Rapid Communication

Was the Black Sea catastrophically flooded in the early Holocene?

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Abstract

A catastrophic flooding of the Black Sea basin was proposed to have occurred during its reconnection to the ocean in the early Holocene. Possible cultural consequences of the flood include the migration of Neolithic farmers from around the Black Sea towards central Europe as well as the creation of flood myths. Stratigraphic and paleo-geomorphologic information from Danube delta aided by radiocarbon ages on articulated mollusks constrain the level in the Black Sea before the marine reconnection to ca. 30 m below the present sea level rather than 80 m or lower. If the flood occurred at all, the sea level increase and the flooded area during the reconnection were significantly smaller than previously proposed.

1. The last Black Sea reconnection to the ocean

From early ideas (Murray, 1900) to modern studies, after a century of research, there is still little consensus on the Black Sea level variations (e.g., Pirazzoli, 1991; Ryan, 2007; Hiscott et al., 2007). The Black Sea is a marginal basin that becomes marine only when the ocean level rises above the depth of the straits connecting it to the Mediterranean: the Bosphorus (current depth: ~35 m) and the Dardanelles (current depth: ~70 m). During the last global lowstand and for much of the subsequent deglacial ocean level rise, the Black Sea functioned as a giant lake with its level controlled by climate (e.g., Ross et al., 1970). Contrary to previous research envisioning a smooth reconnection the ocean (e.g., Ross et al., 1970), Ryan and colleagues proposed that the Black Sea was instead catastrophically flooded and its level rose at least 50 meters from around 90 m or lower below present sea level in a few years time (Ryan et al., 1997; Ryan and Pitman, 2000). The authors suggested that flooding of the vast continental shelf may have led to a migration of Neolithic farmers from around the Black Sea towards central Europe and led to the creation of flood myths. A protracted debate continues on the occurrence of the flood itself as well as on its possible cultural consequences (e.g., Aksu et al., 2002; Ryan et al., 2003; Hiscott et al., 2007; Ryan, 2007; Turney and Brown, 2007; Yanko-Hombach et al., 2007a,b).

Faunal and geochemical reconstructions converge to indicate a rapid transition from a fresh to brackish lake to the ocean-connected modern Black Sea around 9 400 years ago

(~8 400 ^{14}C years BP; Ryan et al., 2003; Major et al., 2006; Hiscott et al., 2007; Bahr et al., 2008), although a weak or transitory inflow of Mediterranean waters before that time is still discussed (e.g., Hiscott et al., 2007). Water level variations accompanying these changes remain, however, contentious. An agreement exists that a lake highstand at ~20-30 m below current sea level (mbsl) was reached sometimes during the deglacial to the earliest Holocene, but the exact timing, cause, and temporal extent of this is disputed (e.g., Ryan et al., 2003; Hiscott et al., 2007; Lericolais et al., 2007a).

2. Constraints on the Black Sea level changes

Proponents of the flood hypothesis advanced a series of arguments in support of a lake level below the Bosphorus threshold immediately preceding the marine reconnection. At several locations on the Black Sea shelf, a pre-Younger Dryas lowstand (<13 250 ^{14}C years BP; Major, 2002) was found to be expressed as an unconformity at the top of desiccated clay-rich deposits with plant remains (e.g., Major, 2002; Ryan et al., 2003). A sandy coquina layer composed of lacustrine mollusks overlies lowstand deposits from just below 100 mbsl and was interpreted as a Younger Dryas trangressive lag (Major, 2002; Ryan, 2003). Supported by bulk carbonate ages of Dimitrov (1982) from the mid-shelf, Major (2002) suggested that the Younger Dryas coquina extended on the shelf shallower than 100 mbsl and was subaerially reworked during a post-Younger Dryas regression. The resulting shell hash was colonized from ~ 90 mbsl to higher than 40 mbsl by more salt-tolerant mollusk species after the reconnection (Major et al., 2006). At depths between 100 mbsl and 70 mbsl, drowned paleo-shoreline features and fields of bedforms, interpreted based on their morphometry as subaerial dune fields (Ryan et al., 2003; Ryan, 2007; Lericolais et al., 2007a, b), were also used to argue for a post-Younger Dryas regression, but these features are yet to be directly dated.

