Chapter

Gas Hydrates in Antarctica

Michela Giustiniani and Umberta Tinivella

Abstract

Few potential distributing areas of gas hydrates have been recognized in literature in Antarctica: the South Shetland continental margin, the Weddell Sea, the Ross Sea continental margin and the Wilkes Land continental margin. The most studied part of Antarctica from gas hydrate point of view is the South Shetland margin, where an important gas hydrate reservoir was well studied with the main purpose to determine the relationship between hydrate stability and environment effects, including climate change. In fact, the climate signals are particularly amplified in transition zones such as the peri-Antarctic regions, suggesting that the monitoring of hydrate system is desirable in order to detect potential hydrate dissociation as predicted by recent modeling offshore Antarctic Peninsula. The main seismic indicator of the gas hydrate presence, the bottom simulating reflector, was recorded in few parts of Antarctica, but in some cases it was associated to opal A/CT transition. The other areas need further studies and measurements in order to confirm or refuse the gas hydrate presence.

Keywords: gas hydrate, BSR, Antarctic Peninsula, climate change, opal A/CT

1. Introduction

Gas hydrate is a solid component (clathrates) composed of water and natural gas of low molecular weight (mainly methane), forming under particular condition of low temperature, high pressure, and proper gas concentration [1]. Pressure and temperature define the stability field of gas hydrate, which is affected by gas mixture and pore-fluids composition (salinity). Moreover, the presence of only a small percentage of higher hydrocarbons (such as ethane and propane) shifts the phase boundary to higher temperature (at constant pressure). Generally, hydrates accumulate anywhere in the ocean-bottom sediments where water depth exceeds about 400 m (**Figure 1**). In Polar Regions, in presence of sub-seawater permafrost, the hydrate could be stable at shallower water as demonstrated recently by [2, 3]. Very deep (abyssal) sediments are generally not thought to house hydrates in large quantities due to the lack of high biologic productivity (necessary to produce the organic matter that is converted to methane) and rapid sedimentation rates (necessary to bury the organic matter), both necessary for hydrate formation on the continental shelves. The conditions for gas hydrate stability are verified also in seawater, but gas concentration is always not sufficient for their formations.

Gas hydrates were discovered in 1810 by Humphry Davy [4] and, since then, they became the interest of scientific and engineering research studies. In fact, the stability of methane hydrates on the sea floor has several implications (i.e., “in [5, 6]”). First, they are considered a huge energy resource (i.e., “in [7]”). Second, natural and anthropogenic disturbances may cause their destabilization causing the

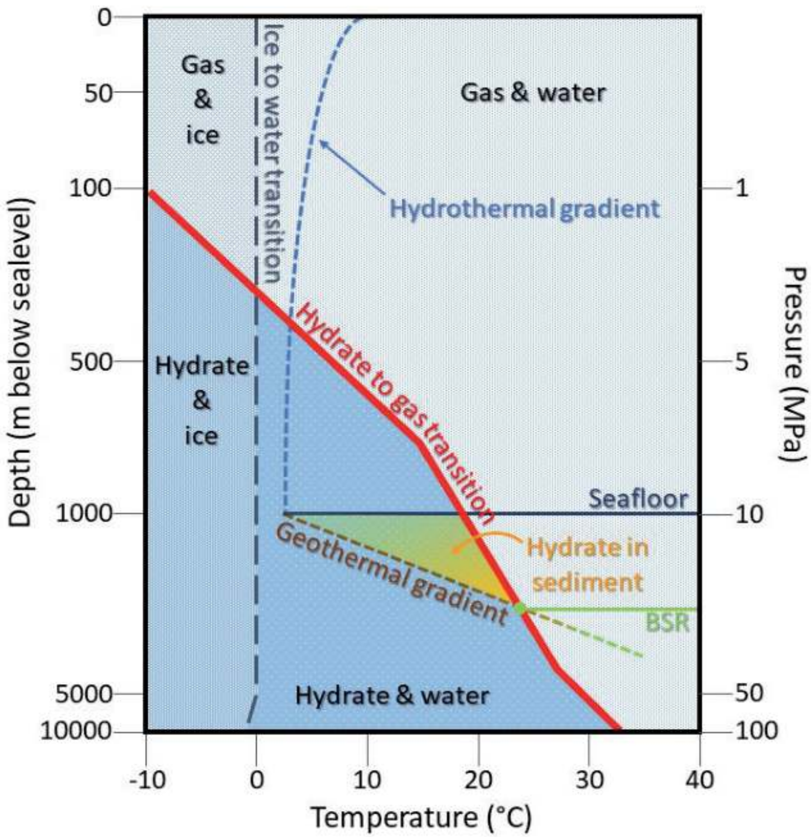

Figure 1.
Schematic diagram of the gas hydrate stability zone in marine environment.

release of huge amounts of fluids (gas and water) and affecting slope stability (i.e., "in [8]"). Finally, methane is an effective greenhouse gas (26 times more powerful than carbon dioxide), and large methane releases may be the cause of sudden episodes of climatic warming in the geologic past (i.e., "in [9]"). Some authors suggested that gas hydrate dissociation influenced significantly climate changes in the late Quaternary period (i.e., "in [10]"). The Clathrate Gun Hypothesis (i.e., "in [11]") suggests that past increases in water temperatures near the seafloor may have induced such a large-scale dissociation, with the methane spike and isotopic anomalies reflected in polar ice cores and in benthic foraminifera [12]. [13] suggested that methane would oxidize fairly quickly in the atmosphere, but could cause enough warming that other mechanisms (for example, release of carbon dioxide from carbonate rocks and decaying biomass) could keep the temperatures elevated.

