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ORIGINAL RESEARCH PAPER

Resurrecting vintage paper seismic records

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Abstract Marine seismic data has been collected for several decades in both academia and industry. Early single channel acquisitions were often, if at all, recorded on magnetic media that are generally no longer supported for replay. Although seismic data over 10 years old has limited quality compared to modern acquisition, thousands of survey km of hard copy records remains world wide in areas with no recent coverage. In addition, many processed multi-channel datasets are now not available as digital files for a variety of reasons. Rising interest in continental margin geology in response to climate change priorities and the UNCLOS submission requirements of maritime states has created a demand to re-use these older records where the cost of new or re-acquisition is not pragmatic. Through creating digital SEG-Y files from images of these records they can be reprocessed and re-interpreted. This paper investigates the practicalities of paper seismic record re-use and measures the performance of a typical conversion option as an indicator of the validity of the concept. Examples of applications of the process illustrate what can be achieved and the limitations that exist so that users can make an informed choice of whether to resurrect their information.

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Introduction

As seismic survey technology has developed so too has the cost of its acquisition, now at several thousands of Euros a day for the simplest of marine systems. Although most data over 10 years old could be improved by new acquisition methods, resources are not often available for re-surveying. In addition any information about existing surveys, and details of how their data may be accessed, can reduce the need for new surveys and avoid any concern over the environmental impact of additional seismic operations. This will be of value to all geoscientists, but especially those operating on lower budgets or in time constrained regional mapping. To this end the adoption of the geospatial metadata standard (DIF 2006) publicized the existence of many hitherto unknown marine seismic data sets owing to their emergence in various databases (Miles 2005; Schaming 2005; Carbotte et al. 2004). This has nurtured a growing demand for access to previously inaccessible or unknown marine and other seismic information of all vintages, driven in part by the requirements of the UNCLOS (Law of the Sea Convention) submissions, IODP proposal requirements and the needs of new regional resource assessment and environmental monitoring programmes in both academia and industry.

Existing records can also regain value when the cost of new acquisition is avoided. With occasional exceptions, marine data has often suffered from poor archiving since modern airgun and streamer technology emerged during the1960s. Although seismic data now use SEG-Y (SEG

1994) or derived formats, even relatively recent surveys from both academia and industry have been unavailable in any digital form for re-processing or replay. Often only paper or plastic film record sections remain as stacked or migrated sections in variable area wiggle trace (VA/WT) displays, single channel EPC thermal graphic recorders or even earlier Mufax thermal printer line-scan monitor prints. Through sub-contracting of acquisition and/or processing to third parties, poor data management or a lack of long term curatorial responsibility, they may not be catalogued as existing at all. Occasionally records assumed to be of limited future use have been discarded after publication of initial results. These issues became exacerbated by attitudes that considered data management produced no scientific output and therefore would receive little funding. Only recently have the rigorous efforts of a few leading marine geophysical database centres, Internet access and software become sufficiently user friendly for institutions to identify data management needs as practicable, scientifically desirable and particularly valuable when cost savings from data re-use can be identified.

The European Commission (EC) recognized this potential legacy of environmental information by funding, what were to be, two successive seismic data rescue and re-use projects under the names of SEISCAN and SEISCANEX (Miles et al. 1997). These projects successively installed and developed five facilities in a European infrastructure to scan, archive and re-process marine seismic records when they were the only surviving record. The work was directed at academic and government funded departments who would not ordinarily have budgets for expensive commercial solutions. To date this EC initiative has processed over 14,000 A0 size images of seismic record sections from Europe and beyond. This represents more than 2,000,000 line km of survey with a re-acquisition cost and added value that could be as high as 30,000,000 Euros.

A common desire of facility users was to be able to convert the data into SEG-Y format for re-processing and display rather than simply archive the images. Although solutions have been available for this conversion (e.g. Chesapeake Tech. Inc. 2007; GEOREX 2007; Fugro 2007; Phoenix Data Solutions 2007), the processing was either too expensive to contract out or of insufficient quantity to qualify in-house expertise in the software application. These comprehensive packages also meet the stringent demands of the commercial sector with full waveform wavelet tracking and integrated navigational reference interfaces.

Consequently there has been interest in the accuracy of the reproduced files—were they a reasonable representation of the original data? Could they realistically be post-processed without generating artefacts or noise, particularly on early non wiggle trace variable density data? To provide a practical conversion option within the project, and to investigate the validity of the process in general, the facility developed its own user friendly seismic image to SEG-Y file transcript algorithm—SeisTrans—that could sit easily on UNIX and Linux PC platforms within the project facilities or as a stand-alone application for hands-on use at academic research centres. It was packaged via a project partner that the EC contracted to provide on-going support and development. To date this module has been installed at 15 research centres world wide for use with both marine and land seismic data of the types described. Old earthquake records which have seismogram traces that cross-over each other during events are a special case and at present are not suited to this technique (Michelini et al. 2005).

This paper will describe the process of generating digital SEG-Y files from scanned images using SeisTrans as an example. It does not attempt to compare solutions but to present what can be expected from SEG-Y files recreated by any method. This will be particularly relevant to the wider academic community so that those considering this option can make informed choices about where it may be beneficial, regardless of the method they consider most appropriate.

