Gulf of Mexico Hydrate Mapping and Interpretation Analysis

Project Area 2 Report
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This report satisfies Mapping and Prospect Identification within Area 2 for BOEM award Gulf of Mexico Gas Hydrate Mapping and Interpretation Analysis, which is Deliverable/Milestone #3 (Table 1).

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Table 1. List of required deliverables and figures.

	Deliverable	Figure #
1	A map showing the distribution of shallow trubidite channel levee systems and shallow salt bodies.	3, 6
2	A map showing the depth to the BSR and the spatial distribution of BSR's.	4, 5, 7
3	Regional seismic cross sections showing the base of gas hydrate stability and the relationship of perspective reservoir intervals to channel levee systems, faults, salt, and other geologic features.	8, 12, 14, 15, 16
4	Subsurface geologic/geophysical maps at the base of gas hydrate stability as determined through mapping, modeling, and the integration of well log data	7
5	Subsurface geologic maps of one or more seismic reflectors within the gas hydrate stability zone (or that cross the gas hydrate stability zone) that have a high probability of containing coarse-grained sand based on well log analysis and the nature of the seismic reflector. Maps will include both strucural and amplitide renderings.	18, 19, 20, 21 (structure maps)
6	Interpreted seismic lines that illustrate geologic fearures related to the prospective reservoirs including BSR's, faults, base of gas hydrate stability, and zones of interest.	8, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21
7	If wells occur in the vicinity of the prospect, annotated well-logs at each gas hydrate prospect showing the thickness of hydrates within the stability zone, interpreted base of gas hydrate stability, and the presence of feree gas beneath the gas hydrate stability zone.	9, 12, 13, 16, 17

1. Study area and data

Project Area 2 is located in the northeastern Gulf of Mexico at the eastern margin of the Mississippi Canyon in ~300-1500 meters of water (Figure 1a, b). In the north, the Area is characterized by several cross-slope ridges with gentle slopes (0.5-2.5 deg) and seafloor escarpments related to mass movement events with head scarps reaching 9 deg (Figure 1b). In the south, the bathymetry map shows cascading seafloor topography related to salt-induced normal faulting. In contrast to Project Area 1, there are no salt diapirs outcropping at the seafloor. Additionally, several sub-circular mound features appear within the faulted regions. These mounds are mud volcanos and/or pingo-like features related to subsurface fluid flow and seafloor gas discharge. The south-eastern part of the study area has been previously characterized by Sawyer et al., 2007 (Figure 1b); we used this study to back up our interpretation of seismic facies and paleo-channel mapping.

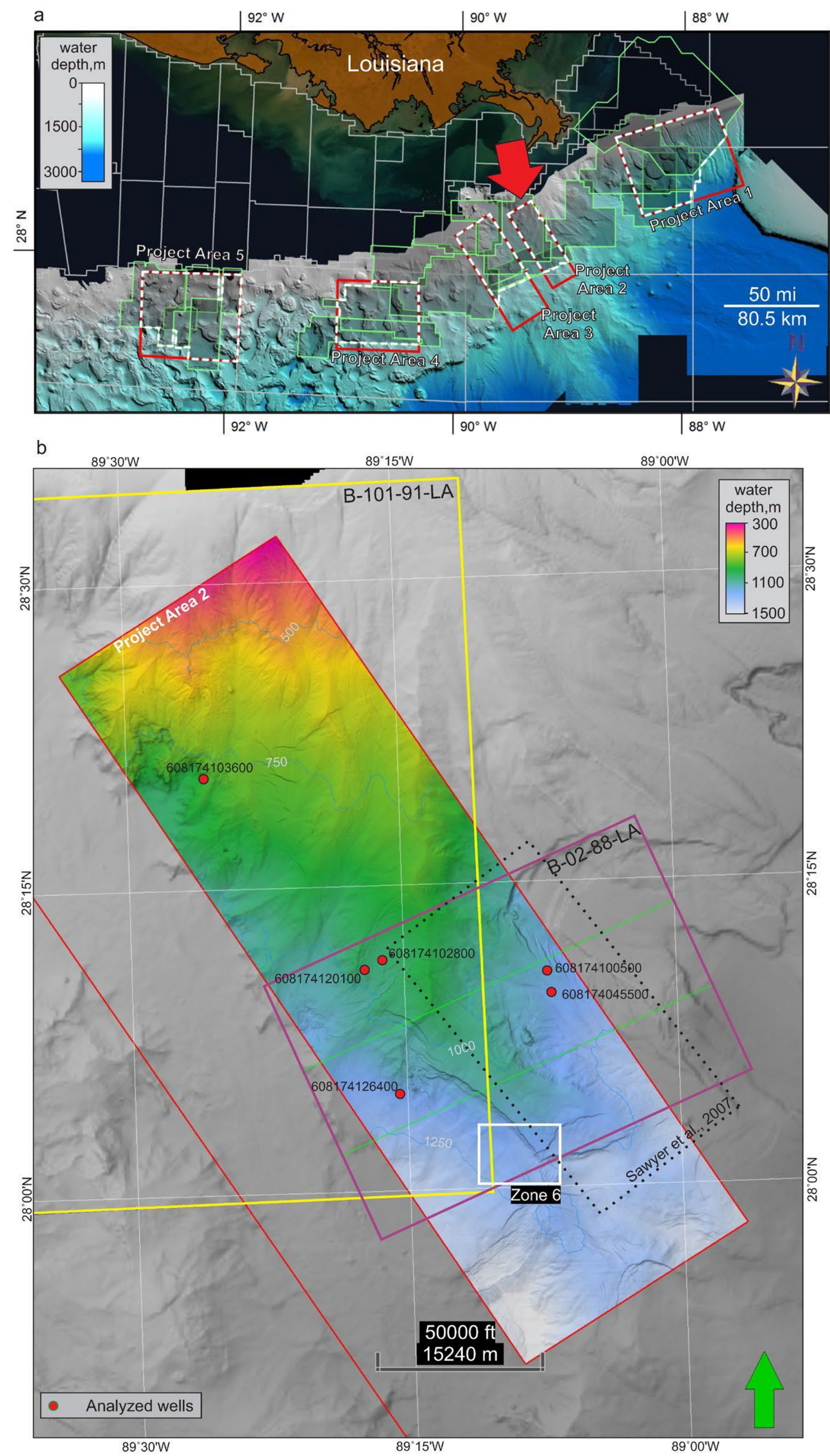

Figure 1 a) A bathymetry map of the northern Gulf of Mexico and five Project Areas. The location of Project Area 2 is defined with the red arrow. b) The bathymetry map and location of two 3D seismic surveys selected for interpretation and analyses based on the data quality assessment. See Table 2 for details. A red box shows Project Area 2. A dashed black box indicates area studied by Sawyer et al., 2007 that was used to back up our interpretation of seismic facies and paleo-channel mapping.

Within Project Area 2, only three seismic surveys were available and uploaded from the NAMSS database for data quality assessment: B-101-91-LA, B-02-88-LA and B-09-88-LA (Figure 1b, Table 2). The total area of Project Area 2 is 1754 km^2 of which ~1418 km^2 (81%) had 3D seismic data coverage. Based on spatial coverage and data quality, we selected two surveys B-101-91-LA and B-02-88-LA (yellow and purple boxes in Figure 1b) to perform further data analyses and interpretation.

Table 2. Details on the 3D seismic surveys uploaded for initial data quality analyses within Project Area 2. Yellow color marks surveys selected for further data interpretation.

Survey number	Survey name/BOEM identifier	Project Area #	Year	Number of 3D volumes	Area of seismic survey (km2)	Frequency range (Hz)	Bin size (m)	Projection	Comments
1	B-02-88-LA/ L88-056	2	1988	3	1089	8-70	30x30	16N NAD27, feet	This survey is a cutoff from B-09-88-LA (only eastern part)
2	B-09-88-LA/ L88-056	2 and 3	1988	4	1951	8-70	30x30	16N NAD27, feet	
3	B-101-91-LA/ L91-101	2 and 3	1991	7	3612	5-90	26x26	16N NAD27, feet	

2. Using RMS for mapping bottom simulating reflections and paleo-channels

To identify the bottom simulating reflections (BSR) in Project Area 2, regional root-mean-square (RMS) amplitude calculations were performed independently within two 3D seismic surveys B-101-91-LA and B-02-88-LA (Figure 2). At the stage of regional mapping for potential BSR distribution, the seafloor horizon and the surface and volumetric attribute analyses within three depth domains were used (please refer to Chapter 2 of the Project Area 1 report for more technical details).

However, given the particularly complex sedimentary system in the study area and generally low data quality, we used an auxiliary seismic horizon, Horizon 2, for mapping the distribution of paleo-channels; in some areas, we used it for mapping the BSR (Figure 3, Figure 10). Horizon 2 is predominantly distributed within the GHSZ, shows relatively coherent structure, and is stratigraphically shallower than most of the channel systems in the study area. We also used Horizon 2 for generation of structure maps within the four out of six zones of interest (Figures 18-21), because it was the nearest continuous reflection above the potential gas hydrate reservoirs.

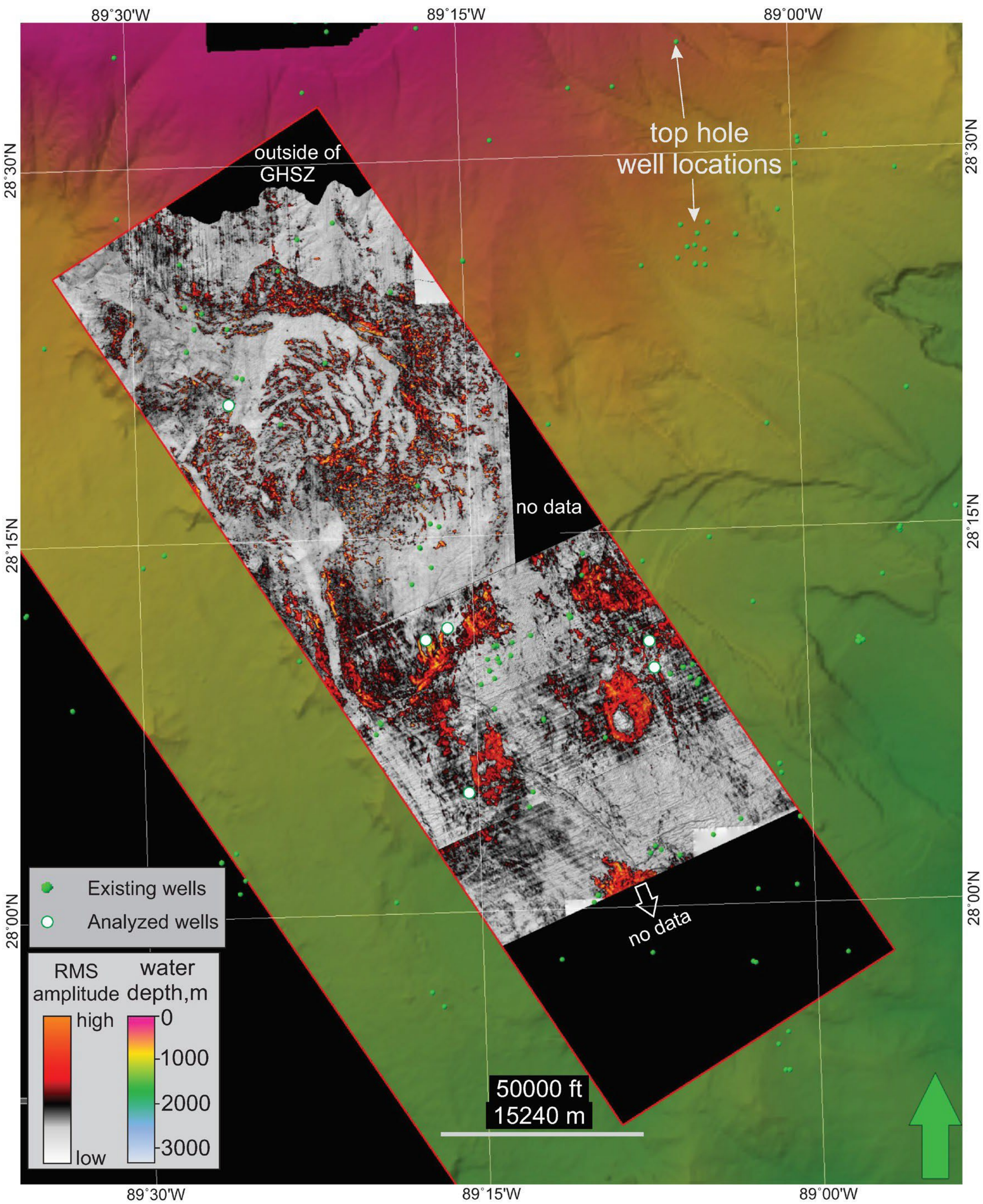

Figure 2. RMS amplitude map at the approximate level of the base of GHSZ within Project Area 2. Green dots show location of the wells drilled in the study area. White circles show wells most proximal to high RMS zones and selected for detailed analyses.

