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THE EVOLUTION AND THE RECENT VOLCANIC ACTIVITY OF PICHINCHA, ECUADOR

V. Lysenko: *The evolution and the recent volcanic activity of Pichincha, Ecuador.* — Sborník ČSGS 88:1:1—12 (1983). — In 1982 a group of Czechoslovak volcanologists conducted extensive exploration of the volcanic chain of Pichincha, Ecuador with the aim of carrying out geological and geomorphological mapping of the Pichincha chain, and studying the increasing volcanic activity in the crater called Guagua Pichincha. The paper treats of the results of the geomorphological mapping with a major interest in the extent af glacial erosion giving at the same time a comprehensive treatment to a possible danger threatening Quito in case of a volcanic eruption of Pichincha.

1. Introduction

In 1981—1982 a group of Czechoslovak volcanologists made major observations of volcanic activity in Ecuador under the sponsorship of the Czech Geological Board. The main purpose of the expedition was the exploration, collecting of samples and actuogeological observations of the volcanoes Sangay and Sumaco with a special concern in the composition of the lavas in relationship to the geotectonic situation of the volcanoes in the orogene, and to the ore forming processes. In response to the requests made by Ecuadorian geologists (Dirreción General Geologia y Minas), the members of this expedition paid most of their attention to the volcano Pichincha because of its very close location to Quito — the capital of Ecuador — and its recently increasing volcanic activity which might become a potential danger to the latter's population. Within 70 days the geologists mapped an area of approximately 100 km^2 in scale 1 : 25 000 (southern and SE slopes), collected samples and carried out detailed studies of volcanic rocks, compiled a detailed map and observed the changes in the activity of the crater (five times they descended into its interior), compiled a geomorphological map of the volcano in scale 1 : 50 000, and drew a map of potential volcanic activity in southern and SE slopes.

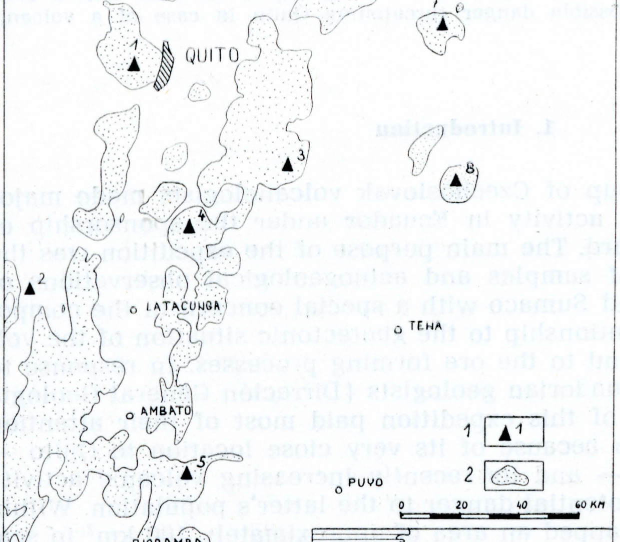
The present paper is a summary of results achieved in geomorphological mapping and observations of the recent volcanic activity of Pichincha. Conceptionally the present results link up with the results achieved in 1972 by a joint Polish-Czechoslovak volcanologic expedition Cotopaxi (Lysenko, 1980).

2. The history and the survey of explorations

The vast volcanic chain Pichincha is a part of the West Cordilleras. It is composed of an original large caldera, old volcanic wreck Condor Huachana (?), Rucu and a stratovolcano Guagua Pichincha with a younger active core. Its exact location is in longitude 78° 30′ WW and latitude 0° 10′ SW, 9 km west of Quito (Fig. 1). Rucu Pichincha rises to 4 698 m, Guagua Pichincha to 4 794 m.

Guagua Pichincha is an active volcano of somma type with a nested crater. Historic records describe periods of increased activity mostly of Peléean type. The most important periods of activity were in 1533—1539, 1560, 1566, 1575, 1577, 1580, 1582—1598, 1660, 1830—1881. The most terrific explosion of pyroclastic rocks, cinders, ash and incandescent gas took place in 1660. It buried Quito with a 40 cm thick layer of ash. The last grand eruption without any effusion ocurred in 1949.

Several authors have described the volcano and its exploration. The history of its activity since 1533 has been studied by T. Wolf (1904) and



1. Pichincha volcano
1 — active volcanoes in Ecuador: Pichincha (1), Quilotoa (2), Antisana (3), Cotopaxi (4), Tungurahua (5), Sangay (6), Reventador (7), Sumaco (8), 2 — extent of Quarternary volcanic deposits.

by Hantke and Parodi (1966). Hall (1977) gives a general estimation of older works in this field and supplies some fundamental data on the volcano. There exist, however, no geological maps of the volcano. In 1978 a geological map was compiled containing sheets of Quito and Nono in scale 1 : 50 000 showing volcanic deposits of Pichincha, and alluvial, colluvial and glacial sediments. The area of the volcano has been several times photographed from the air. We could make use of aerial photographs of the volcano dating from August 24, 1977 in scale 1 : 60 000, and photographs of the active crater in scale 1 : 25 000 from August 20, 1981 and in scale 1 : 15 000 from September 10, 1981.

