Oil & Natural Gas Technology

DOE Award No.: DE-NT0005638

Quarterly Report

October-December 2010

Remote Sensing and Sea-Truth Measurements of Methane Flux to the Atmosphere (HYFLUX project)

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Prepared for:
United States Department of Energy
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January 30, 2010

Office of Fossil Energy

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Executive Summary of HYFLUX Program Work

On 1 October 2008, Texas A&M University - Corpus Christi began work on the National Energy Technology (NETL) funded project Remote Sensing and Sea-truth Measurements of Methane Flux to the Atmosphere (HYFLUX). This portion of the project was Budget Period 1. Project management activities during Quarter 1 were dedicated to completing the project management plan and setting up sub-contracts with Scripps Oceanographic Institution, University of California, Santa Barbara, University of Southern Mississippi, and Texas A&M University-College Station. Discussions in relation to planning for the upcoming cruise were completed by email and conference call among the project investigators at the conclusion of Quarter 2. During Quarter 3, preparation for the seatruth cruise was the major focus of effort for all investigators. During Quarter 4, the investigators completed the seatruth cruise, curated the samples and data collected during the cruise, and submitted a report describing the results of the cruise.

Phase 2, budget period 2 for the project was initiated on 1 October 2009. Figure 1 shows a Gantt style chart outlining tasks during the quarterly period October through December 2010. This is the ninth quarter and next to last scheduled quarter of the project. During budget period two, work on the project had been largely over-shadowed by response to the Gulf of Mexico oil spill particularly for MacDonald, Garcia-Pineda, and Leifer. Kastner was also involved. Consequently, there was a diversion of effort away from project tasks that is being redressed as the project comes to a close. A no-cost extension of project deadlines was requested and has been allowed by DOE NETL managers.

Project investigators are now engaged in final reporting and development of publications for the fieldwork and remote sensing components of the program. A series of conference calls among the investigators has focused attention on the final report with associated publications. Because each of the disciplinary groups, i.e., remote sensing, air-sea flux, water column, bubble flux, and carbonate sequestration, has approached the question of methane flux from hydrate formations separately, care must be taken to coordinate the results into a coherent presentation. The PIs are conducting by-weekly phone conferences toward this goal.

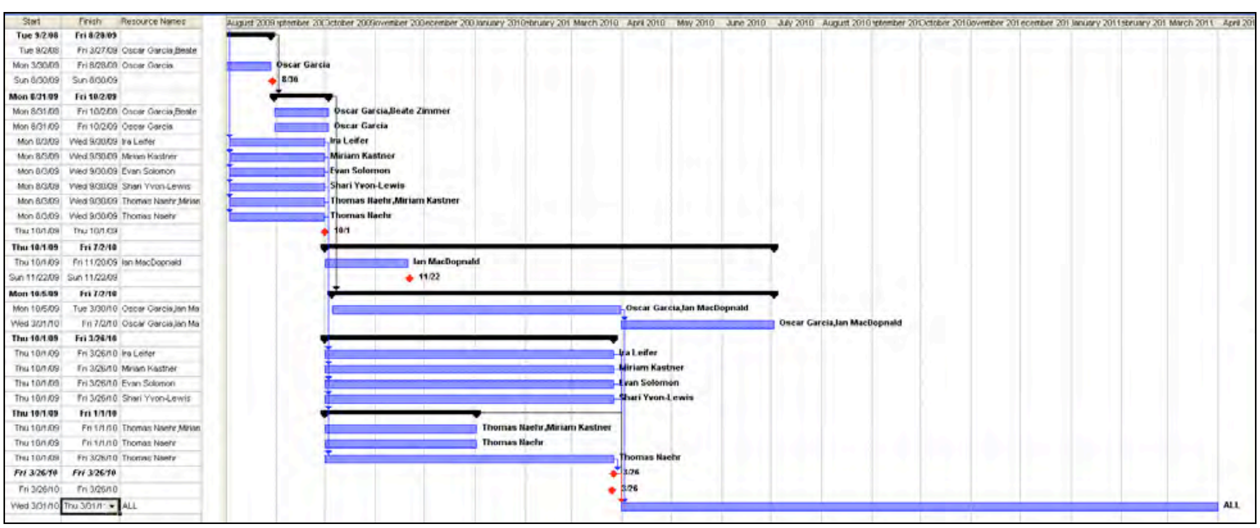


Figure 1: Gantt chart for 4th Quarter 2009 through revised project conclusion.

Progress, Results, and Discussion

Task 6 and 13 Other Regions Hydrocarbon Seep Inventory

Our collaborators at the University of Bremen, Germany completed their report on the Black Sea expedition. The review of ENVISAT SAR had indicated natural oil seeps in the Black Sea territorial waters of Ukraine, Georgia, Russia, and Turkey. Due to difficulty in obtaining permits, only the site off Georgia was investigated. Sampling at the Colkheti seep, which feature prominent SAR targets, produced oily sediment samples, oil and water samples, and a detailed AUV survey of the site. A detailed report on their findings is provided as Appendix A.

Task 13.1 Image Analysis

The image analysis is largely complete. The following discussion briefly describes the procedures used and the data products that are available for ongoing analysis and discussion. Previous effort in this area involved the acquisition, review, and analysis of over 600 synthetic aperture radar (SAR) images. The advent of the BP oil discharge provided the occasion for tuning the TCNNA algorithm used for semi-automated detection of floating oil as well as a major addition of SAR images from the northeastern Gulf of Mexico, which showed natural seeps as well as the discharged oil. By the end of December 2010, the remote sensing group at Florida State University had completed collection of 686 SAR images with preliminary review for weather compliance (Figure 2A). This included extra review to increase the coverage in the eastern Gulf of Mexico, particularly in the region of the recently opened eastern lease area.

Of these 686 SAR images, 307 were judged weather compliant and were analyzed for presence of specular targets related to natural seepage using the TCNNA approach (Figure 2B). Weather compliance was confirmed by the presence of specular targets within the image. The SAR algorithm extracts from the image a polygon outlining the area of suspected oil on the ocean surface (Garcia-Pineda, Zimmer et al. 2009). For each polygon, a manual review of the preliminary file identifies the proximal end of the target with respect to the seafloor source; these targets are designated Oil Slick Origins (OSO). For a given image, OSO targets are clustered in "neighborhoods" equivalent to radial distances of 1.25 km (Garcia-Pineda, MacDonald et al. 2010) and, when multiple OSOs are present, the centroid (average coordinates) of these points defines their common source. The locations on the sea-surface are potentially offset from the sea-floor origin due to lateral drift as the stream of oil rises upward. Previous results indicate that there is a linear relationship between water depth and the maximum about of lateral drift

$$\text{radial drift} = 1.2346 \times \text{water depth} + 796.9$$

For example from a depth of 1500 m, the maximum offset between the seafloor source and the OSO would be about 2648 m. To complete the estimate of where seep formations are located based on satellite detection (Garcia-Pineda, MacDonald et al. 2010), we clustered OSO centroids based on this depth-dependent relationship and then took the average position of OSO centroids (from multiple images) and took these positions as the probable location for seep formations (Figure 3A). This result indicates that there are 1081 seep formations in the Gulf of Mexico, comprising a mean of 1424 individual vents (minimum 1105, maximum 1925). Additional work is underway to develop additional results from this analysis.

