LEIDSE GEOLOGISCHE MEDEDELINGEN, deel 32, 1965 pp. 157—182, separate published 15 - 10 - 1965

LATE QUATERNARY GLACIAL AND VEGETATIONAL SEQUENCE IN VALLE DE LAGUNILLAS, SIERRA NEVADA DEL COCUY, COLOMBIA

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ABSTRACT

In a high Andean valley (6°N. Lat., alt. 3800 to 4400 m) four bodies of glacial drift marked by many end moraines are recognized. Stratigraphically related to the drifts are small bodies of lake sediments, from which core- and outcrop samples were taken. The samples yielded a continuous pollen sequence from which climatic history was derived. The pollen sequence is calibrated by nine C^{14} dates from organic material in the samples. The dated climatic history permits correlation of the sequence with both Colombian pollen zones and northern European zones. It also permits approximate dating of the drifts, which are in good chronologic agreement with those recognized in North America. The results therefore support the view that major climatic events in high-altitude, tropical South America during at least the last 12,000 years were synchronous with those in mid- and high-latitude North America and Europe.

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INTRODUCTION AND ACKNOWLEDGMENTS

The present paper reports the results of field work done, and the subsequent study of samples collected, during a short expedition to the Sierra Nevada del Cocuy, sponsored by the Colombian Committee of the International Geophysical Year. The field study was made January 20 to 31, 1959; the participating members were, besides the authors, Mr. Juan B. Perico and Mrs. Margaret Flint.

One purpose of the expedition was the marking of the termini of existing glaciers, for comparison with measurements in future years. A short account of this work was given in Kraus and van der Hammen, 1960. The other purpose was to study the glacial geology and pollen stratigraphy of the area.

The Valle de Lagunillas was selected for the study of end moraines and for their correlation by means of pollen analysis. This valley, containing a chain of existing and former lakes, lies west of the main central ridge of the Sierra Nevada del Cocuy.

One of us (R.F.F.) made a field- and photogeologic study of the valley and prepared a geologic map. The other members sampled lake sediments and peats, made a general survey of the existing vegetation, and collected plants and recent pollen.

A sketch map of the high part of the Sierra, showing the extent of the youngest bodies of drift, was later prepared by Mrs. Anita van der Hammen-Malo. The pollen diagrams, constructed by one of us (E.G.) and by Mrs. Riate van Mullem, took much time because many of the samples were extremely poor in pollen. Interpretation of the diagrams presented serious problems, arising from the fact that the altitudes represented are very high. Although we have confidence in our interpretation and correlation, which are corroborated by a number of C^{14} dates, we fully realize that further study may bring new points of view to the interpretation of the diagrams.

A similar study of the Sierra Nevada de Santa Marta, on the north coast of Colombia, is now being made in Leiden by Mrs. Joan Lucas-Rappard. Provisional results appear to corroborate our conclusions from the Cocuy, in that they show a similar succession of moraines, correlative in age with ours.

We wish to express our sincere thanks to the Colombian Commission of the International Geophysical Year, especially its President, Father J. E. Ramirez, S.J., for the funds for the expedition; to Dr. Jorge Rodriguez and his collaborators in the Sección de Fotogrametría del Instituto Geográfico "Agustin Codazzi", Bogotá, who developed a contour map of our area, from air photographs and altitudes from our field data; to Mrs. Riate van Mullem for the analysis of part of the pollen samples; and to Dr. J. C. Vogel, Director of the C^{14} dating laboratory in Groningen, for his valued collaboration in providing C^{14} dates from our most critical samples. The expense of this work was defrayed by the Netherlands Foundation of Pure Scientific Research (Z.W.O.).

PHYSICAL DESCRIPTION OF THE AREA

The Sierra Nevada del Cocuy lies in the eastern part of Colombia, between lats. 6°20′ N. and 6°35′ N. It forms the highest part of the Colombian Cordillera Oriental and trends nearly north-south (fig. 1). That part which stands above the snowline (that is, above an altitude of about 4600 m measured on the western slope) has a length of about 33 km and reaches an extreme altitude of about 5490 m in the Alto Ritacuva, a peak near its nothern end. The highest peak near the southern end is Pan de Azucar, with an altitude of about 5150 m. The area of the divide is covered with a nearly continuous chain of ice caps, one to two kilometers in width, and small outlying snowfields. As viewed from a distance and as they appear on aerial photographs, the ice caps in the southern part of the Sierra overlie broad dip slopes and appear to be thin. The one closest to the area mapped is more than 6 km long and 1 to 2 km wide (pl. 1).

The glaciers are nourished by snowfall associated with northeast trade winds; in consequence the eastern slope of the Sierra Nevada, which includes the area of this study, is wetter than the western slope. Although there are no data on local precipitation, probably the higher areas receive at least 1500 mm and perhaps more than 2000 mm of water annually; the western slopes are drier. The climate is seasonal, with a dry period November to March.

The southern part of the Sierra Nevada consists of coarse sandstone and quartzitic sandstone, pale gray to white and many thousands of feet thick, the Cocuy Quartzite of Hettner (1892, p. 15-16), of Cretaceous age. In the Cocuy district there are present two units of the sandstone, separated by shales and a limestone. The upper unit, which forms the crest of the range here, correlates with the Une Sandstone elsewhere in the Cordillera Oriental, according to H. Bürgl (unpublished communication). The beds dip generally west and in places are vertical, imparting a hackly appearance to the higher terrain and a north-south lineation to the topography in general.

A conspicuous valley, Quebrada la Cueva, follows the strike of the sandstone along the western base of the Sierra Nevada, and drains north. Its headward,southern segment is known as Valle de Lagunillas because it contains a chain of lakes. In this segment, 6 km long, the valley floor has a width of 300 to 500 m and a gradient of 1 in 60 (about 87 ft/mi). The gradient is unusually small for a valley in the Colombian Andes, where slopes five to ten times as steep are common. Because of the gentle gradient, erosion thus far has modified very little the morphology of the glacial drift; end moraines, lake beds, and bogs still remain. For this reason Valle de Lagunillas is a favorable place for an attempt to reconstruct events of late Quaternary time

Within the area mapped the valley has only one tributary stream entering from the west. On its higher, up-dip, eastern side it has seven tributaries. Of this total of eight, five are short steep streams occupying ill-defined valleys. The other three are related to a large, conspicuous valley, Valle de la Bocatoma, which today has glacier ice at its head. Two of the three are lateral streams, following the distal bases of massive end moraines more than 100 m high. The third is central, draining a chain of lakes and bogs that occupy the valley axis. The topography suggests that in pre-glacial time the major drainage of the area followed Valle de la Bocatoma and the northern part of Valle de Lagunillas into Quebrada la Cueva (pl. 1).

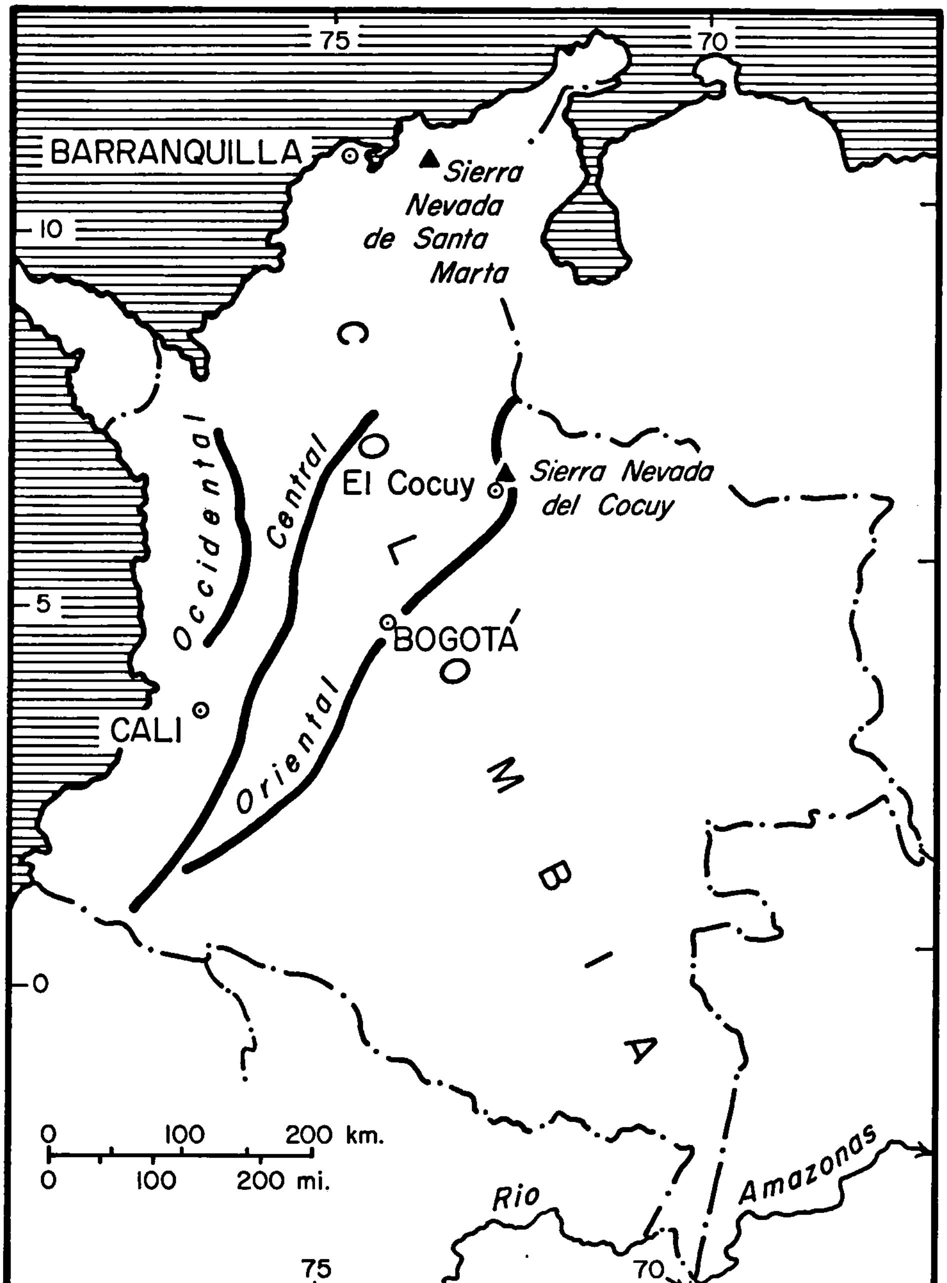

Fig. 1. Sketch map of Colombia showing axes of the three Cordilleras and location of the area discussed.

