THE GEOMORPHOLOGY OF THE RÍO TENO LAHAR, CENTRAL CHILE*

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THE lahar, or volcanic mudflow or debris flow,[1] is a conspicuous yet little known landform in Chile, especially in the Central Valley. Large lahars have been identified in the basins of the Mapocho (at Los Cerrillos and at Pudahuel),[2] Cachapoal, Tinguiririca, and Laja rivers.[3] They may also be present as subsurface features in the Central Valley between Talca and Molina (Fig. 1). South of the Río Bío-Bío large areas that appear to be laharic are found in

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[1] J. B. Scrivenor (The Mudstreams ("Lahars") of Gunong Keloet in Java, *Geol. Mag.*, Vol. 66, 1929, pp. 433–434) and R. W. van Bemmelen (The Geology of Indonesia [3 vols.; The Hague, 1949], Vol. 1A, pp. 191–194) introduced the word "lahar" into earth-science literature to describe the volcanic mud and debris flows that occur frequently in Java. The term refers to a wide range of textures and does not require that the volcanic material be the direct result of volcanism.

[2] A controversy exists over the origin of the deposits in the Santiago area. J. E. Guest and G. P. Jones (Origin of Ash Deposits in the Santiago Area, Central Chile, *Geol. Mag.*, Vol. 107, 1970, pp. 369–381) argue that internal "pipe" structures indicate a nonwelded ignimbrite deposit of pyroclastic flow origin, but Kenneth Segerstrom, Octavio Castillo U., and Eduardo Falcón M. (Quaternary Mudflow Deposits Near Santiago, Chile, *U.S. Geol. Survey Professional Paper 475–D,* Washington, D.C., 1964, pp. 144–148) imply a secondary volcanic mudflow from an area of primary ignimbrite deposit high in the Andes. Since Guest and Jones recognize that the "pipe" structures might also develop in hot lahars, the issue appears to be unresolved at the moment. Romulo Santana-Aguilar (Les cendres volcaniques de la vallée du Cachapoal-Rapel (Chili), *Cahiers de Géographie de Québec,* Vol. 15, No. 35, 1971, pp. 315–332; reference on p. 330) favors the laharic explanation of these deposits.

[3] See Segerstrom, Castillo, and Falcón, *op. cit.* [see footnote 2 above]; Jean Borde: Les Andes de Santiago et leur Avant-Pays, Étude Géomorphologie (Bordeaux, 1966), pp. 286–291; Donald D. MacPhail: El gran lahar del Laja, *in* Estudios Geográficos (by Eusebio Flores S. and others; Santiago, 1966), pp. 133–155; reference on pp. 133–135; and Santana-Aguilar, *op. cit.* [see footnote 2 above].

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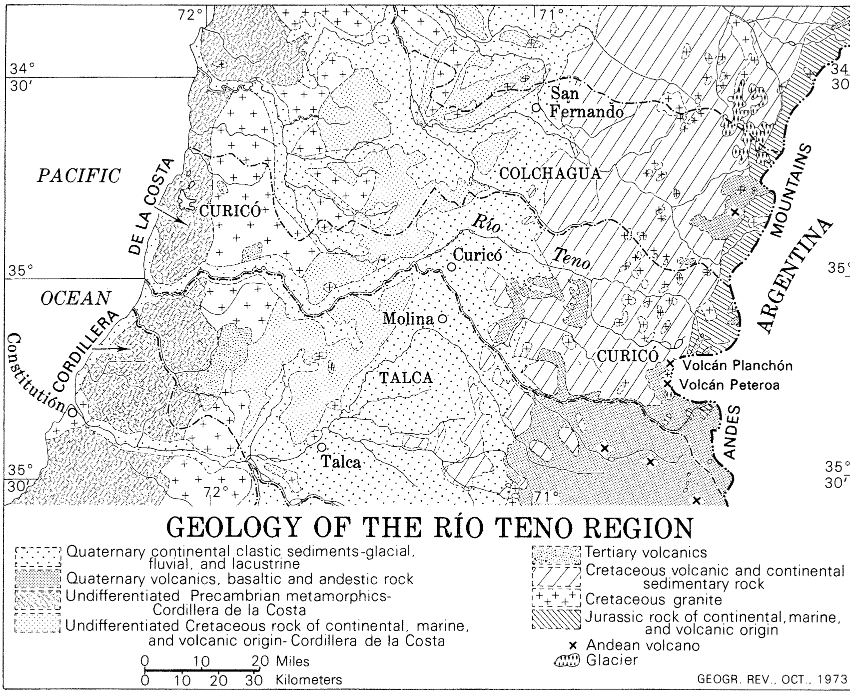

