Reply to Charrach (2019) comment on “Internal deformation and uplift-rate of salt walls detected by a displaced dissolution surface, Dead Sea basin” by Zucker et al. (2019)

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1. Introduction

Mount Sedom is a surface expression of an emergent salt wall that has been rising during the Quaternary and has pierced its overlying sediments (Zak, 1967). A dissolution surface, termed ‘salt mirror’, forms at the ground- or lake-water interface as a sharp horizontal contact between the underlying soluble body and the overlying cap rock. The salt mirror, having formed during a time of relative stability between the rising salt wall and the water table (or lake bottom), was uplifted and removed from the dissolution zone (i.e., fossilized) between 14 and 11 ka. Hence the ‘salt mirror’ can be viewed as a Holocene stratigraphic and structural marker. Zucker et al. (2019) carefully mapped this marker in outcrops and chimney caves in order to define Mount Sedom’s internal structure and movements during the Holocene.

In his Comment, J. Charrach discusses several points taken from his own papers, some of which may be valid and some not. Many of his details about the internal stratigraphy and geochemistry within Sedom Formation are not relevant to the Holocene stage of the Sedom salt tectonics, so we do not address them. The following response to the comments refers to Charrach (2019a) main sections, and is based on our previous papers (e.g., Alsop et al., 2016; Frumkin, 1996; Weinberger et al., 1995, 2006).

2. Geology

Weinberger et al. (1995, 1997) and Alsop et al. (2015, 2016) use geophysical and sedimentological evidence to infer the ‘way-up’ of the Sedom Formation. These evidence support unequivocally the results of Zak (1967) that the Sedom Formation is younging to the east on the eastern limb of the salt anticline. Charrach (2018) argues that the Sedom Formation within the salt wall is younging to the west. This response is hardly the venue for rebutter; suffice it to say that Charrach (2018) hinges his argument mainly on a photo of tepee structures, one that is missing in the paper (Figure 12e). The caption for Figure 12e seems to refer to Figure 12f, but without tracing on the photo, tepee structures remain to be shown.

In his Comment, Charrach (2019a) complains about our use of a widely accepted seismic cross-section (Figure 1d). He states that the section “was reinterpreted in Charrach (2018) and the shape of Mt. Sedom and its eastern extension are subject to question”. Alas, again a figure is not available in the paper cited by the Comment.

3. Cap rock

In this section we find support for our results and interpretations as Charrach (2019a) suggests that (1) “the steps in the salt mirror and the possible faulting should be correlated to the geology of the rocks” and (2) “the surface features of the cap rock give a true representation of the underlying geology”. Indeed, Zucker et al. (2019) demonstrated that (1) “the salt wall rises as a telescopic antenna, with the internal salt units sliding across each other along bedding-plane slip faults, influenced by the subsiding Dead Sea basin”, and (2) based on a Lidar-driven, high-accuracy topographic map “the topography of Mount Sedom is closely associated with the structure of the salt mirror, which lies beneath”.

4. Age of cap rock

The formation of the cap rock signifies the arrival of the Sedom salt wall from depth to the dissolution level near the surface (Weinberger et al., 2006a). The cap rock started to form at the mid-Pleistocene long
before the existence of Lake Lisan and continued to be accumulated underneath the Lisan Formation between ~70 and 14 ka. Accordingly, the Sedom salt mirror, a surface formed at a halocline in a large body of water, ended (fossilized) when Lake Lisan declined abruptly, giving way to the present Dead Sea at the late Pleistocene-Holocene transition. The Holocene groundwater at Sedom is salt-saturated, incapable of forming cap rock or a salt mirror. Charrach (2019b) has challenged other recent studies (Levy et al., 2019) on this matter. Levy et al. (2020) in their Reply show that Charrach (2019a,b) statement about the age of the cap rock disagrees with the available evidence gathered from the entire mountain using geological, geophysical, and geochemical methods.

5. Structural features within Mount Sedom

We agree that most deformation of the Sedom salt wall is observed close to the salt penetration boundaries. In addition, our measurements of faults observed on the surface and the salt mirror elevation in Mount Sedom show explicitly that deformation away from the boundaries is localized mainly along bedding-plane slip faults, proving a ‘telescopic’ mode of rising of the salt wall. Although Charrach (2018) reports “fault breccias” and “slickened sided faults” in the recovered cores from the central part of the mountain, he inconsistently argues for “the lack of deformation away from the margins” (Charrach, 2019a).

6. Measuring points

The field work consisted of elevation measurements (absolute altitudes) and mapping of the salt mirror. Surveying the salt mirror surface in outcrops and caves throughout the region has involved rappingelling into chimney caves in order to cross the thick (~50 m) cap rock and determine the elevation value of the salt mirror underneath. The data from the caves cover approximately 60% of the research area and together with the data from outcrops enable Zucker et al. (2019) to draw structural maps of the salt mirror. Charrach (2019a) criticizes that the majority of the data points are along the SE margin of the mountain. In fact, this dense net of data points zooms into a belt of ~300 m along the SE margin of the mountain, allowing a look at the details of the salt-mirror stepping and kinematics. The salt mirror in the center of Mount Sedom is hardly exposed, so we used available rare sections exposed within caves. Nevertheless, the sporadic data points from this part of the salt wall indicate clearly that the once-flat salt mirror was significantly displaced (>150 m; Zucker et al., 2019) by bedding-plane slip faults. It is this set of data points that help rejecting Charrach (2019a) hypothesis of the Sedom salt wall being a uniform block.

7. Tectonic subsidence and rim syncline formation

Boreholes and seismic data indicate that the source of the Sedom salt layer is located in the deepest part of the southern Dead Sea basin, now buried beneath Plio-Pleistocene sediments of a maximum thickness of 5,500 m (Weinberger et al., 2006a). The Sedom salt flow is driven by the load of the overburden and affected by the differential subsidence of the diapir’s flanks due to displacement along the down-thrown (basinward) steeply dipping fault (Weinberger et al., 2006b). The veneer of sediments (~50 m; Neve and Emery, 1995) accumulated during the Holocene in the southern Dead Sea basin exerts an additional pressure that is negligible with respect to that exerted by the thick Plio-Pleistocene overburden (~5,500 m). Charrach (2019a) suggests to refine the thickness of sediments accumulated during the Holocene to 60–80 m, but this addition of 10–30 m has negligible (<0.5%) effect on the driving forces.

Weinberger et al. (2006b) showed that the shape of the Sedom salt wall in cross section is also dictated by basin subsidence along its eastern margins, becoming more asymmetric as the total subsidence increases. Based on palynological evidence for the Holocene rate of accumulation in the southern Dead Sea basin, we considered a subsidence of about 100 m during this period. Charrach (2018) suggests to refine the subsidence to 124 m, which has some additional effect on the asymmetric shape of the salt wall as detected by the stepping ‘salt mirror’ toward the east.

8. Conclusions

Charrach’s Comment does not present any relevant evidence about the salt mirror which might refute or significantly improve Zucker et al. (2019) detailed measurements and observations. The telescopic behavior of the Sedom salt wall represents a mode of internal deformation that might be applicable to other salt walls worldwide.

References

