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Volcanic impediments in the progressive development of pre-Columbian civilizations in the Ecuadorian Andes

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ABSTRACT

Archaeological investigations in Ecuador have proposed that there appear to be hiatus or anomalous jumps in the progressive development of pre-Columbian indigenous cultures, based upon the fact that their ceramics and tools demonstrate abrupt advances in their sophistication at several horizons in the soil profile. Because some of these horizons are clearly associated with volcanic ash layers, archaeologists have sought a causal relation with volcanism, that is, the eruptive events or their products severely interfered with the early inhabitants, resulting in their abandonment of certain areas.

Geological studies of the young volcanoes in the Ecuadorian Andes carried out during the past two decades now allow us to make a more thorough evaluation of the role of volcanism during the Holocene. This contribution briefly describes the principal Holocene volcanic events and the distribution of the corresponding eruptive products found along the InterAndean Valley, from southern Colombia to central Ecuador. Only those events that were sufficiently large that they could have had a detrimental effect on the valley's early residents are discussed.

Dacitic and rhyolitic ash flows, as well as numerous debris flows (lahars) have occurred frequently and their deposits cover many valleys and floodplains, where early inhabitants probably settled. The enormous Chillos Valley lahar, associated with the 4500 yBP eruption of Cotopaxi volcano, buried soils containing ceramics of the early Formative Period. However, the greatest impact upon mankind was probably not these short-lived violent events, but rather the burying of settlements and agricultural fields by ash fallout, the effect of which may have lasted hundreds of years. Ash fall layers are observed in pre-Columbian cultural horizons in the soil profile, occurring in the InterAndean Valley, the lower flanks of the Andes, and along Ecuador's Pacific coast, the oldest corresponding to the 5800 yBP eruption of Cotopaxi. This brief study provides the archaeologist with a more detailed listing of notable volcanic events that may guide future investigations of past cultures.

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1. Introduction

The idea of possible hiatus in the progressive development of pre-Columbian indigenous cultures in Ecuador, possibly caused by volcanic eruptions (Lathrap et al., 1984; Isaacson and Zeidler, 1999; Zeidler, 2006) has provoked considerable interest and discussion in scientific circles. Abrupt interruptions, rather than smooth transitions in the continuous advancement of pre-Columbian indigenous ceramics and tools prompted the concept of hiatus or gaps possibly caused by outside influences. During the past two decades important advances have been made in understanding Ecuador's volcanic history, and consequently it is now possible to evaluate the role of volcanism in this dilemma. Many volcanic centers are now recognized that have had activity during the Holocene and late Pleistocene and their deposits cover much of the InterAndean Valley and the western coast of Ecuador (Mothes and Hall, 1991) (Fig. 1).

The InterAndean Valley is a structural depression that begins in southern Colombia near the Ecuadorian border and only disappears south of Riobamba. Active volcanoes are found along both the western and eastern cordilleras that form the opposite sides of the Inter-Andean Valley. During the Holocene the Valley apparently enjoyed a rather hospitable climate that promoted good soil formation as well as a landscape with extensive flat lands, as compared to the wet, precipitous outer flanks of the Andes.

The InterAndean Valley was the central axis of the pre-Columbian cultures in the Ecuadorian Sierra, as implied by its many archaeological sites (Gondard and Lopez, 1983; Porras, 1984; Knapp, 1988; Knapp, 1991). It was the most favorable region for agriculture and hunting, as well as for trade and communication up and down the valley as well as across the Andes to the adjacent lowlands (Knapp, 1991). The Valley is also the focus of deposition of many volcanic products, given that active volcanoes border the Valley and the dominant winds transport ash into the basin (Barberi et al., 1988; Hall and Beate, 1991). Consequently, it is highly probable that the indigenous communities suffered the effects of volcanic eruptions

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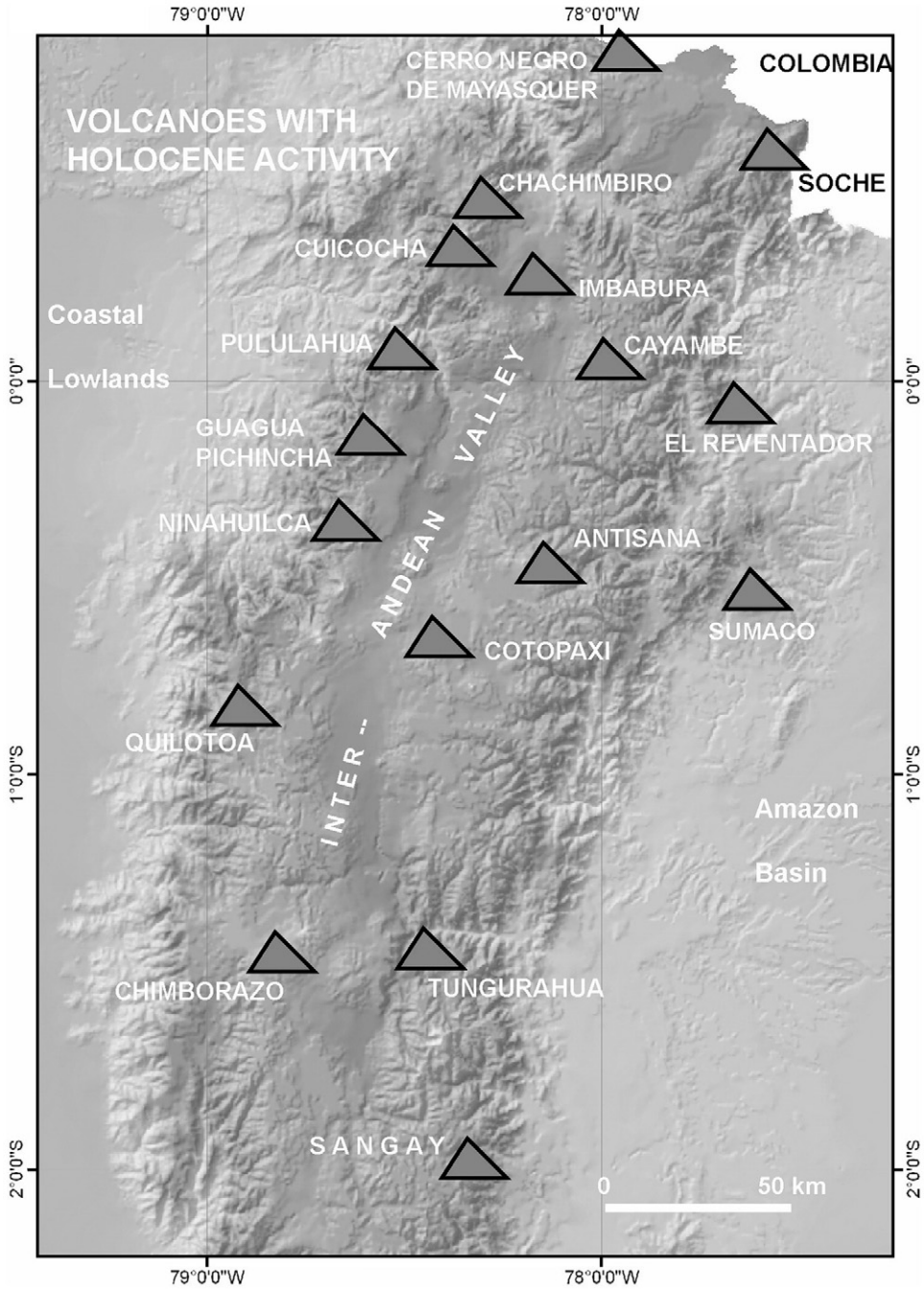

