AVO Attribute Analysis for Gas Hydrate in Shenhu Area*

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Abstract

The variation in seismic energy with change in distance between shot point and receiver reflects differences in lithology and fluid content in strata. AVO (Amplitude Versus Offset) analysis is a technique by which geophysicists attempt to determine thickness, porosity, density, velocity and fluid content of strata. AVO analysis has gained lots of success both onshore and offshore oil and gas exploration, however, it is still in the initial stage in offshore gas hydrate exploration. First, the abnormal AVO attributes are difficult to distinguish when the free gas saturation of sediment is high or low enough. Second, the relationship among gas hydrate, free gas saturation and elastic parameters are not clear. Third, the AVO results fall under the influence of thin-layer, even show multiple solutions. However, AVO analysis showed its broad prospects because the free gas can be distinguished effectively from the results.

In 2003, Guangzhou Marine Geological Survey (GMGS) of China Geological Survey carried out the high-resolution seismic exploration on the continental slope of Northern South China Sea. In addition, in 2007, GMGS carried out the gas hydrate drilling expedition. Many scientific data and samples such as the wire-line logs, in-situ temperatures, properties, geochemical data and sediment cores, pore water, headspace and void gas, etc. were obtained in Shenhu area of the northern slope of South China Sea.

In this research, seismic Line A crossing the drilling site SH2 at which gas hydrate-bearing sediments were recovered between 188m and 228m below seafloor, was selected to study the AVO attributes of gas hydrate in Shenhu area of northern South China Sea. For improving the Signal to Noise Ratio (SNR) of seismic data, amplitude preservation Kirchhoff pre-stack migration has been applied to the 3-D seismic data. Some representative sections were showed, and the characteristics of AVO response for gas hydrate and free gas were analyzed, as well, distribution of thin layers of free gas which were related with gas hydrate were discussed. Lastly, the results showed that intercept, gradient, fluid factor and Poisson's ratio change clearly reflect the location of free gas and BSR, and the spatial relations among blanking zone, BSR, gas hydrate and free gas.

Introduction

AVO (Amplitude Versus Offset) analysis helps people determine thickness, porosity, density, velocity, and fluid content of rocks. At onshore oil or gas fields, AVO analysis has set up lots of success cases (Tinivella et. al., 2008), but in marine gas hydrate exploration, it is unusual, and its results is still controversial (Song et. al., 2001): (1) It's difficult to distinguish the AVO attributes when the free gas saturation is high or low enough; (2) The free gas which related and not related to gas hydrate is ambiguous; (3) Thin-layer will influence the AVO results. Unfortunately, not only gas hydrate but also free gas around gas hydrate is probable thin-layer. However, nobody could reject the technique because AVO analysis shows its broad prospects on free gas identification (Wood et. al., 2008; Rodrigo et. al., 2009; Ryu et. al., 2009).

Since the late 20th century, many researchers have done a lot of AVO analysis and inversion work for gas hydrate (Tinivella and Accaino, 2000). Chunyan Sun et al. (2000) did theoretical study on AVO forward model for BSR. Bihua Niu et al. (2006) used the AVO forward modeling in order to estimate the concentration of gas hydrate in Xisha Trough. For simulating the reflection characteristics of gas hydrate free gas and water-saturated formation, Ruan et al. (2006) used AVO numerical simulation method theoretical, though its accuracy of the result was impacted by thin-layer.

Guangzhou Marine Geological Survey carried out high-resolution seismic exploration on the continental slope of Northern South China Sea between 2005 and 2006. 3D high-resolution seismic data had been collected. After target prediction, ten boreholes were drilled in 2007 in Shenhu area. Gas hydrate samples were recovered and many scientific data were collected (Wu, et. al., 2008). Therefore, Shenhu area becomes an ideal place for the research on gas hydrate. In this paper, AVO analysis was based on Line A, which crosses the successful exampled gas hydrate well SH2 (Figure 2). Some AVO attributes sections were showed and the AVO characteristics of gas hydrate and free gas were analyzed, especially the free gas around gas hydrate. It is useful to do gas hydrate exploration in north South China Sea or any other areas around world.