REGIONAL GLACIATION

Valleys on the slopes of the Sierra Nevada del Cocuy and other high ranges of the Colombian Andes contain glacial drift. In this region drift with morainic topography, little dissected or only moderately dissected, extends down to altitudes of about 3200 m. In some valleys drift that is more conspicuously weathered and much more dissected extends to about 2700 m.

Drift with morainic topography is conspicuous in the west-draining valley followed by the Cusirí Trail between the town of El Cocuy and the map area of Plate 2. Because the bedrock in that sector consists chiefly of very erodible Cretaceous shales and siltstones, the drift derived from them yields readily to mass-wasting. Fine topographic details therefore tend to be smoothed out and exposures are poor. The glacier ice that deposited the drift is believed to have come, across lower intervening ridges, from the Sierra Nevada del Cocuy.

GLACIAL FEATURES OF VALLE DE LAGUNILLAS

The principal glacial features of Valle de Lagunillas are shown on Plate 2. The northern part of that valley is a homocline with varying dip; the southern part, containing the lakes, is an unsymmetrical syncline, with nearly vertical dips in places along its eastern side. Where dips are steep the summits and slopes of strike ridges tend to be hackly. The valley itself is not an overdeepened trough; its form resembles that of a nonglaciated valley. It may have been widened by glacial erosion, but landsliding has occurred so extensively along its sides that it is difficult to assess what has been accomplished directly by glacial erosion. Strike ridges in the valley floor in the vicinity of the lakes, and antedating two successive passages of ice through that part of the valley, are still preserved. Although the ridges have been glacially smoothed, common features of glacial erosion such as streamline hills, stoss-and-lee topography, and polished bedrock surfaces seem to be lacking throughout the valley. The lack probably results from three factors: (1) Resistance of the bedrock to abrasion. (2) Orientation of the valley parallel to rather than at right angles to the axis of the range and the regional slope. Glacier ice would have tended to fill the valley and spill over the interfluve west of it, down the regional slope. (3) The circumstance that the former glaciers in the valley originated mainly in a series of ice caps along the crest of the Sierra rather than in cirques at the valley head. The glacier ice therefore had a dispersed rather than a localized source. There are broad cirques in the summit of the range, but owing to the structure of the bedrock they tend to face east; the west-flowing ice originated more commonly on dip slopes.

The drift in Valle de Lagunillas consists mainly of till heaped up in the form of end moraines. The till consists mainly of pebble-, cobble-, and boulder-size fragments of sandstone in a meager matrix made up largely of sand, though with some finer sizes. Most of the larger fragments are less than 1 m in diameter, but a few exceed 15 m. They are predominantly blocky, being bounded by joint- and stratification surfaces. Remarkably few clasts show any glacial shaping, and striations on them are rare.

Like the larger clasts, the sand and fines appear to consist of comminuted sandstone. Although the sandstone seems to resist abrasion effectively, it yields readily to quarrying in places where glacier ice crossed strike ridges, especially where dips are steep. In such places the common hackly crests testify to glacial quarrying rather than to frost action, because the taluses that should have resulted from frost action are lacking. The till is therefore attributed to glacial quarrying, mainly of ridge summits, and to crushing of the quarried debris.

End moraines are the dominant feature of the floor and lower sideslopes of the valley. The map (pl. 2) shows the axes of many of the moraines, but to show them all would require more detailed mapping than we could do. In one place as many as eight nested moraines were counted across a distance of 200 meters. Individual moraines range in height from two or three up to ten or more meters. They have sharp crests and are convex in the downstream direction. Fragments larger than sand size appear to be more concentrated on the surfaces than in the interiors of the moraines. Probably concentration has resulted from removal of surface fines by sheet runoff.

Outwash sediments are conspicuous by the rarity of their occurrence. In some sections, such as that shown in Figure 4, thin layers of gravel and sand probably represent outwash, but in Section V, the longest one, such sediments are very scarce (pl. 4), and in Sections XI (pl. 9) and IX (pl. 7) there are none at all. The small stream that today carries meltwater from the glacier terminus down Valle de la Bocatoma contains very little sediment, and is not depositing outwash. Apparently the hard, non-erodible character of the bedrock is chiefly responsible for the scarcity of outwash.

Where till overlies gentle slopes of bedrock, minute topographic details of the end moraines are preserved. On steep slopes, however, slumping and landsliding have occurred on a large scale. These mass movements have distorted moraines, reduced their initial altitude, or destroyed their constructional form altogether. This fact makes mapping difficult, as all gradations exist between unaltered moraines and clear-cut landslides in which no trace of morainic form remains. On Plate 2 surficial sediments are mapped as drift if they retain any recognizable morainic topography, even though it has been distorted by downslope movement. More thoroughly reworked sediments are mapped as landslides. Much of the drift along the western slope of Valle de Lagunillas, and some drift on the eastern slope as well, has slid downslope, so that the altitudes of its present upper limit are not necessarily the altitudes of the limit at the time of glacial deposition.

LANDSLIDES

The effects of small-scale slumping of the drift are visible in many places. Landsliding on a larger scale has distorted the form and lowered the positions of entire end moraines in the sector of the Valle de Lagunillas that extends northward from the lakes. In four areas sliding has been so effective that the materials moved are mapped as landslides. Three of these are on the east sideslope of the valley, respectively 0.3 km, 1.7 km, and 2.4 km downstream from the mouth of the central stream that drains Valle de la Bocatoma. The fourth is on the west sideslope opposite Laguna Travesada and Laguna Parada. As three of the slides are in contact with glacial drift, the times of their movement or latest movement, relative to the adjacent drift, can be inferred, as is evident from the map. The slide farthest north postdates the drift lying higher than about 3900 m, but antedates the drift lying below that altitude. This slide therefore occurred during an interval between a local deglaciation and a local readvance. The next slide to the south postdates even the drift lying below 3900 m, and is therefore later than its neighbor by one glacial readvance. The slide southwest of Laguna Travesada and Laguna Parada appears to have experienced repeated movement. Some movement antedates the moraines immediately north of

Laguna Travesada. Another movement postdates that drift but antedates the moraines immediately north of Laguna Parada. Still later and more localized movement postdates the latter moraines. Fresh slump scarps at and near the head of this composite slide indicate movement now or very recently active. The contortion of fine sediments beneath the valley floor, described in the following section, is reasonably explained as a result of similar slides.

VALLEY-FLOOR SEDIMENTS

The segment of Valle de Lagunillas that extends through about 1.7 km downstream from the mouth of the central stream that drains Valle de la Bocatoma, and 2.0 km from the outlet of Laguna Pintada, contains distinctive valley-floor sediments. The principal unit consists of a body of compact pale-gray silt, silty clay, sand, and fine pebble gravel, in places containing concretions. Within the sequence are dark organic-rich layers and, at one locality, peat. Lamination is distinctly parallel. The body is at least 12 m thick. Its base is concealed; and its top, wherever exposed, is in some places not the original top of the body, as it is overlain with sharp contact by pebble gravel, till, or boulders. Section VL-V, described in a subsequent part of this paper, was sampled from the fine sediments of this sequence.

The sediment constitutes a dissected low, terracelike erosion remnant, standing above an alluvial valley floor. Along part of its extent it is banked against the valley-facing side of a group of low bouldery ridges, separated by basins, that have the appearance of end moraines but that may consist, in part, of landslide debris. Elsewhere along the sides of Valle de Lagunillas the stratigraphic relations of the body of fine sediment to drift and landslide debris with which it is in contact are not known, because the bouldery character of the debris defies investigation with ordinary field tools.

Through the southernmost 600 m of its known extent the body of fine sediments is overlain by end moraine, till, or boulders. Intervening between the fine sediments and the overlying deposit is a thin zone of pebble gravel, reasonably interpreted as outwash. In exposures within the southern part of their extent the fine sediments are contorted, with axes of small folds roughly paralleling the axis of the valley and suggesting overthrust toward the west. It is unlikely that the contortion resulted from drag by an overriding glacier as it emerged from Valle de la Bocatoma, as in that case the fold axes should form a wide angle with the valley axis. Furthermore, a thin layer of bedded gravel, not contorted, intervenes between the deformed sediments and the overlying boulders. We suggest that the deformation was caused by a landslide similar to those now visible along the valley sides (pl. 2).

North of the small lake at the western margin of the valley floor the body of fine sediment is cut out by the alluvial floor, which there extends from side to side of the valley. Hence the original northward extent of the body remains undetermined. However, down the valley, in the east bank of the river, immediately downstream from a looped end moraine and midway between the mouths of two tributaries, are exposed similar sediments in which layers of silt, clayey silt, and gyttja are conspicuous; the fines are interbedded with boulder gravel. Because the coarse-bouldery texture of the adjacent end moraine made it impossible to expose the contact between till and fines, it was not determined whether the fines lie against or pass beneath the moraine. It seems likely, however, that this body of fines is not a part of the extensive body exposed farther upstream. Although both are primarily fine grained and primarily lacustrine, the organic sediments of the more extensive body are much more compact than those farther north. In both bodies the presence of organic matter and the absence of erratic coarse fragments suggest nonglacial rather than glacial conditions of sedimentation. The inferred lake or lakes could have resulted from damming of the valley by moraines or landslide debris, both of which are present in the critical sector.

