Geol. Bull. Univ. Peshawar, Vol. 25, pp. 113-121, 1992

Geomorphic evidence of catastrophic flooding along the middle Indus valley

KEVIN CORNWELL[1] & SYED HAMIDULLAH[2]
[1] Department of Geology, University of Nebraska, Lincoln, Nebraska USA
[2] NCE in Geology, University of Peshawar, Pakistan

ABSTRACT: *Catastrophic floods have inundated the middle Indus River valley throughout the late Quaternary. These floods have produced very distinct geomorphic signatures within the valley such as boulder beds, plunge pools, and chutes. These features have been mapped and measured to develop estimates of flood hydraulic parameters. The bedrock nature of the Indus valley along this stretch constrains flood water from lateral migration or significant down cutting within the channel. This constraint results in increased flow velocity and greater flood power.*

INTRODUCTION

Catastrophic floods resulting from the bursting of landslide and glacial dams in the Himalaya have often inundated the middle Indus river valley of northern Pakistan during the Quaternary period. The most recent such flood to course down this stretch of the Indus was the flood of 1929-30 (Mason, 1929) which resulted from the bursting of the Chong Khumdan ice-dam in the Shyok valley of the Karakoram Range. The discharge from the breached ice-dam reached an estimated peak flow rate of 19510 cms (cubic meters per second) and produced a wall of water over 15m high on the plains near Attock.

The largest flood recorded in the middle Indus Valley resulted from the 1841 landslide dam-burst which produced a flood wave over 28m high through the Attock threshold, approximately 400km downstream of the breached dam (Abbott, 1849; Cunningham, 1854; and Becher, 1859). Estimates of peak discharges range from a "conservative 56630 cms" (Hewitt, 1964) to 509000 cms (Shroder et al., 1991). Over 36 such floods have been documented in the Indus valley since the late eighteenth century alone (Table 1).

The turbulent flow of such tremendous quantities of water has produced unique geomorphic features in the Middle Indus valley. Most spectacular are the large boulder beds, plunge pools, chutes, and lacustrine sediments whose remnants are often perched many meters above the modern day river channel.

The majority of floods along the middle Indus valley are a result of breached landslide and ice dams. Precipitation plays a minor role in generating floods since orthographic conditions along the middle and upper Indus valley produce arid environments with low annual precipitation rates. Heavy precipitation events between Besham and Sazin however do stimulated slope failure by adding weight and reducing the shear strength of slopes. Recent deforestation in the area also contributes to slope instability.

Figure 1 outlines the area of the Indus valley investigated in this study. Considerable variation in river stage level along this section of the Indus occurs on an annual basis. With the primary source of water for the Indus coming from glaciers and snowmelt, it is not surprising that the July streamflow (6290 m^3/s) is about 18 times as great as the February streamflow (339 m^3/s)(Code et al., 1986).

The geomorphology of the area is also quite variable with broad floodplains several kilometers wide on gently sloping alluvial fan surfaces (upstream from Shatial) changing suddenly to narrow gorges with thin slivers of floodplain (downstream of Shatial where the gorge and floodplain is less than 1 km wide in many spots). Recent snow melt

