DOWNSTREAM FINING IN A SAND-BED SEGMENT OF THE CANADIAN RIVER, NEW MEXICO, TEXAS, AND OKLAHOMA

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CHAPTER I

INTRODUCTION

Problem Statement and Significance

It has long been recognized that the character of sediment in streams changes as a function of distance. These changes are briefly described in nearly every sedimentology textbook as a tendency of particles to become finer, rounder, and better sorted in a downstream direction. Unfortunately, this has led to the widespread misconception that fluvial sediment changes with distance downstream are among the best-understood tenets of geology. This is not the case. Though a large body of work has examined these changes in gravel-bed rivers, very few studies have been conducted on their sand-bed counterparts. In the concluding statement of a study of Mississippi River sands, Russell and Taylor (1937, p. 267) admitted, "The belief that streams characteristically round their transported sands therefore seems to be without foundation. Apparently this concept is another armchair theory developed without the support of evidence from actual observations."

In one of the few detailed studies concerning all three of these changes (fining, rounding, and sorting) on a sand-bed river, Jerome Pollack (1959, 1961) studied a 1000-kilometer segment of the (South) Canadian River. During a period of low flow, he collected sediment in the Canadian River thalweg near highway bridges at 20 locations. Interestingly, he found that no statistically significant fining trend occurred in the median diameter (ϕ_{50}) within the river segment. In addition, he reported no trend in several other distribution parameters, including sorting (standard deviation) and skewness. From this study, he concluded that the type and magnitude of processes operating in the low-water channel are the same regardless of position along the longitudinal profile[1]. In Pollack's (1961, p. 24) words, all twenty of his samples must represent "deposits of a similar hydraulic environment."

Pollack's sampling strategy is similar to that used in other studies on fine-bed streams (U. S. Waterways Experiment Station, 1935; Nordin and Queen, 1992; Nordin et al., 1977). He used a dredge-like sampler to collect bed material from the thalweg of the low-water channel. However, material from this part of the channel cross-section is not representative of a single discharge event since it is exposed to the full range of flows in the channel. At more elevated positions in the channel cross-section, such as the tops of transverse bars, deposits are less likely to be reworked by low to moderate flows. These sediments are normally deposited immediately after high discharge events and can only be altered by flows comparable to those that deposited them in the first place. Also, according to Middleton (1976, p. 413), the near-bankfull discharge should determine the average grain-size distribution of the bar.

> "It seems probable that the condition that determines the bed characteristics is some flow larger than the annual mean (Wolman and Miller, 1960). For geomorphological studies, Leopold and Wolman (1957) made use of the 'bankfull discharge' and it seems that this might also be appropriate for sediment studies though it has been suggested by Benson and Thomas (1966) that the dominant discharge, defined as that discharge which, over a long period of time, moves the most sediment, is generally much less than bankfull . . .
>
> In the discussion of river sediments that follows, therefore, it has generally been assumed that, where the discharge varies widely, it is the shear velocities that prevail at near-flood discharges that determine the *average* characteristics of the bed material."

---

[1] It is necessary to note that Pollack's study followed an extended regional drought beginning in 1951 and ending with floods in 1957 (Tortorelli, 1991). The effect on Pollack's results is unknown.

The study presented here repeats a portion of Pollack's work on the Canadian River to examine the influence of sample location on conclusions about downstream fining. It revisits 15 of Pollack's sites to collect samples from the highest point on the bar head in an attempt to sample the near-bankfull deposit. As a complement to this study, Simms (2001) simultaneously collected samples within the mean flow channel on the bar tail. Simms' median fining trend was not statistically significant though it was slightly better developed than Pollack's. A diagram showing the sampling locations of all three studies is shown in Figure 1.

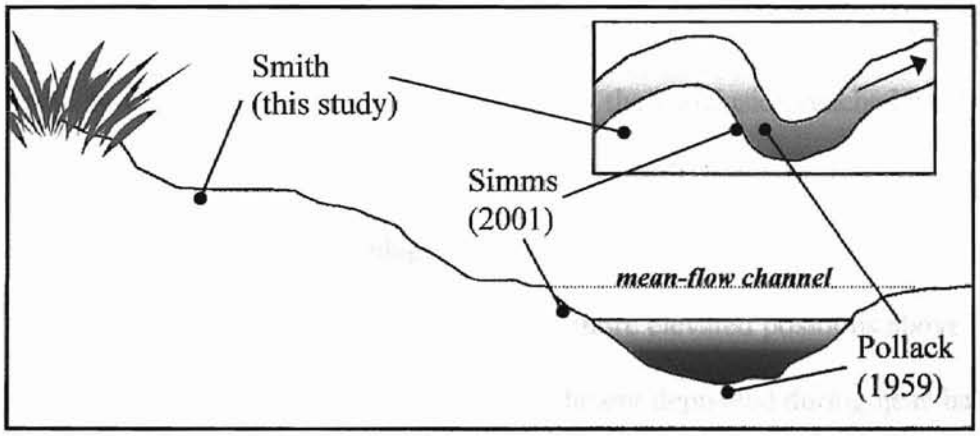


Figure 1. Sampling locations within the channel cross-section at low flow

Knowledge of three-dimensional variation of grain-size and sorting in alluvial materials is important for predicting 1) porosity, which determines the amount of petroleum storage in a reservoir; 2) permeability, which governs well productivity; and 3) continuity of sand bodies, which controls performance in the long-term. Better understanding of these reservoir properties is vital to efficient well-field development. Though this downstream fining study is concerned with only a single time-slice of a modern alluvial valley fill, it can be integrated with data obtained from sediment cores to get a picture of regional variation in rock properties exhibited in alluvial reservoirs and aquifers. At Oklahoma State University, efforts to complete this picture for the Canadian River valley are underway. In addition, future research will expand the study to other modern fluvial systems in Oklahoma.

Purpose and Objectives

The goal of this study is to describe and explain downstream trends in size of bed material along a 1000-kilometer sand-bed segment of the (South) Canadian River. It evaluates the null hypothesis that there is no statistically significant trend in the size distribution of bar sediments along the segment of the South Canadian River from Logan, New Mexico, to Calvin, Oklahoma. This is essentially the conclusion reached by Pollack in his 1959 dissertation; the methodology employed to test it, however, has one major difference. The near-bankfull flow, which in some rivers is responsible for performing the most geomorphic work, is better represented at more elevated positions above the mean-flow channel. Therefore, in this study, the sediment deposited during near-bankfull flow conditions was sampled instead of the low-flow bed deposit. Based on this difference in sampling strategy, general statements about the importance of sampling location in fluvial sediment and its influence on observed trends in grain size may be generated.

In addition to downstream changes in grain size, it is important to know the amount of at-a-site variability. The mean or median grain size can be highly variable with location on a bar. It is an important aspect of this study to know if three or more samples taken from the same area on the bar will have similar grain-size distributions. To address this question, the following study also includes an examination of grain-size variability on one point bar in the study reach.

Study Area

Sourced in the Sangre de Cristo Range of the Rocky Mountains, the Canadian River system drains approximately 121,500 km^2 (47,000 mi^2) in New Mexico, Colorado, Kansas, Texas, and Oklahoma before joining with the Arkansas River at Robert S. Kerr Reservoir (Figure 2). In terms of contributing area the North Canadian River is the Canadian's largest tributary, accounting for 38 percent of the total basin area. It joins the trunk stream at Eufaula Reservoir, about 50 kilometers upstream from the mouth. This study, however, is limited to the sand-bed segment of the main stem above the U.S. Geological Survey gage station at Calvin, Oklahoma (USGS Gage #07231500). This segment extends 1020 kilometers upstream to Logan, New Mexico where the Survey maintains another gage station (USGS Gage #07227000). This length accounts for 71% of the river's 1440-kilometer total length above Calvin.

The gage at Calvin is designated the basin outlet to exclude the North Canadian River and the two large reservoirs (Kerr and Eufaula) from the study. As defined by the Calvin gage site, the Canadian River main stem serves a drainage area of 72,000 km^2 (44,750 mi^2). Total relief in the basin is 3450 meters (11,319 feet) but the elevation drop of the longest channel is only 2430 meters (7970 feet). In addition to the two reservoirs below the study segment, two other reservoirs exist near or within the 1020-kilometer study segment. The U.S. Bureau of Reclamation constructed Lake Meredith's Sanford dam between 1962 and 1965, sixty kilometers northeast of Amarillo, Texas. Two hundred and fifty kilometers upstream, Ute Reservoir was completed by the State of New

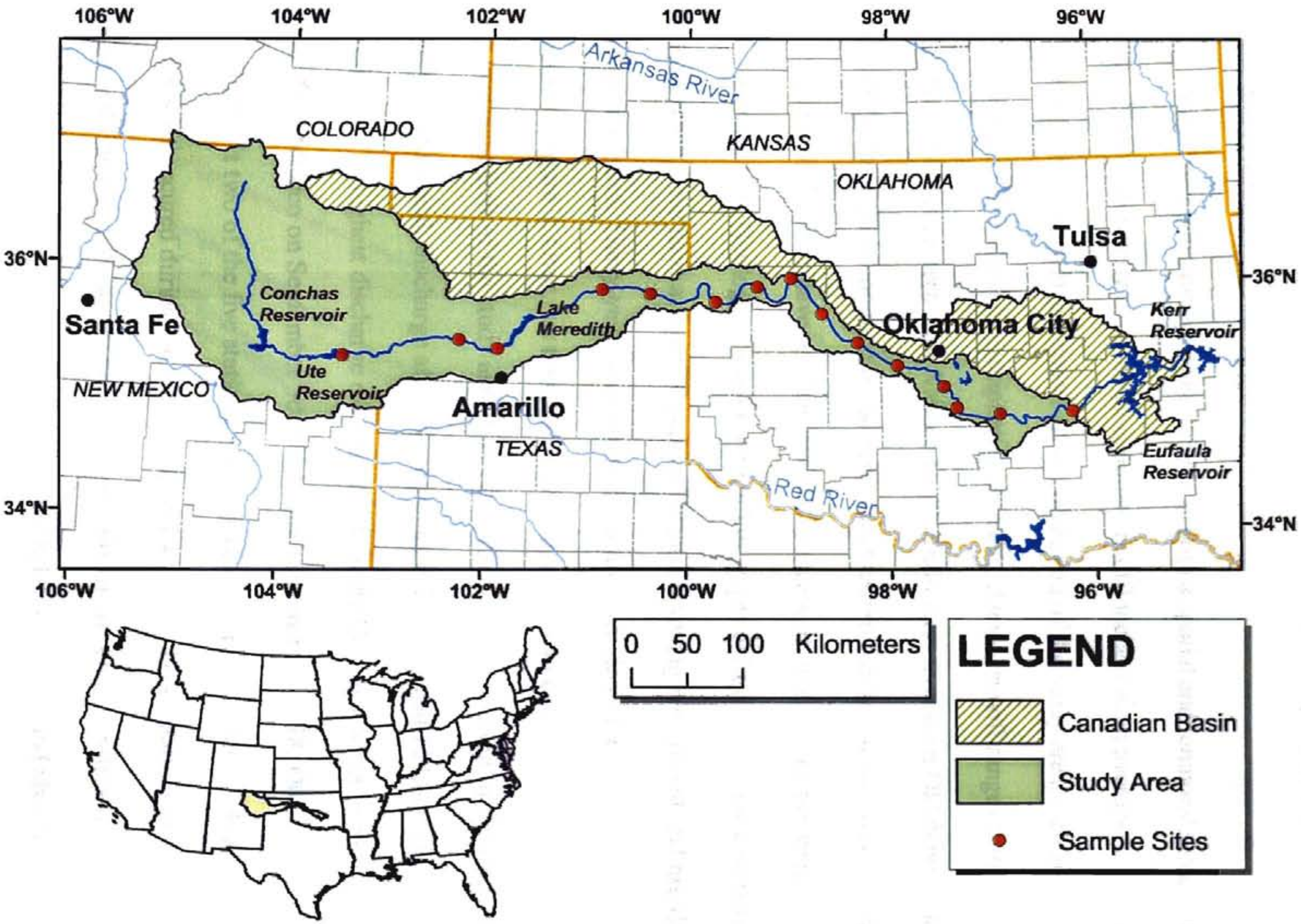


Figure 2. Extent of the Canadian River basin (hachured) with study area (solid)

Mexico near Logan in 1968. The 750-kilometer segment from Sanford dam to Calvin, Oklahoma is the most important in this study since it hosts no impoundments.

Climate and Hydrology

Annual precipitation is highly variable in both a spatial and temporal sense. The upstream limit of the study receives 25 centimeters (10 inches) in an average year, much in the form of freezing rain and snow. At the other end of the study area, Calvin receives 100 centimeters (40 inches) of precipitation annually. Annual runoff ranges from as little as 0.5 centimeters in eastern New Mexico to 20 centimeters in eastern Oklahoma (Gebert et al., 1987). Drought is common in the more arid western reaches of the basin. Today, many reaches of the river have no-flow periods in excess of two months per year.

Several U.S. Geological Survey streamflow gages exist on the main stem within the study reach. Five have at least 50 years of record, showing both recent and pre-dam flow characteristics. Thirty-year flow-duration curves (post-dam) for these gages are presented in Figure 3. Over this time, mean discharge is 43.4 cubic feet per second (cfs) at the upstream limit of the study and 1999 cfs at the downstream limit of the study. The maximum annual peak discharge at the same points is 7940 cfs and 154,000 cfs, respectively. The highest discharge ever recorded on the Canadian River occurred near Logan, New Mexico on September 30, 1904, and is estimated at 278,000 cfs (USGS, NWISWeb). At two of the five stations, a pronounced decrease in annual flow characteristics occured during the 1960s (Figures 4 and 5). These stations at Logan, New Mexico and Canadian, Texas are both less than 200 kilometers downstream of dams. Dams tend to decrease the sediment supply being fed downstream and also decrease the variance of daily flow rates. Immediately downstream of the dam, the result is a decrease

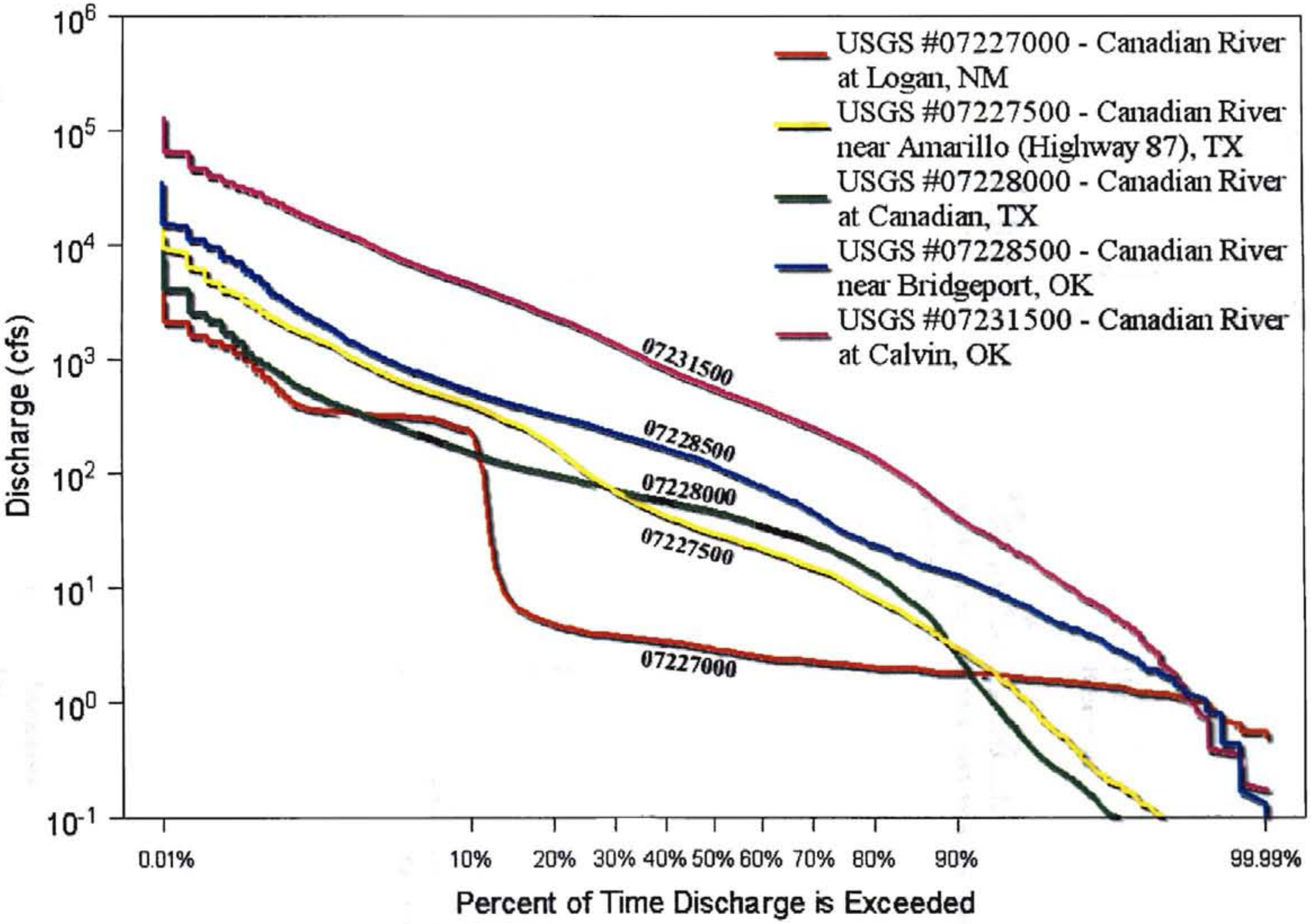


Figure 3. Flow-duration curves (regulated) for selected sites on the Canadian River, water years 1970-2000

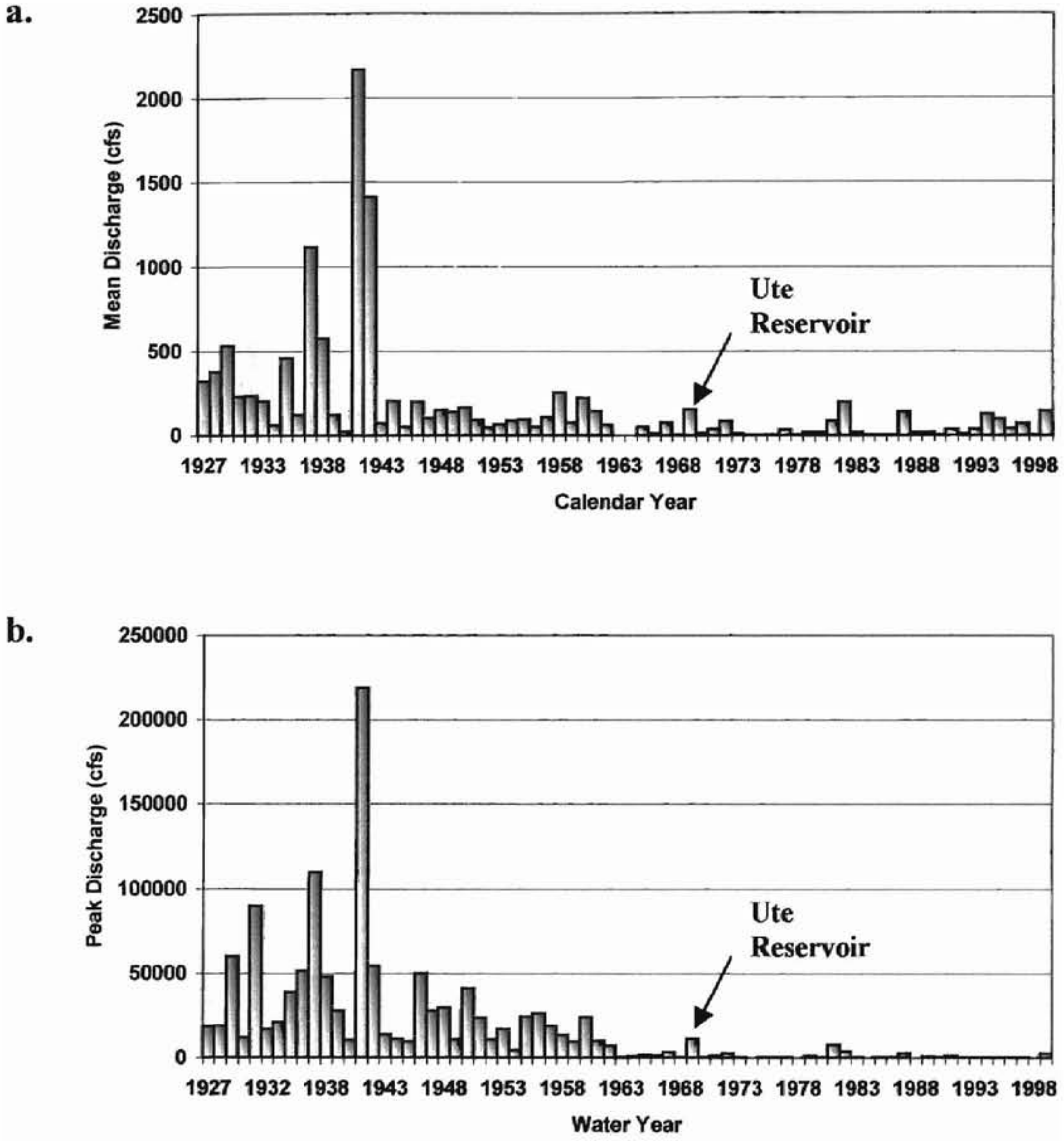
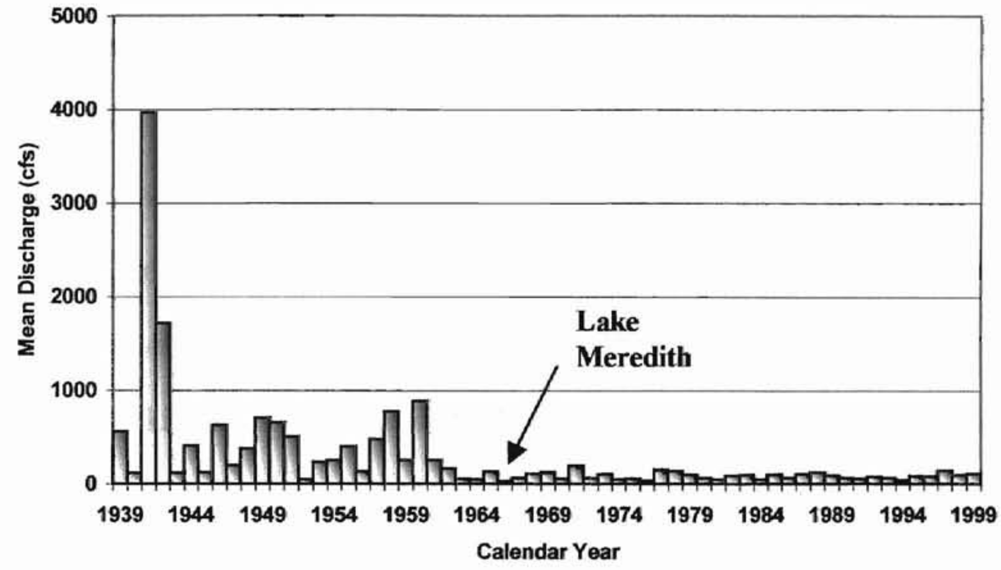


Figure 4. a.) Mean discharge and b.) annual peak discharge at USGS gage #07227000, Canadian River at Logan, New Mexico

a.



b.

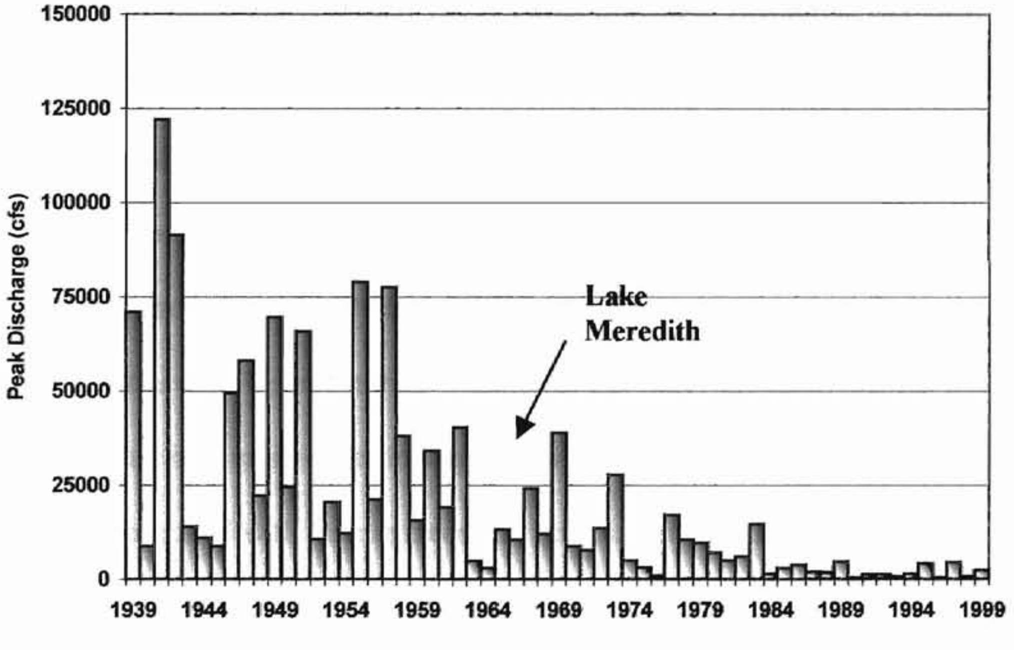


Figure 5. a.) Mean discharge and b.) annual peak discharge at USGS gage #07228000, Canadian River at Canadian, Texas

in the size range of transportable sediment. The effect of dams generally decreases with distance downstream as daily flow and sediment supply approach their original, unregulated rates.

Since the end of the Pleistocene the Canadian main stem has generally been aggrading, though degradation dominated in the late Pliestocene (Ward and Carter, 1999). The present-day river appears to be underfit to the width of its alluvial valley (often exceeding 3 kilometers). According to field observations during this study, the Canadian is a meandering stream with some braided reaches. However, some publications indicate that as little as 30 years ago braiding was much more common over much of the Texas Panhandle (Kessler, 1971; Texas Bureau of Economic Geology, 1992). Where the river enters the state of Oklahoma, it begins to flow through a series of incised meanders whose geometry appears to be inherited from a more humid, post-glacial landscape. In New Mexico, high mesas often confine the channel, sometimes closing to form narrow canyons (Pollack, 1959). The mesas continue into Texas but diminish toward the east. Upon entering Oklahoma, the valley gradually widens and the surrounding terrain becomes gentler in slope. In western Oklahoma, floodplains are usually heavily vegetated with mature trees and shrubs. This floodplain stabilization is possibly a result of over thirty years of flow regulation at Sanford dam and base flow reduction due to groundwater extraction in the High Plains (Ogallala) aquifer. At the time of this report, water levels in the High Plains Aquifer in Roberts County, Texas, near Pampa were 150-200 feet below the Canadian channel (USGS, NWISWeb).

The active channel cross-section of the river is characterized by a relatively high width-depth ratio. Since flooding is fairly rare in the Canadian, the channel configuration may remain the same for more than a decade between major floods. Along most of the study length, a steep-sided, low-to-mean flow channel has been scoured through previously deposited bar sediments.

Between the study endpoints discussed above, the Canadian basin's width rarely exceeds 50 kilometers and is sometimes less than 15 kilometers. Large tributaries are extremely rare along this section of the river (Figure 6). Only two have drainage areas greater than 2000 km^2. Punta de Agua Creek and its tributaries drain a total area of 9200 km^2 (3554 mi^2) before joining the Canadian River near Boys Ranch, Texas[2]. The only other large tributary in the study area is Little River with a drainage area of 2500 km^2 (976 mi^2). It joins the Canadian 10 kilometers above Calvin, Oklahoma.

Bedrock Geology

The Canadian River accepts sediment from several distinct rock types, most of which strike in a direction perpendicular to the river (Figure 7). Around the New Mexico and Texas border, bedrock is Permian and Triassic in age and consists of poorly consolidated fine-grained clastic rocks. In the eastern Texas Panhandle, the bedrock belongs to the Tertiary Ogallala Formation. The Ogallala is composed of a wide range of grain sizes from clay to pebbles whose mineralogy links them to crystalline rocks of the Rocky Mountains. At the Oklahoma border, the overlying Ogallala is removed, exposing Permian fine-grained sandstones, siltstones and shales. These units are very weakly cemented and are often easily disaggregated by hand. Finally, as the river enters the eastern half of Oklahoma, the bedrock changes again to more consolidated and competent Pennsylvanian strata.

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[2] This is also the site of a large gravel-mining operation.

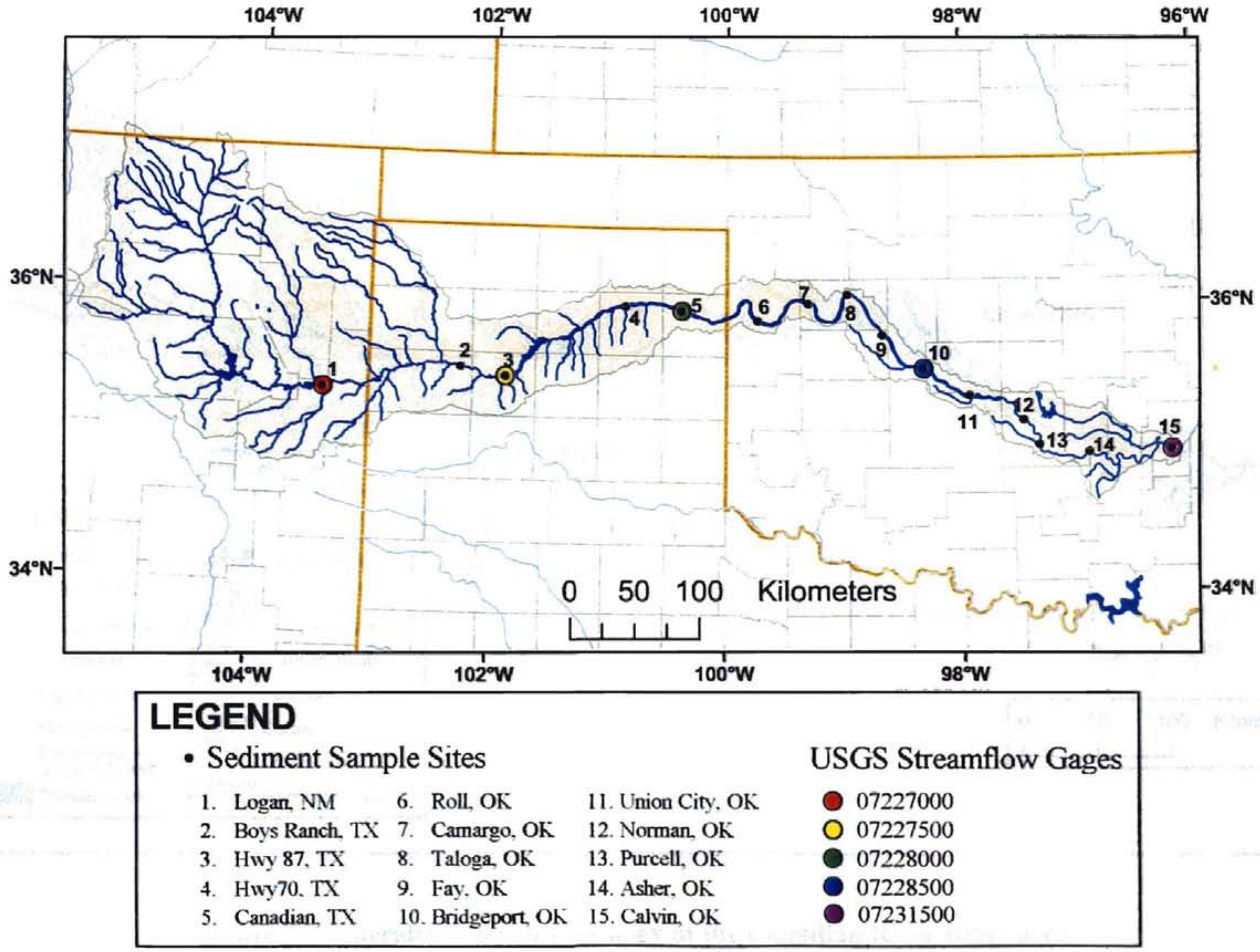

Figure 6. Major tributaries, USGS gage sites, and sediment sample sites on the Canadian River