Supporters of the continuous transgression hypothesis argued that bedforms preserved on the Black Sea shelf in front of the Bosphorus represent barrier islands and associated lagoonal deposits that were drowned as the lake level rose over the outer and mid shelf (Aksu et al., 2002). Subsequent analysis showed that the bedforms were instead part of a “shelf fan” constructed by the dense, bottom-hugging inflow of Mediterranean waters spreading on the shelf from the Bosphorus outlet after the ocean reconnection (Ryan, 2007) that may overlap older erosional relief (Giosan et al., 2005). However, in a core retrieved from 69 mbsl on the southwestern shelf of the Black Sea, sediments interpreted to have accumulated below wave base (taken as ≥ 30 m water depth) span the postulated age of the flood covering the entire interval from before 9 100 to after 8 300 ^{14}C years BP (Hiscott et al., 2007). If we assume that the region around Sakarya River estuary in Turkey was vertically stable over the Holocene, the Black Sea level after the reconnection to the ocean was >18 mbsl after 7 500 BP, the youngest calibrated age for lacustrine sediments before estuarine sedimentation started at that location (Görür et al., 2001).

Ancillary support for a lacustrine highstand above the Bosphorus threshold comes from deltaic deposition in the Sea of Marmara from a proposed Black Sea water outflow between ~10 000 and 9 000 ^{14}C years BP (e.g., Hiscott et al., 2002), but it is highly contested with conflicting ages and different morpho-stratigraphic interpretations (e.g., Gökaşan et al., 2005; Eriş et al., 2007, 2008; cf., Hiscott et al., 2008). Other reconstructions have argued for an elevated lake level in the Black Sea, close to the modern depth of the Bosphorus, at the time of its reconnection to the ocean (e.g, Chepalyga, 1984; Balabanov, 2007; Yanko-Hombach et al., 2007a); however, documentation on the indicative meaning of the stratigraphic or morphologic features used as sea level indicators, on the accuracy of their chronologies, as well as on possible tectonic influences is needed to establish the value of these reconstructions (Pirazzoli, 1991; Giosan, 2007).

3. A Danube delta perspective

The uncertainty surrounding the Black Sea level stems from a lack of reconstructions based on reliable sea level markers (Pirazzoli, 1991; Giosan et al., 2006), a scarcity of radiocarbon ages on *in situ* materials and the difficulty in calibrating radiocarbon ages in a setting with variable reservoir ages (Giosan, 2007; Ryan, 2007; Kwiecien et al., 2008). Compared to other coastal settings around the Black Sea, the Danube delta was vertically stable since at least the last interglacial (Dodonov et al., 2000; Giosan et al., 2006). A sea level reconstruction in the Danube delta shows that the Black Sea level was close to its modern level for the past five millennia (Giosan et al., 2006). Whereas the evolution of the Danube delta since the middle Holocene is more or less known (Fig. 1), earlier deglacial to early Holocene deltaic-estuarine phases remain to be deciphered. Sedimentary deposits immediately underlying the modern delta down to the coarse gravelly fluvial base (Fig. 2a) had been postulated to be as old as early to middle Pleistocene (Liteanu et al., 1961; Liteanu and Pricajan, 1963) to early Holocene (Panin, 1972). Recently, Lericolais et al. (2007c) seismically imaged a clinoform above an erosional surface at 47 mbsl, in front of the present delta coast (Fig. 2; Minereau, 2006), and inferred it to have formed during a Bolling-Allerod lacustrine highstand.

FIGS. 1 and 2 here

Numerous Danube delta drill cores from the late 1950s (Fig. 2) were discussed in early papers (Liteanu et al., 1961; Grossu and Baltac, 1962; Liteanu and Pricajan, 1963; Baltac, 1963, 1964; Panin, 1972, 2007; Romanescu, 1996), but core material has not been preserved to allow further study. In 2007, we drilled a new core to 42 m depth near the present deltaic coast, onshore of the recently surveyed pre-modern clinoform. Facies analysis based on lithology, sedimentary structures and textures, and a high resolution geochemical grain size proxy record, were employed to identify depositional environments (Fig. 3). Radiocarbon ages on articulated mollusks (Table I; Fig. 3) collected from sections with no drilling disturbance (i.e., intact stratification, preserved bedding contacts) provide age control. The dated mollusks were estimated to be *in situ* based on the lack of abrasion and secondary encrustations, non-exotic character (i.e., the lithological and facies characteristics of sediments that preserved them is in agreement with their known modern habitat; Nevesskaya, 1965; Bacescu et al., 1971), and sediment filling similar to the sediment surrounding the shells. We calibrated the radiocarbon ages using Calib 5.0.1 (Reimer et al., 2004); for marine mollusks we assumed a modern value for the reservoir age is 440 ± 40 yr BP with ΔR 75 ± 60 yr (Siani et al., 2001), whereas older ages on lacustrine mollusks were calibrated assuming a null reservoir age for the lacustrine surface waters after the Younger Dryas (Ryan, 2007; Kwiecin et al., 2008).

