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The Antarctic Seismographic Argentinean-Italian Network: technical development and scientific research from 1992 to 2009

M. Russi[1], J.M. Febrer†[2] and M.P. Plasencia Linares[1]

[1] *Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, Trieste, Italy*
[2] *Instituto Antártico Argentino, Buenos Aires, Argentina*

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ABSTRACT For several decades a variety of geophysical surveys have been carried out in the Scotia Sea, but earthquake seismology began to be widely employed only during the 1990s when some instruments were installed in the area following the activation of a temporary broadband seismographic station (ESPZ) by a team of Italian and Argentinean researchers, of the Istituto Nazionale di Oceanografia e Geofisica Sperimentale (OGS) and of the Instituto Antártico Argentino (IAA) respectively, at the Antarctic Argentinean permanent base, Base Esperanza. At the beginning of 1995 ESPZ became the first permanent observatory of the Antarctic Seismographic Argentinean-Italian Network (ASAIN). In this paper, we describe the chronological and technical evolution of the ASAIN, that is financially supported by the Italian Programma Nazionale di Ricerche in Antartide (PNRA) and by the Argentinean Dirección Nacional del Antártico (DNA) and that consists today of five stations installed in Antarctica (ESPZ, JUBA, ORCD, SMAI, BELA) and two in the Argentinean Tierra del Fuego (DSPA, TRVA). The SMAI and BELA stations, both located beyond the Antarctic Polar Circle, were activated between February 2007 and January 2009 as a PNRA/OGS – DNA/IAA contribution to Antarctic Seismology during the International Polar Year. A resume of the scientific results obtained using ASAIN data is also included.

1. Introduction

1.1. The Scotia Sea: geodynamics and seismicity

The Scotia Sea region is a roughly rectangular oceanic area extending from 25° to 75° W and 53° to 61° S, comprised between the major Antarctic and South American Plates and bounded on three sides by the group of islands and oceanic ridges named Scotia Arc, while its western edge is represented by the Shackleton fracture zone and the Drake Passage that separates today's Tierra del Fuego, the southern tip of South America, from the Antarctic Peninsula (Dalziel, 1983, 1984; Barker, 2001) (Fig. 1).

Investigating the tectonic history of the Scotia Sea is crucial to understanding the geological evolution of the Antarctic continent and the influence of the aperture of the Drake Passage in establishing the Circumpolar Antarctic Current.

The birth of the Scotia Sea dates back between 60 Ma and 34 Ma ago (Lawver *et al.*, 1985) as the result of a Tertiary disruption of a continuous Antarctic-Andean margin (Barker and

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† Deceased on May 2, 2008.

Burrell, 1977).

High seismicity levels characterize the area of the South Sandwich Trench (SST), with hypocentral depths up to 300 km, and the South Scotia Ridge (SSR). A lower, but still significant, seismic activity is present along the North Scotia Ridge (NSR), the East Scotia Ridge and in the South Shetland Islands (SSI) area. Important earthquakes also characterize an active spreading centre (SSSR) located between the Scotia and Sandwich plates. Details of the most significant events are reported in Table 1.

To interpret the seismicity patterns and the variety of tectonic processes which characterize the region, including fast back-arc spreading behind the South Sandwich Arc, cessation of volcanism in the South Shetland Islands and the onset of rifting in the Bransfield Strait, several hypotheses, implying the interaction of at least four minor plates (Scotia, Sandwich, Shetland, Drake) with the major ones (South America, Antarctica), have been explored (Forsyth, 1975; Pelayo and Wiens, 1989; Robertson Maurice *et al*., 2003). The analysis of data recorded by a regional broadband seismographic network with the methods of modern seismology can make a significant contribution to this type of investigation (Brancolini *et al*., 2001).

1.2. Seismometry in Antarctica and Sub-Antarctic areas

At the beginning of the 1990s, seismological observations in Antarctica could only benefit from the recordings of 16 instrumented sites operated by 13 countries including only 4 broadband digital stations (Kaminuma, 1992). The main impulse to the installation of permanent seismological observatories in the Antarctic and Sub-Antarctic areas came from the recommendations of the Scientific Committee for Antarctic Research (SCAR) e.g., ICSU SCAR, 1993 and from the strong initiatives put in place by some national Antarctic programs (Fig. 2 and Table 2). Among them the outstanding cooperation project actuated by the Italian Programma Nazionale di Ricerche in Antartide (PNRA) and the Argentinean Dirección Nacional del Antártico (DNA) to realize a broadband regional network in the Scotia Sea and neighboring regions consisting of permanent seismographic stations installed in the Argentinean scientific bases operated there by the DNA. The Istituto Nazionale di Oceanografia e Geofisica Sperimentale (OGS) and the Instituto Antártico Argentino (IAA) coordinate the activities of the ASAIN and operate in the field with the support of the PNRA and the DNA.

1.3. The Argentinean Antarctic bases: general description and logistics

Argentina has been playing a significant role in polar exploration and research for more than a century. The first Argentinean base, Orcadas, was opened on February 22, 1904 on the small stony flat isthmus joining the west and east sides of Laurie Island, in the South Orkney Islands archipelago. The southernmost one (Base Belgrano II), located on a small rocky outcrop (Nunatak Bertrab) emerging from the ice of the polar shelf at the southeastern corner of the Weddell Sea 1350 km from the South Pole, was established in 1952.

To date, thirteen sites host Argentinean scientific bases (Fig. 3). Six bases are permanently garrisoned installations while the remaining seven stations are only open for scientific activities during the austral summer. The Argentinean stations are distributed inside a sector extending from 20° to 80° W and from 60° to 78° S. (Dirección Nacional del Antártico, 1997, 1999).

Increasingly extreme environmental conditions are observed as one approaches the higher latitudes: at the most southern base, Belgrano II, on the Filchner barrier, it is not unusual to record