Study Area

The South China Sea is a marginal sea that is part of the Pacific Ocean. It lies above a drowned continental shelf (Wu et. al., 2009; Pautot et. al., 1986). Because of the interaction of plates, the structure and sedimentary of South China Sea is complex, and it has unique geological characteristics of regional tectonic (Pautot et. al., 1986; Yao, 2001; Yao and Wu, 2005). The northern part of South China Sea has good prospects for gas hydrate occurrence. Shenhu area is located in south of Baiyun Sag and Pearl Depression II (Figure 1). The water depth is from 900m to 1,500m. Seabed is a slope; the northeast is higher than the southwest. Two main trenches lay under the seabed. There are thick hydrocarbon source rocks, such as the Wenchang-Enping Formations of Paleogene (Shi et. al., 2009). Additionally, many faults and a large-scale diapir zone were found in this area (Sun et. al., 2008).

Methodology

Methane and water molecules are major components of gas hydrate (Wu et. al, 2005; Winters et. al, 2007). Methane, the free gas, always migrates through transport channel until it reaches HSZ (gas hydrate stability zone). Crystallization water captures methane, then, they turn into gas hydrate finally (Wu et. al, 2005; Winters et. al, 2007; Taylor et. al., 2000). Therefore, the existence of a large volume of hydrocarbon gas plays an important role in gas hydrate formation (Wu et. al., 2009).

AVO analysis indicates gas from seismic data due to the difference between the P-wave velocity (Vp) and S-wave velocity (Vs). The difference is related to the volume of free gas, which contains in sediments pore space (Diaconescu et. al., 2001; Løseth et. al., 2009). Vp will be significantly reduced if there is free gas in sediment pore space but S-wave is not, because it depends on the rock matrix (Diaconescu et. al., 2001). Different sediments have separate Vp, but some are quite familiar. This brings some fatal troubles to interpreters. For identification of different sediments, Poisson's ratio has been set up. Different rocks have different Poisson's ratio. Poisson's ratio is a significant reference data in oil and gas exploitation.

It is well known that gas hydrate is not quite stable. It is keeping changing balance all the time among three phase, liquid gas and solid. It can be infer that gas will coexist with gas hydrate in the sediment. Especially, at the top and bottom of the gas hydrate. Because the two layers are the phases boundary and the change of temperature and pressure here will influence gas hydrate significantly. Nature gas will release from gas hydrate and move to hydrate unstable zones, which locate against the gas hydrate stable zone. If this process exists and is stable, AVO analysis may capture it and make it as an indirect identification indicator to gas hydrate. The quality of seismic data is a key factor of AVO analysis and interpretation (Niu et. al., 2006; Ruan et. al., 2006; Zhang et. al., 2005). Thanks for the 3D high resolution seismic data from Guangzhou Marine Geological Survey. Six AVO attributes have been collected (Table 1).

Results

Free Gas Identification by AVO Analysis. Free gas under gas hydrate or HSZ is important methane supply. Many explorations confirm that gas hydrate has close spatial relationship with underlying free gas. This suggests possibility and reliability to identify gas hydrate by free gas identification. As usual, the impedance of gas-bearing sediments is significantly lower than the hydrate-bearing sediments, as while, the absolute value of P (reflect amplitude) and G (gradient) are both increased. These will strengthen the energy of P*G profile (Cordon, et. al., 2006); Xu et. al., 2009). This is the main principle of free gas imaging in AVO attributes analysis profile. Figure 3, Figure 4, Figure 5, and Figure 6 show the P * G, Sign (P) * G, Poisson's ratio and fluid factor profiles of Line A, Shenhu area. In Figure 3 and Figure 4, the reflection coefficient of gas-bearing sediments of Line A appeared to increase clearly. The events in P*G profile (Figure 3) showed good continuity and the top interface of free gas zone is clear. In Sign (P)*G profile (Figure 4), because of higher resolution than P*G profile, the distribution of free gas zone could be distinguished easily. Then the thickness of free gas zone could be estimated easily. As the TWT (two-way travel time) of the top interface of P*G profile was more than 1700ms ,deeper than the bottom of hydrate stable zone, it could be infer that the huge natural gas was exist and migrated under gas hydrate. It supported enough methane to the upper HSZ. Strong amplitude positive anomaly in Poisson's ratio profile (Figure 5) told that the event of gas-bearing sediments reflect more energy than others. That is unusual. Generally, the Poisson's ratio will decrease smoothly with the increase of the depth except that there is free gas or any another low-density fluid in the sediment pore. Free gas will cause the decreasing of Poisson's ratio (Tinivella and Accaino, 2000). From the core analysis, some free gas traces were tracked. Therefore, the identification of gas-bearing sediments in the profile by events anomalies, vertical and horizontal, is reliable and easy. Be compare to P*G profile and Sign (P)*G profile, the fact of underlying free gas was verified. There are three characteristics in fluid factor profile (Figure 6): (1) strong amplitude; (2) Negative polarity of free gas zone top interface; (3) Positive polarity of free gas zone bottom. This may help people trace boundary of free gas zone easily and accurately. The reason is that the exit of free gas increased the value of Vp/Vs (Maheswar and Kalachand, 2008). At least it works in Shenhu area.