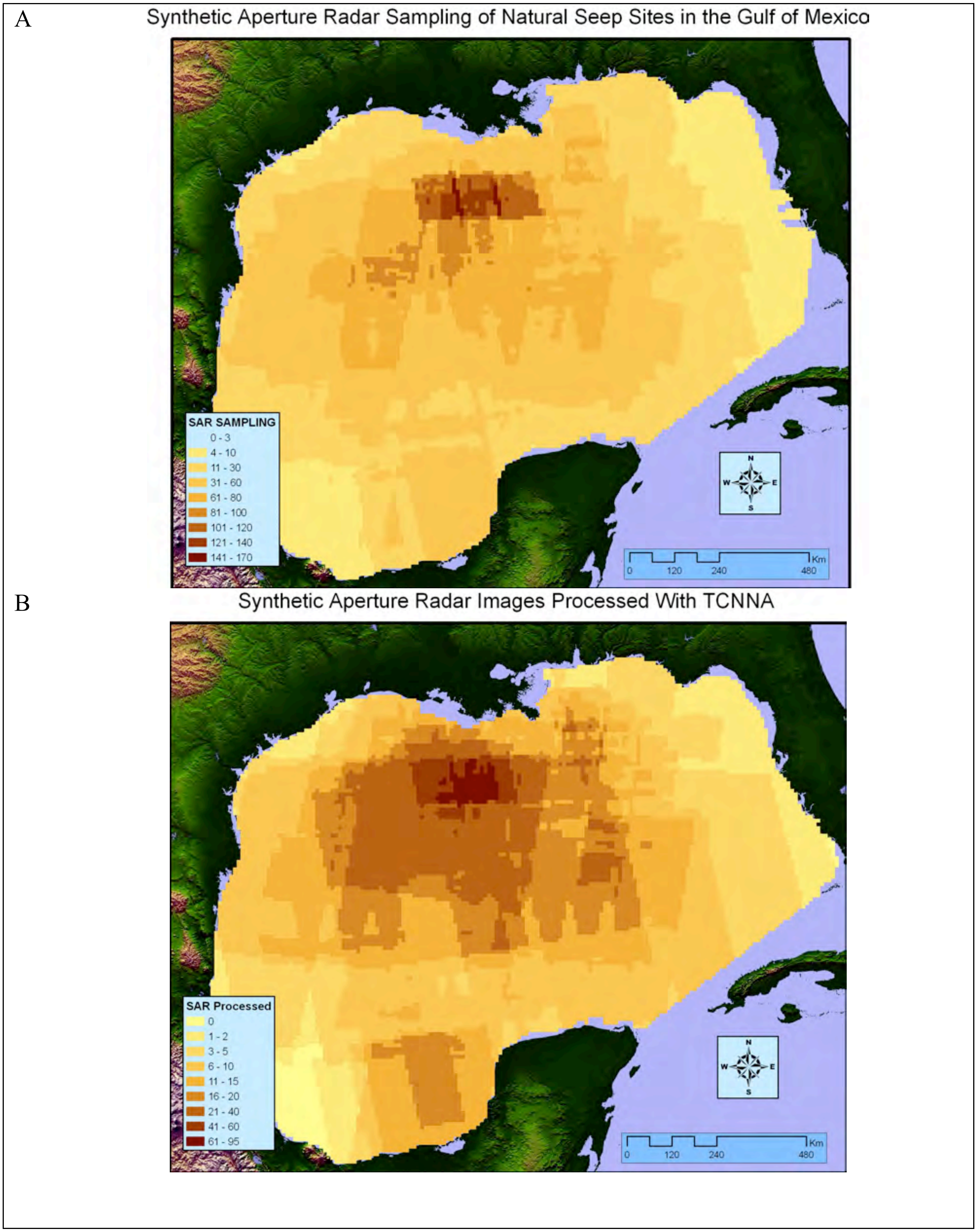
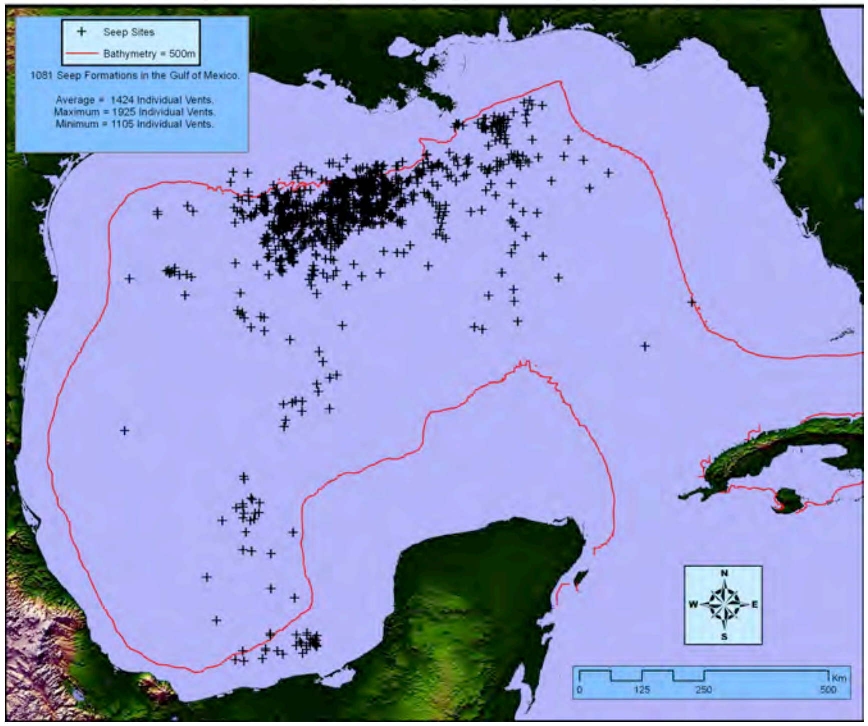


Figure 2 :Final image collection (A) of 686 SAR scenes and distribution of 307 images that were judged weather compliant and fully processed (B).

A



B

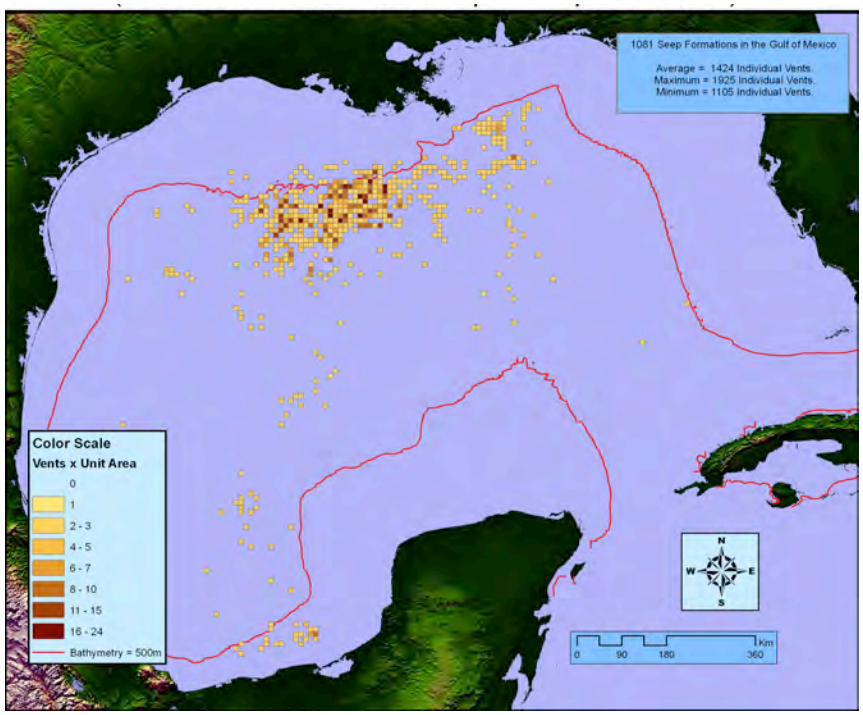


Figure 3: Active seep formation in the Gulf of Mexico: A. Distribution of seep formation centroids; B. Numbers of active vents among 10-km gridded locations.

The co-occurrence of active seep vents and exposed or shallow gas hydrate has been thoroughly documented (see for example: Macdonald, Guinasso et al. 1994; Lapham, Chanton et al. 2003).

Therefore, the number of active vents is one predictor of the amount of hydrate subject to potential destabilization under changing bottom water temperatures. In Figure 3B we show the gridded (10-km) density of vents across the Gulf. As expected, maximum densities were seen in the Green Canyon area of the north-central Gulf slope.

During the BP oil discharge, findings of the National Research Council (National Research Council Committee on Oil in the Sea 2003) were frequently cited as a source for the magnitude of natural oil seepage entering the Gulf on an annual basis. These actual data on which these results were based were entirely the very preliminary analyses of satellite images, e.g. MacDonald et al. (1996) and Mitchell et al. (1999). The TCNNA extraction produces precise and repeatable segmentations of the SAR images from which the area of floating oil can be estimated. Current effort is focused on calculating the mean area of ocean surface covered by oil from natural sources. This preliminary result is a straightforward product of the image and GIS analysis. Research is underway to best determine the time-course of natural oil slicks. Knowing how long oil persists under Gulf of Mexico conditions would permit us to estimate the rate at which oil was being added from the seafloor sources. A separate research question concerns the confidence estimates on these mean values.

Task 13.2 Database Development and Update

This task requires disseminating interpreted satellite images and locations of probable seeps. A graphical user interface has been developed to aid extraction of images and results from the existing ArcGIS database of results and extracted images from the Gulf of Mexico. The project has received significant assistance from the NOAA satellite group, which made collections of new SAR data during the sea-truth cruise and is supporting GUI development by sharing processing routines and procedures. This database was consulted extensively during the Gulf of Mexico oil spill as an authoritative indicator of natural seeps as opposed to spill events.

Recent contact with Bureau of Ocean Energy Management have indicated an interest in linking remote sensing estimates of where natural seeps are located to the BOEM geophysical characterizations of the U.S. EEZ. This would seem like a fruitful collaboration, but consultation with agency sponsors is required.

Task 14 Bubble Flux Analysis

This task is being carried out by Leifer Lab at University of California, Santa Cruz. Efforts during this quarter have focused on two areas, bubble video analysis, and numerical modeling. A short sequence of bubble video has been analyzed, revealing a strongly radius dependent bubble size distribution with a peak at circa 2500 µm radius. Further video representing other bubble vents is being analyzed.

