DETERMING IMPACTS OF LAND-USE ON EROSION AND SEDIMENT DYNAMICS IN SOUTHWESTERN CHINESE RIVERS USING COSMOGENIC ^{10}Be AND SHORT-LIVED RADIOGENIC ISOTOPES

A Thesis Proposal Presented

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Abstract

Cosmogenic and short-lived radiogenic isotopes are commonly used individually as tools to understand depth and rate of erosion in river basins. I propose to use a novel combination of four unique isotopes (*in situ* and meteoric ^{10}Be, ^{137}Cs, and unsupported ^{210}Pb) along with long-term (up to 23 years) sediment yield records and remotely sensed land use data to determine the relationships between land use and erosion depth, intensity, and rate in three watersheds within the Mekong River basin, Yunnan, China. Land use has significant impacts on erosion dynamics, and as humans increasingly alter watersheds it is important to understand the implications of our alterations. I will measure ^{10}Be, ^{137}Cs, and ^{210}Pb for samples ($n \approx 100$) in three watersheds ranging from 265-2652 km^2 selected based on land-use and slope characteristics, or as a part of basin networks. By combining these isotopic data with sediment yield and land use data I will determine if a significant relationship exists between land use and four variables: (1) spatial variation in erosion, (2) temporal variation in erosion, (3) the source depth of sediment, and (4) the efficiency of sediment transport from hillslopes to stream channels.

1. INTRODUCTION

Land-use changes alter the intensity, character, and spatial distribution of erosion in river basins (Foley et al., 2005; Hooke, 2000). Erosion and sediment transport not only affect stream systems, but also communities that rely on rivers and surrounding land for food, water, and energy (Foley et al., 2005). Determining the distribution, type, and intensity of erosion associated with different upland land-uses helps resource managers make informed assessments and implement effective land management (Fürst et al., In Press). I will use a novel combination of isotopes, an unusually long and complete river sediment yield record (up to 23 years; described by Henck et al., 2011; http://depts.washington.edu/shuiwen) and remotely-sensed land use data to characterize the spatial and temporal distribution of sediment erosion, storage, and transport in three watersheds in Yunnan, SW China, to investigate the connection between land use, erosion, and sediment export.

My research seeks to address scientifically and societally relevant questions. I am working to develop and test a new method of basin-scale analysis that will allow inferences of land use, basin characteristics, and erosional regime to be made from detrital sediment samples. Since the Industrial Revolution, the amount of earth moved by humans has exploded with population, and estimates suggest "unintentional" mass movement due to agriculture accounts for nearly twice that of "intentional" mass movement (current worldwide estimate of mass movement is ~6000 kg/yr*person; Hooke, 2000). Given the potential of humans to alter landscapes, understanding the relationship between anthropogenically altered watersheds and erosion is critical.

In order to better understand relationships between erosion and land use, I will employ a combination of sediment yield data and four isotopic systems: meteoric ^{10}Be, *in situ* ^{10}Be, ^{137}Cs, and unsupported ^{210}Pb. Sediment yield measurements, although not accurate in representing upland erosion rates (Trimble, 1977), will be used to indicate how efficiently sediment is transported into and through streams. Concentrations of sediment-associated isotopes are indicative of the depth and character of upland erosion and are used for sediment fingerprinting (Bierman and Steig, 1996; Brown et al., 1995; Brown et al., 1988; Granger et al., 1996; Olley et al., 1993; Whiting et al., 2001); yet, so far, no study has considered all four of these isotopic systems together. The power of this approach comes from the unique relationship each isotope has with soil depth and time. By comparing multiple isotopic measurements of fluvial sediment samples, sediment yield for each watershed, and land use, I will determine if a significant relationship exists between land use and four key variables in each basin: (1) spatial variation in erosion, (2) temporal variation in erosion, (3) the source depth of sediment, and (4) the efficiency of sediment transport from hillslopes to stream channels.

