GEOHAZARDS SUPRISES: A COMPARATIVE LOOK AT GALE AND OGIRI FIELDS IN THE NIGERDELTA REGION

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***Abstract*- An attempt is made in this study towards maximising offset wells information in unravelling onshore geohazards indicators in the Gale field. The Gale field is located about 100km north-west of Port Harcourt, Nigeria. The field consists of a highly faulted and elongated rollover anticline, bounded to the north by a regional growth fault.**

The data used for this study integrates the quadrature and reflectivity amplitude attributes from seismic data, with offset well data. The conventional reflectivity seismic data was 90° phase rotated to derive the quadrature volume. The quadrature seismic was considered a more appropriate reflectivity seismic attribute for use in shallow geohazard analysis as it is known for its characteristic preservation of high frequency spectrum inherent in the data.

Geohazards can be defined as "events caused by geological conditions or processes which represent serious threats to human lives, properties, natural and built-up environment" (Solheim *et al*., 2005). Geohazards exist both onshore and offshore. Onshore, the most common are volcanic eruptions, earthquakes, landslides and debris flows, floods and snow avalanches. Offshore, slope instability and earthquakes are the main threats because of their potential for damaging seafloor installations, and for generating devastating tsunamis, such as the 1998 Papua New Guinea event responsible for more than 2000 deaths, and the past Storegga Slide tsunami (Løvholt, F *et al.*2008). Features like shallow gas, gas hydrates and mud diapirism also represent geohazards in both onshore and offshore regions.

This study highlights an approach in evaluating geohazards in the Gale field through the integration of seismic and well-log data.

A comparative Geohazards assessment was carried out for the planned Ogiri-1 well adjacent to the Gale field. Quadrature data was analysed for the presence of Shallow Gas bodies. Also, semblance analysis was carried out to check for potential hydrocarbon migration pathways (in the upward direction). Offset analysis was also done for neighbouring wells (Ogiri-04, 06, 11, 14 and 15) within the field. A well summary was generated for the planned well trajectory detailing the outcome of the geohazard assessment for each interval along the planned well.

Field data reconnaissance reveal the field consists of a highly faulted and elongated rollover anticline, bounded to the north by a regional growth fault. The data used is the integration of quadrature and reflectivity amplitude attributes from seismic data, with offset well data. The conventional reflectivity seismic data was 90° phase rotated to derive the quadrature volume. The quadrature seismic was considered a more appropriate reflectivity seismic attribute for use in shallow geohazard analysis as it is known for its characteristic preservation of high frequency spectrum inherent in the data.

The results from a geohazards analysis over the Gale field indicate the presence of possible shallow gas within the area of interest and particularly along the shallow section of planned well trajectory. This is further supported by the presence of faults within the vicinity of gas bearing reservoirs at deeper level and a potential for these faults extending to the shallower interval. These faults are likely to serve as migration pathways for gas to seep to the shallower section, hence forming a potential geohazard. In addition, some of the offset wells targeting deeper gas reservoirs penetrated pockets of gas at the shallower interval that stratigraphically correlates with the shallow section that would be penetrated by the planned wells. The results of this work were used to move the proposed drilling location of the Gale planned wells to a nearby area free of shallow gas signatures.

Observations from quadrature 3D seismic data and semblance data show that there is no migration path for hydrocarbon from deep to shallow intervals. There were no observed amplitude bodies around the planned well trajectories. Offset well analysis in the field revealed issues ranging from Losses, stuck pipe, overpull and gas cut as gathered from the daily drilling reports. Review of field geotechnical report did not reveal any Geohazards issues. Based on the Geohazards assessment carried out for this well; the chance occurrence of encountering shallow gas for all the units as shown in the well summary is rated low.

However, the Top-hole drilling still encountered high background gas revealing that subsurface surprises could still occur despite good well control.

***Key Words*: Geohazards, amplitudes, Background gas, faults, Gale, Ogiri, etc.**

Introduction

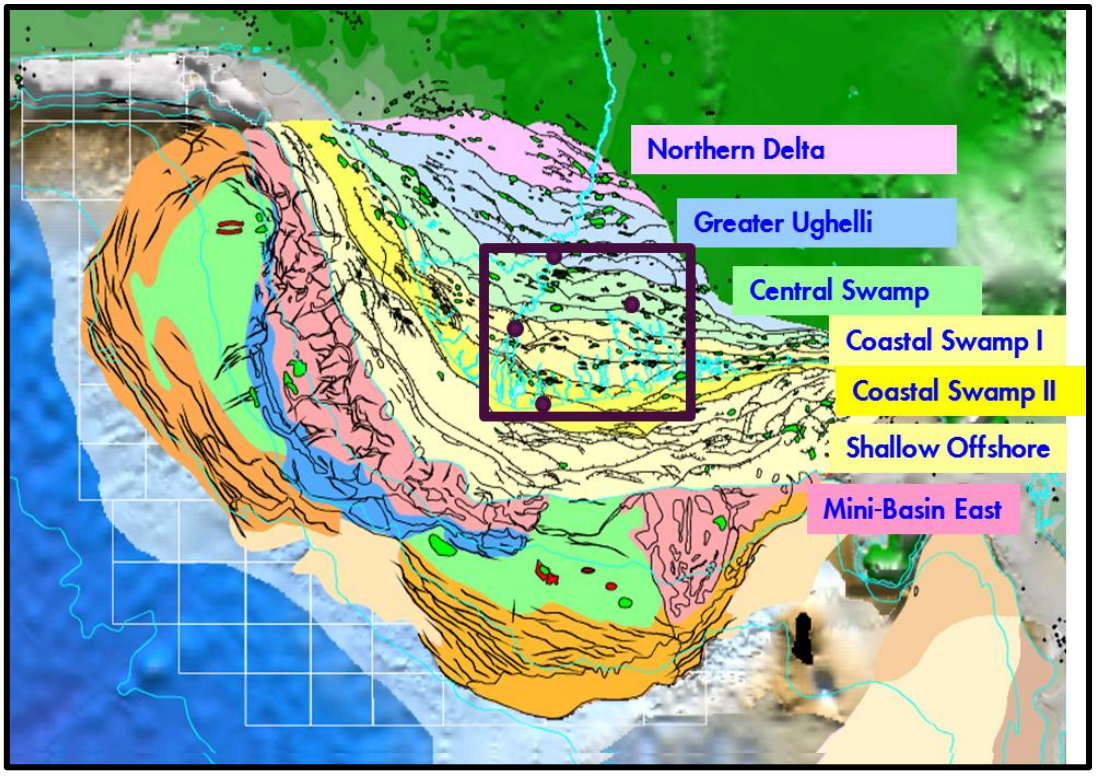
Geohazards are disasters induced by natural processes or human activity (Canals et al., 2004). According to Orange *et al*. (2001), marine geohazards include any feature or process that could harm, endanger, or affect seafloor facilities, risers, anchors, etc. Additionally, the facilities can be designed to avoid or withstand some geohazards. Marine geohazards can also be a local and/or regional site and soil conditions having a potential to develop into seafloor failure events, which cause losses of life or damage to health, environment, or field installations (Kvalstad, 2007).