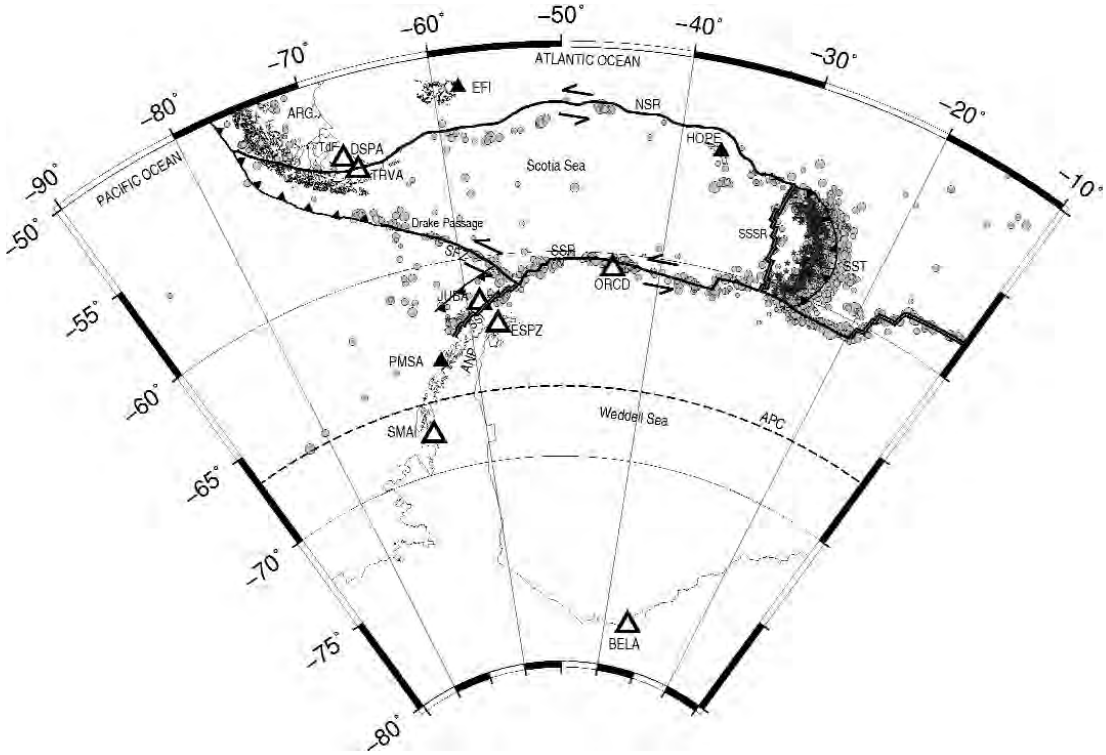

Fig. 1 - ASAIN location and Scotia Sea region seismicity map. The tectonic boundaries (from University of Texas-Institute for Geophysics) are shown as black lines. White triangles: ASAIN stations; black triangles: IRIS consortium stations. Seismicity epicentres from NEIC database 1973 to 2007: light grey circles 0-70 km depth; dim grey stars: 70-300 km depth. Abbreviations: ARG, Argentine; TdF, Tierra del Fuego; SFZ, Shackleton Fracture Zone; ANP, Antarctic Peninsula; SSI, South Shetland Islands; SST, South Sandwich Trench; NSR, North Scotia Ridge; SSR, South Scotia Ridge; APC, Antarctic Polar Circle; SSSR, South Sandwich Spreading Ridge.

temperatures close to -55° C. All sites are characterized by very strong winds; both in summer, when the maximum recorded speeds are around 120 km/h, and in winter, when the 250 km/h are sometimes overpassed by exceptional peaks of over 300 km/h.

Table 1 - Scotia Sea region most relevant earthquakes from USGS (*) and ISC (**) catalogues.

Area	Date	Time	Lat	Long	Depth (km)	Mag
North Scotia Ridge *	1982/03/25	050539.6	-52.73	-46.78	33	6.6 Mw
South Sandwich Trench **	1973/10/06	150737.3	-60.82	-21.55	33	7.5 Ms
East Scotia Ridge *	2004/09/06	124259.4	-55.37	-28.98	10	6.9 Mw
South Shetland Islands *	1992/06/17	083915.4	-60.37	-57.07	10	6.2 Mw
South Scotia Ridge *	2003/08/04	043520.1	-60.53	-43.41	10	7.6 Mw

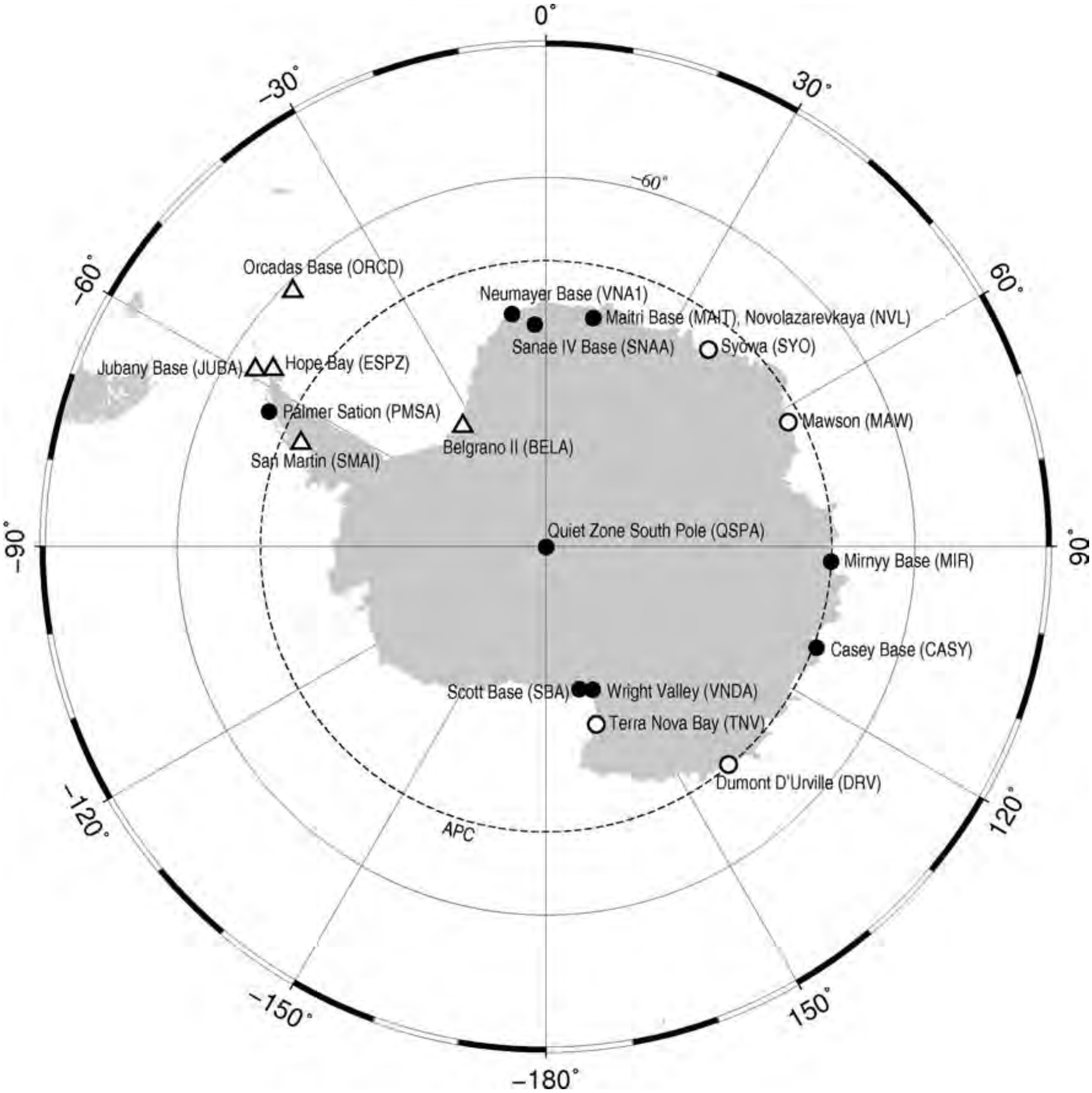

Fig. 2 - The Antarctic Broadband Seismographic Network: white circles = stations installed before the opening of ESPZ station on January 20, 1992; black circles = stations installed after the opening of ESPZ station; white triangles = ASAIN Antarctic stations.

