

Supplementary Materials (Figures: S1 a.b.c and S2 a.b.c)

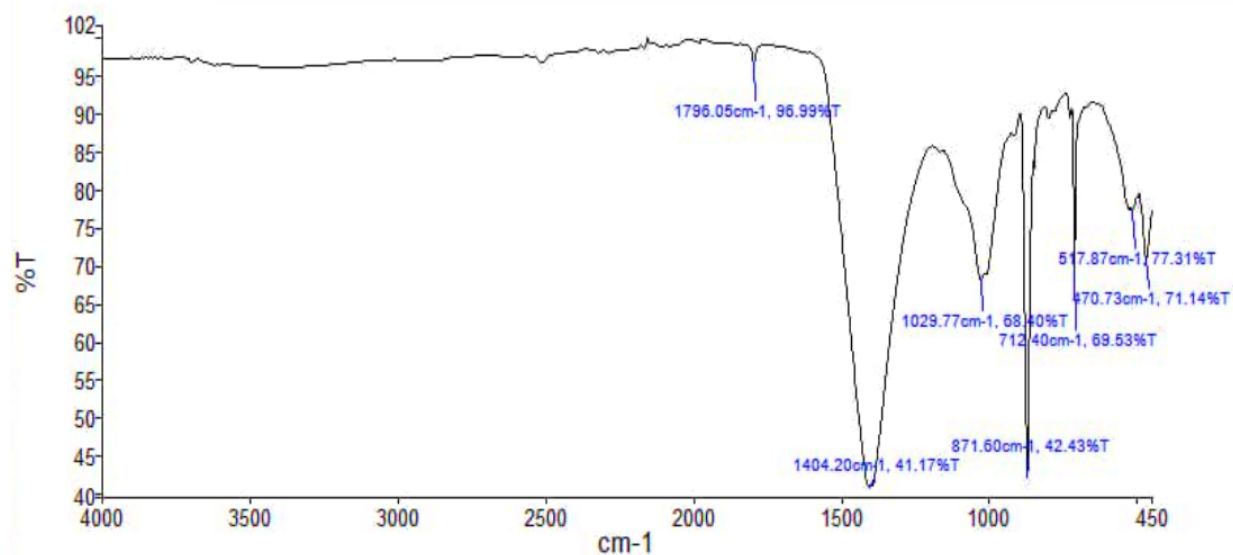


Figure S1.a. FT-IR of Bates Limestone 1

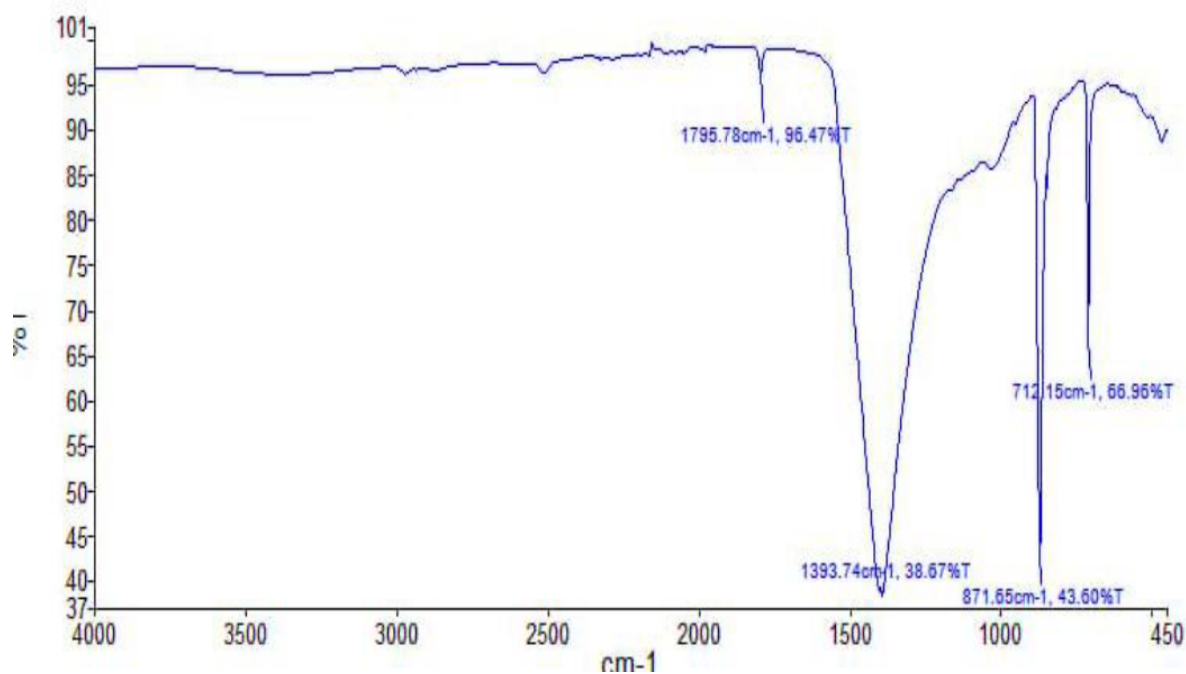


Figure S1.b. FT-IR of Bates Limestone 2

