STSM Scientific Report

COST Action “MIGRATE”

Marine gas hydrate – an indigenous resource of natural gas for Europe

OBS analysis to detect gas hydrates and free gas

Sha Song

COST Action: ES1405

Host institution: Centre of Excellence for Arctic Gas Hydrates, Environment and Climate (CAGE), University of Tromsø

Period: 05/03/2017 to 01/04/2017

Reference code: COST-STSM-ECOST-STSM-ES1405-050317-082155

Purpose of the STSM

The main purpose of this STSM was to learn the approach and get training in analyzing ocean bottom seismometer (OBS) data acquired in an area where gas hydrate and free gas are present. The OBS data were acquired along the South Shetland margin off the Antarctic Peninsula by the R/V OGS Explora in 2004.

The OBS is deployed on the ocean bottom, thus not only it acquires P-wave information, but it can also receive S-wave arrivals, it has four components: 1 hydrophone, 1 vertical geophone and 2 horizontal geophones. The S-wave data are very important and they can help us in understanding the distribution of hydrate within the pore spaces and choosing the proper rock physics model. So, the objective is to extract the P-wave and S-wave velocity structures with the final goal of estimating the presence and the amount of gas hydrate and free gas in the pore space of the sediments.

Finishing this STSM, I will be able to contribute to the WG1 “Resource assessment” and its objective of screening available data in order to reprocess and reinterpret it and find hydrate occurrences. Particularly, the inclusion of S-wave data is important as this technique has not been applied often and widely enough but provides crucial information on the macro-distribution of hydrates thereby impacting their quantification, they may help to further develop detection techniques aiding the objectives of WG1.

Description of the work carried out during the STSM

During the four weeks of STSM, I mainly learnt the approach of ocean bottom seismometer data analysis. Nine OBSs were deployed during that cruise and multichannel seismic (MCS) data were also acquired (Fig.1), I chose OBS 7 to start to study and work. The work was mainly divided into two parts. In the first part, we focused on the OBS processing, including OBS relocation, rotation of three components and seismic processing of four components in order to improve the quality. Then, the data were used to pick the travel times and performed the velocity inversion by using RayInvr software.

