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PALEOHYDROLOGY OF SOME OGALLALA (NEOGENE) STREAMS IN THE SOUTHERN PANHANDLE OF NEBRASKA

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ABSTRACT: Stratification and estimated paleoflow conditions for valley-fill deposits suggest that Ogallala Group streams in western Nebraska were similar to modern streams of south-central Alberta.

Ogallala stratification includes medium-scale (0.5 to 2.0 m thick) trough crossbedded sand and gravel, tabular indistinctly horizontally bedded and imbricated gravel, and horizontally bedded sand and pebbly sand. Valley fills are 15 to 55 m thick and 800 to 1800 m wide at the top. Some are in bedrock-floored channels resembling the "inner channels" of Shepherd and Schumm (1974).

Gradients for three well exposed paleovalley floors range from 0.0014 to 0.0020 (m/m) after tectonic correction. This compares with 0.00135 for the modern North Platte River Valley in Nebraska. The average intermediate diameters of the 10 largest clasts from tabular gravel beds found at 17 sites varied between 0.077 and 0.15 m. The average median intermediate diameter for gravel from four well exposed tabular gravel beds is 0.024 m.

Consistent paleodepth estimates of about 2 m correlate well with the scale of cross-stratification observed in the valley fills. Paleovelocities are estimated at about 2 m/sec, and Froude numbers of about 0.4 are consistent with a lower flow regime in the stability field of dunes. Two-dimensional specific in-channel paleodischarges were 3 to 4 m^2/sec. Total paleodischarge estimates based on slope-discharge relationships for gravel-bed rivers range from 340 to 1240 m^3/sec and are comparable to average annual peak discharges on the North Platte River reported 80 to 90 years ago.

Ogallala streams were probably dominated by macroforms similar to the "crescent-shaped bars" of the North Saskatchewan River. Deposition also took place on longitudinal bars in deeper channels. Shallow upper-flow regime transport and deposition is recorded by horizontally bedded sand and pebbly sand.

INTRODUCTION

The Ogallala Group (Neogene) is a continental deposit of markedly variable thickness that covers most of the southern third of the Nebraska panhandle (Fig. 1). The sediments and sedimentary rocks of the group are dominantly epiclastic and alluvial. Airfall volcanic ash, lacustrine diatomaceous beds, and pedogenic calcareous and siliceous horizons occur within the sequence. Source areas for the epiclastic component were primarily in the Southern Rocky Mountains of southern Wyoming and northern Colorado, but some sediments were derived locally in Nebraska from stream erosion of older Tertiary deposits.

The purposes of this paper are to review briefly the stratigraphic and sedimentologic work done on the Ogallala Group in western Nebraska since 1970, to provide site-specific data on the sediments of individual valley fills and the paleovalleys they occupy where possible, and to provide insight into the nature and behavior of the fluvial systems that produced the group.

PREVIOUS WORK

Robinson (1970) described the Ogallala Group in general terms for parts of Wyoming, Colorado and western Nebraska and demonstrated its complexity. Since his work, regional syntheses have confirmed his general outline of Ogallala geology. Izett (1975) and Scott (1975) have discussed the geology of Cenozoic deposits including the Ogallala and its equivalents in Colorado and adjacent areas. Blackstone (1975) prepared a similar treatment for the Cenozoic rocks of the Laramie Basin of Wyoming. Swinehart and others (1985) described the Cenozoic paleogeography of western Nebraska including the Ogallala.

Historical reviews have been prepared by Schultz (1977) for the Ogallala in general and by Diffendal (1984) for the Ogallala primarily in Nebraska. These works contain references to most of the pre-1970 reports done on the unit across the Great Plains and descriptions of the concepts used earlier to explain its nature and mode of deposition.

General descriptions and site-specific studies of Ogallala paleovalleys and valley fills of Nebraska and adjacent areas have been published by Skinner and others (1977), Swinehart (1979), Scott (1982), Diffendal (1982, 1983, 1985), and Diffendal and others (1985).

Alluvial sediment dispersal patterns, stream drainage patterns and types, and general variations in stream competence through time for Ogallala and younger deposits in western Nebraska have been the subjects of a few studies. Stanley (1971a, b) and Stanley and Wayne (1972) concluded that source areas and dispersal paths for sediments carried by Ogallala streams were different from those of Early Pleistocene streams and that Ogallala streams were not as competent as their Early Pleistocene counterparts. Stanley (1976) studied variations in sandstone petrofacies for the Ogallala and other units in southeastern Wyoming and adjacent parts of Colorado and western Nebraska. Swinehart (1979) and Diffendal (1982) used Stanley's techniques to separate most Ogallala gravels from younger gravels and to trace individual paleodrainages. Breyer (1975) used Markov-chain analysis to conclude that Ogallala streams were braided.

Most Ogallala Group sediments have undergone little diagenesis since deposition and are slightly cemented. Incipient diagenetic changes can be attributed to ". . . pedogenic processes, evaporative concentration of groundwater in the capillary zone, or by groundwater reaction with sediment" (Stanley and Benson, 1979, p. 401).

