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A centennial record of anthropogenic impacts and extreme weather events in southwestern Taiwan: Evidence from sedimentary molecular markers in coastal margin

Li-Jung Kuo [a], Chon-Lin Lee [b,c,*], Patrick Louchouarn [d,e], Chih-An Huh [f], James T. Liu [g], Jian-Cheng Chen [b], Kun-Je Lee [b]

[a] Marine Science Laboratory, Pacific Northwest National Laboratory, Sequim, WA 98382, USA
[b] Department of Marine Environment and Engineering, National Sun Yat-sen University, Kaohsiung 80424, Taiwan
[c] Kuroshio Research Group, Asia-Pacific Ocean Research Center, National Sun Yat-sen University, Kaohsiung 80424, Taiwan
[d] Department of Marine Sciences, Texas A&M University at Galveston, Galveston, TX 77554, USA
[e] Department of Oceanography, Texas A&M University, College Station, TX 77843, USA
[f] Institute of Earth Sciences, Academia Sinica, Nankang, Taipei 11529, Taiwan
[g] Department of Oceanography, National Sun Yat-sen University, Kaohsiung 80424, Taiwan

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ABSTRACT

A 100-year history of human and natural disturbances in southwestern Taiwan was reconstructed using a suite of molecular markers in four dated sediment cores from the upper slope region off the Gaoping River mouth. Trends in polycyclic aromatic hydrocarbons (PAHs) tracked Taiwan's industrialization/urbanization starting in the 1970s, and the enactment of environmental regulatory policies thereafter. The predominant pyrogenic sources include vehicular, smelter, and coal combustion but spatial differences are observed among sub-regions of the shelf. Profiles of lignin oxidation products (LOPs) point to a significant increase in terrestrial organic matter inputs driven by land development after the 1970s. Low lignin diagenetic signature ratios $[(Ad/Al)_v]$ in all sediments suggest quick transport of fresh plant material from land to sea via mountainous rivers. Shifts in PAHs, LOPs, and radionuclides in recent sediments reveal the deposition of turbidites resulting from typhoon-induced floods. Multiproxy analysis illustrates the interplay between anthropogenic activities and natural processes.

1. Introduction

Local, regional, and global environmental changes can be driven by dramatic historical shifts in the functioning of human society, such as the industrial revolution, rapid growth in human population, resource extraction and utilization, and recent environmental management practices (Syvitski et al., 2005; Steffen et al., 2007). To understand the history of these human footprints and evaluate the potential anthropogenic impacts to the environments on a large scale, well-preserved natural archives such as ice or sediment cores have proven useful (Van Metre et al., 2000; McConnell et al., 2007; Brandenberger et al., 2008, 2011; Kuo et al., 2011b; Louchouarn et al., 2012). These archives also serve as excellent media for the assessment of natural perturbations including episodic events (wildfire, extreme weather, etc.) and long-term climate oscillations (Marlon et al., 2009; Brandenberger et al., 2011; Kuo et al., 2011b). Such historical reconstructions allow the benchmarking and long-term assessment of environmental policies/strategies and their influence on reducing the impacts of environmental changes.

To delineate different processes (transport pathways, transformations) and source inputs in environmental archives, different classes of molecular markers are powerful tools because (1) they often are tied to specific sources; (2) change in their internal signatures may be linked to specific alteration processes (bio and physicochemical degradation) or more specific source information; and (3) they can be detected at trace levels (high sensitivity). For example, the presence of specific molecular constituents of the polycyclic aromatic hydrocarbons (PAHs) in the environment can often be correlated with local/regional human activities because they are primarily produced from the incomplete combustion of specific fuels or processes (Hites et al., 1980; Van Metre et al., 2000; Fang et al., 2007; Kuo et al., 2011b; Louchouarn et al., 2012). Although PAHs may also be derived from petrogenic (oil seepage or spills)

* Corresponding author at: Department of Marine Environment and Engineering, National Sun Yat-sen University, Kaohsiung 80424, Taiwan. Tel./fax: +886 7 525 5066.
E-mail address: linnohc@fac.nsysu.edu.tw (C.-L. Lee).

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or biogenic (diagenesis) sources, the distinct compositional signatures and the applications of diagnostic ratios allow for contaminant source discrimination (Yunker et al., 2002; Jiang et al., 2009), making them ideal markers of the changing impact of industrial and urban activities over the years. Other markers can help characterize natural processes (e.g. transfer of organic matter in watersheds, wildfires) and understand the role and potential influence of human activities on such processes. For example, oxidation products of lignin, the second most abundant biopolymer after cellulose, are important markers of vascular plants and help trace natural and human-driven inputs of terrestrial organic carbon to soils and aquatic systems (Hedges et al., 1982; Louchouarn et al., 1999; Goñi et al., 2000; Farella et al., 2001; Houel et al., 2006; Kuo et al., 2008b; Brandenberger et al., 2011). Anhydrosugars (levoglucosan and its isomers) are byproducts of cellulose combustion and thus are specifically tied to plant biomass combustion (Kuo et al., 2008a, 2011a; Louchouarn et al., 2009). Therefore, their presence in environmental archives can help reconstruct climate or human induced fire events (Kuo et al., 2011b).