Fig. 1. Distribution of the principal Ecuadorian volcanoes with Holocene activity and their relation to the InterAndean Valley. Tropical lowlands exist to the east (Amazon Basin) and to the west (coastal lowlands) of the Andes.

repeatedly (Knapp and Ryder, 1983; Isaacson, 1987; Salazar, 1995). In fact, Moreno (1988) concluded: "The chronological gap between 500 BC and 950 AD is possibly the result of an increase in volcanic activity in the northern and central Ecuadorian Andes, which resulted in a demographic dwindling that lasted until about 1000 AD when immigrations again became important".

More specifically, Villalba (1988) found that the ~355 BC eruption of Pululahua volcano covered the Cotocollao village and agricultural fields with 2 cm of volcanic ash which "probably provoked the partial or total abandonment of this pre-Columbian site". Lippi (1998) noted that the Nambillo sites –30 km to the northwest of Quito — had been abandoned twice because of ash falls; he recognizes two distinct ceramic periods, namely one prior to 400-200 BC and another prior to 800 AD, each of which ended in a discontinuity in artifact development. Zeidler (1994) and Isaacson (1994), archaeologists working in the Jama Valley of the central coast of Ecuador, recognized three important ash fall layers, the two oldest of which (~1600 BC and ~355 BC) overlie cultural horizons that subsequently do not reappear and are associated with a hiatus in ceramic development. The 355 BC hiatus and related ash bed belongs to the ~2400 yBP eruption of Pululahua. Recent dating of Guagua Pichincha tephra stratigraphy (Monzier et al., 2006) suggests that both the ~1600 BC event and the third ash layer (~500 AD) are probably from that volcano. In addition to these ash layers Villalba et al. (2006) describe a 20 cm thick rhyolite ash layer with abundant golden biotite, apparently from the 4 yBP eruptions of Cotopaxi, that is associated with the oldest Formative

cultures at Tonsupa, on the northwest coast. In summary, numerous archaeological studies have concluded that volcanism played an important role in pre-Columbian cultural development.

The purpose of this study is to call attention to the larger eruptive events that have occurred during the past 13,000 years in the Ecuadorian Andes. Given that we would like to concentrate only on those events that might have seriously impacted pre-Columbian cultures, we draw attention to those eruptions of greater magnitude that have been radiocarbon-dated or whose age can be estimated by interpolation. The carbon-14 dates presented here are uncalibrated laboratory ages.

Four volcanic phenomena have had the greatest detrimental effects in the InterAndean Valley. First, pyroclastic flows and especially ash flows, given their fatally high temperatures, great speed, and their widespread distribution, would have had the greatest impact, destroying everything in their paths and leaving thick deposits of pyroclastic material over the countryside. Second, large debris flows and lahars have frequently devastated the valley bottoms, both in pre-Columbian as well as in historical times. These flows typically leave extensive deposits, 2–10 m thick, upon the floodplains of river valleys; they are composed of unconsolidated boulders, gravel, and sand, and as such may destroy or bury settlements and useable agricultural lands. It is important to recall that both pyroclastic flows and debris flows characteristically follow river channels of the valleys and can travel tens of kilometers down stream. Thus, both phenomena would have represented considerable danger to pre-existing cultures which chose to live along the floodplains of the InterAndean Valley, generally the lands most suitable for agriculture. Third, the fallout of volcanic ashes and lapilli are generally deposited downwind from an erupting volcano; these often form a mantle, many centimeters thick, that may blanket hundreds to thousands of square kilometers. Because the dominant winds in Ecuador are from the east, most ash is transported to the west of the erupting volcano. Finally, the rare collapse of large volcanoes may generate debris avalanches of enormous volume that leave large aprons of rocky hills and depressions at the base of many volcanoes.

2. Devastating volcanic events of the Holocene

From north to south along the InterAndean Valley (Fig. 1) the volcanic events that might have had the greater devastating impact upon early inhabitants, for the time interval that most likely corresponds to human occupation, will be briefly outlined in this section. Certain archaeological sites in the Quito area are some of the oldest in Ecuador (Bell, 1965) and are dated at about 11,000 yBP (Salazar, 1983).

Two volcanoes in southern-most Colombia have had important Holocene activity. Galeras volcano, near Pasto, Colombia had six eruptive periods between 4500 yBP and the historic events which left the immediate area covered in ash (Calvache, 1995; Calvache et al., 1997). The 4500 yBP event involved a collapse of the western flank of the cone. Azufral de Túquerres volcano, immediately north of the Ecuadorian border, is reported to have had three pyroclastic flows in eruptions dated between 4050 and 3500 yBP, which traveled to the SE and E, covering more than 400 km^2 of the InterAndean Valley (Fontaine, 1994) (Fig. 2).

South of the border the eruption of Soche volcano, dated at 8600 yBP (Beate, 1994), left a widespread mantle of pumice lapilli (Fig. 3) that measures 6 m deep near the volcano and is generally 0.5 to 1.5 m thick in the northern InterAndean Valley and in the adjacent cordilleras. This pumice-rich deposit would have been an obstacle to cross and would have discouraged a return of the fauna and flora for many tens, if not hundreds of years.

Imbabura volcano, located in the environs of today's highly populated Indian communities of Ibarra and Otavalo, had several eruptions in the late Pleistocene. These were characterized by numerous pyroclastic flows that descended the northeast side of the cone and left an extensive alluvial fan of pumiceous material, of limited agricultural use. A dome collapse of Huarmi Imbabura about 8000 yBP generated an avalanche that caused a large seiche in San Pablo lake, located at the western foot of this volcano, that would have destroyed any settlements located along the shores of this lake (Hall and Beate, 1991; von Hillebrandt et al., 1991; Ruiz, 2003) (Fig. 4).

The last eruptions of Cuicocha volcano, located near the cities of Cotacachi and Otavalo, are well documented. They consisted of two large ash flows generated 2900 and 3100 yBP in its caldera (the present Cuicocha lake). They traveled downslope covering the present areas of Quiroga and Cotacachi with up to 20 m of pumiceous material. They extended southeastwards to Otavalo and northwards to Atuntaqui and Imantag (von Hillebrandt and Hall, 1988; von Hillebrandt, 1989) (Figs. 4 and 5). As such, both the event itself as well as the resulting deposits would have been detrimental to cultural development. Athens (1999) describes a pre-existing cultural horizon near Otavalo, dated at 3350 and 3500 yBP, that was covered by the Cuicocha ash flows. Pitzantzi volcano and its 5690 yBP ash fall are shown in Fig. 4 (Beate, 2001).