FIG. 1—Regional geology of Talca, Curicó, and Colchagua provinces. The main area of the Andes, composed of Cretaceous volcanics and sedimentaries with numerous small areas of Cretaceous granite, lies between the Central Valley (a zone of Quaternary continental clastic sediments) and the Quaternary volcanic area along the Argentine border. The Río Teno lahar, northeast of Curicó, is shown in Figure 2. (Adapted from "Mapa Geológico de Chile" [Instituto de Investigaciones Geológicas, Santiago, 1960].)

the vicinity of Collipulli, along the Río Malleco, and south of Victoria in the basin of the Río Cautín. The focus of this paper is the 293-square-kilometer area along the Río Teno, about 10 kilometers north of Curicó, where several thousand small hills, or *cerrillos*, dot the landscape (Fig. 2).[4]

Regional Relationships

The Río Teno lahar, an exceptionally clear example, is easily distinguished from the adjacent alluvial plain, both on the ground and

[4] Random hand samples were collected during a comprehensive field survey in 1967 for subsequent laboratory analysis, and large-scale aerial photographs and topographic maps were studied. Photogrammetric analysis of fifty-five randomly selected cerrillos was undertaken because of some of the peculiarities of the mound fields revealed on large-scale (1:20,000) photo-maps.

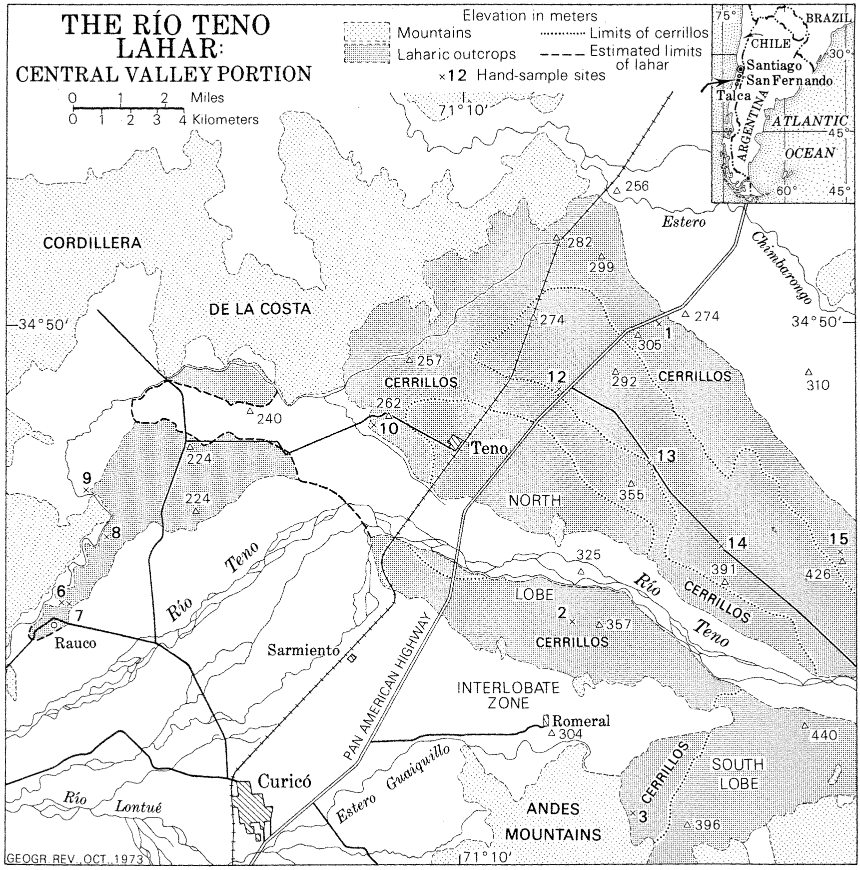

FIG. 2—Distribution of the Río Teno lahar in the Central Valley, north of Curicó.

from the air (Figs. 3, 4, 5, and 6). Acacia-covered cerrillos protrude from fields that are larger and marked by a more extensive and complex irrigation and drainage network than on smaller fields laid out on the alluvium. The surface of the lahar stands 25 to 30 meters above the alluvial plain on the north and about 40 meters above the plain on the south.

The hardened volcanic material of the Río Teno lahar forms an elongated, two-lobed fan (Fig. 2). The larger lobe, which is 13.7 kilometers wide, stretches from the foothills of the Andes northwestward across the Central Valley to the Cordillera de la Costa (Coast Range). The shorter and smaller lobe, 5 kilometers long and 4.5 kilometers wide, veers to the southwest from the principal lobe 6.7 kilometers east of the village of Romeral.