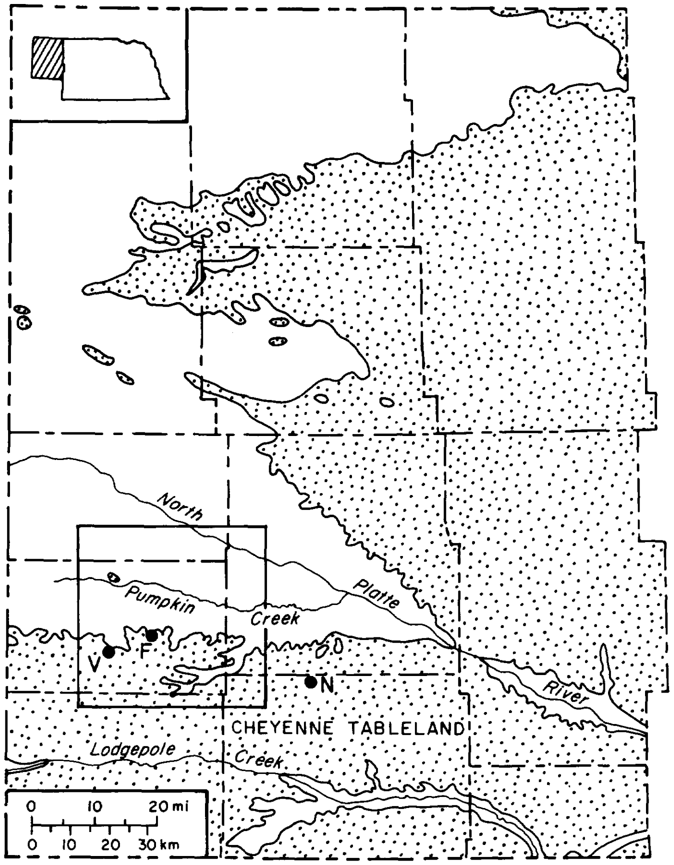

FIG. 1.—Extent of Ogallala Group (stippled) in the Nebraska panhandle. Modified after Swinehart and others (1985) with permission of the Rocky Mountain Section of the Society of Economic Paleontologists and Mineralogists. Black rectangle is the area covered by the satellite image in Figure 2. F is Faden paleovalley, sites 2 and 22; N is Nelson paleovalley, site 6; V is Van Pelt paleovalley, site 20. Site locations are listed in Table 1.

CHARACTERISTICS OF OGALLALA FLUVIAL SYSTEMS

Quaternary erosion of Neogene deposits of the Nebraska panhandle has revealed the nature of both Ogallala paleovalleys and valley-fill deposits. Diffendal and others (1985) have described two paleovalleys filled with Ogallala sediments. The valley wall slopes are a function of the composition of the walls. Valleys cut into siltstones of the Paleogene Brule Formation have slopes of at least 55°. Valleys with coarser grained walls have gentler slopes. Tributary valleys have preserved depths as great as 50 m and widths of more than 1 km (Diffendal, 1982).

Ogallala paleovalley and paleovalley-fill sites examined in this study are listed in Table 1. Sites 1 through 17 were sampled to find the 10 largest distantly derived clasts. Two of these sites and two additional sites were sampled to obtain a measure of the median grain size of exposed massive gravel beds (sites 18 through 21, Table 1). Site 22 was studied solely to examine stratification.

Paleovalley characteristics.—

Ogallala paleovalleys are either alluvial or non-alluvial (Table 1). Prestegaard (1984) has emphasized the importance of non-alluvial controls on stream channel morphology. Carling (1983) has shown that resistance exerted by the walls of narrow bedrock valleys will influence sediment transport. The paleovalley at site 2 divides into two narrow subvalleys, each between 100 and 120 m wide, around a bedrock island that is capped by Ogallala sediments. This arrangement of valley elements is similar to the "inner channels" described by Shepherd and Schumm (1974). At all other locations, estimates of the widths of paleovalleys are based on the widths of preserved valley-fill deposits. Three of the paleovalleys (sites 2, 6, and 20) have floors exposed over distances of from 1.3 to 18 km. The slopes of these floors were used in paleohydrologic analyses and are listed with valley parameters for streams presently in the study region (Table 2).

TABLE 1.—LOCATION OF STUDY SITES

Site	Decription		Type
1	NE 1/4 SE 1/4 NW 1/4	Sec 33, T18N, R50W	NA
2	NW 1/4 SW 1/4 SW 1/4	Sec 8, T18N, R54W	NA
3	SE 1/4 NW 1/4 SW 1/4	Sec 27, T18N, R48W	A
4	SE 1/4 NE 1/4 NW 1/4	Sec 33, T18N, R48W	A
5	C NE 1/4 SE 1/4	Sec 32, T17N, R50W	A
6	SW 1/4 NE 1/4 SW 1/4	Sec 21, T17N, R50W	A
7	SW 1/4 SE 1/4	Sec 27, T17N, R51W	NA
8	SW 1/4 SE 1/4	Sec 19, T18N, R51W	NA
9	NW 1/4 NE 1/4	Sec 36, T18N, R52W	NA
10	NE 1/4 NW 1/4	Sec 31, T17N, R53W	NA
11	C S 1/2	Sec 30, T17N, R53W	NA
12	SW 1/4	Sec 25, T17N, R54W	NA
13	SW 1/4 NW 1/4 SW 1/4	Sec 35, T17N, R54W	NA
14	SE 1/4 NE 1/4	Sec 5, T16N, R54W	NA
15	NE 1/4 NW 1/4	Sec 9, T18N, R54W	NA
16	NE 1/4 SW 1/4 NW 1/4	Sec 15, T18N, R55W	NA
17	N 1/2 NW 1/4 NE 1/4	Sec 13, T18N, R55W	NA
18	NW 1/4 SW 1/4 SW 1/4	Sec 8, T18N, R54W	NA
19	SW 1/4 NE 1/4 SW 1/4	Sec 21, T17N, R50W	A
20	NW 1/4 NE 1/4 NW 1/4	Sec 25, T18N, R56W	NA
21	SW 1/4 NW 1/4 SW 1/4	Sec 19, T14N, R46W	A
22	NE 1/4 NE 1/4 NE 1/4	Sec 18, T18N, R54W	NA