The relationship between gas hydrate and climate change is of great importance in Polar Regions, where the climate signal is amplified. When pressure and temperature at the sea bottom change (eustatic and climatic changes, respectively), the thickness and the depth of the gas hydrate stability zone change accordingly (i.e., "in [14, 15]"). The study of gas hydrates and the parameters, that control their stability field, allow reconstructing the climatic changes in the past, studying the present processes, and formulating predictions. During the glaciations, the consequent sea level drop produces a rising of the base of the stability field of gas hydrates. This change produces the release of remarkable quantities of methane in the water column, and a sensible continental slope instability, which may cause slides, and, in turn, occasionally tsunami waves. In the other hand, during the interglacial period, the sea level rise and the consequent heating produce an overdeepening of the base of the gas hydrate stability and a progressive accumulation of methane within the gas hydrate zone. Therefore, the climatic changes greatly influence the amounts of methane present in the gas hydrate zone: the release of this gas in the atmosphere during the glaciations influences the interglacial phases, while the decrease of methane content in the atmosphere during the interglacial phases again contributes to the global temperature lowering [16].

Seismic data analysis allow recognizing the presence of gas hydrate in marine environments, because the phase transition (from solid above, to fluid and gasses, below) of interstitial water and gas mixture produces a strong reflection, called Bottom Simulating Reflector (BSR) that simulates the sea bottom and presents a phase reversal with respect to the seafloor reflection. The BSR was firstly discovered and associated to gas hydrate presence in marine sediments in the western Gulf of Mexico, off the northern coasts of Colombia and Panama, and along the Pacific Coast of Central America from Panama to Acapulco by [17]. Successively, in marine environment the BSR was detected along continental margins (both active and passive) and in proximity of mud volcanoes (i.e., "in [18]").

Once thought to be devoid of life, the ice-covered parts of Antarctica are now known to be a reservoir of metabolically active microbial cells and organic carbon [19]. The potential for methanogenic archaea to support the degradation of organic carbon to methane beneath the ice, however, has not yet been evaluated. No data exist forrates of methanogenesis in sub-Antarctic marine sediments. [20] presented experimental data from subglacial environments, similar to Antarctica, that demonstrate the potential for overridden organic matter beneath glacial systems to produce methane. They also numerically simulated the accumulation of methane hydrate in Antarctic sedimentary basins and show that pressure/temperature conditions favor methane hydrate formation down to sediment depths of about 300 meters in West Antarctica and 700 meters in East Antarctica. Moreover, [20] calculated that the sub-Antarctic hydrate inventory could be of the same order of magnitude as that of recent estimates made for Arctic permafrost, suggesting that he Antarctic Ice Sheet may be an important component of the global methane budget, with the potential to act as a positive feedback on climate warming during ice-sheet wastage.

The gas hydrates accumulated in the Antarctic margins could be inferred from geophysical and geochemical evidences, such as BSR on the seismic profile, as already mentioned, high concentrations of methane and organic carbon and abnormal varieties of salinity, chlorinity and sulfate of pore waters in boring sediment samples of Deep Sea Drilling Project (DSDP) and Ocean Drilling Program (ODP) sites. Few potential distributing areas of gas hydrates have been recognized in literature: the South Shetland continental margin, the Weddell Sea, the Ross Sea continental margin and the Wilkes Land continental margin (**Figure 2**).

In Antarctic margins, there are advantageous geological conditions for the formation and accumulation of gas hydrates according to analysis of the reservoir conditions, including gas source, sedimentation, heat flow, temperature, pressure and tectonic conditions, etc. In fact, the modeling of the theoretical base of the gas hydrate stability points out that there is considerable potential resource of gas hydrate in the Antarctic margins. In particular, [21, 22] modeled the gas hydrate distribution in the South Shetland Margin based on geophysical data, while [23] reconstructed the theoretical depth of the BSR in the Ross Sea based on the literature data.

The South Shetland margin (SSM, offshore Antarctic Peninsula) is the most studied part of Antarctica from gas hydrate point of view. In this area, an important gas hydrate reservoir was discovered and was well studied in the recent years with the main purpose to determine the relationship between hydrate stability and environment effects, including climate change.

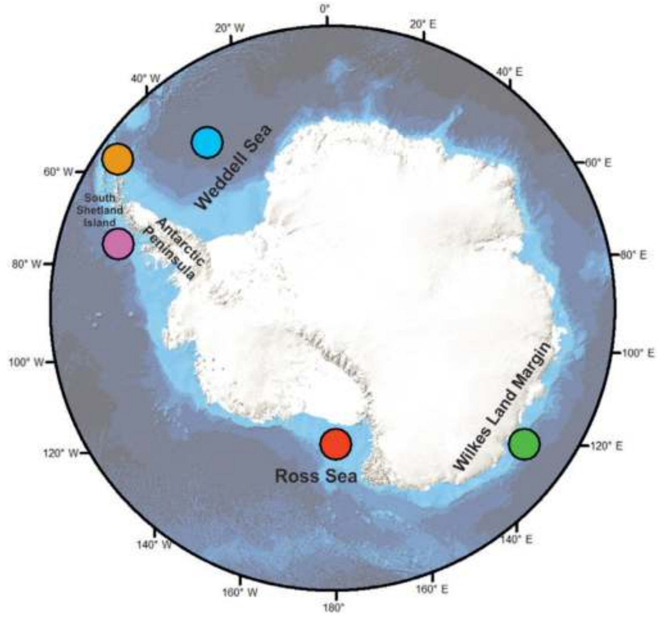

Figure 2.
Map of Antarctica showing the potential areas, indicated by points, where there are indication of gas hydrates presence in literature.