Recent studies of Cayambe volcano (Samaniego et al., 1998; Samaniego et al., 2005), thought to be inactive until recently, have clearly shown that this center had numerous eruptions during the past 3000 to 4000 years that deposited volcanic ash over the extensive agricultural lands to the west. However, these ash layers are thin and localized, and probably did not have an important impact on any village. Pyroclastic flows and lahars are known to have descended the north flank of Cayambe during this period, however these are high, uninhabited areas. Lahars that descended the volcano's western flanks did impact Indian settlements, as fragments of pre-Columbian ceramics are found in lahar deposits near Cayambe city. In addition, a meter- thick ash bed corresponding to the 800 yBP eruption of Quilotoa volcano is observed in the soils of the Cayambe plain, indicating that the area was devastated by a major ash fall several centuries prior to the arrival of the Incas in the late 1400s (Mothes and Hall, 1999).

Pululahua volcano lies immediately north of Quito and its slopes are being occupied today by Quito suburbs. Three eruptive periods are recognized, dated at about 11,000, 10,800 to 6750, and ~2400 yBP, each one having produced pumice as well as block-and-ash flows that traveled westwards as well as eastwards into the InterAndean Valley (Hall and von Hillebrandt, 1988; Andrade, 2002) (Figs. 6 and 7). The ash falls associated with the ~2400 yBP eruption affected the Nueva Era culture near Tulipe to the west (Isaacson, 1987) as well as settlements along the Pacific coast (Isaacson and Zeidler, 1999). At San Mateo near Esmeraldas, reworked ashes cover a soil level containing ceramics, charcoal, and stone tools.

This same ash fall buried a large Late Formative settlement in Cotocollao, a northern Quito suburb, with 10 cm of ash (Villalba, 1988). Tephra that fell over the eastern flanks of Pichincha volcano was washed down into the Quito basin, where it accumulated and formed a widespread 1.5 m thick bed (Alvarado, 1996). Almost certainly, this had the effect of destroying agricultural fields as well as tule reed lakes that existed at that time and would have been the source of food and water.

Guagua Pichincha volcano, located 10 km to the west of the capital city of Quito, has had a long series of eruptions averaging one every 500 years. According to Geotérmica Italiana SRI (1989). Holocene eruptions occurred at 11,750 yBP, 8150 yBP, 1400 yBP, 980 yBP, 1582–1566 AD and 1660 AD. Recent work by Monzier et al. (2006) and Robin et al. (in press) has made slight revisions of these dates. These eruptions left ash fall deposits up to tens of centimeters-thick in the Quito basin (Villalba and Alvarado, 1999), in the InterAndean Valley, east of Quito (Hall and Mothes, 1994), and at archaeological sites to the west and northwest of Pichincha (Lippi, 1998) (Fig. 6).

Debris flows and detrital sedimentation have greatly affected the Quito basin. The erosion of the Pichincha massif and the subsequent deposition of detritus in the basin have resulted in the continuous

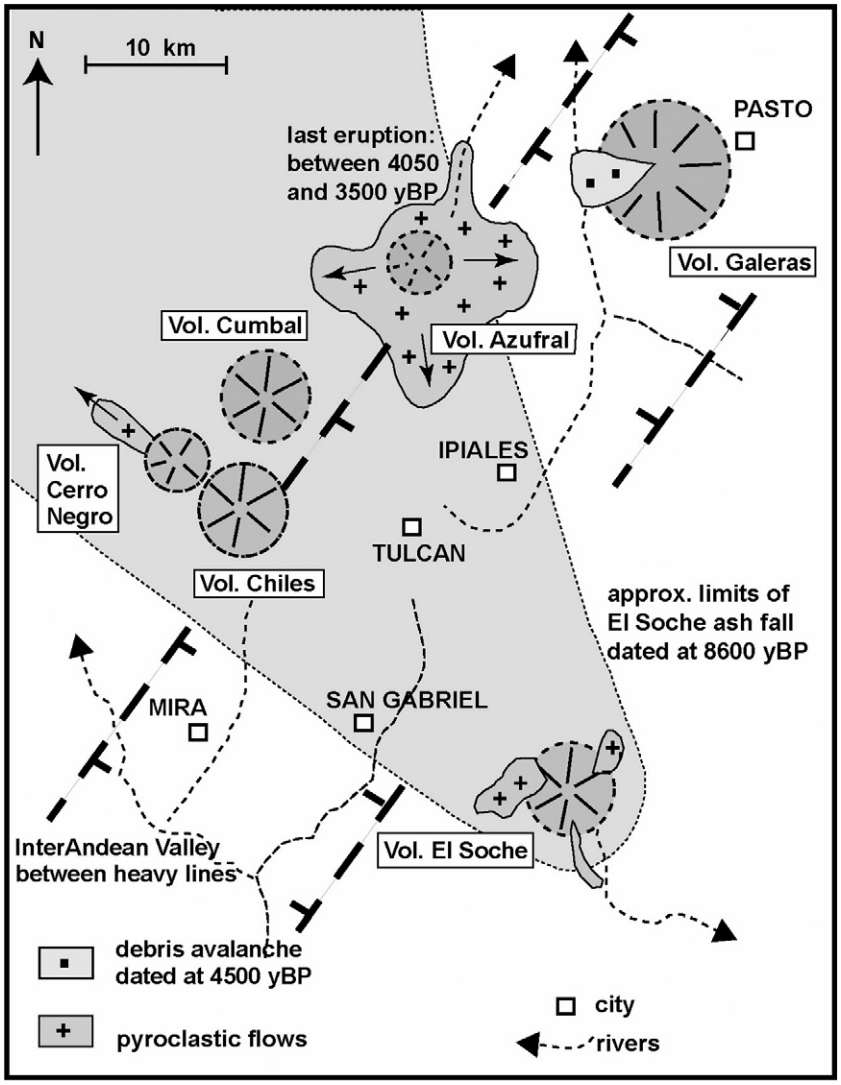

Fig. 2. Significant volcanic events of the Holocene in the border region of Ecuador and Colombia. Eruptions of Galeras, Azufral, Cerro Negro, and Soche volcanoes have affected the InterAndean Valley. Note that the same symbols are used in the subsequent diagrams.

Fig. 3. The 8600 yBP pumice fall deposit from El Soche volcano, overlying a thick soil, as observed immediately north of the volcano (see Fig. 2).