Gas Hydrate Identification on AVO attributes profiles. After review above attributes profiles, the AVO response of free gas could be recognized at the top and bottom interface of blank zone. It could be inferred that one of the components of free gas was methane which decomposition from gas hydrate. Research shows that gas hydrate is not in a stable state, as the change of temperature and pressure, it will be in a dynamic equilibrium state, some gas hydrate will decompose, while some will form (Bohrmann et. al., 2007).

According to the log data of well SH2, the depth of BSR was calculated. It is located at about two hundred meters below seabed. Observed the core example at that depth, sediments around the BSR are not yet consolidated. Under normal circumstances, low impedance combination of sediments at sub-bottom would present positive anomalies on seismic profiles, and the high one, which has been compacted, would present negative anomalies (Steinar et. al., 2009). However, in Figure 7, there was clear blank zone between the sub-bottom and BSR. The most likely reason was that gas hydrate filled the pore of sediment. Hydrate made the porosity reduced on the profile and distributed homogeneously. It reduced the difference in impedance and Poisson's ratio of different sediments, this led the lithology tend to uniformity and the AVO attributes of this structure presented negative anomalies.

In conclusion, the AVO characteristics of gas hydrate in Shenhu area, northern South China Sea, is as follows: (1) Strong bright spot and large difference of Poisson's ratio appears between the bottom of gas hydrate zone and BSR (Figure 7, Figure 8); (2) Medium or weak bright spot and medium or small difference of Poisson's ratio appears at the top of gas hydrate zone; (3) dark spot or blank zone and uniform Poisson's ratio difference appears at the inside of gas hydrate zone

Discussion and Conclusion

Based on the above results of AVO analysis, some conclusions had been drawn:

(1) AVO analysis could suggest reliable and easy way to identify free gas related to gas hydrate. This would be one of trusted references of gas hydrate existence;

(2) In the P*G profiles, the spatial relationship about free gas BSR and gas hydrate could be observed clearly, especially the distribution of free gas and the top interface of free gas;

(3) In the Poisson's ratio profile provides reliable evidence for the free gas zone and its boundary. It could help people determine the bottom of gas hydrate.

However, AVO analysis can only do many works in free gas and boundary identification and determination. It is only an indirect indicator of gas hydrate. However, it is indeed a very valuable reliable and efficient reference. Next, pre-stack inversion, based on AVO theory, will be applied on high-resolution seismic data of Shenhu area. The AVO analysis results all above are the necessary and valuable first step.

Acknowledgments

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References Cited

Bohrmann, G., W.F. Kuhs, S.A. Klapp, K.S. Techmer, H. Klein, M.M. Murshed, and F. Abegg, 2007, Appearance and preservation of natural gas hydrate from Hydrate Ridge sampled during ODP Leg 204 drilling: Marine Geology, v. 244/1-4, p. 1-14.

Cordon, I., J. Dvorkin, and G. Mavko, 2006, Seismic reflections of gas hydrate from perturbational forward modeling: Geophysics, v. 71/6, p. F165-F171.

Diaconescu, C.C., R.M. Kieckhefer, and J.H. Knapp, 2001, Geophysical evidence for gas hydrates in the deep water of the South Caspian Basin, Azerbaijan: Marine and Petroleum Geology, v. 18/2, p. 209-221.

Løseth, H., M. Gading, and L. Wensaas, 2009, Hydrocarbon leakage interpreted on seismic data: Marine and Petroleum Geology, v. 26/7, p. 1304-1319.

Maheswar, O. and S. Kalachand, 2008, Appraisal of gas-hydrate/free-gas from VP/VS ratio in the Makran accretionary prism: Marine and Petroleum Geology, v. 25/7, p. 637-644.

