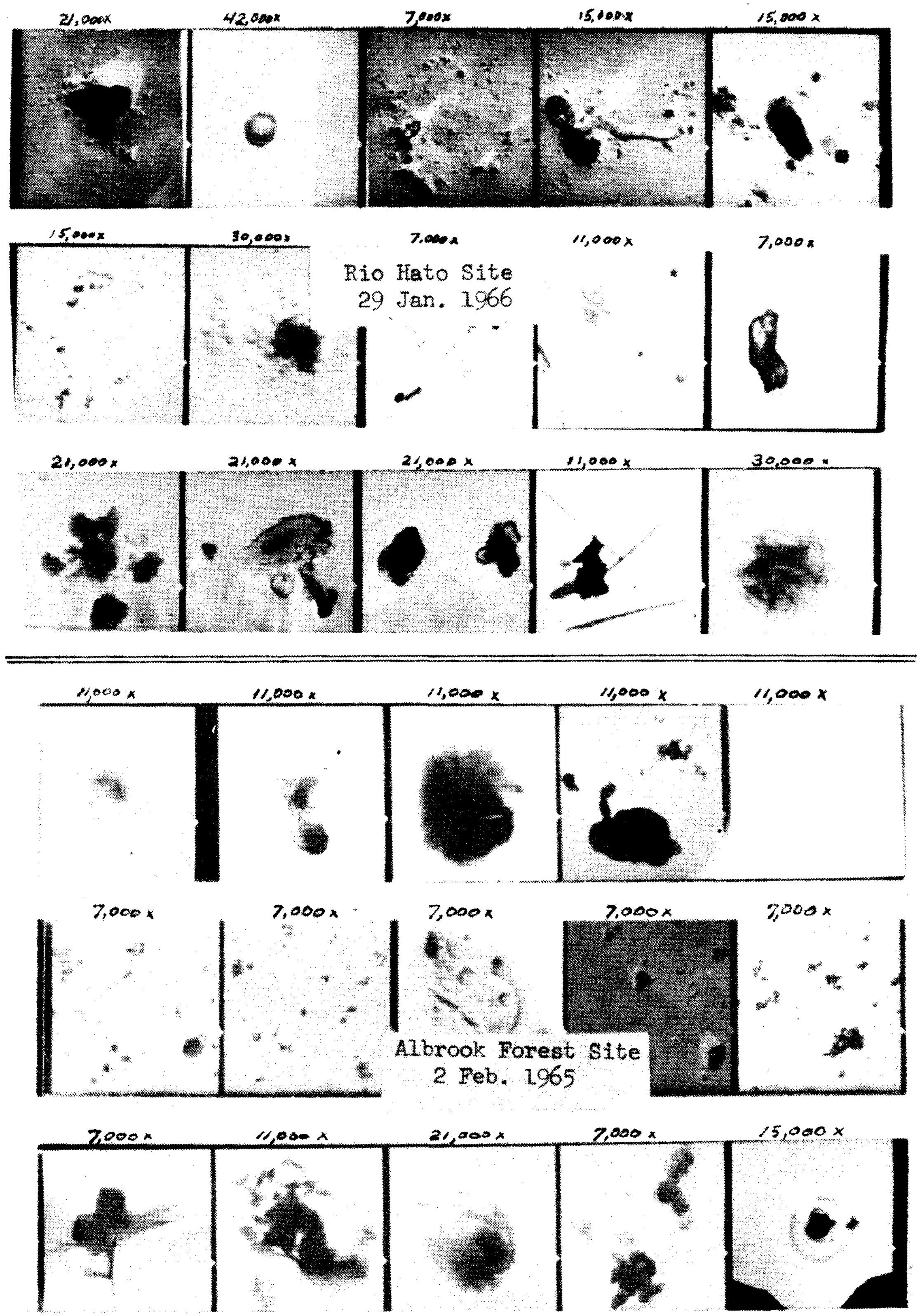


Figure VIII-7. Electron Photomicrographs of Larger Elements of Atmospheric Particulate Matter at Albrook Forest and Rio Hato Sites

—APPENDIX—

VEGETATION INVENTORY

ALBROOK FOREST SITE

REVISED 1 JUNE 1966

VEGETATION INVENTORY*

This Vegetation Inventory (formerly called vegetation locator) shows the bole location, at 120 cm above the ground, of each living tree, shrub, or vine of at least 2.5 cm diameter in the Albrook Forest site. The area is subdivided into a north-south oriented grid of 36 squares each 10 by 10 m. Each grid square is marked by identifying stakes. Stake numbers correspond to numbers shown on the Grid Orientor (See page A-3). Grid center and the center of the Observational Tower coincide.

Location of the pertinent vegetation is shown graphically on the pages representing each of the grid squares (A-14 to A-49). Site positions are estimated to be accurate to 0.5 m. Circles representing each tree are drawn to scale and the diameter (in inches**) is shown for each. Shrubs are indicated by smaller letters and a small circle; the diameter is not given. Only the genus of plants is listed. When more than one species of a genus is present a number is placed in parenthesis following the genus, and the species is listed on pages A-6 and A-7 (alphabetical by genera). In this revision, only the names of plants listed in the grid maps have been corrected. Names listed on the canopy maps (A-9 to A-13) have not been brought up to date. Eleven species of shrubs have been tagged. Tag numbers and species names are listed on page A-8. The grid orientor, page A-3, was revised to show contour lines and elevation above sea level in feet. Page A-4 gives the location of banded Anacardium and Cecropia trees.

The Locator is intended to serve several purposes:

a. Copies are available for observers of visitors for use as required.

b. A master copy will be maintained to record notes concerning phenological events and corrections that are found necessary. Further revisions will be made as the need arises but will not necessarily be at regular intervals.

c. Copies will be provided to any investigator wishing to use the

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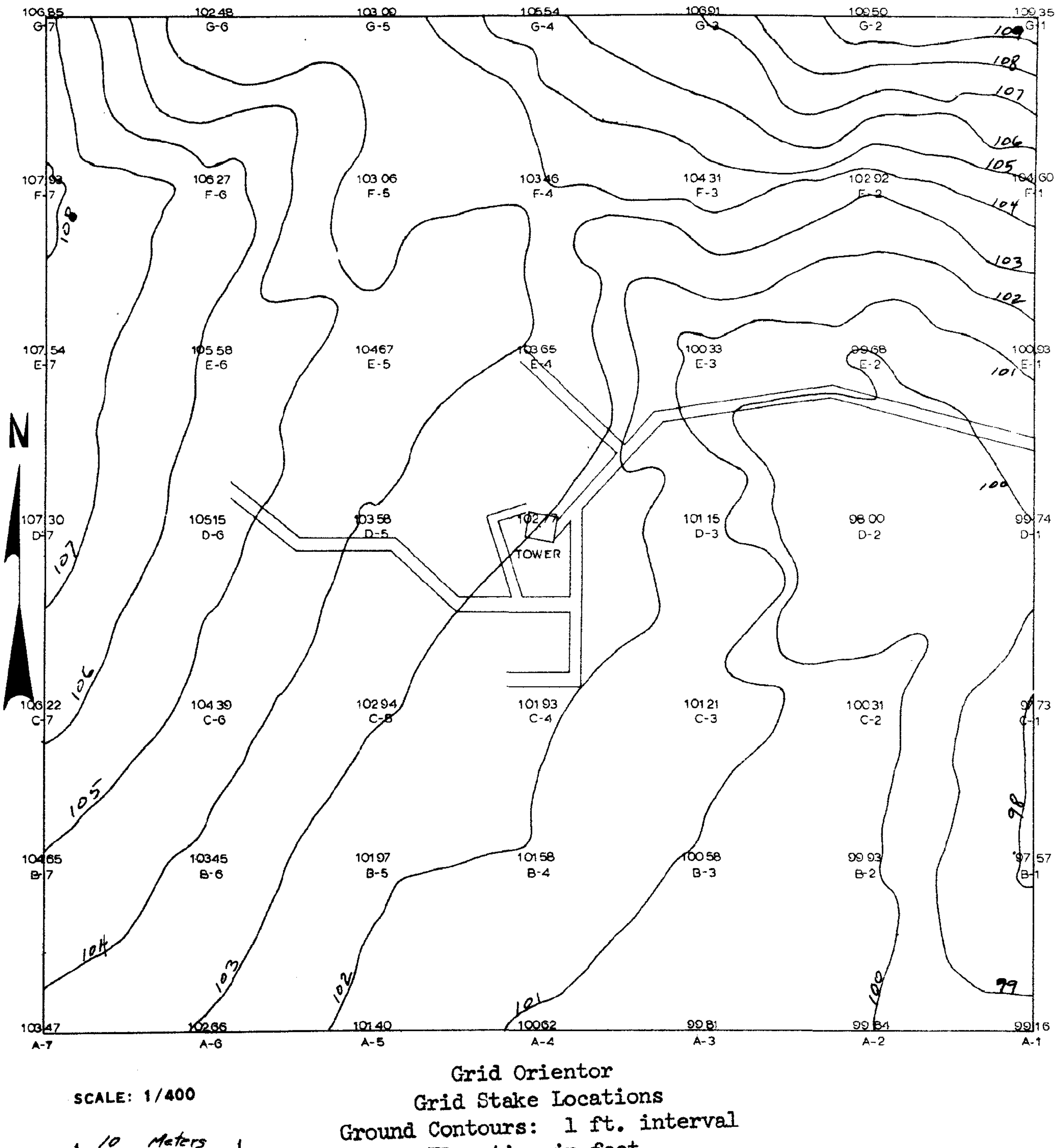
* Prepared by Dr. Robert Hutton, Biological Scientist and by Dr. Edwin Tyson, Biologist, US Army Tropic Test Center, with technical assistance of Carolyn Corn, Botanisht, formerly US Army Tropic Test Center, and Dr. Robert Dressler, Smithsonian Institution and Sister Maria Victoria, University of Missouri, and Kurt Blum, Florida State University. This revision supplants the first edition published in 1 June 1965.

** 1 inch = 2.54 cm

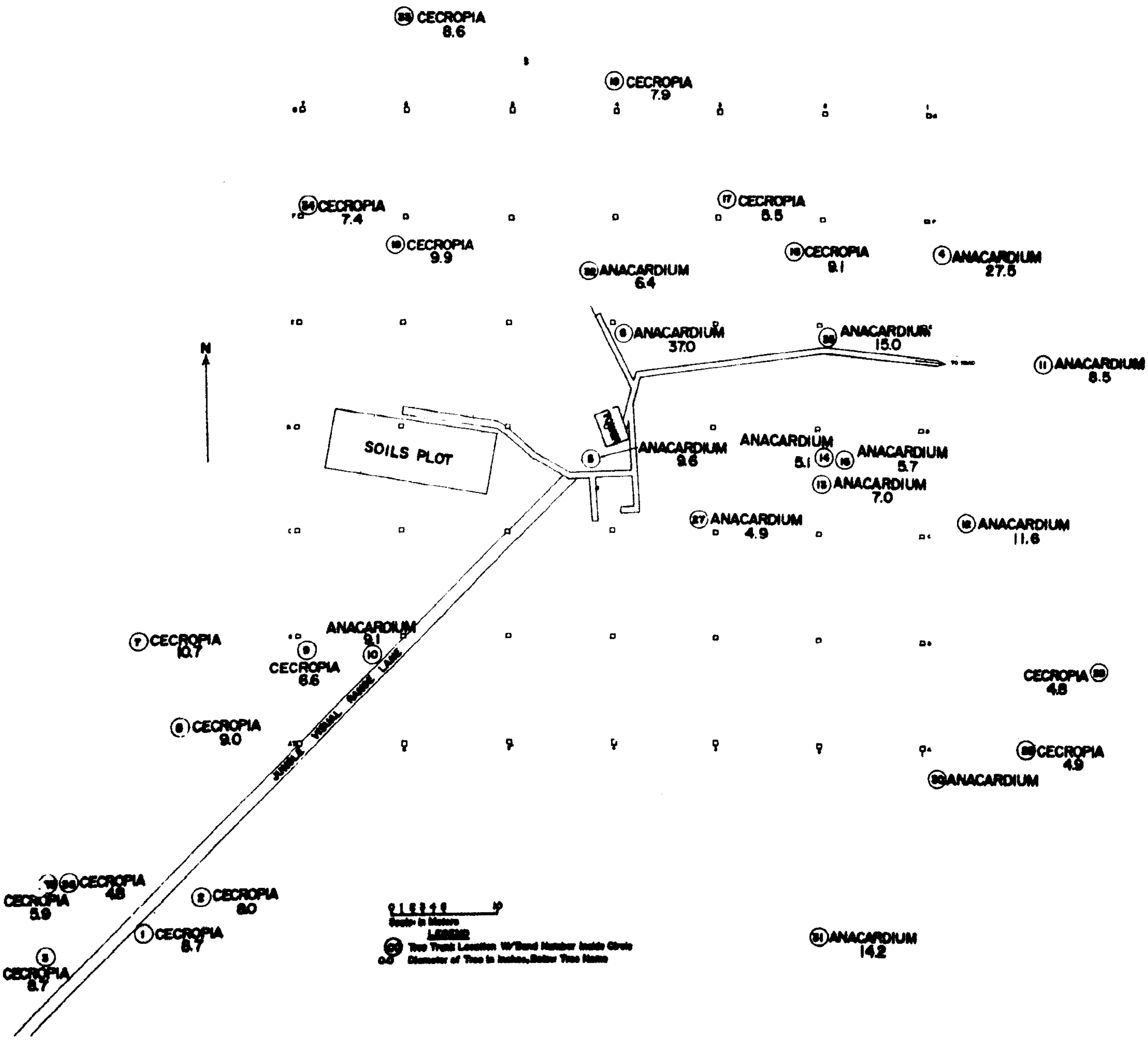
site to record location of points of interest and points that are not to be disturbed by other investigators.

Users are requested to furnish significant observations. Observations will be placed on the master copy as soon as received and will be included in revisions.



Grid Orientor
Grid Stake Locations
Ground Contours: 1 ft. interval
Elevation in feet

MAP OF BANDED TREES (MURPHY)



SYMBOLS

● herbaceous vegetation (Musaceae) unless otherwise marked

ø palm trees with armatures (Bactris sp.)

△ shrubs with stem diameters over on inch

o shrubs with numbered tags and orange flag

✗ vine with arrow pointing to tree to which vine is attached

/ line between symbols indicates a plant with more than one trunk; if used with a vine symbol, the vine crosses the horizontal plane more than once

plant diameter to 1/10 of an inch

(n) unidentified plant of frequent occurrerce

M-n' trees over four inches (Cecropia peltada or Anacardium excelsum) are fitted with aluminum vernier bands for periodic observation of trunk diameter change. Trees bearing an additional number (i.e. M-n'-n' ') are "satellites" of banded trees. Satellite tree is a tree located within a radius in feet equal to the sums of the bole diameters (in inches) of the observed and satellite tree. Tree banding provided by Peter Murphy, Puerto Rico Nuclear Center, Caparra Heights, Puerto Rico.

List of trees and small trees over one inch in diameter

Anacardium excelsum (Bert. + Balb.) Sheels. (Anacardiaceae)

Alibertia edulis (L. Rich) A. Rich (Rubiaceae)

Andira enermis H.B.K. (Fabaceae)

Annona (1) hayessii Suff. (Annonaceae)

Annona (2) purpurea Moc. + Sessi (Annonaceae)

Aphelandra deppeana Schlecht. + Cham (Acanthaceae)

Bactris balanoidea (Oerst.) Wndl. (Phoenicaceae)

Banara guianensis Aubl. (Flacortiaceae)

Belotia panamensis Pittier (Tiliaceae)

Bursera simaruba Sarg. (Burseraceae)

Cavanillesia platanifolia H.B.K. (Bombacaceae)

Cecropia (1) longipes Pittier ? (Moraceae)

Cecropia (2) obtusifolia Bertol. (Moraceae)

Cecropia (3) peltata L. (Moraceae)

Chrysophyllum cainito L. (Sapotaceae)

Conostegia speciosa (Melastomaceae)

Copaifera panamensis (Britton) Standley

Cordia alliodora (Ruiz + Pan) Roem + Schult (Boraginaceae)

Costus villosissimus Jacq. (Costaceae)

Croton panamensis (Klotzsch) Muell. Arg (Euphorbiaceae)

Cupania cinerea Poepp + Endll. (Sapindaceae)

Genipa caruta var americana (Rubiaceae)

Guazuma ulmifolia Lam. (Sterculiaceae)

Heliconia platystochys Baker. (Musaceae)

Helicteres guazumifolia H.B.K. (Sterculiaceae)

Hirtella (1) racemosa L. (Rosaceae)

Hirtella (2) triandra Swartz. (Rosaceae)

Inga (1) hayessii Bents. (Mimosaceae)

Inga (2) oerstediana Willd. (Mimosaceae)

Lacistema aggregatum (Berg.) Rusby (Lacistemaceae)

Lafoensia punicifolia DC. (Lythraceae)

Luehea seemanii Triana + Planch. (Tiliaceae)

Miconia (1) argentea (Swartz) Don. (Melastomaceae)

Miconia (2) impetrolaris (Swartz) DC. (Melastomaceae)

Nectandra sp. (Lauraceae)

Palicourea guianensis Aubl. (Rubiaceae)

Piper (1) aduncum L. (Piperaceae)

Piper (2) reticulatum L. (Piperaceae)

Phoebe costaricana Mez + Pittier (Lauraceae)

Pittoniotis trichantha Griseb (Rubiaceae)

Posequeria latifolia (Rudge) Roem + Schult. (Rubiaceae)

Rourea glibra H.B.K. (Connaraceae)

Sloanea sp. (Eleocarpaceae)

Spondias mombin L. (Anacardiaceae)

Tabebuia péntaphylla (L.) Hemsl. (Bignoniaceae)

Talisia nervosa Radlk. (Sapindaceae)

Trema micrantha (L.) Blume (Ulmaceae)

Xylopia frutescens Aubl. (Annonaceae)

Identifying Numbers of Tagged Shrubs.

Alibertia edulis (L. Ridh.) A. Rich (Rabiaceae)

1785, 1789-1791, 1797-1800, 1882, 1884-B, 1885, 1887-1888, 1890-1892, 1894, 1898-1903, 1906-1907, 1912, 1914, 1921-1922, 1929, 1935, 2513.

Ardesia siebertii Lundel (Myrsinaceae)

1904

Conostegia speciosa Naud. (Melostomaceae)

1784, 1895

Hirtella racemosa Lam. (Amygdalaceae=Rosaceae)

1915, 2515, 2518

Ouratea wrightii (Van Tiegh.) Riley (Ochnaceae)

1874

Palicourea guianensis Aubl. (Rubiaceae)

1782, 1788, 1795, 1876, 1883, 1884, 1889, 1905, 1909-1911, 1930

Piper (1) adunctum L. (Piperaceae)

2512

Piper (2) nov. sp. (Piperaceae)

1920, 1933

Psychotria (1) cuspidata Bredem (Rubiaceae)

1786-1787, 1793, 1796, 1802, 1877-1879, 1919, 1922-B, 1923, 1925-1928, 1931, 1934

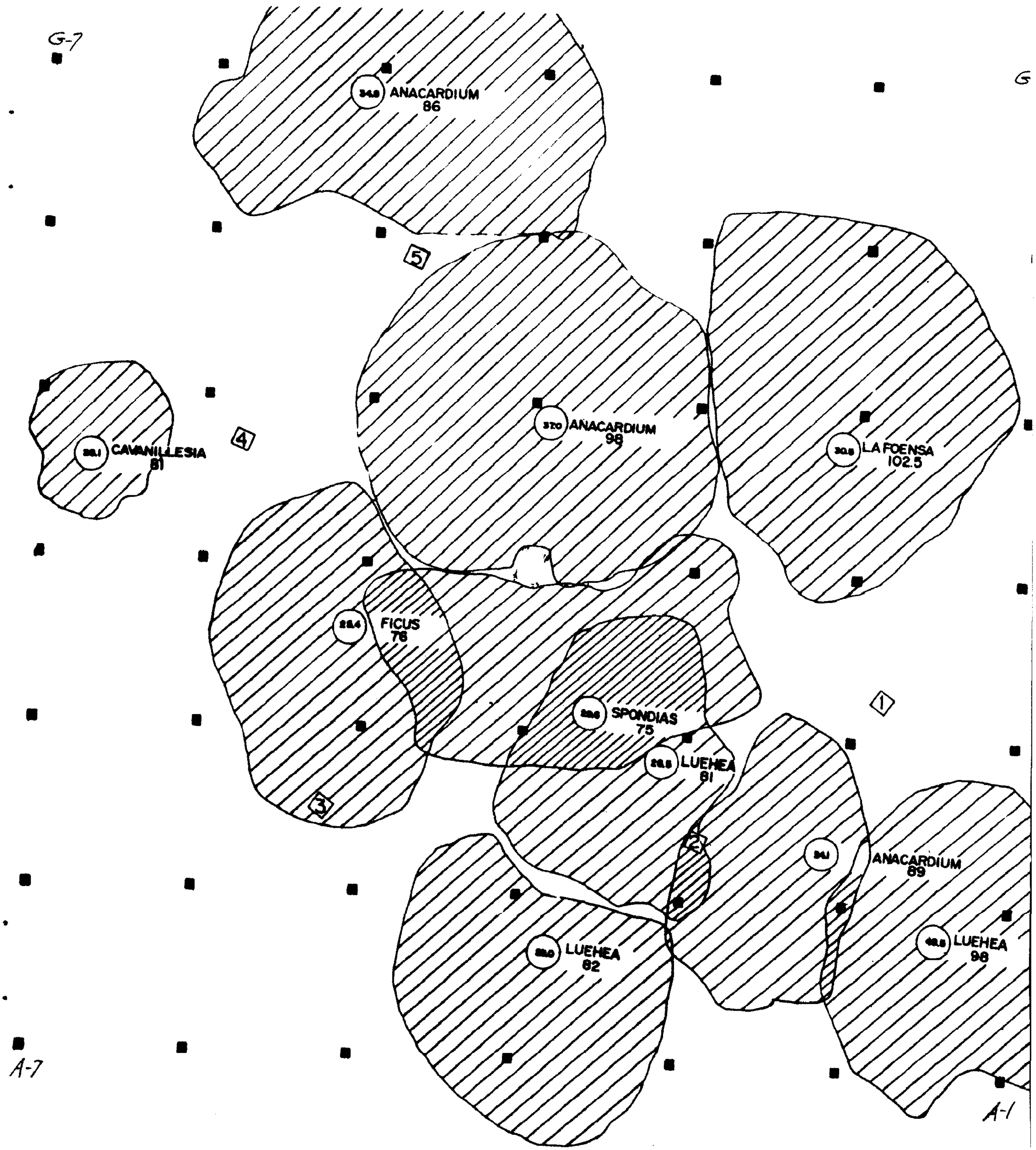
Psychotria (2) horizontalis Swartz (Rubiaceae)