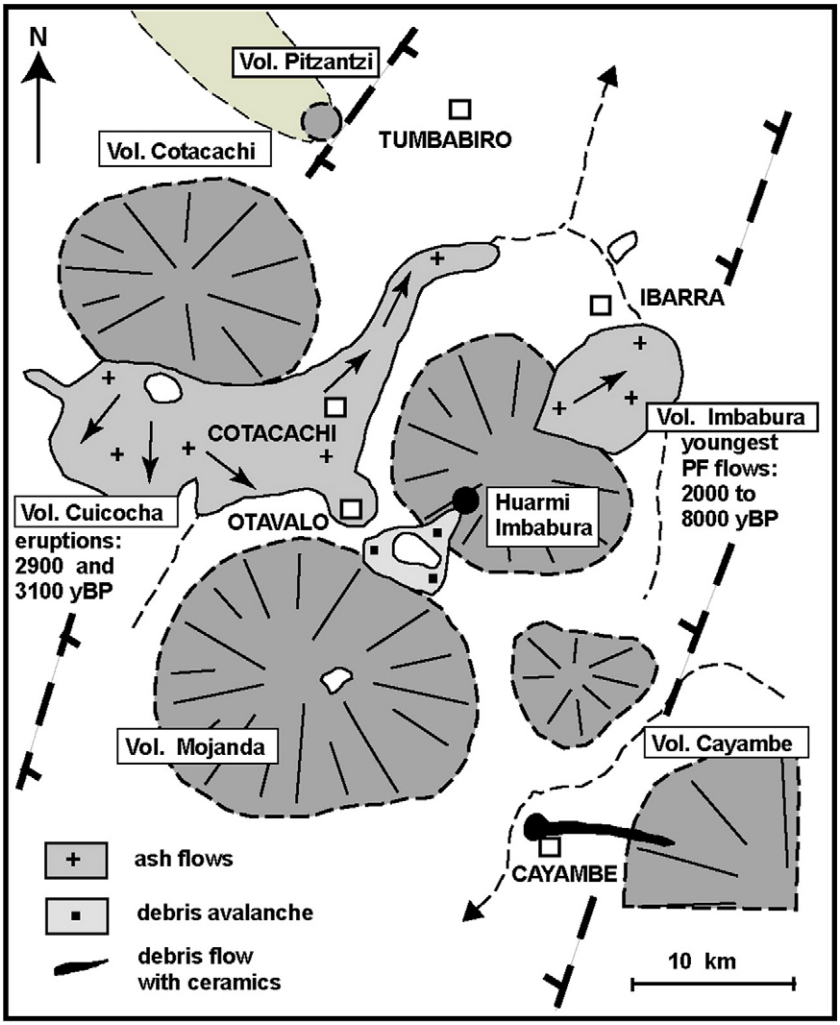

Fig. 4. Significant Holocene volcanic events of the InterAndean Valley in Imbabura Province, north of Quito. Cayambe, Cuicocha, Pitzantzi, and Huarmi Imbabura volcanoes have had eruptions during mid- to late Holocene times.

Fig. 5. Ash flow deposits of the 2900 yBP eruption of Cuicocha volcano, as seen along the highway between Cotacachi and Cuicocha Lake (see Fig. 4).

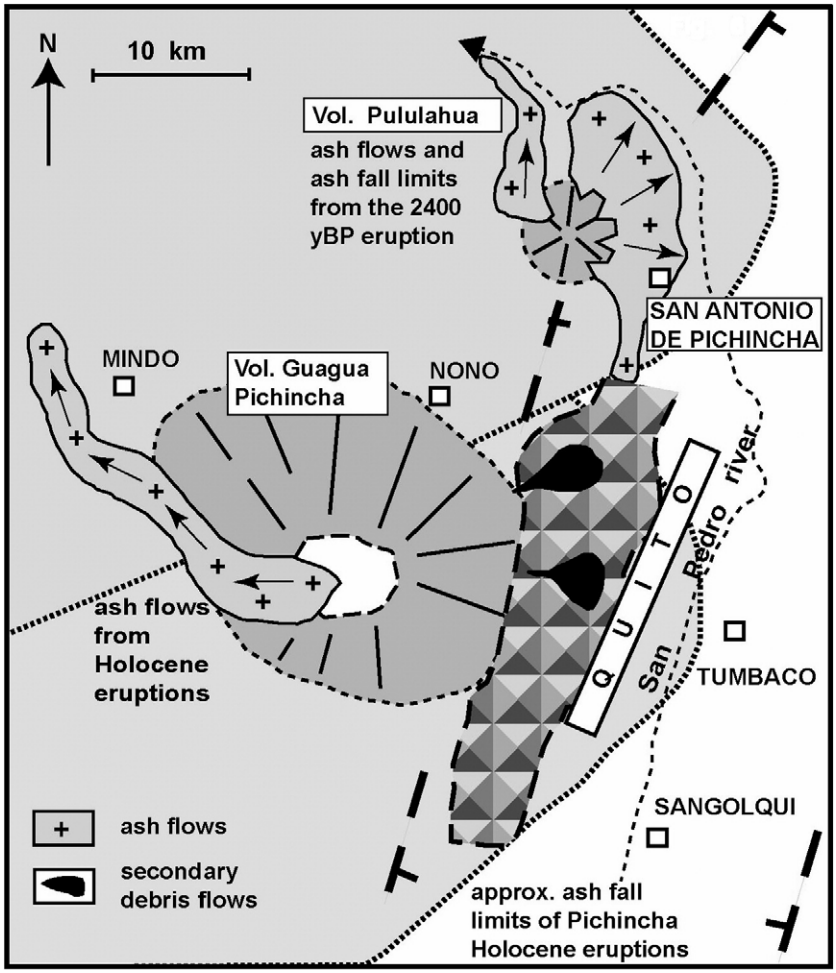

Fig. 6. Significant volcanic events of the Holocene in the greater Quito area. The eruptions of both Guagua Pichincha and Pululahua volcanoes have had important impacts in the greater Quito area.

Fig. 7. Thick ash flow and surge deposits from the 2400 yBP eruption of Pululahua volcano, as seen along the highway west of San Antonio de Pichincha (see Fig. 6).