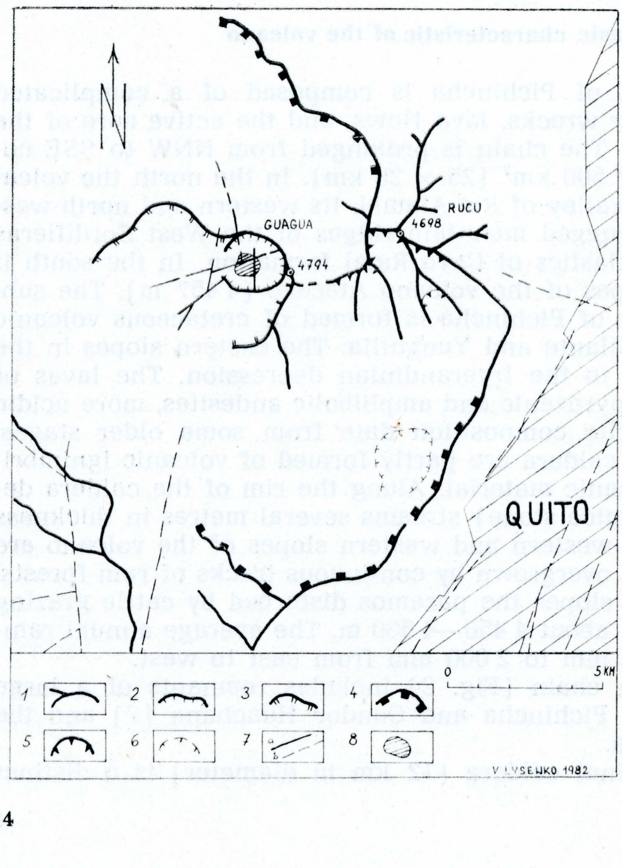
The increasing activity of the volcano in 1981 became the subject of observations by many expert volcanologists, such as geologists from Ecuador (Longo et all., September 1981), a group of experts from UNESCO (October 1981), and professor Barbiery from Italy (October 1981). Their accounts, however, have not been published, and therefore are not included in the references. Also the results of our studies presented to the Dirección General Geologia y Minas in the form of reports are not included. They are records of our observations of volcanic activity carried out on December 1, 1981, December 3—5, 1981, December 24—27, 1981, January 9—12, 1982, and January 28—29, 1982, a record on the activity of the volcano and a record attached to the geological map of southern and SE slopes of the volcano and the danger of further volcanic activity in this area.

3. The basic characteristic of the volcano

The extensive chain of Pichincha is composed of a complicated system of calderas, crater wrecks, lava flows, and the active core of the crater Guagua Pichincha. The chain is prolonged from NNW to SSE covering approx. an area of 500 km^2 (25 $\times$ 20 km). In the north the volcano extends as far as the valley of Rio Alambi, its western and north-western slopes continue in rugged mountain ridges of the West Cordilleras composed of Paleogene clastics of Cayo Rumi formation. In the south it touches the northern slopes of the volcano Atacazo (4 457 m). The substratum of the volcanites of Pichincha is formed of cretaceous volcanic formations of Macuchi, Silante and Yunguilla. The eastern slopes in the area of Quito fall down to the Interandinian depression. The lavas of Pichincha correspond to pyroxenic and amphibolic andesites, more acidic pyroclastic rocks of dacite composition date from some older stages. The walls of the Guagua caldera are partly formed of volcanic ignimbrites and partly of subvolcanic material. Along the rim of the caldera deposits of pyroclastic (pumice stone) streams several metres in thickness may be found. The south-western and western slopes of the volcano are almost inaccessible being overgrown by continuous tracks of rain forests. On southern and eastern slopes the paramos disturbed by cattle grazing reach up to the height of about 4 450—4 500 m. The average annual rainfall increases from 1 000 mm to 2 000 mm from east to west.

The whole mountain chain (Fig. 2) includes remnants of a large caldera, wrecks of Rucu Pichincha and Condor Huachana (?) and the volcano Guagua Pichincha.

The rim of the original caldera (12 km in diameter) is a distinct ridge forming a natural border of the entire mountain chain in the south and south-west. The western part of the caldera is partly covered with young volcanites of the Guagua Pichincha, partly its surface is dissected by streams flowing to the west. An outstanding part in the origin as well as destruction of the caldera has been played by the tectonics. Most probably it has been transforsmed by systems of dislocations of NW—SE and NNE—SSW direction which manifest themselves in the eastern part as photolineations, in the south-western part they have been geologically mapped [Fig. 2]. Along dislocations of N—S direction the whole area was later broken into blocks. The uplift of the cretaceous substratum along these dislocations and the consequent destruction of the south-western and western part of the caldera dates from the earliest Pleistocene or is due to recent neotectonic movements. It is clearly evidenced by reduced Pleistocene volcanic deposits of Atacaza on uplifted blocks south-west of the Pichincha chain. The north- eastern part of the caldera is covered with lava flows and tephratic lava of Rucu Pichincha. The upper parts of the south-eastern ridge of the caldera are formed by levelled surfaces reaching the height of about 3 400—3 450 m and 3 500—3 570 m. The original filling of the caldera is exposed in the walls of deep valleys and gorges in the vicinity of the village Lloa. It is composed of lacustrine, fluvial and glaciofluvial sediments several metres in thickness. Later through the effects of erosion the sediments were



2. Guagua and Rucu Pichincha volcanoes [Lysenko 1982].

1 — ridges, 2 — active crater of Guagua, 3 — caldera of Guagua, 4 — large caldera, 5 — remnants of Rucu crater affected by glacial erosion, 6 — questionable remnant of Condor Huachana, 7 — discovered rift lines (a), presumed rift lines (b), 8 — central dome.

