ARGUMENTS AGAINST HYDROTHERMAL OR EPIGENETIC METAL ENRICHMENTS IN THE JORDAN OIL SHALES

In sedimentary rocks, hyper-enrichments of a wide range of trace metals are often explained by the syn-genetic input of metal-rich hydrothermal solutions or brines into the contemporaneous sea water, or by the post-depositional (epigenetic) stratiform intrusion of metal-rich fluids into sedimentary formations. Here we will argue against a contribution of either of these processes to the trace metal hyper-enrichments in the studied Jordan oil shales.

Ruling out epigenetic enrichments:

- In the cores, no stratiform or strata-cutting metal-rich veins or layers are found, but the metal enrichments appear to be finely dispersed within the sediment.
- The organic matter is of low thermal maturity, implying that the sediments were not affected by post-depositional high-temperature overprint.
- Highest metal enrichments do not stand in any relationship to lowest carbonate contents, which implies that metal enrichments did not form in carbonate dissolution features.
- The classical epigenetic stratiform ore deposits are most strongly enriched in Zn, but also in Pb, and not substantially enriched in Cr and V. However, the Jordan oil shales lack significant Pb enrichments and are instead strongly enriched in Cr and V.
- Fossils (e.g., planktonic and benthic foraminifera, shell fragments) are generally well to moderately preserved with sharp boundaries, and show no signs of dissolution by acidic hydrothermal fluids.

- The sedimentary texture (e.g., bioturbation features, laminations) are pristine throughout the cores and do not show any signs of post-depositional overprint.

Ruling out syn-genetic hydrothermal enrichments:

- There are no signs of volcanic activity on the Eocene paleo-shelf of Jordan, and no signs of hydrothermal mounds, veins or pathways in older (Cretaceous-Paleocene) strata in the area that could have delivered metal-rich hydrothermal solutions.
- Highest trace metal enrichments occur in Units II and IV, where enrichments of Zr and P as well as sedimentary structures and bioturbation features indicate episodic water column mixing. These conditions are not conducive to the spreading of a hydrothermal plume or metal-rich brine, which would require stable salinity stratification.
- Spreading of metal-rich brines is not supported by the continuous presence, and good preservation, of planktonic and benthic fossils as well as bioturbation features that exclude the presence of hyper-saline brines loaded with dissolved or particulate metals at toxic levels.