Niu, B.H., P.F. Wen, N. Wen, 2006. Estimation of hydrate concentration based on AVO modeling of BSR: Chinese Journal of Geophysics, v. 49/1, p. 143-152.

Pautot, G., C. Rangin, A. Briais, P. Tapponnier, P. Beuzart, G. Lericolais, X. Mathieu, J. Wu, S. Han, H. Li, Y. Lu, and J. Zhao, 1986, Spreading direction in the central South China Sea: Nature, v. 321/6066, p. 150-154.

Rodrigo, C., E. Vera, and A. González-Fernández, 2009, Seismic analysis and distribution of a bottom-simulating reflector (BSR) in the Chilean margin offshore of Valdivia (40° S): Journal of South American Earth Sciences, v. 27/1, p. 1-10.

Ruan, A.G., J.B. Li, F.Y. Chu, and X.Y. Li, 2009, AVO numerical simulation of gas hydrates reflectors beneath seafloor: Chinese Journal of Geophysics-Chinese Edition, v. 49/6, p. 1826-1835.

Ryu, B.J., M. Riedel, J-H. Kim, R.D. Hyndman, Y-J. Lee, B-H. Chung, and I.S. Kim, 2009, Gas hydrates in the western deep-water Ulleung Basin, East Sea of Korea: Marine and Petroleum Geology, v. 26/8, p. 1483-1498.

Shi, W.Z., Z. Song, X. Wang, and M. Kong, 2009, Diapir Structure and Its Origin in the Baiyun Depression, Pearl River Mouth Basin, China: Earth Science-Journal of China University of Geoscience, v. 34/5, p. 778-784.

Song, H.B., O. Matsubayashi, N.Y. Wu, and T.Y. Hao, 2001. Geophysical Researches on Marine Gas Hydrates (Ⅱ): Seismic Method: Progress in Geophysics, v. 16/3, p. 110-118.

Steinar-Hustoft, H., S. Bunz, J. Meinert, and S. Chand, 2009, Gas hydrate reservoir and active methane-venting province in sediments on < 20 Ma young oceanic crust in the Fram Strait, offshore NW-Svalbard: Earth and Planetary Science Letters, v. 284/1-2, p. 12-24.

Sun, C.Y., M.Y. Zhang, and B.H. Niu, 2003, Study of Modeling Seismic Bottom Simulating Reflector for Nature Gas Hydrate: Geoscience, v. 17/3, p. 337-344.

Sun, L.T., D. Zhou, C.M. Chen, W.H. Zhan, and Z. Sun, 2008, Fault structure and evolution of Baiyun Sag in Zhujiang River Mouth Basin: Journal of Tropical Oceanography, v. 27/2, p. 25-31.

Taylor, M.H., W.P. Dillon, and I.A. Pecher, 2000, Trapping and migration of methane associated with the gas hydrate stability zone at the Blake Ridge Diapir: new insights from seismic data: Marine Geology, v. 164/1-2, p. 79-89.

Tinivella, U. and F. Accaino, 2000, Compressional velocity structure and Poisson's ratio in marine sediments with gas hydrate and free gas by inversion of reflected and refracted seismic data (South Shetland Islands, Antarctica): Marine Geology, v. 164/1-2, p. 13-27.

Tinivella, U., F. Accaino, and B. Della Vedova, 2008, Gas hydrates and active mud volcanism on the South Shetland continental margin, Antarctic Peninsula: Geo-Marine Letters, v. 28/2, p. 97-106.

Winters, W.J., W.F. Waite, D.H. Mason, L.Y. Gilbert, and I.A. Pecher, 2007, Methane gas hydrate effect on sediment acoustic and strength propertie: Journal of Petroleum Science and Engineering, v. 56/1-3, p. 127-135.

Wood, W.T., P.E. Hart, D.R. Hutchinson, N. Dutta, F. Snyder, R.B. Coffin, and J.F. Gettrust, 2008, Gas and gas hydrate distribution around seafloor seeps in Mississippi Canyon, Northern Gulf of Mexico, using multi-resolution seismic imagery: Marine and Petroleum Geology, v. 25/9, p. 952-959.

Wu, S.G., G. Zhang, Y. Huang, J. Liang, and H.K. Wong, 2005, Gas hydrate occurrence on the continental slope of the northern South China Sea: Marine and Petroleum Geology, v. 22/3, p. 403-412.