1780, 1801

Psychotria (3) undata Benth. (Rubiaceae)

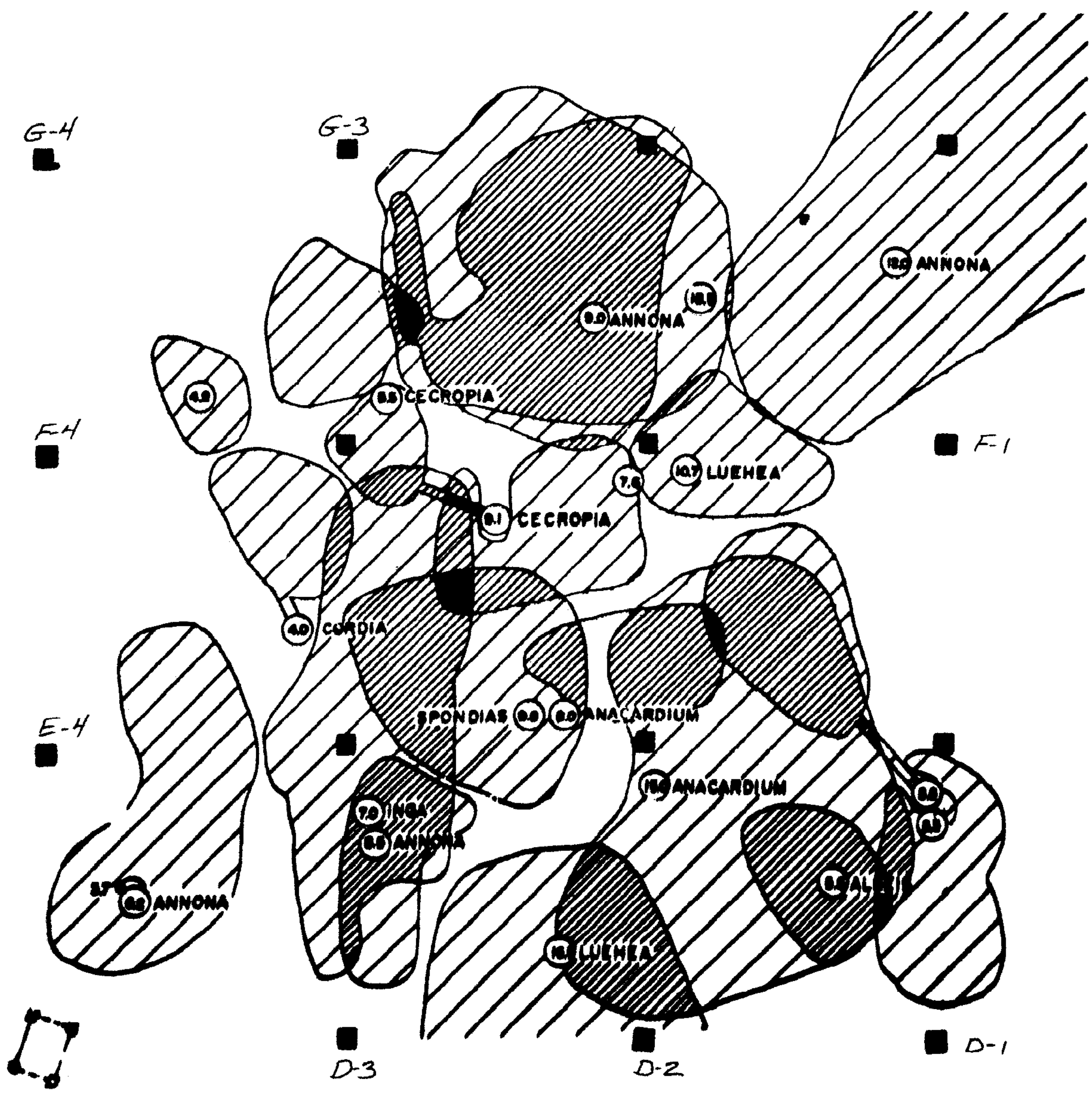
1783, 1792, 1875, 1881, 1886, 1893, 1913, 1916-1918, 2514, 2516

