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Remote sensing, planform, and facies analysis of the Plain of Tineh, Egypt for the remains of the defunct Pelusiac River

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ABSTRACT

The Pelusiac Branch was a distributary river in the Nile Delta that splits off from the main trunk of the Nile River as it flowed toward the Mediterranean. At approximately 25 A.D., it was chocked by sand and silt deposits from prograding beach accretion processes. The lower course of the river and its bifurcation point from the trunk of the Nile have been hypothesized based on ancient texts and maps, as well as previous research, but results have been inconsistent. Previous studies partly mapped the lower course of the Pelusiac River in the Plain of Tineh, east of the Suez Canal, but rapid urbanization related to the inauguration of the Peace Canal mega-irrigation project has covered any trace of the linear feature reported by these previous studies.

The present study used multispectral remote sensing data of GeoEYE-1 and Landsat-TM to locate and accurately map the course of the defunct Pelusiac River within the Plain of Tineh. Remote sensing analysis identified a linear feature that is 135 m wide at its maximum and approximately 13 km long. It extends from the Pelusium ruins to the Suez Canal, just north of the Peace Canal. This remotely located linear feature corresponds to the path of the Pelusiac River during Roman times. Planform geomorphology was applied to determine the hydrological regime and paleodischarge of the river prior to becoming defunct. Planform analysis derived a bankfull paleodischarge value of ~5700 $m^3\ s^{-1}$ and an average discharge of 650 $m^3\ s^{-1}$, using the reach average for the interpreted Pelusiac River. The derived values show a river distributary similar in discharge to the modern dammed Damietta river. Field work completed in April of 2012 derived four sedimentary lithofacies of the upper formation on the plain that included pro-delta, delta-front and delta-plain depositional environments. Diatom and fossil mollusk samples were also identified that support coastal beach and lagoonal environments of deposition. Measured section columns and a shoreline parallel transect were also constructed to portray the paleogeography of the Mediterranean coastline in the Plain of Tineh at ~25 A.D. and indicate that the sampled study area is the downdrift margin of an asymmetric delta with barrier lagoon systems.

1. Introduction

The Nile River is the longest river in the world, flowing 6829 km from its headwaters in the south of Africa to the Mediterranean Sea in the north. The Nile flows from South Africa due north, before bifurcating north of Cairo into the Rosetta and Damietta branches (Fig. 1). The precursor to the modern Nile River, the Neo-Nile, flowed from the Late Pleistocene into the Holocene. The Neo-Nile was a larger river in comparison to the modern Nile, feeding at least seven distributaries within the delta. Historical texts, including "The Histories" by Heredotus in the 5th century B.C., have referenced the existence of these seven major distributaries in the Nile Delta, including the easternmost Pelusiac Branch (Abdel-Kader, 1982). Fig. 1 shows a generalized interpreted flow path for the more well-known branches. From the west, they are the Canopic, Bolbitine (modern Rosetta), Sebbenytic, Pathmytic (modern Damietta), Mendesian, Tanitic, and Pelusiac (Baynes, 1988). Only the Damietta and Rosetta presently flow to the Mediterranean Sea. The other branches have become defunct or have deteriorated into the network of irrigation canals in the delta (Baynes, 1988).

The defunct Pelusiac Branch was an important navigable waterway that extended trade to the east (Sneh and Weissbrod, 1973). As late as the 12th century, Tell el Farama City (ancient Pelusium), located on the mouth of the Pelusiac Branch, was considered the "gateway to the East," since trade heading to the Asian kingdoms passed through the city on its way to Sinai and Asia (Sneh and Weissbrod, 1973). It flowed northeast past the modern-day Suez Canal, into the Mediterranean. The shoreline retreated during the time of the Neo-Nile and various avulsions took place in the Plain of Tineh (Fig. 2A) before it went defunct (Stanley et al., 2008).

Longshore accretion processes created the present day strandplain on the northeastern side of the Nile Delta and are credited with silting up the Pelusiac River mouth. Carbon^{14} dating of mollusks collected in the youngest ridge within the strandplain suggest that the river ceased flowing around 25 A.D. (Sneh and Weissbrod, 1973). Goodfriend and Stanley (1999) suggested that the Pelusiac may have continued to