Wu, N.Y., J. Liang, H. Wang, S. Su, H. Song, Y. Zhu, S. Jiang, and Z. Lu, 2008, Marine Gas Hydrate System: State of the Art: Geoscience, v. 22/3, p. 356-362.

Wu, N.Y., S. Yang, H. Wang, J. Liang, Y. Gong, Z. Lu, D. Wu, and H. Guan, 2009, Gas-bearing fluid influx sub-system for gas hydrate geological system in Shenhu Area, Northern South China Sea: Chinese Journal of Geophysics-Chinese Edition, v. 52/6, p. 1641-1650.

Xu, N., S. Wu, B. Shi, B. Lu, L. Xue, X. Wang, and Y. Jia, 2009, Gas hydrate associated with mud diapirs in southern Okinawa Trough: Marine and Petroleum Geology, v. 26/8, p. 1413-1418.

Yao, B.C., 2001, The gas hydrate in the South China Sea: Tropic Oceanology, v. 20/2, p. 20-28.

Yao, B.C., and N.Y. Wu, 2005, Gas hydrate, a future energy resource: Earth Frontiers, v. 12/1, p. 225-233.

Zhang, L., X.Y. Yin, and C.Y. Sun, 2005, AVO simulation in two-phase media: Progress in Geophysics, v. 20/2, p. 319-322.

