POST-GLACIAL HYDRAULICS, MORPHOLOGY, AND LONG PROFILE ADJUSTMENT OF THE RIO GRANDE RIVER, SAN JUAN MOUNTAINS, COLORADO

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INTRODUCTION:

A flight of unpaired late Quaternary terraces comprised of fluvio-glacial deposits flanks the Northern Rio Grande River for nearly ten miles along the upper Rio Grande valley. Terminal moraines equivalent to Pinedale and Bull Lake Stages of ice advance occur at the upstream origin of these terraces. More than three fluvial terraces extend at least twelve kilometers downvalley from the moraines. These terraces, which converge downstream, cut into sediments deposited by braided streams flowing from the terminus of valley glaciers that flowed down the Rio Grande valley. (see Figure 1 for sequence of terrace remnants). The coarsest terrace sediments were deposited during a catastrophic outburst flood (after the failure of an ice dammed lake) that produced rates of discharge at least as great as 11,092 m3/s.

METHODS AND PURPOSE:

A variety of research methods were useful in gathering pertinent data for this project. A Lietz total geodetic station provided coordinate and elevation data to correlate the terraces, determine channel geometry through cross sections, and construct longitudinal profiles of the individual terrace surfaces. Measurements of the lenghts of the intermediate axes of the ten largest boulders on both terrace tread surfaces and exposures within the terrace deposits were used to reconstruct paleoflow hydraulics. (If the boulder was not fully exposed, the apparent intermediate axis was measured). Determining the origin of the terrace fill material, and correlating the complex flight of terraces, as well as estimating paleohydraulic conditions of the Rio Grande is the objective of this study.

LOCAL GEOLOGY:

The San Juan Mountains are an area of high relief and rugged terrain carved into a two kilometer thick sequence of middle-to-late Tertiary lavas and pyroclastic rocks. The vlocanic rocks unconformably overlie metamorphosed sediments, volcanics, and intrusive rocks of Precambrian age, as well as sedimentary rocks of Paleozoic, Mesozoic, and Cenozoic age.

Although no glaciers exist in this area today, evidence of late Pleistocence glaciation is present throughout the range. Atwood and Mather (1932) mapped glacial deposits in the region and identified three episodes of glacial advance. Although Atwood and Mather inferred that the bulk of glaciers were valley glaciers, aerial photographs and topographic maps reveal evidence of broad regional ice fields and transectional glaciers as well (Carrara et al, 1984; U.S. Forest Service Aerial Photographs 684-175-180 and 684-205-209; Spar City, Creede, Bristol Head, and Workman Creek 71/2' USGS Quadrangles).

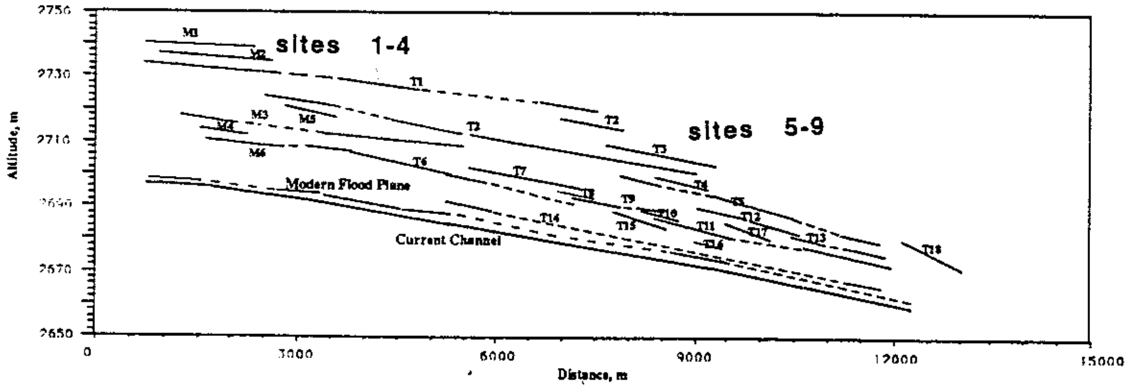

Figure 1: Longitudinal Profiles of terrace sequences along the northern Rio Grande River, San Juan Mountains, Colorado
(M=Moraine, T=Terrace, S=Surface)