All the installations, with the exception of Belgrano II, are located in coastal regions, the only places where sufficiently extended ice-free spaces can be found. The proximity to the sea allows periodic refurbishing of the bases and the turnover of the personnel during the antarctic summer. While the southernmost bases San Martín, on the Pacific side of the Antarctic Peninsula, and Belgrano II, at the southeastern corner of the Weddell Sea, are refurbished only once a year, most locations north of the Antarctic Polar Circle (APC) can be accessed periodically by helicopter or twin otter flights from Marambio base where an Hercules C-130 flight ensures the connection with Argentina about once a month.

Table 2 - The Antarctic Broadband Seismographic Network. Stations located beyond the -60° parallel ordered according to increasing latitude.

Site	Code	Latitude	Longitude	Network/Country
South Pole	QSPA	-89.9279	145.0000	IRIS-USGS
Belgrano II Base	BELA	-77.8950	-34.6269	ASAIN
Scott Base	SBA	-77.8489	166.7574	IRIS-USGS
Wright Valley	VNDA	-77.5169	161.8531	IRIS-USGS
Terra Nova Bay	TNV	-74.6950	164.1240	Italy
Sanae IV Base	SNAA	-71.6707	-2.8379	AWI-GEOFON
Maitri Base	MAIT	-70.7760	11.7360	India
Novolazarevkaya Base	NVL	-70.7667	11.8333	Russia
Neumayer Base	VNA1	-70.6625	-8.2567	AWI-GEOFON
Syowa Base	SYO	-69.0088	39.5921	Japan
San Martín Base	SMAI	-68.1302	-67.1059	ASAIN
Mawson Base	MAW	-67.6039	62.8706	Australia
Dumont D'Urville	DRV	-66.6650	140.0086	France
Mirnyy	MIR	-66.5514	93.0167	Russia
Casey Base	CASY	-66.2792	110.5364	Australia
Palmer Base	PMSA	-64.7742	-64.0490	IRIS-USGS
Esperanza Base	ESPZ	-63.3981	-56.9964	ASAIN
Jubany Base	JUBA	-62.2373	-58.6627	ASAIN
Orcadas Base	ORCD	-60.7361	-44.7381	ASAIN

2. The Antarctic Seismographic Argentinean-Italian Network: technical development

2.1. From 1992 to 2005

The official birth of the Antarctic Seismographic Argentinean-Italian Network ASAIN coincides with the opening date (January 20, 1992) of the ESPZ seismographic station (Fanzutti *et al*., 1992) when a team of OGS and DNA/IAA investigators installed a seismograph at the Argentinean base Esperanza to verify the suitability of the site for the operation of a permanent broadband observatory oriented to the study of the remarkable seismicity of the region.

That day is also a benchmark for the whole scientific community involved in the seismological investigation of the Scotia Sea and Western Antarctica marking the very beginning of the employment of modern seismological techniques in the investigation of the geodynamics

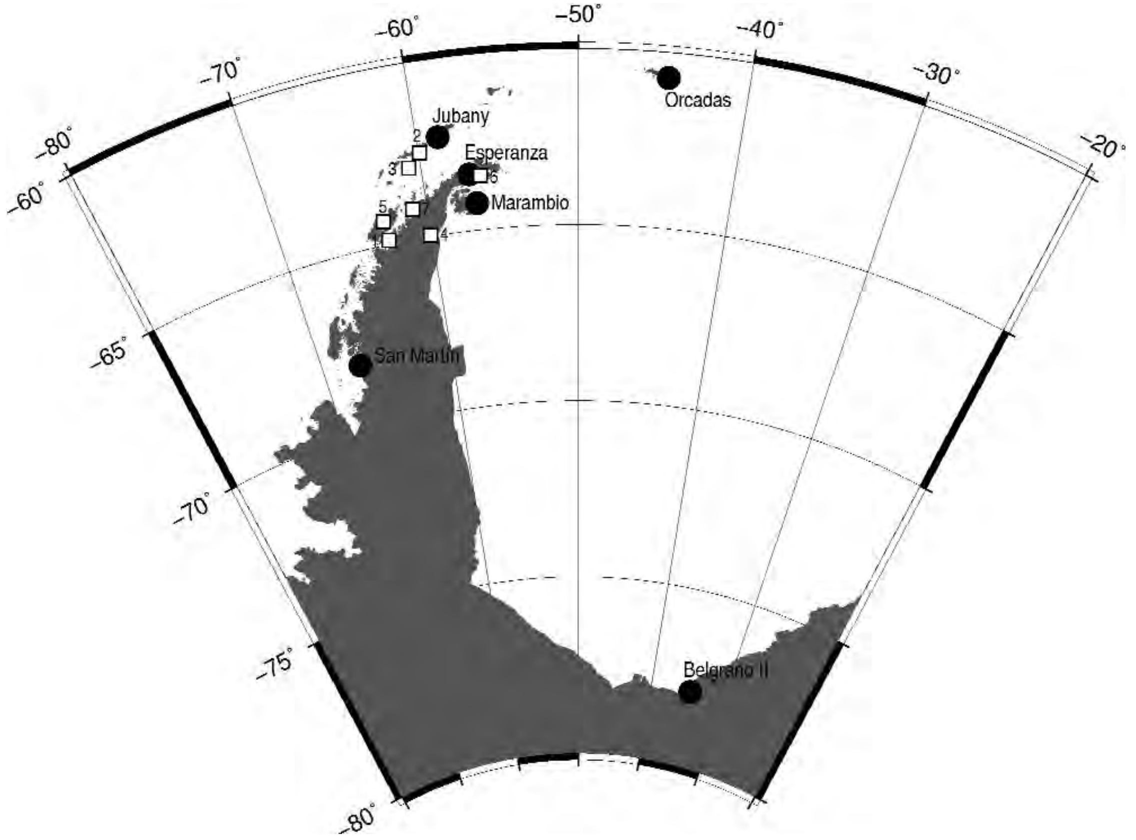

Fig. 3 - Argentinean scientific Antarctic bases. The DNA/IAA manages 13 bases in the Antarctic Scotia Sea and Weddell Sea areas to support scientific activities. Six of them are open during the whole year the other are operated during the Antarctic summer only. The link with the South American continent is ensured by Hercules C-130 flights from Marambio Base to Ushuaia or to Rio Gallegos. Fuel supplies and staff changes at all the bases are ensured by the icebreaker ARA Almirante Irizar and other Argentinean oceanographic ships. Black circles = permanent bases; white squares = summer bases (1 Brown, 2 Cámara, 3 Decepción, 4 Matienzo, 5 Melchior, 6 Petrel, 7 Primavera).

of the Scotia Sea region.

The temporary seismograph was run for three years allowing the Italian and the Argentinean seismological partner groups to obtain a considerable number of high quality recordings of regional and global seismicity (Russi *et al.*, 1994, 1997). At the beginning of 1995 the temporary ESPZ was upgraded to a permanent seismological observatory. The original three-component seismograph (Teledyne Geotech PDAS 100 recorder and BB-13 seismometers) was replaced with up-to-date recorders and sensors (RefTek 72A-08 24-bit digital recorders, Güralp CMG-3T seismometers) allowing the acquisition of continuous three component 1 and 20 samples/s seismic channels with an autonomy of more than 4 weeks. GPS receivers provided the timing signal (Russi *et al.*, 1996).

