QUATERNARY OF SOUTH AMERICA AND ANTARCTIC PENINSULA

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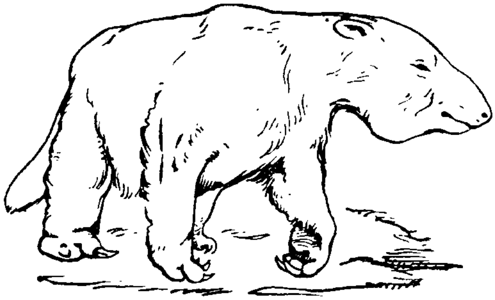
VOLUME 6



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QUATERNARY OF SOUTH AMERICA AND ANTARCTIC PENINSULA

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Contents

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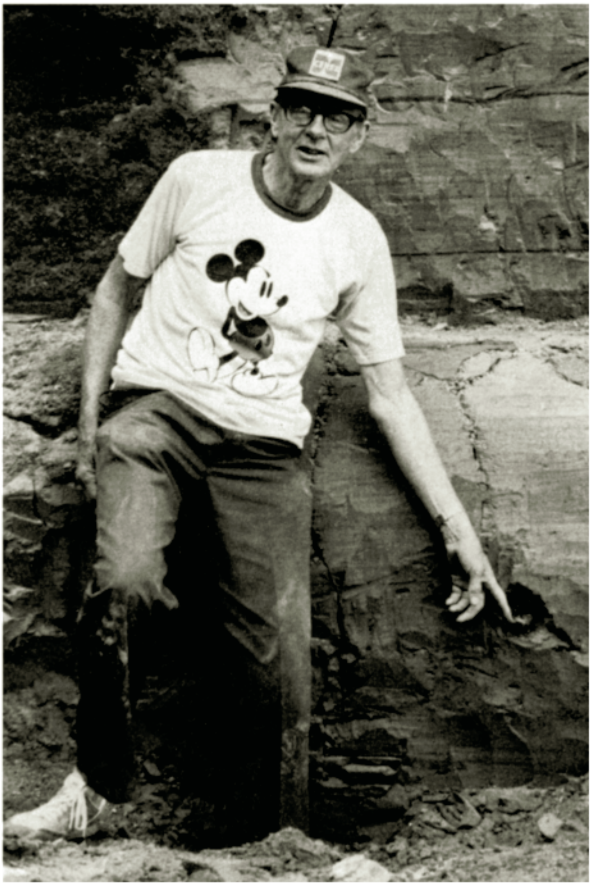
Obituary – John H.Mercer 1922-1987

John Mercer of the Byrd Polar Research Center (formerly the Institute of Polar Studies), Ohio State University, died on July 3, 1987. His passing represents a great loss to all of Quaternary science but specially to those of us engaged in studies in the southern hemisphere.

The original thoughts John was able to express so elegantly in his writing will endure forever. George Denton once said to me: "You think you are the owner of a great thought, and then you discover that John has already written about it". He wrote about the importance of marine ice sheets and the role their inherent instability has played in the history of glaciation. He first proposed an unstable glacial history for the West Antarctic icesheet. Furthermore, he was one of the first to suggest a link between the late-glacial climatic oscillations of northwestern Europe and the break-up of marine ice sheets in the Arctic. He was also a pioneer in proposing mechanisms to link glacial and climatic dynamics on a global scale.

John graduated from Gordonstoun School at the beginning of the World War II. He joined the British Marine Service and spent the war travelling the oceans of the world including the hazardous North Atlantic route from Canada to Russia. On three occasions boats he served on were sunk or incapacitated by enemy action. Following the war he studied geography at Cambridge, and it was then that he travelled to Patagonia beginning a love affair with South America that would continue all his life.

The early trips were adventurous. In 1947, together with H. Gianolini, he attempted to walk across the South Patagonian icefield. The



JOHN H. MERCER 1922-1987

expedition almost succeeded, but bad weather and a sick colleague prevented a successful crossing. Later, in the 1950's he participated in Eric Shipton's successful expeditions to the South Patagonian icefield. These early experiences undoubtedly were fundamentally important in stimulating his interest in the climatic history of the region. During these trips he made enduring friendships with the "estancieros" who referred to him as their "Señor Johnny".

John's discovery of Feruglio's descriptions of the interbedded glacial and lava flows on Cerro Fraile led to one of his most important accomplishments in South America. By applying the most up-to-date dating techniques to the older glacial deposits of the mesetas, he was able to demonstrate a history of glaciation extending back to the Late Miocene.

John was also interested in more recent glacial history. The Lake Region of Chile was his favourite area. "El Alto" was a familiar figure to the residents of Puerto Varas. In reference to his studies in the Lake Region of Chile, Steve Porter commented that John had an uncanny knack for discovering important sites. John is credited with having compiled a glacial chronology for the latest Quaternary history. He provided dates for the major events: the maximum of the last glaciation, the last major readvance, and the initiation of deglaciation. He remained a firm non-believer in the existence of glacial and climatic events that were equivalent in timing to the Younger Dryas Stade of the North Atlantic.

