A deep-towed multichannel seismic streamer for very high-resolution surveys in full ocean depth

Monika Breitzke and Jörg Bialas, research scientists at the GEOMAR Research Centre for Marine Geosciences, Kiel, Germany describe the latest testing of a deep-towed multichannel streamer combined with a sidescan sonar system to achieve improved resolution in deep water with gas hydrates the main interest.

The vertical and lateral resolution of marine subsurface structures in reflection seismic images strongly depends on the marine seismic source and streamer system used for signal generation and data acquisition. The vertical resolution is controlled by the dominant frequency and bandwidth of the reflected signals and can be improved by using high(er)-frequency sources like GI- or waterguns in deep water and boomers or sparkers in shallow water. Deconvolution tries to optimize the vertical resolution by increasing the bandwidth. The lateral resolution is determined by the size of the Fresnel zone whose diameter depends on the source and streamer depth and on the depth of the reflector, respectively, on the velocity above the reflector and on the dominant frequency. Migration increases the in-line resolution by reducing the in-line diameter of the Fresnel zone to approximately half a dominant wavelength, but has no influence on the cross-line resolution (Lindsey, 1989; Yilmaz, 2001). The latter can only be improved by lowering the streamer and - in the ideal case - the source towards to the sea floor.

This effect was first used by deep-towed single hydrophone experiments carried out to acquire high-resolution reflection profiles with reduced diffraction hyperbolae from the basement (Bryan, 1979; Purdy et al., 1980; Purdy and Gove, 1981) or to determine a high-resolution velocity structure of deep ocean sediments (Purdy, 1986). The first 15 - 30 m long deep-towed single-channel streamer and 3.5 kHz echo sounder system was successfully deployed by Bowen (1984) having used a surface airgun source (hybrid system).

The most widely used deep-tow systems are the PASISAR (Passenger Sismique du Système Acoustique Remorqué) of IFREMER (Institut Français de l'Explotation de la Mer/France) (Savoye et al., 1995; Nouze et al., 1997) and the DTAGS (Deep-Towed Acoustics/Geophysics System) of NRL (Naval Research Laboratory/USA) (Gettrust et al., 1991). The hybrid PASISAR comprises a deep-towed single channel analogue streamer, a high-resolution sidescan sonar (170 - 190 kHz) and a 3.5 kHz mud penetrator and uses various types of surface sources (sparker, air- and GI- guns). Depth and position control is based on a pressure sensor mounted on the sidescan sonar vehicle, first arrival times recorded with the mud penetrator and one-way travel times between source and streamer. Survey areas were the Ibera Margin (Sibuet et al., 1996) and the Nankai slope (Cochonat et al., 2002; Foucher et al., 2002).

The fully deep-towed DTAGS consists of a 622 m long, 48 channel digital streamer with two 24 channel subarrays, one with 2.1 m, the other with 21 m group spacing, and a Helmholtz resonator source generating a linear sweep between 250 and 650 Hz. The depths of the source and hydrophone groups and the array heading were measured during several surveys but proved to be not accurate enough (depth; Walia and Hannay, 1999) or completely failed (heading; Gettrust et al., 1991). Surveys concentrated first on the Bermuda Rise (Gettrust et al., 1988; Bowles et al., 1991; Gettrust and Rowe; 1991) and focused later on the Blake Ridge (Rowe and Gettrust, 1993a, b; Wood and Gettrust; 2001) and the Cascadia margin (Gettrust et al., 1999; Riedel et al., 2002; Chapman et al, 2002).

In 2001, GEOMAR Research Centre for Marine Geosciences started to develop a new hybrid deep-tow multichannel digital streamer, combined with a sidescan sonar system, to collect marine seismic data with an improved lateral in- and cross-line resolution particularly in regions of special interest for gas hydrate research. Compared with PASISAR and DTAGS, optimizations concerning the depth and position control, the digital data aquisition, the telemetry system, the modular streamer composition and the sidescan sonar frequency and resolution are included. Financial support for this technological development was provided by the Federal Ministry of Education, Science, Research and Technology (BMBF) within the gas hydrate initiative of the GEOTECHNOLOGIEN program (projects INGGAS and OMEGA).