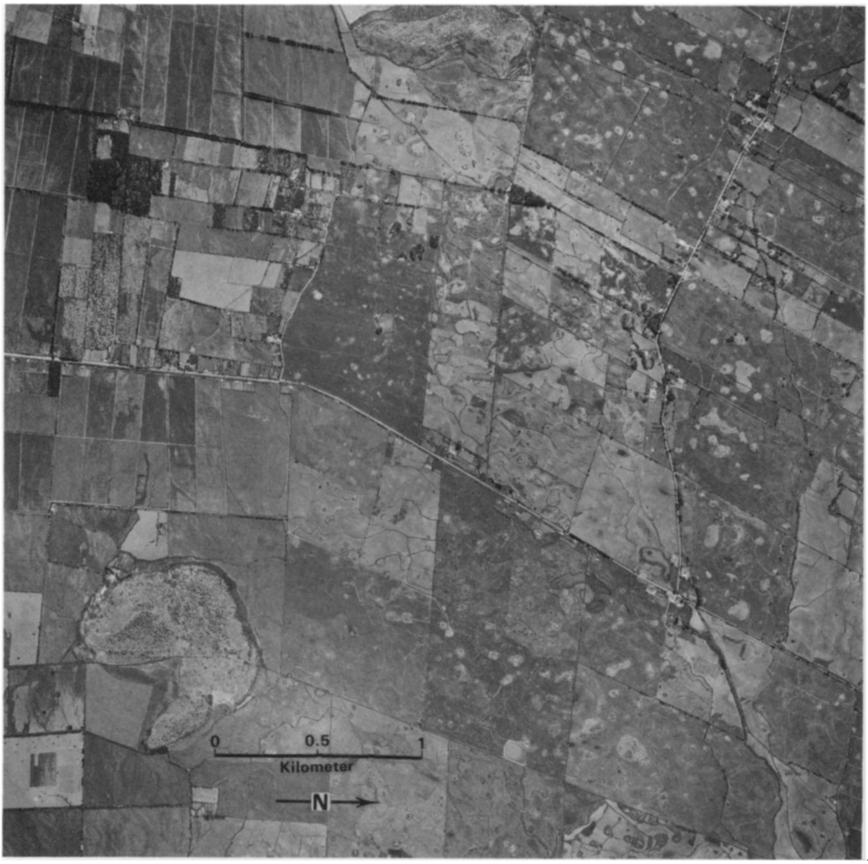

FIG. 3—Aerial photograph of the southern margin of the main lobe of the Río Teno lahar, taken just north of Romeral on November 28, 1961. Hundreds of cerrillos dot the lahar (right). To the left of the two crescent-shaped outcrops of bedrock is the intensively cultivated alluvial plain in the interlobate area. (Photograph courtesy of the Instituto de Investigación de Recursos Naturales of the Corporación de Fomento de la Producción.)

The lobes apparently represent a prehistoric flow of mud and debris that descended the valley of the Río Teno from the Andes. They can be traced along the surface of the high river terraces as far upstream as the resort community of Los Queñes (Fig. 7). These terraces, which flank the middle course of the Teno between Los Queñes and the Central Valley, are capped with an additional 7 to 10 square kilometers of volcanic breccia.

Large lateral moraines, identified on aerial photographs and confirmed by subsequent field checks, appear in the valley of the Río

Claro, a tributary of the Río Teno, 15 kilometers south of Los Queñes and on the same terrace system from which the lahar emerges farther down valley. Valley glaciation, heading into the volcanic massif that rings Planchón and Peteroa volcanoes, on the Argentine border, and the formation of the Río Teno lahar may have occurred during the same period. The correlation has yet to be demonstrated by glacial and soil field studies, however.

The distance along the Claro and Teno rivers from the base of the volcanic peaks to the terminal limit of the lahar is approximately 87 kilometers. This distance is considerable, and the mass that moved down the valley of the Teno was enormous. At least 8.8 billion cubic meters of mud, sand, and erratic stones or blocks were deposited in the Central Valley. This calculation assumes an average thickness of 30 meters, which is a conservative estimate; another 70 to 100 million cubic meters may have layered the terraces of the middle Teno. An estimated total of 8.89 cubic kilometers is equivalent to a hypothetical cone 1 kilometer high with a base 5.8 kilometers in diameter.

The Río Teno has partially breached the large northern lobe of the lahar, although it still flows about 25 meters above the surface of the alluvium in the interlobate area that runs parallel to it east of Romeral. The configuration of the contours on the large-scale topographic map of the site indicates that a well-formed alluvial fan underlies the lahar.[5] The east–west surficial slope of the fan is gently concave, dropping 16 meters per kilometer near the apex and 8 meters per kilometer in the lower part. The northwest–southeast gradients across the laharic surface closely parallel the slope; however, the slightly convex upper region becomes gently concave in the middle section of the deposit.

Physiognomy of the Río Teno Lahar and Its Mound Fields

The cerrillos, or hummocks, form distinct mound fields, but they are not found everywhere on the surface of the lahar. They appear instead as elongated zones that roughly parallel the longer axis of the laharic lobes (Fig. 2). They are especially prominent on the outer and terminal margins of the lahar, although one group arises in the central part of the northern lobe. The hummocky areas are as much as 8 to 12 meters higher than the smoother, oblong depressions adja-

[5] "Curicó 3445–7100," 1:50,000 series (1st edit.; Instituto Geográfico Militar de Chile, Santiago, 1965).