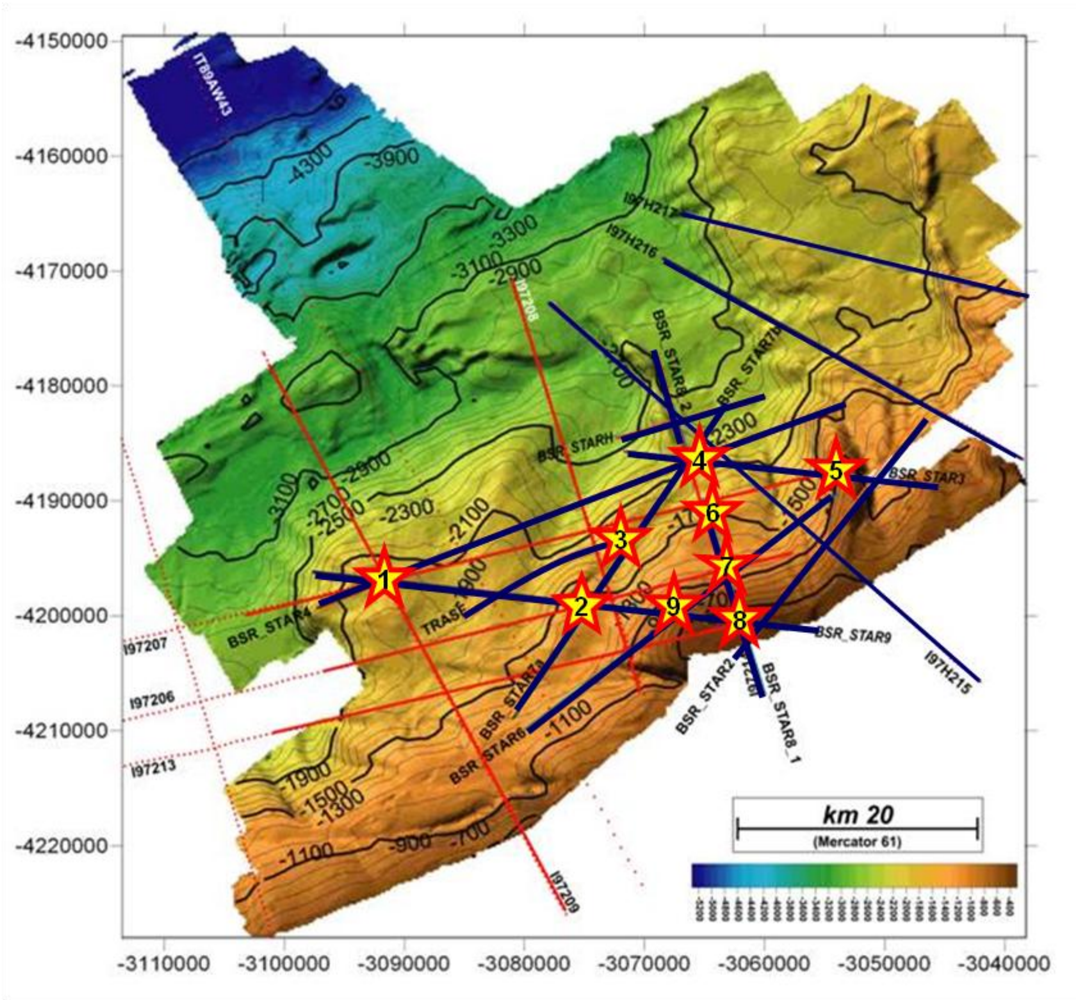


Fig. 1. Bathymetry map with the location of OBS (stars) and MCS data (solid lines)

OBS processing

In OBS seismic experiment carried out at sea, the real locations of OBS on the seafloor usually drift from designed points (deployed locations) since OBSs are of free-fall type and usually affected by sea currents during their descent. So OBS relocation is the key part of OBS data processing, since the inaccurate position will introduce errors to the geometry and to the following processing. The commonly used method is the three-point relocation method, OBS position can be calculated by solving linear equations when the shot position, travel time of direct wave and the sea water velocity are all known. But the accuracy of shot position, errors in picking of first break and the sea water velocity will cause the problem of non-unique position of OBS. In order to solve the problem, we used the hybrid positioning method (combining the search method, three-point relocation method and the least-square method) to obtain the best sea water velocity and position of OBS. Table 1 shows the deployed and inverted position of OBS 7.

Table 1 The deployed and inverted position of OBS 7

OBS 7	X (m)	Y (m)	Z (m)
Deployed Position	-3062930	-4194462	1328
Inverted Position	-3063185	-4194488	1397

In OBS data recording, hydrophones record P-waves (pressure sensitive) and three geophones record both P- and S-waves. However, the vertical component geophones primarily record P-waves while the horizontal components record S-waves. The orientation of horizontal receivers are not known and both the receivers record S-waves, so they needed to be determined from the data. The common method is hodogram analysis of first break arrival, which is a plot of particle motion projected onto the horizontal plane. It gives the orientations of the horizontal components, which are used to rotate the horizontal components to a radial and a transverse component perpendicular to radial. The highest signal quality can be achieved when all three components are included in the rotation.

In order to improve the quality of data, we performed a sequential seismic processing on the four components, the processing included band-pass filtering, amplitude recovery and predictive deconvolution.

Travel time inversion

After OBS processing, we started to perform velocity analysis in order to detect gas hydrates and free gas. We used travel time inversion (Zelt and Smith, 1992) to determine the P-wave and S-wave velocity model. The model for this inversion scheme is parameterized by linear interpolation between an irregular grid of boundary nodes and upper and lower velocity nodes for each layer. A smooth layer boundary simulation is used to avoid scattering and focusing of raypaths and to stabilize inversion. The travel times and their partial derivative with respect to the velocity ad boundary nodes are calculated by ray-tracing. The calculated response of the model is compared with the observed data, and model parameters are updated using correction vector obtained from inversion. The process is repeated until we achieve a satisfactory fit corresponding to a normalized chi-squared value and root-mean square (rms) travel time residual.

a. P-wave velocity inversion

Firstly, we need to set up preliminary velocity-depth model, definition of model horizons is a key consideration when building a realistic velocity-depth model. Thus, it is expedient to gather all possible information about the geology of the area and combine that with the available geophysical data to create a satisfactory model. Also, proper seismic phase identification is important in order to avoid potential gross errors in the final model (Zelt and Smith 1992).

The concurrent 2D multichannel seismic data (Fig.2) provide the basis for determining model horizons. The initial velocity depth model can be set up according to the pre-stack depth migration section and the migration velocity field. By comparing the reflections between migration section and OBS data, we can pick up corresponding reflection events. The eight reflections were identified and picked on the hydrophone component (Fig.3). The picking was done only up to the offsets to which the phases were clearly identifiable. Events that seemed to be contaminated by other arrivals were not included in the modeling.