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Overall system

The newly developed GEOMAR deep-tow system consists of a multichannel digital streamer (High Tech), a conventional marine seismic surface source (air-, GI- or water gun), a dual frequency sidescan sonar system (DTS-1; 75 kHz and 410 kHz; Edge Tech Full Spectrum), a chirp subbottom profiler (2-15 kHz, Edge Tech) and a depressor of 2 tons weight which ensures the deep-towed system stays in depth and as close to the towing ship as possible (Figures 1, 2). The depressor is directly connected with the ship's deep sea cable, and a 40 m long umbilical separates the depressor from the towfish to minimize heave influence and allow a horizontal alignment of tow forces.

In addition to the sidescan sonar and subbottom profiler transducers, the towfish carries two pressure cases, an acoustic release with depth transducer and an optional obstacle avoidance sonar. One pressure case includes the electronic components of the sidescan sonar and subbottom profiler system. The other tube contains a Linux PC responsible for seismic data acquisition and storage, the bottom-side part of the telemetry system and the power supplies for the bottom-side electronics (SEND, Signal-Elektronik und Netz-Dienste). Both coaxial and fibre optic cables can be used for data transmission between towfish and research vessel. The acoustic release is part of the ultra-short base line system POSIDONIA (IXSEA-OCEANO Technologies) used to track the towfish position. The release disconnects the umbilical from the depressor in case of an emergency, i.e. if the depressor is stuck behind an obstacle, so that the towfish and streamer can rise to the surface. Additional syntactic foam on the towfish and streamer ensures positive buoyancy.

Deep-tow streamer and sidescan sonar can be operated independently. In case of pure streamer operation the acoustic release of the POSIDONIA system and the pressure case including the bottom-side part of the telemetry system, the Linux PC and the power supplies are mounted on the depressor.

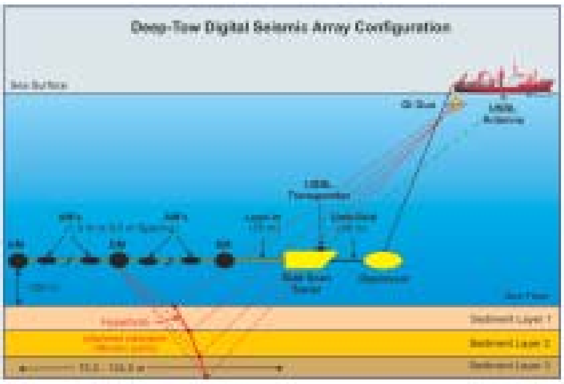

Figure 1 *Sketch of the deep-tow streamer and sidescan sonar system.*

Figure 2 *Photograph of the deep-tow system components, prepared for deployment from the ship's stern during RV Sonne cruise SO162. Front: streamer nodes and cables, middle: 2 tons depressor, back: sidescan sonar towfish.*

Streamer configuration

The streamer is a modular digital seismic array which can be operated in water depths up to 6000 m. It consists of a 50 m lead-in cable towed behind the sidescan sonar fish and single modules for each channel (Figures 1, 2). Two different modules - acoustic and engineering modules - exist. Each acoustic module houses a single hydrophone, low- and high-cut filter, preamplifier and 24-bit AD converter in a pressure vessel. Special engineering modules additionally include a compass, a pressure and a motion sensor (Crossbow Technology) which provide information on the depth, magnetic heading, pitch and roll of the module. Modules are interchangeable and can arbitrarily be connected by cables of 1 m or 6.5 m length. Up to 96 channels can be combined. Selectable sample intervals and preamplifier gains between 0.25-500 ms and 0.36 dB, and two different 2nd and 4th order high-pass filters with 4 Hz low-cut frequency allow to use sufficiently high-frequency seismic sources to guarantee a very high vertical and lateral resolution. At this stage of development the streamer consists of 26 modules including three engineering modules, and the streamer length can be varied between 75 m and 124.5 m.

Positioning system

Depth and position of the towfish are determined by the ultra-short base line (USBL) system POSIDONIA. It mainly consists of a deployable acoustic array with four receivers and one transmitter installed in the moon-pool and calibrated for its particular position, and a responder with remote receiver head mounted on the towfish and housing a pressure sensor. The responder function is triggered via the telemetry system through the coaxial or fibre optic deep sea cable, or a transponder mode is used and triggered through the acoustic array. The USBL positioning principle is based on a bi-directional exchange of submarine acoustic signals (14.5-17.5 kHz) between responder and acoustic array; i.e. the responder is interrogated by an acoustic pulse and sends an M-FSK (multi-frequency shift keying) reply signal received by the acoustic array. From the phase differences between these four received signals and the time delay between sent and received signals the position of the responder can be deduced. Together with (D)GPS, gyro compass and motion sensor information provided by the ship, the POSIDONIA system can determine the depth and position of the towfish with an accuracy of 0.5-1% of the slant range if the towfish's position is within a cone of 60-120° opening angle, and with an accuracy of 2-5% if the position is within a cone of 140-170° opening angle.