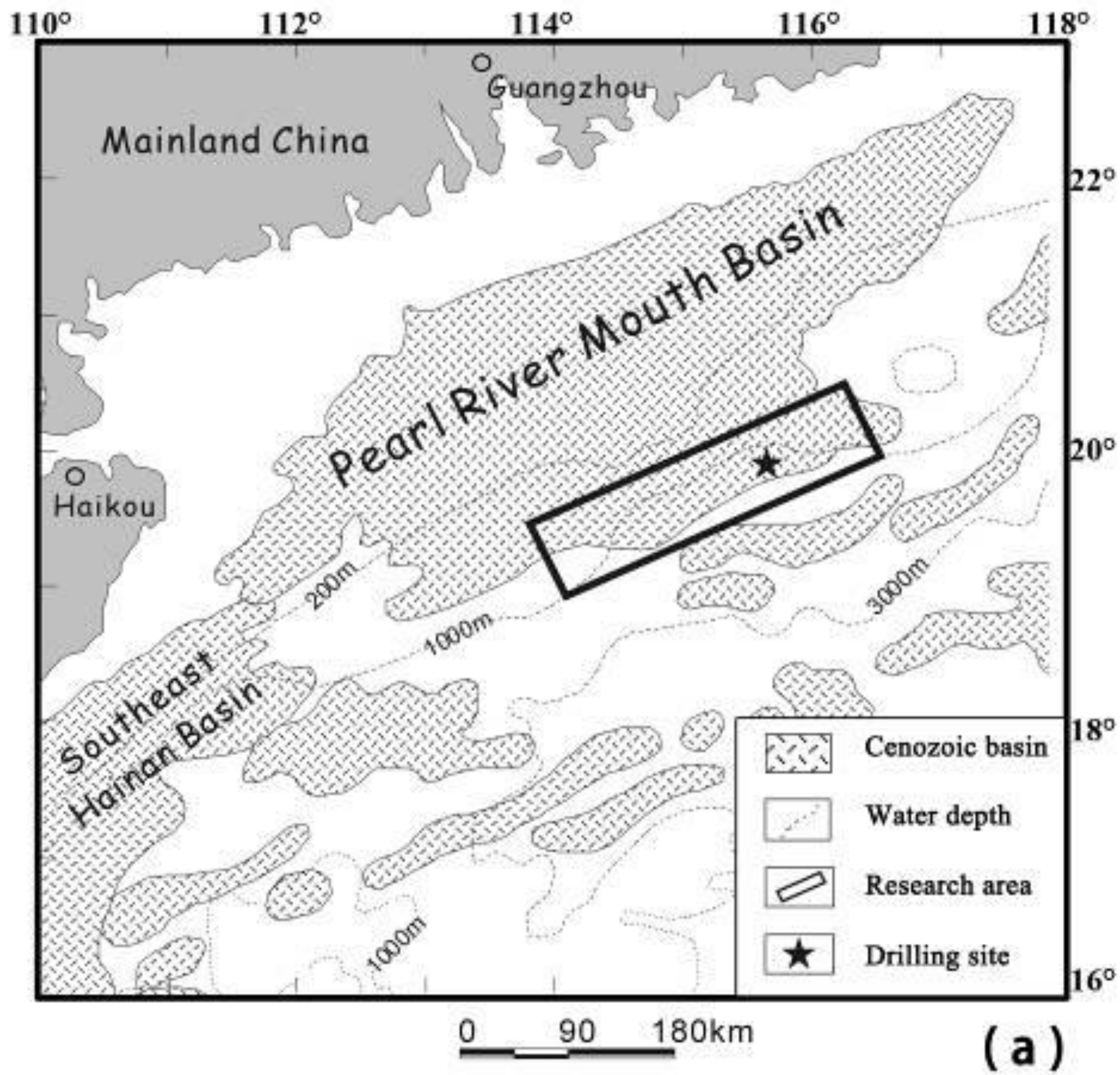

Figure 1. Location of Shenhu area.