Various geological processes and features can inflict hazards (Wu*et al*., 2018). Some of them are well known due to their great destructive power. These include earthquakes, volcanoes, landslides, and associated tsunamis (Ismail-Zadeh, 2016). Others generally do not cause direct damage to societies but can affect engineering structures. These include pockmarks, mud volcanoes, and mobile bedforms (Milkov, 2000; Hovland *et al*., 2002; Bastia *et al*., 2011; Ostanin*et al*., 2012; Ceramicola*et al*., 2014; Vanneste *et al*., 2014; Benjamin *et al*., 2015; Shmatkova*et al*., 2015). Some manifest themselves on the surface of the seafloor, while others are concerned with processes that occur in the subsurface (Chiocci*et al*., 2011; Jia *et al*., 2016).

Geohazards surprises are related to unexpected geohazards occurrences. This could occur during onshore or offshore operations. Geohazards which could be described as "events caused by geological conditions or processes which represent serious threats to human lives, properties, natural and built-up environment" (Solheim et al., 2005) include gas leakages encounter.

The presence of gas leaking from faults or fractures might be detected by the acousticseismic response. This response can be interpreted qualitatively in 3D seismic volumes inconventional slices and vertical sections (Løseth et al., 2009). Gas Leakage showsacoustic changes appearing as vertical chaotic disturbances with amplitude anomalies associated with irregular distribution of low-velocity zones. This vertical incoherence is a result of scattering, attenuation, anddecrease in compressional velocity of waves passing through gas saturated pores (Anderson and Hampton, 1980). The gas leakage oftenappears in vertical sections as cone-shaped distortion when associated with faults (Ilg et al., 2012). When fluids move upward through permeable faults, gas molecules typically get released due the drop in pressure (Bjørkum et. al, 1998).

The GALE and OGIRI fieldsare located in the Northwestern part of the Niger Delta. It is a brown field with high potentials for more hydrocarbon delivery. It has over 35 wells drilled to date. To optimize production, some new wells were planned in the field. Existing 3D seismic data was analysed earlier on for any potential geohazards without any indication of such along the planned well trajectory and the offset wells did not record any geohazards encounter.



Map of Niger delta Depo Belts showing Gale field research arae (Ozumba, Bert et al.)

Objective

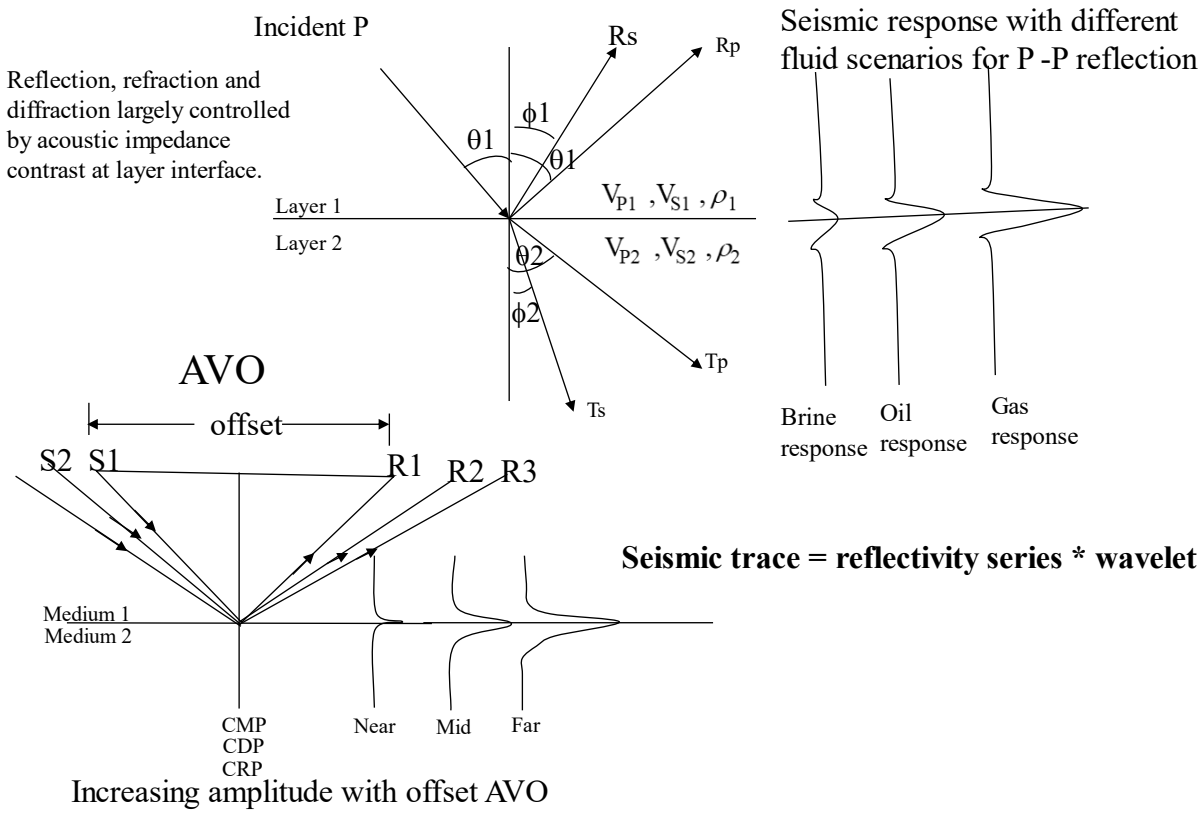
The objectives of this study include:

- To evaluate planned locations and optimize for the presence of any identified geohazards.
- To deliver all production related activities within the field safely.
- To ensure effective communication of risk and risk management strategy prior to execution between Subsurface and Wells.
- To propose control measures for geohazards for safe operations.

