GeoResJ 6 (2015) 44–52

Contents lists available at ScienceDirect

GeoResJ

journal homepage: www.elsevier.com/locate/GRJ

Data rescue to extend the value of vintage seismic data: The OGS-SNAP experience

Paolo Diviacco *, Nigel Wardell, Edy Forlin, Chiara Sauli, Mihai Burca, Alessandro Busato, Jacques Centonze, Claudio Pelos

Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS), Borgo Grotta Gigante 42/c, 34010 Sgonico (Trieste), Italy

ARTICLE INFO

Article history:
Received 25 September 2014
Revised 23 January 2015
Accepted 24 January 2015
Available online 16 March 2015

Keywords:
Data rescue
Seismic data
Digitisation of seismic paper sections
Data enhancement
Data integration
Data dissemination

ABSTRACT

Large amounts of vintage seismic data were rescued and disseminated in an internal project of the Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS). Such types of data would be very difficult to acquire today because they cover many areas that are currently subject to restrictions in obtaining exploration permits. The datasets extend over large geographical areas, covering large geological structures and would be very expensive to acquire today. Additionally, these data are particularly interesting because they were acquired using a high-energy source (dynamite) that would be difficult to obtain permission to use today. Therefore the recovery of these data could be very interesting for both the scientific and commercial communities. The urgency of rescuing tapes before degradation, and scanning and converting the paper sections into a usable form was the main focus, but, at the same time, the project looked ahead and attempted to address possible future exploitation of these data. To this end, considering how end users are likely to search for and use data, a full processing path that goes beyond recovery to consider other aspects was developed. The other concerns integrated into this process are

- data enhancement, to overcome data limitations due to the older technology used during acquisition;
- data integration, to consolidate different data types within the same data space, and
- data discovery, for which a specific web based framework named SNAP (Seismic data Network Access Point) was developed that allows end users to search, locate and preview the data.

1. Introduction

Geophysicists make use of a range of different techniques such as Seismic, Magnetic, Gravity, Electromagnetic and Electrical prospecting (Sheriff [1]). Some of these techniques can be traced back to the 19th century as in the case of Magnetic exploration (Nabighian et al. [2]); others are more recent, such as reflection seismology, which appeared in the second decade of the last century (Romberg [3]). Theoretical and technical advancements in these fields have always been interlaced so that on the one hand the potentialities of the recording were often not fully exploited at the time of data acquisition, and on the other hand, acquisition parameters were often tailored to the available theoretical knowledge and technical know-how. As these limitations have been progressively improved, difficulties continue to persist in integrating previous observations and knowledge. Reasons for limitations on the resolution of the data can extend from very low-level technical issues such as difficulties in recovering data from the storage media, to data processing phenomena such as temporal or spatial aliasing. Higher level issues to be considered include the actual availability of observations due to problematic acquisition processes or to specific commercial, academic or governmental access policies.

2. Objectives

The vast range of causes of possible problems in data recovery, integration and use often limit proper recovery, so that "vintage" data often remained in storage and the value of such data was not fully appreciated. This has been particularly evident in non-commercial environments where entities such as public funded research centers were not able to hire specialist personnel and data recovery from vintage sources has been left to the initiatives of individual researchers (Miles et al. [4], Carbotte et al. [5]). This paper will explore in detail each of the issues related to the problems of recovering vintage seismic data and will describe possible

* Corresponding author. Tel.: +39 040 21401; fax: +39 040 2140438.
E-mail address: pdiviacco@ogs.trieste.it (P. Diviacco).

http://dx.doi.org/10.1016/j.grj.2015.01.006

solutions through the experience gained by OGS during a substantial project to realise the potential value of the vast amount of vintage geophysical data in the OGS archives. Suggestions will be proposed for the integration of the recovered data with more recently acquired data and current research activities

3. Materials and methods

3.1. Data rescue

Data rescue requires extraction of data from a storage system that no longer guarantees their preservation, to another system that is, or at least currently thought to be, more reliable and accessible.

Reasons for considering that a system is no longer usable are (Ross and Gow [6]):

- Media degradation, which can be the result of non-optimal storage conditions (temperature, humidity, or disasters such as lightning strikes).
- Loss of functionality of access devices due to factors such as technological obsolescence, media deterioration etc.
- Loss of manipulation capabilities, such as new hardware and operating systems lacking specific system libraries and other capabilities.
- Loss of presentation capabilities, such as specific software that cannot be run in newer environments.
- Weak links in the creation, storage and documentation chain.
- The activities undertaken within OGS to mitigate these issues are reported below.

3.2. Media Recovery

3.2.1. Tape data

OGS archives have been built up over an extended period of time, mostly as an extended collection of tapes and paper printouts. 21-track tapes were initially used in the 1970s, then standard digital 9 track tapes, and more recently, the 3480/90 and exabyte tape cartridges became the norm. The institute had no funding to maintain tapes in controlled storage conditions so all media underwent a progressive deterioration, the effects of which were particularly severe on the old 21 and 9 track tapes.

The most significant factor leading to deterioration of tapes is the humidity in the environment where the tapes have been stored. Humidity can trigger the process of hydrolysis, which causes the polymer chains of the binder of the tapes to disintegrate. As the polymer chains disintegrate, the binder becomes tacky. Once the process begins, it progresses quickly and is difficult to stop. This process unfortunately creates an adhesive build up that makes the tape almost impossible to play. All this is generally called the 'sticky shed syndrome' (Ross and Gow [6]).

At OGS, in the last few years, the problem was considered so serious that OGS decided to make a major effort to address these issues and recover the data before they were lost permanently. To mitigate this 'sticky shed syndrome', a temporary treatment is employed where the tape is 'baked' at temperatures between 54 and 60 °C for 1 to –8 hours in order that (hopefully) the tape may be stabilised for a short time and allow it to be read. The treatment does not fix the problem permanently, and could even possibly definitively deteriorate the tape, so it is necessary to copy the data onto another, safer, media.

The problem of determining what can be considered a safe media has been debated extensively in the data management community with no definitive solution. The many existing tape formats, CD-ROMs, etc. were not considered long-lasting or secure enough. Nor will they resolve the problem of maintenance of the archive or the loss of functionality of access devices due to technological obsolescence and the loss of manipulation capabilities. Paradoxically, it was easier to fix problems for older technologies than for more recent ones. It turned out to be easier to find spare parts to mend old tape drives than more modern ones, where the components in the newer smaller units are much more densely packed and difficult to access.

