Satellite-Linked Autonomous Pore Pressure Instrument (SAPPI)

A Step Toward a Deep-Sea Observatory for Intermediate Time Spans with Automated Data Transmission into the Laboratory

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Deployment of the free-fall system SAPPI from the RV Sonne in December of 2003 in the Gulf of Cadiz.

A long-standing wish of researchers to get data from the seafloor into the lab with minimal effort has become reality. The Marine Technology and Sensors group at the University of Bremen, Germany, has successfully developed an expendable seafloor monitoring system for medium time spans and complexity. The system consists of two components: a multi-sensor measurement package, including an *in-situ* pore pressure instrument (IPPI) to measure pressure, temperature and low-resolution tilt; and a data buoy pop-up buoy (PUB) which surfaces at a pre-set time and sends the data back to shore via an Iridium satellite-based data link.

In January of 2004, for the first time, the PUB transmitted approximately one megabyte of error-free data from the Gulf of Cadiz to a laboratory in Bremen. This data was collected at the seafloor in a water depth of about 1,200 meters.

Pore Pressure of Marine Sediments

Hydrostatic pressure in pores of highly porous, unconsolidated marine sediment is generally called pore pressure. This pressure may vary considerably depending on the tectonic environment—continental slopes, flanks of mid-ocean ridges or accretionary prisms. Enhanced pore pressure transients have been considered crucial players in the faulting of marine sediments since pioneering research was conducted by M. King Hubbert and William W. Rubey in 1969. Pore pressure measurements on transects across deformation fronts at convergent margins and accretionary prisms are especially important in understanding marine sediment dewatering and energy and fluid flow. Modelling the dynamic behaviour of an accretionary prism shows that the diffuse dewatering process is strongly controlled by the distribution of pore pressure within the sediment.

The predicted large signal in the lateral pore pressure change, especially at the toe of the prism, has never been verified by closely spaced *in-situ* pore pressure measurements due to lack of funds and/or suitable instrumentation. Another process where pore pressure plays a key role is slope stability at continental margins. Landsliding in marine settings is of great interest for both geoscience research and industry. Sub-marine mass movements are being given increasing attention due to the necessity to protect offshore infrastructures and because these movements are a major cause of tsunamis, which can ravage coastal areas.

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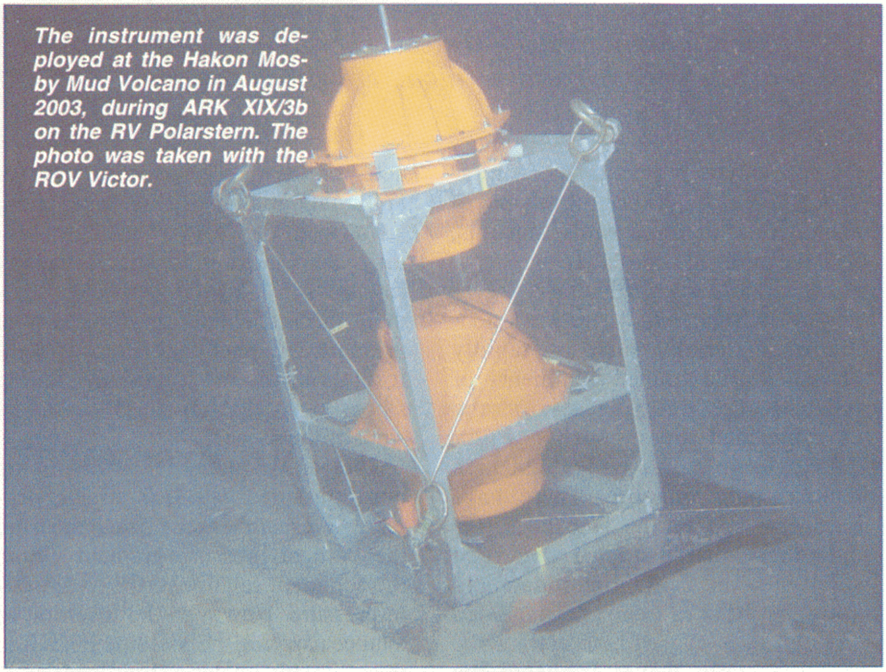
Landslides are particularly prevalent in environments where weak geological materials, such as rapidly deposited fine-grained sediments or fractured rock, are subject to strong environmental stresses such as earthquakes, large storm waves and high internal pore pressure. There have been few sub-marine landslides, yet only those that disrupted populated shoreline or offshore-engineered structures have been documented directly. In most cases, an earthquake or large storm waves triggered the event. Unfortunately, even from those events, little is known about the state of the slope before failure. Many questions are still unanswered (e.g., had the slope already been creeping and was accelerated because of earthquake excitation or wave loading, or was it quasi-stationary before external forces acted on the slope?). Most of what we know about sub-marine landsliding stems from the remote sensing of features associated with slides, namely rupture surfaces and displaced sediment masses. Monitoring *in-situ* pore pressure and other parameters as high-resolution tilt at potentially failing slopes may provide clues as to the state of the slope.