A crucial advantage of the POSIDONIA system is its capability to navigate and control the towfish position precisely, even if it is outside a 60° cone. In the latter case only the azimuth is measured from the responder signal, whereas the depth is taken from the responder depth sensor. Another advantage of the POSIDONIA system is the mobile lay out of its acoustic array which allows a short term installation on almost every research vessel.

Deep-tow system control

The deep-tow streamer recording and control system consists of a top- and a bottom-side part (Figure 3). The top-side part onboard the research vessel includes a Linux Top-PC, a DSC-Link as the laboratory part of the telemetry system and a PC running the Geometrics StrataVisor NX software for seismic data recording and online quality control. The DSC-Link includes two modems for data transmission through coaxial or fibre optic deep sea cable. Additionally, there is a processing unit of the POSIDONIA system and a PC for the online recording and display of the measured positions of the towfish. At the bottom-side, a Linux Bottom-PC with 120 GByte storage capacity and the underwater part of the telemetry system, which handles the data transfer between underwater and onboard systems and provides all necessary power supplies for the bottom electronics, are installed in a pressure-proofed housing mounted on the towfish.

The corresponding components for sidescan sonar data recording and online control - the full spectrum interface unit (FS-IU) and a PC running the Hydrostar Online software (ELAC) on the top-side and the full spectrum deep water (FS-DW) unit with 60 GByte storage capacity in a pressure vessel on the bottom-side - and an optional obstacle avoidance sonar complete the deep-tow recording and control system.

The deep-tow streamer can be controlled remotely from the top-side by the Top-PC. All seismic data are stored underwater on the Bottom-PC in multiplexed format. Depending on the available bandwidth of the deep sea cable, at least a portion of the seismic (and sidescan sonar) data including the engineering data are transmitted to the top side and stored in SEG-Y, SEG-D or SEG-2 format on the hard disc of the Geometrics-PC or on two connected daisy-chained DLT 8000 devices. After optional bandpass filtering and gain ranging, the seismic data is displayed on the Geometrics-PC as shot and continuous common offset gather for online data quality control. Simultaneously, depth and heading values provided by the engineering nodes are graph-

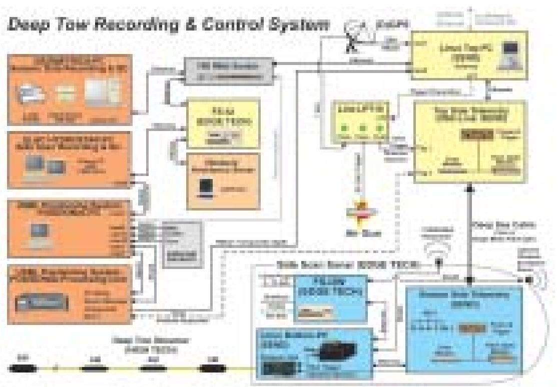

Figure 3 *Laboratory and underwater components of the deep-tow recording and control system.*

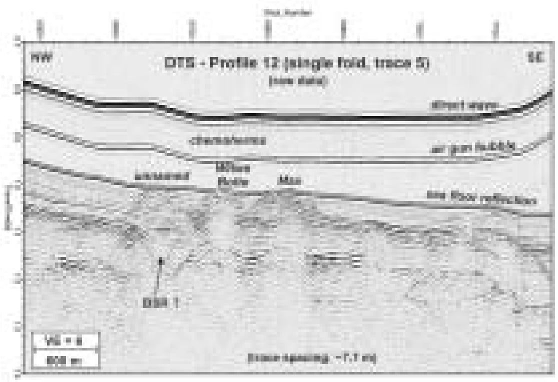

Figure 4 *Single-fold DTS-profile12 recorded in the 'Max & Moritz' chemoherm area off Peru. Trace no. 5 was extracted from each shot gather and bandpass-filtered between 55/110 - 500/1000 Hz. No depth corrections were applied. VE = vertical exaggeration computed for a velocity of 1500 m/s.*

