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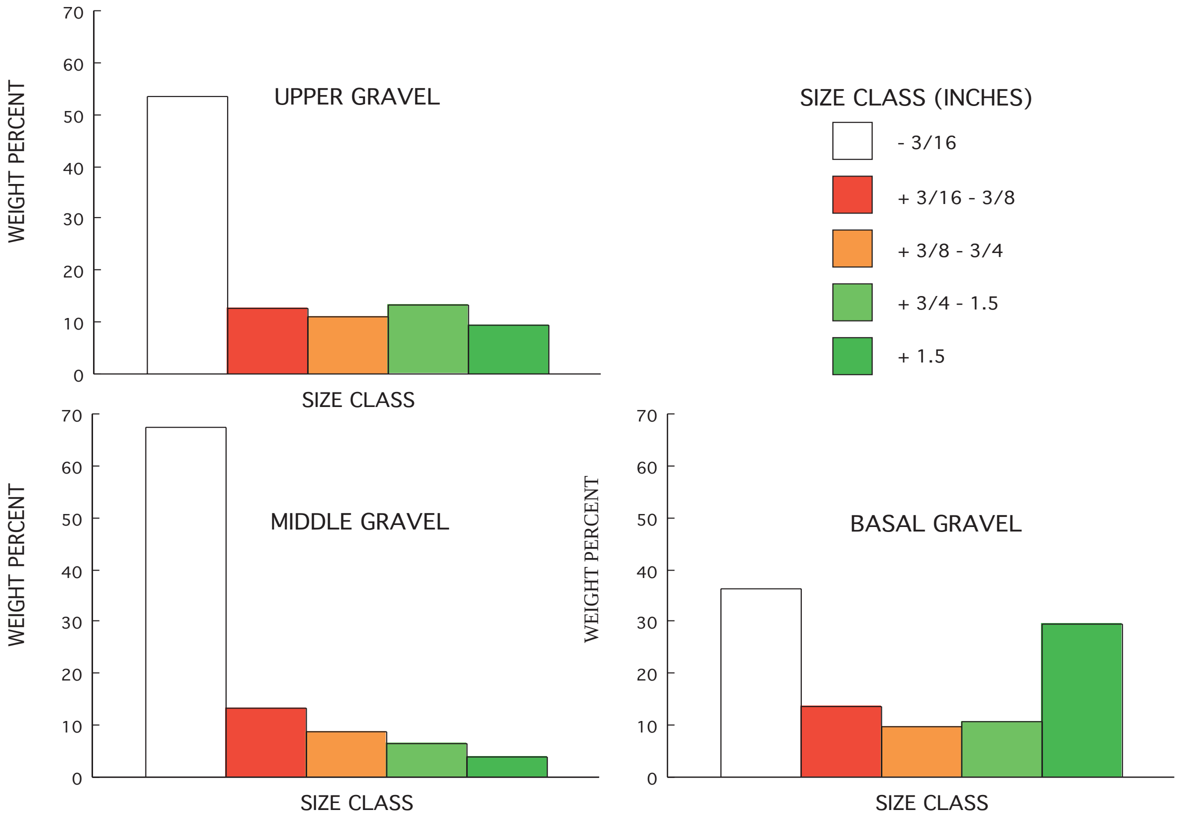
Gravel deposits of the South Platte River valley north of Denver, Colorado
Part B: Quality of gravel deposits for aggregate

by

David A. Lindsey,[1] William H. Langer,[1] and John F. Shary[1]

OPEN-FILE REPORT 98-148-B



Histograms showing average particle size of gravel units in the study area

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GRAVEL DEPOSITS OF THE SOUTH PLATTE RIVER VALLEY NORTH OF DENVER, COLORADO

PART B: QUALITY OF GRAVEL DEPOSITS FOR AGGREGATE

by David A. Lindsey, William H. Langer, and John F. Shary

SUMMARY

The present study focuses on stratigraphic and local variation in the quality of gravel deposits for aggregate beneath the floodplain and low terraces of the South Platte River. Gravels were studied at three sites in a 5.5-mile reach beneath the floodplain and low terraces north of Denver, Colo., upstream from the 1974 limit of gravel mining. Aggregate quality was determined by field and laboratory measures on samples collected under a consistent sampling plan. The main variable affecting aggregate quality in the South Platte River valley is particle size.

The primary differences in particle size of gravels beneath the floodplain and low terraces of the South Platte River north of Denver are stratigraphic. Three gravel units beneath the surface of the floodplain and low terraces are continuous and do not change with elevation of the surface, allowing sampling of gravel without regard to the elevation of the surface. The three gravel units exhibit marked variation in particle size. The basal gravel is composed of coarse pebble-to-cobble gravel, the middle gravel contains more sand than gravel, and the upper gravel contains variable particle sizes with concentrations of sand. Overall, however, the upper gravel is coarser-grained than the middle gravel. Taking into account the differences among gravel units, particle size also varies among the three sample sites. Although particle size appears to decrease downstream, it may also vary in other directions across the valley.

Two other field measures of aggregate quality, pebble lithology and shape, show little significant variation among gravel units and sampling sites. Pooled estimates of pebble lithology show about 25 pct granite, 23 pct gneiss, 31 pct pegmatite, 8 pct quartz, and about 13 pct minor rock types, including mafic rocks, volcanic and shallow intrusive porphyry, sandstone, quartzite, and chert. Among the rock types, only the minor mafic rocks, porphyry, and chert are potentially deleterious to aggregate quality. The abundance of easily-weathered mafic rocks is least in the youngest gravel units. Pebble shape is dominantly equidimensional, with some tendency to form thick disc shapes. Rod- and blade- shapes comprise 16 pct and 15 pct of the pebble size fraction, respectively, but even these shapes have axial ratios above 0.5, suggesting that they are not a significant source of weak particles. Comparison of pebble shape with rock type shows no variation in shape among the major types. Only two of the least abundant rock types, mafic rocks and schist, tend toward disc and blade shapes.

Roundness of gravel pebbles shows a pronounced tendency to decrease downstream, in accord with earlier results from modern stream gravels in the South Platte. The origin of downstream decrease in gravel roundness is not well understood but may be caused by selective abrasion and breakage during transport in the river. Among rock types represented in pebbles, pegmatite has the lowest roundness values. The relation between roundness and quality has not been studied for South Platte gravel, but variation in the abundance of rounded particles may have a subtle effect on suitability.

Los Angeles abrasion tests show a narrow range in values (39.47-44.48 percent loss) among gravels from the three stratigraphic units. Also, tests on major rock types in the gravel showed a narrow range of values. Two minor rock types, mafic rocks and porphyry, showed lower loss to abrasion than other rock types. The abundance of mafic rocks and porphyry in gravels of the South Platte is too minor to affect overall Los Angeles abrasion values.

SCOPE AND PURPOSE OF STUDY

Study of the aggregate quality of gravel deposits beneath the floodplain and low (post-Piney Creek) terraces of the South Platte River north of Denver was undertaken to assess the effects of stratigraphy on variation in measures of quality. Sampling for aggregate quality was conducted in the three gravel pits where the stratigraphic framework reported in Part A was established. The three pits selected for study of aggregate quality are located on the floodplain and low terraces of the South Platte upstream from the lower limit of gravel mining in 1974 (Figures 1, 2, and 3 of Part A) and are among those that, as of 1997, continue to be a major source of gravel for the Denver market.

Low (post-Piney Creek) terraces are only slightly higher than the floodplain of the South Platte River and can be distinguished only on aerial photographs. The gravel units beneath the surface are continuous and do not change with elevation of the surface (see discussion of gravel stratigraphy in Part A). Therefore, both the terraces and the floodplain are considered as a single physiographic unit, and the gravels beneath them can be sampled without regard to the elevation of the surface.

The discovery of distinct, traceable layers of gravel beneath the floodplain and low terraces of the South Platte River (see Part A) indicated that gravel stratigraphy should be examined as a potential source of variability in the quality of gravel for aggregate. Thus, stratigraphy is incorporated into the sample design for measurement of quality. Earlier study of present-day gravel bars in the South Platte River (Lindsey and Shary, 1997) indicated a potential for large local variation in particle size within the same depositional unit. Thus, the sample design incorporates a sampling level to measure and average local variation in aggregate quality. Averaging of sample measurements over stratigraphic units and locations provides the best method of obtaining reliable estimates of aggregate quality in the area of major gravel production.

Sampling was limited to accessible parts of each pit where a consistent sampling plan could be implemented. Thus, comparisons of aggregate quality are valid among the sample sites and the gravel units selected for study, but not necessarily among gravel pits, which cover larger areas than do the sample sites. Each gravel pit provides a window for sampling gravel deposits, but sampling of an entire pit, which changes in size and location over time and may differ in size from its neighbors, is not necessary or even desirable to obtain consistent data on gravel quality. Implementation of a consistent sampling plan, including consistent distances among samples, is necessary if statistically valid comparisons are to be made among sample sites and gravel units.

Estimates of aggregate quality downstream from the 1974 limit of gravel mining are beyond the scope of the present study. Such estimates, particularly in the region between the 1974 and 1997 limits of gravel mining, are needed to assess downstream variation in gravel quality in the South Platte River valley. Reconnaissance data on thickness, particle size, and composition of gravels in the South Platte and tributary streams have been published (Colton and Fitch, 1974; Schwochow, 1974).

ACKNOWLEDGEMENTS

We thank employees of Western Mobile and Camas Cooley for granting access to company gravel pits and for sharing their knowledge of individual gravel deposits and mining operations.

SAMPLING AND METHODS

Samples for particle size and pebble (0.75-1.5 inch) lithology, shape, and roundness were collected from the upper, middle, and basal gravels at one site in each of three gravel pits (see Table 1 and Figure 1 of Part A for geographic locations of sample sites; Figure 1 of this Part shows the structure of the sample plan). For clarity, each gravel (upper, middle, and basal) will be referred to as a “gravel unit” in the sampling plan. Sample site A is located farthest upstream and site C farthest downstream. Sites A and B are 3.7 miles (mi) apart; sites B and C are 1.8 mi apart. At each site, three sections spaced about 500 feet (ft) apart (over a total distance of 1,000 ft) were selected for sampling each gravel unit. Section spacing was guided by results of a pilot study of river gravel, which showed that major local varation in gravel quality exists between gravel bars spaced about 600-900 ft apart (Lindsey and Shary, 1997). Vertical trench samples of each gravel unit were cut across stratification with a shovel. Several samples of the upper gravel were prepared by blending trench samples of locally heterogenous beds, but all other samples consisted of a single trench sample. Most samples weighed 30-55 pounds (lbs) (median weight of 44 lbs). The basal gravel was not available for sampling at two sections at site A and at one section at site B. Thus each gravel unit and each sample site were represented by 6-9 samples. A total of 24 samples were analyzed for particle size and 23 samples for pebble lithology, shape, and roundness.

Each sample was processed in the field by dry sieving and the weight of each fraction recorded with a hand scale. Sieves having mesh openings of 1 1/2, 3/4, 3/8, and 3/16 inches were used to separate gravel-size particles. Sand (<3/16 inch) was collected in the pan and weighed but not split into size fractions. The 0.75-1.5 inch pebble fraction was reserved for lithologic identification, shape, and roundness determinations. Due to an oversight, no pebbles were collected from the middle gravel at one section at site A. Except for two samples where only 25 and 35 pebbles were available from the sieved sample, a split of 50 pebbles was classified by lithology and roundness and measured with a ruler to determine the long (A), intermediate (B), and short (C) dimensions. Assignment of pebbles to lithologic categories was simplified and systematized to assure consistency (Lindsey and Shary, 1997, tab. 3). Thus, lithology, shape, and roundness were determined for a total of 1110 pebbles. Study methods, statistical analysis, and interpretation of particle size, shape, and roundness are described by Pettijohn (1975), and additional details on methods of measurement and statistical analysis of particle size are provided by Krumbein and Pettijohn (1938). All sample results are compiled in Appendix tables A1, A2, A3, and A4.