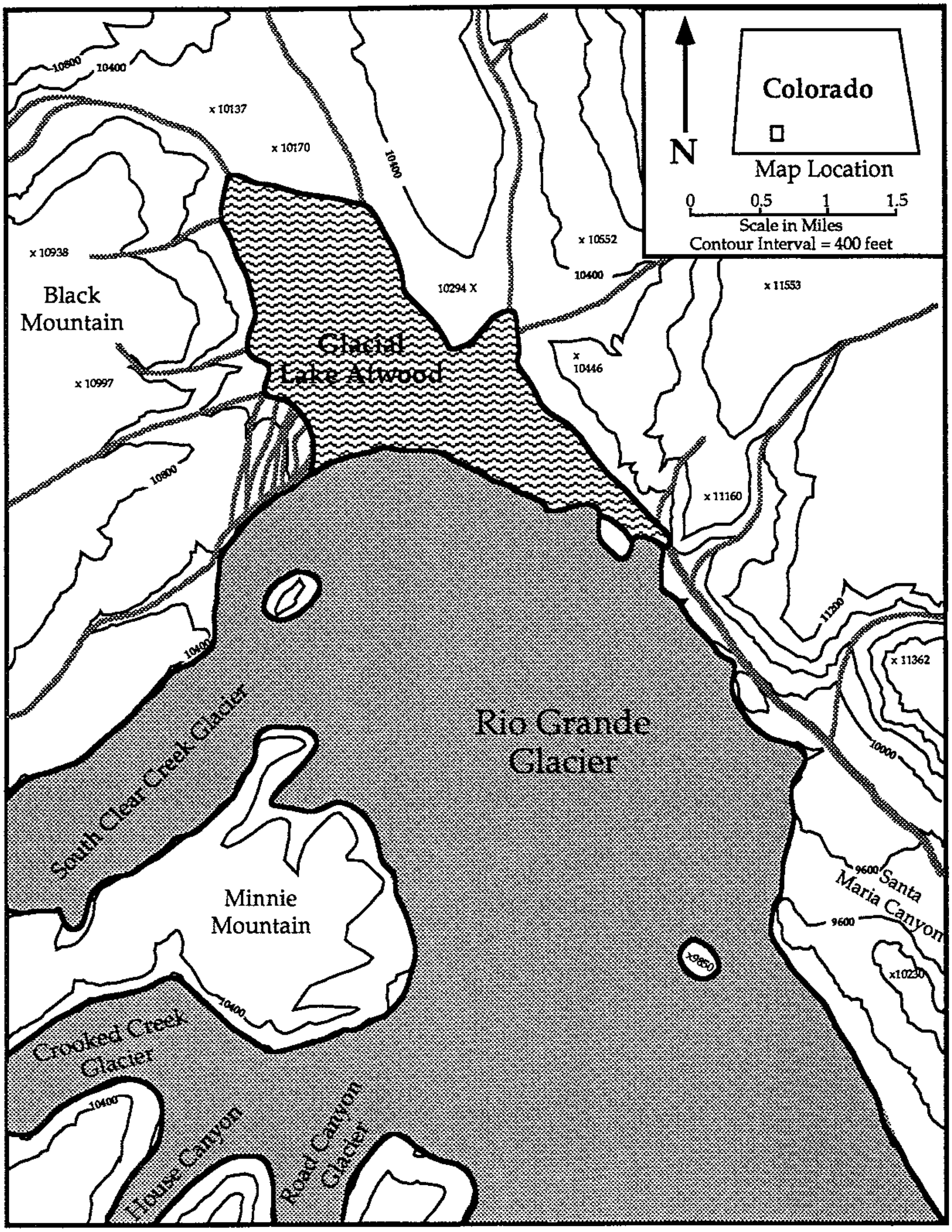

Figure 2: The Clear Creek Graben at the last glacial maximum. The Rio Grande Glacier is formed by the confluence of ice flowing out of South Clear Creek Canyon, Crooked Creek Canyon, House Canyon and Road Canyon. The ice dammed off several streams causing Glacial Lake Atwood to be formed (surface elevation 10,150 feet). At its maximum extent Glacial Lake Atwood had a volume of 6,600,000 cubic meters. The lake drained around the eastern edge of the glacier along the wall of the graben, then down through Santa Maria Canyon.

PALEOHYDRAULIC METHODS:

Rates of fluid flow governing the entrainment and transport of large particles are often difficult to measure, since most field evidence is after-the-event and indirect. (Large particles in this paper are arbitrarily defined as those having an intermediate particle diameter, d, > 15mm.) Reviews of fluvial geomorphology by Dury (1972) and Schumm (1971) have emphasized the trend toward quantitative studies and the plea for increased use of empirical methods when estimating past hydraulic conditions from evidence of the geologic record (Baker 1973).

Empirical relations in coarse sediment transport:

Differences in particle characteristics and bed conditions affect the critical flow value of a particular particle. For example, variations in grain shape, distribution of surface particles, and orientation and packing of particles account for differences in critical flow values. Therefore only a range of values for critical flow, rather than a unique threshold flow, can be determined for any given grain size. Because defining a threshold flow poses so many difficulties, this study concentrates on estimates based on empirical relations of known sediment movement, rather than on a threshold-flow basis.