Between the end of 1995 and the beginning of 1997 the ESPZ installation was replicated at Ushuaia (USHU, Lapataia bay, Tierra del Fuego, Argentina) and at Orcadas Base (ORCD) on the

Laurie Island (South Orkney Islands) using identical hardware and acquisition parameters. This ASAIN configuration operated unaltered, with only minor improvements in the acquisition and data playback techniques, up to the 2000-2001 campaign (Russi and Febrer, 2001).

The ASAIN was further expanded between 2001 and 2002 when the JUBA (Base Jubany, South Shetland Islands) and the DSPA (Estancia Despedida, Tierra del Fuego) stations started up (Russi *et al*., 2004; Sabbione *et al*., 2001).

Another benchmark in the development of the ASAIN network is represented by the 2002-2003 Antarctic campaign. A steadily progressive upgrading and homogenization of the instrumentation went on, the purpose of which was to prepare the conditions apt to guarantee the remote real-time accessibility to the ASAIN recordings, already started when the Jubany station was opened, but extensive connection tests between the OGS and the Antarctic stations using Inmarsat dial up terminals were performed one year later. Between 2003 and 2005 satellital communication channels linking the Antarctic bases with Argentina were activated by the DNA/IAA and extensive testing of Internet connection among the ASAIN stations, the OGS and the DNA/IAA gave optimal results. The availability of satellital communication links produced a quick conversion of the ASAIN from local recording to remote data acquisition techniques allowing continuous remote real-time monitoring of the network operation from the OGS, the storage of all the recorded data on the OGS archiving facilities and the ASAIN participation in the Virtual European Broadband Seismographic Network (VEBSN, http://www.orfeus-eu.org/Data-info/vebsn-contributors.html).

2.2. The International Polar Yearactivities and the ASAIN contribution: SMAI and BELA stations (2006-2009)

Once the planned ASAIN configuration and the upgrading to real-time recording in the Antarctic sites had materialized, two more steps were still necessary: the real-time connection of the ASAIN Tierra del Fuego sites and the expansion of the network to latitudes behind the APC. Both tasks were fulfilled between 2007 and the beginning of 2009 as a contribution to the International Polar Year (IPY) activities. The “IPY ASAIN Branch” consists of two stations: SMAI on the Pacific side of the Antarctic Peninsula and BELA at the southeastern corner of the Weddell Sea (Figs. 1 and 2). Behind the obvious objective of installing some instruments in strategic locations still void of seismographic stations, to contribute top quality data to the global network, a specific task for the “IPY ASAIN Branch” is to provide a better geographic coverage to lower the azimuthal gaps in the computation of the source parameters, especially when dealing with earthquakes along the SSR and in the Drake Passage, and to provide the means of increasing the path coverage when performing surface wave and regional tomography studies.

The PNRA/OGS – DNA/IAA “IPY ASAIN Branch” plan was prepared during the 2005 and 2006 campaigns when OGS researchers performed a preliminary survey at San Martín and Belgrano II travelling on board the Argentinean icebreaker ARA Almirante Irizar. The project was then realized in two steps during the IPY activities period.

The SMAI Station at Base San Martín started operations on February 2, 2007. The base is managed by the personnel of the Argentinean Comando Antártico de Ejército (CAE) and started being funded on March 21, 1951. It is located almost immediately south of the APC on Barry Island, a small island in the Marguerite Bay, between the big islands of Belgrano and Alejandro II (Table 3). Awesome glaciers which descend from the Pacific side of the Antarctic Peninsula directly into the sea, surround the base. The temperatures vary between a maximum of 8°C in the summer to minima around -37°C during the winter. The scientific activities hosted at the base include Geodesy, Oceanography, Glaciology and Seismology.

The BELA station started recording on January 16, 2009, two months before the IPY activities ended, at base Belgrano II, where the OGS researchers installed the seismometer during the short stay of the Russian polar vessel Vasiliy Golovnin which hosted the Italian personnel during the long, heavy crossing of the South Atlantic and the Weddell Sea (Cravos, 2009).

The base started being funded on February 5, 1979 and is located on a granitic outcrop emerging from the Filchner barrier (Table 3). It is the southernmost permanent Argentinean scientific station, at only 1350 km about from the South Pole and is completely surrounded by polar shelf glaciers. The base is managed by the personnel of the CAE and occupies an area of about one hectare emerging from the top of Nunatak Bertrab. The temperature varies between a mean maximum of 0°C in the summer to minima around -54°C. The scientific activities hosted in the base include Geodesy, measurements of atmospheric ozone and solar radiation, Astronomy and Seismology. It is to be noted that only the QSPA station is operated at a lesser distance from the South Pole.

SMAI and BELA are equipped with the same type of instrumentation used at the other ASAIN stations, the only exception being the BELA seismometer: Güralp CMG-3ESPCD instead of the CMG-3T. We expect to replace it by 2011 with a seismometer capable of operating at extremely low temperatures without any need for specific protections.

Tierra del Fuego experienced a major earthquake in 1949 when only a few people were living there at the time, so no damage was suffered by the inhabitants and by then very small towns of Ushuaia and Río Grande. Before 1995 the only information available about its seismicity came from historical information and from teleseismic recordings of the biggest events. No recordings of medium and low level seismicity were available yet; only after the opening of the USHU and DSPA stations, did instrumental monitoring of local seismicity become possible. The recordings show a rather continuous release of energy activity with low magnitude events mostly clustered along the main tectonic lineaments such as the Magallanes - Fagnano fault system, the South-America-Scotia plate boundary with a more dispersed activity along the North Scotia Ridge immediately offshore the Tierra del Fuego coast and in the northern part of the island. The epicentres (Fig. 4) seem to be consistent with the old historical earthquake locations (Febrer *et al.*, 2001).

USHU was closed at the end of 2005 and the sensor was moved to Termas del Río Valdéz where a new ASAIN station (TRVA) has been opened. Recently, TRVA has been connected to a radio transmitter which is used to send the data to Tolhuin, a small town on the eastern side of the Fagnano Lake (Fig. 1). From Tolhuin the data are broadcast via Internet to the Estación Astronómica Río Grande (EARG) and the Universidad Nacional de La Plata (UNLP) in Argentina and to the OGS Trieste (Italy) using the ASAIN real-time communication techniques. A similar system is used to receive DSPA recordings.

2.3. Instrumentation

The seismometers, the storage and the communication techniques used in the ASAIN sites have been subject to substantial technological changes during the life of the network and a