In summary, in the absence of stratigraphic evidence adequate to fix definitely the position of the body of lake sediments in the sequence, the body probably post-dates the moraines near its northern end, and certainly antedates the drift that overlies its southern part. If the lacustrine body antedated the moraines near its northern end, it would have had to be glacially overridden throughout its exposed length; but the absence of overlying coarse debris throughout most of that distance makes overriding very unlikely.

SEQUENCE OF DRIFT BODIES

Some notion of sequence can be gained from data on the apparent relative ages of various sedimentary bodies in the area, and from this an attempt can be made to reconstruct events in their proper order. First the drift can be subdivided tentatively into four age groups, here designated I, II, III, and IV. These units of drift are numbered rather than named, because named localities or natural features are too few to permit unambiguous naming of the drifts.

Drift IV, the youngest, is almost white, indicating little if any weathering since deposition. It has almost no cover of vegetation, and it extends eastward to the existing ice cap. These observations indicate that the drift is very recent. On the map area Drift IV occupies the upstream half of Valle de la Bocatoma, forming in it a lobe with a terminus at altitude about 4100 m. Also it includes, immediately north of that valley, the patch of drift occupying a broad dip slope and measuring 900 m in length along the eastern edge of the map area.

In the Valle de la Bocatoma Drift IV includes two conspicuous end moraines, one (moraine no. 3, fig. 6) at the outer limit of that drift, and the other (no. 4, fig. 6) nearly 1 km farther up the valley. Moraine no. 3 is a product of glacial readvance, as is indicated by the sharply defined weathering difference between Drift IV and Drift III, described in the following paragraph. Moraine no. 4 could be the product either of readvance or of a protracted equilibrium state during general recession.

Drift III is pale gray in hue, is only very sparsely covered with vegetation, and in Valle de la Bocatoma is characterized by massive lateral moraines, far larger than others in the map area. It is present in the downstream half of Valle de la Bocatoma, extending past the mouth of that valley, across to the western side of Valle de Lagunillas, and down the axis of that valley through a few hundred meters. It is judged from air photographs that the drift in the basin area along the northeastern edge of the map, including Laguna Seca, is also part of Drift III. The characteristics of Drift III imply that it is older than Drift IV.

Like Drift IV, Drift III is characterized by two conspicuous end moraines, shown in Figure 6. Moraine no. 1 is close to the outer limit of that drift, whereas no. 2 lies about 500 m farther up Valle de la Bocatoma. The physical evidence observed does not indicate whether moraine no. 2 is the product of a readvance or of an episode of stability during glacial recession. In either case the time lapse between the episodes of construction of no. 1 and no. 2 was not great enough to result in a noticeable difference in intensity of weathering between the two moraines.

Drift II has a gray hue that is only very slightly darker than that of Drift III, but the drift is more extensively covered with vegetation, and is expressed topogra-

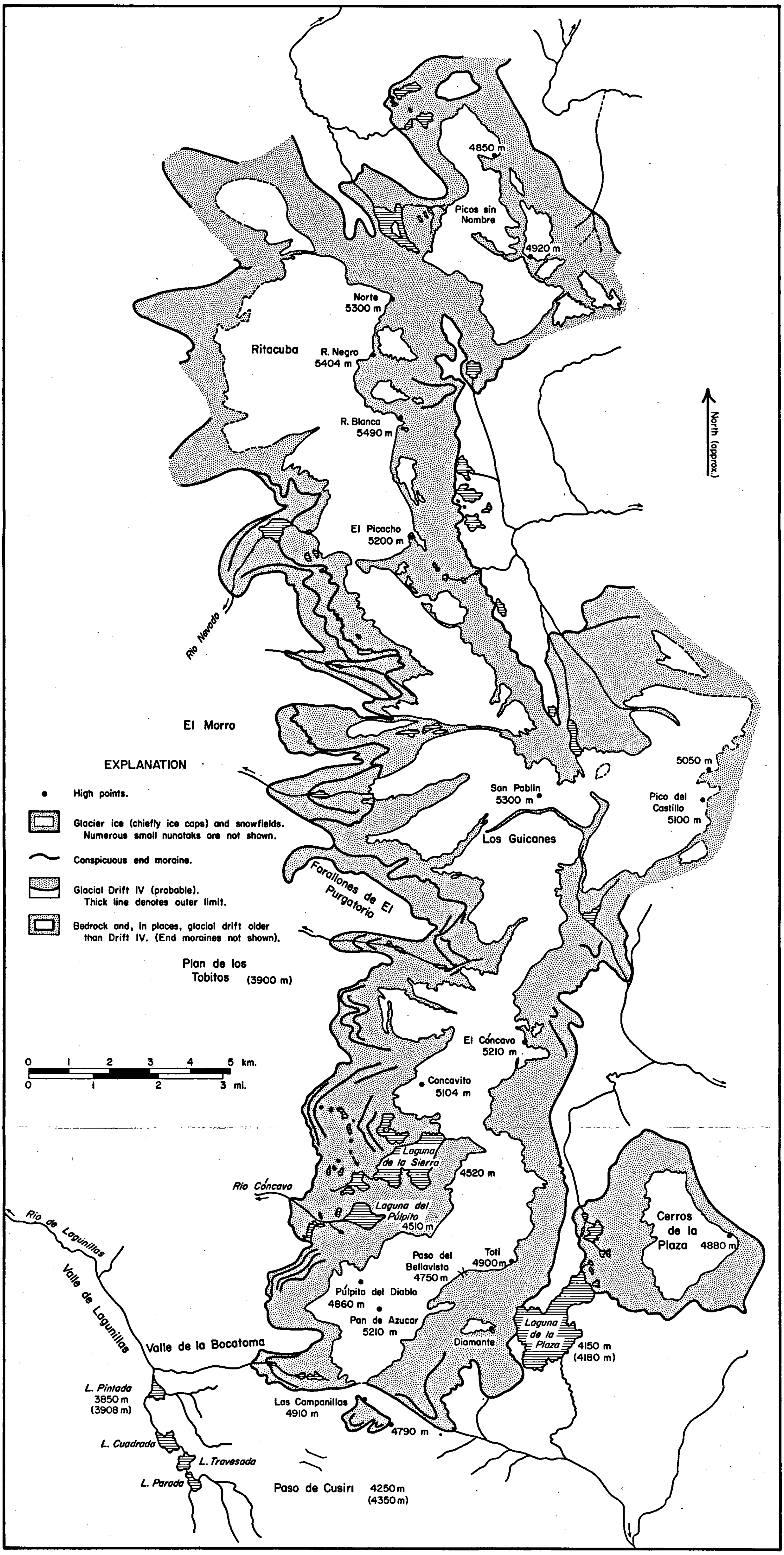

PLATE 1. Photogeologic sketch map of highest part of Sierra Nevada del Cocuy, showing extent of ice caps in 1955, area covered by drift believed to be Drift IV, and conspicuous end moraines. Uncorrected sketch by Anita van der Hammen-Malo, 1960, from photographs by U.S. Air Force. Names and altitudes from Erwin Kraus (unpublished), except altitudes in parentheses, which were measured during the 1959 expedition.

PLATE 2. Reconnaissance map of surficial geology, Valle de Lagunillas. Sketched by R. F. Flint from field observations and aerial photographs January, 1959.
Base prepared from U.S. Air Force aerial photographs by Instituto Geográfico Agustín Codazzi, Bogotá, in collaboration with the Servicio Geológico Nacional, for the International Geophysical Year. Scale, altitudes, and contours are approximate only.

phically in smaller and more numerous end moraines, although they are about as sharp and distinct as those of Drift III. These observations suggest that the age difference between the two drifts is small. Drift II forms a lobe in the area of Lagunas Parada, Travesada, and Cuadrada; the lobe terminates south and southeast of Laguna Pintada. Likewise Drift II forms the low-altitude drift in the northern part of Valle de Lagunillas, that is, the drift at altitudes less than about 4000 m. Its upper limit is uncertain because of discontinuities in its areal distribution and because of landsliding.

Drift I is present in the small area south and southeast of Laguna Pintada, where it can be readily compared with the adjacent terminus of the overlying Drift II. Unlike Drift II it is not a continuous sheet, but consists of isolated end moraines and boulders scattered sparsely over glacially smoothed bedrock. Its moraines are lower and smoother and have fewer surface boulders than the moraines of Drift II. The bedrock surface in the area of Drift I is somewhat roughened by weathering, and the edges and corners formed by joints and stratification planes are slightly rounded. The rock, however, is hardly any darker in hue than that in the area of Drift II. These observations are consistent with the fact that Drift I is overlain by Drift II. It is not known whether the drift on the higher sideslopes in the northern part of Valle de Lagunillas is entirely Drift I or in part Drift II as well, because much of it has been deformed by slumping and very little of the bedrock beneath it is exposed.

The scheme suggested above is very tentative and subject to revision, because it is based on tenuous evidence, consisting chiefly of slight differences in hue of the rocks, vegetation cover, and areal position of drift bodies. Quartzitic sandstone is unpromising material for recording small weathering differences, and the short time available in the field precluded a program of repeated detailed comparisons. As the smallest difference among the drifts tentatively recognized is that between Drifts II and III, it could be argued that these two bodies are correlative. However, consideration of the source and spatial relations of the two drifts does not favor that argument, as shown in the discussion that follows.

The differences among the drift bodies do not afford a basis for evaluating the absolute length of the intervals between glaciations. But the inconspicuousness of the differences suggests that the span of time represented by the entire sequence of drift bodies was not large.