NA = Nonalluvial valley; A = Alluvial valley

Paleovalley-fill characteristics.—

Individual valley-fill deposits, seen as distinctive erosional remnants (Fig. 2), vary between 800 and 1800 m in width, between 15 and 55 m in preserved thickness, and occupy non-alluvial paleovalleys. The relatively great width of these paleovalleys probably rendered non-alluvial control of sediment transport and deposition important only near steep valley walls. Similarities in grain size and stratification observed at alluvial and non-alluvial sites and summarized below suggest this is true.

TABLE 2.—COMPARISON OF MODERN LAND SURFACE AND STREAMS TO PALEOVALLEYS AND FILLS

Topographic Feature	Slope (m/m)	Width (m)	Depth (m)
LODGEPOLE CREEK VALLEY	0.0027	7000	60
PUMPKIN CREEK VALLEY	0.0046	16000	200
NORTH PLATTE VALLEY	0.00135	25000	180
CHEYENNE TABLELAND	0.0027		
FADEN PALEOVALLEY	0.0041	1800	55
VAN PELT PALEOVALLEY	0.0043	1100	25
NELSON PALEOVALLEY	0.0047	800	12

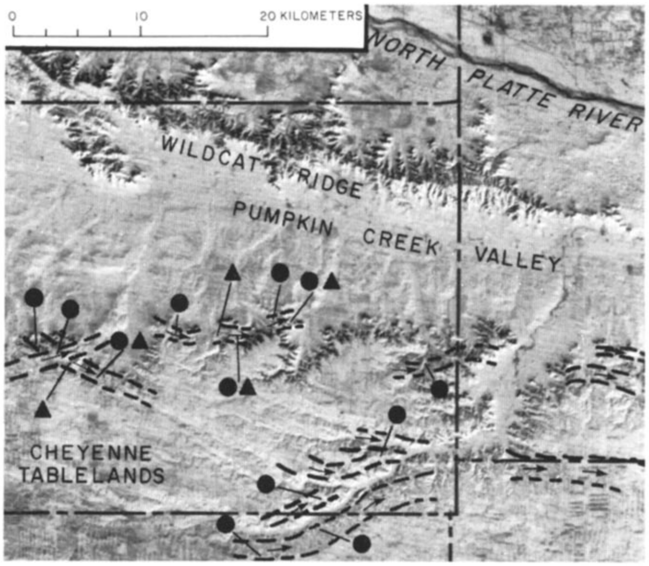

FIG. 2.—Satellite image of the area noted in Figure 1. Dashed lines mark sides of Ogallala valley fills. Arrows point in the direction of flow. Triangles are locations of locally derived megaclast blocks; circles are megaclast boulders.

Locally derived megaclasts are present in Ogallala valley-fill deposits. Rounded clasts as much as 2 m in largest exposed dimension were observed in the troughs of crossbedded sands and gravels (Fig. 3). They are similar to the large intraclasts described by Gibling and Rust (1984) from the Pennsylvanian Morien Group of Nova Scotia. Megaclast rounding, similar to the shape modification of some Morien intraclasts, may have been produced by undercutting and overturning of each clast while the megaclast surface was "sandblasted" by fluvial sand and gravel. The megaclasts were excluded from subsequent paleohydrologic analyses because of the uncertainties about their transport histories and the mechanisms responsible for their transport (see Miall, 1976, for a paleohydraulic treatment of similar clasts).

Granitic, metamorphic, and volcanic pebbles from the Front, Laramie, and possibly the Medicine Bow and Park Ranges of Colorado and southern Wyoming are common in Ogallala gravels. Rhyolite-bearing feldspathic sands and plagioclase sands comprise most Ogallala sandstones (Stanley, 1971a, b, 1976; Swinehart, 1979; Diffendal, 1982).

Bedding and sedimentary structures were impossible to observe at many sites where Ogallala deposits are either very poorly cemented or uncemented. Well indurated sedimentary rocks with a very fine-grained calcite cement occur at sites 2, 22, and 20 (Fig. 3A, B, C). All three of these valley fills are close to bedrock valley walls. Sites 6 and 21 (Fig. 3D, E) are not, and they are very poorly cemented or non-cemented. Restricted groundwater circulation in rock-walled valleys may have affected cement development.

Locally derived sediment covers the floors of many of the Ogallala paleovalleys. Fine, massive gravel composed of locally derived and fluvially reworked calcareous concretions from the underlying Brule Formation occurs at site 20 (Fig. 3C). Similar sediments cover floors of other Cenozoic paleovalleys in the area (Diffendal and others, 1985). This suggests that valley-cutting occurred prior to incorporation of valleys into regional drainage systems.

