Memorandum

To: Dr. Sez Atamturktur

From: Dr. Denis Brosnan

Date: May 2, 2012

Subject: ASR in Fort Sumter Core Drill Specimens

The purpose of this memorandum is to alert you to the fact that I have found evidence of alkali-silica reaction or "ASR" in several materials subjected to forensic analysis after recovery from core drilling at Fort Sumter National Monument. The specimens where ASR was identified are listed in the table below:

Core Specimen	Material	Core Location
6-1-25	Masonry mortar	Right Face
4-2-22	Tabby concrete	Left Face
7-2-11	Tabby concrete	Gorge Wall

As you are aware, ASR involves expansion reactions between alkali sources and siliceous aggregates that cause cracking within mortars and concrete[1]. ASR is usually diagnosed using petrographic techniques[2] with "global swelling" or three-dimensional expansion leading to crack initiation and propagation. The physical properties of the concrete – to include strength and elastic modulus – are likely affected by ASR. In this study, both tabby concrete specimens exhibited ASR, while two of four mortar specimens exhibited ASR.

The petrographic evidence for core 4-2-22, tabby concrete, is shown in Figure 1. The ASR has resulted in fragmentation at the immediate periphery of the quartz (sand), and a tell-tale crack is present in this microstructure. A similar phenomenon is seen in core 6-1-25, a mortar (Figure 2).

The results of examination of core 7-2-11 using scanning electron microscopy are given in Figure 3. The quartz sand chemistry is reflected in the energy dispersive X-ray analysis for Spectrum 4, where the sand exhibits about 98% SiO_2 and 1.7% CaO[3] (See Figure 3a). By contrast, the fractured periphery of the sand grain (Spectrums 1 and 2) as a result of ASR

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[1] P. Rivard, B. Fournier, and G. Ballivy, The Damage Rating Index Method for ASR Affected Concrete – A Critical Review of Petrographic Features of Deterioration and Evaluation Criteria, *Cement, Concrete, and Aggregates*, Vol. 24, No. 2, Paper ID CCA11228_242, Available online at: www.astm.org.

[2] P. Rivard, B. Fournier, and G. Ballivy, Quantitative Petrographic Technique for Concrete Damage due to ASR: Experimental and Application, *Cement, Concrete, and Aggregates*, CCAGDP, Vol. 22, No. 1, June 2000, pp. 63–72.

[3] A carbon level in the low pressure SEM of below 10% is usually attributed to carbon dioxide gas in the chamber interacting with the electron beam thereby generating carbon X-rays.

exhibits a lesser quantity of silicon (or SiO_2), greater alkali (Spectrum 1), and substantially more calcium. The area bounded by Spectrum 3 is probably a shell fragment, while Spectrum 5 is the binder phase of calcium carbonate and/or natural cement in the concrete. Cracks are also seen in Figure 3 seemingly emanating from the periphery of the quartz grain – the consequence of global swelling at the periphery of the quartz.

Chlorine is detected in Spectrums 2 and 4 suggesting sea water infiltration of this material. It should be noted at detection of low levels of elements can be limited by the detection limits of the SEM/EDAX[4]. This simply says a lack of detection does not necessarily mean an element is not present – it is simply below the detection limit. Further, the EDAX is affected by the inherent inhomogeneous nature of early hand mixed mortars or concretes.

In addition to global swelling, directional swelling due to ASR can result in splitting of aggregate in concrete (Reference 2). An example is shown in Figure 4, but it is unclear if internal swelling (as in a porous aggregate) is possible in sand grains of high density and hardness. Fracture of strong aggregate indicates the matrix phase (binder phase) of this mortar exhibited very high strength.

In summary, the ASR found within the infill of the Ft. Sumter walls is likely a result of long-term wet conditions and the presence of sea water infiltration (and possibly salt present in the original batch ingredients). Since ASR was not identified on mortar specimens previously examined from the outer Fort walls, care should be taken in your research and modeling endeavors.

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[4] EDAX is shorthand for Energy Dispersive X-ray Analysis, a technique common is electron microscopy.

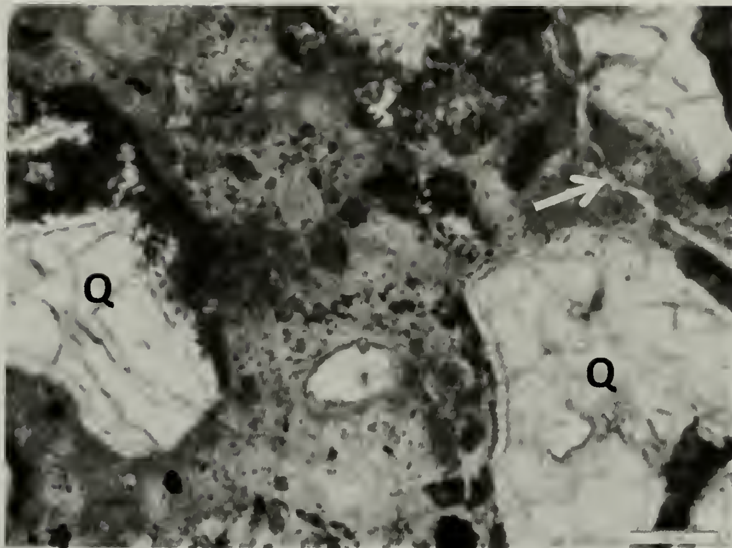

Figure 1: ASR Damage to the Periphery of Quartz Grains (Q) With Crack (arrow)