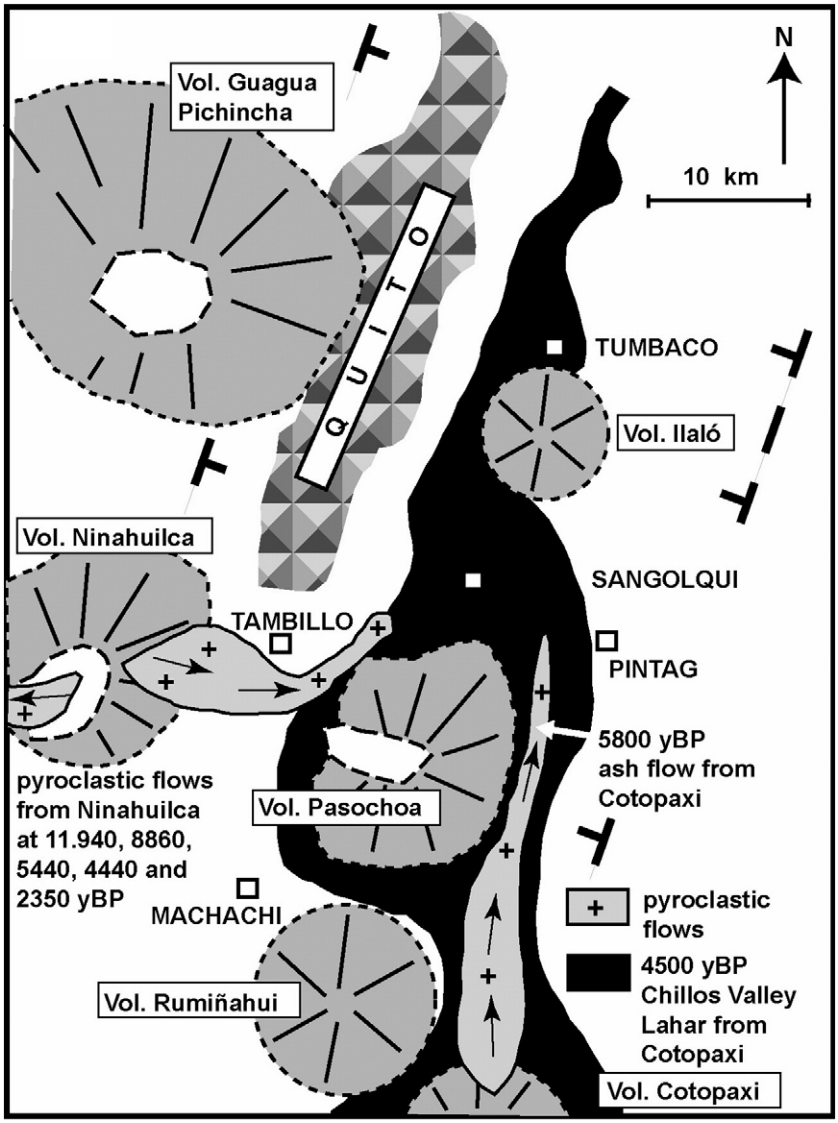

Fig. 8. Significant Holocene volcanic events in the InterAndean Valley south of Quito. Note the width of the valley covered by Cotopaxi's Chillos Valley Lahar.

burial of the surface, which amounts to several meters of sand and gravel every thousand years. As an example, there are more than 16 m of material that overlie an organic level dated at 6100 yBP in the north-central part of the basin (Alvarado, 1996). Such detrital infill had the effect of pushing the tule reed lakes toward the eastern side of the basin (El Batán), where early cultures probably resided. While buried ridged fields are found toward the middle of the basin, few archaeological remains are associated with them, suggesting that the early inhabitants did not reside there, but more likely along its margins.

The Quito basin also received ash infalls that disrupted the inhabitants. Tephra layers, both primary as well as reworked, from the 800 yBP eruption of Quilotoa, the 2400 yBP eruption of Pululahua, and others from Guagua Pichincha are readily observed in many excavations, often infilling and burying agricultural ridged fields. Ashes from a 5800 yBP eruption of Cotopaxi were washed into the basin and form a formidable layer 1–2 m thick, whose impact must have been total (Knapp, 1988; Knapp and Mothes, 1999).

The deposition of these various volcanic products probably had the effect of temporarily burying the flora- and fauna-rich paleo-lakes. These lakes were favorable sites for cultural development, offering fertile banks for agriculture and hunting. Peat layers interbedded in the lake sediments have been dated at between 6600 and 6100 yBP, and these are overlain by tephra from Pululahua and Cotopaxi, respectively.

High-discharge debris flows, formed by the remobilization of pyroclastic flow deposits on Pichincha's west side, have frequently traveled down the Cristal and Blanco rivers to the Mindo area, where Yumbo archaeological horizons are found underlying these lahar deposits (P. Mothes, unpub. notes).

Ninahuilca volcano, located at the southwest extreme of the Quito basin, has had at least five eruptive cycles during the Holocene (Maruri, 1993; Almeida, 1996). Their corresponding radiocarbon ages are 2269–2350, 4440, 5440, 8860, and about 11,940 yBP (Isaacson, 1987; Almeida, 1996; Hidalgo et al., in press). Each cycle was characterized by many pyroclastic flows that descended the western valleys of the Andes as far as Alluriquín, as well as into the InterAndean Valley, affecting the areas of today's villages of Tambillo and Amaguaña (Hall and Maruri, 1992) (Fig. 8). Their deposits are tens of meters thick and consequently would have blocked communication for an appreciable time. In addition, Ninahuilca's eruptions left important ash layers up to 10 cm thick in the Quito basin and the Machachi valley, and some evidence of ash fall layers on the coastal plain have been found.

Cotopaxi volcano's eruptions and eruptive products have had a long, continuous impact upon Ecuadorian society (Hall and Mothes,

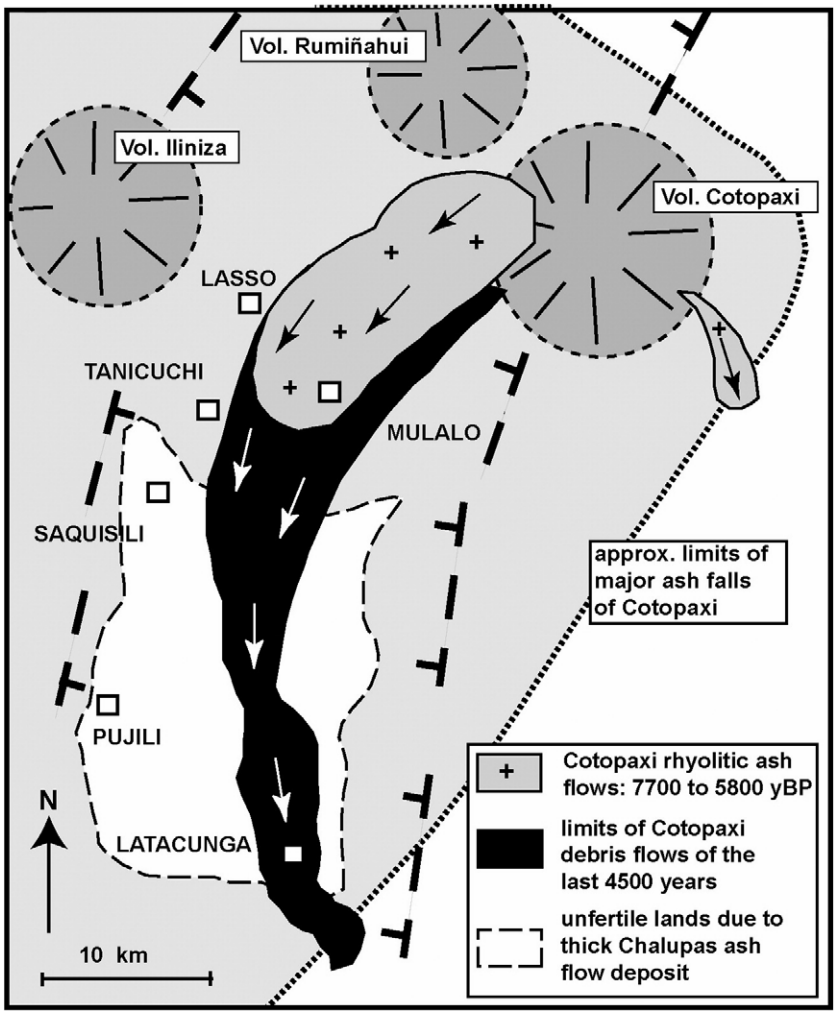

Fig. 9. Significant mid-Holocene and historic volcanic events from Cotopaxi have greatly affected the InterAndean Valley near Latacunga.