FIG. 4—Panorama of irrigated farmland in the central mound field, Río Teno lahar. The rounded, symmetrical cerrillo, approximately 20 meters high and 90 meters long, joins the cerrillo behind the eucalyptus grove to form a monticulate crest.

FIG. 5—An acacia-covered elongated cerrillo on the main north lobe of the Río Teno lahar.

FIG. 6—Near Los Queñes (Site 18) the lahar rests on a terrace overlooking the present floodplain of the Río Teno.

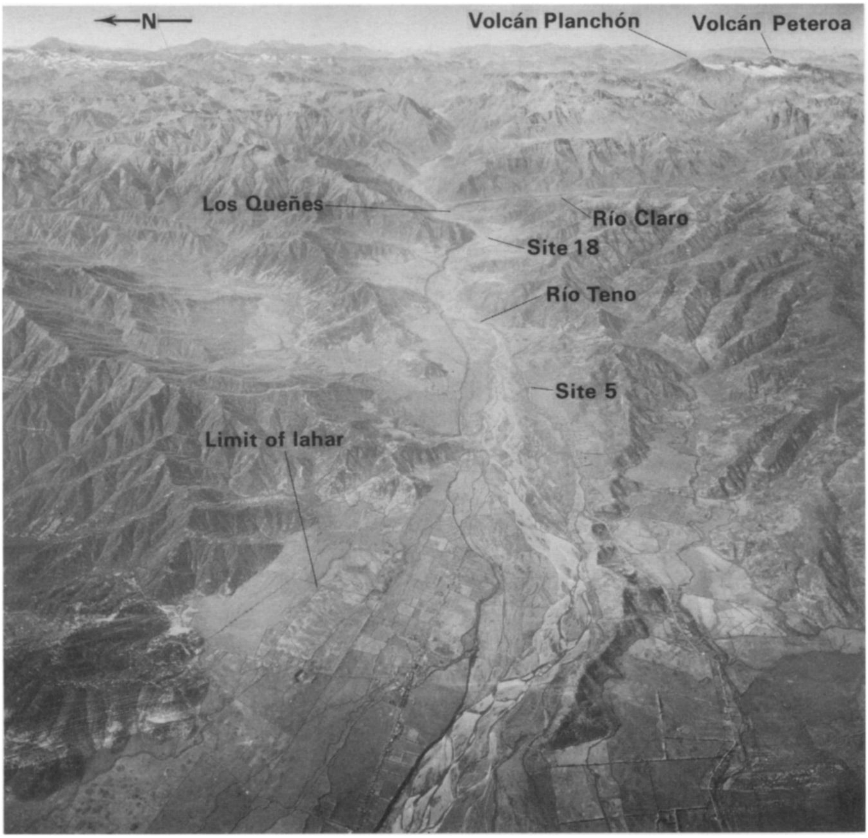

FIG. 7—Oblique aerial view of the middle stretch of the Río Teno, looking eastward toward Argentina, taken in 1944. The Río Claro, whose headwaters are on the flanks of Planchón and Peteroa volcanoes, has a classic glaciated profile in its upper reaches, in contrast with the V-shaped profiles of the valleys downstream from Los Queñes. (Photograph courtesy of the Instituto Geográfico Militar.)

cent. The lower, more level sectors are difficult to explain, for no strong evidence confirms that they are products of postdepositional stream erosion. They may be subsidence phenomena.

A random sample of fifty-five hummocks was analyzed stereometrically. The height of the samples ranged from 2.6 meters to 11.6 meters. The largest proportion (42 percent) rose between 4 and 6 meters; almost two-thirds, however, were between 4 and 8 meters high. The bases of the mounds varied from 11.2 to 123.9 meters in length. The dominant base measurements of the mounds increased by a rough factor of ten over the height. Thirty-eight percent of the hillocks measured between 40 to 60 meters at the base, and almost two-thirds were calculated to be between 40 and 80 meters.[6]

The laharic mounds are also abundant on the terraces of the middle Teno, downstream from the confluence of the Río Claro with the Río Teno (Fig. 7). On the first major south-bank terrace, downstream

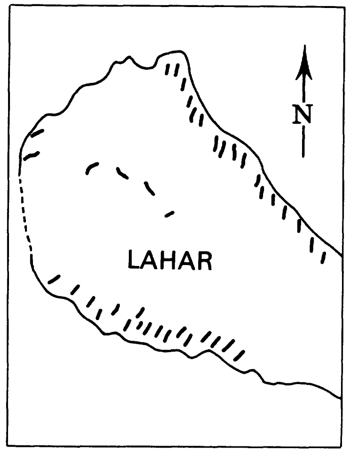

FIG. 8—Schematic of the parallel orientation of monticulate crest lines along the margins of the northern lobe of the Río Teno lahar.

and to the west of Los Queñes, part of the hummocky terrace surface has been obliterated by stream action. There, the lahar rests on 27.4 meters of stratified alluvium and volcanic ash, which are the chief components of the valley bluffs of the present river (Fig. 6). Farther west, along the south bank of the Teno (Fig. 7, Site 5), the laharic debris is 10.4 meters thick and is situated on the alluvial gravel exposed for another 2.4 meters. The contrast in the physical attributes of the laharic and alluvial strata is striking. The texture of the laharic matrix is gritty, and the enclosed erratic stones are subangular. The alluvium, on the other hand, is silty and smooth to the touch; the stones of the stream gravel are well rounded and polished.

