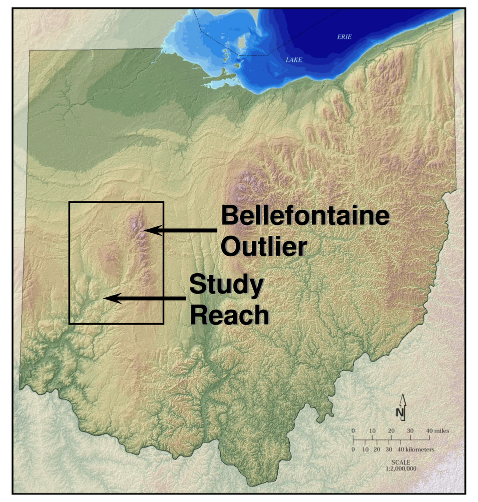
Grain Size Distributions, Porosities, and Permeabilities of a Gravelly Point Bar Deposit, Mad River, Ohio, USA

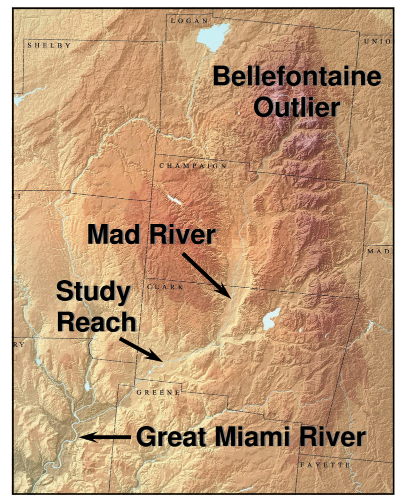
Michael J. Zaleha & Emily S. Moore
Department of Geology, Wittenberg University, Springfield, Ohio 45501-0720
mzaleha@wittenberg.edu

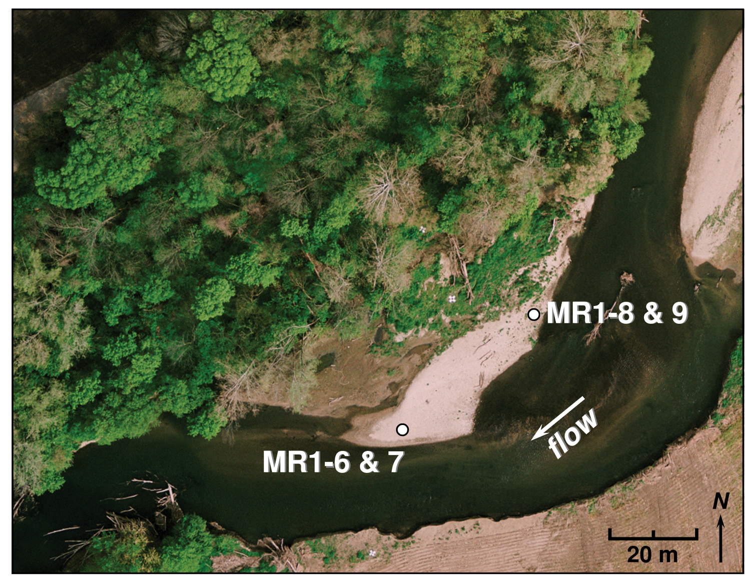
Abstract

Understanding the grain size distribution, porosity, and permeability of gravelly river deposits is critical to the effective development and management of hydrocarbon reservoirs and aquifers composed of such deposits. The purpose of this study was to determine the grain size distributions, porosities, and permeabilities of a gravelly point bar of the Mad River, Ohio. Two sites on the bar were sampled, one on the upstream part of the bar, and one on the downstream part. Armor layers were sampled separately from underlying subsurface deposits. Bulk grain size analyses (sample sizes 46-76 kg) were conducted to determine mean grain size (D_m) and sorting. D_m and sorting for upstream armor layer and subsurface samples are 22.63 mm and moderate (0.81 Φ) and 10.56 mm and poor (1.73 Φ), respectively. D_m and sorting for downstream armor layer and subsurface samples are 23.75 mm and poor (1.46 Φ) and 7.46 mm and very poor (2.20 Φ), respectively. The armor layers are coarser and better sorted than subsurface samples, consistent with the winnowing of fines. Subsurface samples indicate a slight fining from the upstream to the downstream part of the bar, reflecting flow around the bar whereby the locus of maximum velocity shifts from the inner bank upstream to the outer bank downstream. Porosities of subsurface samples were determined by digital image analysis using the computer software jPOR macro of ImageJ. Images were acquired by photographing slices of *in situ* cores impregnated with phosphorescent epoxy under black light. Porosities of 8 slices from the upstream core ranged from 26.6-34.6%, mean of 30.3%. Porosities of 20 slices from two downstream cores ranged from 14.8-33.0%, mean of 23.8%. Permeabilities were calculated using the Kozeny-Carmen equation, which requires harmonic means (calculated from the grain size distributions) and porosities. Permeabilities for the upstream and downstream subsurface samples are 560 and 260 darcys, respectively. The somewhat higher permeability of the upstream sample is attributable to its higher porosity because the harmonic means were similar. The higher porosity is, in turn, attributable to the somewhat better sorting of the upstream sample. These results contribute to our knowledge of the textural characteristics of gravelly river bar deposits and fluid flow through those deposits.

