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Dead Sea Deep Cores: A Window Into Past Climate and Seismicity

The area surrounding the Dead Sea was the locus of humankind's migration out of Africa and thus has been the home of peoples since the Stone Age. For this reason, understanding the climate and tectonic history of the region provides valuable insight into archaeology and studies of human history and helps to gain a better picture of future climate and tectonic scenarios.

The deposits at the bottom of the Dead Sea are a geological archive of the environmental conditions (e.g., rains, floods, dust storms, droughts) during ice ages and warm ages, as well as of seismic activity in this key region. An International Continental Scientific Drilling Program (ICDP) deep drilling project was performed in the Dead Sea between November 2010 and March 2011. The project was funded by the ICDP and agencies in Israel, Germany, Japan, Norway, Switzerland, and the United States. Drilling was conducted using the new Large Lake Drilling Facility (Figure 1), a barge with a drilling rig run by DOSECC, Inc. (Drilling, Observation and Sampling of the Earth's Continental Crust), a nonprofit corporation dedicated to advancing scientific drilling worldwide. The main purpose of the project was to recover a long, continuous core to provide a high resolution record of the paleoclimate, paleoenvironment, paleoseismicity, and paleomagnetism of the Dead Sea Basin. With this, scientists are beginning to piece together a record of the climate and seismic history of the Middle East during the past several hundred thousand years in millennial to decadal to annual time resolution.

Regional Setting and the Collection of Cores

The Dead Sea, located in the Dead Sea Basin at the lowest continental elevation on Earth (currently 425 meters below mean sea level), is a terminal lake that evolved from previous water bodies that occupied the tectonic depressions along the Dead Sea Transform Fault. The history of these water bodies commenced with the late Neogene ingression (~6–3 million years ago) of the Mediterranean Sea into the valley, forming a backwater called the Sedom Lagoon. A series of terminal lakes (lakes with no outlets) filled the basin after the disconnection of the lagoon from the Mediterranean [*Stein,* 2001]. The lakes received their water from two major sources: calcium chloride brines that evolved from the ancient remnant solution of the Sedom Lagoon, and freshwater runoff. The limnology of the lakes was controlled by the regional hydrology, which reflects the climate conditions in the watershed [*Stein et al.,* 1997]. Over the past several hundred thousand years the lakes expanded and contracted with changing climate conditions due to the supply of freshwater. The modern Dead Sea is the latest of these series of lakes.

The location of the Dead Sea Basin, at the boundary between the Arabian-Sahara deserts and the Mediterranean climate zones, enhances its sensitivity to the starkly contrasting (arid versus temperate) climate and hydrological conditions of these regions. Moreover, because the formation of the basin is a consequence of tectonic activity along the Dead Sea Transform Fault [*Ben-Avraham,* 1997], its sediments preserve the history of seismic activity [e.g., *Marco et al.,* 1996; *Migowski et al.,* 2004], which are important to hazard assessments of the region. Two sites were cored (Figure 1) as part of the ICDP-funded venture into the Dead Sea. One was in the deepest basin in the center of the Dead Sea, at a water depth of 297 meters, and recovered cores down to about 460 meters below the sediment surface. The second site, in several meters of water, recovered cores down to roughly 350 meters below the sediment surface. For another picture of the drilling facility, see Figure S1 in the online supplement to this brief report (http://www.agu.org/journals/eo/v092/i049/2011EO490001/2011EO490001_suppl.pdf).

Preliminary Results and Future Plans.

Opening and description of the recovered cores occurred in June and October 2011 at the GFZ German Research Centre for Geosciences in Potsdam, Germany. The cores have two main sedimentary facies: (1) marly sequences of millimeter-thick laminated layers of inorganic aragonite and silty detritus composed mainly of calcite and quartz and (2) sequences of rock salt and marls (see Figure S2 in the online supplement). The aragonite and detritus laminations reflect deposition in dry (summer) and wetter and stormy (winter) seasons, respectively. Moreover, the aragonite provides the potential to establish a calendar chronology, through uranium-thorium dating and oxygen isotope stratigraphy [e.g., *Haase-Schramm et al.,* 2004; *Torfstein et al.,* 2009]. Gypsum layers are scattered throughout, indicating sustained dry periods. Provisional interpretation of the lithology of the core through time strongly indicates that the salt layers are deposited during arid interglacials and that long salt-free marly intervals are wetter glacials, together spanning an interval of about 200,000 years. This interval bleeds into the time frame of the interglacial labeled in oxygen isotope records of ocean sediments as marine isotope stage 7.