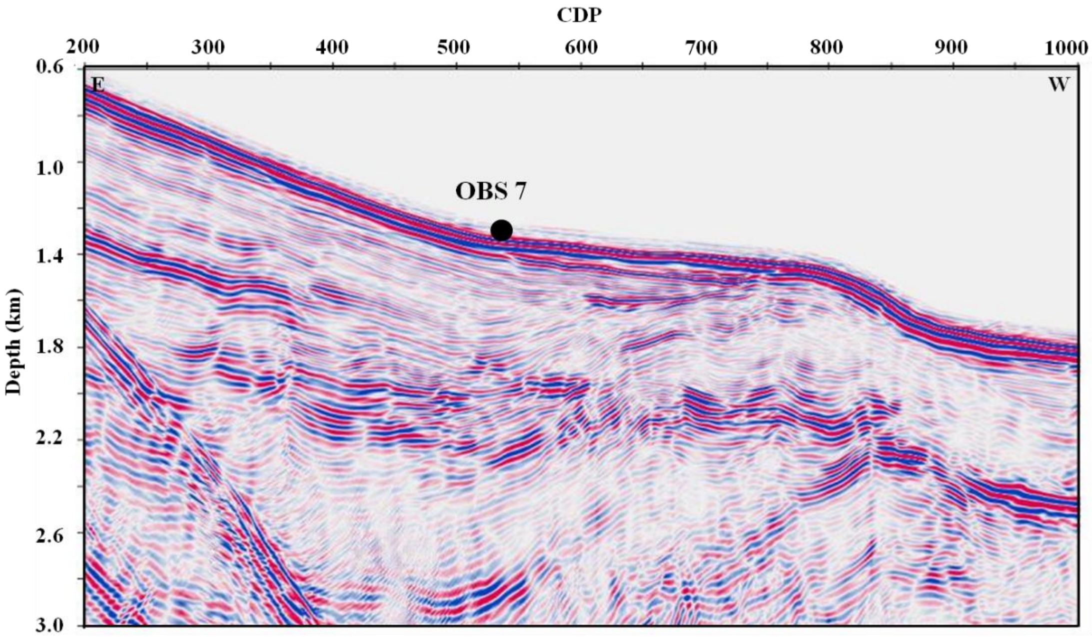


Fig. 2. A part of pre-stack depth migration section of MCS line I97214

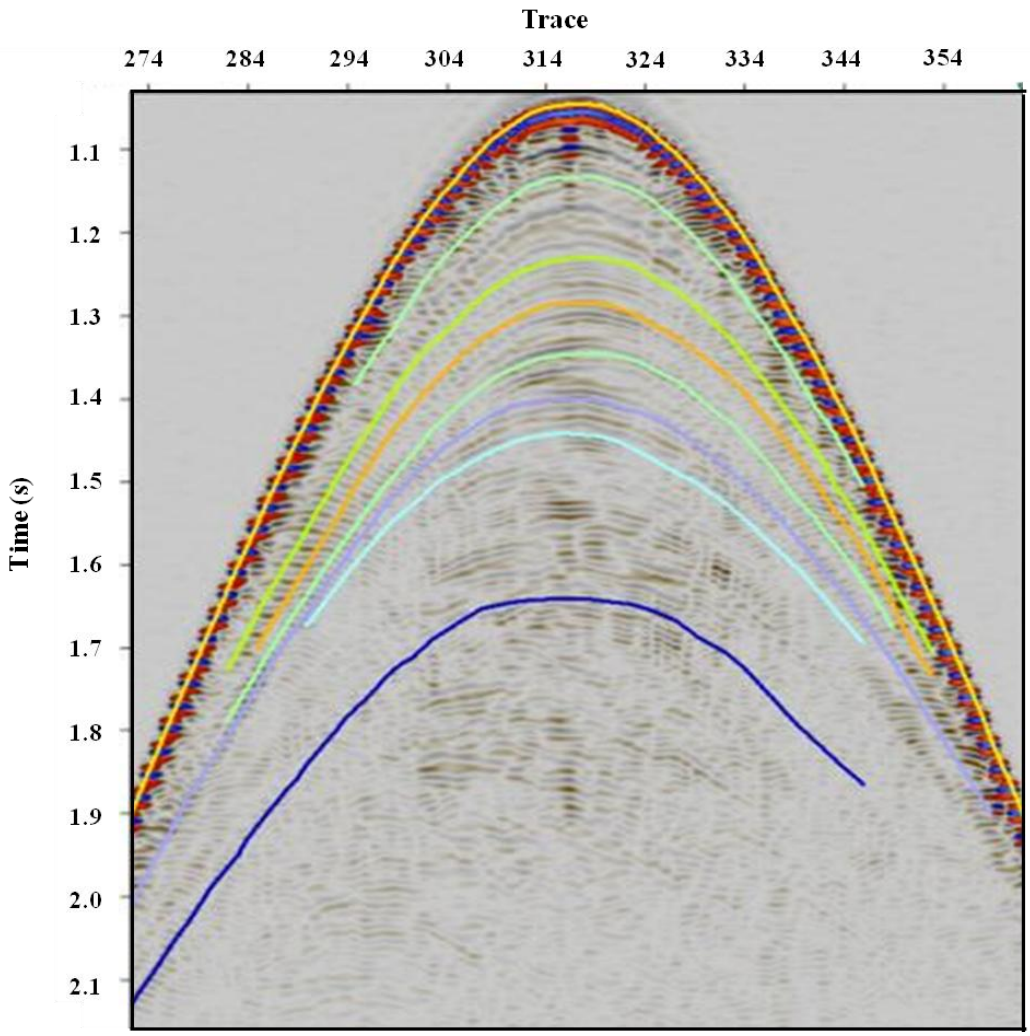


Fig. 3. The picked reflections on the hydrophone component of OBS 7

After setting up the initial velocity–depth model and picking the travel times, the inversion of travel times of Zelt and Smith was performed. The inversion employed a forward ray-tracing step and damped least-squares inversion step to modify the model parameters (velocities and/or depth of layers) by minimizing the difference between the observed and calculated travel times.