SOURCE AND SPATIAL RELATIONS OF THE DRIFT

The drift lithology, consisting essentially of a single rock type, indicates that the glaciers responsible for all the drift shown on the map originated within the outcrop area of Cretaceous sandstones, an area which in this sector extends eastward across the crest of the Sierra Nevada. The directions of convexity of end moraines show that glacier ice came not only down Valle de la Bocatoma into Valle de Lagunillas, but also from the sharpcrested, hogback-like ridge of bedrock that bounds the latter valley on the east. Although conceivably a thin local sheet-like glacier could have formed on the upper slopes of the ridge itself, the narrow top and steep sideslopes would not have favored the accumulation of much ice. Furthermore there are, on the eastern slope of the ridge, no end moraines such as would be expected if a glacier had been centered on the ridge itself. It is likely, therefore, that the ice entered Valle de Lagunillas not *from* the ridge but *over* it.

If ice entered Valle de Lagunillas over the ridge, it must first have filled the basins between the ridge and the crest of the Sierra Nevada farther east, where the existing ice cap lies. Indeed it is evident from the air photographs that those basins formerly contained ice. When the basins were thus filled the ice in them must have been more than 600m thick in order to overtop the inclosing ridge and flow west into Valle de Lagunillas, although over the heights it could have been relatively thin.

A very moderate expansion of the existing ice cap, with moderate increase in its thickness, would suffice to bring a tongue of ice down Valle de la Bocotoma again. However, a much greater increase in thickness would be needed to get ice into Valle de Lagunillas by overtopping the ridge. The theoretical difference in ice thickness is reflected in the distribution of Drift IV. Although that drift body extends more than half way down the length of Valle de la Bocatoma, it is not present at all in Valle de Lagunillas, whose southern end is at least as close to the ice cap as is the terminus of Drift IV in Valle de la Bocatoma. Evidently, at the recent time when Drift IV was being deposited, the ice cap was too thin to overtop the ridge.

If it were assumed that Drift III is correlative with the lobe of Drift II that terminates north of Laguna Cuadrada, this question would be unanswered: Why did the ice of the latter lobe, so thick that it could overtop the ridge along a wide front and continue northwest for 2.5 km, stop short of the mouth of Valle de la Bocatoma? Or conversely, why did the ice lobe in Valle de la Bocatoma, with no barriers to surmount, not extend far down Valle de Lagunillas instead of terminating near Laguna Pintada? These questions constitute an argument for a time difference between the two drifts. It appears probable that when Drift III was emplaced, the area of the lakes contained no glacier ice at all.

Consideration of the effects of the ridge as a barrier to relatively thin ice leads to the opinion that major thinning of the ice-cap source must have intervened between the time of Drift II and that of Drift III, even though weathering differences and apparent elapsed time were small. In contrast, thinning between the times of Drifts III and IV could have been much less.

The direction of convexity of the higher end moraines along the north-eastern and northern side of Valle de Lagunillas suggests that during the deglaciation in which the moraines were built, very thin lobes of glacier ice were draped along the valley side with sources in the sharp ridge crest to the east. This could have happened while the basin east of the crest was still filled with ice. Similar broad, thin "spillovers" are represented likewise in Drift IV, on air photographs of the region east of the map area.

RECONSTRUCTION OF GLACIAL EVENTS

The foregoing interpretation of the sequence and spatial relations of the drift bodies suggests the following reconstruction of events, listed in chronologic order:

1. Glaciation (Drift I), with ice occupying valleys very nearly throughout the map area. Whether this was an independent glaciation, or a readvance in a later part of a more extensive glaciation, is not known.
2. Deglaciation, at least as far up Valle de Lagunillas as the position of Laguna Cuadrada. Interval of weathering and mass-wasting.
3. Glaciation (Drift II), in which ice, thinner than the ice of Drift I, occupied Valle de la Bocatoma, and Valle de Lagunillas nearly as far north as did the preceding glaciation. The lobe that entered the area of the lakes from over the ridge southeast of them failed to coalesce with the lobe descending Valle de la Bocatoma. Failure of the latter lobe to form a sublobe projecting southward toward Laguna Cuadrada probably resulted from the presence of a very steep, north-facing bedrock slope in the area immediately south of Laguna Pintada.

4. Deglaciation, accompanied by landsliding on the north side of Valle de Lagunillas and in the area west of Lagunas Travesada and Parada. Formation of a lake in the northern half of Valle de Lagunillas.

5. Nonglacial interval, with probably complete deglaciation of the area shown in Plate 2. Lacustrine sedimentation in Valle de Lagunillas; the lake later drained. Local deformation of lake sediments, probably by landsliding.

6. Glaciation (Drift III) by much thinner ice, which partly filled the basin northeast of Valle de la Bocatoma; also a lobe flowed down that valley and abutted against the western side of Valle de Lagunillas. Meltwater from the northern sector of its terminus deposited local thin gravel outwash on the lake sediments. The area of the present lakes remained ice free.

7. Deglaciation of Valle de la Bocatoma to some altitude above 4100 m; including a recessional pause at, or readvance to, moraine no. 2. Slight weathering.

8. Renewed glacial invasion (Drift IV) down Valle de la Bocatoma, about as far as altitude 4100. Expansion of the ice cap down a dip slope on to the map area north of that valley.

9. Deglaciation, including a recessional pause at, or readvance to, moraine no. 4; evacuation of Valle de la Bocatoma up to the position of the existing glacier.

The climatic snowline on the western side of the Sierra Nevada lies today in the neighborhood of 4600 m. There is little information from which to judge its position when the glacier in Valle de Lagunillas stood at the outer limit of Drift I, other than the altitude of the up-valley ends of lateral moraines. On the assumption that those features mark the snowline of that time, the critical altitude would have been a little less than 4100 m, about 500 m below that of today. When glaciers had their greatest recognized extent, reaching down to about 2700 m, the snowline must have been depressed more — perhaps much more — than 1000 m below its present position.

Absolute dates of the bodies of glacial drift were determined by reference to C^{14}-dated organic materials having known stratigraphic relations to the drift bodies. Study of the pollen stratigraphy yielded a record of climatic changes, which was consistent with the sequence derived from the drift.

The foregoing interpretation of the glacial stratigraphy was made in 1959; the paleobotanic interpretation was completed in 1964. The agreement between the two records developed independently, and between them and the C^{14} dates, leads us to have confidence in the validity of our results.

EXISTING VEGETATION AND CLIMATE

Andean Forest

Four successive vegetation belts exist in the Sierra (fig.2). On the western flank the upper limit of forest today lies at approximately 3,300 m.; on the eastern flank (Cuatrecasas, 1934) it lies as high as 4,000 m., probably because precipitation is greater on the eastern flank. Abnormally high patches noted by us in the Valle de Lagunillas, on the drier western flank, at 4,000 m., probably owe their presence to local factors such as protection from the wind. Before human influence the tree limit probably stood higher, because patches of forest are present at much higher altitudes. We conclude that the maximum potential forest limit, under optimal conditions of

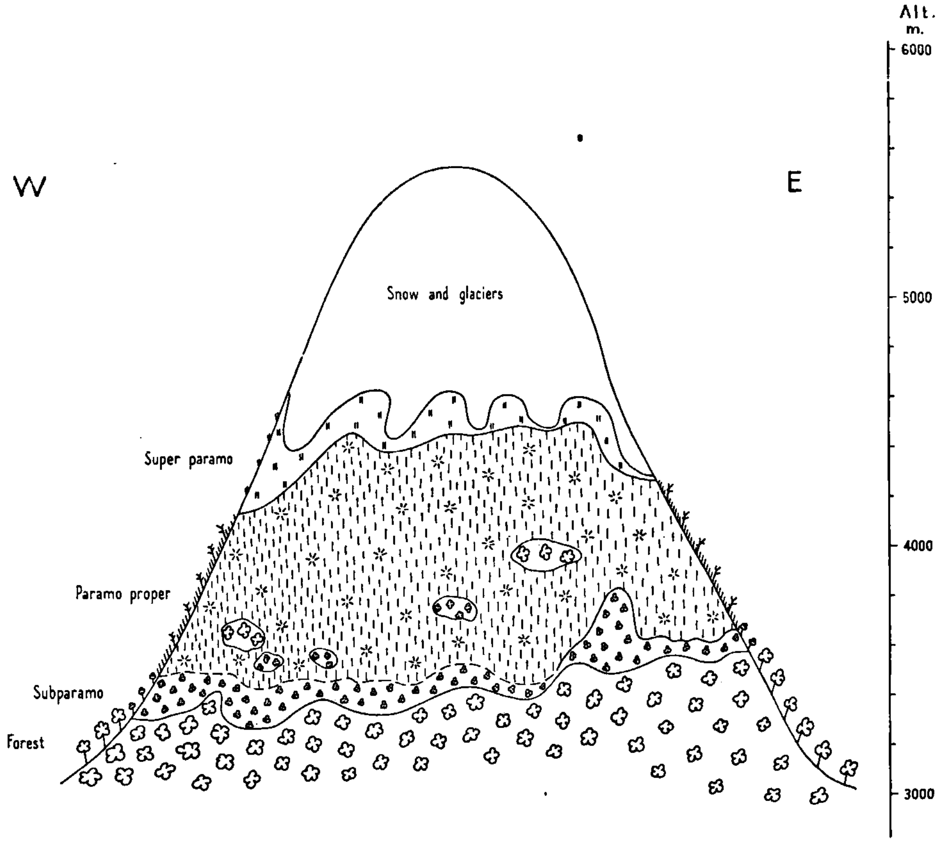

Fig. 2. Idealized profile across Sierra Nevada del Cocuy, showing approximate present positions of vegetation zones.

cloudiness, humidity and wind protection, lies at 4,000 m., but that so high an altitude is reached only rarely. Normally the "tree limit" lies between 3,300 m and 3,600 m.