Garnett Williams derived empirical relations for determining the minimum unit stream power, bed shear stress, and mean flow velocity capable of moving cobbles and boulders. These derived equations can be used to estimate the minimum paleoflows required to transport boulders on ancient deposits. The empirically derived equations can then be compared with conventional hydraulic equations. This procedure was applied to field data gathered along the terrace sequences of the northern Rio Grande.

APPLICATION OF BASIC EMPIRICAL RELATIONS IN COARSE SEDIMENT TRANSPORT TO THE RIO GRANDE TERRACE DEPOSITS:

Origin of the boulder deposit:

Scattered boulders in glacial outwash deposits on the terrace surfaces flanking the northern Rio Grande (ranging in diameter from 178-1060 mm) present evidence for catastrophic flooding. Ice rafting is ruled out for the transport of the boulders because there is a clear distinction between particle sizes located in the upstream part of the study area (sites one through four) and those located further downstream (sites five through nine). If ice rafting had occured, there would be a distribution of boulders throughout the entire study area, with boulder transportation occuring from the terminus of the glacier downstream. Instead, a change in particle size from a normal distribution to an irregular distribution occurs at the convergence of two valleys. The cumulative frequency curve (Figure 2) illustrates the dichotomy between these two areas. (see Figure 1 for location of these sites). Scott MacMillan (personal communication 1992) indicated definitive evidence of the presence of a glacial lake located northeast of the present day Rio Grande. Evidence suggests that a catastrophic outburst flood provided the impetus for the failure of this lake and transported large boulders into the Rio Grande valley.