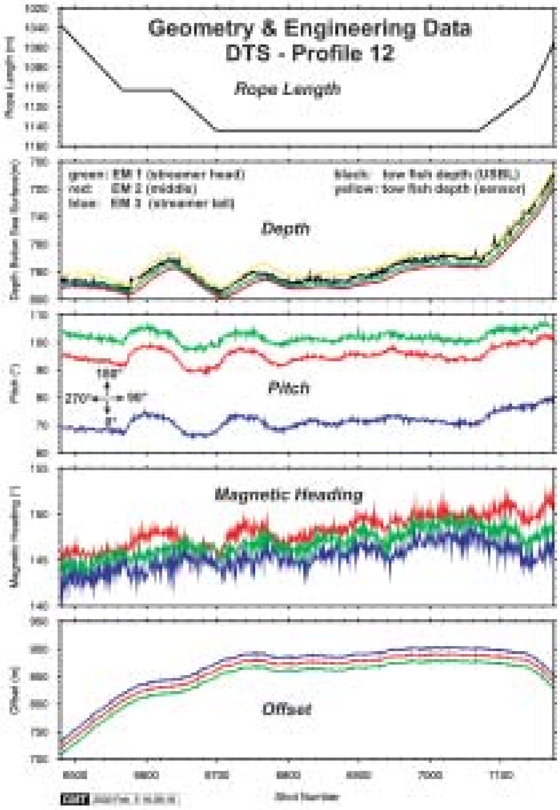

Figure 5 *Depth, pitch and magnetic heading values recorded by the three engineering nodes of the deep-tow streamer along DTS-profile 12, as well as rope length of the ship's deep sea cable and offset between source and receiver computed for the 3 engineering nodes after geometry processing.*

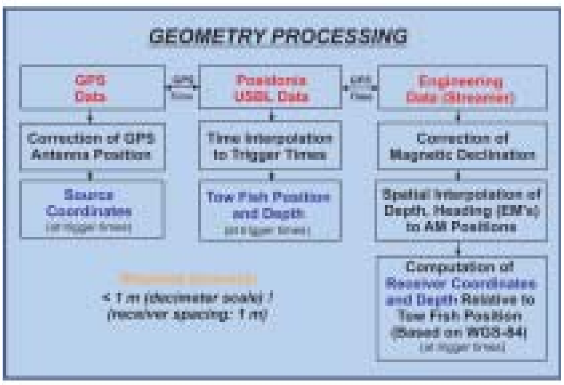

Figure 6 *Sketch of the steps necessary to compute the geographical coordinates of the seismic source, towfish and each streamer node at each trigger time.*

ically displayed on the Top-PC to facilitate an online depth and position control. Commands which control the recording parameters like sample interval, record length, delay, filter or pre-amplifer gain, and which initialize the data transfer between underwater and onboard systems, are sent from the top- to the bottom-side by the telemetry system via low-speed downlink, whereas the seismic (and sidescan sonar) data is transferred from the underwater to the top-side by the telemetry system via high-speed uplink through the coaxial or fibre optic deep sea cable.

All bottom- and top-side components as well as air gun shooting are synchronized by (D)GPS time-based trigger signals generated by the Top-PC via the LPT10 link. Additionally, all surface and underwater components controlling the deep-tow device are linked via ethernet with the Top-PC as gateway and form a cluster within the computer network onboard the research vessel.

Field test

The complete deep-tow streamer and sidescan sonar system was first deployed during *RV Sonne* cruise SO162 off Peru in 2002 (Reston and Bialas, 2002). Various tests were completed to find an optimum towing velocity and depth above the sea floor to achieve the best signal-to-noise ratio and lateral resolution of subsurface structures in both sidescan sonar and reflection seismic images. A height of 100-120 m (75 kHz sidescan sonar mode) or 20 m (410 kHz sidescan sonar mode) proved to be applicable with both systems. A towing speed of 2.5 to 3 kn turned out to be a good compromise between sidescan sonar and streamer demands for towfish stability and induced noise.

A grid of 10 closely spaced profiles of 5 km length and 100 m spacing were also collected in an area where some chemoherms (named 'Max', 'Moritz' and 'Witwe Bolte') were found during a previous cruise in about 1000 m water depth (Bialas and Kukowski, 2000a, b). The streamer configuration used for this survey had an overall length of 74 m and consisted of 22 acoustic and three engineering nodes. Node spacing was 1 m to allow a very high resolution imaging of subsurface structures by close subsurface reflection points. A Prakla-type Bolt air gun (1.6 l) was used as seismic source and excited frequencies between 50-300 Hz. Data recording parameters were 3.072 s recording time and 0.25 ms sample interval. Shot interval was 5 s and average ship velocity 3 kn resulting in an average shot point spacing of 7.7 m.