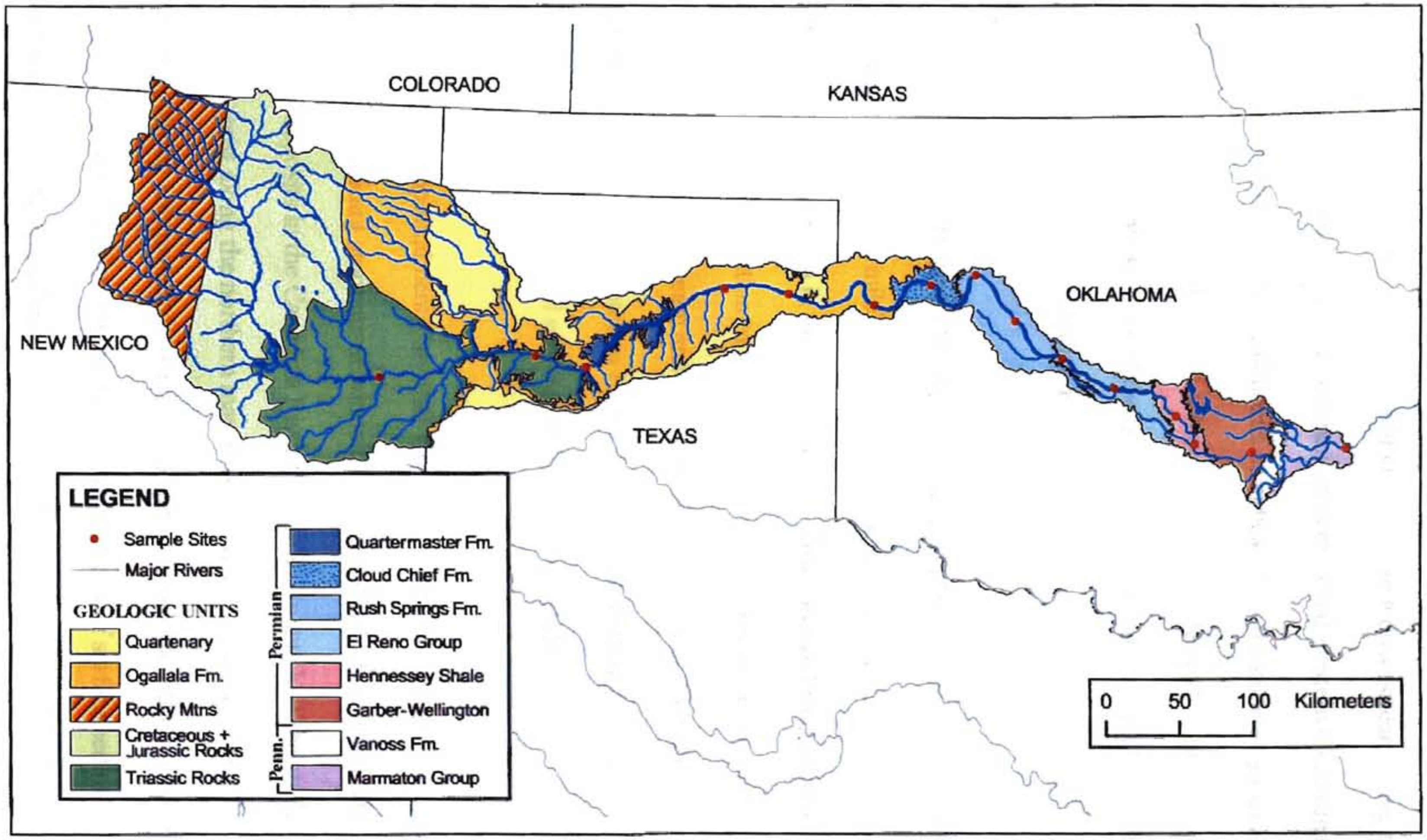

Figure 7. Generalized bedrock geology of the Canadian River study area

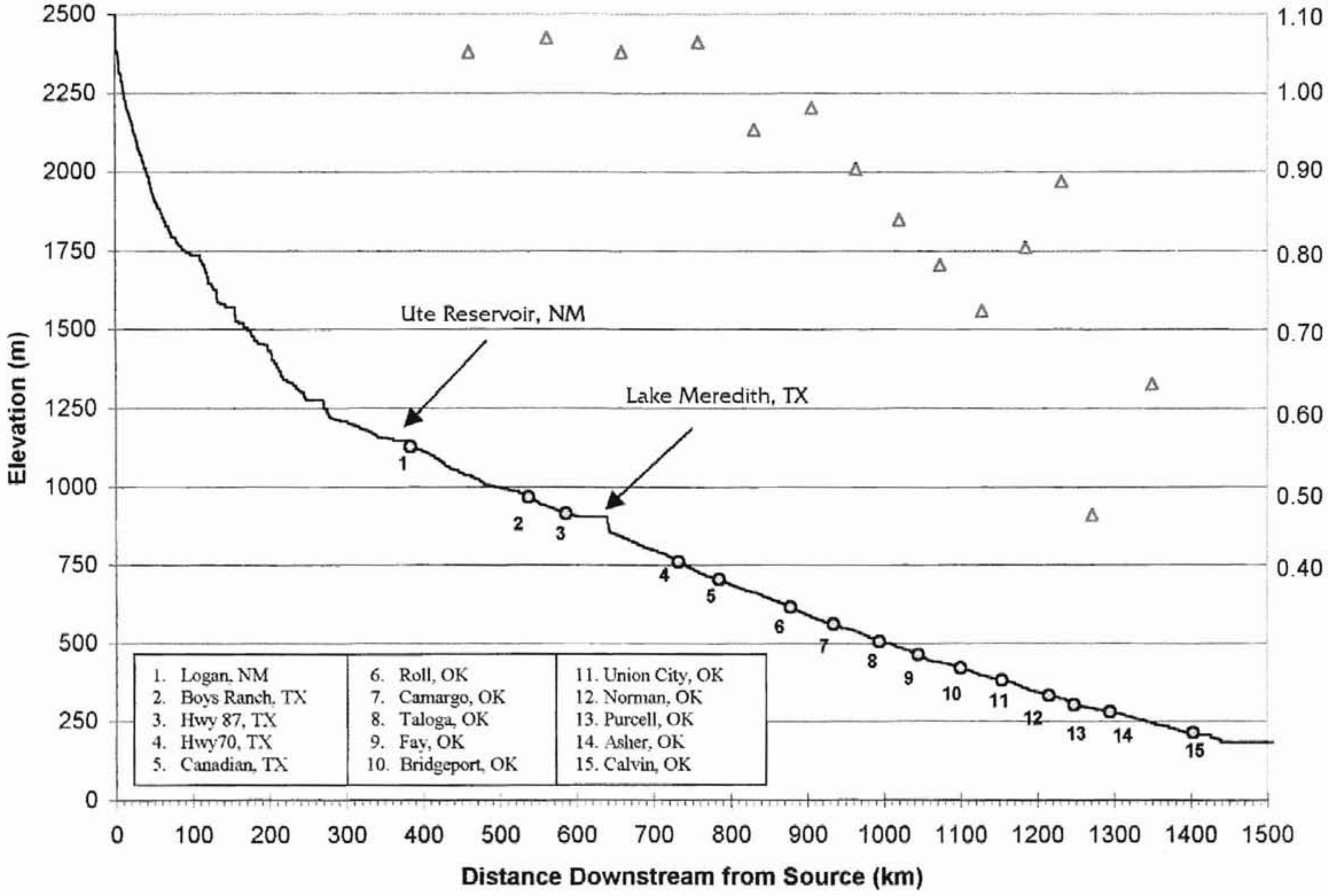

Figure 8. Canadian River longitudinal profile (solid line) and average channel gradient (open triangles) constructed using RiverTools™ DEM analysis software

Figure 9. Eolian sorting of point bar material at Purcell, Oklahoma;
***Note:* Ripple crests are 2-4 centimeters apart.**

and ripples migrating perpendicularly to the river's course. Certainly, much of the windblown sediment could be contributed by exposed bedrock sources; however, the majority of the eolian material is probably derived from within the channel. Therefore, it is likely that winnowing of fines by wind may occur after bar deposition. This is not likely to be a severe problem since it would occur in only the top few millimeters of the bar. The influence of eolian activities on the fluvial samples in this study remains uncertain.

CHAPTER II

LITERATURE REVIEW

Previous Work on the Canadian River

Aside from the aforementioned dissertation by Pollack, very little work has been performed on the Canadian River specifically and none has been published within the last ten years. Kessler and Cooper (1970) and Kessler (1971) summarized the results of their study on the development of a braided reach of the Canadian River in the Texas Panhandle. They examined vegetation changes on aerial photographs to identify channel sequences of differing age. Furthermore, they emphasized the importance of rare, extremely high discharge events in determining the sedimentation pattern in the Canadian valley. According to Kessler (1971), over a 32-year period of record, major changes in the morphology of the channel were accomplished during only 40 days of flooding. It is during these rare flows that they say the active channel may shift laterally up to 300 meters per day. Kessler and Cooper (1970) reported that typical daily discharges ranged from 0.1 to 10 cfs, but occasionally the river passed an average daily discharge over 20,000 cfs. Today, 20,000 cfs peak flows are rare due to more than 30 years of regulation by Sanford Dam[3]. Major channel shifts are even less frequent because old channel sequences have become heavily vegetated. In addition to flood flows, the authors also recognized the importance of eolian processes in constructing channel sequences.

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[3] since 1970, only one annual peak flow has exceeded 20,000 cfs

Previous Work on Other Sand-bed Rivers

A substantial volume of work exists on the morphology, dynamics, and sampling of gravel-bed rivers. By comparison, sand-bed rivers have not received near as much attention by geomorphologists and sedimentologists. Though some of the results of gravel-bed studies are transferable to their finer counterparts, many are not (Russell and Taylor, 1937). The numerical modeling of Hoey and Ferguson (1994) suggested that the downstream fining processes dominant in coarse-bed streams are not necessarily the dominant processes in finer-bed streams. Sand-bed streams represent a vital part of the downstream fining puzzle and add a different perspective to our understanding of fluvial sediment change.

Two major sand-bed rivers have been the objects of studies on downstream fining. In the early 1930s, scientists at the U.S. Waterways Experiment Station analyzed the change in size of bed materials in the Mississippi River from Cairo, Illinois to the Gulf of Mexico. They used a pipe dredge to collect 531 thalweg sediment samples along the 1700-kilometer reach. They found that the mean sand size (gravel and mud omitted) decreased from 0.7 millimeters to less than 0.2 millimeters (U. S. Waterways Experiment Station, 1935). Later, Russel and Taylor (1937) attributed this change to size-selective sorting in which larger particles are "left upstream as a result of a progressive decrease in the transporting ability of the river." Over the last 160 kilometers (100 miles) of the Mississippi River, the mean grain size remains relatively constant around 0.15 millimeters. This value is near the lower limit of fine sand, which Russell and Taylor (1937) believed was a limit of attrition for the Mississippi River.

Nordin and Queen (1992) repeated the Mississippi study to document any changes that occurred since the Waterways Experiment Station conducted its study in 1932. Before analyzing any sediment data, they found that the river's length was more than 160 kilometers (100 miles) shorter due to meander cutoffs. The principal conclusion of the study was that, above the Old River Control Structure (520 kilometers from the mouth), the thalweg bed material was generally finer than was observed in 1932 according to the median grain diameter. Below Old River there was no change in the median grain size. However, the shape of the grain-size distributions as a whole has changed across most of the study area. First, the researchers noted significant reductions in the amounts of gravel, very-coarse sand, and coarse sand in the upper reaches of the study between Cairo, Illinois and Baton Rouge, Louisiana. They speculate that the gravel deficit may be the result of mining. The study also found increased proportions of fine sand over most of the study reach, but especially in the segment between Old River and the mouth. The researchers believed this fraction was transported seasonally and derived either from the bed of the Missouri as it degraded in response to dam emplacement or from local sources in response to meander cutoffs. The percentage of very-fine sand decreased across the entire study area. The magnitude of this change, however, increased with proximity to the mouth. The authors attribute the decrease in very fine sand to the trapping of fine sediment behind dams. They also suggest that protection works (by drecreasing supply of the finer fraction) and channel straightening efforts (by increasing transportability of the finer fraction) could also explain the decrease. Since these bank and course control methods are more prevalent in the Lower Mississippi, the latter hypothesis could also be used to explain why the deficit of very-fine sand increases as the river approaches the mouth.

Nordin et al. (1980) performed the same study on another world-class river, the Amazon. Contrary to the findings reported by the Waterways Experiment Station, Amazon researchers found median grain size in the thalweg to be nearly constant over twice as long a distance (3200 kilometers) as the Mississippi. Their principal conclusion was that the volume of sediment input by tributaries dilutes any reduction in size by attrition in the mainstem. Though no trend was apparent when all their data were plotted together, they did notice a weak fining trend if just the samples taken in crossings between bends (meanders?) were plotted. They also found that median grain size fluctuates around a baseline of approximately 0.2 millimeters, which corresponds to fine sand in the Wentworth nomenclature.

Folk and Ward (1957) sampled a single bar on the Brazos River of Texas. Though the sediment sizes ranged from pebble to clay, the minimum mean grain size of any of his samples was around 0.11 millimeters. The convergence of minimum mean grain-size around very fine sand in three different settings may be suggestive of a lower limit of mean grain-size in the fluvial system.

Definition of Fining

As yet, no concrete definition of downstream fining has been accepted in the scientific community. As a result, the literature uses a variety of statistics, including the mean and several percentile grain sizes, to calculate rates of fining. Traditionally, the mean or median grain size seemed the logical choice to represent the distribution. Recent studies have begun to recognize that mean or median grain-size is not necessarily the best parameter to use in studies of downstream fining. Rice (1999, p. 33) listed four reasons why the coarser material is better suited in some instances:

> ". . . it is most easily distinguished amongst all the material on a bar; it has potentially the largest range in signal (hence the greatest resolution) along the river; it can be related most directly to suggested controlling hydraulic mechanisms (for example, competence and abrasion); and it is generally considered to exert the greatest influence on channel roughness."

Though Rice's opinions were formed while studying gravel-bed rivers, they are also pertinent to sand-bed studies.

Many researchers have adopted coarser percentiles, especially the 90^{th}-percentile grain size, when studying downstream fining in gravel-bed streams. Unfortunately, when distributions are crafted as cumulative curves of weight percent finer (as is usually the case in sand-bed streams), these percentiles are also most sensitive to outliers. A few coarse pebbles comprising 5% of the total sample weight can easily shift the ϕ_{90} by more than 1 ϕ unit.

Furthermore, statistics calculated using millimeter data are different from those calculated using ϕ-scaled data. The mean grain-size, for example, is not representative when using sieve analysis data in millimeters. This is because the diameter difference between consecutive sieves is not constant. The ϕ diameter[4] normalizes the difference in size between consecutive sieves making simple arithmetic calculations possible.

Differences in sampling procedures contribute additional complication. In sand-bed streams, less than one kilogram of sediment is required to accurately represent the population (Church et al., 1987). Bulk sampling, which captures all sediment in a small area, is the most efficient sampling method in these streams. On the other hand, very coarse gravels can require as much as 1000-kilogram sample weights (Church et al., 1987). In these cases, bulk sampling is abandoned in favor of count procedures that measure the diameter of several randomly selected particles within a reach. Therefore, sampling of gravel-bed streams is usually accomplished by recording the size of individual particles and sampling of sand-bed streams is accomplished by weighing grain-size classes. Most publications fail to mention that these two procedures measure entirely different properties of the sediment mixture. In addition, different biases are inherent in each procedure, making clear comparisons between streams with coarse and fine bed material loads a challenge if not an impossibility. A good review of the many problems associated with comparing studies by different researchers can be found in Hoey and Bluck (1999).

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[4] The ϕ diameter is the negative, base 2 logarithm of the millimeter diameter; $d_\phi = -\log_2(d_{mm})$

Finally, trends are usually assumed to imitate exponential functions after Sternberg (1875) though some researchers, such as Rice (1999), have had success fitting power or logarithmic models to their data. The variety of methods by which fining can be calculated and reported causes much confusion when translating the results of one study to another.

Attrition/Selective Sorting

Literature on the subject of sediment fining in streams usually regards attrition as the dominant cause. Attrition, here, is defined as the sum of all physical and chemical processes by which particles are shaped and reduced in size during transport. This term should not be confused with abrasion, a special type of attrition, in which wear is caused by the rubbing together of particles. Particle-bed collision is the major component of attrition since particle-particle collisions are generally less frequent and less severe (Parker, 1991). These particle-bed collisions are also much less rigorous in a sand bed river since a large number of sand-sized particles are better able to distribute the stresses generated upon impact than are a smaller number of pebbles (Moss, 1972). In early studies of downstream fining, researchers (Russell, 1939; Krumbein, 1941) recognized the link between mean bed grain-size and the effectiveness of attrition. Russell and Taylor (1937) suggested that as grains approach a certain mass, they become incapable of generating enough force to cause fracture during contact with the bed. Attrition effects could be most advanced in the coarser fraction of the sediment load for several other reasons. First, these particles (as individuals) have greater surface area providing greater opportunity for wear. Second, these particles are in more frequent contact with the bed, as they tend to move by traction instead of saltation. Finally, coarse particles are more likely to be multi-mineralic and have a predispostion to fracture. Sand and smaller grains tend to be mono-minerallic quartz, which has no inherent plane of weakness.

In the past, selective sorting was often regarded as a less efficient, secondary process causing downstream fining. Most recent publications, however, recognize the role of selective sorting in bed material fining. The term selective sorting is meant to include size sorting produced by erosional, transportational, and depositional processes. In small, sand-bed streams, sorting may be the dominant process. Russell (1939) explained that fining by size-selective sorting is most effective in aggrading streams that experience large fluctuations in discharge and competency. Rare high discharge events may supply a load of coarse material to the stream that mean flows are incapable of transporting. In this case, the time lag between fine and coarse particle movement is at a maximum. In an aggradational, sand-bed setting, it is likely that coarse particles, such as pebbles, would be swept over and buried by slightly more mobile coarse-sand fractions. Mackin (1948) referred to this as "a permanent withdrawal from circulation of the coarser fractions" paired with a "running ahead of the fines." Therefore, the active layer downstream would become progressively finer as coarser particles are preferentially buried and finer particles are preferentially transported. Middleton (1976) observed that this simple mechanism of downstream fining can operate even when competency and capacity do not decrease downstream.

Gravel-Sand Transition

An interesting phenomenon encountered in downstream fining research is the abrupt gravel-sand transition, in which bed materials consist of a bimodal mixture of sand and gravel. After careful treatment of the topic, Sambrook-Smith and Ferguson (1995) proposed several possible reasons for the rapid transition. First, researchers have associated this transition with a sharp reduction in channel gradient. The establishment of a local base level can cause the transition if it reduces stream competency to the point that gravel is no longer transported long distances. Second, a large influx of fine sediment from banks, tributaries, or human activities could produce enough fines to outpopulate the gravel in the bed. Third, attrition of upstream gravels may be capable of producing enough fines to dominate the bed, without the need of lateral inputs. Finally, the gap between sand and gravel beds may represent a grain-size class that is either not commonly derived by attrition or not available in the basin's sediment supply.

Equal Mobility

In gravel-bed rivers, selective sorting has received less attention as a legitimate fining process. To explain the relative ineffectiveness of sorting processes, some researchers have adopted the "equal-mobility" hypothesis of Parker et al. (1982). Equal mobility is satisfied when all particles in a stream have an equal chance of being transported. In a stream with a sufficiently wide range of grain sizes, smaller particles are often protected or hidden between larger particles. As a result, the entrainment of all particles is dependent on the entrainment of some larger class of framework gravels. Therefore, all sediment will be transported when the river achieves the critical shear stress necessary to move the larger gravels.

Equal mobility is only truly satisfied when all particles in the mixture are exactly the same size. However, for fluvial processes, one-half ϕ is often regarded as the lower limit of sorting (standard deviation of grain size) in fluvial systems (Paola and Seal, 1995; Folk, 1957; Folk and Ward, 1957). Such well-sorted fluvial sediments usually occur only when mean or median grain-size approaches 3.0 ϕ or 0.125 millimeters, corresponding to the break between fine and very fine sand on the Wentworth scale. When the standard deviation (sorting) is at a minimum, the range of shear stresses necessary to mobilize all the sediment in the channel is also at a minimum. Equal mobility breaks down entirely when bed material becomes strongly bimodal, as is supposed to occur at the gravel-sand transition (Wilcock, 1993).

Sternberg's Relationship

Often cited in studies of fluvial sediment is the work of Sternberg (1875) who observed downstream fining of sediment in the Rhine River of Germany. Sternberg's fining relationship (Equation 1) states that the grain diameter (D) in millimeters at any location along a river is a function of the diameter at the headwaters (D_0) and the distance downstream from the headwaters (x). It is analogous to the exponential decay of radioactive isotopes as well as many other natural phenomena. However, there is some debate regarding the validity of an exponential relationship between millimeter grain size and distance downstream in all streams. In addition, the relationship is too simplistic to be functional, fitting only for ideal conditions. In reality there is a suite of variables that change systematically in a downstream direction as well as a number of processes controlling the rates at which they vary. The beginning of a solution to this problem is an updated version of Sternberg's relationship (Equation 2) presented by Knighton (1982).

$$D = D_0 e^{-ax}$$

Equation 1. Sternberg's Relationship

$$D = D_0 e^{-(k_1 + k_2)x}$$

Equation 2. Revised Sternberg Relationship (Knighton, 1982)

Instead of lumping all fining processes in a single rate constant, he proposes a more correct expression where k_1 is the rate of fining accomplished by attrition and k_2 is the rate of fining accomplished by selective sorting. If the two processes operate independently, k_1 and k_2 should be additive. Knighton's definition of attrition encompasses all mechanical weathering that occurs during transport. Changes in grain size, however, can occur even during periods of low or nonexistent discharge. Processes such as frost action and chemical weathering act on sediment stored in channel bars and floodplains. In some environments, frost action may be a very significant agent of fining (Bradley, 1970; Bradley et al., 1972). Knighton (1998) also recognizes the ability of chemical and physical weathering to reduce particle sizes of stored sediment. Though the rate of fining by in-storage attrition will most likely be small, it should be a separate entity since it is controlled by a fundamentally different fining process. In addition it suggests that the storage time of sediment could be as important as the distance of transport (Paola and Seal, 1995) in determining how much fining occurs. Unfortunately, from a practical point of view this may be irrelevant since the contribution of each fining process, individually, is extremely hard to quantify.

CHAPTER III

METHODOLOGY

Downstream Fining

Bed Material Sampling

Between episodes of high-flow, suspended sediment load is deposited and temporarily stored as bar deposits. Bed material was sampled at the point on a mid-channel or point bar that records nearest the bankfull discharge or highest non-flood discharge. This point was assumed to coincide with the topographically highest point on the upstream end of the bar.

Sample sites were determined by river access, namely where public roads cross the river. Pollack (1959) used the same strategy in his study of the Canadian River. Three of his 20 sites have since been inundated or disturbed by reservoirs. To maximize the comparative power of this study, the remaining 17 locations on the river were revisited. Two of these sites were omitted from my study. The channel at Byng, OK, was not sampled because high waters made its point bars inaccessible. Pollack's site at Electric City, TX was not sampled because, due to its location immediately below a water supply dam in an arid region, it received inadequate flows to maintain an active channel. Fortunately, economics dictate that bridges are built across rivers at fairly evenly spaced intervals. Therefore, the 15 remaining sample sites are well spaced over the river. Their names and locations on the river are shown in Figure 6. Since bridges can interfere with the natural deposition of suspended sediment, a sample taken upstream from each bridge is preferable to one taken downstream from it. Since the purpose was to determine changes in the grain-size distribution by position on the active bar, only surface samples were collected. No attempt was made to determine the characteristics of sediment with depth on the bar. There are two concerns with this sampling method: the probability that surface deposits were altered by wind; and the difference in the magnitude of events represented by different samples.

When I arrived at a bar to be sampled, I located exact collection points according to the following criteria. First, I walked to the upstream end of the bar. Next, I tried to find the highest point in that area. On a bar where total relief is usually around 0.5 meters, it was sometimes very difficult to identify one spot as the highest. Finally, if several spots appeared to be the highest on the bar, I sampled the ones that were visibly coarsest. This third criterion was seldom necessary and was used in no more than three of the fifteen samples.

Some of the reasoning behind the choice of sampling location on the bar can be found in Bunte and Abt (2001). They explain (for gravel-bed rivers) that bed material is coarsest at the upstream end of bars since it is the zone of highest shear stress. Theoretically, the coarser material should be deposited by higher flows. They also indicate that the lowest zone of shear stress corresponds to the bar tail, where finer-sized sediment is deposited. In this manner, bars tend to cover the full range of particle sizes. In addition to this "downbar fining," they suggest a distinct "landward fining" that progresses from the bar toe to the bank. However, the sample location used in the downstream fining study seeks, not necessarily to select the coarsest material on the bar, but rather the material that is most characteristic of the near-bankfull flow conditions. The highest points, locations that could only have received deposition during such an event, should best approximate these conditions. Points below these locations are subject to additional deposition as well as removal of fine sediment by subordinate flows.

Once the exact sample site was located, a 1-kilogram mass of sediment was taken from the top 3 centimeters of the bar using a garden trowel. According to Church el al. (1987), a total sample mass of 1 kilogram is more than sufficient for sediment with a maximum diameter less than 8 millimeters (-3.00 ϕ). When maximum particle size was greater than 8 millimeters, I collected larger bulk samples.

Usually, the sample was taken from an area of about 30 x 30 centimeters, centered on the designated sample point. Then, the sediment was placed in a watertight plastic bag and sealed for later sieving in the laboratory. At a minimum, three samples from each location were collected and their analysis results averaged. When the variability between samples at a site was large, a larger number of samples were taken.

Laboratory Analysis

In the laboratory, each sediment sample was spread on newsprint for four to six days of drying. Most samples became remarkably hardened for such a short period of drying, and large aggregates were broken by hand. To attack the problem of aggregates in the sample, Folk and Ward (1957) used a mortar and rubber pestle to mechanically disaggregate samples before performing a size-frequency analysis. After sieving, they examined each size fraction under a microscope to calculate the percentage of aggregates, deducting this from the total sample weight. However, all mechanical disaggregation techniques would also break apart fragments of clastic rock, which should be counted as single grains. In this study, no attempt beyond gentle, by-hand disaggregation was made.

Next, the samples were run through 8-inch diameter brass sieves using a Ro-Tap™ machine. The mesh size of the sieves ranged from –4.64 ϕ (25 mm) to 4.72 ϕ (0.038 mm), mostly at 0.25 ϕ intervals[5]. Based on experience with similar samples, sieve stacks were run according to the scheme in Table 1. Upon unstacking, each sieve was lightly shaken. If fine sediment was observed passing through, the sieves were restacked and placed in the Ro-Tap™ for an additional 5 minutes. This scenario occurred only a few times, usually while processing larger volumes of sediment. Finally, the contents of each sieve were weighed to the nearest gram on an electronic mass balance. For clarity of interpretation, the sieve data are normalized by the total sample weight.

U.S. Standard Sieve Numbers	mm Interval	ϕ Interval	Run Time (minutes)
1/2,5/16,1/4,4,5,6,8,10,12	>2.00	< -0.75	3
14,16,18,20,25,30	1.68 to 0.59	-0.75 to 0.75	8
35,40,50,60,70,80	0.59 to 0.177	0.75 to 2.5	14
100,120,140,170,200,230	0.177 to 0.0625	2.5 to 4.0	18
270,325,Pan	0.0625 to 0.031	4.0 to 5.0	8

Table 1. Sieve run times for U.S. Standard sieves used in grain-size analysis

When the data are plotted by hand on probability paper as grain size (ϕ) versus cumulative percent finer, percentile grain-sizes can be interpolated from a curve drawn through the points. The ϕ_5, ϕ_{16}, ϕ_{50}, ϕ_{84}, and ϕ_{95} were calculated for the average distribution at each site. These values represent the grain size at which 5, 16, 50, 84, and 95 percent (by mass) of the total sample is finer. If the average distribution at a site contained more than 2% gravel-sized particles by mass, the percentiles were recalculated for only the sub-gravel grain sizes.

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[5] Two intervals in the sub-gravel range were 0.50 Φ: 1.25 to 1.75 and 4.00 to 4.50)

Since measurement of sub-pebble grain size is traditionally done as a discrete analysis over several ranges of grain size, common definitions of mean and standard deviation, which are based on continuous distributions, do not apply. Mathematical derivation of statistical parameters that describe the mean and standard deviation of this type of distribution has required a creative approach. Folk (1957) composed many of the most popular statistical equations used in grain-size analyses and published them in his text Petrology of Sedimentary Rocks. When used in this study, the mean grain size given is Folk's Graphic Mean (Equation 3), which is found by averaging the grain sizes, in ϕ units, corresponding to the 16th, 50th, and 84th percentile. Grain-size sorting is represented by Folk's Inclusive Graphic Standard Deviation (Equation 4).

$$M_z = \frac{\phi_{16} + \phi_{50} + \phi_{84}}{3}$$

Equation 3. Graphic Mean (Folk, 1957)

$$\sigma_i = \left| \frac{\phi_{84} - \phi_{16}}{4} \right| + \left| \frac{\phi_{95} - \phi_{05}}{6.6} \right|$$

Equation 4. Inclusive Graphic Standard Deviation (Folk, 1957)

It is important to note that these equations are only meant to be used in conjunction with the ϕ scale. When millimeter scale data are input into the Folk equations, they yield a different result. It is best to calculate the parameters in ϕ units and translate the answer into millimeters as a last step. In this study, all calculations and relationships are made using ϕ grain-size.

DEM Manipulation

One-degree Digital Elevation Model (DEM) data at a scale of 1:250,000 are available on the USGS EROS website at http://edcwww.cr.usgs.gov/pub/data/DEM/250/. For a river length of this regional scale, this is the most appropriate scale as it provides acceptable resolution while minimizing data storage and processing requirements. A total of 27 DEM files are required to obtain a complete coverage of the South Canadian drainage basin. Elevation data were first processed with Research Systems' RiverTools™ software to produce a detailed longitudinal profile of the entire Canadian main stem.

Downstream distances to each sample point must be known to construct a downstream fining profile. These distances were found by matching each site's approximate latitude and longitude coordinates (taken from a map) with those appearing in the longitudinal profile data (from RiverTools™). Though the coordinates never matched exactly, the distances are accurate enough for a project at this scale. Average channel gradient for each reach was calculated by dividing the elevation difference by the river distance between samples. The value calculated was then attributed to the downstream site.

GIS Data Manipulation

To explore the influence of local hillslope processes on the grain-size distribution, a creative approach of data collection was necessary. The result was a pseudo-measurement, called near-channel slope, which was obtained from DEM data. Not to be confused with the channel gradient, near-channel slope calculated at a site is simply an average of the slopes between DEM grid points in a 1.6-kilometer buffer of the river. Average near-channel slopes were calculated by processing the DEM data with ESRI ArcView™ 3.2. Two Avenue™ scripts and one ArcView™ extension were necessary to get the DEMs into a usable format. *Demshift.ave* was used to convert each grid into geographic coordinates and *merggrid.ave* was used to merge the 27 individual files into one before processing. The Grid Projector extension was also necessary to display the DEM data in a projected view. Once patched together, the DEMs were analyzed for slope using the "Derive Slope" option, and a new grid was created. A helpful guide to DEM manipulation can be found on ESRI's™ website (Price, 2000).

To tie near-channel slope to sample sites, a 1.6-kilometer (1 mile) buffer was created around the Canadian trunk stream. This buffer was then segmented at each sample location, creating fifteen zones. The "Summarize Zones" function was used to average the slope in each zone and the results became an attribute of the downstream sample site defining that zone. In other words, the near-channel slope for each site is calculated over a 3.2-kilometer (2-mile) wide strip between itself and the next upstream site.

Bar Variability

Site Selection

For this study, it is important to assess the spatial variation in grain size that exists within a single bar. Due to the implications on sampling strategy, it is important to know if there is an appreciable change in surface grain-size parameters with location on the bar. The site at Camargo, Oklahoma (sample site #7) was chosen for a detailed study of local grain-size variability. This bar was selected for many reasons. First, it is approximately midway between the ends of the study area. Second, its grain sizes are intermediate along the fining trend. Most importantly, though, all samples taken from Camargo in the downstream fining study (including those collected by Simms, 2001) were bimodal. The coarser mode is at 1.75 ϕ and the finer mode is at 3.00 ϕ. To see if this bimodality was characteristic of the reach or just a singularity, I decided to sample the next downstream bar (on the opposite bank). About six months passed between the initial visit and the variability study.

The bar examined for variability is small, measuring only 66 meters in length and 30 meters in width. These dimensions are far from characteristic of the river but they facilitate a more rapid, higher resolution survey. The exact width is difficult to determine because much of the bar has been covered with eolian deposits since its last period of activity. The total relief of the bar, referenced to the low-water line, is about one half meter. Such low relief is typical of bars in this area as the channel has a high width-depth ratio. About 150 to 250 millimeters above the datum, an abrupt change in slope occurs where low to mean flows have scoured a mean-flow channel. Above 250 millimeters, no obvious evidence of scouring was observed. Contouring of elevation survey data coupled with aerial photo examination reveal a subtle high-water sub-channel dissecting the bar. This feature trends northeast across the bar and bottoms at an elevation of approximately 300 millimeters. For the purposes of this study, three distinct zones are recognized on the bar surface: the low to mean flow channel (0 - 250 millimeters), the mean to bankfull channel (250 - 500 millimeters), and the windblown deposits which cover most of the bar above 500 millimeters (Figure 10).

Data Collection

Thirty-six fluvial sediment samples were collected during a period of no discharge[6]. A measuring tape was used to create a grid of sample points at approximately 6 meter (20 foot) spacing along north-south and east-west transects (Figure 3). Of the 36 sites, seven are considered to be in the mean-flow channel and one is in the low-flow channel. For comparison with fluvial sediment, an additional sample was taken from windblown deposits on the southern part of the bar. Once sample points were identified and flagged, an elevation survey was conducted. Measurements were obtained using a Topcon Rotating Infrared Laser Level (RL-60B) and a Topcon Level Sensor (LS-70B) attached to a standard leveling rod. The specifications of the laser level list a precision of ± 1 millimeter, and the leveling rod is graduated to centimeters. Total instrument error is estimated at ± 6 millimeters. Since the rod had no spirit level, deviations of the rod from plumb could add a few millimeters to that range. All measurements were referenced to the water surface (designated WS) for simplicity. A contour map of elevation survey data appears as Figure 11.

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[6] Though there was no flow, the channel still contained water in shallow, discontinuous pools.