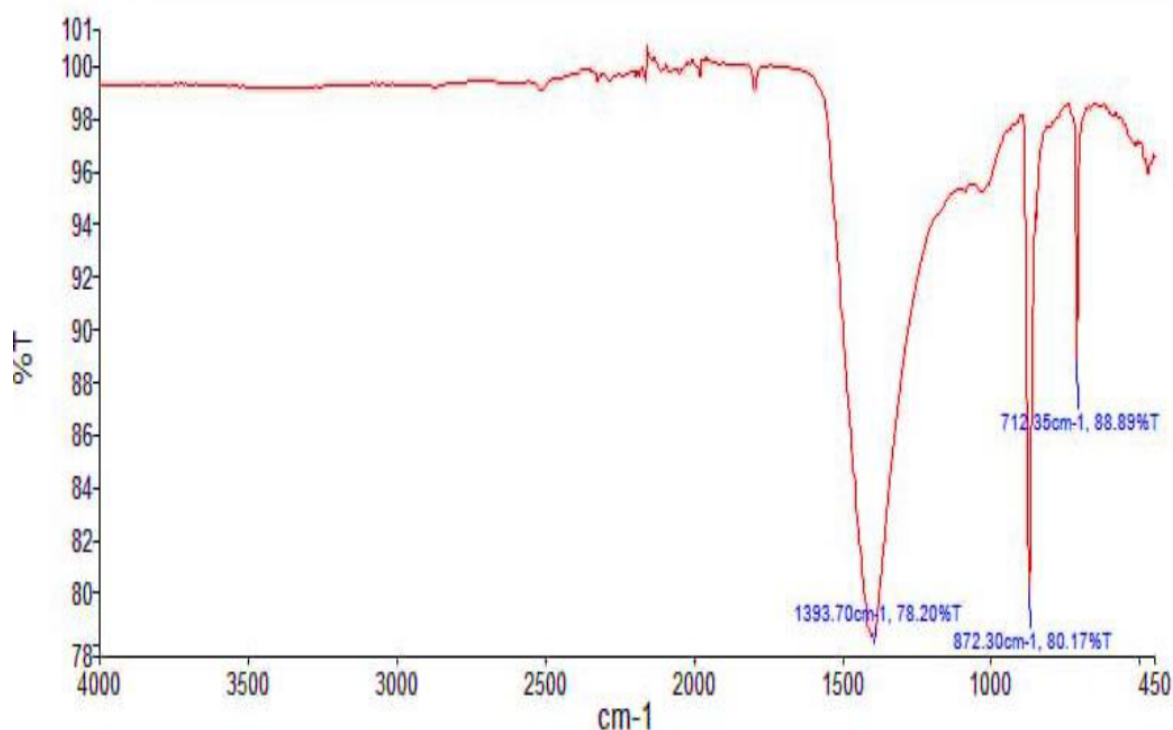


Figure S1.c. FT-IR of Nakhleen Limestone

Figures S1. Fourier Transform Infrared (FT-IR) Spectra of Geogenic Natural Raw Limestones: (a) Bates-1, (b) Bates-2, and (c) Wadi Nakhleen.

