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SUPPLEMENTAL MATERIAL

Relating Strait Depth to Exchange Rate and Salinity

The exchange fluxes of shallow and narrow straits between neighboring basins of different climatic forcings are topographically controlled (e.g., Whitehead, 1998). Important factors that affect the exchange strength are (1) the inertia of the water, (2) the Coriolis force, which alters the momentum of the water and (3) the pressure gradient, which is influenced by the density difference of the neighboring basins. Other forces may also be important (e.g., friction between interfaces or tides). However, because they have been shown to play secondary roles (e.g., Bormans and Garrett, 1989; Simon and Meijer, 2015), we ignore them for simplicity. Moreover we choose to work with steady-state theory, because the time-scales of the examined events (hundreds of kyrs) are much larger than the residence time of comparable basins today (e.g., kyrs in Mediterranean Sea, Meijer, 2012 and in the Black Sea, Lane-Serff et al.,, 1997).

Hydraulic control theory (equation S1) for a rectangular cross-sectional channel balances the inertia and the pressure gradient, but ignores the Coriolis force.

$$Q_{OB}^2 + Q_{BO}^2 = k * h^3 * (S_{Basin} - S_{Ocean}), \quad \text{(S1; equation 2 in main text)}$$

The *constant k* defined in the 'Method' section is:

$$k = w^2 g\boldsymbol{\beta}/8\,\boldsymbol{\rho} \quad (S2)$$

where w is the gateway width, g is the acceleration due to gravity, $\boldsymbol{\beta}$ is the haline contraction coefficient (0.77 $(kg/m^3)/(g/l)$) and $\boldsymbol{\rho}$ is the water density. This specific setting is for the case that inflow and outflow occupy approximately the same cross-sectional area. All of these parameters will determine the size of *k*. For the present-day Strait of Gibraltar *k* would be of the order of 10^5 $(m^3/s^2)/(g/l)$ and for the Bosphorus of the order of 10^3 $(m^3/s^2)/(g/l)$. Instead of changing each parameter individually, we examine various *k* in a sensitivity test (Fig. S1). Fig. S1 shows that, although various values for *k* lead to different combination of gateway depth and basin salinity, the patterns demonstrated by each panel of Fig. S1 stay the same. This exchange theory has a non-linear dependency of gateway depth to exchange flux and therefore basin salinity. This also holds true for theories that that consider the Coriolis force (e.g., Whitehead, 1998, equation 12), which shows a quadratic relationship between exchange flux and gateway depth ($Q \propto h^2$).

The relative importance of salinity and temperature in controlling seawater density is determined by the ratio of the coefficients of haline contraction to thermal expansion, which is typically about 4:1 (e.g., Johnson et al., 2007). Simon and Meijer (2017) demonstrated that in the Mediterranean Messinian Salinity Crisis the impact of temperature changes relative to salinity changes can be neglected. In the Black/Caspian Sea region present-day temperature ranges from <5^{o}C during winter to <25-30^{o}C during summer (Ginzburg et al., 2004). If this temperature span would be imposed as a variation at a single location at the surface, the density would change by an amount equivalent to a change in surface salinity of <5g/l. Present-day salinity in the Paratethys region ranges from <20g/l in the Balck Sea to <10g/l in the Caspian Sea. It follows that temperature and salinity both play a role. However, during the middle Miocene the salt concentration reached up to absolute values of <350g/l, while the proto-Mediterranean and rivers added much fresher water (<36g/l or less). Therefore, we ignore the effect of temperature on the water density, because the ranges of salinity (0-350 g/l) imply that it will play the dominant role.

Intermediate steps to derive equation (3)

The conservation of water and salt yield:

$Q_{BO} = Q_{OB} + C_{Basin}$ (S3, equation 1 in main text)

$Q_{BO} = Q_{OB} * S_{Ocean}/S_{Basin}$ (S4; equation 1 in main text)

Via rearrangement these equations can be written as:

$Q_{BO} = C_{Basin} * S_{Ocean} /(S_{Ocean} - S_{Basin})$ (S5)

$Q_{OB} = C_{Basin} * S_{Basin} /(S_{Ocean} - S_{Basin})$ (S6)

This allows to express the influx and ouflux solitarily as functions of the freshwater budget C_{Basin} and the two salinities (S_{Ocean} and S_{Basin}). By feeding equations S5 and S6 into the Hydraulic control equation (S1), S1 can be made independent of the gateway exchange fluxes:

$$(S_{Ocean}^2 + S_{Basin}^2) * |S_{Basin} - S_{Ocean}|^{-3} = k * h^3 * C_{Basin}^{-2} \qquad \text{(S7; equation 3 in main text)}$$

Equation S7 is the result, which allows a direct connection between basin salinities to gateway depth (h), freshwater budget (C_{Basin}) and constant k. Equation S7 has been used to create Figures 2 and DR1.

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FIGURE CAPTION

Figure DR1. The central panel is identical to the text Figure 2. The other panels show results for smaller (bottom) and larger (top) values of *k.*