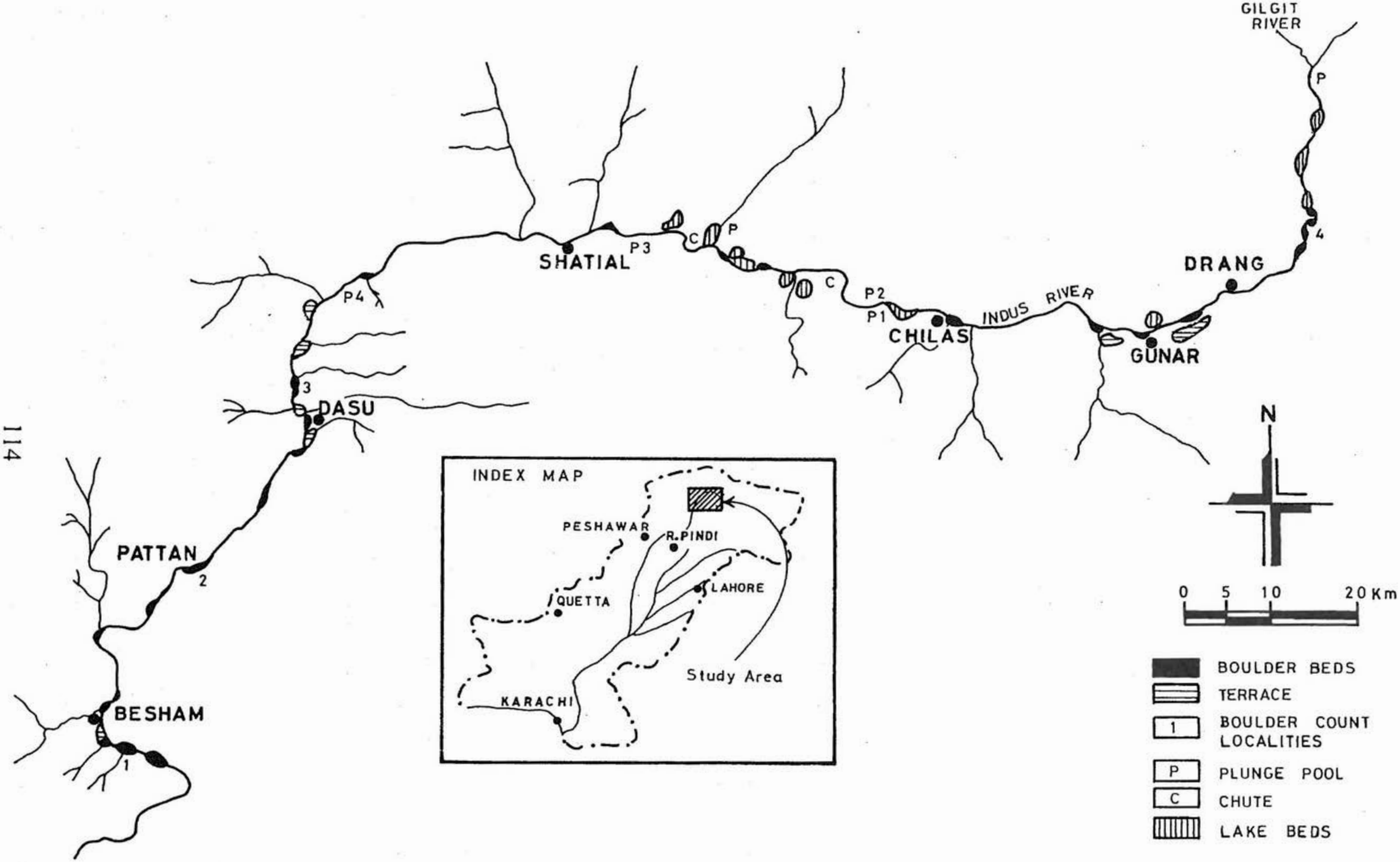

Fig. 1. Outline map of the study area (represented by inset in the index map) along Indus valley with positions of the features investigated.

TABLE 1. HISTORIC CATASTROPHIC FLOODS DOWN THE MIDDLE INDUS VALLEY (MODIFIED AFTER SHRODER PERS. COMMUN.;& HEWITT, 1964).

Date	Flood	Effects and Depth at Attock
1780(?)	Shyok glacier flood (?)	?
1826	Upper Shyok glacier flood	?
1833a	Upper Shyok glacier flood (?)	nil
1833b	Yashkuk Yaz glacier (Hunza Valley)	~10 m
1835	Shyok glacier flood	nil
1839	Shyok glacier flood	nil
1841	Lichar (Hatu Pir) landslide	~28 m
1842	Shyok glacier flood	nil
1844	Gilgit River flood (Ishkuman Valley)	nil
1848	Shyok glacier flood	nil
1850a	Shyok glacier flood	nil
1850b	Tarshing glacier (Astor Valley)	nil
1855a	Middle Indus flood (Shyok area)	nil
1855b	Middle Indus flood (Shyok area)	measurble
1858	Phungurh, Hunza - rockslide	~24 m
1865	Gilgit River flood (Ishkuman Valley)	nil
1873(?)	Hunza River flood (Batura glacier?)	nil
1879(?)	Upper Shyok Valley (?)	~10 m
1882	Upper Shyok Valley (?)	~10 m
1884	Shimshal Valley flood	nil
1893a	Shimshal Valley flood	nil
1893b	Shimshal Valley flood	~ 2 m
1901	Upper Shyok Valley flood (?)	~ 6 m
1903	Upper Shyok Valley flood	nil
1905	Shimshal Valley flood	nil
1906	Shimshal Valley flood	~ 3 m
1907	Shimshal Valley (Khurdopin-Virjerab glacier)	nil
1926	Upper Shyok Valley flood	~ 5 m
1927	Shimshal Valley flood (Khurdopin glacier)	nil
1928	Upper Hunza Valley flood	nil
1929	Upper Shyok Valley flood	+15 m
1931	Landslide near Chilas	nil
1932	Upper Shyok Valley flood	~ 5 m
1933	Upper Shyok Valley flood	~ 4 m
1959	Shimshal Valley flood	nil
1974	Hunza Valley flood (Balt Bare glacier)	nil