In addition, the numerical bubble model has been improved in terms of its treatment of temperature gradients. Specifically, a CTD profile can be selected and the temperature-dependency of gas parameters like solubility and diffusivity is explicitly looked up. However, the temperature dependency of the rise velocity is set at the depth of release. Future plans to completely incorporate temperature effects will involve an iterative approach (to avoid excessive computational costs), with the necessary structure now outlined in the code. The numerical model also now allows easy selection of different bubble size distributions for simulations, and new standard graphical outputs to allow exploration of the models treatment of different gases.

Several parameters also have been added, including a parameterization that attempts to account for bubble oiliness, and improved compressibility calculations for natural gas mixtures, as well as being able to select for type 2 hydrates. This is in anticipation of new solubility parameterizations being incorporated thanks to collaboration with Gregor Rehder.

Plans are in place to compare model output with vertical geochemical data from Miriam Kastner and Evan Solomon, to validate the model. The model then will be run for a range of depths and a global bubble size distribution to derive a transfer efficiency for methane to the mixed layer for emissions with respect to depth. This effort is planned for completion in time for a submission to a special issue of GML, due in May 2011.

Task 15 Water Sample Flux Analysis

This task is being carried out by Evan Solomon at University of Washington in association with Kastner Lab. Analysis has been completed all the pore fluid analyses including the Rhizon samples. The group has also analyzed about 70% of the samples for methane C isotopes; these samples were reanalyzed for methane concentrations. These samples were also analyzed for DIC concentrations and C isotopes. Solomon has additionally analyzed 3 ROV profiles and 4 CTD casts at MC118 for C1-C4 concentrations.

Task 16 Water Column Flux Analysis

To date, preliminary flux calculations have been completed by for the MC118 and the GC600 site.

Task 17 Air-Sea Flux Analysis

Lei Hu and Shari Yvon-Lewis have revised a manuscript describing the fluxes of methane based on surface water and atmosphere concentrations. This text is being reviewed by other members of the team prior to being submitted to Earth and Planetary Science Letters. Present effort is directed at estimating the surface cross-section of anomalous methane concentrations resulting from persistent seeps sampled during the 2009 cruise.

Task 18 Initiation of Sediment Analysis

This task is being carried out by Naehr Lab at Texas A&M University-Corpus Christi. The analytical tasks have been completed and are presently in QA/QC phase. Pore water and sediment data are currently being used to model carbonate precipitation rates (see Task 19).

Task 19 Initiation of AOM and Carbonate Precipitation Study

This task is being carried out by Naehr Lab at Texas A&M University-Corpus Christi. Porewater and sediment data are used to model carbonate precipitation rates. We are using data from site GC 600 to model rates of AOM and authigenic carbonate precipitation. Due to some operational difficulties with the C.CANDI modeling software, we will now be using an alternate modeling approach (i.e., Ussler & Paull, 2008)[1] to determine AOM and carbonate precipitation rates.

[1]Ussler III, W. and Paull, C.K., 2008. Rates of anaerobic oxidation of methane and authigenic carbonate mineralization in methane-rich deep-sea sediments inferred from models and geochemical profiles. Earth and Planetary Science Letters, 266(3-4): 271-287.

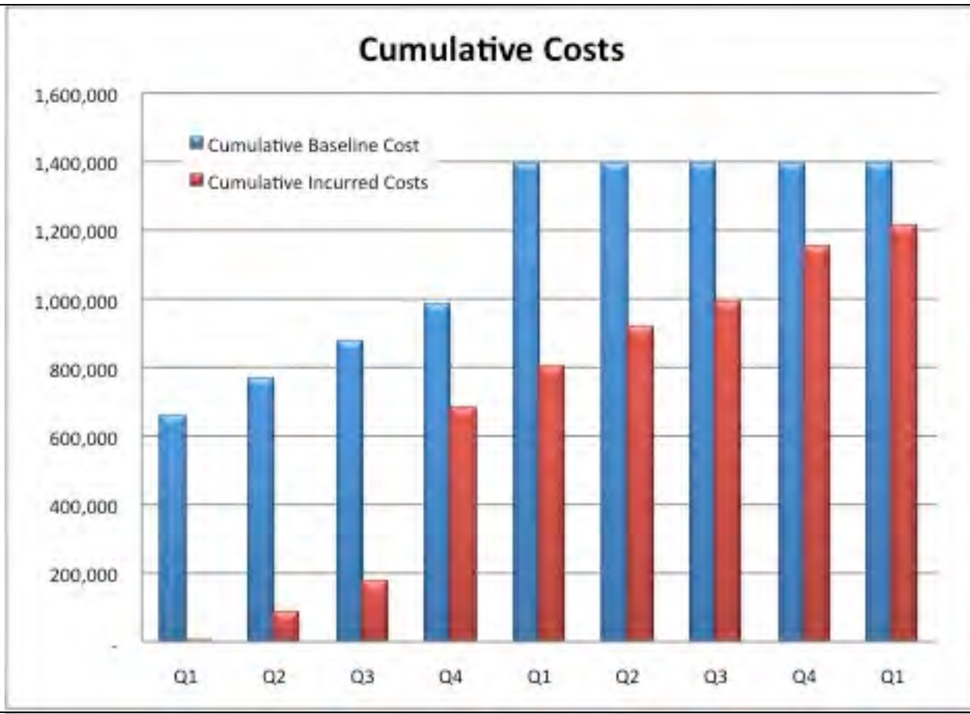
Presentations and publications

No presentations or presentations have cited the HYFLUX project in the October to December 2010 time period. MacDonald will travel to Boston over 15 and 16 March to participate in a DOE and USGS hydrate program review.

Conclusion

The HYFLUX project concluded its relatively higher risk field portion and has reached >85% completion of the analytical phase. Completion of reporting phase was delayed due to issues arising from the Gulf of Mexico oil spill.

Cost Status



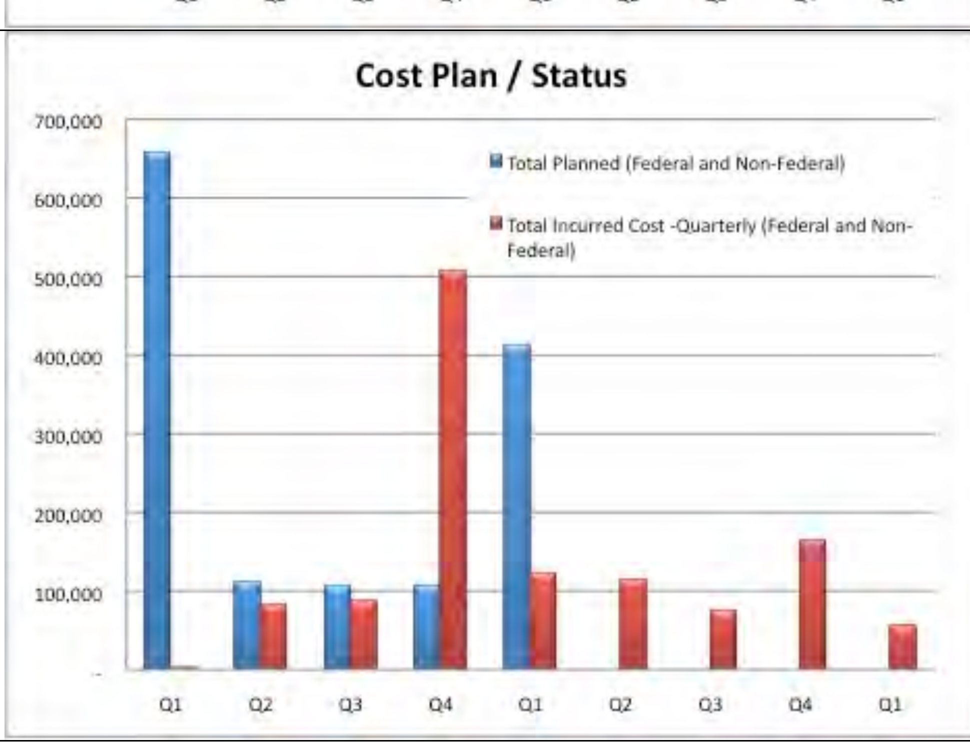


Figure 4: Expenditures by Quarter. Cumulative projected costs (upper panel) and cost status as of Quarter 9.

Milestone Status

No Milestones achieved during this reporting period.

Problems or Delays

A no-cost extension of the project was granted. Final reporting will be completed prior to 31 July 2011.

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National Research Council Committee on Oil in the Sea (2003). Oil in the Sea III: Inputs, fates and effects. ISBN: 0-309-50551-8.