Record sections

The suitability of a record section for conversion and reprocessing depends on the relevance of the survey location to current scientific needs, the data quality, physical condition of the media and its uniqueness—because not all seismic paper records either need, or are suitable for reconstruction to SEG-Y files. Their information may be sufficient as an image, as determined by the scientific task needs. It is also important to stress that if the required data records are not already to hand their actual location may not always be trivial—even at the investigator's location! Survey chiefs and Principle Investigators are often no longer available, and curatorial responsibility can have been in doubt for some time. Third party data sets may have 'owners' who suffer from 'data shyness'—reluctance by some researchers to share data of any age. This can be because of the staff time involved in locating and sorting records, informal confidentiality agreements or the fact that they do not know where they are! Paper seismic records come in many sizes, flat, folded or rolled and often fragile from storage (Fig. 1). Plastic film records may be in rolled sheets and with a background hue. All these types can be handled by modern A0 scanners, although the operation requires considerable user time.

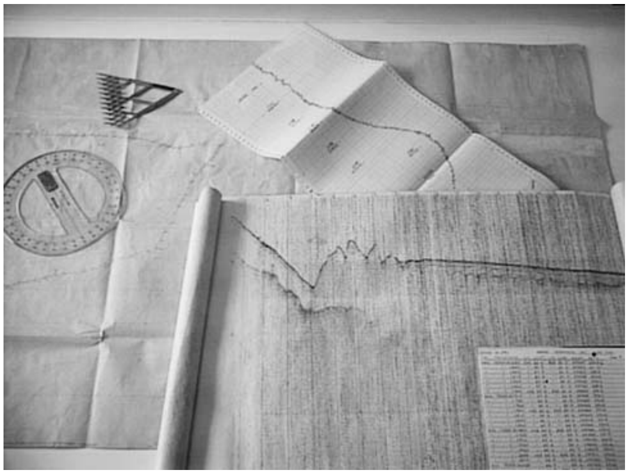


Fig. 1 Example of a paper data set from a marine survey circa 1971. Hand drawn charts, potential field plots (normally still available as ascii data files), seismic records and survey logs

Record sections also need to be entered into metadata files so that documentation of derived datasets from scanning and processing will avoid the creation of subsequent layers of '*data sediment*'. Metadata DIFs can easily be created as short text files and are compatible with .xml scripts for later migration to a database appropriate for the location (DIF 2006). Derived images require unique acronym naming in each metadata DIF for subsequent management and future tagging of generated files. These DIFs can also include the survey details contained in seismic logs, cruise reports or on the seismic records themselves to provide information for the seismic geometry necessary in post processing. Ideally these documents should also be stored as PDF files. On basic EPC and Mufax paper records the gun firing rate determines the number of traces per hour along a record section. Knowing this improves the accuracy of the SEG-Y conversion and contributes to geometry calculations. However, gun rate is not always included in survey reports or logs, and may have to be derived analytically or occasionally through inspection of the trace display; the gun rate can often change.

Scanning of the record sections as 300 dpi 1-bit greyscale (black and white) A0 tiff images is also a quality assurance process useful in ensuring definition of the seismic record, linearity of axes and the prevention of damage to the original. It also generates manageable file sizes of 3.6 Mb compressed. In principle any length of record can be scanned into a single file with continuous feed systems. The record registration process described below can compensate for some non-linearity due to stretching, folding or scan-walk but it is preferable to minimise the errors at the scanning stage.

The conversion process

SEG-Y conversion algorithm

Many software solutions for SEG-Y conversion follow similar steps in the processing to reconstruct the seismic waveform. The method described here is a trace pixel sampling and numerical derivation routine applicable to all originals. It differs from other methods essentially in how the trace is reconstructed to full waveform from an often clipped image displayed on the seismic record. Although applicable to all data types SeisTrans was specifically designed for line scan data by measuring the positive wavelet energy in the black pixels and deriving the negative wavelet numerically. This is in contrast to the alternative full waveform wavelet tracking of other methods. It illustrates one process and provides a measure of the work involved in manipulating various paper records, processing data files and the results to be expected.

To register the image for digital sampling each observed trace is overlain with a trace baseline as shown in Fig. 2. With these, lines at sample rate spacing determine sample patches over the image, along and between each seismic trace. The digital file is built by construction of a series of finite values between 0 and 1 determined by the proportion of black pixels in each patch (Fig. 3); i.e. a patch with 10 pixels can have a value of 0–1 in 0.1 steps. This can affect the sensitivity of the technique to small scale originals and higher frequency sources. These values have a positive bias from the positioning of the trace baselines, and do not sample the negative wiggle trace segment where this is

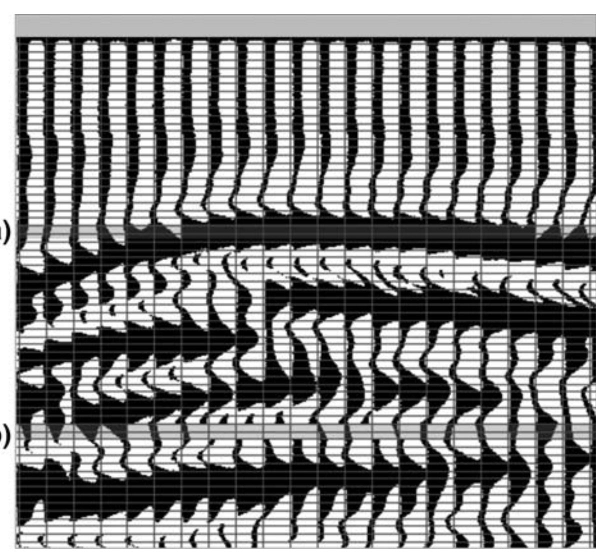


Fig. 2 Detail of conversion trace baselines and 4 ms time intervals defining sample patches. Note the trace baselines are placed to the left of centre of the trace. This is also the case for line-scan traces. Also shown is the optional averaging across time lines (a,b)