Considering these factors, we eventually decided to transcribe all the OGS archive onto a RAID Hard Disk storage system that would be routinely and constantly mirrored in a independent physical location. Similar storage hardware has been installed at the OGS main site and at another research institute distant from OGS but connected by a high speed network link. This prevents critical situations such as fire, electrical failures or extreme temperatures from causing data loss. This decision was also motivated by the increasing reliability and lowering costs of this kind of media. Such storage systems allow all data to be consolidated on a shared space that can be linked directly to the OGS web based discovery portal, SNAP.

3.2.2. Paper data

Information stored on paper can be much safer than on other media. As highlighted by Umberto Eco [7] there are many instances of long lasting paper-based storage. For example, 500 year-old books are still readable, while currently very few computers are able to read data from a floppy disk from the eighties. OGS does not address ancient manuscripts, although in some domains such as archeology or natural hazard studies, scanned and georeferenced ancient maps are very common. The OGS archives contain mainly stacked seismic sections and location maps plotted on plain or tracing paper. Paper prints date back to the seventies and were produced using photographic or electrostatic paper. Their archival stability depends upon processing, display and storage conditions. In the case of the OGS archive, although not optimal, these were not dramatically detrimental. Photographic paper prints did not undergo severe deterioration while electrostatic paper prints were more of a concern, especially since the latter were essentially prints taken during high resolution acoustic profiling with no simultaneous digital copy. The additional problem with paper data, besides their storage conditions and ability to be copied, is that they cannot be used 'as is' with modern software for geophysical analysis. It was therefore decided to solve both the problem of durability and integration of these data by moving them to the central digital storage system. Paper sections and maps were first digitally scanned using large dimension (A0) scanners to obtain high resolution (300 dpi, a software factory preset that cannot be changed) raster files. Later, seismic profiles were converted to actual (SEG-Y) digital seismic files while maps were georeferenced and navigation or positioning digitized manually (Fig. 1).

3.2.3. Conversion to SEG-Y

A number of commercial (e.g. ImageToSEG-Y) and open source (e.g. IMAGE2SEGY or Seismic Unix and NetPBM) software exist to convert seismic images to digital SEG-Y data. OGS already had experience of this type of software in the EU funded project SEISCANEX (EVR1-CT2001-40016) (Miles et al. [4]) where a program, SEISTRANS, had been developed in collaboration with Caldera Graphics to perform this conversion. The program searches down defined 'traces' identifying sample patches and assigning values based upon the proportion of black pixels in each patch. The software recovers the negative phase of the signal through a mean adjustment and filtering. The resulting seismic traces are saved as a standard SEG-Y [SEG-Y] format that can be used within modern processing or interpretation software.

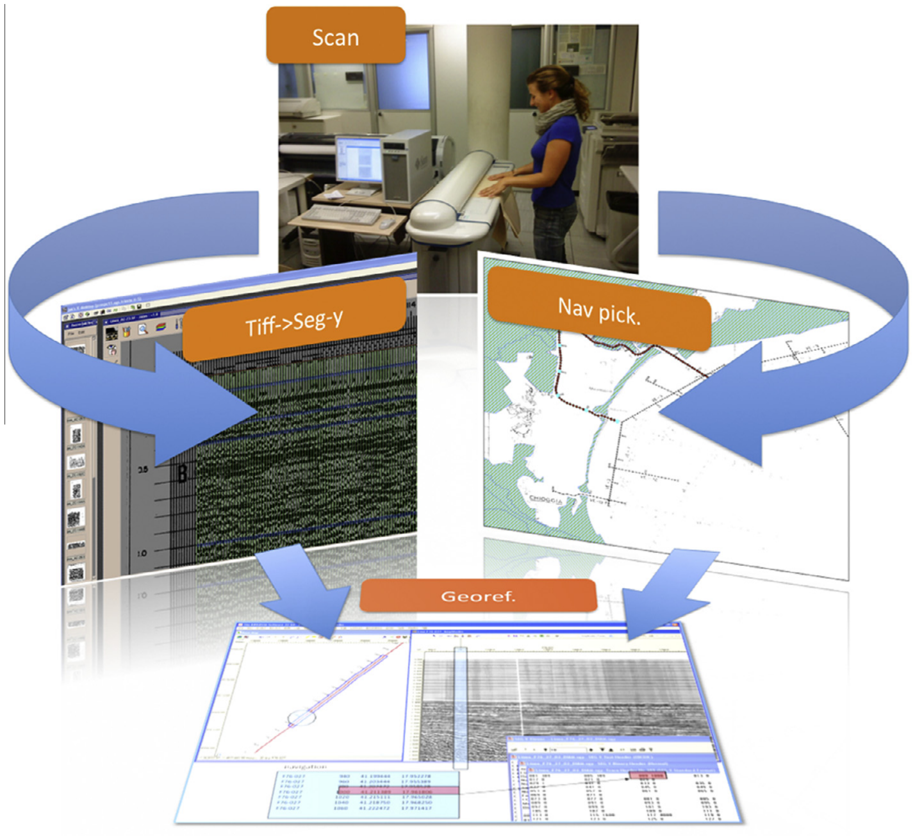

Fig. 1. Paper data undergo scanning, digitizing (maps), image to SEG-Y file conversion and georeferencing to obtain proper digital data.

3.2.4. Positioning information

Data need to be georeferenced, otherwise they are of no use. Information on positioning was available in digital form for more recent data, but had to be picked manually for older data. Scanned maps were first georeferenced using available information and then each profile or vessel track-line was digitized using the relative shot point index. Shot points can be interpolated linearly, but this is often not necessary as the interpretation or processing software used by the end user commonly has such functionality. What is very important, less simple and very time consuming is re-organizing the shot indices such that they are consistent within the same seismic line. Often, due to technical or local issues, the acquisition of a seismic line was aborted while a problem was fixed; the line was then restarted further along the ship's track resulting in gaps in the recording that had to be 'filled in' through a second pass. The result was shot indexing that was non-sequential along the geographic extension of the line. Whereas this was not a problem when the interpretation was being carried out by hand on paper sections, it can have serious drawbacks in the digital world as is shown in Fig. 2.

If this is not accounted for in the navigation file, interpretation software will extrapolate data positions inconsistently stretching the seismic data into a false geographic data distribution. Correcting these problems is laborious because intervention is needed to manually check the headers in the seismic data with the indexing and positioning in the navigation files. For this reason, it is very important to have detailed information on the events that occurred during the acquisition, such as looping of seismic lines, drops in the positioning system, anomalies or errors, so that the original data and navigation can be corrected. Modern systems allow this information to be recorded close to the observed event, in a digital and standardized format (Diviacco et al. [8]) while historically this was written by hand in paper logbooks. In these cases understandability of the annotations depends on language (and calligraphy). Each crew recorded events in their own native speaking language. Additionally no kind of controlled or standard vocabulary was used, which created some misunderstandings.