FIGS. 3 and 4 here

Beach ridge and shoreface sands of the St. George II lobe, younger than 2 000 years, overlie amalgamated sand and muds of the delta front and prodelta clays; both facies accumulated as the Sulina lobe was constructed between ~3 600 and 2 000 years ago (Figs. 3 and 4). Under these typically deltaic coarsening and shallowing upward deposits of the modern delta, lies a condensed interval composed of muds with two intercalated shell coquina beds (Figs. 3 and 4). The age of 4 400 to 4 900 years at the base of the upper coquina indicates that these sediments had been accumulating in a starved shelf setting during the development of first open-sea Danube delta lobe, the St. George I (~ 5 000 to 3 600 years old). Below the lower coquina at ~39 mbsl, amalgamated sands and muds typical of a delta front facies were deposited since at least 9 700 until ~9500 years ago (8 860±45 and 8 660±45 ^{14}C years BP; Figs. 3 and 4), corresponding to the clinoform described by Lericolais et al. (2007c). Data from a previous borehole drilled at this location show that fluvial gravels underlie this deltaic unit below ~ 49 mbsl (Fig. 3).

We used data from previously drilled cores to examine two surfaces below the modern Danube delta deposits. The first occurrence of gravels was used to plot the minimum depth of fluvial deposits (Fig. 2a). The reconstructed surface suggests that the Danube flowed at lowstand along two to three paleo-drainage directions, already recognized on the shelf as anastomosed channel networks (Popescu et al., 2004). The change in fauna from lacustrine to marine, aided by the change in facies from lacustrine delta front amalgamated sands and muds or coquina beds to estuarine/prodelta clayey deposits, was employed to reconstruct the lacustrine-marine separation surface (Fig. 2b). Although diachronous, this surface shows a vast lobe-like landscape of low relief, located between ~35 and 25 mbsl, which was rapidly inundated during the marine transgression. Stratigraphic interpretation of a transect of cores (Fig. 3) on the alignment continuing the seismic line of Lericolais et al. (2007c), supported by radiocarbon ages from our new drill core and the shallow cores of Giosan et al. (2006), shows that the early Holocene Danube built a thin ramp delta similar to the modern Volga delta (Overeem et al., 2003). The reconstructed flat surface of the delta implies that the subaerial delta plain at the time was located around 30 mbsl (Fig. 2b). Networks of anastomosed channels (Popescu et al., 2004) suggest that earlier ramp deltaic lobes prograded father onto the shelf.

4. Was there a Black Sea flood?

In the early Holocene (9 800-9 500 years BP or 8 660 ^{14}C years BP), immediately before the Black Sea reconnection to the ocean at ~ 9 400 years BP (8 400 ^{14}C years BP), the Danube was building a ramp delta lobe that requires the contemporaneous level of the isolated Black Sea to be above 40 mbsl. Morphology of the lacustrine-marine contact and stratigraphic reconstructions indicate that the lake level at the time was around 30 mbsl.

The vertical range of values for modeled sea levels in the Sea of Marmara (Lambeck et al., 2007) and eustatic sea level curves (e.g., Fairbanks, 1989; Bard et al., 1990, 1996; Hanebuth et al., 2000; Yokoyama et al., 2000) cannot overrule a level higher than 30 mbsl at the Bosphorus, and thus, an abrupt rise of the Black Sea level, during the reconnection. However, if the reconnection was an abrupt event, the increase of the Black Sea level necessary to equalize its level to the contemporaneous ocean level was significantly smaller than the ~50 meters previously proposed. Even a minor flooding of the Black Sea is expected to have left sedimentary imprints around the Black Sea (e.g., Siddall et al., 2004). For example, the drowning of the early Holocene Danube delta may be explained by a rapid increase of Black Sea level during the reconnection. The transgression leading to the early Holocene lake highstand may have been itself rapid (Ryan, 2007) to flood early deltas of the Danube on the outer and middle shelf (Popescu et al., 2004; Lericolais et al., 2007c).

