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Broadband Seismology in the Scotia Sea Region, Antarctica
Italian and Argentinean contributions to the Scotia Sea Broadband Network

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Abstract - Several national Antarctic programs have concentrated efforts on developing a regional seismographic network to further our understanding of geodynamic processes in the Scotia Sea region and its neotectonic evolution. The Italian *Programma Nazionale di Ricerche in Antartide* (PNRA) and the Argentinean *Direccion Nacional del Antartico* (DNA) support the Argentinean-Italian Seismographic Network in Antarctica (ASAIN) since the early nineties. The ASAIN consists of three digital broad-band seismographic stations installed at Base Esperanza (ESPZ, Antarctic Peninsula, 1992), Ushuaia (USHU, Tierra del Fuego Argentina, 1996) and Base Orcadas (ORCD, South Orkney Is., 1997).

Besides enhancing regional seismicity maps, ASAIN seismograms have been used to derive regional S-wave velocity models. These models provide input parameters for investigating the focal mechanism of major regional earthquakes through waveform inversion methods.

The new velocity models and the greater number of stations will allow for a better resolution of focal parameters. This will in turn contribute to seismic source studies which help determine plate boundaries and intra-plate processes.

INTRODUCTION

In the past decade scientists have concentrated on the seismology of Antarctica, and many permanent, broad-band seismographic stations have been installed on the continent (Kaminuma, 1992).

These stations improve the detection threshold of seismicity in the Southern Hemisphere where, due the prevalence of oceanic masses, the density of seismographic stations is much lower than in the Northern Hemisphere (Rouland et al., 1992).

The highest density of seismographic stations in the Antarctic continent and neighbouring areas is found in the Antarctic Peninsula-Scotia Sea where most of the seismicity characterising the Antarctic continent is concentrated.

Researchers have long been aware that seismology can improve our knowledge of the Scotia Sea region; nevertheless, extensive seismic studies were not possible until the early nineties when digital broad-band seismographs and high capacity storage devices became available. Since then, several seismographic stations have been installed and operate as permanent stations in scientific bases or as temporary installations in remote locations.

The ASAIN dataset is an important contribution to the seismological database provided by all these installations. The data helps improve the resolution of earthquake hypocentres and first motion determinations. Italian and Argentinean researchers have used it to investigate the structural characteristics of the lithosphere and upper mantle in the Scotia sea and the properties of seismic sources active in the region.

Shear wave velocity models for the main geological and tectonic features in the Scotia Sea region have been derived by combining ASAIN data with that collected by other broad-band stations operating in the region (Vuan et al.,1997, 1999, 2000b). The investigation of source mechanisms using moment tensor inversion techniques is under way (Vuan et al., 2000a; this volume).

The following is a history of the development of ASAIN. The technical characteristics of instrumentation employed in each station and statistics on the periods of successful operation of the network are also described. A brief summary of scientific results obtained using the ASAIN dataset and proposals for the development of the network are included.

THE SCOTIA SEA OGS-IAA SEISMOGRAPHIC NETWORK (ASAIN)

THE ORIGINS (1992-1994)

The Scotia Sea region shows a relevant level of seismicity. Earthquakes with magnitudes of up to 7 Ms and more have been observed. Exhaustive descriptions of the general pattern of regional seismicity derived from teleseismic recordings can be found in Pelayo and Wiens, 1989.

Earthquake epicentres follow the main bathymetric features and clearly highlight the composite nature of the Scotia Sea region which appears to be an ensemble of