3.3. Documentation and data intelligibility

A specific issue that links to the last point is retirement of key people able to "understand" how data were recorded with vintage systems. This is a very important issue that stems from the distinction between data recovery (i.e. the recovery of data from media) and data intelligibility (i.e. understanding what these data actually represent). If the former is a developed technique, the latter strongly depends on the specific context and practices that were applied during data acquisition. Although within the commercial world there is notable sensibility and culture in standardization and documentation/reporting, probably because data representation is a top-down process, in public research institutes this model is generally not standardized. Here, projects and data acquisition details are devised from people's background and practices. In most cases funding structures call for collaborative projects, where different practices intermingle, often with unpredictable results. If all of the details of data collection are not properly documented it can be very difficult to restore data to full intelligibility. Within SNAP, two tasks were undertaken to address these issues:

- Digitise old documentation, when this is fairly 'standard', such that this paperless copy could be easily preserved, located and used later when attempting to reconstruct the original survey history.
- Standardization of "eccentric" configurations to meet a common framework, meaning a detailed editing of data to produce new versions that can be seamlessly ingested by standard

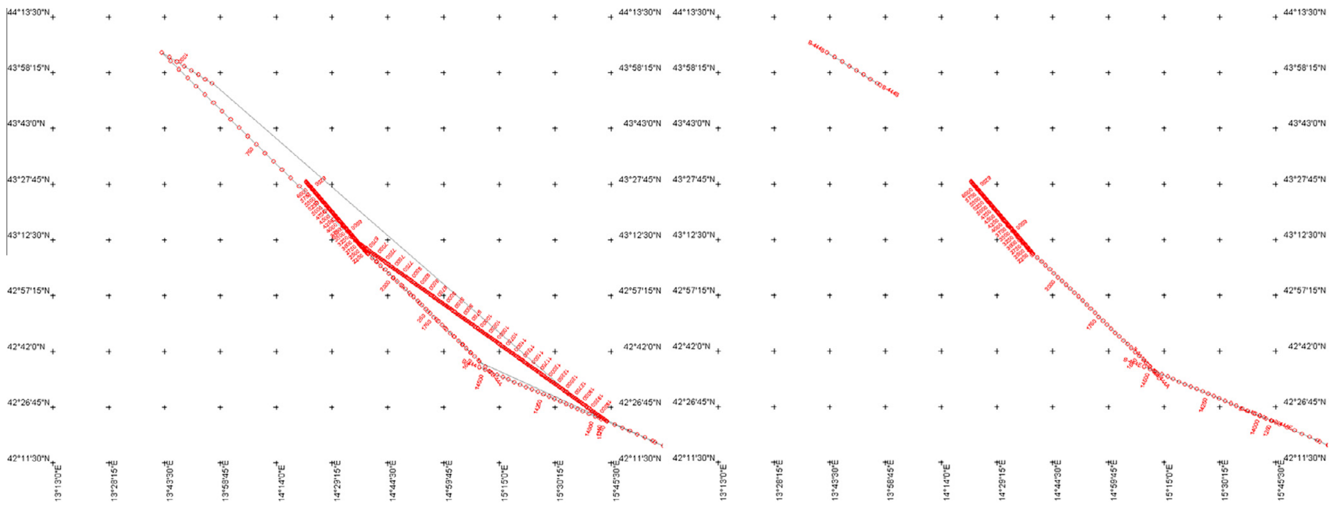

Fig. 2. Non edited seismic line navigation showing artifacts resulting from inconsistent shot index and positioning association (left) and the corrected version (right).

modern interpretation software. This task was carried out in close cooperation with people that participated in the surveys (and are often close to retirement) to ensure all information is obtained.

To ensure data are easy to find and use, documentation and ancillary information about the data (metadata) need to be clearly connected with the data. Both paths applied within SNAP take this into account.

3.4. Processing of seismic data

To enhance the quality of digitized seismic data restored from paper sections, a specific processing path has been devised that attenuates lateral discontinuities and artefacts introduced in the process of converting the scanned images to actual SEG-Y data. The danger of these features is that during the process of seismic migration this 'noise' can introduce further characteristic migration artefacts (smiles) that can significantly degrade the quality and therefore the interpretability of the data themselves (see Fig. 4 center seismic section). In Fig. 3 it is possible to follow how the method improves the data. Considering the image on the left, the seismic section is characterized by areas with different mean amplitude values. This is a result of the paper sections being folded; when exposed to light or air, ink degradation results. Another common issue is that random noise introduced during the scanning process can corrupt the continuity of the signal. To address such problems, a specific processing workflow that made use of non-conventional techniques, such as, the Tau-P transform considering only null ray parameter values, was designed. Finite Difference post-stack time migration was also applied using velocity fields that were obtained by integrating stacking velocities from vintage velocity analyses and average velocities obtained from sonic well logs (when available). The results of such processing can be seen in Fig. 3 (center and right). The original scanned and converted data (left) have been first processed to reduce noise and resolve amplitude issues (central section). In the final migrated section, on the right, most of the problems have been resolved and the continuity of the signal has been considerably improved. The need for specific processing steps before migration is demonstrated in Fig. 4. Noise and artefacts are rather evident in the central panel without application of the specialized processing workflow, while the section on the right, with the specialized processing, shows much more continuity in the seismic reflectors.

3.5. Addressing issues due to tape reading

OGS acquired extensive surveys of multichannel seismic data during the seventies. The data were originally stored on 21-track magnetic tapes. As previously discussed, transcription of such media can be problematic, and in fact, reading these 21-track tapes nearly 30 years after data were recorded, not all the field records were recovered. In extreme cases, blocks of 50–80 shots were lost creating large gaps in the processed data, limiting the potential for migration and seriously affecting the usefulness of these data. Fortunately, the original data were not totally lost; paper copies of the original processing existed in the OGS archives. These data had previously been scanned and converted into SEG-Y and a 'reverse processing' methodology was devised to decompose these traces back into their original components and to recreate the missing field records.