2. BACKGROUND

This research will focus on three separate watersheds ranging from 262-2652 km^2 and between 27°-21° N in the Mekong River basin, Yunnan province, SW China (figure 1). The Mekong River watershed extends from the east-central Tibetan plateau at the headwaters to the east and south towards its outlet in the South China Sea, and is one of the International Rivers of Yunnan and Tibet (IRYT), situated between the Salween River to the west and the Yangtze River to the east. Climatically, the watersheds of interest experience annual monsoons from May through October, which account for >80% of the mean annual rainfall for the region (>1000 mm/year; based on rainfall data for the prefectural city of Lincang 1971-2000; China, 2006). The middle and lower Mekong basin is primarily located within the Indochina and Sibumasu crustal units. Basins 35 and 49 are within the Lanping Simao unit, a component of the Indochina crustal extrusion, and primarily composed of thick terrestrial Jurassic and early Cenozoic redbeds (Akciz et al., 2008). Basin 11 is within the Chengling-Mengliang and Linchang units, a component of the Sibumasu crustal extrusion, and primarily composed of low to high-grade metamorphic rocks (Akciz et al., 2008). The region is dominated by east-west trending right-lateral strike-slip faults accommodating the northward movement of India relative to China (Burg et al., 1997); however, strike-slip faulting is unlikely to have significant impact on erosion dynamics (Henck et al., 2011). Previous studies have used ^{10}Be to estimate millennial scale erosion rates in the Mekong River Basin that range from 0.1-0.4 mm yr^{-1}, with the highest erosion rates found in the narrowest portion of the Mekong River corridor (Henck et al., 2011).

Until recently, quantitative measures of basin-wide denudation rates were unreliable, primarily based on short-term sediment yield measurements and the assumption of steady state. Studies have shown that sediment yield does not accurately represent upland erosion because large amounts of sediment can be stored as colluvium or as upland fluvial deposits (Trimble, 1977). As a result, sediment yield is more appropriate for assessing the transport efficiency of a stream system rather than total denudation. Over the past 20 years, the field of sediment-related rare isotopes has provided new tools for scientists to accurately measure denudation rates (Banner, 2004; Bierman and Nichols, 2004). Meteoric and *in situ* ^{10}Be, ^{137}Cs, and ^{210}Pb are all examples of well-studied and widely applied isotopic systems that exhibit unique relationships to fluvial-borne sediment.

2.1. Background of Isotopic Systems Used

- ***In situ* ^{10}Be (t1/2 = 1.38 My)** is produced at a known rate within several meters of the Earth's surface; its concentration in quartz is a proxy for 10^3-10^6 year basin-scale erosion rates and thus long-term erosion (Bierman and Steig, 1996; Brown et al., 1995; Granger et al., 1996). *In situ* ^{10}Be concentrations can also be used as a sediment tracer when measured above and below a stream confluence (Clapp et al., 2002).

- **Meteoric ^{10}Be (t1/2 = 1.38 My)** is produced in the atmosphere (Lal and Peters, 1967), and comes to Earth through dry-fall and precipitation, coating sediment, and accumulating in soil. Meteoric ^{10}Be adheres strongly to sediment grains, constraining its lateral migration; however, pedogenic processes (pH <5) are able to mobilize meteoric ^{10}Be vertically, resulting in its accumulation in soil horizons (Brown et al., 1988). Meteoric ^{10}Be can also be used as a tracer in a similar manner to *in situ* ^{10}Be (Reusser and Bierman, 2010)

- **^{137}Cs (t1/2 = 30 y) and unsupported ^{210}Pb (t1/2 = 22.2 y)** are short-lived radionuclides that accumulate on the Earth's surface through dry-fall and precipitation, concentrating in the top few decimeters of soil (Kaste et al., 2007; Walling and Woodward, 1992). Sediment derived from deeper than the zone of ^{137}Cs and unsupported ^{210}Pb accumulation is devoid of these isotopes, indicating a minimum depth of erosion.

Each of these isotopic concentrations is useful individually; however, when combined, they create a powerful matrix that indicates erosion depth, temporal variations in erosion (based on half-life), and spatial distribution of erosion. Specifically, this collection of isotopes provides a way to isolate individual sub-basins with unique isotopic signatures and compare land use and long-term erosion rates to the depth and dominant style of erosion (e.g. shallow sheetwash and rilling vs. deep gullying and landsliding; figure 2). Sediment yield (when combined with ^{10}Be erosion rate estimates) can be used to assess the efficiency of the stream network; i.e. *how much sediment eroded in upland basins is actually exported from the system?*

3. METHODOLOGY AND RESEARCH PLAN

In order to accomplish my research goals I will measure a combination of four unique sediment-related isotopic systems (*in situ* and meteoric ^{10}Be, ^{137}Cs, and unsupported ^{210}Pb) in each sample and combine that information with sediment yield data and remotely sensed land-use mapping. In order to collect samples in useful and relevant locations, I will use a GIS modeling approach for each basin and select sample locations at the outflow of appropriate sub-basins or as a part of a basin network.