Appendix A: Preliminary results of the Black Sea SAR project

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Preliminary results of the Black Sea SAR project

In advance to the MSM 15/2 cruise to Ukrainian and Georgian parts of the Black Sea in May 2010 approximately 120 ENVISAT *Advanced Synthetic Aperture* (ASAR) *Image Mode Precision images* (IM_P) with a resolution of about 30 m were analyses in order to identify sites where natural oil seepage occurs. All images were loaded to a geographic information system and analysed manually. The origins of potential natural oil slicks (OSOs) were marked in an image specific point shape file. All resulting point shape files were overlaid to identify OSO cluster. The cluster identification was done manually, since we struggled to get as nice results as you achieve applying the dendrogram and cluster analysis. (I believe it's mainly due to the fact that we do not have knowledge on surface currents and possible depth dependent deflections of bubble plumes).
In the Ukrainian parts of the Black Sea many *potential* OSOs were identified upon first image analyses, however no site showing persistent slicks could be identified. Also, no evidence for oil seepage in Ukrainian waters was found during the cruise, though many sites of gas seepage have been found and were known before.
The situation is different for Georgia. The analysis of 40 ASAR IM_P scenes in the study area yielded clear evidence for oil seepage between 2003 and 2010 (the years images were available for). In the following a number of figures illustrating preliminary results of the image analyses, cruise MSM15/2 and archived data from the cruises M72/3 in 2007(Bohrmann et al. 2008) and TTR15 (IOC Technical Series No. 72*)* in 2005 are shown.
The image analyses allowed identifyingg 8 sites where natural oil seepage occurs (Fig. 1). The most pronounced oil slicks and the highest persistency of oil slicks were found above two structures named Colkheti Seep and Pechori Mound, followed by site G1. Sites G2 to G6 do not show oil slicks on most of the analysed images, but the occurrence of seepage seems very likely. Tab. 1 gives an overview of how many images covering the different sites were available and how many of them showed oil slicks. Plate 1.1 and 1.2 present sub-scenes of ASAR images showing oil slicks at the different sites. The most prominent sites are Colkheti Seep and Pechori Mound which are shown in detail in Fig. 2, 3 and 4. These sites have been known from previous cruises (to my knowledge they were first mentioned in the TTR-15 cruise report 2005, but Gerhard and Heiko might prove me wrong).
Oil seepage has been observed at Colkheti Seep during one ROV dive in 2007 and the presence of oil in the shallow sediments was proven by gravity coring in 2005, 2007 and 2010. From cruise M72/3 (2007) hydroacoustic data acquired with the PARASOUND echosounder is available and a number of acoustic anomalies were detected. This *anomalies* do not appear as clear 'flares' but are rather blurred or undefined features and might thus not be useful to pinpoint locations of gas emanation. However, they are plotted in all following figures. Beside these sites, four distinct flares at Colkheti Seep and two at Pechori Mound were found. Their locations are indicated on all maps as well. Plate 2a) to c) shows sample echograms of these flares. The location where oil and gas seepage was documented during a ROV dive in 2007 is also indicated on Fig. 2 and 3. During MSM15/2 cruise last year surfacing oily bubbles were observed (see Plate 3a) and b)). This location is marked in the figures, too.
The bathymetry of Pechori Mound and surrounding areas was recorded with ship mounted MBES and processed to a 10 m resolution. The bathymetry of Colkheti Seep is based on an AUV survey in 2010, has a resolution of 1 m and shows the local morphology very detailed.
As ancillary data Fig. 6 and 7 show details of two sidescan sonar lines acquired with the MAK system during TTR-15 cruise with RV Prof. Logachev. However, the sidescan records do not allow clearly identifying different sediment properties or small scale morphological features of the seep sites as most of the differences in backscatter intensity seem to originate from the main morphological structures.
The site which follows Pechori and Colkheti in seepage intensity and persistency is G1 (see Fig. 1). This site was crossed by one PARASOUND line during the cruise in 2010 and a clear gas flare was found right at the location of the OSO cluster centre. An echograph of this flare is shown in Plate 2d). However, no further data is available for this location and neither for the sites G3 to G6.

Plate 3 shows again some images which confirm seepage at Colkheti seep. 3e) and g) give an impression how the seafloor and the crater structures in the bathymetry (Fig. 3) look like.
The last Fig. 8 illustrates the location of shale diapirs (originating from the Miocene Maikop formation (?)) which might create pathways and traps for the oil which is seeping out at the identified locations. The information on location and extent of these diapiric structures is taken from a map published by Tugolesov et al. (1985).

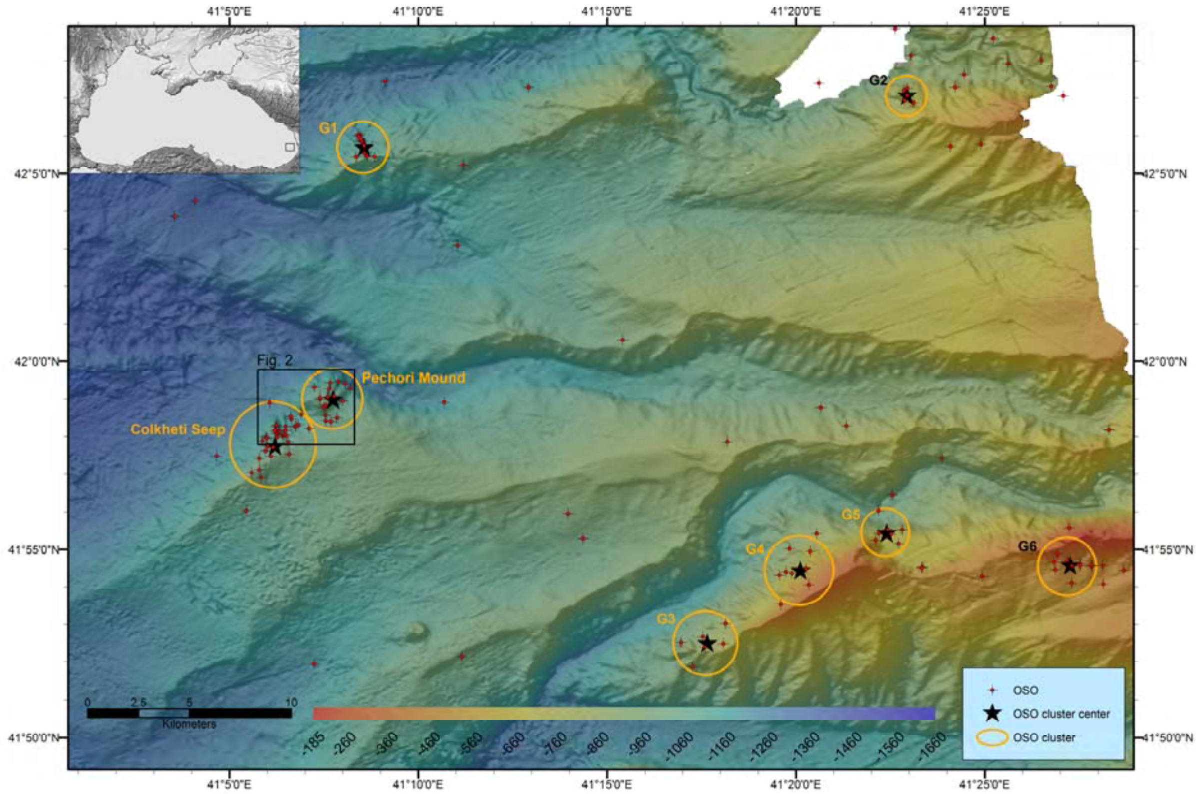


Fig 1. Shaded bathymetry of the study area offshore Georgia. Cluster of origins of natural oil slicks (OSOs) are indicated by circles, their spatial centres by stars. Individual OSOs are marked by crosses. The inset shows the location of the study area in the Black Sea.

Tab. 1 Number of images covering the individual oil seep sites indicated in Fig. 1 and the number of images showing evidence of active oil seepage.

Site name	No. images covering site	No. images showing activity
Colkheti Seep & Pechori Mound	13	12
G1	12	9
G2	17	8
G3	17	8
G4	17	8
G5	17	12
G6	17	9

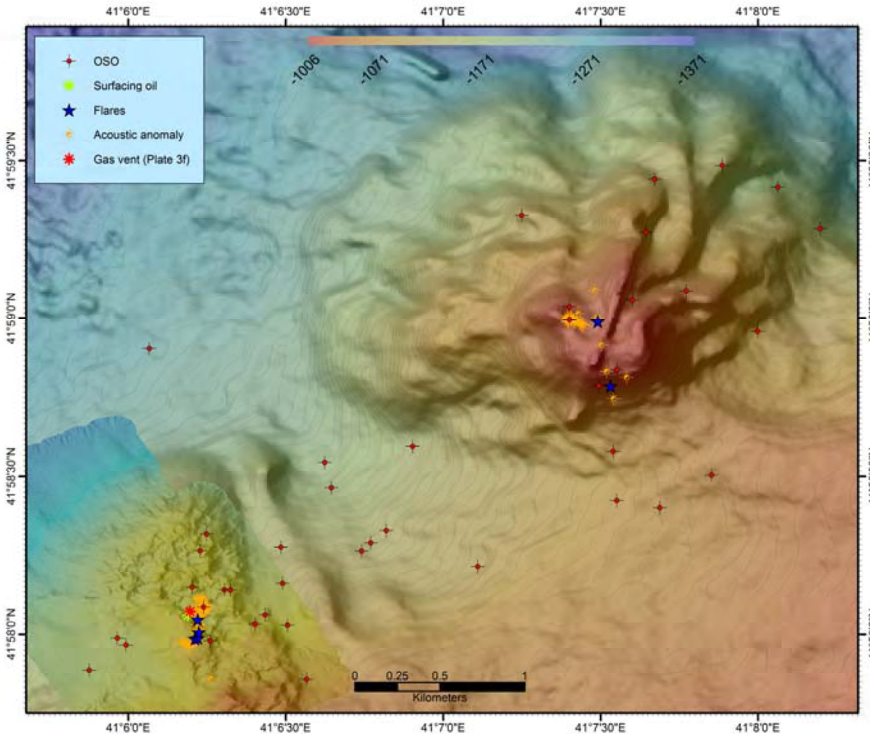


Fig. 2. Shaded bathymetry of Pechori Mound (upper right structure) and Colkheti Seep (lower left) (for location compare Fig. 1) with 5 m contour lines. Locations of acoustic anomalies and district gas flares detected with the PARASOUND echosounder are indicated as well as the location of one gas vent which was investigated during a ROV dive. Origins of sea surface oil slicks and the location of a site where surfacing oil bubbles were observed are shown.