2008) (Figs. 8 and 9). During the last 4000 years the eruptive activity has chiefly been andesitic in nature, whose impacts (pyroclastic flows and ash falls) have been mainly restricted to the cone and adjacent areas. The obvious exceptions are the debris flows that have been generated upon the higher slopes of the volcano and then traveled hundreds of kilometers down the river valleys. A small Inca fortress near Cotopaxi was affected by ash falls. However, between 13,000 and 4500 yBP there was a series of six rhyolitic eruptions of large scale, each generating ash flows that traveled tens of kilometers down the western, northern, and southeastern flanks of the cone and left deposits up to 10 m thick. Thick pumice fall deposits from each cycle were left in the upper Latacunga valley directly to the west of the volcano; given the extension and thickness (>10 m) of this rhyolitic ash cover in the Latacunga valley as well as the frequency of these ash falls, it is doubtful that past cultures inhabited this valley during this long period (Fig. 10). Even today the agriculture is very marginal because of poor nutritive soils and dry porous subsoils.

One of the events of greatest impact was the Chillos Valley lahar (Hall and Mothes, 1992; Mothes et al., 1998), a cohesive debris flow that was generated by the mobilization of ash flow material by melted snow and ice during the 4500 yBP eruption of Cotopaxi. To the north this flow descended the Pita and San Pedro river valleys, leaving a mud swath up to 12 km in width in the Chillos Valley. It has been traced 326 km down those rivers to the Pacific Ocean. It also descended the Cutuchi river to the west for many tens of kilometers. The lahar left a 2 m thick deposit everywhere it traveled, which buried a soil bearing thin-walled ceramics of the Valdivian type (P. Norton, pers.com., 1992) (Fig. 11). It is interesting to speculate that the surface of the Chillos Valley lahar deposit was never again occupied in the Tumbaco nor the Chillos valleys, at least not until the Spanish came in 1534. This suggests that the indigenous cultures had recognized the permanent danger along the bottom of these valleys and/or the poor soil quality of the deposit. Archaeological studies in the Tumbaco Valley (Buys et al., 1994) corroborate this hypothesis, since no young archaeological sites are found on top of the deposit, only along the limits of the lahar deposit.

During the past 4000 years Cotopaxi's andesitic activity has frequently left thin (up to 10 cm) beds of scoria and pumice lapilli upon the flanks of the cone, but also upon agricultural areas up to 20 km to the west, northwest, and southwest of the volcano. The accumulation of this tephra forms a 10–20 m thick mantle of porous and sterile lapilli unfavorable for most agricultural pursuits. Furthermore, the valley bottoms around Cotopaxi are covered by wide rocky floodplains left by debris flows, again dissuading permanent occupation. The Inca ruins at San Agustin de Callo were affected by light lapilli falls, but luckily debris flows only arrived at the limits of their settlement because they had chosen a slightly elevated site for its location (Brown, 2001). Early Spanish settlers readily built homes and textile mills along these dangerous rivers, which were rapidly destroyed by the debris flows of the 18th and 19th centuries (Mothes et al., 2004).

During the pre-Columbian period, Quilotoa volcano, located about 45 km to the west of Latacunga and the InterAndean Valley, had only one eruption (Mothes and Hall, 1992; Hall and Mothes, in press). This

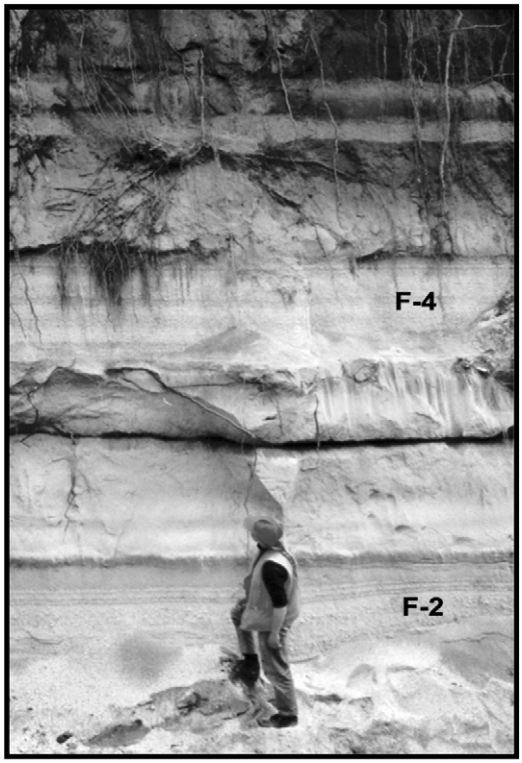

Fig. 10. The series of pumice lapilli and ash fall deposits from Cotopaxi that occurred between 8000 and 5800 yBP and covered much of the upper Latacunga Valley, as witnessed here near Lasso (see Fig. 9). The F-2 and F-4 plinian pumice units are dated at 7700 and 5900 yBP, respectively.

eruption, well radiocarbon-dated at 800 yBP, began with an ash fall of tremendous extension, as well as thick ash flows that covered much of the Toachi Valley, past home of the Yumbo culture. The ash flows filled the valleys around the volcano, leaving an arid sterile landscape that has persisted until today. More importantly, the ash fall distribution covers a very large area of the Ecuadorian Andes (Mothes and Hall, in press), permitting it to be used as an excellent stratigraphic guide unit, generally 10–15 cm in thickness (Fig. 12). It is often found filling the furrows of raised fields with the concomitant abandonment of the area by the inhabitants. Examples of this event are observed at Sigchos (Mothes and Hall, 1992), Chillogallo (Knapp and Ryder, 1983), Quito (Villalba and Alvarado, 1999), Cayambe (Mothes and Hall, 1999; Knapp and Mothes, 1999) and in the Machachi Valley.

Tungurahua volcan has been very active during the Holocene, and especially during the past 3000 years (INECEL, 1989; Hall et al., 1999; Le Pennec et al., in press). Numerous eruptions, a large sector collapse of the NW flank some 3000 yBP, and many lava and debris flows have greatly affected the floodplains of the encircling Chambo and Pastaza rivers, certainly dissuading any occupation of the area. Few archaeological sites have been found in the immediate area. Furthermore, the frequent volcanic activity, the tortuous canyon, and its steep cliffs, might have dissuaded the InterAndean Valley residents from using the obvious Pastaza valley as a communication route to the Amazon Basin, preferring instead the well-documented, less dangerous Riobamba–Huamboya–Palora route. However, in Guano to the SW of V. Tungurahua, numerous buried sites of an early Puruha culture were found by Jijón y Caamaño (1927) in the sector of San Sebastián. He reported various occupational levels that were abandoned during periods of important ash falls, then later reoccupied.

3. Discussion

Here it is worthwhile to discuss the history of the main eruptions that have affected the InterAndean Valley, as well as to infer the environmental conditions of the Holocene, with the purpose of evaluating the Valley as a hospitable, favorable site for human settlement.