3.1 Sampling Strategy

In order to assess appropriate sub-basins for sampling I created and employed a GIS model to delineate all watersheds greater than 6 km^2 within each parent basin (11, 35, 49). The resulting nested watersheds were then sorted based on mean slope (from 30 m DEM) and projected over Google Earth imagery. Sample sites at sub-basin outlets were chosen to represent the range of mean slopes and land uses based on visual inspection of Google Earth imagery (figure 3). Particular care was taken to select sites that represent end-member mean slope and land use as well as appropriate intermediate slopes and land uses.

In addition to sample sites selected based on sub-basin properties, a series of stream network sites were chosen at significant confluences and along the main stem. Network sites at stream confluences consist of three discrete samples: one on each branch upstream of the confluence, and one below the confluence (figure 3). This will allow me to generate sediment-mixing models based on isotopic concentrations and track relative sediment contribution throughout the watershed. In total, approximately 100 samples will be collected from basins 11, 35, and 49.

In situ and meteoric ^{10}Be will be measured for each sample using standard UVM Cosmogenic Nuclide Laboratory procedures (http://www.uvm.edu/cosmolab/) and ^{137}Cs and ^{210}Pb sample splits will be mailed to Oberlin College for gamma counting by students of Amanda Schmidt, our collaborator at Oberlin.

Daily sediment yield data (suspended sediment*discharge) recorded by Chinese government hydrology stations at the outlet of each parent basin have been acquired from the Chinese hydrology database maintained by the University of Washington. Suspended sediment is measured using a Jakowski sampler and the 0.2-0.8 method (Ministry of Water Conservancy and Electric Power, 1962, 1975; report written in Chinese, citation is through interpretation of Amanda Schmidt). Eighteen years of sediment yield data is available for basin 35, and greater than 20 years of data available for basins 11 and 49.

Land use and land cover for each basin will be modeled using rule-set based object oriented classification techniques in Trimble Developer eCognition software from Landsat-7 ETM+ scenes (already acquired) for each basin (e.g. Platt and Rapoza, 2008). Summary statistics for thematic land-use rasters will be generated using Geospatial Modeling Environment, an open-source software extension of ArcGIS and R. The moderate resolution of Landsat-7 scenes (30 m pixels) matches available DEM's of the area; however, it will limit the detail of detectable features to those at least 3600-10000 m^2 (0.0036-0.01 km^2).

To test for possible relationships, each isotopic system will be compared to land-use, mean local relief (or mean basin slope), and each other. Appropriate spatial statistics and multiple regression models will also be applied to test for relationships.

4. COMPLETED WORK

As of April 1, 2013, 37 detrital sediment samples collected by Amanda Schmidt (formerly Henck) in 2005 and 2006 in the Salween, Mekong, and Yangtze basins were processed for meteoric ^{10}Be measurement. Thirteen of these samples have been measured at SUERC, Glasgow, Scotland, and the remainder will be measured in May 2013. These data will be used to complement the *in situ* ^{10}Be measured for the same samples, published by Henck et al. (2011).

Candidate sample sites have also been selected within Basins 11, 35, and 49, (figure 3) and Landsat-7 scenes have been selected and converted from level-1 USGS products to stacked multi-spectral images using ERDAS Imagine software.

5. POTENTIAL IMPACT OF RESEARCH

There are three important areas that my research has the potential to influence. (1) I am working to develop and test a new method of detrital sediment analysis using a combination of cosmogenic and short-lived radiogenic nuclides. (2) Results from my research will contribute to scientific understanding of erosion dynamics relative to land use in monsoon-dominated, moderate to high-relief subtropical regions. (3) The findings of my research will be relevant to environmental planners, policy makers, hydroelectric energy developers, and other stakeholders who rely of river resources.