Background theory

In seismic reflection, the layers or bands observed in a seismic section are termed reflections. These reflections in the seismic data result due to contrasts in the seismic impedance (density * seismic velocity) across a geologic boundary. For a seismic wave intersecting a layer or boundary at normal incidence, the ratio of the reflected-to-incident amplitude is the acoustic impedance (R), which defines the strength or amplitude of the seismic reflection.

$R = (\rho 2V2 - \rho 1V1) / (\rho 2V2 + \rho 1V1)$
where, ρ is the density of the rock, V1 and V2 are seismic velocities on either side of the boundary. EPA, 2023



Generation of the Quadrature Data

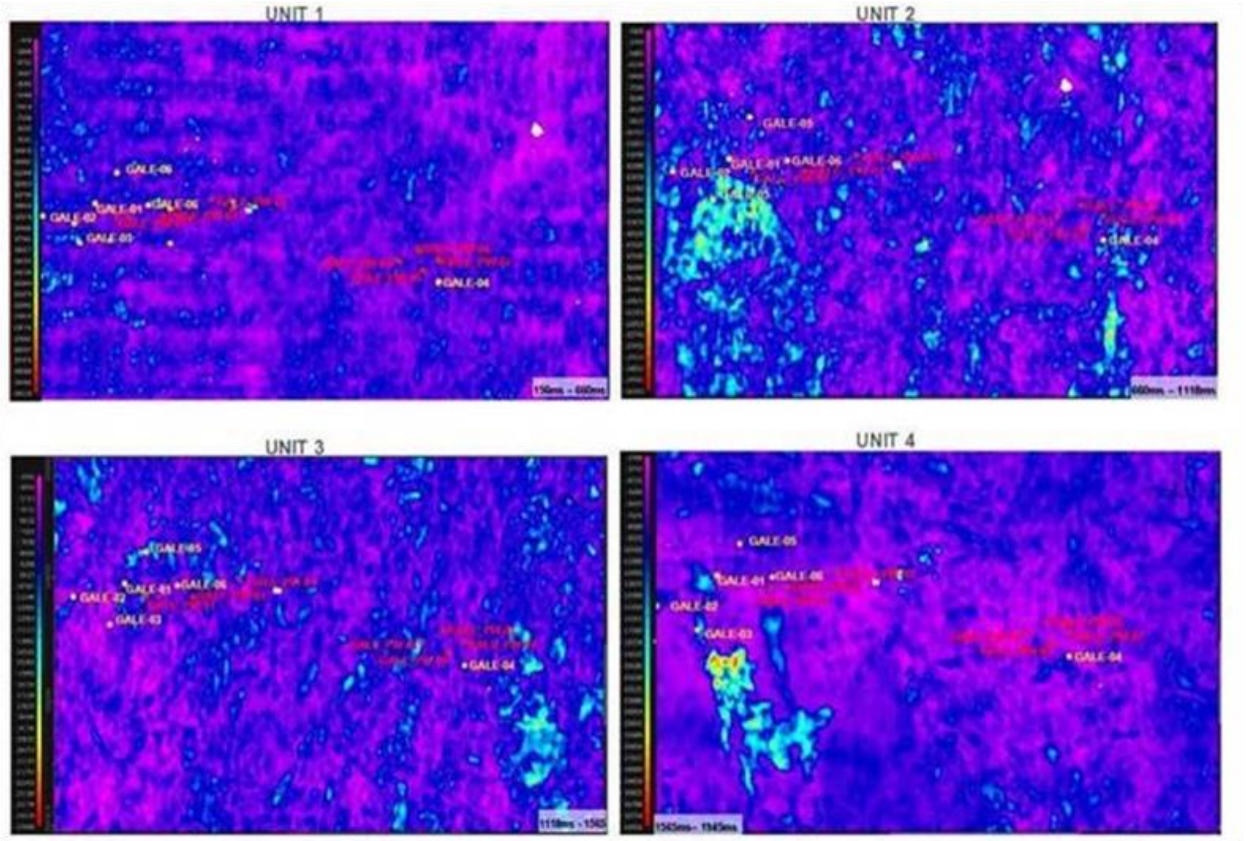
The quadrature component of a signal is the 90° out-of-phase component, the part of an
Induced signal which is out-of-phase with the generating signal (Barnes, 2006). Quadrature seismic volume was generated from the GALE 3D Reflectivity seismic volume (Pre-Stack Depth Migration_Full_Gale) to aid in events interpretation and analysis. Geohazards assessment was then carried out for the planned wells in the GALE field. The Quadrature seismic is considered a more appropriate reflectivity seismic attribute for use in shallow geohazard analysis as it is known for its characteristic preservation of high frequency spectrum inherent in the data.

Materials and method

In order to carry out this study, the data used include3D seismic volumes, Horizon interpretations, offset well data (well logs, field velocity data, daily drilling reports), Field geotechnical information, planned well trajectories and casing depths information.

Amplitude Analysis

Amplitude extraction was based on the Pre-Stack Depth Migration_Full_Gale seismic data. The seismic data was subdivided into intervals/units using shallow interpretations created for this purpose. Interval amplitudes were extracted as minimum extremum. Four intervals were analysed (Units 1, 2, 3 and 4). Areas of high amplitude proxy of gas were avoided and new planned well trajectories replanned and updated. Some other amplitudes within the area were de-risked as they were tested by offset well (GALE-04) but did not find. On the western flank, the amplitudes are not close to the planned wells. The offset wells did not find hydrocarbon. In unit 4, there are observed amplitude bodies which are not likely hydrocarbon related, as offset wells through this interval did not indicate hydrocarbon. In units 1 and 3, there are no observed anomalous amplitude bodies around the planned wells.



Amplitude extraction over Units 1-4

Fault Analysis

A semblance volume was generated to analyse for near surface faulting. There was no near surface faulting observed within the area of interest in the GALE field. No near surface faulting was observed from available data within the AOI (area of interest), shallowest faulting observed starts from 1500 ms (5330 feet subsea).

Faulting was analysed from shallow to near reservoir intervals, as part of DEP requirements to demonstrate that there is no migration path for hydrocarbon from deep to shallow intervals.

Planned well trajectory is in red, and existing wells have their trajectories in black. No near surface faulting was observed from available data within the AOI (area of interest), shallowest faulting observed starts from 1500 ms (5392 ftss).