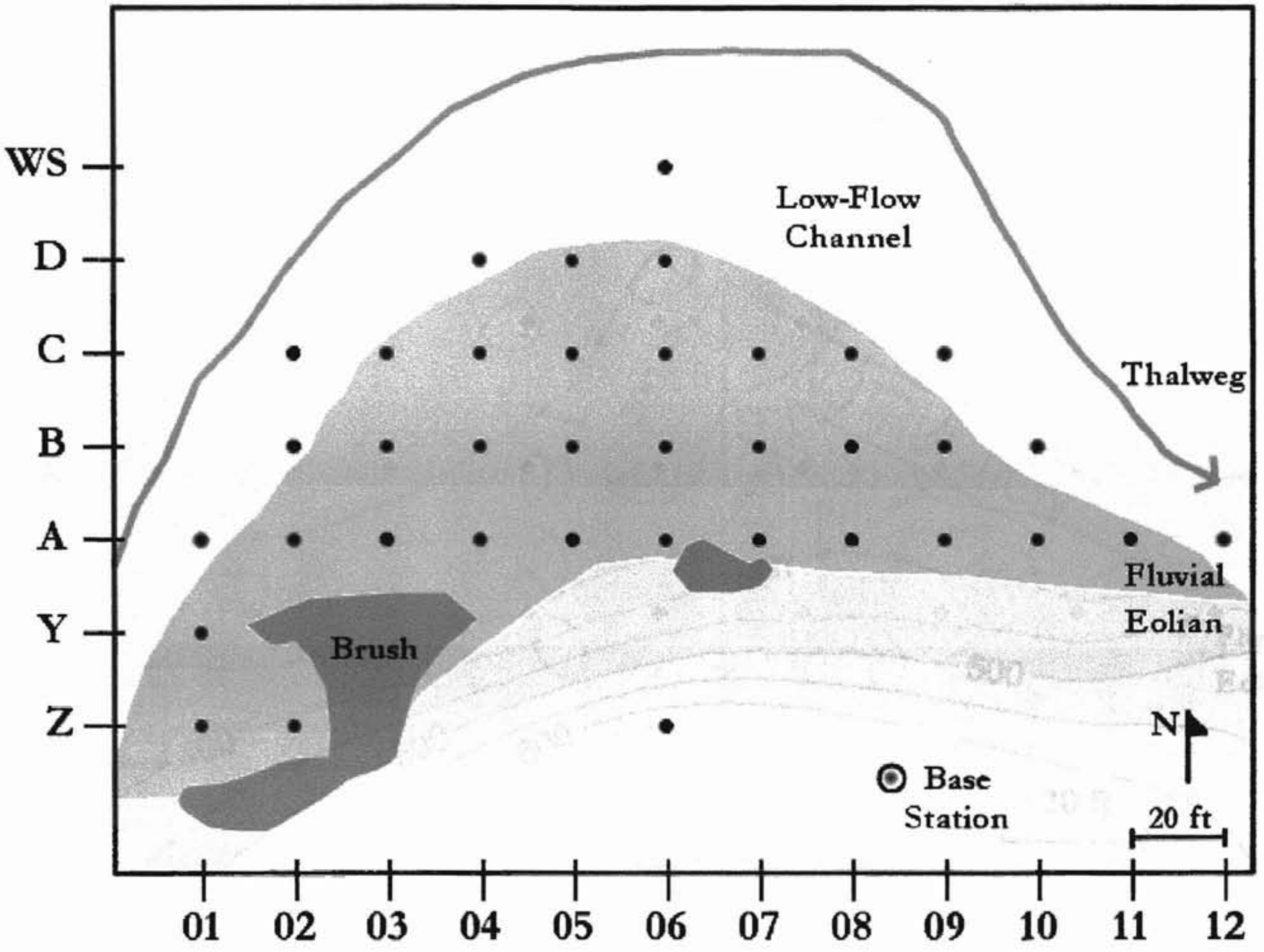


Figure 10. Sample locations used in bar variability study near Camargo, Oklahoma

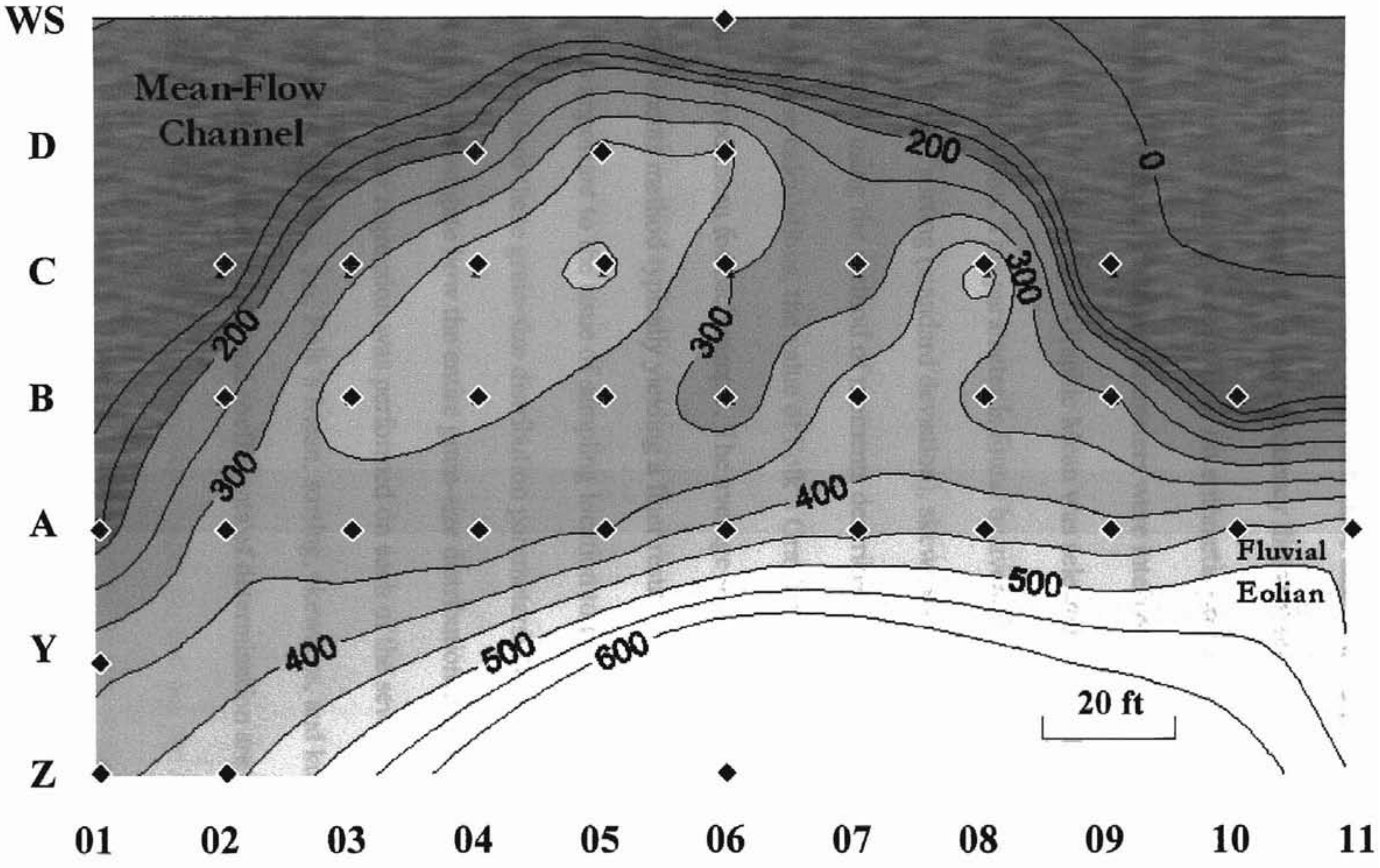


Figure 11. Elevation contour map of the point bar near Camargo used in the variability study; *Note:* Contour interval is 50 millimeters; diamonds indicate sample locations

Data Processing

The weight measurements obtained by sieving were placed into a spreadsheet to calculate the percent of sample finer than each sieve size. The transformed data can then be used to construct a cumulative size-frequency distribution curve when it is plotted as sieve size (ϕ) versus weight percent finer on arithmetic probability paper. The values for three commonly used distribution parameters were interpolated from the plot: ϕ_{16}, ϕ_{50}, and ϕ_{84}. Folk's (1957) Graphic Mean was selected to describe the average grain-size of the distribution. This parameter is found by averaging ϕ_{16}, ϕ_{50}, and ϕ_{84}. In addition, values of sorting (standard deviation), skewness, and kurtosis were calculated for each sample using the method of moments described in Folk (1957). To ensure the validity of these calculations, the value of Folk's Graphic Mean was compared to the moments-derived mean for each sample. The average percent difference was only 0.2%, with the moments method typically yielding a finer result.

It is important to the issue of sampling location to know if there are certain areas on sand bars where these grain-size distribution parameters are at a minimum or maximum. To investigate how the entire grain-size distribution changes spatially on the bar surface, bivariate regression was performed on each of the seven parameters mentioned above (ϕ_{16}, ϕ_{50}, ϕ_{84}, Folk's Mean, sorting, skewness, and kurtosis). Scatterplots with regression lines and coefficients of determination are presented in Appendix C.

CHAPTER IV

RESULTS AND DISCUSSION

Downstream Fining

Controls on the Significance and Rate of Fining Trend

Graphical methods, such as cumulative curves (Figure 12) and areaplots (Figure 13) are the most accurate ways to display grain-size data because they show changes in the entire distribution. Unfortunately, to test these changes, researchers must generally select a single numerical parameter such as the mean or median diameter, standard deviation, or skewness to represent the distribution. The chosen parameter always has advantages and disadvantages that change depending on the physical property being studied.

In this study, the ϕ_{50} or median diameter was used because that statistic was preferred by Pollack. However, both the significance and rate of downstream fining are highly dependent on the parameter used to represent the distribution at each site. The fining trends for five percentile grain sizes (ϕ_5, ϕ_{16}, ϕ_{50}, ϕ_{84}, and ϕ_{95}) are drawn in Figure 14 and tabulated with the mean grain size in Table 2. Together, these parameters cover 90 percent of the distribution. The slope of the regression line, or the strength of the fining trend, increases steadily, reaching nearly 0.0050 when ϕ_{95} is used. However, the significance of the trend reaches a maximum at ϕ_{50}. In ϕ_{84} and ϕ_{95}, the skewness created by a few heavy pebbles causes the significance to decline. In this study, the most significant trend is likely to occur in some parameter close to the ϕ_{50}.

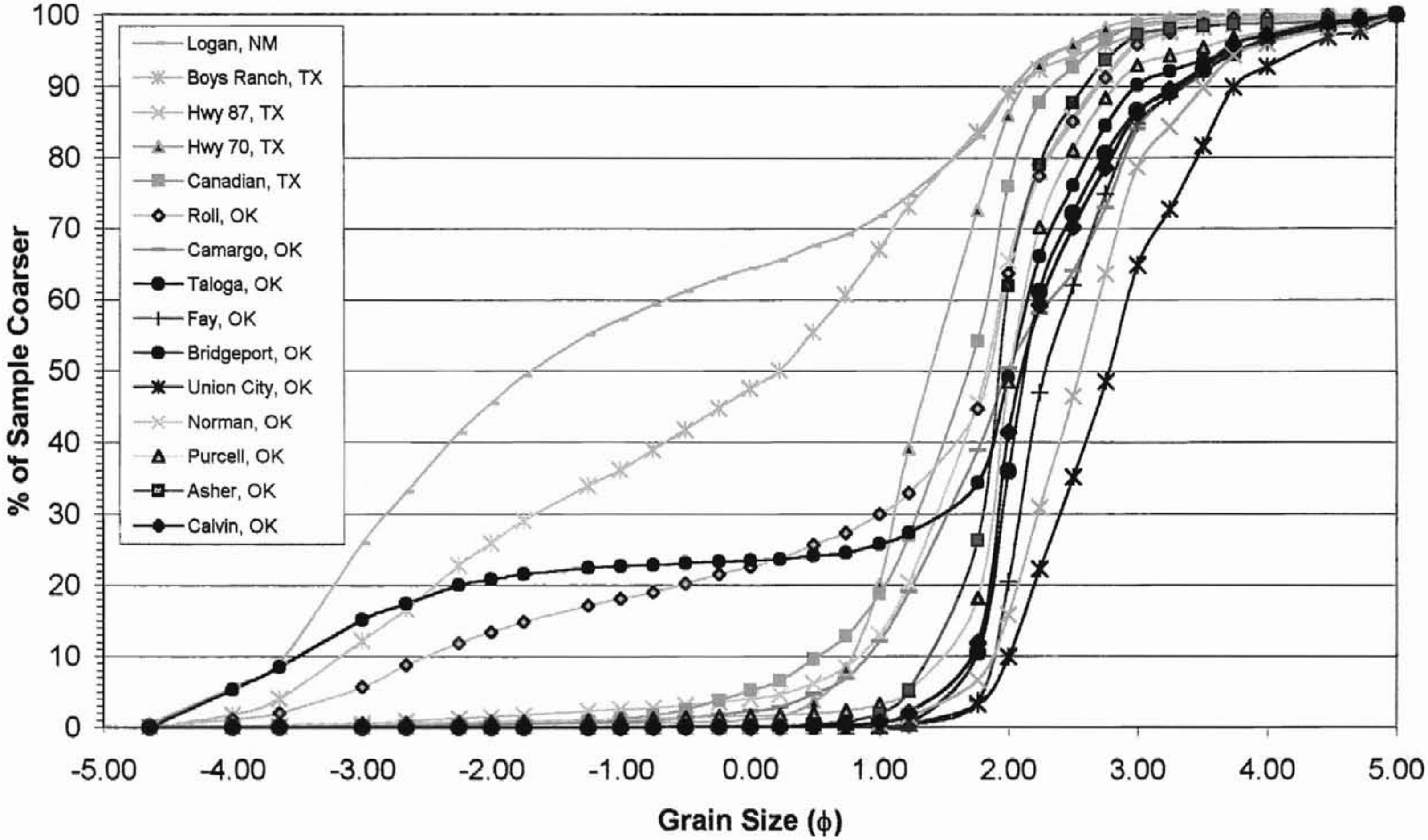


Figure 12. Site-averaged cumulative grain-size distributions of Canadian River bar material

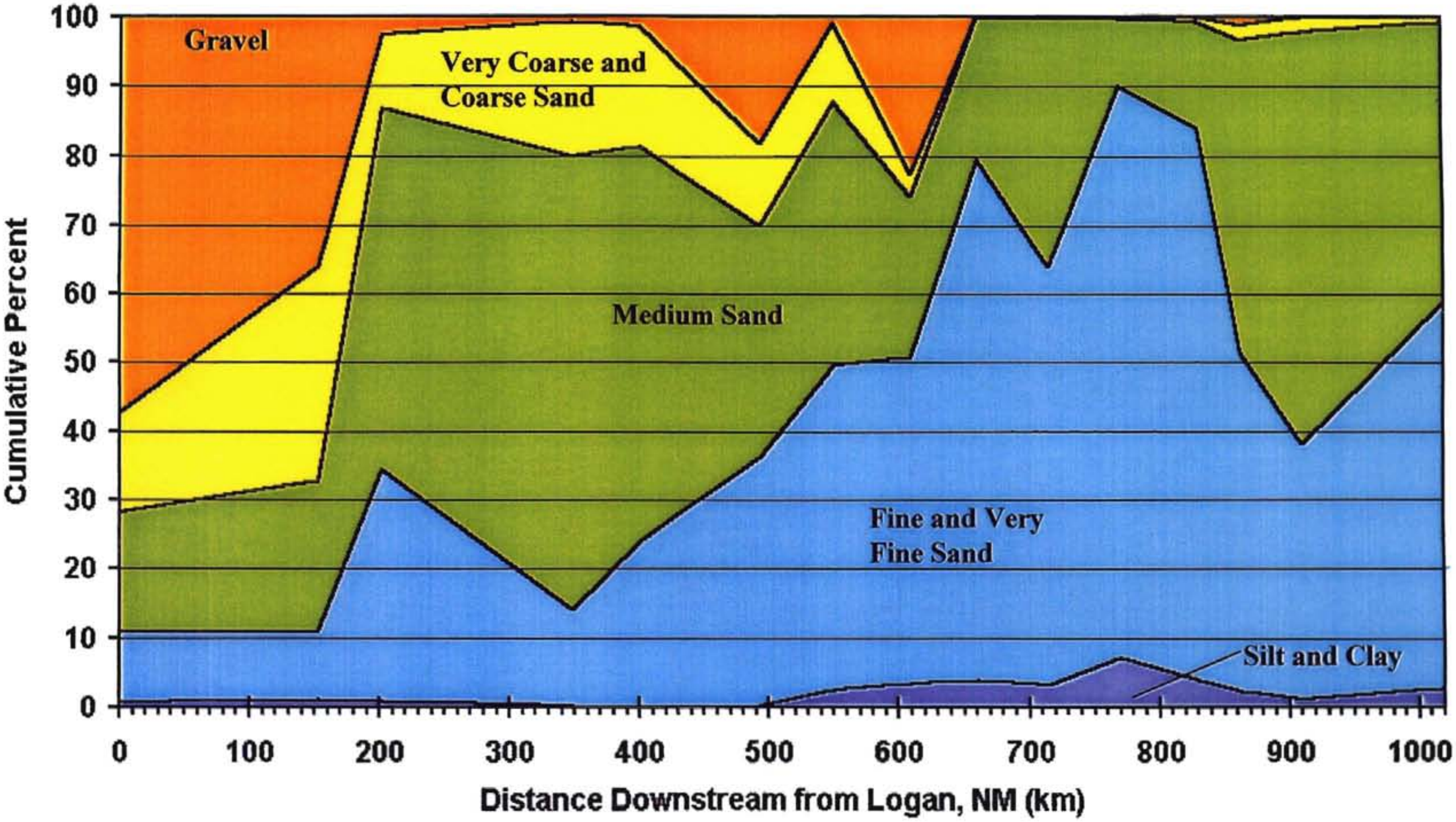


Figure 13. Proportions of Wentworth grain-size classes as percent (by mass) of total sample

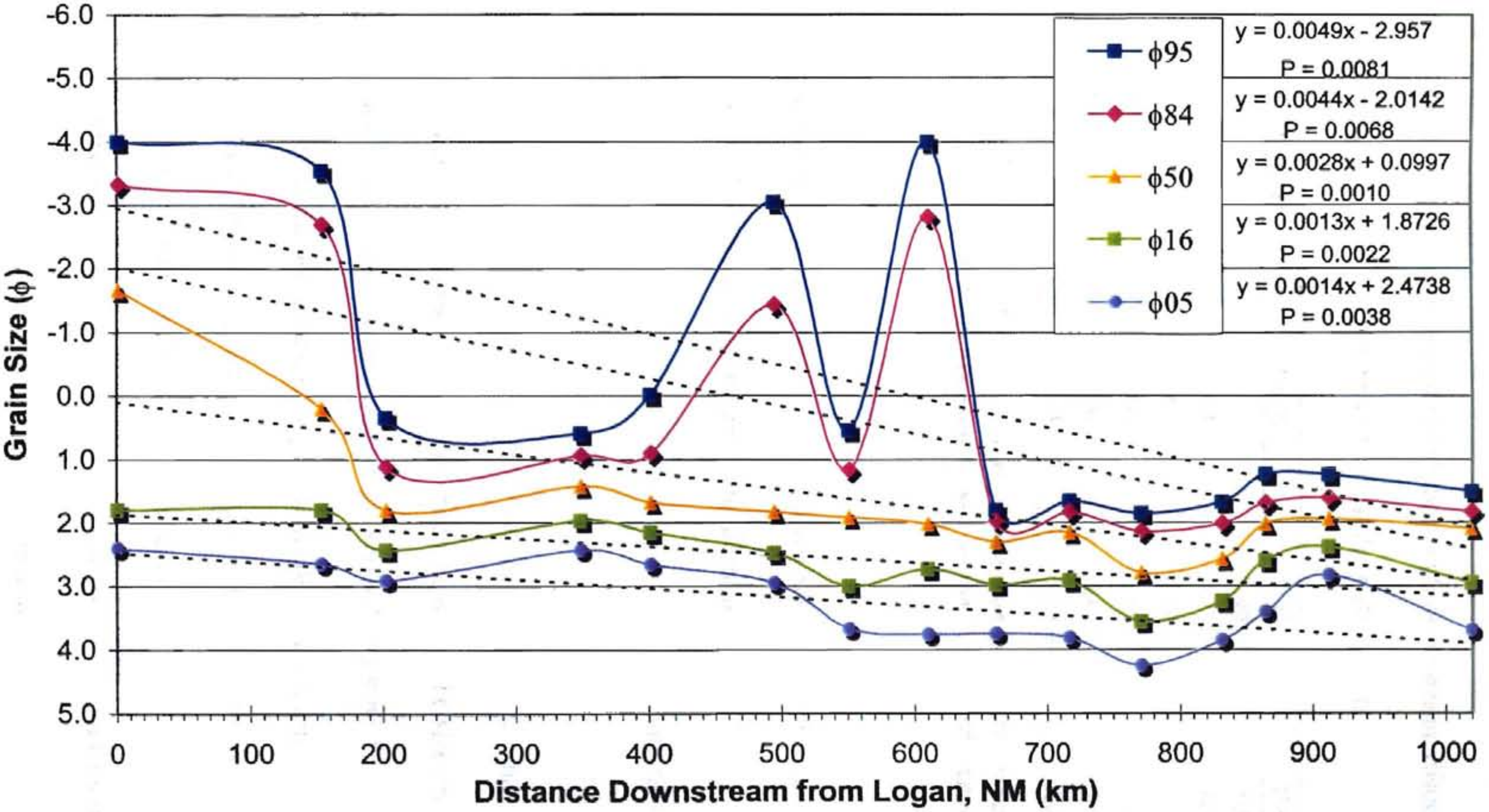


Figure 14. Effect of parameter choice on rate and significance of downstream fining trend in the Canadian River

At most sites, the mean grain size is slightly coarser than the median, indicating a tendency toward coarse fraction skewness (negative skewness in the case of the ϕ scale). This parameter shows the strongest corellation with downstream distance. However, it is also more sensitive to heavy pebble outliers in the distribution.

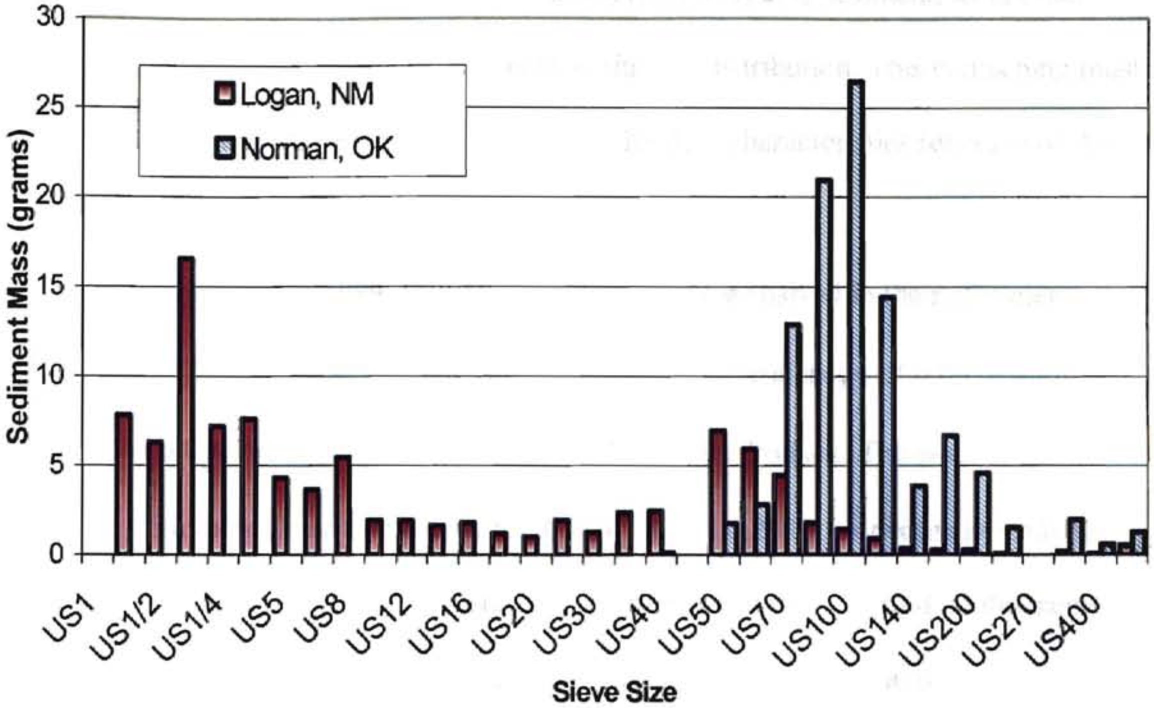
Parameter	**Slope**	**r^2**	**P-value**
ϕ05*	0.0014	0.4864	0.0038
ϕ16*	0.0013	0.5269	0.0022
ϕ50*	0.0028	0.5806	0.0010
ϕ84*	0.0044	0.4422	0.0068
ϕ95*	0.0049	0.4289	0.0081
Mean*	0.0049	0.5950	0.0008

Table 2. Regression statistics for six grain-size parameters versus distance downstream; All trends are significant at the 95% confidence level

Significance and Rate of Fining Trend

According to the ϕ_{50} statistic, the coarsest sample site is Logan, New Mexico (#1) with a value of –1.66 ϕ (3.2 millimeters). The finest is Union City, Oklahoma (#11) with a value of 2.79 ϕ (0.14 millimeters). The size-by-weight distributions for Logan and Norman (the second finest site with a median of 2.57 ϕ or 0.17 millimeters) with photos of the bed material are shown in Figure 15. The median grain size has halved four times over the 830 kilometers between these two sites, however the size change of the sand mode is much smaller. Since fining rates in gravel-bed and sand-bed streams tend to be controlled by different processes, it may be advisible in some sand-bed studies to remove the gravel fraction before computing descriptive statistics on the distribution. For this study, though, the full range of grain sizes was used.

After the median grain-size reaches a minimum at Union City (#11), it increases by nearly 1 ϕ over the next three sample sites, violating Sternberg's relationship. This



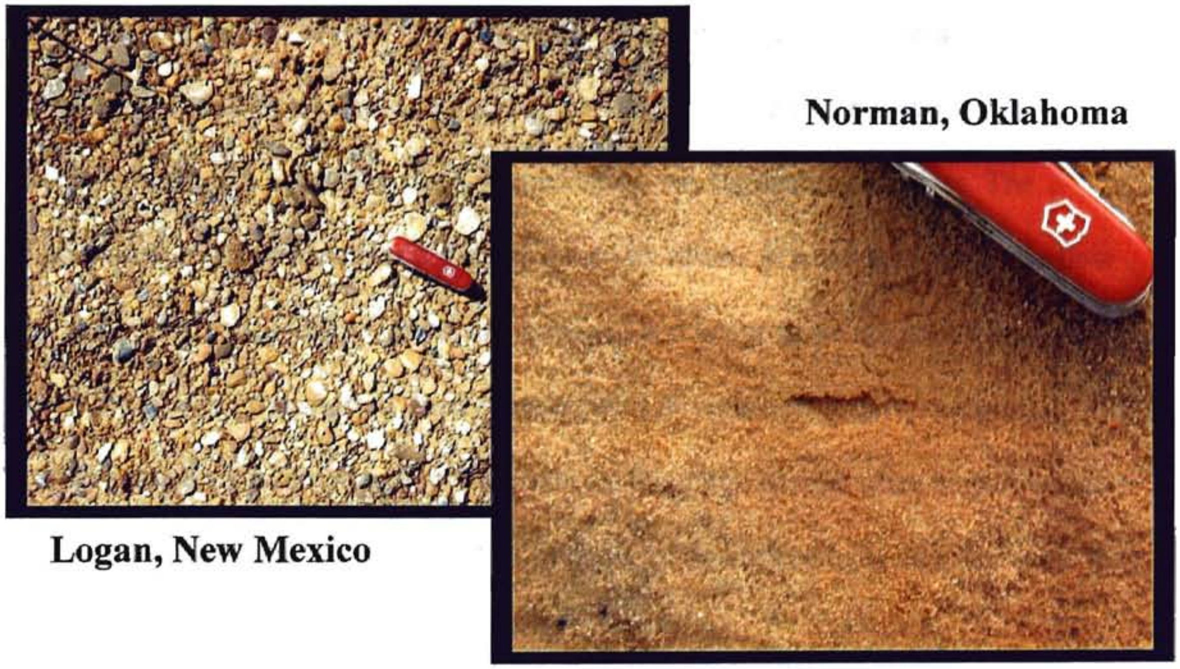


Figure 15. Grain-size distributions of Canadian sediment at Logan, NM, and Norman, OK with photos of the bed material at each location

increase is not caused by an increase in the proportion of coarse sediment, as in other sites, but rather by a coarsening of the entire grain-size distribution. This coarsening must reflect either a change in the sediment supply or the flow characteristics (energy) of the river.

On average, the median diameter is reduced by 1 ϕ (halved in the millimeter scale) every 357 kilometers. This corresponds to a fining trend slope of 0.0028 ϕ/km compared to 0.0007 ϕ/km for Simms and 0.0003 ϕ/km for Pollack. The p-value associated with these three trends is 0.0010, 0.1473, and 0.2041, respectively. Only the median fining trend calculated in this study is significant at a 95% level of confidence. Figure 16 shows the results of all three analyses, in which an interesting pattern appears. Rates of fining increase as the researcher samples higher above the low-flow channel.

Unfortunately, several problems arise when comparing the three study results. First, Pollack's data were collected in the late 1950's, before two reservoirs (Ute Reservoir and Lake Meredith) were created along this segment of the river. The emplacement of dams in semiarid regions generally results in a constriction of the flow regime downstream as higher flows are managed and lower flows are maintained. Coarse particles that were transported during unregulated flows are no longer transported. Smaller particles, on the other hand, become slightly more mobile when a minimum flow rate is maintained by releases. The effect of dams on downstream reaches decreases with distance.

Dams may, therefore, induce downstream fining by selective sorting, making nearby reaches coarser and downstream reaches finer. This supposition is supported by Hoey and Ferguson (1994) and Robinson and Slingerland (1998) who modeled the effect

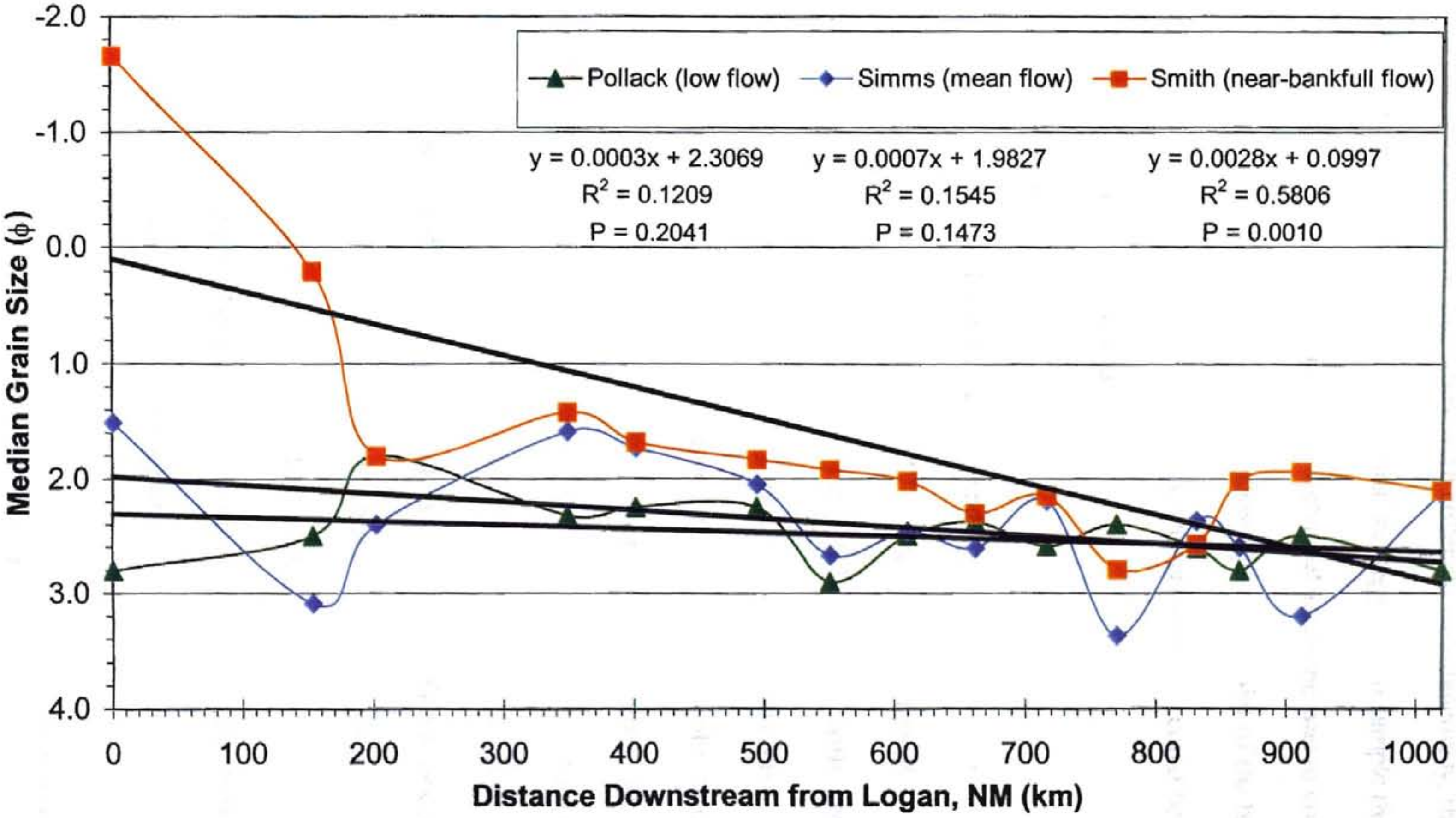


Figure 16. Effect of sample location on rate and significance of bed material fining trend in the Canadian River

of decreasing sediment supply on grain sizes and fining rates. Also, though Simms' samples and the samples for this study were collected simultaneously, they were collected on opposite ends of the bar. Simms' strategy was to sample the downstream end of the bar at the periphery of the mean-flow channel and mine was to collect sediment recording the near-bankfull event on the highest upstream point of the bar. Therefore, two spatial variables, elevation and upstream-downstream position, could be responsible for the at-a-site difference in mean grain-sizes.

Microscope Analysis

When the 15 samples are examined under a simple optical microscope, individual quartz grains appear to dominate (Figure 17)[7]. Contribution of locally derived bedrock is judged to be important at Highway 87 (#3) and Roll (#6) since both samples contain fragments of red, fine-grained sedimentary rock. At both of these sites, the river was cutting laterally into fine-grained Permian rocks. At the former site, natural erosion was accelerated by disturbance of local hillslopes for recreation (Figure 18). At the latter site, steep cut banks contained fine sandstones, siltstones, and shales of the Permian Cloud Chief Formation. Much of the bar at Roll (#6) was covered with a scattering of large fragments of fragile, red, fine-grained clastic rock. In a few places, larger clasts appeared to have been deposited intact and later disintegrated by frost action or some other process (Figure 19). It is unlikely that these particles traveled very far downstream before being deposited. In fact, many of them may be derived from the large cut bank that is visible just a few kilometers upstream in the background of Figure 20. In the microscope view of

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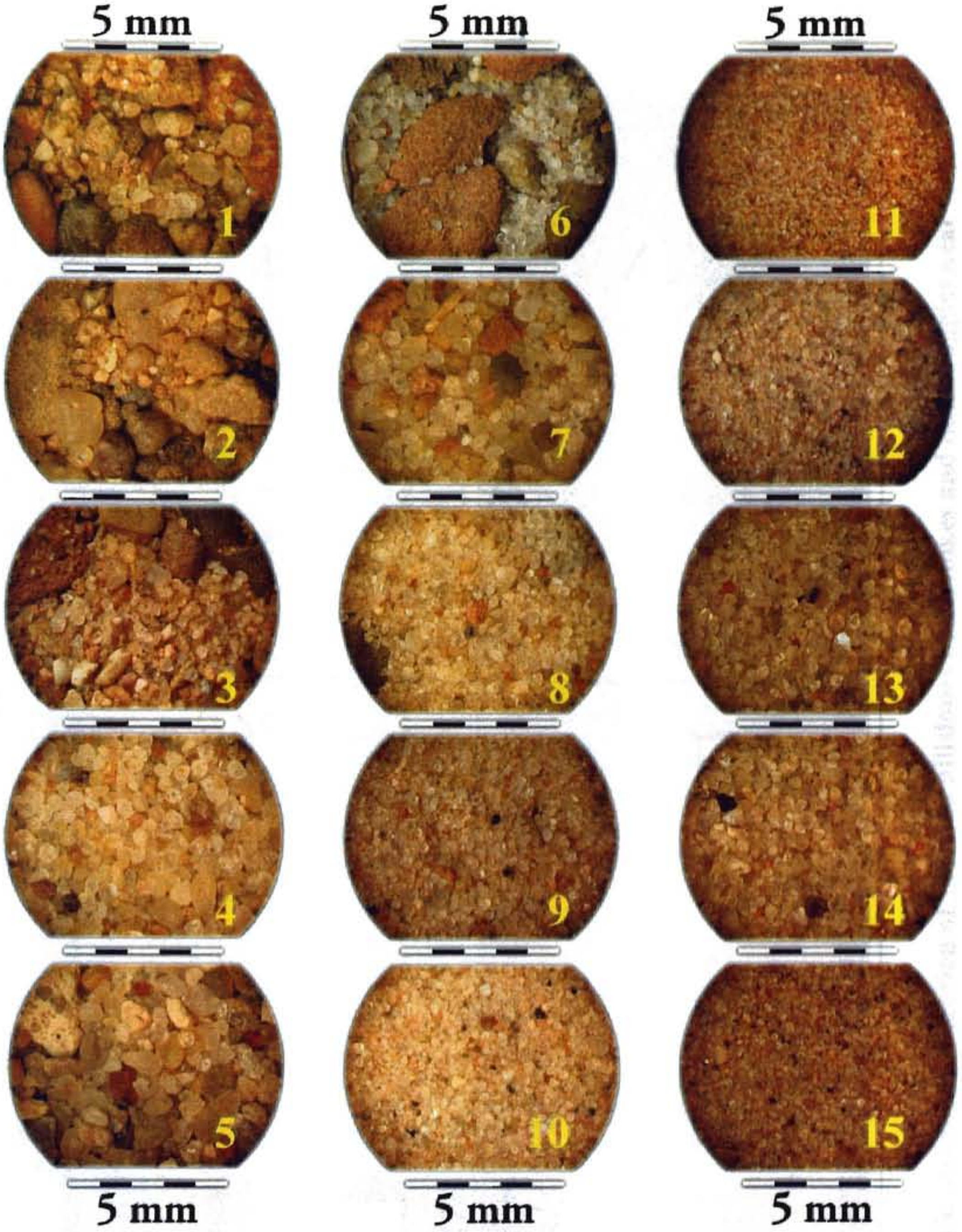
[7] Microphotographs are biased toward the finer components of the grain-size distribution. Larger clasts could not be photographed since they would occupy most of the field of view.