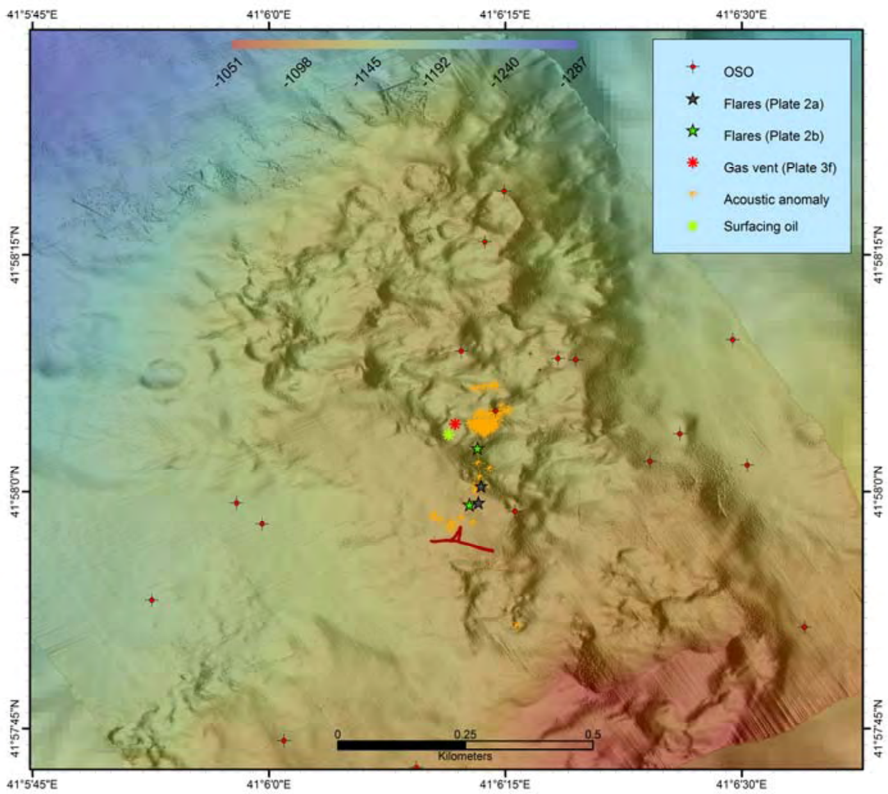


Fig 3. Shaded AUV bathymetry of the Colkheti Seep (1 m resolution) with 5 m contour lines showing the rough topography of the seep site. Acoustic anomalies in the water column detected by the PARASOUND echosounder are indicated. The red star shows a bubble stream found during a ROV dive (red and black line). Next to it the green star indicated the location of surfacing bubbles observed on the sea surface 3 years later.

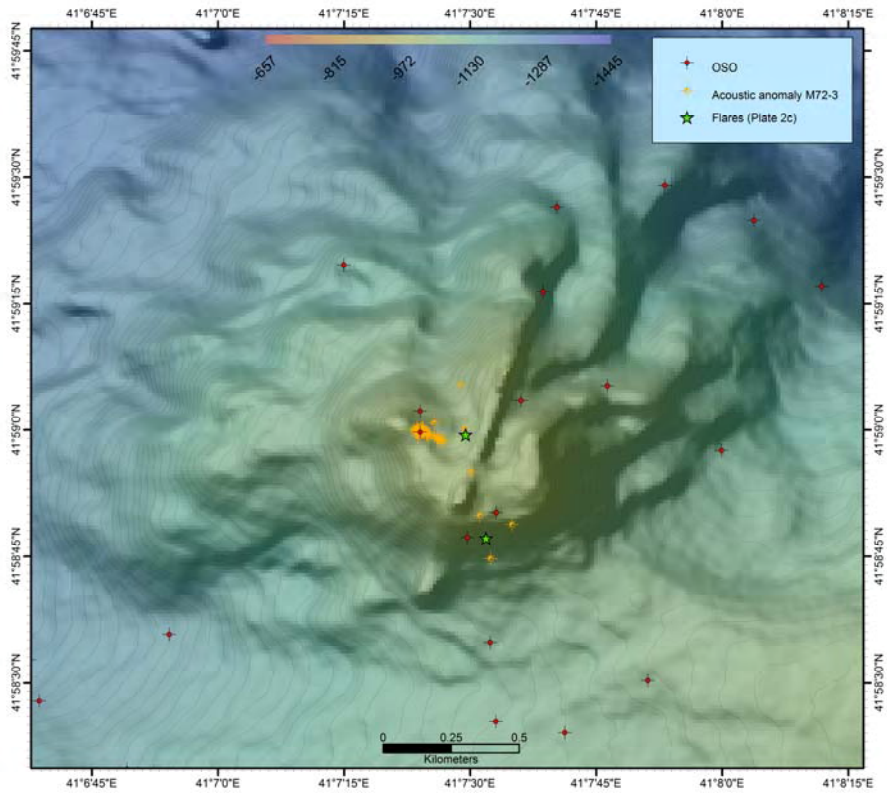


Fig 4. Shaded bathymetry with 5 m contour lines of Pechori Mound. Locations of acoustic anomalies and distinct flares in the water column detected by the PARASOUND echosounder are indicated.

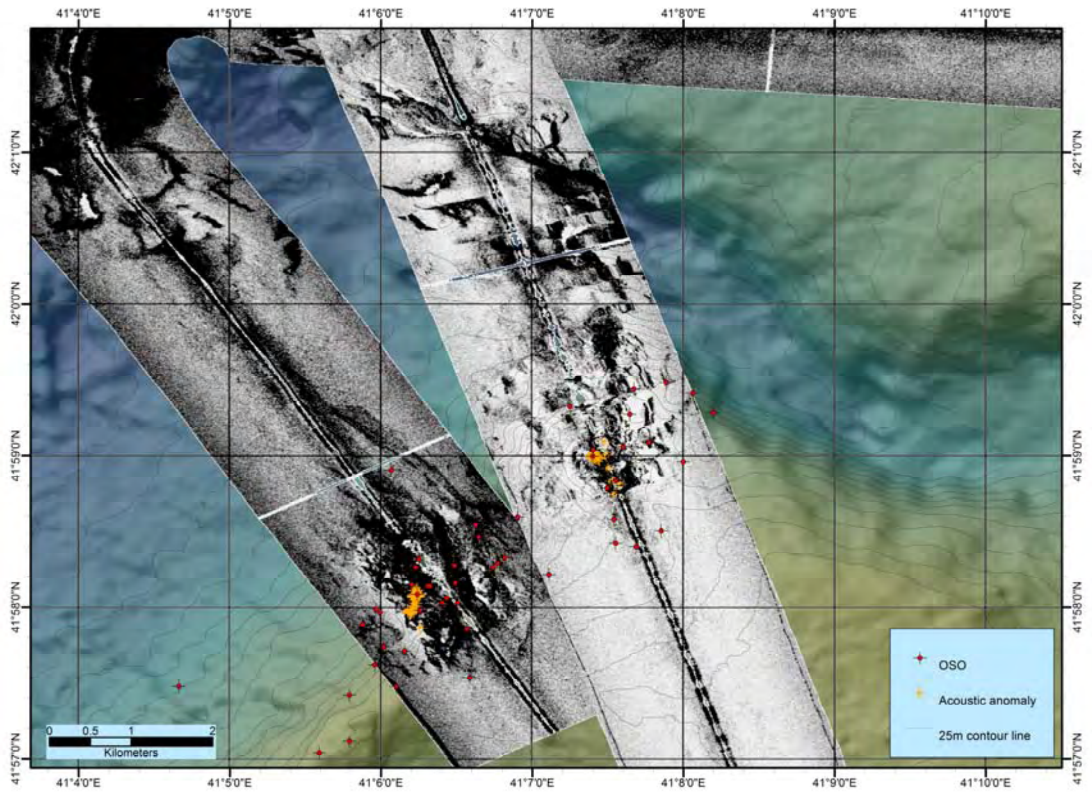


Fig 5. MAK sidescan sonar mosaic covering Colkheti Seep, Pechori Mound and the surrounding areas. OSOs and acoustic anomalies hinting to gas bubble release are shown (compare Fig. 3 and 4).