John made pioneering glacial studies in the Chilean Channels during which he established a chronology for neoglaciations which is the standard for South America. John also conducted studies on the Quelccaya icecap of Peru and made important contributions to its recent glacial history.

He also studied glacial geology in Alaska, the Canadian Arctic, Greenland, New Zealand, and Antarctica. I once asked him if he had ever felt guilty about devoting his life to something so esoteric as climate studies. He replied that he had and, as a consequence, had spent two years in Samoa surveying the island's population.

Those of us who were fortunate to study with John knew him as a shy, gentle man who detested arrogance and pomposity. Above all he was a field scientist with a love for the simple things in life: a night under the Patagonian stars; the crackle of a calafate camp fire; the smell of burnt mutton; and the warmth afforded by a glass or two of wine from a penguin jug.

Like many others I was introduced to South America field studies by John Mercer. He was a stimulating and enjoyable field companion whose friendship I will deeply miss.

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The diamictons of Río Blanco basin, Cordón del Plata, Mendoza

ABSTRACT

Both the sediments and the geomorphic setting of the diamictons along Río Blanco on the piedmont east of the Cordón del Plata indicate that they could not have been deposited there by a glacier tongue, as I and several earlier observers have suggested. Rather, they must have been deposits of long-runout debris flows, as argued by Polanski. Below 2600m, which is the altitude of the most extensive moraines of the last major glaciation, a late Pleistocene debris-flow fan fills the valley. From 2,200 m to the mountain front the narrow, V-shaped valley could not have been scoured by glacial ice. The debris flows that deposited these piedmont diamictons incorporated glacially transported clasts, so some of the flows recognized along the Río Blanco trench may have taken place when glacier ice lay in the cirques and upper valleys. Others, however, probably are unrelated to glacial events.

RESUMEN

Un nuevo examen de los diamictos y su correspondiente geomorfología en la parte pedemontana al este del Cordón del Plata indican que ellos no pudieron haber sido depositados por una lengua glacial, como lo han sugerido mis estudios anteriores y los de varios investigadores. En contraposición, esos diamictos son depósitos de flujos de escombros, como lo sugirió Polanski. Rasgos litológicos indican que las corrientes de escombros que depositaron los diamictos comenzaron en o pasaron pos una de las morenas que fueron transportadas por los glaciares. Algunos de los flujos de escombros pudieron haber ocurrido durante una glaciación mayor, cuando una lengua

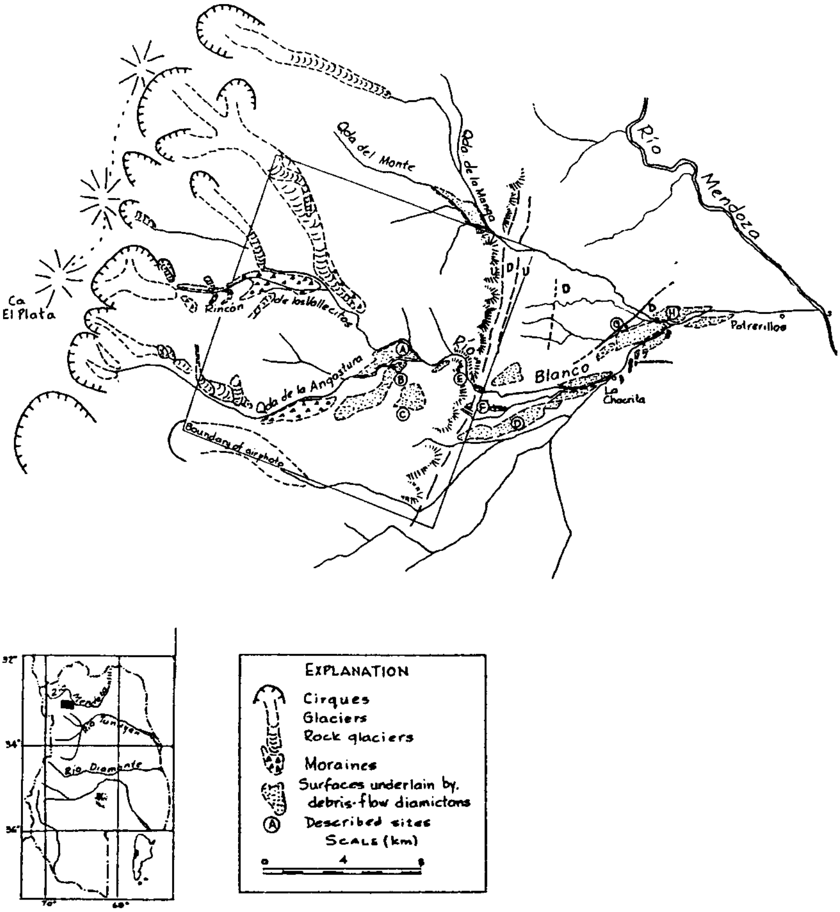

Figure 1. Distributions of diamictons in the Río Blanco basin. Letters indicate the locations of sites mentioned in the text. "D": down-faulted block; "U": up-faulted block. Map prepared from NASA ERTS E-2022-13455, 13 Feb. 1975 and airphotos, scale 1/50,000, from the Institute of Military Geography, Argentine Army.

glacial llenaba el circo y la parte superior de la quebrada aguas abajo del circo. Sin embargo, ninguna de las capas de diamictos localizadas en la parte más baja de las morrenas extremas de la última glaciación, cuya altitud alcanza 2600 m, fueron depositadas directamente por un glaciar; es probable que algunos de los diamictos fueron depositados por flujos durante intervalos interglaciales. Ningún glaciar pudo haber pasado por la quebrada, la cual es angosta y tiene una clara forma de "V".