6. RESEARCH TIMELINE

Spring 2013

- Conduct preliminary meteoric lab work- *Completed*
- Select candidate sample sites- *Completed*
- Conduct preliminary remote sensing work- *In Progress*

May-June 2013

- May 20-June 13 sample collection in China

June-July 2013

- Sample preparation (crush, sieve, powder), send radionuclide splits to Oberlin for gamma counting
- Quartz extraction

Fall 2013

- Be extraction for meteoric and *in situ* samples at UVM

- Travel to Oberlin to learn ^{137}Cs and ^{210}Pb radionuclide method and work with Oberlin undergraduates
- Finish any leftover computer analysis (LULC Classification or GIS work)
- Begin writing thesis (introduction, background, methods)
- Present progress report

Winter 2013-2014

- Finish Be extraction and travel to SUERC, Glasgow, Scotland, to learn AMS procedure
- Measure Be samples in Scotland

Spring 2014

- Data analysis and begin writing discussion
- Present results at relevant conference(s)

Summer 2014

- Finish writing

Fall 2014

- Defend thesis

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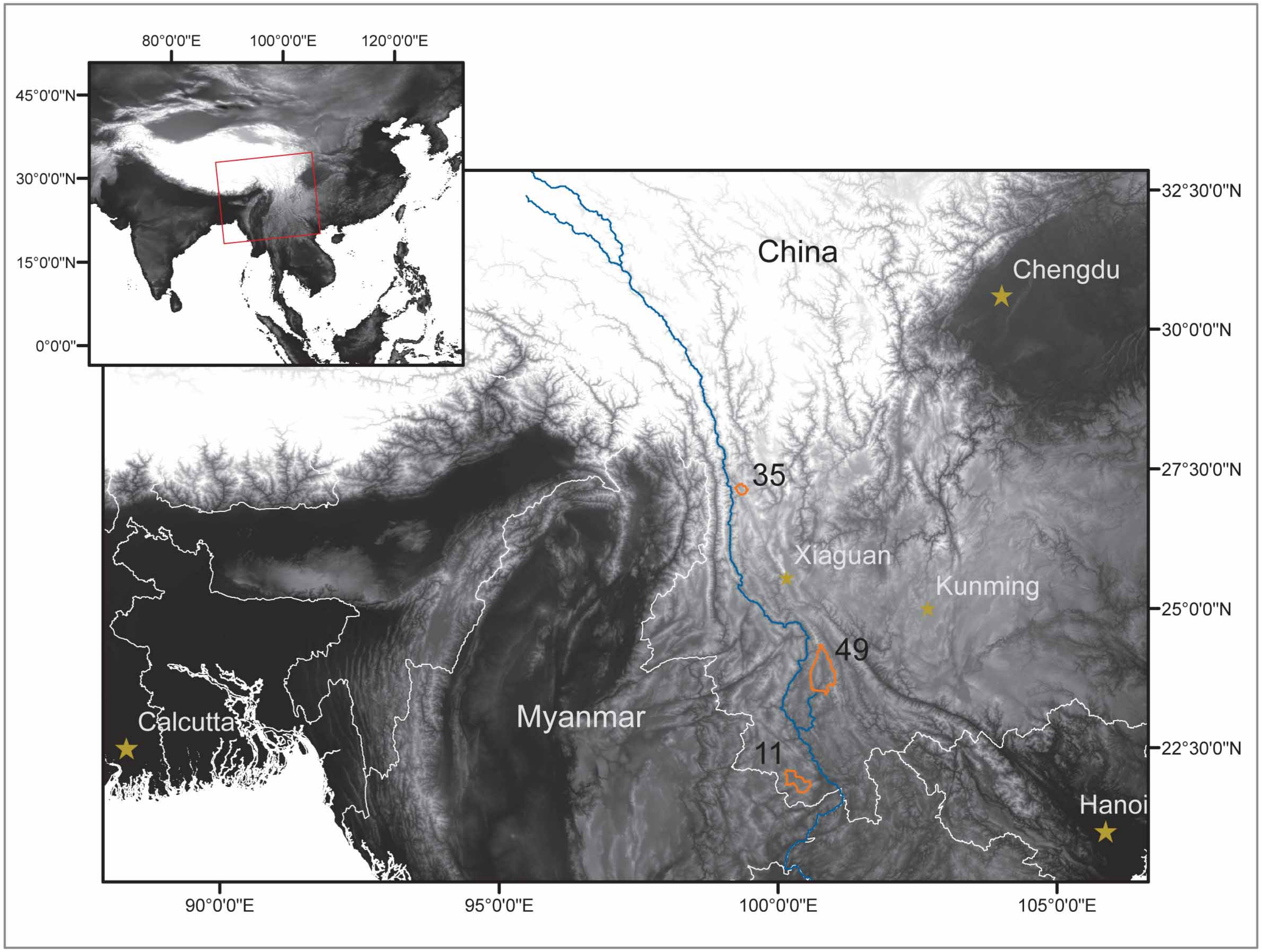

Figure 1. Map of Asia and regional map of study area showing the basins of interest in orange (11, 35, and 49) and the Mekong River in blue.