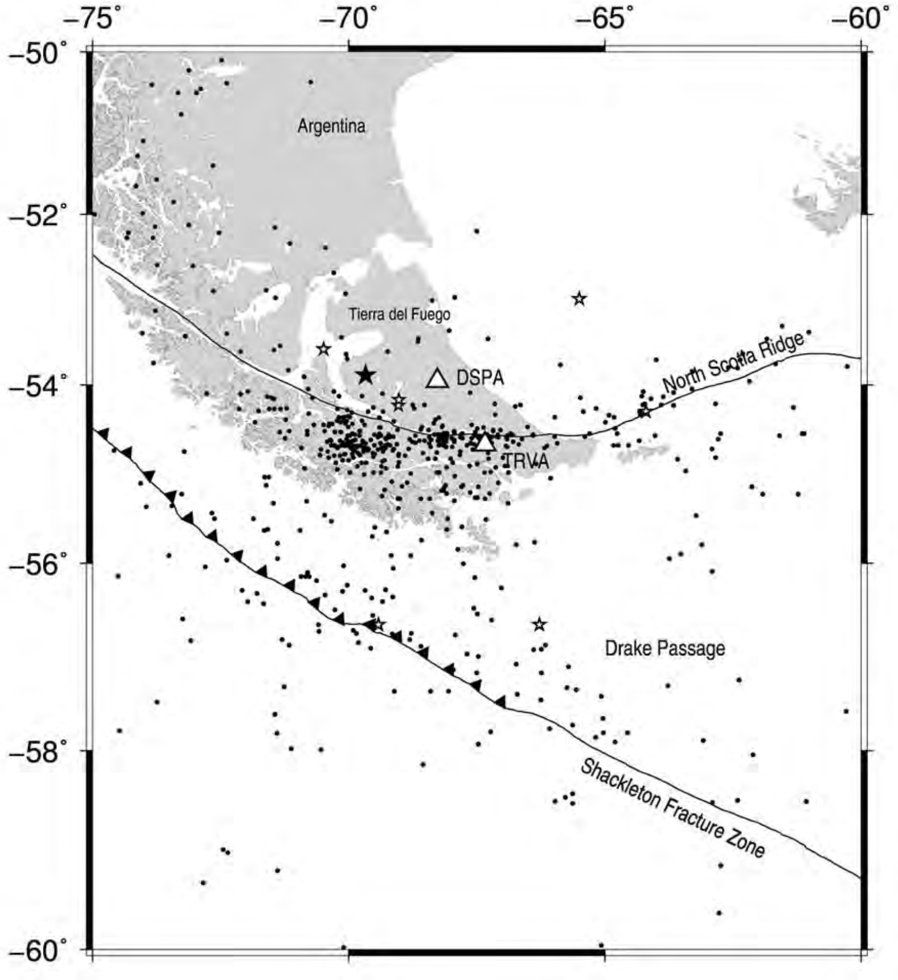

Fig. 4 - Epicentral map of Tierra del Fuego seismicity as reported in the "Tierra del Fuego Reference Earthquake Catalogue" (Sabbione *et al*., 2007). Stars: historical earthquakes (from Febrer *et al*., 2001). The black star marks the epicentre of the December 17, 1949 7.5 magnitude event. The black lines represent the traces of the North Scotia Ridge and of the Shackleton fracturezone.

constant commitment of the managing institutions has been that of a continuous upgrading of the instrumentation using the most advanced standards. ESPZ, from 1992 to 1994, operated a BB-13 triplet and a Teledyne Geotech PDAS 100 recorder. Synchronization to a radio signal was performed manually. Details about the instrumentation, the seismometer refuge, data formats and archiving techniques can be found in Russi *et al*. (1996).

At the beginning of 1995, this equipment was dismissed and was replaced by a CMG-3T broadband sensor and a RefTek 72A-08 digital recorder with GPS time base (Fig. 5). Similar equipment configurations were then replicated at the USHU and ORCD stations.

Between 2001 and 2003 a major upgrade in the ASAIN hardware took place. The RefTek recorders were disconnected and were replaced by Güralp DM24 24 bit digitizers connected to a PC server running Scream! software to control the acquisition settings, local data storage on high

Table 3 - ASAIN stations identification data and instrumental characteristics chronology.

Station	**Site**	**Latitude**	**Longitude**	**Operation Dates**	**Instrumentation**	**Channels**
ESPZ	Hope Bay	-63.3981	-56.9964	1992-1994	BB13/PDAS 100/Timing Radio	V, N-S, E-W continuous 0.2 and 2 samples/s.
				1995-2000	CMG-3T/RefTek 72A-08 /Timing GPS	V, N-S, E-W continuous 1 and 20 samples/s.
				2001-2002	CMG-3T/CMG DM24/Timing GPS	V, N-S, E-W continuous 1 and 20 samples/s.
				2005-Present	CMG-3TD/CMG-DM24/Timing GPS	V, N-S, E-W continuous 2, 20 and 40 samples/s
ORCD	South Orkney Islands	-60.7381	-44.7361	1997-2004	CMG-3T/RefTek 72A-08 /Timing GPS	V, N-S, E-W continuous 1 and 20 samples/s.
				2004-Present	CMG-3T/CMG DM24/Timing GPS	V, N-S, E-W continuous 2, 20 and 40 samples/s
JUBA	South Shetland Islands	-62.2373	-58.6627	2002-Present	CMG-3T/CMG DM24/Timing GPS	V, N-S, E-W continuous 2 and 20, add 40 samples/s 2004.
SMAI	Marguerite Bay	-68.1302	-67.1059	2007-Present	CMG-3T/CMG DM24/Timing GPS	V, N-S, E-W continuous 2, 20 and 40 samples/s
BELA	Filchner Barrier	-77.8950	-34.6269	2009-Present	CMG-3ESPCD/CMG DM24/Timing GPS	V, N-S, E-W continuous 2, 20 and 40 samples/s
USHU	Tierra del Fuego	-54.6803	-68.5569	1995-2000	CMG-3T/RefTek 72A-08 /Timing GPS	V, N-S, E-W continuous 1 and 20 samples/s.
				2001-2005	CMG-40T/CMG DM24/Timing GPS	V, N-S, E-W continuous 2 and 20, add 40 samples/s 2004.
DSPA	Tierra del Fuego	-53.9536	-68.2668	2002-Present	CMG-3T/CMG DM24 /Timing GPS	V, N-S, E-W continuous 2 and 20, add 40 samples/s 2004
TRVA	Tierra del Fuego	-54.6803	-67.3394	2005-Present	CMG-3TD/CMG-DM24 /Timing GPS	V, N-S, E-W continuous 2, 20 and 40 samples/s

capacity disks and networking functions. This scheme has also been applied to all the stations installed after 2003. Scream! software is used today both to control data acquisition locally and to manage remote connection with the OGS data server. All ASAIN 20 samples/s and 2 samples/s data channels are routinely transmitted, in real-time, to the OGS server. Each night the complete 40, 20, and 2 sample/s ASAIN data set, recorded during the previous 24 hours, DSPA and TRVA stations included, is retransmitted to the OGS server to eliminate possible gaps in the real-time data (Fig. 6).