2. The South Shetland Margin (the Antarctic Peninsula)

As mentioned before, the Polar Regions and, in particular, the transition zones, such as the Antarctic Peninsula, are strongly affected by the climate signals. For this reason, several studies are focused on characterizing the South Shetland Margin and the gas hydrate reservoir here present. In the following, we resume the main results related to the geophysical studies.

2.1 Geological setting

The SSM is located in the northeastern tip of the Pacific margin of the Antarctic Peninsula, characterized by the subduction of the Antarctic and the former Phoenix plates beneath the South Shetland micro-continental block. Along the continental margin, a trench-accretionary prism-fore-arc basin sequence can be recognized (i.e., "in [24, 25]"). The Phoenix plate started to subduct beneath the Antarctic plate from late Paleozoic time [26] and progressed from the southwest to the northeast along the margin. Active spreading at the Antarctic Phoenix ridge ceased about 4 Ma ago [27], when the last ridge-crest segment of the Phoenix plate reached the south margin of the Hero Fracture Zone. The subduction process is presently believed to have taken place as a result of sinking and roll-back of the oceanic plate coupled with the extension of the Bransfield Strait marginal basin (i.e., "in [24, 27]"). The Phoenix plate is from about the Shackleton Fracture Zone to the northeastern side, while by the Hero Fracture Zone to the southwestern side, which intersect the continental lithosphere.

2.2 Geophysical data

Different Antarctic expeditions have taken place off the Antarctic Peninsula, in order to verify the existence of a potential gas hydrate reservoir and to reconstruct the tectonic setting of the margin. In this region, the presence of the diffused and discontinuous BRS was discovered during the Italian Antarctic cruses of 1989–1990, 1996/1997, and 2004–2005 onboard the R/V OGS-Explora within the framework of a research program supported by the Italian National Antarctic Program (PNRA; i.e., **Figure 3**; [28–33]. During the first leg, only seismic data were acquired, while during the last two legs Ocean Bottom Seismometer (OBS) and other geophysical data were acquired.

The multidisciplinary dataset, including multibeam bathymetry, seismic profiles (multichannel seismic and OBS data and chirp), and two gravity cores clearly shows active mud volcanism sustained by hydrocarbon venting in the region. The multibeam bathymetric data was indispensable to reconstruct the seabed, covering an area of about 5500 km^2 slides and fluid expulsion related to gas hydrate dissociation or the presence of faults were detected by chirp sub-bottom profiles. The two gravity cores recover 1.07 m and 2.98 m of sediment. Several laboratory measurements were performed on these cores, such as the computer aided tomography and the interstitial fluid analyses to detect gas presence.

2.3 Gas hydrate and related features

The bathymetric map of the SSM provides evidence of four mud volcanoes (**Figure 3**; [18, 31]), which are associated to the presence of gas hydrate. This active mud volcanism might be favored by the reactivation of pre-existing faults and weakness zones because of the regional extensional tectonics of the South Shetland trench and margin [34], the adjacent Bransfield Strait back-arc basin [35], and the complex tectonic interaction at the Elephant Island triple junction [36].

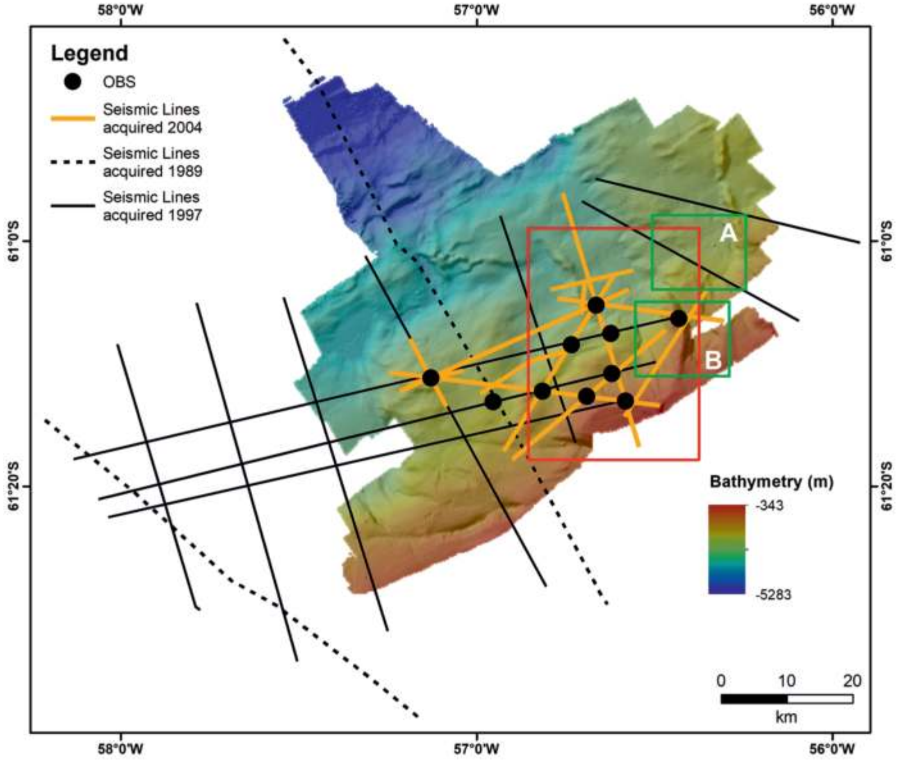

Figure 3.
*Map of the investigated area with the location of the acquired data during the surveys. Red rectangle indicates the seafloor reflectivity reported in **Figure 5**. Green rectangles indicate the position of the zoom reported in **Figure 6**.*

The chirp data (location in **Figure 4**) confirm the presence of a few slides, which are probably related to gas hydrate dissociation and several fluid expulsion sites, probably related to active mud volcanism sustained by a hydrocarbon reservoir. Note that, as expected, low values of seafloor reflectivity are identified in correspondence of these features (**Figure 5**). Moreover, the bathymetry shows the presence of ancient slides that could be linked to gas hydrates (**Figure 6**).