These reconstructed shots can then be inserted into the processing sequence with the original field data to produce a continuous stack (Fig 5). Even after the reconstruction of the missing shots, modern processing failed to give improved results due to the low fold of the original datasets. The original data acquisition parameters (24 channel, 2400 m cable shooting every 100 m, producing a 12-fold stack with 50 m trace interval) resulted in spatial aliasing in the presence of strong dip, creating problems in the attenuation of the multiples and the imaging of complex structures. To overcome these problems, a second methodology was devised to pad the original field data and increase the spatial sampling and hence the fold coverage. The Tau-P or slantstack technique was preferred as it is not specifically data dependent and uses the whole of the record to interpolate the traces. Fourfold interpolation, in both the shot and receiver domains, increased the spatial sampling from 50 m to 12.5 m and allowed much improved seismic imaging, especially of the near-vertical flanks of the salt structures (Fig. 6).

3.6. Integration with other data

As mentioned at the beginning of this work, one of the main motivations for this restoration project was to be able to use the recovered data with modern interpretation software where horizons and faults can be followed across multiple seismic sections and integrated with borehole data (Fig. 7). To achieve this, all converted SEG-Y data, after positioning correction, were loaded, together with more recent data, into IHS Kingdom.

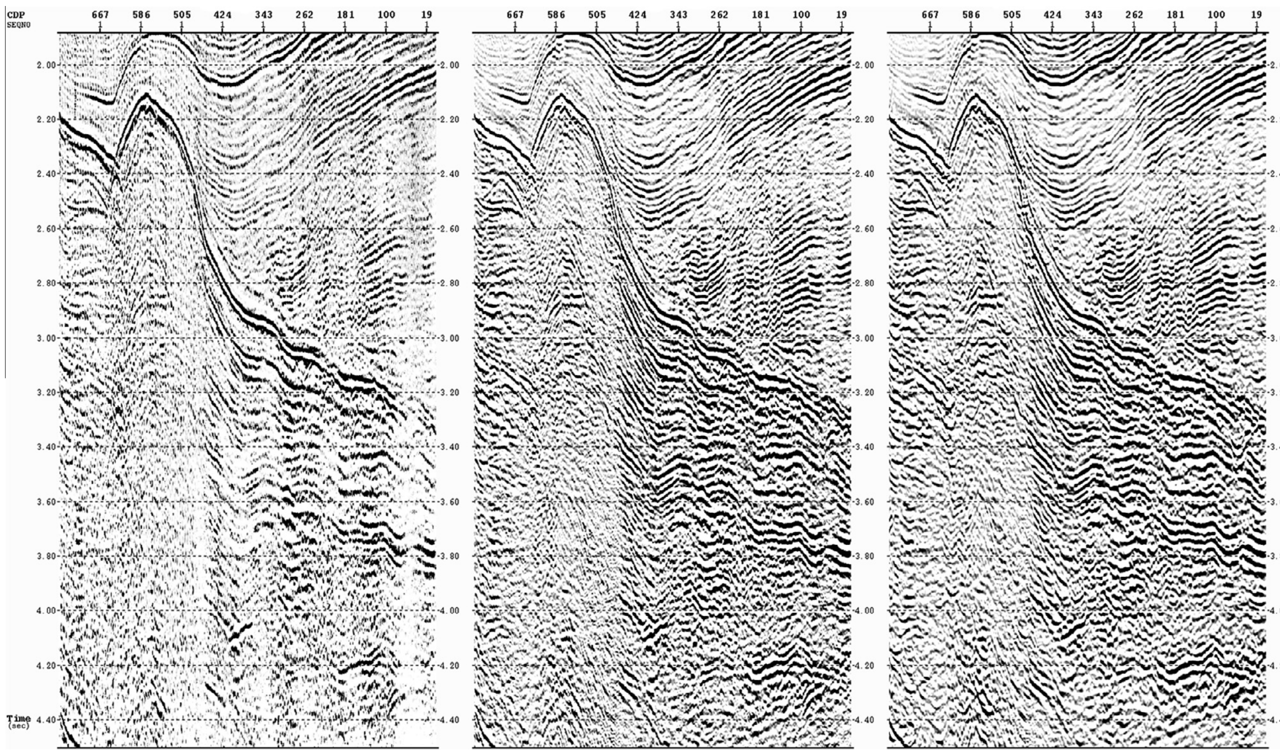

Fig. 3. Original scanned seismic section converted to SEG-Y (left). Same data processed to correct amplitude anomalies from the scanning process and restore continuity of the signal using the Tau-P transform (center). Final migrated section (right).

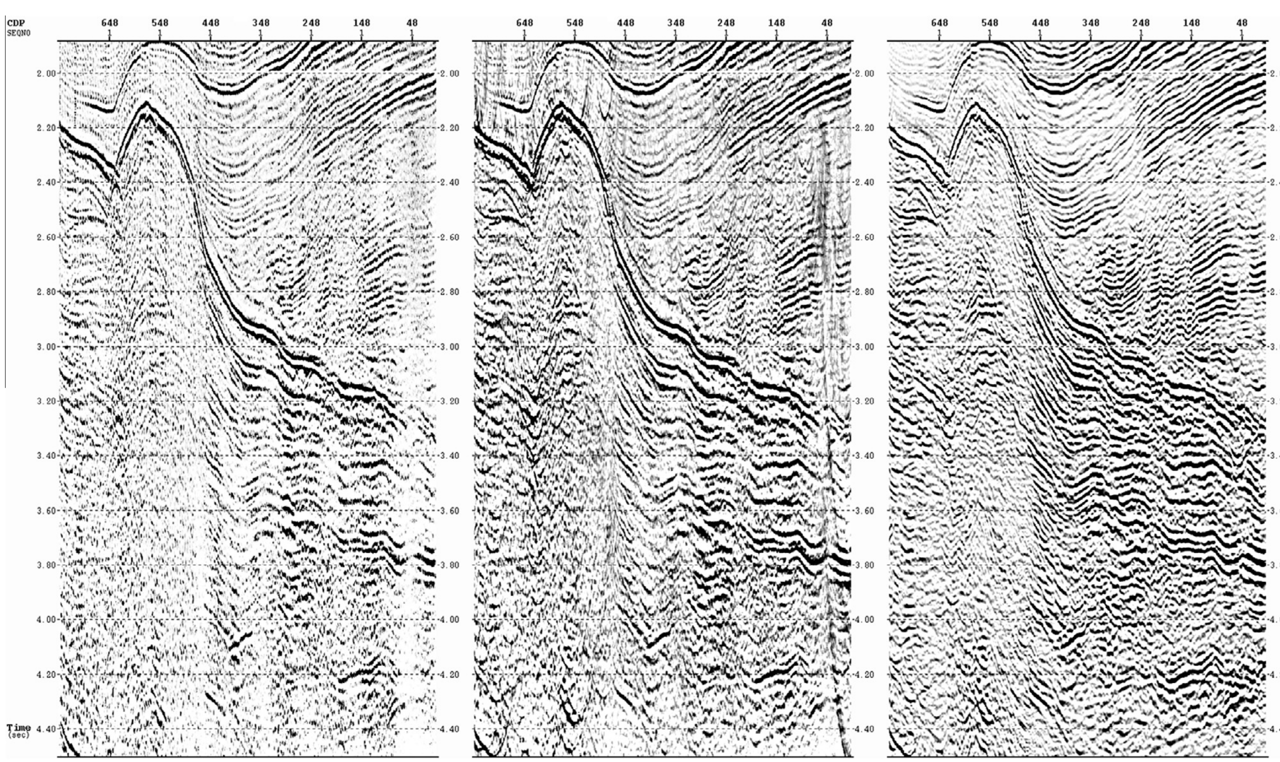

Fig. 4. Original scanned section (left) and a comparison between a migration of the original scanned data (center) and a migration of Tau P processed data (right).