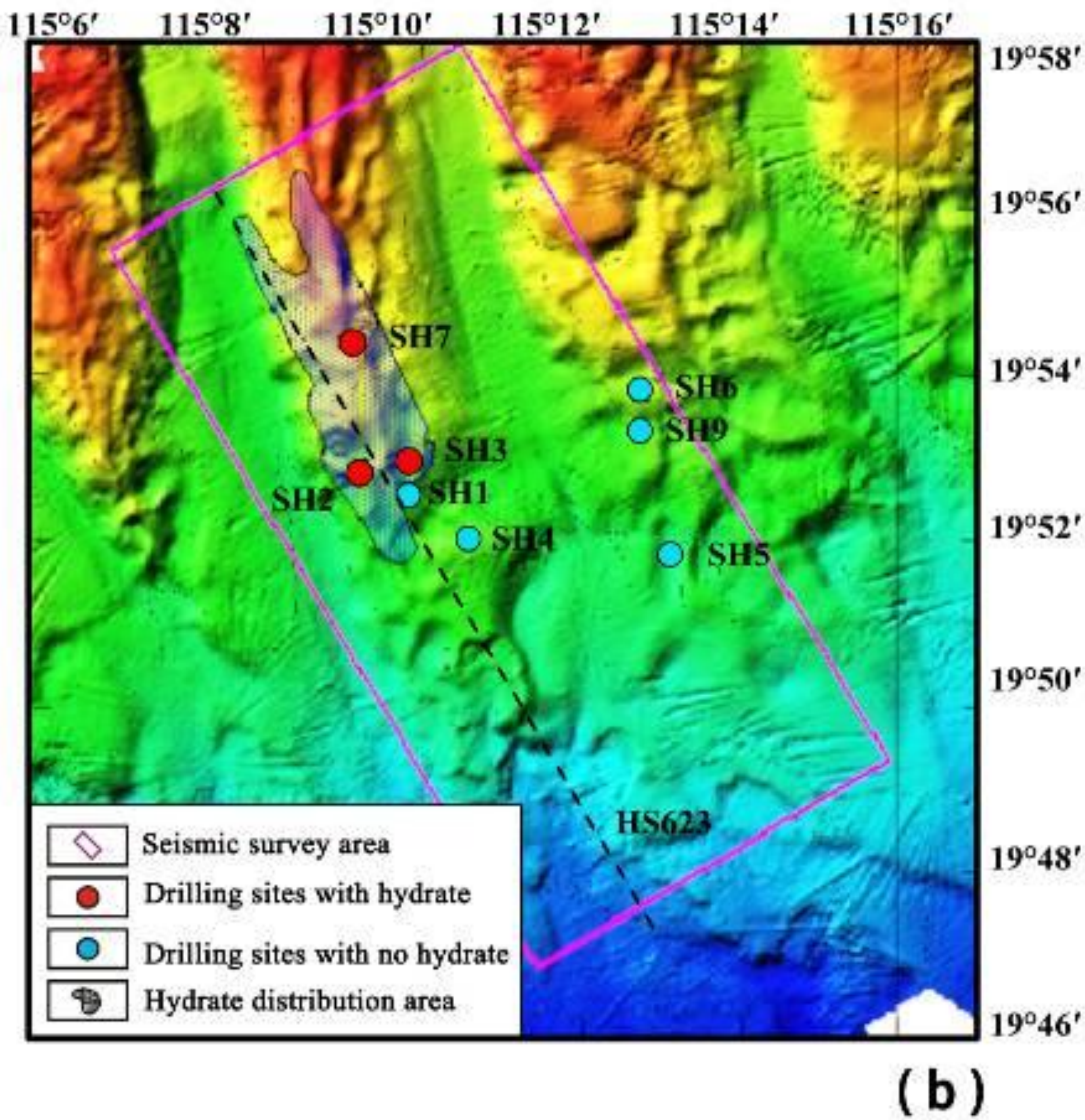

Figure 2. Line A and drilling site SH2 in survey

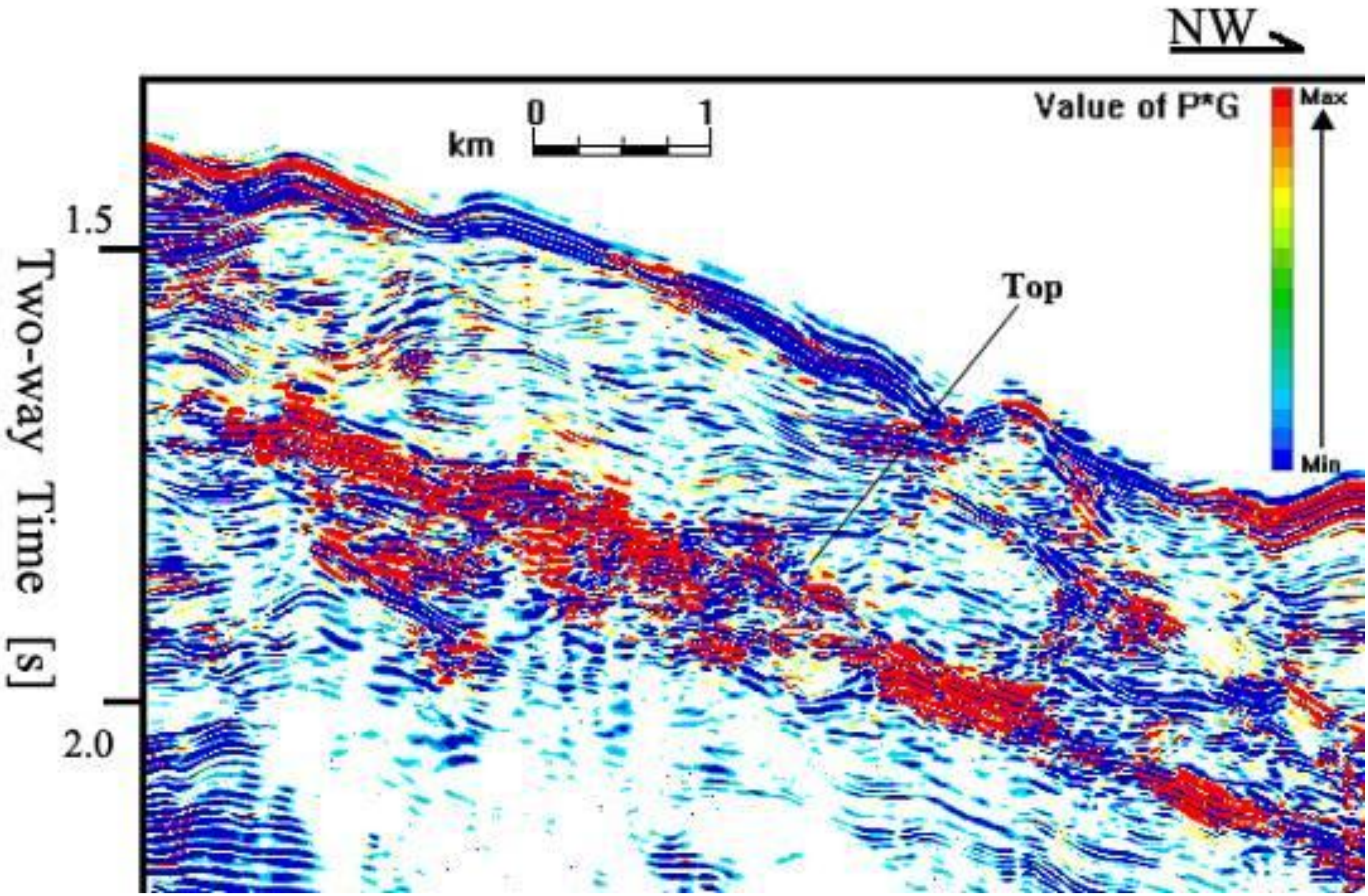