runoff levels (spring, 1992) were still apparent on the valley floor and walls (observed in November, 1992) as a light gray pasting of alluvial sands and silts. The height of the spring runoff mark varied from approximately 4 m above the observed fall 1992 levels in constricted sections of the valley to <3 m in more open stretches.

GEOMORPHIC FEATURES

Boulder Beds

The most frequently observed flood features are boulder beds. Figure 1 illustrates the distribution of these deposits along the middle Indus valley. The boulder beds are most prominent along bends of the river channel

TABLE 2. SIZE DISTRIBUTION OF BOULDER COUNTS.

Boulder diameter in m	Besham	LOCALITY Pattan	Dasu
0.0 - 0.5	13	6	6
0.6 - 1.0	33	38	30
1.1 - 1.5	35	18	29
1.6 - 2.0	6	13	16
2.1 - 2.5	6	9	13
2.6 - 3.0	5	6	4
3.1 - 4.0	1	6	1
> 4.0	1	4	1
-average diameter	1.2	1.5	1.4
-largest diameter measured	4.3	6.1	5.5
-largest volume measured	35 m^3	136 m^3	190 m^3

and in areas where the valley widens or becomes suddenly constricted. Along channel bends, differential flow velocities produce a decrease in load capacity. This variation of load capacity results in the deposition of sediment along the inside of the bend. The sudden widening of the channel and subsequent reduction in flow velocity initiates deposition of the sediment load. A sudden constriction of the channel would result in a ponding of the initial flood wave behind the constriction and a decrease in the carrying capacity. The relative size of the deposited sediment is a function of the velocity differences (which would effect carrying capacity) and the size of the bed load.

The dimensions of 100 boulders at three different localities (~2 km east of Besham, at Pattan, and ~1 km north of Dasu; Figs. 1-4) were measured. Boulders were measured for length, width, and breadth (to the nearest 0.25 m) to determine the approximate volume of the boulders. A straight line was plotted through the boulder field perpendicular to the river flow and the first 100 boulders that were encountered were measured. The boulders varied significantly in size with diameters ranging from <0.25 m to >6.0 m. Although the boulder beds seemed to contain an overly large proportion of large boulders it was apparent that local villagers had made good use of the smaller more manageable boulders in the construction of fences, homes, roads, bridges and other structures. Table 2 illustrates the relative distribution of boulder sizes encountered in the three boulder beds. The category with the most frequently occurring boulder diameters generally range between 0.6 and 1.0 m (except for Besham). Considering the relative size of these boulders (i.e. not conveniently moved by human hands) this is not surprising.

The range and distribution of boulders at Pattan may be a function of recent tectonic events. In 1974 this area experienced a devastating earthquake which all but wiped out the village of Pattan. As nearly all of the larger boulders observed are lithologically similar to the areal bedrock, it is likely that at least some of these boulders were brought to the valley floor during the earthquake. The degree of rounding and the distribution of these boulders as well as their orientation within the floodplain however, suggests a more systematic mechanism of emplacement (Fig. 3).

The largest diameter boulders (>4.0 m) were recorded at Pattan and Dasu (Figs. 3 & 4). Both of these localities occur where the Indus grades from a narrow gorge to a broader valley. The constriction of the channel up-

TABLE 3. PLUNGE POOL CHARACTRISTICS

Dimensions	Localities					
	P1a	P1b	P1c	P2	P3	P4
length	79	57	210	131	170	158
width	27	24	30	26	55	30
depth	2	2	2	5	8	6
total area	1675	1074	4948	2695	7343	3723

(all measurements in m, area in m2)

stream would increase the flow velocity and carrying capacity of the flood waters through the gorge. The sudden widening of the floodplain would decrease flow velocity and cause sediment deposition.