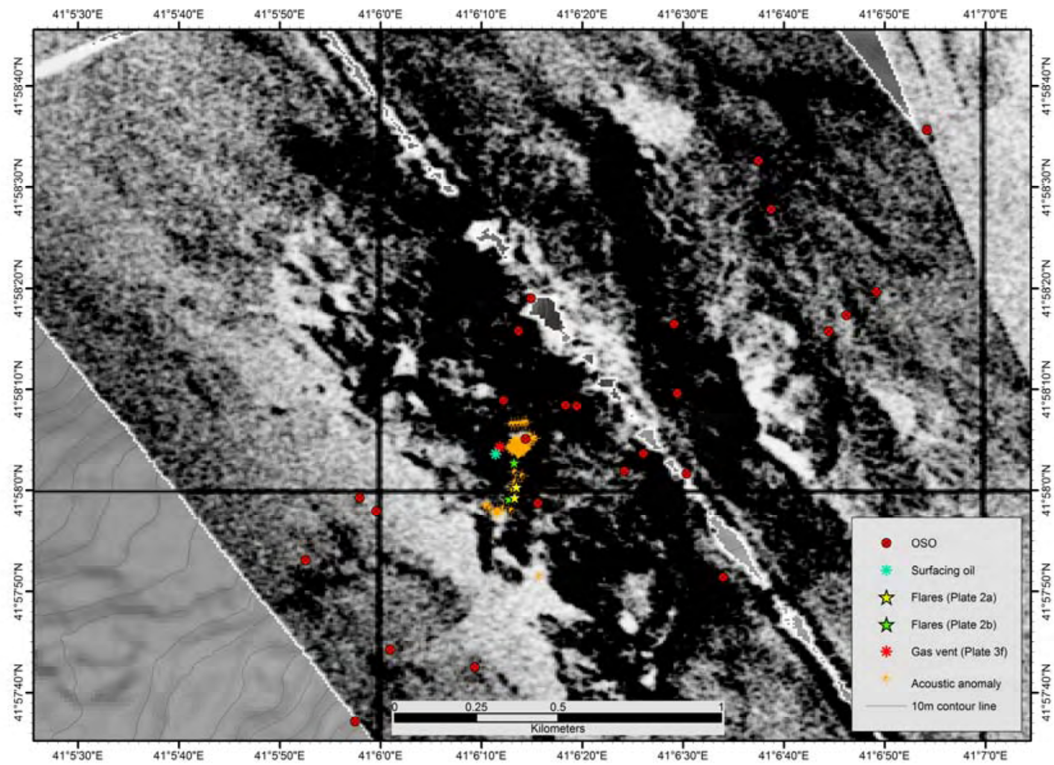


Fig 6. Detail of MAK sidescan sonar mosaic covering Colkheti Seep

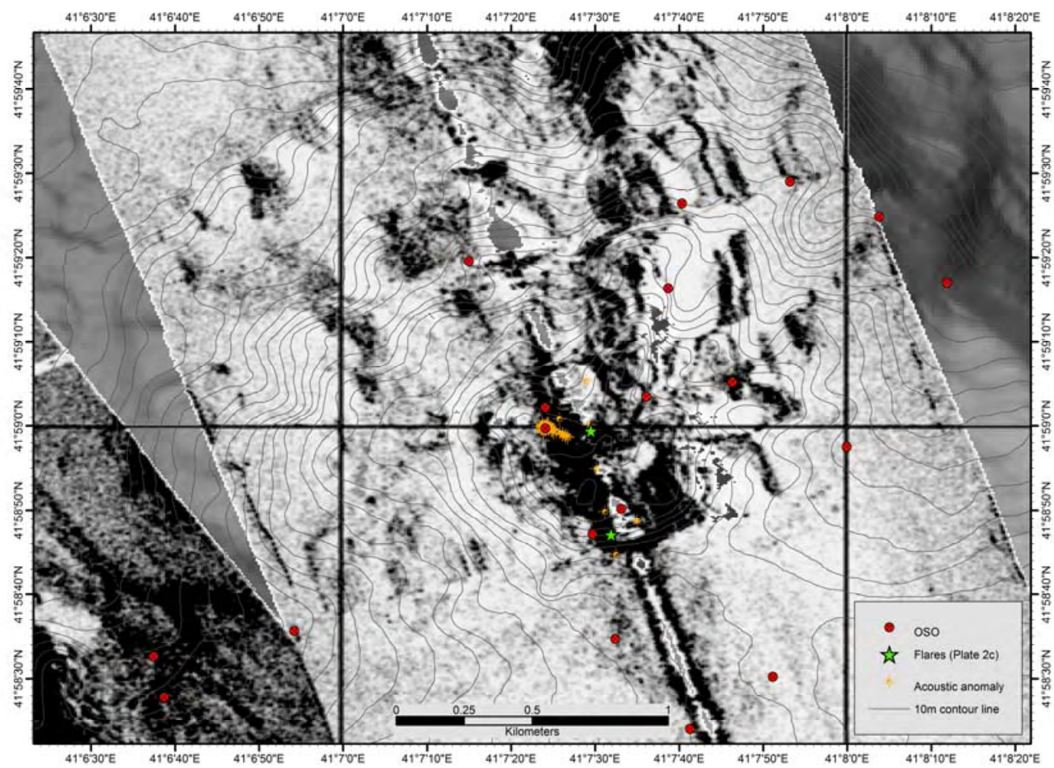


Fig 7. Detail of MAK sidescan sonar mosaic covering Pechori Mound.

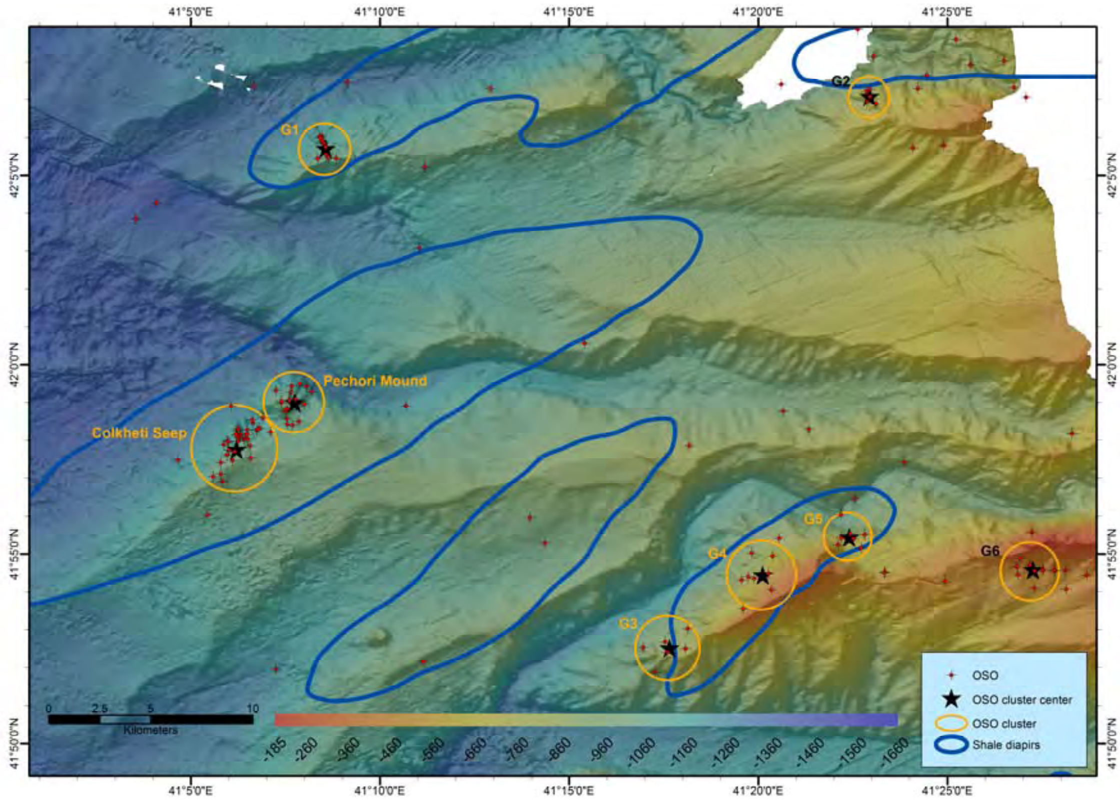


Fig 8. Overview map of the study area and oil seepage sites. The blue lines indicate the location of shale diapirs which might create pathways and traps for higher hydrocarbons originating from the Maikopian formation (location and shape of the diapiric structures from Tugolesov et al. 1985).