In the higher patches of forest we recognize an assemblage dominated by *Polylepis*. At 3,300 m we noted the following species: *Polylepis* (Rosaceae), *Weinmannia* (Cunoniaceae), *Gynoxys* (Compositae), *Escallonia* (Escalloniaceae), *Hesperomeles* (Rosaceae), and *Acaena* (2 spp). According to Cuatrecasas (1958), at 4,000 m on the western slope patches of dense forest occur, with dominance of *Polylepis*, and in addition *Escallonia*, *Rapanea* (Myrsinaceae), *Weinmannia*, *Miconia* (Melastomataceae), and *Gynoxys*.

Subpáramo

Extending upward from the Andean forest is a belt of irregular width called the subpáramo. It is the transition zone between the Andean forest and the páramo proper, and hence includes both scattered trees and páramo elements. Cuatrecasas (1958) listed the following genera in the shrubby vegetation of the subpáramo:

Hypericum (Hypericaceae)	*Desfontainia* (Desfontainiaceae)
Aragoa (Scrophulariaceae)	*Gaultheria* (Ericaceae)
Arcytophyllum (Rubiaceae)	*Rubus* (Rosaceae)
Baccharis (Compositae)	*Ternstroemia* (Theaceae)
Senecio (Compositae)	*Monnina* (Polygalaceae)
Diplostephium (Compositae)	*Miconia* (Melastomataceae)
Loricaria (Compositae)	*Monochaetum* (Melastomataceae)
Gynoxys (Compositae)	*Cavendishia* (Vacciniaceae)
Stevia (Compositae)	*Plutarchia* (Vacciniaceae)
Eupatorium (Compositae)	*Pernettya* (Vacciniaceae)
Ilex (Aquifoliaceae)	*Gaylussacia* (Vacciniaceae)
Brachyotum (Melastomataceae)	*Befaria* (Ericaceae)
Purpurella (Melastomataceae)	*Symplocos* (Symplocaceae)
Macleania (Vacciniaceae)	*Syphocampylus* (Lobeliaceae)
Vaccinium (Vacciniaceae)	*Berberis* (Berberidiaceae)
Disterigma (Vacciniaceae)	*Rapanea* (Myrsinaceae)

Scattered among the shrubs, he found trees of the following genera:

Miconia (Melastomataceae)	*Escallonia* (Escalloniaceae)
Purpurella (Melastomataceae)	*Weinmannia* (Cunoniaceae)
Senecio (Compositae)	*Polylepis* (Rosaceae)
Diplostephium (Compositae)	*Hesperomeles* (Rosaceae)
Gynoxys (Compositae)	*Befaria* (Ericaceae)

Páramo

Above the subpáramo lies the páramo proper, reaching up to about 4,500 m in the Sierra Nevada del Cocuy. It consists of meadows, with *Espeletia* as the most characteristic plant. In this belt Cuatrecasas (1958) included meadows of Gramineae (*Calamagrostis* and *Festuca*) and the Caulirrosuletum (with *Espeletia* spp.). In sheltered places there are patches of subpáramo shrub composed of the following elements (Cuatrecasas, 1958):

Diplostephium	*Valeriana arborea*	*Gynoxys*
Miconia	*Senecio*	*Polylepis*

The same author listed the following genera in the páramo proper:

Hypericum	*Lycopodium*	*Erigeron*	*Plantago*
Pernettya	*Lupinus*	*Sisyringium*	*Ranunculus*
Senecio	*Vaccinium*	*Gentiana*	*Bartschia*
Bomarea	*Loricaria*	*Lysipomia*	*Lucillia*
Draba	*Werneria*	*Gaultheria*	*Castilleja*
Geranium	*Halenia*	*Aster*	*Jamesonia*

An additional páramo plant found in our area, is *Distichia tolimensis*, forming strong carpets on very damp soil or even floating on lake water.

Superpáramo

Lying between the páramo and the snowline is the superpáramo belt, in a landscape of bare bedrock, moraines, and stony ground. Vegetation is very sparse and irregular, and does not include the *Espeletias*. Within this belt the most characteristic species belong to the genera *Senecio* (many species), *Cerastium*, *Draba*, *Agrostis*, *Bromus*, *Poa* and *Luzula* (Cuatrecasas, 1958). In our area vegetation of this type, although generally confined to altitudes above 4,500 m, occurs as low as 4,100 m on young moraines. In the area of Laguna de la Plaza at 4,350 m, we made the following list of genera growing at the transition zone between páramo and superpáramo:

Gentiana	*Plantago*	*Carex*	*Halenia*
Paepalanthus	*Bartschia*	*Cerastium*	*Ranunculus*
Rhizocephalum	*Werneria*	*Lachemilla*	*Lupinus*
Azorella	*Jamesonia*	*Elaphoglossum*	*Loricaria*
Senecio	*Luzula*	*Espeletia*	*Draba*
Agrostis			

BORINGS, SECTIONS, AND RADIOCARBON DATES

Continuous sampling (mostly by core boring) of sediments containing organic matter was done at the seven localities numbered III to XI in Figure 3.

Stratigraphic sections, pollen profiles, and C^{14} dates from samples are grouped into three geographical areas and are set forth below. All C^{14} dates were measured by

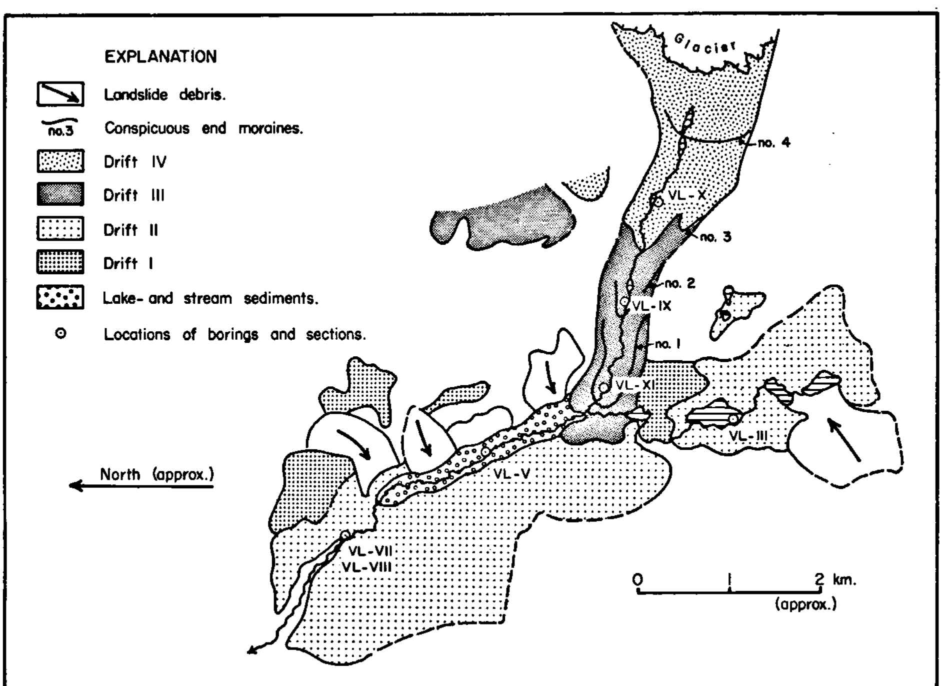

Fig. 3. Sketch map showing locations of core borings.

Dr. J. C. Vogel in the Groningen C^{14} Laboratory, with the financial support of the Netherlands Foundation for Pure Scientific Research (Z.W.O.). Material suitable for dating was found only in section V and in the small basin represented by sections VII and VIII.

Northern part of Valle de Lagunillas

VL–VII and *VL–VIII* (pls. 5, 6): Two cores taken at ca. 3,880 m in a small dissected basin lying between two of the end moraines of Drift II.

The section cored consists of thin layers of clay and sand, alternating with layers of peat and gravel (fig. 4; pls. 5, 6).

VL–VII (pl. 5): Depth 135 cm; 11 samples were analyzed; VL–VIII (pl. 6): Depth 170 cm; 17 samples were analyzed.

Two samples were taken for radiocarbon dates:

Core VL–VIII, sample Col 56, lab. no. GrN–3504.

Peat from depth 112 to 125 cm .... 6,510 $\pm$ 85 B.P.

Core VL–VIII, sample Col 57, lab. no. GrN–3112.

Peat from depth 150 to 155 cm .... 9,830 $\pm$ 90 B.P.

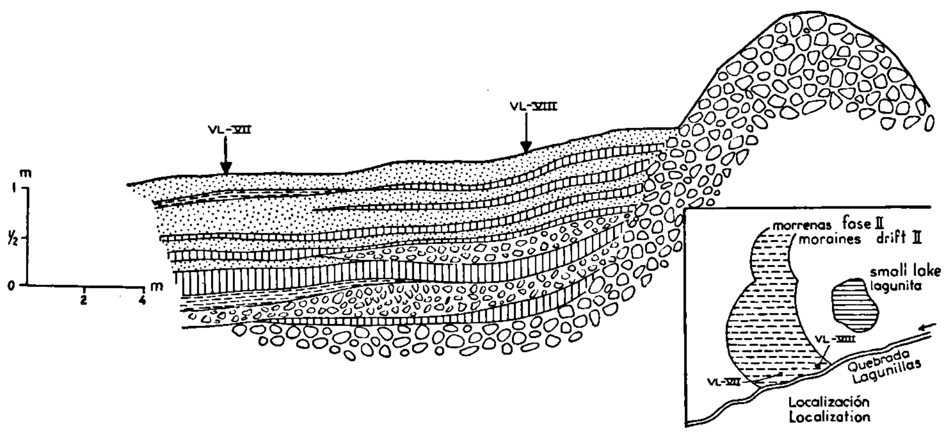

Fig. 4. Index map and section of locality of borings VL—VII and VL—VIII.