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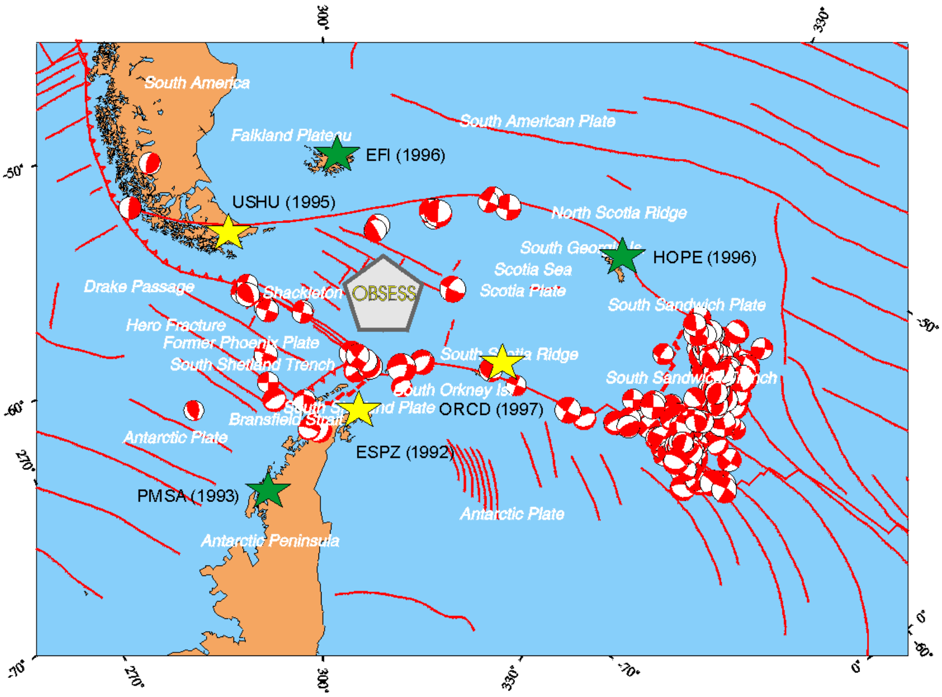

Fig. 1 - OGS-IAA and IRIS broad-band stations installed in the Scotia Sea region from 1992 to 1997 superimposed on the plot of regional earthquake source mechanisms. The black square in the centre of the Scotia Sea represents the area where the OBSESS experiment should take place.

small plates enclosed by the much larger South American and Antarctic plates (Barker, 1970, Barker and Hill, 1980).

The maximum density of events, with hypocentral depths extending from shallow to more than 300 km, is concentrated in the South Sandwich Is. area (where the South American plate is subducted below the South Sandwich plate) and along the North and South Scotia ridges. Diffuse seismicity is also evident west of the Drake Passage, in the South Shetland Is. and Bransfield Strait areas.

The map of source mechanisms of regional earthquakes (Fig. 1) indicates that seismology can be a very promising tool to investigate the tectonic evolution and structure of the lithosphere. Data recorded at teleseismic distances gives a broad picture of seismicity in the Scotia Sea region, but cannot provide details of the structure of the lithosphere or of source mechanisms on regional and local scales.

At the beginning of 1992 OGS and IAA researchers, supported by the Italian PNRA and the Argentinean DNA, installed a digital seismograph on the tip of the Antarctic Peninsula at the Argentinean Base Esperanza (Fanzutti et al.,1992) (Fig. 2).

This experimental installation was set up to collect sufficient data to test the quality of the site.

Base Esperanza station started operating on January 20, 1992. The instrumentation consisted of a BB-13 Teledyne Geotech broad-band seismometer triplet (Z, N-S, E-W components), with flat response to acceleration in the range from dc to 20 Hz., connected to a PDAS-100 Teledyne-Geotech digital recorder. The equipment was installed on a cement pillar, about 2.5m x 1.5 m wide and anchored to the underlying groundrock, erected in the interior of a wooden building at the base. Power for the instruments was provided by a set of batteries float-charged by a battery charger connected to the base's main power generators. Correct timing was obtained by synchronising the PDAS-100 internal clock with a radio time signal.

Two continuous data streams were recorded for each seismic channel at 2 sps and 0.2 sps. These rather low sampling rates, adopted because of the low storage capability (8 megabyte of CMOS static, internal, non-volatile random access memory), allowed about three days of continuous recording before storage on 1.44 Mb floppy disks was necessary.

THE "BROAD-BAND SEISMOLOGY IN THE SCOTIA SEA REGION" PROJECT AND NETWORK DEVELOPMENT (1995-1997)

During Antarctic summer 1994 seismic noise was measured at a few sites located within 2 km of the base and within 600 m of the shore (more distant sites were not easily accessible). The differences in the average seismic noise levels with respect to the original installation site

Fig. 2 - A view of Base Esperanza. The square in the centre marks the position where the seismographic station is installed.

were not big enough to justify the logistic effort needed to move the station to a new site; it was therefore decided to transform the temporary installation into a permanent seismological observatory by placing the new seismographs in the same location as the old ones (Russi, 1994).