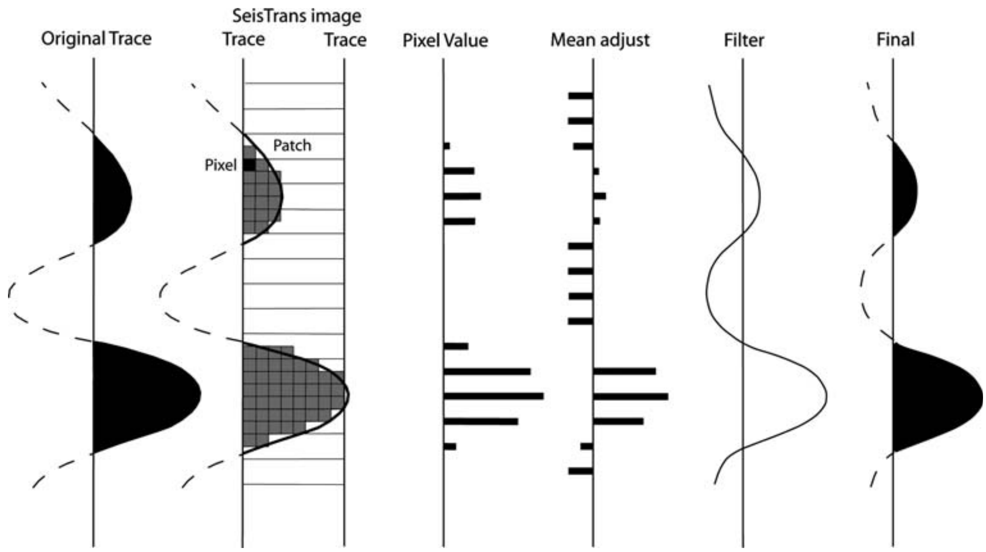


Fig. 3 The conversion sums pixels of over 50% black content to give a value for each patch. Mean adjustment allocates a negative mean value to zero value patches to emulate negative trace elements. These values are written to a SEG-Y file and the filter creates a new wiggle trace

present. To rectify this each trace is adjusted to have a mean value of zero, with the adjusted mean value being subtracted from patches of zero value to emulate the negative wavelet. In order to re-create the sampled signal the file generated is band pass filtered appropriate to the original record display. Patches are often around 20 pixels in size for 4 ms sampling rates at 300 dpi but this will depend on the trace spacing and scale of the original.

It must be remembered that this technique will not be able to use the full waveform of any clipped traces that would have been available from the original magnetic media—those that can be estimated by wavelet tracking techniques. However, as described below, this limitation only generates artefacts where each trace overwrites adjacent traces owing to high gain display. In these cases the user inspection of original versus created seismic sections, which can be made at trace and smaller scales, has been found practical and flexible for converting data of varying quality.

In principle the routine can be applied to any acoustic data set as long as the scan resolution can define the trace structure with sufficient pixels (5–10). However many high resolution seismic and side-scan sonar records are only resolvable as 8-bit greyscale images and are not presently compatible with this approach, but can be converted by alternative routines.

Navigation and geometry header editing

The SEG-Y binary reel header contains information about the data, most of which is optional. In fact none of it is actually required to be valid, although some fields are strongly recommended. It can include an extended textural file header that contains navigation projections, processing history and acquisition parameters often not available for scanned originals. However some SEG-Y conversion packages do permit navigational fixes to be uploaded into the header files either from a file or via trace picking.

The 240-byte binary trace header contains trace attributes consisting of 2-byte and 4-byte integer values that change on a trace by trace basis. Some of these may be set by the navigation and geometry parameters (if present). However all the three headers' parameters can be set using any of the proprietary or freeware header editors to assist in later processing. A record section consisting of a series of CDP stacks may not require the full acquisition geometry for further processing, but it will need some x-y navigation if it is to be integrated with other surveys. How this is achieved varies on a case to case basis particularly in the academic datasets. Processing such as migration can be achieved without use of file header navigation details if rudimentary information is available—and often that is all there is!

Method of application

In creating a waveform SeisTrans typically uses interactive, iterative and repeatable steps in a dedicated graphics window. The scanned image is placed into the module to open a work window (Fig. 4). Zoom, pan and resolution selection permit the user to control the accuracy of cursor picks, scaling and editing.