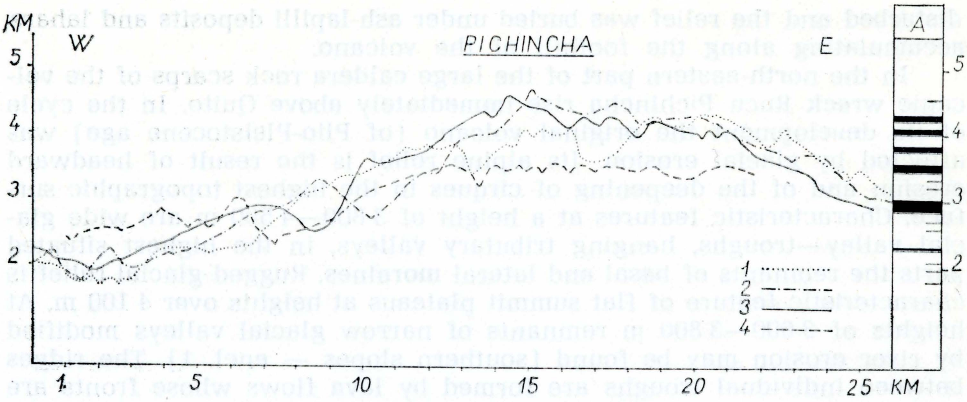
disturbed and the relief was buried under ash-lapilli deposits and lahars, accumulating along the foothill of the volcano.

In the north-eastern part of the large caldera rock scarps of the volcanic wreck Rucu Pichincha rise immediately above Quito. In the cycle of its development the original volcano (of Plio-Pleistocene age) was affected by glacial erosion. Its alpine relief is the result of headward erosion and of the deepening of cirques in the highest topographic surface. Characteristic features at a height of 3 800—4 500 m are wide glacial valley—troughs, hanging tributary valleys, in the highest situated parts the remnants of basal and lateral moraines. Rugged glacial relief is characteristic feature of flat summit plateaus at heights over 4 100 m. At heights of 3 600—3 800 m remnants of narrow glacial valleys modified by river erosion may be found (southern slopes — encl. 1). The ridges between individual troughs are formed by lava flows whose fronts are slightly inclined, e. g. Cotopaxi (Lysenko 1980). Lava plateaus often influence the outline of the glacial relief. Fig. 3 shows four E—W profiles of Guagua and Rucu. Locally limited denudation plains or lava plateaus (black zones) are marked. The glacial relief in its highest levels have been recently affected by cryogene processes, by rainfall erosion, and by the development of gorges and landslides. At the foot of glacial troughs narrow valleys with streams have cut down into the flat floor.

In 1977 Hall mentioned the volcanic centre Condor Huachana which is supposed to be located south of Rucu or south-east of Guagua. Since we had no more detailed description I mapped its suggested location with regard to the morphology of the surrounding country (Fig. 2). Limited time prevented us also from carrrying out a more detailed petrographic investigation so that this volcanic centre keeps on remaining unexplored and is therefore marked in the text with a question mark.

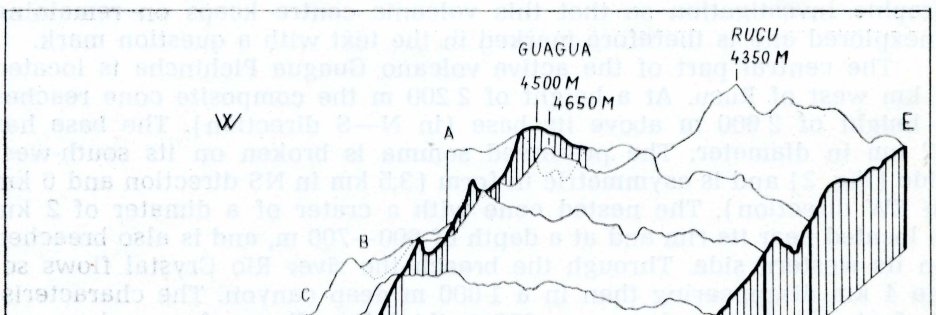
The central part of the active volcano Guagua Pichincha is located 5 km west of Rucu. At a height of 2 200 m the composite cone reaches a height of 2 600 m above its base (in N—S direction). The base has 12 km in diameter. The preserved somma is broken on its south-west side (Fig. 2) and is asymmetric in form (3,5 km in NS direction and 6 km in EW direction). The nested cone with a crater of a dimater of 2 km is located near its rim and at a depth of 600—700 m, and is also breached on its western side. Through the breach the river Rio Crystal flows some 4 km disappearing then in a 1 000 m deep canyon. The characteristic features of the volcano are 200 m thick lava flows of several generations. They are partly exposed in the walls of deep canyons. The fronts of lava flows display numerous breccias, the slopes are covered with ash showing levels of lapilli tephras.