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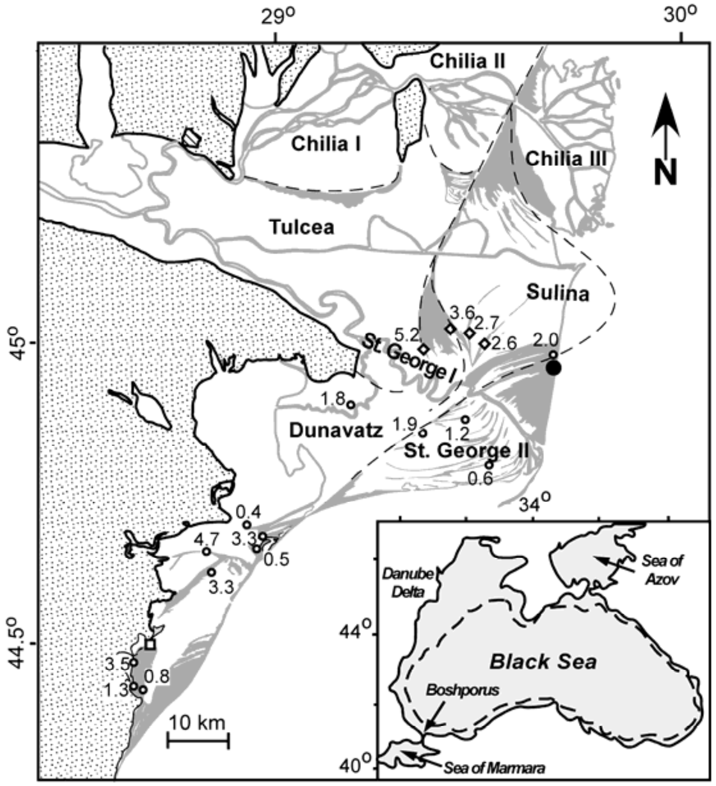
Figure captions

Fig. 1. Modern Danube delta morphology and lobe development sequence (after Giosan et al., 2006). Sand ridges are in grey and named lobes are delineated by dashed lines. The chronology is in cal. ka BP (diamonds - optically stimulated luminescence ages and calibrated radiocarbon ages; unfilled circles – calibrated radiocarbon ages). Location of the new drill core discussed in text is indicated by the black filled circle. Inset shows the Black Sea region with the location of Danube delta. The extent of the Black Sea shelf is approximated by the 100 m depth contour (dashed line).

Fig. 2. Left - Isobaths of fluvial gravels showing flow directions (arrowed thick dashed lines) for the Danube at lowstand. Right – Isobaths of the marine flooding surface. Thick dashed line delineates an early Holocene delta lobe. Seismic line of Lericolais et al. (2007c) is indicated by thin black line. The thin dashed line I-I'with numbered boreholes is discussed in Fig. 4. In both maps, uplands are hachured; current coastline and bathymetry are indicated by grey dashed lines; unfilled circles indicate location of boreholes; black dots indicate individual lowstand channels clustering into anastomosed networks (Popescu et al., 2004). Location of new drill core discussed in text is indicated by the black filled circle.

Fig. 3. Interpreted log data from CV core and, below 42 m, the co-located previous borehole (958). Ages are from radiocarbon ages on articulated mollusks in cal. ka BP. Lithology: c – clays; m – muds; fs – fine sands; ms – medium sands; cs – coarse sands; g – gravels. The ratio of Si/Fe (from XRF core scanning) is used as proxy for grain size (i.e., sand content and layers). Core photos at indicated positions show typical facies and contacts: A. shoreface sands with coffee grounds layers; B. delta front amalgamated sands and muds; C. prodelta clays overlaying the upper coquina layer; D. muds and the lower coquina of the shelf condensed interval (SCI); E. delta front amalgamated sands and muds of the early Holocene lobe.

Fig. 4. Longitudinal cross section of the Danube delta deposits based on borehole and shallow core chronostratigraphy (line I-I' in Fig. 2). Modern and earlier lobes are identified. Ages are in cal. ka BP. Arrows locate the approximate position of ages shallow cores projected onto line I-I'.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Boshporus
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Sea of Marmara