The ***study area*** is a reach of the Mad River in southwestern Clark Co., west-central Ohio. The Mad River originates in an isolated, topographically high area known as the Bellefontaine Outlier. The river flows south and then southwest to its confluence with the Great Miami River. The Mad River lies within the glaciated region of Ohio.



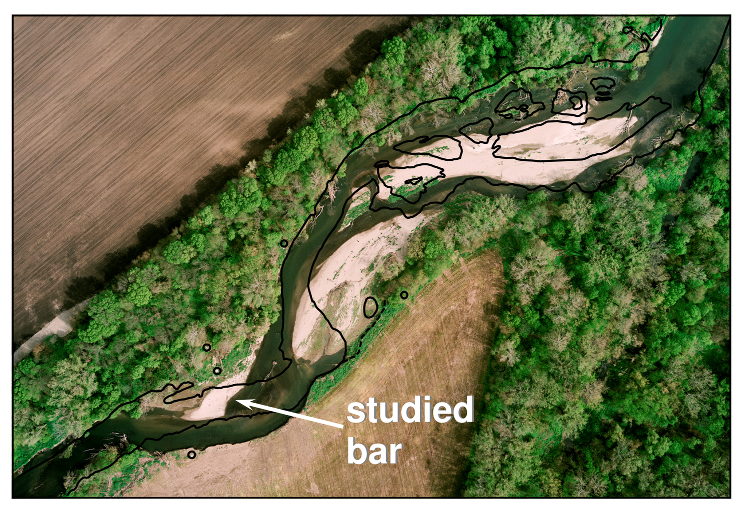




The ***studied point bar and sample sites***. MR1-8 & 9 are upstream samples. MR1-6 & 7 are downstream samples. MR1-6 & 8 are armor layers. MR1-7 & 9 are subsurface samples.

The gravel-bed Mad River flows through a low-relief valley approximately 5 km wide that is filled with 80 m of glaciofluvial outwash and a meters-thick veneer of Holocene fluvial deposits. In the study reach, bankfull channel width is 50 m to 70 m and bankfull depth is 3 m to 4 m. Grain sizes of channel-bar deposits are dominantly coarse to very coarse gravel and small cobbles. Overbank deposits are dominantly clay to coarse sand. Outwash deposits are typically gravel.

Examination of historical aerial imagery and painting grains for use as tracers indicate that ***bed sediment is mobile*** during bankfull flows and that the ***bars actively migrate***. The aerial photograph in this image was taken in 2012. The superimposed line drawing is of the channel banks and bars traced from an aerial photograph taken in 2009. Flow is from upper right to lower left. Small circles are positions of survey markers for scaling aerial imagery.