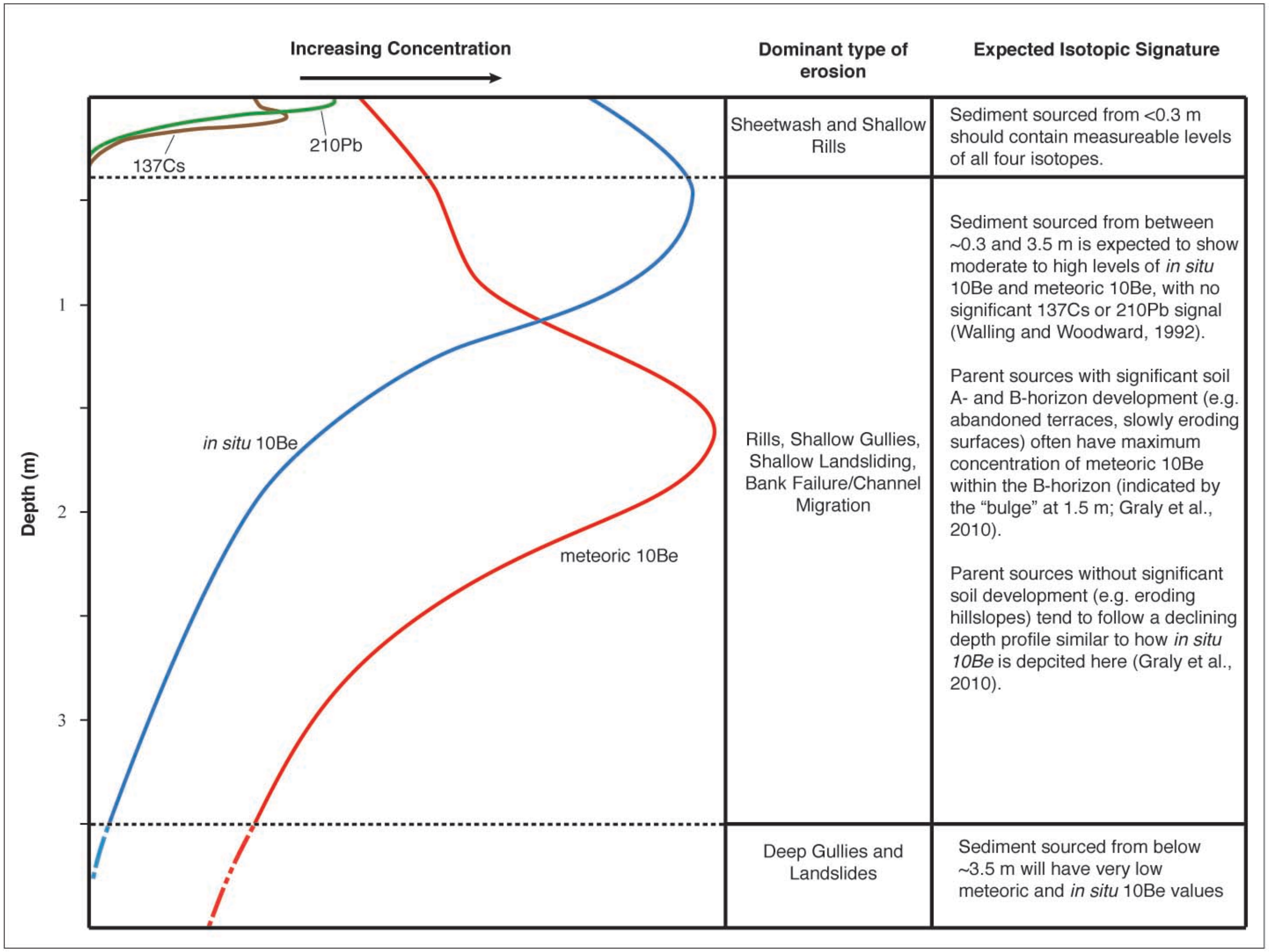

Figure 2. A conceptual plot of isotope concentration vs. depth (modified from Pavich et al., 1986; Perg et al., 2001; Walling and Woodward, 1992) and active depth of different erosional processes. Suites of erosional processes can be inferred based on relative concentrations of each isotope in a sample (e.g. high levels of ^{137}Cs and ^{210}Pb indicate surface and shallow (<30cm) erosion). Isotope concentration (X-axis scale) is not standardized (e.g. the concentration of meteoric ^{10}Be at a given depth cannot be compared to the concentration of *in situ* ^{10}Be or ^{137}Cs at that depth).