1. Logan, NM
2. Boys Ranch, TX
3. Hwy 87, TX
4. Hwy70, TX
5. Canadian, TX
6. Roll, OK
7. Camargo, OK
8. Taloga, OK
9. Fay, OK
10. Bridgeport, OK
11. Union City, OK
12. Norman, OK
13. Purcell, OK
14. Asher, OK
15. Calvin, OK

Figure 17. Microscope photos of unsieved samples from each sample location; *Note*: Photos are biased toward finer components of the sample.

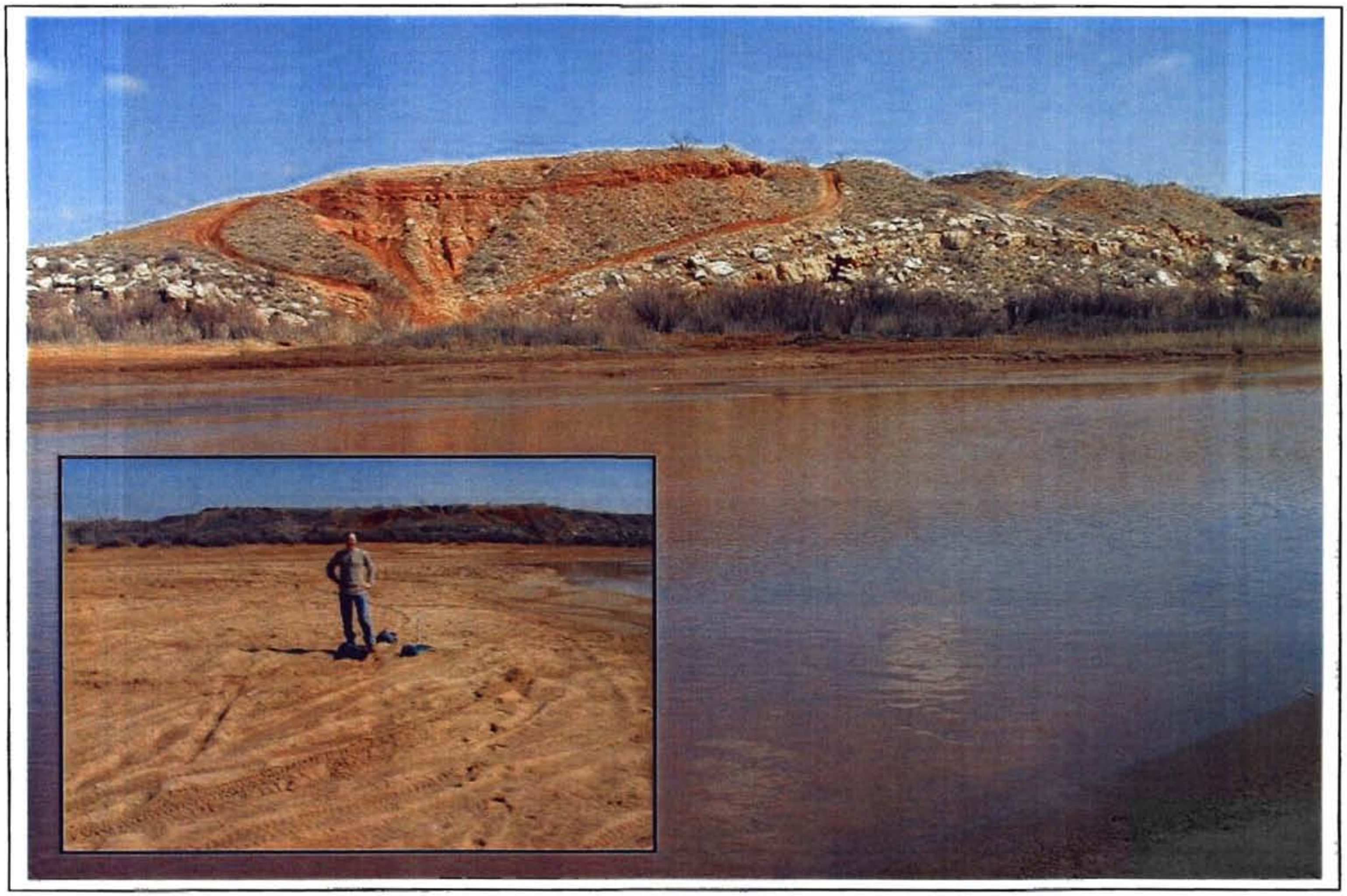


Figure 18. Accelerated erosion of Permian hillslopes by dirtbikes and dune buggies near Amarillo (Highway 87), Texas

Figure 19. In-storage attrition of locally derived, fine sandstone clast near Roll, Oklahoma

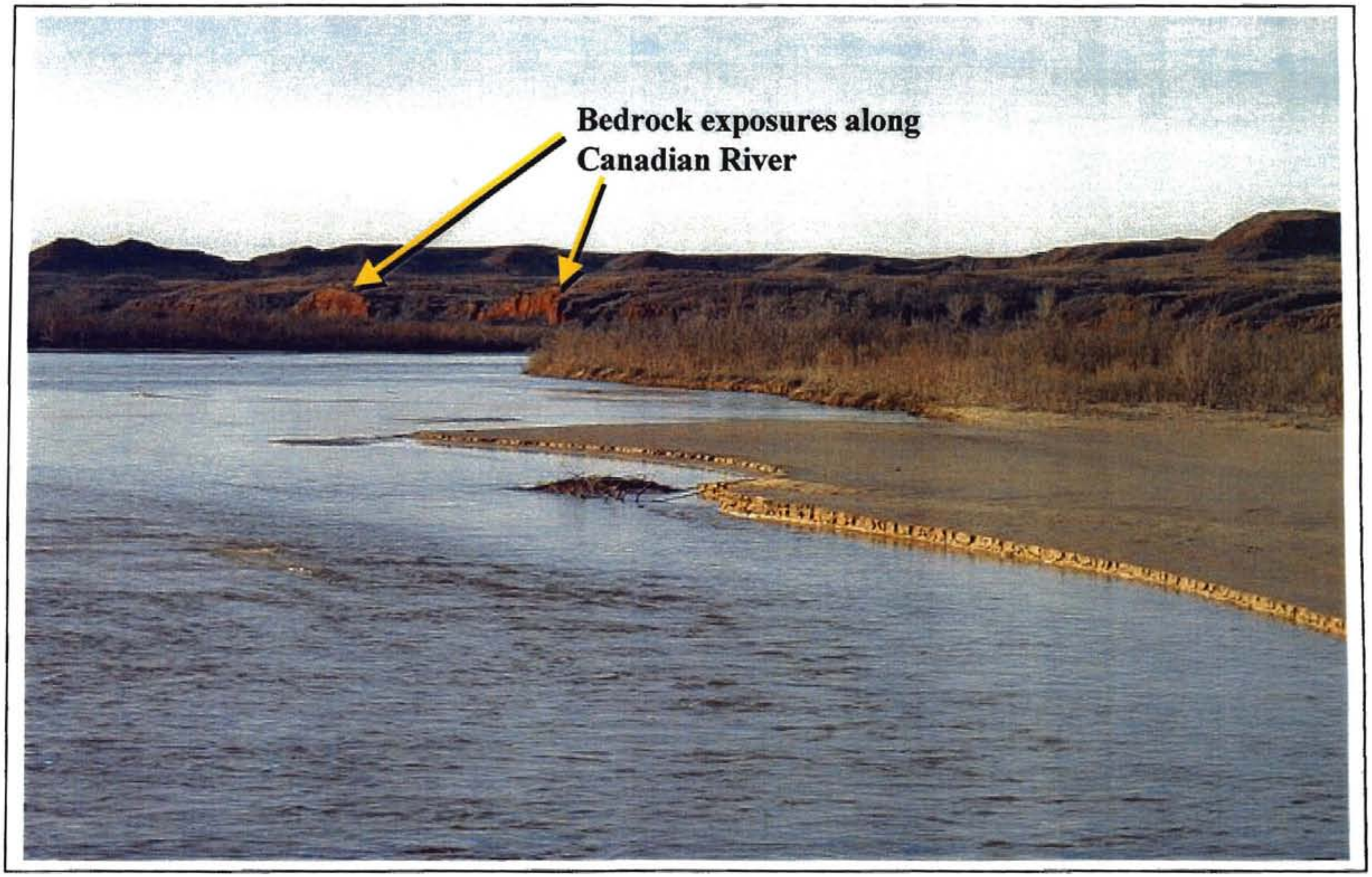


Figure 20. Photograph of the bar sample site at Roll, Oklahoma, with possible sources of bedrock contribution in cutbanks upstream

site #6, these large sedimentary rock fragments show a progressive decrease in both quantity and size over the next three sites (#7-9). At site #10 they are no longer identifiable in the sample.

At Taloga, Oklahoma (site 8) large, rounded, quartzite pebbles were found on the bar surface (Figure 21). The immediate source of these particles is unknown, though it is probably a very short distance upstream. It is my opinion that pebbles cannot travel far in an aggrading, sand-bed river before being removed from circulation by burial. The most likely scenario is that they were eroded from older bar deposits nearby. Before they became stored in the Canadian bars, they probably came from the Ogallala Formation. Before that, they were most likely weathered from metamorphic rocks in the Rocky Mountains and carried down the slope of Ogallala alluvial fans by a more competent stream, ancestral to the Canadian.

Certainly, bank lithology is an important factor determining the rate of downstream fining. Disintegration of poorly consolidated siltstones and shales (like at Roll, Oklahoma) are likely to accelerate apparent fining, contributing gravel-sized clasts that are very quickly broken into a host of silt and clay-sized particles. On the other hand, fining by attrition of crystalline rock fragments would not be as rapid. It is my opinion that, when the right conditions are met, in-situ weathering can significantly contribute to particle attrition. Bradley et al. (1972) arrived at the same conclusion, believing that splitting of foliated metamorphics created a platy gravel fraction that is more easily transported and broken further.

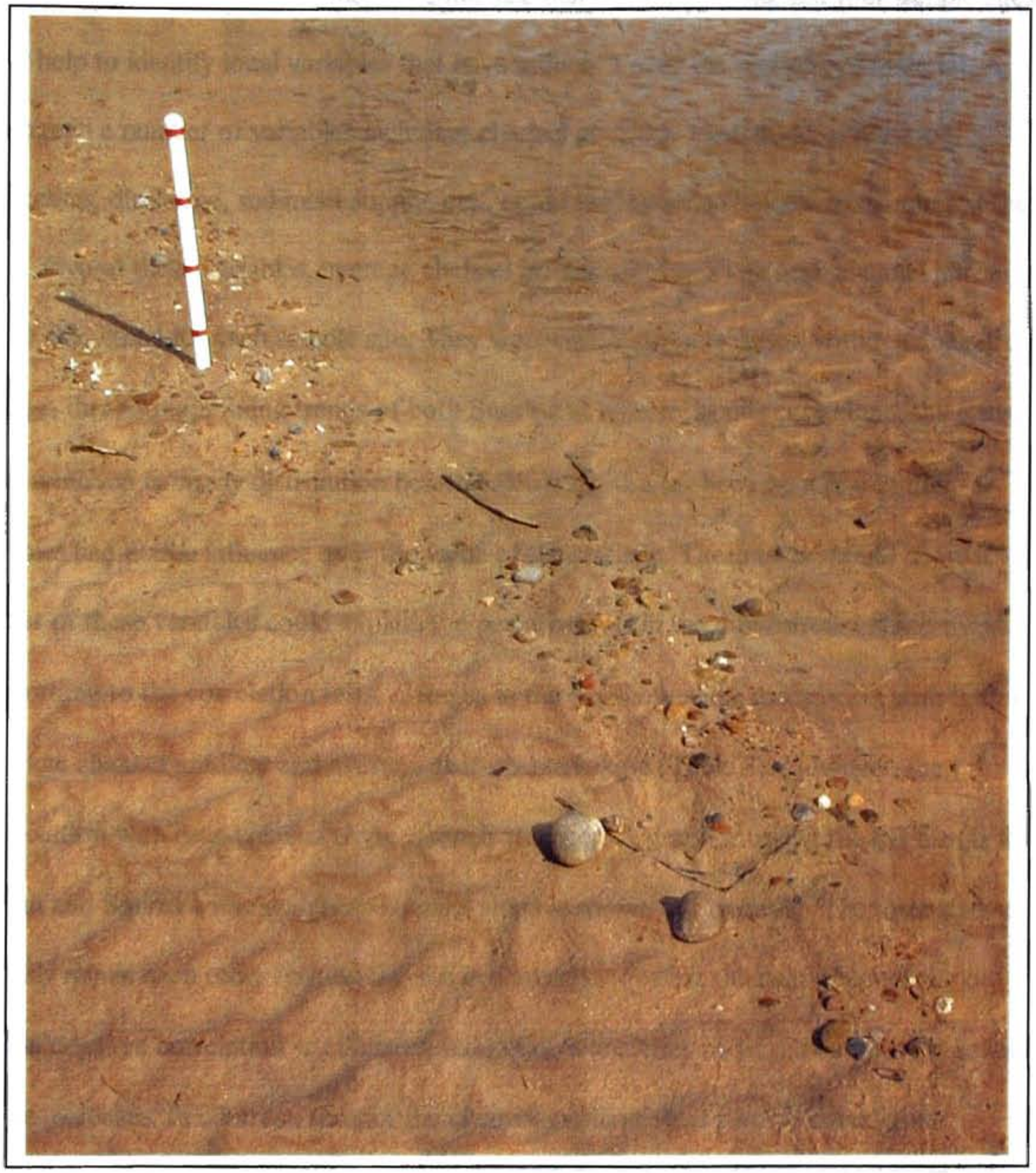


Figure 21. Large quartzite pebbles atop medium sand near Taloga, Oklahoma; *Note*: Stick graduations are 6 inches.

Other Observations

The sharp increase in median grain size that occurs over the last four sample sites may help to identify local variables that have influence over the size of bed material. A change in a number of variables including channel gradient, magnitude of hillslope processes, discharge, sediment supply, etc., could theoretically cause a coarsening of the bed. Two of these variables, average channel gradient and average near-channel hill slope were calculated for each sample site. They were tested for correlation with residuals from the ϕ_{84} downstream fining trends of both Smith and Simms. In this case alone, the gravel was removed from my distribution before calculating the ϕ_{84} because a few outlier pebbles had undue influence over the value of the statistic. These tests should show if either of these variables could explain the perturbations in the downstream fining trend. According to the correlation tests, changes in the ϕ_{84} show some association with both the average channel gradient and average near-channel slope (Table 3). However, the association with near-channel slope is much stronger. A graph showing the ϕ_{84} trends for Smith and Simms with mean near-channel slope is shown in Figure 22. The three datasets closely mimic each other beyond the site at Camargo. Testing the near-channel slope yields negaitve correlation coefficients, indicating a tendency toward a coarser ϕ_{84} as the slope increases. In contrast, tests of the channel gradient yield positve correlation

	average channel gradient values (m/km)	mean near-channel slope values (m/km)	ϕ84 fining trend residuals	
			Smith	Simms
gradient	1.0000	--	--	--
slope	-0.4073	1.0000	--	--
Smith residuals	0.2528	-0.3476	1.0000	--
Simms residuals	0.0051	-0.4543	0.1341	1.0000

Table 3. Correlation matrix for ϕ_{84} residuals, average channel gradient, and mean near-channel slope

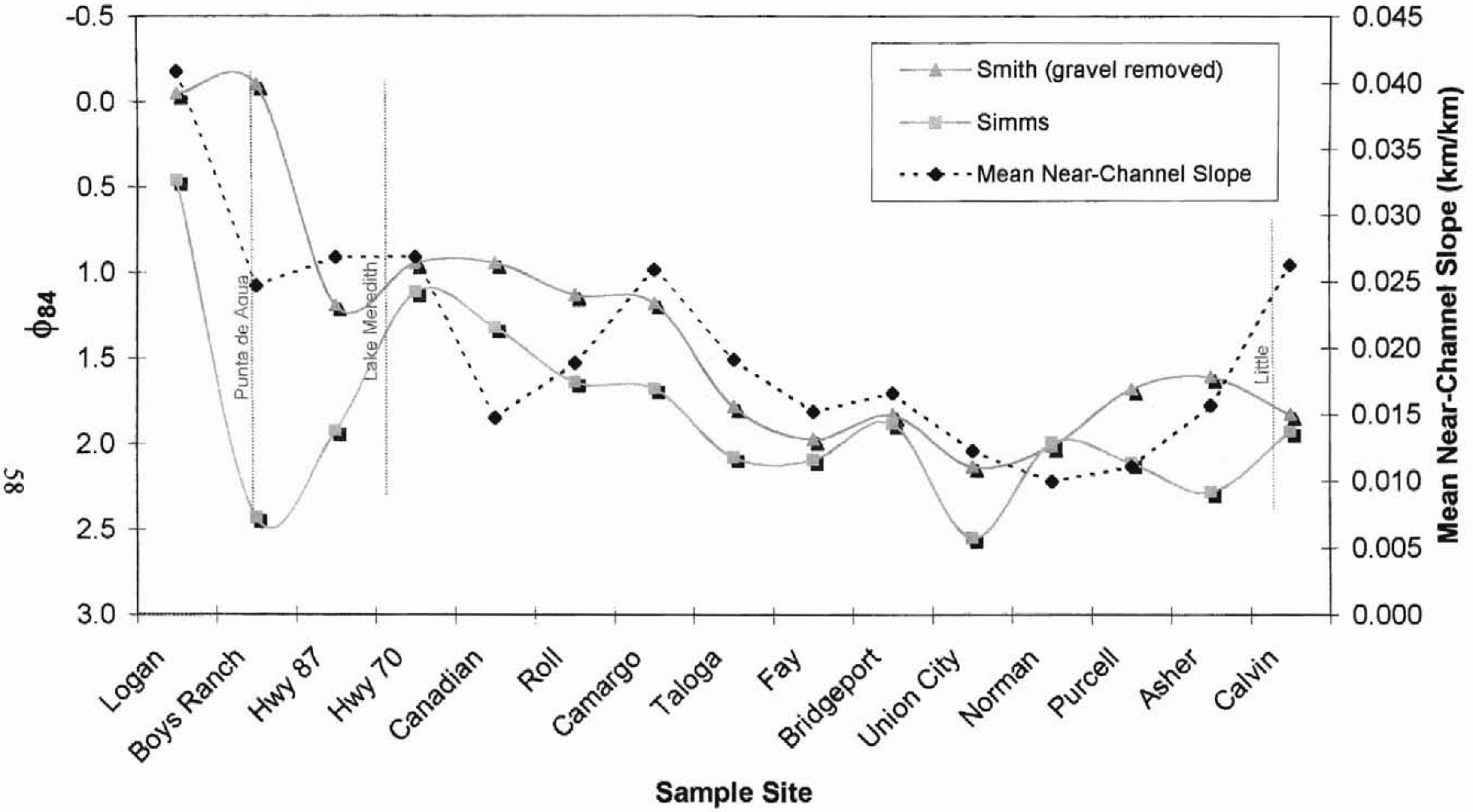


Figure 22. Smith ϕ_{84} and Simms ϕ_{84} fining trends with mean slope over an area 1.6 kilometers from the Canadian trunk stream

coefficients, indicating a tendency toward a finer ϕ_{84} as the gradient increases. The results of the channel gradient tests are counterintuitive and probably have little worth given the poor agreement between tests with Simms' data and mine. The near-channel slope, on the other hand, does appear to have some value as a predictor of perturbations in the ϕ_{84} downstream fining trend in the Canadian River.

It is important to realize that many other variables besides slope could be responsible for the overall coarsening of bed material in the last four sample sites. At the coarsest of these four sites (#14 at Asher, Oklahoma), the bedrock is Lower Permian Garber Sandstone, which is generally coarser grained than the other Permian units that crop out upstream. Also, an increase in the magnitude and frequency of floods occurs in this more humid section of the river. Any combination of these properties could be the cause of the bed coarsening. Unfortunately, no data was collected in the course of this study to test the effects of these two additional variables.

Sorting Profile

In addition to the fining profile, the sorting profile can yield important information about how sediment is changed downstream. Figure 23 shows the sorting profiles of Pollack, Simms, and Smith. In my profile, the gravel fraction (> 2 mm) has been removed from the distribution because a few outlier gravels had excessive influence over the value of sorting at a few locations. The comparison of Simms and Pollack's data is the most interesting. Both datasets approximate sinusoidal trends similar to Knighton (1982), but over a longer distance. However, only one of the peaks appears to be associated with a tributary. Most occur along a reach of the river with no significant tributaries. The large peak at Roll (550 km) is probably associated with the contribution

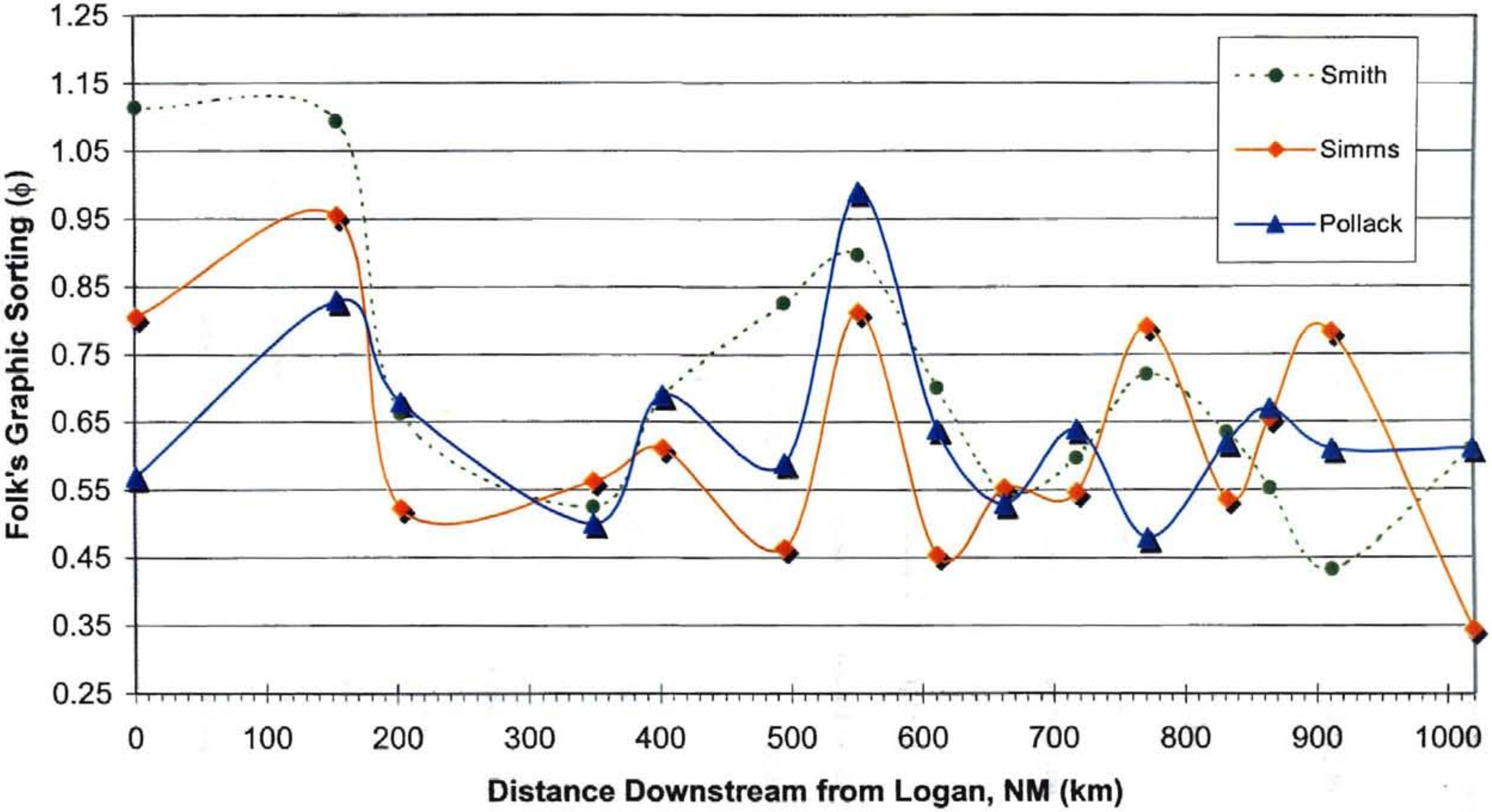


Figure 23. Sorting of bed material on the Canadian River

of bedrock from a cut bank a short distance upstream. For the Canadian River, it is likely that most changes in sorting result from bank contribution and not tributary inputs. No data was collected during this study to test this hypothesis.

Up to 650 kilometers downstream of Logan, the trends of Pollack and Simms closely mimic each other even though the two datasets were collected more than 40 years apart. Furthermore, the emplacement of Sanford dam appears to have caused few changes over that time. At first the similarity of the trends seems to indicate that sorting is tied to local properties, but this is not necessarily the case. It is also possible that flow regulation at the dam has prevented flows that are capable of redistributing the bed material. After the 650-kilometer mark, the peaks no longer coincide but appear to be out of phase. Perhaps sites downstream of this mark are outside the zone of regulation and have received high enough flows to significantly reorganize channel sediments.

Grain-size and sorting limits

Interestingly, minimum median grain-size and sorting in the Canadian River are very similar to those reported on larger rivers (Paola and Seal, 1995; Folk and Ward, 1957; U. S. Waterways Experiment Station, 1935; Russell and Taylor, 1937; Nordin et al., 1980; Nordin and Queen, 1992). The minimum ϕ_{50} is 2.79 ϕ (0.14 millimeters) and the minimum sorting is 0.43 ϕ. Perhaps these values are universal limits on fluvial systems below which fining and sorting processes are incapable of operating. However, much more data must be collected on sand-bed streams before this conclusion is justified.

Bar Variability

Camargo Bar Statistics

In any research where sampling is performed within a population, a test of variability between samples in that population is warranted (Knighton, 1982; Paola and Seal, 1995). It is an important aspect of this study to know the amount of variation that exists on a bar. In other words, do three samples of sediment from the same general area of a bar yield the same statistical parameters or is there a significant difference between them?

Total variation on the bar at Camargo is very small. The standard deviation of all parameters is less than 0.2 ϕ. The maximum difference in any two means is only 0.71 ϕ and the maximum difference in ϕ_{50} is 0.84 ϕ. For this bar, at least, mean and median grain-size is remarkably uniform across the entire surface. In fact, the entire distribution at each site is also very similar whether or not it is in the mean-flow channel. The only remarkable difference is in skewness. This parameter is slightly greater (more skewed toward fines) in the part of the bar above 250 millimeters. Furthermore, samples taken in the low-flow channel can have high negative skewness.

Sufficient data exist to create an east-west (parallel to flow) elevation profile along transect A (Figure 24). This line contains 12 sample points, two of which are in the mean-flow channel. Superimposed on this cross-section is a histogram of median grain size. In a general sense, the upstream end of the bar is coarser than the downstream end. However, the upstream end is topographically lower than the downstream end. In fact, site A11 on the trailing edge of the bar, was the topographically highest position recorded in the survey. Also, it is among the finer samples. These findings are contrary to the assumptions of the sampling strategy. It appears that the highest point is not necessarily on the upstream end of the bar. Furthermore, the highest point isn't necessarily the

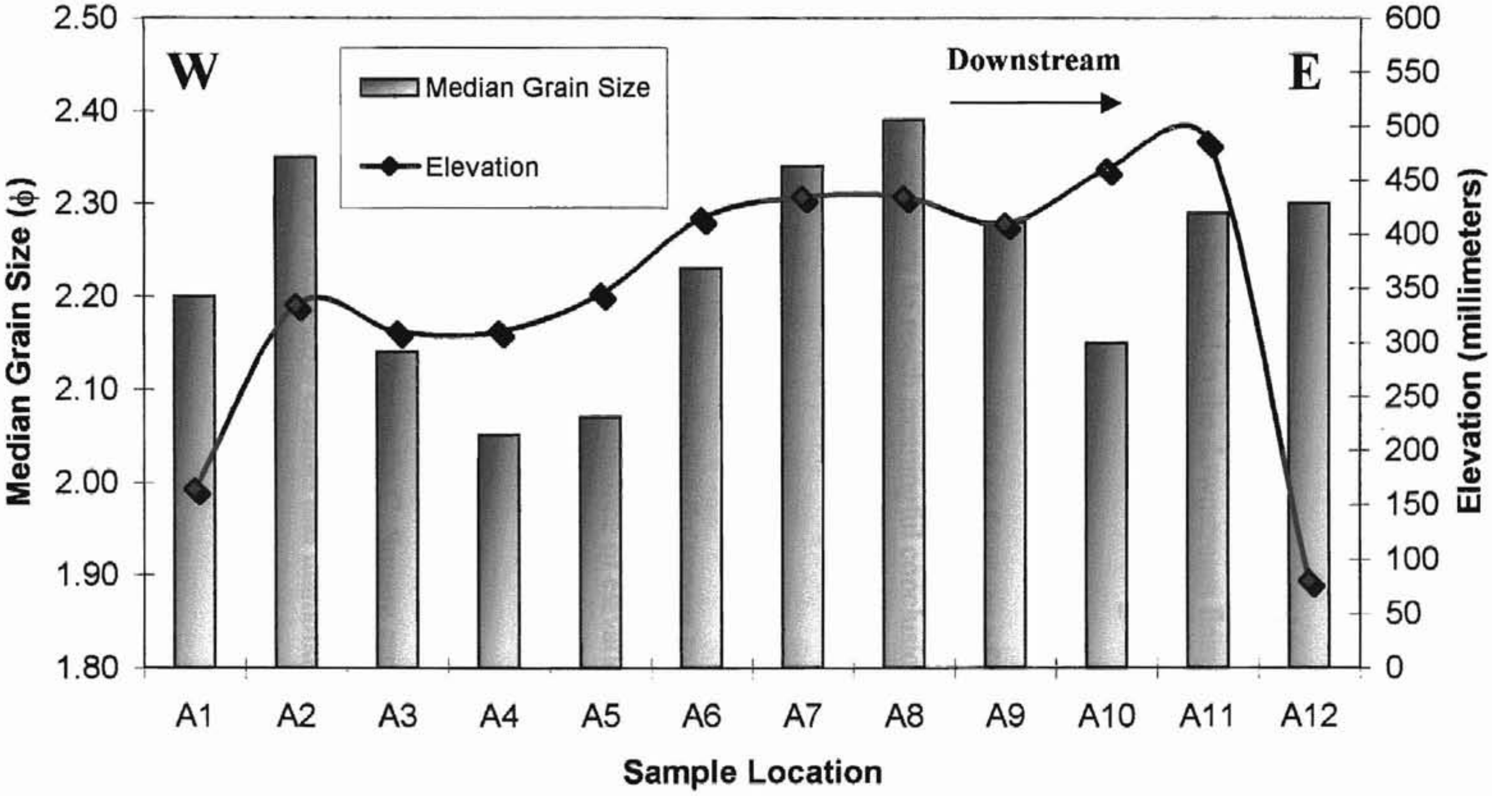


Figure 24. Grain-size and elevation change across transect A on a bar near Camargo, Oklahoma

coarsest. That Simms' samples were finer in 14 of the 15 sites of the downstream fining study suggests that this bar is atypical of the river.

Of the 36 fluvial samples, the coarsest median grain size was found at Z2, one of the highest positions on the upstream end of the bar. In contrast, the coarsest mean was found at site B6. This site is the second closest topographically to the mean-flow channel.

If this bar had been included in the downstream fining study, there would probably be no difference between the mean or median grain sizes of Mr. Simms and my own. Again, this result contradicts expectations following the results of the downstream fining study where Simms' location was finer at fourteen of fifteen sites. Certainly, more sand bar studies are necessary to reach meaningful conclusions about the variability of grain-size and the implications it may have on sampling strategies.

Regression Analysis

Many changes in grain-size distribution do appear to be closely related to changes in bar surface elevation. To assess the significance of elevation in determining grain-size frequency distributions, linear regression analysis was performed treating each of the seven parameters mentioned above as dependent variables. For all relationships analyzed herein, a scatterplot can be found in Appendix C. Square symbols are used to represent samples taken in the low to mean-flow channel and diamonds represent the 28 samples above 250 mm. Each plot contains a best-fit regression line drawn through only those points above the mean-flow channel. The upper-right hand corner of the plot displays the equation of the regression line and the coefficient of determination (r^2). This statistic quantifies the strength of the relationship but gives no indication of its significance. For this reason, the P-value is included when regression results are tabulated. In this study, a relationship is considered significant if the P-value is at or below 0.0500, corresponding to a 95% confidence level.

Initially, few trends were discernable when all 36 data points were plotted versus elevation. However, when the points are stratified by position inside or outside of the mean channel, many relationships become apparent in the 250 to 500 millimeter zone. On the other hand, no remarkable relationships are present within the 0 to 250 millimeter range. For the purpose of clarity, regression results are omitted for this zone and the focus of the remaining discussion is placed on the 250 to 500 millimeter elevation range. However, the lower zone data is still useful for comparisons with the upper zone.

Parameter	Linear Regression Results (X = elevation)			
	Slope	Intercept	r^2	P-value
ϕ_{16}*	0.00152	2.249	0.4144	0.0002
ϕ_{50}*	0.00150	1.630	0.2234	0.0111
ϕ_{84}*	0.00134	1.189	0.2734	0.0043
ϕ_{mean}*	0.00146	1.689	0.3226	0.0016
Sorting	-0.00008	0.687	0.0124	0.5723
Skewness*	-0.00324	1.761	0.2479	0.0070
Kurtosis*	-0.01058	8.916	0.4053	0.0003

Table 4. Regression statistics for grain-size distribution parameters and bar elevation for sites between 250 and 500 millimeters; asterisks indicate significant relationships

The three percentile measures, ϕ_{16}, ϕ_{50}, and ϕ_{86}, all show a significant increase in value with increasing elevation (Table 4). It is important to remember that, since the Krumbein phi (ϕ) scale is the negative, base-2 logarithm of the millimeter diameter scale, an increase in ϕ value indicates a decrease in grain-diameter. So in other words, as elevation increases, the grain-size tends to decrease producing a fining upward trend on the bar surface. The strongest relationship exhibited by any of the three percentile measures is that of ϕ_{16}. Folk's Graphic Mean also shows a significant increase with elevation. In this case it proves to be of greater significance than the ϕ_{50}, supporting Folk and Ward's (1957) claim that the median size is not nearly as useful a measure of central tendency as is the mean. Highly significant trends are also present in the skewness and kurtosis regressions. Skewness decreases (becomes less positive) with increasing elevation. This means that, higher on the bar, the grain-size distribution has a smaller tail of fines, approaching normality near the bankfull stage. Kurtosis plots display the same pattern, reaching an apex just above the mean-flow channel at 275 mm. Above this level on the bar, kurtosis is highly correlatable with elevation, becoming steadily less leptokurtic. Interestingly, samples taken from the highest and lowest locations have the almost identical values. Finally, sorting (standard deviation of grain-size) is the only parameter that shows no significant trend with elevation in the mean to bankfull stage zone. It should be noted though, that samples from the low to mean-flow channel typically exhibit much better sorting than those above the mean channel. This is expected since sorting is sensitive to changes in skewness.