Just west of Chilas, flood cobbles and gravels are draped over lacustrine sediments that have been preserved on the lee side of a meander bend of the Indus valley. The gravels extend from the river bank to about 180 m above the floor of the valley. The contact between the flood gravels and the alluvial fan sediments is quite sharp. Where the flood gravels are well rounded and of variable lithologies, the overlying alluvial fan sediments are angular with lithologies typifying nearby exposures. Square meter sections were surveyed in three different places in the gravel bed and three hundred gravels and cobbles in each square meter were measured to determine minimum grain diameters. The average diameter measured 1.79 cm while the range of diameters stretched from 11.4 cm to 0.25 cm. While these diameters pale in comparison to the boulder sizes remember that they

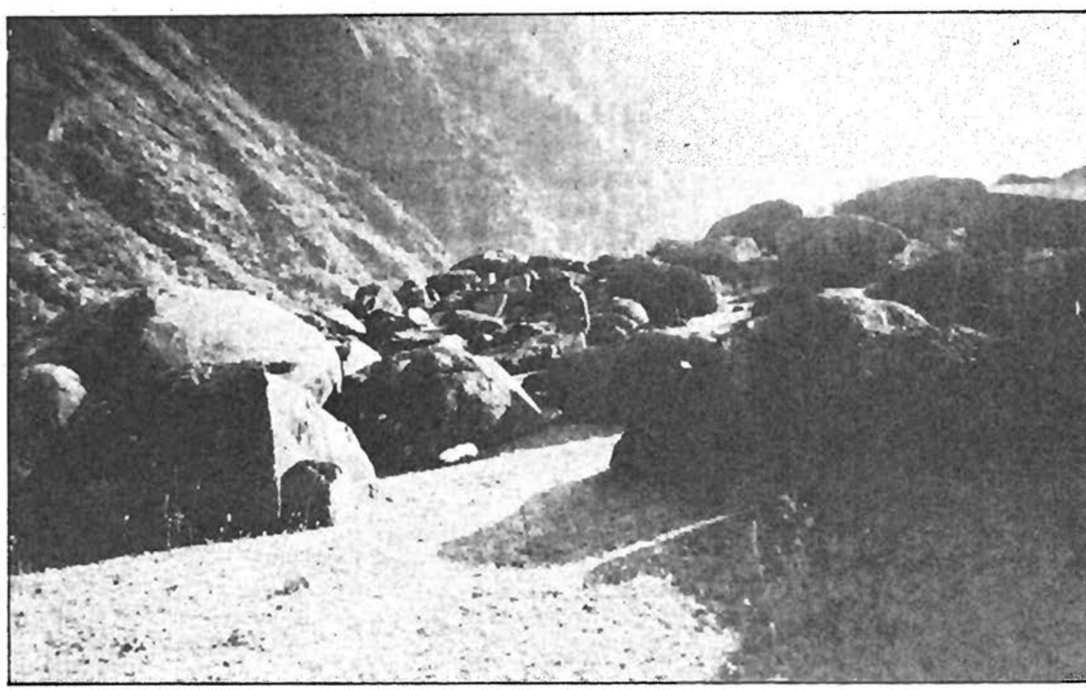

Fig. 2. A view of the boulder bed 2km east of Besham.

are perched about 180 m above the modern day valley floor.

Plunge Pools and Chutes

Plunge pools were observed at various locations along the east-west trend of the Indus valley (Fig. 1) in areas where bedrock protrudes through floodplain/alluvial fan sediments in the valley floor. The flow of flood waters and debris around and over these protrusion often produces linear depressions scoured into the bedrock or the surrounding unconsolidated sediments. Bedrock at P1 (Pool 1) and P2 consisted of Chilas Complex norite and at P3 and P4 were Chilas Complex retrograde amphibolites. Where possible the dimensions of these pools were measured (Table 3).

The exposed bedrock was smoothly polished and had occasional erosional pockets worn into the surface. In one locality (P3) large caves were carved into the bedrock. Two such caves were observed but were being inhabited by people and access was not obtainable. The formation of these features is likely a result of vortices that set up in the turbulent flow of flood waters. The differential erosion of the surface can be attributed to the abrasive action of the larger grain sharp sediments suspended in eddies and to the direct action of fluid stresses (Reineck & Singh, 1980).