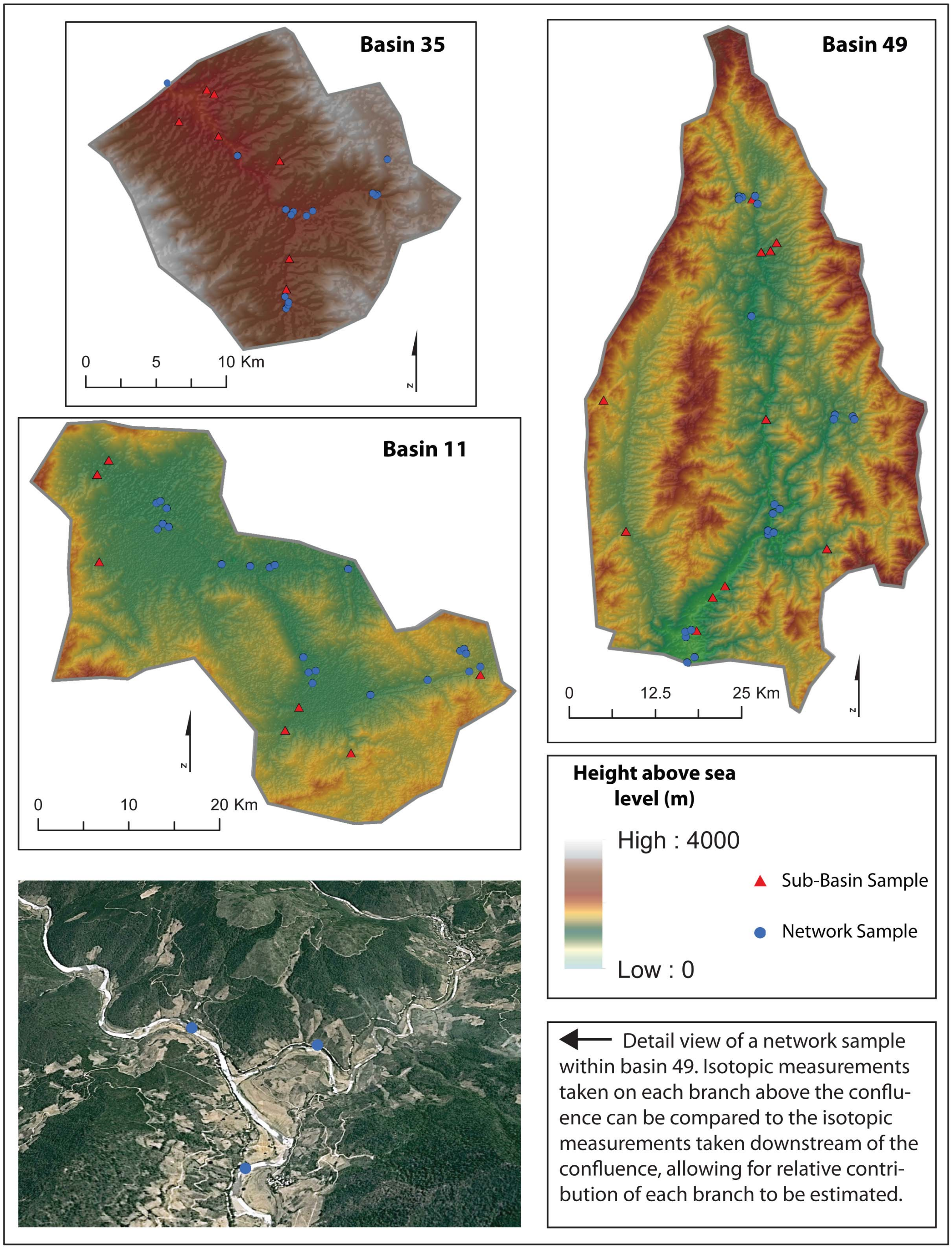

Figure 3. Digital elevation models of each basin with candidate sample locations overlaid. Sample sites chosen based on the sub-basin characteristics (i.e. land-use, mean slope) are denoted by red triangles. Blue circles denote sample sites chosen as part of a basin network. Detail view shows Google Earth imagery showing several common land-uses (e.g. agriculture, forest, clear-cut) with the locations of three network samples in Basin 49.