The Australian Geophysical Observing System Ocean Bottom Seismograph Resource

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ABSTRACT:
The Australian Geophysical Observing System (AGOS) has recently acquired the Australian National Pool of twenty ocean bottom seismographs (OBS) available to Australian researchers and suitable for multi-scale experiments at sea, and for onshore-offshore combined observations. The OBS facility will greatly enhance Australian research capabilities in the area of Earth imaging and natural hazard assessment.

The OBS record a range of seismic and acoustic signals, providing baseline data for scientific and regulatory purposes including:

- Seismic waves from earthquakes.
- Seismic waves from artificial sources such as marine air-guns and onshore vibrators.
- Noises from seafloor construction (platforms, etc.) for environmental monitoring purposes.
- Sounds produced by whales which can contribute to studies of migration paths and behaviour.
- Noise from deep sea trawling on the Extended Continental Shelf, beyond the Exclusive Economic Zone which may be used to detect illegal fishing, for example when nets touch the Australian seafloor.
- Monitoring of underground CO^2 geo-sequestration activities.

This paper describes the properties and capabilities of the OBS recorders and looks at some sample results arising from a sea trial deployment of the recorders at a depth of one kilometre within the area of a marine 3D seismic survey off the coast of north Western Australia. The OBS instrumentation successfully recorded data from the active seismic source to distances in excess of 30 km resulting in a significant increase in the recording aperture of the survey in comparison with the eight kilometre long streamers towed by the seismic vessel.

Keywords: OBS, AGOS, offshore seismicity, active marine seismic survey, 3D seismic

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1 Equipment Description

The Australian Geophysical Observing System (AGOS) Ocean Bottom Seismograph (OBS) resource includes the following equipment;

- Twenty Guralp Systems designed portable, self-contained, triaxial ocean-bottom seismometer, hydrophone, digitiser and data-recording systems.
- Two Guralp Systems deck units that fulfil a range of tasks including battery charging, configuration, clock synchronisation, data transfer and data storage from the OBS units.
- Two Edgetech ORE Offshore Acoustic deck unit transceivers and transponders for communicating with the OBS units once deployed, and
- Associated ancillary equipment including cabling, ballast molds, and packaging including crates, a shipping container and pallet jack.

Each portable OBS unit comprises a high density polyethylene (HDPE) skeleton that supports four syntactic foam buoyancy modules and the titanium canisters that contain the electronic components and batteries. The skeleton in turn rests upon the two sacrificial concrete ballasts.

Figure 1. Photo of OBS recorders prior to initial deployments, note that ballasts have not yet been attached.

The components mounted to the HDPE cradle include the 6TG OBS sensor, hydrophone, acoustic release transponder, mechanical release device for the concrete ballasts, back-up burn wire release for the concrete ballasts and two cable systems connecting the various components.

The syntactic foam that the buoyancy modules are built from consists of glass microspheres within a matrix of epoxy resin and is capable of resisting the crushing forces at six km depth (approximately 600 atmospheres or 8,760 PSI) without significant deformation. The primary materials that comprise the OBS are titanium, HDPE, syntactic foam and carbon fibre, all the external metal components are comprised of titanium for strength and to resist corrosion.

The primary electronics canister has two waterproof compartments separated by a pressure rated bulkhead. The top compartment is a Vitrovex glass hemisphere bonded to a titanium mounting ring and contains a marine Automatic Identification System (AIS), aerial, AIS GPS module and a group of strobe lights and their electronic controller. The glass hemisphere is sealed against the titanium bulkhead of the lower compartment that contains the data recording and ballast release systems so that the OBS can still be recovered with data intact even if the glass hemisphere suffers a catastrophic failure.

The lower compartment within the primary electronics canister is a titanium cylinder with multiple O-ring sealed bulkheads top and bottom that contains:

- The Guralp CMG-CD24 digitiser.
- The acoustic release board which activates the mechanical release and the burn-wire. This board can also communicate basic state of health information such as mass positions and battery conditions during the deployment.
- A multi-port serial to USB converter to allow communications between the deck units and the AIS, strobe microcontroller and digitiser.
- The rechargeable lithium battery for the release system, strobe lights and VHF AIS radio transmitter, and
- An independent rechargeable lithium battery for the backup timed burn wire release system.

The main rechargeable lithium battery for the digitiser, the 6TG sensor and the hydrophone is contained within a separate sealed titanium cylinder mounted low in the HPDE cradle in order to keep the centre of gravity below the centre of buoyancy. Battery capacity for the main battery is sufficient for 12 months operation.