Offset Well Ties

Offset well analysis was carried out using offset wells from the GALE field. Offset wells used are GALE-01, GALE-03, GALE-05, GALE-06, and GALE-08. Analysis was done in two segments: the eastern flank and the western flank. On the western flank, GALE-04 was used as the main calibration well due to proximity. Observations from the offset well analysis indicate subsurface no geohazard. High amplitude observed in Unit 2 is not Hydrocarbon related as it was tested by GALE-04.

On the western flank, the main calibration well is GALE-05. Observations from the offset well analysis indicate no geohazard issues were generally observed down to the surface casing (13 3/8") depths. However, gas cut and overpull were observed at the reservoir sections. Planned well trajectory is coloured red and the existing wells are in black. The drilling issues highlighted are based on the offset well data from the daily drilling reports. These are overlain on the seismic data to know their intervals of occurrence Planned wells trajectory is coloured red and the existing well is in black. The drilling issues highlighted are based on the offset well data from the daily drilling reports. These are overlain on the seismic data in order to know the intervals these are occurring planned wells trajectory is coloured red and the existing well is in black. The drilling issues highlighted are based on the offset well data from the daily drilling reports. These are overlain on the seismic data in order to know the intervals these are occurring.

Tophole/Well Summary

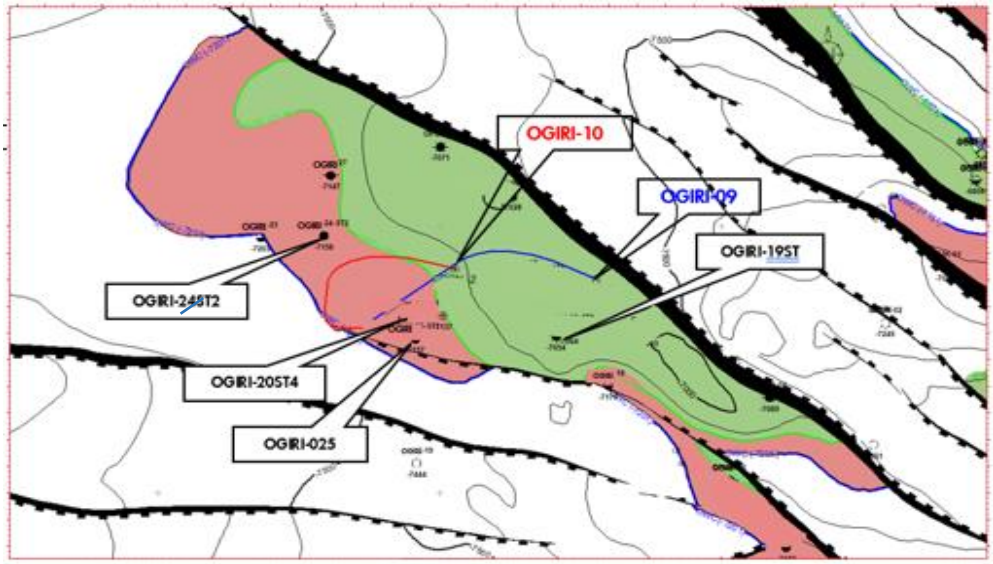
Tophole summary was generated for the 7 GALE planned wells. They were analyzed for shallow gas and other geohazards in the GALE field. The probability of encountering shallow gas and other geohazards was rated low in the tophole/well summary section of the wells.

A representative Gale field well summary: GALE_PW-01

Geohazard assessment was carried out for the planned GALE_ PW-01 well. Quadrature data was analysed for the presence of Shallow Gas bodies. Also, semblance analysis was carried out to check for potential hydrocarbon migration pathways (in the upward direction). Offset analysis was also done for neighbouring wells within the field. A well summary was generated for the planned well trajectory detailing the outcome of the geohazard assessment for each interval along the planned well.

The OgiriWell Overview

The Ogiri-09 well was planned to be drilled horizontally as to develop 4.17 MMstb of oil from X1000 reservoir. Expected initial potential was – 1700 barrels of oil per day (bopd).



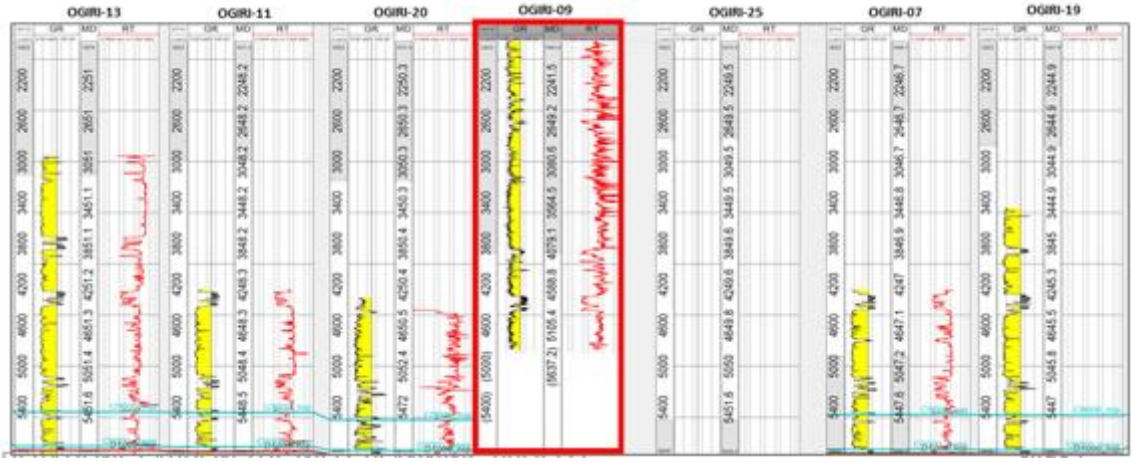
Ogiri field B1000 structure map

Subsurface Uncertainties

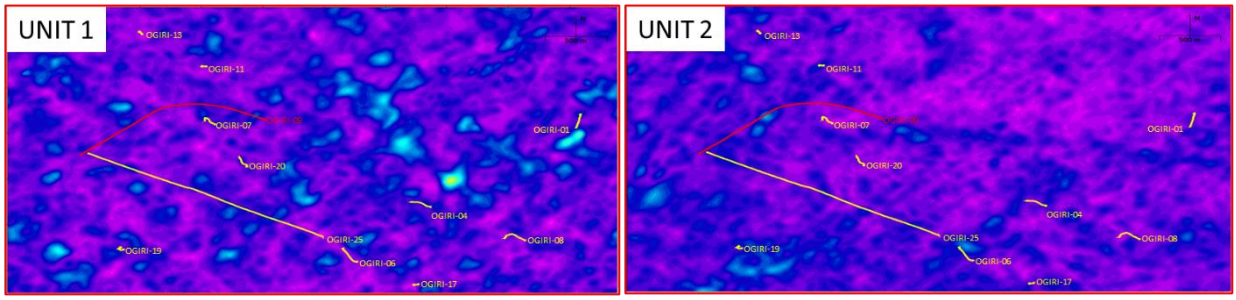
Some associated uncertainties with the drilling of this new well were already outlined. These border around Structure, Present Gas Oil Contact, Position, dip and sealing capacity of intra-reservoir shale.