Definition of axes and scales

This is a standard requirement that defines a rectangular work area on the seismic image by selection of the nominal

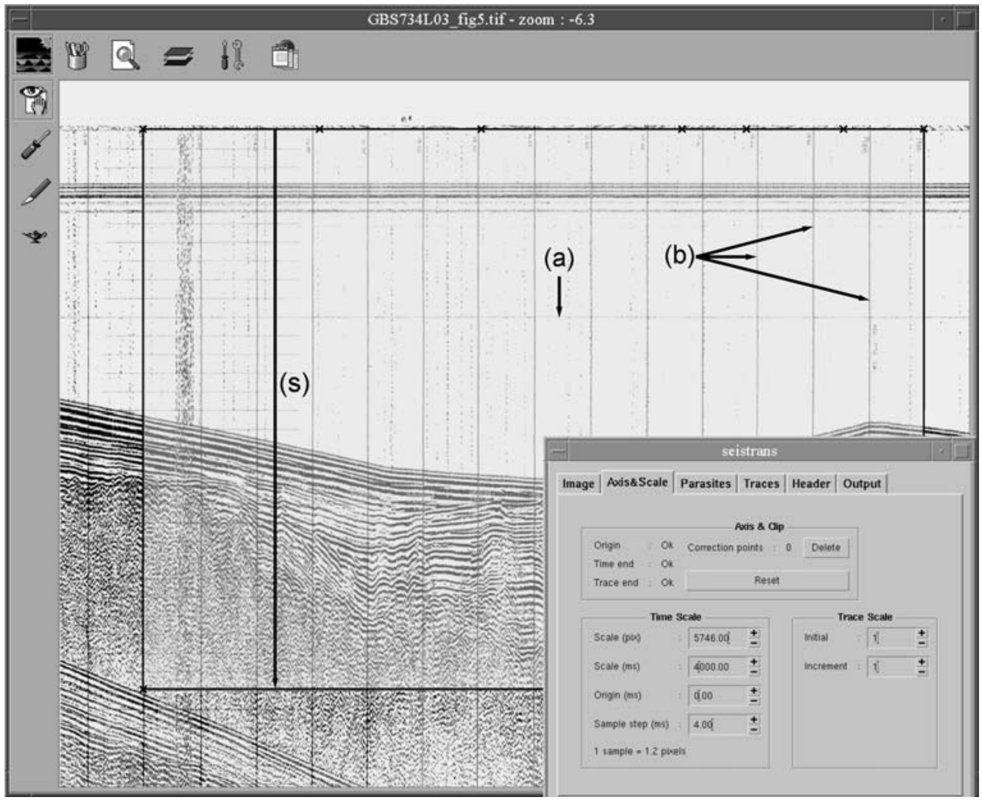


Fig. 4 A line-scan EPC image in the work area of '*Axis and Scale*' is defined by three initial registration picks (top left, bottom left and top right) and adjusted with additional time zero picks (x) along the top. (s) = Time Scale calibration in ms/pixel; Parasites (a) = twt 'time lines' and (b) = navigation 'time lines' for edit. The SeisTrans 'Axis and Scale' window is shown inset

'zero', a known start of record time on the first trace, an end time on the first trace plus the start time on the last trace (Fig. 4). These corner picks can be adjusted to correctly register the image by examining the accuracy of the calculated fourth corner position of the processing area. Intermediate points along the 'zero' time axis can be inserted to 'rubber sheet' adjust the horizontal for any non linearity from record shrinkage or drift during scanning.

At this stage options to smooth the image in the processing area can be made from a choice of four filters that reduce image pixel noise prior to sampling. However this filtering can weaken the clipped traces within the water layer optionally used in the auto trace selection (below). An on-off blink view compares the filtered and original image to aid selection of the appropriate smoothing factor.

When registered the two-way time (twt) scale is calibrated with the pixels by dragging a rule down a seismic trace on the image between integral seconds using the cursor (Fig. 4, S).

Trace scaling (numbering) controls the number given to the first trace and its increment (+ or −) to match original record section trace numbers.

Elimination of record time lines (Parasites)

Elimination of, or optional interpolation across, lines that are not part of the data such as twt lines along the record (seconds or 100 ms intervals) and navigation time lines down the record (1/2 or 1 h marks on analogue EPC records) is necessary to avoid generation of seismic artefacts in the data file (Fig. 4). Each line can be picked or, after several selections, identified by auto selection from previous pick spacing. The picks can also be adjusted. The thickness across which interpolation is made can be selected for the lines (default = 4 ms). This reduces all non seismic trace artefacts on the digitized record section. Removal of hand drawn interpretation lines on the section image, particularly colour, can usually be made using samplers and image filters before digitization (NOTE: scanning is not mandatory as a software generated digital image can also be used).

Definition of traces

The selection of traces for the transcription process differs according to the type of original seismic section. Ideally each computed trace should correspond to an actual trace on the image and is easier to achieve for VA/WT displays than line compressed line-scans. Traces are computed by the trace baselines to cover the observed trace width (Fig. 2). The baselines are best located at the left edge of the variable area portion of a trace or EPC scan line to measure the ratio of black to white pixels in each patch. Wiggle trace sections with clipped (straight line) traces above the seabed reflection, as in Fig. 2, can use an automatic selection option. When this is not possible, through the absence of mute traces or noisy (uneven width) traces, the manual selection option will require either some knowledge of the firing rate or a good estimate followed by some iteration. Trace baselines are laid on the image allowing the user to zoom and accurately define their correct locations (Fig. 2). EPC line-scan sections are more subjective without accurate airgun firing rate information, but good calculations can be made using zoom to iterate between known navigational time lines as firing rates normally ranged between 10 and 20 seconds.