In the mound fields, especially on the margins, the hillocks commonly form low ridges. Hundreds of monticulate crests have been

[6] The standard error (.95) is 0.72 meters in height and 5.8 meters in base dimension for fifty-five random stereometric observations.

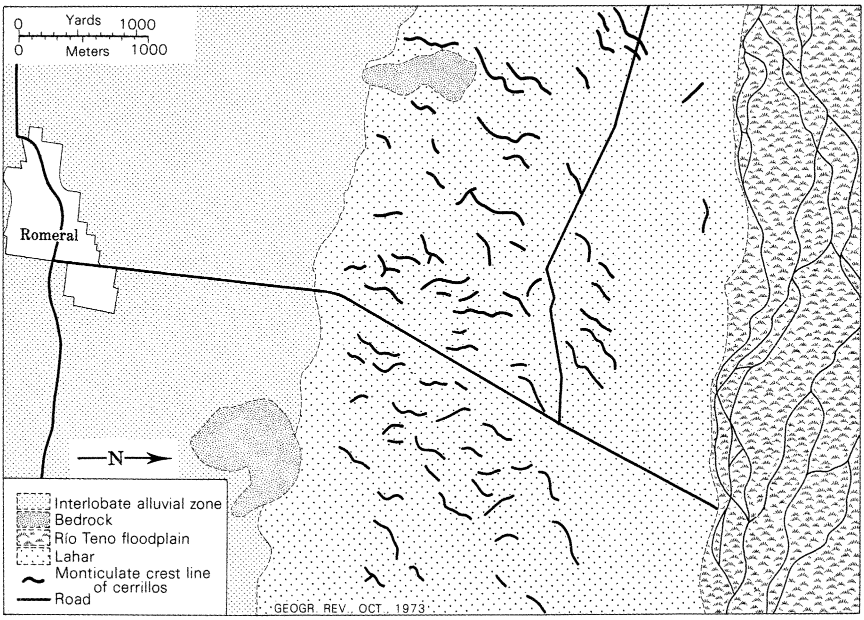

FIG. 9—Monticulate crest-line patterns of cerrillos on the southern flank of the northern lobe of the Río Teno lahar. The same area is shown in Figure 3.

created by coalescing cerrillos on both the northern and southern flanks of the lahar (Fig. 8). They are also found, though to a lesser extent, in the area of the central mound field (Fig. 4). The crests range in length from 100 to 400 meters, but most are from 100 to 200 meters long. A distinguishing feature of the low ridges is a prevailing axial orientation of the roughly parallel crest lines with respect to the adjacent margin of the lahar (Fig. 9). Aerial photographs reveal that the drainage and irrigation systems also parallel the crest lines. The hummocks themselves tend to group lineally or in tandem, in an extension of the crest-line pattern. Because no evidence of postdepositional erosion is clearly visible where the elongated crests are found, these features are presumed to result from deposition of the lahar and to be associated with the dynamics of movement in the laharic flow. In the central mound field, orientation is more random than it is along the northern and southern limits of the lahar.

LITHOLOGY

The lahar is grayish and consists of subangular to subrounded fragments of porphyritic to fine-grained andesite ranging from silt-sized grains to boulders several meters in diameter. An assemblage of fragments that represent three distinct andesitic lithologies makes up nearly 80 percent of both the erratics and the matrix. A finely vesicular porphyry with a black, glassy groundmass is most abundant. Another porphyry, almost as common, shows flow lines of small andesine laths in a dense black groundmass. A third has large phenocrysts of labradorite and olivine in a gray, felty groundmass. In the rocks examined, unzoned labradorite and magnesium-rich olivine make up most of the large phenocrysts; andesine, with minor oligoclase, forms the majority of the smaller phenocrysts and microlites. The presence of magnetite in minutely disseminated grains explains the dark color of individual clasts.

Rocks other than andesites are rare. Only a half-dozen grains of chert and granite are present in the seventeen thin sections of matrix examined, and no such rock appears in the pebble-sized samples. Only two pebbles show the well-rounded outlines characteristic of stream sediments, which is remarkable in view of the broad belt of Cretaceous continental sediments and granites plus Quaternary alluvium that lie between the lahar and its probable source area. The monolithic composition suggests that the lahar traveled in hydraulic equilibrium down the Río Teno Valley.

