Lacustrine clay mineral assemblages as a proxy for land-use and climate changes over the last 4 kyr: The Amik Lake case study, Southern Turkey

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ABSTRACT

Lake sediments are sensitive to landscape changes and most of these changes seem to be modulated by land-use (anthropogenic factors) coupled to palaeoenvironmental/palaeoclimatic changes. In its detrital fraction, the lacustrine sediments record the history of soil erosion within its catchment via the inputs of clays and others detrital products. Within a Mediterranean context, the study investigates the upper sediments infilling the central part of the Amik basin in southern Turkey. This tectonic basin was occupied and exploited by modern human at least since 6000–7000 BCE. We focus on the clay mineralogy (x-ray diffraction on oriented aggregates) and magnetic susceptibility measurements (Bartington) of the sedimentary record in the area over the last 4000 years, to assess environmental changes in relation with the different land uses and/or weathering during the successive Bronze, Iron, Roman, Islamic/Ottoman and Modern civilizations. The clay fraction of Amik Lake sediments comprises smectite, kaolinite, illite, chlorite and chlorite/smectite mixed layers that are the inherited clay phases. A relative change in abundance and crystallinity and chemistry of illite attests that environmental conditions evolved in the Amik Plain from the Bronze to Modern Age in relation with climates and/or land-use changes. The history of the Amik Lake reveals different soil erosion episode. The most intense erosion phase occurred during the Bronze/Iron Ages as indicated by the clay and magnetic susceptibility proxies. The Roman period was an exceptional period with soil erosion products arriving from the watershed, probably due the water channelization. A reduction of soil erosion occurred during the post Roman period until nowadays. Significant pedogenesis transformations are evidenced, especially during the Islamic/Ottoman periods suggesting intense chemical weathering conditions related to climate change.

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1. Introduction

Soil-forming environments and erosion processes are strongly influenced by land-use practices which changed through human history in a given area (e.g. Lawrence et al., 2015). Other influencing factors, such as permanent parameters (seismology, lithology, relief), and variable factors (climate, hydrology, vegetation cover) have also an impact on sediment yield and erosion rates (e.g. Edwards and Whittington, 2001; Lucke et al., 2005; Dodson et al., 2004; Pelle et al., 2013; Vogel et al., 2016). These natural and anthropogenic factors are difficult to untangle (Berglund, 2003; Ackermann et al., 2014). Indeed, soil erosion can be induced by climate changes (strong precipitations, seasonality and aridity) as well as more intense land-use (Pécsi, 1990; Günster and Skowronek, 2001; Casana, 2008; Ziehlofer et al., 2008; Jalut et al., 2009; Varga et al., 2011; Costantini et al., 2012; Sauer et al., 2015).

This problematic is particularly acute in the Amik Plain area (also known as the Plain of Antioch) in the southern Turkey, which has a long history of dense human settlement dating back at least to the Pottery Neolithic (7000 BCE) (Braidwood and Braidwood, 1960). Numerous studies were undertaken in the region in order to reconstruct the environmental and settlements history through an interdisciplinary regional research program, incorporating archaeological settlement survey, geomorphological and paleoenvironmental analyzes, and targeted excavations at key sites of various periods (Braidwood and Braidwood, 1960; Yener et al., 2000; Yener and Batiuk, 2010; Lawrence et al., 2015). A first major settlement phase occurred during the Bronze-Iron Ages, 3000–500 BCE (Wilkinson, 2000; Casana, 2007). The lands around

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tells and on low-dipping reliefs were used for wheat culture and orchards (Wilkinson, 2000; Casana, 2007). A second settlement phase more intensive occurred during the Hellenistic, Roman and Late Roman periods (300 BC-650 AD), and was associated with the conversion of upland areas for an intensive agricultural production (Wilkinson, 1997, 2000). This change was linked to the birth and growth of the city of Antioch, one of the largest city in the Roman Empire, and may be up to 500 000 inhabitants including its suburbs. During the Late Roman period, the Amik Plain was more densely occupied than at any time in its history (Casana, 2008). Agricultural farming associated with an irrigation network was developed around the city of Antioch and in the Amik Basin in order to feed its large population. Around 700–900 AD, numerous Roman sites were progressively abandoned in the basin and in the Highlands (Casana, 2007).

The spatial and temporal extent and organisation of the settlements in the Amik Plain are well constrained but not its possible impact on the environment (Yener et al., 2000; Wilkinson et al., 2001). In the present paper we propose to consider this issue by characterizing soil erosion in the Amik Plain using clay mineralogy and magnetic susceptibility as proxy indicators. An overview of the climatic conditions that prevailed in this area is also the main objective. To achieve this, a 6 m long sedimentary record was analyzed to define the clay types deposited in the plain and their weathering characteristics. Clay mineralogy is then used to try to untangle soil erosion, land-use and climate change in this critical zone.