The broad and rather low cone has survived since the earliest phase of glaciation. The glacial relief developed in the entire summit part, extends as low as 3 600 m in the south and still lower in the north. In the NW and west flat glacial vallyes pass into wide, deep canyons. Headward erosion proceeded (Rio Crystal) as far as the close proximity of the crater rim. In the lower parts of preserved glacial valleys we discovered some morainic deposits in localities Pumipamba and Loma Jaramillo at a height of 3 400 m (Fig. 3, encl. 1). The cross section of the Pumipamba locality shows chaotic masses of morainic material in its original location in the lava flow where it was later affected by river



3. Profiles of Pichincha volcano (Lysenko 1982).

erosion and then buried again under pyroclastic material. Both the rim of the caldera and that of the crater are broken by trough-shaped depressions through which pyroclastic flows advance from the crater when the volcano starts its activity. The origin of these depressions according to their shape may be considered glacial. The rim of the nested cone displays six such depressions. They are the remnants of the original glacial cap and glacial tongues dating from the time preceding the total wreck of the cone peak.



4. Series of cross sections of Pichincha (Lysenko 1982).
1 — Cerro Yanayacu, 2 — Guagua crater, 3 — Cer- Chiquirigual, 4 — Loma Rumipamba, A — remnants of dunudation plateaus and lava plateaus.

A series of cross sections (Fig. 4) of the central part of the chain shows the glacial valleys between Guagua and Rucu (profiles A—D) and on Rucu (profiles B—C). The valleys are in cross sections. Profiles B and C show the glaciation of several levels. The highest-situated level is represented by up to 3 km wide, flat, through-shaped valleys with floors slightly declining along the slope of the volcano. The lower level is formed by vallyes up to 1 km wide, in their upper parts trough-shaped, in lower part U-shaped. The highest-situated glacial valleys extend as far as the summit part of Guagua and Rucu at a height of 4 350—4 650 m, the central level of erosion being at a height of 4 000 m (±50 m) — 4 280 m, and the lowest level at a height of 3 600—3 900 m. The lower limit of occurrence of remnants of glacial valleys at a heights of about 3 400 meters is not continuous. At the present time frost heaving and solifluction takes place on eastern slopes covered with most recent pyroclastic material (heights above 4 400 m).

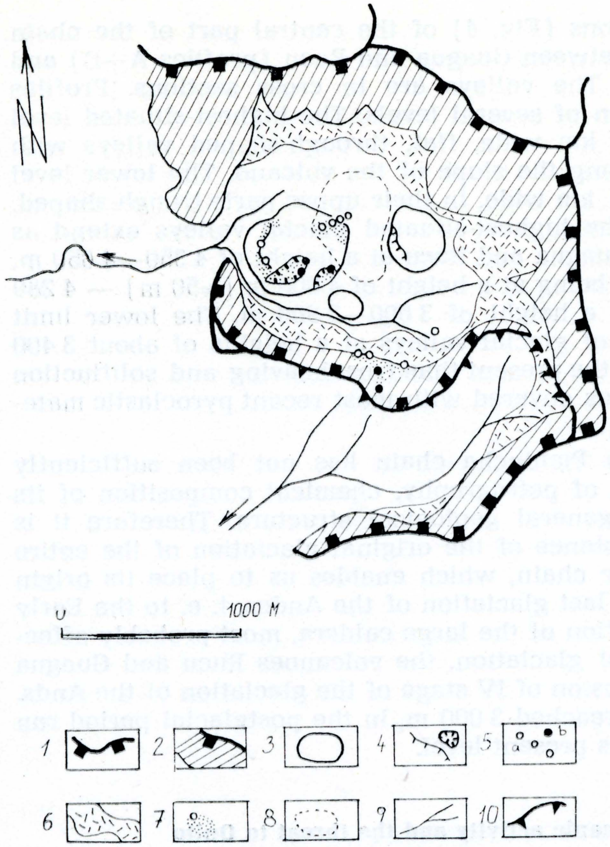
Up to the present the Pichincha chain has not been sufficiently studied from the viewpoint of petrography, chemical composition of its volcanic deposits and its general geological structure. Therefore it is important to verify the existence of the original glaciation of the entire summit part of the volcanic chain, which enables us to place its origin to the period preceding the last glaciation of the Andes, i. e. to the Early Pleistocene. With the exception of the large caldera, most probably affected also by earlier stages of glaciation, the volcanoes Rucu and Guagua were modified by glacial erosion of IV stage of the glaciation of the Ands. At that time the snow line reached 3 000 m, in the postglacial period ran by 500—700 m lower than its present level.

4. The recent volcanic activity and the threat to Quito

The active crater of the nested cone of Guagua Pichincha has a diameter of 900—1 000 m. The floor of the crater is at a height of 4 000 m. Three lava domes are the basic morphological feature of the floor. The large central dome has a diameter of 330 m and a height of 75 m, the two remaining are comparatively smaller (Fig. 5). Their rocky walls are lined with talus deposits at their foot. Under the eastern wall of the crater springs the river Rio Crystal and drains the crater to the west, the western part of the crater floor being considerably eroded by its flow. The crater might have a repose period in the past during which its floor was a flat plain. Also glacial erosion might have played an important part.

The central elevation is crossed by tift lines of WSW—ENE and N—S, NNW—SSE direction (Fig. 2). The recent increased activity takes place along these rift lines not only in the dome but also in the southern wall of the crater (Fig. 5).