After identification and measurement, pebble samples from each of the three gravel units were combined and prepared for Los Angeles abrasion tests. Enough material was available for one test each on the middle and basal gravel units and two tests on the upper gravel unit. In addition, large pebbles and cobbles of all abundant and most minor rock types were collected from the pit floor at site B and prepared for abrasion tests. Samples were prepared using the criteria of ASTM C131, with a nominal weight of 5,000 grams in grading category A. Procedures for ASTM C131 are described by Meininger (1994). All abrasion tests were performed in the laboratories of Western Mobile. Additionally, bulk specific gravity of crushed samples was determined on the excess material not needed for abrasion tests, as described by Landgren (1994). Because samples

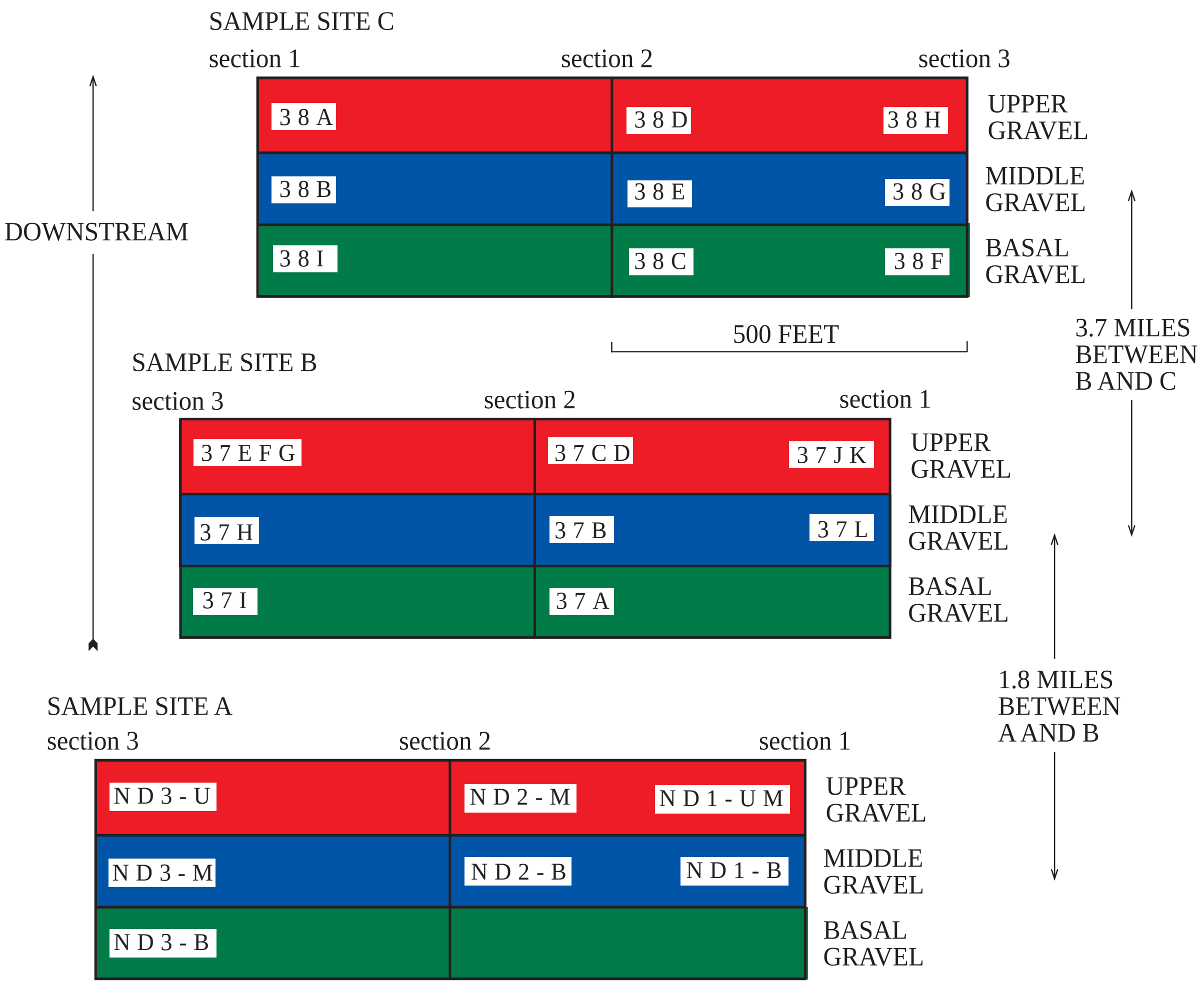

Figure 1.—Schematic representation of sample plan for gravel deposits beneath the floodplain and low terraces of the South Platte River valley north of Denver, Colo. Three sections were sampled at each of three sites (A, B, and C, at the Cooley North Dahlia, Western Mobile Howe, and Western Mobile Mann Lake pits, respectively).

consisted mainly of impermeable rock, water absorption should be negligible and was not determined.

STATISTICAL ANALYSIS OF VARIATION

Variation in gravel quality among units and sites may be analyzed by means of a factorial experiment (factorial experiments are discussed by Snedecor and Cochran, 1967), where each measurement is classified by gravel unit and by sampling site. Gravel units are upper, middle, and basal and represent successive episodes of alluvial reworking. Sample sites are spatially separate (1.8 mi between A and B, 3.7 mi between B and C) and may represent downstream variation or, alternatively, random local variation. Samples from multiple sections at each site represent repeated measurements in the experiment. Thus, it is possible to examine the effects of stratigraphy (gravel unit) and sample site (location) on each property measured, and to determine whether the effects of each factor interact. Interaction is indicated where a measurement varies depending on the selection of gravel unit or sample site. For example, if particle size varies by gravel unit, it may do so at certain sites and not others, and the variation in particle size by gravel unit may be said to interact with location. If interaction between factors is absent, it is possible to examine variation within a factor without complication. The accompanying example for PCT > 3/4 inch (weight percent gravel>3/4 inch) illustrates analysis of a factorial experiment (Table 1). In the example for PCT > 3/4 inch, the F-test indicates significant differences in mean values among both gravel units and sample sites, but it does not otherwise specify the nature of the differences. The test for interaction shows virtually no effect of one factor on the other; effects of gravel unit and sample site on PCT > 3/4 inch are judged to be independent. The source of variation for each factor can be examined by computing the means of repeated measurements (sections) for each (Table 2). After computing means and statistics for each gravel

Table 1.—Example of a factorial analysis of variance for differences among means, PCT > 3/4 inch particle size for gravel units and sample sites, and for interaction between gravel unit and sample site means. PCT, cumulative weight percent; DF, degrees of freedom; F-value, ratio of sum of squares to mean square; P-value, probability of a Type 1 error (of falsely rejecting the null hypothesis that the differences among means is zero).

	DF	Sum of squares	Mean square	F-value	P-value
Gravel unit	2	2867.511	1433.755	13.075	.0005
Sample site	2	1231.426	615.713	5.615	.0151
Interaction	4	28.869	7.217	0.066	.9912
Residual	15	1644.817	109.654		

Gravel unit	N	Mean	Standard deviation	Standard error
Upper gravel	9	25.304	12.256	4.119
Middle gravel	9	12.703	9.916	3.304
Basal gravel	6	40.143	13.236	5.404

Table 2.—Mean value, standard deviation, and standard error for PCT > 3/4 inch particle size for each gravel unit. Data calculated for use in tests for differences among gravel units. N = number of measurements.

Table 3.—Results of Fisher's PLSD (Protected Least Significant Difference) for differences between mean values, PCT > 3/4 inch particle size, for three gravel units. P-value, probability of a Type 1 error (of falsely rejecting the null hypothesis that the differences among means is zero). Significance: **, .05-.01 level; ***, <.01 level.

Units compared	Mean difference	Critical difference	P-value	Significance
Upper gravel vs middle gravel	12.601	10.522	.0221	**
Upper gravel vs basal gravel	-14.839	11.764	.0168	**
Middle gravel vs basal gravel	-27.440	11.764	.0002	***

Sample site	N	Mean	Standard deviation	Standard error
A	7	24.071	13.025	4.923
B	8	32.184	16.222	5.735
C	9	17.439	15.116	5.039

Table 4.—Mean value, standard deviation, and standard error for PCT > 3/4 inch particle size for each sample site. Data calculated for use in tests for differences among sample sites. N = number of measurements.

Table 5.—Results of Fisher's PLSD (Protected Least Significant Difference) for differences between mean values, PCT > 3/4 inch particle size, for three sample sites. P-value, probability of a Type 1 error (of falsely rejecting the null hypothesis that the differences among means is zero). Significance: **, .05-.01 level; NS, not significant at 0.10 level.

Sites compared	Mean difference	Critical difference	P-value	Significance
A vs B	-8.113	11.552	.1551	NS
A vs C	6.632	11.248	.2281	NS
B vs C	14.745	10.845	.0110	**

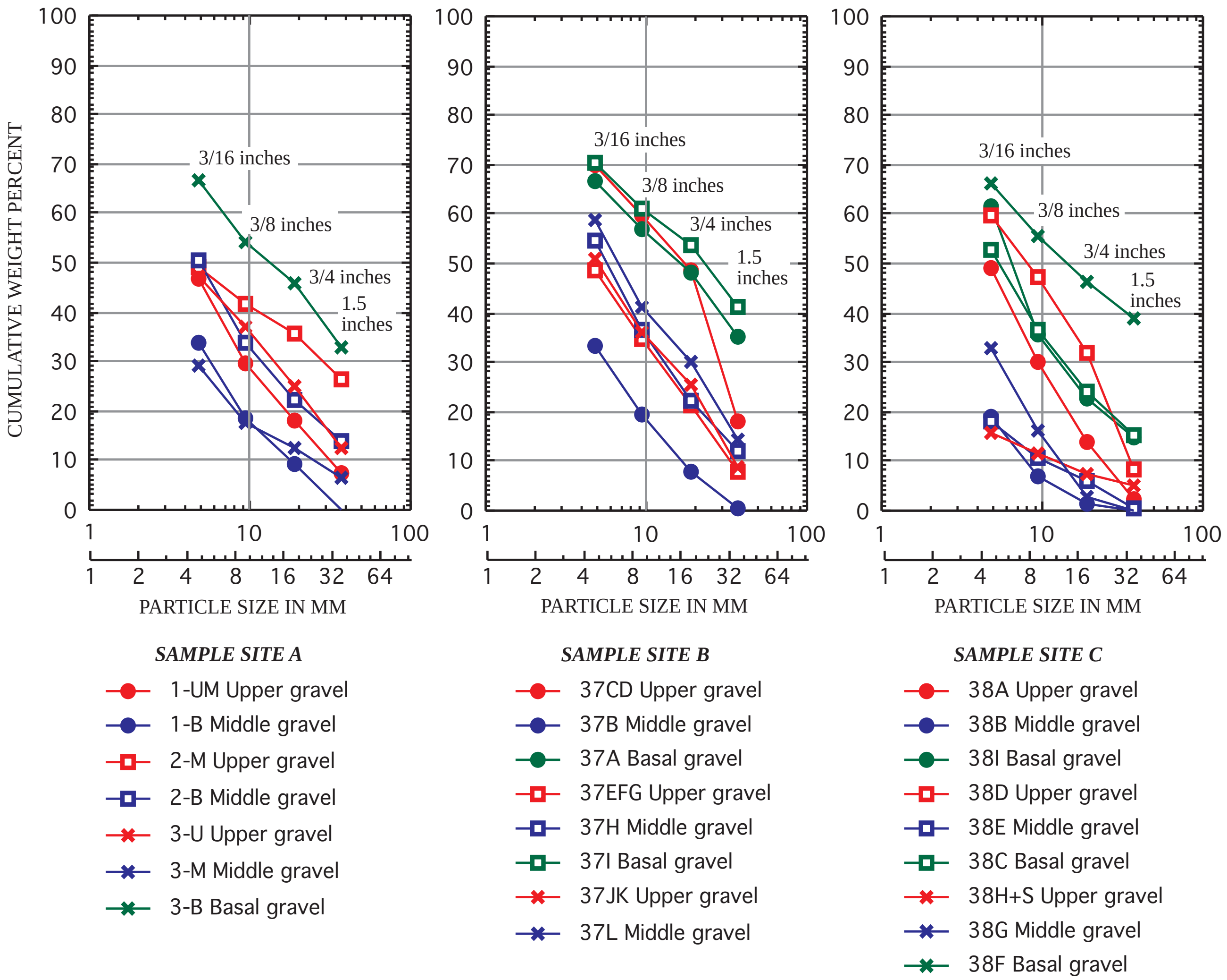

Figure 2.—Cumulative frequency distributions of coarse particle size for gravels beneath the floodplain and low terraces of the South Platte River valley north of Denver, Colo. Sieve size in inches shown within charts; particle size in millimeters (MM) shown by two logaraithmic scales (base 10 and base 2) below charts.

unit, testing for differences between the means is conducted (Table 3). The P-values for all three comparisons show significant differences among the means for gravel units, with a probability of about two percent or less for a Type I error. Likewise, means for each sample site can be calculated (Table 4). Means for each site are then compared by testing for differences (Table 5). Only the P-value for sample site B vs C indicates a significant difference between the means for PCT > 3/4 inch gravel, with slightly more than a one percent probability of a Type I error.