Since 2005, 20 samples/s data recorded by ASAIN stations are retransmitted in the original raw Güralp Compress Format (GCF) to the ORFEUS Data Centre (ODC) where they are converted into MiniSEED format and included in the VEBSN archives. Today ESPZ, JUBA,

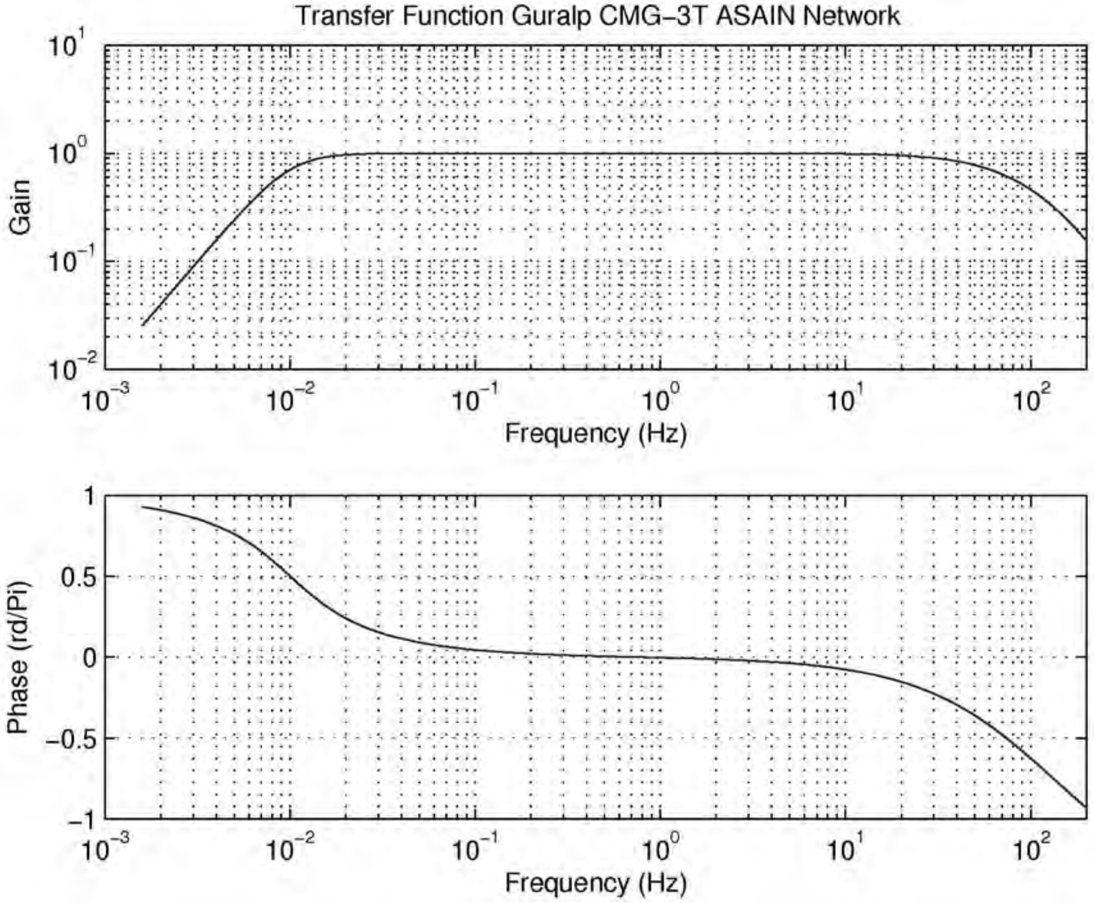

Fig. 5 - Transfer function for a Güralp CMG-3T seismometer.

ORCD, SMAI are available at ODC on a routine basis. In the near future also BELA data will be added.

As is easily understood, the environmental and accessibility conditions in the whole Scotia Sea area are such that provision of spare parts is very difficult and in most cases it is possible only during the Antarctic summer. As a consequence, during the winter, when the whole area is practically totally isolated, it is not possible to remedy major failures of the instrumentation on site. A partial solution to these problems has been offered by the availability of satellite links and Internet connections allowing remote control of the instrumentation and direct communication with the Argentinean personnel taking care of the seismographs during the long periods of inaccessibility. Nevertheless, before the availability of remotely operable instrumentation, both the difficult accessibility of the sites and the coexistence of hardware produced by different factories were sources of deep problems. Now the availability of Internet, remotely accessible equipment and the employment of technically homogeneous instrumentation in every ASAIN site have significantly reduced this kind of trouble. Today, the availability of Internet lines allows one

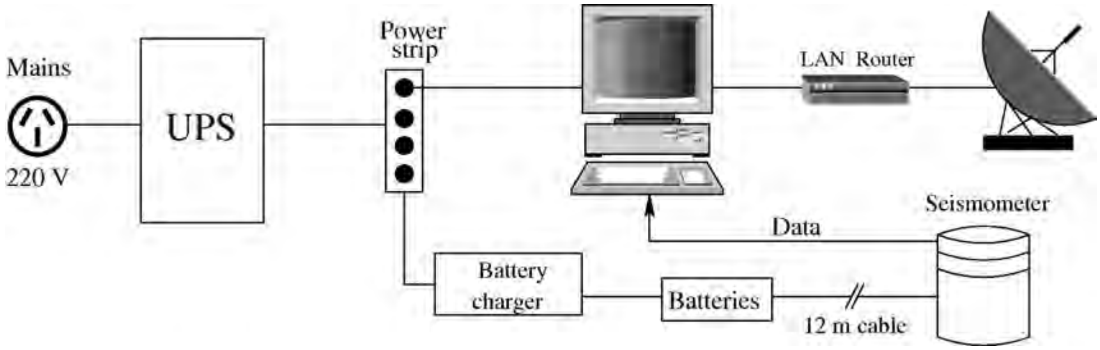

Fig. 6 - Schematic sketch of the hardware structure of an ASAIN station.

to control the efficiency and the operation parameter settings remotely and to instruct the operators to perform some simple maintenance in the case of minor problems. Table 3 resumes the evolution and the characteristics of ASAIN instrumentation. Fig. 7 shows the overall performance of the ASAIN since its beginning.

2.4. The international context

The ASAIN was born as a temporary experiment conducted by the DNA/IAA and OGS groups with a very specific purpose but soon, after the data were processed and the results of their analysis were published, the international interest grew quickly and became very high after the installation of the ORCD station in 1997. All the countries working in West Antarctica expressed their interest in exchanging seismological information acquired by broadband seismographic stations operated in the Scotia Sea and its vicinities so that an official "Memorandum of understanding" was signed on the basis of the draft prepared in Thessaloniki by OGS, Saint Louis University and the British Antarctic Survey (BAS) representatives during the IASPEI 1997 assembly. Two years later, OGS hosted the Workshop "Broadband Seismic Observations and Geodynamics of the Scotia Sea Region" with the support of the International Centre for Theoretical Physics and the cooperation of the Dipartimento di Scienze della Terra of the Trieste University (Italy). Most organizations interested in Antarctic Seismology participated in the workshop and the results of the meeting are synthesized in the concluding document of the participants plenary (Brancolini *et al.*, 2001). In the document, a strategy for the progress of the field activities and the continuation of seismological investigation in the Scotia Sea and surrounding regions is sketched emphasizing the importance of:

- increasing the resolving power of the Scotia Sea broadband network with new installations in key areas, including sea floor broadband seismographs, to provide the data necessary for detailed investigations;
- making real-time ASAIN data freely available to the whole scientific community via ORFEUS and/or IRIS data centres;
- investigating the present lithospheric structure in the Scotia Sea and in neighbouring areasusing broadband seismographic recordings integrated with other available

