Migration, Electrical Resistivity Ground Imaging (ERGI), and Textural Characteristics of Gravel Bars, Mad River, Ohio, USA

Michael J. Zaleha

Department of Geology, Wittenberg University, Springfield, Ohio 45501-0720

mzaleha@wittenberg.edu

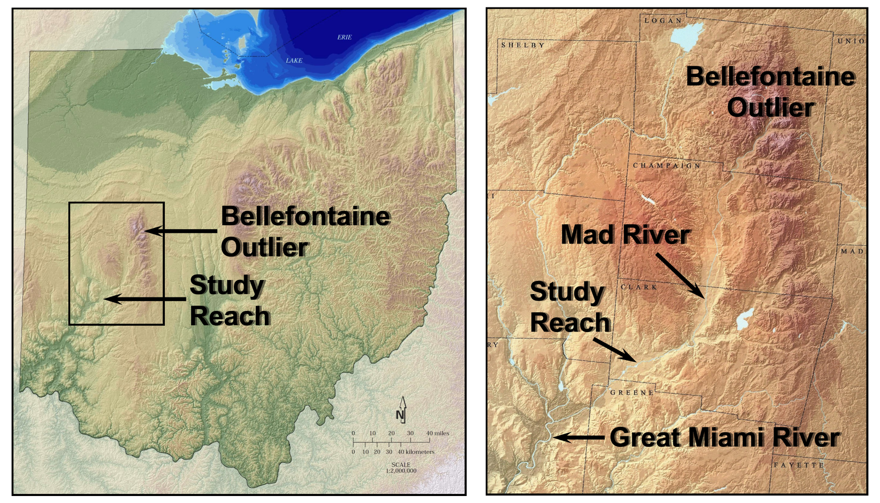
Abstract

A ~500 m-long study reach of the gravel-bed Mad River developed point bars and a braid bar from an initially straight reach which was channelized prior to 1968. The river has a bankfull width of 50-70 m, a bankfull depth of 3-4 m, and a sinuosity of 1.12. Examination of historical aerial imagery indicates that the channel migrated by expansion from 1968 to 1994, by expansion and translation from 1994 to 2000, and by translation from 2000 to 2014. Downstream translation is ¼ to ½ of the channel wavelength. Short-term migration rates are ~1-10 m/yr, with an average rate of ~8 m/yr from 2005 to 2014.

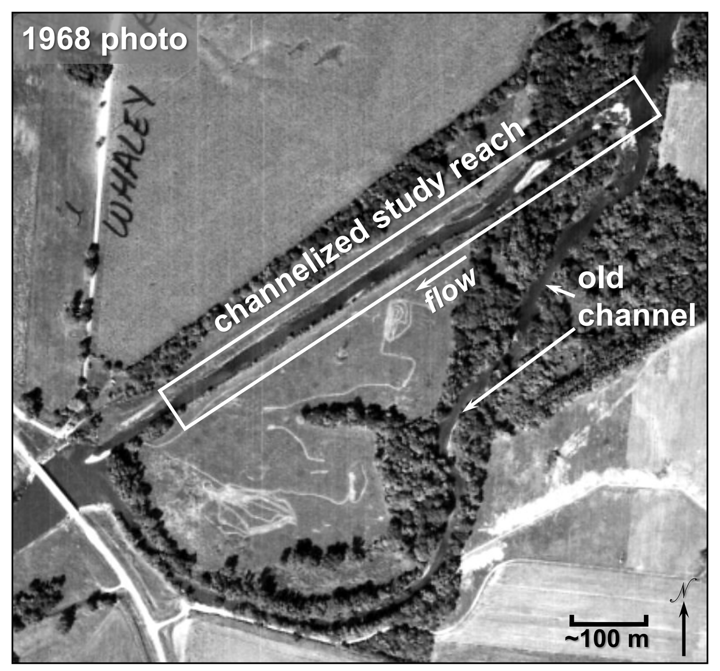
Along-channel and cross-channel ERGI surveys were conducted on one point bar. Bar deposits are distinguishable from underlying glaciofluvial deposits (resistivities, ρ's, of ~140-340 Ωm). Well-drained surface gravels (ρ's of ~160-1900 Ωm) are discernable from gravel-bar deposits below the water table (ρ's of ~50-150 Ωm). Laterally, resistivities generally vary little, likely reflecting homogeneity of bar deposits due to the preferential preservation of downstream parts of the bar associated with translation. However, some variations are evident, likely reflecting differences in water content possibly associated with variations in grain size, sorting, and/or porosity. Additionally, the finer-grain fill of an inner-bank, bar-tail swale (silty sand, ρ's of ~17-40 Ωm) associated with accretionary topography is discernible from laterally adjacent and subjacent bar gravels.