INTRODUCTION

Recently, Wayne and Corte (1983) and Wayne (1984) reiterated the concept that glacial ice may have extended a considerable distance onto the piedmont east of the Cordón del Plata during the Pleistocene and interpreted the sediments to include deposits of at least four glaciations. These conclusions were based on the presence of three identifiable diamictons beyond the outermost moraines of the last major glaciation and several other features of these sediments that made reasonable their identification as till. These specific features are:

1. Their lithology, which is similar to that of unquestioned tills higher in the valleys.
2. The surface textures of many of the quartz grains, which indicate glacial grinding.
3. Presence of a few striated quartzite boulders in the diamictons.
4. A boulder fabric in some exposures that would have been expected as a result of glacial deposition.
5. Valley walls that had been scoured and polished by glaciers larger than those that deposited the moraines of the last major glaciation in them. In addition, the large size of most of the cirques suggests strongly that they have been occupied by glaciers several times, not just once.

A more thorough study and analysis of the deposits and their geomorphic relationships, however, has caused me to question our earlier interpretation that these diamictons were deposited by tongues of glacial ice that extended onto the piedmont. Rather, I now believe it to be more likely that all the diamictons below and beyond the most extensive moraines of the latest or Vallecitos (=Wisconsin/Würm) glaciation (Figure 1), about 2600 m in the basin of Río Blanco, were deposited as debris flows, as suggested by Polanski (1953, 1962, 1966). It is my purpose in this report to clarify and modify, where necessary, the interpretations presented earlier.

CHARACTERISTICS OF DEBRIS FLOWS AND THEIR SEDIMENTS

Although the importance of mudflow and debris-flow sediments in the accumulation of alluvial fans on the piedmont of semiarid mountains has long been recognized (Blackwelder, 1928; Sharp and Nobles, 1953; Polanski, 1953, 1962, 1966; Beaty, 1963, 1974), both the process and the deposits have been investigated more thoroughly only in recent years (Lindsay, 1968; Fisher, 1971; Hsü, 1975, 1978; Innes, 1983; Costa and Williams, 1984). Many diamictons that result from debris flow are difficult to distinguish from ice-laid till; debris flows are as capable as glaciers of transporting huge blocks of rock for long distances. Debris flows generally contain large amounts of rock flour (silt and sand-sized particles) but little clay. The final sediment produced may range from clast-supported, with insufficient fine material to fill the interstices, to a matrix-supported material with scattered clasts.

Because diamictons produced by mudflow or debris flow and those deposited by glacial ice often appear indistinguishable (Dreimanis and Lundqvist, 1984), several recent efforts have been made to find means to differentiate them. Landim and Frakes (1968) found that, although some overlap existed, statistical evaluation of clay-to granule-sized particles generally permitted these different sediments to be identified. Most fabric studies of diamictons have involved ice-laid sediments, and glacial geologists have generally thought of mudflows as developing either weak fabrics or none. Lindsay (1968) and Mills (1984), however, demonstrated that mudflows and debris flows also develop fabrics, and that under some conditions the fabric is similar to that in a till. Fisher (1971) showed that some mudflow/debris flow deposits show inverse grading--that is, the coarsest clasts are near the top. Inverse grading, however, is not particularly evident in many exposures of debris-flow diamictons.

In review papers, Polanski (1966) and, more recently, Innes (1983) pointed out that confusion has long existed in the terminology of the materials deposited by debris flows and summarized the conditions reported to cause them to take place. They also indicated that much work remains to fully understand debris flows and their deposits. In this report, I have used the term diamicton, which was introduced by Flint, Sanders, and Rogers (1960a, b) as a nongenetic term to apply to mixtures of unsorted debris with a range of clast sizes from clay to large boulders. Most of the other terms available for sediments of this type have genetic implications (till, till-like), are inappropiate (fanglomerate), or awkward (pebbly mudstone), although a term proposed by Harrington (1946), cenoglomerate, appears to be equally nongenetic and was the one preferred by Polanski (1966).

Diamictons deposited by debris flows are likely to change in composition from their distal to proximal zones. The lead or distal part of a debris flow generally is highly charged with large clasts, but farther upstream, where larger amounts of water become mixed with the sediment, clast sizes generally become smaller and the frequency of large fragments diminishes. It may be difficult, therefore, to identify the diamicton resulting from a particular debris flow along a valley unless outcrops are virtually continuous. Late phases of debris flows become muddy stream flow, and often anastamosing channels are cut into the top of the diamicton deposited in the early part of the episode by the surges of floodwater that follow debris deposition (Beaty, 1963). See also Pierson (1986).