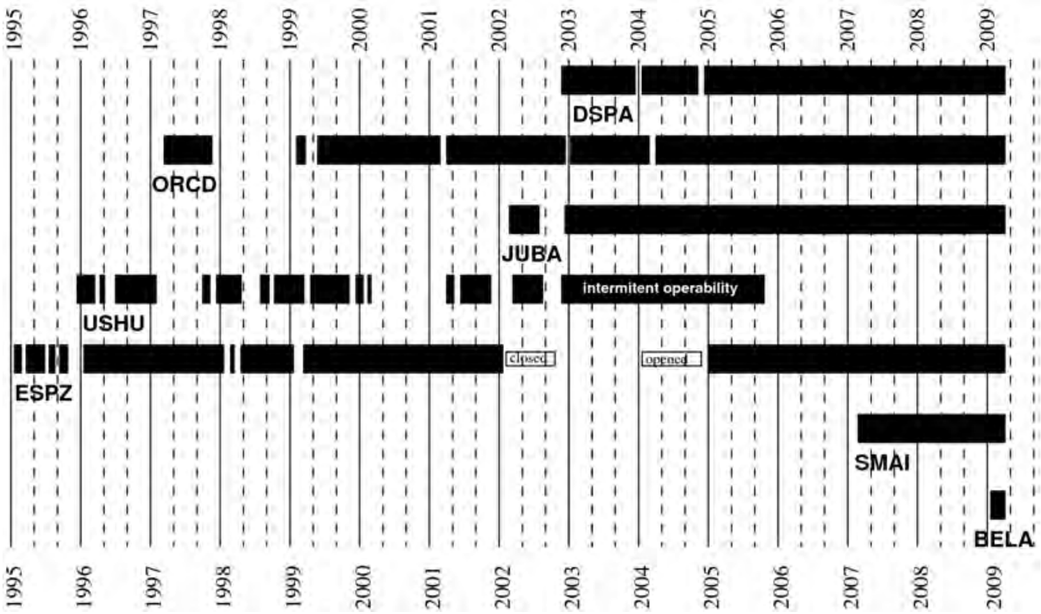

Fig. 7 - Overall performance of the ASAIN since 1995.

geophysicalmeasurements;
- strengthening international cooperation among the institutions involved in the seismological study of the Western Antarctic.

Since then the ASAIN has been modeled accordingly and the same policy will be followed in planning its future. Today the complete set of 20 samples/s seismic channels recorded by the ASAIN Antarctic stations is freely and quickly accessible to the whole scientific community via the ORFEUS web site connecting it to the VEBSN page but, when necessary, data originally recorded in GCF or other formats can be requested from OGS.

3. Scientific research

The main goal of the research work conducted by means of the ASAIN data by the Italian and Argentinean seismologists is the determination of the lithospheric structure underlying the Scotia Sea region and the analysis of the physical properties of the seismic sources generating its relevant seismicity. Initially, when only ESPZ station data were available, the research work was mainly oriented towards defining the best analysis methods to be applied to the data. After some tests, based on surface wave dispersion analysis by the Frequency Time Analysis method (Levshin *et al.*, 1992), performed on the ESPZ data set, recorded during the first year of operation (Russi *et al.*, 1994) the analysis of the dispersion properties was extended to a wider data set recorded by two ASAIN (ESPZ, USHU) and two IRIS stations (PMSA, EFI). After extracting the surface wave dispersion curves (mainly the fundamental mode) the “Hedgehog” inversion scheme (Valyus, 1972; Panza, 1981) was applied to obtain a general overview of the crust and

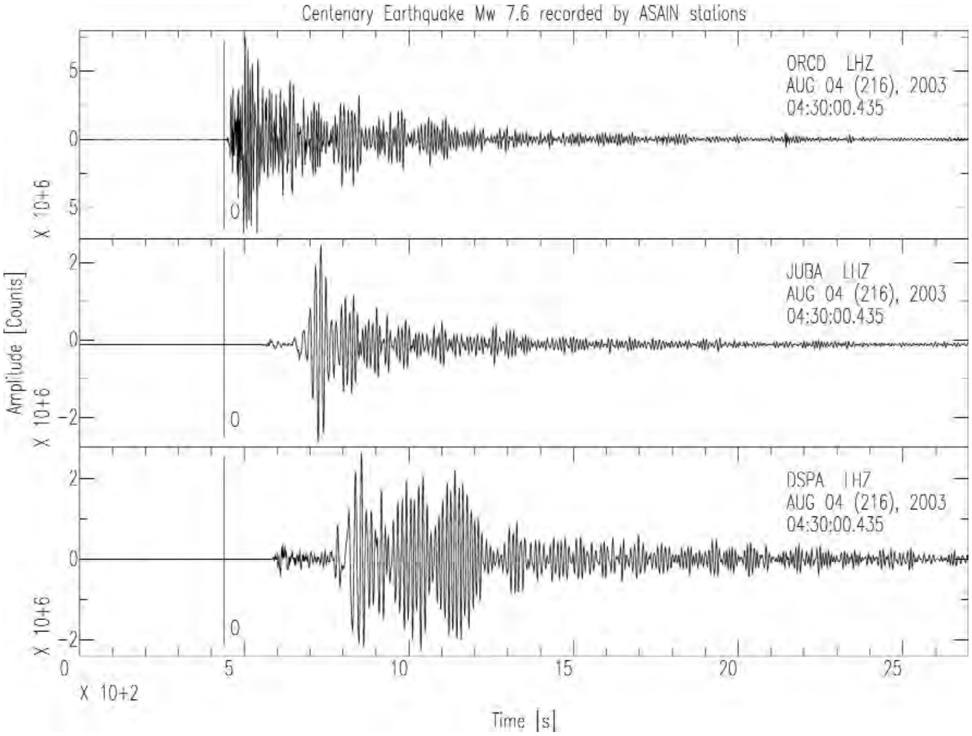

Fig. 8 - August 4, 2003 Centenary Earthquake seismograms recorded by CMG 3T seismometers at ASAIN sites.

upper mantle seismic velocities (Russi *et al.*, 1996, 1997). North Scotia Ridge and South Scotia Ridge show similar S-wave velocities between 2.0 km/s at the surface to 3.2 km/s to depths of 8 km, increasing slowly in the lower crust to reach a value of 3.8 km/s, with Moho depths estimated between 17 km to 20 km and 16 km to 19 km, respectively. The Scotia Sea, bounded by the two ridges, shows a faster and thinner crust and average Moho depth between 9 km and 12 km (Vuan *et al.*, 1997, 1999). Vuan *et al.* (2000) then group velocity tomography was applied to the fundamental mode of Rayleigh and Love waves, in the period range from 15 s to 50 s, to more than 150 events, using the Backus-Gilbert formalism (Ditmar and Yanovskaya, 1987; Yanovskaya and Ditmar, 1990) to obtain smoothed curves in correspondence of the main geological and tectonic feature, and from their nonlinear inversion, the shear wave velocity versus depth profiles. From the regionalized curves the “Hedgehog” nonlinear inversion scheme was employed to derive the shear velocity models for the main geological and tectonic features identifying each with a spatial extension exceeding 200 km according to the limitations imposed by the resolution limits of the available data set.