Often the floor of the plunge pools were littered with well rounded cobbles and boulders and covered with and surrounded by alluvial and aeolian sands but in at least one instance (P4) was filled with stagnant water. .It is suspected that many such pools develop during flood events but are subsequently buried by the deposition of more recent alluvium and aeolian sediments.

Bedrock chutes were observed in two locations. These occurred in areas where bedrock benches outcrop through the floodplain along valley meanders. The bedrock attitude of the chutes is generally lower in the upstream direction than the downstream. The floors of these chutes, while covered for the most part with alluvium, exhibit a relatively smooth though uneven surface that probably results from abrasion by transported sediments and debris.

The movement of Pleistocene glaciers along this part of the middle Indus valley certainly would have influenced the formation of chutes and pools, however the development of plunge pools and chutes may also be a function of bedrock structural conditions. Where plunge pools were observed the orientation of bedding planes within the bedrock were perpendicular to water flow direction perhaps inducing erosion along beds of weaker resistance. The bedrock structure along reaches that contained chutes appeared to be parallel to water flow direction possibly inducing vertical erosion in weaker strata.

Erratics

Although it is likely that at least some of the observed boulders within the middle Indus valley were emplaced via ice-rafting, the collection of boulders at various location along the middle Indus valley is believed to be a function of the traction and entrainment action of flood waters. Much discussion in the past has been attributed to the origin and distribution of erratics in the plains near Attock and the authors would defer to Desio and Orombelli (1983) for a more complete description.

FLOOD POWER

The geomorphic effectiveness of large scale floods are not so much a function of magnitude or frequency but more of shear stress and stream power (Baker et al., 1987). Boulders from each of three different boulder beds were observed and measured to evaluate rock types and the average intermediate axial diameters.

Evaluation of the mean-flow stress required to move boulders of these dimensions was carried out using Komar's (1989) expression:

$$T_{ti} = 0.045(p_s - p)gD_{50}^{0.65}D_{bi}^{0.35}$$

where T_{ti} = mean-flow stress

p_s = density of boulder

p = density of water

D_{50} = median diameter of the sediment bed

D_{bi} = intermediate axial diameter of boulder.

TABLE 4. FLOOD HYDRAULIC PARAMETERS.

	Shear Stress Newtons*m-2	Mean Flow Velocity	Power per unit area m/s	energy gradient* watts*m-2
Middle Indus, Pakistan				
Besham	358	10.8	3884	0.005
Pattan	405	12.9	5214	. 0.007
Dasu	390	12.2	4777	0.008
Q-Chang Jiang, China				
	175	11.8	2000	0.0002
Cho-Shui River, Taiwan (1979)				
	400	7.0	2778	0.007
Laurel Run, Pa., USA (1977)				
	322	5.7	1848	0.009
Kelley Barnes Dam, Ga., USA (1977)				
	373	3.9	1462	0.01
Teton River, Id., USA (1976)				
	819	13.1	10713	0.005