Writing the SEG-Y file

The official SEG-Y format has three header files: EBCDIC text header, binary reel header and binary trace header. The 3,200 bytes SEG-Y EBCDIC header record can be edited in the SeisTrans window prior to creating and writing the

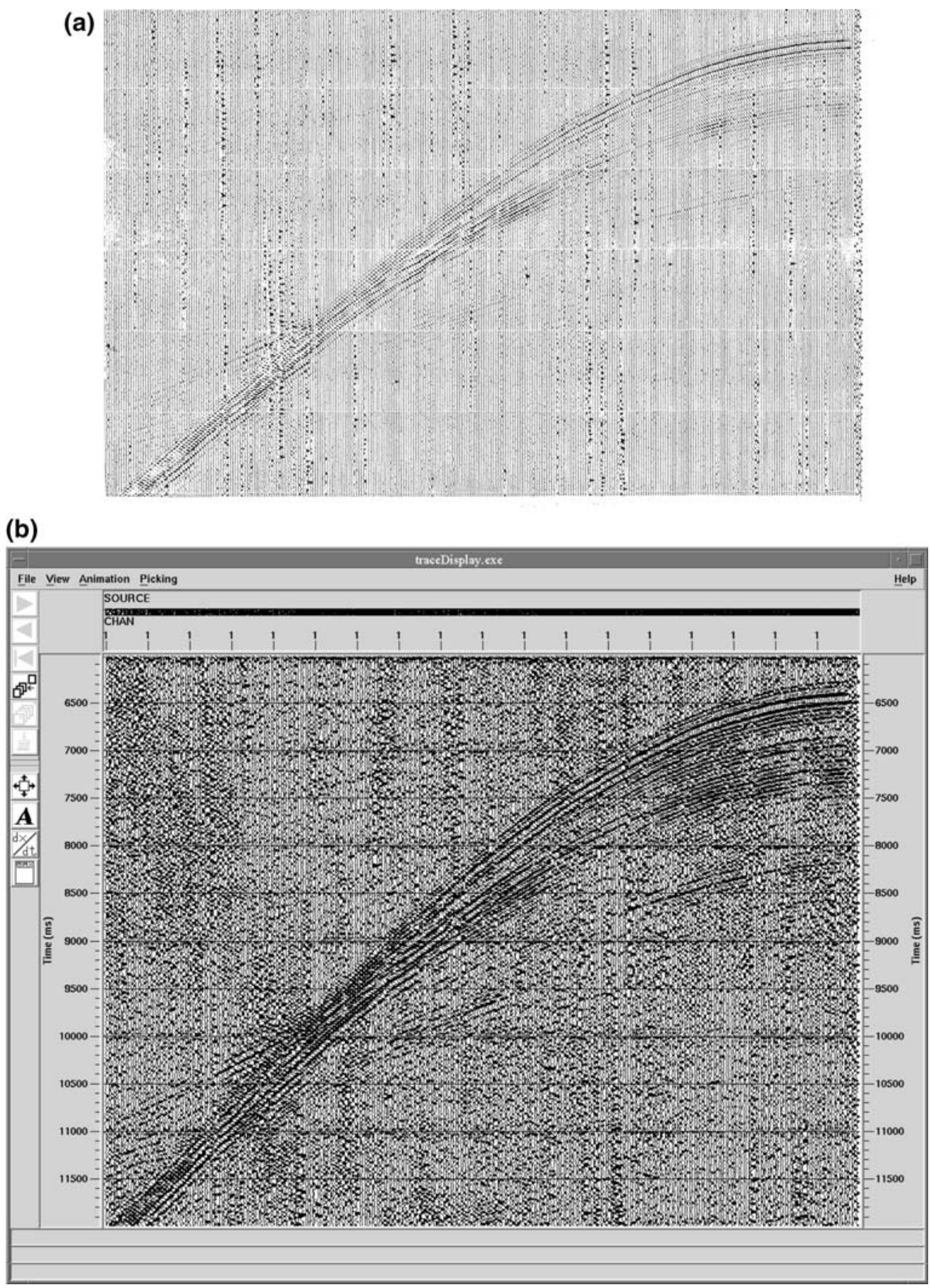


Fig. 5 (**a**) Scanned image of an ink jet pen record of sonobuoy station 1763 from the Bay of Biscay printed in 1976, analogue recorded on 2-track audio tape (now unreadable). The VA/WT record has a 6 s twt delay—the near range direct water wave was scanned separately. Horizontal range is ~17 km. Time lines (1 s) are blank in this case but muted in the same way. (**b**) Promax display of the SEG-Y created file with individual trace scaling. Enhanced sediment and basement head wave refractions can be seen emerging from the reflected hyperbolae

SEG-Y file, default is a standard entry. The binary header is embedded with default Job ID, Line Number and reel Number plus the Sample Interval and Number of Samples per Trace.

Each trace header is embedded with:

Trace Sequence Number = 1−N.
Original Field Record Number = Initial Shot Number defined by user−N by increment defined by user (see window in Fig. 4).
Trace Identification Code = 1 for seismic data, 3 for dummy traces.
Number of Samples this Trace = 3,000 (example).
Sample interval this Trace = 4,000 μs.

Final output options exist to write to a file with or without headers, view the data as an image for quality control or to show the patches.

Real data case histories

Sonobuoy—Bay of Biscay

A Bay of Biscay consortium submission for UNCLOS in 2006 required an accurate sediment velocity profile to substantiate, or modify, multi-channel stacking velocities used to compute sediment thickness at a specific location. No recent sonobuoy data were readily available but a station occupied in 1976 happened to be stored as a 30 year old printed wiggle trace seismic section. An earlier interpretation of interval velocities using the wide angle numerical method was attached to the record section, but for the submission a more rigorous analysis was needed. The original record had been plotted on a 35 cm sweep early jet pen recorder in an attempt to aid the identification of reflected hyperbolae. Traces are 1.5 mm apart and the record was annotated as band pass filtered at 5–25 Hz. Having been stored flat the record was in good order and produced the scanned image in Fig. 5. After conversion the section is shown in Fig. 5b with time varied gain in a Promax seismic processing package (Halliburton 2007) trace display prior to re-interpretation.