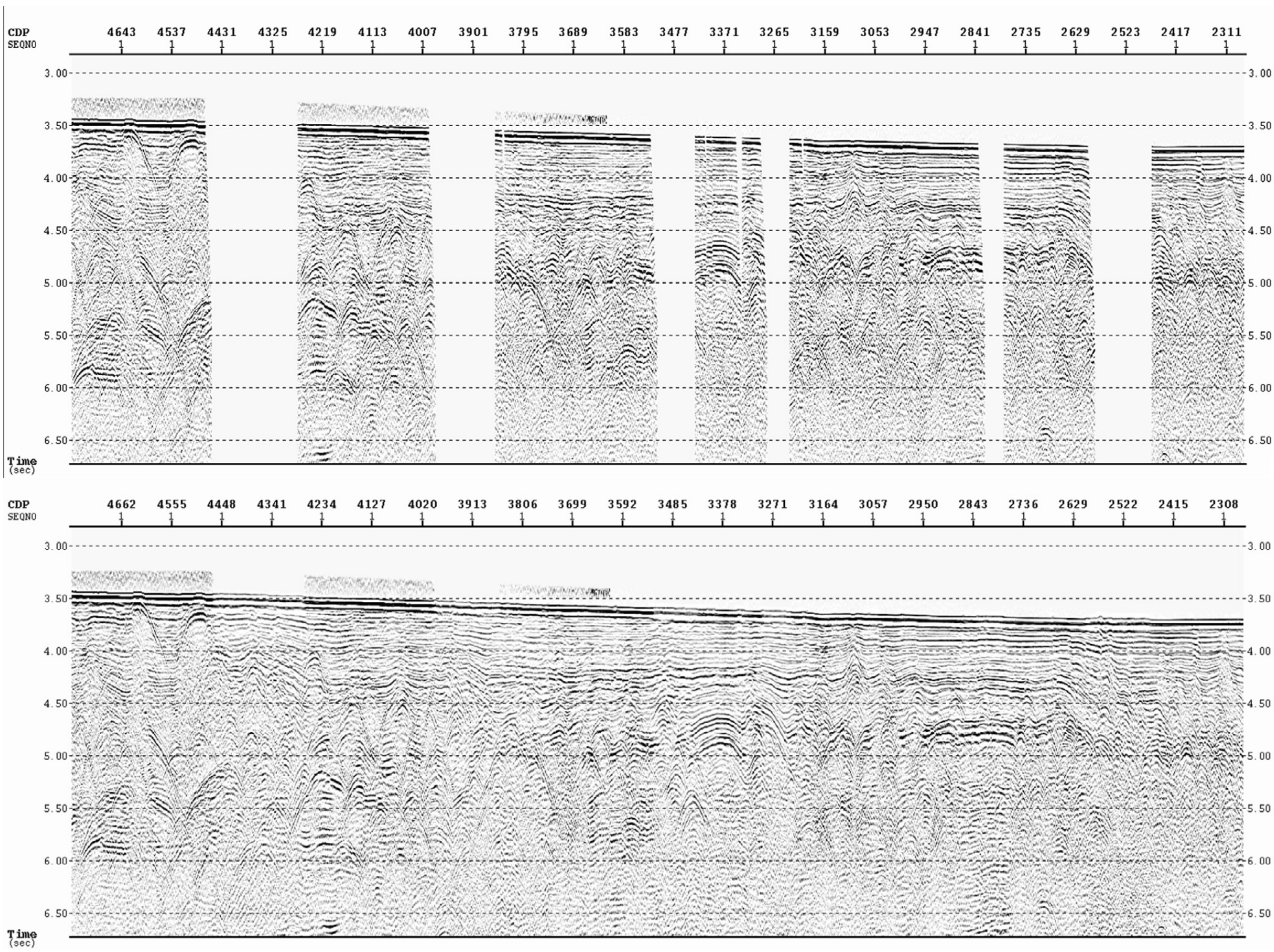

Fig. 5. Effects of tape transcription problems (upper section) and results of data recovering and reconstruction (lower section).

Vintage OGS Geophysical data were acquired mainly in the Mediterranean and Polar areas. To avoid repeatedly converting positioning information from one projection to another (which would add errors at each step), navigation was kept in standard geodetic (WGS84) coordinates as geographic latitude and longitude.

At the same time, since interpretation deals also with distances and volumes, within the interpretation software, different projections have been identified for the larger geographical areas: Transverse Mercator in the case of the Mediterranean Sea and Polar Stereographic in the polar areas.

Smaller projects can be extracted from the larger geographic areas, with local datum and projections, such as UTM, where research teams actually work. These working areas are shared in the OGS internal network so that all researchers can access the data for the projects on which they are collaborating. These can also be accessed from outside OGS using a virtual private network (VPN) or a remote desktop such as VNC tunneled via a secure shell (ssh).

3.7. Data sharing

An important task of data management is sharing observations with other colleagues, either within a working team or within the scientific community as a whole. Most of contemporary philosophers of Science have already highlighted the importance of this, for example, Latour and Woolgar [9] for whom "Science is a social construct". OGS has committed a lot of efforts into developing a specific web-based infrastructure named Seismic data Network Access Point (SNAP) where all data OGS manages can be located and interactively previewed (Fig. 8) by OGS and non-OGS scientists. During data search, specific web-based data preview software allows end-users to take an additional step beyond metadata browsing. One very important point in the process of data selections is, in fact, to estimate the actual usability of the data. This can hardly be captured by quality or lineage textual information in the metadata. A preview of the actual data is necessary. SNAP offers all of this. A specific viewer has been devised that uses web services to interact with the server in order to interactively process the actual seismic data. The position of the cursor in the seismic section is continuously updated and mirrored in the positioning map. The seismic viewer can be used to visualise static images as well, but obviously it is not possible to apply any processing to the data. OGS is currently working on an extension of the system towards the creation of a full collaborative system that would enable teams of researchers to work together on the data residing in SNAP, thus increasing further the visibility of data and further advancing collaboration between researchers and institutions.