Bulk grain size analyses of subsurface bar deposits yield mean grain sizes of 7.3-11.3 mm, and sorting of 1.73 Φ (poor) to 2.20 Φ (very poor). Armor layers are substantially coarser, with mean grain sizes of 16.0-32.0 mm, and better sorted (0.81-1.46 Φ, moderate to poor), consistent with the winnowing of fines. Porosities of subsurface gravels were determined by digital image analysis of successive slices through *in situ* cores impregnated with phosphorescent epoxy. Porosities range from 23.3-30.3%. Permeabilities of the gravels were calculated using the Kozeny-Carman equation, applying values of porosities and harmonic means of grain sizes (which range from 0.99-1.52 mm). Permeabilities range from 118-560 darcys. Results are important for the effective development and management of aquifers and hydrocarbon reservoirs composed of similar 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.

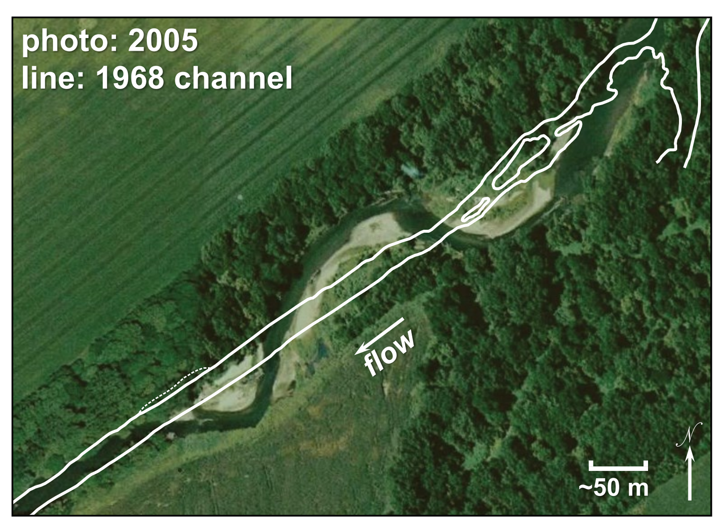


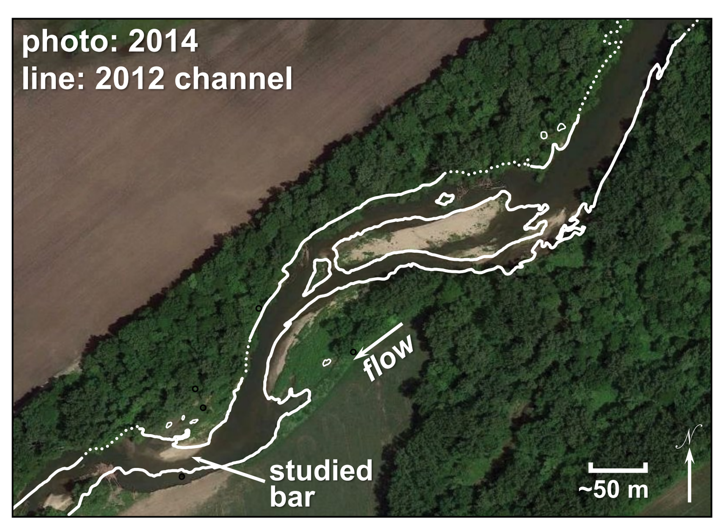
Channel Migration



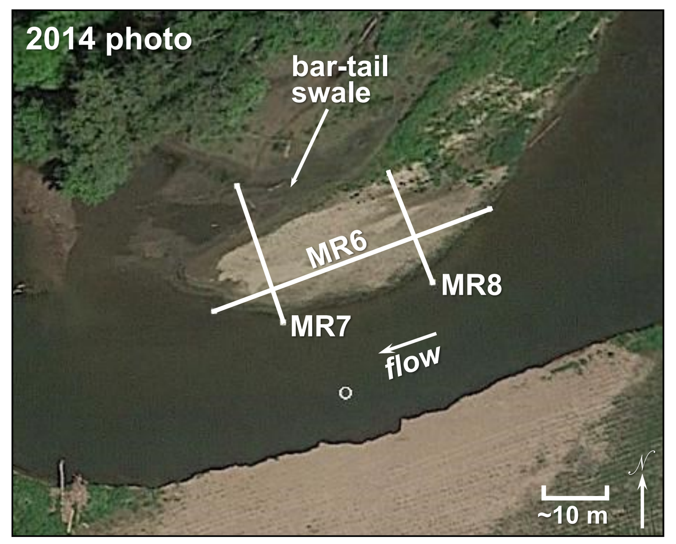
Left. 1968 aerial photo of the study reach which was channelized prior to this time. The old, natural channel is also shown.

Below. Aerial photos and line drawings of the study reach showing ***changes in channel position and bar migration*** through time. The current study reach developed point bars and braid bars from the initially straight, channelized reach. Examination of additional aerial photographs indicate that the channel migrated by expansion from 1968 to 1994, by expansion & translation from 1994 to 2000, and by translation from 2000 to 2014. Downstream translation is on the order of 1/4 to 1/2 of the channel wavelength. Short-term migration rates are on the order of 1-10 m/yr, with an average rate of ~8 m/yr from 2005 to 2014.