VL–V (pl. 4, fig. 5). Samples from an exposed sequence, 806 cm long, from the deformed lake sediments north of the western limit of Drift III (fig. 5), at alt. 3880 m. Between depths 0 and 200 cm the material consists of sand and pebbles alternating with layers of clay and peat. Between 200 and 392 cm it is peat with thin layers of sand and clay. Between 392 and 620 cm it is clay with intercalations of peat. Between 620 and 806 cm it is rhythmically layered sand and clay, probably varves. In all, 69 samples were analyzed.

Nine samples were taken for C^{14} dating, of which 7 were measured as follows:

VL–V, sample Col 53, lab. no. GrN–3598.

Peat from depth 198 to 206 cm .... 8,190 $\pm$ 100 B.P.

Idem (same sample) .... GrN–4003. 8,200 $\pm$ 100 B.P.

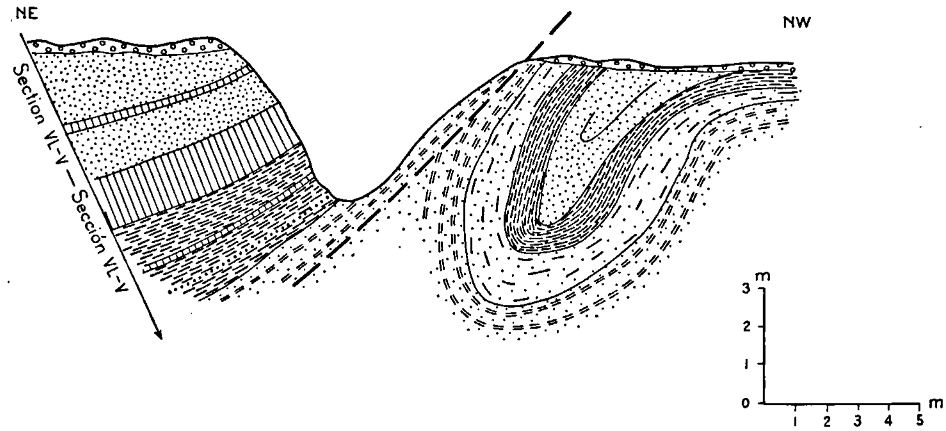

Fig. 5. Schematic cross section of sediments exposed along Rio de Lagunillas near site of Section VL—V.

VL–V, sample Col 52, lab. no. GrN–4141.
Peat from depth 232 to 252 cm .... 10,030 ± 90 B.P.
VL–V, sample Col 51, lab. no. GrN–4140.
Peat from depth 275 to 300 cm .... 10,400 ± 120 B.P.
VL–V, sample Col 50, lab. no. GrN–4083.
Peat from depth 326 to 350 cm .... 11,350 ± 140 B.P.
VL–V, sample Col 49, lab. no. GrN–4036.
Peat from depth 372 to 378 cm .... 11,900 ± 120 B.P.
VL–V, sample Col 48, lab. no. GrN–4002.
Peat from depth 472 to 486 cm .... 12,140 ± 120 B.P.
VL–V, sample Col 47, lab. no. GrN–4037.
Pieces of wood from depth 547 to 564 cm .... 12,310 ± 160 B.P.
VL–V, sample Col 46, lab. no. GrN–3247.
Peat from depth 626 to 631 cm .... 12,320 ± 100 B.P.

Valle de la Bocatoma

Two cores were taken and one exposed section was sampled (figs. 3,6).
VL–IX (pl. 7). Core, 350 cm long, taken from a swamp of *Distichia tolimensis*, at 4,050 m behind moraines in the lower part of the valley. The deposits consist of layers of clay with intercalations of sand. For the pollen diagram 14 samples were used.

VL–X (pl. 8). Core, 65 cm long, from a lakelet behind a moraine in Drift IV, at 4,220 m. The deposits consist of clay and sand. For the pollen diagram 4 samples were used.

VL–XI (pl. 9). Samples from a section 300 cm long, exposed near the main stream, downstream from site VL–IX at about 3,990 m altitude. The deposits consist of thin layers of clay and sand, rhythmically laminated in the lower part. For the diagram 9 samples were used.

Southern part of Valle de Lagunillas

VL–III (pl. 3). Core from beneath Laguna Cuadrada, altitude 4,000 m. The upper part of the section, 120 cm long, could not be sampled, as it consisted of a carpet of *Sphagnum*, 40 cm thick, floating on 80 cm of water. The rest of the sediments consist of clay with fine sand. For the pollen diagram 28 samples were analyzed.

DISCUSSION OF THE INTERPRETATION OF THE DIAGRAMS

In the construction and interpretation of the diagrams the same methods and principles were followed as those used for the Quaternary pollen analytical work done earlier in Colombia, (van der Hammen and Gonzalez, 1960a; 1960b). In most cases 150 to 200 grains, of the types included in the pollen sum, were counted per sample. These types are:

Gramineae	*Hedyosmum*	*Weinmannia*	*Miconia*
Acaena	*Myrica*	*Rapanea*	Urticaceae
Alnus	*Styloceras*	*Symplocos*	*Vallea*
Podocarpus	*Bocconia*	*Drymis*	*Dodonaea*
Quercus	*Juglans*	*Ilex*	

The percentage of other plants was calculated on the basis of the sum already mentioned. The width of the diagram represents 100 percent of the species included in the pollen sum. On the left are the trees (*Quercus*, *Alnus*, *Podocarpus* and the total of other forest elements)and on the right the elements of open vegetation (Gramineae, *Acaena*). Some diagrams show excessively high percentages of Gramineae, due to generally local factors, (as in the case of samples from peat bogs). As this makes interpretation difficult, the zoning was achieved principally on the basis of the curves of various elements not included in the pollen sum, rather than on the basis of the diagram as a whole.

The results of our earlier investigations on Quaternary palynology in Colombia were of course most useful for the present study. The zoning given here for the Holocene is tentative in some diagrams. Due to many local factors such as those observed in Diagrams VL–V, VL–VII and VL–VIII, in which Gramineae are completely dominant because of local influences, such zoning is difficult, and interpretation can only be achieved on the basis of the fluctuations in the rest of the curves in relation to the other diagrams. This difficulty does not apply to the diagrams worked out on the basis of samples of lake sediments, and in this report we have based the zoning for the the Holocene principally on these. The Late-Glacial presents no great difficulties, except perhaps with Diagram VL–XI, which shows in its lower part sediments very poor in pollen.

In several of the diagrams of the higher sites, and in the lower (Late-Glacial) parts of the others, the samples were so poor in pollen that, even after counting several slides, it was impossible to reach a statistically desirable minimum number of grains. We have, nevertheless, put these spectra into the diagrams because in general they fitted very well into the trends of the main general diagram.

The number of grains included in the pollen sum is always mentioned with each spectrum; this makes it possible to evaluate each of these spectra in the diagrams. For a correct interpretation of the pollen diagrams, some knowledge of the present local pollen rain is of course most important. The only knowledge we have,

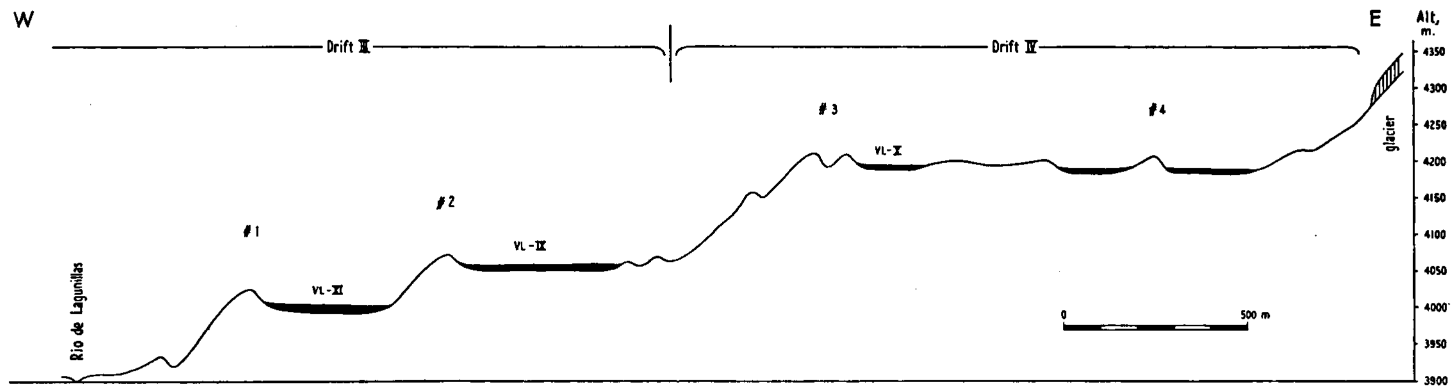

Fig. 6. Long profile of Valle de la Bocatoma, showing locations of four end moraines, three analyzed sections (IX, X, XI), and terminus of glacier in 1959.

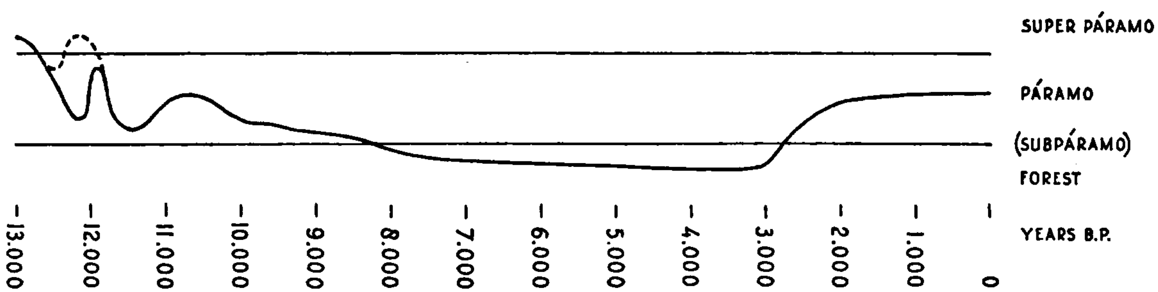

Fig. 7. Estimated displacement of vegetation zones through the last 13,000 years at altitude about 3900 m in Valle de Lagunillas.

has been derived from the uppermost spectra of the sediments of existing lakes. In the páramo-zone proper, we have the uppermost spectra of Diagram VL–III (alt. 4000 m), which shows a proportion of about 75 percent grass pollen to 25 percent tree pollen. This seems to be quite normal in comparison with data from other páramos (van der Hammen & Gonzalez, 1960 a, b; van der Hammen 1960, 1962), where the usual relation was 50 percent grass pollen to 50 percent tree pollen at sites 250 m above the upper limit of the forest.