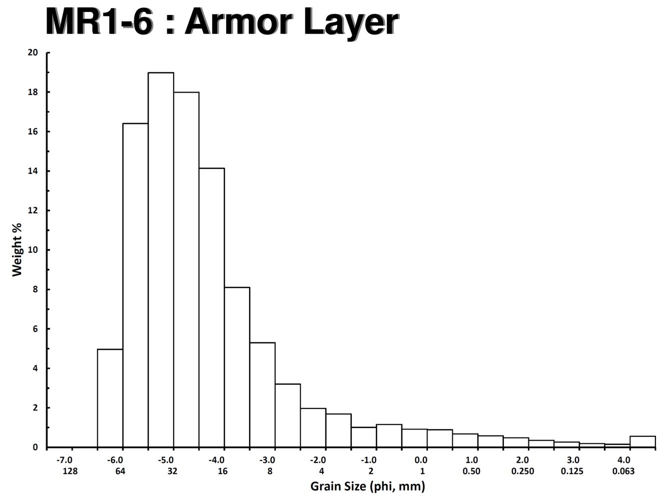


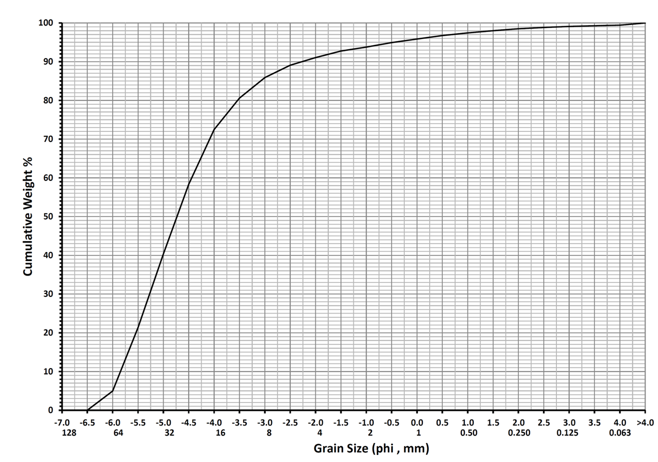
Bar surface showing typical grain sizes present. Scale in inches (top) & millimeters (bottom).

Grain size distributions presented as weight percent histograms and cumulative weight percent curves. Size classes are half-phi intervals.