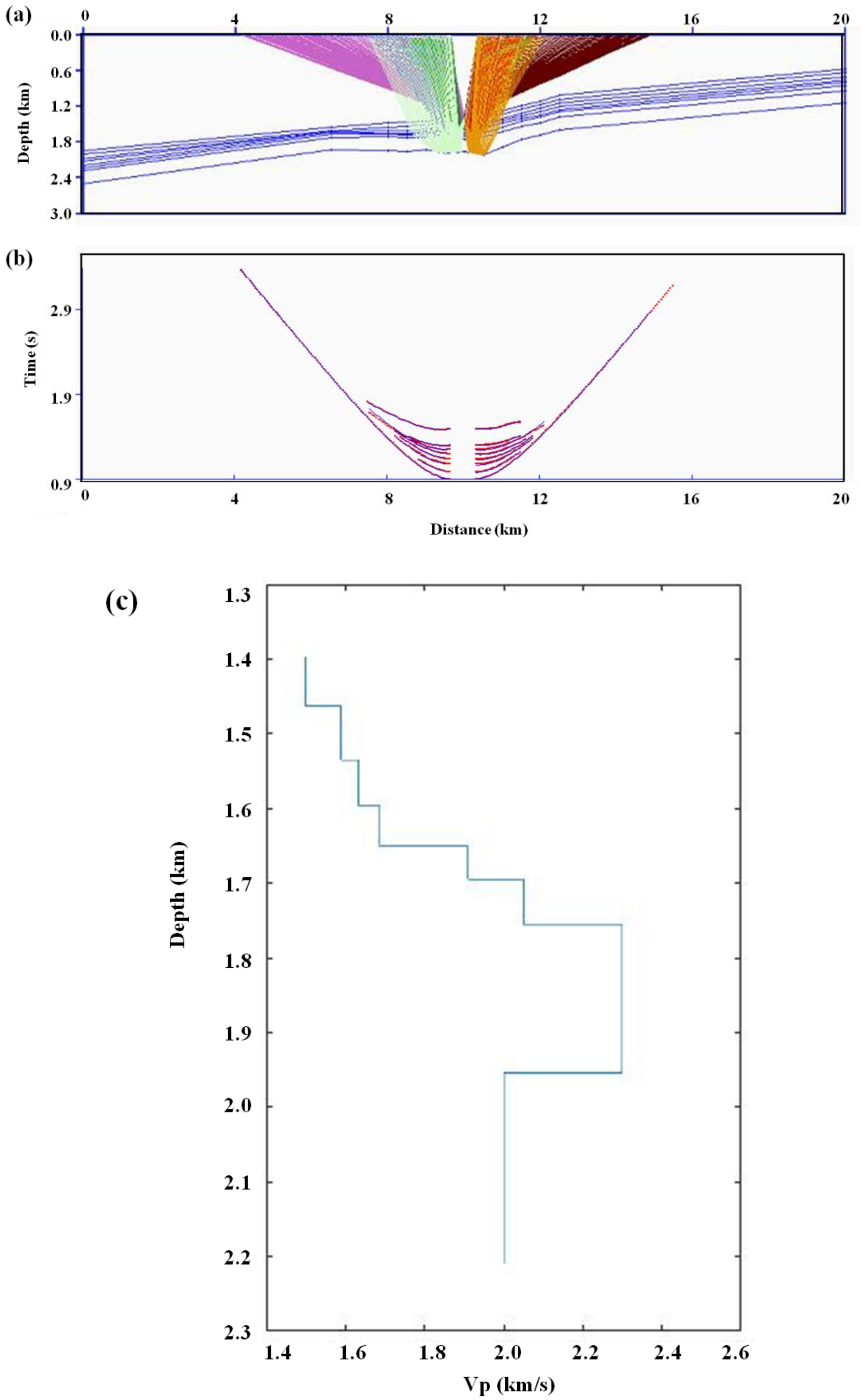
b. S-wave velocity inversion

S-wave velocity model can be obtained by inverting the Poisson's ratio within RayInvr once a satisfactory P-wave velocity model had been established (Exleyet al., 2010). The depths of the subsurface layers, and the corresponding P-wave velocities are held constant during the travel time modeling of the converted S-waves, and the only variable parameter is the Poisson’s ratio, which is finally translated into S-wave velocity. However, estimating the S-wave velocity model is relatively difficult and time consuming because it relies heavily on the correlation of events on P and S-wave components.

Description of the main results obtained

During the STSM, I have learnt how to analyze ocean bottom seismometer (OBS) data, the main steps and methods are: (a) OBS processing, including locate and orient three components of the OBS instrument by inversion of first arrival and hodogram analysis, seismic processing of four components in order to improve the data quality; (b) P-wave velocity analysis. Firstly, set up initial velocity-depth model combining the multichannel seismic data and OBS data; then pick the corresponding reflections on the hydrophone or vertical component; finally, perform the inversion of travel times of Zelt and Smith by using the RayInvr software. (c) PP- to PS-wave data correlation based on synthetic seismograms and travel time tables; (d) S-wave velocity analysis. S-wave velocity model can be obtained by inverting the Poisson's ratio. In addition, I have learnt how to use the inversion software (RayInvr) and how to perform the travel time inversion and obtain a good velocity model. It is worth to mention that this exchange contributes to my knowledge about the indirect methods used to detect gas hydrate and free gas and seismic processing that can be useful to my PhD and my future research career.

We performed the traveltime inversion and obtained the P-wave velocity model. When we perform the inversion, the picked travel time error is an important inversion parameter, here we give this error the same value to all the horizons as 0.002 s. Finally, the comparison between the observed and the calculated travel times shows a very good agreement (Fig. 