The intention of this survey was to gather experience in the handling and operation of the deep-tow system during 2.5D surveys. The result was that in 1000 m water depth, curves between profiles of 500–600 m spacing can be manouevred without any problems, particularly due to the online control of the towfish and streamer depth by the POSIDONIA system and the engineering data of the streamer, so that in future high-resolution 2.5D deep-tow seismic surveys with a close profile spacing of few tens of metres will be possible if profiles are planned appropriately. Furthermore, data transfer rates proved to be high enough even for an 18 mm coaxial deep sea cable, that all seismic (and sidescan sonar) data could be transmitted online from the bottom- to the top-side, displayed as common shot and offset gathers and stored on DLT tape.

Raw seismic and engineering data example

To get an overview on the collected seismic data one trace was extracted from each shot gather and displayed as single-fold seismogram section. Figure 4 shows such a data example recorded along DTS-profile 12 of the small grid mentioned above. Signal penetration is about 0.4 s TWT or 300 m depth, respectively. Three chemoherms embedded within a weakly reflecting sequence of hemipelagic or turbiditic sediments can be identified. Beneath this sequence occur two strong reflectors and several ‘bright spots', which might be interpreted as carbonate crusts and/or local accumulations of free gas. A spatially limited, weak BSR can also be observed. Some of the strong reflections seem to continue across the chemoherms but are difficult to trace because much of the incident signal energy is scattered at the top and trace spacing of about 7.7 m provides only coarse lateral resolution.

Figure 5 displays the depth, magnetic heading, roll and pitch values recorded by the three engineering nodes along DTS-profile 12 and compares them with the rope length of the deep sea cable and the offsets between source and engineering nodes. This data set indicates that the immersion depths measured by the engineering nodes agree well with the depth of the towfish provided by the POSIDONIA system. Variations in immersion depth can be related to variations in rope length. At the beginning of the profile it takes some time to stabilize the deep-towed system in a certain depth. Pitch values indicate that the streamer is slightly bowed towards the sea floor. Magnetic heading values show some degree of scatter which, however, is in the order of the accuracy (1°) of the orientation sensors. Offset values indicate that variations in rope length do not only affect the immersion depths but also change the offset between source and receiver – a fact which is important for later data processing.

Preliminary deep-tow multichannel seismic data processing

The asymmetric source and receiver geometry of the hybrid deep-tow system causes subsurface reflection points to lie on a hyperbola even in the case of a plane-layered subsurface (cf. Figure 1), so that special data processing techniques were developed which take this geometry into account, considering the varying immersion depths and offsets and stack common reflection points instead of common midpoints.

Primarily based on the recorded DGPS, USBL and engineering data geographical coordinates of the source, the towfish and each streamer node were computed by time and spatial interpolations of these data sets (Figure 6). The required (relative) accuracy for these coordinates is on the sub-meter scale, and thus one magnitude higher than for conventional surface streamer data. Subsequently, the varying immersion depths of the streamer nodes were reduced to a common reference depth. As these corrections can be in the order of several tens of metres, a Kirchhoff wave equation extrapolation algorithm (Shtivelman and Canning, 1988) is applied instead of a simple static correction, so that *all* subsurface structures in all depths could correctly be reconstructed. Finally, a Kirchhoff 3D-prestack depth migration was computed which considers all multichannel deep-tow seismic data and stacks them with respect to common reflection points. Figure 7 shows DTS-profile 12 after such a first preliminary prestack depth migration having used a constant migration velocity of 1500 m/s. Though some residual migration hyperbolae are still apparent in this preliminary migrated section, which are mainly a result of amplitude distortions produced by the datum correction algorithm because the limited spatial extent of the shot gathers, some remarkable features can be observed. The strong reflector below the hemipelagic or turbiditic sequence is almost continuous, even below the chemoherms. A second strong reflector occurs about 100 m beneath the first strong reflector and appears to be more continuous than in the single-fold time section. Several short reflectors can be observed below this second strong reflector down to 1250-1300 m depth, whereas the single-fold time section only shows weak reflections here. The high resolution of this preliminary prestack-depth-migrated section and the possibility to identify small scale faults is a result of the reduced Fresnel zone, but also a result of the very close trace spacing (0.5 m) after prestack depth migration. Additionally, the S/N ratio is improved compared to the single-fold section, because it includes the complete multichannel information of the survey resulting in a three-fold coverage in the depth-migrated section.