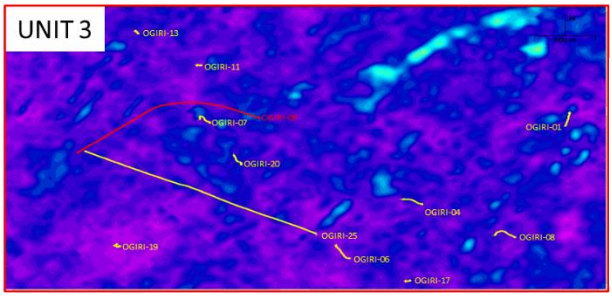
Offset Wells in Surface Hole Section:

Some of the OGIRI offset wells were reviewed and found to have recorded, continental sands; good correlation across the field, no history of high background gas (BG) and Low chance of occurrence of shallow gas.



Ogiri -07, 09, 11, 13, 19 and 25 well logs correlation pane.





- Amplitudes were extracted over Unit 1, Unit 2, 3 and Unit 4 intervals
- There are some observed amplitude bodies in these intervals (Unit1-3) but not along the planned well trajectories.
- Planned well is in Red while the Offset wells are in Yellow.

Amplitude extraction over units 1 to 3

RESULTS

Observations from quadrature 3D seismic data and semblance data show that there is no migration path for hydrocarbon from deep to shallow intervals. Observed high amplitude traversed by the planned well at Unit 2 was tested by offset well (GALE-04) but did not encounter hydrocarbon. Offset well analysis in the field revealed intervals with gas cut and overpull were observed at the reservoir sections in GALE-05.

Unit 4 is characterized by the presence of a clay filled canyon with sand intercalations. GALE-04 penetrated this canyon without incidents. High amplitude body is found close to the suggested 13 3/8" casing point.

Based on the geohazards assessment carried out for this well; the chances of encountering shallow gas for all the units as shown in the well summary is rated low.

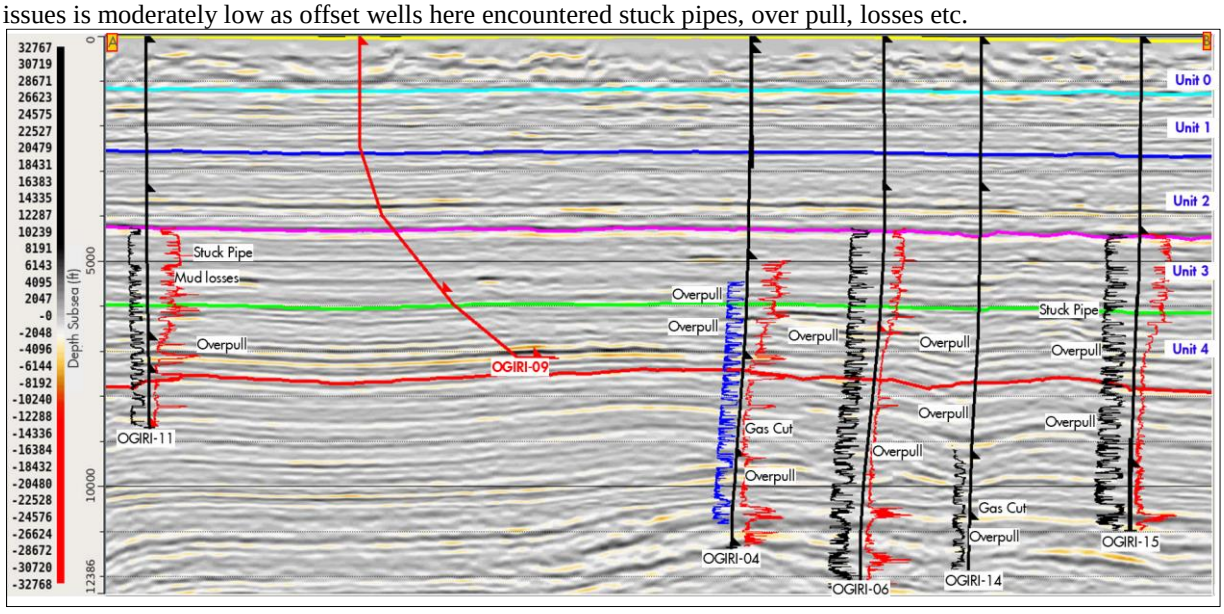
OGIRI Pre-Drill Geohazards Assessments

Geohazard assessment was carried out for the planned OGIRI-1 well. Quadrature data was analysed for the presence of Shallow Gas bodies. Also, semblance analysis was carried out to check for potential hydrocarbon migration pathways (in the upward direction). Offset analysis was also done for neighbouring wells (OGIRI-04, 06, 11, 14 and 15) within the field. A well summary was generated for the planned well trajectory detailing the outcome of the geohazard assessment for each interval along the planned well.