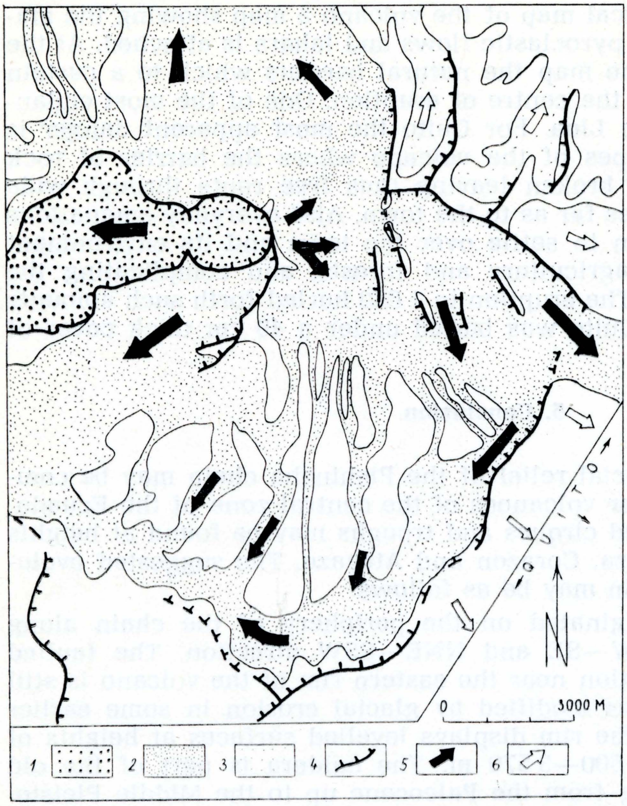
Since 1975, when there were some small emanations from the dome, the volcanic activity was of diminishing intensity. In 1981, however, gas started sputtering out in the southern wall. The temperature of the dome interior has been rising and fresh ash deposits appear in its environment (approx. 5 thousand m^3). An increased seismism has been recorded in the area. In September five smaller earth tremors with earthquake



5. Crater of Guagua Pichincha (Lysenko 1982). 1 — rim of caldera and of nested crater, 2 — rock walls of crater, 3 — central dome, vaults, 4 — crater depressions, 5 — exhalations of SO_2 (a) and vapour (b), 6 — talus deposits, 7 — fumarole fields, 8 — zone of recent maximum ash fall, 9 — river bed, 10 — atrio with remnant of trough.

centres in Quito, south of Quito and in Aloasi took place. During the 75 days of our stay the activity kept on increasing. In the north-east part of the dome we observed large fissures of WSW—ENE direction with at least 4 emissions of vapour. In the southern slope of the dome some new craters of approx. 40—50 m in diameter gave emanations of SO_2 along wide vertical fissures of N—S direction. The fissures are partly filled with sublimation products, such as sulphur, partly form fissure caves with druses and deposits of crystalline sulphur. From the heighest-situated cave a grey-blackish flow of molten sulphur was pouring down. During the individual descents into the crater we observed that the temperature within the dome was rising. On January 29, we observed hot vapour emananions in the whole western part of the dome along lines of E—W direction. Aside from the original three emanations in the southern wall of the crater another three came into being during our observations of the Pichincha, two of them emanations of SO_2. Ash accumulations covered the slopes up to the height of 100—150 m. Two different kinds of ash may be noted, grey ash and black ash coming from greater deapths.

The exhalations of SO_2 took place along rift lines of N—S direction, the exhalations of vapour along rift lines of E—W direction. On crossings



6. Map showing the maximum danger of ash, pyroclastic and mud flows 1 — zone of maximum accumulation, 2 — medium-accumulation, 3 — minimum accumulation, 4 — morphological barriers, 5 — directions of primary flows, 6 — directions of secondary flows.

of these main rift lines (Fig. 2) in the eastern and north-eastern part of the dome centres of explosive activity are located.

Since recorded history the eruptions in this region have been of Peléean type, i. e. with unexpected eruptions of lava, ash, incandescent gases and hot vapour sweeping down the slopes with a speed of several hundred kilometres per hour, in the northern part of the West Cordilleras being accompanied by earthquakes. Without long-lasting detailed observations and a systematic exploration of the volcano any forecasting of eruptions and of the degree of their violence becomes science-fiction. It is necessary to carry out a detailed geological and geomorphological mapping of the whole volcano and its close neighbourhood, to study the changes in the chemism in the course of its evolution, to install cameras for infra-photographies, to observe fumaroles, to study the changes in the chemism of exhalations and vapour, to observe the changes in elevation, to install seismographs along the periphery of the volcano which would be telemetrically connected with a recording station, to install tiltmeters, to determine the ratios of some elements and compounds, such as $F:CO_2$, $SO_2:CO_2$, $S:Cl_2$, to observe the increase of radon, etc. Eruptions announce their approach by seismic disturbances and subterranean rumbling.

To the geomorphological map of the volcano a map showing the maximum danger of ash and pyroclastic flows and lahars is attached. At the same time I marked in the map the natural barriers which to a certain extent protect Quito from the centre of eruption. One of the most endangered areas is the village Lloa. For Quito the most apparent danger is posed by the eastern slopes of the volcano where the barrier of rock scarps of Rucu has been broken leaving thus free route through wide glacial valleys extending as far as to the town. Also everyday emanations of cinders or ash threaten to settle over the town and its environment doing much damage to agriculture and forests, and complicating the conditions of traffic, etc. The eruption in 1 660 hurled forth such amounts of ash and cinders that Quito was buried under a 40 cm thick cover of ash.

