LATE QUATERNARY GEOLOGY, STRATIGRAPHY, AND PALAEOECOLOGY OF THE LAST GLACIATION IN THE COLOMBIAN CENTRAL CORDILLERA (RUIZ-TOLIMA MASSIF)

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The Ruiz-Tolima volcanic massif on the Central Cordillera is one of the most glaciated massifs in the Colombian Andes: 38km2 out of 110 km2 of glacier ice that covers the Sierra Nevada del Cocuy, the Sierra Nevada de Santa Marta, the Nevado del Huila, as well as this massif.

The present ice caps are located above 4700m over three major composite, andesitic stratovolcanoes: Nevado del Ruiz (5400m) covered by a 21km2 ice cap, Nevado Santa Isabel (5200m) by a 10km2 ice cap, and Nevado del Tolima (5200m) by a 7km2 ice cap. Today, the ELA (equilibrium line altitude of glacier ice) is located at approximately 5100m and the snowline at 4750-4650m. The ice caps are more extensive at the eastern side than at the western side, and the same was the case during the last glaciation: a few glacier tongues reach 350m below the snow-line.

Evidence of Late Pleistocene glaciation is found on about 26,000km2 in the Colombian Andes, i.e. 7.5% of its total area; the Ruiz-Tolima represented 5-10% of this glaciated part of the Andes. The very abundant, recent glacial landforms and deposits cover a very extensive area in the high mountains above 3200m: approximately 800km2 during the Late Glacial in this massif and 1200km2 during the maximum glacial stade of the last glaciation (Middle Pleniglacial). During the Middle to Upper Pleniglacial, the ice fronts were located at 3200-3400m (some valley glaciers down to 2800-2900m) and at 3600-3800m during the Upper Pleniglacial and Late Glacial. Thus, the ELA decrease reached about 1200-1400m during the glacial stades, whereas the average annual temperature was 7-8° lower. This fact suggests an increase of the moisture and of effective rainfall.

Three characteristics describe the ice caps and recent glaciated areas of the Ruiz-Tolima massif. Those ice caps are residual, thin, and retreating. The ice margins are reduced and covered by pyroclastic debris. The volcanic, structural landforms partly control the older glacial landforms and deposits. A few landforms and formations result from both the glacial erosion and the volcanic activity.

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the Late Glacial Otún, the Upper Pleniglacial Murillo, and the probably Middle Pleniglacial Rio Recio. Each one is subdivided into two subsystems.

Twenty-six measured profiles of tephra (ash, lapilli) and soils (Andepts, Humitropepts, Dystrandepts) on each moraine system in the massif were studied for stratigraphic relations, using tephro-stratigraphy, soil study, sedimentology, mineralogy, palynology, and C14 datings, palynology of the sections hand-drilled in peat-bogs and lakes, as well as of the major soil profiles. Heavy mineral suites of the major tephra-fall deposits were also determined in order to fix stratigraphic markers.

Six major stratigraphic, chronological, and bioclimatic periods are distinguished.

Upper Holocene, since 3600-3000 y.B.P.

A young, humic, cumulic Andept covered by a grass-páramo vegetation in a cold, wet climate is formed in historical and upper Holocene tephra: 1595 and 1845 AD, 500-300 y.B.P., 800-700, 1200-1000, and 2600-2000 y. B.P. The Ruiz glacial stade ("inner" Ruiz, 1600's to the end of 1800's, and "outer" Ruiz, pre-historical, perhaps 2900-2600 y.B.P.) belongs to a Neoglacial period.

During an apparently wetter period that occurred between 1700-1600 y.B.P. and 1200-1100 y.B.P., the forest climbed slightly. Major eruptive activity happened in the massif between 2600-2000 y.B.P., between 3600-3500, and ca. 3100 y.B.P. A violent explosion ca. 3600 y.B.P. left a pumice-fall layer, used as a stratigraphic marker, that underlies all the present soils.

Middle Holocene (7500-3600 y.B.P)

During the hypsithermal period, somewhat warmer (1-2°) and more humid than the Actual, apparently without violent volcanic activity, an andic, acid, perhydrated Humitropept was formed up to 4200m. The forest climbed 300-500m higher than today. Many apparently weak eruptions occurred between 6200 and 5800 y.B.P., ca. 5500 y.B.P, and 4700 y.B.P., but probably did not inhibit the soil formation. Two short, cold periods occurred ca. 6200 y.B.P. and especially 7400-7200 y.B.P., when the early Holocene Santa Isabel glacial stade left some local moraines near the Nevado Santa Isabel, as well as periglacial deposits.

Early Holocene (10,000-7500 y.B.P.)