Fluid analyses made to the gravity cores revealed the presence of several hydrocarbon gases, such as methane, ethane, propane, butane, pentane and hexane, and traces of aromatic hydrocarbons of >C12 carbon chain length, suggesting a thermogenic origin of the gas.

A strong and continuous BSR was recognized through the analysis of the seismic lines and OBS data, allowing the detection of a large gas hydrate reservoir on the SSM. [33] reported an example of seismic and OBS data. The elastic properties of the different layers across the BSR were modeled by using Tinivella theoretical models in order to quantify the concentrations of gas hydrates and free gas in the pore space [37, 38].

Poisson's ratio near the OBS location was evaluated by the joint inversion of compressional and shear wave arrivals in the vertical and horizontal components of OBS data. Useful information about physical properties of marine sediments in areas where no well data are available were obtained through Amplitude Versus Offset (AVO) analysis and OBS data [29, 38]. In detail, the sediments seems not cemented by the presence of hydrate (due to AVO behavior) and the free gas below the BSR seems uniformly distributed in the pore space (due to the low Poisson ratio) and not in overpressure condition (due to low P-converted wave amplitude; [39]).

Analysis of geophysical data evidences that the accumulation of fluids within sediments is strictly related to tectonics features, such as faults and folds. The concept of hydrate porosity (HP), which is directly related to the fluid content, was introduced in order to better understand the relationship between gas hydrate presence and geological features. HP represents the difference between the

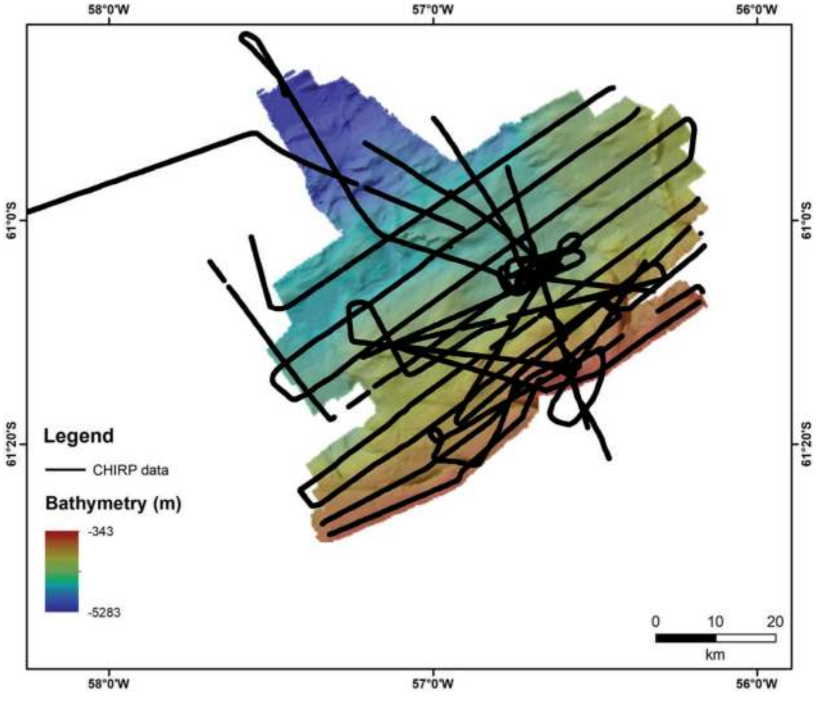

Figure 4.
Map of the investigated area with the location of the CHIRP data.