Debris flows, like all flows, follow existing channels, filling them with sediment and spilling over onto an adjacent valley flat only if the sediment volume is sufficiently great or if boulders provide temporary blockage (Beaty, 1963). Both in and out of channels, the frontal margin of most bouldery debris flows is blunt and lobate. Mudflows and debris flows of small magnitude are fairly common, but those capable of moving long distances involve large volumes of debris (Hsü, 1975) and take place much less frequently. Large ones involve immense masses of rock debris that move rapidly down a steep mountain slope, generating so much kinetic energy that motion may continue for distances of several kilometers through foothill valleys and across the more gentle piedmont slopes. Debris flows may be wet or they may be nearly dry. Freshly deposited debris-flow sediments may be remobilized by subsequent surges and so continue downslope or down valley after they have stopped one or more times.

Large scale debris flows--including those with which we are concerned in this report--may originate in several ways (Polanski, 1966; Eisbacher, 1982). Commonly, they result from supersaturation of an unconsolidated or weathered mantle on steep slopes, either as a result of intense storms (Beaty,

1963) or from the rapid melting of a thick snowpack. They may also result from sudden outbursts of glacial meltwater that is heavily loaded with debris or from the rupture of a moraine or glacier dam that holds a lake (Lliboutry **et al.**, 1977; Clague **et al.**, 1985). An additional means, and one that involves some of the largest volumes with greatest runout, is the rockfall-generated Sturtzstrom described by Heim in 1882 (Hsü 1975; 1978).

Debris flows that originate on weathered slopes are likely to incorporate a large amount of weathered rock debris; those that involve steep morainal accumulations or emerge from the margin of a glacier should include a high proportion of fresh rock material. Huge rockfalls from a mountain cliff may result in great masses of both weathered and fresh debris. Debris flows take place periodically, spasmodically, catastrophically. Small ones may occur regularly; large ones are relatively infrequent and individual events may be decades or centuries apart (Whalley, Douglas, and Jonsson, 1983). Frequencies of very large scale, long-distance-runout debris flows are evidently variable, some on the order of decades or less (Plafker and Eriksen, 1978), yet others may be separated by millenia or longer periods of time.

RIO BLANCO VALLEY DEPOSITS

Diamictons are exposed in many places along the Río Blanco valley between the moraines in the valleys of Angostura, Vallecitos and Potrerillos (Figure 1), and are dominated by abundant large quartzite clasts, most of which are fresh and unweathered. Non-quartzite clasts, mainly granites and rhyolites, constitute 5-20% of the rocks in diamictons. Most of the diamictons are matrix-supported, although in a few exposures the number of cobble-to-boulder-sized clasts is so great that the matrix scarcely fills the interstices. The matrix contains a small amount of clay but is dominated by silt, sand, and granules. Although most of the sand-sized grains in the diamicton are rock (quartzite) fragments, 10 to 20% are single-crystal quartz grains, many of which have surface textures characteristic of glacial grinding (Wayne, 1984; Wayne and Corte, 1983). At least 4 separate beds of diamicton are exposed along Río Blanco in stream and road cuts.

A large fan-shaped and boulder-strewn accumulation separates the channels of the two creeks, Angostura and Vallecitos, that join to form Río Blanco (Figure 1, site A; Figures 2, 3, 4). From just above their junction at 2200 m to the outermost moraine about 2600 m, its average slope is 8 degrees. Both creeks, Angostura and Vallecitos, flow along the lateral margins of the fan where they were forced by the sediment accumulation. Cleanly swept banks along Arroyo Angostura expose two diamictons beneath the surface, which is covered by a network of shallow, anastomosing channels that are bordered by levees. The uppermost diamicton is medium gray (2.5Y 5/4), 3 to 4 m thick where it is exposed through midfan, and is capped with a loess veneer 20 to 30 cm thick. The boulders that litter its surface are probably a lag produced by washing shortly after deposition. It overlies another diamicton, somethat browner (10YR 4/3), that has remnants of a weathered zone at its top; the lower diamicton matrix is calcareous, as are all the diamictons exposed farther downstream along Río Blanco, but the upper one is not. A similar fan has formed at the piedmont edge where Quebrada de la Manga emerges from the mountain front (Figure 1). The channels cut into its surface, however, are more sharply defined and fresher looking than those on the surface of the head of Río Blanco.

Along its south valley wall, Arroyo Angostura has undercut a slope in which two additional superimposed diamictons can be examined (Figura 1, site B; Figure 2). The lowermost part of this exposure (Wayne and Corte, 1983, figure 7; Wayne, 1984, p. 406) is a calcareous diamicton that contains grusified granite clasts, a strongly developed buried alfisol profile has been developed on it. This buried paleosol is overlain by a thick (6m) boulder-rich diamicton that has an aridisol profile with a 20 cm thick stage III petrocalcic horizon (Birkeland, 1984, p. 357-359) and thin silt cap. The calcium carbonate grains in the matrix of this and the other diamictons downstream along Río Blanco must be secondary, deposited by groundwater movement. No carbonate rocks have been recognized in the basin of Río Blanco.