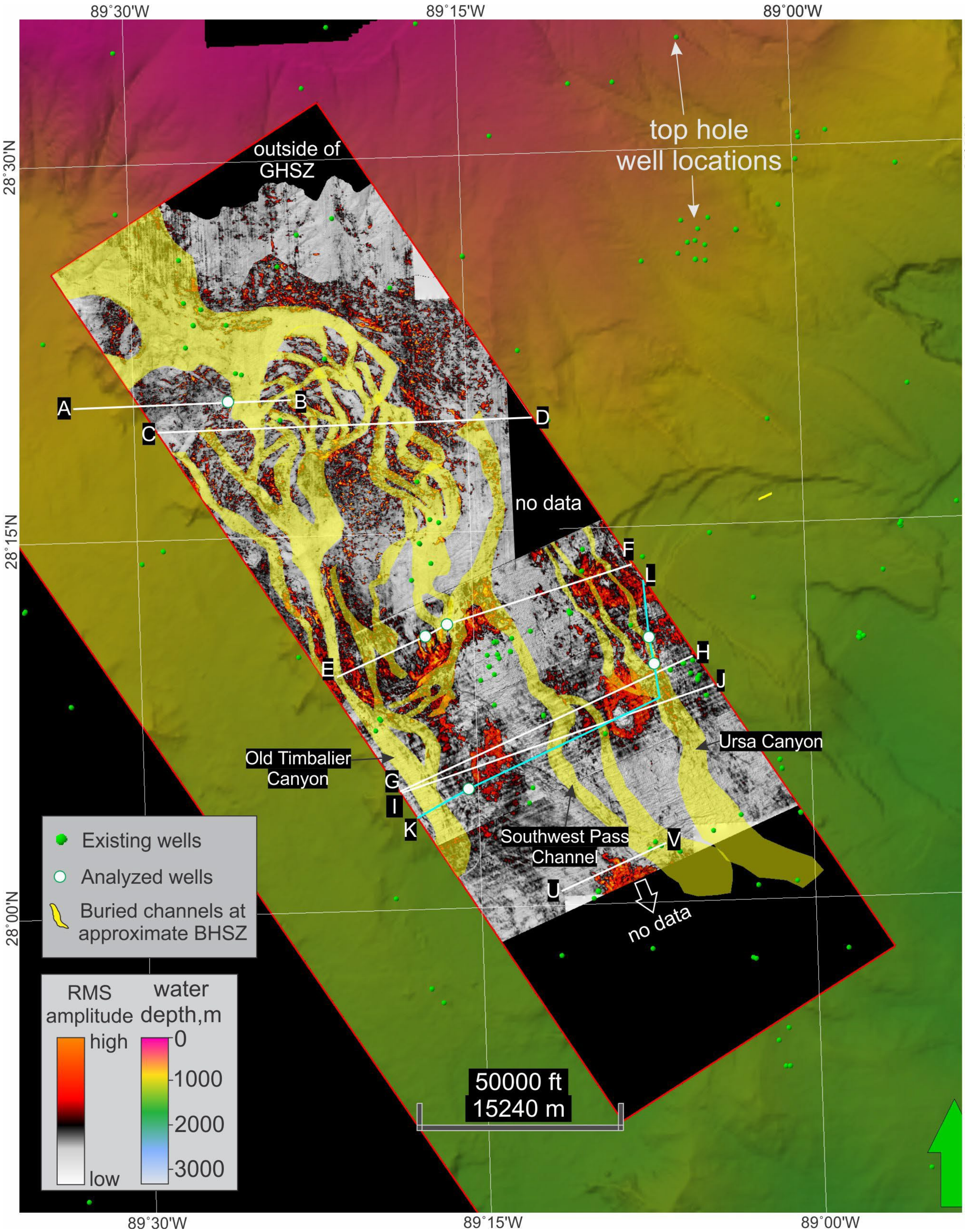

Figure 3. Interpreted RMS amplitude map showing complex paleo-channel systems within Project Area 2. Green dots show surface well locations. White and blue lines are seismic sections crossing major high-amplitude systems that potentially contain gas hydrate.

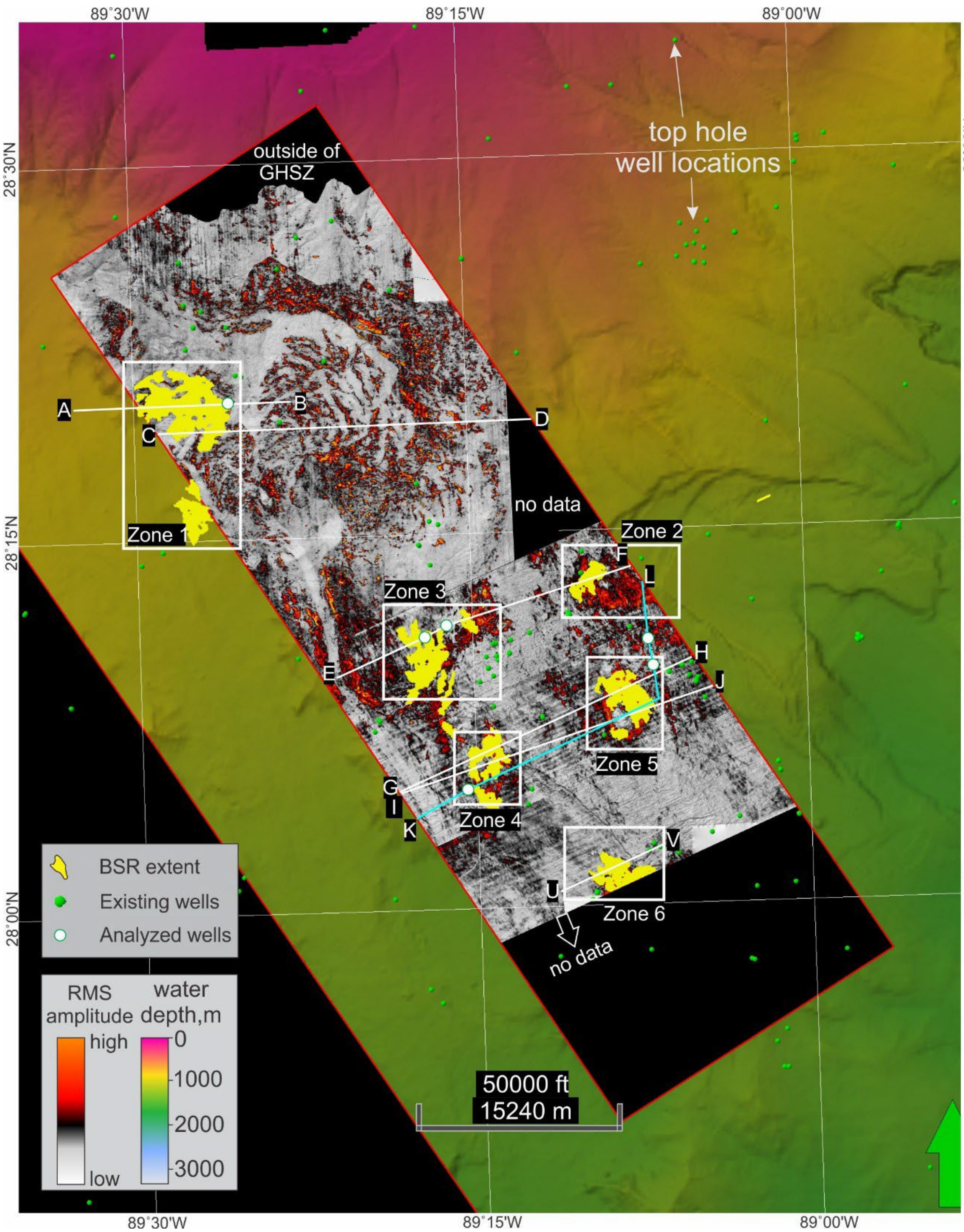

Figure 4. Amplitude map showing the distribution of BSRs within Project Area 2. Green dots show the surface well locations. White and blue lines are seismic sections crossing major high-amplitude systems that potentially contain gas hydrate.

3. Results in Project Area 2

3.1 Paleo-channels

In the northern part of the study area, we map an entangled system of channels that spread across the most part of Project Area 2 (Figures 3, 6). Based on seismic attribute analyses and manual line-by-line interpretation, complex network of channels lies ~300 msec below the seafloor and includes more than 13 individual meandering channels (Figures 3, 6, 10). The channels belonging to the same seismic stratigraphic interval developed during the same time period and likely on a gentle slope that allowed for extensive lateral shifting and merging.

Downslope, these channels interflow and merge into three large channel-levee systems that have been previously named Old Timbalier Canyon (western), Southwest Pass Canyon (central) and Ursa Canyon (eastern) (Figures 3, 6, 14) (Sawyer et al., 2007). We extend the channel interpretation south beyond the data coverage limits (Figures 3, 6) based on schematics from Sawyer et al., 2007, that we geo-referenced and integrated into the Petrel project for reference.

All three channel systems generated significant levee complexes in the southern part of the Project Area 2, which is confirmed by our seismic analyses and well log data (Figures 16, 17). Accordingly, Sawyer et al., 2007 indicated that the channel-levee unit (named the Blue Unit) is sand and mud-rich. Given the relatively short distance between the channel axes (5-7 km), their distal levees and overbank facies could overlap creating an extensive sand-rich drape at the approximate base of GHSZ.

3.2 Bottom-simulating reflections

BSRs in the Project Area 2 concentrate within six distinct zones (Figures 4, 5, 6). In the northern part of the area, we map typical continuous BSR at 1500-1600 msec TWT (~400 msec below the seafloor) (Figures 4, 8). It is observed on the flank of a wide low-amplitude erosional feature upslope from the meandring channel network (Figure 6). Downslope, where channels merge and become more organized, we map high-amplitude clustered BSRs (Zones 2 through 6) (Figures 4, 5, 6), similar to BSR features observed in Perdido Canyon and GC955 (Portnov et al., 2019). The distribution of these clustered BSRs is governed by the underlying salt bodies, which creates a structural framework favorable for shallow hydrocarbon entrapment at the base of GHSZ. Potential gas hydrate reservoirs likely exist in sand-bearing intervals within thick and extensive levees of Old Timbalier Canyon, Southwest Pass Channel and Ursa Canyon. Levee facies are interpreted from typical upwardly concave discontinuous seismic reflection packages (Figures 14, 15) on the flanks of central channel infills. This interpretation agrees with the previously published reconstructions from Sawyer et al., 2007 and low gamma ray units (<65 API) that we observed in several wells drilled through the target sand-bearing intervals (Figures 12, 17), but, unfortunately outside of the mapped BSRs.