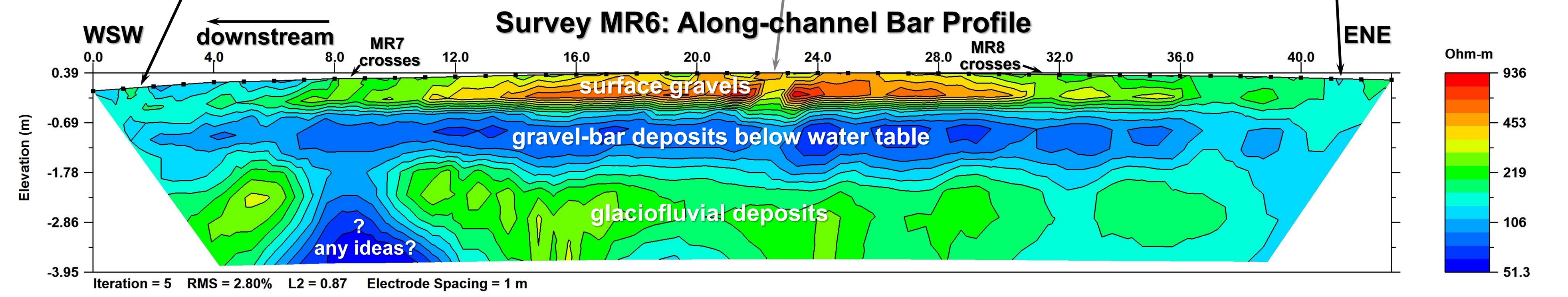


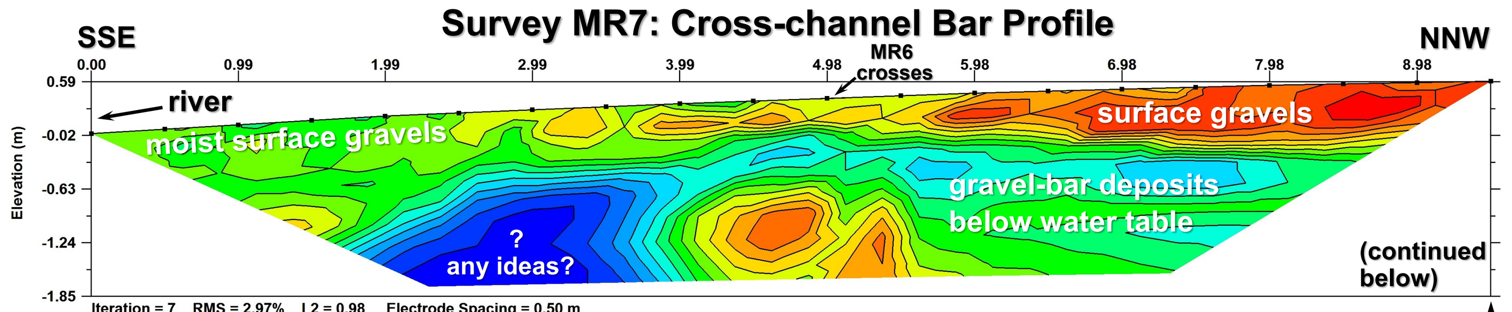
Electrical Resistivity Ground Imaging (ERGI)



2014 aerial photo of the ***studied point bar & locations of the ERGI surveys.*** The Mad River flows through a low-relief valley ~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 50-70 m and bankfull depth is 3-4 m. Channel-bar deposits are dominantly coarse to very coarse gravel & small cobbles. Outwash deposits are typically gravel.

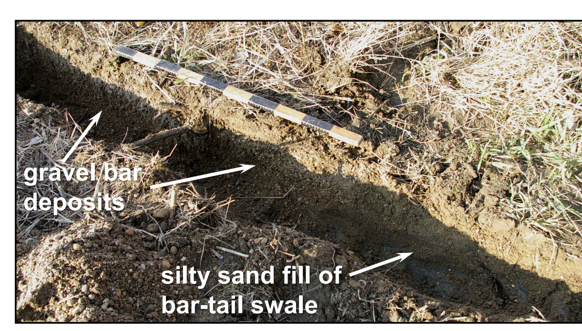
Trenches in upper bar deposits. Flow is to the left in all photos. Scales in decimeters and centimeters.