Several bedding styles and sedimentary structures were observed in Ogallala valley fills (Fig. 3). Fines are very rare in these deposits, but a bed of laminated fine sand and silt 1 m thick was observed at site 21 (Fig. 3E). This unit was probably deformed by vertebrates before the emplacement of overlying gravels (Loope, pers. commun.).

Horizontally bedded sands and fine gravels with a few intercalated scour-and-fill structures predominate at site 20 (Fig. 3C). These sediments were probably deposited from shallow upper flow regimes and are similar to sandy proximal braided stream deposits (Rust, 1978). Horizontally bedded sand was the principal bedding type formed by the 1965 Bijou Creek flood (McKee and others, 1967). The two horizontally bedded sand and gravel units separated by the erosional bounding surface shown in the lower part of Figure 3C have maximum preserved thicknesses of 1.5 to 2 m. Typical thicknesses for horizontally bedded sands deposited during the Bijou Creek flood were just under 1 m, but thicknesses of nearly 4 m were recorded (McKee and others, 1967).

Ten- to 40-cm-thick trough crossbeds of sand and fine gravel at sites 2 and 20 (Figs. 3A, 3C) also occur in many fluvial depositional systems and are very common in braided stream environments (Ore, 1964; Miall, 1977; Rust, 1978).

Beds of massive to imbricated and indistinctly normally graded, medium to coarse pebbles are present at site 2 (Fig. 3A). Each bed is nearly 1 m thick, and similar beds were observed at sites 19, 20, and 21. Foreset bedding was not observed in any of these units, and we believe that the beds were deposited as longitudinal bars. The largest distantly derived clasts always occurred in massive beds.

Medium-scale trough crossbedded sands and gravels with preserved trough-fill sequences as much as 1.5 m thick occur at sites 6, 21, and 22 (Figs. 3D, 3E, 3B). The lower unit of Figure 3A appears to consist of planar crossbedding in the section available, but nearby exposures revealed features of similar scale to be trough crossbedded. The very large locally derived megaclasts of siltstone or sandstone discussed previously are associated with many of the troughs and massive gravels.

Troughs exposed at gravel pits at sites 6 and 21 (Figs. 3D, 3E) reveal the internal structure of large Ogallala troughfills. Coarse and medium pebbles occur both as lag deposits along the base of individual troughs and as discrete graded crossbeds 5 to 10 cm thick that have either openwork textures or a medium sand matrix. Gravel crossbeds are separated by single or stacked, 2- to 5-cm-thick sandy graded crossbeds. Granule-size clasts are generally concentrated at the base of these crossbeds, and grain size fines upward to medium sand at the top. Floating pebbles are common in the sandy crossbeds.

Trough crossbedding composed exclusively of coarse gravel- to cobble-size clasts was observed in exposures of indurated Ogallala valley-fills (Figs. 3A, 3B). Set thicknesses are as great as 1.5 to 2 m. Individual crossbeds are