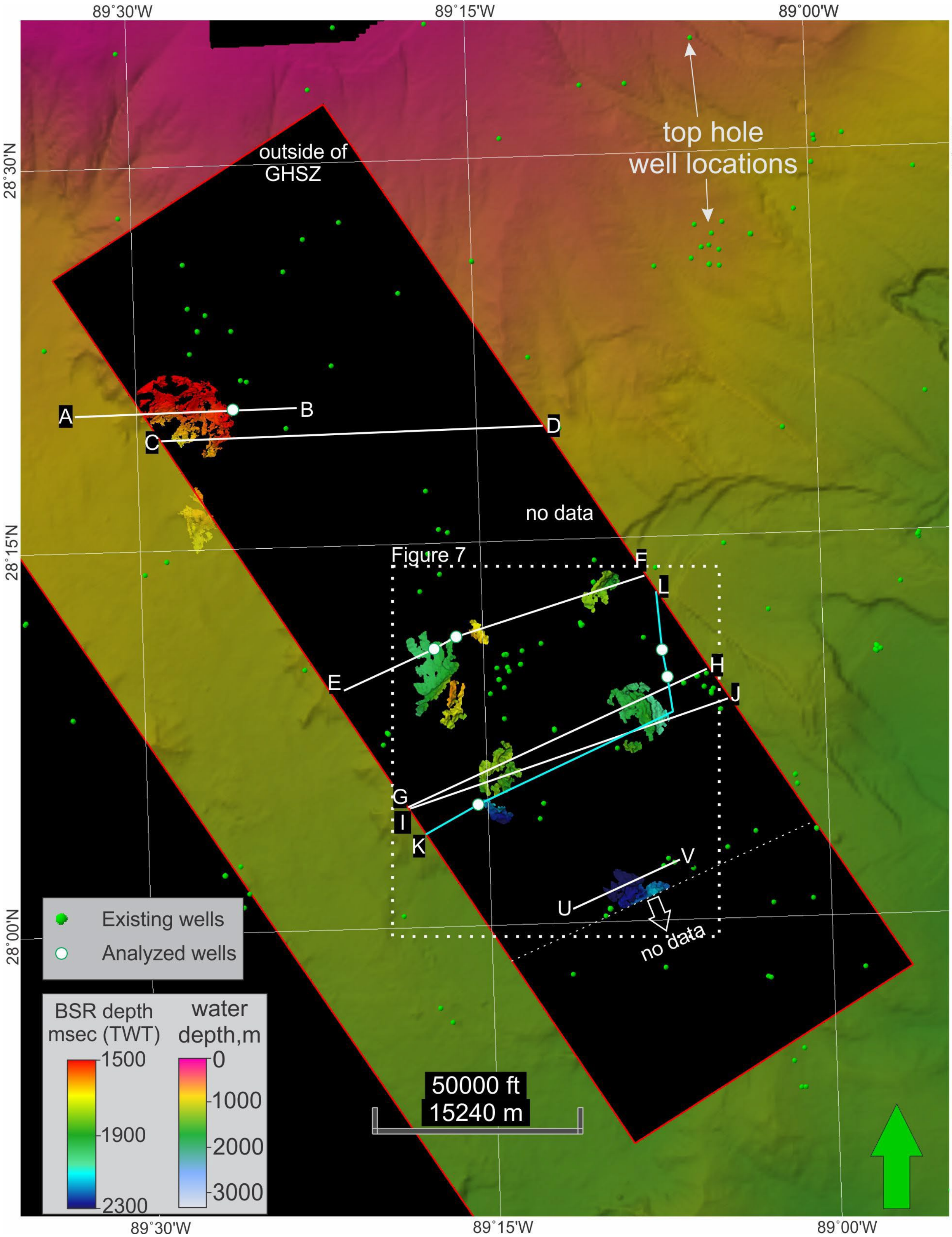

Figure 5. Depth of manually and semi-automatically mapped BSR. White and blue lines are seismic sections crossing major high-amplitude systems that potentially contain gas hydrate.

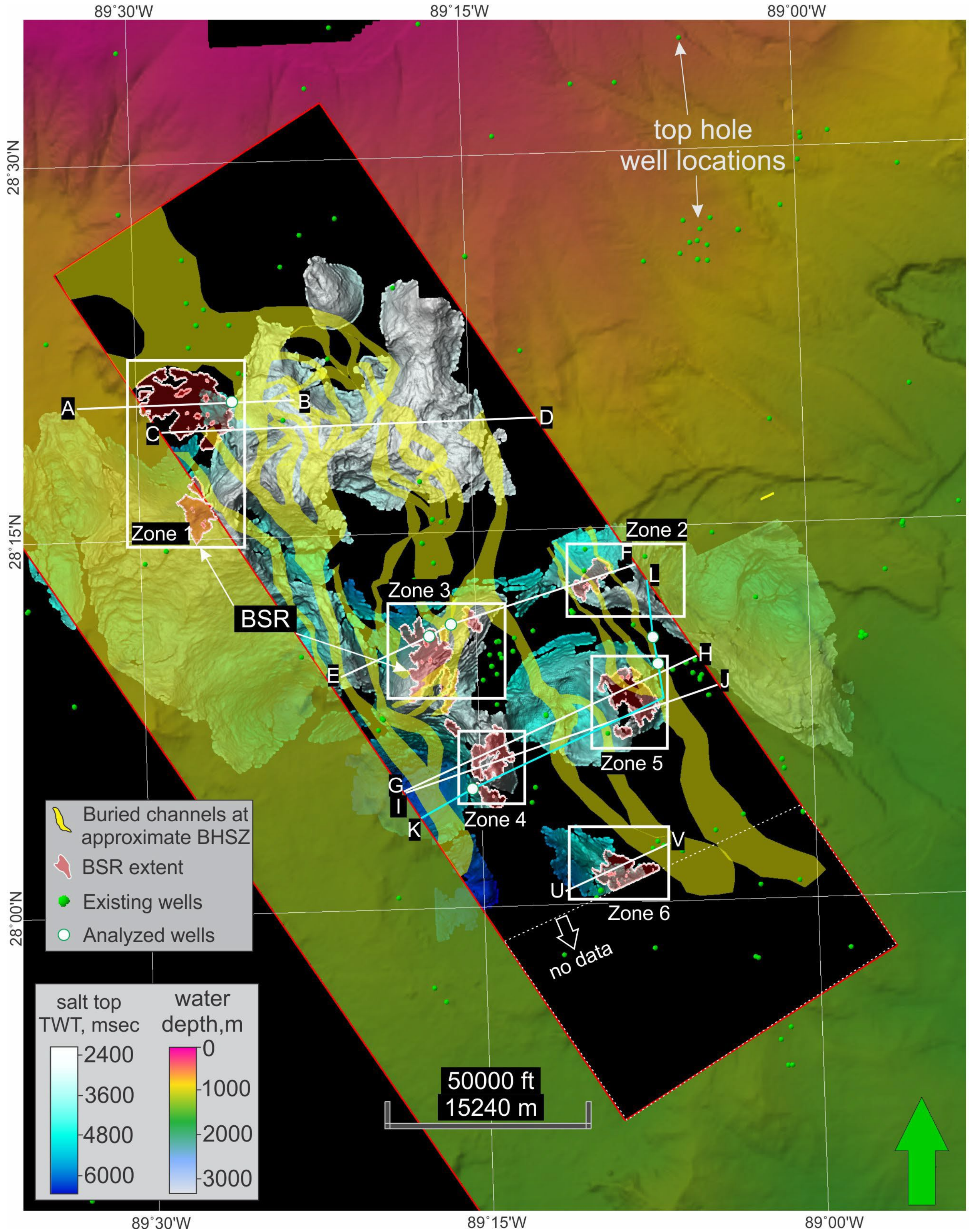

Figure 6. Top of salt depth (blue-green white), paleo-channels and BSR distribution interpreted from RMS attribute maps. White and blue lines are seismic sections crossing major high-amplitude systems that potentially contain gas hydrate.

3.3 Map of peak-leading reflections above BSR

We show the average positive amplitude attribute above the manually mapped clustered BSRs in Zones 2 through 6 (Figure 7). In Zone 1, the map of average positive amplitudes above the BSR showed extremely dispersed attribute values that provided no meaningful geological information and therefore was not included in the current report. Zone 3 showed several extended strong peak-leading structures likely indicating gas/gas hydrate associated with independent narrow paleo-channel infills and/or levees. On the contrary, Zones 2, 4 and 6 show more cohesive peak-leading responses that are likely to indicate more massive gas hydrate reservoirs with significant saturation. Zone 5 shows more dispersed and lower-amplitude peak-leading reflections and thus is less prospective for large gas hydrate reservoirs (Figure 7).

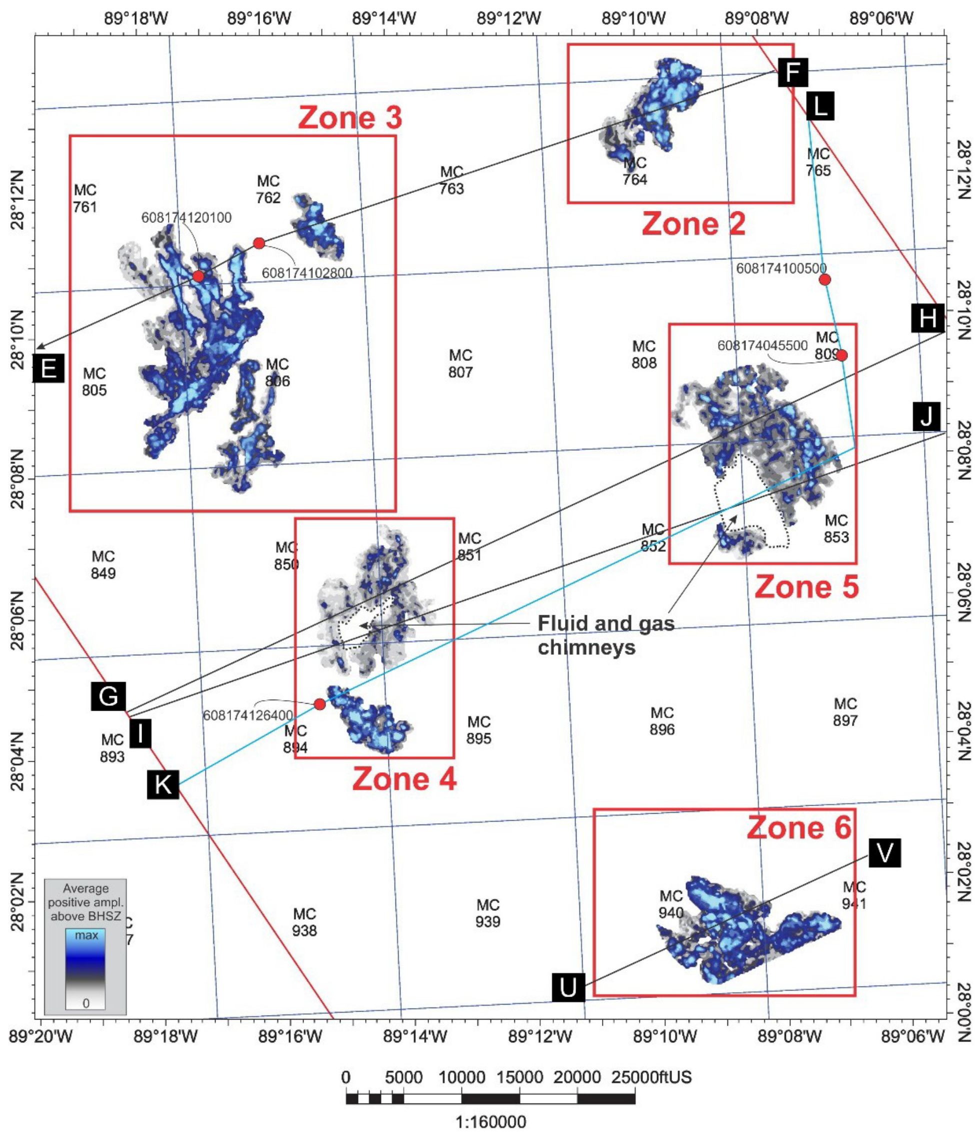

Figure 7. Map of the average positive amplitude attribute above the interpreted clustered BSRs in Zones 2-6. Strong positive amplitudes potentially indicate higher hydrate concentrations.