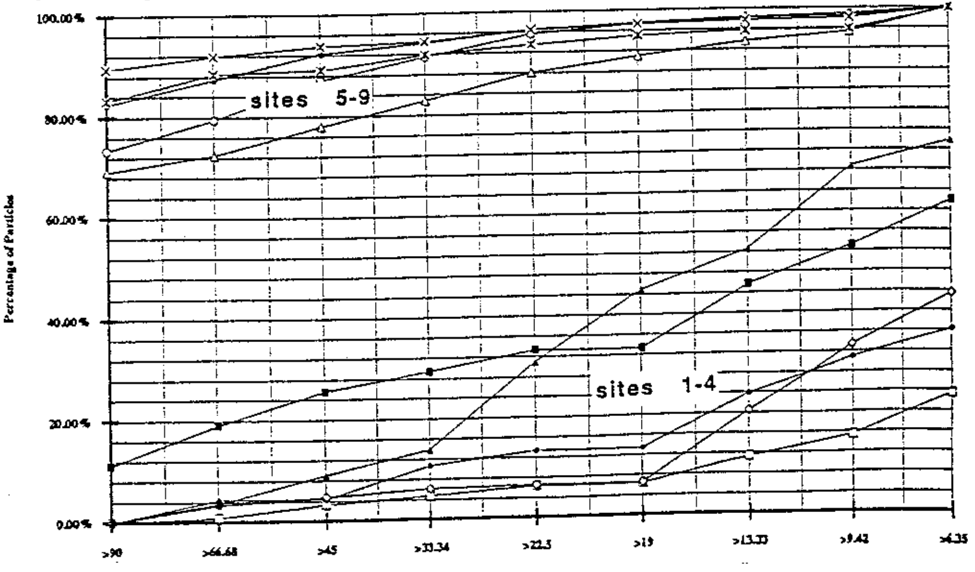

Figure 2: Cumulative frequency curves for sites 1-9. (Sites 1-9 occur in increasing distance downstream). Note the dichotomy in particle size distribution between sites 1-4 and sites 5-9. This dichotomy marks the transition in particle sizes after a catastrophic flood. (Note: X axis not linear).

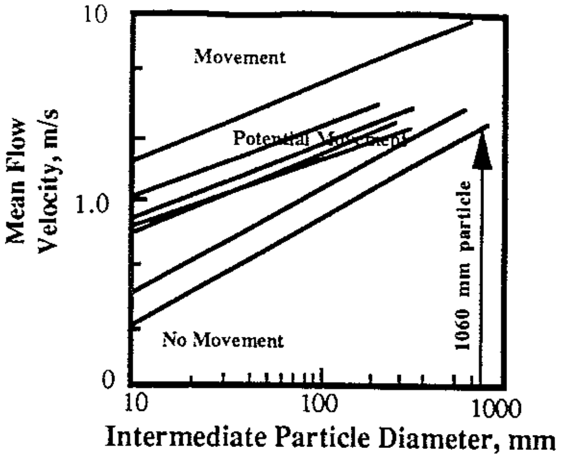

Figure 5: Approximation of the likelihood of particle movement for a given particle diameter and mean flow velocity. (Source: Williams 1983).

of bed shear stress ($\tau = \gamma DS$) yields a depth ($D = \tau / \gamma S$). Using the previous estimates of $\tau = 240 N/m^2$ and $S = 0.0035$ (from longitudinal profile data), depth is 7 m. An alternative way of estimating depth is by rearranging the equation for unit stream power ($\omega = \gamma QS / Ws = \gamma VDS$ and $D = \omega / \gamma VS$). From a previously calculated V of 2.5m/s, $\omega = 750W/m^2$, and a slope of .0035, D= 8.7 m. The average of the two independent estimates, 7.85m, is a better representation of depth than one estimate alone.

The next two obtainable variables are water surface width and cross sectional flow area. When calculating these variables, two important assumptions must be made: (1) that the modern channel is not significantly different than that of the transporting flows and (2) that the wetted perimeter did not deform appreciably during the catastrophic event (Williams 1983).

Considering those restrictions, a particular water surface width corresponding to a mean depth of 7.85m can be estimated. Sucessively larger flow areas and the associated water surfacewidth were measured on a cross section of the Northern Rio Grande. The relation D= A/Ws yields the mean depth for each width (Williams 1983). A general graph was then constructed with Ws as a function of D. A best fit line provided the appropriate relation between D and Ws. The width associated with a depth of 7.85 m was 180 m. The product of width and depth yields a cross sectional flow area of 1413 m^2.