UPPER CANOPY COVERAGE



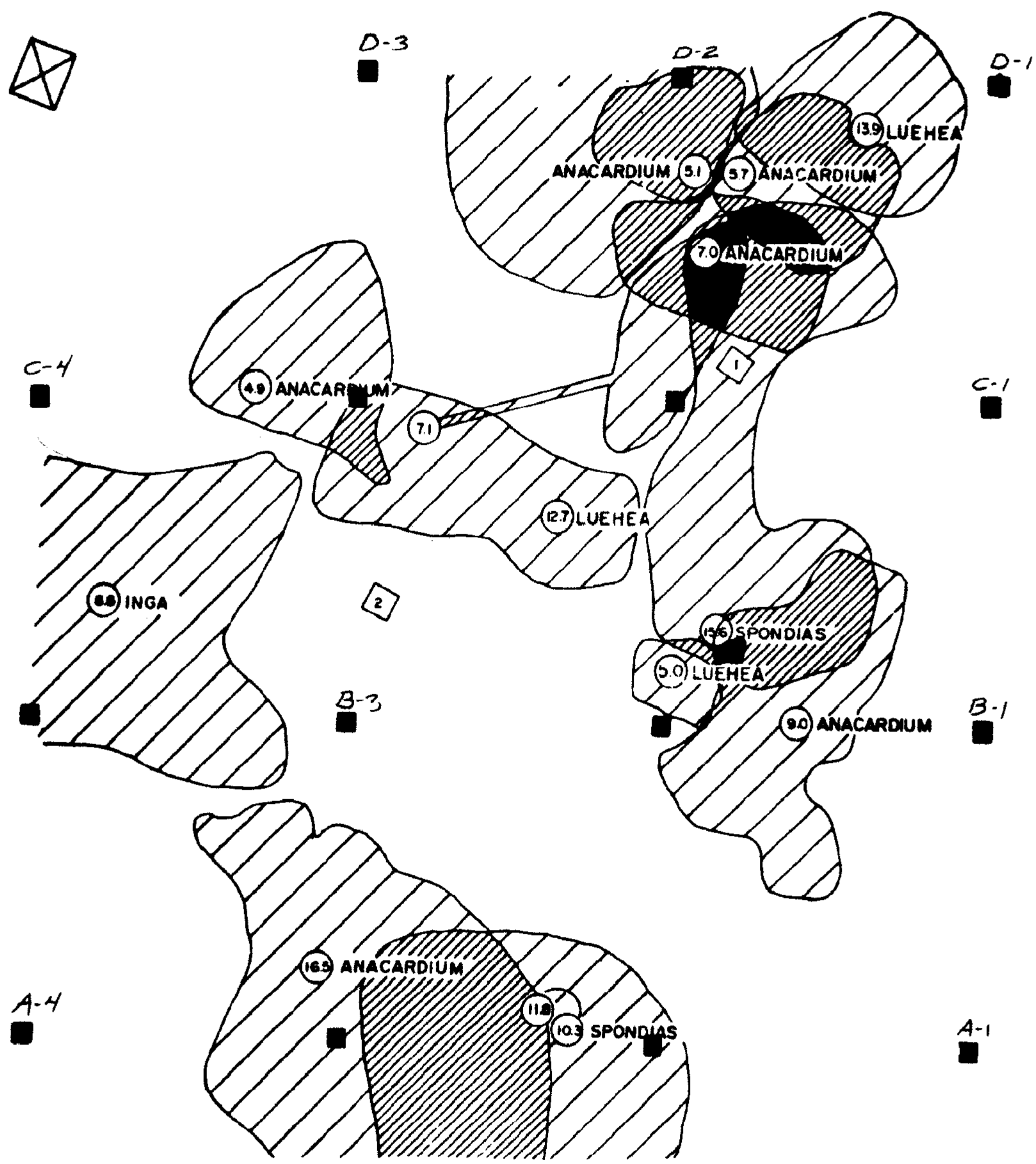
LOWER CANOPY COVERAGE

NE Quadrant



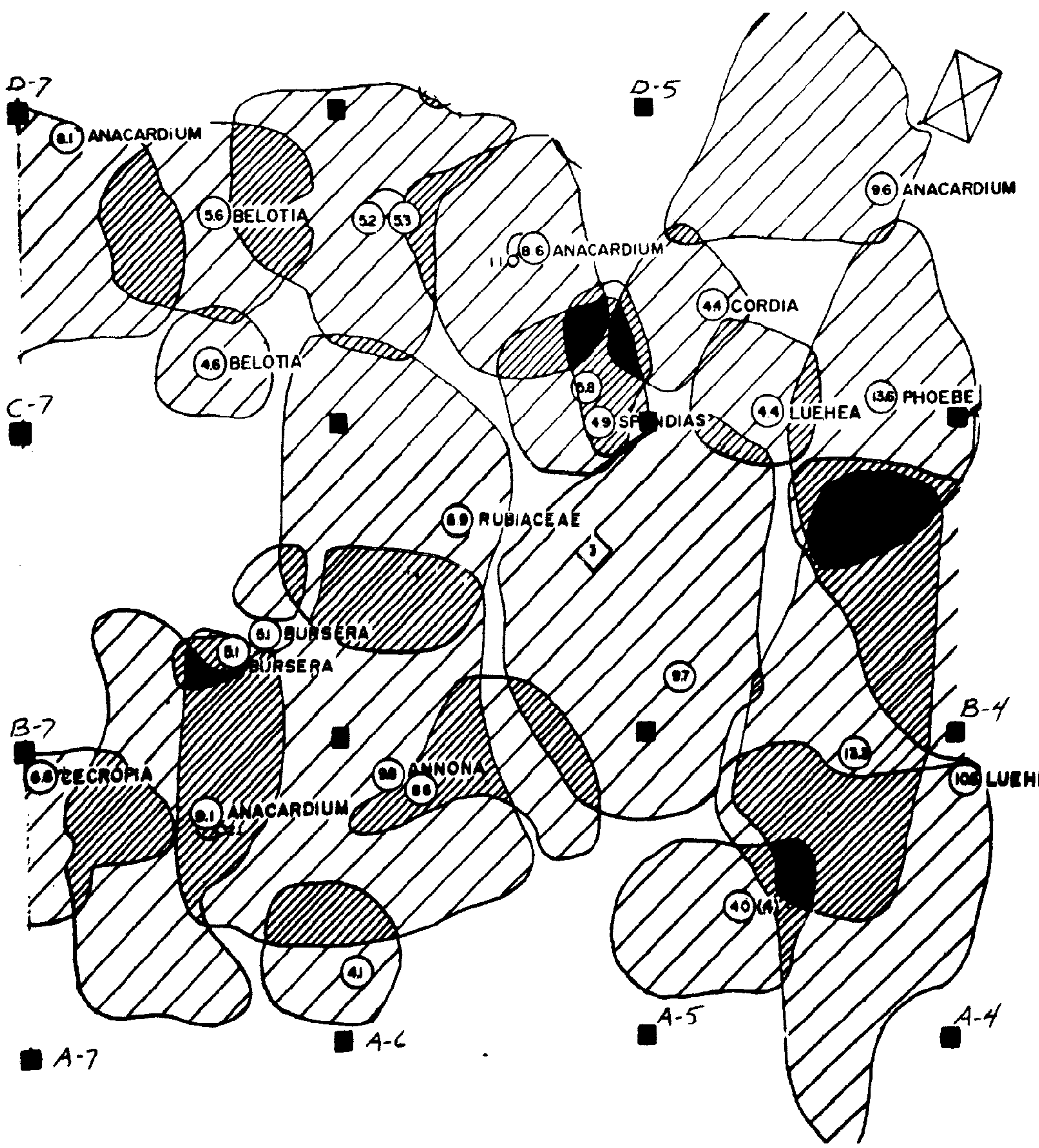
LOWER CANOPY COVERAGE

SE Quadrant



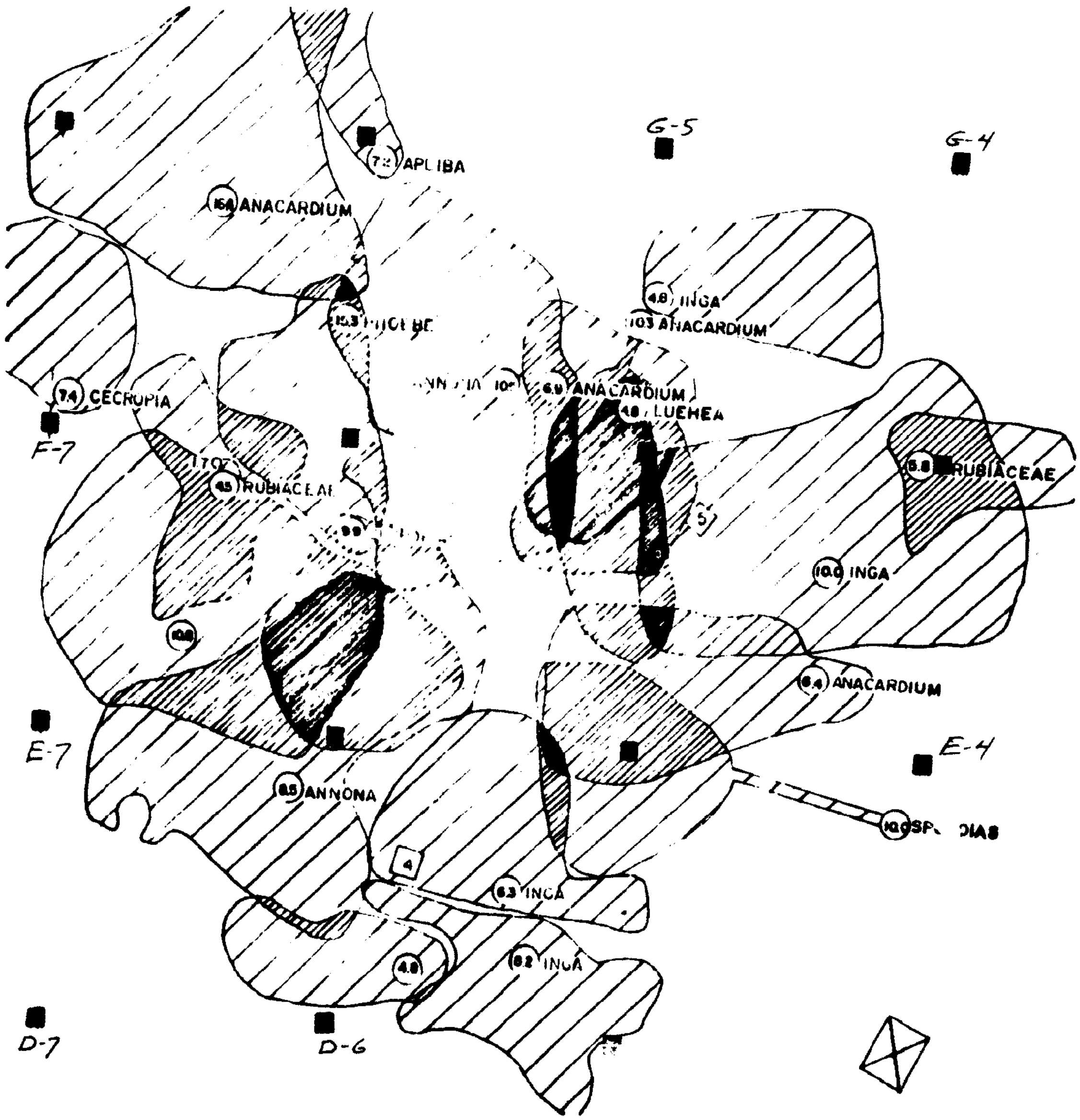
LOWER CANOPY COVERAGE

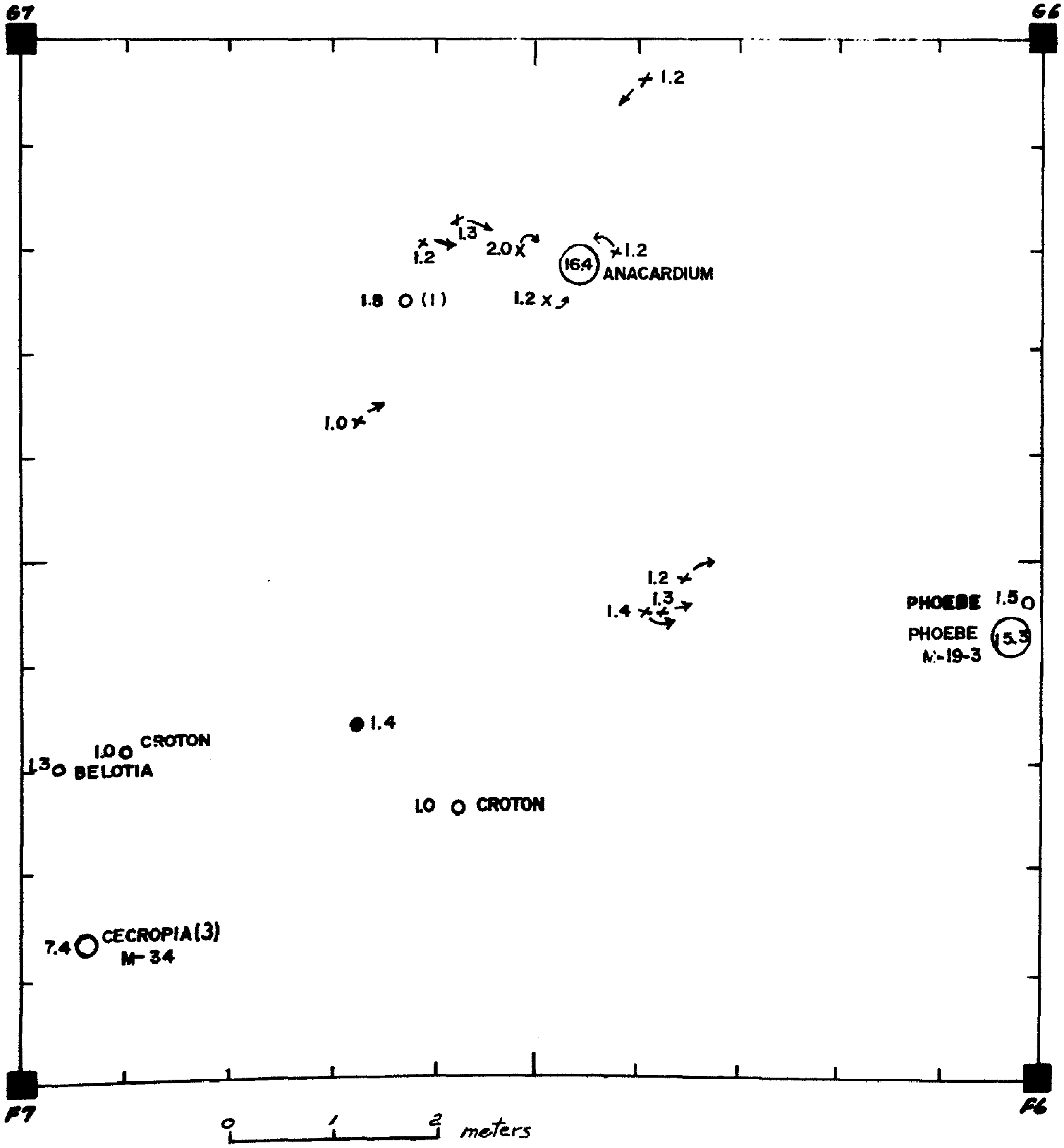
SW Quadrant

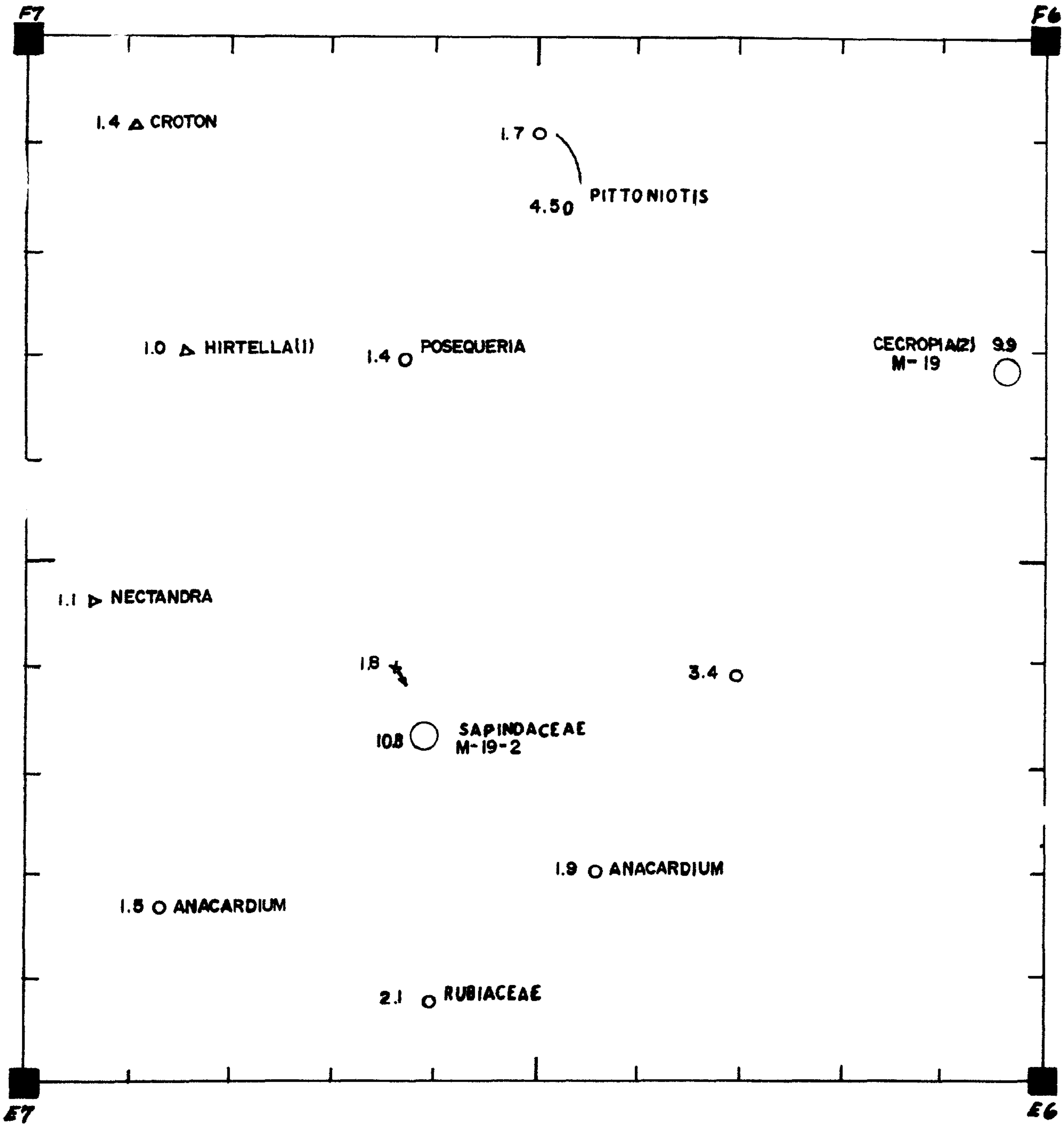


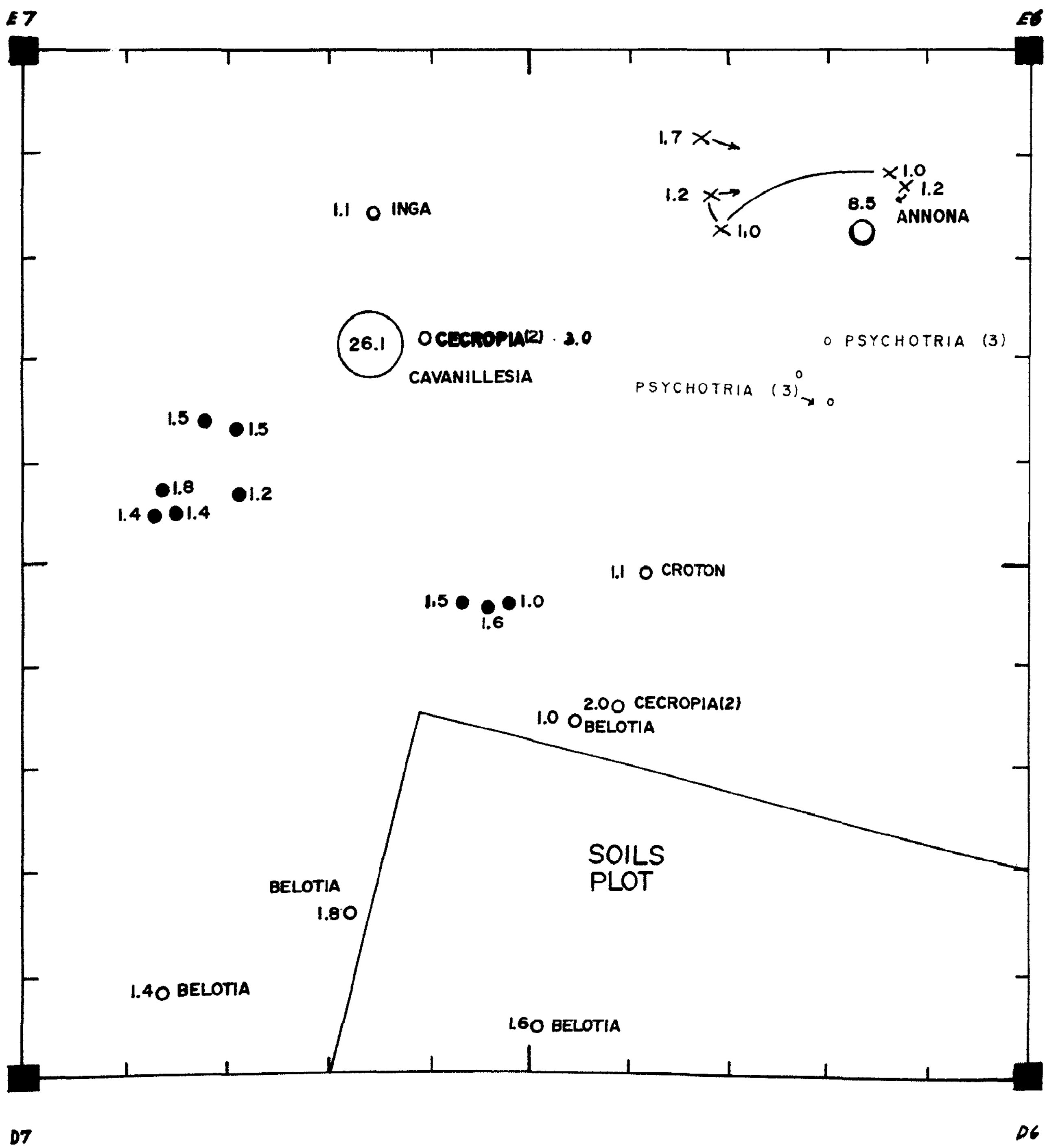
LOWER CANOPY COVERAGE

NW Quadrant




G7
G6
F7
F6
1.2
1.3
2.0
1.2
1.2
16.4
ANACARDIUM
1.8
(1)
1.2
1.0
1.2
1.3
1.4
PHOEBE 1.5
PHOEBE
15.3
M-19-3
1.4
1.0 CROTON
1.3 BELOTIA
1.0 CROTON
7.4
CECROPIA (3)
M-34
0
1
2
meters


F7
F6
1.4 CROTON
1.7
PITTONIOTIS
4.5
1.0 HIRTELLA(1)
1.4 POSEQUERIA
CECROPIA(2) 9.9
M-19
1.1 NECTANDRA
1.8
3.4
10.8 SAPINDACEAE
M-19-2
1.9 ANACARDIUM
1.5 ANACARDIUM
2.1 RUBIACEAE
E7
E6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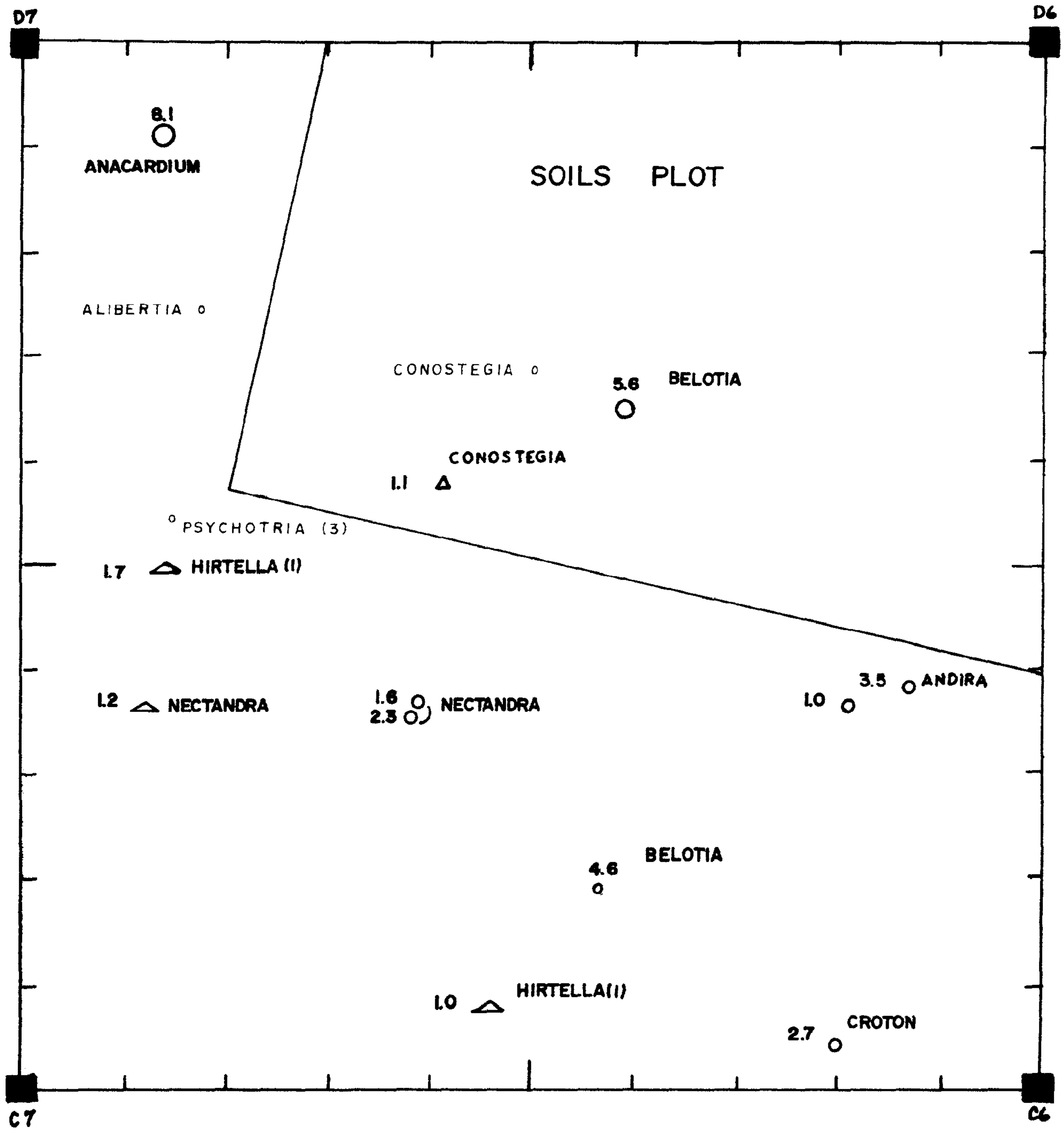
E6
1.7
1.2
1.0
1.0
1.2
8.5
ANNONA
1.1 INGA
26.1
CECROPIA(2) 3.0
CAVANILLESIA
PSYCHOTRIA (3)
PSYCHOTRIA (3)
1.5
1.5
1.8
1.2
1.4
1.4
1.1 CROTON
1.5
1.0
1.6
2.0 CECROPIA(2)
1.0 BELOTIA
SOILS PLOT
BELOTIA
1.8
1.4 BELOTIA
1.6 BELOTIA
D7
D6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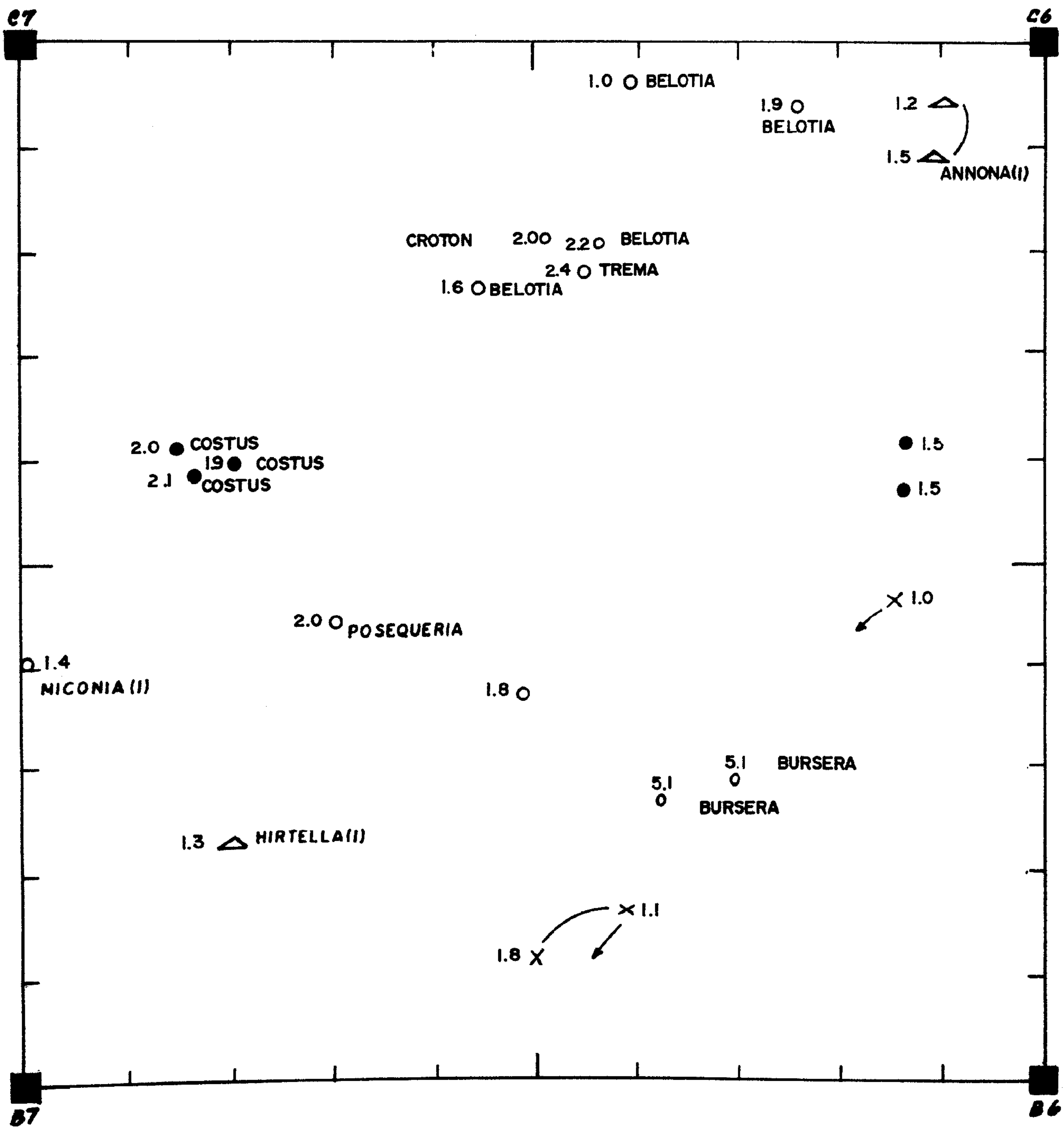
D6
8.1
ANACARDIUM
SOILS PLOT
ALIBERTIA
CONOSTEGIA
5.6
BELOTIA
CONOSTEGIA
1.1
PSYCHOTRIA (3)
1.7
HIRTELLA (1)
1.2
NECTANDRA
1.6
2.3
NECTANDRA
3.5
ANDIRA
1.0
4.6
BELOTIA
1.0
HIRTELLA(1)
2.7
CROTON
C7
C6


C7
C6
1.0 BELOTIA
1.9
BELOTIA
1.2
1.5
ANNONA(I)
CROTON
2.00
2.2
BELOTIA
2.4
TREMA
1.6
BELOTIA
2.0
COSTUS
1.9
COSTUS
2.1
COSTUS
1.5
1.5
1.0
2.0
POSEQUERIA
1.4
NICONIA (I)
1.8
5.1
BURSERA
5.1
BURSERA
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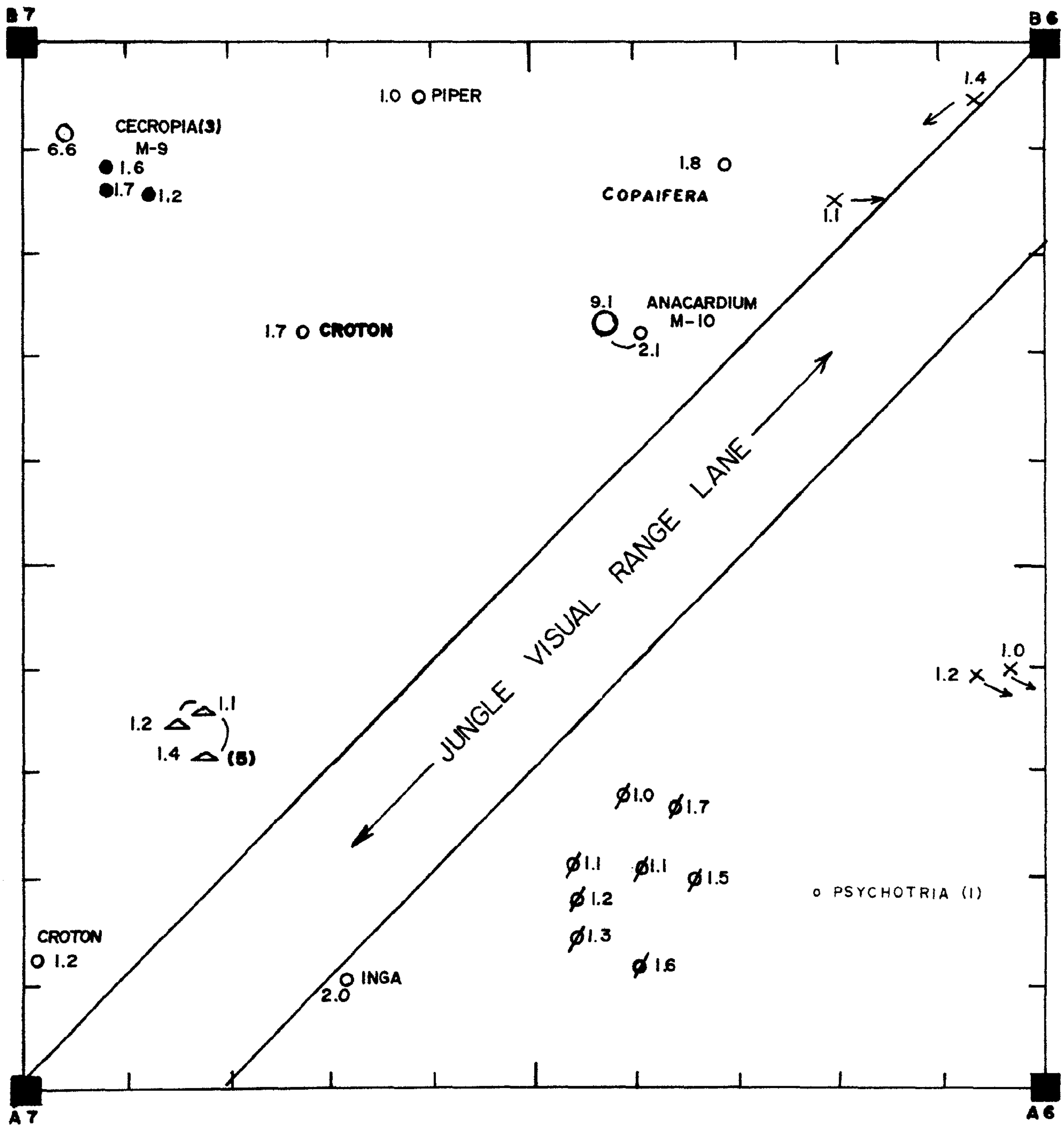
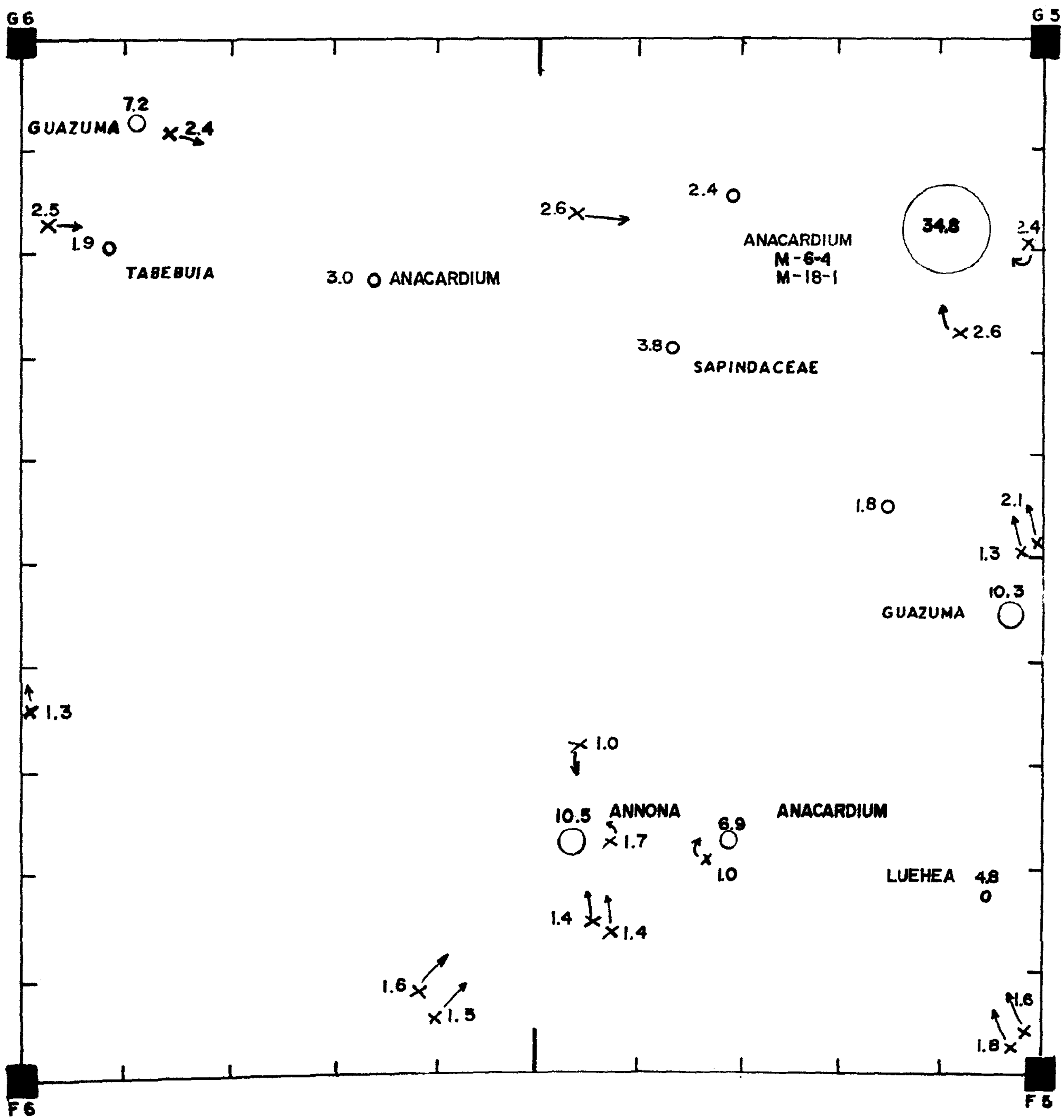
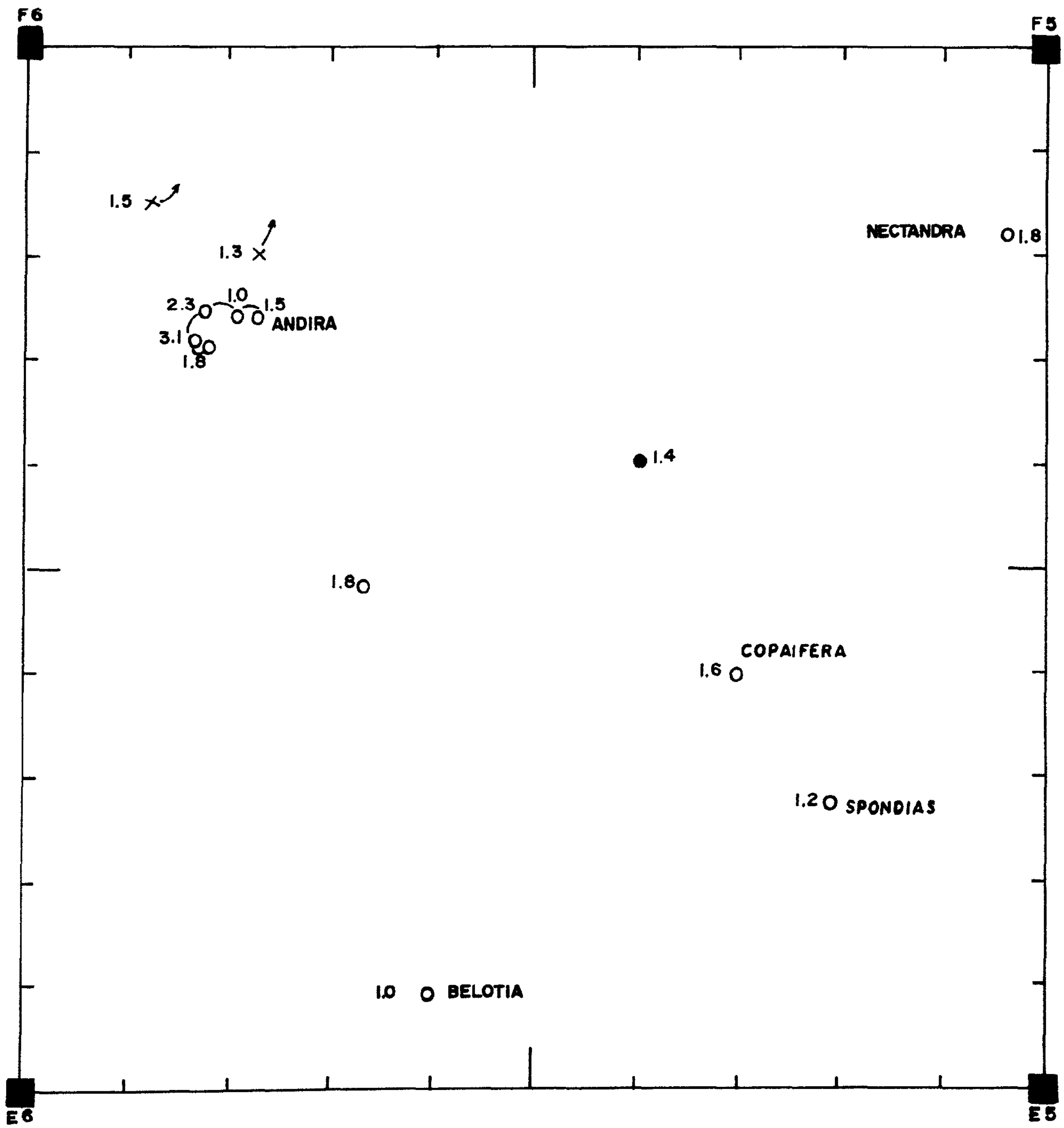
HIRTELLA(I)
1.1
1.8
B7
B6