3.4 Fluid flow features

Seismic and bathymetry data show robust evidence for intensive vertical fluid flow in Zones 2, 4 and 5 (Figures 7, 14, 15, 18, 19, 20). Large (up to 1.5 km in diameter) gas chimneys observed in the seismic data (Figure 14b) break through the entire salt roof from the depths of 1500-3000 msec all the way up to the seafloor. At the seafloor, gas chimneys terminate with high-amplitude peak-leading wipeout zones likely indicating presence of acoustically-hard autigenic carbonate and/or gas hydrate (Figure 14b). The BSRs mapped in Zone 4 bend around the gas chimney; similarly in Zones 2 and 5 they are located directly next to the gas chimneys (Figures 14, 15, 18, 19, 20). Such configuration implies mechanism of long-range gas migration towards the base of GHSZ where it converts to gas hydrate.

3.5 Well data

As expected, there are no publically available well log data from the regions of BSR distribution in the Project Area 2. We used six wells that are located close to the BSRs and several wells drilled through the channels to confirm presence of sand-bearing sediments that may host hydrates (Figure 1). Please note, that due to absence of digital well log data and acoustic/VSP data, the logs are tied to the seismic data based on assumed reasonable seismic velocity and qualitative gamma ray analyses.

Well 608174103600 was drilled at the eastern edge of the continuous BSR in Zone 1 (Figure 1, 4, 8). Log data in this well do not show any increase in resistivity within the interval of approximate base of GHSZ (Figure 9). Well 608174120100 in Zone 3 was drilled exactly between two potentially hydrate-bearing narrow channels (Figures 7, 11, 12). It shows only a marginal increase in resistivity to ~1.5-2 Ωm within the GHSZ. Well 608174102800 (Figures 7, 11, 13) has gamma ray values ranging from 30 to 60 API within the GHSZ, indicating sand-dominated depositional environment. However, resistivity is generally close the background (1-1.5 Ωm) throughout and at the base of GHSZ (Figure 13). There is also a sonic velocity log in well 608174102800 starting from the mudline. It shows disperse range of values and likely does not provide a reliable source of information, yet the compressional slowness measures 80-120 usec/ft (or increased velocity from 2500-3800 m/sec) within the low gamma ray sand-bearing sections of the GHSZ (Figure 13); it is possible that these measurements were collected within a cased zone. In Zone 4, well 608174126400 has increases in resistivity to 2 Ωm within the GHSZ correlating with low gamma ray intervals (Figure 16) potentially indicating a low concentration of gas hydrate. Below the GHSZ, within a higher-amplitude seismic interval, resistivity values show more chaotic character with a range of values 0.7-2.5 ohm m. In Figure 17 we show wells 6081740405500 and 608174100500 drilled through the Ursa Canyon system. These wells clearly show thick (up to 200 msec TWT) low gamma ray intervals approximately at the regional base of GHSZ. These sand-bearing units extending across Project Area 2 and could be reservoirs for gas hydrate.

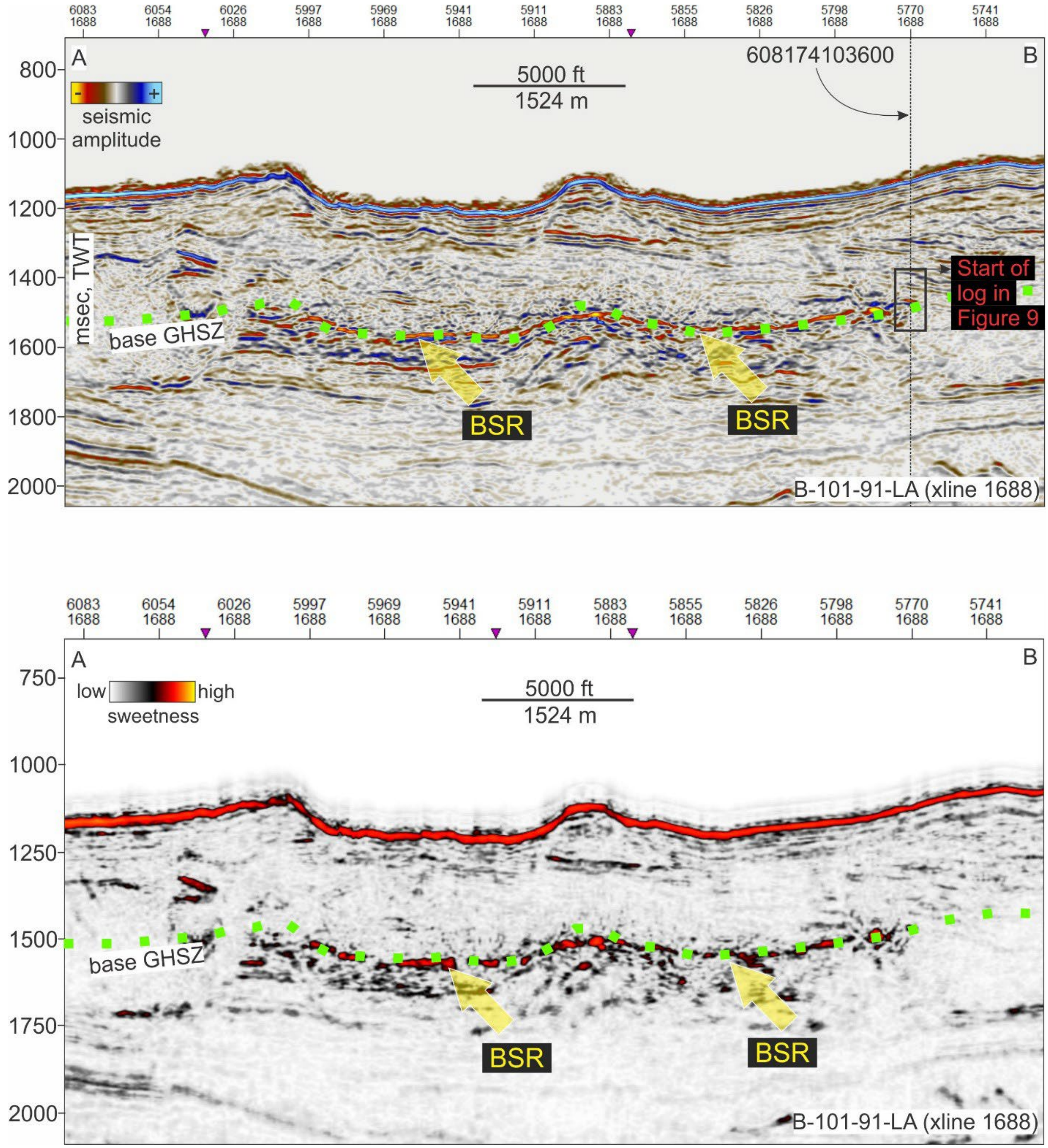

Figure 8. BSR in Zone 1 in the seismic amplitude cross section (top) and in sweetness attribute cross-section (bottom). Seismic line location shown on Figures 3, 4, 5 and 6.

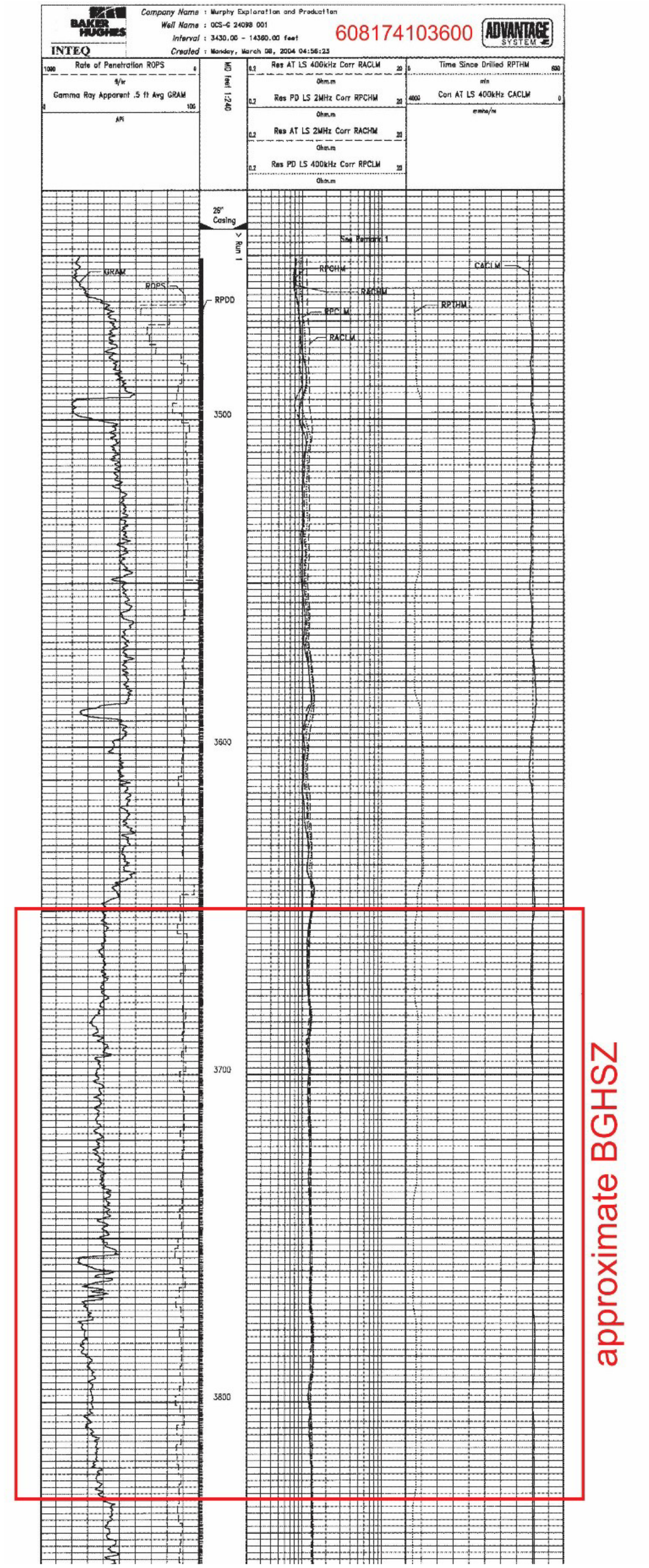

Figure 9. Top of the resistivity and gamma ray logs in well 60817103600 at the margin of BSR in Zone 1 (see Figure 8 for well location) showing no resistivity increase at the base of GHSZ.

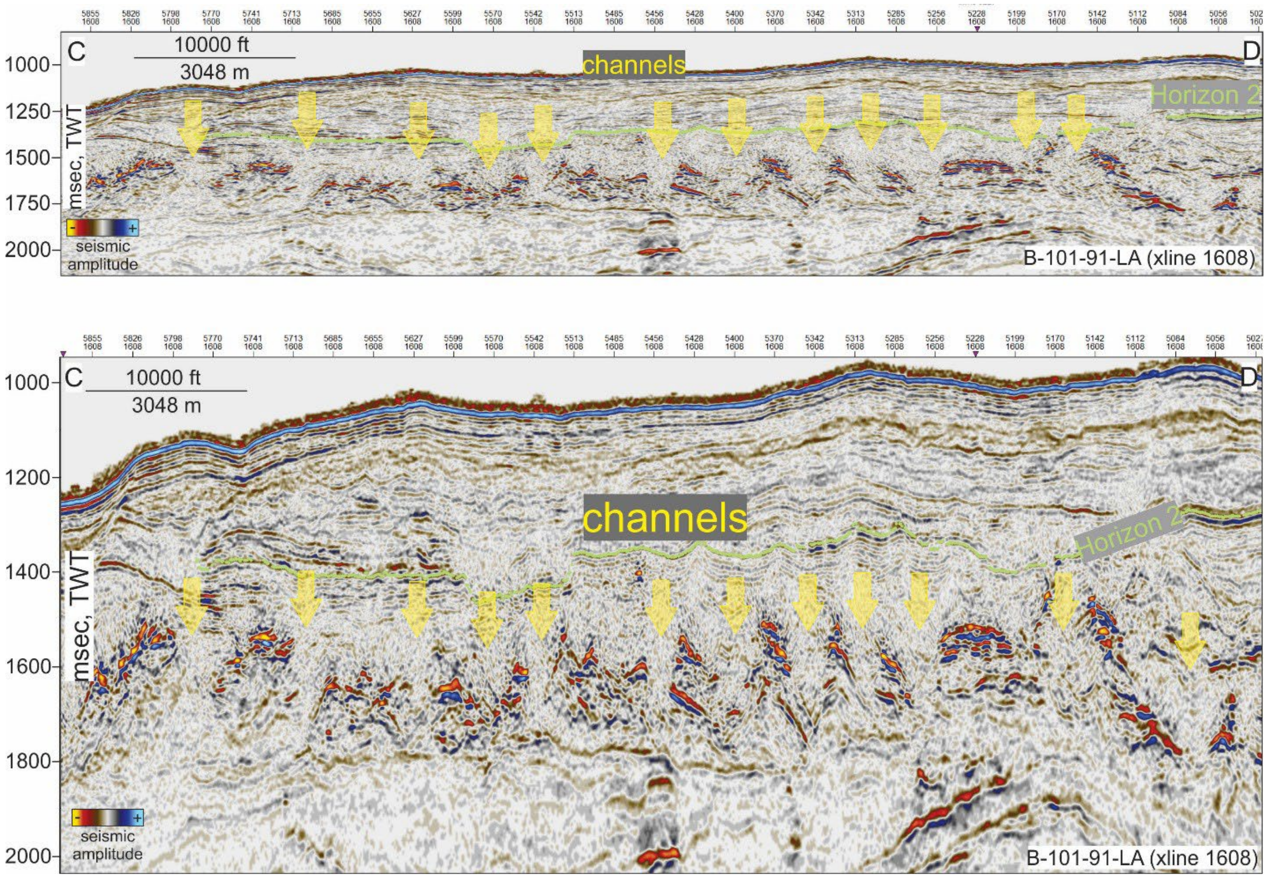

Figure 10. Example of the paleo-channel network in the seismic cross-section from the northern part of Project Area 2 (line location is on Figures 3, 4, 5, 6).