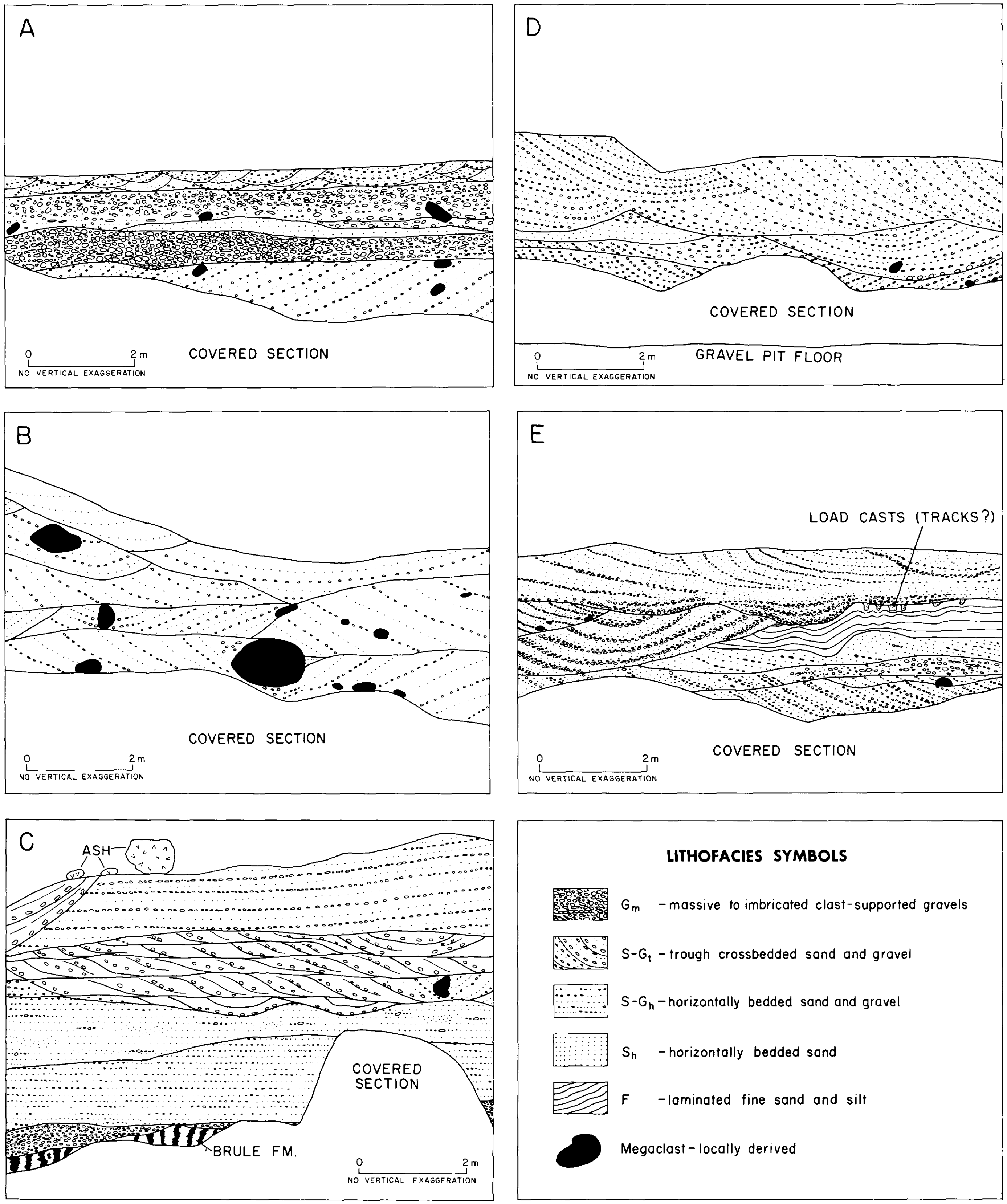

FIG. 3.—Scale outcrop maps of lithified fluvial sequences in rock-walled valley (A-C, sites 2, 22, and 20) and unconsolidated sediments in alluvial valleys (D and E, sites 6 and 21). See Table 1 for site locations.

very poorly sorted and appear massive or indistinctly normally graded. Differences in overall grain size between adjacent crossbeds allow them to be identified.

The stratification types present in the Ogallala suggest deposition in braided stream systems. Kraus (1984) described a G_t assemblage for her lithosome *F* of the Willwood Formation of Wyoming that is very similar to the collection of lithofacies described above for the Ogallala. She compared the G_t assemblage to the upper mid-fan sediments of the Scott outwash fan (Boothroyd and Ashley, 1975). The Ogallala sediments also resemble those of the Donjek-type braided stream (Williams and Rust, 1969; Rust, 1972; Miall, 1977, 1978). This is consistent with the paleogeographic position of Ogallala streams in western Nebraska. They were beyond proximal longitudinal bar-dominated braided streams that may have existed near the Southern Rocky Mountain front. Ogallala streams of western Nebraska were also quite different from the modern South Platte and Platte River systems which are dominated by deposition of sandy planar-tabular crossbeds and small-scale sandy trough crossbeds (Smith, 1971; Blodgett and Stanley, 1980; Crowley, 1983).

PALEOHYDROLOGY

Paleoflow parameters were estimated for sampled sites in Table 1. Valley slopes were corrected for tectonic tilting and were used as estimates of the energy grade lines for Ogallala streams. Values of D_{10x}, the average intermediate diameter of the 10 largest clasts, were used to infer flow magnitudes.

Methods and results.—

A number of methods are available for the estimation of paleoflow conditions for coarse alluvial sediments (Baker and Ritter, 1975; Bradley and Mears, 1980; Maizels, 1983; Costa, 1983; Williams, 1983; Baker, 1984; Steer and Abbott, 1984). Most are based on estimation of the tractive force necessary to move the largest clasts transported by a stream-flow event.

The methods we employ are based on threshold of motion estimates. Results must be regarded as qualitative (Maizels, 1983; Church, pers. commun.), and they apply, strictly speaking, only to gravel-floored riffle stretches of Ogallala streams.

Several authors have investigated the conditions necessary to entrain single coarse clasts from both natural and artificial stream beds. Parker and others (1982) and Andrews (1983) have studied this problem for bedload transport in natural flows having mixed particle-size beds. In each of these works, the Shield's parameter (dimensionless critical shear stress parameter) is found using a power relationship of the form $\tau^*_{ci} = a(D_i/D_{50})^b$, where D_i = diameter of the *i*th percentile of the bed surface material and D_{50} = the diameter of the median subsurface material, both in meters. Both papers present values of the constant, *a*, and the coefficient, *b*, that are similar. We used the relationship of Andrews (1983), $\tau^*_{ci} = 0.0834\ (D_i/D_{50})^{-0.872}$, because it was derived from large data sets from three rivers with the western United States.

D_{50} was evaluated by a modified grid-by-number sampling technique (Kellerhals and Bray, 1971). At sites 18–21 (Table 1), a horizontal line was placed along the center of a well exposed massive gravel bed. The exposed intermediate diameters of 50 pebbles located at 10-cm intervals were measured and ranked by size. The diameter of the 25th pebble in the ordered set was taken as a measure of D_{50} for the site. The average for all four sites was 0.024 ± 0.002 m where the plus-minus indicates the range in values. Using this average and values of D_{10x} for D_i in the equation of Andrews (1983), an average value for the dimensionless critical shear-stress parameter of 0.021 ± .006 was derived for sites 1–17. A shear-stress value of 0.02 was used for these sites in all subsequent calculations. Unique values rather than an average were used for sites 18–21.