The new equipment started operating on 5 February 1995. It is based on a Guralp CMG-3T Seismometer, with flat velocity response in the 0.01 Hz-50 Hz band, coupled with a Reftek 72A-08 digital recorder. The time base is provided via a GPS receiver. 1 sps continuous, 10 sps and 50 sps LTA/STA-triggered sampling rates were initially selected (it was later decided to change the parameter setting, and two continuous data streams at 1 and 20 sps have been recorded since then) (Russi et al., 1996).

In the meanwhile, the project "Broad-band Seismology in the Scotia Sea Region (submitted to the PNRA by the OGS), which includes a plan for the installation of two more stations at Ushuaia (Tierra del Fuego) and at the Argentinean Base Orcadas (South Orkney Is.), was approved. The whole network was installed and managed in the framework of a Memorandum of Understanding between the OGS and the IAA, with the financial support of the Italian PNRA and the Argentinean DNA.

Ushuaia (USHU) station was installed in December 1995, while Base Orcadas (ORCD) station started operating in March 1997. The technical characteristics and performances are identical to those of station ESPZ (Guralp CMG-3T seismometer and Reftek 72A-08 digital recorder with GPS timing) even if some details of the installations differ from one site to the other.

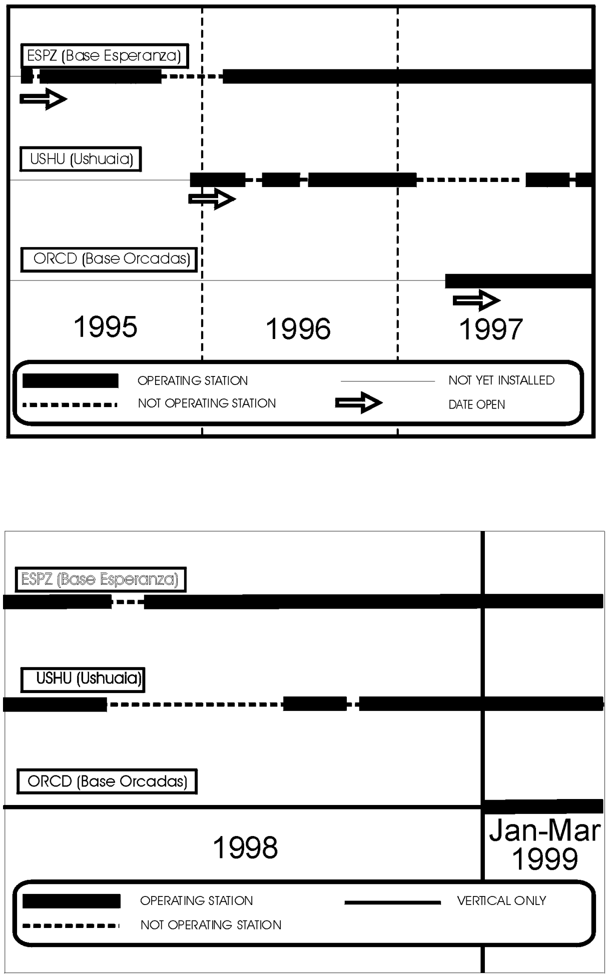

Fig. 3 - OGS-IAA stations operation graph February 1995 -March 1999.

Each station is equipped with a 600 Mb to 1200 Mb Reftek 72A-05 SCSI disk. The recording parameters - continuous data streams at 1 sps and 20 sps for the three seismic channels - are the same for the whole network.

THE SEISMOLOGICAL DATABASE AND RESEARCH

The seismograms recorded by the ASAIN, including those of local, regional and teleseismic events, have provided a large database. Many recorded regional events do not appear in the global catalogues, even if the seismic noise at ASAIN stations is rather strong.

Figure 3 shows the operation reports for the three stations, since the installation of Reftek 72A-08-CMG-3T seismographs at Base Esperanza, from early 1995 to March 1999.

The Esperanza station seismograms are the main contribution to the ASAIN database due to the long period of operation (almost 8 years).

The 1992-1994 regional seismicity recordings have been used to perform tests based on surface waveform analysis. Even using data from only one station, it has been possible to retrieve information on the large-scale structure of the lithosphere in the Scotia Sea, therefore providing guidelines for future research developments (Russi et al., 1994, Russi et al. 1996).