The test for differences among individual means illustrated here is Fisher's PLSD (Protected Least Significant Difference) test. Application of Fisher's protected test is relevant only to factors that show significant differences in the general F-test. It also assumes equal sample numbers (in this case, at each section and for each factor) and homogenous variances; when these conditions are not met, Fisher's test is prone to over-detect significant differences. In consideration of the limitations of Fisher's test, the more conservative Scheffe's F-test was also used. Scheffe's F-test is not dependent on the assumptions of Fisher's test and is less likely to lead to the conclusion that two means are different when they are not (for discussion of tests among means in factorial experiments, see Abacus Concepts, 1996).

The mean values for each gravel unit and each sample site may be graphed separately if no interaction exists, or together to show interaction. Although most measures studied here do not show interaction, graphs showing means for each gravel unit at each sample site are presented to fully display the data. For some measures of particle shape, the graphs show interaction between gravel units and sample sites (location).

PARTICLE SIZE

The distribution of gravel particle size shows considerable variation among the 24 samples, both within sample sites and within gravel units (Figure 2). In general, gravel (> 3/16

Table 6.—Summary statistics for particle size, 24 samples from three sample sites, gravel deposits beneath the floodplain and low terraces of the South Platte River valley north of Denver, Colo. PCT, cumulative weight percent; MM, millimeters; weighted mean, adjusted for thickness of each gravel unit; —, not applicable.

SIZE PARAMETER	MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM	SKEWNESS	KURTOSIS	MEDIAN	WEIGHTED MEAN
PCT > 1.5 INCHES	13.4	12.7	0	41	0.94	-0.21	10.3	11.6
PCT > 3/4 INCHES	24.3	15.6	1.5	53	0.38	-0.93	22.5	21..8
PCT > 3/8 INCHES	34.5	16.1	7	61	0.00	-0.95	36.0	31..7
PCT > 3/16 INCHES	47.9	16.6	16	70	-0.52	-0.74	49.8	44.9
MEDIAN SIZE IN MM	7.1	6.9	.02	25	1.32	0.54	5	3.5
ESTIMATED MAXIMUM SIZE IN MM	156	184.9	40	800	2.19	4.44	75	80
LOG ESTIMATED MAXIMUM SIZE IN MM	1.996	.392	1.602	2.903	0.83	-0.43	1.874	--

inch size) ranges from as little as 16-30 pct of some samples to as much as 70 pct of the coarsest samples, with an overall mean of 48 pct > 3/16 inch gravel for all 24 samples (Table 6). The overall mean for PCT > 3/4 inch gravel is only 24 weight pct. The mean median particle size for all samples, estimated from cumulative frequency plots (Figure 2), is about 7 mm (Table 6), slightly less than the 3/8 inch (9.5 mm) sieve size. The 24-sample frequency distribution of most particle size parameters is not appreciably skewed, so that mean values for all parameters are close to the medians. Weighted mean values (that is, means calculated from values that are weighted for thickness of gravel units where sampled) are slightly smaller than unweighted means. Although the thicknesses of gravel units overlap greatly, the coarse-grained basal unit is generally thinner (4-8 ft, average 6.3 ft) than the middle (3-12 ft, average 7.6 ft) and upper (3-15 ft, average 8.7 ft) gravel units at the three sample sites. Total thickness of gravel at each site varies within a narrow range of 20-23 ft, however, because at any one section, differences in thickness of one gravel unit are compensated by the other two units. Weighted means are prerequisite for calculating gravel resources but, given the small differences in average thickness of gravel units and the overall constant total thickness of gravel, unweighted means were judged adequate for statistical comparison and tests for differences among gravel units and sample sites. Unweighted values were used for simplicity in statistical calculations.

The size of the largest clasts in a gravel is of interest because it may affect choices of crushing equipment; largest size is also an indicator of maximum stream power during prehistoric floods. The largest clasts were not measured directly, but were estimated by projecting the curves of cumulative frequency distributions. Values for estimated maximum size form a skewed frequency distribution, so log transformation of values was done to normalize the data. The best estimate of mean largest size for all 24 samples is about 200 mm (8 inches).

Particle size varies primarily according to gravel unit (Table 7, Figure 3). Size is largest in the basal unit and smallest in the middle unit. The contrast in particle size between the upper and middle units is not as great as between these units and the basal unit, but the upper unit is consistently finer-grained than the basal unit. Nearly every indicator of particle size shows this pattern of variation (Figure 3). A secondary source of variation in particle size is sample site (location). Particle size tends to be smaller at site C (downstream) than at site B, but particle size at site A cannot be distinguished from that at sites B and C (Table 7). Geographic variation among sites may be a downstream effect or may represent local variation across the floodplain and low terraces. No interaction between variation in particle size among units and sites was observed.

Variation in particle size by unit is interpreted in terms of variations in stream power through time. Stream power is a function of discharge and gradient; variation of either of these will account for differences in particle size of stream deposits. The South

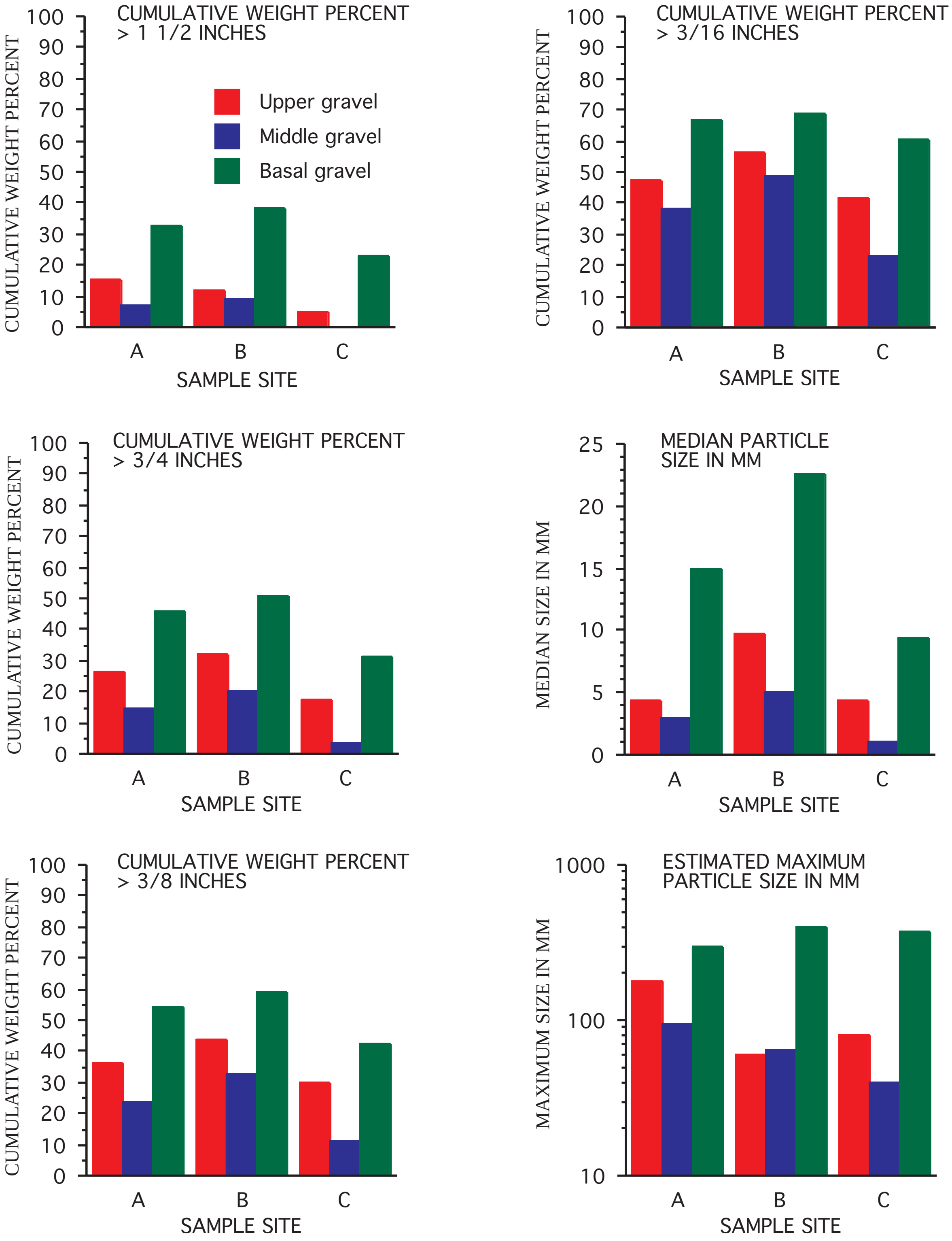

Figure 3.—Interaction plots for particle size parameters versus gravel unit and sample site, gravels beneath the floodplain and low terraces of the South Platte River valley north of Denver, Colo. MM, millimeters.

Table 7.—Summary of tests for differences among gravel units and sampling sites, mean values for particle size parameters, gravel deposits beneath the floodplain and low terraces of the South Platte River valley north of Denver, Colo. Sites: A, upstream; B, middle; and C, downstream; PCT, cumulative weight percent; *, significant difference at 0.10 level; **, significant difference at 0.05 level; ***, significant difference at 0.01 level; NS, no significant difference detected at 0.10 level (Fisher's PLSD multiple t-test); +, ++, +++, significant differences at 0.10, 0.05, and 0.01 levels, respectively (Scheffe's F-test). No interaction detected among gravel units and sampling sites.

COMPARISON	PCT >1 1/2 INCHES	PCT >3/4 INCHES	PCT > 3/8 INCHES	PCT > 3/16 INCHES	MEDIAN SIZE	ESTIMATED MAXIMUM SIZE
UPPER GRAVEL VS MIDDLE GRAVEL	NS	** +	** +	*	NS	NS
UPPER GRAVEL VS BASAL GRAVEL	*** ++	** +	** +	** +	*** ++	*** +++
MIDDLE GRAVEL VS BASAL GRAVEL	*** +++	*** +++	*** +++	*** +++	*** +++	*** +++
SITE A VS B	NS	NS	*	NS	** +	NS
SITE A VS C	NS	NS	NS	NS	NS	NS
SITE B VS C	* NS	** ++	** ++	** +	** ++	NS

Platte first deposited the coarse basal unit during Pinedale glacial time, when discharge was greater than today. After glacial meltwater disappeared, the subsequent, much smaller South Platte deposited the middle gravel unit. Within the last 1,000 years, the modern South Platte has been reworking the middle unit, concentrating coarse particles in the upper gravel and flushing fine sediment downstream.

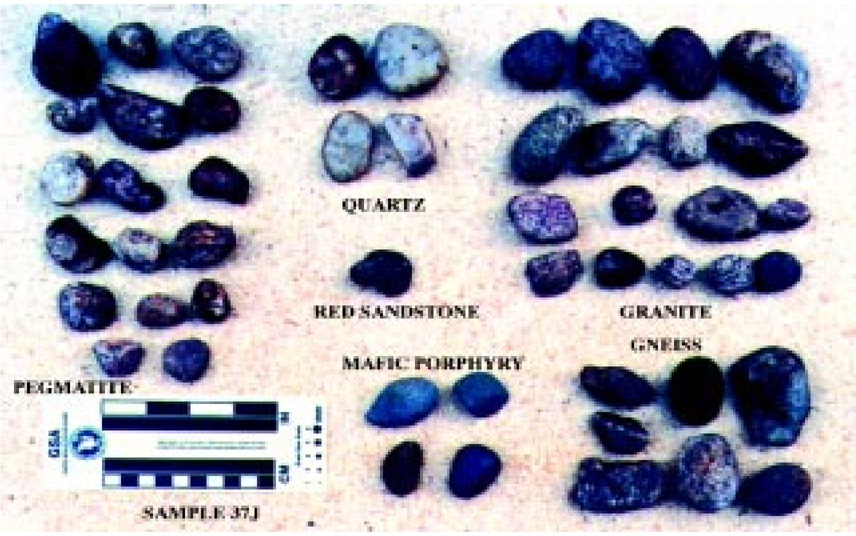

Figure 4.—Photograph of rock types represented in pebbles from gravel beneath the floodplain and low terraces of the South Platte River valley north of Denver, Colo. Scale in inches and cm.