B7
B6
A7
A6
1.0 PIPER
CECROPIA(3)
M-9
6.6
1.6
1.7
1.2
1.8
COPAIFERA
1.4
1.1
9.1
ANACARDIUM
M-10
2.1
1.7 CROTON
JUNGLE VISUAL RANGE LANE
1.0
1.2
1.1
1.2
1.4
(5)
1.0
1.7
1.1
1.1
1.5
1.2
1.3
1.6
PSYCHOTRIA (1)
CROTON
1.2
INGA
2.0


G6
G5
F6
F5
GUAZUMA
7.2
2.4
2.5
1.9
TABEBUIA
3.0
ANACARDIUM
2.6
2.4
ANACARDIUM
M-6-4
M-18-1
34.8
2.4
2.6
3.8
SAPINDACEAE
1.8
2.1
1.3
10.3
GUAZUMA
1.3
1.0
10.5
ANNONA
1.7
6.9
1.0
ANACARDIUM
LUEHEA
4.8
1.4
1.4
1.6
1.5
1.6
1.8



F6
F5
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1.3
NECTANDRA
1.8
2.3
1.0
1.5
ANDIRA
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1.4
1.8
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SPONDIAS
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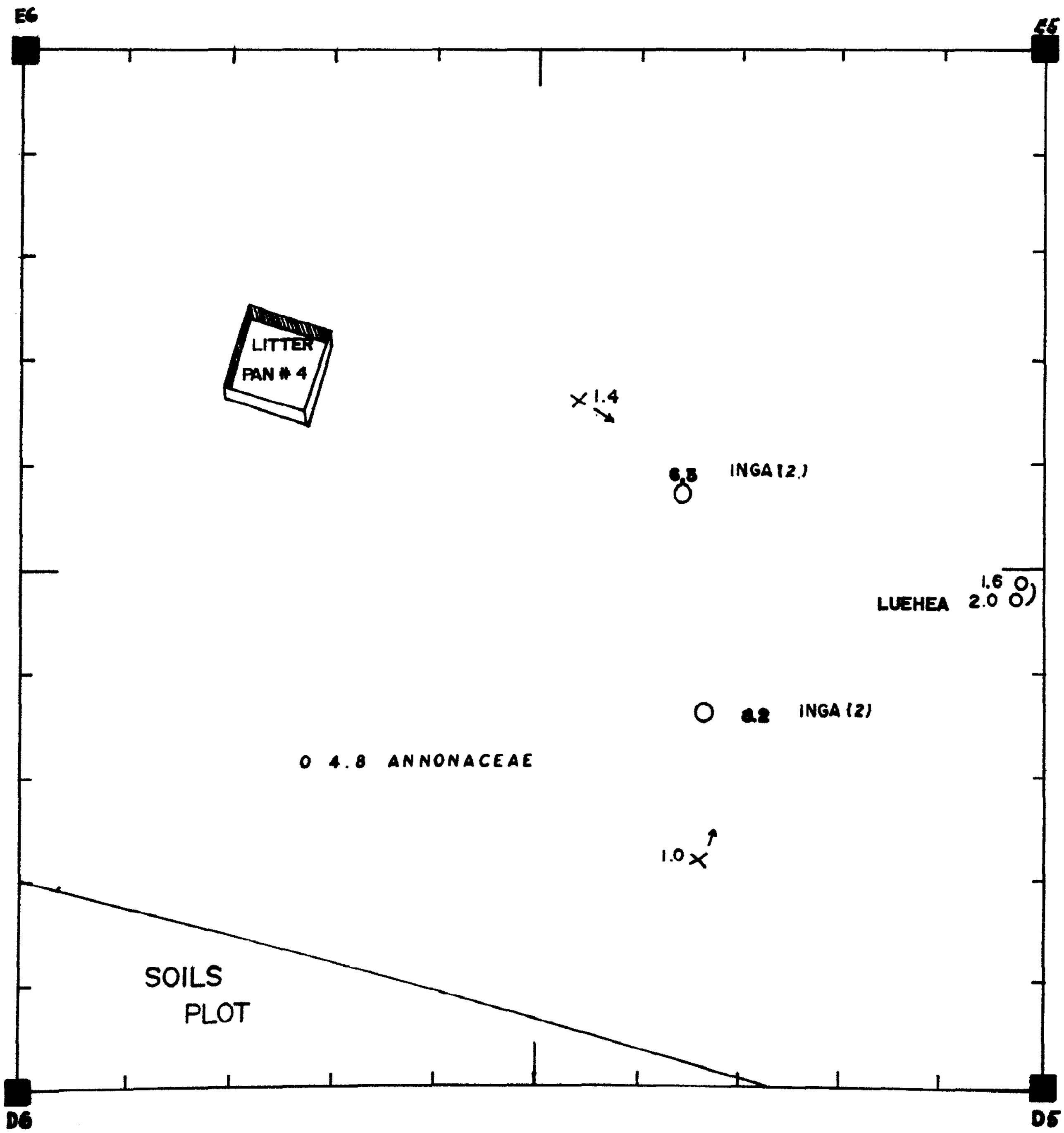
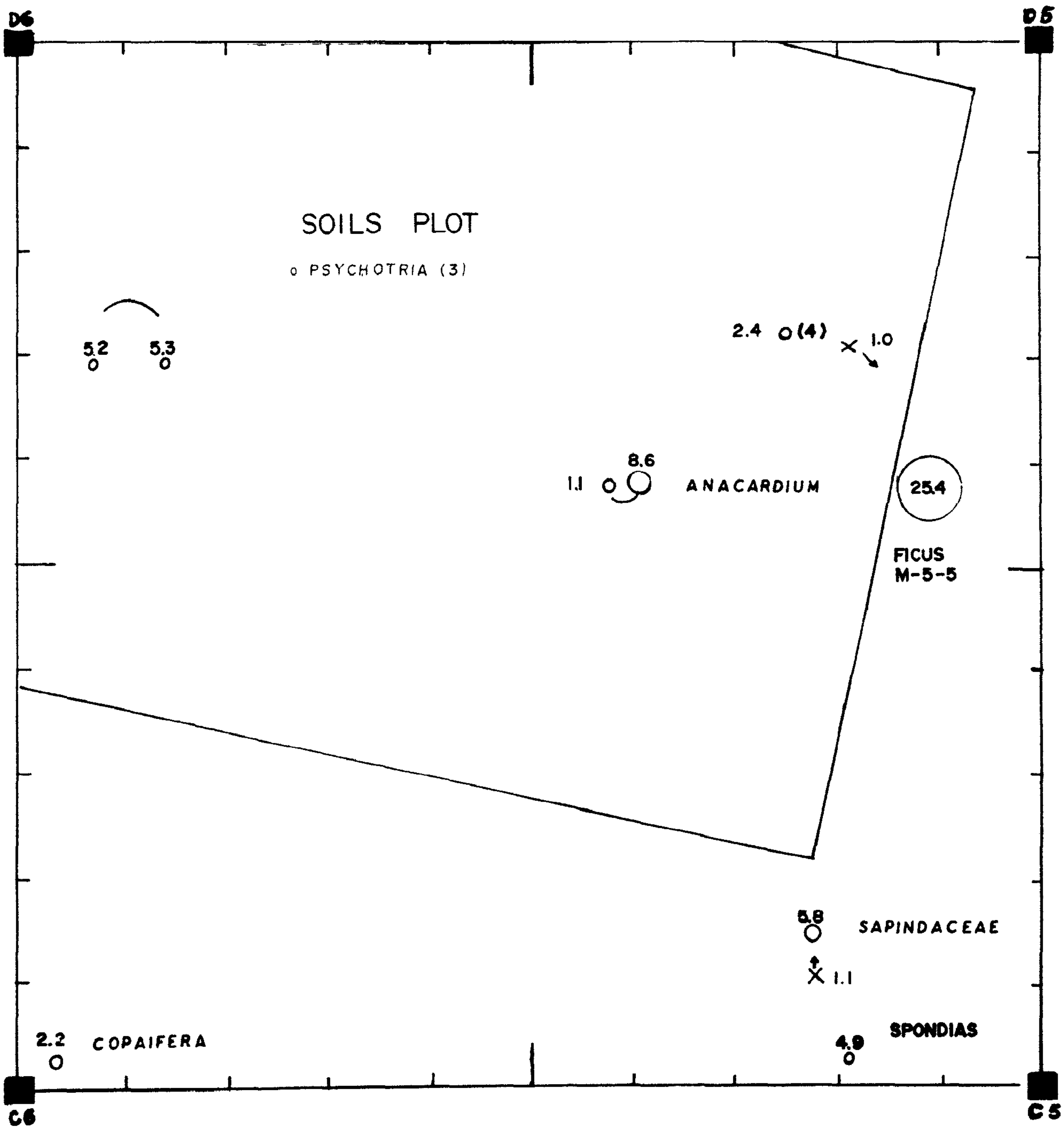
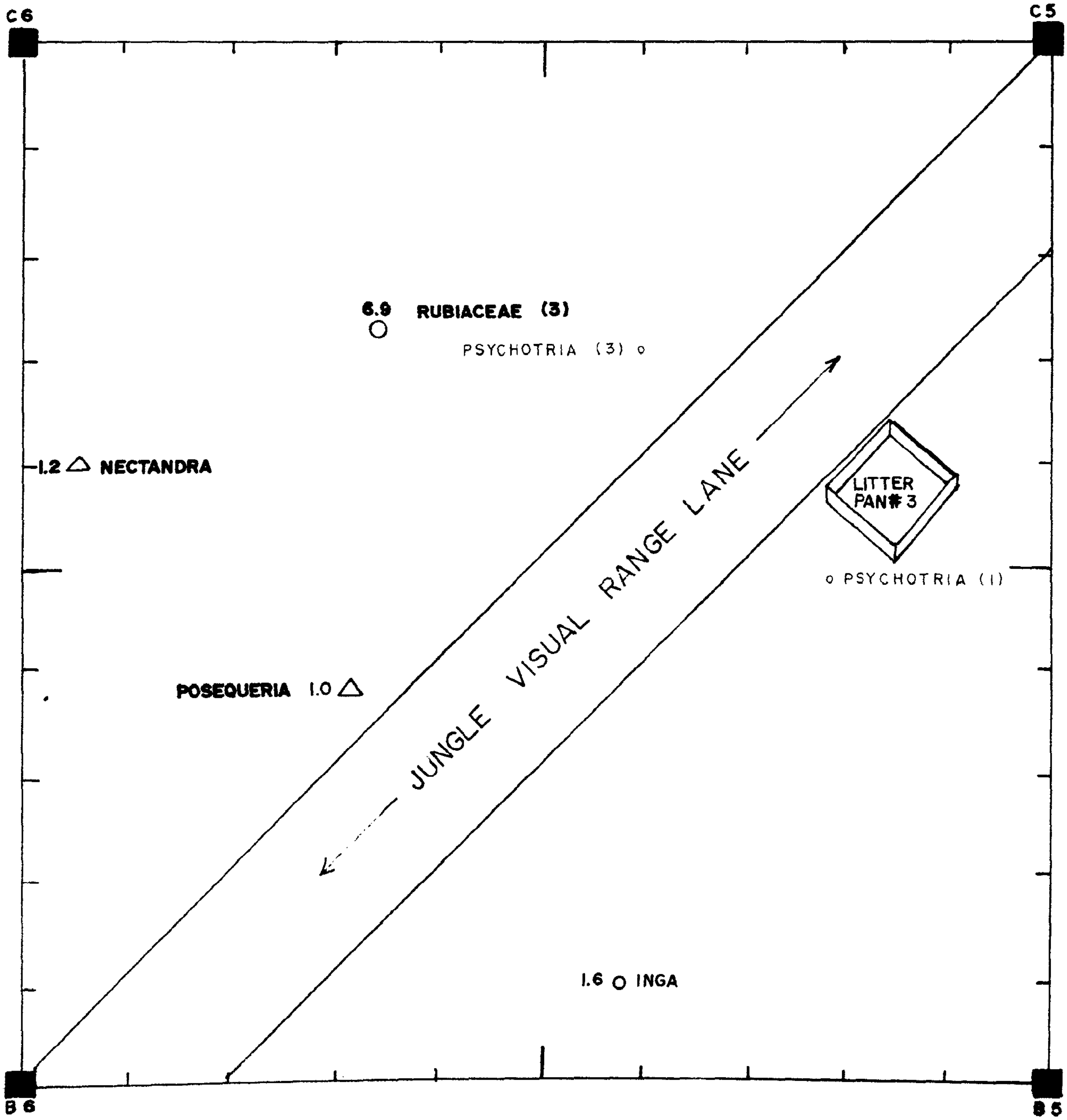
BELOTIA
E6
E5


E6
E5
LITTER
PAN # 4
1.4
INGA (2)
1.6
LUEHEA 2.0
INGA (2)
4.8 ANNONACEAE
1.0
SOILS
PLOT
D6
D5


D6
D5
SOILS PLOT
o PSYCHOTRIA (3)
5.2
5.3
2.4
(4)
1.0
8.6
1.1
ANACARDIUM
25.4
FICUS
M-5-5
5.8
SAPINDACEAE
1.1
SPONDIAS
2.2
COPAIFERA
4.9
C6
C5


C6
C5
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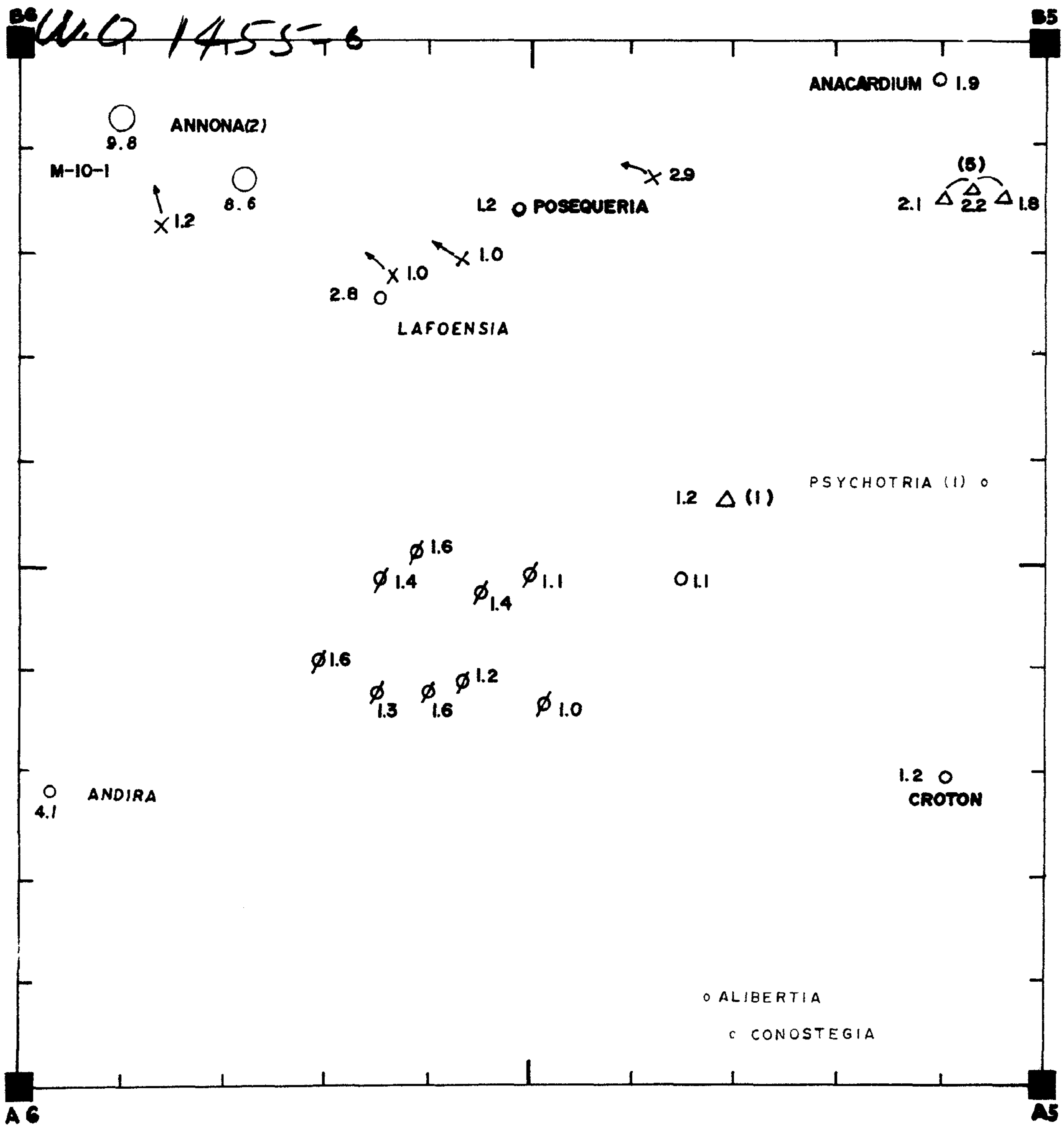
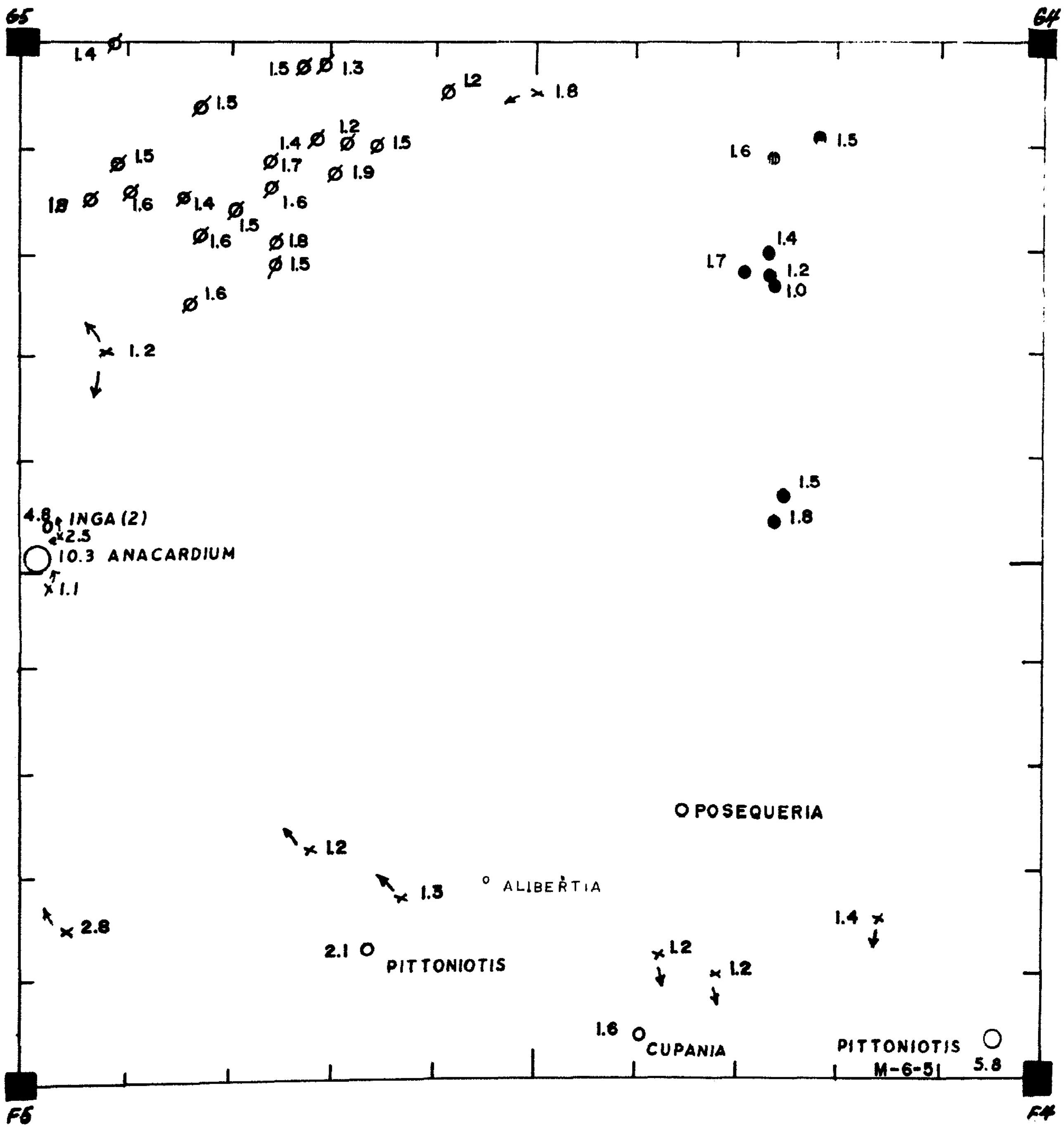
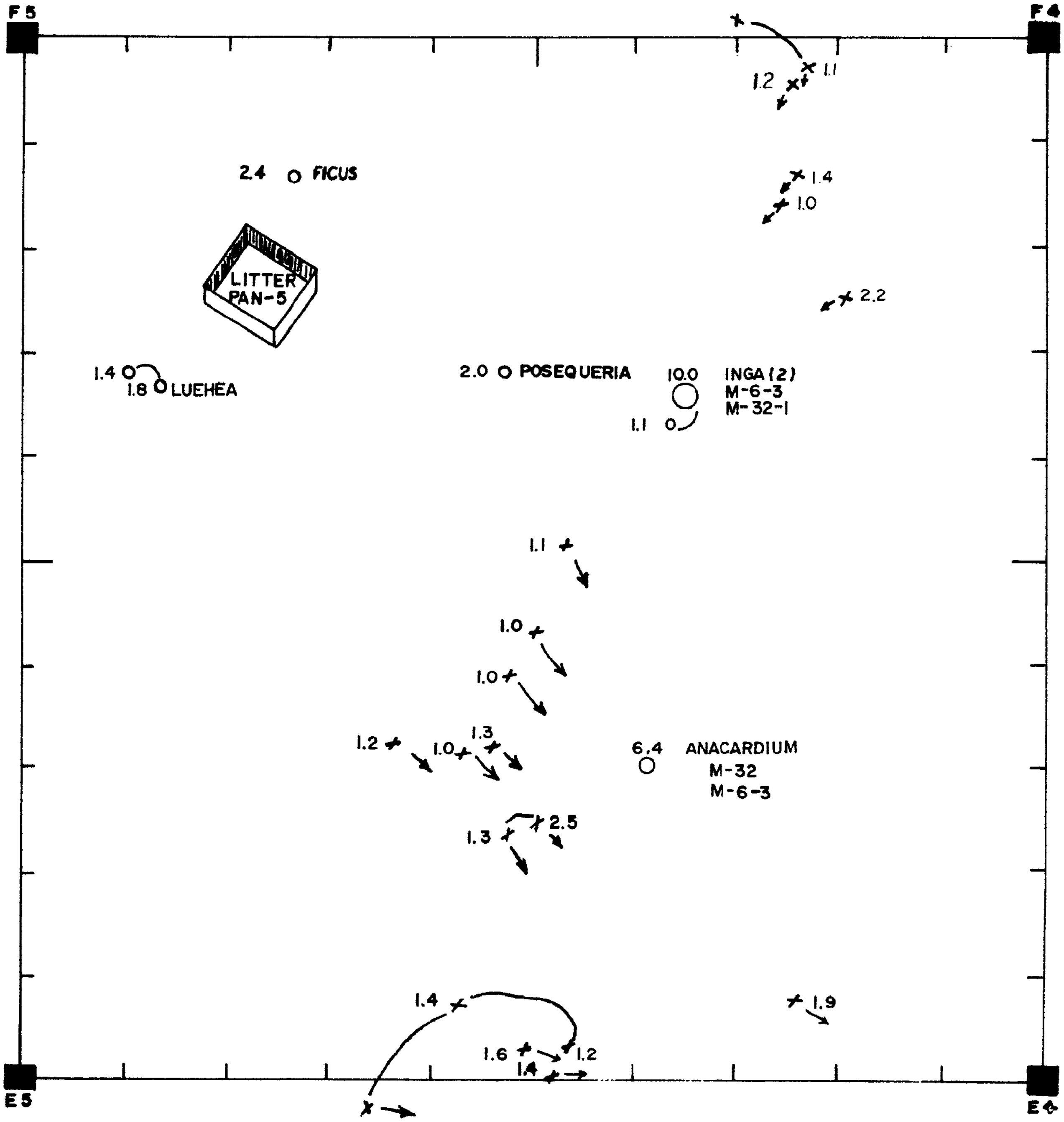
PSYCHOTRIA (3)
1.2 NECTANDRA
LITTER PAN# 3
JUNGLE VISUAL RANGE LANE
PSYCHOTRIA (1)
POSEQUERIA 1.0
1.6 INGA
B6
B5