Some examples of regional earthquakes and teleseisms recorded by ASAIN are displayed in figure 4.

Results which contribute to our understanding of the structure of the lithosphere in the Scotia Sea region have been obtained through the analysis of dispersion properties of Rayleigh and Love waves in the ASAIN dataset and in GSN station recordings (operated by the IRIS consortium: PMSA, EFI and HOPE) (Fig.1) (Russi et al., 1997, Vuan et al. 1999) using the Frequency-Time Analysis (FTAN) technique (Levshin et al., 1992).

Group velocity tomographic maps in the 15s to 50s period range were obtained (Vuan et al., 2000b) by extending the study to more then 300 regional earthquakes, resulting in more than 1000 epicentre-to-station ray paths, and by extrapolating results to a regional scale through a generalised 2-D inversion method (Ditmar and Yanovskaja, 1987, Yanovskaja and Ditmar, 1990).

Local, smoothed dispersion curves at 2x2 degrees and, using a non-linear inversion scheme, the corresponding S-wave velocity models are retrieved from the maps.

The SSR1.0 model (Vuan et al., 2000c; in preparation) consists of 648 tiles in which the crust and upper mantle are layered according to the CRUST5.1 global model (Mooney et al., 1997).

Compared to existing global models, this one provides better details on plate boundaries, sedimentary basins and tectonic and geological features up to 50 km deep, and it can be applied to a wide range of seismological and non-seismological problems.