Note: These spectra illustrate the diagnostic vibrational fingerprints of the **carbonate groups**. The dominant peaks at **1393–1404 cm⁻¹** (Asymmetric C–O elongation), **710 cm⁻¹** (In-plane bending), and **870 cm⁻¹** (Out-of-plane bending) confirm the presence of a well-defined calcite crystalline phase. The sharp band at **1798 cm⁻¹** further validates the structural integrity of the **calcium carbonate** matrix, identifying these materials as high-purity natural adsorbents suitable for toxic metal and fluoride sequestration.

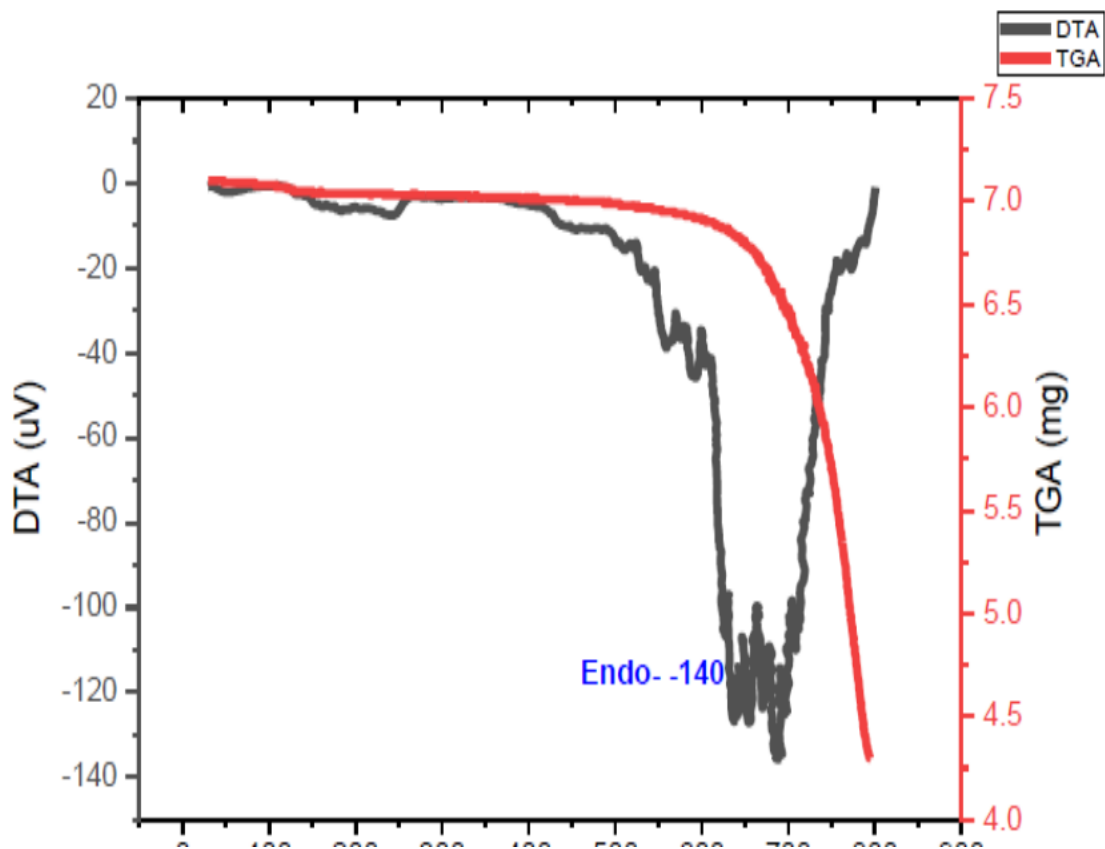


Figure S2.a.TGA-DTA Curve of Baties Limestone 1

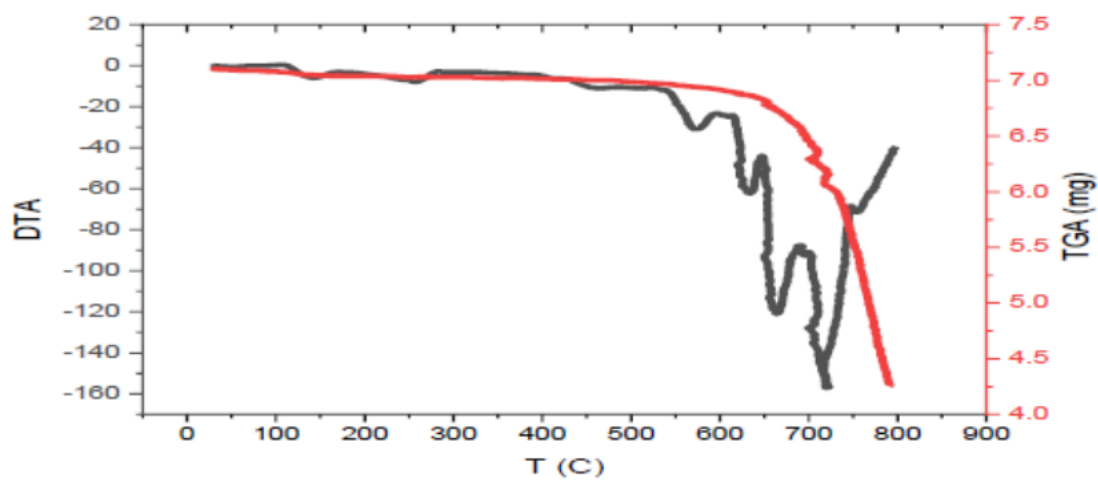


Figure S2.b.TGA-DTA Curve of Baties Limestone 2