B6
W.O 1455-6
B5
ANACARDIUM 1.9
ANNONA(2)
9.8
M-10-1
1.2
8.6
2.9
L2 POSEQUERIA
(5)
2.1 2.2 1.8
1.0
1.0
2.8
LAFOENSIA
PSYCHOTRIA (1)
1.2 (1)
1.6
1.4
1.4
1.1
1.1
1.6
1.2
1.3
1.6
1.0
1.2
CROTON
ANDIRA
4.1
ALIBERTIA
CONOSTEGIA
A6
A5


65
64
F5
F4
INGA (2)
10.3 ANACARDIUM
POSEQUERIA
ALIBERTIA
PITTONIOTIS
CUPANIA
PITTONIOTIS
M-6-51
5.8


F5
F4
E5
E4
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LITTER
PAN-5
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1.4
1.8
LUEHEA
2.0
POSEQUERIA
10.0
INGA (2)
M-6-3
M-32-1
1.1
1.1
1.0
1.0
1.3
1.2
1.0
6.4
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M-6-3
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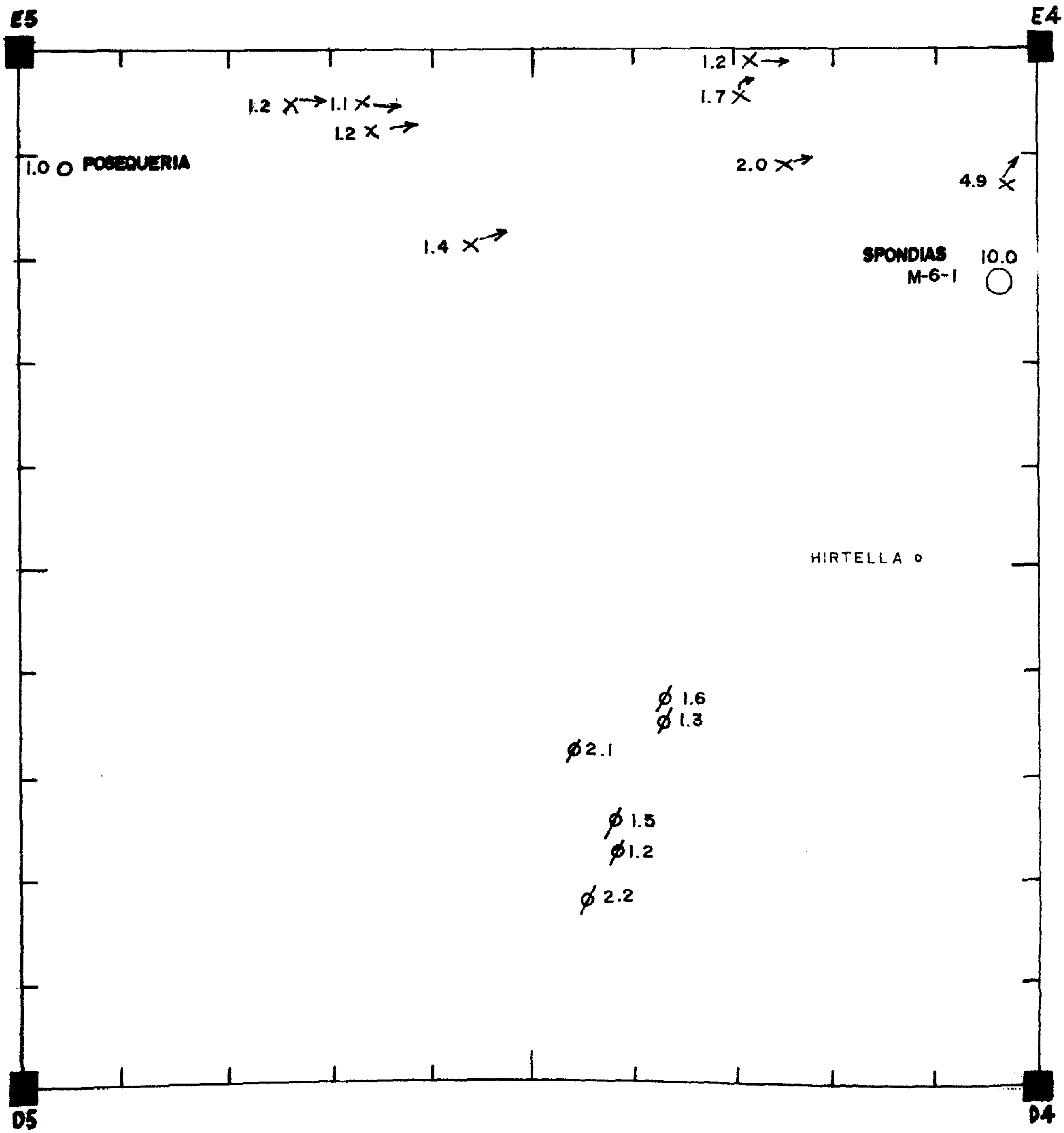
1.2
1.4


E5
E4
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1.7
1.2
1.0 POSEQUERIA
2.0
4.9
1.4
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M-6-1
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HIRTELLA
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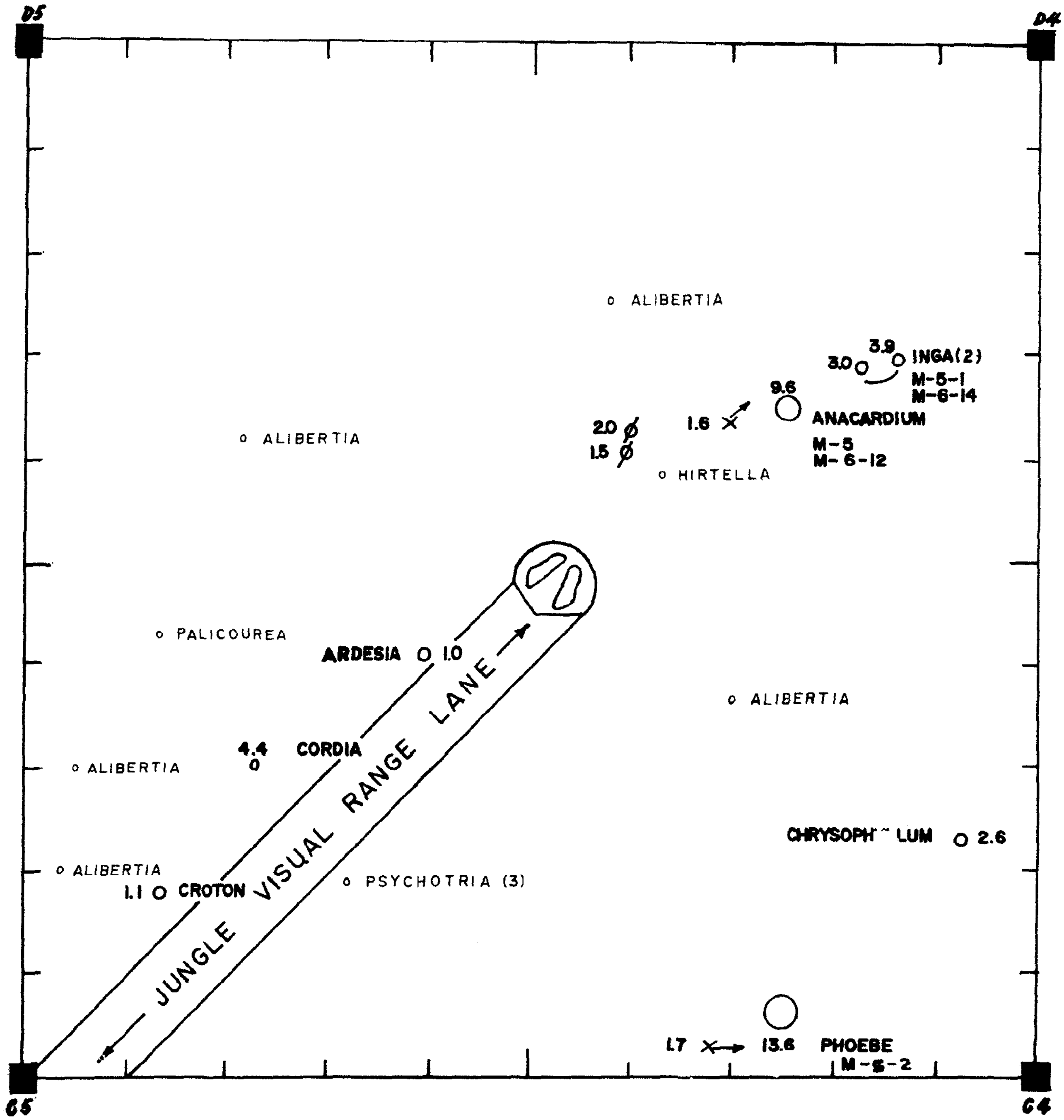
1.3
2.1
1.5
1.2
2.2
D5
D4


D5
D4
G5
G4
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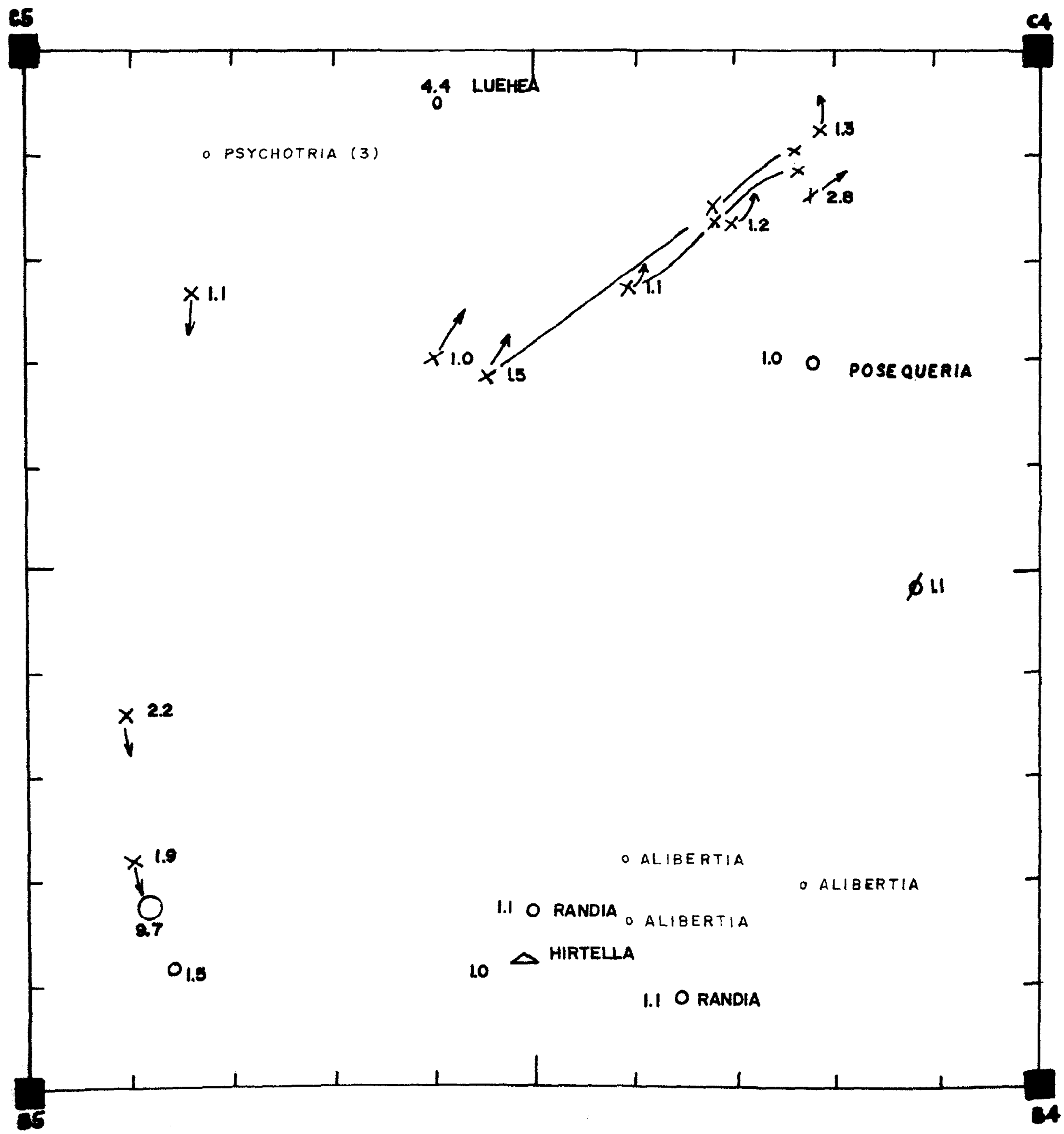
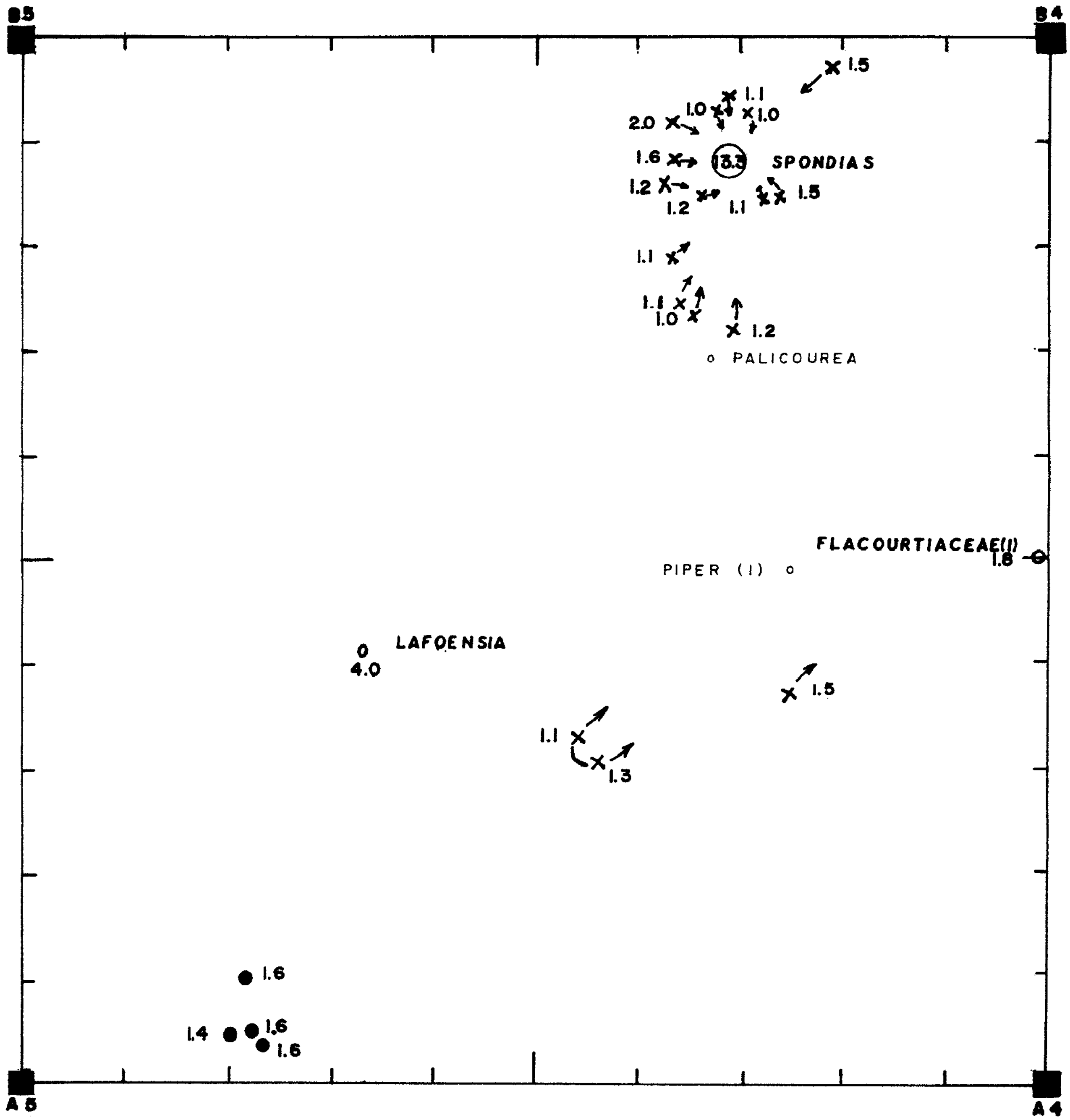
3.9
3.0
INGA(2)
M-5-1
M-6-14
9.6
ANACARDIUM
M-5
M-6-12
2.0
1.5
1.6
ALIBERTIA
HIRTELLA
PALICOUREA
ARDESIA
1.0
ALIBERTIA
4.4
CORDIA
ALIBERTIA
CHRYSOPH~LUM
2.6
ALIBERTIA
1.1
CROTON
PSYCHOTRIA (3)
JUNGLE VISUAL RANGE LANE
1.7
13.6
PHOEBE
M-S-2


C5
C4
B5
B4
4.4 LUEHEA
0
o PSYCHOTRIA (3)
1.3
2.8
1.2
1.1
1.1
1.0
1.5
1.0
POSEQUERIA
1.1
2.2
1.9
9.7
1.5
o ALIBERTIA
o ALIBERTIA
o ALIBERTIA
1.1 RANDIA
1.0
HIRTELLA
1.1 RANDIA