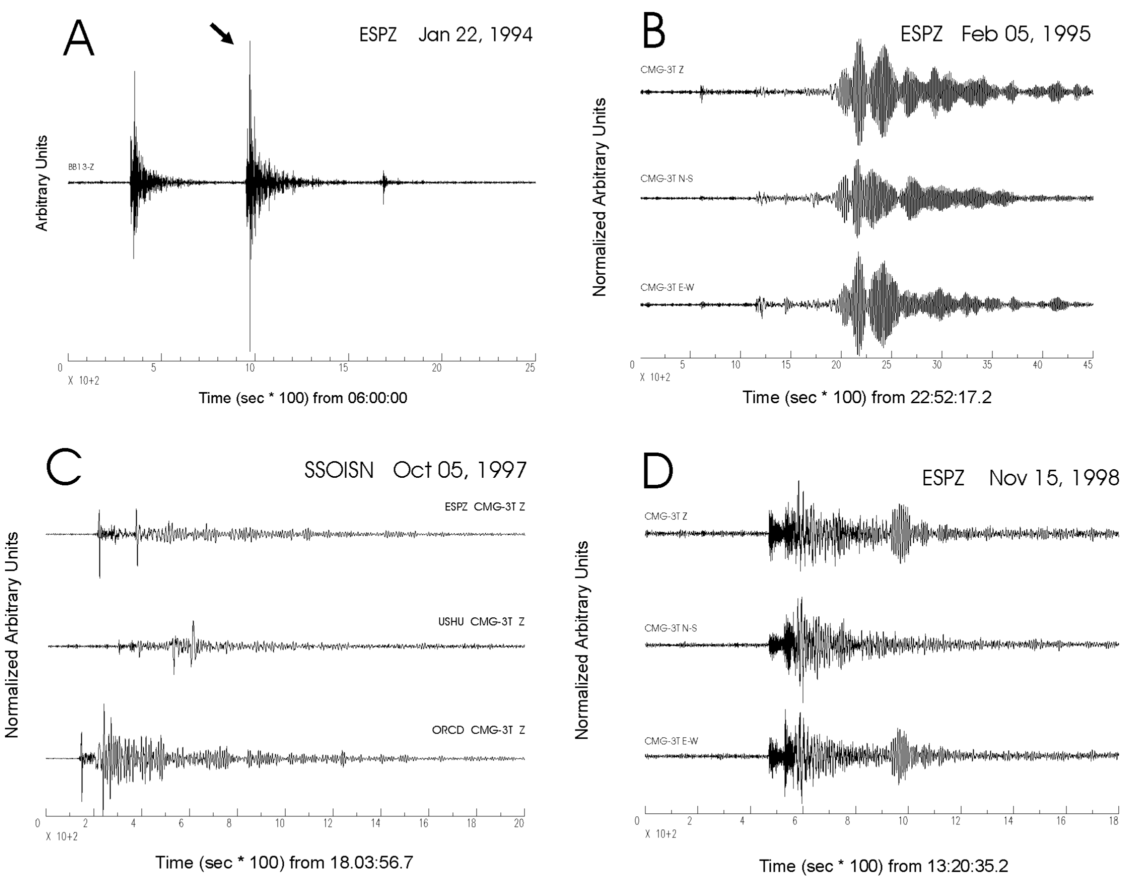

Fig. 4 - A) top left- vertical sequence ESPZ station recording. of January 22, 1994 Bridgeman Is. sequence. The arrow marks the main event (Origin Time: 06:15:26.1, Lat. 62.11 S, Long. 56.12 W, Depth 10, mb 5.1). B) top right. February 5, 1995 New Zealand teleseism Z, N-S, E-W seismograms (Origin time 22:51:05.1, Lat. 37.76 S, Long. 178.75 E, Depth 21, mb 6.5). The first significant earthquake recorded by the ESPZ permanent Observatory Reftek72A-08 - Guralp CMG-3T seismographs after station upgrade. C) bottom left. ESPZ recordings of November 15, 1998 regional event in the South Scotia Ridge (Origin Time: 13:27:12.8, Lat. 60.86 S, Long. 47.30 W, Depth 15.0, mb 5.3). D) bottom right. ASAIN vertical component recordings of October 5, 1997 South Sandwich Is. deep focus earthquake (Origin Time: 18:04:30.0, Lat. 59.74 S, Lon 29.20 W, Depth 274 km, mb 6.0).

ONGOING AND FUTURE ASAIN DEVELOPMENTS

The development of the Scotia Sea region seismological project by the PNRA-DNA takes into consideration both SCAR recommendations and suggestions from the scientific community on the basis of research results which can be summarised as follows:

a - The existing ASAIN (USHU, ESPZ, ORCD) and IRIS (PMSA, EFI, HOPE) networks and the transformation of some temporary stations operating in the South Shetland area into permanent observatories by the PASSCAL-NSF SEPA (Seismic Experiment in Patagonia and Antarctica) program (Wiens et al., 1997, Robertson et al. 1999) will provide sufficient coverage for local studies in the South Shetland Is. and in the Antarctic Peninsula.
The regional distribution of surface wave epicentre-to-station great circle paths for Rayleigh and Love surface waves shown in figure 5 indicates a large void, located approximately at the centre of the triangle whose vertices coincide with ESPZ, USHU and ORCD stations. By enhancing path coverage at this location, one would significantly improve the shear-velocity models obtained by PNRA researchers for the Scotia Sea region geological and tectonic features (Vuan et al., 2000b). In this key area, the continuous, unattended recording of global and regional seismicity for one year or more is only possible by means of a broad-band ocean-bottom seismometer deployed on the sea-floor of the Scotia Sea (OBSESS experiment, Fig.1).

b - A more complete dataset is necessary to investigate important tectonic processes such as shallow mantle flows from the Pacific to the Atlantic Oceans and to examine aspects of subduction in the South Sandwich and South Shetland Is. trench systems. Such a dataset might be obtained by integrating the existing network and OBSESS with few very broad-band, ocean-bottom seismometers.

Based on the above considerations, the following short- and medium-term priorities in the development of the PNRA - DNA joint seismological project have been established:

1. To guarantee the continuity of operations at Base Esperanza, Ushuaia and Base Orcadas. Upgrades to

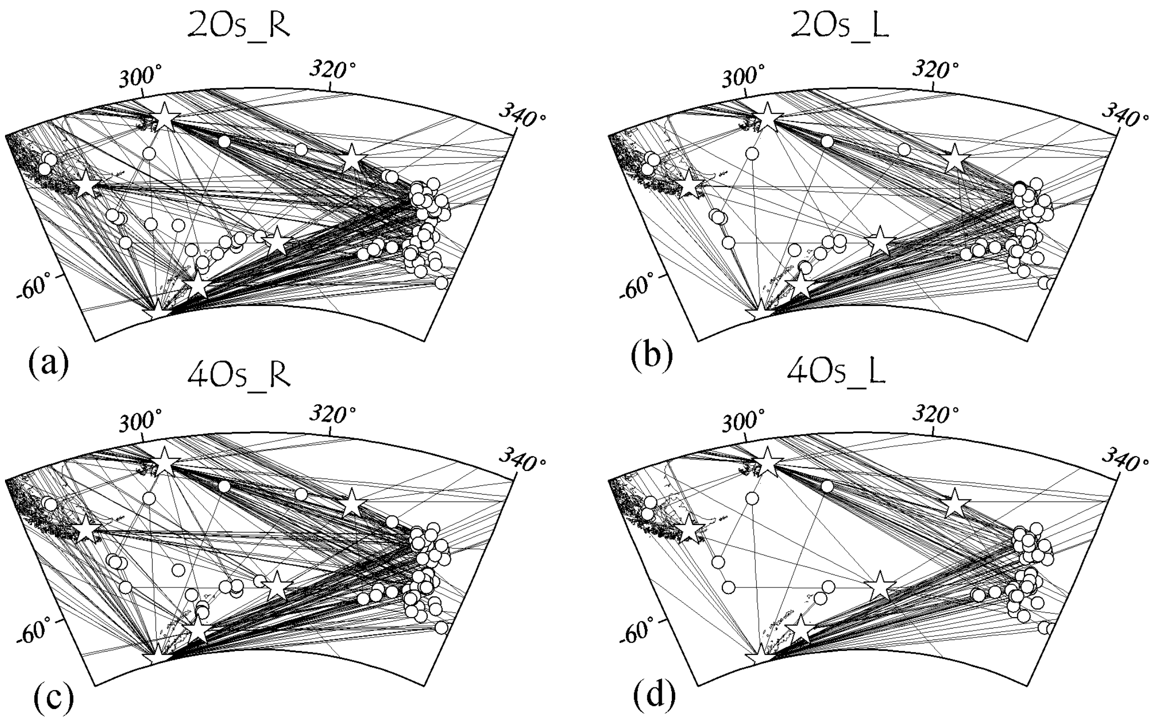

Fig. 5 - (a) Epicentre-to-station path coverage for 20s Rayleigh Waves, (b) Love waves at 20s, (c) Rayleigh waves at 40s, (d) Love waves at 40s.

existing station instrumentation and duplication of equipment at each site is necessary in order to avoid long gaps in data due to instrumentation failure or other operational problems.

2. To improve the accessibility of ASAIN data by involving International Data Centres in the distribution of data to the scientific community.
3. To continuously encourage free distribution of data recorded by seismographic stations operated in the Scotia Sea region and in adjacent areas of interest.
4. To define a project (Ocean Bottom Seismology Experiment in the Scotia Sea, OBSESS, Fig. 1) for the deployment of a broad-band, sea-bottom seismograph and its unattended, continuous operation on the sea-floor of the Scotia Sea.

CONCLUSIONS

Until 1992 the tectonic setting and evolution of this area was studied through the analysis of teleseismic recordings of major earthquakes along with data collected by means of nonseismological methods (Forsyth, 1975; Pelayo and Wiens, 1989).

Since 1992 three permanent broad band seismographic stations installed at Base Esperanza, Ushuaia and Base Orcadas have been jointly operated by PNRA and DNA.

Their recordings and those collected by IRIS consortium stations, installed almost simultaneously, have been successfully employed to investigate the lithosphere and ongoing geodynamic processes in the Scotia Sea area.

It is necessary to integrate the land network with OBS-type instruments in order to refine results and improve the resolution of the existing dataset.

Ocean-bottom seismometers, including broad-band instruments (Bransfield Strait Ocean-Bottom Seismograph, BSOBS), were recently deployed and operated for five months, to investigate the seismicity and tectonics of the Bransfield Strait and South Shetland Is. areas (Wiens, personal communication).

Geologists and seismologists consider the one-year continuous, unattended operation of a broad-band OBS in the middle of the Scotia Sea (OBSESS experiment, Fig. 1) a real challenge. It would provide very useful data for the investigation of key processes such shallow sub-lithospheric mantle flow from the Pacific to the Atlantic by shear-wave splitting and subduction at the South Sandwich and South Shetland trench systems (Robertson et. al, 1999; Barker, 2000; this volume).

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