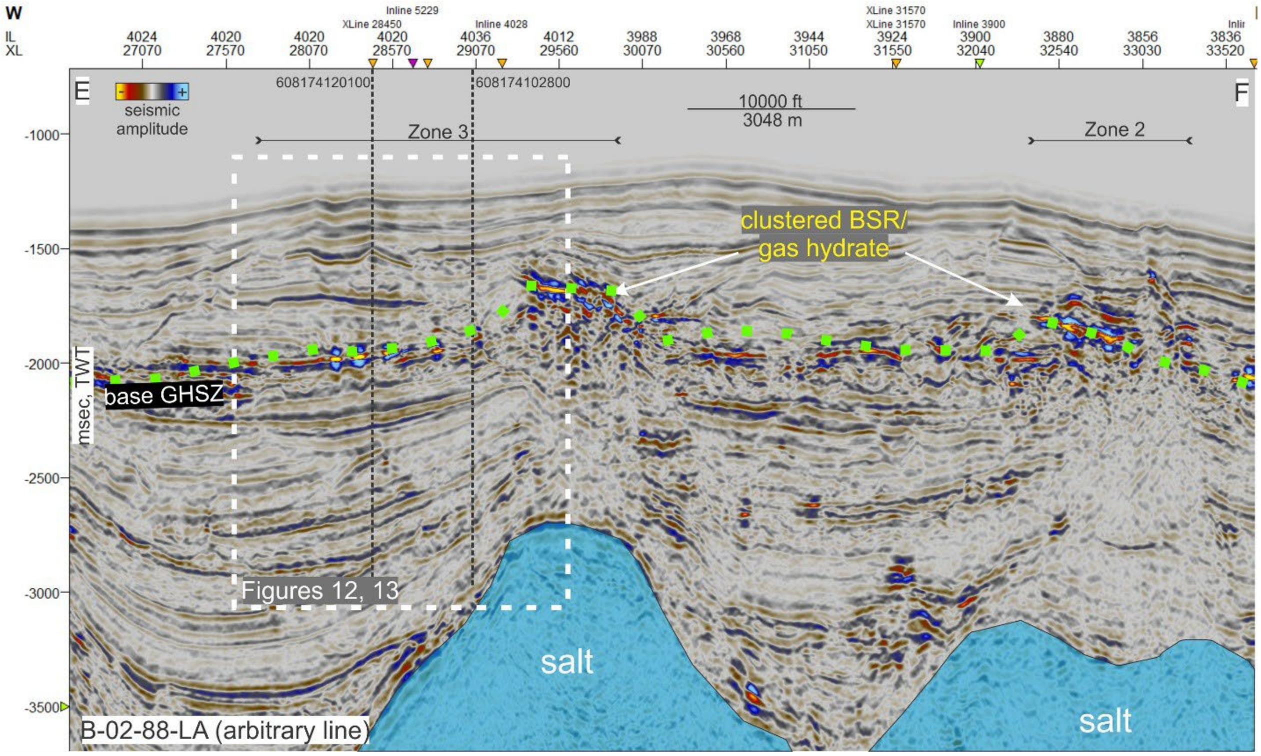

Figure 11. Regional seismic cross-section through Zone 2 and 3 indicating approximate BHSZ (note its temperature-induced shallowing above salt crests where we interpret clustered BSRs). Dashed box shows seismic section in Figures 12 and 13 and location of wells 608174120100 and 608174102800.

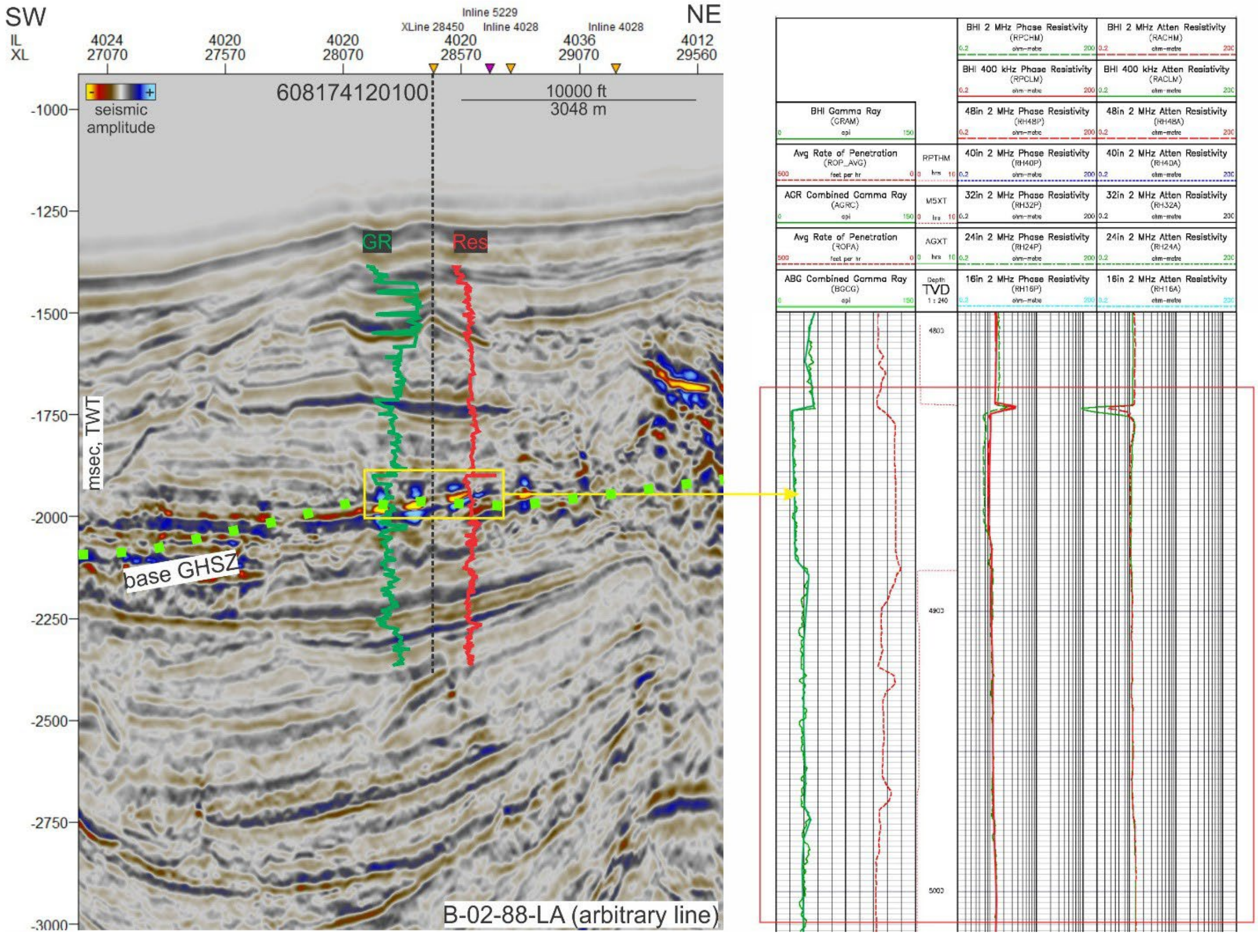

Figure 12. Manually digitized gamma ray (GR) and resistivity (Res) logs in well 608174120100 (left) and section of the actual logs from this well (right) at the inferred BHSZ indicated by yellow box. Note that the seismic well tie is approximate.

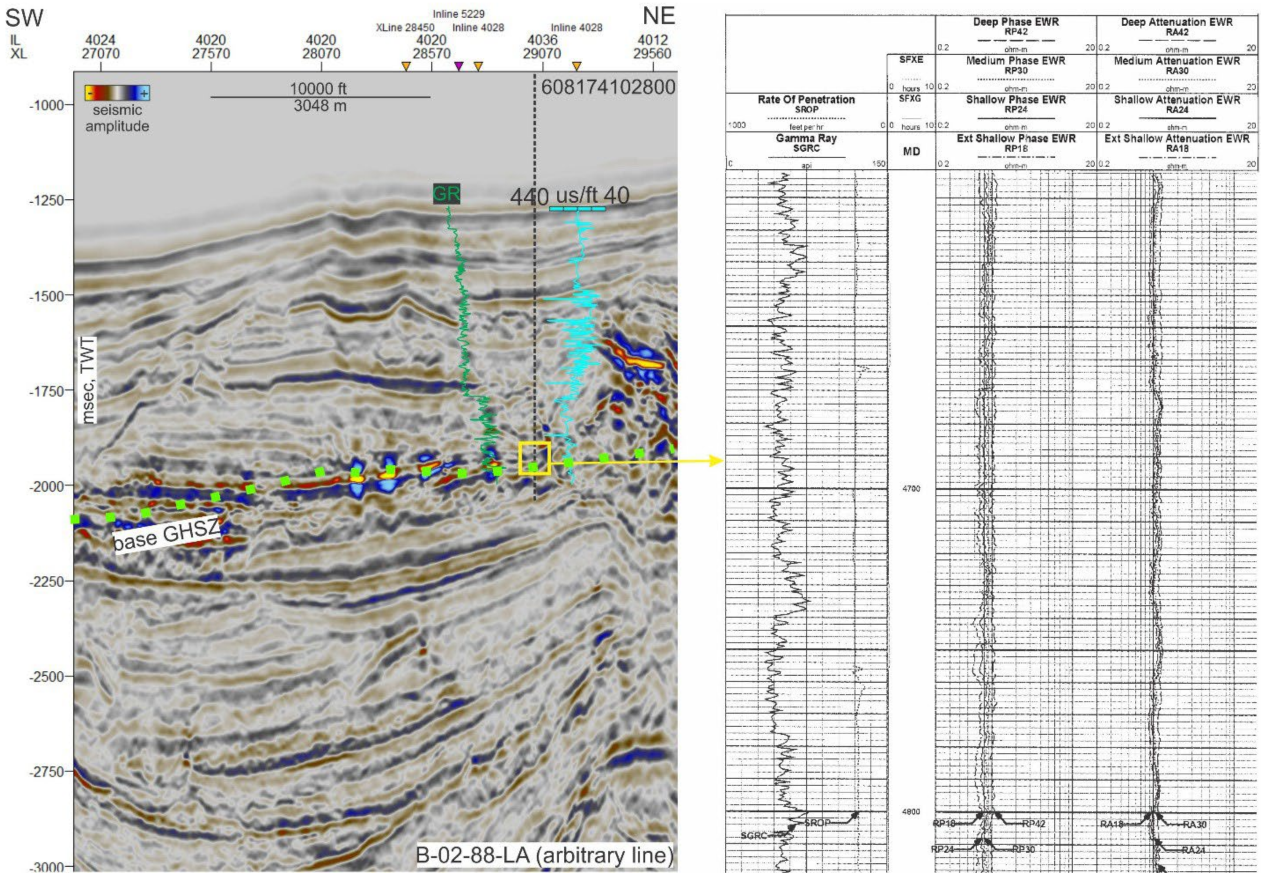

Figure 13. Manually digitized gamma ray (GR) and sonic (blue curve) logs in well 608174102800 (left) and section of the actual logs from this well (right) at the inferred BHSZ indicated by yellow box. Note that the seismic well tie is approximate.