3.8. Standards

Data and metadata standards used within the OGS-SNAP initiative result from the convergence of three paths, and namely:

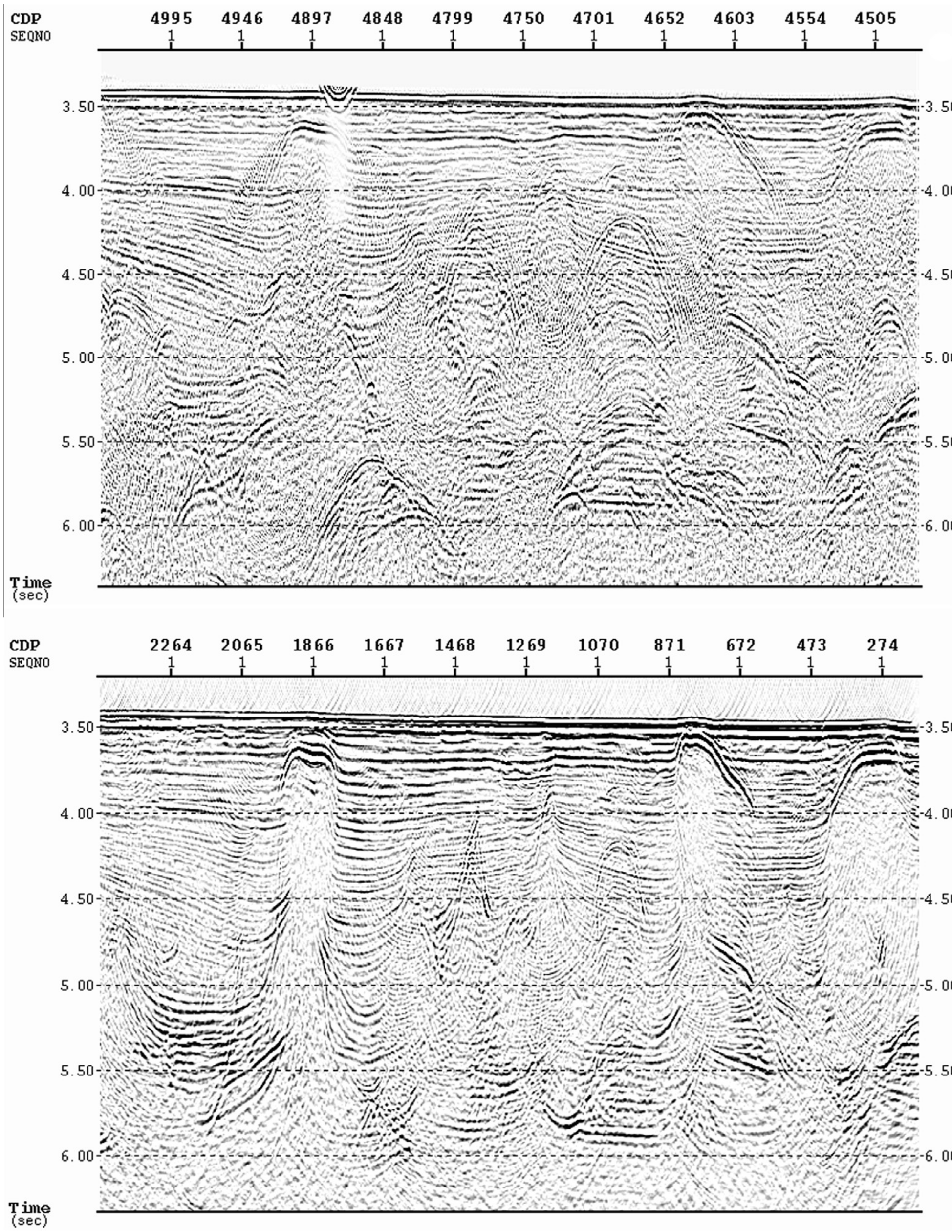

Fig. 6. Comparison of migrated seismic section showing diapiric structures without reprocessing (upper section) and with reprocessing (lower section).

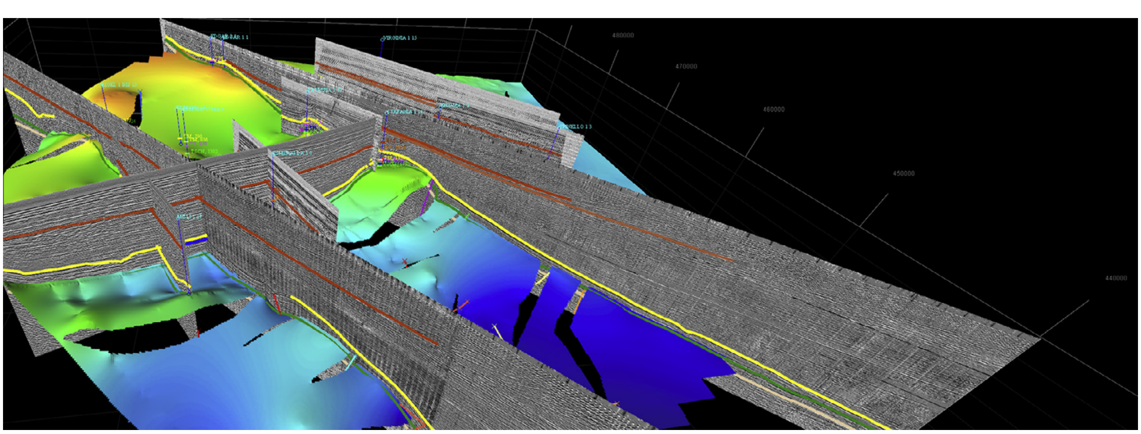

Fig. 7. 3D fence diagram that integrates several seismic sections and boreholes. Here it is possible to follow the distribution of faults and of seismic horizons.