The application of these results to bars far upstream and downstream from Camargo is probably not justified. The elevation trends would probably hold only for rivers, like the Canadian, which experience large bankfull flows followed by long periods of low flow. The significance of the elevation regression is probably at a maximum immediately after the bankfull event and decreases the longer the bar is exposed to succeeding erosional and depositional events, including eolian events.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Currently, the most significant barrier to our understanding of sediment fining in sand-bed rivers is simply a lack of published data collected under a consistent sampling scheme. This void in sedimentologic research is surprising considering the worldwide ubiquity of such systems. Many more sand-bed studies must be performed in a variety of geologic settings before the subject of downstream fining is fully understood. Some of the most interesting findings resulted from simple comparisons of my data with Pollack (1959) and Simms (2001).

1) Contrary to the work of Pollack (1959), significant downstream fining of bed material was observed over a 1000-kilometer sand-bed segment of the Canadian River. This decreasing grain-size trend is significant to a 99% level of confidence for both the median (ϕ_{50}) and mean (Folk's Graphic Mean) grain size.

2) Both the fining rate and the significance of the fining trend depended on the percentile grain-size used in regression analysis. The fining rate increased when coarser percentiles were used. The significance of the fining trend also increased when coarser percentiles were used until the median (ϕ_{50}) was reached. The ϕ_{84} and ϕ_{95} fining trend showed decreased significance due to the variation introduced by the presence of a few large outlier pebbles in some samples.

3) The fining rate and significance of the fining trend also depended on from where in the channel cross-section samples are taken. Positions atop bars and out of the scoured mean-to-low-flow channel produced stronger and more significant trends.

4) Total variation of mean and median grain size was very small (less than 1 ϕ) on a point bar near Camargo, Oklahoma.

5) Site-to-site changes in grain size and sorting could be caused by changes in the type of bank materials (especially sedimentary bedrock exposures) as well as changes in near-channel hill slope.

A need also exists to understand what causes the perturbations or deviations from the fining trend, not just the processes that cause fining to occur. Some of the most promising variables recognized in this study are the bank lithology, near-channel slopes, and variations in discharge. Bed material provenance studies could yield important results, especially if they include the mapping of possible sites of bedrock contribution along the river. The correlation of coarse-percentile downstream fining residuals with near-channel slopes is an interesting relationship. Steeper hillslopes could increase the discharge of both local sediment and runoff to the trunk stream. It remains unknown whether the bed coarsening over the last four sites is a result of local sediment contribution or flow contribution.

In addition to changes in surface texture downstream, it is important to consider the change in the fining profile over time. This would require extensive coring of the valley fill at each location using depth as a proxy for time. Unfortunately, conventional time-stratigraphic correlation between bars one thousand kilometers apart would be very difficult unless a catastrophic event, shift in upstream sediment supply, or a distinct change in the basin-wide climate occurred. Variation in grain-size over the thickness and width of the valley fill is extremely important in petroleum exploration and production in alluvial reservoirs. A small change in mean or median grain size can result in a significant change in well permeability on a per foot basis. This information could be used to calculate more accurate basin modeling parameters. Likewise, the rate of groundwater extraction from alluvial aquifers is governed by the same grain-size characteristics of the alluvium.

REFERENCES CITED

Bradley, W. C., 1970, "Effect of weathering on abrasion of granitic gravel, Colorado River, Texas." Geological Society of America Bulletin, v. 81, p. 61-80

Bradley, W. C., Fahnestock, R. K., and Rowekamp, E. T., 1972, "Coarse sediment transport by flood flows on Knik River, Alaska." Geological Society of America Bulletin, v. 83, p. 1261-1284.

Bunte, Kristin and Steven R. Abt, 2001. Sampling Surface and Subsurface Particle-Size Distributions in Wadable Gravel- and Cobble-Bed Streams for Analyses in Sediment Transport, Hydraulics, and Streambed Monitoring. U.S. Forest Service, General Technical Report RMRS-GTR-74. 428 p.

Church, M., D. G. McLean and J. F. Walcott, 1987. River bed gravels: sampling and analysis. In: *Sediment Transport in Gravel-Bed Rivers*, C. R. Thorne, J. C. Bathurst and R. D. Hey (eds.), John Wiley and Sons, Chichester, p. 43-88.

Folk, R. L., 1957. Petrology of Sedimentary Rocks. Hemphill's Book Store, Austin, Texas, 113 p.

Folk, R. L., and Ward, W. C., 1957, "Brazos River bar: A study in the significance of grain size parameters." Journal of Sedimentary Petrology, v. 27, p. 3-26.

Gebert, Wallace A., David J. Graczyk, and William R. Krug, 1987. Average Annual Runoff in the United States, 1951-80. U.S. Geological Survey, Hydrologic Investigations Atlas 710.

Hoey, T. B., and B. J. Bluck 1999, "Identifying the controls over downstream fining of river gravels." Journal of Sedimentary Research, v. 69, p. 40-50.

Hoey, T. B., and R. I. Ferguson, 1994, "Numerical simulation of downstream fining by selective transport in gravel-bed rivers: Model development and illustration." Water Resources Research, v. 30, p. 2251-2260.

Kessler, L. G., and Cooper, F. G., 1970, "Channel sequences and braided stream development in the South Canadian River, Hutchinson, Roberts, and Hemphill Counties, Texas." Transactions of the Gulf Coast Association of Geological Societies, v. 20, p. 263-273.

Kessler, L. G., 1971, "Characteristics of the braided stream depositional environment with examples from the South Canadian River, Texas." Wyoming Geological Society Earth Science Bulletin, v. 4, p. 25-35.

Knighton, A. D., 1982, "Longitudinal changes in the size and shape of stream bed material: evidence of variable transport conditions." Catena, v.9, p. 24-34.

_____________, 1998. Fluvial Forms and Processes, A New Perspective. Arnold, London.

Krumbein, W. C., 1941, "The effects of abrasion on the size, shape and roundness of rock fragments." Journal of Geology, v. 49, p. 482-520.

Mackin, J. H., 1948, "The concept of the graded river." Geological Society of America Bulletin, v. 5, p. 463-511.

Middleton, G. V., 1976, "Hydraulic interpretation of sand size distributions." Journal of Geology, v. 84, p. 405-426.

Moss, A. J., 1972, "Initial fluviatile fragmentation of granitic quartz." Journal of Sedimentary Petrology, v. 42, p. 905-916.

Nordin, C. F., Jr., R. H. Meade, W. F. Curtis, N. J. Bósio, and P. M. B. Landim, 1980, "Size distribution of Amazon River bed sediment." Nature, v. 286, p. 52-53.

Nordin, C. F., Jr., R. H. Meade, H. A. Mahoney, and B. M. Delaney, 1977. Particle Size of Sediments Collected from the Bed of the Amazon River and its Tributaries in June and July 1976. U. S. Geological Survey, Open-File Report 77-400. 18 p.

Nordin, C. F., Jr., and B. S. Queen, 1992. Particle Size Distributions of Bed Sediments Along the Thalweg of the Mississippi River, Cairo, Illinois, to Head of Passes, September 1989. U. S. Waterways Experiment Station. 93 p.

Parker, G., Klingeman, P. C., and McLean, D. C., 1982, "Bedload and size distribution in paved gravel-bed streams." American Society of Civil Engineers, Proceedings, Journal of the Hydraulics Division, v. 108, p. 544-571.

Parker, G., 1991, "Selective sorting and abrasion of river gravel, I." Journal of Hydraulic Engineering, v. 117, p. 131-149.

Pollack, J. M., 1959. Significance of Compositional and Textural Properties of South Canadian River Channel Deposits, New Mexico, Texas, and Oklahoma. Doctoral Thesis. University of Oklahoma.

___________, 1961, "Significance of compositional and textural properties of South Canadian River channel sands, New Mexico, Texas, and Oklahoma." Journal of Sedimentary Petrology, v. 31, p. 15-37.

Paola, C., and R. Seal, 1995, "Grain size patchiness as a cause of selective deposition and downstream fining." Water Resources Research, v. 31, p. 1395-1407.

Price, M., "Using 1:250,000-Scale DEM Data." ArcUser, April-June 2000. http://www.esri.com/news/arcuser/0400/webdata9.html.

Rice, S. P., 1999, "The nature and controls on downstream fining within sedimentary links." Journal of Sedimentary Research, v. 69, p. 32-39.

Robinson, R. A. J., and R. L. Slingerland, 1998, "Origin of fluvial grain-size trends in a foreland basin: the Pocono Formation on the Central Appalachian Basin." Journal of Sedimentary Research, v. 68, p. 473-486.

Russell, R. D., 1939, "Effects of transportation on sedimentary particles." In *Recent Marine Sediments*, ed. Trask, p. 32-47.

Russell R. D., and R. E. Taylor, 1937, "Roundness and shape of Mississippi River sands." Journal of Geology, v. 45, p. 225-267.

Sambrook-Smith, G. H., and R. I. Ferguson, 1995, "The gravel-sand transition along river channels." Journal of Sedimentary Research, v. A65, no. 2, p. 423-430.

Simms, A. R., 2001. Downstream fining along the South Canadian River. Unpublished Bachelor's Thesis, Oklahoma State University School of Geology, Advised by Dr. Stanley T. Paxton, 17 p.

Sternberg H., 1875, "Untersuchungen uber Langen- und Querprofil geschiebefuhrender Flusse." Zeitschrift fur Bauwesen, v. 25, p. 483-506.

Texas Bureau of Economic Geology, 1992. Geologic Map of Texas. 4 sheets.

Tortorelli, R.L., "Floods and Droughts: Oklahoma." In *National Water Summary 1988-89*, U. S. Geological Survey, Water Supply Paper 2375.

U. S. Geological Survey NWISWeb, http://waterdata.usgs.gov/usa/nwis/nwis.

U. S. Waterways Experiment Station, 1935. Studies of River Bed Materials and their Movement: with Special Reference to the Lower Mississippi River. 161 p.

Ward, P. A., III, and B. J. Carter, 1999, "Rates of stream incision in the middle part of the Arkansas River basin based on late Tertiary to mid-Pleistocene volcanic ash." Geomorphology, v. 27, p. 205-228.

Wilcock, P. R., 1993, "Critical shear stress of natural sediments." Journal of Hydraulic Engineering, v. 119, p. 491-505.

APPENDICES

APPENDIX A

RAW SIEVE ANALYSIS DATA

		01 - Logan, New Mexico									
Sieve Size		1		2		3		4		5	
US Standard	ϕ	Mass (g)	%	Mass (g)	%	Mass (g)	%	Mass (g)	%	Mass (g)	%
US1	-4.64	0	0.00	0	0.00	0	0.00	0	0.00	21	1.94
US5/8	-4.00	17	1.25	8	0.59	5	0.40	86	7.87	177	16.34
US1/2	-3.64	38	2.79	53	3.92	37	2.99	69	6.31	11	1.02
US5/16	-3.00	133	9.75	206	15.25	187	15.12	181	16.56	298	27.52
US1/4	-2.66	71	5.21	92	6.81	84	6.79	79	7.23	101	9.33
US4	-2.25	105	7.70	111	8.22	117	9.46	83	7.59	94	8.68
US5	-2.00	64	4.69	58	4.29	52	4.20	47	4.30	32	2.95
US6	-1.75	58	4.25	61	4.52	53	4.28	40	3.66	27	2.49
US8	-1.25	88	6.45	100	7.40	84	6.79	60	5.49	32	2.95
US10	-1.00	33	2.42	40	2.96	29	2.34	21	1.92	11	1.02
US12	-0.75	31	2.27	39	2.89	30	2.43	21	1.92	9	0.83
US14	-0.50	28	2.05	39	2.89	30	2.43	18	1.65	9	0.83
US16	-0.24	29	2.13	32	2.37	26	2.10	20	1.83	7	0.65
US18	0.00	26	1.91	23	1.70	19	1.54	13	1.19	5	0.46
US20	0.23	22	1.61	18	1.33	16	1.29	11	1.01	5	0.46
US25	0.49	42	3.08	29	2.15	27	2.18	21	1.92	10	0.92
US30	0.74	37	2.71	19	1.41	20	1.62	14	1.28	8	0.74
US35	1.00	52	3.81	29	2.15	33	2.67	26	2.38	22	2.03
US40	1.23	60	4.40	32	2.37	36	2.91	27	2.47	26	2.40
US50	1.76	167	12.24	101	7.48	105	8.49	76	6.95	64	5.91
US60	2.00	110	8.06	86	6.37	84	6.79	65	5.95	40	3.69
US70	2.24	70	5.13	70	5.18	65	5.25	49	4.48	33	3.05
US80	2.50	29	2.13	34	2.52	31	2.51	20	1.83	15	1.39
US100	2.75	21	1.54	27	2.00	26	2.10	16	1.46	13	1.20
US120	3.00	12	0.88	16	1.18	16	1.29	10	0.91	7	0.65
US140	3.25	5	0.37	7	0.52	6	0.49	4	0.37	2	0.18
US170	3.51	4	0.29	5	0.37	5	0.40	3	0.27	1	0.09
US200	3.74	3	0.22	5	0.37	4	0.32	3	0.27	0	0.00
US230	4.00	1	0.07	2	0.15	2	0.16	1	0.09	0	0.00
US325	4.47	2	0.15	3	0.22	3	0.24	2	0.18	1	0.09
US400	4.72	1	0.07	0	0.00	0	0.00	1	0.09	0	0.00
PAN	—	5	0.37	6	0.44	5	0.40	6	0.55	2	0.18
	Totals	**1364**	**100**	**1351**	**100**	**1237**	**100**	**1093**	**100**	**1083**	**100**

		02 - Boys Ranch, Texas							
Sieve Size		1		2		3		4	
US Standard	ϕ	Mass (g)	%	Mass (g)	%	Mass (g)	%	Mass (g)	%
US1	-4.64	0	0.00	0	0.00	0	0.00	0	0.00
US5/8	-4.00	17	0.99	44	2.46	30	1.78	36	2.08
US1/2	-3.64	33	1.92	45	2.52	45	2.67	34	1.96
US5/16	-3.00	75	4.36	204	11.42	170	10.08	112	6.46
US1/4	-2.66	51	2.96	99	5.54	73	4.33	92	5.31
US4	-2.25	77	4.47	112	6.27	108	6.41	126	7.27
US5	-2.00	52	3.02	54	3.02	47	2.79	67	3.87
US6	-1.75	55	3.20	44	2.46	46	2.73	66	3.81
US8	-1.25	113	6.57	76	4.26	69	4.09	76	4.39
US10	-1.00	56	3.25	28	1.57	30	1.78	37	2.14
US12	-0.75	64	3.72	26	1.46	30	1.78	76	4.39
US14	-0.50	86	5.00	30	1.68	39	2.31	46	2.65
US16	-0.24	88	5.11	34	1.90	39	2.31	47	2.71
US18	0.00	74	4.30	33	1.85	38	2.25	43	2.48
US20	0.23	62	3.60	36	2.02	36	2.14	42	2.42
US25	0.49	112	6.51	92	5.15	80	4.74	89	5.14
US30	0.74	88	5.11	108	6.05	78	4.63	95	5.48
US35	1.00	99	5.75	122	6.83	96	5.69	122	7.04
US40	1.23	92	5.35	116	6.49	93	5.52	117	6.75
US50	1.76	175	10.17	203	11.37	203	12.04	149	8.60
US60	2.00	88	5.11	100	5.60	119	7.06	55	3.17
US70	2.24	60	3.49	67	3.75	75	4.45	38	2.19
US80	2.50	31	1.80	31	1.74	38	2.25	28	1.62
US100	2.75	24	1.39	28	1.57	32	1.90	27	1.56
US120	3.00	17	0.99	20	1.12	24	1.42	35	2.02
US140	3.25	7	0.41	8	0.45	10	0.59	17	0.98
US170	3.51	5	0.29	6	0.34	7	0.42	15	0.87
US200	3.74	4	0.23	5	0.28	6	0.36	13	0.75
US230	4.00	2	0.12	2	0.11	3	0.18	8	0.46
US325	4.47	4	0.23	4	0.22	5	0.30	9	0.52
US400	4.72	1	0.06	1	0.06	3	0.18	3	0.17
PAN	—	9	0.52	8	0.45	14	0.83	13	0.75
	Totals	**1721**	**100**	**1786**	**100**	**1686**	**100**	**1733**	**100**

				03 - Highway 87, Texas					
Sieve Size				1		2		3	
US Standard	Wentworth	mm	ϕ	Mass (g)	%	Mass (g)	%	Mass (g)	%
US1	Pebble	25.0000	-4.64	0	0.00	0	0.00	0	0.00
US5/8		16.0000	-4.00	0	0.00	0	0.00	0	0.00
US1/2		12.5000	-3.64	0	0.00	0	0.00	6	0.43
US5/16		8.0000	-3.00	0	0.00	0	0.00	14	1.00
US1/4		6.3000	-2.66	0	0.00	0	0.00	16	1.15
US4		4.7500	-2.25	2	0.16	0	0.00	17	1.22
US5		4.0000	-2.00	0	0.00	0	0.00	10	0.72
US6	Granule	3.3600	-1.75	0	0.00	0	0.00	10	0.72
US8		2.3800	-1.25	1	0.08	0	0.00	21	1.51
US10		2.0000	-1.00	1	0.08	0	0.00	9	0.65
US12	VC Sand	1.6800	-0.75	1	0.08	0	0.00	9	0.65
US14		1.4100	-0.50	2	0.16	0	0.00	13	0.93
US16		1.1800	-0.24	2	0.16	0	0.00	15	1.08
US18		1.0000	0.00	4	0.31	0	0.00	15	1.08
US20	C Sand	0.8500	0.23	6	0.47	2	0.14	15	1.08
US25		0.7100	0.49	26	2.02	5	0.34	32	2.30
US30		0.6000	0.74	47	3.66	10	0.69	38	2.73
US35		0.5000	1.00	86	6.69	39	2.67	61	4.38
US40	M Sand	0.4250	1.23	120	9.34	81	5.56	98	7.03
US50		0.2950	1.76	312	24.28	378	25.93	355	25.47
US60		0.2500	2.00	199	15.49	370	25.38	265	19.01
US70	F Sand	0.2120	2.24	144	11.21	200	13.72	171	12.27
US80		0.1770	2.50	106	8.25	123	8.44	89	6.38
US100		0.1490	2.75	95	7.39	94	6.45	57	4.09
US120		0.1250	3.00	83	6.46	75	5.14	29	2.08
US140	VF Sand	0.1050	3.25	22	1.71	26	1.78	8	0.57
US170		0.0880	3.51	10	0.78	17	1.17	5	0.36
US200		0.0750	3.74	6	0.47	14	0.96	5	0.36
US230		0.0625	4.00	2	0.16	6	0.41	2	0.14
US325	C Silt	0.0450	4.47	3	0.23	9	0.62	4	0.29
US400		0.0380	4.72	0	0.00	1	0.07	0	0.00
PAN	M Silt - Clay	—	—	5	0.39	8	0.55	5	0.36
			Totals	**1285**	**100**	**1458**	**100**	**1394**	**100**

				04 - Highway 70, Texas					
Sieve Size				**1**		**2**		**3**	
US Standard	**Wentworth**	**mm**	**ϕ**	**Mass (g)**	**%**	**Mass (g)**	**%**	**Mass (g)**	**%**
US1	Pebble	25.0000	-4.64	0	0.00	0	0.00	0	0.00
US5/8		16.0000	-4.00	0	0.00	0	0.00	0	0.00
US1/2		12.5000	-3.64	0	0.00	0	0.00	0	0.00
US5/16		8.0000	-3.00	0	0.00	6	0.53	7	0.62
US1/4		6.3000	-2.66	0	0.00	1	0.09	1	0.09
US4		4.7500	-2.25	0	0.00	0	0.00	0	0.00
US5		4.0000	-2.00	0	0.00	0	0.00	2	0.18
US6	Granule	3.3600	-1.75	1	0.10	0	0.00	1	0.09
US8		2.3800	-1.25	0	0.00	0	0.00	2	0.18
US10		2.0000	-1.00	1	0.10	0	0.00	0	0.00
US12	VC Sand	1.6800	-0.75	0	0.00	1	0.09	0	0.00
US14		1.4100	-0.50	0	0.00	0	0.00	1	0.09
US16		1.1800	-0.24	0	0.00	1	0.09	3	0.26
US18		1.0000	0.00	2	0.19	3	0.26	4	0.35
US20	C Sand	0.8500	0.23	4	0.39	4	0.35	6	0.53
US25		0.7100	0.49	21	2.03	21	1.84	27	2.37
US30		0.6000	0.74	45	4.35	52	4.56	59	5.19
US35		0.5000	1.00	118	11.40	129	11.32	144	12.66
US40	M Sand	0.4250	1.23	174	16.81	230	20.18	228	20.05
US50		0.2950	1.76	335	32.37	394	34.56	383	33.69
US60		0.2500	2.00	155	14.98	154	13.51	130	11.43
US70	F Sand	0.2120	2.24	91	8.79	70	6.14	67	5.89
US80		0.1770	2.50	37	3.57	31	2.72	29	2.55
US100		0.1490	2.75	30	2.90	24	2.11	23	2.02
US120		0.1250	3.00	13	1.26	12	1.05	12	1.06
US140	VF Sand	0.1050	3.25	3	0.29	3	0.26	3	0.26
US170		0.0880	3.51	2	0.19	2	0.18	2	0.18
US200		0.0750	3.74	1	0.10	1	0.09	1	0.09
US230		0.0625	4.00	0	0.00	0	0.00	0	0.00
US325	C Silt	0.0450	4.47	1	0.10	1	0.09	1	0.09
US400		0.0380	4.72	0	0.00	0	0.00	0	0.00
PAN	M Silt - Clay	—	—	1	0.10	0	0.00	1	0.09
			Totals	**1035**	**100**	**1140**	**100**	**1137**	**100**

				05 - Canadian, Texas					
Sieve Size				1		2		3	
US Standard	Wentworth	mm	ϕ	Mass (g)	%	Mass (g)	%	Mass (g)	%
US1	Pebble	25.0000	-4.64	0	0.00	0	0.00	0	0.00
US5/8		16.0000	-4.00	0	0.00	0	0.00	0	0.00
US1/2		12.5000	-3.64	0	0.00	0	0.00	0	0.00
US5/16		8.0000	-3.00	0	0.00	3	0.27	0	0.00
US1/4		6.3000	-2.66	0	0.00	0	0.00	0	0.00
US4		4.7500	-2.25	2	0.27	3	0.27	4	0.51
US5		4.0000	-2.00	0	0.00	0	0.00	1	0.13
US6	Granule	3.3600	-1.75	0	0.00	2	0.18	0	0.00
US8		2.3800	-1.25	2	0.27	6	0.54	3	0.38
US10		2.0000	-1.00	2	0.27	4	0.36	4	0.51
US12	VC Sand	1.6800	-0.75	2	0.27	7	0.63	3	0.38
US14		1.4100	-0.50	4	0.53	14	1.25	5	0.64
US16		1.1800	-0.24	7	0.94	22	1.97	7	0.89
US18		1.0000	0.00	7	0.94	24	2.14	8	1.02
US20	C Sand	0.8500	0.23	7	0.94	23	2.06	9	1.15
US25		0.7100	0.49	14	1.87	47	4.20	25	3.19
US30		0.6000	0.74	14	1.87	45	4.02	30	3.83
US35		0.5000	1.00	35	4.68	79	7.06	47	5.99
US40	M Sand	0.4250	1.23	52	6.95	102	9.12	66	8.42
US50		0.2950	1.76	195	26.07	301	26.90	226	28.83
US60		0.2500	2.00	184	24.60	213	19.03	170	21.68
US70	F Sand	0.2120	2.24	108	14.44	111	9.92	86	10.97
US80		0.1770	2.50	47	6.28	43	3.84	36	4.59
US100		0.1490	2.75	36	4.81	35	3.13	29	3.70
US120		0.1250	3.00	18	2.41	19	1.70	16	2.04
US140	VF Sand	0.1050	3.25	5	0.67	6	0.54	4	0.51
US170		0.0880	3.51	3	0.40	4	0.36	3	0.38
US200		0.0750	3.74	2	0.27	3	0.27	2	0.26
US230		0.0625	4.00	1	0.13	1	0.09	0	0.00
US325	C Silt	0.0450	4.47	1	0.13	1	0.09	0	0.00
US400		0.0380	4.72	0	0.00	0	0.00	0	0.00
PAN	M Silt - Clay	—	—	0	0.00	1	0.09	0	0.00
			Totals	**748**	**100**	**1119**	**100**	**784**	**100**

				06 - Roll, Oklahoma					
Sieve Size				1		2		3	
US Standard	Wentworth	mm	ϕ	Mass (g)	%	Mass (g)	%	Mass (g)	%
US1	Pebble	25.0000	-4.64	0	0.00	0	0.00	0	0.00
US5/8		16.0000	-4.00	33	2.64	0	0.00	9	0.71
US1/2		12.5000	-3.64	9	0.72	15	1.26	11	0.86
US5/16		8.0000	-3.00	59	4.72	38	3.18	38	2.98
US1/4		6.3000	-2.66	38	3.04	40	3.35	36	2.82
US4		4.7500	-2.25	29	2.32	48	4.02	40	3.13
US5		4.0000	-2.00	14	1.12	25	2.09	18	1.41
US6	Granule	3.3600	-1.75	12	0.96	22	1.84	19	1.49
US8		2.3800	-1.25	20	1.60	37	3.10	29	2.27
US10		2.0000	-1.00	9	0.72	12	1.00	14	1.10
US12	VC Sand	1.6800	-0.75	8	0.64	13	1.09	14	1.10
US14		1.4100	-0.50	7	0.56	18	1.51	20	1.57
US16		1.1800	-0.24	6	0.48	20	1.67	20	1.57
US18		1.0000	0.00	5	0.40	19	1.59	18	1.41
US20	C Sand	0.8500	0.23	5	0.40	19	1.59	15	1.18
US25		0.7100	0.49	10	0.80	36	3.01	28	2.19
US30		0.6000	0.74	10	0.80	27	2.26	24	1.88
US35		0.5000	1.00	24	1.92	38	3.18	34	2.66
US40	M Sand	0.4250	1.23	31	2.48	39	3.26	38	2.98
US50		0.2950	1.76	153	12.24	137	11.46	150	11.76
US60		0.2500	2.00	268	21.44	178	14.90	266	20.85
US70	F Sand	0.2120	2.24	196	15.68	153	12.80	160	12.54
US80		0.1770	2.50	99	7.92	92	7.70	95	7.45
US100		0.1490	2.75	82	6.56	72	6.03	72	5.64
US120		0.1250	3.00	66	5.28	52	4.35	56	4.39
US140	VF Sand	0.1050	3.25	25	2.00	18	1.51	20	1.57
US170		0.0880	3.51	14	1.12	12	1.00	14	1.10
US200		0.0750	3.74	11	0.88	9	0.75	12	0.94
US230		0.0625	4.00	3	0.24	3	0.25	3	0.24
US325	C Silt	0.0450	4.47	3	0.24	2	0.17	2	0.16
US400		0.0380	4.72	0	0.00	0	0.00	0	0.00
PAN	M Silt - Clay	—	—	1	0.08	1	0.08	1	0.08
			Totals	**1250**	**100**	**1195**	**100**	**1276**	**100**

		07 - Camargo, Oklahoma							
Sieve Size		1		2		3		4	
US Standard	ϕ	Mass (g)	%	Mass (g)	%	Mass (g)	%	Mass (g)	%
US1	-4.64	0	0.00	0	0.00	0	0.00	0	0.00
US5/8	-4.00	0	0.00	0	0.00	0	0.00	3	0.27
US1/2	-3.64	2	0.16	0	0.00	0	0.00	0	0.00
US5/16	-3.00	2	0.16	0	0.00	0	0.00	1	0.09
US1/4	-2.66	0	0.00	0	0.00	0	0.00	4	0.36
US4	-2.25	2	0.16	0	0.00	2	0.19	3	0.27
US5	-2.00	1	0.08	0	0.00	0	0.00	2	0.18
US6	-1.75	1	0.08	0	0.00	0	0.00	2	0.18
US8	-1.25	4	0.32	0	0.00	0	0.00	4	0.36
US10	-1.00	3	0.24	0	0.00	1	0.10	2	0.18
US12	-0.75	3	0.24	0	0.00	1	0.10	3	0.27
US14	-0.50	6	0.49	5	0.40	1	0.10	5	0.45
US16	-0.24	8	0.65	2	0.16	2	0.19	7	0.63
US18	0.00	9	0.73	3	0.24	3	0.29	8	0.72
US20	0.23	10	0.81	4	0.32	4	0.39	11	0.99
US25	0.49	27	2.19	14	1.11	11	1.06	32	2.87
US30	0.74	30	2.44	19	1.50	13	1.25	41	3.68
US35	1.00	70	5.69	53	4.20	35	3.38	86	7.72
US40	1.23	101	8.20	71	5.62	46	4.44	108	9.69
US50	1.76	301	24.45	220	17.42	141	13.60	261	23.43
US60	2.00	163	13.24	151	11.96	97	9.35	130	11.67
US70	2.24	99	8.04	97	7.68	91	8.78	71	6.37
US80	2.50	72	5.85	91	7.21	79	7.62	36	3.23
US100	2.75	105	8.53	114	9.03	138	13.31	51	4.58
US120	3.00	102	8.29	179	14.17	154	14.85	76	6.82
US140	3.25	38	3.09	78	6.18	61	5.88	46	4.13
US170	3.51	25	2.03	68	5.38	51	4.92	41	3.68
US200	3.74	19	1.54	51	4.04	44	4.24	37	3.32
US230	4.00	8	0.65	16	1.27	18	1.74	14	1.26
US325	4.47	11	0.89	20	1.58	27	2.60	19	1.71
US400	4.72	3	0.24	3	0.24	6	0.58	4	0.36
PAN	—	6	0.49	4	0.32	11	1.06	6	0.54
	Totals	**1231**	**100**	**1263**	**100**	**1037**	**100**	**1114**	**100**

		08 - Taloga, Oklahoma							
Sieve Size		**1**		**2**		**3**		**4**	
US Standard	**ϕ**	**Mass (g)**	**%**	**Mass (g)**	**%**	**Mass (g)**	**%**	**Mass (g)**	**%**
US1	-4.64	0	0.00	0	0.00	0	0.00	0	0.00
US5/8	-4.00	143	10.65	68	5.92	52	4.65	0	0.00
US1/2	-3.64	94	7.00	22	1.92	41	3.66	0	0.00
US5/16	-3.00	147	10.95	119	10.37	62	5.54	0	0.00
US1/4	-2.66	45	3.35	51	4.44	14	1.25	0	0.00
US4	-2.25	49	3.65	35	3.05	22	1.97	17	1.67
US5	-2.00	16	1.19	14	1.22	8	0.71	3	0.29
US6	-1.75	15	1.12	11	0.96	8	0.71	2	0.20
US8	-1.25	20	1.49	12	1.05	8	0.71	3	0.29
US10	-1.00	5	0.37	3	0.26	2	0.18	0	0.00
US12	-0.75	5	0.37	3	0.26	2	0.18	0	0.00
US14	-0.50	5	0.37	3	0.26	2	0.18	1	0.10
US16	-0.24	6	0.45	2	0.17	1	0.09	2	0.20
US18	0.00	4	0.30	2	0.17	1	0.09	1	0.10
US20	0.23	4	0.30	2	0.17	1	0.09	3	0.29
US25	0.49	10	0.74	6	0.52	3	0.27	4	0.39
US30	0.74	8	0.60	5	0.44	2	0.18	3	0.29
US35	1.00	21	1.56	20	1.74	7	0.63	10	0.98
US40	1.23	22	1.64	27	2.35	9	0.80	13	1.27
US50	1.76	76	5.66	100	8.71	53	4.74	89	8.72
US60	2.00	125	9.31	125	10.89	196	17.52	222	21.74
US70	2.24	154	11.47	153	13.33	186	16.62	269	26.35
US80	2.50	95	7.07	97	8.45	129	11.53	130	12.73
US100	2.75	82	6.11	84	7.32	108	9.65	108	10.58
US120	3.00	57	4.24	59	5.14	78	6.97	66	6.46
US140	3.25	22	1.64	22	1.92	26	2.32	19	1.86
US170	3.51	21	1.56	19	1.66	21	1.88	12	1.18
US200	3.74	11	0.82	24	2.09	23	2.06	0	0.00
US230	4.00	33	2.46	14	1.22	13	1.16	21	2.06
US325	4.47	28	2.08	27	2.35	24	2.14	12	1.18
US400	4.72	8	0.60	7	0.61	6	0.54	4	0.39
PAN	—	12	0.89	12	1.05	11	0.98	7	0.69
	Totals	**1343**	**100**	**1148**	**100**	**1119**	**100**	**1021**	**100**