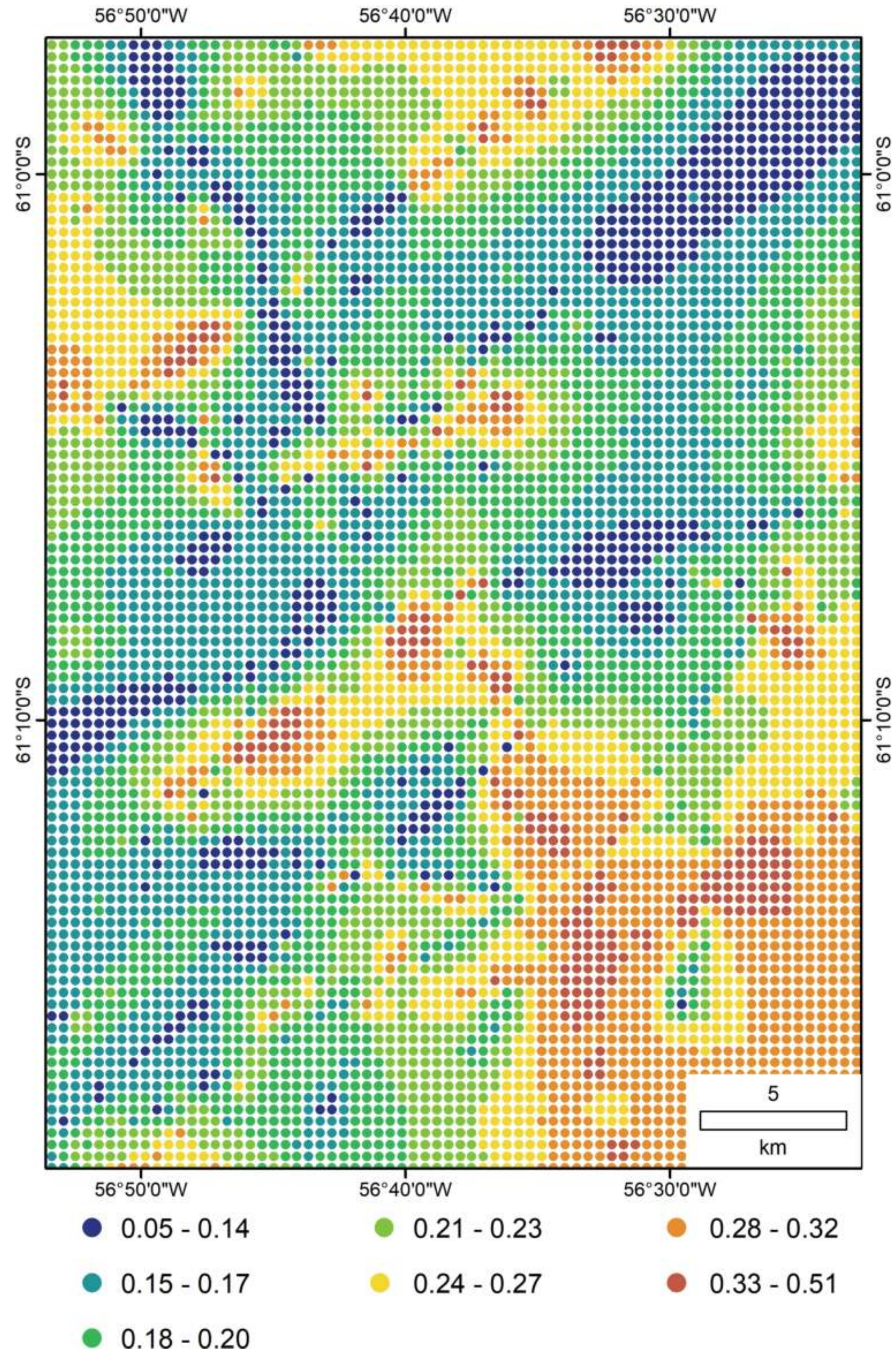

Figure 5.
*Map of the seafloor reflectivity extracted from the CHIRP DATA. The location of the area is reports in **Figure 3**.*

reference porosity (i.e., the porosity without gas hydrate) and the effective porosity (i.e., the porosity reduced by the gas hydrate presence; [40]). The detailed analysis of the reservoir revealed a close relationship between HP, and consequently gas hydrate accumulation, and geological features, such as syncline-anticline structures and fractures distribution within sediments [40]. In particular, a relationship is

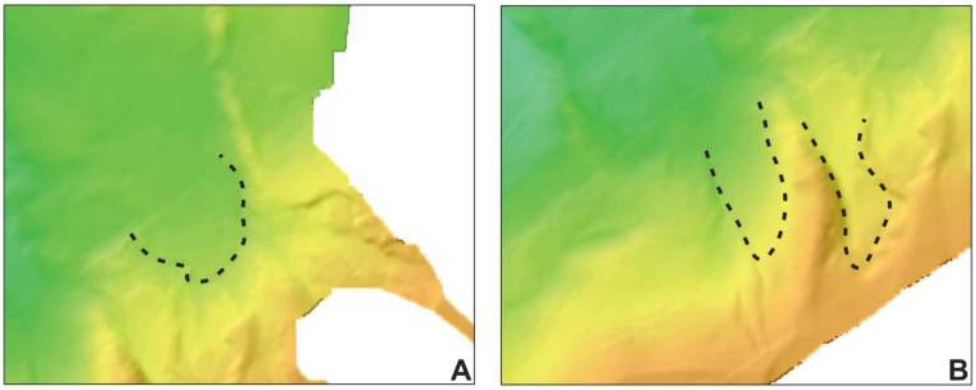

Figure 6.
Example of ancient slides highlighted with a black dash lines on the bathymetric data. The position of the two zoom is reported in ***Figure 3****. The bathymetric data scale is reported in* ***Figure 3****.*

underlined between the HP values and the distance from the hinge of the anticline: the HP increases toward the limbs of anticline. The microfracturing model supports the idea that the synclines favors the hydrate accumulation above the BSR, while the anticlines favors the free gas accumulation below the BSR, when important faults acting as preferential path-way for fluids escapes [40].

All available seismic profiles and OBS data were analyzed in order to obtain 2D seismic velocity models, then translated in terms of concentrations of gas hydrate and free gas in the pore space by using Tinivella theoretical models [37, 38]. The jointly interpolation of the 2D models allowed obtaining a 3D model of gas hydrate concentration from the seafloor to the BSR, as shown in **Figure 7**. The total volume of hydrate, estimated in the area (600 km^2) where the interpolation is reliable, is 16×10^9 m^3. The gas hydrate concentration is affected by error estimated equal to about ±25%, as deduced from sensitivity tests and from error analysis related to the interpolation procedure. The estimated amount of gas hydrate can vary in a range of 12×10^9–20×10^9 m^3. Moreover, considering that 1 m^3 of gas hydrate corresponds to about 140 m^3 of free gas in standard conditions, the total free gas trapped in this reservoir ranges between 1.68×10^{12} and 2.8×10^{12} m^3. This estimation does not take into account the free gas contained within pore space below the hydrate layer, so this values could be underestimated [41].

2.4 Modeling of gas hydrate versus climate change

In the past years, scientists are taking an interest in modeling warming-induced hydrate dissociation in the Antarctic region. Over the period 1958 to 2008, the Antarctic Peninsula shows an unusually high rate of warming [42], the strongest of the Southern Hemisphere and one of three strongest on Earth [43]. Predicting future warming in this area is challenging because of the lack of a sound physical mechanism that explains the present regional warming [43], but some models predict that in the 21st century the Antarctic Peninsula may not experience the strongest warming of Antarctica [44]. Ocean warming in West Antarctica is predicted to be of 0.5 ± 0.4° C by 2100, about half of global mean warming, considering the A1B scenario [45], which assumes modest reductions in greenhouse-gas emissions after mid-21st century. A long-term ocean warming similar to that predicted in West Antarctica may be sufficient to trigger dissociation of a shallow hydrate reservoir in the SSM. This hypothesis has been preliminary tested by [22] based on steady-state modeling of the evolution of the base of the hydrate stability zone assuming a 1.4° C increase by the end of the 21st century.