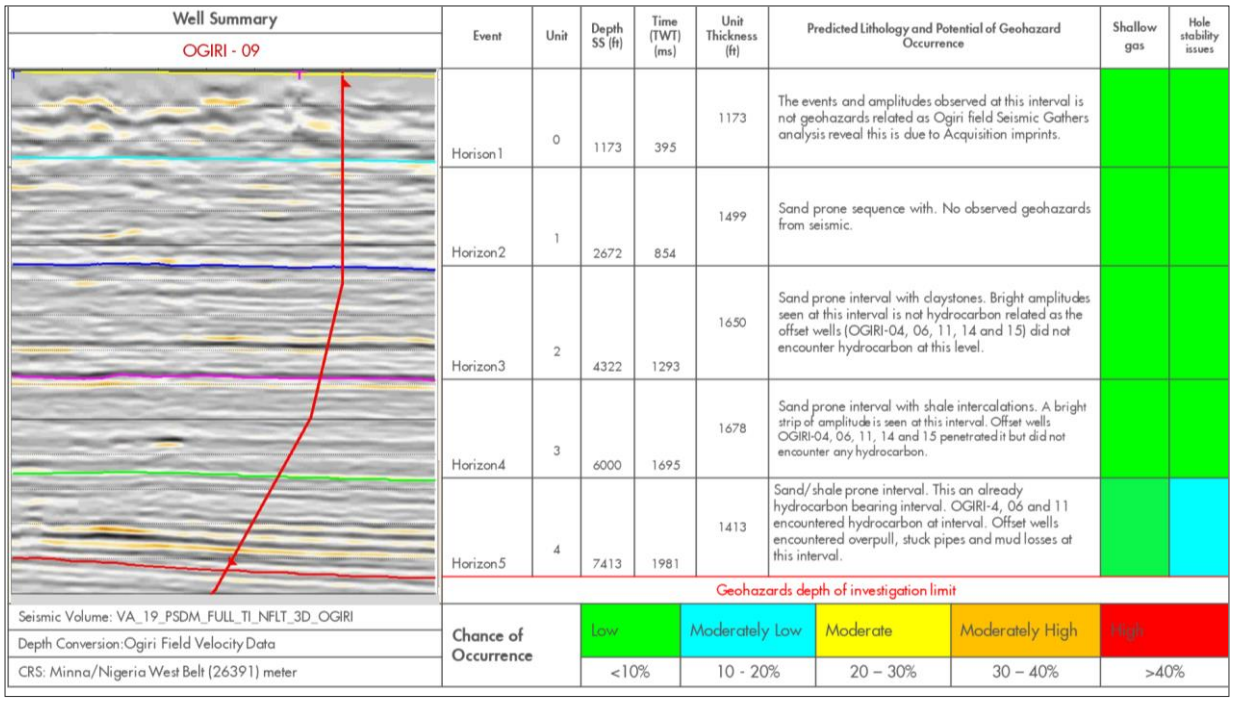
Observations from quadrature 3D seismic data and semblance data show that there is no migration path for hydrocarbon from deep to shallow intervals. There were no observed amplitude bodies around the Planned well trajectories.

Offset well analysis in the field revealed issues ranging from Losses, stuck pipe, overpull and gas cut as gathered from the daily drilling reports. Review of field geotechnical report did not reveal any geohazards issues.

Based on the geohazards assessment carried out for this well; the chance occurrence of encountering shallow gas for all the units as shown in the well summary is rated low. However, the rating at Unit 4 (which is already within reservoir regions) for other drilling issues is moderately low as offset wells here encountered stuck pipes, over pull, losses etc.



Offset well analysis for Ogiri-09

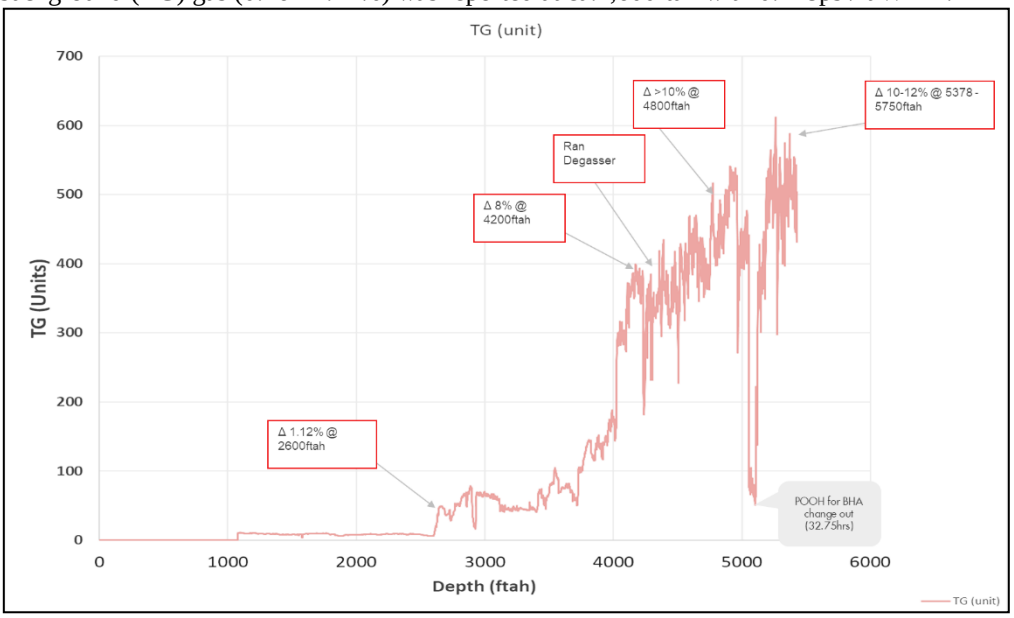


Well Summary OGIRI - 09	Event	Unit	Depth SS (ft)	Time (TWT) (ms)	Unit Thickness (ft)	Predicted Lithology and Potential of Geohazard Occurrence	Shallow gas	Hole stability issues
	Horison1	0	1173	395	1173	The events and amplitudes observed at this interval is not geohazards related as Ogiri field Seismic Gathers analysis reveal this is due to Acquisition imprints.		
	Horizon2	1	2672	854	1499	Sand prone sequence with. No observed geohazards from seismic.		
	Horizon3	2	4322	1293	1650	Sand prone interval with claystones. Bright amplitudes seen at this interval is not hydrocarbon related as the offset wells (OGIRI-04, 06, 11, 14 and 15) did not encounter hydrocarbon at this level.		
	Horizon4	3	6000	1695	1678	Sand prone interval with shale intercalations. A bright strip of amplitude is seen at this interval. Offset wells OGIRI-04, 06, 11, 14 and 15 penetrated it but did not encounter any hydrocarbon.		
	Horizon5	4	7413	1981	1413	Sand/shale prone interval. This an already hydrocarbon bearing interval. OGIRI-4, 06 and 11 encountered hydrocarbon at interval. Offset wells encountered overpull, stuck pipes and mud losses at this interval.		
	Geohazards depth of investigation limit							
Seismic Volume: VA_19_PSDM_FULL_TI_NFLT_3D_OGIRI Depth Conversion:Ogiri Field Velocity Data CRS: Minna/Nigeria West Belt (26391) meter	Chance of Occurrence		Low	Moderately Low	Moderate	Moderately High	High	
			<10%	10 - 20%	20 – 30%	30 – 40%	>40%	

Well summary for OGIRI-09

Incident Summary

OGIRI-09 well was spudded and drilling commenced with 17-1/2'' hole. A few hours later, the onset of elevated background (BG) gas (0.16 - 1.12%) was reported at ca.2,600ftah with 0.478psi/ft WBM.