* - water surface slope

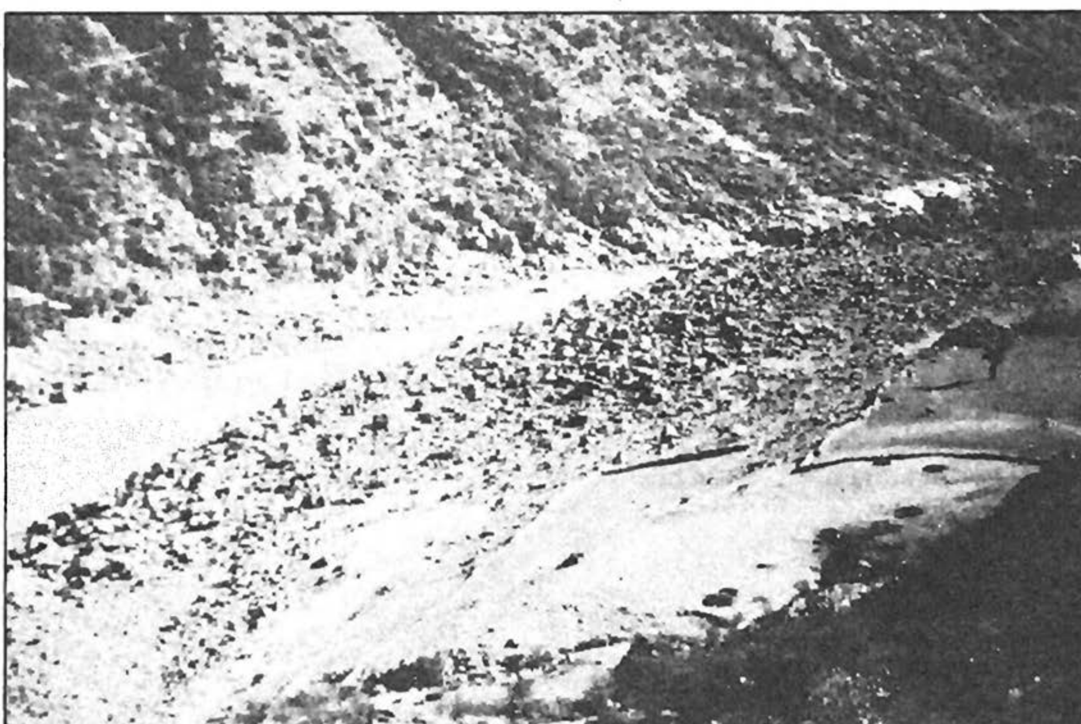

Fig. 3. A view of the Pattan boulder bed.

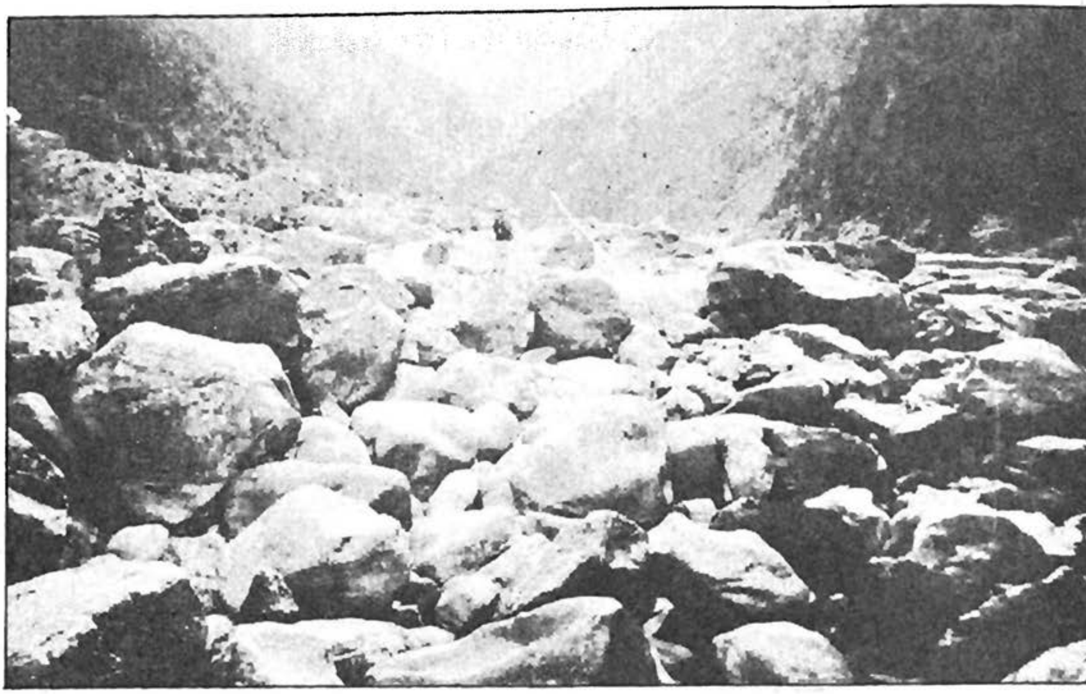

Fig. 4. A view of the boulder bed 1km north of Dasu.

The largest variable in this expression is the median diameter of the flood sediment bed since in this case we were not looking at an isolated flood deposit but of an aggregation of sediments likely deposited at different times and under different processes. A median sediment bed diameter of 11 cm (small cobble) was chosen based on the relative size of grains observed within the flood gravels more than 180m above the valley floor. We consider this value to be conservative. A doubling of the median diameter of the sediment bed results in the increase in shear stress and power by about 30%. It should also be noted that the above equation defined by Komar has not been applied to extremely large D_{bi}/D_{50} ratios. The ratios of D_{bi}/D_{50} in these cases were all near the upper limit of application. The density of the boulders were determined from the rock type that comprised the majority of the boulders, and the largest boulder measured was included in the calculation to provide an estimate of peak mean flow stress required to move boulders of this size.