PEBBLE LITHOLOGY

The 0.75-1.5 inch size fraction consists of about 25 pct granite, 23 pct gneiss, 31 pct pegmatite, 8 pct quartz, and about 13 pct minor rock types, including mafic rocks, volcanic and shallow intrusive porphyry, sandstone, quartzite, and chert (Figure 4; Table 8). Mafic rocks consist of mainly diabase and subordinate amphibolite from the Precambrian Front Range. Volcanic and shallow intrusive porphyry includes mafic, intermediate and felsic varieties; mafic porphyries include shoshonite from North and South Table Mountain; felsic volcanic rocks include welded tuff, probably derived from the Oligocene Wall Mountain Tuff south of Denver. Sandstone includes red arkose, mostly derived from the Pennsylvanian and Permian Fountain Formation along the mountain front, and light colored quartz sandstone, derived from the Cretaceous Dakota Group along the mountain front. Quartzite ranges from dark to light-colored metaquartzite, probably derived from thin beds of quartzite in Precambrian gneiss of the Front Range. Chert (and rare petrified wood, not encountered

Table 8.—Summary statistics for sample means of pebble lithology, 23 samples from three sample sites, gravel deposits beneath the floodplain and low terraces of the South Platte River valley north of Denver, Colo. Lithologic identification determined for 50 pebbles per sample, 0.75-1.5 inch size fraction, except two samples for which 25 and 35 pebbles were identified. Mafic rocks are diabase and amphibolite; porphry includes mafic, intermediate, and felsic volcanic and shallow intrusive rocks. —, abundance too small to calculate statistics.

LITHOLOGY	MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM	SKEWNESS	KURTOSIS	MEDIAN
PCT GRANITE	24.52	7.94	10	42	0.67	-0.35	22
PCT GNEISS	23.27	5.68	14	34	0.22	-0.64	22
PCT PEGMATITE	31.22	11.71	10	58	0.39	-0.11	30
PCT QUARTZ	7.64	6.38	2	32	2.63	7.42	6
PCT MAFIC ROCKS	1.13	1.69	0	6	1.42	1.25	0
PCT PORPHYRY	4.24	3.58	0	12	0.79	-0.32	4
PCT SANDSTONE	4.25	4.14	0	16	1.24	1.04	2
PCT SCHIST	2.17	2.62	0	8	1.07	-0.01	2
PCT QUARTZITE	1.39	2.13	0	8	1.56	1.99	0
PCT CHERT	0.17	--	0	2	--	--	0

in the pebble counts but observed at various sample sites) is probably derived from the Cretaceous and Paleocene Denver Formation, through which the South Platte River flows in the vicinity of the study area. Among the rock types identified, only a few minor constituents, such as volcanic porphyry, mafic rocks, schist, and chert, are potentially deleterious (weak or chemically reactive, Langer and Knepper, 1995). The rock types are the same as those identified in gravel bars of the South Platte; abundance of some rocks varies somewhat from those in gravel bars (Lindsey and Shary, 1997). The sample frequency distributions for most rock types except quartz are not highly skewed (Table 8), so mean values are close to median values for all rock types except some of the minor ones. No transformations were necessary prior to further data analysis.

Pebble lithology varies widely among samples, probably because the number of pebbles classified (50) for each sample was small. However, comparisons among gravel units and sites generally rely on three samples of 50 pebbles each, which should improve stability of estimates for the most abundant rock types. The abundance of granite, gneiss, pegmatite, quartz, and even porphyry is reasonably consistent among units and sites, with only a few erratic values (Figure 5). No interaction among values for gravel units and sites was detected, thus allowing isolation of any variation within units and sites. Plots of mean values and tests of signficance (Table 9) show few significant differences in pebble lithology among gravel units or sample sites. Two possible exceptions among abundant rock types are percent gneiss, which increases weakly but systematically, downstream from sites A through B to C, and percent pegmatite, which may be more abundant at site A than site B (Figure 5, Table 9). Among minor rock types, the percent of mafic rocks and schist show detectable decreases from the basal gravel to overlying units. However, because mafic rocks and schist are minor constituents, any improvement in gravel quality from the basal gravel to the middle and upper gravel units is minor. The upward decrease in mafic rocks and schist is interpreted as the effect of weathering and abrasion on relatively weak rocks during reworking. Downstream decrease in abundance of mafic rocks and schist, comparable to that observed in stream gravel in the South Platte River (Lindsey and Shary, 1997), is not observed among the three sites sampled. The downstream distance studied here is not comparable to that studied in the modern stream, and may not be sufficient to record differences noted in stream gravel. Likewise, no decrease in pegmatite abundance, observed in river gravel, was noted among gravel units or sample sites.

PEBBLE SHAPE

Pebbles of the 0.75-1.5 inch size fraction are dominantly disc-shaped (44 pct) and spherical (25 pct), with lesser quantities of rod- (16 pct) and blade-shapes (15 pct) making up the rest of the pebbles (Table 10). Sample frequency distributions for shape parameters are not highly

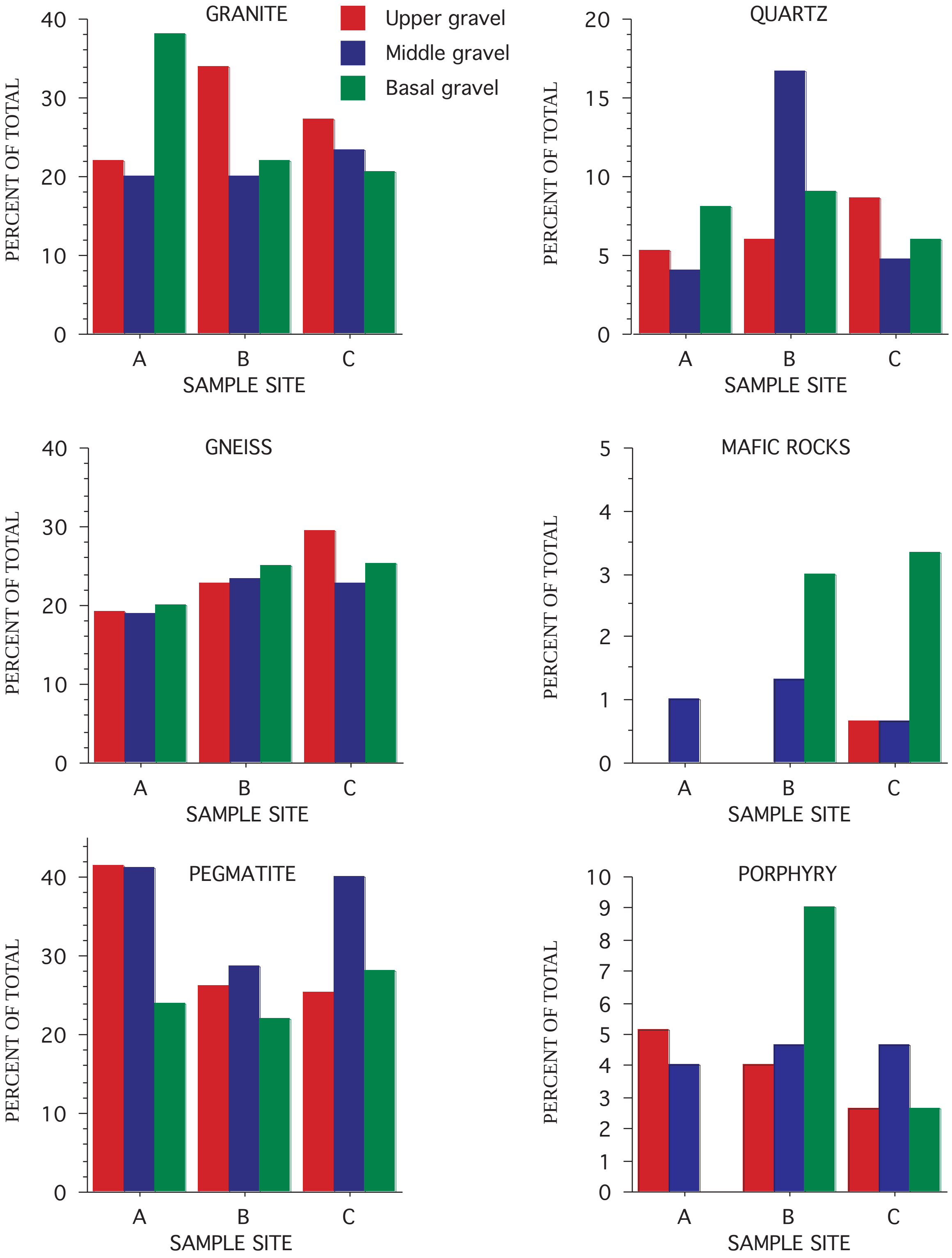

Figure 5.—Interaction plots for pebble lithology versus gravel unit and sample site, gravels beneath the floodplain and low terraces of the South Platte River valley north of Denver, Colo.

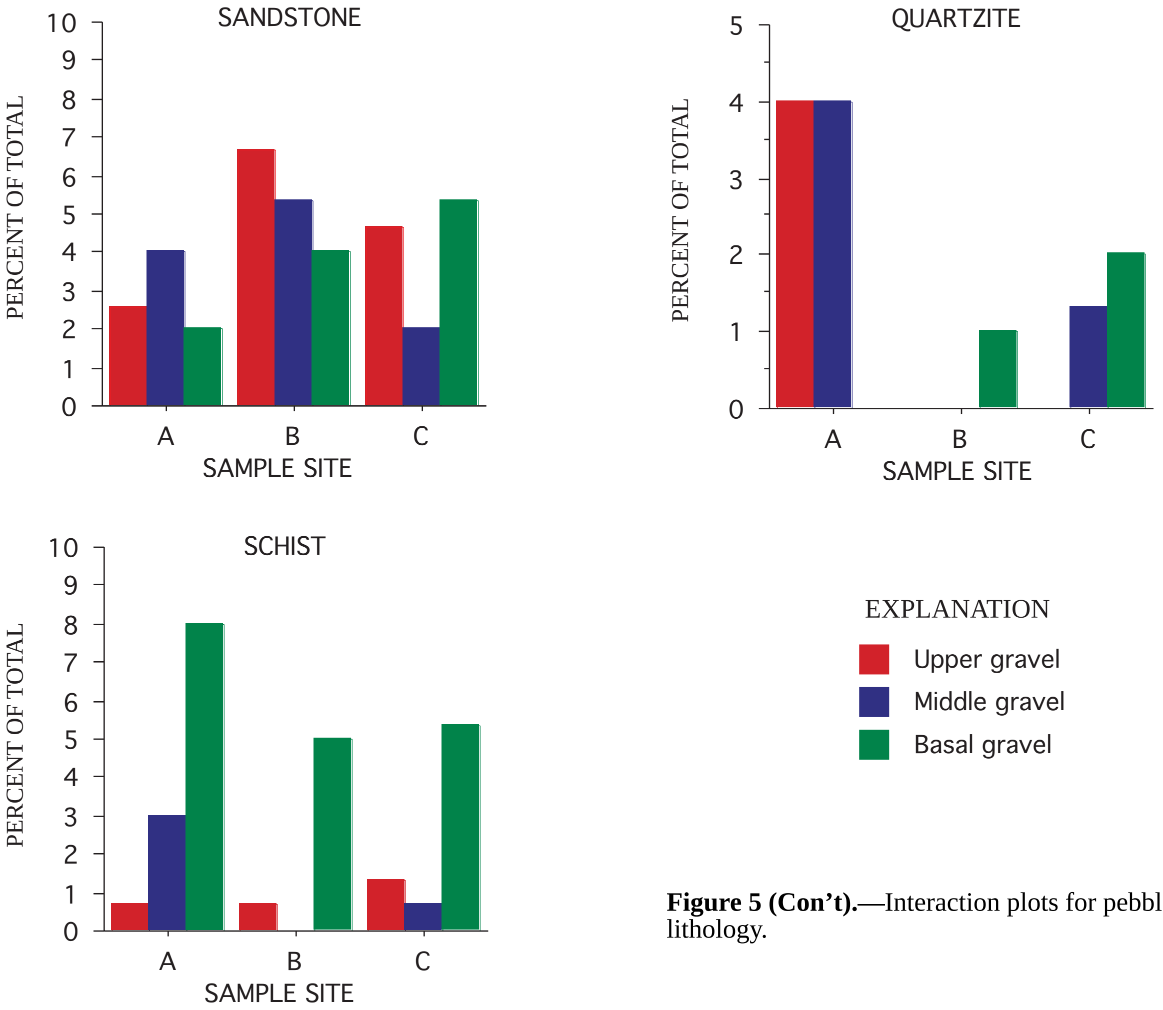

Figure 5 (Con't).—Interaction plots for pebble lithology.