The matrix of the lahar is composed principally of silt and sand-sized grains interspersed among the larger fragments. Fewer than 10 percent are clay-sized, and many of these seem to be finely comminuted andesite glass and plagioclase. The total content of interstitial clay minerals is about 4 percent. Roughly rounded bubble cavities, up to 1 or 2 millimeters in diameter, are common in the finer matrix samples and indicate a mudflow origin.[7]

Alteration

Clasts in the lahar show small and variable amounts of alteration. In a few fragments the olivine phenocrysts are partially replaced by bowlingite, calcite, and kaolinite and the plagioclase phenocrysts contain calcite, chlorite, chalcedony. Fractures in the groundmass are marked by poorly crystallized reddish clay, probably iron-rich montmorillonite. In several fragments the magnetite grains are extensively altered to hematite.

[7] William B. Bull: Alluvial Fans and Near-Surface Subsidence in Western Fresno County, California, *U.S. Geol. Survey Professional Paper 437-A*, Washington, D.C., 1964, pp. A24–A26; and Dwight R. Crandell: Postglacial Lahars from Mount Rainier Volcano, Washington, *U.S. Geol. Survey Professional Paper 677*, Washington, D.C., 1971, p. 6.

Differences in the extent to which lithologically similar fragments have been modified probably indicate that the weathering processes in the source area affected only rocks near the surface. If hydrothermal alteration was significant, it presumably occurred in zones high in the Andes. Further change after the lahar came to rest is best indicated by delicate chloritic rims lining some of the bubble cavities in the finer-grained matrix and by pervasive limonite staining seen in the near-surface matrix samples but not in those from the base of the lahar. When the chronology of other lahars in similar climates becomes better known, it may be possible to use these late diagenetic alterations to estimate the age of the deposits.

Geochronological Considerations

A reliable date for the Río Teno lahar could be useful in establishing the geochronology of the Quaternary period in Central Chile. The lahar appears to be late Pleistocene; samples were collected to calculate a more precise estimate.

What looked like vegetal remnants at Site 3, near the Estero Guaiquillo (Fig. 2), and at Site 18, on a terrace about 30 meters higher than the floodplain of the middle Teno (Fig. 7), were collected for carbon-14 dating. Fossil plants were embedded in the basal part of the matrix, presumably where the lahar passed over vegetation growing on the valley bottom. Unfortunately, carbon was not sufficient for determining age. Only a scant 0.03 percent of carbon remained in the rock mass tested. X-ray analysis showed essentially the same mineral content in the fossil and in the surrounding matrix; thus the "fossils" were only casts.

Possible Origin of the Lahar

Until recently the origin of most laharic deposits in Chile was identified as glacial. Descriptions of the Cerrillos de Teno, for example, mentioned drumlins[8] and moraines.[9] Jean Borde, a geographer on the Faculté des Lettres et Sciences Humaines of the Université de Bordeaux, was one of the first scientists to recognize the significance of the Chilean lahars.[10] The first published identification of the Río Teno as a lahar appeared in 1964, among the descriptions

[8] Juan Brüggen M.: Fundamentos de la Geología de Chile (Instituto Geográfico Militar, Santiago, 1950), p. 221.

[9] Humberto Fuenzalida Villegas: Orografía, *in* Geografía Económica de Chile (rev. edit.; Santiago, 1965), pp. 6–34; reference on p. 21.

[10] Borde, *op. cit.* [see footnote 3 above].

of soils issued by the Chilean government's Proyecto Aerofotogramétrico.[11]

The dominantly volcanic character of the Río Teno rocks indicates that the source area is in the vicinity of Peteroa and Planchón volcanoes (Figs. 1 and 7). Between the high Andes and the Central Valley is a large area consisting of Cretaceous volcanic and continental sedimentary rock and of Cretaceous granites—rock types that are noticeably absent in the lahar. Also, aerial photographs show glacial geomorphic features only to the east of Los Queñes, not adjacent to and west of it, where the lahar is located. Thus the designation of the Río Teno cerrillos and associated materials as features of glacial deposition are not supported either by theoretical rationale or by empirical data.

To reconstruct one sequence of events that could have produced the great lahar along the Río Teno, it may be useful to recall the formation of lahars on the flanks of Volcán Calbuco east of Puerto Montt, Chile, in 1961. As a result of the violent interaction of incandescent lava with the mountain's ice cap during an eruption, lahars were discharged down three flanking valleys, which they filled with a chaotic mixture of erratic blocks and mud.[12] Even though the lahars were hot, no conspicuous mound fields were reported or photographed in the terminal area, perhaps because blocks sufficiently large and numerous were not involved in the lower valley areas after the eruption. Erik Klohn reported that one of the lahars which reached the shores of Lago Llanquihue, 11.3 kilometers north of the volcano, was still steaming ten days after deposition yet had hardened sufficiently after two days to permit the passage of motor vehicles over its surface.[13] He also noticed that escaping steam formed small craters on the surface, and he estimated that fresh lava constituted about 30 percent of the mass.