The additional diamictons are presented beneath much higher surfaces in this area. One caps the ridge that extends eastward from the moraine-choked middle segment of Quebrada de la Angostura but is about 200 m above the present creek bed (Figure 1, site C). This diamicton has a thick stage IV petrocalcic horizon and the igneous boulders in it are highly weathered. It was deposited along the valley of Arroyo Vallecitos when it

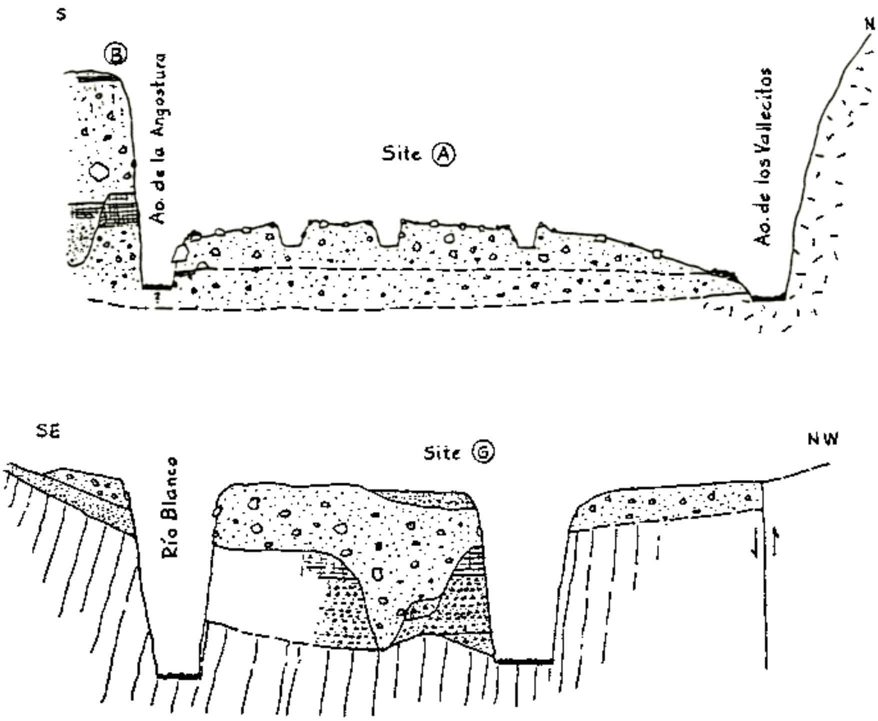

Figure 2. Diagrammatic sections across the Río Blanco valley at Sites B-A and at G.

flowed southeastward as a tributary of Río Tunuyán, before it was diverted eastward into Río Mendoza (Wayne, 1985). The other forms the cap of the Mesón del Plata just to the east of the mountain front. The soil profile on it, too, is an aridisol with a thick petrocalcic horizon;
traces of shallow channels are still recognizable on the surface of the Mesón del Plata (Figure 1, site D).

Two diamictons are exposed in at least 4 places through the "narrows", a rock-walled twisting valley of Río Blanco downstream from the junction of the two creeks that form it (Figure 1, site E; 2,5). East of the front of the Cordón del Plata, Río Blanco flows through a steep-walled trench cut below the piedmont plain and exposes in several places the sediments, both diamictons and alluvial gravels, that underlie the sloping alluvial surface. Two narrow ridges of diamicton

Figure 3. Part of airphoto N° 6904B-40-5512 showing valley characteristics between lower Vallecitos moraines and piedmont.

stand above the alluvial slope that has been cut across the sediments filling the Río Blanco valley. The ridges are topographically lower than the deposits of the Mesón del Plata, yet clearly higher than those beneath the alluvial plain. The soil profile on the one that stands as a low ridge in midvalley near the west end of the Mesón del Plata is an aridisol with a strongly cemented K horizon about 30 cm thick (Figure 1, site F). Both quartzite and rhyolite boulders are present along the ridge.

Figure 4. Bouldery surface of debris flow fan upstream from the junction of Arroyo Vallecitos and Arroyo Angostura (Site A).

Previous workers (Corte, 1957; Polanski, 1953; Wayne and Corte, 1983) have recognized only a single diamicton within the valley and below the remnant that caps the Mesón del Plata. Although only one diamicton, generally overlying and/or capped by bouldery gravel, can be seen in most of the cleanly swept cliffs along Río Blanco, at least 3 are present within the sediment fill of the valley. Two of these can be seen in almost continuous section along a small tributary that enters Río Blanco across a concrete-surfaced ford upstream from Potrerillos (Figure 1, Site G). In this group of exposures, which are on the downthrown side of a fault with a displacement of a few 10's of meters, a poorly sorted thin basal gravel (diamicton?) rests on red Tertiary sandstone. It is overlain by a bed of coarse gravel capped by a noncalcareous red (2.5YR 5/8) sandy silt bed about 2 m thick (Figures 2, 6). The level top of this alluvially deposited fine-grained layer is buried beneath a younger bouldery diamicton, olive (5Y 5/3) in color, which not only covers the old alluvial surface but also fills a gully that evidently had been eroded through the beds beneath it (Figure 7). It can also be seen as a greenish-gray layer capping the steeply dipping Tertiary rocks of Los Mogotes Formation along the south side of the valley of

Figure 5. Two superimposed diamictons exposed in the narrows of Río Blanco valley (Site E).