Generally speaking we may say that within the páramo belt the percentage of grass pollen increases and the percentage of tree pollen decreases, upward beyond the upper limit of the forest. This tendency apparently no longer holds for the superpáramo belt, including areas with very sparse vegetation, on the youngest moraines. We are forced to this conclusion by the uppermost spectra of Diagram X, from a site at 4220 m within the area of Drift IV, which is almost devoid of vegetation. In these spectra, the percentage of tree pollen (from lower altitudes) is as high as 75 percent, and the grass pollen as low as 25 percent, whereas pollen density is very low.

This phenomenon, known also from other high mountain areas, such as the Alps, may be explained in the following way. In the regions above the upper forest limit the pollen rain contains a "background" of blown up or air-lifted tree pollen from lower levels. The absolute quantity of this pollen decreases with the altitude. In the pollen spectra the percentage of this tree pollen is diminished by the great quantity of locally produced herb pollen. But when the local herb-vegetation is lacking, at greater altitudes and on very young moraines, and the local herb pollen production is very low, the "background" of tree pollen dominates in the pollen rain, and the pollen spectra show a high tree pollen percentage combined with low pollen densities. Similar spectra are found in the lowermost part of Diagram VL–V and Diagram VL–III, representing the earlier Late-Glacial. It will be clear that these parts of the diagrams reflect the most unfavourable climatic conditions and that a successive rise of the Gramineae pollen percentage indicates an amelioration of the climate. Hence the interpretation of the Late-Glacial diagrams from altitudes around 4000 m is complicated, as for instance a rise of the Gramineae curve may have been caused by either an amelioration or a deterioration of climate.

It is clear then that for the Holocene our interpretation of the diagrams is "normal" (because we know the vegetation belts were formerly much higher than now), with the exception of the diagram for the highest site (VL–X). The interpretation given above is illustrated by Figure 7, a curve showing fluctuations of the vegetation belts at an altitude of 3900 m, based on Diagrams VL–III and VL–V. Because of the difficulties mentioned above, two slightly different interpretations are possible for the time prior to 11,800 B.P. Before about 11,800 B.P. resp. 12,300, fluctuation was between superpáramo and páramo; after that time it was between páramo and forest. The two interpretations are indicated by the continuous and the broken lines in fig. 7.

ZONING AND CORRELATION OF THE DIAGRAMS

General remarks

In this paper the pollen-stratigraphic zones and zone numbers (I to VIII) are the same as those already established for the Late-Glacial and Holocene of the Cordillera Oriental (van der Hammen and Gonzalez, 1960b). Difficulties were encountered because our localities lie between the very high altitudes of 3900 and 4200 m. The area has a poor vegetation cover, the number of pollen grains in many of the samples is very low, and in the spectra from very high localities the percentage of tree pollen blown up complicates the picture. In the peat deposits there is also the problem of overrepresentation of local pollen (Gramineae, etc.). Because of these difficulties, determination of zone boundaries is not in all cases precise. Nevertheless we think our interpretation has a good degree of probability.

Table 1 shows the local zones into which we have classified the pollen sequence. The depths at which the zone boundaries occur in each section analyzed are also shown.

Correlation of the Cocuy diagrams with those from the Bogotá area was accomplished principally by comparison of the main diagrams and separate curves from Laguna de la América (Páramo de Palacio; van der Hammen and Gonzalez, 1960b) with Diagram VL–III from Laguna Quadrada in Valle de Lagunillas. The latter diagram then became the main reference diagram for the other diagrams of the Cocuy area; the principal reference diagram for Zone I is of course our well-dated Diagram VI–V.

Zone I

Zone I is especially well developed in the diagram of section VL–V. That diagram makes possible a clear subdivision of Zone I into three subzones (Ia, Ib, Ic). As mentioned earlier, Zone I shows partly reversal of the visual diagram picture as related to climate: during Zone-I time the changes of vegetation that occurred in our area apparently involved only the open páramo belt and the superpáramo, where the pollen rain is greatly influenced by the airlift of pollen grains from anemophilous trees of the Andean forest belt below.

Zone I is characterized, at 4000 m or lower, by high percentages of *Acaena* (at higher altitudes high percentages of *Acaena* may be present also in younger zones). Zone Ia shows superpáramo conditions, Zone Ib and Ic páramo conditions. The second part of zone Ib could eventually be interpreted as representing superparámo conditions, but this seems less probable to us. The two possibilities of interpretation are shown in fig. 7. It is not easy to establish exactly the upper limit of Zone I in Diagram VL–V. This is due to the fact that sedimentation was rapid, so that the diagram is much longer than normal. (Similar conditions are shown, for Zone I, in the very long section of Gulickshof, Netherlands; van der Hammen, 1951). The boundary between I and II should be placed somewhere between 390 and 365 cm. Comparison of the various curves with those of the diagram from Páramo de Palacio (Compositae, *Acaena*, *Alnus*, "*Valeriana*" *stenophylla*, etc.) strongly suggests that it may be at 365 cm. We know from other diagrams (Páramo de Palacio etc.) that amelioration of climate was considerable in I/II time(compare also the complete deglaciation inferred from physical evidence, p. 167, item 5). In Diagram VL–V the position of boundary I/II is visually obscured, because lake sediments were replaced by peat, formed from a vegetation with abundant local production of Gramineae pollen that soon reached values of nearly 100 percent. From the C^{14} dates it is clear that Subzone Ib corresponds with the Bölling Interstadial and Subzone Ic with the Earlier Dryas Zone in Europe. Zone I as a whole corresponds then to the Older Dryas of Europe.

In Diagram VL–III the picture is much less clear, because of the small pollen content of the samples and the relatively long stratigraphic distance between them. Nevertheless, by comparison of the curves, it is possible to recognize Zone I as a whole, and probably also Subzones Ia, Ib, and Ic.

Zone II

The interval 540 to 460 cm in diagram VL–III can be correlated, on the basis of the various curves, with the interval 326 to 365 (–390?) cm in Diagram VL–V. The two intervals correlate in the same way with Zone II of the Páramo de Palacio sequence (van der Hammen and Gonzalez, 1960a). There is a relative minimum in the Compositae curve (and a high top of Compositae just before or at the base of the zone), a rise of the *Isoetes* curve at the beginning, and a rise of the curves of *Hedyosmum* and Urticaceae.

Typical for the Cocuy area is apparently a decline of the *Podocarpus* curve at the boundary between Zones II and III; the same may prove to be the case for the rise of the Caryophyllaceae curve at that boundary.

The C^{14} dates from Zone II (VL–V), combined with calculations based on rate of sedimentation, show that that zone should correspond in age with the Alleröd interstadial in Europe. We arrived at the same conclusion for Zone II in Páramo de Palacio (van der Hammen and Gonzalez, 1961b), where, also, the vegetation changes closely parallel those in Europe.

Zone III

The interval 460 to 425 cm in Diagram VL–III corresponds approximately to the interval 326 to 258 cm in Diagram VL–V, and with Zone III from Páramo de Palacio. The general picture of the main diagram (VL–III) is not so clear as in the diagram from Páramo de Palacio, but several curves show very good correspondence. At the upper limit of the zone the *Hedyosmum* curve decreases, and there is a maximum of the Urticaceae curve. In the Cocuy area this upper limit also marks the beginning of the continuous *Plantago* curve, and a considerable rise of the Cyperaceae curve. There is also a marked isolated maximum of Cyperaceae in the middle of Zone III. There is little doubt that the lowermost part of Diagram VL–XI corresponds with the end of Zone III. One C^{14} date in the middle of this zone (from section VL–V) confirms the correspondence of Zone III with the Younger Dryas unit of the European sequence. A similar correspondence was suggested for the diagram from Páramo de Palacio (van der Hammen and Gonzalez, 1961b).

Zone IV

The interval 425 to 390 (–370) cm in Diagram VL–III corresponds with the interval 258 (–267) to 222 cm in VL–V. It seems also to correspond with the interval 155 to about 140 cm in VL–VIII. Near the top there is a maximum of *Plantago*, followed by a rise of Umbelliferae and *Lycopodium*. There is also a small minimum of *Alnus*. Although it is not possible to correlate directly with the diagram from Páramo de Palacio, it is probable that the interval corresponds with Zone IV in that diagram. The C^{14} dates from 232–252 cm in Section VL–V and from 150–155 cm in Section VL–VIII seem to confirm this opinion. The uppermost 110 cm of the diagram for VL–XI correspond probably to Zone IV. This interpretation of the diagram is confirmed by the relatively high *Hedyosmum* percentage, a rising curve of the Compositae, and tops of the curves of several spores (compare *Jamesonia* and Monolete psil. in VL–V).

Zones V and VI

The interval 390 (–370) to 300 cm in Section VL–III, and the corresponding intervals in the other diagrams (tab. 1), are characterized at the top by decline of the Urticaceae and rise of *Hedyosmum*. The top of the interval, therefore, corresponds with the boundary between Zones VI and VII in the diagram of Páramo de Palacio. Accordingly it is likely that the interval as a whole corresponds with Zones V and VI. One can not indicate with certainty the boundary between the two zones in the Cocuy diagrams. The boundary could be represented by the local rise of *Lycopodium* in the middle of our interval. At the boundary VI/VII there is also locally a minimum of Compositae, a maximum of *Lycopodium* and of several types of Trilete spores, and a rise of Cyperaceae.