The general method for determining pore pressures *in situ* is straight forward; a researcher only has to measure the vertical pressure gradient within the sediment relative to the hydrostatic pressure. However, the insertion of a lance carrying the pressure ports into the sediment creates a significant pressure disturbance that takes hours or even weeks to dissipate.

The measuring principle outlined above was first realized in a free-fall piezometer pop-up pore pressure instrument (PUPPI), developed at the former Institute of Oceanographic Sciences in the United Kingdom. The



The instrument was deployed at the Hakon Mosby Mud Volcano in August 2003, during ARK XIX/3b on the RV Polarstern. The photo was taken with the ROV Victor.

instrument consists of a lance carrying pressure ports, a sensor package including data acquisition and an acoustic release that separates the buoyant electronics package from the anchor and allows the package to ascend to the sea surface. On the surface, a ship recovers the package. Model calculations show that the complete decay of the initial disturbance may take several weeks, depending on the permeability of the sediment. To overcome the long decay time, a tethered instrument with a considerably thinner lance than PUPPI was developed by Earl E. Davis in 1991. Unfortunately, the hope that the pressure disturbance would dissipate within hours did not come true.

All attempts up to the present to measure pore pressure in marine sediment with the help of lance-attached pressure sensors could not yield a technically reliable and easily usable system. Also, PUPPI has proven to be very expensive to deploy. Therefore, only a few isolated measurements have been made in the past 15 years. The goal during the subproject New Tools to Quantify Energy and Fluid Flux Through Gas Hydrate-Bearing Sediments (FLUX), within the German Ministry for Education and Research-funded project Integrated Geophysical Characterisation and Quantification of Gas Hydrates (INGGAS), was to build and test the prototype of an expendable instrument for *in-situ* measurement of pore pressure, based on the design and experiences gained in the past decade from measurements with PUPPI and tethered instruments.

Results of the Project

During the two years of the INGGAS-FLUX project, a system was developed for deep-sea (up to 6,000 meters) applications and two prototypes were built and deployed during two cruises. As mentioned above, the system consists of an IPPI and a PUB. Both components are housed in glass spheres (the IPPI in a 17-inch housing and the PUB in a 13-inch housing). This is an economic solution for housing the electronics package and providing flotation at the same time. Protective shells are readily available. Both systems are mounted in a frame attached to a four-meter-long lance, which carries temperature sensors and pressure ports.

IPPI consists of a differential pressure transducer, three temperature sensors (thermistors), a valve multiplier and a tilt sensor. A data acquisition and controlling unit digitises the collected analogue signals, controls the status of the valve multiplier and stores the data, which is then transmitted through an infrared data link to the PUB. The use of a valve multiplier allows one differential pressure sensor to monitor four ports. IPPI is programmed to switch each pressure port in sequence, while the last port is open to seawater and used as a zero reference value to monitor a possible sensor drift.

