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Short communication

Evolution of Chilia lobes of the Danube delta: Reorganization of deltaic processes under cultural pressures

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ABSTRACT

The growth of Chilia deltaic lobes reflects a drastic reorganization of the Danube delta that accompanied its rapid expansion in the late Holocene. Using new cores collected at the apices of the two older Chilia lobes, together with historical maps and satellite photos, we find that a partial avulsion since ~1500 years BP led to a gradual rejuvenation of the Chilia distributary. This process led to the successive infilling of a lake and a lagoon and subsequently to the construction of an open coast lobe at the Black Sea coast. The Chilia branch became the largest Danube distributary, reaching its maximum sediment load in the last 300 years as the southernmost St. George branch lost its previous dominance. Here, we propose that the intensive deforestation of Danube's lower watershed leading to this delta reorganization has historical cultural causes: an increase in sheep and timber demand associated to the Ottoman Empire expansion in Eastern Europe followed by the adoption of maize agriculture as a result of the Columbian Exchange. Rapid industrialization-driven damming during the Communist Era led to the current generalized sediment deficit for the Danube. Under these conditions, the modern Chilia lobe is rapidly remodeled by waves and may join the Sulina coast to impede navigation on the Sulina canal.

Human impacts in the Danube delta

Watershed deforestation over the last two millennia led to the rapid expansion and morphological diversification of the Danube delta (Fig. 1) coupled with a complete transformation of the ecosystem in the receiving marine basin, the Black Sea (Giosan et al., 2012). During this period the central wave-dominated lobe of Sulina was slowly abandoned and the southernmost arm of the Danube, the St. George, was reactivated and started to build its second wave-dominated delta lobe at the open coast. Simultaneously, secondary distributaries branching off from the St. George branch built the Dunavatz bayhead lobe into the southern Razelm lagoon (Fig. 1). This intense deltaic activity accompanied drastic changes in Danube's flow regime. Many small deltas had grown during intervals of enhanced anthropogenic pressure in their watersheds (Grove and Rackham, 2001; Maselli and Trincardi, 2013). However, finding specific causes, whether natural or anthropogenic, for such a sweeping reorganization of a major delta built by a continental-scale river like Danube requires detailed reconstructions of its depositional history. Here we provide a first look at the Danube's deltaic reorganization along its main distributary, the Chilia, and discuss potential links to hydroclimate, population growth and cultural changes in the watershed. For this reconstruction, we used sediment core-based depositional histories together with a morphological analysis of historical cartographic material and recent satellite photography (see complete methods in Supplementary data).

History of Chilia delta lobes

The Chilia arm, which flows along the northern rim of Danube delta (Fig. 1), has successively built three lobes (Antipa, 1910) and it was first mapped in detail at the end of the 18th century (Fig. 2a). The depositional architecture of these lobes was controlled by the entrenched drainage pattern formed during the last lowstand in the Black Sea, by the pre-Holocene loess relief developed within and adjacent to this lowstand drainage and by the development of Danube's own deltaic deposits that are older than Chilia's (Ghenea and Mihailescu, 1991; Giosan et al., 2006, 2009; Carozza et al., 2012a). The oldest Chilia lobe (Fig. 2b and c) filled the Pardina