4(b)). The ray tracing through the model (Fig. 4(a)) and the corresponding travel time fit (Fig. 4(b)) are shown for seismic data from the OBS 7. Fig. 4(c) shows the P-wave velocity-depth profile extracted at the station of OBS7. The RMS travel time residual of 0.008 s was achieved with a normalized chi-square value of 29.127 for this OBS station. The inversion summary from OBS 7 is shown in Table 2.



(a)
0
4
8
12
16
20
Depth (km)
0.0
0.6
1.2
1.8
2.4
3.0
(b)
Time (s)
2.9
1.9
0.9
Distance (km)
(c)
Depth (km)
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
1.4
1.6
1.8
2.0
2.2
2.4
2.6
Vp (km/s)

Fig. 4. (a) Ray diagram through the model. (b) The fit between the observed (red dots) and the calculated (blue lines) travel times. The time is reduced with a velocity of 8 km/s. (c) The P-wave velocity-depth profile obtained at the station of OBS7.

Table 2 The summary of the travel time inversion for OBS 7

phase	npts	Trms	chi-squared
1	213	0.006	32.891
2	47	0.003	9.925
3	67	0.008	69.430
4	64	0.006	9.416
5	64	0.006	9.731
6	93	0.015	60.529
7	58	0.008	17.165
8	81	0.003	2.702

Number of data points used: 687

RMS traveltime residual: 0.008

Normalized chi-squared: 29.127

We know that correlation of events on P and S-wave components is very difficult and time consuming, what's more, the geometry is very complicated and the data quality is poor, so it is huge work to obtain a good S-wave velocity model in one month. Now we are working on it and hope to get a good velocity model.

Future collaboration with the host institution

The collabration with the host institution has been very successful and productive. My knowledge about OBS data analysis has been improved. Due to the short time of STSM, we have only got the P-wave velocity model. Furthermore, other OBS data also need to be processed and analyzed. So I hope to continue the collabration with the host institution.

Foreseen publications/articles resulting from the STSM

OBS data are very useful and necessary to investigate deeper layers and to obtain P-wave and S-wave velocity structures. We are working on the S-wave velocity analysis and other OBS data in order to estimate the presence and the amount of gas hydrate and free gas. We are planning to publish the results in a scientific article.