A succession of events similar to the Calbuco eruption may have occurred in the headwaters of the Río Teno, but an eruption in the upper Teno watershed, including the Río Claro area, would have had to be of much greater magnitude than that of Calbuco. The moraines along the Río Claro indicate that the valley may have been

[11] "Suelos, Descripciones, Proyecto Aerofotogramétrico Chile/O.E.A./B.I.D.," *Inst. de Investigación de Recursos Naturales (IREN), CORFO, No. 2,* Santiago, Chile, 1964, p. 365.

[12] Alfred Rittmann: Les Volcans et leur Activité (Paris, 1963), pp. 98–102.

[13] Erik Klohn: The February 1961 Eruption of Calbuco Volcano, *Bull. Seismol. Soc. of America,* Vol. 53, 1963, pp. 1435–1436.

occupied by glacial ice for several kilometers below the Planchón-Peteroa massif when the lahar was formed. A sustained eruption could have produced a massive amount of ash and debris and could have transformed a large quantity of ice into water almost instantly.

Several other possible sources of the lahar can be hypothesized. Meltwater from rapid ablation of valley glaciers or the sudden release of a glacier-dammed lake in the upper valley, perhaps during a strong seismic shock, is possible. A "rain" lahar could have occurred—though this seems improbable because of the enormous mass of material set in motion. Hot gases might have contributed to the down-valley movement of the Río Teno deposits,[14] but the lithology of the deposit indicates that it was not so formed. Although a few rock fragments contain altered glassy material, the matrix is predominantly nonvesicular. Dwight R. Crandell maintains that except for its great size and length the Río Teno lahar might have been formed by a block-and-ash flow.[15] It is possible that mud was extruded directly from the volcanoes in Chile, as it was in Japan and California;[16] it would be difficult, however, to account for the large blocks and for the paucity of clay in the Río Teno lahar.

Whatever the cause, the mud-and-rock mass descended into and across the Central Valley, where the Cordillera de la Costa blocked further movement downstream. After the lahar came to rest, the river attempted to reestablish its course. In the process, it may have flowed initially across the surface of the lahar in several distributaries, some of which cut into the lahar. The process continues today as the Río Teno dissects the lahar in the Central Valley. In the middle section of the valley, the Río Teno more easily breached a thinner region of the tough volcanic breccia, and the laharic material is now cap rock on the surface of 30-meter terraces (Fig. 6).

Crandell wisely cautions that a single deep lahar may cover every

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[14] Charles M. Gilbert: Welded Tuff in Eastern California, *Bull. Geol. Soc. of America,* Vol. 49, 1938, pp. 1829–1862, especially pp. 1854–1859; Howel Williams: Glowing Avalanche Deposits of the Sudbury Basin, *Ontario Dept. of Mines Sixty-fifth Annual Rept., Vol. 65, Part 3,* Toronto, 1957, pp. 57–89; and Robert L. Smith: Ash Flows, *Bull. Geol. Soc. of America,* Vol. 71, 1960, pp. 795–841.

[15] Personal communication, Jan. 13, 1972.

[16] Y. Ōinouye: A Few Interesting Phenomena on the Eruption of Usu, *Journ. of Geol.,* Vol. 25, 1917, pp. 258–288, especially p. 274; Cordell Durrell: Andesite Breccia Dikes near Blairsden, California, *Bull. Geol. Soc. of America,* Vol. 55, 1944, pp. 255–272, especially pp. 260–261; and Ryohei Morimoto and Joyo Ossaka: Low Temperature Mud-Explosion of Mt. Yaké, Prefs. Nagano-Gifu, Central Japan, on 17th June 1962 as an Example of Endogenous Katamorphism of Volcanic Rock at the Destructive Stage of the Volcano, *Bull. Volcanologique,* Vol. 27, 1964, pp. 49–50.

preexisting terrace in a valley before the fluid material drains down the valley.[17] Thus the lahar on the high terrace system is not necessarily the oldest. The entire valley may have been temporarily inundated with material from a lahar of the magnitude of that of the Río Teno.

Possible Origin of the Cerrillos

The cerrillos present an interesting problem. Were they formed around large erratics that came down with the great mass of mud, sand, and other debris, or are they the result of subsidence in areas where hot gases and liquids escaped immediately after deposition, as Borde suggested?[18] Could they be a type of erosional remnant? This is a possibility, although a remote one.