Table 9.—Summary of tests for differences among gravel units and sampling sites, mean values for pebble lithology, 0.75-1.5 inch size, gravel deposits beneath the floodplain and low terraces of the South Platte River valley north of Denver, Colo. Sites: A, upstream; B, middle; and C, downstream; *, significant difference at 0.10 level; **, significant difference at 0.05 level; ***, significant difference at 0.01 level; NS, no significant difference detected at 0.10 level (Fisher's PLSD multiple t-test); +, ++, +++, significant differences at 0.10, 0.05, and 0.01 levels, respectively (Scheffe's F-test). No interaction detected among gravel units and sampling sites.

COMPARISON	PCT GRANITE	PCT GNEISS	PCT PEGMATITE	PCT QUARTZ	PCT MAFIC ROCKS	PCT PORPHYRY	PCT SANDSTONE	PCT SCHIST	PCT QUARTZITE
UPPER GRAVEL VS MIDDLE GRAVEL	*	NS	NS	NS	NS	NS	NS	NS	NS
UPPER GRAVEL VS BASAL GRAVEL	NS	NS	NS	NS	*** ++	NS	NS	*** +++	NS
MIDDLE GRAVEL VS BASAL GRAVEL	NS	NS	NS	NS	*	NS	NS	*** +++	NS
SITE A VS B	NS	NS	*	NS	NS	NS	NS	NS	*** ++
SITE A VS C	NS	*	NS	NS	NS	NS	NS	NS	** +
SITE B VS C	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 10.—Summary statistics for sample means of pebble shape, 23 samples from three sample sites, gravel deposits beneath the floodplain and low terraces of the South Platte River valley north of Denver, Colo. Shape calculated from measured lengths of long (A), intermediate (B), and short (C) pebble axes (Pettijohn, 1975, p. 54), 50 pebbles per sample, 0.75-1.5 inch size fraction, except two samples for which 25 and 35 pebbles were identified. B/A is inversely proportional to elongation; C/B is inversely proportional to flatness. Sphericity (Ψ) = $\sqrt[3]{(BC/A^2)}$ measures degree of equidimensional shape (Krumbein, 1941); when $A=B=C$, $\Psi = 1$. Shape classified as spherical, disc-, rod-, and blade-shaped by criteria of Zingg (Pettijohn, 1975, fig. 3-18). PCT, percent.

SHAPE PARAMETER	MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM	SKEWNESS	KURTOSIS	MEDIAN
MEAN B/A	0.740	0.022	0.690	0.780	-0.60	0.08	0.740
MEAN C/B	0.628	0.042	0..560	0.720	0.47	-0.70	0.620
MEAN SPHERICITY (Ψ)	0.692	0.016	0.668	0.723	0.43	-0.78	0.690
PCT SPHERICAL	25.39	6.62	14	38	0.37	-0.81	24
PCT DISC-SHAPED	43.99	9.76	20	56	-0.95	0.07	46
PCT ROD-SHAPED	16.00	5.39	6	28	0.07	-0.65	18
PCT BLADE-SHAPED	14.62	4.28	6	22	-0.10	-0.58	14

Table 11.—Summary of tests for differences among gravel units and sampling sites, mean values for pebble shape, 0.75-1.5 inch size, gravel deposits beneath the floodplain and low terraces of the South Platte River valley north of Denver, Colo. Sites: A, upstream; B, middle; and C, downstream; *, significant difference at 0.10 level; **, significant at 0.05 level; NS, no significant difference at 0.10 level (Fisher's PLSD multiple t-test); no significant differences detected by Scheffe's F-test; interaction detected between gravel units and sample sites for some shape parameters.

COMPARISON	MEAN B/A	MEAN C/B	MEAN SPHERICITY (Ψ)	PCT SPHERICAL	PCT DISC-SHAPED	PCT ROD-SHAPED	PCT BLADE-SHAPED
UPPER GRAVEL VS MIDDLE GRAVEL	NS	NS	NS	NS	NS	NS	NS
UPPER GRAVEL VS BASAL GRAVEL	NS	NS	NS	NS	NS	NS	NS
MIDDLE GRAVEL VS BASAL GRAVEL	NS	NS	NS	NS	NS	NS	NS
SITE A VS B	NS	NS	NS	NS	NS	*	NS
SITE A VS C	NS	NS	NS	NS	NS	NS	NS
SITE B VS C	NS	*	NS	*	*	**	NS
INTERACTION BETWEEN GRAVEL UNITS AND SAMPLING SITES	*	NS	**	NS	NS	NS	**

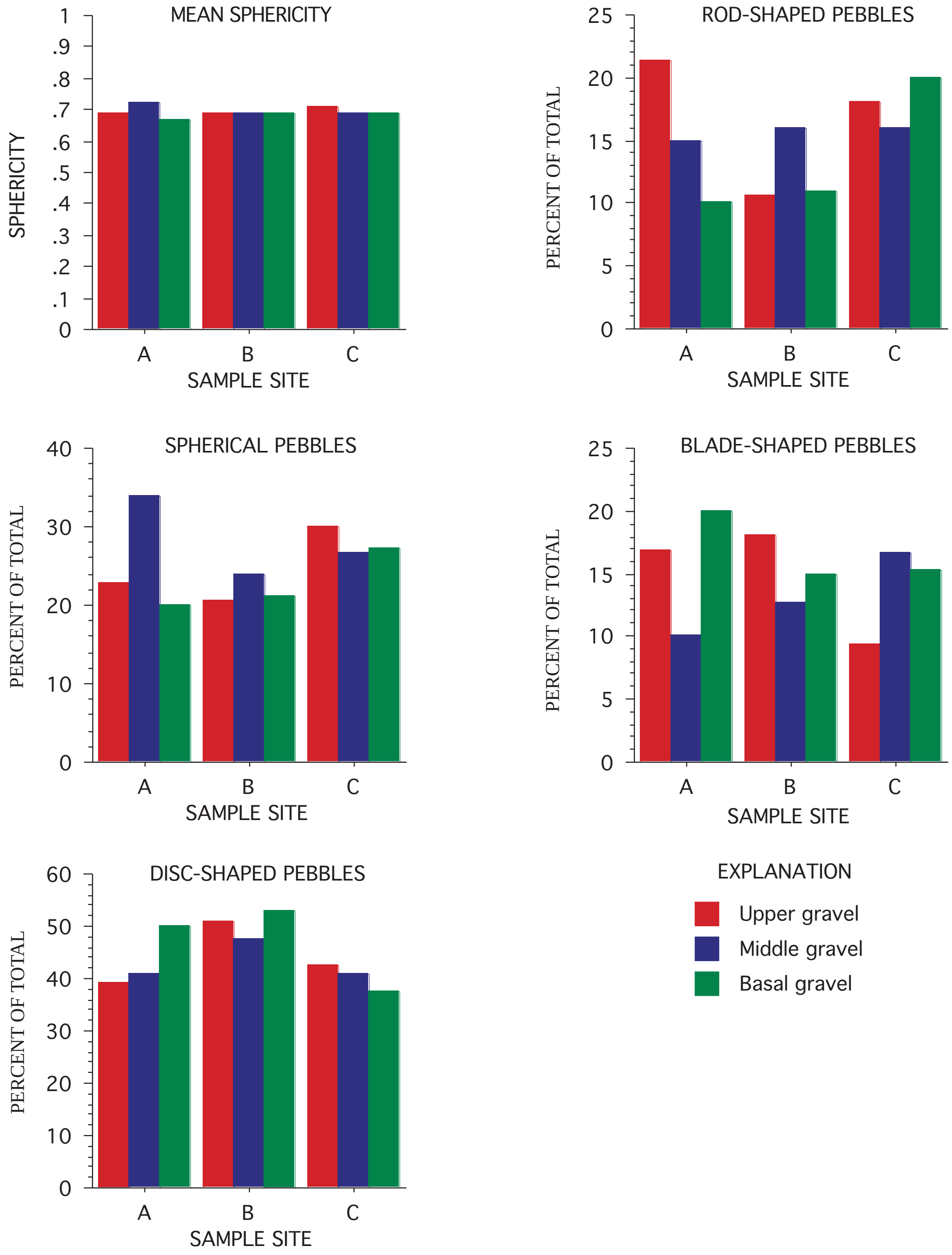

Figure 6.—Interaction plots for pebble shape versus gravel unit and sample site, gravels beneath the floodplain and low terraces of the South Platte River valley north of Denver, Colo.

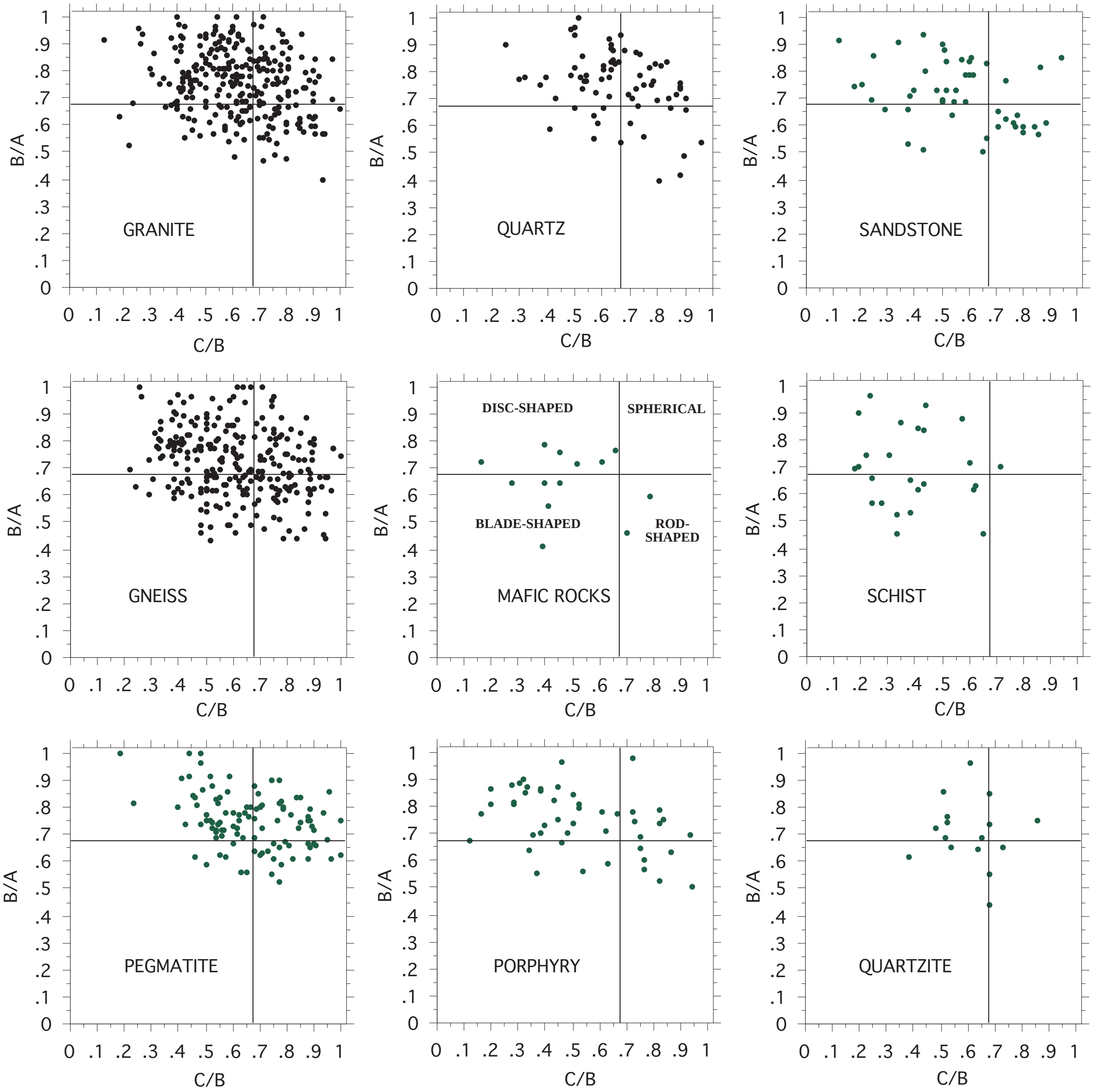

Figure 7.—Zingg diagrams showing pebble shape for common rock types in gravel deposits beneath the floodplain and low terraces of the South Platte River valley north of Denver, Colo. Based on classification of 1110 pebbles from 0.75-1.5 inch size fraction.

skewed, so mean values are close to median values and no transformations were necessary prior to further data analysis.