Line CM-16 NE Atlantic

These data were acquired by S&A Geophysical in July 1977 for the UK Institute of Oceanographic Sciences (NERC) as part of its continental margin studies programme. The original record section is a CDP VA/WT stack from a 48 channel array with a shot point every 50 m and band pass filtered 8–60 Hz. No original tapes were available for replay and the data were required in SEG-Y format again as part of an UNCLOS submission. The record section had been folded on production and remained so for nearly 30 years. This posed a problem for feeding through the A0 scanner as these folds behaved differentially through the drive and created some non linear drift of time lines which needed to be removed, most noticeably in the 100 ms twt lines. This will not always be the case but is usually overcome by sandwiching the record section between two sheets of Mylar film secured as an envelope. Figure 6a shows a detail of this image of the un-migrated record. After the image was transcribed to SEG-Y the only

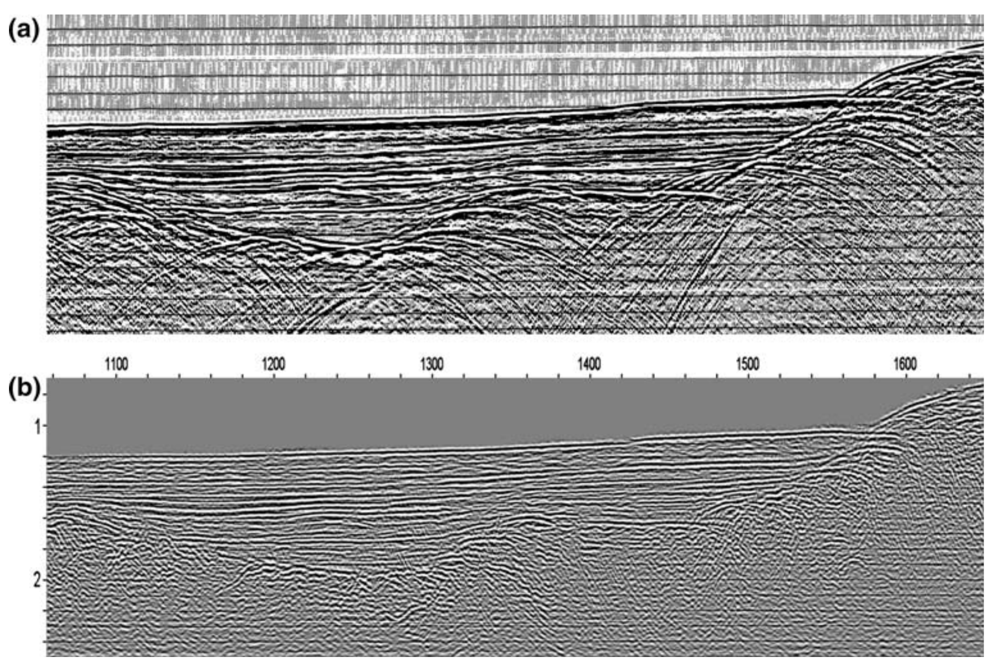


Fig. 6 (**a**) Line CM-16 extract from scanned image of un-migrated BP filtered CDP stack VA/WT record acquired in 1977, time lines at 0.2 s. (**b**) The data window after SEG-Y conversion and migration using rms stacking velocities, variable density display