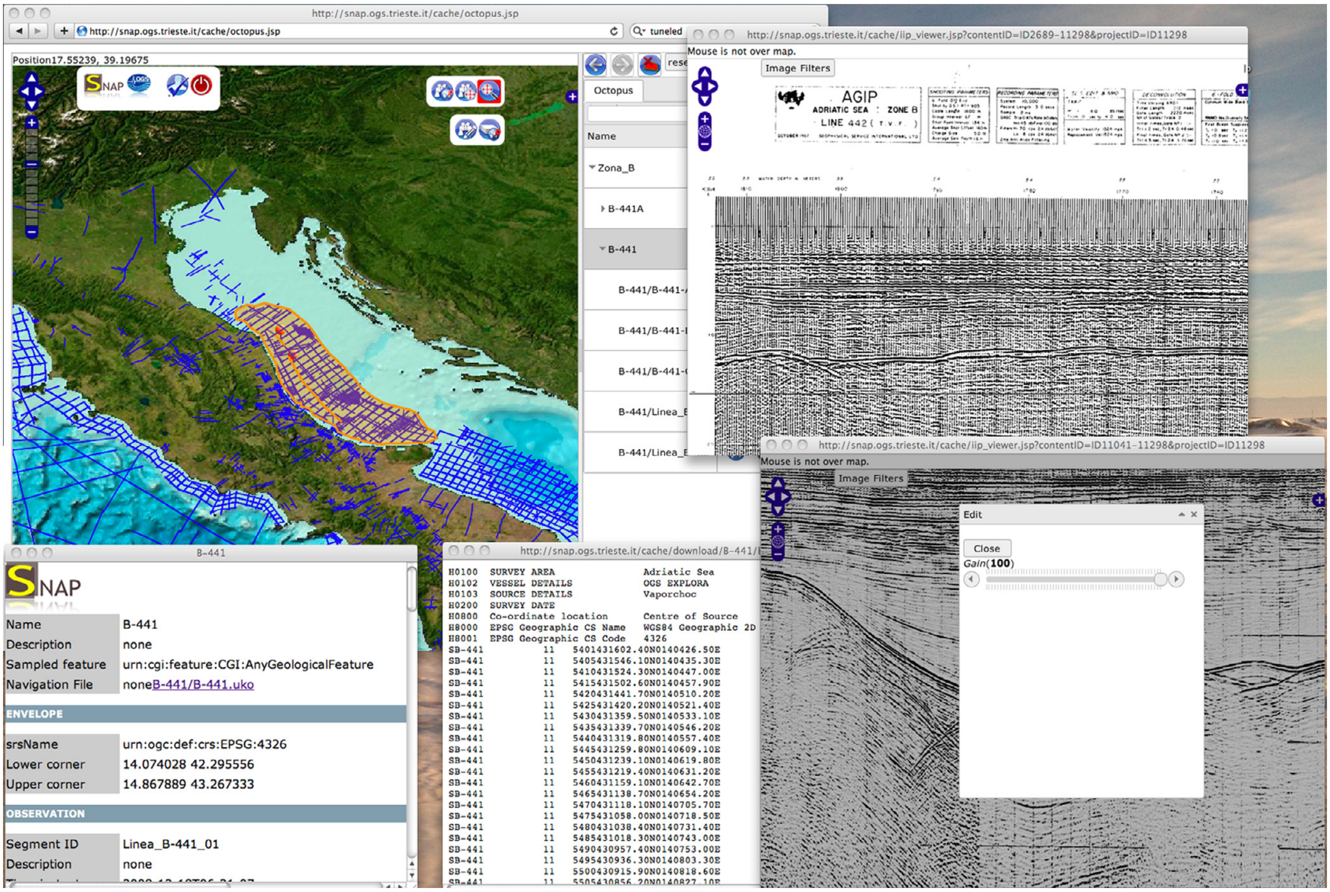

Fig. 8. SNAP, the OGS web based data access system. Seismic data can be searched geographically and textually (upper left). Once data are found it is possible to read their metadata (lower left) and download positioning in a UKOOA file (lower center). Data can be visualized either as a static image file (upper right) or as actual Seg-Y data, where basic processing on the data is possible (lower right).

1. The past experience of OGS in handling seismic data within the institute itself and international initiatives such as for example the Antarctic Seismic Data Library System [SDLS].
2. The commitment for interoperability with European data infrastructures such as SeaDataNet [SeaDataNet], GeoSeas [GeoSeas] and Emodnet [Emodnet].
3. The projection towards interoperability with a larger set of international initiatives following the current research done within the ODIP project [ODIP].

3.8.1. Data standards

Data standards in geophysics, and in seismic in particular, have always been conditioned by commercial traditions and practices. Considering that seismic data correspond to large arrays of values, they are not stored within a database but rather as files. The most commonly used standard for storing and exchanging seismic data is the Society of Exploration Geophysics (SEG) SEG-Y format [SEG-Y]. Delving into all the details of this format is well beyond the scope of this paper; it is interesting to note, however, some interesting issues that had to be considered carefully during the development of SNAP. These are related to the fact that through time the SEG-Y standard has remained quite rigid, while new technologies emerged. The pressure to accommodate these new requirements forced many dialects and interpretations of the same data structure, that came into conflict when different teams and communities interacted. The most problematic issue relates to the use of the SEG-Y trace headers. These are structured blocks of 240 bytes positioned within the seismic data file, at the beginning of each seismic data trace, and holding information such as trace length, sampling interval, etc., but no provision exists for example for storing floating point values. Historically, all values have to be integer, but in certain special cases the inclusion of a scaling factor is provided to overcome this apparent omission. Our solution was to upload data files with the minimal set of needed information and leave the less standardized information to external files and metadata (please see the following section).

An example of the use of an ancillary file is positioning data, for which we adopted an external ASCII file in the UKOOA P1/90 format that was defined by the UK Offshore Operators Association in the early 90s for use in the oil industry. This format has been adopted in SNAP as it allows a minimal set of required information to be loaded.

3.8.2. Metadata standards

Within SNAP, metadata is used both for data usage, meaning processing, integration or interpretation, and for data discovery. The same parameter, such as, the seismic data sampling frequency can be needed on one side to set a frequency filter and on the other to understand whether a dataset can be used for engineering or for oil prospecting. This information needs to reside in multiple locations: it must be contained in the data file that can be downloaded from SNAP for further processing; it must reside in the database on the top of which the web interface is run, and, at the same time it must be available to other initiatives that need to know what kind of data SNAP can offer. Not all of these applications need the same set of information. Processing needs data related information, discovery needs contextual information. Within SNAP, seismic data files are pre-loaded with all processing-related metadata so that scientists can find all they need. The SNAP discovery facility relies on and queries a database that contains all the relevant metadata and links to the data. Most of the metadata have been extracted automatically from seismic data during upload in the system, while several parameters still need manual intervention. Of course the internal intricacies of the system are hidden from the end-user who simply searches and finds what he/she is looking for from the web interface.