Shape of the 0.75-1.5 inch fraction is remarkably consistent among gravel units and sample sites (Figure 6, Table 11). No significant differences in pebble shape among gravel units were found, and only pebbles at sites B and C were found to differ in shape. Even differences in shape at sites B versus C were not detected by the more conservative Scheffe's F-test. Fisher's F-test between gravel units and sites revealed significant interaction for some shape parameters, especially sphericity and percent blade-shaped pebbles (Table 11). That is, shape may vary among gravel units depending upon which site is examined, or vice versa, but these differences are confined to blade-shaped pebbles.

An examination of pebble shape by rock type shows that shape varies only among the least abundant rock types. All 1110 individual measurements of shape that make up the 23 samples were sorted by rock type and plotted on Zingg diagrams (Figure 7). The shape fields for abundant rock types (granite, geniss, pegmatite, and quartz) are indistinguishable. Only some of the least abundant rock types, mafic rocks and schist, tend to plot mainly in the disc- and blade-shaped fields. Mafic rocks and schist, which on average make up only about one percent and two percent of all rock types,

Table 12.—Summary statistics for sample means of pebble roundness, 23 samples from three sample sites, gravel deposits beneath the floodplain and low terraces of the South Platte River valley north of Denver, Colo. Roundness estimated by visual comparison with roundness classes (Pettijohn, 1975, fig. 3-24), 50 pebbles per sample, 0.75-1.5 inch size fraction, except two samples for which 25 and 35 pebbles were determined. Mean roundness = class abundance X mid-point values of Pettijohn (1975, table 3-9). Classes defined as follows: A, angular; B, subangular; C, subrounded; D, rounded; E, well-rounded. PCT, percent.

ROUNDNESS PARAMETER	MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM	SKEWNESS	KURTOSIS	MEDIAN
AVERAGE ROUNDNESS	0.508	0.057	0.369	0.614	-0.39	0.01	0.515
PCT A	1.91	2.59	0	8	1.23	0.41	0
PCT B	10.86	7.42	0	32	1.00	1.01	10
PCT C	23.38	6.01	12	32	-0.33	-0.85	24
PCT D	33.45	7.02	22	48	0.30	-0.49	34
PCT E	30.40	11.00	8	52	0.07	-0.63	30

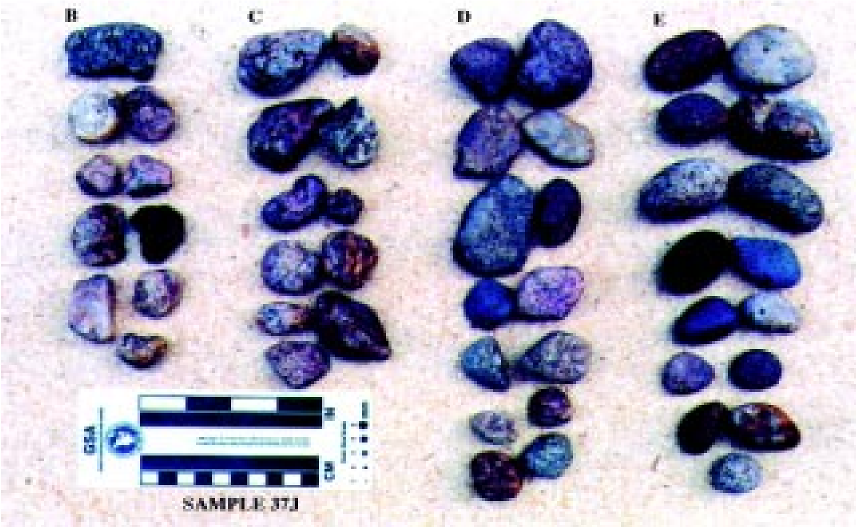

Figure 8.—Photograph of typical roundness classes of pebbles from gravel beneath the floodplain and low terraces of the South Platte River valley north of Denver, Colo.

respectively, are not sufficiently abundant to affect the overall distribution of pebble shapes. On first consideration, the absence of any tendency for gneiss and sandstone to form dominantly disc- and blade-shapes may seem perplexing, but examination of foliated and layered pebbles as well as larger clasts reveals that shape is commonly controlled by joint surfaces that cut across rock fabrics. Rock fabric commonly transects the long and flat dimensions of clasts.

PEBBLE ROUNDNESS

Pebbles of the 0.75-1.5 inch size fraction are dominantly rounded (class D = 33 pct), well-rounded (class E = 30 pct), and subrounded (class C = 23 pct); a few pebbles are subangular (class B = 11 pct) to angular (class A = 2 pct) (Table 12, Figure 8). Except for moderate skewness of percent subangular and angular pebbles, sample frequency distributions for roundness parameters are not highly skewed, so mean values are close to median values and no transformations were necessary prior to further data analysis.

Mean values for most roundness parameters do not differ significantly among gravel units, but significant differences were found between sites A and C and B and C (Table 13). Additionally, mean roundness may differ between sites A and B. No evidence was found for interaction of roundness of pebbles in gravel units versus sample sites. Plots of mean roundness parameters for gravel units and sample sites show a systematic decrease in roundness downstream, from site A through B to C, for all three gravel units (Figure 9). The downstream trend is most evident for mean roundness. Plots of individual roundness classes show that the downstream decrease in mean roundness is a function of both 1) a downstream increase in the percent of angular (class A) and subangular (class B) pebbles and 2) a corresponding downstream decrease in the percent of well-rounded (class E) pebbles. The proportion of subrounded (class C) and rounded (class D) pebbles remains constant. The downstream decrease in pebble roundness observed in the gravels is in accord with the decrease observed in pebble roundness in gravel bars of the modern South Platte (Lindsey and

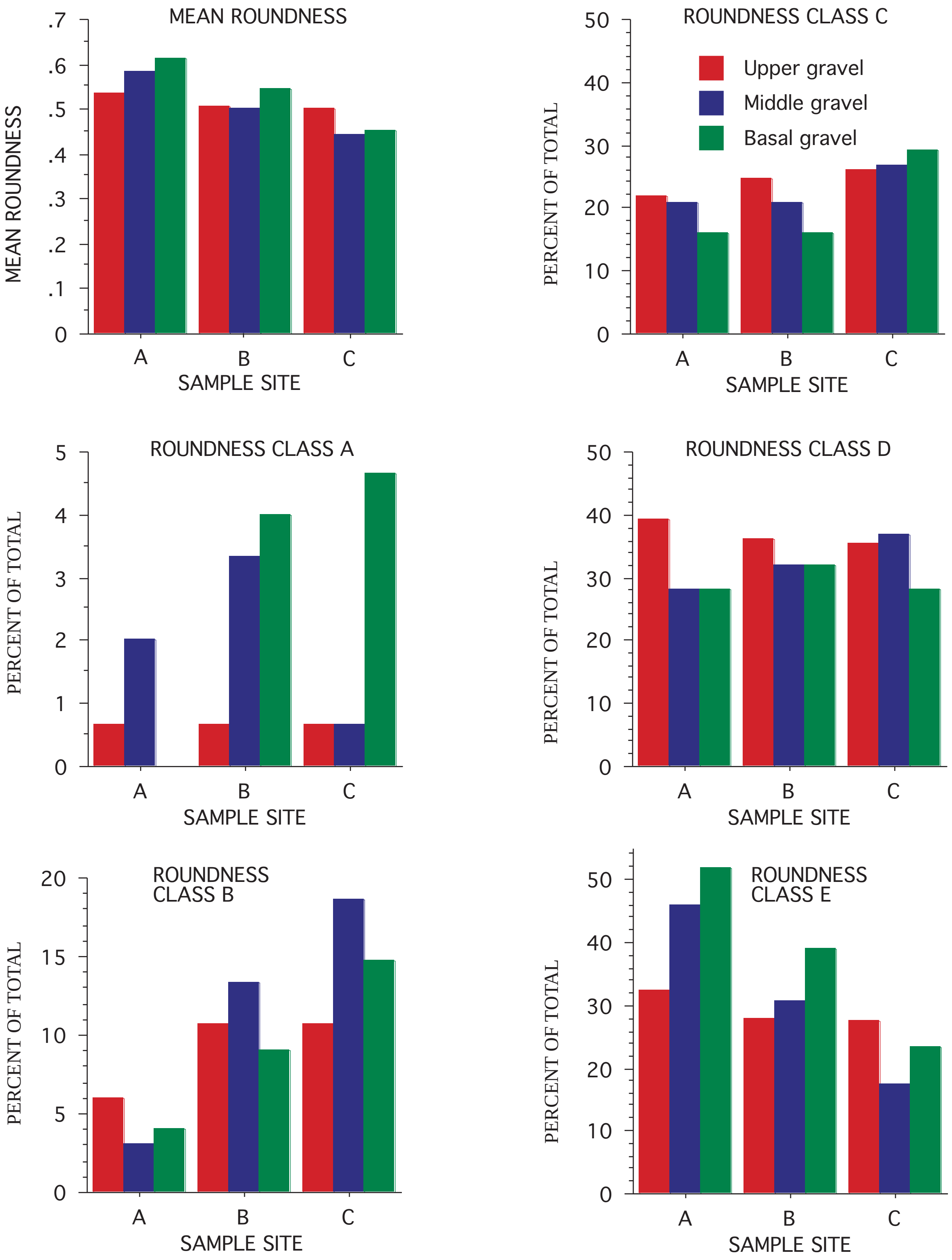

Figure 9.—Interaction plots for pebble roundness versus gravel unit and sample site, gravels beneath the floodplain and low terraces of the South Platte River valley north of Denver, Colo.

Table 13.—Summary of tests for differences among gravel units and sampling sites, mean values for particle roundness, 0.75-1.5 inch size, gravel deposits beneath the floodplain of the South Platte River valley north of Denver, Colo. Sites: A, upstream; B, middle: and C, downstream; *, significant difference at 0.10 level; **, significant difference at 0.05 level; ***, significant difference at 0.01 level; NS, no significant difference detected at 0.10 level (Fisher's PLSD multiple t-test); +, ++,+++, significant difference detected at 0.10, 0.05, and 0.01 levels, respectively (Scheffe's F-test). No interaction detected among gravel units and sampling sites.

COMPARISON	MEAN ROUNDNESS	PCT A	PCT B	PCT C	PCT D	PCT E
UPPER GRAVEL VS MIDDLE GRAVEL	NS	NS	NS	NS	NS	NS
UPPER GRAVEL VS BASAL GRAVEL	NS	**	NS	NS	*	NS
MIDDLE GRAVEL VS BASAL GRAVEL	NS	NS	NS	NS	NS	NS
SITE A VS B	** +	NS	NS	NS	NS	*
SITE A VS C	*** +++	NS	** +	**	NS	*** ++
SITE B VS C	** +	NS	NS	** +	NS	** +

Shary, 1997). However, downstream decrease in roundness in gravel bars was observed over a distance of about 18 miles, in contrast to the distance between sample sites A and C, which is only 5.5 miles.