B5
B4
A5
A4
SPONDIAS
13.3
PALICOUREA
FLACOURTIACEAE(I)
PIPER (I)
LAFOENSIA
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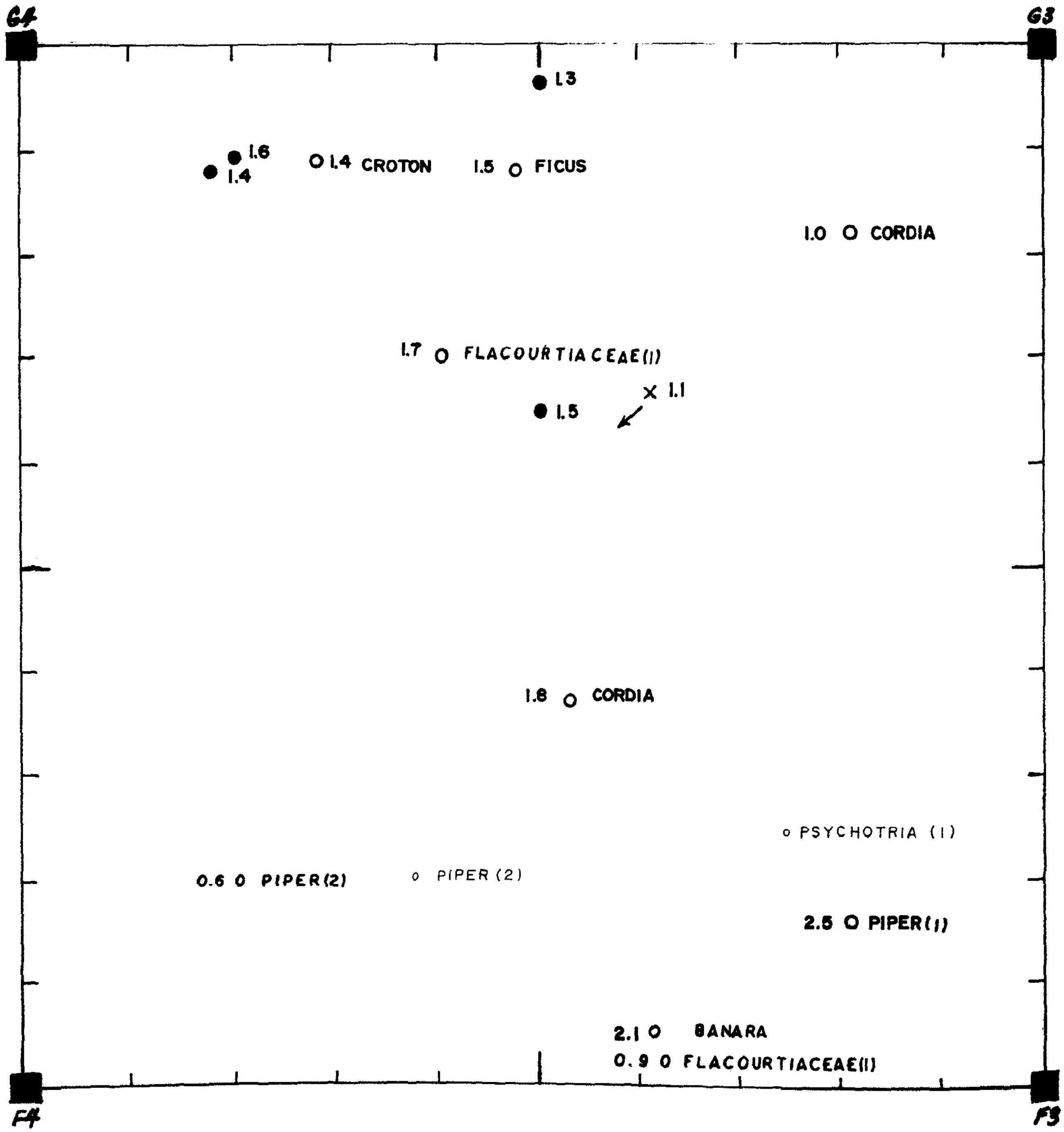
2.0
1.6
1.2
1.1
1.0
1.5
1.3
1.4


G4
G3
1.3
1.6
1.4
O 1.4 CROTON
1.5 O FICUS
1.0 O CORDIA
1.7 O FLACOURTIACEAE(1)
X 1.1
1.5
1.8 O CORDIA
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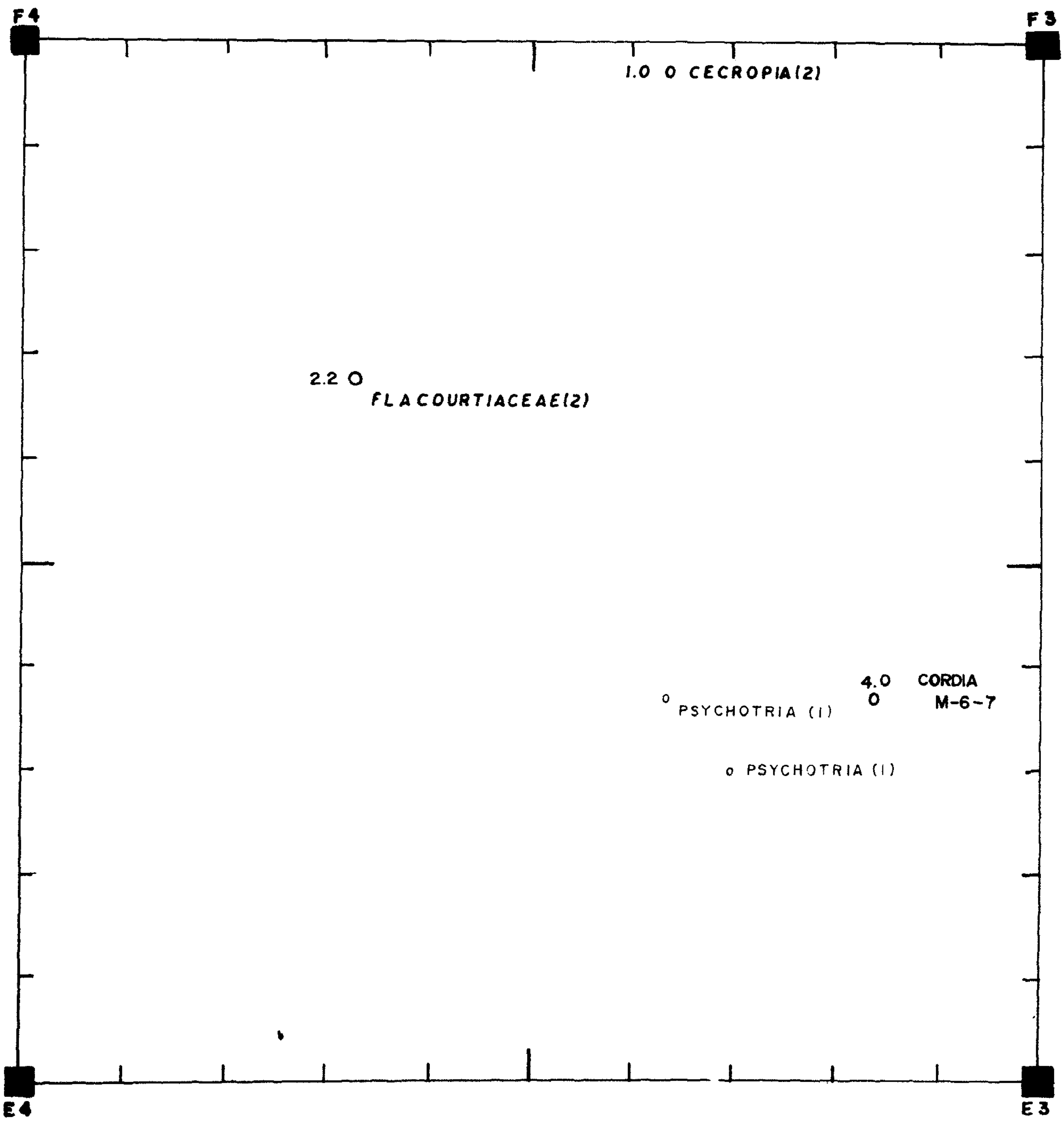
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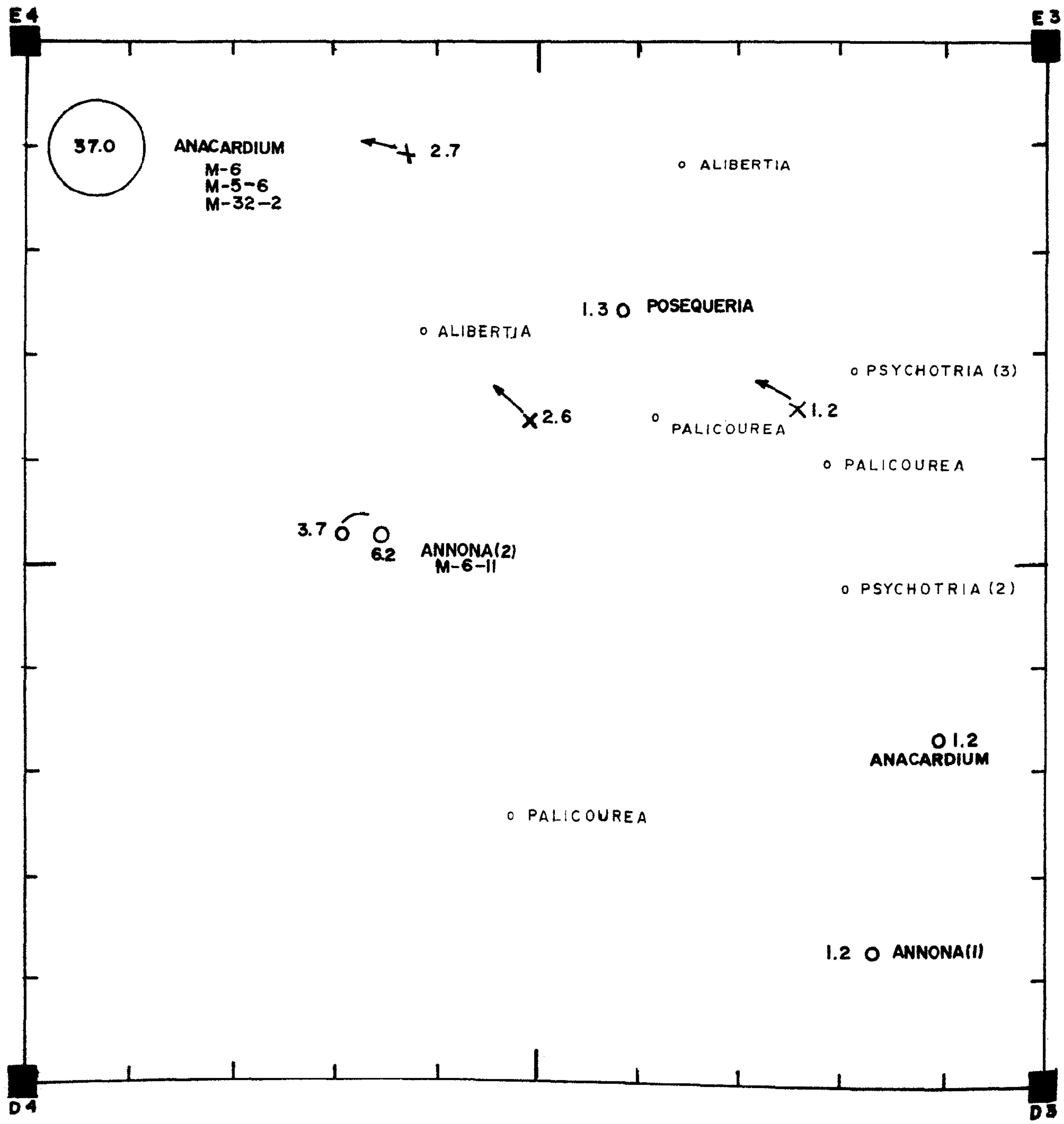
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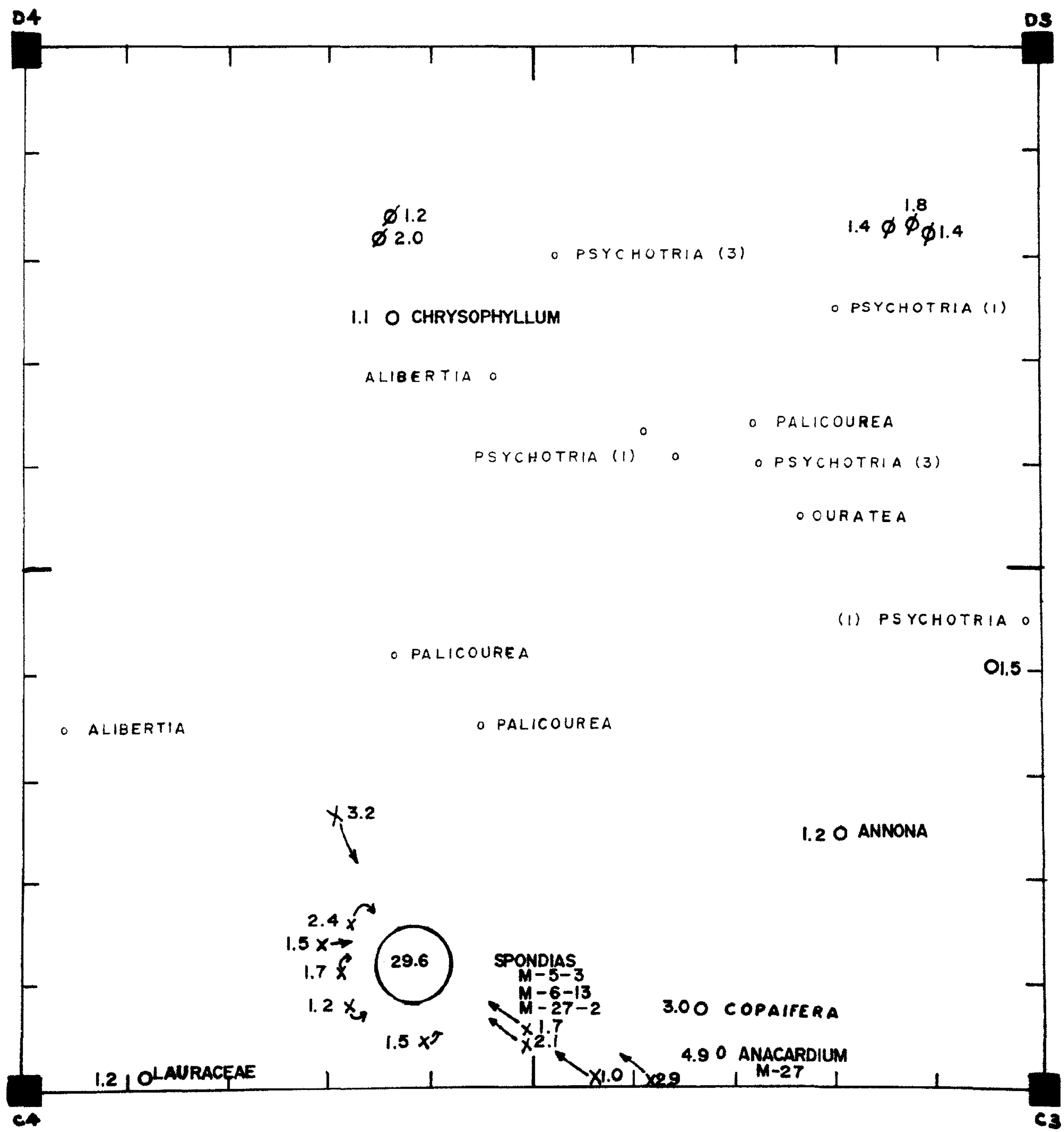
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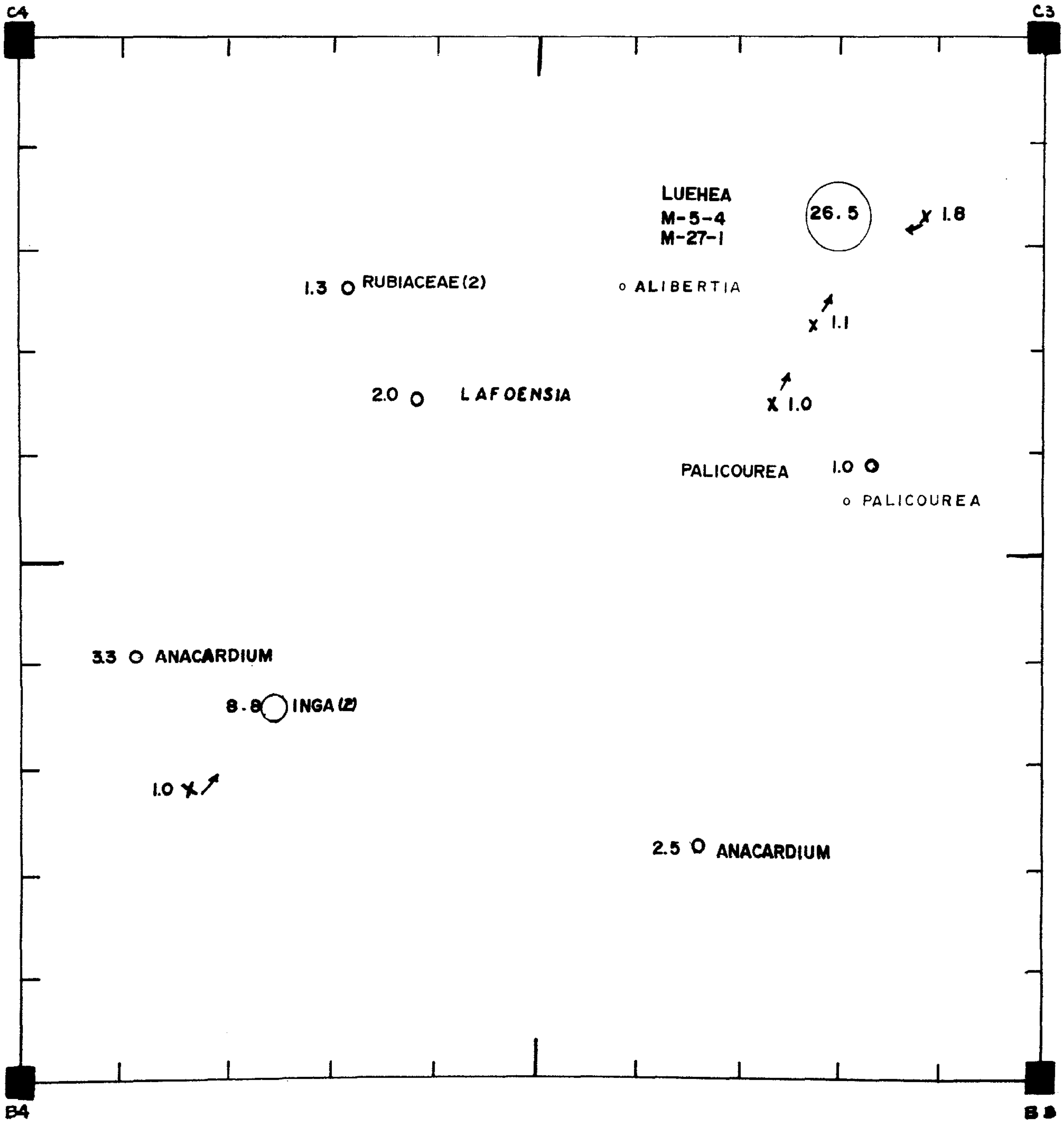
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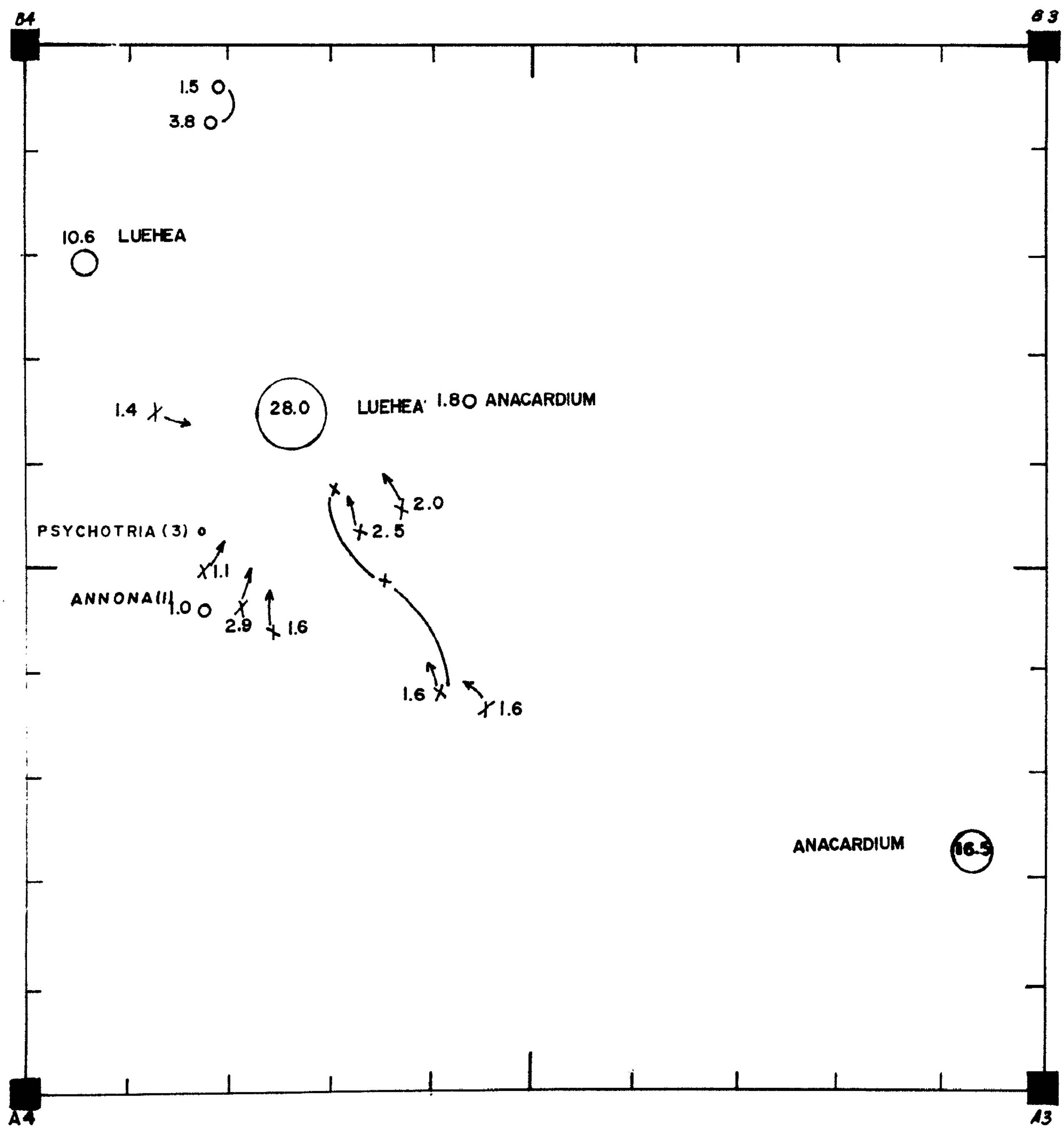

