MEANDERING CHANNELS IN A NON-VEGETATED AREA: QUINN RIVER, NV AS A MARTIAN ANALOG.

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Introduction: Sinuous channels (eroded into positive relief) which run through an area of approximately 200,000 km^2 were found in the Aeolis and Zephyri Plana region located around the equator between 140° and 170°E on Mars [*1*, *2*]. Highly sinuous, unconfined meanders require small channel width to average depth ratios, which in turn require cohesive channel banks. On Earth, this cohesion is obtained most commonly by clay-rich sediment and vegetation cover. Roots can physically hold sediments intact and also retain moisture in the root zone, allowing minerals to weather thoroughly to clay. Dense plant cover also encourages fine sediment deposition. However, this discovery of highly sinuous Martian meandering channels raises the question of how meandering can occur in the absence of vegetation.

The Quinn River, located in the east branch of the Black Rock Desert near Winnemucca, Nevada is a sinuous channel that flows through lacustrine sediments on the floor of paleolake Lahontan where vegetation cover is sparse. This river shows evidence of active migration with recent cutoff events occurring within the past 40 years (Fig.1). This site was chosen based on a hypothesis that abundant silt/clay and/or salt deposits can provide enough cohesion for the channel to meander.

Fig. 1. Evolution of meandering channel found within the target site. One can see that meander loop was cutoff around 1986. By 2006, the loop that was cutoff has been completely abandoned. (Images obtained from Google Earth and USGS Earth Explorer)

Methodology: Various data were collected to characterize the Quinn River channel banks and bed during two multi-day field seasons (Jun., 2010 and Oct., 2011) and two one-day trips (Dec., 2009 and May, 2011. During the multi-day field seasons, lake, channel bed, and flood plain sediment samples were collected from 52 locations at various depths (typically at 0, 20, 40, 60, 80 cm below the surface). Sediment samples were used for the particle size analysis (PSA), Atterberg limits tests, chemical analysis, and scanning electron microscope (SEM) imaging. Bank shear strength was measured using two different methods: hand-held field vane shear tester and the submerged jet test apparatus developed by USDA-ARS. The bank shear strength measurements were taken at the locations sediments were collected so that comparison of the particle size and the shear strength can be made. The vane shear tester measures the geotechnical properties of the soil and was used at up to 6 different depths (0, 20, 40, 60, 80, and 100 cm). On the other hand, the submerged jet test apparatus measures hydraulic resistance of the soil [*3*].This test was conducted at 4 different locations along the bank slope surface at various heights above the channel. Also GPS surveying was conducted to construct channel and floodplain cross-sectional profiles to supplement 1 m LiDAR coverage.

In the spring of 2011, the Quinn River experienced unusually high flows. A quick trip was made to sample river water and measure flow characteristics.

Results/Discussion: Results from the PSA indicate that Quinn river banks and bed consist of fine sediment. All of the samples have at least 38% silt/clay and some of them consist entirely of silt/clay (Fig.2). Sandy sediments are found at the top of the flood plain and in old scroll bars away from the current channel location. Samples collected from the Quinn River bed and banks also effervesce in dilute hydrochloric acid indicating that there are abundant CO_3 salts.

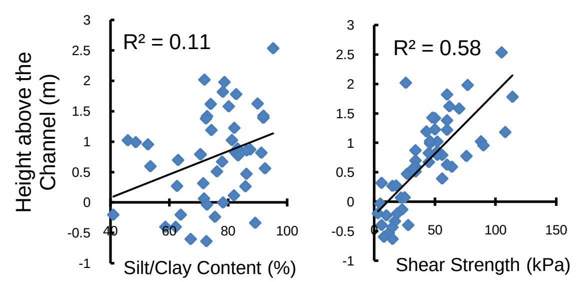


Fig. 2. Graph of mud content (left) and vane shear measurement (right) against the height above the channel. Shear strength increases with the height while mud content does not show the same relationship. Note that all samples contain at least about 40% silt/clay.

Images from SEM analysis confirm the abundance of mud and salt in the sediment. Undisturbed sediment images show sediment particles draped/wrapped with clay and salts (Fig.3). Because the sediment samples had to be completely dried in order to coat samples with carbon, it is inevitable to cause salt crystals to grow as water evaporates. Thus, large salt crystals we see in the SEM images may not be representative of natural conditions. Nonetheless it is evident both from

SEM images, Energy-dispersive X-ray Spectroscopy (EDS) analysis, and Ion Chromatography analysis that there are plenty of salts in the sediment and river water (Table1, Fig.4).

Table 1. Elemental analysis of Quinn River water collected in 2010 and 2011. In 2010, sample was collected when river was stagnant while in 2011, water was collected during the high flows.