Based on the strong evidence for downstream decrease in rounding, reworking of older, coarser gravel of the basal and middle units might be expected produce more angular and fewer well-rounded pebbles. That a decrease in pebble roundness by reworking into younger deposits is not observed, however, may indicate that the processes responsible for downstream decrease in roundness are mainly abrasion and breakage during transport and not exposure to weathering during reworking. In gravel deposited during a short interval, such as in river bars in the modern South Platte, or in an individual depositional unit beneath the floodplain and low terraces, the time of exposure to weathering may not be sufficient to affect rounding. Thus, any downstream change observed in a single depositional unit would logically stem from the transport process.

The effect of rock type on roundness was investigated for a subset of 535 pebbles (0.75-1.5 inch size fraction) that were classified both by rock type and roundness (Figure 10). For all rock types except pegmatite, the distribution of roundness is skewed toward rounded (class D) and well-rounded (class E) classes. Only pegmatite pebbles vary from this pattern; the modal roundness class for pegmatite is subrounded (class C), with abundant pebbles in both subangular (class B) and rounded (class D) classes. This finding is difficult to reconcile with the observed distribution of percent pegmatite, which does not increase downstream. In a study of pebble lithology and roundness in the gravel bars of the South Platte River, roundness was found to decrease downstream and appeared to be related to a corresponding increase in abundance of pegmatite pebbles downstream (Lindsey and Shary, 1997), as would be predicted from comparison of pebble roundness by lithology (Figure 10). Perhaps the lack of accord between downstream pebble roundness and percent pegmatite in this study indicates that estimates of abundance of pegmatite (and other rocks) for sample sites are not sufficiently reliable to detect whatever differences exist among sites. Estimates of pebble roundness are assumed to be reliable because, although based on the same number of pebbles and samples, results show systematic variation and highly significant differences in mean values among sample sites.

Conceptually, roundness may affect the tendency of particles to shift under load in some applications (Marek, 1991). Differences in roundness observed in South Platte gravel may introduce subtle variation in the suitability of coarse gravel for some applications, such as road base, but careful research would be required to verify that possibility.

LOS ANGELES (LA) ABRASION TESTS AND SPECIFIC GRAVITY

Los Angeles (LA) abrasion tests were performed to look for possible differences in quality among gravel units and to determine possible effects of rock type on degradation during handling. Test results, as well as

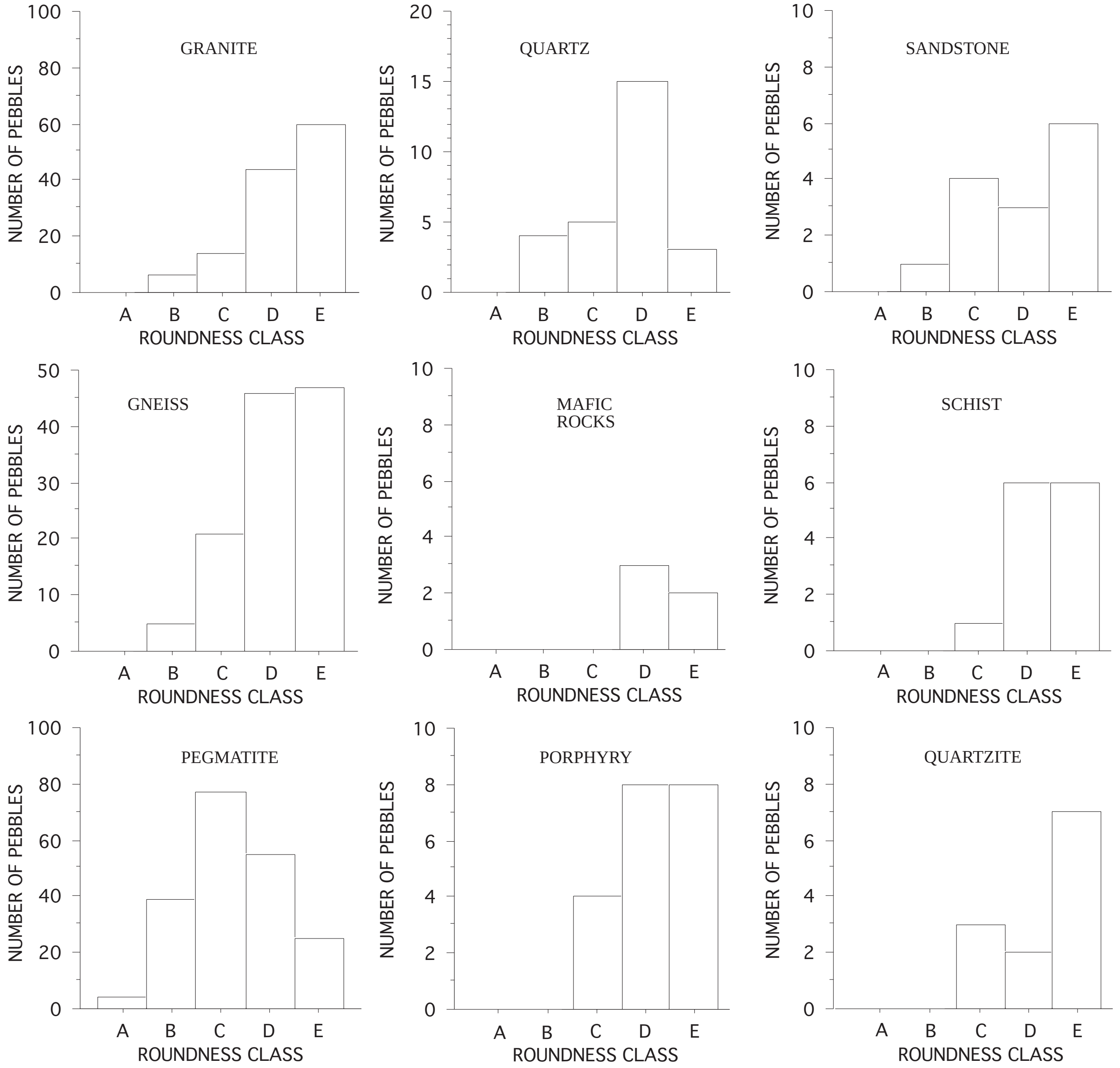

Figure 10.—Pebble roundness for common rock types in gravel deposits beneath the floodplain and low terraces of the South Platte River valley north of Denver, Colo. Based on classification of 535 pebbles from 0.75-1.5 inch size fraction. Roundness classes defined as follows: A, angular; B, subangular; C, subrounded; D, rounded; E, well-rounded.

specific gravity of material tested, are reported in Table 14.

LA abrasion tests of pebbles from the individual gravel units show a narrow range of 39.47-44.48 percent loss, with the most loss (44.48 pct) in the basal gravel. Differences in loss among gravel units may not be significant, however, because tests of the two samples of upper gravel ranged from 39.47 to 42.00 pct. Specific gravity of the gravels varies within a narrow range of 2.62-2.64. Evidently, no significant advantage in LA values would be gained by selective mining of a particular gravel unit.

Tests of individual rock types from site B yielded values that are all below those of pebbles from gravel units. This seeming inconsistency is readily explained by the fact that samples of individual rock types consisted of clasts that were mostly larger than the 1.5 inch maximum size of the pebble size fraction used in lithologic, shape, and roundness studies. (Although clasts larger than 1.5 inches are not abundant, they can be collected from a large area of the pit floor and were utilized because they provide the only practical means of accumulating enough material for testing each rock type). When crushed, the >1.5 inch clasts yield a higher ratio of fresh rock to weathered rock (from surface rinds) than the smaller 0.75-1.5 inch pebbles. The relatively high ratio of fresh to weathered rock in the samples of individual rock types assured that they would survive tumbling better than the pebble samples and thus yield the lowest LA values. Thus, LA values for large crushed clasts such as

Table 14.—Los Angeles (LA) abrasion test results and specific gravity for individual rock types and for the pebble (0.75-1.5 inch) fraction of gravels beneath the floodplain and low terraces of the South Platte River valley north of Denver, Colo. Weight before LA test refers to grading A of ASTM C 131 test specification (Meininger, 1994); weight after LA test refers to the sample weight retained on the 1.7 mm (No. 12) sieve after 500 revolutions in a cylinder at 30-33 rpm. The test cyclinder was charged with steel balls weighing 4978.3 grams. Tests were performed in laboratories of Western Mobile. Dry and wet weights were determined on excess material not used in abrasion test; aggregate adsorption in water not determined.

SAMPLE	WEIGHT BEFORE LA TEST (GRAMS)	WEIGHT AFTER LA TEST (GRAMS)	PERCENT LOSS	DRY WEIGHT (GRAMS)	WET WEIGHT (GRAMS)	SPECIFIC GRAVITY
UPPER GRAVEL 1	5000.3	3026.8	39.47	3000.4	1853.6	2.62
UPPER GRAVEL 2	5001.1	2900.6	42.00	3002.4	1858.8	2.63
MIDDLE GRAVEL	5000.4	2932.2	41.36	3000.3	1856.9	2.62
BASAL GRAVEL	5000.4	2776.2	44.48	3000.0	1865.7	2.64
GRANITE	5000.3	3014.0	39.72	3000.7	1859.3	2.63
GNEISS	5001.3	3153.2	36.95	3000.4	1872.4	2.66
PEGMATITE	5000.9	3124.5	37.52	3000.3	1857.0	2.62
QUARTZ	4994.6	3179.1	36.35	3000.2	1874.1	2.66
MAFIC ROCKS	5001.4	3667.0	26.68	3000.2	1915.7	2.77
PORPHYRY	5000.4	4051.0	18.99	3000.5	1873.3	2.66
SANDSTONE	5001.0	3076.6	38.48	3001.9	1834.5	2.57

cobbles and boulders of individual rock types cannot be compared directly with values from gravel or the pebble samples reported here. The LA values for individual rock types can be compared with one another, however, to predict the relative effect of changes in abundance of rock types in gravel.

All of the abundant rock types in gravel (granite, gneiss, pegmatite, and quartz) have LA values within a narrow range of 36.35-39.72 (Table 14). The narrow range of LA values for abundant rock types indicates that values would not be expected to vary greatly from place to place as long as the same rock types dominate the pebble population and the degree of weathering of gravel remains constant. The only significant variation in LA values that might arise from pebble lithology is limited to the abundance of two minor rock types, mafic rocks (LA value of 26.68) and porphyry (LA value of 18.99). Mafic rocks constitute slightly more than one pct of the 0.75-1.5 inch pebble fraction, and porphyry makes up slightly more than four pct of the pebble fraction. Because mafic rocks and porphyry are minor components of the gravel, any loss of these rock types that might occur during weathering and abrasion as gravel is reworked and transported downstream should yield only a slight increase in LA values.

The most noticeable variation in specific gravity among rock types is for mafic rocks (2.77) and sandstone (2.57). The high specific gravity of

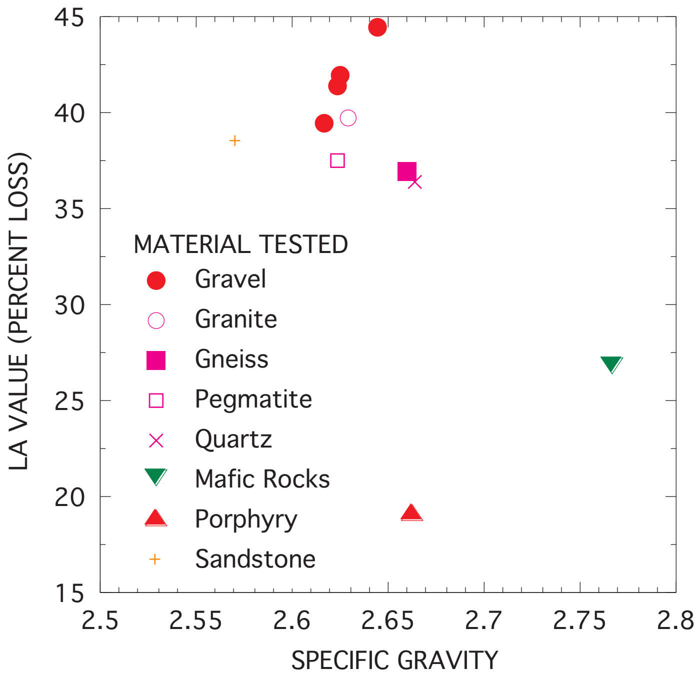

Figure 11.—Los Angeles abrasion (expressed as percent loss after abrasion) versus specific gravity for common rock types and for three gravel units beneath the floodplain and low terraces of the South Platte River valley north of Denver, Colo.

mafic rocks is attributed to their high content of heavy iron- and magnesium-bearing minerals; the low specific gravity of sandstone probably reflects the presence of pore space between sand grains. The abundance of both mafic rocks and sandstone is small and, therefore, the expected effect on specific gravity of gravel should be minor.