Within the interval there are two C^{14} dates, which confirm its interpretation as including Zones V and VI. They are, respectively, sample Col. 56 (GrN–3504) from Section VL–VIII, and sample Col. 53 (GrN–3598 and GrN–4003) from Section VL–V. The lowermost part of Diagram VL–IX (330 to 270 cm) also belongs to the upper part of the interval that includes Zones V and VI.

	Colombian pollen zones	VI-V	VI-III	VI-XI	VI-IX	VI-VIII	VI-VII	VI-X	European Units (probable correlation and time (yr B.P.))	
	Altitude (Meters):	3890	4000	3990	4050	3890	3890	4220		
HOLOCENE			120		80					
	VIII							—60—	Subatlantic	
		00	210		170	28?	ca 25			2800
	VII								Subboreal	
		103-130	300		270 (240)	ca 100	(ca 75?)			5000
	VI								Atlantic	
			360 (320?)		330 ?	125?	ca 125			7500
	V								Boreal	
		222	390 (370)	030 ?		ca 140				9000-9500
	IV								Preboreal	
		258 - 267	425 (-415)	ca 110 -300-		155				10100
LATE-GLACIAL	III								Younger Dryas	
		326	460							10900
	II								Allerød interstadial	
		365	540							11900
	I c								Earlier Dryas	
		440								12300
	I b								Bølling interstadial	
		650	650							
	I a	740							(Earliest Dryas)	

Table 1. Stratigraphic interpretation of the pollen diagrams from Valle de Lagunillas and correlation of the diagrams with pollen zones established from elsewhere in the Cordillera Oriental and with European units.
Depths of zone boundaries are shown in centimeters. Hiatuses in the uppermost parts of the stratigraphic sections are indicated by vertical hatching.

Zones VII and VIII

The rise of Gramineae around 210 cm in Diagram VL–III corresponds very well with the boundary between Zones VII and VIII in the diagram of Páramo de Palacio. Two other features seem to be important, partly for local and partly for regional correlation: (a) A maximum of Compositae in Zone VII, low percentages of Gramineae and a peak of *Alnus* in its lower part, and a maximum of *Plantago* in the middle. (b) A decrease of Cyperaceae and Compositae and locally an increase of *Isoetes* at the base of Zone VIII.

There is no doubt that the main part of Diagram VL–IX belongs to Zone VII (270 to 170 cm) and Zone VIII (170 to 80 cm).

DATES AND CORRELATION OF THE BODIES OF GLACIAL DRIFT

In the Cocuy area only the pollen sequence has stratigraphic continuity. Therefore the stratigraphic positions and approximate dates of the bodies of glacial drift, and

Yr. B.P. x1000			Pollen zones Europe	Pollen zones Colombia	Glacial-drift bodies	Moraines	Possible correlation
2	Holocene	Hypsithermal	Subatlantic	VIII	Drift IV	Moraine no. 4 Moraine no. 3	(Late) Neoglaciation (Early)
4	Holocene	Hypsithermal	Subboreal	VII	Drift III		
6	Holocene	Hypsithermal	Atlantic	VI	Drift III		
8	Holocene	Hypsithermal	Boreal	V	Drift III	Moraine no. 2	
	Holocene		Preboreal	IV	Drift III		
10	Holocene	Late Glacial	Younger Dryas	III	Drift III	Moraine no. 1	Valders
	Pleistocene	Late Glacial	Allerød	II	Drift II		
12	Pleistocene	Late Glacial	Earlier Dryas	Ic	Drift II		
	Pleistocene	Late Glacial	Bølling	Ib	Drift II		
	Pleistocene	Late Glacial	Earliest Dryas	Ia	Drift II		Mankato
14	Pleistocene	Pleniglacial			Drift I		Glaciation of pre-Mankato Wisconsin Age

Table 2. Correlation of drift bodies on Sierra Nevada del Cocuy with glacial maxima in North America and with pollen zones in Europe.

certain end moraines, are known only in relation to the dated pollen sequence. With the proposed interpretations of the pollen diagrams and with the C^{14} dates, it is possible to approximate the ages of the drift bodies and of some end moraines, and to correlate the related glaciations with North American or European glaciations (tab. 2). There is striking climatic similarity and contemporaneity between the Late-Glacial succession in the Cocuy area and that of Europe. The contemporaneity of the Bölling Interstadial and the Earlier Dryas unit with our Subzones Ib and Ic seems, for instance, to be proved by Diagram VL–V and by the series of C^{14} dates.

Sections III and V both start around the transition of Subzone Ia into Subzone Ib (tab. 1). The base of Section III directly overlies glacial boulders, and the base of Section V consists of sandy "varves", which become coarser downward. These facts make it probable that sedimentation in the two lakes represented by these sections started immediately after retreat of the glacier that deposited Drift II. The date of retreat was shortly before 12,320 $\pm$ 100 B.P. (GrN–3247). Hence we conclude that Drift II was formed shortly before the Bölling Interstadial in the narrow sense — that is, during Earliest Dryas time. Drift II seems to correspond in age with the Mankato Drift in the United States, the data of the maximum of which is believed to be around 12,500 to 13,000 B.P.

Sections XI and IX immediately overlie Drift III. Section XI, situated upstream from end moraine no. 1 (fig. 3), starts apparently at the very end of Zone III with "varves", whereas the upper part of the section corresponds to Zone IV. These facts strongly suggest that the glacier responsible for building end moraine no. 1, a part of Drift III, retired from the downstream part of Valle de la Bocatoma at the end of Younger Dryas time, close to the beginning of the Holocene. Hence probably at least the outer part of Drift III was deposited during Younger Dryas time, and if so it probably corresponds to the Valders Drift in central United States.

Section IX, situated immediately upstream from end moraine no. 2 (fig. 3), has its base somewhere below the boundary between Pollen Zones VI and VII, most likely near the base of Zone VI. Therefore, using the dates in Table 1, we can assign end moraine no. 2, somewhat older than the base of the section, a minimum date of around 7500 years B.P. That minimum date would not bar correlation of the moraine with the Cochrane readvance (8000 years B.P. or older, presumably a Boreal event) in the eastern part of North America, and its correlatives, with various local names, in the North American Cordillera. But it does not exclude other possibilities, such as the Larstig moraine in the Alps (Mayr, 1964). There is not enough evidence to enable us to correlate moraine no. 2 with any feature elsewehere.

The locality of Section X is about 1500 meters downstream from the 1959 position of the glacier terminus. The section, only 65 cm thick, directly overlies Drift IV, and probably began to accumulate soon after deglaciation had uncovered the locality. We can reasonably compare its thickness with the thicknesses of the other sections, especially VL–IX, the nearest one. In the latter section, as also in Sections VL–III and the one at Páramo de Palacio, the thickness of the sediments within Pollen Zone VIII is 90 cm. We know that the sedimentation of Zone VIII began about 2800 years ago (tab. 1; van der Hammen & Gonzalez, 1960b, 1962). Ninety centimeters of sediment deposited in 2800 years implies an average rate of accumulation of 1 cm/31 yr. If we reasonably assume a similar rate for Section VL–X, the age of the base of that section would be 2015 years. On this basis one can infer that Drift IV as a whole correlates with part or all of the drift of the (post-Hypsithermal) Neoglaciation in Cordilleran North America. One could suggest, further, that end moraine no. 3 (fig. 3) might correspond to the glacier maxima dated in the Alps as 900 to 300 BC (Mayr, 1964). End moraine no. 4 might then correlate with the widely recognized maximum dated at about 150 to about 300 B.P. These suggestions as to possible correlation of moraines 3 and 4 are no more than reasonable guesses, controlled only within wide limits. The suggested correlations of Drifts II and III are more closely controlled and seem to us to be very probable.

Although the sequence of climatic changes indicated both by the pollen record and by the glacial drifts agrees very well with the northern European sequence, nothing in our area, not even end moraine no. 2, clearly matches the Cochrane Glaciation. A Cochrane correlative could be buried beneath Drift IV, as is possible also at localities in Alaska (Heusser and Marcus, 1964, p. 77; fig. 1) and Yukon Territory (George Denton, oral communication, 1965).

On the other hand the pollen diagram of Zone V reveals no evidence of climatic cooling, as is likewise the case with Zone V in the published diagrams from other localities in Colombia and from Europe. The absence of indications of cooling is remarkable in view of geologic evidence of the Cochrane glacial readvance in North America, an event whose C^{14} dates imply correlation with the Boreal.

End moraines in the Valle de Lagunillas are so abundant and so well defined that those pertaining to Drift II were compared with the end moraines pertaining to the Mankato Drift in southeastern South Dakota (Flint, 1955, p.l 1; fig. 31). In general pattern the two series are similar, consisting of lobate end moraines having conspicuous lateral elements, each with several subsidiary terminal elements. In the absence of close control by C^{14} dates, however, it was not found possible to make more detailed comparison than that between Drift II as a whole and the Mankato Drift as a whole.

The dates of the drift bodies imply that rates of weathering and rates of development of a vegetation cover have been very slow since the area began to be deglaciated. In the 12,000 years since the Drift II glaciation and even in the 18,000 years, more or less, since Drift I time (if Drift I is assumed to be equivalent to the classical Wisconsin maximum in North America), very little weathering has occurred and vegetation has formed only a very discontinuous ground cover.

However, these slow rates of development have been influenced strongly by (1) prevailing low temperatures and (2) relative stability, both physical and chemical, of quartz, the nearly unique constituent of the bedrock and the drift. In consequence these rates can not properly be compared with those in other areas in which the relevant conditions have been different.

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