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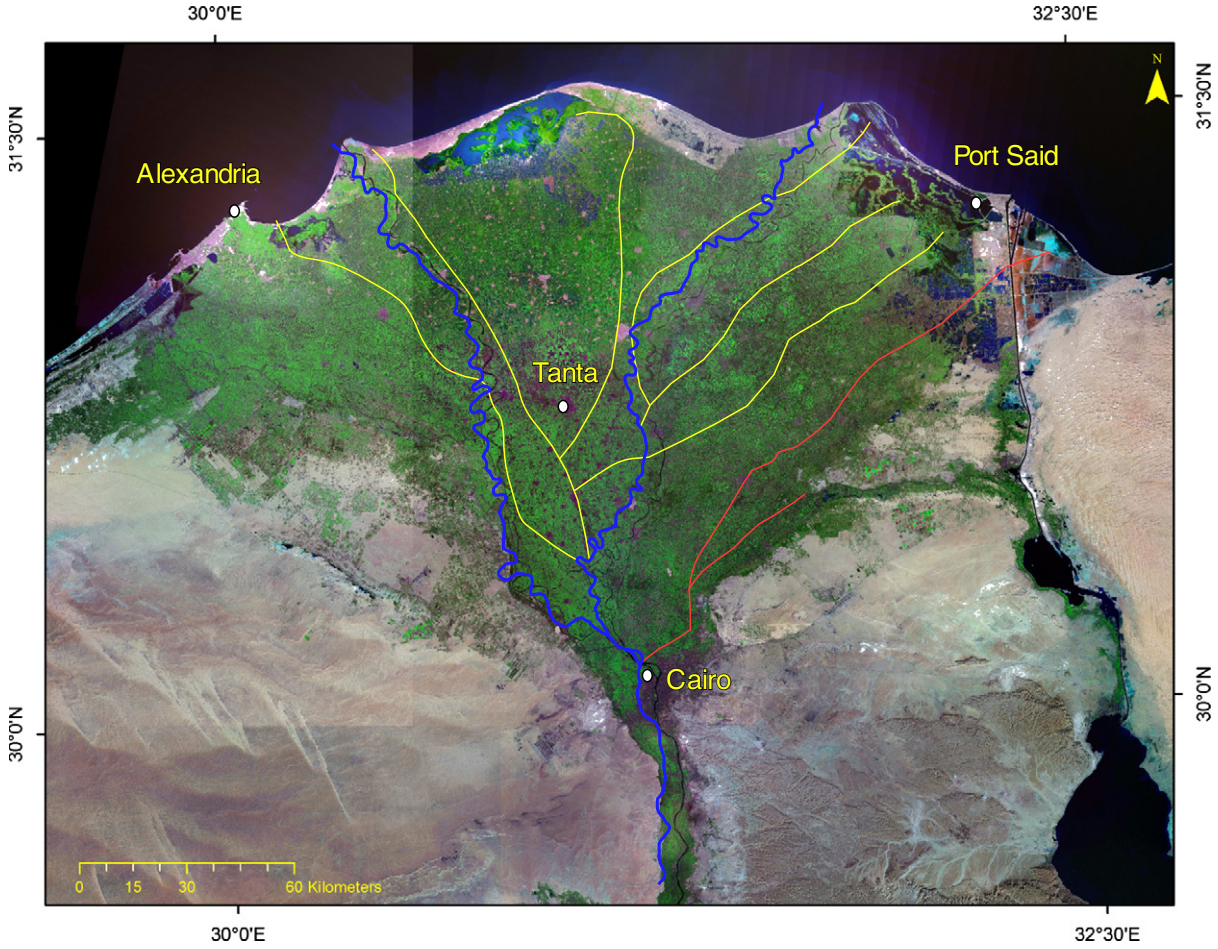

Fig. 1. Map of the Nile Delta showing past and present river branches during the Quaternary. Only the modern Rosetta and Damietta branches reach the Mediterranean today (in blue). The Pelusiac, shown in red, is the easternmost branch and emptied into the Mediterranean, past the modern day Pelusium ruins. River path information is derived from Said (1981).

flow as late as mid-800 A.D., but ruins older than Roman design have not been found in the strandplain area.

This study adopted integrated approach and used remote sensing, planform and facies analysis with field observations, to reconstruct paloegeography, channel morphology and geological development of the Pelusiac River and its accompanied delta. This work shed light on the sea-level oscillations and coastal accretion of Mediterranean Sea in one of the most important historical site in Egypt during Holocene time. Studies of this nature help in the development of fluvial facies models (Galloway and Hobday, 1996), mathematical and flume test modeling (Peakall et al., 2007; Duan and Julien, 2010), understanding of channel formation and evolution mechanics (Peakall et al., 2007; Duan and Julien, 2010). This study also provided an opportunity to test empirical equations, and estimation of paleohydraulic parameters.

2. Geologic setting of the study area

The Nile Delta is one of the largest deltas in the world, covering 22,000 km^2 of area (Wright and Coleman, 1973) and represents more than 60% of the inhabited area of Egypt. It begins near Cairo and extends both west and east as it forms the inverted Greek letter delta (Δ) shape that is bounded by the Mediterranean Sea. The Nile Delta is a wave-dominated delta system, as classified by Galloway (1975). Although the effects of tide and river influences are minimal today, the influence of the Nile River was greater in the past. The changes are due in large part to changing climate, although some change is accredited to increasing human modification of the river. The damming of the Nile at the Aswan High Dam in Aswan, Egypt has severely decreased the discharge of sediment reaching the Mediterranean. The Nile Delta saw three different main avulsions during the Quaternary: the older Proto-Nile, the Pre-Nile, and the Neo-Nile, occurring prior to the modern Nile River flowing today (Rizzini et al., 1978; Said, 1981). The modern Nile Delta reached its current configuration approximately 10,000 years ago (Rizzini et al., 1978). The delta plain and strandplain in the Plain of Tineh consist of Holocene age sediments of Bilgas Formation.

The Nile Delta has been tectonically inactive throughout the Quaternary, with the exception of small-scale earthquakes along the existing minor faults. The main structural feature on the plain is the Pelusium Line Fault, which is a transcontinental shear trending northeast to southwest. Although the feature is considered active, no appreciable movement has occurred in modern times (Said, 1981). The Pelusiac Fault (Fig. 2B) extends southwest from the Levant to the southeastern part of the Mediterranean and northwest part of Sinai, until it ends on the eastern extent of the Nile Delta (Stanley, 2005; Stanley et al., 2008).

The focus of this study lies in the easternmost part of the Nile River Delta in Egypt, in the Plain of Tineh (Fig. 2). The strandplain that defines the modern day coast of the Mediterranean lies east of Port Said (Coutellier and Stanley, 1987; Stanley and Warne, 1998) and contains a series of low accretionary ridges. The wide deltaic plain extending through most of the southern part of the delta ranges from 1 to 2 m above sea level south of the strandplain (Fig. 2). It comprises muddy, deltaic deposits covered by a salt crust. The width of the strandplain varies from 1 km in the east to 12.5 km in the west (Sneh and Weissbrod, 1973). To the southeast, linear dunes and coastal ridges,