Paleodepth estimates were calculated from the relationship $d_c = \tau^*_{ci}[(\gamma_s - \gamma)/\gamma]D/S$, where d_c = critical flow depth required to transport a clast of diameter, D (D_{10x} was used for this value); γ_s = the specific weight of sediment, taken as 2650 kg/m^3 and γ = the specific weight of water, taken as 1000 kg/m^3 for clear water and 1250 kg/m^3 for a suspended sediment concentration of 10 percent; and S = the slope of the energy grade line, taken as valley slope. The use of two values for the specific weight of water follows the methods of Maizels (1983) to account for uncertainties in the suspended sediment content of flows in Ogallala streams.

We have also used two values for the valley slope in estimating flow depths at each site. One of us (RFD) has noted that many Ogallala valley fills in western Nebraska are erosionally truncated to the west and buried by younger sediments to the east. This suggests that tectonic tilting of the area has taken place since deposition of Ogallala sediments. In order to correct for this post-depositional tilting, we constructed an uplift curve (Fig. 4) based on a map of crustal movement during the past 10 million years in the High Plains and Southern Rocky Mountain regions (Gable and Hatton, 1983). Post-depositional tilting of the study area in the direction of paleovalley elongation is estimated at 0.0027 (m/m). By subtracting this from the present paleovalley slopes (Table 2), estimates of slopes at the time of deposition of 0.0014, 0.0017, and 0.0020 (m/m) were calculated. These are comparable to a slope of 0.00135 for the modern North Platte River Valley in western Nebraska. Both the high and low values were used in the estimation of Ogallala stream-flow conditions. Each site provided four estimates of depth, one each for the different combinations of valley slope and specific weight of water. Flow depths in Ogallala streams at the time of re-entrainment of large distantly derived clasts from riffle segments were between 1.6 and 2.6 m, with the most likely depths near 2 m (Table 3).

Paleovelocity was estimated using equations of Bray (1979), who used data gathered from 67 gravel-bed rivers in Alberta to empirically derive statistically significant relationships between water surface slope and both Manning's n ($r^2 = 0.298$) and $1/\sqrt{f}$ ($r^2 = 0.473$), where f is the widely used dimensionless friction factor. Substitution of these expressions into the original Manning equation and the Darcy-Weisbach friction equation yields power equa-

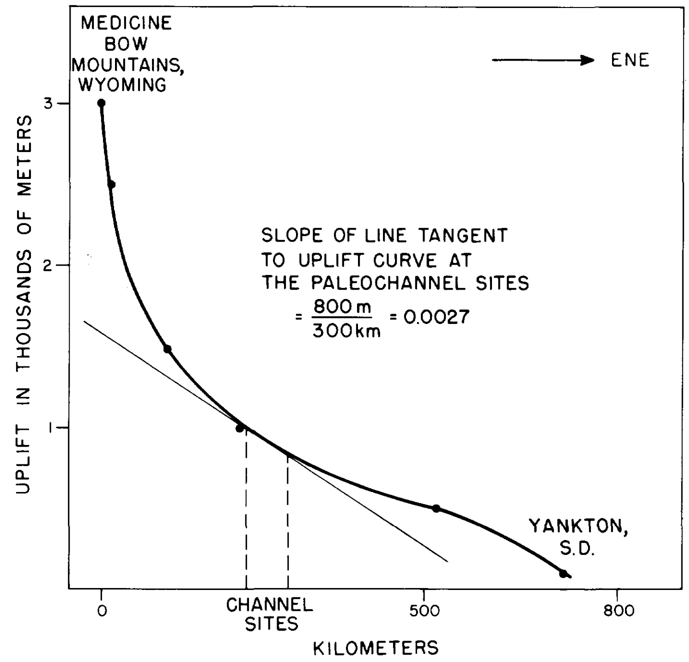

FIG. 4.—Uplift curve based on data from Gable and Hatton (1983). Line tangent to the curve at the channel sites has a slope of 0.0027 (m/m). See text for explanation.

tions similar to the Lacey equation, where $V = ad^bS^c$. An expression for the best fit of the Lacey equation to the Alberta data [Bray, 1979, see equation (41)] was also used. Richards (1982) has commented that such power equations are a limited representation of the general logarithmic resistance equation and are useful only within confined grain size conditions. We feel justified in using Bray's expressions for Ogallala valley fills because of the similarities in both valley slope and grain size between the Alberta rivers and the paleovalley fills.

The following equations were used to estimate paleovelocity:

1. $V_1 = 9.62\, d^{0.667}S^{0.323}$ (Manning equation) (1)
2. $V_2 = 6.16\, d^{0.5}S^{0.244}$ (Darcy-Weisbach equation) (2)
3. $V_3 = 8.0\, d^{0.60}S^{0.29}$ (Lacey equation), (3)

where d = flow depth and S = water surface slope. Each of the two slope estimates was matched with the four depth estimates for the 21 sites (Table 3). Flow velocities were in the range of 1.5 to 2.3 m/sec with the most likely velocities slightly less than 2 m/sec.

Estimates of specific in-channel discharge, a sort of two-dimensional discharge (units of m^2/sec; Maizels, 1983), were calculated for each site by multiplying the average paleodepth estimate by the most commonly occurring average paleovelocity estimate (Table 3). In cases where channel width can be estimated, it can be multiplied by specific in-channel discharge to obtain total in-channel discharge. Specific in-channel discharges for Ogallala streams are between 2.1 and 5.7 m^2/sec with the most likely values between 3 and 4 m^2/sec (Table 3).