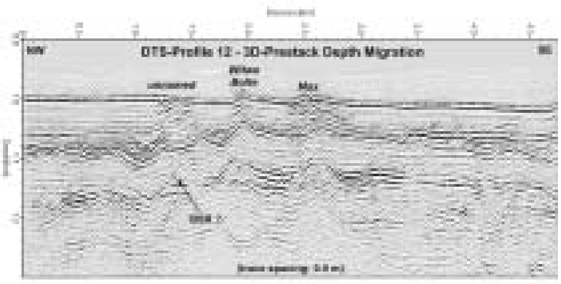

Figure 7 *DTS-profile 12 after datum correction by wavefield extrapolation to 800 m (reference) depth and Kirchhoff 3D-prestack depth migration.*

Outlook

Future plans particularly aim at an improved multichannel data processing. The geometry processing will be improved by including the information of the first arrival times of the direct wave to reduce residual depth variations. Amplitude problems still present in the wave equation extrapolation for datum correction will be reduced by numerical expansion of each shot gather so that a larger spatial extent of the streamer is simulated. Concerning the prestack depth migration, a velocity model including vertically and laterally varying velocities will be considered.

Acknowledgements

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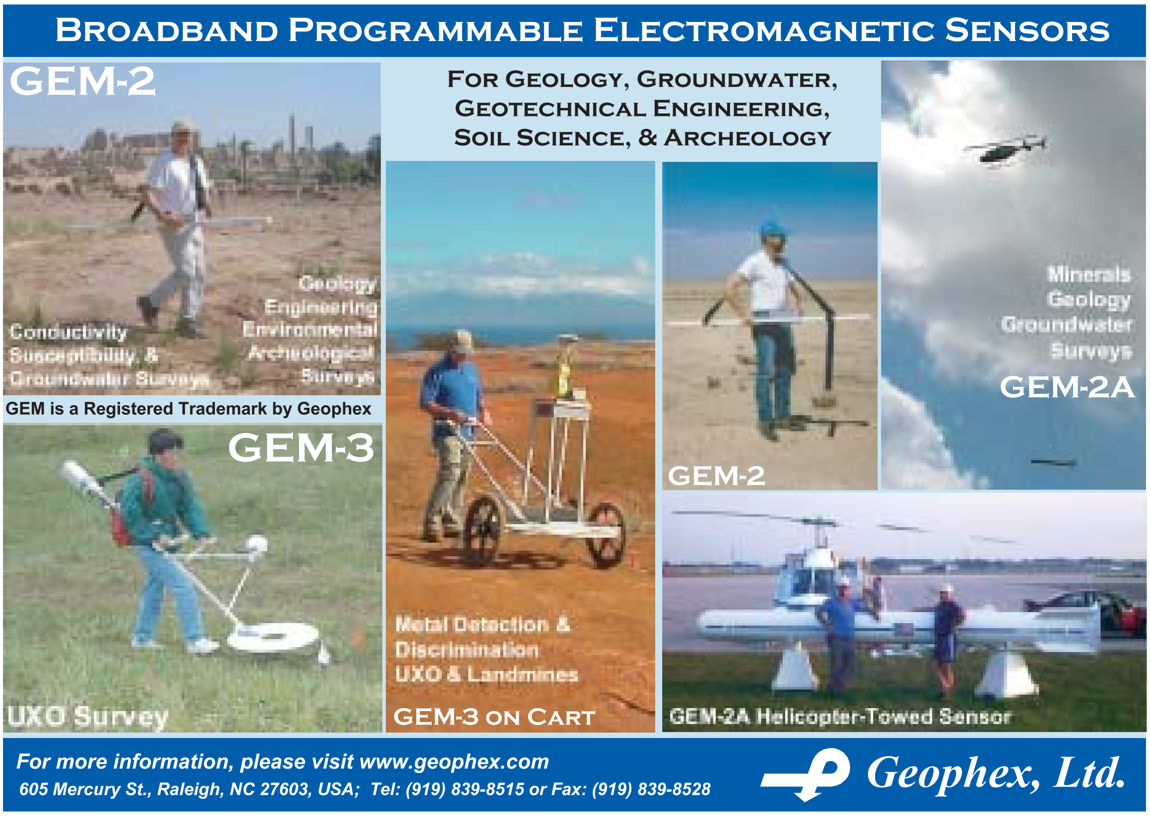

Geophex celebrates its 20th anniversary