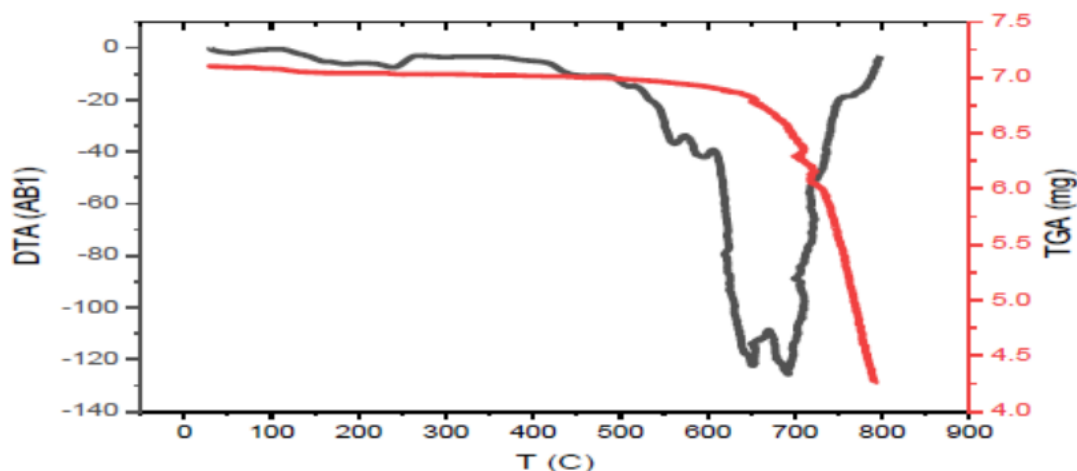


Figure S2.c.TGA-DTA Curve of Nakhleen Limestone

Figures S2. Simultaneous Thermal Analysis (TG-DTA) Curves depicting the calcination profile of (a) Bates-1, (b) Bates-2, and (c) Wadi Nakhleen limestone samples.

Note: The thermal evolution curves reveal **three critical stages**: (1) Minor moisture loss at 200°C, (2) dehydration of structure-bound water, and (3) the primary endothermic calcination peak between 550–700°C. The weight stability observed in Fig. S2c at 56.06% aligns precisely with the theoretical yield of CaO after CaCO_3 decomposition, proving that the Wadi Nakhleen sample is an almost absolute geogenic carbonate with 99.73% purity.