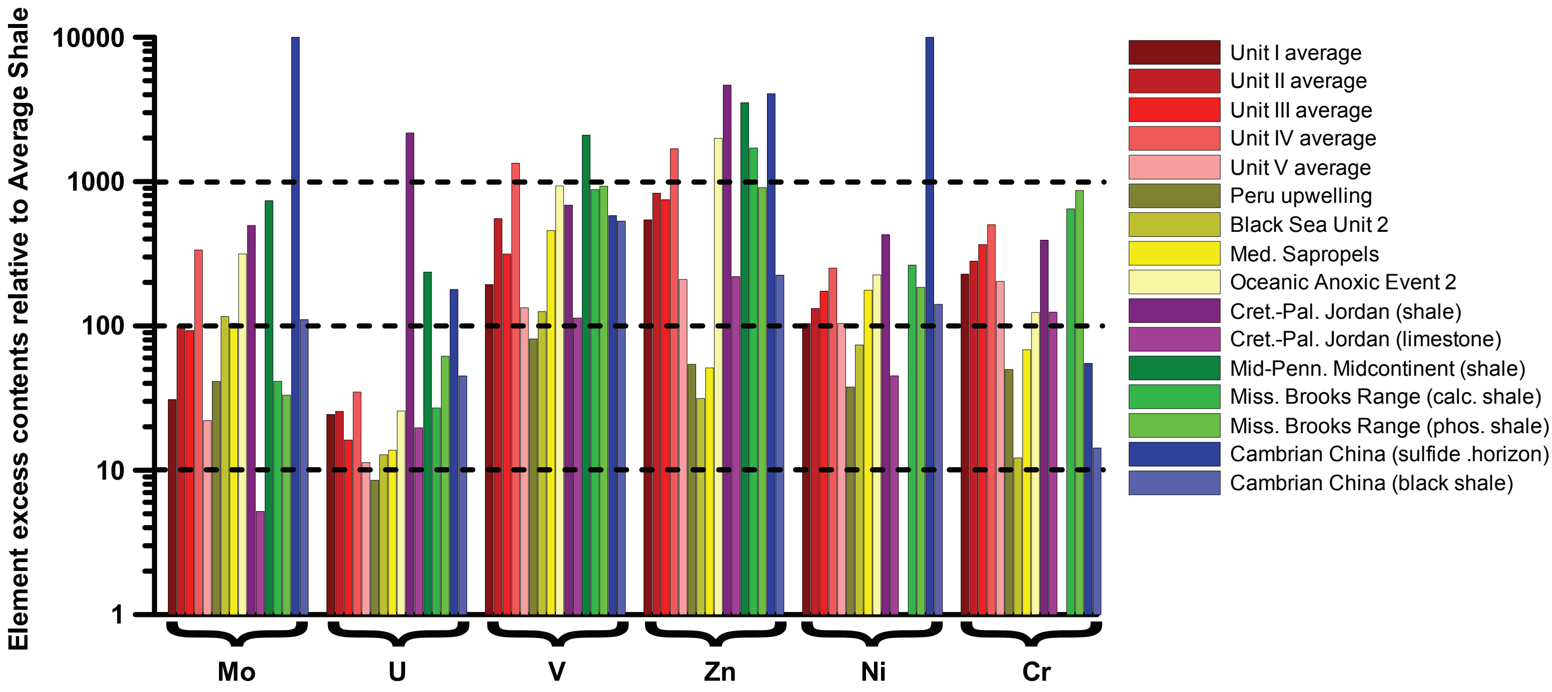

Figure DR1

Element excess contents relative to average shale composition (Wedepohl, 1971, 1991) for Jordan oil shales (average for Units I-V in cores OS22 and OS23) and various modern and ancient organic-rich lithologies deposited under anoxic/sulfidic conditions (data from Brumsack, 2006; Fleurance et al., 2013; Coveney and Glascock, 1989; Slack et al., 2015; Lehmann et al., 2007).

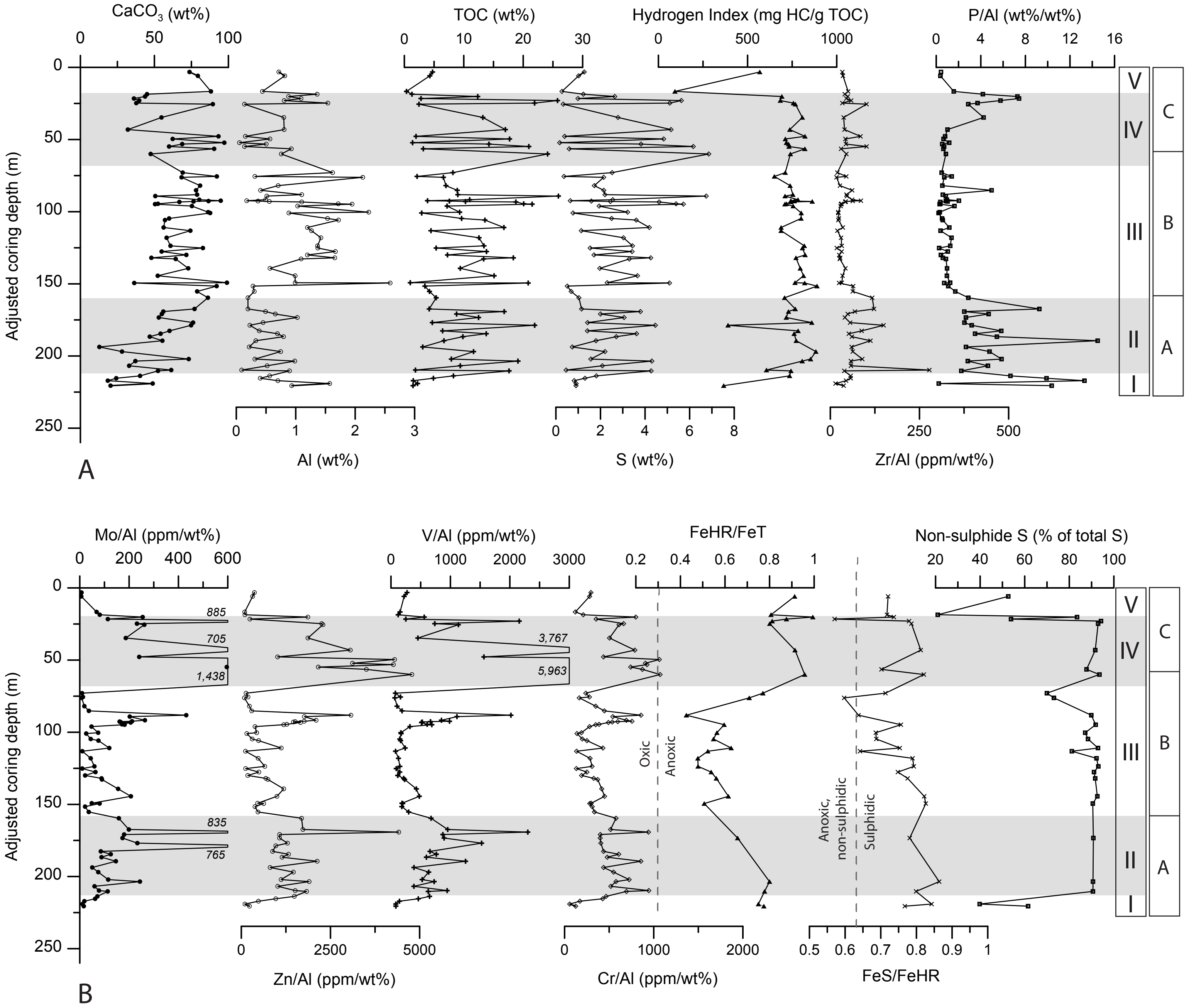

Figure DR2

Core OS22 records of (A) CaCO3 (wt%), Al (wt%), TOC (wt%), S (wt%), P/Al (wt%/wt%), and Zr/Al (wt %/ppm); and (B) Mo/Al (ppm/wt%), Zn/Al (ppm/wt%), V/Al (ppm/wt%), Cr/Al (ppm/wt%), FeHR/FeT, FeS/FeHR and non-sulphide S (% of total S), against adjusted drilling depth (meters, 0 m = top of black shale succession). Columns on right are geochemical Units (I-V) and lithological units (A-C).