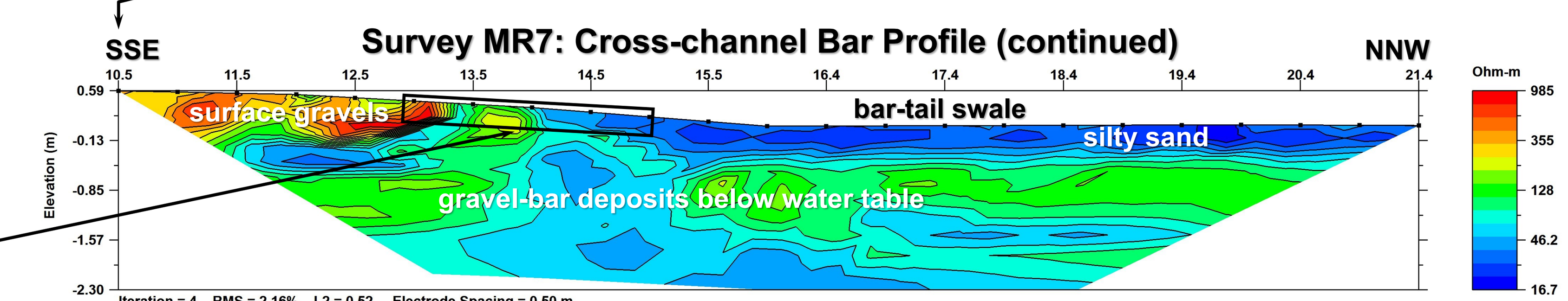


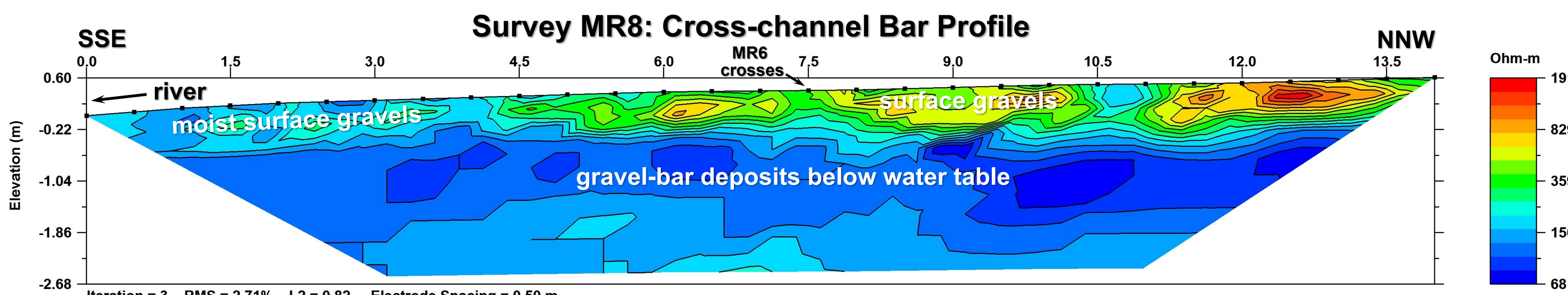


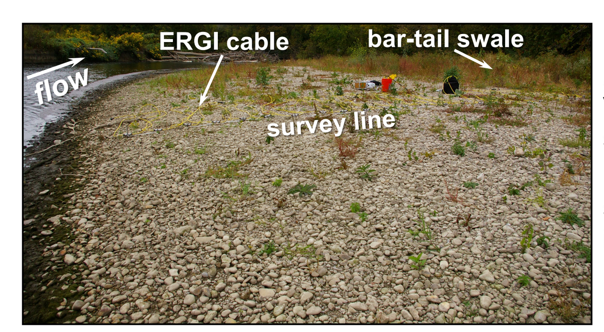
ERGI Survey MR6 (above). View is downstream, SSW. Resistivity surveys were conducted with a ***Super Sting R1 IP resistivity meter*** and an array of 28 electrodes. All surveys employed a dipole-dipole array.

Lateral ***transition from gravel bar deposits to the silty sand fill*** of the bar-tail swale associated with ***ERGI Survey MR7***. Meter stick for scale.