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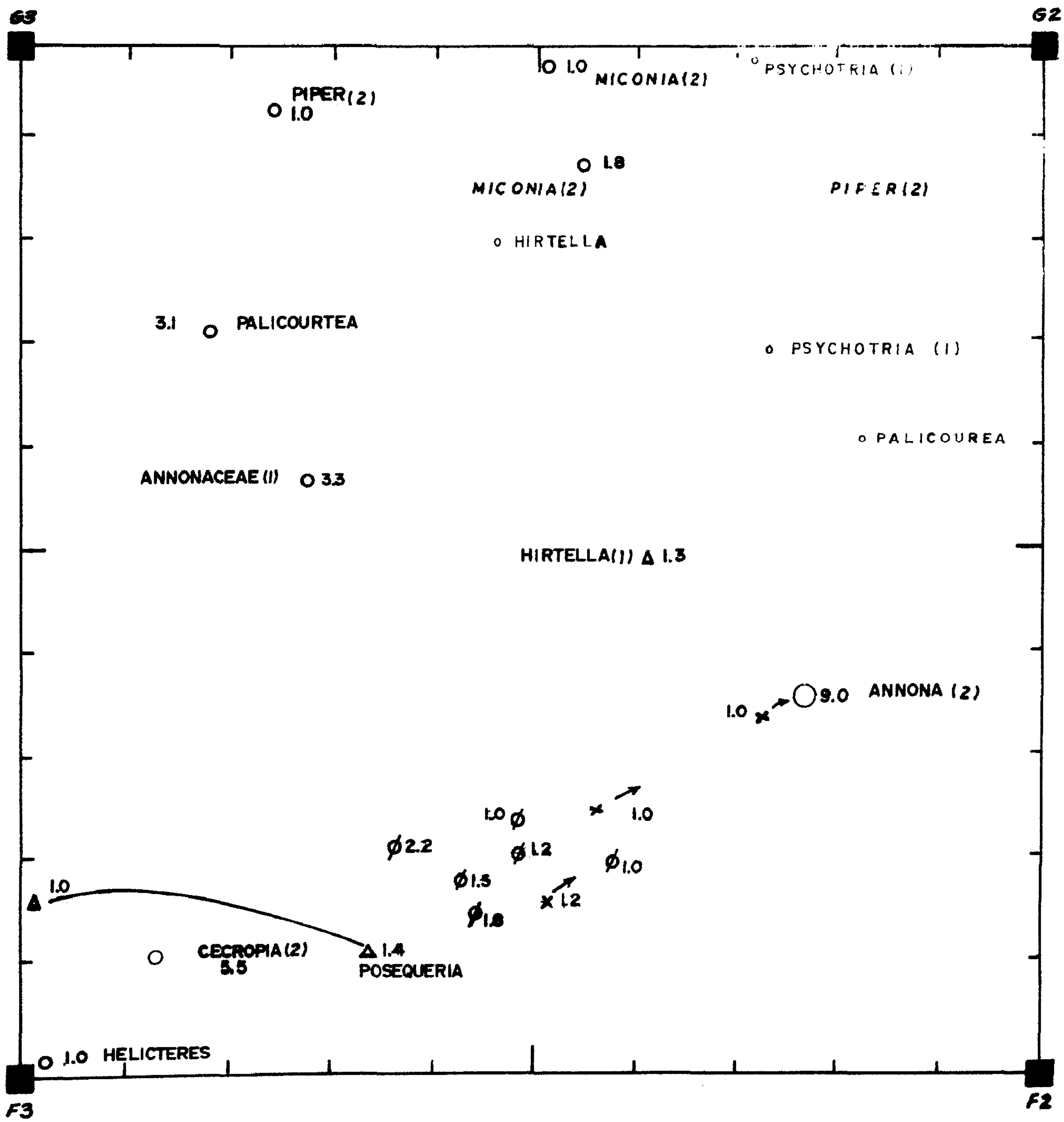
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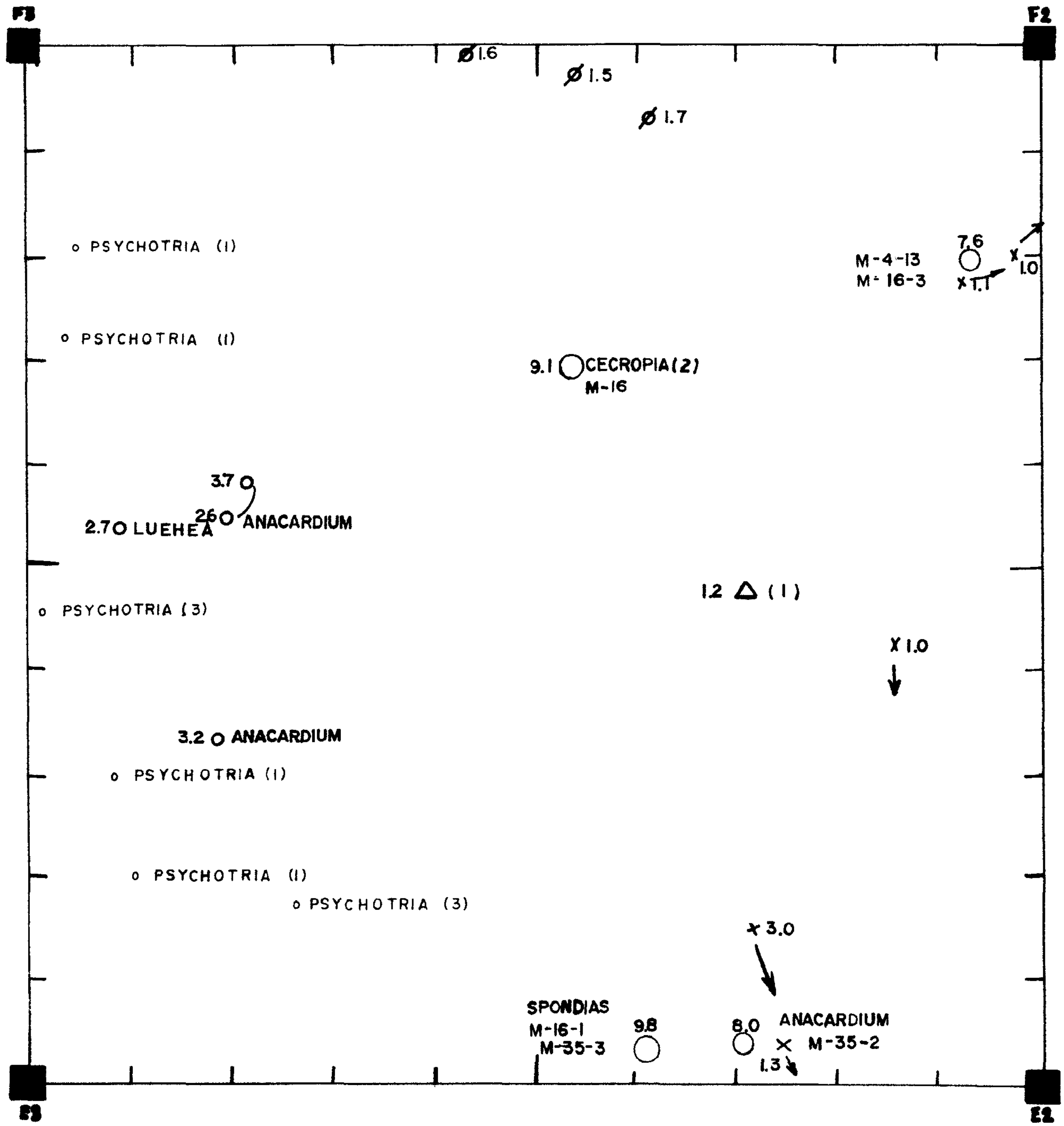