The preceeding calculations provide the neccesary information to estimate the minimum discharge during the catastrophic event. The product of width, mean depth, and velocity gives an approximation of discharge, Q, of 11092 m^3. This number is only a minimum value for discharge and is based upon empirical relation of known sediment movement.

CONCLUSIONS:

Research on climatic river terraces provides important geomorphic information. Studying the particular terraces in the Rio Grandevalley is a key to reconstructing the complex glacial history of the San Juan region. This study in particular considers the chain of fluvial processes and responses that connect paleoclimatic events to discernable field evidence. Williams' empirical relations of unit stream power, bed shear stress, and mean flow velocity allow for a quick estimation of the minimum values of the variables needed to transport a particle of a given size. By appliying these empirical relations of known sediment movement to terrace sediments deposited by a catastrophic flood, the associated values of other hydraulic variables can then be estimated. These estimates, however, represent only the minimum values required to transport particles with a diameter of 1060 mm. It is likely that the rates of flow were much higher.

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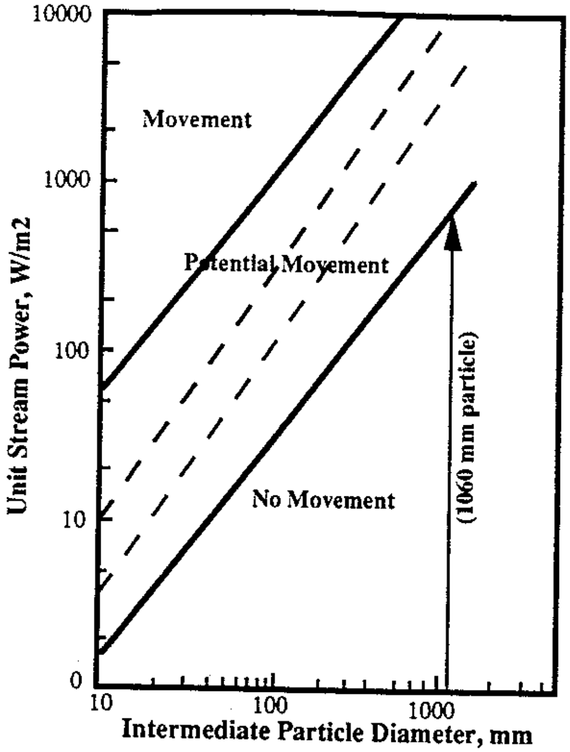

Figure 3: Approximation of the likelihood of particle movement for a given particle diameter and unit stream power. (Source: Williams 1983).

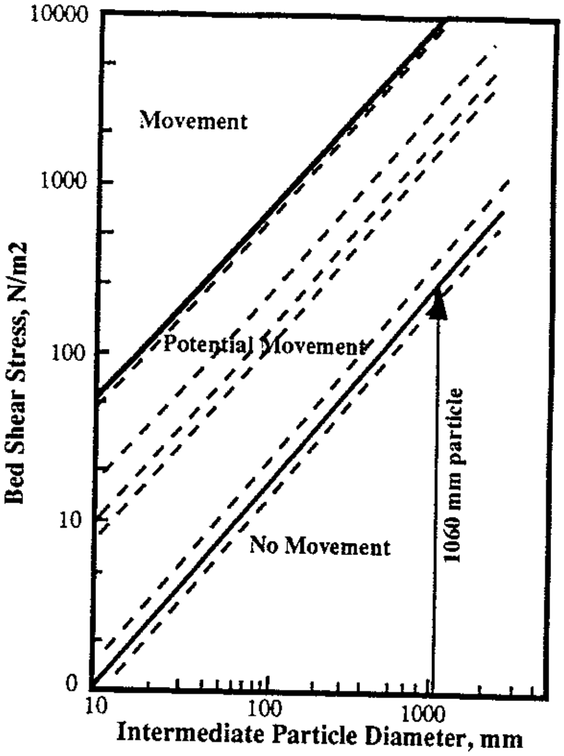

Figure 4: Approximation of the likelihood of particle movement for a given particle diameter and bed shear stress. (Source: Williams 1983).