The 6TG-OBS sensor is a broadband seismometer system comprising three orthogonally mounted sensors mounted on gimbals within a 194 mm diameter titanium sphere. The gimbals will automatically compensate for up to 50 degrees of tilt in any direction. There is also a MEMS compass and tiltmeter built into the sensor canister so the sensor orientation can be logged upon deployment and whenever the sensor is re-centred by the gimbal system.

In addition to these primary components the HDPE frame supports the acoustic transponder for “in water” communications, the mechanical ballast release system comprising a mechanical clamp that grips a rope attached to a system of pulleys, levers and carbon fibre leaf springs that release the ballast and the back-up burn wire system.

The OBS units are rated to operate at depths of up to 6 km below the ocean surface, battery capacities are sufficient for up to 12 months deployment and each unit has 30 Gb of internal data storage, sufficient for more than 12 months of continuous triaxial seismic data at 100 samples/second. Sample rates as high as 1000 samples a second are possible but will impact power use and data storage capacity.

2 Deployments Operations

Prior to deployment, units to be deployed need each of the three battery systems to be charged. The three systems are: the main battery canister that powers the sensor, digitiser and hydrophone, the release system battery that powers the mechanical release, AIS, strobe system and burn wire system and a third lower capacity battery that powers the timed release burn wire system. To charge a single OBS from a fully discharged state may take up to 48 hours due to current restrictions on the waterproof connectors used throughout the OBS.

Additionally the pair of sacrificial concrete ballasts need to be prepared and fitted to each OBS unit. Each ballast cylinder should have a mass of between 21 and 26 kg to ensure that the OBS has negative buoyancy when both ballasts are attached but positive buoyancy should only one unit be released during recovery operations.

Each unit is then checked for correct operations before being loaded on board a suitable vessel. Once the vessel is located above the proposed deployment location final configuration operations are undertaken including setting up desired recording parameters, setting a back-up burn wire date if required, synchronising the digitiser clock to GPS time and setting the separate MEMs compass clock that records the sensor orientation. Prior to deployment overboard the ballast release system is “fine tuned” and checked for correct operation as experience has shown the system is susceptible to variable performance arising from small changes to parameters arising through transportation or on-board rough handling.

Shifting the 200 + kg recorder (once ballasts are attached) from the boat deck into the ocean involves hoisting the instrument using an A frame or crane and then lowering to water level before pulling a quick release snap hook that releases the OBS unit that will sink to the sea floor at a rate of 1 metre/sec.

From this point until the unit is recovered back on deck the only communication possible with the OBS is through the acoustic pinger unit. Communications are limited to an instruction to centre the sensor masses, a request to return a state of health message that details the mass positions and battery condition, an instruction to initiate the mechanical release of the ballast so that the recorder returns to the surface, an instruction to initiate the burn-wire release and ranging requests that can be used to determine the distance of the recorder from the shipboard acoustic transponder. During the descent of the OBS the range of the OBS may be checked at regular intervals to ensure the unit is descending reasonably.

Although the position at which the OBS is released is well constrained the instrument may drift due to currents a considerable distance and GPS location is not possible beneath the ocean surface so once the OBS has settled on the sea floor, the ranging function is used to locate the OBS using triangulation in a fashion familiar to all seismologists. Indeed although Guralp supply a purpose written software module to locate the OBS on the sea floor the results were confirmed using the SRC's eqFocus software and a model based on the water velocity profile and the results of both systems agreed within about 10 metres at depths of around one kilometre beneath the ocean surface.

3 Recovery Operations

Recovery of OBS systems has long been recognised as problematic whether tethered or “pop up” systems. In order to maximise the likelihood of successful instrument recovery the OBS systems in the AGOS pool incorporate a number of “fall back” and redundant recovery systems.

The OBS is designed to have positive buoyancy once the sacrificial concrete ballast is released; even if only one of the two ballast cylinders is successfully released the OBS will still have positive buoyancy albeit with a slower ascent rate.

The primary release mechanism is a mechanical system that is triggered via a message to the acoustic transponder. Upon receiving the correctly coded message the transponder initiates the opening of a mechanical jaw that clamps onto a rope and pulley system that is connected to two levers connected to a toggle attached to the sacrificial ballasts. The toggle is held within the jaws of a fixed and a pivoting lever that are held closed against the force of carbon fibre leaf springs by the tension in the rope. Releasing the rope causes the pivoting lever to open, thereby releasing the toggle attached to the ballast. A further pair of carbon fibre leaf springs per ballast provides additional lift off force by pushing off the concrete ballast in case the OBS has settled into loose sediments.