These regionalized models were then extensively employed as input parameters in the application of the INPAR technique used to retrieve the moment tensor of the regional seismicity (Vuan *et al.*, 2001; Guidarelli *et al.*, 2003; Guidarelli and Panza, 2006) and by Vuan *et al.* (2005a, 2005b) for a specific study of the crustal and upper mantle S-wave velocity structure beneath the Bransfield Strait. Recently, a study has been performed by Plasencia Linares (2008) using the

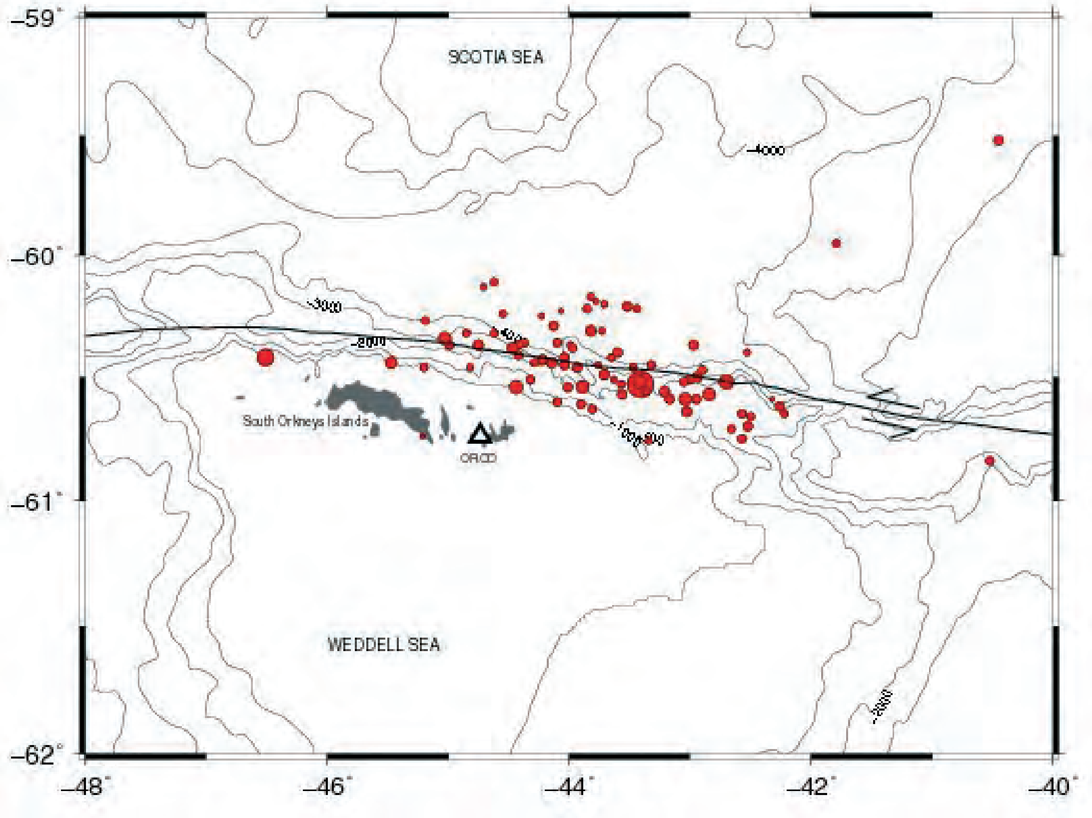

Fig. 9 - Centenary Earthquake main shock and aftershock ($M_s > 3.5$) epicentral map.

data set recorded by ASAIN and IRIS stations located in the area, to investigate the seismic sources that generated the Orcadas Centenary Earthquake and its aftershock sequence. This sequence started when a major earthquake, 7.6 M_w, shook the South Orkney Islands and the whole Scotia Sea area on August 4, 2003 at 04:37:19 GMT (Fig. 8) along the Scotia Sea-Antarctic Plate margin (Plasencia Linares *et al.*, 2004). The epicentre was located along the South Scotia Ridge at 60° 55' S, 43° 49' W, about 70 km NE of the Argentinean base Orcadas. The aftershock series lasted for more than one year and several thousands of events were recorded by the ORCD station. About ten aftershocks exceeded magnitude 5.0 and were recorded by the whole ASAIN (Fig. 9). All the most relevant aftershocks have been also recorded and localized by the GSN Network but the application of the INdirect PARameterization (INPAR) method to ASAIN data allowed the determining of the source parameters also for events not listed in the Global Centroid Moment Tensor Harvard catalogue (Plasencia Linares, 2008). Details about the INPAR method can be found in Sileny *et al.* (1992) and Campus *et al.* (1996). A synthetic description is also available in Guidarelli and Panza (2006).

The main event, which was nicknamed Centenary Earthquake, because it happened exactly one hundred years after the foundation of the Orcadas base, caused minor damage to the base

Fig. 10 - Laurie Island map (a) and images (shot on August 6, 2003) of the fractures in the ice pack observed after the Centenary Earthquake main shock. Vertical displacements of the pack up to 2 m were measured (b). The pack is gradually leaving the Scotia bay (c) and one day later it will completely disappear. A big snow and ice avalanche can be seen (d).

structures but no casualties among the Argentinean personnel. Several ice falls from the mountains surrounding the base were observed (Fig. 10d) but the most astonishing visible effect was represented by the large fractures in the ice pack surrounding the island which showed vertical displacements reaching 2 m amplitudes (Fig. 10b). The fractures in the ice mainly followed the shoreline topography all along the coast of the Uruguay bay for several kilometres (Figs. 10c and 10d). No connection with the focal mechanism seems to be conjecturable.

Besides allowing us to fill a significant seismic gap in the seismicity map of the South Scotia Ridge (Fig. 9) the analysis of the Centenary Earthquake sequence resulted in an increase of seismological information about the characteristics of the seismic sources acting in the region that confirm the hypotheses of the existence both of transpressive and transtensive areas along the northern border of the South Orkney Microcontinent (SOM) found in the literature (Pelayo and Wiens, 1989; Acosta and Uchupi, 1996). Considering that the main shock is characterized by a normal faulting mechanism with a small strike slip component and that all the analyzed aftershocks present normal faulting mechanisms, we can conclude that after the main shock a relaxation process began in the area. Some authors suggest the existence of a subduction zone in the northern part of the SOM (Kavoun and Vinnikovskaya, 1994; Lodolo 2008; Maldonado *et al.*, 1998), but the results of this study do not confirm this hypothesis, also taking account that there is no evidence of deep seismicity and magmatism.

4. Conclusions

The PNRA and the DNA/IAA realized in the period 1992 – 2009 the ASAIN which consists of seven broadband stations installed in Antarctica (5 sites) and Tierra del Fuego (2 sites). The broadband recordings are transmitted via satellite data links to the OGS, IAA and ORFEUS data centre and can be freely accessed and retrieved via Internet by connecting to the VEBSN database.

The scientific research undertaken in parallel with the growth of the network by the Trieste University, the OGS and the IAA have led to regional S-wave velocity models for the main geological units and determination of the focal mechanisms for the main regional earthquakes in a remote and not easily accessible area in the southern hemisphere.

The studies also clarified the fact that a network based only on land stations is not enough to investigate all the issues and that the integration with seismographs located at the bottom of the sea is necessary to make substantial progress. Today, the technologies are mature and some temporary experiments using Ocean Bottom Seismograph (OBS) have been already done by other groups [e.g., SEPA (Wiens *et al*., 1997); and TENAP (Della Vedova *et al*., 1998) projects] but the addition of some permanent sea-bottom broadband station to the existing land network would represent an important step toward the optimization of the ASAIN.

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Corresponding author: Marino Russi
Istituto Nazionale di Oceanografia e di Geofisica Sperimentale
Borgo Grotta Gigante 42/c , 34010 Sgonico (Trieste), Italy
phone: +39 040 2140256; fax: +39 040 327307; e-mail: mrussi@inogs.it