An important discovery is a mud-free layer of rounded pebbles, possibly reflecting a beach deposit, more than 230 meters deep in the core taken from the deep basin, deposited at an age provisionally estimated to be the last interglacial. The pebble layer overlies about 40 meters of mainly salt, and

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A Library of Georeferenced Photos From the Field

A picture is worth a thousand words, and every day hundreds of scientists, students, and environmentally aware citizens are taking field photos to document their observations of rocks, glaciers, soils, forests, wetlands, croplands, rangelands, livestock, and birds and mammals, as well as important events such as droughts, floods, wildfires, insect emergences, and infectious disease outbreaks. Where are those field photos stored? Can they be shared in a timely fashion to support education, research, and the leisure activities of citizens across the world? What are the financial and intellectual costs if those field photos are lost or not shared?

Recently, researchers at the University of Oklahoma developed and released the Global Geo-Referenced Field Photo Library (hereinafter referred to as the Field Photo Library; http://www.eomf.ou.edu/photos/), a Web-based data portal designed for researchers and educators who wish to archive and share field photos from across the world, each tagged with exact positioning data (Figure 1). The data portal has a simple user interface that allows people to upload, query, and download georeferenced field photos in the library.

The idea behind this is simple: Changes in land use and land cover have significant impacts on weather, climate, hydrology, biodiversity, and food security across various spatial and temporal scales. Tracking land use and land cover changes through georeferenced photos gives a visual picture (ground truth) to numerical data, allowing scientists, policy makers, and the public the opportunity to visualize the evolution of landscapes at small scales. Thus, these photos are invaluable for documenting land use and land cover changes.

Using the Library

Through its privacy control feature, photo contributors to the Field Photo Library can designate whether their photos are publicly available (i.e., public mode) or available only to the owner of the photos (i.e., private mode). This privacy control feature warrants priority use of the field photos by the photo contributors for their own research activities if needed. Photo contributors with "private" photos are regularly notified and encouraged to make their photos "public." An interactive graphical user interface is also available for users to interpret and classify field photos (e.g., various land cover types); to enter field notes; and to build thematic databases from the photos, ranging from crop-specific themes (e.g., paddy rice, sugarcane, and winter wheat) to general land cover types (e.g., forests, cropland). After selection of specific photos (e.g., by time, keywords, geographical domains, and land cover types) a user can download both photos and associated data in several formats (e.g., as comma-separated values (.csv), an Excel file (.xls(x)), a zipped Keyhole Markup Language file (.kmz), and an ArcGIS Esri shapefile (.shp)). These files can then be used for spatial analyses in geographical information systems (e.g., ArcGIS), image processing (e.g., Exelis's Environment for Visualizing Images (ENVI) and Intergraph's Earth Resources Data Analysis System (ERDAS)), and Google Earth.

The Field Photo Library was initially set up to aid the effort to track changes in land use and land cover from airborne and spaceborne remote sensing. Georeferenced field photos are used as in situ or ground reference data for algorithm development and validation of remote sensing data products. Many research projects have carried out field expeditions, often repeatedly in the same study areas, without a means of sharing field photo data. By using the Field Photo Library, researchers can contribute to a spatially and temporally extensive database of detailed ground reference information that can be accessed from any location in the world. For example, a user can query and download thousands of georeferenced field

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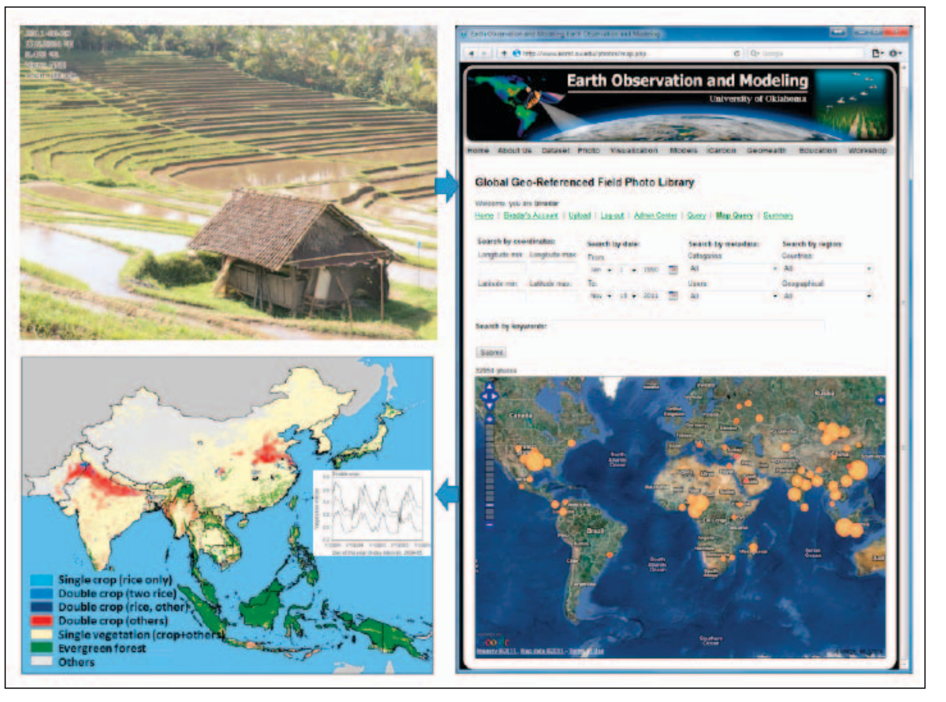