In case of mechanical failure of the rope clamping jaws there is a secondary release mechanism triggered via a message to the acoustic transponder that initiates an electrical burn wire that will release tension on the rope and jettison the ballasts.

In case of failure of the acoustic transponder or electrical failure there is a third release mechanism that triggers the burn wire at a preconfigured date and time, powered by a separate battery and electrical system.

Recovery operations commence with whatever sacrifices/obeisance is considered necessary to whichever deities are considered responsible for calm sea conditions. Once the recovery vessel has arrived at the deployment location the ballast release code is transmitted to the OBS using the acoustic transponder. The OBS will then jettison both ballasts and begin to ascend at a rate of approximately half a metre per second. For deep deployments this means there is considerable delay (up to over 3 hours) between the release of the ballast and the arrival of the OBS on the ocean surface. During the ascent period the OBS is subject to ocean currents so is unlikely to pop up directly above the computed deployment location, however the acoustic transponders ranging function can be used to confirm the OBS has commenced ascent and to track the distance from the OBS to the ship until the OBS surfaces.

Upon surfacing the OBS will enable both the flashing strobe lights inside the Vitrovex glass dome and the AIS system that transmits the GPS location and identification of the OBS unit via VHF radio. If the OBS has not been located by visual means then the AIS data will allow the recovery vessel to navigate to the vicinity of the OBS where a rope can be attached using a gaff type hook on a pole and the A frame used to raise and swing the OBS back on board.

As soon as the OBS is back on board the internal digitiser clock should be synchronised against GPS time and the drift of the internal clock logged as soon as possible to minimise changes due to thermal drift. Once the clock drift has been logged the unit may be powered down and the data recovered at leisure either on board or once the instruments have returned to shore.

4 Challenges Involved in OBS operations

There are a number of obvious differences between deploying seismic equipment on land versus at sea, however some of the consequences are not so obvious and therefore worth discussion.

4.1 Communications - Unless a cabling system is used there are only limited communications available at significant ocean depths. Cabled OBS systems have their own issues that are beyond the scope of this paper. Without effective communications to the seismograph all data required must be stored locally at the recorder. Large memory capacity is therefore required.

4.2 Location Uncertainty - As GPS is unfortunately not available on the ocean floor the location computed for the OBS position is not going to be as well constrained as for land based systems. Furthermore there is unlikely to be reliable data regarding the surface conditions of the ocean floor available in terms of whether it is uneven, rocky, sandy, shallow or steep sloping. If the OBS drifts underneath an overhanging ledge or tumbles down a steep ravine ending up inverted then the chances of recovery are slim.

4.3 Timing – Younger seismologists may be unaware of a time prior to GPS when clock drifts were routinely calculated for all seismic recorder clocks. This is the procedure that must be used for OBS deployment, fortunately the clock drift during the deployment will be almost perfectly linear due to the extremely stable temperatures at depth, however during descent, ascent, and on deck there will be temperature related clock drift and this was an issue during the sea trail test deployments off Exmouth where temperatures on deck exceeded 40 degrees Celsius.

4.4 Marine Operations – Shipboard operations introduce an entirely new set of complications many seismologists will not be familiar with. Once swell conditions increase the chance of damaging the OBS by swinging it into the ship’s hull or A frame increase significantly. In certain conditions deployment or recovery operations would need to be suspended, postponed or re-scheduled.

5 Results to date

All twenty OBSs from the AGOS National Pool have now been successfully trialled. Following a test in shallow water, the nodes were deployed on the North West Australian margin in a water depth of 1100 metres, within the area of Woodside Petroleum’s Centaurus 3D marine seismic survey. Seismic signals from the airgun array (3480 in^3 volume, 2000 psi pressure) were recorded to offsets in excess of thirty kilometres and could have been recorded to even larger offsets, had the acquisition geometry allowed larger separations between sources and receivers. This is a major extension of the recording aperture compared to eight-kilometre long streamers used on that survey.