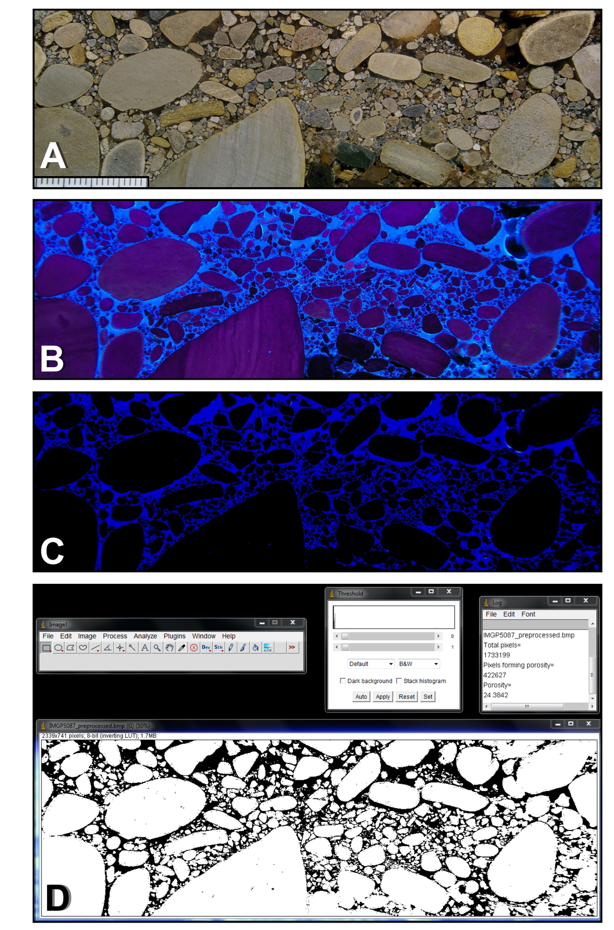


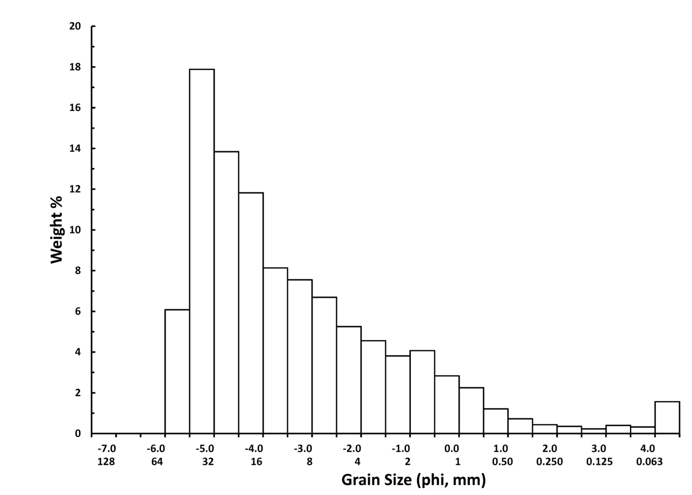
ERGI survey MR8. View is downstream, southwest. Bar-tail swale of ERGI survey MR7 (above) is also visible.

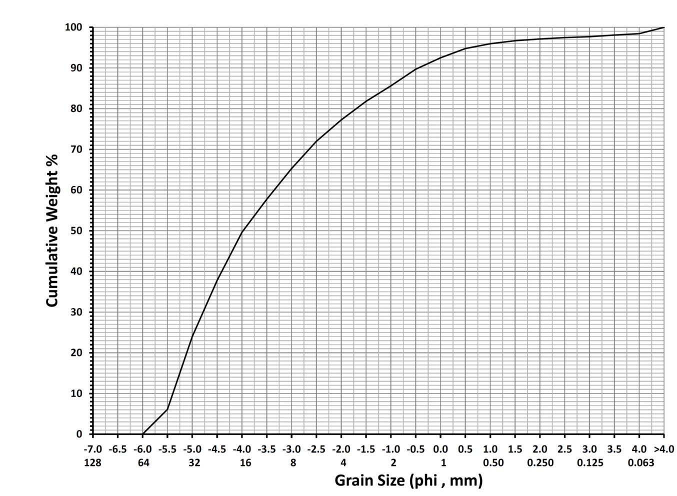
Grain Size, Porosities, & Permeabilities

Textural analyses were performed on the same point bar as the ERGI surveys.

In situ epoxy sediment cores were taken in the field for porosity analyses. The epoxy was impregnated with fluorescent dye which was easily distinguishable from grains under black light. A minimum of 10, ~1.5 cm-thick slices of each core were used for each analysis. The images to the right illustrate the steps involved in ***digital image analysis*** used to determine the porosity of the 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%.







Grain size distribution of a representative subsurface sample (MR1-13, bar apex) as a weight percent histogram and cumulative weight percent curve. Size classes are half-phi intervals. 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 35 kg to 111 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.

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 performed on point-bar deposits in 2013 (*left*) and 2014 (*right*). Bar migration occurred between the two sampling times.

	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} **(mm)**	27.86	9.85	22.63	13.00
$D_{harmonic\ mean}$ **(mm)**		1.41		1.32
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

	upstream		***bar apex***		***downstream***	
sample (sample mass)	***armor layer MR1-10 (111 kg)***	***subsurface MR1-11 (65 kg)***	***armor layer MR1-12 (46 kg)***	***subsurface MR1-13 (35 kg)***	***armor layer MR1-14 (41 kg)***	***subsurface MR1-15 (50 kg)***
mean grain size (mm)	32.00	8.57	24.25	11.31	16.00	7.31
D_{50} **(mm)**	36.76	10.56	25.99	16.00	17.15	9.19
$D_{harmonic\ mean}$ **(mm)**		1.52		1.13		0.99
sorting	moderate (0.92 Φ)	very poor (2.04 Φ)	moderate (0.91 Φ)	poor (1.94 Φ)	poor (1.13 Φ)	poor (1.97 Φ)
porosity (%)		23.4		23.6		23.3
permeability (darcys)		284		162		118