Taiwan experienced rapid population and economic growth in the past five decades. A recent survey revealed that the population density of Taiwan (640 Pop. km^{-2}) is the 2nd highest in the world among countries with population over 10 millions (Interior National Indicators, Ministry of the Interior, 2014). The issue of population density is exacerbated at the regional level, since most people live in the west coastal plains. Kaohsiung City, the largest industrial city in Taiwan, is located in the southwest coastal plain, north of the Gaoping River (GPR) mouth. GPR is characterized as a mountainous river draining the largest watershed (3257 km^2) in Taiwan resulting in a very high sediment yield (1.5×10^4 - ton km^{-2} yr^{-1}), with sediment discharge (49 Mt yr^{-1}) to the sea happening mainly during the rainy season (June–October) (Dadson et al., 2003). The combination of intense urban/industrial development and large and rapid transfer of materials through surface runoff along the southwest coastal zone thus suggests that the coastal zone receives large inputs of natural/anthropogenic substances from point and nonpoint sources through river discharge. Our earlier investigations on the spatial distributions of sedimentary PAHs in the surface sediments of this coastal zone have shown that sediments carried clear signatures of local/regional pollution source inputs, which were linked, in some instances, to extreme flood events resulting from typhoons (Fang et al., 2007; Jiang et al., 2009; Lin et al., 2013).

In the present study, four dated sediment cores from the coastal margin off southwestern Taiwan were used to elucidate the history in the past 100 years of regional human development, pollution, and extreme weather events. These sediment cores are located in two major depositional lobes flanking the Gaoping Submarine Canyon (GPSC), ~1 km seaward off the GPR mouth (Huh et al., 2009) and thus they are considered good archiving materials for detailed historical trend reconstructions for this region. Two distinct classes of molecular markers, PAHs and lignin oxidation products (LOPs), were used to provide insights into the historical inputs of anthropogenic and natural substances. An analysis of spatial differences along the coast is also made through comparison of these four cores. To our knowledge, this is the first report of detailed century-long records of hydrocarbon and lignin inputs to the coastal shelf of southwestern Taiwan.

2. Materials and methods

2.1. Sample collection

The study area and sampling sites are shown in Fig. 1. Four sediment cores were collected on the upper slope off the Gaoping River mouth using a box corer onboard research vessel *R/V Ocean Researcher-I* (OR1) in cruises #OR1-789 (core L10) and #OR1-791 (cores L26, L30, and X1) during April 2-14, 2006. Cores L26 and L30 were located north of Gaoping Submarine Canyon (GPSC), whereas X1 and L10 were to the south of GPSC. The water depths at the sampling sites ranged from ~300 m (cores L26, X1) to ~670 m (cores L10, L30). After collection, subcores were immediately taken and sectioned at 2-cm intervals throughout the entire core (total length: 32, 40, 34, 42 cm for L10, L26, L30, X1, respectively). The sectioned sediments were placed into pre-combusted (450 °C for 4 h) amber glass bottles and stored at −20 °C. Sediments were later thawed, filtered through a 1 mm sieve to remove large detritus, shells and pieces of gravel, and then freeze-dried.

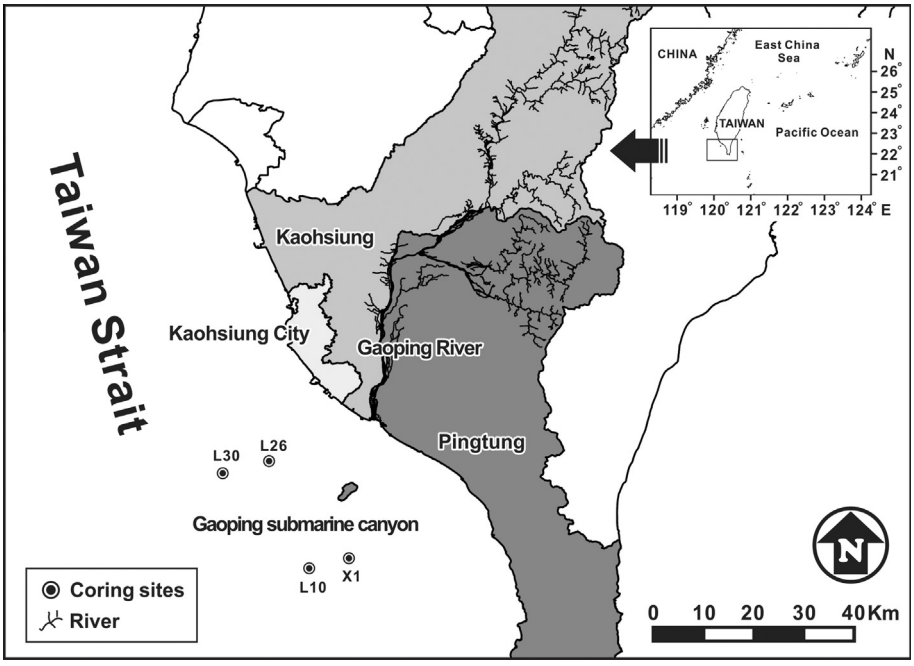

Fig. 1. Locations of four sediment cores used in this study.