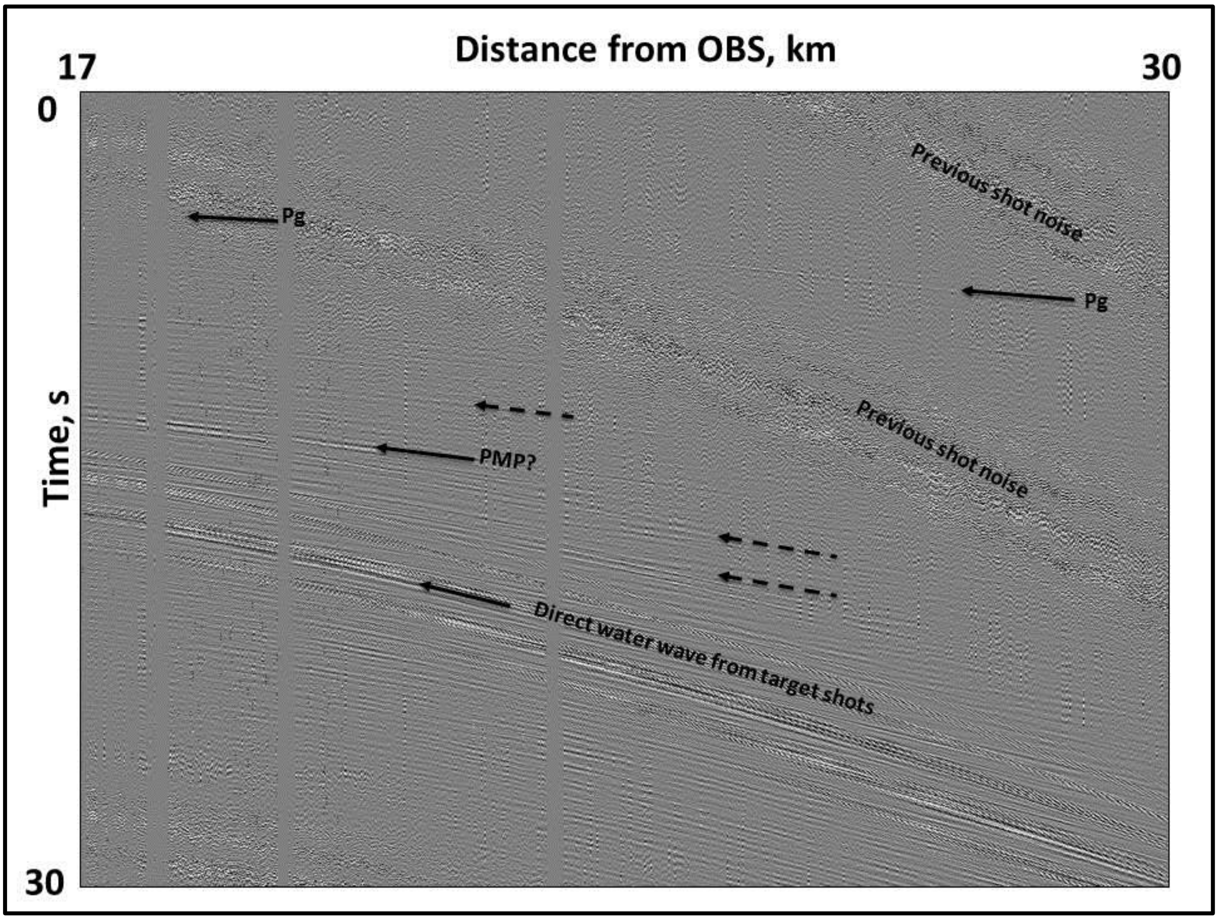

Figure 2. Example of OBS data recorded from airgun source during Centaurus 3D marine seismic survey undertaken by Woodside Petroleum on the Australian NW Margin in 2014. A number of useful phases recorded from target shots (marked by dashed arrows) are clearly visible to the background of previous shots noise. Pg – crustal refractions recorded as first arrivals, PMP? – possible Moho reflections.

Possible PMP reflections from the bottom of the crust have been identified on some records.(see Figure 2). The dilemma of the previous shot noise treatment (filter it out, or leave it in for the full wave form inversion processing) remains open for debate and further testing.

Since then the instrumentation has also been deployed in very shallow water (under 20 m) to record vibrator-generated signal from a land seismic line across the Canning Basin. This experiment has implications for seismic studies of the near-coastal transition zone where conventional marine reflection data cannot be recorded due to shallow water.

The OBS units record 4 channels (3 seismic, 1 hydrophone) continuously and save data natively to the GCF format that can be extracted and converted to MiniSEED, SAC, SUDS, SEGy and CSS formats.

6 Accessing the Equipment Pool

Access to the OBS pool is via a simple proposal assessed by ANSIR (Australian National Seismic Resource) Access Committee for scientific merit. Proponents have to meet the costs of transport of equipment to the vessel and vessel costs, insurance of the equipment and also the support of trained technicians if they do not have the necessary in-house experience.

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