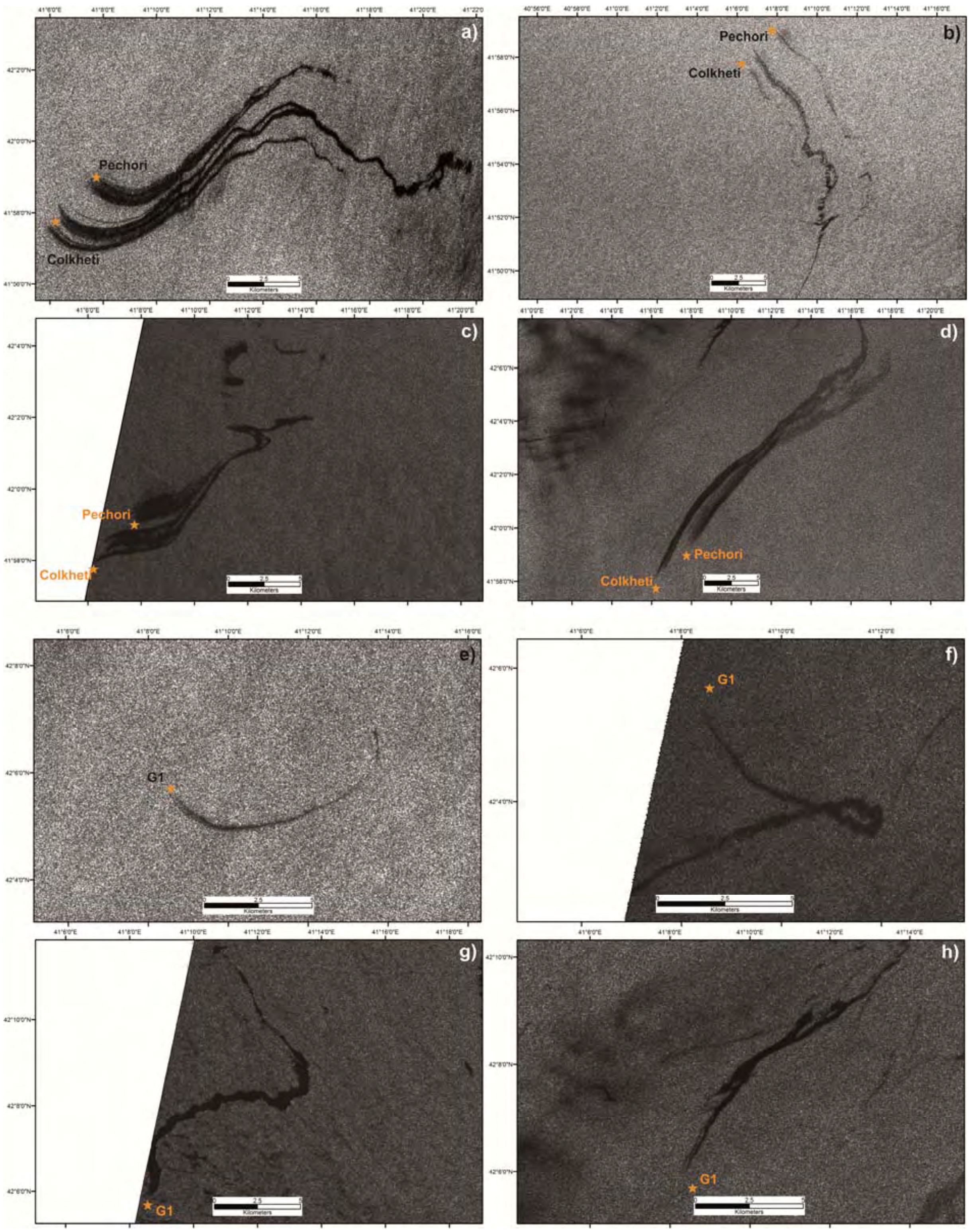


Plate 1.1. All images show sub-scenes of ENVISAT ASAR IMP images. Images a) to d) show oil slicks at Colkheti Seep and Pechori Mound. Images were acquired on 15 Sep 2003, 29 Dec 2003, 07 Feb 2007 and 14 May 2009. Images e) to h) show oil slicks at site G1 on 15 Sep 2003, 02 Jun 2004, 01 Aug 2007 and 14 May 2009. Note different scales of the sub-scenes. For location of the sites see Fig. 1. All images provided by the *European Space Agency*.

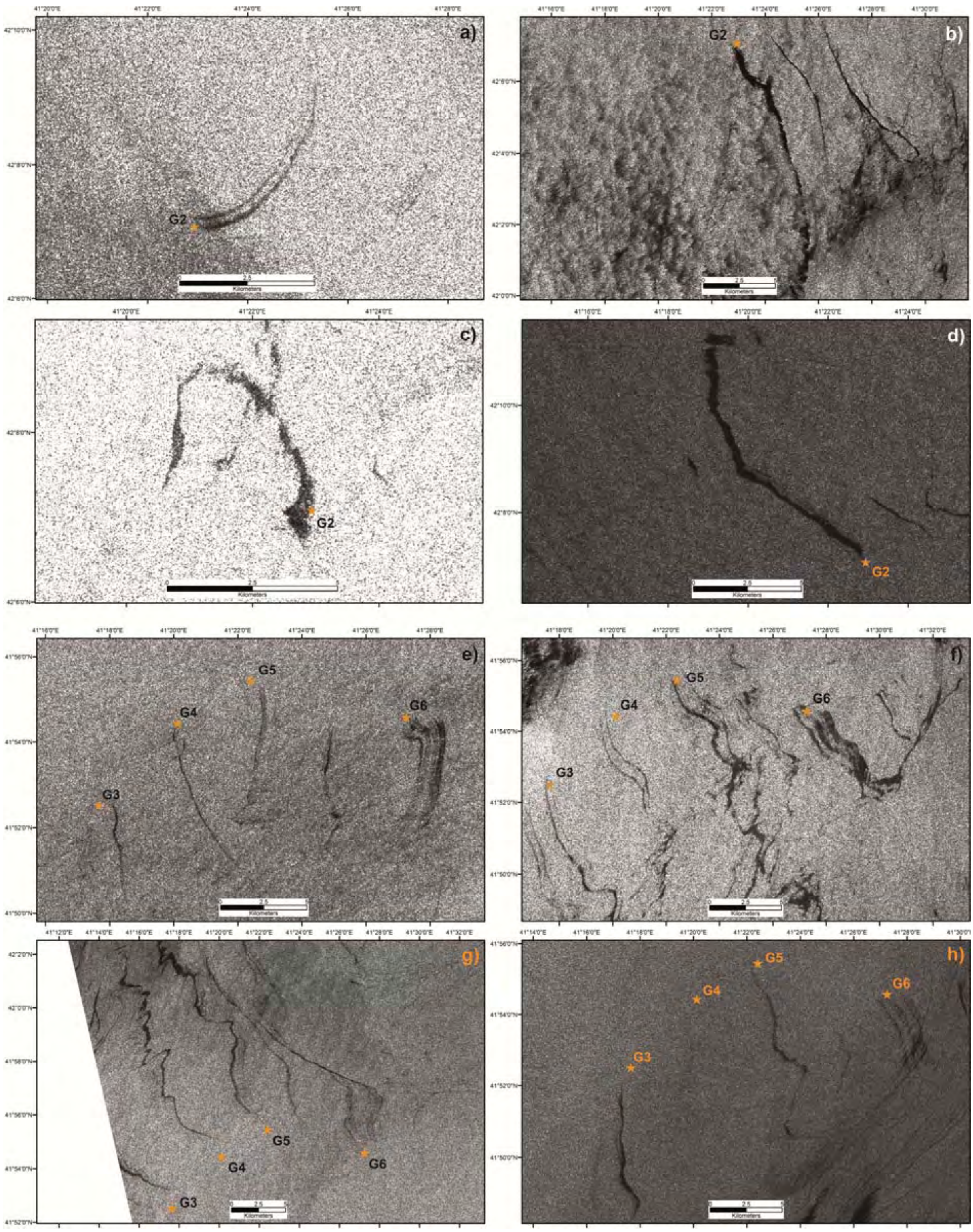


Plate 1.2. All images show sub-scenes of ENVISAT ASAR IMP images. Images a) to d) show oil slicks at site G2. Images were acquired on 15 Sep 2003, 29 Jul 2004, 31 Jul 2006 and 01 Aug 2007. Images e) to h) show oil slicks at sites G3 to G6 on 29 Dec 2003, 29 Jul 2004, 12 Oct 2006 and 08 Apr 2008. Note different scales of the sub-scenes. For location of the sites see Fig. 1. All images provided by the *European Space Agency*.