Fig. 1. A data flow that shows (clockwise from top left) acquisition of georeferenced field photos, ingestion into the Field Photo Library, and application for satellite-based mapping of land use and land cover change. In this example, a photo of a rice paddy from Bali, Indonesia, was uploaded into the database, where users can see the concentration of photos uploaded by other people (orange and red circles on the world map). The photo was then seen in the context of satellite-derived land use and land cover for other regions of Asia. The inset at bottom left is a graph that shows an example of phenological patterns for the specific location where the photo was taken, derived from data recorded every 8 days from satellite-based Moderate Resolution Imaging Spectroradiometer (MODIS) sensors. Users can choose the interval they want graphed—the example shows data from 2004 to 2005.

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together they indicate an extreme lake level drop during that time.

The cores have been sampled for radiometric dating to provide the chronological framework for further studies, as well as for biological studies. The planned future studies will range from continuing studies of the biology, to the changes in the regional magnetic field, to the hydrological conditions (from the lake precipitates aragonite, gypsum, and salt), to atmospheric circulation (from eolian dust), to tectonics-seismology (from earthquake layers).

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Fig. 1. The Drilling, Observation and Sampling of the Earth's Continental Crust, Inc. (DOSECC), drilling rig in the Dead Sea, drilling at a water depth of 300 meters. Inset shows locations of the drill sites in the Dead Sea (white circles). The map illustrates the location of the Dead Sea Basin, in between the Arabian-Sahara desert belt and the Mediterranean climate zone.

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photos of paddy rice fields and use the downloaded data along with Google Earth to select specific rice fields as regions of interest, which are then used as an input data layer for image classification or evaluation of regional and global land cover maps from various research groups (see Figure 1). Such use of field photos and remote sensing data is common, for example, in the Geo-Wiki Project (http://www.geo-wiki.org), a global network of volunteers who seek to help improve the quality of global land cover maps. Integration of the Field Photo Library in research workflow provides a fast and effective means of developing and evaluating satellite-based land data products at regional and global scales [e.g., *Biradar et al.*, 2009; *Xiao et al.*, 2006].

The Field Photo Library can host various types of georeferenced field photos, which are also used to support location-based research activities. For example, cryologists can use georeferenced field photos to document the spatial distribution and dynamics of glaciers. Hydrologists use georeferenced field photos to record and map water bodies, wells, and irrigation. In addition, georeferenced field photos that depict wildlife or plants provide basic data on species occurrence, which can be analyzed in conjunction with spatially explicit environmental data to generate ecological niche models that predict species distributions [*Elith et al.*, 2006]. Archived field photos can also aid in the synthesis of other widespread citizen science data sets (e.g., eBird, which allows bird watchers to geospatially track the birds they have observed; Project Monarch Health, which recruits citizen scientists to sample wild monarch butterflies for surveillance of a protozoan parasite; and Project BudBurst, which encourages citizen scientists to monitor plant phenology as the seasons change) by providing links between habitat types and observations made within them. In addition, the Field Photo Library provides add-on Web services that can, for instance, link individual field photos with time series satellite images from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensors on board the Terra and Aqua satellites from the NASA Earth Observing System (EOS).

Project Status and Future Opportunities

Through the efforts of just a few scientists, the Field Photo Library already houses tens of thousands of photos from five continents (35,404 public photos as of 1 October 2011; see Figure 1). Several companies offer free photo sharing and archiving (e.g., Flickr and Picasa). However, these Web services are designed for personal use, and it is a daunting task to filter through millions of personal photos in search of georeferenced photos that provide scientific information of interest. The Field Photo Library is specialized for scientific applications and educational purposes. Although there are currently no quality control measures in place, except for irregular visual inspection of publicly shared photos, it is hoped that because scientists and educators contribute to the site the vast majority of photos are applicable to many research endeavors. The Field Photo Library's data portal also differs from commercial sites in that funding is not related to advertising or the whims of the Internet market.

The Field Photo Library was established using funds from NASA, the National Institutes of Health (NIH), and the National Science Foundation (NSF) and will be maintained through new research grants. Continued funding will depend on whether the site is widely used by scientists. All scientists are encouraged to contribute photos; the continued success of this project will provide a means of documenting how Earth changes with unprecedented detail, accuracy, spatial extent, and temporal scope.

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