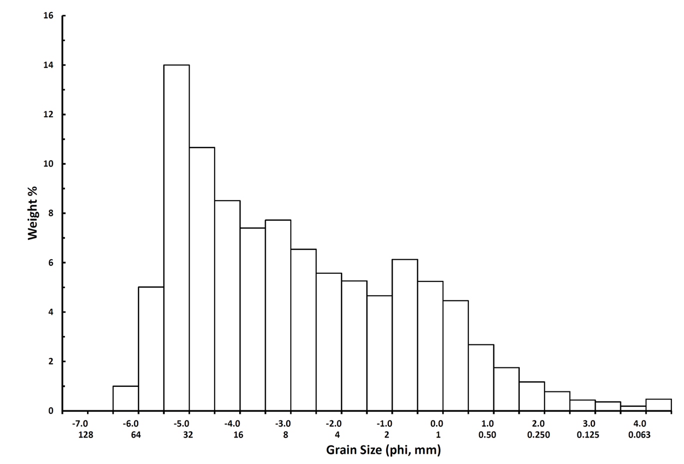
Downstream

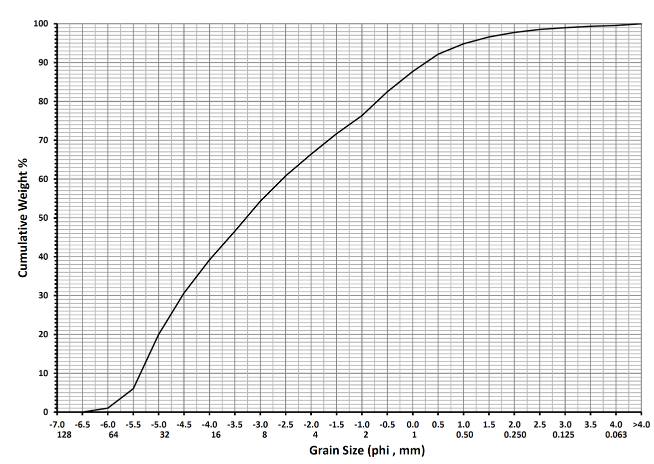
MR1-6 : Armor Layer





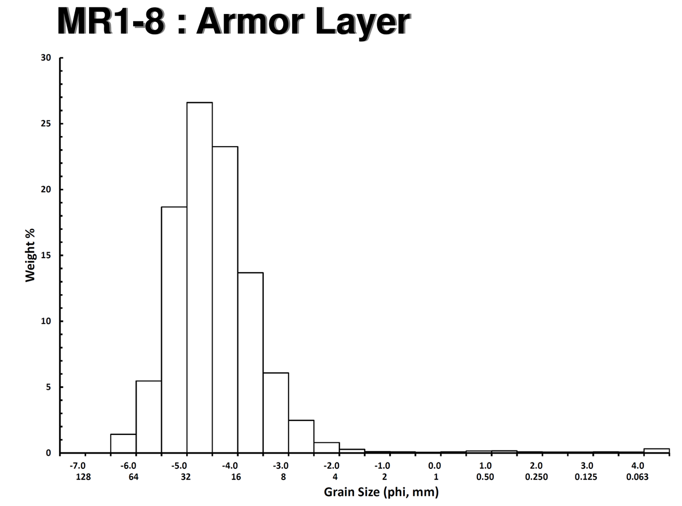
MR1-7 : Subsurface

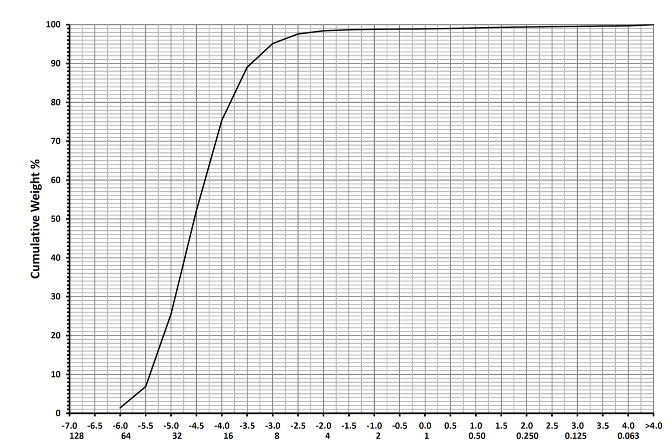




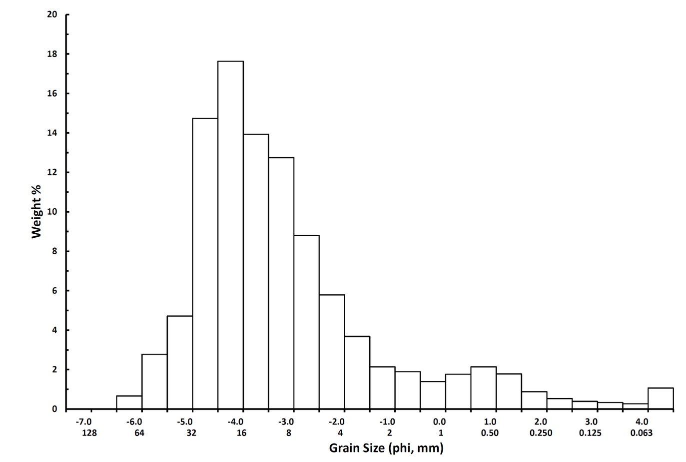
Upstream

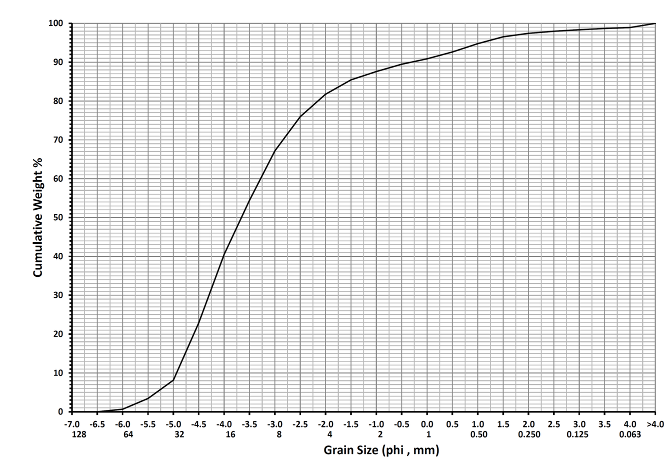
MR1-8 : Armor Layer





MR1-9 : Subsurface

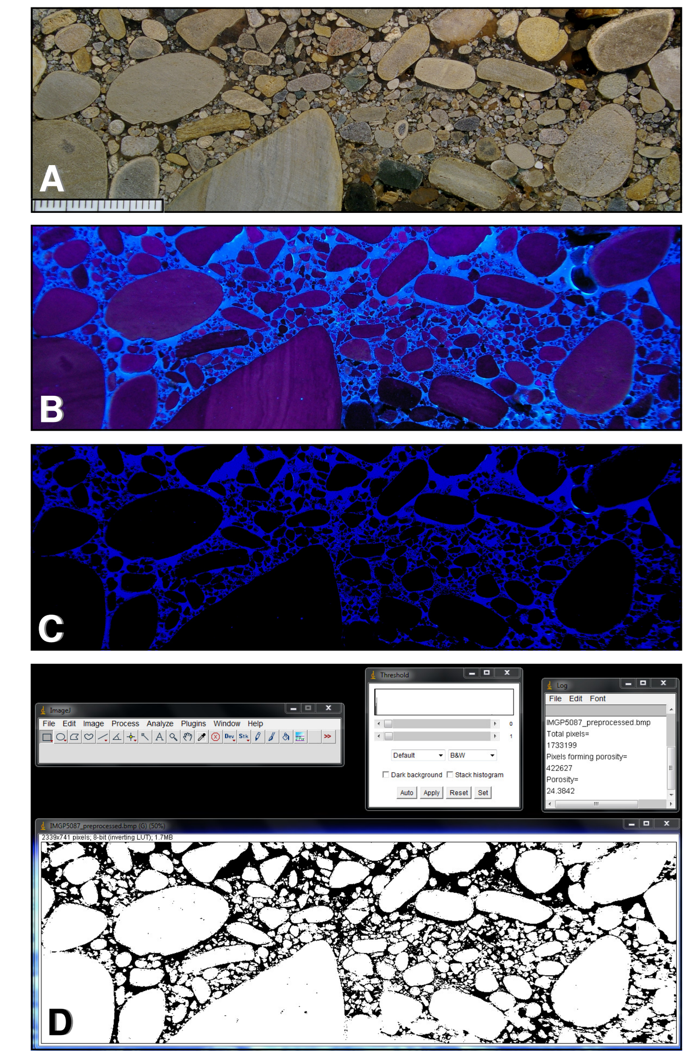




Grain size analyses were performed using the ***bulk sampling method***. The mass of the largest clast was <1% of the entire sample, which ranged from 46 kg to 76 kg. Large clasts were sorted in the field using a gravelometer (template). Grain size fractions <16 mm were returned to the lab and sieved using a sieve shaker.

In situ ***epoxy cores*** were taken in the field for later porosity analyses. The epoxy was impregnated with fluorescent dye which was easily distinguishable from grains under black light.

Images illustrating the steps involved in ***digital image analysis*** used to determine the porosity of sediment cores. **(A)** Core slice under normal light. Scale in millimeters. **(B)** Core slice under black light. **(C)** Black light image of (B) preprocessed in Microsoft Picture Manager. **(D)** Screen shot of the jPOR ImageJ macro showing main menu bar (upper left), image processing settings (upper middle), porosity calculator (upper right), and processed image (bottom). Scales of all core images are the same. The optical porosity for the processed image with the current settings is 24.4%. Previous work on samples of known porosities indicate that the porosity of a given slice is best determined by taking the mean of porosities of the image processed in two slightly different ways. The two different processing settings for this image yielded porosities of 24.4% and 31.1%, with a mean porosity for the slice of 27.8%.