The mean flow velocity of the flood waters were estimated after Costa (1983) using the equation:

$$V_c = 0.18 * d^{0.49}$$

where V_c = threshold mean flow velocity
$d^{0.49}$ = intermediate particle diameter

By knowing the mean flow stress (T_{ti}) and the mean flow velocity (V_c) an estimate of stream power per unit area (Bagnold, 1966) can be deduced by the equation :

$$W = T_{ti} * V$$

where W = stream power per unit area
T_{ti} = mean flow stress (shear stress) and
V = mean flow velocity.

The results of these calculations as well as values from other dam-failure events (from Baker and Costa, 1987) are listed below in Table 4. The Indus data is not applied to specific flood events as these are not known, but are applied to the flood conditions that would be required to move and deposit boulders of the sizes observed along the Indus valley.

All of the above referenced floods occurred in bedrock channels and resulted from dam failures. Baker et al., (1987) suggested that narrow, deep flows in exceptionally steep bedrock streams produce the largest values of shear stress (exceeding 2,000 NM^{-2}) and power (exceeding $2*10^3$ Wm^{-2}). Bedrock channels constrain the width of the flow channel during floods as well as the depth of scour and thus raise the discharge. Larger discharges produce rises in flow velocity and depth of flooding in these channels. At several localities along the middle Indus valley these condition hold. In others, floodplains and alluvium define the channel parameters.

Acknowledgment: We would like to thank the U.S. Educational Foundation in Pakistan and the Geologic Society of America for supporting this work and the National Centre of Excellence in Geology, University of Peshawar for helping us overcome logistic difficulties.

REFERENCES

Abbott, J., 1849. Report on the Cataclysm of the Indus taken from the Lips of an Eye Witness. J. Asiatic. Soc. Bengal, 17, 231-233.

Bagnold, R.A., 1966. An approach to the sediment transport problem from general physics. USGS Prof. Paper, 422-I, 37p.

Baker, V.R. & Costa, J.E., 1987. Flood Power. In: Catastrophic Flooding (L. Mayer & D. Nash eds.). Allen and Unwin London.

Becher, J., 1859. Letter addressed to R.H. Davies, Esq.,Secretary of the Government of the Punjab and its Dependencies, 1st July, 1859 (on the 1859 Indus Flood). J. Asiatic Soc. Bengal, 28, 219-228.

Code, J.A., & Sirhindi, S., 1986. Engineering Implications of Impoundment of the Indus River by an Earthquake-induced landslide. In: Landslide Dams: Processes, Risk, and Mitigation (R.L. Schuster ed.). Geotechnical Spec. Pub., 3, 97-110.

Costa, J.E., 1983. Paleohydraulic reconstruction of flash-flood peaks from boulder deposits in the Colorado front range. Geol. Soc. Amer. Bull., 94, 986-1004.

Cunningham, A., 1854. Ladak, physical, statistical, historical, with notices of the surrounding countries: Sagar, Delhi.

Desio, A. & Orombelli, G., 1983. The "Punjab Erratics" and the Maximum Extent of the Glaciers in the Middle Indus Valley (Pakistan) during the Pleistocene. Lincei - Memorie Sc. fisiche, ecc. 1983 - S. VIII, v. XVII, Sez. II, 3, 135-180.

Hewitt, K., 1964. The Karakoram Ice Dam. Indus, 5, 18-30.

Komar, P.D., 1989. Flow-Competence Evaluations of the Hydraulic Parameters of Floods: an Assessment of the Technique. In: Floods: Hydrological, Sedimentological, and Geomorphological Implications (K. Beven, & P. Carling ed.). Wiley and Sons, 107-133.

Mason, K. 1929. Indus Floods and Shyok Glaciers. The Himalayan Journal, 1, 10-29.

Reineck, H.E., & Singh, I.B., 1980. Depositional Sedimentary Environments. Springer-Verlag, Berlin-Heidelberg.

Shroder, J.F. Jr., Cornwell, K., & Khan, M.S., 1991. Catastrophic Breakout Floods in the western Himalaya,Pakistan. Geol. Soc. Amer. Abs. with Prog., 23, no. 5.