The strong effect of abundant rock types on LA values and specific gravity of gravel is visualized by plotting percent loss versus specific gravity (Figure 11). In the plot, values for gravel group closely with those for abundant rock types; values for sandstone, mafic rocks, and porphyry plot far from points for gravel. Where sandstone, mafic rocks, and porphyry are only minor constituents of gravel, they can not be expected to influence LA values and specific gravity. If one or more minor rock types were abundant, they could cause major variation in LA values and specific gravity.

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U. S. English to metric conversion factors for distance and weight measures:

1 inch (in) = 2.540 centimeters (cm)
1 foot (ft) = 0.3048 meters (m)
1 mile (mi) = 1.609 kilometers (km)
1 pound (lb) = 0.4536 kilograms (kg)

APPENDIX TABLES

Table A1.—Particle-size parameters for 24 samples of gravel beneath the floodplain and low terraces of the South Platte River valley north of Denver, Colo. PCT, cumulative weight percent in inches; MM, millimeters; *, particle size adjusted for unsampled sand interval.

SAMPLE NUMBER	GRAVEL UNIT	SAMPLE SITE	SECTION	PCT > 1 1/2 INCHES	PCT > 3/4 INCHES	PCT > 3/8 INCHES	PCT > 3/16 INCHES	MEDIAN SIZE (MM)	ESTIMATED MAXIMUM SIZE (MM)	LOG ESTIMATED MAXIMUM SIZE (MM)
ND1-UM	Upper	A	1	7.2	18.1	29.5	46.6	4.0	60	1.778
ND1-B	Middle	A	1	.1	9.2	18.4	33.9	2.0	40	1.602
ND2-M	Upper	A	2	26.4	35.8	41.5	49.1	5.0	400	2.602
ND2-B	Middle	A	2	13.8	22.0	33.9	50.5	5.0	150	2.176
ND3-U	Upper	A	3	12.5	24.9	36.9	47.0	4.0	80	1.903
ND3-M	Middle	A	3	6.6	12.3	17.7	29.3	2.0	90	1.954
ND3-B	Basal	A	3	32.7	46.0	54.1	66.5	15.0	300	2.477
37A	Basal	B	2	35.0	48.1	57.1	66.5	20.0	300	2.477
37B	Middle	B	2	.3	7.7	19.3	33.3	2.0	40	1.602
37CD	Upper	B	2	17.9	48.7	59.7	70.0	20.0	60	1.778
37EFG	Upper	B	3	8.0	21.5	34.7	48.4	4.0	60	1.778
37H	Middle	B	3	12.0	22.2	36.6	54.5	6.0	70	1.845
37I	Basal	B	3	41.4	53.5	61.3	70.5	25.0	500	2.699
37JK	Upper	B	1	8.6	25.6	36.1	50.7	5.0	60	1.778
37L	Middle	B	1	14.2	30.3	41.3	59.0	7.0	80	1.903
38A	Upper	C	1	2.3	13.7	30.3	49.0	5.0	40	1.602
38B	Middle	C	1	0.0	1.5	6.8	18.9	.8	40	1.602
38C	Basal	C	2	15.5	24.1	36.4	52.6	5.0	150	2.176
38D	Upper	C	2	8.3	31.9	47.0	59.8	8.0	50	1.699
38E	Middle	C	2	.3	6.1	10.8	18.2	.2	40	1.602
38F	Basal	C	3	38.9	46.5	55.6	66.1	17.0	800	2.903
38G	Middle	C	3	0.0	3.0	16.2	32.7	2.0	40	1.602
38H+Sand*	Upper	C	3	4.9	7.5	11.4	15.6	2.0E-2	150	2.176
38I	Basal	C	1	14.9	22.8	35.8	61.8	6.0	150	2.176

Table A2.—Lithology of pebbles for 23 samples of gravel beneath the floodplain and low terraces of the South Platte River valley north of Denver, Colo. Lithologic identification determined for 50 pebbles per sample, 0.75-1.5 inch size fraction, except samples ND2-M and 37B, for which 25 and 35 pebbles were identified, respectively. PCT, percent.

SAMPLE NUMBER	GRAVEL UNIT	SAMPLE SITE	SECTION	PCT GRANITE	PCT GNEISS	PCT PEGMATITE	PCT QUARTZ	PCT MAFIC ROCKS	PCT PORPHYRY	PCT SANDSTONE	PCT SCHIST	PCT QUARTZITE	PCT CHERT
ND1-UM	Upper	A	1	10	18	58	4	0	2	2	2	4	0
ND1-B	Middle	A	1	20	16	42	4	2	4	6	2	4	0
ND2-M	Upper	A	2	20	17	40	6	0	11	6	0	0	0
ND3-U	Upper	A	3	36	22	26	6	0	2	0	0	8	0
ND3-M	Middle	A	3	20	22	40	4	0	4	2	4	4	0
ND3-B	Basal	A	3	38	20	24	8	0	0	2	8	0	0
37A	Basal	B	2	22	20	22	14	4	10	0	8	0	0
37B	Middle	B	2	20	24	24	32	0	0	0	0	0	0
37CD	Upper	B	2	34	28	14	6	0	2	16	0	0	0
37EG	Upper	B	3	34	26	30	4	0	2	2	2	0	0
37H	Middle	B	3	18	22	46	2	2	2	8	0	0	0
37I	Basal	B	3	22	30	22	4	2	8	8	2	2	0
37K	Upper	B	1	34	14	34	8	0	8	2	0	0	0
37L	Middle	B	1	22	24	16	16	2	12	8	0	0	0
38A	Upper	C	1	42	34	10	12	0	0	2	0	0	0
38B	Middle	C	1	22	14	52	2	2	6	0	0	2	0
38C	Basal	C	2	18	20	28	8	0	6	12	4	2	2
38D	Upper	C	2	18	28	30	8	2	4	8	2	0	0
38E	Middle	C	2	24	24	36	4	0	4	4	2	2	0
38F	Basal	C	3	26	22	30	6	4	0	2	6	4	0
38G	Middle	C	3	24	30	32	8	0	4	2	0	0	0
38H	Upper	C	3	22	26	36	6	0	4	4	2	0	0
38I	Basal	C	1	18	34	26	4	6	2	2	6	0	2

Table A3.—Mean shape of pebbles for 23 samples of gravel beneath the floodplain and low terraces of the South Platte River valley north of Denver, Colo. Mean shape calculated from measured lengths of long (A), intermediate (B), and short (C) pebble axes (Pettijohn, 1975, p. 54), 50 pebbles per sample, 0.75-1.5 inch size fraction, except samples ND2-M and 37B, for which 25 and 35 pebbles were identified, respectively. B/A is inversely proportional to elongation; C/B is inversely proportional to flatness. Sphericity (Ψ) = $\sqrt[3]{(BC/A^2)}$ measures degree of equidimensional shape (Krumbein, 1941); when A=B=C, Ψ = 1. Shape classified as spherical, disc-, rod-, and blade-shaped by criteria of Zingg (Pettijohn, 1975, fig. 3-18). PCT, percent.

SAMPLE NUMBER	GRAVEL UNIT	SAMPLE SITE	SECTION	MEAN A (MM)	MEAN B (MM)	MEAN C (MM)	MEAN B/A	MEAN C/B	MEAN SPHERICITY (Ψ)	PCT SPHERICAL	PCT DISC-SHAPED	PCT ROD-SHAPED	PCT BLADE-SHAPED
ND1-UM	Upper	A	1	38.880	26.000	18.540	.690	.720	.694	34	20	28	18
ND1-B	Middle	A	1	38.580	28.720	18.820	.760	.670	.723	36	38	12	14
ND2-M	Upper	A	2	48.257	34.743	21.171	.740	.620	.694	20	46	20	14
ND3-U	Upper	A	3	37.500	26.540	15.520	.720	.600	.671	14	52	16	18
ND3-M	Middle	A	3	37.840	28.580	18.080	.770	.640	.717	32	44	18	6
ND3-B	Basal	A	3	37.800	27.380	15.320	.740	.570	.669	20	50	10	20
37A	Basal	B	2	37.480	28.680	16.620	.780	.590	.695	20	56	12	12
37B	Middle	B	2	37.120	27.160	16.600	.750	.630	.699	16	52	20	12
37CD	Upper	B	2	39.360	28.420	17.100	.750	.610	.690	20	54	12	14
37EG	Upper	B	3	35.160	25.480	15.060	.740	.600	.679	22	46	10	22
37H	Middle	B	3	35.060	24.420	16.120	.700	.670	.686	30	34	22	14
37I	Basal	B	3	38.760	27.820	16.200	.740	.590	.681	22	50	10	18
37K	Upper	B	1	39.260	28.600	16.840	.750	.600	.688	20	52	10	18
37L	Middle	B	1	36.800	27.600	14.960	.760	.560	.674	26	56	6	12
38A	Upper	C	1	35.980	26.680	17.580	.760	.670	.720	28	46	18	8
38B	Middle	C	1	37.260	27.180	16.080	.740	.600	.681	26	48	10	16
38C	Basal	C	2	34.860	25.140	16.560	.740	.680	.712	38	26	20	16
38D	Upper	C	2	37.620	27.400	18.560	.740	.690	.714	36	36	20	8
38E	Middle	C	2	38.760	28.020	17.000	.740	.610	.687	24	46	18	12
38F	Basal	C	3	37.320	25.860	15.580	.710	.620	.668	22	38	22	18
38G	Middle	C	3	37.020	26.100	17.440	.710	.680	.694	30	28	20	22
38H	Upper	C	3	38.400	28.200	17.080	.750	.630	.698	26	46	16	12
38I	Basal	C	1	38.100	27.480	16.200	.740	.600	.679	22	48	18	12

Table A4.—Roundness of pebbles for 23 samples of gravel beneath the floodplain and low terraces of the South Platte River valley north of Denver, Colo. Estimated by visual comparison with roundness classes (Pettijohn, 1975, fig. 3-24), 50 pebbles per sample, 0.75-1.5 inch size fraction, except samples ND2-M and 37B, for which 25 and 35 pebbles were determined, respectively. Mean roundness = class abundance X mid-point values of Pettijohn (1975, table 3-9). Classes defined as follows: A, angular; B, subangular; C, subrounded; D, rounded; E, well rounded. PCT, percent.

SAMPLE NUMBER	GRAVEL UNIT	SAMPLE SITE	SECTION	MEAN ROUNDNESS	PCT A	PCT B	PCT C	PCT D	PCT E
ND1-UM	Upper	A	1	.51	0	2	28	48	22
ND1-B	Middle	A	1	.56	4	6	22	22	46
ND2-M	Upper	A	2	.55	0	6	26	31	37
ND3-U	Upper	A	3	.55	2	10	12	38	38
ND3-M	Middle	A	3	.60	0	0	20	34	46
ND3-B	Basal	A	3	.61	0	4	16	28	52
37A	Basal	B	2	.54	0	8	20	38	34
37B	Middle	B	2	.54	4	4	24	32	36
37CD	Upper	B	2	.53	0	6	28	34	32
37EG	Upper	B	3	.50	2	6	24	46	22
37H	Middle	B	3	.44	4	22	18	38	18
37I	Basal	B	3	.55	8	10	12	26	44
37K	Upper	B	1	.49	0	20	22	28	30
37L	Middle	B	1	.53	2	14	20	26	38
38A	Upper	C	1	.52	2	4	30	34	30
38B	Middle	C	1	.37	0	32	32	28	8
38C	Basal	C	2	.44	8	18	28	22	24
38D	Upper	C	2	.54	0	12	16	38	34
38E	Middle	C	2	.50	0	10	22	44	24
38F	Basal	C	3	.44	6	12	30	34	18
38G	Middle	C	3	.46	2	14	26	38	20
38H	Upper	C	3	.45	0	16	32	34	18
38I	Basal	C	1	.49	0	14	30	28	28