5. Conclusion

The height of the glacial relief of the Pichincha chain may be compared to the relief of other volcanoes of the central zone of the Ecuadorian Andes. Well preserved cirques and troughs may be found at heights of 4 000—4 200 m in Iliniza, Corazon and Atacazo. The suggested evolution of the Pichincha chain may be as follows:

a) The large caldera originated on the periphery of the chain along fissure systems of NW—SE and NNE—SSW direction. The faulted zone of NE—SW direction near the eastern rim of the volcano is still active. The caldera was modified by glacial erosion in some earlier stages of glaciation. The rim displays levelled surfaces at heights of 3 400—3 450 m and 3 500—3 570 m. The caldera is part of the old volcanic system dating from the Paleocene up to the Middle Pleistocene (?).

b) The volcanoes Condor Huachana (?), Rucu and Guagua came into being gradually their activity being progressively greater as one goes from east to west along a riftline of E—W direction or at the crossing of the latter with rift lines of NNE—SSW direcion. Their evolution is parallel to the evolution of the adjacent volcanoes, such as Atacazo etc. They originated as nested cones within a caldera.
   The peak of the Guagua Pichincha has collapsed several times. After the first collapse the caldera Guagua came into being. Another collapse took place after a new nested cone had been built giving thus rise to the present active crater.
   Vast glacial erosion producting the alpine relief of the summit chain of Rucu may have taken place in stage III of glaciation which was strongest in the Andes (compare Morurco peak near Cotopaxi — Lysenko 1980). Guagua Pichincha was most probably modified by glacial erosion only in the last stage of glaciation (Late Pleistocene) producing glacial features, such as trough-shaped depressions along the rim of the crater, radial glacial valleys, inversion of lava flows on the flanks of the summit chain.
   The volcanoes are undoubtedly of Pleistocene age. Rucu might date from the Middle Pleistocene, Guagua might be younger (Late Pleistocene).

c) The period of activity of the nested cone of Guagua Pichincha was most probably preceded by a period of repose after its second collapse. It was accompanied by postglacial erosion of a small glacier extending at that time some 500—700 m lower than the present snow limit. The subsequent activity shown in the most recent profiles and in historic records was predominantly of Peléean type. The active centres are located on rift lines of N—S and WSW—ENE direction. The main products are sand flows and extensive deposits of cinders, ash and pumice stone. Any larger eruption of Pichincha may cause only complications to people in Quito but may not be any real danger to their lives. *(Translated by Z. Náglová)*

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Souhrn

VÝVOJ A SOUČASNÁ AKTIVITA VULKÁNU PICHINCHA V ECUADORU

V roce 1981—82 působila v Ecuadoru pod záštitou Českého geologického úřadu čs. vulkanologická expedice. Hlavním cílem byl průzkum, odběr vzorků a aktuologická pozorování sopek Sangay a Sumaco, vše se zaměřením na sledování vztahu složení láv ke geotektonické pozici sopek v orogénu a tím i ke zrudnění. Vzhledem k vzrůstající aktivitě vulkánu Pichincha, který je v bezprostřední blízkosti hlavního města Ecuadoru Quita, zařadili členové výpravy do programu i průzkum Pichinchy. Výsledky geomorfologického mapování a sledování její aktivity jsou předmětem této práce.

Rozsáhlý vulkanický komplex Pichincha vystupuje v pásmu Západní Kordillery, východními svahy spadá do Quita. Komplex sestává z původní velké kaldery, starších vulkanických trosek Rucu Pichincha a stratovulkánu Guagua Pichincha s mladým aktivním centrem. Výška Rucu je 4 698 m, Guagua 4 794 m n. m. Celý komplex zaujímá přibližně plochu 500 km^2. Lávy Pichinchy odpovídají pyroxenickým a amfibolickým andezitům, kyselejší pyroklastika složení dacitu patří starším stadiím. Stěny kaldery Guagua tvoří v malé míře sopečné ignimbrity, subvulkanické průniky. Po obvodu kalderu jsou řádově metrové mocné uloženiny pyroklastických (pemzových) proudů.

Komplex Pichincha ve svém vývoji prošel několika stadii pleistocenního zalednění. Z období glaciální eroze kromě běžných glaciálních tvarů jako jsou karty, trogy, plochá neckovitá údolí, uloženiny morén, glacifluviální uloženiny, zůstaly relikty zarovnaných povrchů. U velké kaldery ve výšce 3 400—3 450 m a 3 500 až 3 570 m u Rucu a Guagua jde o úrovně glaciálních údolí, dna spojených karů a o glaciálně modelované povrchy svahů. Svahové plošiny většinou odpovídají plošinám lávových proudů. Nejnižší hranice výskytu reliktů glaciálních údolí je ve výšce kolem 3 400 m. Další pásmo je mezi 3 600—3 900 m, střední v rozpětí 4 000 m (± 50 m) — 4 280 m a nejvyšší zasahuje do vrcholové partie Guagua 4 350—4 650 m. Ověření glaciální eroze v prostoru komplexu Pichincha a zejména ve vrcholové části aktivnyho stratovulkánu Guagua umožňuje s větší jistotou provést nástin vývoje celého komplexu:

a) Vznik velké kaldery je predisponován systémy poruch SZ—JV a SSV—JJZ. Kaldera přísluší k systému starého vulkanického patra stáří paleocén—stř. pleistocén (?).

b) Postupný vývoj vulkánů Condor Huachana (nejistý relikt), Rucu a Guagua jako důsledek posuzování aktivity od východu k západu na linii poruch přibližně v.—z.

směru a jejich křížení s pásmem poruch SSV a JJZ. U Guagua Pichinchy nastává opakovaný kolaps vrcholu vulkánu. Nejprve vzniká kaldera a posléze po vytvoření nového vloženého kužele dochází k druhému kolapsu a vzniku současného aktivního kráteru.