Year	Elements (ppm)								
	Mg	Ca	Na	K	F	Cl	Br	NO_3	SO_4
2010	34.3	22.9	4422	33.5	1.4	4559	4.4	20.6	1225
2011	9.6	41.1	81.9	11.8	0.5	30.6			38.2

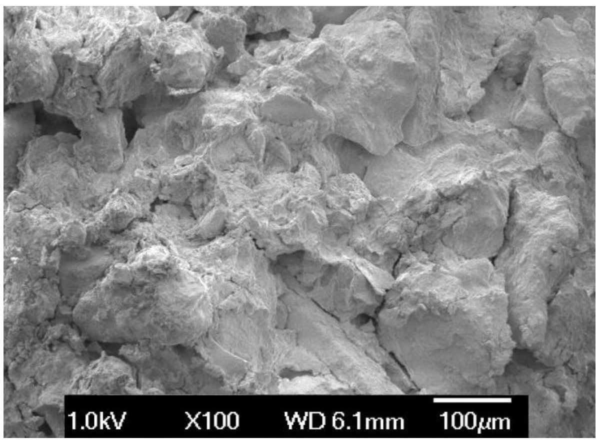


Fig. 3. SEM image of a sediment sample at x100 magnification. Sediment grains are coated with mud.

Salts can cause flocculation and deposition of fine sediments that would otherwise remain in suspension. We have conducted experiments measuring the rate of deposition in different solutions. One representative sample from the Quinn River was mixed with four different solutions (DI water, DI water with 60 mL of $(NaPO_3)_6$, Sea water (35 ppm of NaCl), Salt concentration similar to the Quinn River (11.29 ppm NaCl + 0.49 ppm $MgSO_4 \cdot 7H_2O$)) in separate 1L cylinders following the procedure for hydrometer particle size analysis. All the sediment had settled within 40 min in both solutions with high salt content while sediments in solutions with no salt remained partially in suspension after 24 hours. Fine sediments in the solution with dispersant was still in suspension a week later.

Vane shear stress measurements at Quinn river are in the range of values measured for vegetated banks (25 kPa < τ < 50 kPa; *e.g.*, [*4-6*]). This shows that silt/clay with chemical cementation can provide similar bank strength as the vegetation. Shear stress showed a positive correlation with height above the bank. However, there was no clear correlation between silt/clay content and the height above the channel. The observed increase in shear strength with bank height could be related to the water content and increased clay strength when dry or be the result of chemical cementation. Ion Chromatography analysis of the sediment samples showed decrease in salt content with height above the channel indicating that the increase in shear stress with the height above the channel is not associated with amount of salt present in the sediment.

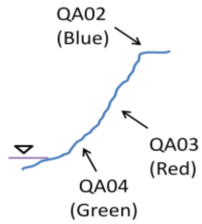
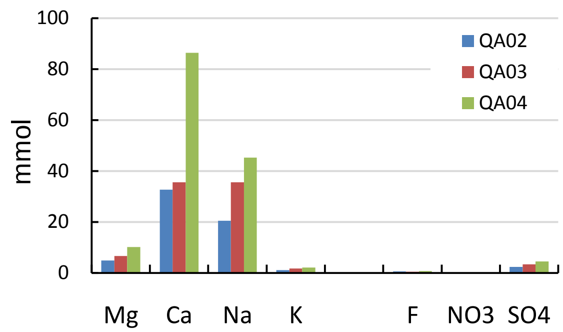


Fig. 5. Elemental analysis of sediments collected along the Quinn River. Cross-sectional view of channel bank showing the locations where samples were collected (Top). The graph shows decrease in salt concentration with height above the bank (Bottom).



Conclusion: Highly sinuous channels on Mars show that meandering channels can occur without vegetation. Although the relative importance of silt/clay content versus salt cementation on bank cohesion could not be determined, our deposition rate experiment tells us that deposition of fine sediments in Quinn River is encouraged by the presence of salts. Meandering rivers can form in an area with sparse vegetation with cohesion provided by abundant silt/clay and salt. Clays and salts have been found on Mars although spectroscopic data for the area on Mars where sinuous channels are found show no sign of clay minerals thus far.

The Quinn River is a mud-dominated sinuous channel flowing through a non-vegetated surface with high clay/silt content and carbonate cementation. The Quinn River is thus a possible analog to the sinuous Martian channels with bank cohesion provided by silt/clay with salt aiding flocculation of mud and possibly additional cohesion by chemical cementation.

References: [1] Burr, D. M. *et al.* (2009) *Icarus*, *200*, 52-76. [2] Burr, D. M. *et al.* (2010) *JGR*, *115*, E07011, doi:10.1029/2009JE003496. [3] Hanson, G. J., Cook, K. R. (2004) *Appl. Eng. Agric.*, *20*, 455-62. [4] Allmendinger, N. E. *et al.* (2005) *Geol. Soc. Am. Bull.*, *117*, 229-43. [5] Tal, M., Paola, C. (2010) *Earth Surf. Processes and Landforms*, *35*, 1014-28. [6] Micheli, E. R., Kirchner, J. W. (2002) *Earth Surf. Processes and Landforms*, *27*, 627-39.