Estimates of total paleodischarge for Ogallala streams are difficult to make. From the limited outcrops available, it is impossible to reconstruct the total across-valley area of the Ogallala paleovalleys that may have been occupied by riffled channels at any given time. Even if this information were available, there is no way of calculating paleodischarge across the three-dimensional bedforms that must have been present outside the channels and that produced the trough crossbeds preserved in the valley fills (Fig. 3).

Steer and Abbott (1984) presented several equations to estimate bankfull or dominant (channel-forming) discharge for gravel-bed streams. All are power relationships based on slope. Application of equations (32), (34), and (36) of Steer and Abbott (1984, p. 38) to the slopes 0.0014 and 0.0020 (m/m) results in paleodischarge estimates of 340 to 1240 m^3/sec. Williams (1975) suggested that average an-

TABLE 3.—RESULTS OF THE PALEOHYDROLOGIC ANALYSES

Site	D_{10x}(m)	d_c(m)	V_1(m/s)	V_2(m/s)	V_3(m/s)	Specific Discharge (m^2/s)	Froude Number
1	0.113 ± 0.015	2.0 ± 0.6	1.8 ± 0.2	1.9 ± 0.3	1.9 ± 0.2	3.8 ± 1.8	0.41
2	0.124 ± 0.011	2.2 ± 0.6	1.9 ± 0.2	2.1 ± 0.3	2.0 ± 0.3	4.4 ± 1.8	0.43
3	0.087 ± 0.006	1.6 ± 0.4	1.6 ± 0.2	1.6 ± 0.2	1.6 ± 0.2	2.6 ± 0.8	0.40
4	0.115 ± 0.010	2.0 ± 0.6	1.8 ± 0.2	2.0 ± 0.2	1.9 ± 0.3	3.8 ± 1.2	0.43
5	0.116 ± 0.007	2.0 ± 0.6	1.9 ± 0.2	2.0 ± 0.2	1.9 ± 0.2	3.8 ± 1.2	0.43
6	0.077 ± 0.010	1.4 ± 0.4	1.5 ± 0.2	1.5 ± 0.2	1.5 ± 0.2	2.1 ± 0.6	0.40
7	0.109 ± 0.016	2.0 ± 0.6	1.8 ± 0.2	1.9 ± 0.3	1.9 ± 0.2	3.8 ± 1.8	0.43
8	0.099 ± 0.009	1.8 ± 0.6	1.7 ± 0.2	1.8 ± 0.2	1.8 ± 0.2	3.2 ± 1.2	0.43
9	0.100 ± 0.008	1.8 ± 0.6	1.7 ± 0.2	1.8 ± 0.2	1.8 ± 0.2	3.2 ± 1.2	0.43
10	0.114 ± 0.009	2.0 ± 0.6	1.8 ± 0.2	1.9 ± 0.3	1.9 ± 0.3	3.8 ± 1.8	0.43
11	0.127 ± 0.014	2.2 ± 0.6	1.9 ± 0.2	2.1 ± 0.3	2.0 ± 0.3	4.6 ± 1.8	0.43
12	0.117 ± 0.018	2.0 ± 0.6	1.9 ± 0.2	2.0 ± 0.3	2.0 ± 0.2	4.0 ± 1.8	0.45
13	0.118 ± 0.022	2.2 ± 0.6	1.9 ± 0.2	2.0 ± 0.3	2.0 ± 0.2	4.4 ± 1.8	0.43
14	0.121 ± 0.016	2.2 ± 0.6	1.9 ± 0.2	2.0 ± 0.3	2.0 ± 0.2	4.4 ± 1.8	0.43
15	0.107 ± 0.005	2.0 ± 0.6	1.8 ± 0.2	1.9 ± 0.2	1.9 ± 0.2	3.8 ± 1.2	0.43
16	0.135 ± 0.014	2.4 ± 0.6	2.0 ± 0.2	2.2 ± 0.3	2.1 ± 0.3	5.0 ± 1.8	0.43
17	0.150 ± 0.036	2.6 ± 0.8	2.1 ± 0.2	2.3 ± 0.3	2.2 ± 0.3	5.7 ± 2.4	0.44
18	0.104 ± 0.015	1.9 ± 0.5	1.7 ± 0.2	1.8 ± 0.3	1.8 ± 0.2	3.4 ± 1.5	0.42
19	0.053 ± 0.008	1.9 ± 0.5	1.8 ± 0.2	1.9 ± 0.2	1.8 ± 0.2	3.4 ± 1.0	0.42
20	0.056 ± 0.008	2.0 ± 0.5	1.8 ± 0.2	1.9 ± 0.3	1.9 ± 0.2	3.8 ± 1.5	0.43
21	0.049 ± 0.004	1.7 ± 0.5	1.7 ± 0.2	1.8 ± 0.2	1.8 ± 0.2	3.1 ± 1.0	0.44

Expressions for d_c, V_1, V_2, V_3, specific discharge and Froude number are found in the text.

nual peak flows of the North Platte River at North Platte, Nebraska were between 450 and 650 m^3/sec near the turn of this century. These historic discharges were probably subject to upstream control of flow (Bentall, 1982), and pre-control peak annual flows may have been greater than the values cited by Williams (1975).