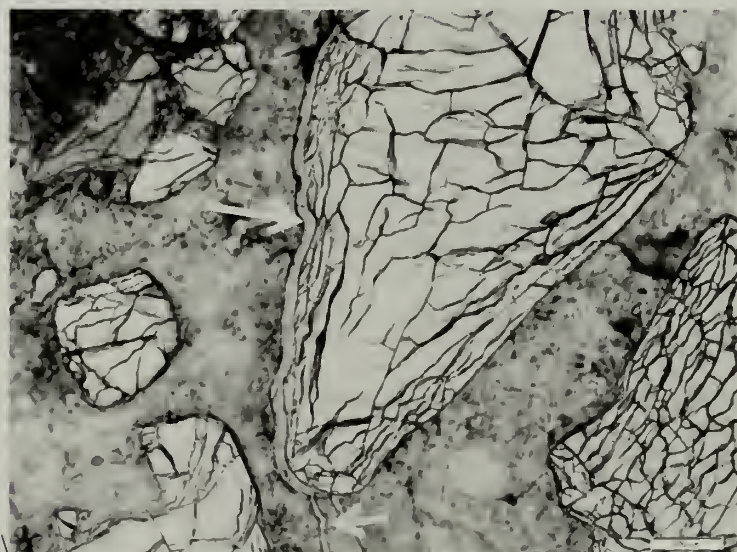

Figure 2: Peripheral Fragmentation of Quartz with Cracks Extension (arrows)

Spectrum	C	O	Na	Mg	Al	Si	S	Cl	K	Ca	Ti	Fe	Total
Spectrum 1	8.90	46.28	0.39	0.61	8.79	21.93			0.91	9.78	0.58	1.84	100.00
Spectrum 2	13.09	43.11		0.83	4.68	15.44		0.44		19.95	1.00	1.47	100.00
Spectrum 3	15.51	48.60		0.49	0.24	1.01				34.15			100.00
Spectrum 4	6.99	50.16		0.29		41.45				1.11			100.00
Spectrum 5	25.26	43.23		6.57	1.12	8.85	0.27	1.25		12.56		0.88	100.00

Figure 3: Scanning Electron Micrograph with EDAX Elemental Analysis (Weight %)

Spectrum	Na_2O	K_2O	CaO	MgO	Al_2O_3	SiO_2	TiO_2	Fe_2O_3
1	0.64		16.98	1.25	18.46	58.20	1.20	3.26
2			37.88	1.87	12.00	44.83	2.33	1.08
3			93.32	1.58	0.88	4.21		
4			1.71	0.53		97.82		
5			34.69	21.48	4.18	37.38		2.25

Figure 3a: Oxide Equivalents for Figure 3 on a Calcined Weight Basis (Weight %)

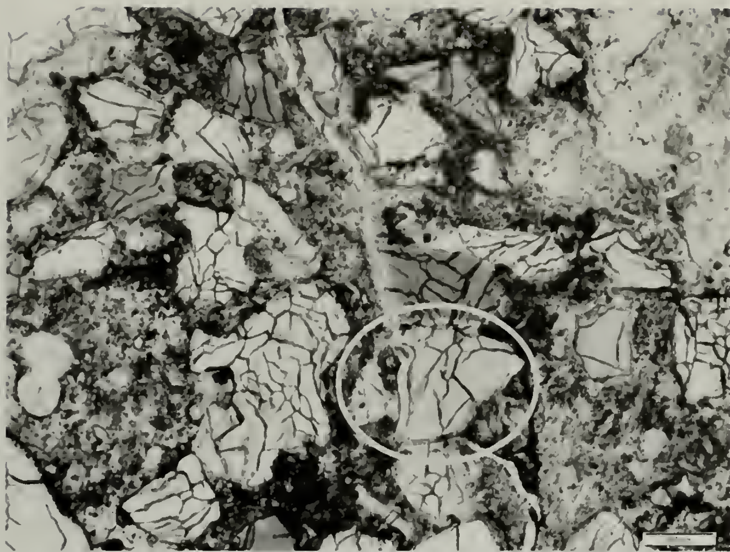

Figure 4: Fracture of Quartz Grain in Core 6-1-25 (circled)