Río Blanco between La Chacrita and Potrerillos, and its lobate margin overlaps an alluvial fan that was deposited by a small stream emerging from the badlands south of Río Blanco. Although rock chips are common, few boulders can be seen at the surface. The soil profile contains a large amount of silt and there is a Bk horizon (stage II+) at a depth of 40 to 60 cm beneath the surface. In some places, a post-depositional stream has planed the surface and covered it with alluvium (Figure 2). The diamicton that caps the Tertiary sediments on the north side of the stream at site G (Figure 2) contains a noticeable number of strongly weathered rhyolitic clasts, in contrast to the high abundance of quartzites in the thick diamicton exposed along the stream. These features indicate that two different diamictons are exposed at this site.

ORIGIN OF THE DIAMICTONS

The dominance of quartzite clasts in the diamictons along Río Blanco suggests that most of them came from the upper part of Quebrada de la Angostura, although the presence of rhyolitic material means that at least some of the debris came from one

Figure 6. Diamicton overlying irregular surface on Tertiary sandstones, with a second and younger diamicton filling a gully cut through it (Site G).

of the Vallecitos valleys. A virtual absence of striated cobbles and boulders in the Río Blanco diamictons was cited by Polanski (1953) as a line of evidence against glacial deposition, but alpine glaciers generally produce few striated clasts. Evenson et al. (1986) have pointed out that a high proportion of the sediment attributed to valley glaciers and deposited as till has really been moved little by ice; rather, most of it is delivered by running water or rock fall to the ice, which may deposit it after minimal transport. Even though only 4 striated clasts were observed in this investigation, they along with the presence of glacially fractured quartz grains make it seem likely that the diamictons in the Río Blanco valley between the lowest moraines (about 2600 m) and Potrerillos (1400 m) were derived at least in part from glacially deposited sediments. Unfortunately, whether the debris flows that extended so far down the piedmont slope were generated from the front of an active glacier, from saturation of moraines and weathered rock debris in the upper valley by intense storms or by snow-pack melt can not be determined. Relative dating and internal stratigraphy indicate that several such events took place through a long span of time, perhaps several hundred thousand

Figure 7. Two diamictons with intervening alluvial sediments exposed in piedmont channel (Site G).

years, after erosion had cut the valleys to their maximum depth, and as the river has re-excavated the alluvial and mud-flow accumulations that have repeatedly filled its valley.

Although these diamictons were thought to be deposits of two glaciations by Wayne and Corte (1983), and the sediments do show evidence of glacial action, glacier ice could not have transported them so far from the cordillera without having greatly enlarged the valley through the "narrows", where Río Blanco leaves the cordillera. The narrowness and twisted nature of the valley through this reach (Figure 3), as well as the weathered rock surfaces of the valley walls, indicate that a glacier could not have passed through it in order to deposit the diamictons that the stream exposes along its banks. Ice would also have smoothed the irregular surface of poorly consolidated Tertiary clastic rocks upon which the diamictons lie. Corte (1957, p.13) noted the "V" shape of the Río Blanco valley, but suggested that glacier ice plugged the bottom of the valley and that the moving part of the glacier flowed across the "dead" ice plug at a higher level. It would be unusual, however, for an ice stream to behave in this way.

Three diamictons can be recognized in the high banks of Río Blanco for about 9 km east of the east margin of the

Cordillera (Figures 1, 6), where the stream reaches an altitude of 1525 m; a single one can be followed along the banks nearly to the Río Mendoza valley, at 1400 m. Debris flows with the runout distances of these could readily have moved this far, however, without eroding the underlying material. In passing through the constricted valley at the "narrows", such flows probably would have thickened sufficiently to generate a sequence of surges (Jian **et al.**, 1983) that would have kept the debris moving well out onto the piedmont. The two diamictons (Figure 5) that seem superimposed in some exposures in the narrows may, in fact, represent surges rather than two depositional events (Fisher, 1971, p.920). Material formerly transported by glacial ice surely made up a significant part of the debris-flow masses, which, for the one with the greatest run-out distance, may have exceeded 20 x 10^6 m^3 in volume.

Saturation of glacially deposited material and generation of small debris flows from the margins of the present debris-covered glaciers above 3500 m in Quebrada de la Angostura is a fairly common event. A larger-than-usual debris flow in December 1982, caused by rapid melting of an unusually heavy snowpack, nearly filled the channel downstream to 2250 m, but most of the sediment had been removed through stream erosion within a few weeks, and by December 1984, only remnants were visible along the channel sides.