The metadata are also made available using a metadata structure that has been the subject of an extensive study coordinated by OGS during the GeoSeas EU FP7 projects. The resulting model is based on a three layers structure. The top one, relies on the Common Data Index (CDI) XML standard developed within the SeaDataNet EU project. It provides ISO19115/ISO19139 compliant cross-domain metadata. The request, emerging in the geophysical data community, for more detailed metadata drove the decision to extend the CDI not only through a simple addition of domain specific parameters, but through the introduction of an intermediate layer that could link the generic (CDI) and domain specific metadata. This was done relying on the Observations and Measurements (O&M) OGC standard. This allows ancillary information, such as UKOOA navigation files, survey event logs or the actual data to be linked to the tools that interactively visualize them and provide means to link to a SensorML [SensorML] document where all domain specific metadata can be found Diviacco and Busato [10], Diviacco and Busato [11], Diviacco et al. [12] and Diviacco [13].

Data in general, and rescued data in particular need lineage information where end-users might find information on the processing sequence that was applied to the data. Currently this is very difficult to do or can be done only within closed commercial systems. So far our solution was to write in the text reel header of the SEG-Y files a sentence stating that data was recovered from paper sections. A very interesting possibility that the combination of O&M and SensorML can offer, and that we are currently working on, is the possibility to report events, such as the data processing sequence, using a SensorML event list. Leveraging the results and software developed by OGS and other partners within the EU project Eurofleets [Eurofleets], it is possible to enter processing steps, parameters and values in a standardized way to later produce SensorML documents that can be linked from O&M and therefore associated to data.

4. Results

The key results project can be summarized as follows:

1. Rescue of all tape data owned by OGS, via transcription onto secure mirrored storage systems.
2. Processing of former tape data to reduce transcription errors and alleviate inconsistencies resulting from missing shot records.
3. Digitization of paper seismic sections.
4. Conversion of digitized paper sections to usable digital seismic data (SEG-Y).
5. Processing of rescued SEG-Y paper sections to enhance seismic signals on sections and reduce artefacts due to folding of paper sections and ink degradation
6. Correction of positioning anomalies.
7. Integration of all available data ready for use in modern geophysical interpretation packages.
8. Development of a web based platform (http://snap.ogs.trieste.it) to disseminate rescued data within the scientific and commercial communities, where all data and metadata that have been uploaded and have been made available.

5. Conclusions

This paper details the work carried out through an OGS-funded project, that aims to allow the scientific community to access a large amount of "vintage" seismic data recovered from several internal and external archives. This project comprised several phases and activities, from restoration of data, to clearance, to integration and to dissemination of the rescued data. Through experience gained during this project, the authors assert that all these steps are necessary since only by the use of the data does their full value emerge. All steps have to be considered and devised considering the project as a whole; each one, following on after careful consideration from the previous step and anticipating the next, to maintain a harmonized data space, standards and software interoperability. This, from an end user point of view, would mean easy data discovery, access and usage of the recovered data, which will foster a collaborative environment for researchers and institutions.

References

[1] Sheriff RE. Encyclopedic dictionary of Exploration Geophysics. Tulsa, Oklahoma: The society of Exploration geophysics; 1973.
[2] Nabighian MN, Grauch VJS, Hansen RO, LaFehr TR, Li Y, Peirce JW, Ruder ME, Philips JD. The historical development of the magnetic method in exploration. Geophysics 2005;70(6). Nov–Dec 2005.
[3] Romberg FE. Exploration geophysics: a review. Geol Soc Am Bull 1961; 72(no6):883–932. http://dx.doi.org/10.1130/0016-7606(1961)72[883:EGAR]2.0.CO;2.
[4] Miles P, Schaming M, Lovera R. Resurrecting vintage paper seismic records, Mar Geophys Res doi:10.1007/s11001-007-9034-5.
[5] Carbotte SM, Arko R, Chayes DN, Haxby W, Lehnert K, O'Hara S, Ryan WBF, Weissel RA, Shipley T, Gahagan L, Johnson K, Shank T. New integrated data management system for Ridge 2000 and MARGINS research. Eos Trans AGU 2004;85(51):21. http://www.marine-geo.org.
[6] Ross S, Gow A. Digital archaeology: rescuing neglected and damaged data resources. HATII- University of Glasgow; 1999.
[7] Eco U. Non fate il funerale dei libri. L'Espresso, La bustina di Minerva 2005;63:636.
[8] Diviacco P, De Cauwer K, Leadbetter A, Sorribas J, Stojanov Y, Busato A, Cova A. Bridging semantically different paradigms in the field of marine acquisition event logging. Earth Sci Inform, 2014. http://dx.doi.org/10.1007/s12145-014-0192-0.
[9] Latour B, Woolgar S. Laboratory life: the construction of scientific facts. Princeton (NJ): Princeton University Press; 1979.
[10] Diviacco P, Busato A. Maps, graphs and annotations as boundary objects in knowledge networks, distributed cognition and collaborative e-research. In: Diviacco P, Fox P, Pshenichny C, Leadbetter A, editors. Collaborative knowledge in scientific research networks. Hershey (PA): IGI Global; in print.
[11] Diviacco P, Busato A. The Geo-Seas Seismic data viewer: a Tool to facilitate the control of data access. Bollettino di Geofisica Teorica ed Applicata 2013;54/2.
[12] Diviacco P, Lowry R, Schaap D. Marine seismic metadata for an integrated European scale data infrastructure: the FP7 Geo-Seas project,. Bollettino di Geofisica Teorica ed Applicata 2013.
[13] Diviacco P. Addressing conflicting cognitive models in collaborative E-research: a case study in exploration geophysics. In: Collaborative and distributed E-research: innovations in technologies, strategies and applications. IGI Global press; 2012. http://dx.doi.org/10.4018/978-1-4666-0125-3.ch012.

Further reading

[14] [IMAGE2SEGY] <http://ww2.icm.csic.es/gma/en/content/image2segy>.
[15] [ImageToSEG-Y] <http://www.chesapeake tech.com/image-to-seg.pdf>.
[16] [SEG-Y] <http://www.seg.org/documents/10161/77915/seg_y_rev1.pdf>.
[17] [SDLS] <http://sdls.ogs.trieste.it/>.
[18] [SeaDataNet] <http://www.seadatanet.org/>.
[19] [GeoSeas] <http://www.geo-seas.eu/>.
[20] [Emodnet] <http://www.emodnet.eu/>.
[21] [ODIP] <http://www.odip.org/>.