Sieve Size				09 - Fay, Oklahoma					
				1		2		3	
US Standard	Wentworth	mm	ϕ	Mass (g)	%	Mass (g)	%	Mass (g)	%
US1	Pebble	25.0000	-4.64	0	0.00	0	0.00	0	0.00
US5/8		16.0000	-4.00	0	0.00	0	0.00	0	0.00
US1/2		12.5000	-3.64	0	0.00	0	0.00	0	0.00
US5/16		8.0000	-3.00	0	0.00	0	0.00	0	0.00
US1/4		6.3000	-2.66	0	0.00	0	0.00	0	0.00
US4		4.7500	-2.25	0	0.00	2	0.21	0	0.00
US5		4.0000	-2.00	0	0.00	0	0.00	0	0.00
US6	Granule	3.3600	-1.75	0	0.00	0	0.00	0	0.00
US8		2.3800	-1.25	0	0.00	1	0.11	0	0.00
US10		2.0000	-1.00	0	0.00	0	0.00	0	0.00
US12	VC Sand	1.6800	-0.75	0	0.00	0	0.00	0	0.00
US14		1.4100	-0.50	0	0.00	1	0.11	0	0.00
US16		1.1800	-0.24	0	0.00	0	0.00	0	0.00
US18		1.0000	0.00	0	0.00	0	0.00	0	0.00
US20	C Sand	0.8500	0.23	0	0.00	0	0.00	0	0.00
US25		0.7100	0.49	0	0.00	0	0.00	0	0.00
US30		0.6000	0.74	0	0.00	0	0.00	1	0.13
US35		0.5000	1.00	0	0.00	0	0.00	0	0.00
US40	M Sand	0.4250	1.23	1	0.12	2	0.21	0	0.00
US50		0.2950	1.76	30	3.66	35	3.76	23	2.94
US60		0.2500	2.00	143	17.44	174	18.69	110	14.08
US70	F Sand	0.2120	2.24	223	27.20	230	24.70	216	27.66
US80		0.1770	2.50	141	17.20	119	12.78	118	15.11
US100		0.1490	2.75	111	13.54	101	10.85	110	14.08
US120		0.1250	3.00	79	9.63	87	9.34	84	10.76
US140	VF Sand	0.1050	3.25	28	3.41	38	4.08	32	4.10
US170		0.0880	3.51	20	2.44	37	3.97	26	3.33
US200		0.0750	3.74	18	2.20	36	3.87	24	3.07
US230		0.0625	4.00	7	0.85	15	1.61	9	1.15
US325	C Silt	0.0450	4.47	10	1.22	27	2.90	15	1.92
US400		0.0380	4.72	3	0.37	7	0.75	4	0.51
PAN	M Silt - Clay	—	—	6	0.73	19	2.04	9	1.15
			Totals	**820**	**100**	**931**	**100**	**781**	**100**

				10 - Bridgeport, Oklahoma					
Sieve Size				**1**		**2**		**3**	
US Standard	**Wentworth**	**mm**	**ϕ**	**Mass (g)**	**%**	**Mass (g)**	**%**	**Mass (g)**	**%**
US1	Pebble	25.0000	-4.64	0	0.00	0	0.00	0	0.00
US5/8		16.0000	-4.00	0	0.00	0	0.00	0	0.00
US1/2		12.5000	-3.64	0	0.00	0	0.00	0	0.00
US5/16		8.0000	-3.00	0	0.00	0	0.00	0	0.00
US1/4		6.3000	-2.66	0	0.00	0	0.00	0	0.00
US4		4.7500	-2.25	0	0.00	0	0.00	0	0.00
US5		4.0000	-2.00	0	0.00	0	0.00	0	0.00
US6	Granule	3.3600	-1.75	0	0.00	0	0.00	0	0.00
US8		2.3800	-1.25	0	0.00	0	0.00	0	0.00
US10		2.0000	-1.00	0	0.00	0	0.00	0	0.00
US12	VC Sand	1.6800	-0.75	0	0.00	0	0.00	0	0.00
US14		1.4100	-0.50	0	0.00	0	0.00	0	0.00
US16		1.1800	-0.24	0	0.00	0	0.00	0	0.00
US18		1.0000	0.00	0	0.00	0	0.00	0	0.00
US20	C Sand	0.8500	0.23	0	0.00	0	0.00	0	0.00
US25		0.7100	0.49	0	0.00	0	0.00	0	0.00
US30		0.6000	0.74	0	0.00	0	0.00	0	0.00
US35		0.5000	1.00	0	0.00	2	0.21	0	0.00
US40	M Sand	0.4250	1.23	2	0.28	5	0.52	2	0.22
US50		0.2950	1.76	50	6.93	180	18.85	42	4.61
US60		0.2500	2.00	201	27.84	183	19.16	266	29.17
US70	F Sand	0.2120	2.24	187	25.90	257	26.91	208	22.81
US80		0.1770	2.50	77	10.66	96	10.05	113	12.39
US100		0.1490	2.75	60	8.31	73	7.64	83	9.10
US120		0.1250	3.00	40	5.54	48	5.03	70	7.68
US140	VF Sand	0.1050	3.25	20	2.77	13	1.36	33	3.62
US170		0.0880	3.51	20	2.77	31	3.25	29	3.18
US200		0.0750	3.74	24	3.32	26	2.72	10	1.10
US230		0.0625	4.00	12	1.66	11	1.15	31	3.40
US325	C Silt	0.0450	4.47	18	2.49	18	1.88	17	1.86
US400		0.0380	4.72	5	0.69	5	0.52	3	0.33
PAN	M Silt - Clay	—	—	6	0.83	7	0.73	5	0.55
			Totals	**722**	**100**	**955**	**100**	**912**	**100**

		11 - Union City, Oklahoma							
Sieve Size		1		2		3		4	
US Standard	ϕ	Mass (g)	%	Mass (g)	%	Mass (g)	%	Mass (g)	%
US1	-4.64	0	0.00	0	0.00	0	0.00	0	0.00
US5/8	-4.00	0	0.00	0	0.00	0	0.00	0	0.00
US1/2	-3.64	0	0.00	0	0.00	0	0.00	0	0.00
US5/16	-3.00	0	0.00	0	0.00	0	0.00	0	0.00
US1/4	-2.66	0	0.00	0	0.00	0	0.00	0	0.00
US4	-2.25	0	0.00	0	0.00	0	0.00	0	0.00
US5	-2.00	0	0.00	0	0.00	0	0.00	0	0.00
US6	-1.75	0	0.00	0	0.00	0	0.00	0	0.00
US8	-1.25	0	0.00	0	0.00	0	0.00	0	0.00
US10	-1.00	0	0.00	0	0.00	0	0.00	0	0.00
US12	-0.75	0	0.00	0	0.00	0	0.00	0	0.00
US14	-0.50	0	0.00	0	0.00	0	0.00	0	0.00
US16	-0.24	0	0.00	0	0.00	0	0.00	0	0.00
US18	0.00	0	0.00	0	0.00	0	0.00	0	0.00
US20	0.23	0	0.00	0	0.00	0	0.00	0	0.00
US25	0.49	0	0.00	0	0.00	0	0.00	0	0.00
US30	0.74	0	0.00	0	0.00	0	0.00	0	0.00
US35	1.00	1	0.15	0	0.00	0	0.00	5	0.56
US40	1.23	0	0.00	0	0.00	0	0.00	12	1.34
US50	1.76	4	0.58	3	0.52	9	1.51	76	8.50
US60	2.00	17	2.48	18	3.10	41	6.89	125	13.98
US70	2.24	51	7.43	56	9.64	106	17.82	133	14.88
US80	2.50	71	10.35	60	10.33	111	18.66	103	11.52
US100	2.75	86	12.54	71	12.22	101	16.97	109	12.19
US120	3.00	133	19.39	101	17.38	98	16.47	108	12.08
US140	3.25	72	10.50	56	9.64	38	6.39	44	4.92
US170	3.51	92	13.41	67	11.53	32	5.38	46	5.15
US200	3.74	80	11.66	65	11.19	28	4.71	50	5.59
US230	4.00	25	3.64	25	4.30	10	1.68	17	1.90
US325	4.47	35	5.10	34	5.85	12	2.02	31	3.47
US400	4.72	6	0.87	7	1.20	3	0.50	7	0.78
PAN	—	13	1.90	18	3.10	6	1.01	28	3.13
	Totals	**686**	**100**	**581**	**100**	**595**	**100**	**894**	**100**

		12 - Norman, Oklahoma							
Sieve Size		1		2		3		4	
US Standard	φ	Mass (g)	%	Mass (g)	%	Mass (g)	%	Mass (g)	%
US1	-4.64	0	0.00	0	0.00	0	0.00	0	0.00
US5/8	-4.00	0	0.00	0	0.00	0	0.00	0	0.00
US1/2	-3.64	0	0.00	0	0.00	0	0.00	0	0.00
US5/16	-3.00	0	0.00	0	0.00	0	0.00	0	0.00
US1/4	-2.66	0	0.00	0	0.00	0	0.00	0	0.00
US4	-2.25	0	0.00	0	0.00	0	0.00	0	0.00
US5	-2.00	0	0.00	0	0.00	0	0.00	0	0.00
US6	-1.75	0	0.00	0	0.00	0	0.00	0	0.00
US8	-1.25	0	0.00	0	0.00	0	0.00	0	0.00
US10	-1.00	0	0.00	0	0.00	0	0.00	0	0.00
US12	-0.75	0	0.00	0	0.00	0	0.00	0	0.00
US14	-0.50	0	0.00	0	0.00	0	0.00	0	0.00
US16	-0.24	0	0.00	0	0.00	0	0.00	0	0.00
US18	0.00	0	0.00	0	0.00	0	0.00	0	0.00
US20	0.23	0	0.00	0	0.00	0	0.00	0	0.00
US25	0.49	0	0.00	1	0.13	1	0.12	0	0.00
US30	0.74	1	0.13	3	0.39	2	0.24	0	0.00
US35	1.00	2	0.26	6	0.78	5	0.61	0	0.00
US40	1.23	4	0.52	13	1.68	10	1.21	1	0.12
US50	1.76	24	3.15	71	9.20	53	6.42	15	1.76
US60	2.00	53	6.96	128	16.58	86	10.42	24	2.81
US70	2.24	107	14.04	145	18.78	118	14.30	110	12.90
US80	2.50	121	15.88	100	12.95	105	12.73	179	20.98
US100	2.75	138	18.11	84	10.88	110	13.33	226	26.49
US120	3.00	139	18.24	79	10.23	139	16.85	123	14.42
US140	3.25	52	6.82	36	4.66	63	7.64	33	3.87
US170	3.51	37	4.86	31	4.02	50	6.06	57	6.68
US200	3.74	36	4.72	32	4.15	41	4.97	39	4.57
US230	4.00	13	1.71	12	1.55	13	1.58	13	1.52
US325	4.47	20	2.62	17	2.20	17	2.06	17	1.99
US400	4.72	2	0.26	1	0.13	2	0.24	5	0.59
PAN	—	13	1.71	13	1.68	10	1.21	11	1.29
	Totals	**762**	**100**	**772**	**100**	**825**	**100**	**853**	**100**

		13 - Purcell, Oklahoma							
Sieve Size		**1**		**2**		**3**		**4**	
US Standard	**ϕ**	**Mass (g)**	**%**	**Mass (g)**	**%**	**Mass (g)**	**%**	**Mass (g)**	**%**
US1	-4.64	0	0.00	0	0.00	0	0.00	9	0.78
US5/8	-4.00	0	0.00	0	0.00	0	0.00	0	0.00
US1/2	-3.64	0	0.00	0	0.00	0	0.00	9	0.78
US5/16	-3.00	0	0.00	0	0.00	0	0.00	7	0.61
US1/4	-2.66	0	0.00	0	0.00	0	0.00	4	0.35
US4	-2.25	0	0.00	0	0.00	0	0.00	4	0.35
US5	-2.00	0	0.00	0	0.00	0	0.00	3	0.26
US6	-1.75	0	0.00	0	0.00	0	0.00	4	0.35
US8	-1.25	0	0.00	0	0.00	0	0.00	10	0.87
US10	-1.00	0	0.00	0	0.00	0	0.00	3	0.26
US12	-0.75	0	0.00	0	0.00	0	0.00	4	0.35
US14	-0.50	0	0.00	2	0.23	0	0.00	5	0.43
US16	-0.24	0	0.00	0	0.00	0	0.00	5	0.43
US18	0.00	0	0.00	0	0.00	0	0.00	5	0.43
US20	0.23	0	0.00	0	0.00	0	0.00	4	0.35
US25	0.49	0	0.00	0	0.00	2	0.21	9	0.78
US30	0.74	2	0.20	1	0.11	4	0.42	9	0.78
US35	1.00	8	0.82	3	0.34	5	0.53	23	2.00
US40	1.23	18	1.84	10	1.13	13	1.37	35	3.04
US50	1.76	136	13.89	90	10.14	100	10.55	202	17.55
US60	2.00	296	30.23	264	29.73	297	31.33	345	29.97
US70	2.24	220	22.47	236	26.58	216	22.78	174	15.12
US80	2.50	117	11.95	112	12.61	105	11.08	90	7.82
US100	2.75	72	7.35	73	8.22	77	8.12	65	5.65
US120	3.00	44	4.49	45	5.07	46	4.85	41	3.56
US140	3.25	13	1.33	14	1.58	15	1.58	14	1.22
US170	3.51	10	1.02	10	1.13	12	1.27	12	1.04
US200	3.74	12	1.23	11	1.24	16	1.69	17	1.48
US230	4.00	7	0.72	5	0.56	10	1.05	10	0.87
US325	4.47	14	1.43	7	0.79	19	2.00	19	1.65
US400	4.72	4	0.41	2	0.23	5	0.53	3	0.26
PAN	---	6	0.61	3	0.34	6	0.63	7	0.61
	Totals	**979**	**100**	**888**	**100**	**948**	**100**	**1151**	**100**

				14 - Asher, Oklahoma					
Sieve Size				1		2		3	
US Standard	Wentworth	mm	ϕ	Mass (g)	%	Mass (g)	%	Mass (g)	%
US1	Pebble	25.0000	-4.64	0	0.00	0	0.00	0	0.00
US5/8		16.0000	-4.00	0	0.00	0	0.00	0	0.00
US1/2		12.5000	-3.64	0	0.00	0	0.00	0	0.00
US5/16		8.0000	-3.00	0	0.00	0	0.00	0	0.00
US1/4		6.3000	-2.66	0	0.00	0	0.00	0	0.00
US4		4.7500	-2.25	0	0.00	0	0.00	0	0.00
US5		4.0000	-2.00	0	0.00	0	0.00	0	0.00
US6	Granule	3.3600	-1.75	0	0.00	0	0.00	0	0.00
US8		2.3800	-1.25	0	0.00	0	0.00	0	0.00
US10		2.0000	-1.00	0	0.00	0	0.00	0	0.00
US12	VC Sand	1.6800	-0.75	0	0.00	0	0.00	0	0.00
US14		1.4100	-0.50	0	0.00	0	0.00	1	0.08
US16		1.1800	-0.24	0	0.00	1	0.08	1	0.08
US18		1.0000	0.00	1	0.09	0	0.00	0	0.00
US20	C Sand	0.8500	0.23	1	0.09	1	0.08	1	0.08
US25		0.7100	0.49	1	0.09	4	0.31	4	0.32
US30		0.6000	0.74	1	0.09	6	0.46	7	0.57
US35		0.5000	1.00	10	0.89	22	1.70	11	0.89
US40	M Sand	0.4250	1.23	24	2.13	43	3.33	52	4.22
US50		0.2950	1.76	241	21.35	242	18.75	286	23.21
US60		0.2500	2.00	429	38.00	479	37.10	394	31.98
US70	F Sand	0.2120	2.24	184	16.30	213	16.50	223	18.10
US80		0.1770	2.50	105	9.30	102	7.90	111	9.01
US100		0.1490	2.75	66	5.85	79	6.12	73	5.93
US120		0.1250	3.00	36	3.19	57	4.42	38	3.08
US140	VF Sand	0.1050	3.25	8	0.71	15	1.16	9	0.73
US170		0.0880	3.51	4	0.35	7	0.54	4	0.32
US200		0.0750	3.74	2	0.18	4	0.31	3	0.24
US230		0.0625	4.00	1	0.09	1	0.08	1	0.08
US325	C Silt	0.0450	4.47	5	0.44	3	0.23	3	0.24
US400		0.0380	4.72	2	0.18	1	0.08	1	0.08
PAN	M Silt - Clay	—	—	8	0.71	11	0.85	9	0.73
			Totals	1129	100	1291	100	1232	100

				15 - Calvin, Oklahoma					
Sieve Size				1		2		3	
US Standard	Wentworth	mm	ϕ	Mass (g)	%	Mass (g)	%	Mass (g)	%
US1	Pebble	25.0000	-4.64	0	0.00	0	0.00	0	0.00
US5/8		16.0000	-4.00	0	0.00	0	0.00	0	0.00
US1/2		12.5000	-3.64	0	0.00	0	0.00	0	0.00
US5/16		8.0000	-3.00	0	0.00	0	0.00	0	0.00
US1/4		6.3000	-2.66	0	0.00	0	0.00	0	0.00
US4		4.7500	-2.25	0	0.00	0	0.00	0	0.00
US5		4.0000	-2.00	0	0.00	0	0.00	0	0.00
US6	Granule	3.3600	-1.75	0	0.00	0	0.00	0	0.00
US8		2.3800	-1.25	0	0.00	0	0.00	0	0.00
US10		2.0000	-1.00	0	0.00	0	0.00	0	0.00
US12	VC Sand	1.6800	-0.75	0	0.00	0	0.00	0	0.00
US14		1.4100	-0.50	0	0.00	0	0.00	0	0.00
US16		1.1800	-0.24	0	0.00	0	0.00	0	0.00
US18		1.0000	0.00	0	0.00	0	0.00	0	0.00
US20	C Sand	0.8500	0.23	0	0.00	0	0.00	0	0.00
US25		0.7100	0.49	0	0.00	3	0.23	0	0.00
US30		0.6000	0.74	0	0.00	3	0.23	2	0.20
US35		0.5000	1.00	4	0.34	11	0.83	4	0.40
US40	M Sand	0.4250	1.23	8	0.68	28	2.12	10	1.00
US50		0.2950	1.76	82	6.93	205	15.51	72	7.21
US60		0.2500	2.00	394	33.31	482	36.46	186	18.62
US70	F Sand	0.2120	2.24	215	18.17	223	16.87	187	18.72
US80		0.1770	2.50	138	11.67	108	8.17	130	13.01
US100		0.1490	2.75	101	8.54	77	5.82	107	10.71
US120		0.1250	3.00	87	7.35	60	4.54	112	11.21
US140	VF Sand	0.1050	3.25	36	3.04	25	1.89	50	5.01
US170		0.0880	3.51	32	2.70	21	1.59	44	4.40
US200		0.0750	3.74	35	2.96	44	3.33	41	4.10
US230		0.0625	4.00	15	1.27	10	0.76	16	1.60
US325	C Silt	0.0450	4.47	23	1.94	14	1.06	24	2.40
US400		0.0380	4.72	5	0.42	3	0.23	5	0.50
PAN	M Silt - Clay	—	—	8	0.68	5	0.38	9	0.90
			Totals	**1183**	**100**	**1322**	**100**	**999**	**100**

APPENDIX B

PROCESSED SIEVE ANALYSIS DATA

				01 - Logan, New Mexico			02 - Boys Ranch, Texas			03 - Highway 87, Texas		
Screen Size				Average Distribution			Average Distribution			Average Distribution		
US Standard	Wentworth	ϕ	mm	Mass (g)	%	% coarser	Mass (g)	%	% coarser	Mass (g)	%	% coarser
US1	Pebble	-4.64	25.0000	4	0.39	0.39	0	0.00	0.00	0	0.00	0.00
US5/8		-4.00	16.0000	59	5.29	5.68	32	1.83	1.83	0	0.00	0.00
US1/2		-3.64	12.5000	42	3.41	9.08	39	2.27	4.09	2	0.14	0.14
US5/16		-3.00	8.0000	201	16.84	25.92	140	8.08	12.18	5	0.33	0.48
US1/4		-2.66	6.3000	85	7.07	32.99	79	4.54	16.71	5	0.38	0.86
US4		-2.25	4.7500	102	8.33	41.32	106	6.11	22.82	6	0.46	1.32
US5		-2.00	4.0000	51	4.09	45.41	55	3.17	25.99	3	0.24	1.56
US6	Granule	-1.75	3.3600	48	3.84	49.25	53	3.05	29.04	3	0.24	1.80
US8		-1.25	2.3800	73	5.82	55.07	84	4.82	33.87	7	0.53	2.33
US10		-1.00	2.0000	27	2.13	57.20	38	2.18	36.05	3	0.24	2.57
US12	VC Sand	-0.75	1.6800	26	2.07	59.27	49	2.83	38.88	3	0.24	2.81
US14		-0.50	1.4100	25	1.97	61.24	50	2.91	41.80	5	0.36	3.17
US16		-0.24	1.1800	23	1.81	63.05	52	3.01	44.81	6	0.41	3.58
US18		0.00	1.0000	17	1.36	64.41	47	2.72	47.53	6	0.46	4.04
US20	C Sand	0.23	0.8500	14	1.14	65.55	44	2.54	50.07	8	0.56	4.60
US25		0.49	0.7100	26	2.05	67.61	93	5.38	55.46	21	1.55	6.16
US30		0.74	0.6000	20	1.55	69.16	92	5.32	60.77	32	2.36	8.51
US35		1.00	0.5000	32	2.61	71.76	110	6.33	67.10	62	4.58	13.10
US40	M Sand	1.23	0.4250	36	2.91	74.67	105	6.03	73.13	100	7.31	20.40
US50		1.76	0.2950	103	8.21	82.89	183	10.54	83.67	348	25.22	45.63
US60		2.00	0.2500	77	6.17	89.06	91	5.24	88.91	278	19.96	65.59
US70	F Sand	2.24	0.2120	57	4.62	93.68	60	3.47	92.38	172	12.40	77.98
US80		2.50	0.1770	26	2.07	95.75	32	1.85	94.23	106	7.69	85.67
US100		2.75	0.1490	21	1.66	97.41	28	1.60	95.83	82	5.98	91.65
US120		3.00	0.1250	12	0.98	98.40	24	1.39	97.22	62	4.56	96.21
US140	VF Sand	3.25	0.1050	5	0.38	98.78	11	0.61	97.83	19	1.36	97.57
US170		3.51	0.0880	4	0.29	99.07	8	0.48	98.31	11	0.77	98.33
US200		3.74	0.0750	3	0.24	99.31	7	0.40	98.71	8	0.60	98.93
US230		4.00	0.0625	1	0.09	99.40	4	0.22	98.93	3	0.24	99.17
US325	C Silt	4.47	0.0450	2	0.18	99.58	6	0.32	99.25	5	0.38	99.54
US400		4.72	0.0380	0	0.03	99.61	2	0.12	99.36	0	0.02	99.57
PAN	M Silt - Clay	5.00	0.0313	5	0.39	100.00	11	0.64	100.00	6	0.43	100.00
			Totals	**1226**	**100**	**100**	**1732**	**100**	**100**	**1379**	**100**	**100**

				04 - Highway 70, Texas			05 - Canadian, Texas			06 - Roll, Oklahoma		
Screen Size				Average Distribution			Average Distribution			Average Distribution		
US Standard	Wentworth	ϕ	mm	Mass (g)	%	% coarser	Mass (g)	%	% coarser	Mass (g)	%	% coarser
US1	Pebble	-4.64	25.0000	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US5/8		-4.00	16.0000	0	0.00	0.00	0	0.00	0.00	14	1.12	1.12
US1/2		-3.64	12.5000	0	0.00	0.00	0	0.00	0.00	12	0.95	2.06
US5/16		-3.00	8.0000	4	0.38	0.38	1	0.09	0.09	45	3.63	5.69
US1/4		-2.66	6.3000	1	0.06	0.44	0	0.00	0.09	38	3.07	8.76
US4		-2.25	4.7500	0	0.00	0.44	3	0.35	0.44	39	3.16	11.91
US5		-2.00	4.0000	1	0.06	0.50	0	0.04	0.48	19	1.54	13.45
US6	Granule	-1.75	3.3600	1	0.06	0.56	1	0.06	0.54	18	1.43	14.88
US8		-1.25	2.3800	1	0.06	0.62	4	0.40	0.94	29	2.32	17.21
US10		-1.00	2.0000	0	0.03	0.65	3	0.38	1.31	12	0.94	18.15
US12	VC Sand	-0.75	1.6800	0	0.03	0.68	4	0.43	1.74	12	0.94	19.09
US14		-0.50	1.4100	0	0.03	0.71	8	0.81	2.55	15	1.21	20.30
US16		-0.24	1.1800	1	0.12	0.83	12	1.26	3.81	15	1.24	21.54
US18		0.00	1.0000	3	0.27	1.10	13	1.37	5.18	14	1.13	22.67
US20	C Sand	0.23	0.8500	5	0.42	1.52	13	1.38	6.56	13	1.06	23.73
US25		0.49	0.7100	23	2.08	3.60	29	3.09	9.65	25	2.00	25.73
US30		0.74	0.6000	52	4.70	8.30	30	3.24	12.89	20	1.65	27.38
US35		1.00	0.5000	130	11.79	20.09	54	5.91	18.80	32	2.59	29.97
US40	M Sand	1.23	0.4250	211	19.01	39.11	73	8.16	26.96	36	2.91	32.87
US50		1.76	0.2950	371	33.54	72.64	241	27.27	54.22	147	11.82	44.69
US60		2.00	0.2500	146	13.31	85.95	189	21.77	76.00	237	19.06	63.75
US70	F Sand	2.24	0.2120	76	6.94	92.89	102	11.78	87.77	170	13.67	77.43
US80		2.50	0.1770	32	2.95	95.84	42	4.91	92.68	95	7.69	85.12
US100		2.75	0.1490	26	2.34	98.18	33	3.88	96.56	75	6.08	91.19
US120		3.00	0.1250	12	1.12	99.30	18	2.05	98.61	58	4.67	95.87
US140	VF Sand	3.25	0.1050	3	0.27	99.58	5	0.57	99.18	21	1.69	97.56
US170		3.51	0.0880	2	0.18	99.76	3	0.38	99.56	13	1.07	98.63
US200		3.74	0.0750	1	0.09	99.85	2	0.26	99.82	11	0.86	99.49
US230		4.00	0.0625	0	0.00	99.85	1	0.07	99.90	3	0.24	99.73
US325	C Silt	4.47	0.0450	1	0.09	99.94	1	0.07	99.97	2	0.19	99.92
US400		4.72	0.0380	0	0.00	99.94	0	0.00	99.97	0	0.00	99.92
PAN	M Silt - Clay	5.00	0.0313	1	0.06	100.00	0	0.03	100.00	1	0.08	100.00
			Totals	1104	100	100	884	100	100	1240	100	100

				07 - Camargo, Oklahoma			08 - Taloga, Oklahoma			09 - Fay, Oklahoma		
Screen Size				Average Distribution			Average Distribution			Average Distribution		
US Standard	Wentworth	ϕ	mm	Mass (g)	%	% coarser	Mass (g)	%	% coarser	Mass (g)	%	% coarser
US1	Pebble	-4.64	25.0000	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US5/8		-4.00	16.0000	1	0.07	0.07	66	5.30	5.30	0	0.00	0.00
US1/2		-3.64	12.5000	1	0.04	0.11	39	3.14	8.45	0	0.00	0.00
US5/16		-3.00	8.0000	1	0.06	0.17	82	6.71	15.16	0	0.00	0.00
US1/4		-2.66	6.3000	1	0.09	0.26	28	2.26	17.42	0	0.00	0.00
US4		-2.25	4.7500	2	0.16	0.42	31	2.58	20.01	1	0.07	0.07
US5		-2.00	4.0000	1	0.07	0.48	10	0.85	20.86	0	0.00	0.07
US6	Granule	-1.75	3.3600	1	0.07	0.55	9	0.75	21.61	0	0.00	0.07
US8		-1.25	2.3800	2	0.17	0.72	11	0.89	22.49	0	0.04	0.11
US10		-1.00	2.0000	2	0.13	0.85	3	0.20	22.70	0	0.00	0.11
US12	VC Sand	-0.75	1.6800	2	0.15	1.00	3	0.20	22.90	0	0.00	0.11
US14		-0.50	1.4100	4	0.36	1.36	3	0.23	23.13	0	0.04	0.14
US16		-0.24	1.1800	5	0.41	1.77	3	0.23	23.35	0	0.00	0.14
US18		0.00	1.0000	6	0.49	2.26	2	0.16	23.52	0	0.00	0.14
US20	C Sand	0.23	0.8500	7	0.63	2.88	3	0.21	23.73	0	0.00	0.14
US25		0.49	0.7100	21	1.81	4.69	6	0.48	24.21	0	0.00	0.14
US30		0.74	0.6000	26	2.22	6.91	5	0.38	24.59	0	0.04	0.19
US35		1.00	0.5000	61	5.24	12.16	15	1.23	25.82	0	0.00	0.19
US40	M Sand	1.23	0.4250	82	6.99	19.15	18	1.52	27.33	1	0.11	0.30
US50		1.76	0.2950	231	19.72	38.87	80	6.96	34.29	29	3.45	3.75
US60		2.00	0.2500	135	11.56	50.43	167	14.86	49.15	142	16.74	20.49
US70	F Sand	2.24	0.2120	90	7.72	58.14	191	16.94	66.09	223	26.52	47.01
US80		2.50	0.1770	70	5.98	64.12	113	9.95	76.04	126	15.03	62.04
US100		2.75	0.1490	102	8.86	72.98	96	8.41	84.45	107	12.82	74.86
US120		3.00	0.1250	128	11.03	84.01	65	5.70	90.16	83	9.91	84.77
US140	VF Sand	3.25	0.1050	56	4.82	88.83	22	1.93	92.09	33	3.86	88.64
US170		3.51	0.0880	46	4.00	92.83	18	1.57	93.66	28	3.25	91.88
US200		3.74	0.0750	38	3.29	96.12	15	1.24	94.90	26	3.04	94.93
US230		4.00	0.0625	14	1.23	97.35	20	1.72	96.63	10	1.21	96.13
US325	C Silt	4.47	0.0450	19	1.70	99.04	23	1.94	98.56	17	2.01	98.15
US400		4.72	0.0380	4	0.35	99.40	6	0.53	99.10	5	0.54	98.69
PAN	M Silt - Clay	5.00	0.0313	7	0.60	100.00	11	0.90	100.00	11	1.31	100.00
			Totals	1161	100	100	1158	100	100	844	100	100

				10 - Bridgeport, Oklahoma			11 - Union City, Oklahoma			12 - Norman, Oklahoma		
Screen Size				Average Distribution			Average Distribution			Average Distribution		
US Standard	Wentworth	ϕ	mm	Mass (g)	%	% coarser	Mass (g)	%	% coarser	Mass (g)	%	% coarser
US1	Pebble	-4.64	25.0000	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US5/8		-4.00	16.0000	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US1/2		-3.64	12.5000	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US5/16		-3.00	8.0000	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US1/4		-2.66	6.3000	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US4		-2.25	4.7500	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US5		-2.00	4.0000	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US6	Granule	-1.75	3.3600	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US8		-1.25	2.3800	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US10		-1.00	2.0000	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US12	VC Sand	-0.75	1.6800	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US14		-0.50	1.4100	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US16		-0.24	1.1800	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US18		0.00	1.0000	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US20	C Sand	0.23	0.8500	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US25		0.49	0.7100	0	0.00	0.00	0	0.00	0.00	1	0.06	0.06
US30		0.74	0.6000	0	0.00	0.00	0	0.00	0.00	2	0.19	0.25
US35		1.00	0.5000	1	0.07	0.07	2	0.18	0.18	3	0.41	0.66
US40	M Sand	1.23	0.4250	3	0.34	0.41	3	0.34	0.51	7	0.88	1.55
US50		1.76	0.2950	91	10.13	10.54	23	2.78	3.29	41	5.13	6.68
US60		2.00	0.2500	217	25.39	35.93	50	6.61	9.90	73	9.19	15.87
US70	F Sand	2.24	0.2120	217	25.21	61.13	87	12.44	22.34	120	15.01	30.88
US80		2.50	0.1770	95	11.04	72.17	86	12.71	35.06	126	15.64	46.52
US100		2.75	0.1490	72	8.35	80.52	92	13.48	48.54	140	17.20	63.72
US120		3.00	0.1250	53	6.08	86.60	110	16.33	64.87	120	14.94	78.66
US140	VF Sand	3.25	0.1050	22	2.58	89.18	53	7.86	72.73	46	5.75	84.41
US170		3.51	0.0880	27	3.07	92.25	59	8.87	81.60	44	5.40	89.81
US200		3.74	0.0750	20	2.38	94.63	56	8.29	89.88	37	4.60	94.41
US230		4.00	0.0625	18	2.07	96.70	19	2.88	92.77	13	1.59	96.00
US325	C Silt	4.47	0.0450	18	2.08	98.78	28	4.11	96.87	18	2.22	98.22
US400		4.72	0.0380	4	0.52	99.30	6	0.84	97.72	3	0.31	98.53
PAN	M Silt - Clay	5.00	0.0313	6	0.70	100.00	16	2.28	100.00	12	1.47	100.00
			Totals	863	100	100	689	100	100	803	100	100

				13 - Purcell, Oklahoma			14 - Asher, Oklahoma			15 - Calvin, Oklahoma		
Screen Size				Average Distribution			Average Distribution			Average Distribution		
US Standard	Wentworth	ϕ	mm	Mass (g)	%	% coarser	Mass (g)	%	% coarser	Mass (g)	%	% coarser
US1	Pebble	-4.64	25.0000	2	0.20	0.20	0	0.00	0.00	0	0.00	0.00
US5/8		-4.00	16.0000	0	0.00	0.20	0	0.00	0.00	0	0.00	0.00
US1/2		-3.64	12.5000	2	0.20	0.39	0	0.00	0.00	0	0.00	0.00
US5/16		-3.00	8.0000	2	0.15	0.54	0	0.00	0.00	0	0.00	0.00
US1/4		-2.66	6.3000	1	0.09	0.63	0	0.00	0.00	0	0.00	0.00
US4		-2.25	4.7500	1	0.09	0.72	0	0.00	0.00	0	0.00	0.00
US5		-2.00	4.0000	1	0.07	0.78	0	0.00	0.00	0	0.00	0.00
US6	Granule	-1.75	3.3600	1	0.09	0.87	0	0.00	0.00	0	0.00	0.00
US8		-1.25	2.3800	3	0.22	1.09	0	0.00	0.00	0	0.00	0.00
US10		-1.00	2.0000	1	0.07	1.15	0	0.00	0.00	0	0.00	0.00
US12	VC Sand	-0.75	1.6800	1	0.09	1.24	0	0.00	0.00	0	0.00	0.00
US14		-0.50	1.4100	2	0.16	1.40	0	0.03	0.03	0	0.00	0.00
US16		-0.24	1.1800	1	0.11	1.51	1	0.05	0.08	0	0.00	0.00
US18		0.00	1.0000	1	0.11	1.62	0	0.03	0.11	0	0.00	0.00
US20	C Sand	0.23	0.8500	1	0.09	1.71	1	0.08	0.19	0	0.00	0.00
US25		0.49	0.7100	3	0.25	1.96	3	0.24	0.43	1	0.08	0.08
US30		0.74	0.6000	4	0.38	2.34	5	0.37	0.81	2	0.14	0.22
US35		1.00	0.5000	10	0.92	3.26	14	1.16	1.97	6	0.52	0.74
US40	M Sand	1.23	0.4250	19	1.84	5.10	40	3.23	5.19	15	1.27	2.01
US50		1.76	0.2950	132	13.03	18.13	256	21.10	26.30	120	9.88	11.89
US60		2.00	0.2500	301	30.32	48.45	434	35.69	61.99	354	29.46	41.35
US70	F Sand	2.24	0.2120	212	21.74	70.19	207	16.97	78.95	208	17.92	59.27
US80		2.50	0.1770	106	10.86	81.05	106	8.74	87.69	125	10.95	70.22
US100		2.75	0.1490	72	7.34	88.39	73	5.96	93.66	95	8.36	78.58
US120		3.00	0.1250	44	4.49	92.88	44	3.56	97.22	86	7.70	86.28
US140	VF Sand	3.25	0.1050	14	1.43	94.31	11	0.87	98.09	37	3.31	89.59
US170		3.51	0.0880	11	1.11	95.42	5	0.41	98.49	32	2.90	92.49
US200		3.74	0.0750	14	1.41	96.83	3	0.24	98.74	40	3.46	95.95
US230		4.00	0.0625	8	0.80	97.63	1	0.08	98.82	14	1.21	97.16
US325	C Silt	4.47	0.0450	15	1.47	99.10	4	0.31	99.12	20	1.80	98.96
US400		4.72	0.0380	4	0.36	99.45	1	0.11	99.24	4	0.38	99.35
PAN	M Silt - Clay	5.00	0.0313	6	0.55	100.00	9	0.76	100.00	7	0.65	100.00
			Totals	**992**	**100**	**100**	**1217**	**100**	**100**	**1168**	**100**	**100**