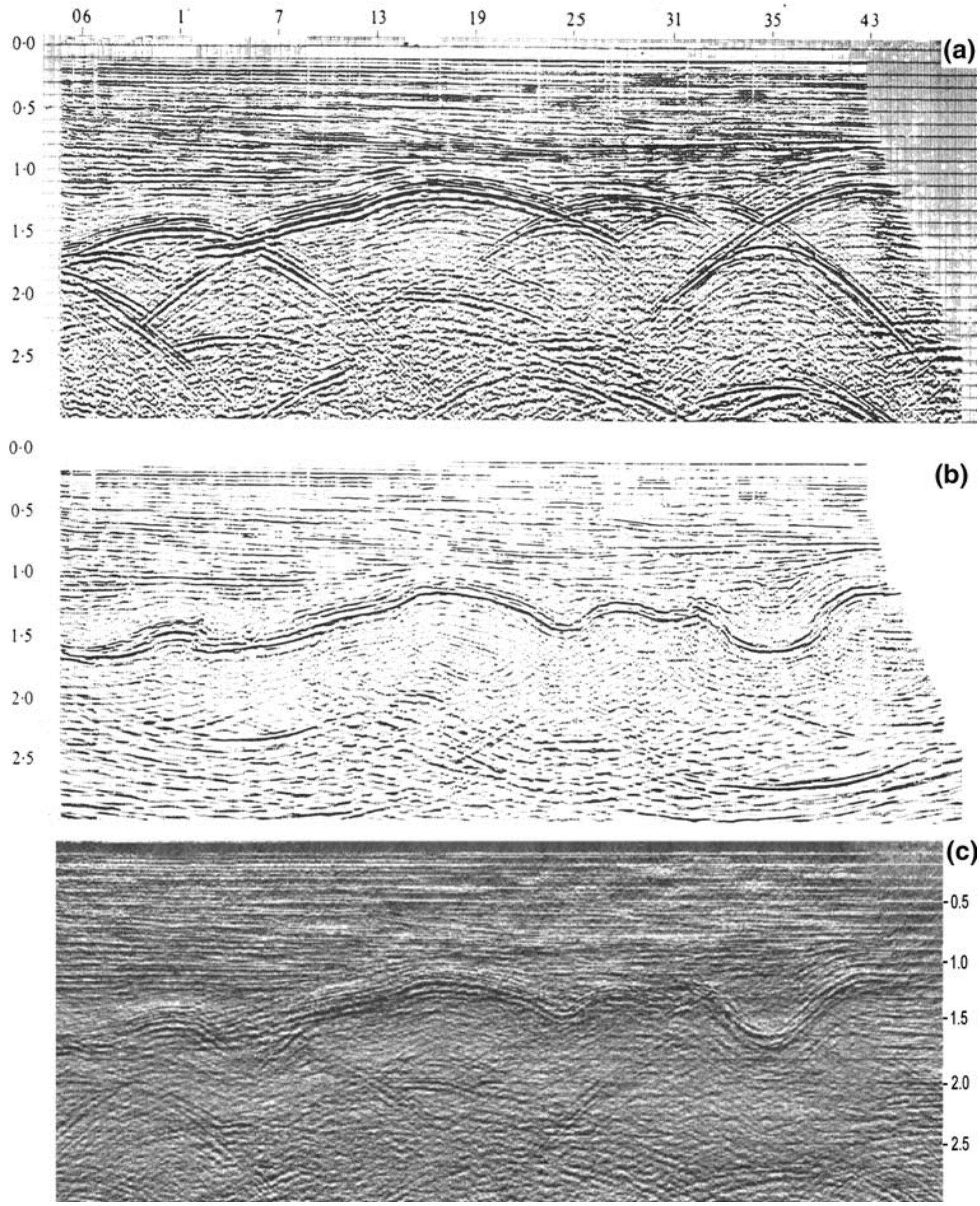
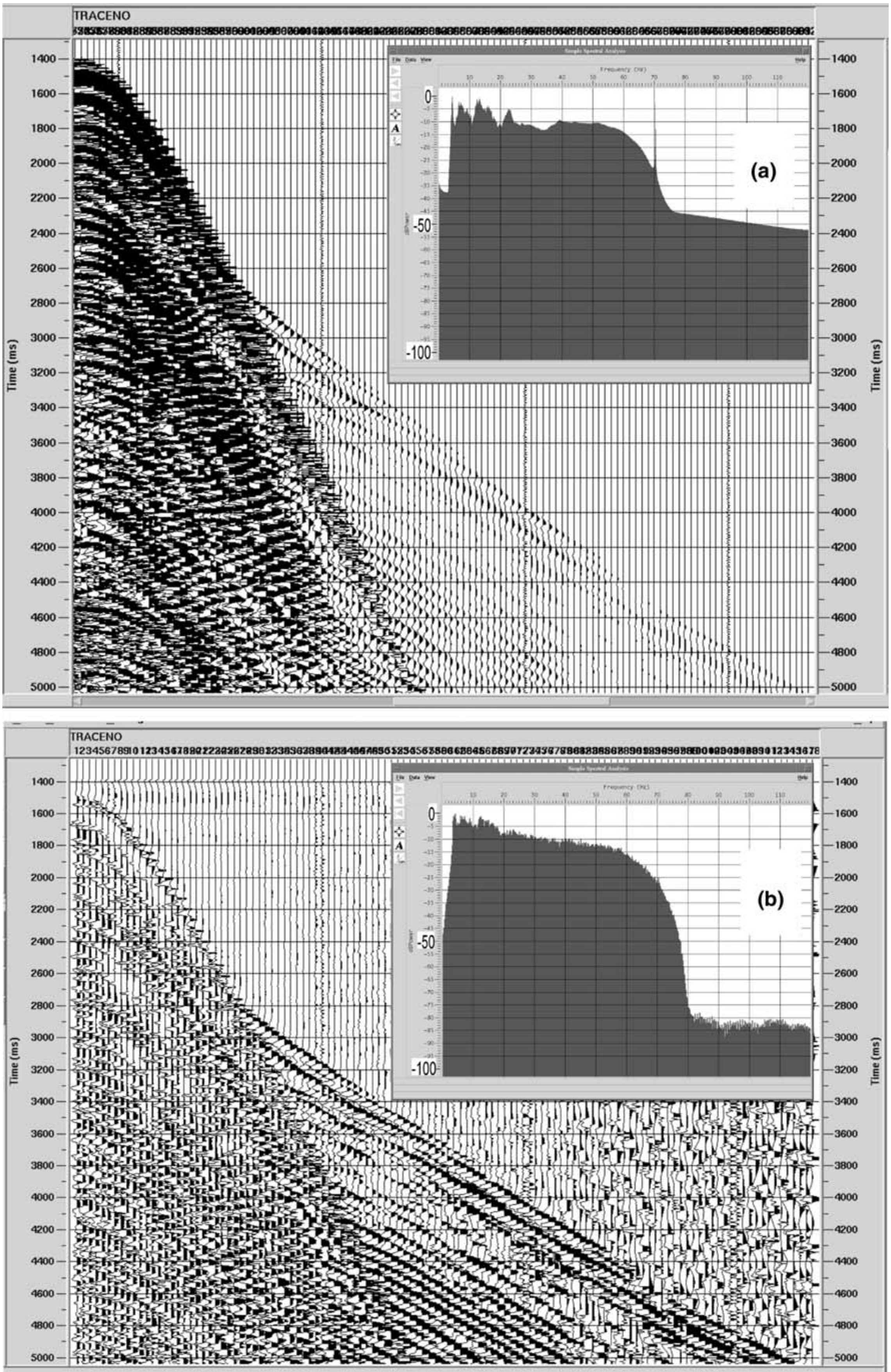