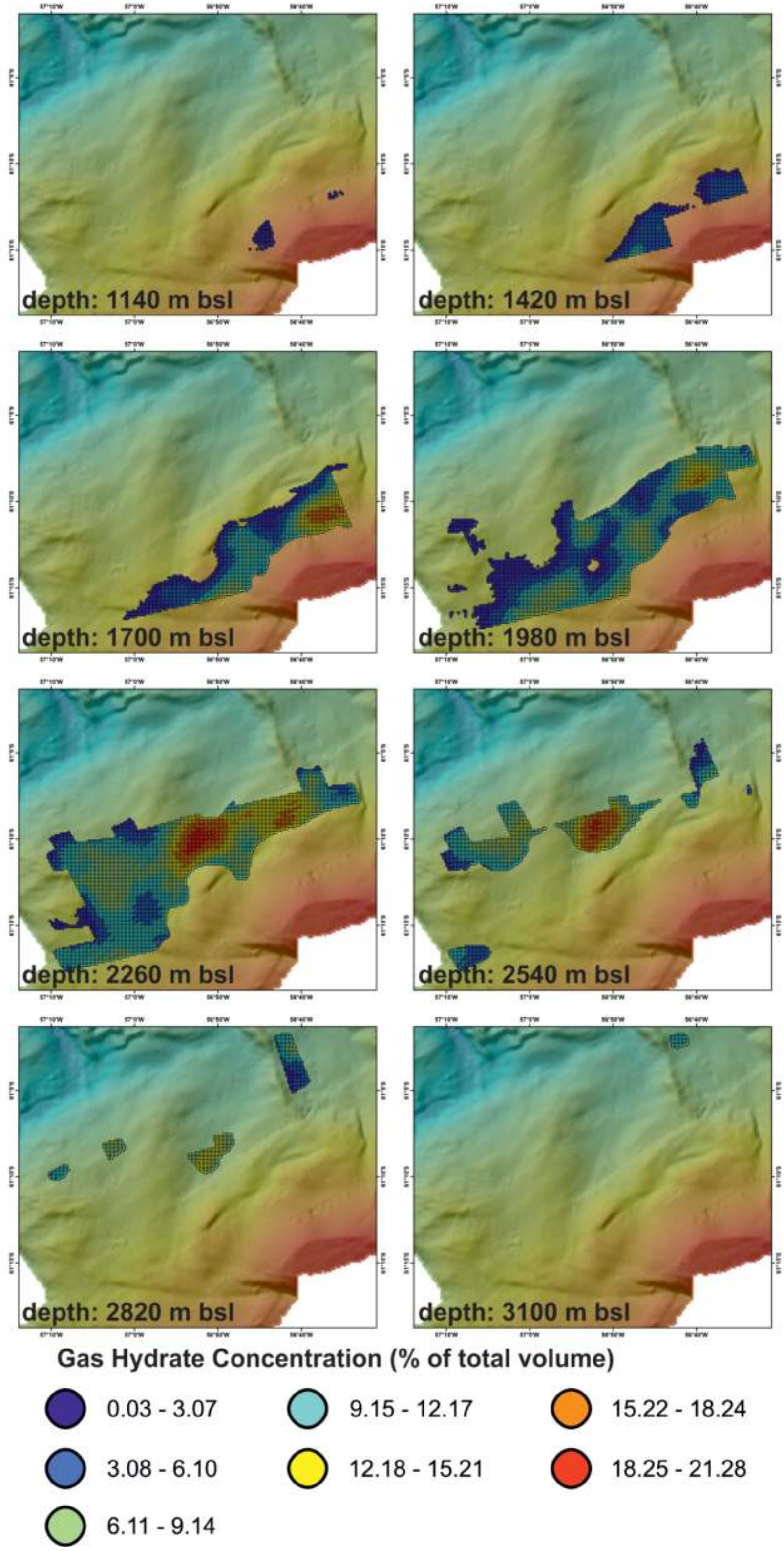

Figure 7.
Map of the gas hydrate concentrations at different depth from seafloor (in meters).

Successively, it was modeled the transient response to ocean warming of the hydrate system in the SSM between 375 and 450 mwd for the period 1958–2100 CE, using constraints in input parameters from seismic observations [22, 46].

TOUGH-HYDRATE (T-H) code [47] was employ for the modeling, with past temperatures given by the US National Oceanographic Data Center and two future temperature scenarios given by extrapolation of the temperature trends over the periods 1960–2010 and 1980–2010. The result of the transient modeling shows that methane emissions may occur at water depths between 375 m and 425 m if the future seabed temperatures follow a similar trend to that over the period 1980 to 2010 of 0.0238° C y-1), while emissions would not occur with a seabed warming rate an order of magnitude smaller [46]. Hydrate dissociation would initiate at the top of the hydrate layer, and the overpressure generated would not be sufficient to cause, by itself, shallow slope failures or shallow vertical fractures over the 21st century. Hydrate-sourced methane emissions at 375 mwd would start at ca. 2028 and may extend to deeper waters at an average rate of 0.91 mwd y^{-1}. Over the 21st century, the potential amount of dissociated methane liberated to the ocean may be between 1.06 and 1.21–10^3 mol y^{-1} per meter along the margin [46]. This modeling underlines that the SSM is one of the key areas to observe and understand the effects of warming-induced hydrate dissociation in the Southern Hemisphere during the coming decades [46].