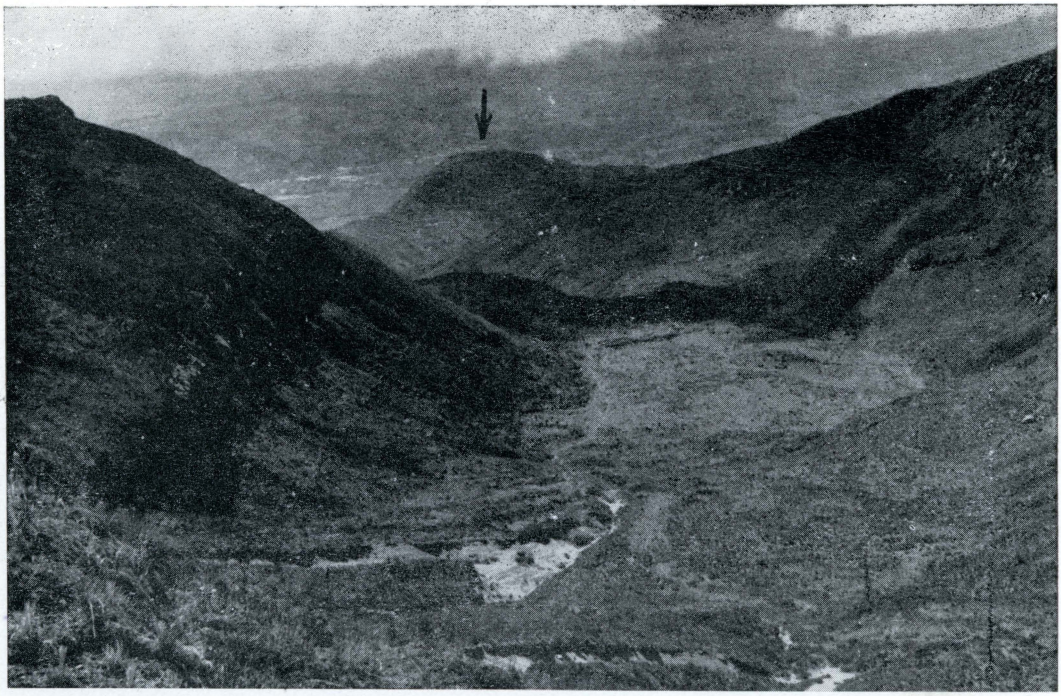
Mohutnost glaciální eroze s alpinským reliefem vrcholového masívu Rucu může být důsledkem III. stadia zalednění. Vulkán Guagua prošel pravděpodobně pouze posledním stadiem zalednění. Horní hranice vzniku je u Rucu pravděpodobně středním pleistocén, u Guagua mladší pleistocén.

c) Období aktivity vloženého kráteru Guagua. Po zklidnění aktivity po druhém kolapsu se explozivní aktivita vulkánu soustřeďovala do lokálních center na dně kráteru (dómy), ve stěnách zůstala ve formě solfatar a fumarol. Aktivní centra jsou rozložena na poruchách směrů S—J a ZJZ—VSV. Aktivita tak, jak ji udávají historické prameny, byla převážně peléjského typu. Hlavními produkty, které lze sledovat v nejmladších profilech, jsou pískovcové proudy a mocné napadávky popelů a pemz.

V případě větší erupce se jako nejnebezpečnější úsek pro Quito jeví přímý východní směr z Guagua přes Rucu Pichincha. Existují zde snížené úseky v přirozených morfologických bariérách, které mohou usnadnit průnik popelových a pyroklastických proudů. Jinak jde více méně o tzv. sekundární proudy vzniklé v důsledku většího nahromadění napadávek na svazích. Kromě sesuvů mohou být za zvýšených srážek základem pro vznik laharů. Jisté nebezpečí a hlavně komplikace pro město představuje i běžný spad sopečného popela, který např. při erupci r. 1660 vytvořil vrstvu 40 cm mocnou.

1. Eastern slopes and rocky peak of Rucu Pichincha above Quito.
2. Central part of Rucu Pichincha (4 698 m).

3. Cirque under rocky peak of Rucu Pichincha. Steps formed by lava flows.
4. Eastern slopes of Rucu. Trough valley with remnants of transverse hanging valley. Flat valley of higher level (Cruzloma) in background.



5. Trough valley in eastern slope of Rucu. Flank of large caldera marked with arrow.
6. Gorges on floor of glacial valley Gradas between Rucu and Guagua. Atacazo in backgraund.