During this period, less cold and less wet than the Late Glacial, the grass-páramo vegetation occupied the altitudinal zone between 3700 and 4100m. In spite of a few eruptions that expelled ash between 10,000-9000 and 7400 y.B.P., a humic Andept was formed in the grass-páramo and a humic, Acid Andept was formed in the high-andean forest below 3700m.

Late Glacial (14,000-10,000 y.B.P.)

The Late Glacial consists of four relatively short periods:
- the Late Otún glacial stade between 10,800 (or 11,400) and 10,000 y. B.P. occurred during the cold and dry El Abra stadial;
- the San Carlos interstade, between 12,400 and 10,800 y.B.P. (or 11,400) during the less cold but humid Guantiva interstadial;
- the early Otún glacial stade happened between 13,300 and 12,400 y.B.P.

(= Lagunillas tardio, Eastern Cordillera) during the cold and humid Ciega stadial;
- the Letras interstade, between 14,000 and 13,300-13,000 y.B.P. during the Susacá interstadial, was less cold but more humid than the Pleniglacial.

Three eruptive periods occurred: between 14,000 and 13,000 y.B.P., between 11,500 and 10,800, and between 10,800-10,000 y.B.P. The first two were very violent and the source of the pumice-rich tephra fall was perhaps the Nevado del Quindío and Nevado del Tolima. The upper forest limit rose to 3400-3600m during the interstadials and went down to 3100-3200m during the stadials.

Upper Pleniglacial

The late Murillo glacial stade (= Lagunillas temprano) built moraines between probably 20,000 and 14,000 y.B.P. during the cold and dry Fúquene stadial, down to 3400-3200m. Many eruptions, apparently not violent, occurred during this period.
During the less cold but more humid Saravita interstadial (24,000-20,000 y.B.P.), the high-andean forest rose to 3400m. The timberline descended to 3200-3000m during the stadials.
The early Murillo glacial stade (= Rio Cóncavo) left moraines between approximately 27,000 and 24,000 y.B.P. and the upper forest limit was depressed, the páramo covering the mountain down to 3200m.

Middle to Lower Pleniglacial

The humid Otoño "interstadial complex" (>27,000 y.B.P.) was found in a sequence of peat. The high-andean forest rose to 3300-3400m and Humitropepts were found in those high-altitude profiles that are dated at ca. 28,000 y.B.P.

The Middle (and Lower ?) Pleniglacial is made up of at least the La Bodega interstadial, stadial II, Berlín interval, and stadial I.

The late Rio Recio glacial stade, perhaps of stadial II age before 33,000 y.B.P. or of stadial I age before 40,000 y.B.P., corresponds to a period when the forest limit may have descended as low as 3100-2900m. Before the Berlín interval (before 48,000 y.B.P. or more), the early Rio Recio glacial stade occurred, but its unknown age might be of Lower Pleniglacial (or even Early Glacial age ?).

Data of this chrono-sequence suggest the following concluding remarks.

The erosion landforms created by the past glaciers were different during the Pleniglacial and Late Glacial periods. Today, the glaciers are not very erosive, except the catastrophic floods and debris flows triggered by interactions between hot tephra and ice cap during an explosion (as suggested by the November 13, 1985, eruption of Nevado del Ruiz). The Late and Pleniglacial landforms suggest that erosive processes induced by glaciers were significantly strong,slightly before the Late Glacial, especially between 27,000-24,000 y.B.P., and before 40,000 y.B.P. The glaciers were thick alpine-like tongues coming out of more extensive and thicker ice caps than today. This resulted from a strong ELA decrease (1000-1400m) and perhaps more severe erosive processes between glacier ice and bedrock.

The palaeoecological data suggest at least two palaeoclimatic

changes:

(1) a 5-8° decrease of the average annual temperature and a strong increase of the moisture during the Middle Pleniglacial and some of the stadials, except between 21,000 and 14,000 y.B.P. The upper forest limit decreased ca. 700-1100m, perhaps even 1200-1400m.

(2) a dissymmetry of the glaciated areas between the east and the west flanks. Glaciers descended 200m more on the east flank, whereas the west slopes were almost always more humid than today. This dissymmetry may be due to more powerful trade winds from NE and SE than equatorial westerlies. Moreover, the more extensive glaciated areas to the east are areas that have a specific topography of wide amphitheaters, where snow was better preserved than on the steep west slopes.

A regional correlation exists between the glacial stades, stadials, and interstadials of the Central and Eastern Cordilleras. However, this correlation is not yet clear for the period older than 30,000 y.B.P. A good correlation exists between the chronostratigraphy in the equatorial Andes and the rest of the Andes (Chile, Peru, Bolivia, Ecuador, and Venezuela) for the Holocene and Late Glacial, but the correlation is not so precise or less well known for the Pleniglacial. Today, we do not yet know with certainty any glacial deposit older than the last glaciation. However, glacial deposit older than the last glaciation may be eroded or buried by lavas or sediments in this massif.

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