3. Weddell Sea

The Weddell Sea is considered a potential area for gas hydrate accumulation (i.e., "in [48]"), even if a clear indication of hydrate presence is missed. It is important to underline that, in this part of Antarctica, acquisition of data was very difficult in the past due to presence of ice shelves. Only in the last years, the extraordinary rapid climate warming, which is occurring in the northern tip of the Antarctic Peninsula [49, 50], caused the reduction of land ice along West Antarctica and the ice shelves destruction in the surrounding seas (i.e., "in [51, 52]"). In north-western of Weddell Sea, [53] detected the presence of gaseous hydrocarbons (from methane to n-pentane) in the seabed sediments and the bubbling of methane suggesting the presence of gas accumulations in the substrate of the NW Weddell Sea. They observed a release of methane from the frozen ocean substrate adjacent to Seymour Island, linked to climate instability during Late Cenozoic, when vast areas of the Antarctic continental shelf were flooded during the marine transgression that occurred *c*. 18,000 years ago, after the Last Glacial Maximum. The heat flow from the sea to the marine substrate, now flooded, would have destabilized frozen gas accumulations, which were originally formed into terrestrial permafrost during the Last Glacial Maximum, similarly to what would have happened in the Arctic [53].

Seismic data acquired in 1985 over the south-eastern continental shelf and the margin of the South Orkney microcontinent as a site survey for ODP Leg 113 [54], show a BSR lying at 500–800 ms. The widespread cause of the reflection was interpreted as a break-up unconformity associated with the 25–30 Ma opening of the Jane Basin to the east [55]. In places, the detected BSR cuts across beddings, and in this case this physical boundary may be either depositional or of secondary origin related to the diagenesis of biogenic silica, possibly combined with a major variation of the detrital input [56]. So, also in this case, the BSR is not produced by gas hydrate and free gas presence, suggesting that a careful analysis of seismic data is necessary before to interpret a BSR as the base of gas hydrate stability zone.

So, potentially, in this area, all conditions to have gas hydrate are verified, even if the small amount of data acquired cannot confirm or reject this hypothesis.

4. Wilkes Land margin

[57] inferred gas hydrates to be present in sediments offshore Wilkes Land. A multichannel seismic-reflection survey revealed a reflector showing the characteristics of a BSR [58]: (1) the reflector is at a depth consistent with the pressure/temperature stability field of gas hydrate, and (2) the reflector shows a reversal of polarity. Unfortunately, a third criterion that the subbottom depth of the reflector increases with increasing depth of water is not met, possibly because of oceanward increasing geothermal gradients as in the case of the inferred gas hydrate off Japan [59]. In addition, other seismic data acquired in 1993 by Japan National Oil Corporation in collaboration with Geological Survey of Japan [60] revealed possible BSRs that could be associated to zones with gas hydrate.

Clearly, additional data are required to confirm and eventually characterize the presence and the distribution of gas hydrate in the Wilkes Land Margin.

5. The Ross Sea

In the last two decades, the Ross Sea Embayment area has been considered a laboratory of growing interest for the reconstruction of the past Antarctic environment, the onset of Antarctic Eocene-Paleocene glaciation, climates studies, the understanding of the tectonic deformation and global sea level changes that all have driven glacial history [23].

The main Ross Sea elongated N-S sedimentary troughs, such as the Victoria Land Basin, the Drigalsky Basin, the northern continuation of the Northern Basin, the Central Basin, the Joides Basin and the Eastern Basin are bounded by basement highs and morphological banks. They were formed during the late Cretaceous major rifting phase and later during the Cenozoic, while a widespread igneous activity affected the West Antarctic Rift System ([23] and references therein).

The potential presence of gas hydrate is supported by the identification of hydrocarbons in the Ross Sea area. In fact, in the central and eastern Ross Sea, the cored Miocene muddy sediments at the DSDP sites showed high contents of total hydrocarbon gas (mainly methane; [61]). In the western Ross Sea, analysis of sediments from gravity cores showed the presence of hydrocarbon gases with low concentrations of methane [62] and in the McMurdo Sound, both CIROS-1 and MSSTS-1 wells, detected small amount of organic carbon [63, 64]. Moreover, [65] supposed the presence of a BSR, an indirect indication of the presence of gas hydrate, on a seismic line, located in the Victoria Land Basin. Moreover, in the same part of the Ross Sea, an extensive field of pockmarks at 450–500 m depth and unusual flat-topped seafloor mounds was identified on a detailed multibeam dataset [66, 67]. One hypothesis discussed by the authors is that these features may be carbonate banks because of their proximity to the inferred subsurface gas hydrate, although their preferred interpretation is that the features are of volcanic origin.

At this stage, to confirm or refuse the presence of gas hydrate in the Ross Sea more measurements are necessary. Recently, [23] performed a modeling of the base of gas hydrate stability based on the steady-state approach by using literature data, such as bathymetric and well data, sea bottom temperature, a variable geothermal gradient and assuming that the natural gas is methane, in order to identify the areas where the gas hydrate stability is verified The modeling was performed in the whole Ross Sea (**Figure 8**).