One hypothesis that might explain these long runout diamictons as well as the presence of glacially-derived materials in them would be a major rockfall from the cirque headwall onto a glacier surface, perhaps seismically induced. The cirque headwall of Quebrada de la Angostura is a cliff that rises nearly 1000 m above the floor of the valley (Figure 8). Today, it is not occupied by a glacier, but during de maximum of the last glaciation, the cliff surely stood at least 500 m above the surface of the ice that filled the cirque. A major rockfall (or avalanche) onto the surface of a glacier in the head of Quebrada de la Angostura surely would have generated a debris of massive proportions. Such a rockfall would pick up snow and ice as it passed down over the glacier surface and incorporate meltwater as it followed the valley beyond the margin of the ice tongue. A debris flow of this magnitude could readily continue in motion until it reached the valley of Río Mendoza, particularly if it were following a channel through the piedmont zone. Although

Figure 8. Cerro El Plata, showing a large cirque at head of Quebrada de la Angostura.

such a hypothesis regarding the origin of one or more of the diamictons of the Río Blanco valley is speculative, it would account for all of the observed features of the sediments that suggest a glacial origin for some of the materials as well as for the geomorphic characteristics of the valley below 2600 m that make it unlikely that glacier ice ever passed through it. That rockfall/ debris-flow sediments accumulate in the central Andes in this manner was clearly demonstrated at Nevados Huascarán in 1962 and 1970 (Plafker and Ericksen, 1978; Browning, 1973); Keefer (1984) called attention to the importance of seismic events as a triggering mechanism. The piedmont fault that contributed to preservation of the diamictons near La Chacrita is evidence of Late Quaternary seismic activity in the area.

STRATIGRAPHIC-CLIMATIC INTERPRETATIONS OF THE DIAMICTONS

Soil profile characteristics, stratigraphic superposition, topographic position, morphologic changes, and degree of alteration of glacially fractured quartz grains all provide guides to establish a relative age framework for this sequence of diamictons and associated sediments. The oldest of the diamictons associated with Río Blanco lies in a fragment of a trough that trends southeastward and stands about 200 m above the present channel (Figure 1, site C). Wayne (1985) pointed out that it was deposited at a time when the headwater parts of the Río Blanco basin drained southeastward toward the valley of Río Tunuyán and that it is probably either late Pliocene or early Pleistocene in age. During an episode of structural deformation along the front of the Cordón del Plata, the part of the basin that became Río Blanco was diverted eastward into Río Mendoza and the diamicton that now caps the Mesón del Plata (Figure 1, site D) was deposited along it. Remnants of channels can be seen on the surface of the Mesón del Plata. Both groups of diamictons and their associated gravels constitute the unit Polanski (1962) named the Mesón del Plata Formation. The other diamictons preserved along the Río Blanco valley, both within the Cordón del Plata and on the piedmont to the east, were emplaced after the river had entrenched its channel to the new base level at Río Mendoza. Nearly all of these diamictons are associated with fluvial sediments and are included within Polanski's (1962, 1972) La Invernada Formation.

During glaciations, Río Mendoza flowed at a higher level than now, as evidenced by the gravel terraces along it (Brunotte, 1983). During times of glaciations in the Andes, the higher base level along Río Mendoza surely caused aggradation along Río Blanco and all other tributaries; hence it would be logical to correlate the alluvial sediments of the higher terraces with glaciations. The diamictons observed in the base of the exposures along the valley of Río Blanco may have been deposited during interglaciations, when Río Mendoza provided a lower base level for its tributaries, as it does now.

The youngest diamicton in this sequence underlies the surface of the large fan between 2600 and 2200 m that fills the valley just upstream from the junction of Arroyo de la Angostura and Arroyo de los Vallecitos (Figures 1, Site A, 2, 3). It is littered with unweathered boulders, about 10% of which are granites, and is covered by a topographically fresh network of levee-bordered channels. The loess veneer, soil profile development, and rounding of granitic clasts are comparable to those of the outermost Vallecitos moraines at 2600-2650 m in the valley at the head of the fan. It seems likely, then that this particular debris flow, which is 3 to 4 m thick and comprises at least 2×10^6 m^3, took place while an ice tongue lay in the valley above it during the last (Wisconsinan) glaciation (Wayne and Corte, 1983, fig. 2).

The upper 30-40 cm of the soil profile developed on the diamicton that underlies the terrace surface just upstream from the junction of Río Blanco and Quebrada de la Manga is rich in silt, which surely must be loess, and the lower part shows Stage II+ carbonate buildup (Birkeland, 1984, p. 357-359). This diamicton underlies part of the main terrace surface, which is graded to a surface of aggradation along Río Mendoza, that probably was produced during a major glaciation. The bulbous end of the debris flow, which terminated between La Chacrita and Potrerillos (Fig. 1), protrudes above the surface of the terrace, and its south border rests on the distal edge of an alluvial fan on the south side of Río Blanco. Because of its soil profile characteristics, stratigraphic position, and geomorphic development, I suspect it, also, may have accumulated during a late Quaternary glaciation, when base level along Río Mendoza was higher than it is now, although it surely predates the Late Wisconsinan (Marine Oxygen Isotope Stage 2).

The base of the lowest diamicton exposed in the sequence along the road and stream cuts a short distance west of Potrerillos is only slightly above the modern stream bed. To interpret it as having been left by a debris flow during an interglaciation, when base level was low, would seem reasonable. A complicating factor, though, must be considered. This and other diamicton exposures in this area lie on the downthrown side of a fault (Fig. 1,2), which evidently has been active in late Quaternary time. The diamictons have been offset, but alluvial sediments obscure the trace of the fault across the middle of the valley of Río Blanco.