APPENDIX C

CAMARGO GRAIN-SIZE VARIABILITY DATA

Elevations 0 - 250 millimeters

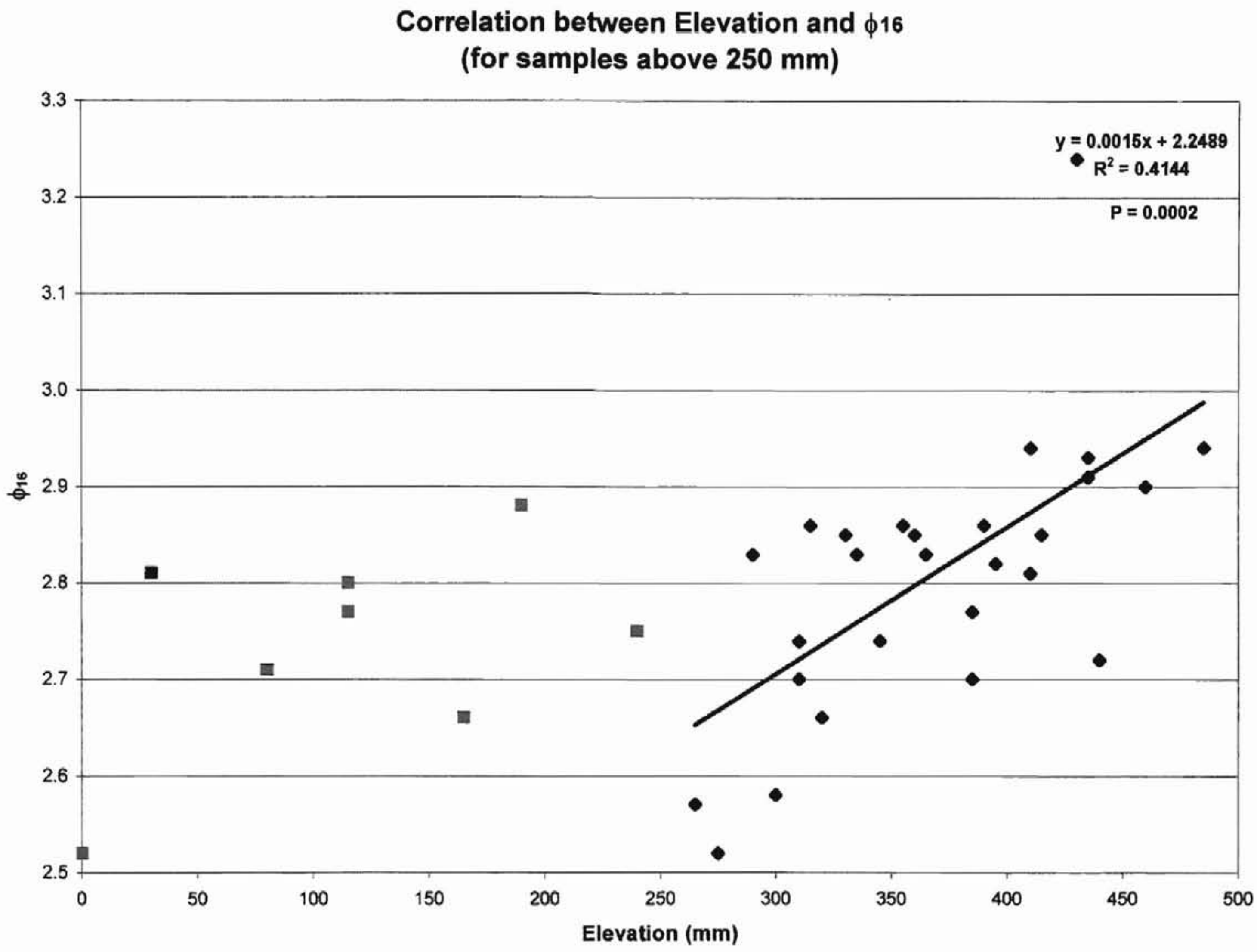
Site ID (Figure 10)	Elevation (mm)	Mass (g)	ϕ16=	ϕ50=	ϕ84=	Mean (ϕ)	Sorting (ϕ)	Skewness	Kurtosis
A1	165	1074	2.66	2.20	1.72	2.19	0.542	-0.011	4.399
A12	80	949	2.71	2.30	1.84	2.28	0.502	-0.650	5.314
B2	240	954	2.75	2.25	1.69	2.23	0.616	0.105	5.631
B10	115	1220	2.77	2.12	1.70	2.20	0.585	0.571	4.193
C2	115	1154	2.80	2.07	1.51	2.13	0.655	0.255	3.330
C9	30	1480	2.81	2.10	1.63	2.18	0.674	0.283	4.759
D4	190	1154	2.88	2.46	2.04	2.46	0.484	0.067	5.352
WL	0	1318	2.52	2.14	1.78	2.15	0.437	-0.288	4.061
AVERAGE	**117**	**1163**	**2.738**	**2.205**	**1.739**	**2.227**	**0.562**	**0.042**	**4.630**
STDEV	**81**	**179**	**0.110**	**0.129**	**0.156**	**0.106**	**0.085**	**0.374**	**0.781**

Elevations 250 - 500 millimeters

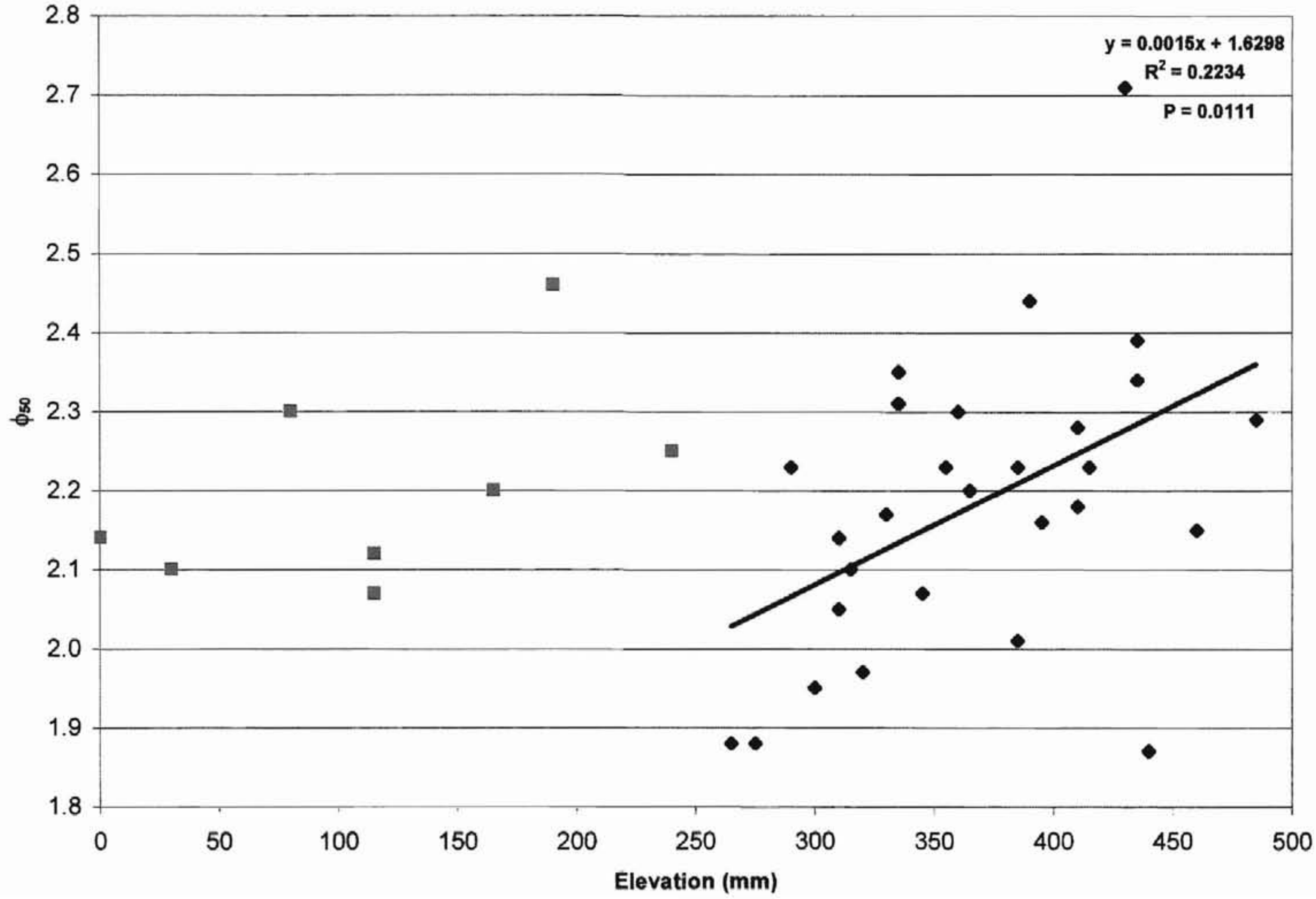
Site ID (Figure 10)	Elevation (mm)	Mass (g)	ϕ16=	ϕ50=	ϕ84=	Mean (ϕ)	Sorting (ϕ)	Skewness	Kurtosis
A2	335	974	2.83	2.35	1.72	2.30	0.653	0.555	5.146
A3	310	1030	2.70	2.14	1.59	2.14	0.704	1.033	5.505
A4	310	992	2.74	2.05	1.54	2.11	0.732	1.308	5.979
A5	345	933	2.74	2.07	1.56	2.12	0.663	0.773	5.053
A6	415	1021	2.85	2.23	1.78	2.29	0.618	0.592	4.749
A7	435	862	2.91	2.34	1.82	2.36	0.636	-0.015	4.344
A8	435	846	2.93	2.39	1.85	2.39	0.637	0.268	4.164
A9	410	822	2.94	2.28	1.77	2.33	0.628	0.352	3.337
A10	460	876	2.90	2.15	1.67	2.24	0.668	0.526	3.504
A11	485	740	2.94	2.29	1.84	2.36	0.643	0.550	4.151
B3	390	953	2.86	2.44	1.72	2.34	0.695	0.174	4.774
B4	365	1146	2.83	2.20	1.63	2.22	0.683	0.461	4.745
B5	320	1163	2.66	1.97	1.55	2.06	0.692	1.150	6.175
B6	275	1081	2.52	1.88	1.39	1.93	0.642	1.202	6.539
B7	385	1102	2.70	2.01	1.57	2.09	0.670	0.671	5.520
B8	330	1111	2.85	2.17	1.71	2.24	0.703	0.677	4.977
B9	315	1228	2.86	2.10	1.67	2.21	0.716	0.633	4.981
C3	290	1208	2.83	2.23	1.63	2.23	0.675	0.215	5.306
C4	395	982	2.82	2.16	1.71	2.23	0.617	0.588	4.733
C5	410	1077	2.81	2.18	1.69	2.23	0.637	0.356	4.838
C6	300	1186	2.58	1.95	1.51	2.01	0.629	0.886	6.232
C7	265	1288	2.57	1.88	1.51	1.99	0.623	1.020	5.810
C8	430	1142	3.24	2.71	1.97	2.64	0.676	-0.084	3.752
D5	360	1047	2.85	2.30	1.91	2.35	0.567	-0.025	5.309
D6	355	1156	2.86	2.23	1.66	2.25	0.638	0.157	3.493
Z1	385	1066	2.77	2.23	1.95	2.32	0.593	0.231	7.541
Z2	440	1087	2.72	1.87	1.39	1.99	0.751	1.027	4.399
Y2	335	1113	2.83	2.31	1.75	2.30	0.646	0.688	5.755
AVERAGE	**367**	**1044**	**2.809**	**2.183**	**1.681**	**2.224**	**0.658**	**0.570**	**5.029**
STDEV	**59**	**133**	**0.140**	**0.188**	**0.151**	**0.151**	**0.042**	**0.384**	**0.980**

Eolian

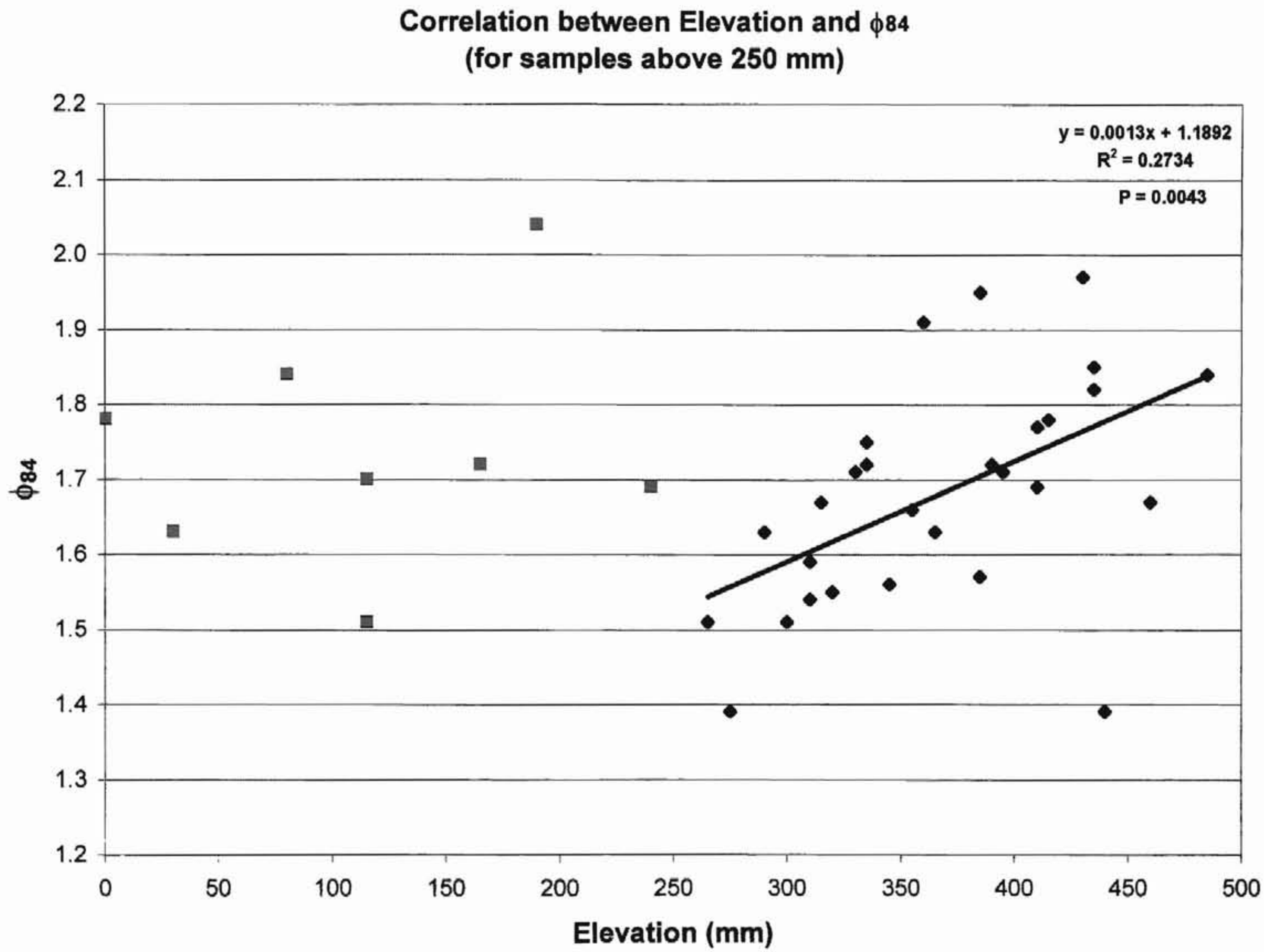
Site ID (Figure 10)	Elevation (mm)	Mass (g)	ϕ16=	ϕ50=	ϕ84=	Mean (ϕ)	Sorting (ϕ)	Skewness	Kurtosis
Z6	1075	1614	2.84	2.29	1.87	2.33	0.558	0.876	4.374

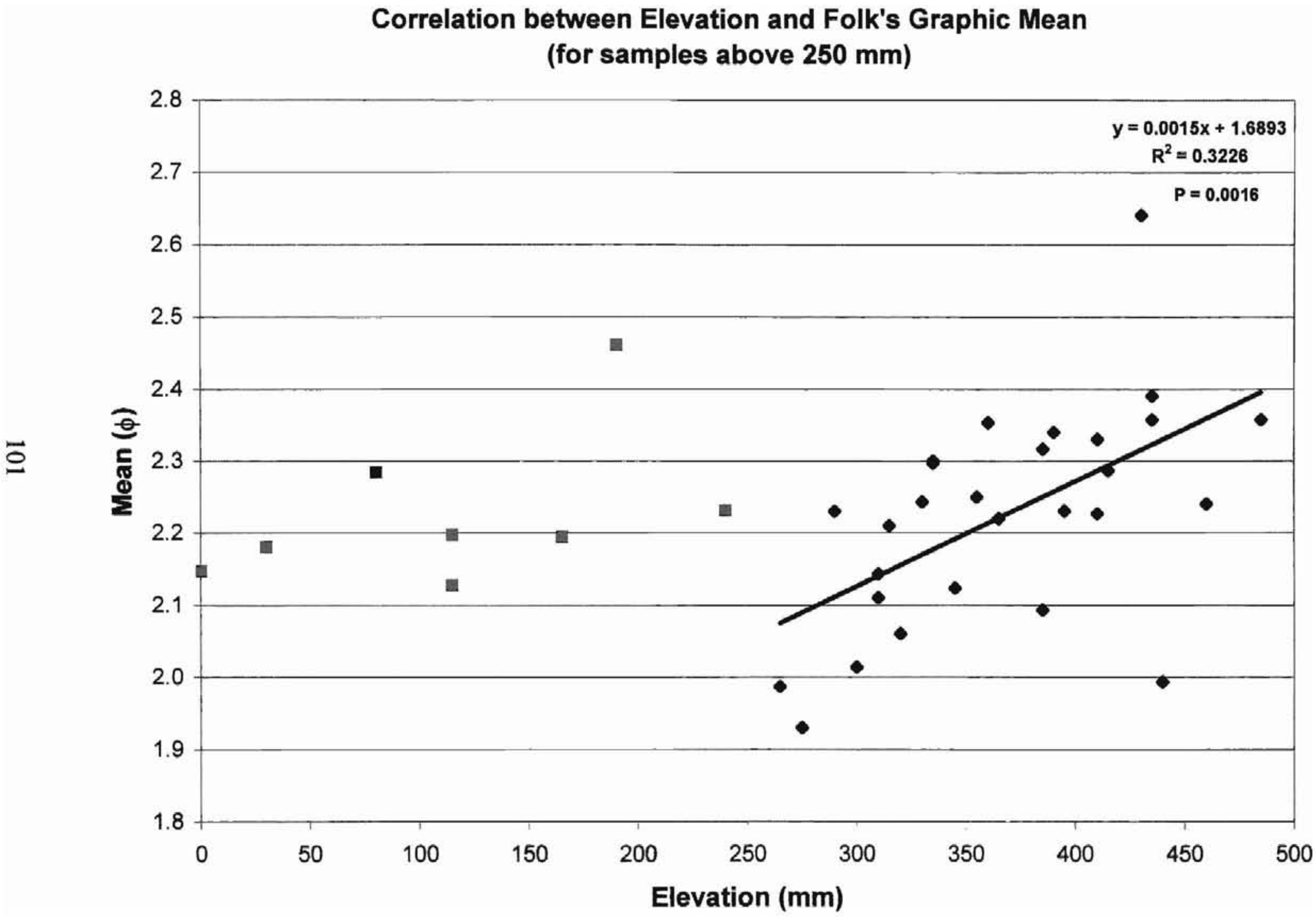


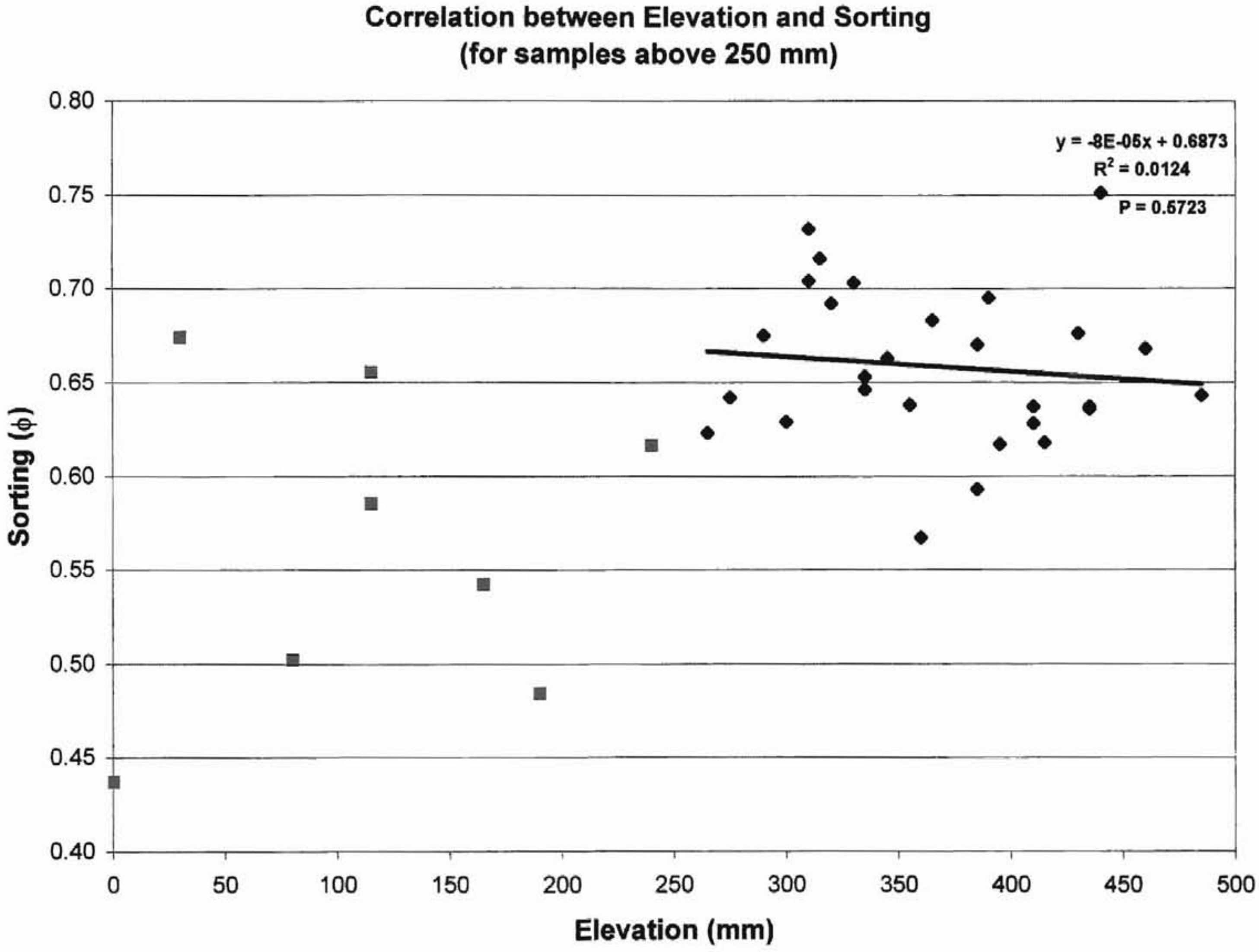
Correlation between Elevation and ϕ_{16}
(for samples above 250 mm)

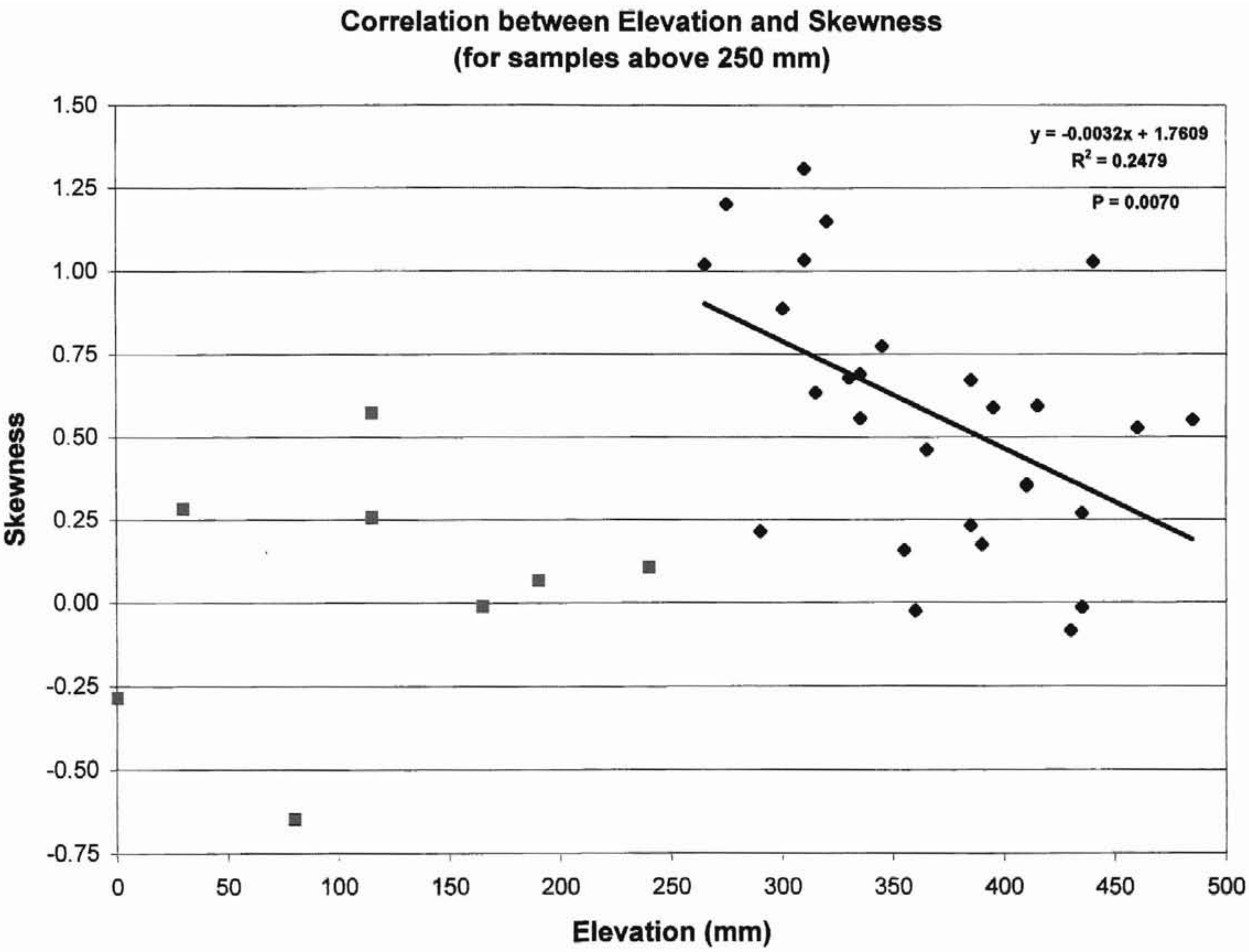


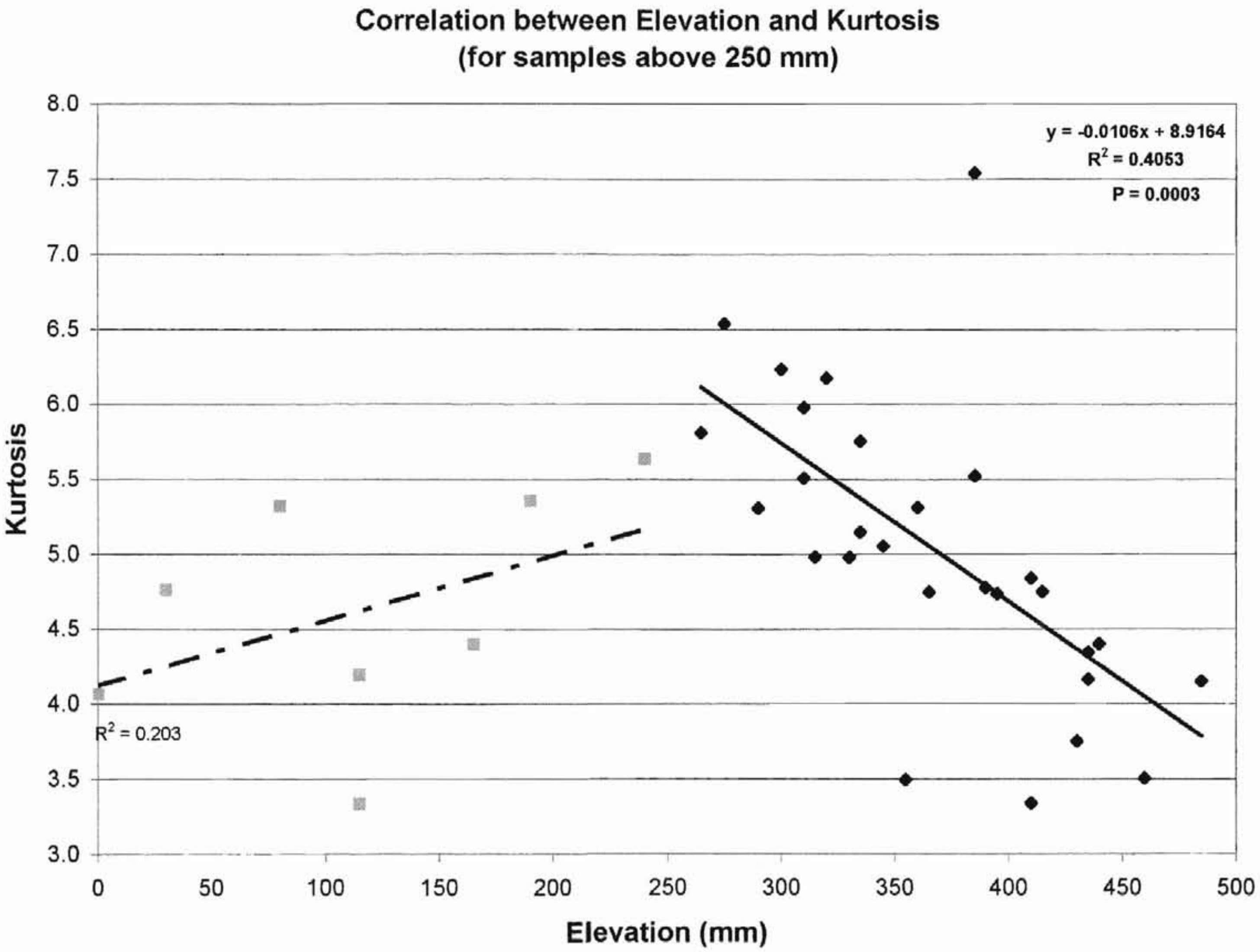
Correlation between Elevation and ϕ_{50}
(for samples above 250 mm)


Correlation between Elevation and ϕ84
(for samples above 250 mm)
y = 0.0013x + 1.1892
R2 = 0.2734
P = 0.0043
ϕ84
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
0
50
100
150
200
250
300
350
400
450
500
Elevation (mm)


Correlation between Elevation and Folk's Graphic Mean
(for samples above 250 mm)
y = 0.0015x + 1.6893
R^2 = 0.3226
P = 0.0016
Mean (ϕ)
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
0
50
100
150
200
250
300
350
400
450
500
Elevation (mm)


Correlation between Elevation and Sorting
(for samples above 250 mm)
y = -8E-05x + 0.6873
R^2 = 0.0124
P = 0.5723
Sorting (ϕ)
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0
50
100
150
200
250
300
350
400
450
500
Elevation (mm)


Correlation between Elevation and Skewness
(for samples above 250 mm)
y = -0.0032x + 1.7609
R^2 = 0.2479
P = 0.0070
Skewness
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
-0.50
-0.75
0
50
100
150
200
250
300
350
400
450
500
Elevation (mm)


Correlation between Elevation and Kurtosis
(for samples above 250 mm)
y = -0.0106x + 8.9164
R^2 = 0.4053
P = 0.0003
R^2 = 0.203
Kurtosis
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
0
50
100
150
200
250
300
350
400
450
500
Elevation (mm)

APPENDIX D

SIMMS' RAW SIEVE ANALYSIS DATA

				01 - Logan, New Mexico				02 - Boys Ranch, Texas			
Sieve Size				**1**		**2**		**1**		**2**	
US Standard	**Wentworth**	**mm**	**φ**	**Mass (g)**	**%**	**Mass (g)**	**%**	**Mass (g)**	**%**	**Mass (g)**	**%**
US4	Pebble	4.750	-2.25	0	0.00	2	0.22	0	0.00	0	0.00
US5		4.000	-2.00	0	0.00	2	0.22	0	0.00	0	0.00
US6	Granule	3.360	-1.75	2	0.19	3	0.32	0	0.00	0	0.00
US8		2.380	-1.25	9	0.83	10	1.08	0	0.00	0	0.00
US10		2.000	-1.00	6	0.56	7	0.75	0	0.00	0	0.00
US12	VC Sand	1.680	-0.75	8	0.74	10	1.08	0	0.00	0	0.00
US14		1.410	-0.50	14	1.30	18	1.94	0	0.00	0	0.00
US16		1.180	-0.24	20	1.85	26	2.80	0	0.00	0	0.00
US18		1.000	0.00	20	1.85	27	2.91	0	0.00	0	0.00
US20	C Sand	0.850	0.23	20	1.85	27	2.91	0	0.00	0	0.00
US25		0.710	0.49	42	3.89	54	5.82	0	0.00	0	0.00
US30		0.600	0.74	43	3.98	54	5.82	0	0.00	0	0.00
US35		0.500	1.00	62	5.74	77	8.30	1	0.13	2	0.22
US40	M Sand	0.425	1.23	81	7.49	90	9.70	2	0.25	3	0.33
US50		0.295	1.76	287	26.55	219	23.60	13	1.65	20	2.21
US60		0.250	2.00	269	24.88	155	16.70	19	2.42	32	3.53
US70	F Sand	0.212	2.24	127	11.75	93	10.02	34	4.33	62	6.84
US80		0.177	2.50	44	4.07	34	3.66	51	6.49	76	8.38
US100		0.149	2.75	19	1.76	13	1.40	88	11.20	124	13.67
US120		0.125	3.00	4	0.37	3	0.32	128	16.28	141	15.55
US140	VF Sand	0.105	3.25	0	0.00	0	0.00	69	8.78	68	7.50
US170		0.088	3.51	0	0.00	0	0.00	67	8.52	66	7.28
US200		0.075	3.74	0	0.00	0	0.00	71	9.03	71	7.83
US230		0.063	4.00	0	0.00	0	0.00	33	4.20	30	3.31
US325	C Silt	0.045	4.24	0	0.00	0	0.00	71	9.03	76	8.38
US400		0.038	4.47	0	0.00	0	0.00	7	0.89	10	1.10
PAN	M Silt - Clay	---	---	4	0.37	4	0.43	132	16.79	126	13.89
			Totals	**1081**	**100**	**928**	**100**	**786**	**100**	**907**	**100**