Flow estimates:

1. Unit Stream Power, Bed Shear Stress, and Mean Flow Velocity:
Various authors have acquired data for flows that have moved particles of a given grain size. Williams compiled this data and defined the lowest unit stream power reported to transport a particular size particle. An approximate limiting line was fitted to the lower boundary of data points. This lower line represents the lowest unit stream power required to initiate transport (Williams 1983). The slope of this line was adopted for Figure 2. A given grain size remains stationary until unit stream power exceeds the value indicated by the line. A similar graphical procedure was followed for bed shear stress, τ, and mean flow velocity, V (Figures 3 and 4). As with unit stream power, there is a zone of potential movement for a given particle size. The equations for boundary lines, with d in mm, are as follows (Williams 1983):

For unit stream power, ω: (Equation 1)
$\omega = 2.9d^{1.3}$ (upper line) $\omega = 0.079d^{1.3}$ (lower line)
For bed shear stress, τ: (Equation 2)
$\tau = 3.9d^{1.0}$ (upper line) $\tau = 1.7d^{1.0}$ (lower line)
For mean flow velocity: (Equation 3)
$V = 0.046d^{0.5}$(upper line) $V = 0.065d^{0.5}$(lower line)

The lower boundary of the potential movement zone of Figures 3, 4, and 5 (Equations 1, 2, 3) presents the minimum flow strength required to transport a particle an appreciable distance. Using d= 1060mm (the largest boulder measured on the Rio Grande terraces), the approximate flows conditions are $\omega = 750$ W/m^2, $\tau = 240$ N/m^2 and V= 2.5 m/s. These numbers represent only the minimum flow capable of transporting the boulders present on the terraces along the Rio Grande.

2. Depth, Cross Sectional Flow Area, Water Surface Width, and Discharge:
Minimum values of other flow variables can also be estimated. Assuming that the slope of the modern channel represents the energy gradient of the transporting flow, then rearrangement of the basic definition

Geomorphic History of the Santa Maria Canyon, San Juan Mountains, Colorado

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Introduction

The Santa Maria Canyon is a small, steep-sided canyon that parallels the Rio Grande Valley for 12 km between Antelope Park and Clear Creek Park (Figure 1). Separated from the Rio Grande Valley by Long Ridge, the canyon at one time connected drainage between Clear Creek Park and the Rio Grande River below Hogback Mountain.

The project focused on mapping and describing geomorphic features in the canyon and using them to identify, sequence, and model events in the valley's formation. Evidence suggests three major episodes in the valley's history: glacial deposits and erratics indicate glaciation, paleochannels and boulder deposits indicate flooding, and young alluvial fill indicates recent and active hillslope erosion.

Project Methods

Field work emphasized reconnaissance mapping to identify geomorphic features and to sequence the events that caused them. I made observations on foot and from aerial photographs (USDA, 1985). Test pits provided further information about landform type. I collected basalt and andesite clasts to measure weathering rind thickness as a relative dating indicator. Carson (pers. comm., 1992) measured rind thicknesses and included Santa Maria Canyon stones in the set he collected from the Antelope Park area.

In order to model the hydraulics indicated by paleochannels and boulder deposits, I measured cross-sections and boulder diameters. Cross-sections were made with a hand level and stadia rod and were supplemented with information from the Workman Creek Quadrangle (USGS, 1963). I determined slopes from the quadrangle map and survey data taken with a Total Station. To determine maximum boulder size, I measured the three axes of the 10 largest boulders found in sections 50 m long and spanning the width of the channels.

I calculated velocity, depth, and discharge using averages of the median boulder axes, channel cross-sections and slope, and the paleohydraulic methods of Baker (1974), Williams (1983), and the empirical method of Costa (1983).