Fig. 1

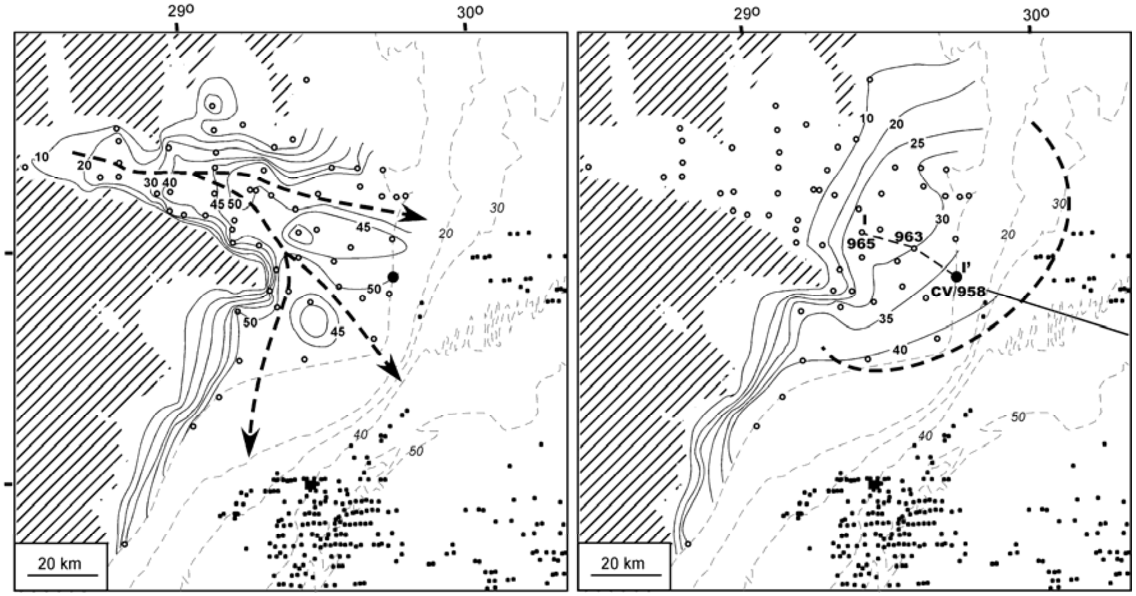
29o
30o
10
20
30
40
45
50
45
50
45
50
20
30
45o
40
50
44.5o
20 km
29o
30o
10
20
25
30
965
963
I'
CV 958
35
40
20
30
40
50
20 km