				03 - Highway 87, Texas				04 - Highway 70, Texas			
Sieve Size				1		2		1		2	
US Standard	Wentworth	mm	ϕ	Mass (g)	%	Mass (g)	%	Mass (g)	%	Mass (g)	%
US4	Pebble	4.750	-2.25	0	0.00	0	0.00	0	0.00	0	0.00
US5		4.000	-2.00	0	0.00	0	0.00	0	0.00	0	0.00
US6	Granule	3.360	-1.75	0	0.00	0	0.00	0	0.00	0	0.00
US8		2.380	-1.25	0	0.00	0	0.00	0	0.00	0	0.00
US10		2.000	-1.00	0	0.00	0	0.00	0	0.00	0	0.00
US12	VC Sand	1.680	-0.75	0	0.00	0	0.00	0	0.00	0	0.00
US14		1.410	-0.50	4	0.47	0	0.00	2	0.21	0	0.00
US16		1.180	-0.24	0	0.00	0	0.00	1	0.10	0	0.00
US18		1.000	0.00	0	0.00	0	0.00	2	0.21	1	0.11
US20	C Sand	0.850	0.23	0	0.00	0	0.00	3	0.31	2	0.21
US25		0.710	0.49	2	0.23	0	0.00	13	1.34	10	1.07
US30		0.600	0.74	2	0.23	0	0.00	27	2.78	25	2.68
US35		0.500	1.00	10	1.17	2	0.25	71	7.31	75	8.03
US40	M Sand	0.425	1.23	20	2.33	3	0.37	113	11.64	130	13.92
US50		0.295	1.76	106	12.37	17	2.09	336	34.60	356	38.12
US60		0.250	2.00	135	15.75	37	4.55	201	20.70	191	20.45
US70	F Sand	0.212	2.24	152	17.74	130	15.97	107	11.02	86	9.21
US80		0.177	2.50	127	14.82	205	25.18	41	4.22	30	3.21
US100		0.149	2.75	115	13.42	158	19.41	27	2.78	18	1.93
US120		0.125	3.00	105	12.25	162	19.90	12	1.24	6	0.64
US140	VF Sand	0.105	3.25	31	3.62	44	5.41	5	0.51	2	0.21
US170		0.088	3.51	18	2.10	23	2.83	4	0.41	1	0.11
US200		0.075	3.74	12	1.40	14	1.72	3	0.31	1	0.11
US230		0.063	4.00	5	0.58	5	0.61	1	0.10	0	0.00
US325	C Silt	0.045	4.24	7	0.82	7	0.86	1	0.10	0	0.00
US400		0.038	4.47	0	0.00	0	0.00	0	0.00	0	0.00
PAN	M Silt - Clay	---	---	6	0.70	7	0.86	1	0.10	0	0.00
			Totals	**857**	**100**	**814**	**100**	**971**	**100**	**934**	**100**

				05 - Canadian, Texas				06 - Roll, Oklahoma			
Sieve Size				1		2		1		2	
US Standard	Wentworth	mm	ϕ	Mass (g)	%	Mass (g)	%	Mass (g)	%	Mass (g)	%
US4	Pebble	4.750	-2.25	0	0.00	0	0.00	0	0.00	0	0.00
US5		4.000	-2.00	0	0.00	0	0.00	0	0.00	0	0.00
US6	Granule	3.360	-1.75	0	0.00	0	0.00	0	0.00	0	0.00
US8		2.380	-1.25	0	0.00	0	0.00	0	0.00	0	0.00
US10		2.000	-1.00	0	0.00	0	0.00	0	0.00	0	0.00
US12	VC Sand	1.680	-0.75	0	0.00	0	0.00	0	0.00	0	0.00
US14		1.410	-0.50	0	0.00	0	0.00	0	0.00	0	0.00
US16		1.180	-0.24	0	0.00	0	0.00	0	0.00	0	0.00
US18		1.000	0.00	0	0.00	0	0.00	0	0.00	0	0.00
US20	C Sand	0.850	0.23	0	0.00	0	0.00	0	0.00	0	0.00
US25		0.710	0.49	3	0.35	3	0.33	2	0.27	2	0.27
US30		0.600	0.74	6	0.70	4	0.43	2	0.27	2	0.27
US35		0.500	1.00	33	3.87	27	2.93	11	1.47	13	1.79
US40	M Sand	0.425	1.23	85	9.96	64	6.93	19	2.53	22	3.02
US50		0.295	1.76	366	42.91	328	35.54	110	14.67	112	15.38
US60		0.250	2.00	208	24.38	270	29.25	188	25.07	194	26.65
US70	F Sand	0.212	2.24	88	10.32	127	13.76	185	24.67	169	23.21
US80		0.177	2.50	30	3.52	51	5.53	95	12.67	81	11.13
US100		0.149	2.75	23	2.70	34	3.68	81	10.80	75	10.30
US120		0.125	3.00	9	1.06	13	1.41	42	5.60	42	5.77
US140	VF Sand	0.105	3.25	2	0.23	2	0.22	9	1.20	10	1.37
US170		0.088	3.51	0	0.00	0	0.00	4	0.53	4	0.55
US200		0.075	3.74	0	0.00	0	0.00	2	0.27	2	0.27
US230		0.063	4.00	0	0.00	0	0.00	0	0.00	0	0.00
US325	C Silt	0.045	4.24	0	0.00	0	0.00	0	0.00	0	0.00
US400		0.038	4.47	0	0.00	0	0.00	0	0.00	0	0.00
PAN	M Silt - Clay	---	---	0	0.00	0	0.00	0	0.00	0	0.00
			Totals	**853**	**100**	**923**	**100**	**750**	**100**	**728**	**100**

				07 - Camargo, Oklahoma				08 - Taloga, Oklahoma			
Sieve Size				1		2		1		2	
US Standard	Wentworth	mm	ϕ	Mass (g)	%	Mass (g)	%	Mass (g)	%	Mass (g)	%
US4	Pebble	4.750	-2.25	0	0.00	0	0.00	0	0.00	0	0.00
US5		4.000	-2.00	0	0.00	0	0.00	0	0.00	0	0.00
US6	Granule	3.360	-1.75	0	0.00	0	0.00	0	0.00	0	0.00
US8		2.380	-1.25	0	0.00	0	0.00	0	0.00	0	0.00
US10		2.000	-1.00	0	0.00	0	0.00	0	0.00	0	0.00
US12	VC Sand	1.680	-0.75	0	0.00	0	0.00	0	0.00	0	0.00
US14		1.410	-0.50	0	0.00	0	0.00	0	0.00	0	0.00
US16		1.180	-0.24	0	0.00	0	0.00	0	0.00	0	0.00
US18		1.000	0.00	0	0.00	0	0.00	0	0.00	0	0.00
US20	C Sand	0.850	0.23	0	0.00	0	0.00	0	0.00	0	0.00
US25		0.710	0.49	2	0.29	2	0.29	0	0.00	0	0.00
US30		0.600	0.74	2	0.29	2	0.29	0	0.00	0	0.00
US35		0.500	1.00	13	1.86	11	1.59	0	0.00	0	0.00
US40	M Sand	0.425	1.23	22	3.15	17	2.45	1	0.14	1	0.14
US50		0.295	1.76	104	14.90	83	11.98	17	2.38	14	1.98
US60		0.250	2.00	87	12.46	73	10.53	66	9.26	52	7.34
US70	F Sand	0.212	2.24	60	8.60	47	6.78	175	24.54	143	20.20
US80		0.177	2.50	40	5.73	27	3.90	144	20.20	153	21.61
US100		0.149	2.75	89	12.75	68	9.81	135	18.93	150	21.19
US120		0.125	3.00	123	17.62	130	18.76	104	14.59	113	15.96
US140	VF Sand	0.105	3.25	55	7.88	68	9.81	25	3.51	28	3.95
US170		0.088	3.51	39	5.59	63	9.09	14	1.96	16	2.26
US200		0.075	3.74	31	4.44	50	7.22	3	0.42	4	0.56
US230		0.063	4.00	12	1.72	19	2.74	15	2.10	18	2.54
US325	C Silt	0.045	4.24	14	2.01	23	3.32	9	1.26	10	1.41
US400		0.038	4.47	2	0.29	4	0.58	2	0.28	2	0.28
PAN	M Silt - Clay	---	---	3	0.43	6	0.87	3	0.42	4	0.56
			Totals	**698**	**100**	**693**	**100**	**713**	**100**	**708**	**100**

				09 - Fay, Oklahoma				10 - Bridgeport, Oklahoma			
Sieve Size				1		2		1		2	
US Standard	Wentworth	mm	ϕ	Mass (g)	%	Mass (g)	%	Mass (g)	%	Mass (g)	%
US4	Pebble	4.750	-2.25	0	0.00	0	0.00	0	0.00	0	0.00
US5		4.000	-2.00	0	0.00	0	0.00	0	0.00	0	0.00
US6	Granule	3.360	-1.75	0	0.00	0	0.00	0	0.00	0	0.00
US8		2.380	-1.25	0	0.00	0	0.00	0	0.00	0	0.00
US10		2.000	-1.00	0	0.00	0	0.00	0	0.00	0	0.00
US12	VC Sand	1.680	-0.75	0	0.00	0	0.00	0	0.00	0	0.00
US14		1.410	-0.50	0	0.00	0	0.00	0	0.00	0	0.00
US16		1.180	-0.24	0	0.00	0	0.00	0	0.00	0	0.00
US18		1.000	0.00	0	0.00	0	0.00	0	0.00	0	0.00
US20	C Sand	0.850	0.23	0	0.00	0	0.00	0	0.00	0	0.00
US25		0.710	0.49	0	0.00	0	0.00	0	0.00	0	0.00
US30		0.600	0.74	0	0.00	0	0.00	0	0.00	0	0.00
US35		0.500	1.00	0	0.00	0	0.00	0	0.00	3	0.59
US40	M Sand	0.425	1.23	0	0.00	0	0.00	1	0.24	7	1.37
US50		0.295	1.76	12	2.40	10	1.44	22	5.19	46	9.02
US60		0.250	2.00	49	9.82	44	6.35	77	18.16	113	22.16
US70	F Sand	0.212	2.24	99	19.84	111	16.02	122	28.77	129	25.29
US80		0.177	2.50	81	16.23	110	15.87	68	16.04	66	12.94
US100		0.149	2.75	88	17.64	123	17.75	54	12.74	51	10.00
US120		0.125	3.00	83	16.63	131	18.90	33	7.78	33	6.47
US140	VF Sand	0.105	3.25	33	6.61	51	7.36	14	3.30	15	2.94
US170		0.088	3.51	26	5.21	42	6.06	11	2.59	14	2.75
US200		0.075	3.74	12	2.40	27	3.90	9	2.12	13	2.55
US230		0.063	4.00	12	2.40	19	2.74	6	1.42	8	1.57
US325	C Silt	0.045	4.24	4	0.80	15	2.16	5	1.18	7	1.37
US400		0.038	4.47	0	0.00	4	0.58	0	0.00	2	0.39
PAN	M Silt - Clay	---	---	0	0.00	6	0.87	2	0.47	3	0.59
			Totals	**499**	**100**	**693**	**100**	**424**	**100**	**510**	**100**

				11 - Union City, Oklahoma							
Sieve Size				**1**		**2**		**3**		**4**	
US Standard	**Wentworth**	**mm**	**ϕ**	**Mass (g)**	**%**	**Mass (g)**	**%**	**Mass (g)**	**%**	**Mass (g)**	**%**
US4	Pebble	4.750	-2.25	0	0.00	0	0.00	0	0.00	0	0.00
US5		4.000	-2.00	0	0.00	0	0.00	0	0.00	0	0.00
US6	Granule	3.360	-1.75	0	0.00	0	0.00	0	0.00	0	0.00
US8		2.380	-1.25	0	0.00	0	0.00	0	0.00	0	0.00
US10		2.000	-1.00	0	0.00	0	0.00	0	0.00	0	0.00
US12	VC Sand	1.680	-0.75	0	0.00	0	0.00	0	0.00	0	0.00
US14		1.410	-0.50	0	0.00	0	0.00	0	0.00	4	0.76
US16		1.180	-0.24	0	0.00	0	0.00	0	0.00	0	0.00
US18		1.000	0.00	0	0.00	0	0.00	0	0.00	0	0.00
US20	C Sand	0.850	0.23	0	0.00	0	0.00	0	0.00	0	0.00
US25		0.710	0.49	0	0.00	0	0.00	0	0.00	0	0.00
US30		0.600	0.74	0	0.00	0	0.00	0	0.00	0	0.00
US35		0.500	1.00	0	0.00	0	0.00	3	0.65	3	0.57
US40	M Sand	0.425	1.23	0	0.00	0	0.00	4	0.86	5	0.95
US50		0.295	1.76	3	0.53	2	0.31	19	4.10	20	3.78
US60		0.250	2.00	7	1.24	5	0.77	28	6.05	26	4.91
US70	F Sand	0.212	2.24	21	3.73	15	2.30	34	7.34	32	6.05
US80		0.177	2.50	21	3.73	19	2.91	27	5.83	26	4.91
US100		0.149	2.75	32	5.68	35	5.37	51	11.02	54	10.21
US120		0.125	3.00	58	10.30	58	8.90	78	16.85	89	16.82
US140	VF Sand	0.105	3.25	43	7.64	44	6.75	46	9.94	52	9.83
US170		0.088	3.51	101	17.94	114	17.48	51	11.02	56	10.59
US200		0.075	3.74	122	21.67	147	22.55	50	10.80	53	10.02
US230		0.063	4.00	53	9.41	74	11.35	23	4.97	29	5.48
US325	C Silt	0.045	4.24	65	11.55	86	13.19	26	5.62	36	6.81
US400		0.038	4.47	12	2.13	16	2.45	6	1.30	11	2.08
PAN	M Silt - Clay	---	---	25	4.44	37	5.67	17	3.67	33	6.24
			Totals	**563**	**100**	**652**	**100**	**463**	**100**	**529**	**100**

				12 - Norman, Oklahoma				13 - Purcell, Oklahoma			
Sieve Size				1		2		1		2	
US Standard	Wentworth	mm	ϕ	Mass (g)	%	Mass (g)	%	Mass (g)	%	Mass (g)	%
US4	Pebble	4.750	-2.25	0	0.00	0	0.00	0	0.00	0	0.00
US5		4.000	-2.00	0	0.00	0	0.00	0	0.00	0	0.00
US6	Granule	3.360	-1.75	0	0.00	0	0.00	0	0.00	0	0.00
US8		2.380	-1.25	0	0.00	0	0.00	0	0.00	0	0.00
US10		2.000	-1.00	0	0.00	0	0.00	0	0.00	0	0.00
US12	VC Sand	1.680	-0.75	0	0.00	0	0.00	0	0.00	0	0.00
US14		1.410	-0.50	0	0.00	0	0.00	16	2.43	13	1.55
US16		1.180	-0.24	0	0.00	0	0.00	0	0.00	2	0.24
US18		1.000	0.00	0	0.00	0	0.00	0	0.00	3	0.36
US20	C Sand	0.850	0.23	0	0.00	0	0.00	0	0.00	2	0.24
US25		0.710	0.49	0	0.00	0	0.00	1	0.15	3	0.36
US30		0.600	0.74	0	0.00	0	0.00	1	0.15	2	0.24
US35		0.500	1.00	0	0.00	0	0.00	2	0.30	10	1.19
US40	M Sand	0.425	1.23	2	0.38	3	0.41	4	0.61	11	1.31
US50		0.295	1.76	22	4.22	49	6.72	19	2.89	32	3.81
US60		0.250	2.00	45	8.64	81	11.11	28	4.26	24	2.86
US70	F Sand	0.212	2.24	121	23.22	198	27.16	113	17.17	84	10.01
US80		0.177	2.50	96	18.43	120	16.46	123	18.69	116	13.83
US100		0.149	2.75	84	16.12	136	18.66	125	19.00	167	19.90
US120		0.125	3.00	78	14.97	14	1.92	112	17.02	163	19.43
US140	VF Sand	0.105	3.25	19	3.65	32	4.39	27	4.10	49	5.84
US170		0.088	3.51	28	5.37	43	5.90	40	6.08	64	7.63
US200		0.075	3.74	16	3.07	28	3.84	27	4.10	48	5.72
US230		0.063	4.00	4	0.77	8	1.10	8	1.22	16	1.91
US325	C Silt	0.045	4.24	5	0.96	11	1.51	9	1.37	20	2.38
US400		0.038	4.47	0	0.00	2	0.27	1	0.15	4	0.48
PAN	M Silt - Clay	---	---	1	0.19	4	0.55	2	0.30	6	0.72
			Totals	**521**	**100**	**729**	**100**	**658**	**100**	**839**	**100**

				14 - Asher, Oklahoma				15 - Calvin, Oklahoma			
Sieve Size				1		2		1		2	
US Standard	Wentworth	mm	ϕ	Mass (g)	%	Mass (g)	%	Mass (g)	%	Mass (g)	%
US4	Pebble	4.750	-2.25	0	0.00	0	0.00	0	0.00	0	0.00
US5		4.000	-2.00	0	0.00	0	0.00	0	0.00	0	0.00
US6	Granule	3.360	-1.75	0	0.00	0	0.00	0	0.00	0	0.00
US8		2.380	-1.25	0	0.00	0	0.00	0	0.00	0	0.00
US10		2.000	-1.00	0	0.00	0	0.00	0	0.00	0	0.00
US12	VC Sand	1.680	-0.75	0	0.00	0	0.00	0	0.00	0	0.00
US14		1.410	-0.50	0	0.00	0	0.00	0	0.00	0	0.00
US16		1.180	-0.24	0	0.00	0	0.00	0	0.00	0	0.00
US18		1.000	0.00	0	0.00	0	0.00	0	0.00	0	0.00
US20	C Sand	0.850	0.23	0	0.00	0	0.00	0	0.00	0	0.00
US25		0.710	0.49	0	0.00	0	0.00	0	0.00	0	0.00
US30		0.600	0.74	0	0.00	0	0.00	0	0.00	0	0.00
US35		0.500	1.00	2	0.21	0	0.00	0	0.00	0	0.00
US40	M Sand	0.425	1.23	4	0.42	1	0.09	1	0.10	3	0.25
US50		0.295	1.76	37	3.91	11	1.01	19	1.87	47	3.98
US60		0.250	2.00	90	9.51	20	1.83	226	22.27	422	35.76
US70	F Sand	0.212	2.24	121	12.79	32	2.93	332	32.71	278	23.56
US80		0.177	2.50	78	8.25	31	2.84	207	20.39	187	15.85
US100		0.149	2.75	79	8.35	55	5.04	99	9.75	119	10.08
US120		0.125	3.00	108	11.42	169	15.48	90	8.87	82	6.95
US140	VF Sand	0.105	3.25	78	8.25	149	13.64	21	2.07	20	1.69
US170		0.088	3.51	105	11.10	238	21.79	10	0.99	10	0.85
US200		0.075	3.74	104	10.99	177	16.21	6	0.59	7	0.59
US230		0.063	4.00	30	3.17	38	3.48	2	0.20	2	0.17
US325	C Silt	0.045	4.24	70	7.40	113	10.35	1	0.10	1	0.08
US400		0.038	4.47	10	1.06	7	0.64	0	0.00	0	0.00
PAN	M Silt - Clay	---	---	30	3.17	51	4.67	1	0.10	2	0.17
			Totals	**946**	**100**	**1092**	**100**	**1015**	**100**	**1180**	**100**

APPENDIX E

SIMMS' PROCESSED SIEVE ANALYSIS DATA

				01 - Logan, New Mexico			02 - Boys Ranch, Texas			03 - Highway 87, Texas		
Sieve Size				Average Distribution			Average Distribution			Average Distribution		
US Standard	Wentworth	mm	ϕ	Mass (g)	%	% coarser	Mass (g)	%	% coarser	Mass (g)	%	% coarser
US4	Pebble	4.750	-2.25	1	0.10	0.10	0	0.00	0.00	0	0.00	0.00
US5		4.000	-2.00	1	0.10	0.20	0	0.00	0.00	0	0.00	0.00
US6	Granule	3.360	-1.75	3	0.25	0.45	0	0.00	0.00	0	0.00	0.00
US8		2.380	-1.25	10	0.95	1.39	0	0.00	0.00	0	0.00	0.00
US10		2.000	-1.00	7	0.65	2.04	0	0.00	0.00	0	0.00	0.00
US12	VC Sand	1.680	-0.75	9	0.90	2.94	0	0.00	0.00	0	0.00	0.00
US14		1.410	-0.50	16	1.59	4.53	0	0.00	0.00	2	0.24	0.24
US16		1.180	-0.24	23	2.29	6.82	0	0.00	0.00	0	0.00	0.24
US18		1.000	0.00	24	2.34	9.16	0	0.00	0.00	0	0.00	0.24
US20	C Sand	0.850	0.23	24	2.34	11.50	0	0.00	0.00	0	0.00	0.24
US25		0.710	0.49	48	4.78	16.28	0	0.00	0.00	1	0.12	0.36
US30		0.600	0.74	49	4.83	21.11	0	0.00	0.00	1	0.12	0.48
US35		0.500	1.00	70	6.92	28.02	2	0.18	0.18	6	0.72	1.20
US40	M Sand	0.425	1.23	86	8.51	36.54	3	0.30	0.47	12	1.38	2.57
US50		0.295	1.76	253	25.19	61.72	17	1.95	2.42	62	7.36	9.93
US60		0.250	2.00	212	21.11	82.83	26	3.01	5.43	86	10.29	20.23
US70	F Sand	0.212	2.24	110	10.95	93.78	48	5.67	11.10	141	16.88	37.10
US80		0.177	2.50	39	3.88	97.66	64	7.50	18.61	166	19.87	56.97
US100		0.149	2.75	16	1.59	99.25	106	12.52	31.13	137	16.34	73.31
US120		0.125	3.00	4	0.35	99.60	135	15.89	47.02	134	15.98	89.29
US140	VF Sand	0.105	3.25	0	0.00	99.60	69	8.09	55.11	38	4.49	93.78
US170		0.088	3.51	0	0.00	99.60	67	7.86	62.97	21	2.45	96.23
US200		0.075	3.74	0	0.00	99.60	71	8.39	71.35	13	1.56	97.79
US230		0.063	4.00	0	0.00	99.60	32	3.72	75.07	5	0.60	98.38
US325	C Silt	0.045	4.24	0	0.00	99.60	74	8.68	83.76	7	0.84	99.22
US400		0.038	4.47	0	0.00	99.60	9	1.00	84.76	0	0.00	99.22
PAN	M Silt - Clay	—	—	4	0.40	100.00	129	15.24	100.00	7	0.78	100.00
			Totals	**1005**	**100**	**100**	**847**	**100**	**100**	**836**	**100**	**100**

				04 - Highway 70, Texas			05 - Canadian, Texas			06 - Roll, Oklahoma		
Sieve Size				Average Distribution			Average Distribution			Average Distribution		
US Standard	Wentworth	mm	ϕ	Mass (g)	%	% coarser	Mass (g)	%	% coarser	Mass (g)	%	% coarser
US4	Pebble	4.750	-2.25	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US5		4.000	-2.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US6	Granule	3.360	-1.75	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US8		2.380	-1.25	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US10		2.000	-1.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US12	VC Sand	1.680	-0.75	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US14		1.410	-0.50	1	0.10	0.10	0	0.00	0.00	0	0.00	0.00
US16		1.180	-0.24	1	0.05	0.16	0	0.00	0.00	0	0.00	0.00
US18		1.000	0.00	2	0.16	0.31	0	0.00	0.00	0	0.00	0.00
US20	C Sand	0.850	0.23	3	0.26	0.58	0	0.00	0.00	0	0.00	0.00
US25		0.710	0.49	12	1.21	1.78	3	0.34	0.34	2	0.27	0.27
US30		0.600	0.74	26	2.73	4.51	5	0.56	0.90	2	0.27	0.54
US35		0.500	1.00	73	7.66	12.18	30	3.38	4.28	12	1.62	2.17
US40	M Sand	0.425	1.23	122	12.76	24.93	75	8.39	12.67	21	2.77	4.94
US50		0.295	1.76	346	36.33	61.26	347	39.08	51.75	111	15.02	19.96
US60		0.250	2.00	196	20.58	81.84	239	26.91	78.66	191	25.85	45.81
US70	F Sand	0.212	2.24	97	10.13	91.97	108	12.11	90.77	177	23.95	69.76
US80		0.177	2.50	36	3.73	95.70	41	4.56	95.33	88	11.91	81.66
US100		0.149	2.75	23	2.36	98.06	29	3.21	98.54	78	10.55	92.22
US120		0.125	3.00	9	0.94	99.00	11	1.24	99.77	42	5.68	97.90
US140	VF Sand	0.105	3.25	4	0.37	99.37	2	0.23	100.00	10	1.29	99.19
US170		0.088	3.51	3	0.26	99.63	0	0.00	100.00	4	0.54	99.73
US200		0.075	3.74	2	0.21	99.84	0	0.00	100.00	2	0.27	100.00
US230		0.063	4.00	1	0.05	99.90	0	0.00	100.00	0	0.00	100.00
US325	C Silt	0.045	4.24	1	0.05	99.95	0	0.00	100.00	0	0.00	100.00
US400		0.038	4.47	0	0.00	99.95	0	0.00	100.00	0	0.00	100.00
PAN	M Silt - Clay	—	—	1	0.05	100.00	0	0.00	100.00	0	0.00	100.00
			Totals	**953**	**100**	**100**	**888**	**100**	**100**	**739**	**100**	**100**

				07 - Camargo, Oklahoma			08 - Taloga, Oklahoma			09 - Fay, Oklahoma		
Sieve Size				Average Distribution			Average Distribution			Average Distribution		
US Standard	Wentworth	mm	ϕ	Mass (g)	%	% coarser	Mass (g)	%	% coarser	Mass (g)	%	% coarser
US4	Pebble	4.750	-2.25	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US5		4.000	-2.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US6	Granule	3.360	-1.75	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US8		2.380	-1.25	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US10		2.000	-1.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US12	VC Sand	1.680	-0.75	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US14		1.410	-0.50	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US16		1.180	-0.24	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US18		1.000	0.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US20	C Sand	0.850	0.23	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US25		0.710	0.49	2	0.29	0.29	0	0.00	0.00	0	0.00	0.00
US30		0.600	0.74	2	0.29	0.58	0	0.00	0.00	0	0.00	0.00
US35		0.500	1.00	12	1.73	2.30	0	0.00	0.00	0	0.00	0.00
US40	M Sand	0.425	1.23	20	2.80	5.10	1	0.14	0.14	0	0.00	0.00
US50		0.295	1.76	94	13.44	18.55	16	2.18	2.32	11	1.85	1.85
US60		0.250	2.00	80	11.50	30.05	59	8.30	10.63	47	7.80	9.65
US70	F Sand	0.212	2.24	54	7.69	37.74	159	22.38	33.00	105	17.62	27.27
US80		0.177	2.50	34	4.82	42.56	149	20.90	53.91	96	16.02	43.29
US100		0.149	2.75	79	11.29	53.85	143	20.06	73.96	106	17.70	60.99
US120		0.125	3.00	127	18.19	72.03	109	15.27	89.23	107	17.95	78.94
US140	VF Sand	0.105	3.25	62	8.84	80.88	27	3.73	92.96	42	7.05	85.99
US170		0.088	3.51	51	7.33	88.21	15	2.11	95.07	34	5.70	91.69
US200		0.075	3.74	41	5.82	94.03	4	0.49	95.57	20	3.27	94.97
US230		0.063	4.00	16	2.23	96.26	17	2.32	97.89	16	2.60	97.57
US325	C Silt	0.045	4.24	19	2.66	98.92	10	1.34	99.23	10	1.59	99.16
US400		0.038	4.47	3	0.43	99.35	2	0.28	99.51	2	0.34	99.50
PAN	M Silt - Clay	—	—	5	0.65	100.00	4	0.49	100.00	3	0.50	100.00
			Totals	**696**	**100**	**100**	**711**	**100**	**100**	**596**	**100**	**100**

				10 - Bridgeport, Oklahoma			11 - Union City, Oklahoma			12 - Norman, Oklahoma		
Sieve Size				Average Distribution			Average Distribution			Average Distribution		
US Standard	Wentworth	mm	ϕ	Mass (g)	%	% coarser	Mass (g)	%	% coarser	Mass (g)	%	% coarser
US4	Pebble	4.750	-2.25	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US5		4.000	-2.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US6	Granule	3.360	-1.75	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US8		2.380	-1.25	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US10		2.000	-1.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US12	VC Sand	1.680	-0.75	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US14		1.410	-0.50	0	0.00	0.00	2	0.40	0.40	0	0.00	0.00
US16		1.180	-0.24	0	0.00	0.00	0	0.00	0.40	0	0.00	0.00
US18		1.000	0.00	0	0.00	0.00	0	0.00	0.40	0	0.00	0.00
US20	C Sand	0.850	0.23	0	0.00	0.00	0	0.00	0.40	0	0.00	0.00
US25		0.710	0.49	0	0.00	0.00	0	0.00	0.40	0	0.00	0.00
US30		0.600	0.74	0	0.00	0.00	0	0.00	0.40	0	0.00	0.00
US35		0.500	1.00	2	0.32	0.32	3	0.60	1.01	0	0.00	0.00
US40	M Sand	0.425	1.23	4	0.86	1.18	5	0.91	1.92	3	0.40	0.40
US50		0.295	1.76	34	7.28	8.46	20	3.93	5.85	36	5.68	6.08
US60		0.250	2.00	95	20.34	28.80	27	5.44	11.29	63	10.08	16.16
US70	F Sand	0.212	2.24	126	26.87	55.67	33	6.65	17.94	160	25.52	41.68
US80		0.177	2.50	67	14.35	70.02	27	5.34	23.29	108	17.28	58.96
US100		0.149	2.75	53	11.24	81.26	53	10.58	33.87	110	17.60	76.56
US120		0.125	3.00	33	7.07	88.33	84	16.83	50.71	46	7.36	83.92
US140	VF Sand	0.105	3.25	15	3.10	91.43	49	9.88	60.58	26	4.08	88.00
US170		0.088	3.51	13	2.68	94.11	54	10.79	71.37	36	5.68	93.68
US200		0.075	3.74	11	2.36	96.47	52	10.38	81.75	22	3.52	97.20
US230		0.063	4.00	7	1.50	97.97	26	5.24	87.00	6	0.96	98.16
US325	C Silt	0.045	4.24	6	1.28	99.25	31	6.25	93.25	8	1.28	99.44
US400		0.038	4.47	1	0.21	99.46	9	1.71	94.96	1	0.16	99.60
PAN	M Silt - Clay	—	—	3	0.54	100.00	25	5.04	100.00	3	0.40	100.00
			Totals	**467**	**100**	**100**	**496**	**100**	**100**	**625**	**100**	**100**

				13 - Purcell, Oklahoma			14 - Asher, Oklahoma			15 - Calvin, Oklahoma		
Sieve Size				Average Distribution			Average Distribution			Average Distribution		
US Standard	Wentworth	mm	ϕ	Mass (g)	%	% coarser	Mass (g)	%	% coarser	Mass (g)	%	% coarser
US4	Pebble	4.750	-2.25	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US5		4.000	-2.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US6	Granule	3.360	-1.75	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US8		2.380	-1.25	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US10		2.000	-1.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US12	VC Sand	1.680	-0.75	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
US14		1.410	-0.50	15	1.94	1.94	0	0.00	0.00	0	0.00	0.00
US16		1.180	-0.24	1	0.13	2.07	0	0.00	0.00	0	0.00	0.00
US18		1.000	0.00	2	0.20	2.27	0	0.00	0.00	0	0.00	0.00
US20	C Sand	0.850	0.23	1	0.13	2.40	0	0.00	0.00	0	0.00	0.00
US25		0.710	0.49	2	0.27	2.67	0	0.00	0.00	0	0.00	0.00
US30		0.600	0.74	2	0.20	2.87	0	0.00	0.00	0	0.00	0.00
US35		0.500	1.00	6	0.80	3.67	1	0.10	0.10	0	0.00	0.00
US40	M Sand	0.425	1.23	8	1.00	4.68	3	0.25	0.34	2	0.18	0.18
US50		0.295	1.76	26	3.41	8.08	24	2.36	2.70	33	3.01	3.19
US60		0.250	2.00	26	3.47	11.56	55	5.40	8.10	324	29.52	32.71
US70	F Sand	0.212	2.24	99	13.16	24.72	77	7.51	15.60	305	27.79	60.50
US80		0.177	2.50	120	15.97	40.68	55	5.35	20.95	197	17.95	78.45
US100		0.149	2.75	146	19.51	60.19	67	6.58	27.53	109	9.93	88.38
US120		0.125	3.00	138	18.37	78.56	139	13.59	41.12	86	7.84	96.22
US140	VF Sand	0.105	3.25	38	5.08	83.63	114	11.14	52.26	21	1.87	98.09
US170		0.088	3.51	52	6.95	90.58	172	16.83	69.09	10	0.91	99.00
US200		0.075	3.74	38	5.01	95.59	141	13.79	82.88	7	0.59	99.59
US230		0.063	4.00	12	1.60	97.19	34	3.34	86.21	2	0.18	99.77
US325	C Silt	0.045	4.24	15	1.94	99.13	92	8.98	95.19	1	0.09	99.86
US400		0.038	4.47	3	0.33	99.47	9	0.83	96.03	0	0.00	99.86
PAN	M Silt - Clay	—	—	4	0.53	100.00	41	3.97	100.00	2	0.14	100.00
			Totals	**749**	**100**	**100**	**1019**	**100**	**100**	**1098**	**100**	**100**

VITA 2

S. Jerrod Smith

Candidate for the Degree of

Master of Science

Thesis: DOWNSTREAM FINING IN A SAND-BED SEGMENT OF THE CANADIAN RIVER, NEW MEXICO, TEXAS, AND OKLAHOMA

Major Field: Geology

Biographical:

Personal Data: Born on July 6, 1977, to Robert and Kathleen Smith in Oklahoma City, Oklahoma

Education: Graduate of Yukon High School in Yukon, Oklahoma in 1995; Bachelor of Science degree in Geology conferred by Oklahoma State University in 1999; awarded Geographical Information Systems Certificate by the Department of Geography in 2001. Completed the requirements for the Master of Science degree in Geology at Oklahoma State in August, 2002.

Experience: Employed by the Department of Geology from 1997-1999 as a research assistant, 1999 as department webmaster, and 1999-2001 as a graduate teaching assistant. Currently empoyed as a hydrologist at the United States Geological Survey, Water Resources Division in Oklahoma City, Oklahoma