The mound fields of the Río Teno lahar may have originated, as field and laboratory evidence suggests, in the same manner as those in other parts of the world did.[19] The surface morphology seems to coincide with differential fluid flow and with subsidence. Where road cuts and quarries expose the cores of the hillocks in the Río Teno area, the overall rock texture observed was coarser than in the adjacent laharic mass, owing to greater numbers of erratics. Observed diameters of smaller fragments found in such mounds ranged in size from 1 or 2 centimeters to 50 or 70 centimeters. Similar dimensions were observed in the White Island mudflow of 1914 in New Zealand.[20]

Subsidence may have played a role in the formation of the cerrillos.[21] Water probably did provide the lubrication needed to transport the enormous mass, and a considerable amount of water could have been present during the movement. And although the texture may vary, the exposed profiles of the cerrillos manifest the same matrix composition and the same type of erratic found elsewhere in the lahar. Microscopic study of samples taken throughout the lahar shows a consistent grain-to-grain contact. All of the foregoing, together with the roughly parallel alignment of the monticulate crest lines along the edges of the lahar, strongly suggests that the hum-

[17] Crandell, *op. cit.* [see footnote 7 above], p. 7.

[18] Borde, *op. cit.* [see footnote 3 above].

[19] C. A. Cotton: Volcanoes as Landscape Forms (Christchurch, London, and elsewhere, 1944), pp. 247–253; and Cliff Ollier: Volcanoes (Cambridge, England, and London, 1969), pp. 79–80 and 161–162.

[20] J. A. Bartrum: White Island Volcano, *New Zealand Journ. of Sci. and Technol.*, Vol. 8, 1925–1926, pp. 261–266. More recently, Crandell (*op. cit.* [see footnote 7 above], pp. 18–22) reported mound fields on a postglacial lahar that originated on Mt. Rainier.

[21] Borde, *op. cit.* [see footnote 3 above].

mocks result from fluid processes of deposition, not from subsidence per se.

In summary, the properties of the Río Teno lahar that collectively argue for its essentially volcanic rather than glacial or alluvial origin are: the presence of mound fields, which occur in many of the world's lahars; the thick laharic fill that is found where the valley widens, far from the probable volcanic source, and is deepest in the Central Valley; the extremely high percentage of volcanic materials and the absence of other rock types over which a glacier would have passed (Figs. 1 and 7); the low content of clay-sized materials, which are common to most glaciers; the fact that this lahar is interbedded with alluvial material near the Estero Guaiquillo, a Río Teno tributary; and the presence of many air spaces, formed by air trapped in the matrix.[22] The monticulate crest lines may prove to be another criterion of identification. If the crest lines of the cerrillos are a product of glacial deposition, it will be difficult to explain the roughly parallel alignment of the crests and intervening drainageways along the margins. Finally, on the basis of evidence accumulated to date, it is hard to say whether the lahar was hot or cold at the time of deposition.

Environmental Significance of the Chilean Lahars

Even though we still do not understand completely the great Chilean lahars, they appear to have flowed during the Pleistocene, when glacial activity was more intense than it is now.[23] The lahars covered deep alluvial soils and left thick layers of hard volcanic rock debris as they descended the valleys of the Andes. As the Río Teno area reveals, the impact of the lahars on the present environment has been considerable. Highly productive soils, with the capacity of being used intensively, were replaced by soils of marginal capability, and the quality of the land diminished substantially.[24] The soils are exceptionally stony and impervious, and drainage problems are serious. The abundance of soil moisture generally has an adverse effect on the planting of wheat, one of the principal crops of Central Chile. Every cultivated area in the hollows among the mound fields contains at least one rock pile, and rock walls (for which the subangular boulders

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[22] D. R. Mullineaux and D. R. Crandell: Recent Lahars from Mount St. Helens, Washington, *Geol. Soc. of America Bull.,* Vol. 73, 1962, pp. 855–869; reference on pp. 857–859; and Crandell, *op. cit.* [see footnote 7 above], pp. 3–8.

[23] Luis Lliboutry: Nieves y Glaciares de Chile: Fundamentos de Glaciología (Santiago, 1956), pp. 425–430.

[24] Suelos, Descripciones [see footnote 11 above].

are admirably suited) separate the fields (Fig. 4). The cerrillos, in addition to supporting stands of acacia, sometimes serve as building sites, as places in which to accumulate bothersome stones from the fields, and as rock quarries.

The common occurrence of the lahar as a geomorphic entity in Central Chile will require a substantial reevaluation of the physical character of the Central Valley. The persistent popular image of the region is one of immense fertility, because of deep and extensive alluvial soils;[25] yet the most productive soils are in fact restricted to densely populated and isolated enclaves in the great longitudinal trough. Truly prime agricultural lands are limited and are often separated from each other by surficial or subsurface laharic deposits that contribute only to marginal productivity when they are cultivated. Comprehensive knowledge of the lahars is fundamental for effective regional management and planning, because they produce one of the significant "problem" landscapes of the country. Alternatively, they suggest the importance of conserving the limited amount of highly productive land to feed the nation's growing and dominant urban population.

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[25] See Pierre Crossen: Agricultural Development and Productivity: Lessons from the Chilean Experience (Baltimore and London, 1970); and Theodore W. Schultz: Transforming Traditional Agriculture (New Haven and London, 1964).