Average depth and velocity estimates were also used to calculate Froude numbers for in-channel flow over riffles (Table 3). All sites have Froude numbers between 0.40 and 0.45. These suggest that flows remained in the stability field of dunes in the lower flow regime (Guy and others, 1966). This result agrees well with field observation of trough crossbedding in Ogallala valley fills.

DISCUSSION

The high and low ranges for the values of the flow conditions estimated for sites 1 through 17 (Table 3) are for sites with D_{10x} significantly higher or lower than the average for the 17 sites. The sites that produced high and low estimates have estimated dimensionless critical shear-stress parameters that are different than 0.02. Paleoflow estimates calculated for sites 18 through 21, where a unique dimensionless critical shear-stress parameter was established for each site, are very similar despite differences in D_{10x} between the sites. Clearly, the use of a single dimensionless critical shear-stress parameter for all sites is unsatisfactory. Our estimates of paleodepth, paleovelocity, and specific in-channel paleodischarge fall into a relatively narrow range only because of the relative uniformity in D_{10x} between sites (note that we have assumed a narrow range for D_{50}, as well).

In order to explore the possibility that tectonic tilting of the study site has not occurred, paleoflow estimates were made for site 5 using slope values of 0.0041 and 0.0047. All other factors were kept the same. This scenario assumes that erosion of Ogallala paleovalleys to the west and their burial to the east represent modification of a Miocene depositional surface strictly by erosion and deposition. Estimated depth was 0.8 ± 0.1 m, velocity was 1.4 ± 0.2 m/sec, and specific in-channel discharge was 1.1 ± 0.2 m^2/sec. The flow depth seems too shallow to accommodate the large crossbeds described above. The calculated Froude number was 0.50, which suggests transition to a plane-bed stage rather than a stable dune-stage bed.

Estimation of bankfull stage or dominant paleodischarge using the methods of Steer and Abbott (1984) and paleovalley slopes of 0.0041 and 0.0047 gives results of 42 to 84 m^3/sec. It seems likely that the Ogallala valley-fill sediments were transported and deposited by streams of greater size.

SUMMARY AND CONCLUSIONS

Paleoflow depths estimated for riffled channels of Ogallala streams using valley slopes of 0.0014 and 0.0020 (m/m) are close to 2 m. This compares favorably with the observation that maximum preserved thicknesses of individual trough-scour fills (Fig. 3) are 1.5 to 2 m. Paleodepths calculated using uncorrected valley slopes are 0.8 m, about one-half the value suggested by stratification. Velocities slightly less than 2 m/sec, estimated using the corrected slopes, produce Froude numbers that are consistent with the trough cross-stratification in Ogallala valley-fill deposits (Fig. 3), but this result is misleading since the largest Ogallala trough crossbeds were probably made by migrating macroforms, as discussed below.

Paleodischarge is impossible to reconstruct from Ogallala deposits, but estimates based on valley slopes give quantities that are the same order of magnitude as average annual peak flows on the North Platte River for the period of 80–90 years ago. Estimates of paleodischarge based on uncorrected valley slopes are an order of magnitude smaller.

Control of the North Platte since before its earliest gauging measurements render strict comparisons between it and Ogallala streams difficult. The best modern models for flow conditions in Ogallala streams probably are among the 67 gravel-bed rivers from Alberta (Bray, 1979). The Pembina River near Entwistle, the North Saskatchewan River near Rocky Mountain House, and the Red Deer River at Red Deer have bankfull discharges estimated at between 200 and 700 m^3/sec (Bray, 1979). All have sources near the Continental Divide of the Canadian Rockies, and the three sites mentioned above are 100 to 150 km from the divide. In these respects they are probably similar to the Ogallala streams that had sources near the Continental Divide in the Rocky Mountains of Colorado 200 to 250 km from our study area.

Flow depths for the three Canadian streams listed above are given as 1.7 to 1.8 m. In addition, Galay and Neill (1967) discussed large crescent-shaped bars (probably macroforms in the terminology of Crowley, 1983) from the North Saskatchewan River near Drayton Valley, Alberta. These are 150 to 300 m in length, 1.8 to 3 m high, are composed of gravel with a mean size of about 5 cm, and form in flow depths of about 3 m. The bars are shaped much like sandy subaerial barchan dunes, and deposition on the curved slipfaces of these bars would presumably produce large trough crossbeds. The North Saskatchewan River flows in a straight reach about 240 to 370 m wide and appears to have one sinuous channel or thalweg 100 m wide (Galay and Neill, 1967). Such a channel in an Ogallala stream could have carried an estimated discharge of 300 to 400 m^3/sec during bankfull conditions.

Macroforms described from the modern South Platte and Platte Rivers of Colorado and Nebraska have maximum vertical heights and preserved slipfaces that are similar to the flow depths that produced them. Flow acceleration over a Platte River macroform may cause upper flow regimes to develop (Crowley, 1983). The sandy planar-tabular crossbedding produced by migration of these forms is in marked contrast to the massive gravels and trough crossbedding of the Ogallala deposits. This suggests that the Ogallala streams were dominated by a different "North Saskatchewan"—type macroform. To the authors' knowledge, such macroforms have not been described for the North Platte River. In this respect, the Ogallala valley fills may be unique in the western Nebraska panhandle. It is also possible that control of the flow on the North Platte River during the past 100 years has changed the bedforms present in the river.

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