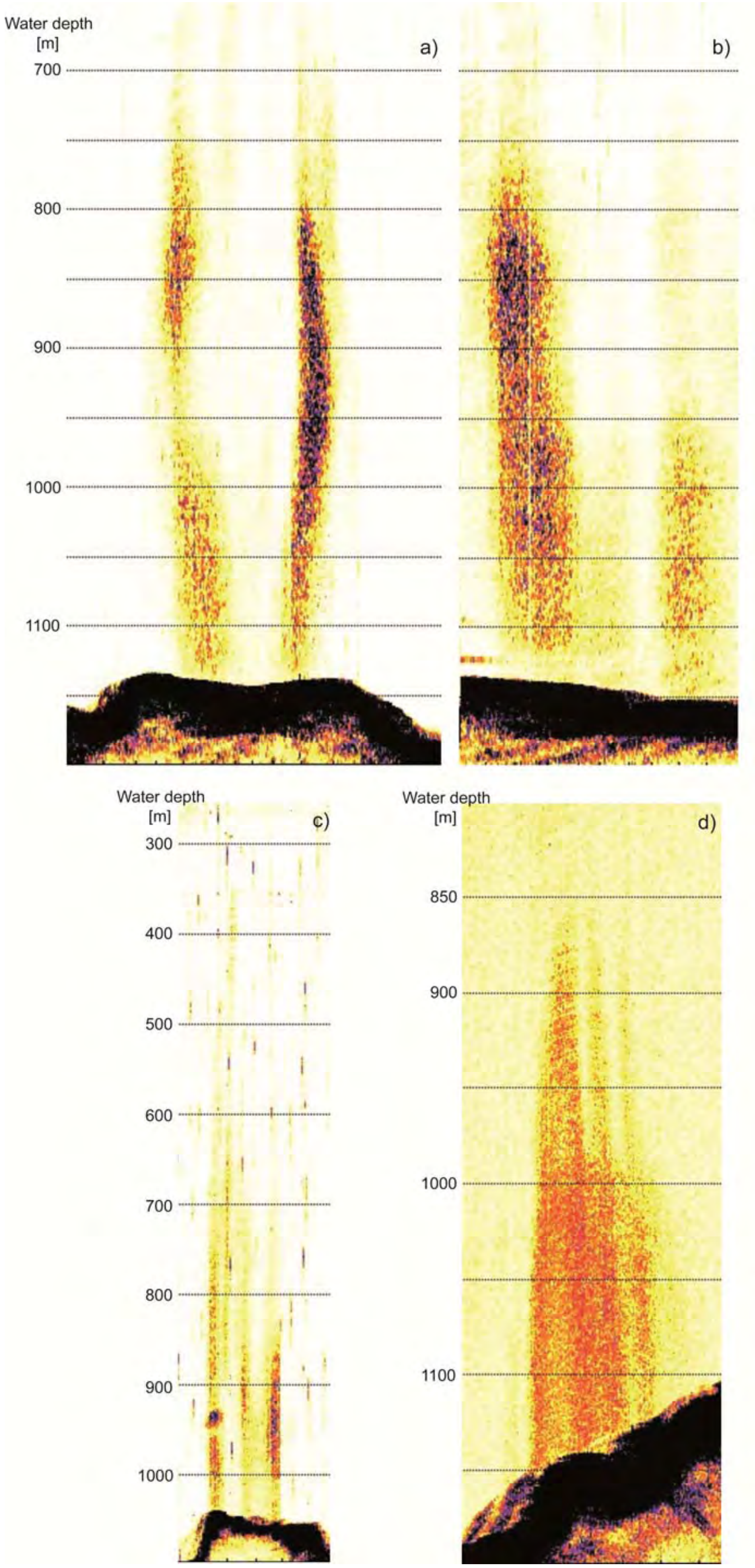
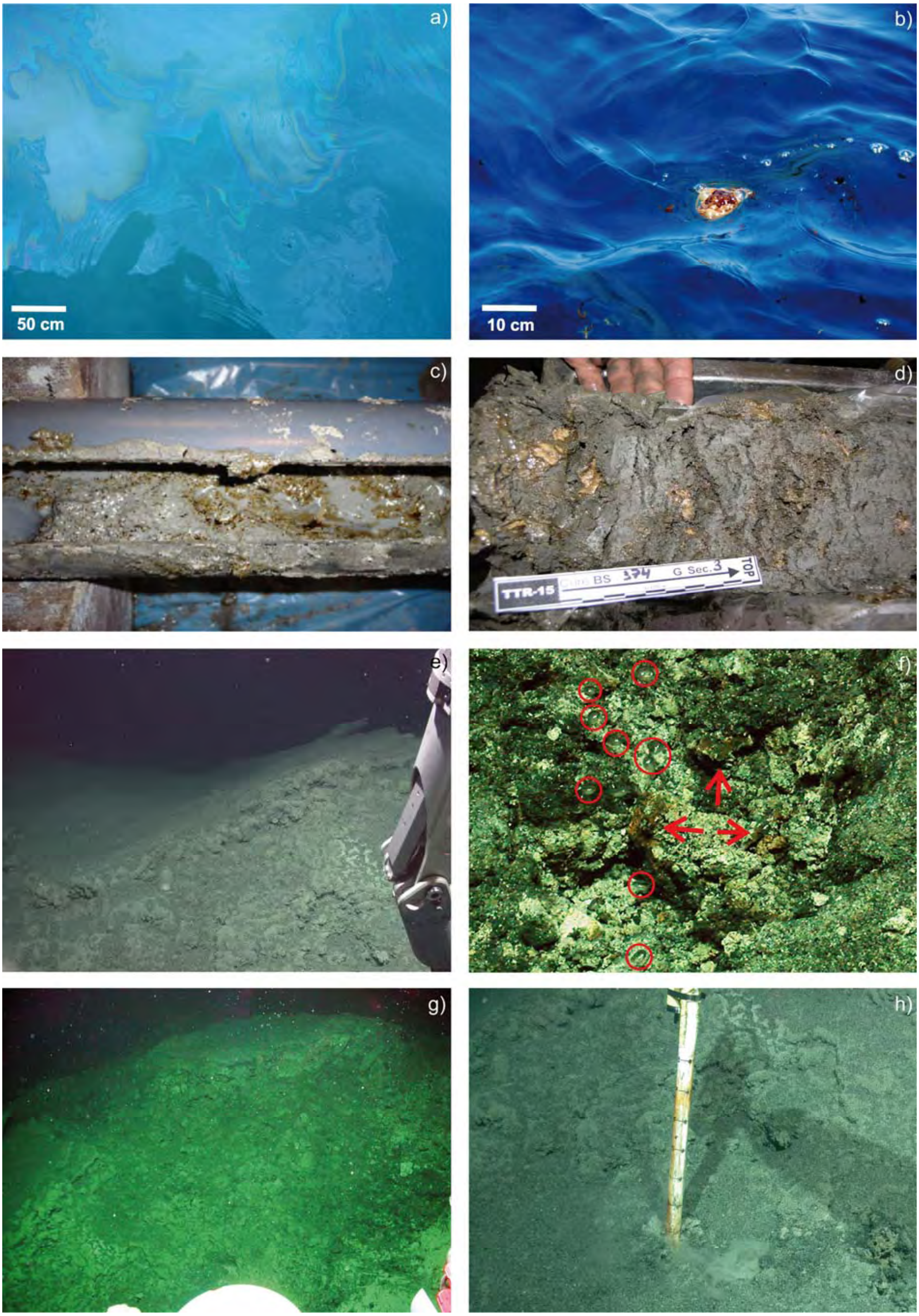


Plate 2. PARASOUND echograms showing acoustic anomalies ('flares') originating from rising gas bubbles or oil coated gas bubbles. Echograms a) and b) show two flares at the Colkheti seep (locations indicated in Fig. 2). Echogram c) shows flares emanating from Pechori Mound (locations indicated in Fig. 2). d) Depicts gas emissions at the G1 site (see Fig. 1).



a)
50 cm
b)
10 cm
c)
d)
TTR-15
Core BS 374 G Sec.3
TOP
e)
f)
g)
h)

Plate 3. a) Thin (sub millimetre) film originating from oily bubbles reaching the sea surface above Colkheti Seep on May 26th 2010; location indicated on Fig. 2. b) Thick oil patch and 'lints' of oil; locations as in a). Image c) shows a section of a core liner from a Dynamic Autoclave Piston Corer, recovered at Colkheti seep. The brownish traces are an oil-water mix. d) Section o a gravity core recovered at Colkheti seep, showing oily sediments and gas hydrate flakes. e) Image taken by ROV QUEST 4000 next to a bubble emission site at Colkheti seep in 2007 (location indicated in Fig. 2); the image gives an impression on the rough morphology/ crater structures which can be identified on the AUV bathmetry in Fig. 3. f) Shows a close up of bubbles (red circles) and oily sediments (red arrows) at the vent location (e), Fig. 2 & 3). Image g) was taken at the same location as e) but towards the bubble stream. h) A temperature lance deployed by the ROV next to the gas vent is covered by oil after recovery.

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