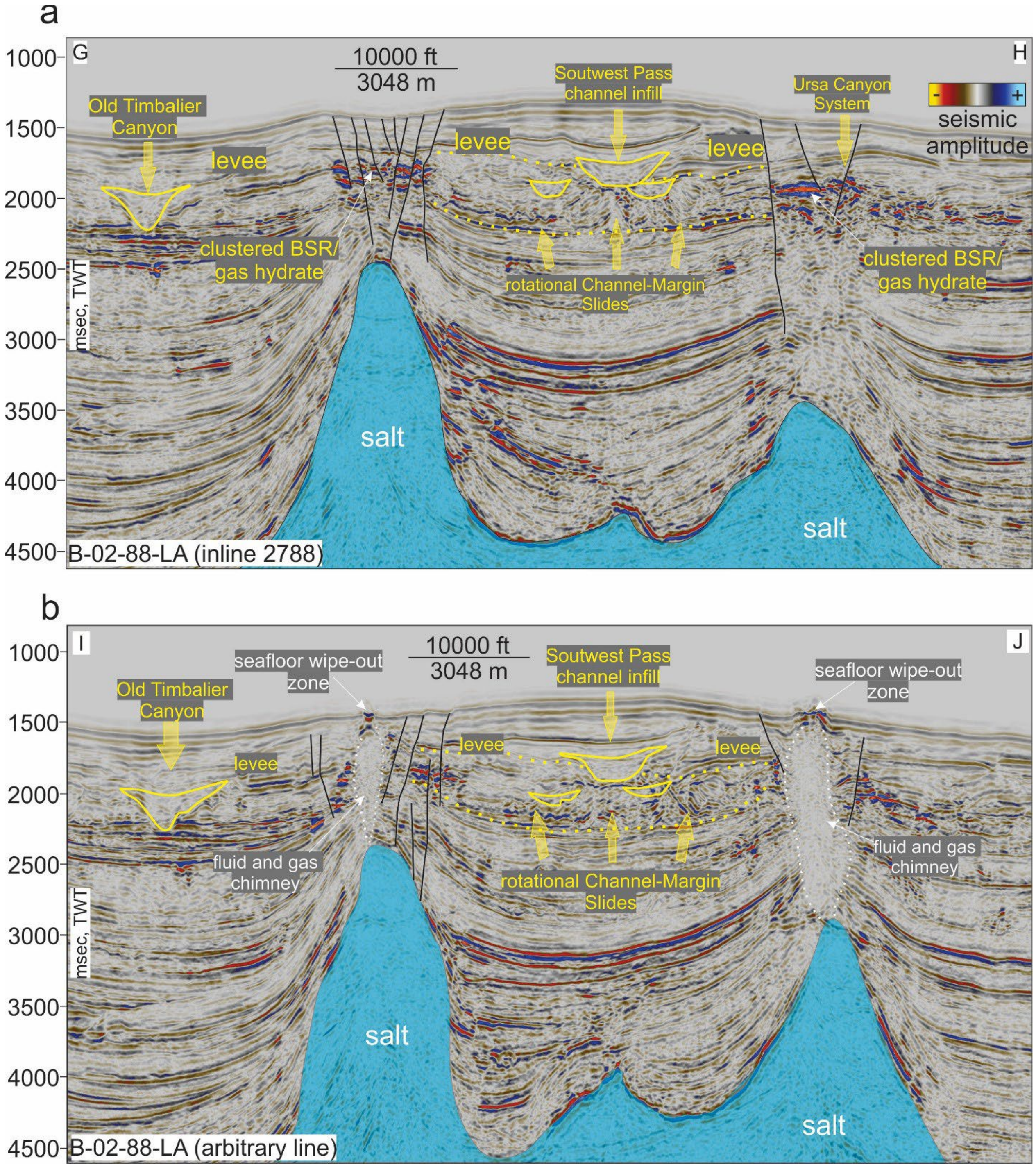

Figure 14. a) Regional seismic section G-H across Zones 4 and 5 showing major elements of the depositional system: Old Timbalier Canyon, Southwest Pass Canyon, Ursa Canyon and their levees with potential sand-bearing units. b) Regional seismic cross-section I-J subparallel to G-H showing areas of active fluid flow within Zones 4 and 5. The location of the lines is shown in Figures 3, 4, 5, 6 and 7.

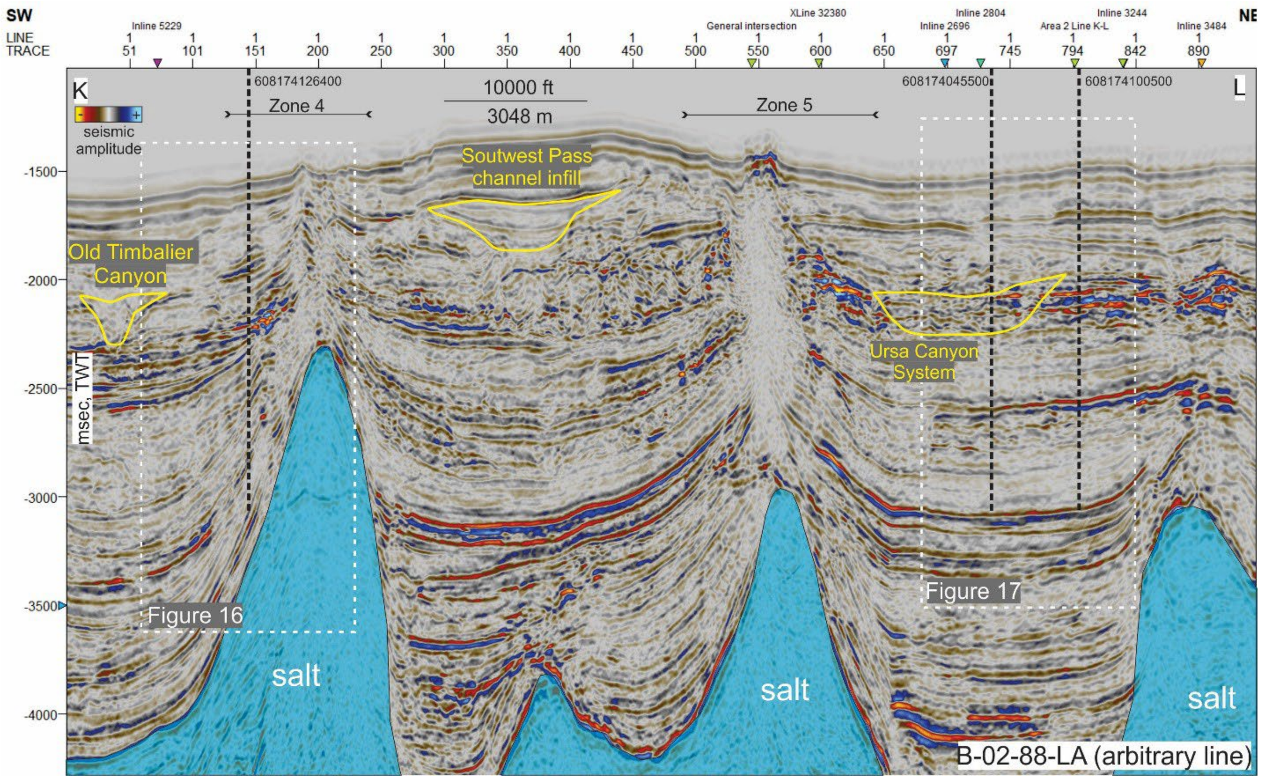

Figure 15. Regional seismic section K-L across Zones 4 and 5 connecting wells 608174126400, 608174045500 and 608174100500. The location of the lines is indicated in Figures 3, 4, 5, 6 and 7. Dashed white boxes show seismic sections in Figures 16 and 17.

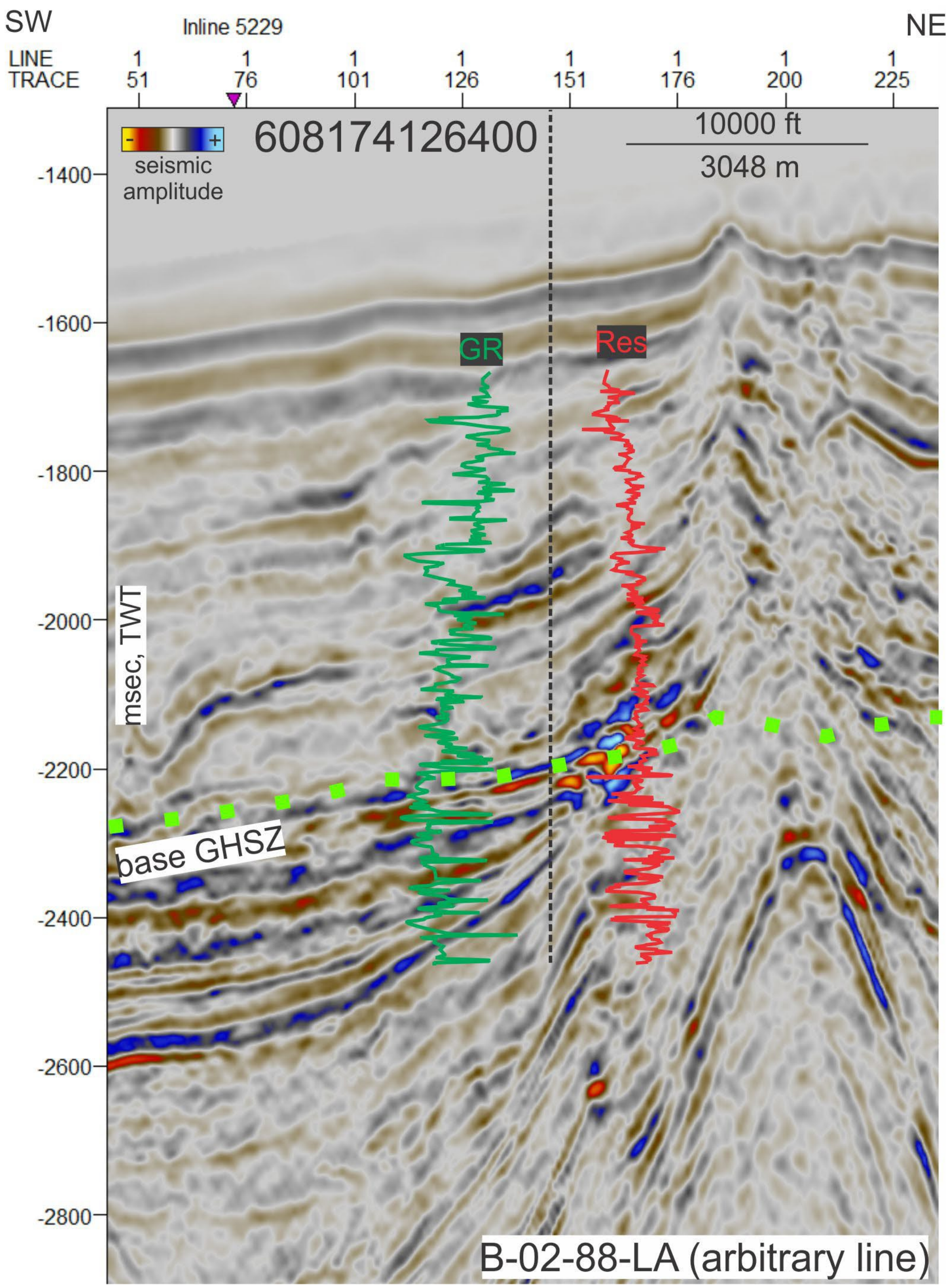

Figure 16. Manually digitized gamma ray (GR) and resistivity (Res) logs in well 608174126400 in Zone 4. Note that the seismic well tie is approximate.