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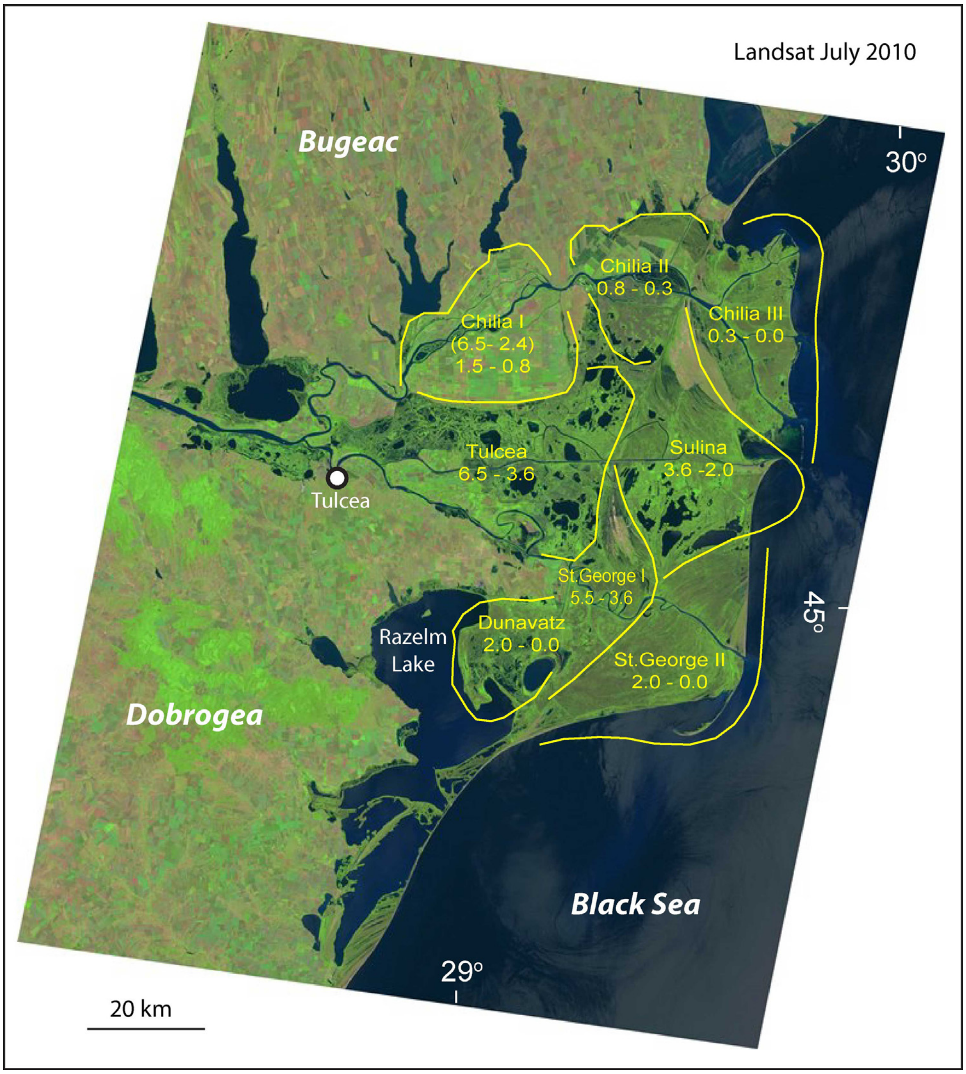

Fig. 1. Danube delta geography and its evolution phases (modified from Giosan et al., 2013). Yellow lines delineate delta lobes in the order of their build-up (Giosan et al., 2006, 2009 and results herein): (1) Tulcea, (2) Chilia I, (3) St. George I, (4) Sulina, (5) St. George II, (6) Dunavatz, (7) Chilia II, and (8) Chilia III. Estimated ages for the development of each lobe (Giosan et al., 2006, 2012 and present study) are given below each lobe name in cal. ka BP.

basin, which, at the time, was a shallow lake located at the confluence of two pre-Holocene valleys (i.e., Catlabug and Chitai) incised by minor Danube tributaries. This basin was probably bounded on all sides by loess deposits including toward the south, where the Stipoc lacustrine strandplain overlies a submerged loess platform (Ghenea and Mihailescu, 1991). Because most of the Chilia I lobe was drained for agriculture in the 20th century, we reconstructed the original channel network (Fig. 2b) using historic topographic maps (CSADGGA, 1965) and supporting information from short and drill cores described in the region (Popp, 1961; Liteanu and Pricajan, 1963).

The original morphology of Chilia I was similar to shallow lacustrine deltas developing in other deltaic lakes (Tye and Coleman, 1989) with multiple anastomosing secondary distributaries (Fig. 2b). Bounded by well-developed natural levee deposits, the main course of the Chilia arm is centrally located within the lobe running WSW to ENE. Secondary channels bifurcate all along this course rather than preferentially at its upstream apex. This channel network pattern suggests that the Chilia I expanded rapidly as a river dominated lobe into the deepest part of the paleo-Pardina lake. Only marginal deltaic expansion occurred northward into the remnant Catlabug and Chitai lakes and flow leakage toward the adjacent southeastern Matita-Merhei basin appears to have been minor. Secondary channels were preferentially developed toward the south of main course into the shallower parts of this paleo-lake (Ghenea and Mihailescu, 1991). As attested by the numerous unfilled ponds (Fig. 2b), the discharge of these secondary channels must have been small. All in all, this peculiar channel pattern suggests that the Chilia loess gap located between the Bugeac Plateau and the Chilia Promontory (Fig. 2b) already existed before Chilia I lobe started to develop. A closed Chilia gap would have instead redirected the lobe expansion northward into Catlabug and Chitai lakes and/or south into the Matita-Merhei basin.

The growth chronology for the Chilia I lobe has been unknown so far. Our new 6.5 m long KP1/K1 vibracore collected in a drained pond near the apex of the Chilia I lobe shows two cycles of interdistributary fine grained deposits (Fig. 3). In the first cycle between 6250 ± 250 and 2600 ± 250 years BP, sedimentation was slower (~1 m/ka) compared to the second cycle after 1470 ± 60 years BP (~2 m/ka). This depositional history shows that the Chilia I lobe developed in two phases. A smaller proto-Chilia distributary started the lobe growth after 6500 years BP in the same time as the Tulcea bayhead lobe grew adjacently to the south (Carozza et al., 2012b).