Ogiri-09 Increase in Total Background Gas with Depth

The Background Gas reading increased continually to 8% @ 4,500ftah and stabilized as drilling progressed to 5,378ftah. Degasser ran with no noticeable effect. Mud logger's sensors were re-calibrated several times and recertified alright. Pooling Out Of Hole (POOH) was initiated for Bottom Hole Assembly change, no gas influx reported.

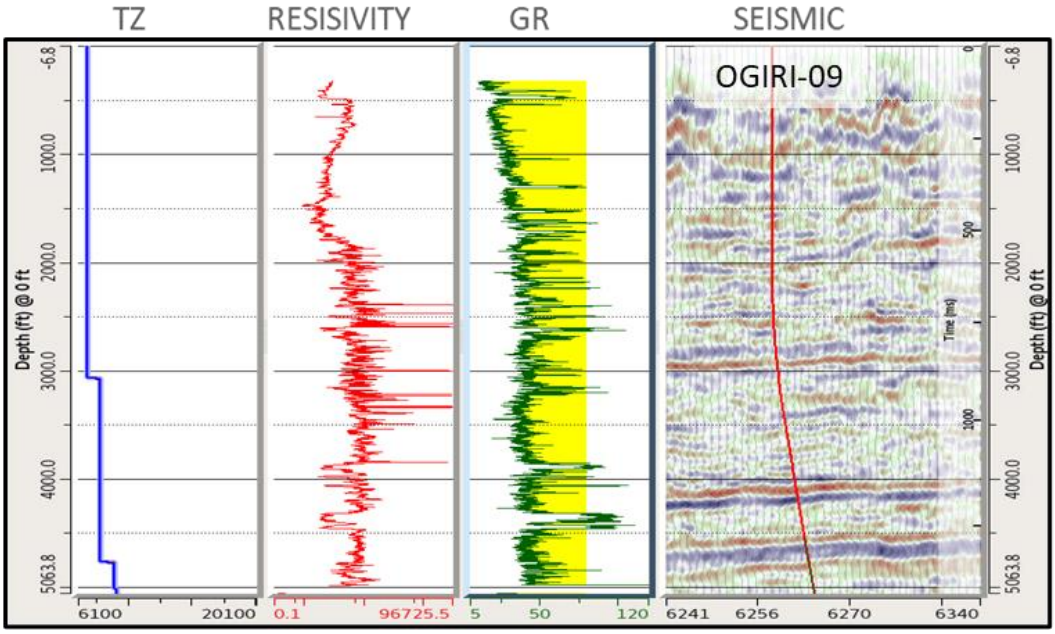
The drilling team Rigged Back In Hole (RBIH) and carried out bottoms up circulation; peak gas reading of 2% recorded. Drilling re-commenced from 5,378ftah to 5,750ftah; increased BG gas reading of 10 - 12% (Lower Explosive Limit is 10%). Decision was taken to Pool Out Of Hole and case off hole section.

From the geohazards analysis, no indications of shallow geohazard were prognosed from seismic data and offset well analysis and top-hole was still at the Fresh-saline water interphase as predicted.

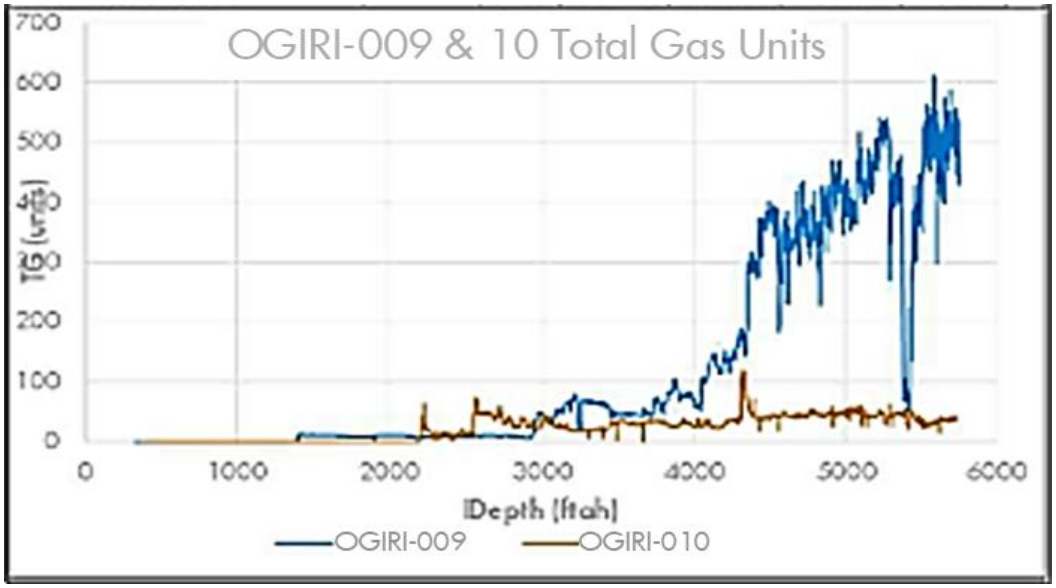
Chronicle Of High Background Gas Incident

Drilling activities were initiated with a view to safely completing Ogiri-009-hole section, successfully drill to the total depth, complete well, hook up and start production.However, Ogiri-09 well successfully spudded as part of re-entry campaign to the field after over 10years of no drilling activity. During the surface hole (17 1/2") elevated background gas of 2% was first recorded at ca 2600ftah then 8% @4500ftah and 12% @5,378ftah. Actual source of high BG is still not fully known. However,is believed

by the drilling team that there are two potential gas sources – (1) Recharge from deeper gas bearing reservoir, (2) Shallow Biogenic gas. Some composition analysis based on Mud log indicate indicates mostly C1; suggesting more likely biogenic origin. A new well Ogiri-10 drilled from the same surface location but did not encounter high background gas.



Logs and seismic data from the shallow top-hole section do not suggest hydrocarbon presence.



A display of Ogiri-09 and 19 Total Background Gas Units

Conclusion

Geohazards studies were carried out in both the Gale and Ogiri fields. Analysed offset wells in both fields did not indicate the presence of geohazards along the planned/optimised wells.Observed high amplitudes were avoided and planned well trajectories optimised.