The results from the modeling suggested that depth and distribution of the base of the gas hydrate stability zone are correlated with the bathymetry. In fact,

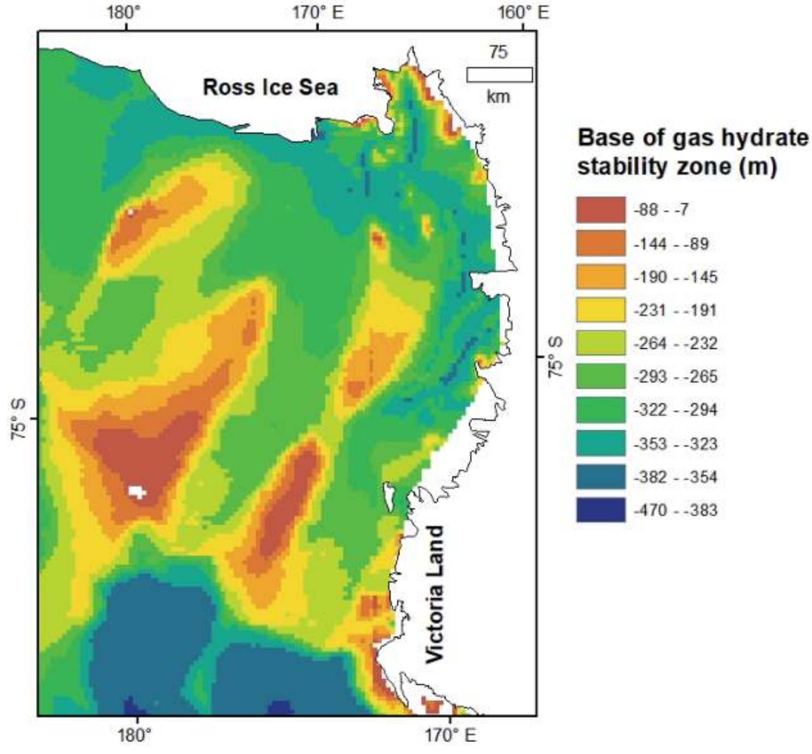

Figure 8.
Distribution of the base of the gas hydrate stability zone from the seafloor (in meters). The geothermal gradient is supposed to be equal to 49°C/km (modified after [23]).

in proximity of the banks, the gas hydrate stability zone results display thickness less than 100 m. On the other hand, the thickness of the gas hydrate stability zone increases in proximity of the basins to values exceeding 400 m related to bathymetry increase and seafloor temperature decrease. Moreover, the existence and dynamics of the gas hydrate distribution is strictly related to the existence and evolution of the shallow geological and geomorphological features below the sea floor, as suggested in the past by several authors. So, the presence of some geological and geomorphological features are in agreement with the gas hydrate presence in this part of Antarctica [23].

6. Opal-A/opal-CT phase boundary

Silica diagenesis consists of precipitation from an initial amorphous phase (opal A) to an intermediate phase (opal CT) and finally to the final form with quartz crystallization. The presence of large amounts of biogenic silica in marine sediments can affect their physical properties [68]. In fact, diagenetic alteration of biogenic opal-A to opal-CT causes a drastic reduction of porosity (about 20 vol% according to [69]), which contributes to sediment consolidation at depth.

It is possible to recognize the passage from one phase to another on seismic profiles because of the presence of a high amplitude reflector, produced by a positive impedance contrast between the overlying silica-rich sediments and the underlying sediments in which biogenic silica is dissolved. This reflector simulates the seafloor morphology, so it is still called BSR. This BSR is different from the hydrate-related BSR, as well documented in literature (i.e., "in [70]"). The positive polarity, the depth, no noticeable drop of frequency, and compressional velocity below the

BSR suggest the absence of the gas hydrate and the diagenetic-related origin of the observed BSR. Moreover, diagenesis-related BSR have a constant depth below seafloor or even decreasing sub-bottom depth with increasing water depth due to earlier opal transition at greater pressures.

6.1 Pacific margin

In the Pacific margin of the Antarctic Peninsula, several seismic lines where acquired with the main purpose to study sediment drift presented in the northwest part. There lines were analyzed in detail in order to extract information about the petrophysical properties relevant to seismic stratigraphy studies in the continental shelf and rise [71, 72]. In particular, a seismic line showed the presence of an anomalous reflector, interpreted as a BSR [73]. Borehole data are also available, thanks to the ODP Leg 178 [74].

In order to understand the nature of the observed BSR, [73] performed a detailed study concluding that the BSR observed in the seismic line is due to opal-A/opal-CT phase boundary and not to the gas hydrate presence. Moreover, they attempted a quantitative estimation of biogenic silica content within marine sediments using seismic reflection and physical properties data across the silica diagenesis-induced BSR. The estimated biogenic silica content increases with depth and reaches a maximum of 23.3 wt % above the BSR. Such quantifications are of prime importance for submarine slope stability assessment as the deep seated transformation of biogenic silica from opal-A to opal-CT is able to trigger slope instability not only at local scale but also at regional scale, as previously shown by [69, 75].

7. Conclusions

The most important area from gas hydrate point of view in Antarctica is the South Shetland Margin where a huge hydrate reservoir is present; it is very well documented in literature thanks to several geophysical acquisition legs performed. The analyses of geophysical data allows concluding that the accumulation of fluids within sediments is strictly related with tectonics features, such as faults and folds, revealing a close relationship between gas hydrate accumulation and geological features. Moreover, the hydrocarbons trapped and detected in the sediment cores may indicate the existence of deeper reserves, confirming that the BSR should be considered as an indicator of conventional deep reservoir. Finally, due to the warming measured in this part of Antarctica, a monitoring of the evolution of the gas hydrate reservoirs offshore Antarctic Peninsula is required for an environmental in-depth analysis.

The main seismic indicator of the gas hydrate presence, the BSR, was recorded in few parts of Antarctica (Pacific and Atlantic margin of Antarctic Peninsula, Wilkes Land margin), but it was associated to opal A/CT transition. The other potential areas for gas hydrate presence (Ross Sea, Weddell Sea and Wilkes Land Margin) needs further measurements in order to confirm or refuse the hypothesis of their presence.

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Conflict of interest

The authors declare no conflict of interest.

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