3.1. Periods of eruptive activity

A revision of the more important eruptive events suggests that they may be grouped as follows: 13,000–9000 yBP, 8600–8200 yBP,

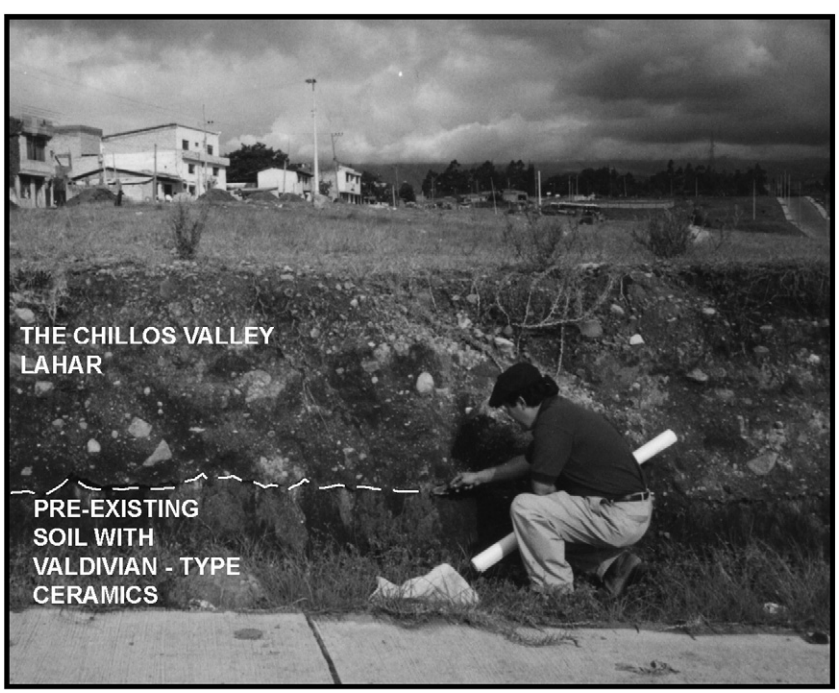

Fig. 11. Exposed in Cashaloma housing subdivision near Sangolquí, a typical deposit of the Chillos Valley Lahar (4500 yBP) overlies a pre-existing soil carrying ceramic fragments of Valdivian-type from the Early Formative Period (see Fig. 8).

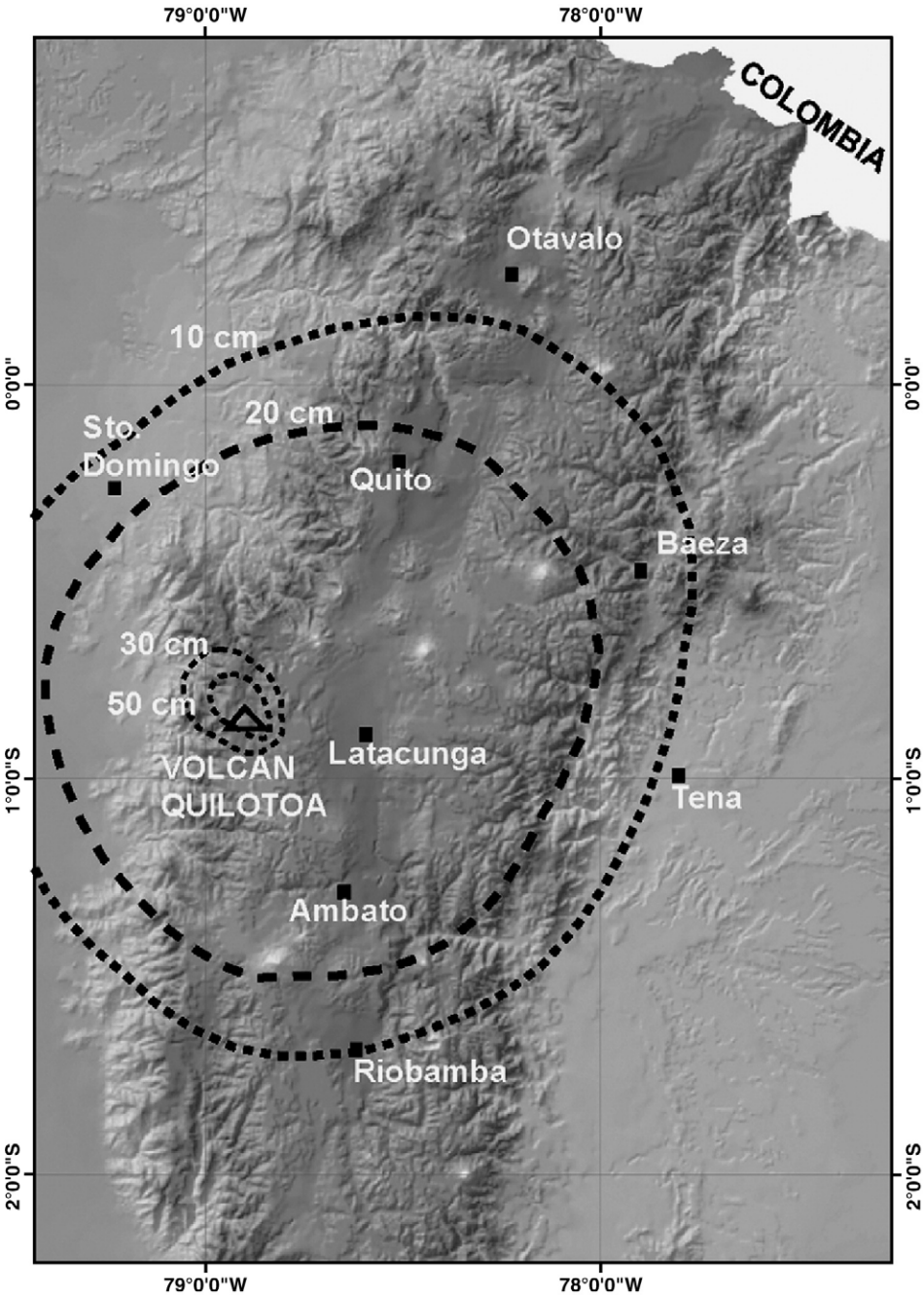

Fig. 12. Distribution of Quilotoa's 800 yBP ash that covers more than 48,000 km^2 with up to 10 cm of ash and more than 810,000 km^2 with a 1 mm layer.

7700–5700 yBP, 4500 yBP, 4050–2900 yBP, 2400 yBP, and 980–810 yBP. In each of these periods there is a large VEI>4 eruption or a series of events whose overall impact was severe. In most of these events, it was not the event itself that may have affected the inhabitants or provoked their leaving the area, but more likely it was a secondary impact, such as a widespread covering of pumice and ash that made the area inhospitable for decades or hundreds of years. Between these eruptive periods, there were relatively quiet intervals that lasted a thousand or more years, sufficiently long intervals that would apparently favor a reoccupation of the zone. As an example, a long quiet interval prevailed in the Imbabura region between 8000 and 4000 yBP that saw the introduction of maize (Athens, 1999). This tranquility ended abruptly with the eruptions of Azufral and Cuicocha volcanoes. As such, then, these periods of greater volcanic activity may have resulted in 8 possible hiatuses in the progressive development of the indigenous cultures, established in the InterAndean Valley and on the upper outer flanks of the Andes.

3.2. Character of the InterAndean Valley landscape in the Early Holocene

It is of interest to attempt to deduce the nature of the living conditions of the InterAndean Valley during its early occupation.