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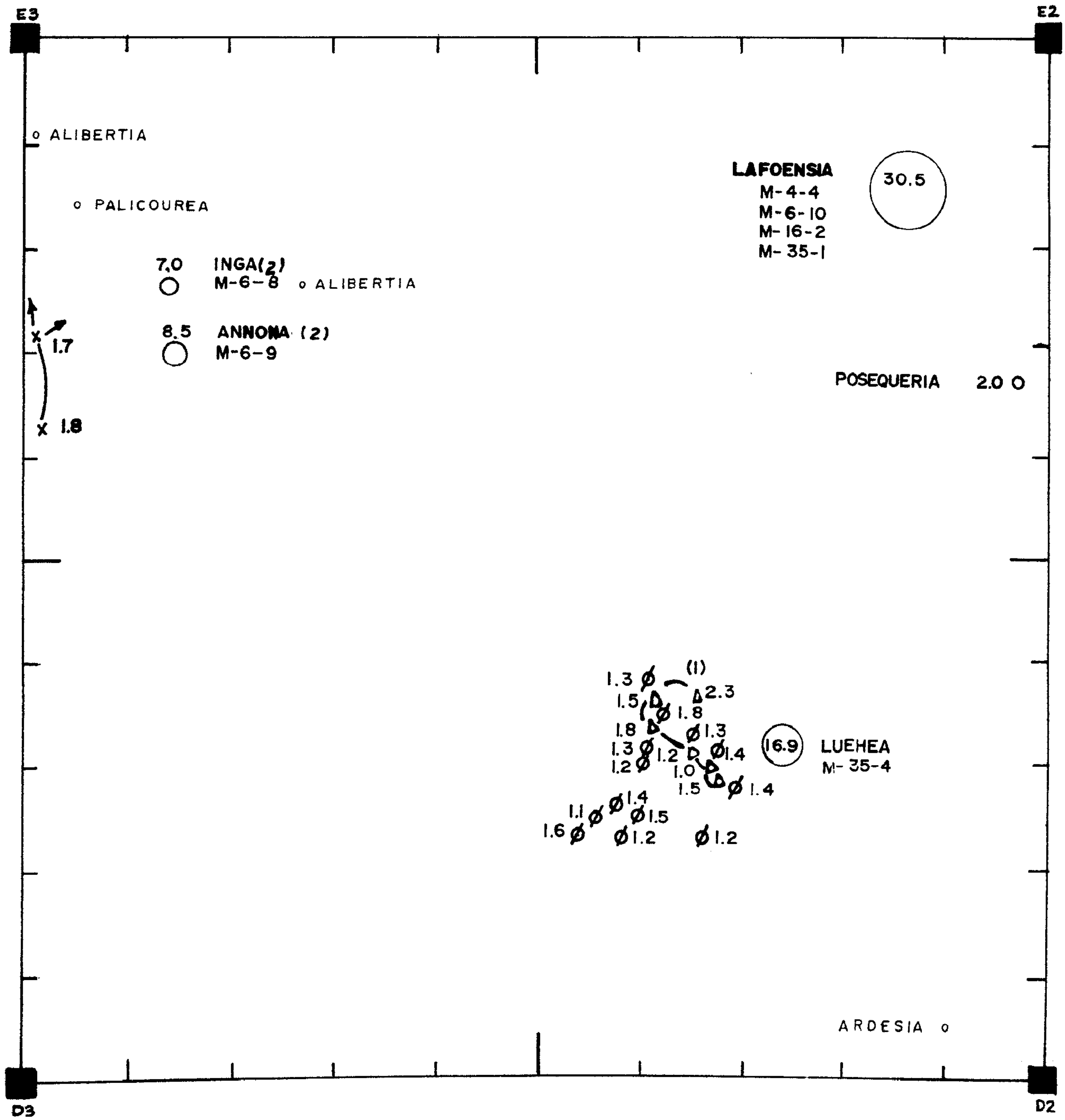
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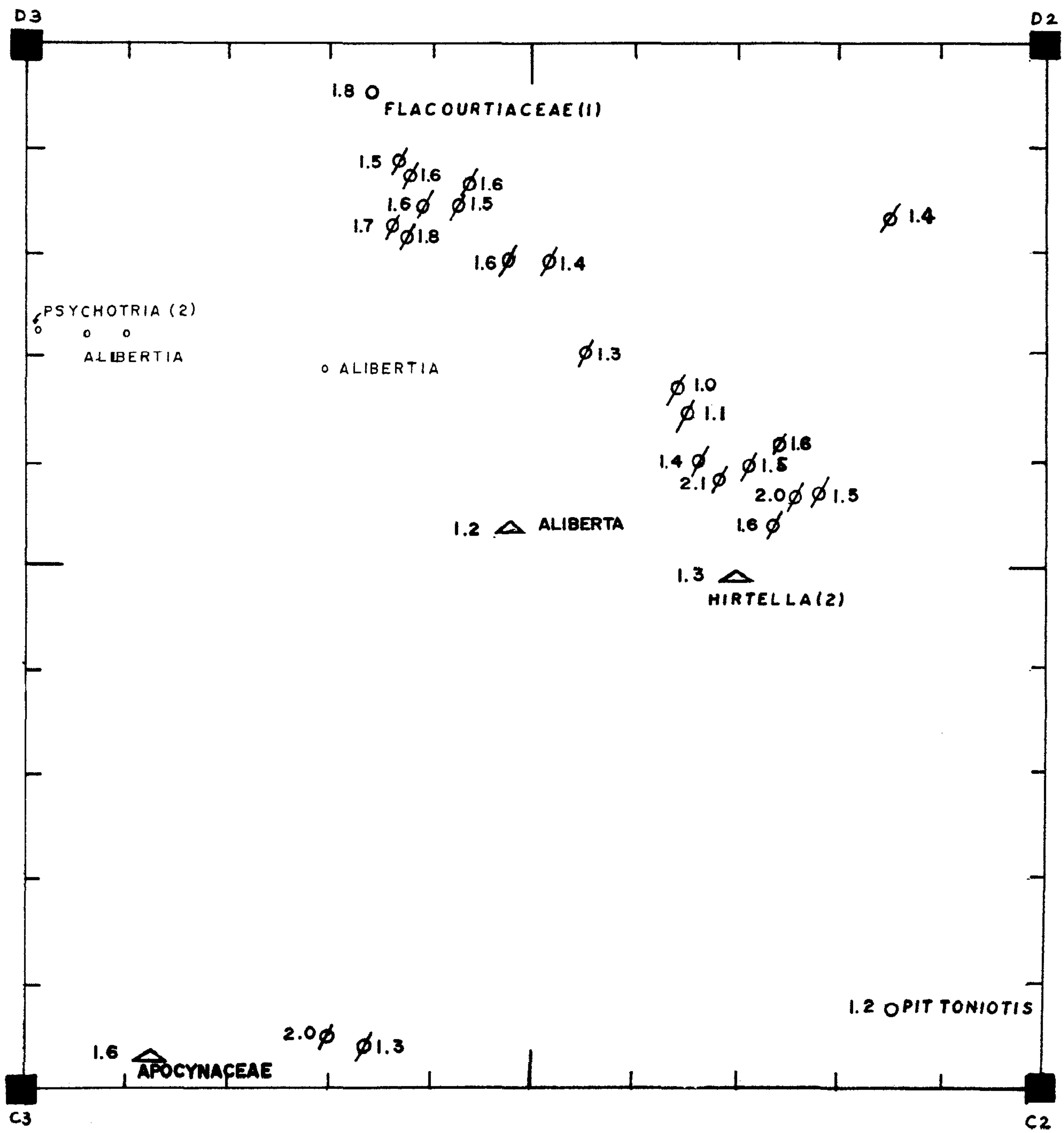
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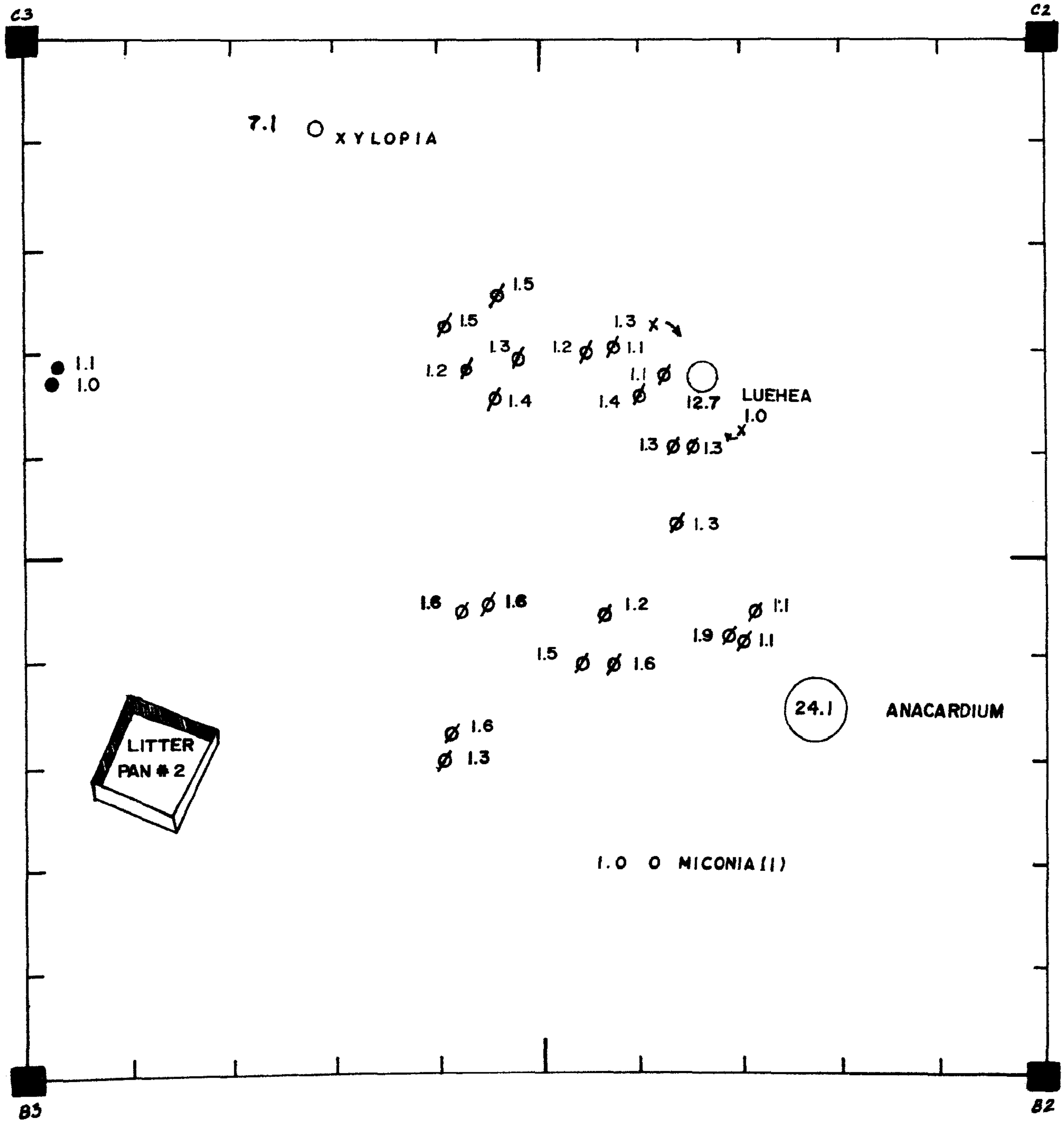
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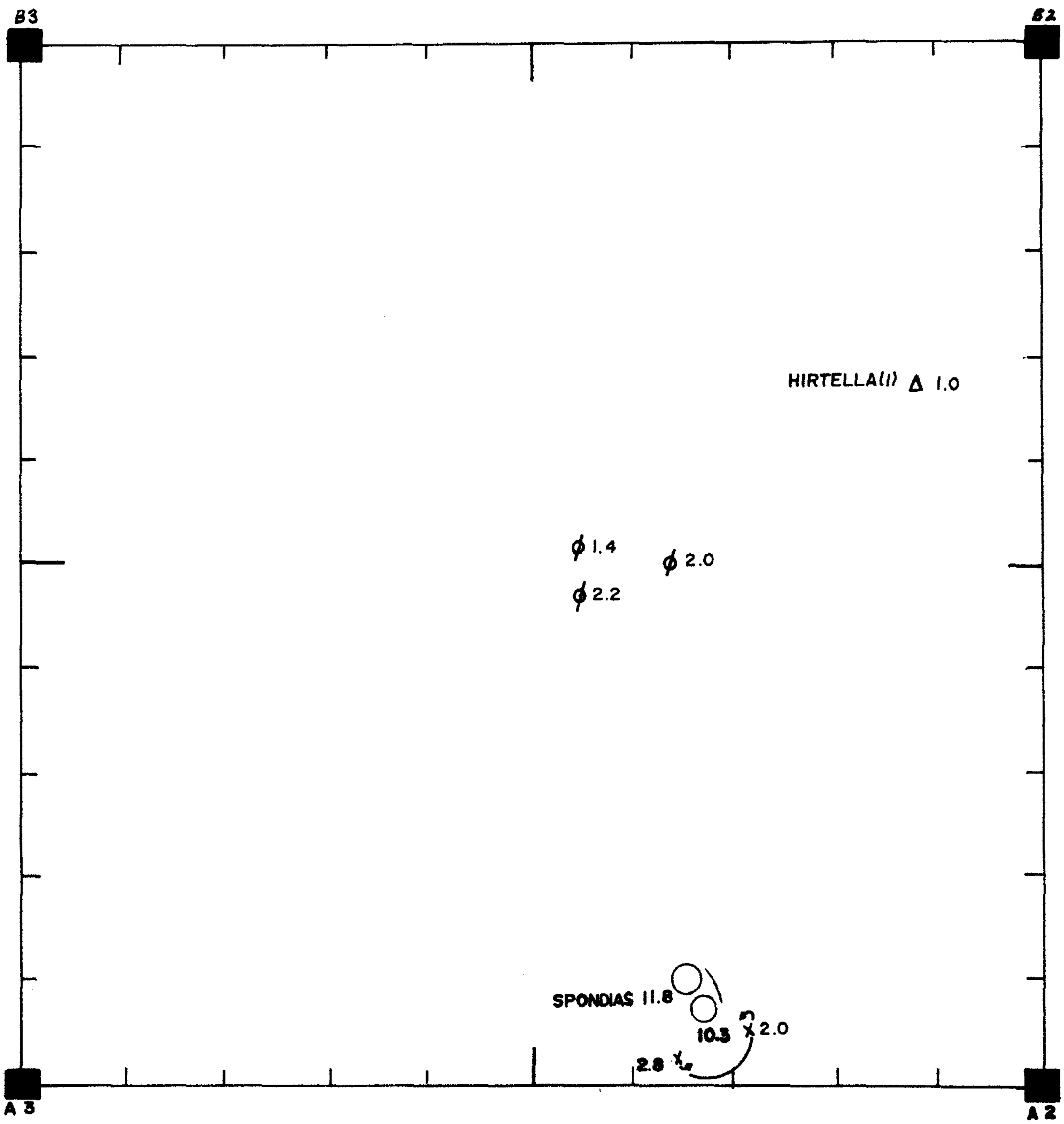
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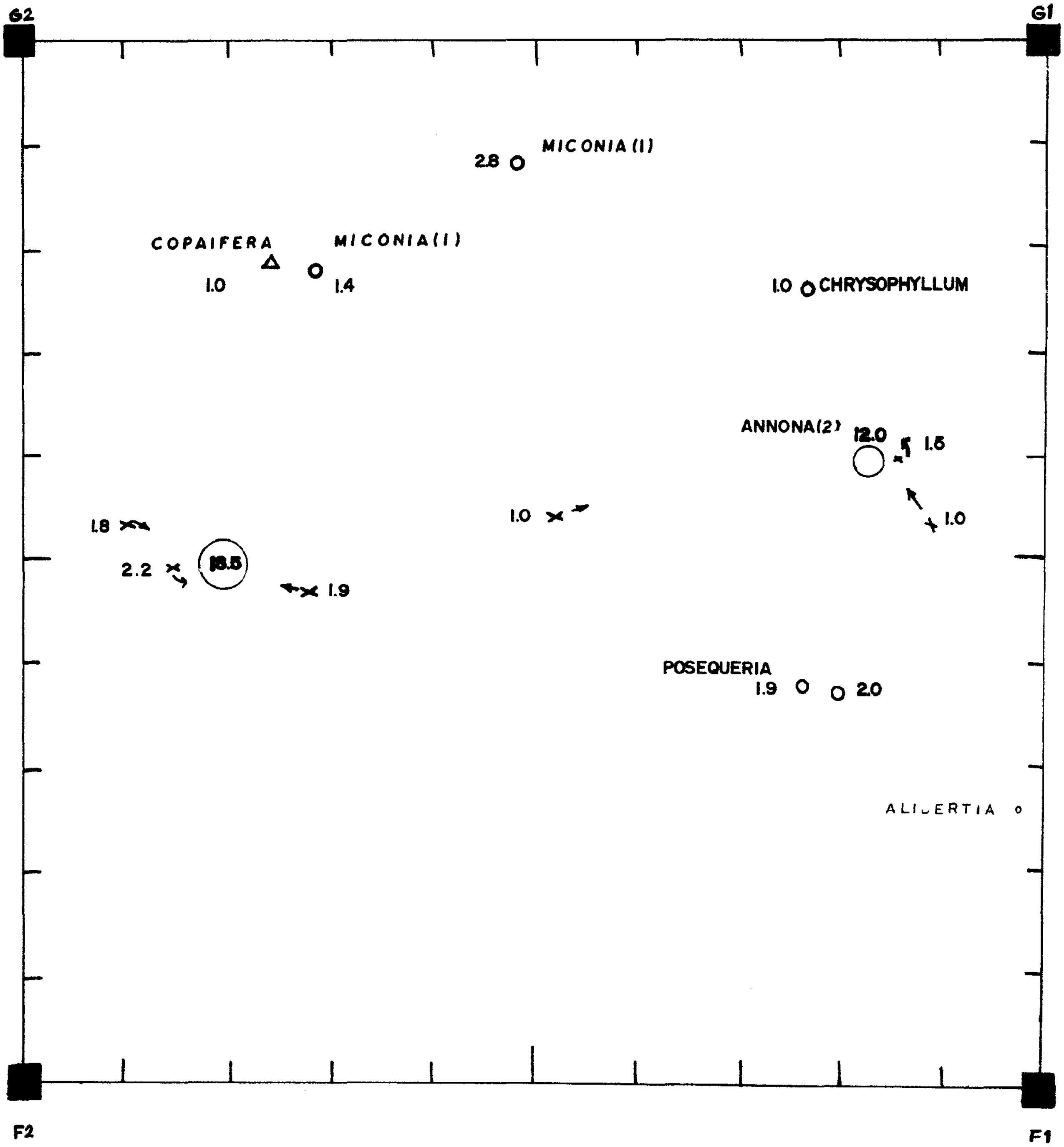
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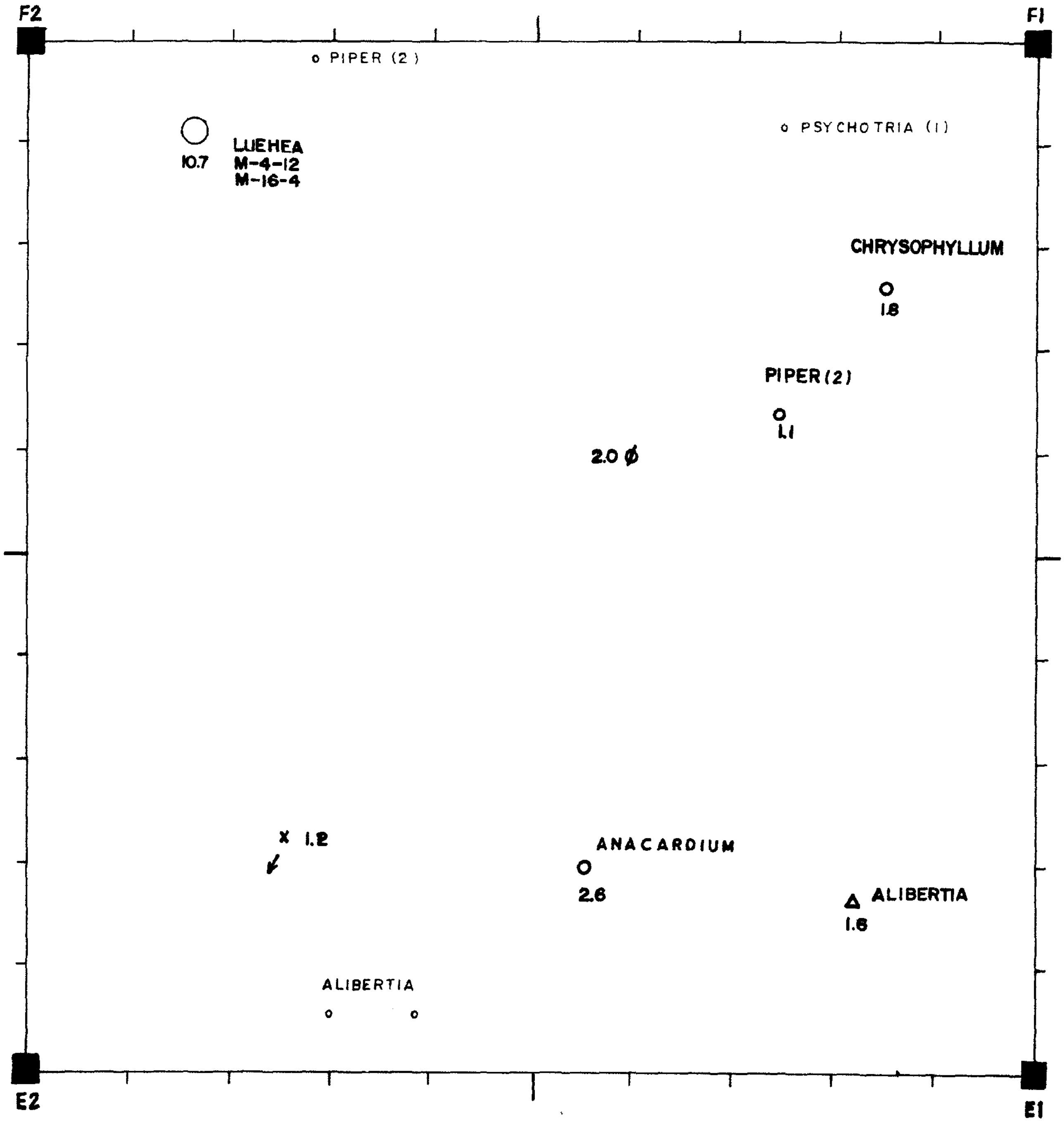
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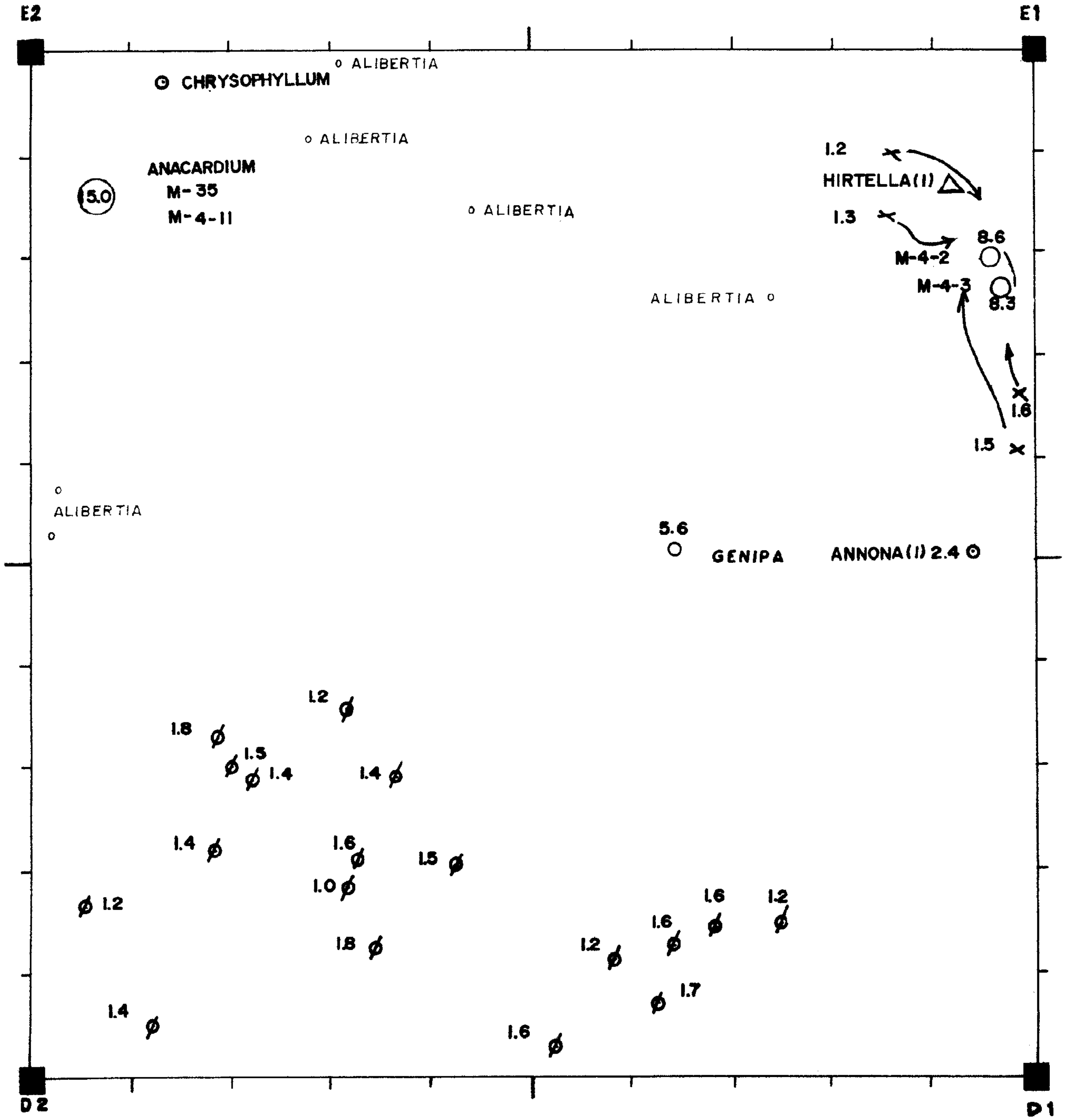
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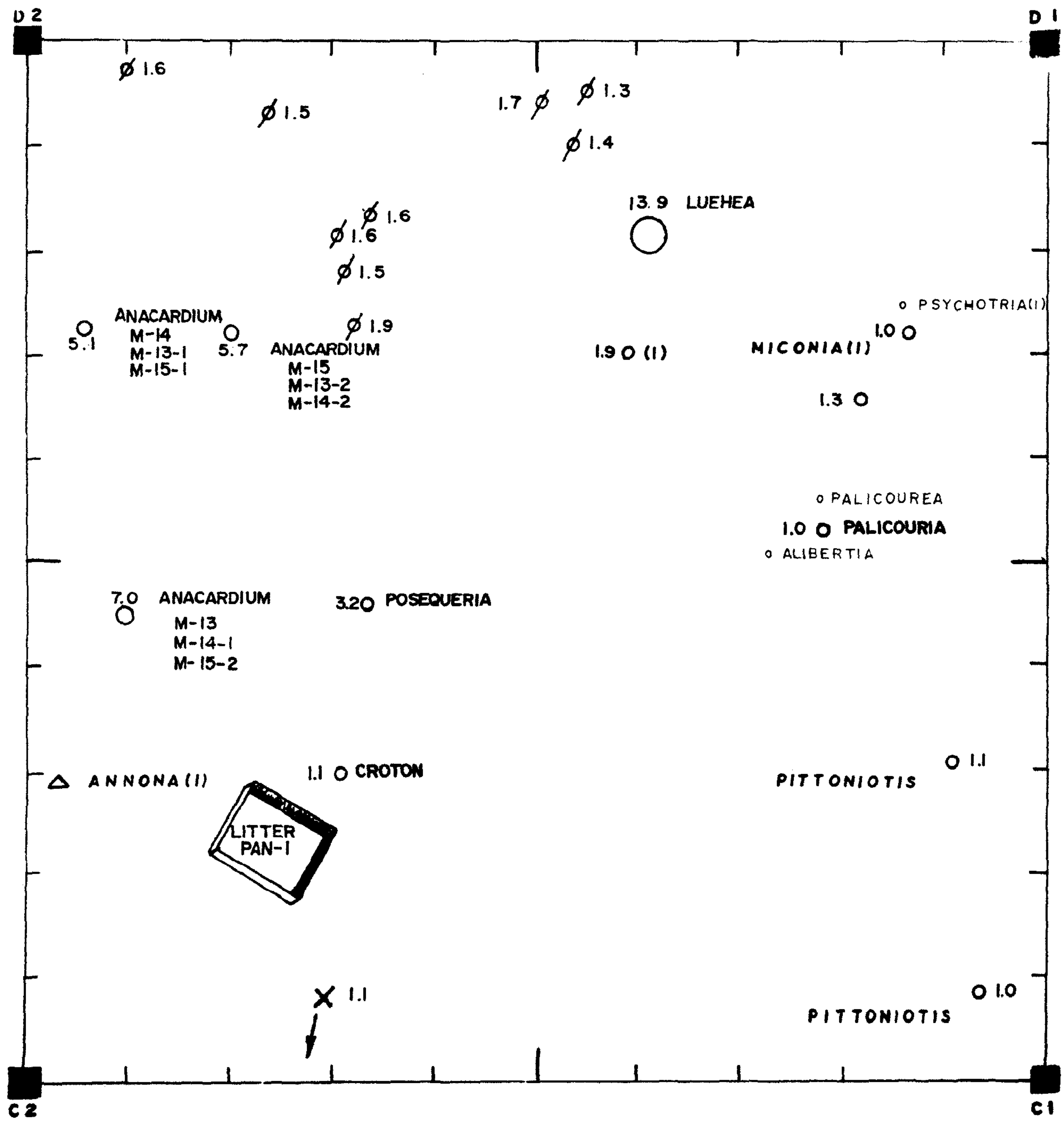
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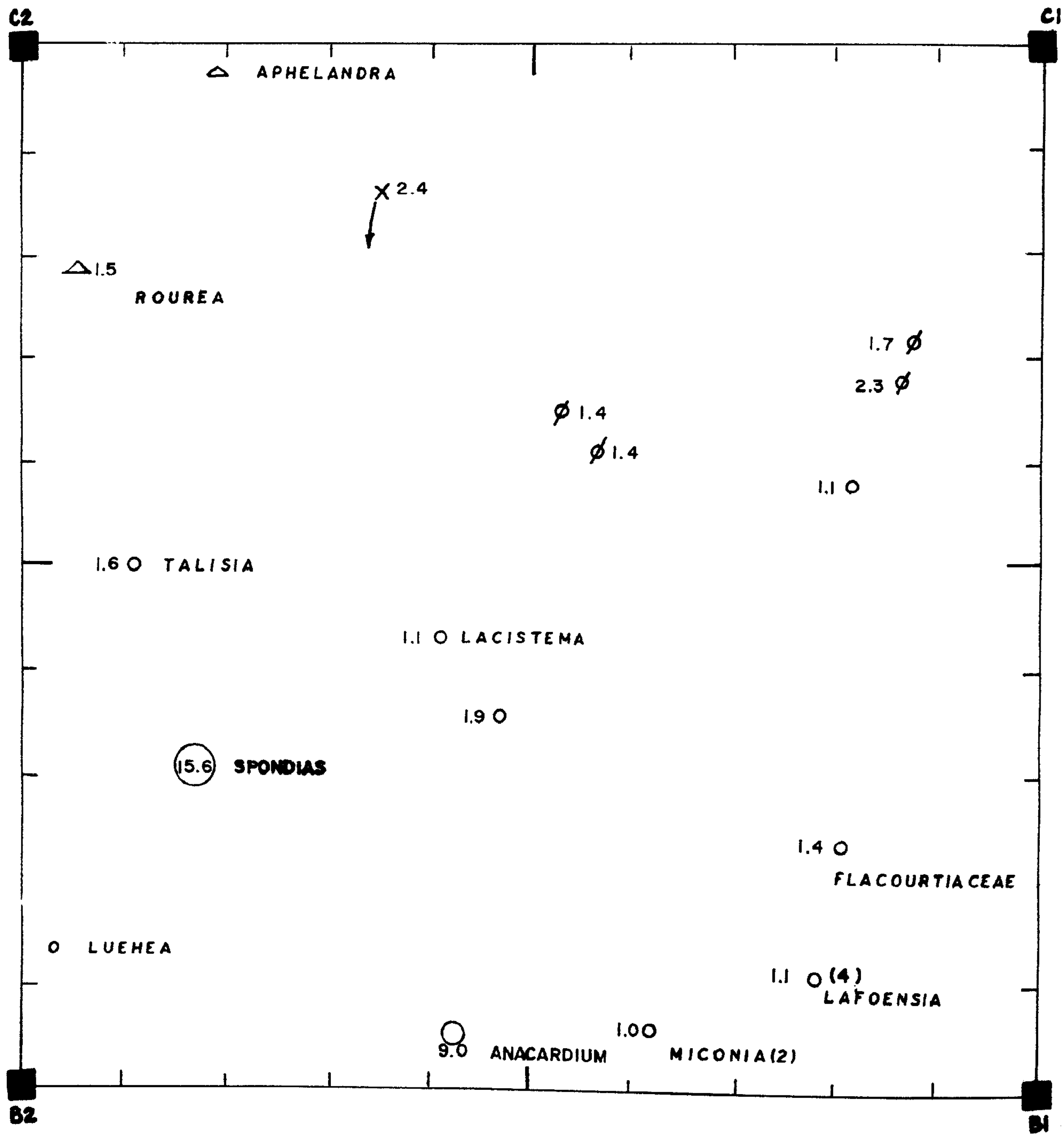
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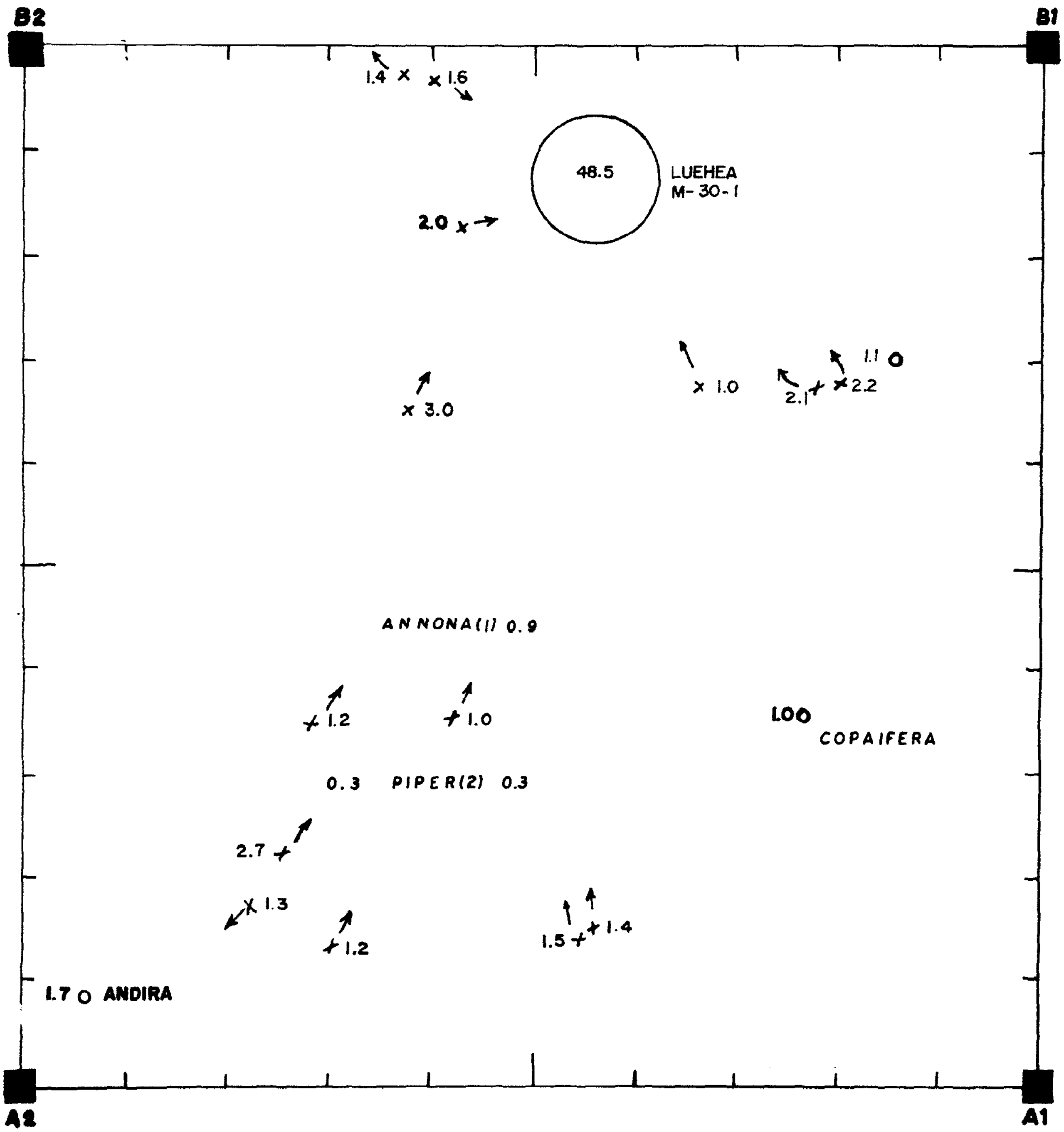

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5. AUTHOR(S) (Last name, first name, initial)

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
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This Climate section covers data collected, instrumentation, maintenance problems, and limited data analysis.

The Soils and Hydrology section describes data collection and methods. Data analyses include relationships between moisture content and dry density, moisture content and strength, soil temperature in vertical profile and air temperature, groundwater and rainfall in open and forest sites; and an analysis of seasonal variation in soil strength in open forest sites.

The Vegetation section includes: (a) A description of the project herbarium. (b) A study of leaf density and horizontal profile of Albrook forest canopy. (c) A paper on forest litter dealing with kind and amount of material, and timing of accumulation. (d) A paper on the capability of litter from grass, brush, and forest land to support fire. An inventory of plants is given in an appendix.

The section, Microbiology and Chemistry of the Atmosphere, contains: (a) A paper on the deposition of microorganisms on surfaces dealing with data collection methods and analyses comparing bacterial and fungal deposition. (b) A paper on distribution of airborne microorganisms dealing with data collection methods and analyses of bacterial and fungal content of air. (c) A paper on chemicals in the atmosphere gi ing analytical laboratory procedures, and preliminary determinations. (d) A paper on microorganisms as sources of atmospheric contamination with results of an exploratory use of a gas chromatograph in sensing volatile organics. (e) A paper on condensation nuclei and particulate matter in the air with observations on detection techniques.

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