Permeability was calculated using the Kozeny-Carman equation:

$$k = \frac{D_{hm}^2 \Phi^3}{180(1-\Phi)^2}$$

k permeability
D_{hm} harmonic mean
Φ porosity

Results of grain size analyses, porosity determinations, and permeability calculations.

	downstream		upstream	
sample *(sample mass)*	***armor layer MR1-6*** *(73 kg)*	***subsurface MR1-7*** *(65 kg)*	***armor layer MR1-8*** *(76 kg)*	***subsurface MR1-9*** *(46 kg)*
mean grain size (mm)	23.75	7.46	22.63	10.56
D_{50}	27.86	9.85	22.63	13.00
sorting	poor (1.46 Φ)	very poor (2.20 Φ)	moderate (0.81 Φ)	poor (1.73 Φ)
porosity (%)		23.8		30.3
permeability (darcys)		260		560

Grain size analyses indicate that armor layers are coarser and better sorted than subsurface sediment, consistent with the winnowing of fines. Subsurface samples indicate a slight fining from the upstream to the downstream part of the bar, reflecting flow around the bar whereby the locus of maximum velocity shifts from the inner bank upstream to the outer bank downstream.

The higher ***porosity*** of the upstream sample is attributable to the somewhat better sorting of the upstream sample.

The somewhat higher ***permeability*** of the upstream sample is attributable to its higher porosity because the harmonic means were similar (D_{hm} upstream: 1.31 mm, D_{hm} downstream: 1.41 mm).

Acknowledgements

We would like to thank Bob Ritzi, Wright State University, for useful discussions concerning the applications of harmonic means and the Kozeny-Carman equation. The City of Dayton, Ohio, is gratefully acknowledged for permitting access to the field site.