First, ice caps and glaciers covered the higher parts of the Cordillera Real up until 13,000 yBP and to a lesser degree during the Younger Dryas glaciation between 11,000 and 10,000 yBP (Clapperton, 1993; Clapperton et al., 1997). In the Western Cordillera cirque glaciers persisted until around 13,000 yBP but had disappeared before the Younger Dryas period, while in the Eastern Cordillera glaciers have remained at the highest elevations until the present. During these glacial periods the climate in the InterAndean Valley was apparently characterized by cooler temperatures

and windy conditions, resulting in drier, more arid conditions than today. Furthermore, it is likely that the cangahua (indurated volcanic tuff) that covers the Valley (Hall and Mothes, 1997) formed the early Holocene landscape which consisted of widespread dry grassy tablelands. These unfavorable conditions deterred the transformation of fresh ash to soil. During the Holocene the progressive warming of the climate increased the regional humidity, permitting soil development and a greater return of the vegetation. As such, the Valley slowly became more favorable for settlements, agriculture, and hunting, while the higher slopes around the Valley remained less hospitable.

As a special case, the Latacunga and Salcedo parts of the InterAndean Valley probably remained unfavorable during the Holocene, since the very thick, widespread deposits of the Chalupas ash flow (Beate, 1985) forms a porous, dry surface, essentially of little agricultural value even today (Fig. 9). Consequently, this landscape was probably not inhabited, with the possible exception of the river banks, although there too, Cotopaxi's debris-flow deposits would have dissuaded the most fervent farmer.

In conclusion, it would seem that the early inhabitants most likely lived along the floodplains of the larger rivers, and possibly along the lower slopes of the cordilleras. However, those floodplains constituted, then as today, the zones of greater risk of volcanic disasters.

3.3. Loss of favorable terrain

As we have seen, the conditions for settling, hunting, and farming in the InterAndean Valley in the early Holocene were not favorable. In addition, active volcanism continuously threatened those settlements located along river floodplains, as well as the areas immediately downwind from ash-producing volcanoes, or down slope from pyroclastic flow-generating eruptive centers. These volcanic events are sufficiently serious in their own right, possibly worse is the fact that these events often left deposits that were not favorable for agriculture, especially the more Si-rich ash-fall deposits or the rocky terrain left by debris flows. The exception would be fine-grained ash fall deposit of andesitic composition, whose minerals more readily break down and improve the soil.

As examples, the terrains covered by Holocene ash flows of rhyolitic and dacitic composition (e.g. Cuicocha, Cotopaxi, Quilotoa) are composed of porous pumiceous ashy materials, poor in nutrients. Downslope from Cuicocha lake the areas underlain by the ash flow are still only marginally useful after 3000 years. Similarly, the Latacunga valley underlain by the Chalupas deposits supports only marginal agriculture, except where streams have supplied fine-grained sediments along few floodplains. In these and other examples the ash flow deposits are so thick that the base of the flows are not exposed and the flow's direct impact upon mankind can not be verified.

Laharic deposits are common in most drainages that head on active volcanoes. Large debris flows often leave their channels and spread out hundreds of meters over the adjacent floodplains, burying previous soils under 0.5 to 2 m of rocky gravelly deposits. Such terrains remain abandoned and unusable even today. This problem is especially acute in the Latacunga and Pita river valleys due to the frequent activity of Cotopaxi volcano.

The enormous Chillos Valley Lahar is a special case, given its gigantic volume and extent that effectively covered all of the fertile land in both the Chillos and Latacunga valleys (Mothes et al., 1998). This laharic deposit has a siliceous ash-rich, silt- and fine sand-size matrix that is hard and compact, which may explain why its surface was rarely re-occupied by the indigenous inhabitants.

Ash-fall deposits also present serious, long-lasting problems, due to their widespread distribution often measured in hundreds or thousands of square kilometers, their tendency to leave a uniformly-thick layer of lapilli or ash over hills and valleys alike, and their tendency to deposit coarse scoria or pumice, especially near the volcano, which does not favor rapid soil formation especially in dry climates. However, most of these ash-fall beds are less than 10 cm thick, and possibly do not represent a severe impact. Ideally, the decomposition of fine-grained andesitic ashes generally improves the soil, while that of coarser-grained or siliceous materials do not favor the rapid development of useable soils in the relatively dry climates of the InterAndean Valley. In the Holocene the more notable ash falls have originated from El Soche, Pululahua, Guagua Pichincha, Cotopaxi, Ninahuilca, Quilotoa, Tungurahua, and Sangay volcanoes (Monzier et al., 1999; Barba et al., in press). In the case of Cotopaxi the accumulation of 20–40 cm thick pumiceous deposits in the InterAndean Valley has left a landscape whose present soil is porous, low in nutrients and organic material, and basically unsuited for agriculture or livestock. Drier climates and frequent ash coverings would delay soil formation. Examples of this are to be found in the Otavalo–Cotacachi, San Antonio de Pichincha, and the upper Latacunga valleys; all have vast ash mantles in a dry micro-climate with corresponding poor soil formation.

4. Conclusions

This study has pointed out the areas most affected by Holocene volcanic activity along Ecuador's InterAndean Valley and its timing. Because it is generally thought that the early pre-Columbian groups had migrated southward down the Valley from the north, eruptive events in and near the Valley would have had the effect of slowing or stopping their southward progress. For those peoples already established in Ecuador large eruptive events probably had the effect of persuading them to abandon the area, a conclusion reached in many of the archaeological studies referenced in the Introduction.

The greatest impact upon human settlement was probably not the short-lived violent eruptive events, but rather the extended loss of hospitable, fertile lands due to burial by eruption products. These products often cover the countryside and leave it in sterile condition, porous and low in nutrients (especially deposits of pumiceous ash falls and flows of siliceous composition), or as a surface that is rocky, indurated, and difficult to cultivate (as in the case of lahars and debris avalanches), more so when the deposits are thick. In such cases it might have been necessary to abandon the area for long periods of time, possibly hundreds to thousands of years.

Less hazardous lands for settlement and agriculture were to be found along river floodplains distant from active volcanoes. As discussed, floodplains that were overrun by volcanic events (e.g. Chillos Valley lahar) were not always re-occupied by the pre-Columbian inhabitants. The more suitable regions were the Quito, Cayambe, Ibarra, and San Pablo basins, among others. Notably, it is precisely these regions where pre-Columbian ridged field terrains are found (Knapp, 1988). Furthermore, one often observes two or three superimposed ridged field horizons in the soil profile, each having been capped by ash from a known eruption. These successive horizons confirm a long term occupation of certain areas, as well as their abandonment, since the inhabitants made no attempt to clean the ash out of the furrows and new soils formed upon the ridged field horizons. Interestingly, ridged field agriculture is thought to imply a dense population, possibly measured in thousands of residents per square kilometer (Knapp, 1988; Knapp and Mothes, 1999), implying that the ash falls would have had severe impacts upon the early residents.

Additional radiometric dating and chemical correlation of the ash layers with their sources will greatly aid on-going archaeological studies which in turn might reveal other pre-historic abandonments and migrations and clarify their nature.

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