A bed of volcanic ash caps the diamicton exposed at the base of the steep banks of Río Blanco at Potrerillos (Fig.1, site H) and is in turn overlain by a thick accumulation of coarse gravel (Corte, 1957, Fig. 3; Polanski, 1966, Fig. 2; Wayne and Corte, 1983, Fig. 8). The base of this diamicton lies at the level of the present bed of Río Blanco, but this site, too, is on the downthrown side of the fault that has contributed to preservation of the diamictons downstream from La Chacrita. The volcanic ash dated tentatively as "probably in the 100-200,000 year range" (Glen Izett, letter, 18 Dec. 1980). The zircon microphenocrysts have a low uranium content and a low fission-track density.

Recently, electron microprobe analysis have shown that the chemical composition of glass chards in these volcanic ash lenses is very similar to that of pumice clasts in pyroclastic deposits expelled in a series of closely-spaced eruptions from the Maipo volcano approximately 450,000 years ago (Sterns et al. , 1983). The use of electron microprobe analyses to identify ash beds has become a reliable stratigraphic technique (Smith and Westgate, 1969; Sarna-Wojcicki et al., 1984). The overall similarity of these three ash lenses to the published analyses of the Maipo pumice makes it seem likely that the Maipo volcano was the source of the ash over the diamicton near Potrerillos. A difference in FeO, MgO and CaO, as well as in fission track density in zircons, however, makes it difficult to accept a correlation with the 450 ka pumice from Maipo. In addition, 1987 field studies showed that two volcanic ash lenses separated by alluvial sediments are present in some exposures in the piedmont plain near Mendoza. At this time, then, correlation of the ash bed that overlies the diamicton near Potrerillos with the 450 ka eruption of Maipo can neither be confirmed nor ruled out.

In either event, our suggestion (Wayne and Corte, 1983) that th diamicton at Potrerillos, based largely on the 100-200 ka age of the ash that overlies it, was deposited during a glaciation associated with Oxygen Isotope Stage 6 will need further re-evaluation as more data are accumulated. Should that ash lens be the same as the 450 ka ignimbrites of Maipo, considerably greater time would be available for emplacement of the other diamicton of the Río Blanco valley. Evidence available at this time, however, indicate that it is more likely to be younger.

A greater problem exists with efforts to place the diamictons upstream within a stratigraphic frame. The two exposed along Arroyo Angostura near its junction with Arroyo de los Vallecitos (Fig. 1, site B) seem particularly difficult to fix, since a glacial correlation is not necessarily valid. The soil profile that has developed on the uppermost of the two at this location is a Stage III-IV caliche about 20 to 30 cm thick, which surely formed under conditions more arid than the present at this site. The length of time necessary to develop a carbonate-rich horizon of this character probably was at least several tens of thousands of years. A K horizon of similar characteristics has formed on the surface of the diamicton ridge that stands as an erosional remnant above the alluvial plain just east of the mountain front, and below which Río Blanco has entrenched its channel (Fig. 1, site F). Because of these similarities of soil profile development and the observations that both remnants are well above the valley flat (12 to 15 m), they may be isolated parts of the same deposit. The debris flow that deposited them probably took place when Río Blanco was graded to a higher base level than now, perhaps during a glaciation.

Less arid conditions must have existed, though, when the lower diamicton at site B of Fig. 1 underwent weathering. The paleosol includes a well developed blocky orange-brown Bt horizon and shows little accumulation of carbonate (Wayne, 1984, p. 406), although the matrix of the unweathered diamicton beneath the paleosol contains secondary $CaCO_3$ grains. These are characteristics of a soil profile that formed under relatively warm, humid conditions. If so, it would suggest that the climate of the Cordón del Plata piedmont was somewhat different during part of Pleistocene time than it is now.

Because all of these diamictons contain quartz grains that show, under scanning electron microscope examination, surface textures associated with glacier transport, this part of the Andes evidently supported valley glaciers prior to the last glaciation, although it is unlikely that the older ice tongues were extensive enough to leave deposits beyond those that reached about 2600 m during the last glaciation. Although earlier glaciers may have reached nearly the same altitudes as those of the Vallecitos (Wisconsinan) ice in the Río Blanco basin, even slight uplift in this part of the Andes would have carried them high enough that they now would be buried beneath the moraines of the last glaciation. Where younger glaciers overrun the deposits of an older one in alpine valleys, rarely does a record of the older one remain identifiable (Gibbons **et al.**, 1984). Recognition of pre-Vallecitos glaciations in the Cordón del Plata, therefore, is likely to result only by indirect means such as those presented here. There can be little doubt, though, that the cirques of the Cordón del Plata have been excavated several times by Pleistocene glaciers.

CONCLUSIONS

The diamictons and associated fluvial and airfall sediments that fill the valley of Río Blanco below the outer moraines of the last glaciation are here interpreted to be sediments deposited by large scale debris flows rather than the result of glacial or neotectonic activity. Some of them, particularly the older ones, are associated with late Pliocene and/or early Pleistocene tectonic activity in the Cordón del Plata. Those that fill the piedmont valley of Río Blanco are more likely a result of extreme precipitation events and fluctuations in base level that resulted from outwash deposition and interglacial entrenchment along Río Mendoza. Late Quaternary faulting has preserved some of the deposits. Correlations are based primarily on stratigraphic position, surface morphology and soil profile characteristics.

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