Learning from the comparative studies show that subsurface surprises could still occur despite good well control.There is therefore need to address log data gap in shallow intervals- acquire surface hole logs and where there have been no drilling activities in a producing field for many years, additional risk of postproduction gas risk should be considered, and adequate mitigation measures put in place even though shallow risk level is low.

Prior to drilling execution, effective communication of risk and risk management strategy is necessary between the Subsurface and Well Engineeringteams is key for common risk appreciation and management.

Based on learning from Ogiri-09, updated procedure was put in place to manage similar issues and was successfully deployed in subsequent well (Ogiri-10).

REFERENCES:

1. Anderson, A. L., and L. D. Hampton, 1980a, Acoustics of gas-bearing sediments: 1. Background: Journa of the Acoustical Society of America, 67, 1865–1889
2. Bastia, R.; Radhakrishna, M. and Nayak, S. (2011). Identification and characterization of marine geohazards in the deep water eastern offshore of India: Constraints from multibeam bathymetry, side scan sonar and 3D high-resolution seismic data. *Nat. Hazards*, 57, 107–120.
3. Benjamin, U.; Huuse, M. and Hodgetts, D. (2015). Canyon-confined pockmarks on the western Niger Delta slope. *J. Afr. Earth Sci*., 107, 15–27.
4. Bjørkum, P. A., Walderhaug, O. and Nadeau, P. H., 1998, Physical constraints on hydrocarbon leakage and trapping revisited: EAGE Petroleum Geoscience, 4, 237-239 Chopra, S., Marfurt, K. J., 2007, Seismic attributes for prospect identification and reservoir characterization: SEG geophysical developments series, no. 11
5. Canals, M.; Lastras, G.; Urgeles, R.; Casamor, J. L.; Mienert, J.; Cattaneo, A.; De Batist, M.; Haflidason, H.; Imbo, Y. and Laberg, J. S. (2004). Slope failure dynamics and impacts from
6. Ceramicola, S.; Praeg, D.; Coste, M.; Forlin, E.; Cova, A.; Colizza, E. and Critelli, S. (2014). Submarine Mass-Movements Along the Slopes of the Active Ionian Continental Margins and Their Consequences for Marine Geohazards (Mediterranean Sea). In Submarine Mass Movements and Their Consequences, Advances in Natural and Technological Hazards Research; Krastel, S., Behrmann, J., Völker, D., Stipp, M., Berndt, C., Urgeles, R., Chaytor, J., Huhn, K., Strasser, M., Harbitz, C.B., Eds.; Springer: Cham, Switzerland, pp. 295–306.
7. Chiocci, F. L. and Cattaneo, A. (2011). Urgeles, R. Seafloor mapping for geohazard assessment: state of the art. *Mar. Geophys. Res*., 32, 1–11.
8. Hovland, M.; Gardner, J. V. and Judd, A.G. (2002). The significance of pockmarks to understanding fluid flow processes and geohazards. *Geofluids*, 2, 127–136. https://doi.org/10.2118/167569-MS.
9. Ilg, B. R., Hemmings-Sykes, S., Nicol, A., Baur, J., Fohrmann, M., Funnell, R., and Milner, M., 2012, Normal faults and gas migration in an active plate boundary, southern
10. Ismail-Zadeh, A. T. (2016). Geohazard research, modeling, and assessment for disaster risk reduction. *Russ. J. Earth Sci*., 16, ES3002.
11. Kvalstad, T. J. (2007). What is the Current "Best Practice" in Offshore Geohazard Investigations? A State-of-the-Art Review. In Proceedings of the Offshore Technology Conference, Houston, TX, USA, 30 April–3 May 2007.
12. Løseth, H., M. Gading, and L. Wensaas, 2009, Hydrocarbon leakage interpreted on seismic data: Marine and Petroleum Geology, v. 26, no. 7, 1304–1319.
13. Milkov, A. V. (2000). Worldwide distribution of submarine mud volcanoes and associated gas hydrates. *Mar. Geol*., 167, 29–42.
14. Taranaki Basin, offshore, New Zealand: AAPG Bulletin, v. 96, No. 9, 1733-1756
15. Mohammed Alarfaj and Don C. Lawton, CREWES Research Report — Volume 24 (2012)
16. Ostanin, I.; Anka, Z.; Di Primio, R. and Bernal, A. (2012). Hydrocarbon leakage above the Snøhvit gas field, Hammerfest Basin SW Barents Sea. *First Break*, 30, 55–60.
17. EPA (Environmental Protection Agency) March 2023. https://www.epa.gov/environmental-geophysics/seismic-reflectivity
18. Løvholt, F.; Pedersen, G.; Gisler, G. Oceanic propagation of a potential tsunami from the La Palma Island. J. Geophys. Res. 2008, 113, C09026.
19. Orange, D.; Angell, M.; Pawlowski, B.; Meaux, D.; Gee, L.; Kleiner, A. and Anderson, B. (2001). Visualizing Seafloor, Seismic, Gravity and Magnetics Data in the Deepwater Gulf of Mexico Improves Understanding of Geohazards, Salt and Seeps. In Proceedings of the Offshore Technology Conference, Houston, TX, USA, 30 April–3 May 2001.
20. Shmatkova, A. A.; Shmatkov, A. A.; Gainanov, V. G. and Buenz, S. (2015). Identification of Geohazards Based on the Data of Marine High-Resolution 3D Seismic Observations in the Norwegian Sea. *Moscow Univer. Geol. Bull*., 70, 53–61.
21. Solheim, A.; Bhasin, R.; De Blasio, F. V.; Blikra, L. H.; Boyle, S.; Braathen, A.; Dehls, J.; Elverhøi, A.; Etzelmüller, B. and Glimsdal, S. (2005). International Centre for Geohazards (ICG): Assessment, prevention and mitigation of geohazards. *Norw. J. Geol*., 85, 45–62.
22. Wu, S.; Wang, D. and Völker, D. (2018). Deep-Sea Geohazards in the South China Sea. *J. Ocean Univ. China*, 17, 1–7.
23. Vanneste, M.; Sultan, N.; Garziglia, S.; Forsberg, C. F. and L'Heureux, J. S. (2014). Seafloor instabilities and sediment deformation processes: The need for integrated, multi-disciplinary investigations. *Mar. Geol*., 352, 183–214.