Fig. 7 (**a**) Raw stacked and (**b**) migrated seismic section published in Sheriff and Geldart 1995 (reproduced with permission of Cambridge University Press, courtesy AGIP). (**c**) New migration of (**a**) using one of a revised set of velocities following scanning of the book page (Lovera 2005). Two way times in seconds

issue was that the (almost) straight twt lines were quite thick and needed 6 ms windows for time line removal, but this was still not totally effective. It is also unavoidable that where a time line coincides with the seabed, or other horizon, some loss of data will ensue when it is removed, although the 'average across' option can minimise this.

The generated SEG-Y file was loaded into Seismic Unix (SU) (Cohen et al. 2007), displayed and then migrated using the rms velocities given on the record section. The result is displayed as a variable density plot in Fig. 6b where migration has collapsed the hyperbolas observed on Fig. 6a to increase the lateral resolution. From here the data can be treated as any other seismic file and post processed as required. Adjacent files can be stitched in seismic processing packages.

Fig. 8 (**a**) Trace Display of original OBS SEG-Y file with power spectrum (inset), band pass filtered 3-4-50-80 Hz. (**b**) Trace Display of SEG-Y file created by scanning a print of (**a**), power spectrum (inset) and with the same filter. Power spectra at same scales, vertical axes 0 to −100 dB, Horizontal axes 1–120 Hz


TRACENO
Time (ms)
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
Simple Spectral Analysis
File Data View
Help
Frequency (Hz)
10 20 30 40 50 60 70 80 90 100 110
0
-50
-100
(a)
(b)

Reworking a section

Figure 7a and b show a stacked and migrated seismic section as illustrated in the book on seismic processing by Sheriff and Geldart (1995). It is selected here to show that through conversion and reprocessing a seismic section now only available as a printed illustration in a historical document or report can be reprocessed—sometimes the case for key seismic sections from earlier studies. Here Lovera (2005) has derived new velocities to re-apply the migration to the SEG-Y file created from Fig. 7a. Figure 7c shows one attempt at this process which has not fully collapsed the basement hyperbolae and some un-muted time lines remain. It does not suggest that at this stage it improves the original processing, only that it is possible to create and migrate a section from a document image.

Limitations

The accuracy of this conversion technique depends on the information inherent in the original record and the application of the conversion process. In Fig. 8 we have tested the method with a known data set where the digital information is available and of wide dynamic and frequency range, namely the hydrophone channel of an ocean bottom seismometer. Figure 8a is the filtered trace display read from the original SEG-Y file with the inset showing the average power spectrum from a simple spectral analysis using the filters given in the figure caption. Clearly the hyperbolic direct water wave and sub-seafloor reflections are of high amplitude and overwrite each other in order to be able to distinguish the emerging refracted head waves in this display. It was printed and then scanned at 300 dpi 1-bit greyscale to generate an image input to the SEG-Y conversion algorithm.

The derived SEG-Y data from this image is displayed with the same band pass filter to emulate the original dataset in Fig. 8b, again with the average power spectrum. The result shows loss of detail in the hyperbolic arrivals owing to the overlapping wavelets where the full waveform could not be deciphered by the trace spacing definition of the sample patches. This is also reflected in the flatter power spectrum of the derived data set. The head wave arrivals have been clearly reconstructed. This section also illustrates the almost complete suppression of the horizontal time lines which can be an issue for record sections with multiple time lines if the images cannot be linearly registered.

This example illustrates that the technique can only reconstruct wavelets that can be resolved within the sampling patches. Simply put, if the eye cannot resolve the wavelet, the technique will not perform well. It is one case where conversion routines that overlay constructed wave forms may be able to converge to reconstructing the overlapping wavelet energy better, but with additional user manipulation.

Conclusion

The scan to SEG-Y technique can be applied using any of the software packages available for UNIX, Linux or PC machines, or contracted out through commercial processing outlets. Each package uses its own algorithm and requires different amounts of user interaction. The trace matching option is good for estimating the energy in severely clipped traces and for detailed matching of VA/WT plots. The pixel-patch technique illustrated here also requires minimal user training and is especially useful for older line scan records. The process of SEG-Y conversion can be expensive for large data sets whether through contract costs or person hours. Therefore prospective users need to consider its application to individual tasks, the resources required to locate records plus scan them and finally to actually process the images. But for specialist research and small data sets a hands-on user application can be cost and time effective, especially when the alternatives are to either not use the data at all, or to try and re-acquire it. The processing illustrated here shows that the derived SEG-Y data sets can be sufficiently representative of the original in frequency, amplitude and phase to recreate the seismic structure for re-use. The technique can be applied to almost all seismic survey data sets and the results operate successfully within contemporary seismic processing packages.

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