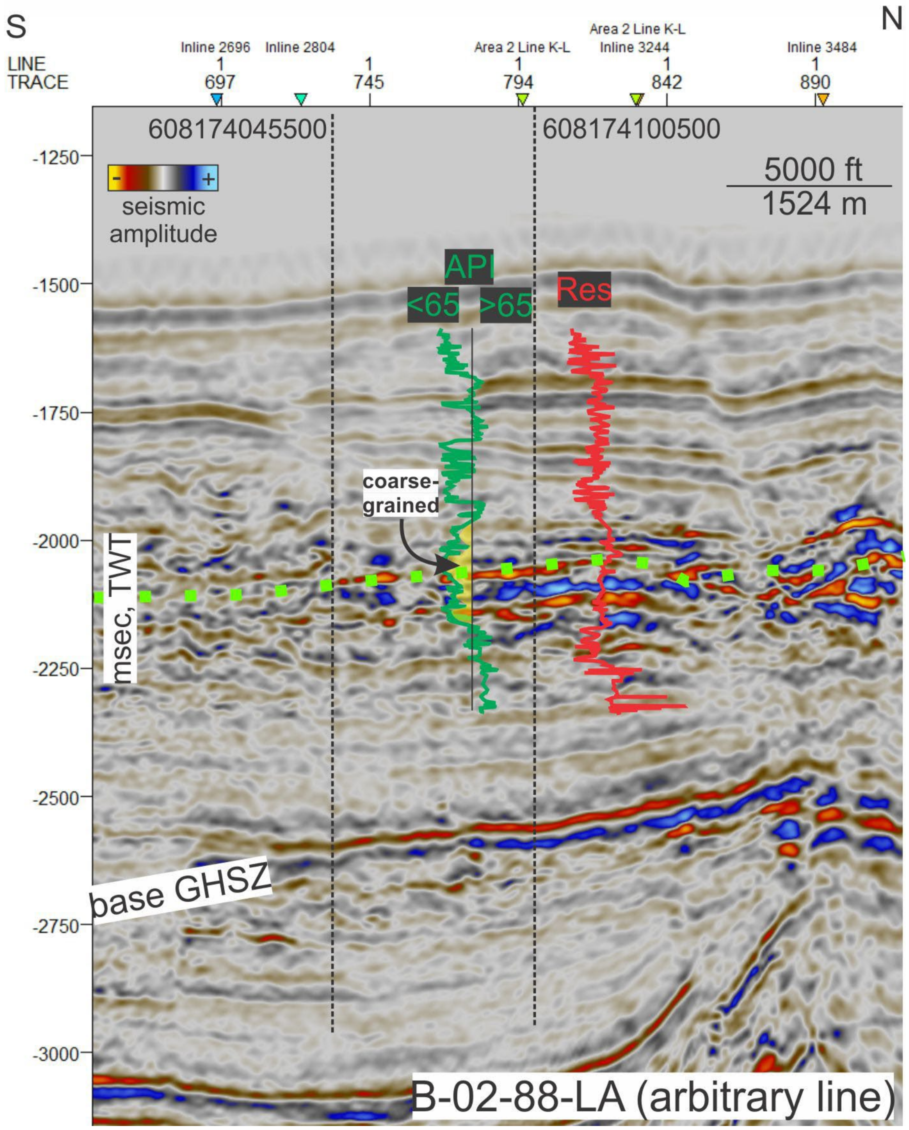

Figure 17. Manually digitized gamma ray (GR) and resistivity (Res) logs in well 608174100500 located between Zones 2 and 5 showing low gamma ray intervals associated with sand-bearing units that may host hydrate within Zones 2 and 5. Note that the seismic well tie is approximate.

3.6 Structure maps

Generating structure maps for potential hydrate-bearing areas was complicated due to sand-dominated stratigraphy throughout the upper sediment section and generally low seismic data quality. We generated structure maps for 4 out of 6 Zones using Horizon 2 – the closest coherent horizon overlying the target reservoir intervals (Figures 18, 19, 20, 21).

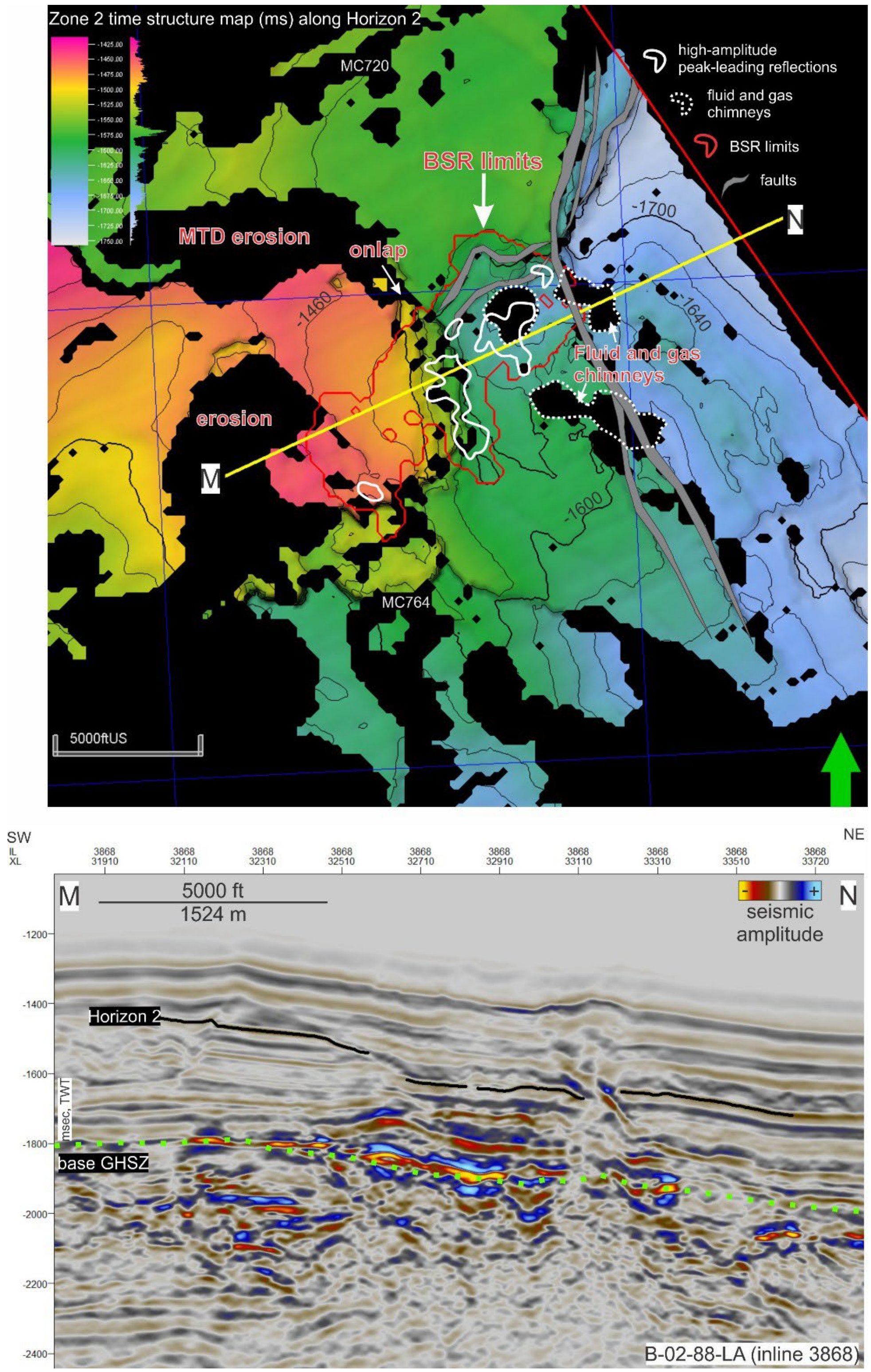

Figure 18. Time structure map along Horizon 2 within Zone 2 showing BSR limits (red), zones of strongest positive amplitudes (white), faults and fluid and gas chimneys. Seismic section MN shows reference Horizon 2 and a BSR.

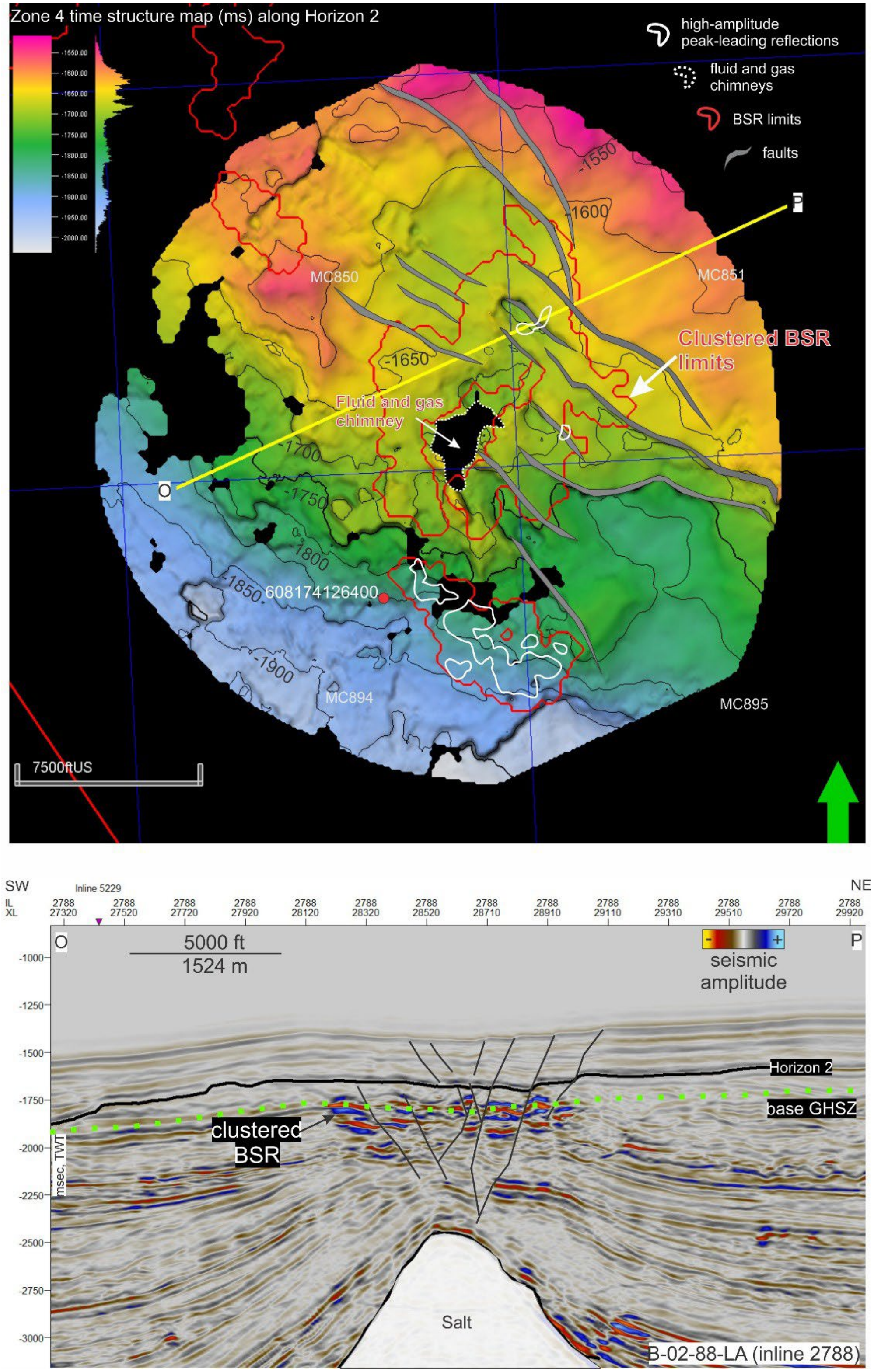

Figure 19. Time structure map along Horizon 2 within Zone 4 showing BSR limits (red), zones of strongest positive amplitudes (white), faults and fluid and gas chimneys. Seismic section OP shows reference Horizon 2 and a clustered BSR.