2. Regional, tectonic and geological setting

The Amik Plain is situated in the Southern Mediterranean basin within the borders of the Hatay province. It is surrounded by several mountain ranges and plateaus. To the west part, the Amanus Mountain culminating at 2250 m, is an ophiolitic complex and within the borders of the Hatay province. It is surrounded by low nus Mountain culminating at 2250 m, is an ophiolitic complex and within the borders of the Hatay province. It is surrounded by agricultural farming associated with an irrigation network was developed around the city of Antioch and in the Amik Basin in order to feed its large population. Around 700–900 AD, numerous Roman sites were progressively abandoned in the basin and in the highlands (Casana, 2007).

The site (N 36°20.655”, E 036°20.948”) is located just at the border of the Kumtepe village, near the former eastern border of the Amik Lake defined by a low sandy ridge containing Roman pottery and lacustrine shells (Yener et al., 2000). In this area, the major water inflow is provided by the Afrin River (Fig. 1). In addition the site stands near the DSF fault (Karabacak et al., 2010) and is adjacent to the following archaeological sites: Tell Kara Tepe (AS86) and Kurdü which are Bronze and Early-Middle Chalcolithic sites, respectively (Yener et al., 2000). It also lies near a Roman canal draining the water from the Afrin River, which ceased to be used after the 2nd century CE (Casana, 2012).

Sediments were collected in a trench every 1 cm during the summer time, July 1st, 2012. At this period the water table was 1.5 m deep. The sampling was extended to 6 m depth thanks to a drill core.

3. Methods

3.2. Magnetic susceptibility and X-ray diffraction studies

Magnetic susceptibility (MS) performed every 1 cm using MS2 magnetic susceptibility system. Magnetic susceptibility was used as a first indicator of input of terrigenous materials, allochthonous to the lake (Hubert-Ferrari et al., 2012).

Mineralogical and geochemical analyzes were performed at 5 cm resolution to highlight the occurrence of environmental changes. Furthermore, clay mineralogy was carried out at lower resolution (10–20 cm) depending mainly on the changes in chemical and mineralogical composition. In particular, sample selection for clay mineralogy analysis was based on the peaks shape on the bulk XRD diffractogram at (001) reflections and the possible presence of the mixed layers clays mineral (10–14 Å).

The clay mineralogical analysis was performed by X-ray diffraction (XRD), using a Bruker D8 ADVANCE diffractometer, equipped with a Cu-Kα radiation on the <2 μm fraction (Universality of Liège, Belgium). For the clay fraction analysis the whole sediment was decarbonated with HCl (0.1 mol/L) and the <2 μm fraction separated by settling in a water column. Samples were mounted as oriented aggregates on glass slides (Moore and Reynolds, 1997). For each sample three X-ray patterns were recorded: air-dried (N), ethylene-glycol solvated for 24 h (EG), and heated at 500 °C for 4 h (H).

The background noise of the X-ray patterns was removed and profile parameters such as line positions, Full Width at Half Height Width (FWHM), peak intensities were calculated by the DIF-FRAC.SUITE EVA software (BRUKER). The peak intensities are related to the size of the coherent scattering domain (CSDS) representing regions of the crystal lattice in which X-ray diffraction is coherent, to the number of crystalline defects, to the presence of the mixed-layering component (e.g. illite/smectite and chlorite/smectite) (Renac and Meunier, 1995) and to the hydration state of these minerals (Ferrage et al., 2007). When the number of coherently stacked sheets is high (i.e broad CSDS), the interference function induces intense and narrow peaks, and then the FWHM is small. Conversely, when the number of sheets is small, the peaks are broader and less intense, the FWHM is wide and the coherent scattering domain is small. In the case of clay minerals in soil, the coherent domain size is generally small except for the primary and phyllosilicates minerals inherited little affected by weathering (Righi et al., 1993; Righi et al., 1995; Lanson, 1997; Chipera and Bish, 2001; Velde and Meunier, 2008; Hubert et al., 2009).

The shape and symmetry of the air dried XRD diffractograms were investigated. The asymmetry of the peak with a broad coherent scattering domain size (CSDS) distribution is due to the presence of several phases with close, but distinct crystallographic characteristics (Lanson and Besson, 1992).

Semi-quantitative estimations of the main clay species were
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