7. Camp in valley Gradas at a height of 4 050 m. Flanks built of lava flows. Parama zone.

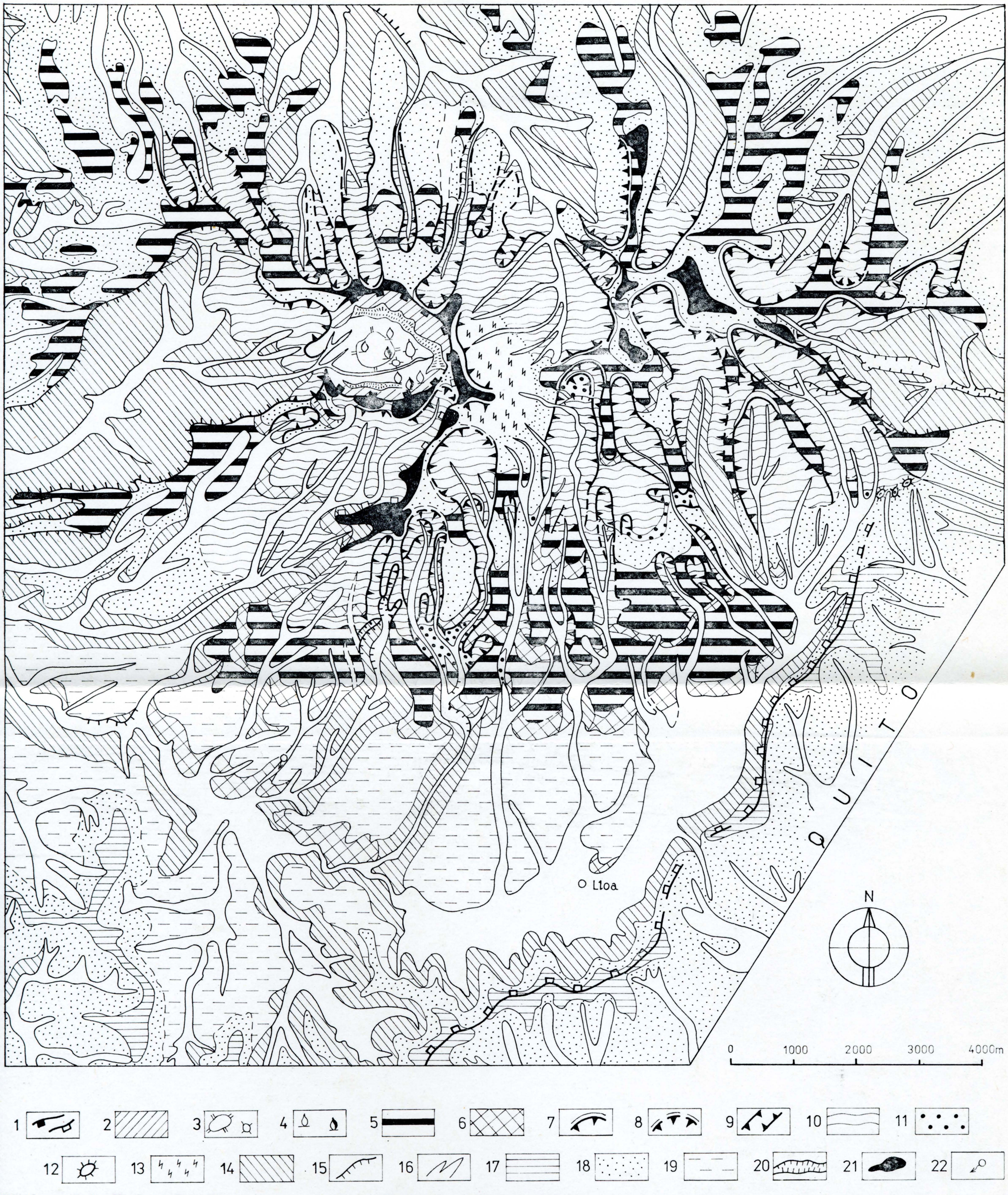
8. Guagua Pichincha — eastern solifluction slopes with erosion furrows. Remnants of trough depressions between rocky peaks.

9. Guagua Pichincha. Rock mass covered with pumiceous tephras. Slopes furrowed by erosion and solifluction. Height 4 400—4 700 m.

10. Guagua Pichincha — rim of southern wall of active crater. View from atrio.

11. Central dome in Guagua Pichincha crater. To the right wide fissure with exhalations of vapour. View towards west.

12. Detail of wide fissure with exhalations of vapour. Adjacent area covered with fresh deposits of ash.
(All photographs by *V. Lysenko*)



To the article *V. Lysenko:* The evolution and the recent activity of Pichincha, Ecuador

Enclosure 1. Geological map of central part of Pichincha volcanic chain

1 — rim of crater (a), rim of caldera (b), 2 — rock walls of crater, 3 — domes, 4 — exhalations of H_2O (a), SO_2 (b), 5 — remnants of peneplanes and lava plateaus, 6 — fronts of lava flows, 7 — cirques, cirque steps, 8 — remnants of cirques and cirque steps, 9 — troughs, 10 — surface affected by glacial erosion, 11 — moraines, 12 — remnants of eroded frontal moraine, 13 — solifluction slopes, 14 — steep denudation slopes, 15 — erosion levels, ledges, 16 — vallyes of streams, 17 — peneplane surfaces of large caldera, 18 — flanks of lava flows, 19 — volcanic proluvial accumulation slopes, 20 — talus deposits, 21 — rocky peaks, 22 — thermal spring.