Fig. 2

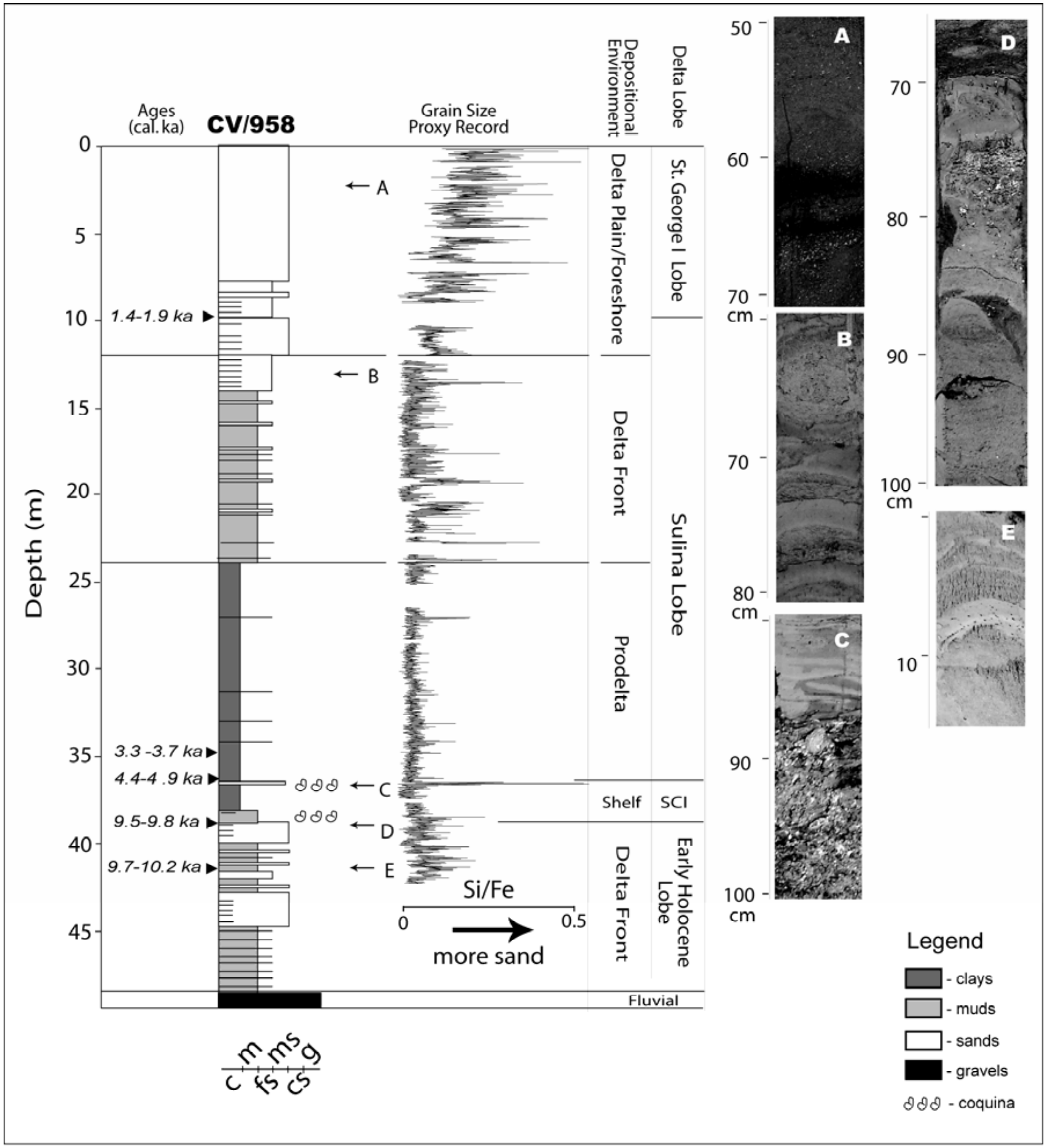
Ages (cal. ka)
CV/958
Grain Size Proxy Record
Depositional Environment
Delta Lobe
Depth (m)
0
5
10
15
20
25
30
35
40
45
1.4-1.9 ka
3.3 -3.7 ka
4.4-4 .9 ka
9.5-9.8 ka
9.7-10.2 ka
A
B
C
D
E
Si/Fe
0
0.5
more sand
Delta Plain/Foreshore
Delta Front
Prodelta
Shelf
Delta Front
Fluvial
St. George I Lobe
Sulina Lobe
SCI
Early Holocene Lobe
c
m
fs
ms
cs
g
50
60
70
cm
70
80
cm
90
100
cm
70
80
90
100
cm
10
Legend
- clays
- muds
- sands
- gravels
- coquina

Fig. 3

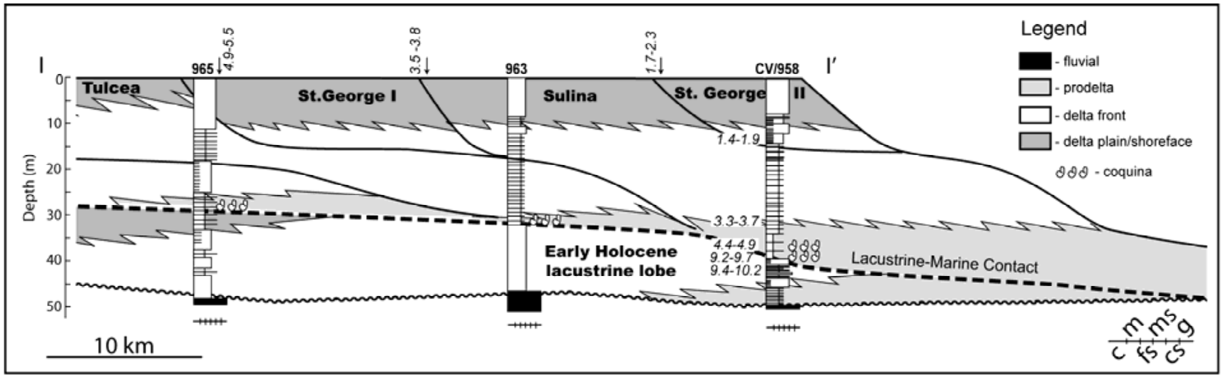
I
965
4.9-5.5
3.5 -3.8
963
1.7-2.3
CV/958
I′
Legend
- fluvial
- prodelta
- delta front
- delta plain/shoreface
- coquina
Tulcea
St.George I
Sulina
St. George II
1.4-1.9
3.3-3.7
4.4-4.9
9.2-9.7
9.4-10.2
Early Holocene lacustrine lobe
Lacustrine-Marine Contact
Depth (m)
0
10
20
30
40
50
10 km
c
m
fs
ms
cs
g

Fig. 4