The heart of the PUB is a low-power microprocessor, which controls the data management and satellite link. The buoy is mechanically attached to the frame with a self-contained burnwire release. A safety release will eventually open in case the burn-wire system fails. After ascent, a sensor detects that the buoy is in upright position for satellite sight and starts the data transmission. The buoy contacts a modem located onshore, in this case, in a laboratory at the University of Bremen. If the phone link is interrupted for any reason, the system shuts down and tries to reconnect at a later time to transmit the remaining data. After finishing its task, the PUB sinks to the seafloor.

Numerous tests of the components in the laboratory and in the Baltic and North Sea helped to iron out initial design problems. The final test of the system was achieved by deploying two buoys in 2003, one during cruise ARK XIX/3b from the RV *Polarstern* at the Hakon Mosby Mud Volcano and one during cruise SO-175 in the Gulf of Cadiz.

Experimental Settings

The entire northern part of the region around Gibraltar is characterised by rapid sediment deposition and active deformation due to numerous, devastating earthquakes. High pore pressures and the venting of pore water and gas indicate low friction between geologic blocks. This setting is found in a lobe-like imbricate sediment wedge 200 by 160 kilometers in area. Mud volcanoes, carbonate mounds and sub-marine landslides are typical for this wedge. The SAPPI deployment took place at the Captain Arutyunov mud volcano, an active feature located at 35° 39.71' N/7° 19.97' W in 1,324 meters water depth.

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The mud volcano was investigated before deployment by taking sediment cores, which revealed the presence of gas hydrate in very soupy, clay-rich sediments smelling of hydrogen sulfide.

Performance and Results

The results from the Gulf of Cadiz shows that the buoy eventually transmitted the data in less than an hour on the evening of January 16, 2004. The binary data set is 1.042 megabytes large and was transmitted without any data glitches or errors. The transmission speed exceeded our expectations and was 40 percent above the nominal data rate quoted by Iridium. The received data set consists of about eight days of data, and all components of the data acquisition system worked reliably and performed as expected. The measured tilt of about 6° C indicates a proper penetration of the lance in the subsurface sediments. The record of the lowermost sensor shows temperature variations on the order of 0.2° C. The sequential switching of four ports to one port for the pressure transducer worked remarkably well over the complete period of time. A drift of about 250 Pascal was observed by the zero differential pressure-reference port.

We see our first results as extremely encouraging. They show that the idea of *in-situ* measurement and data transmission via satellite link from an autonomous buoy is a valid concept for moderate amounts of data (up to four megabytes). Both components of the system were developed in cooperation with small, highly specialised companies in northern Germany. This seems to be the first system worldwide that is able to transmit such a large volume of data error-free in a very short time from a drifting buoy to the laboratory. Hardware and communication costs are quite low compared to the cost of ship time, making the system economical. The results from the *in-situ* pore pressure measurements are very promising, but still need careful optimisation and fine-tuning by more extensive laboratory research.

Possible Applications

Currently, we are only capable of obtaining snapshots of processes taking place at the seafloor, and we still lack insight into the time-scales at which those processes occur. It is obvious to us that a buoy like this will have numerous applications in marine sciences where monitoring is the primary research goal. In many cases, the cost of collecting the instruments and the data is much higher than the actual hardware cost.

Worldwide initiatives and programs depend on the transmission of large volumes of data. It is possible that in the case of a mass production of the buoy, the price will drop considerably and one might end up with a low-cost bottle-post system.

We expect that *in-situ* pore pressure measurement will be an invaluable tool in all cases where subsurface pore pressure changes are associated with large scale events like the build-up of tectonic stress and earthquake precursors, eruptions of sub-marine mud volcanoes and slope stability changes. Monitoring pore pressure will also be a major issue once the industry begins the commercial exploitation of sub-marine gas hydrate fields.

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Marcel Kruse obtained his degree in electronic engineering in 1995. He now runs his own company, supplying polar and marine expeditions with a variety of buoys for hydrographic measurements.