Glaciation

Ice covered the Southern Rocky Mountains twice in the last 150,000 years. The earlier event is thought to correlate with the Bull Lake Glaciation of Wyoming, occurring between 140,000 and 150,000 yr B.P.(Porter et al., 1983). The younger event was at a maximum between around 23,500 yr B.P. and 10,000 yr B.P. and is thought to correlate with the Pinedale event of Wyoming (Madole, 1986 and Elias et al., 1991). Atwood and Mather (1932) concluded that ice from the Rio Grande Glacier flowed over Antelope Mountain and Long Ridge and into the Santa Maria Canyon during the earlier event. Thinner ice during the more recent glaciation reached an elevation of 9,400 ft (2865 m) on Antelope Mountain and Long Ridge, too low an elevation to flow into the canyon. Atwood and Mather (1932) did not map any glacial deposits in the Santa Maria Canyon.

Erratics and a small deposit of glacial drift 2 km upvalley of the Canyon mouth indicate glaciation of the Santa Maria Canyon (Figure 2). We found crystalline erratics on top of Antelope Mountain (elevation 3100 m (10172 ft)) on the northeast ridge above the canyon mouth. I also found erratics on a low bedrock ridge in the middle canyon (elevation 2804 m (9,200 ft)). The drift deposit consisted of 4 small hillocks elongated parallel to valley orientation.

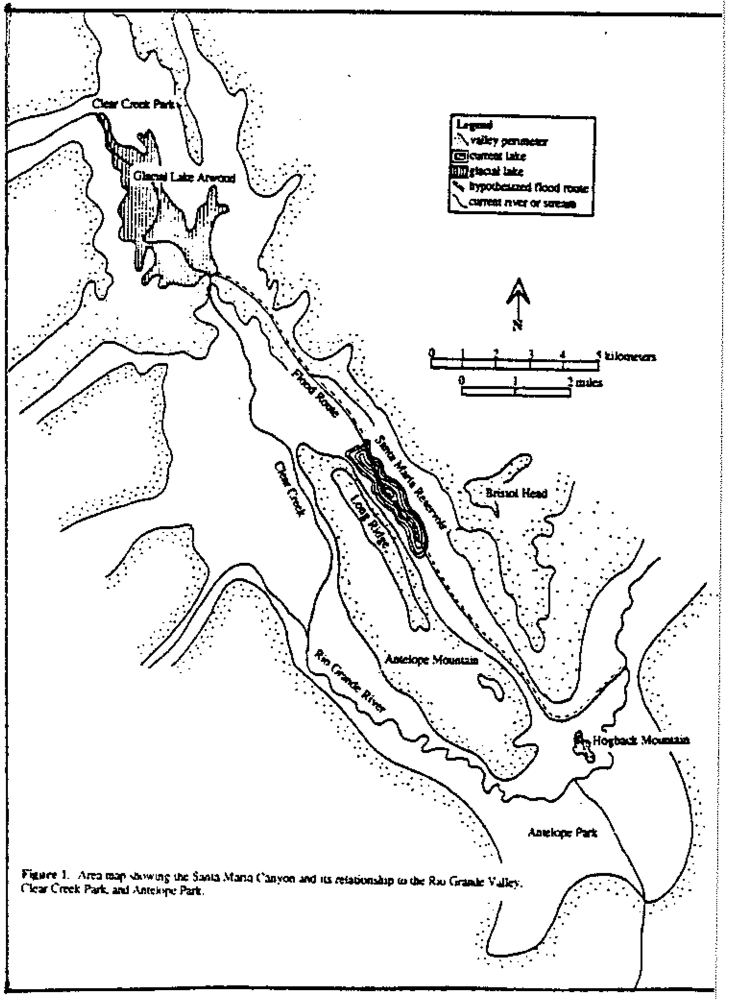

Figure 1. Area map showing the Santa Maria Canyon and its relationship to the Rio Grande Valley, Clear Creek Park, and Antelope Park.