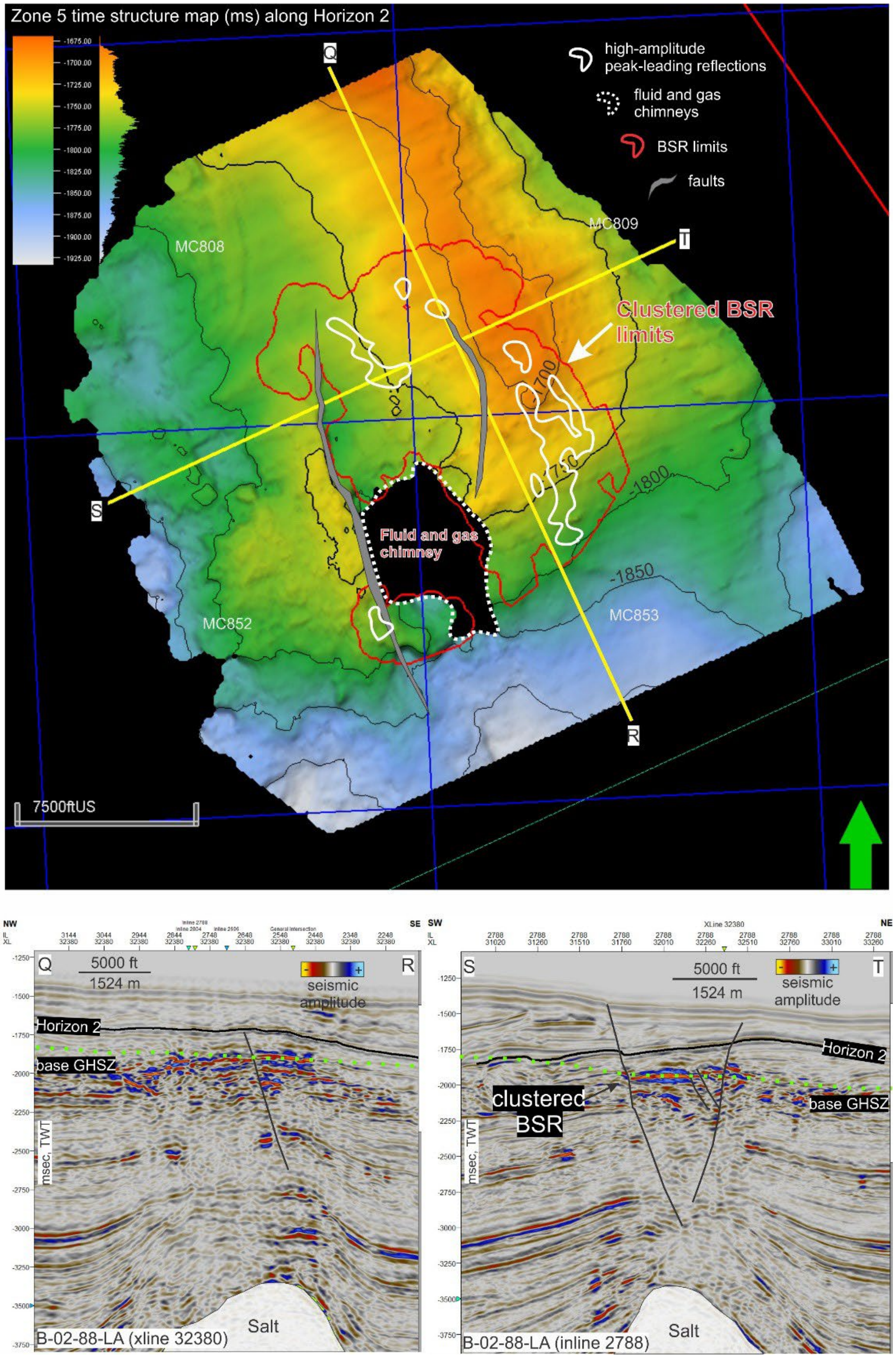

Figure 20. Time structure map along Horizon 2 within Zone 5 showing BSR limits (red), zones of strongest positive amplitudes (white), faults and fluid and gas chimneys. Seismic sections QR and ST show reference Horizon 2 and a clustered BSR.

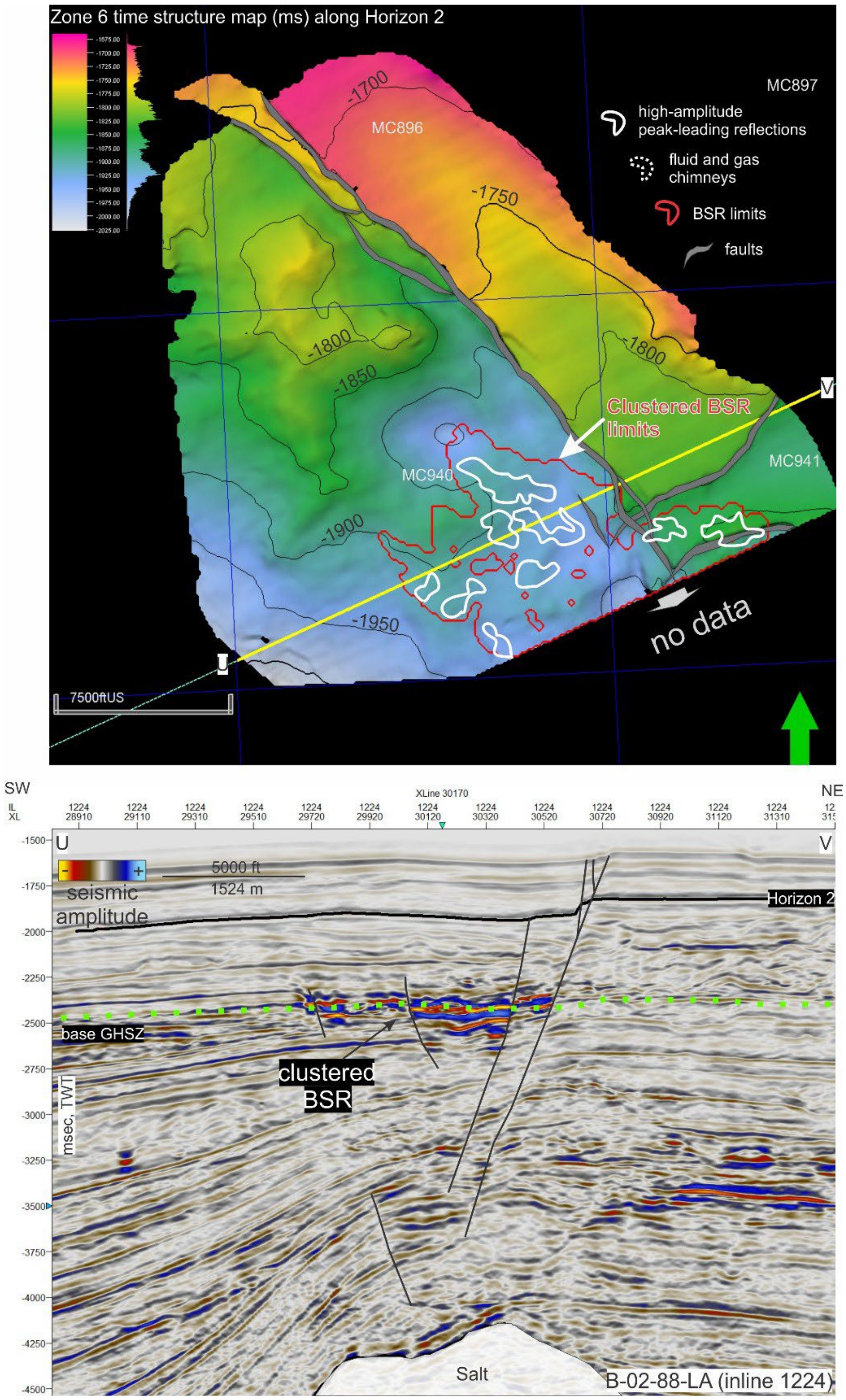

Figure 21. Time structure map along Horizon 2 within Zone 6 showing BSR limits (red), zones of strongest positive amplitudes (white), faults and fluid and gas chimneys. Seismic section UV shows reference Horizon 2 and a clustered BSR.

4. Gas resource estimates

The thickness of sand-bearing units that may be reservoirs for gas hydrate is large and varies greatly across the Project Area 2. Based on the seismic data in Zones 2-6, high-amplitude units associated with clustered BSRs range in thickness from 70 to 200 msec. However, these units may be mainly filled with gas, and most of the gas hydrate occur above in the overlying sections. Such configuration was earlier described in a similar clustered BSR system in the Perdido Canyon (Portnov et al., 2019). In Sawyer et al., 2009 thickness of low gamma ray, sand-rich units in IODP Expedition 308 wells reach max 50 m with porosity ranging between 40% in mud-dominated units to 55% in sand-bearing. However, 55% porosity is very high for sand-bearing sediments, therefore we used the same minimal and maximal values as in Project Area 1 (30% and 40% respectively). We applied min and max sand thicknesses of 10 and 50 m. Similar to Project Area 1, we used min and max gas hydrate saturations within these sand units of 50 and 90%.

The total area of mapped clustered BSRs in Zones 2-6 is ~45 km^2, which results in minimum and maximum gas resource estimates of 11.07 and 132 BCM respectively at STP (standard temperature and pressure) conditions (which uses a gas hydrate to gas conversion factor = 164). Given that 90% gas hydrate saturation should be confined to the areas with high-amplitude peak-leading amplitudes (Figure 7) that occupy ~42% of the mapped BSR areas, the maximum estimate can be adjusted to ~55.4 BCM. Such calculations give reasonable range for resource estimates between 11.07 and 55 BCM.

The resource estimate for in Zone 1, where a continuous BSR is observed can be misleading because existing data do not give any reliable information about the distribution and thickness of lithofacies in this area. Yet, it is still considered prospective due to large area, confident continuous BSR and relatively shallow depths.

5. Conclusions

Potential gas hydrate occurrences in Project Area 2 are associated with several buried channel-levee systems that deposited sand-bearing units at the approximate BHSZ. In the southern part of Project Area 2, underlying salt bodies create an anticlinal framework favorable for entrapment of gas at the BHSZ and formation of clustered BSRs that are good indicators of high-saturation gas hydrate reservoirs in turbidites (Portnov et al., 2019). We see robust evidence of vertical fluid flow and gas migration through the salt roof towards the seafloor. Potentially these large gas migration systems feed overlying gas hydrate reservoirs distributed in close proximity to seismic gas chimneys. Based on the distribution of strong peak-leading amplitudes, Zones 2, 3 and 6 may be considered as higher-priority. Resource estimates in Project Area 2 are significantly higher compared to Project Area 1 due to large BSR area and thicker sand units as evidenced by the seismic data and existing literature (Sawyer et al., 2007 and Sawyer et al., 2009).

6. References

Portnov, A., A.E. Cook, D.E. Sawyer, C. Yang, J.I.T. Hillman, W.F. Waite (2019) “Clustered BSRs: Evidence for gas hydrate-bearing turbidite complexes in folded regions, example from the Perdido Fold Belt, northern Gulf of Mexico”. Earth and Planetary Science Letters, v. 528, p. 115843.https://doi.org/10.1016/j.epsl.2019.115843

Sawyer, D.E., P.B. Flemings, B. Dugan (2009) “Retrogressive failures recorded in mass transport deposits in the Ursa Basin, Northern Gulf of Mexico” Journal of Geophysical Research: Solid Earth 114 (B10)

Sawyer, D.E., P.B. Flemings R.C. Shipp, C.D. Winker (2007) “Seismic geomorphology, lithology, and evolution of the late Pleistocene Mars-Ursa turbidite region, Mississippi Canyon area, northern Gulf of Mexico” AAPG bulletin 91 (2), 215-234