Figure 3. P*G profile of Line A

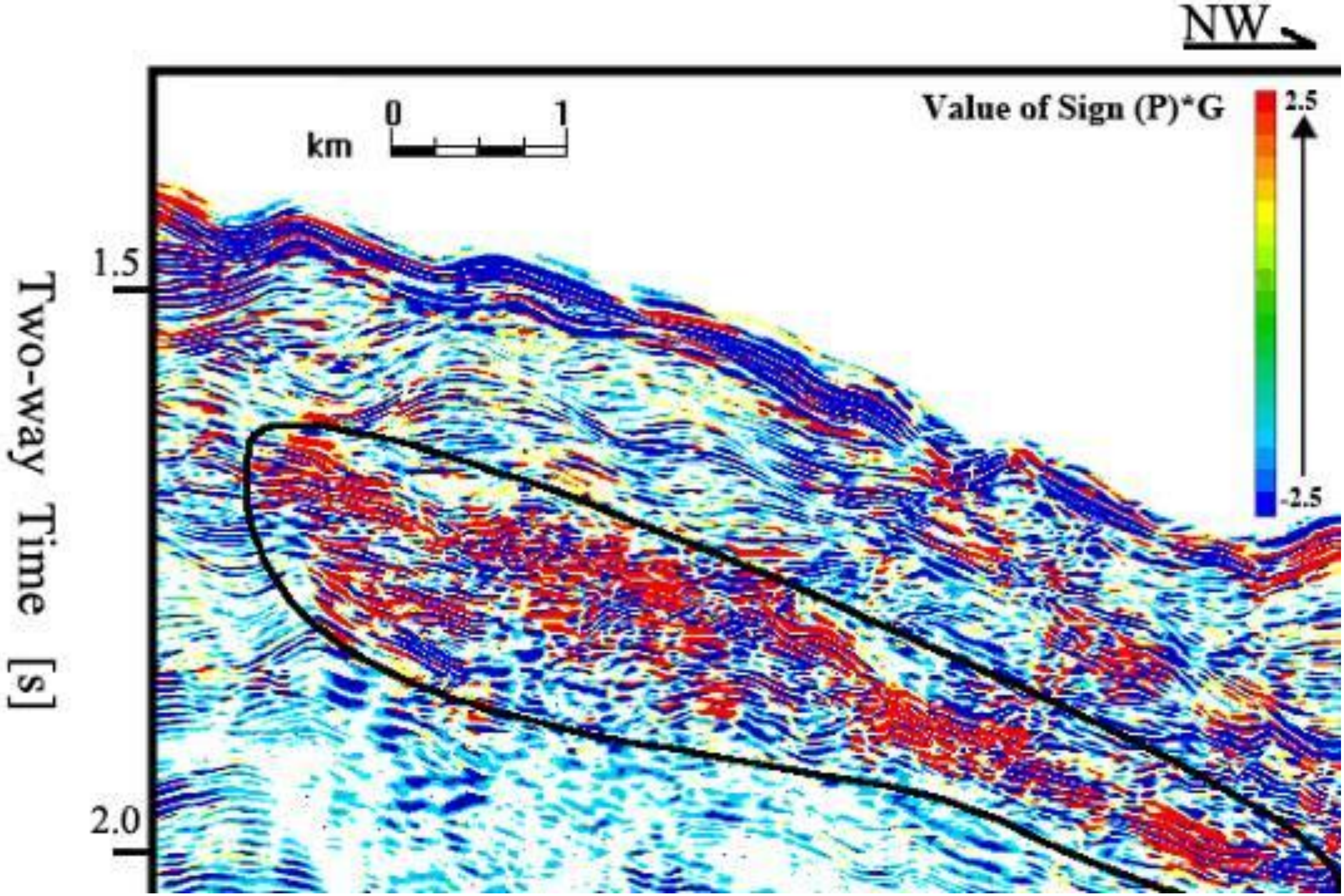

Figure 4. Sign (P)*G profile of Line A.

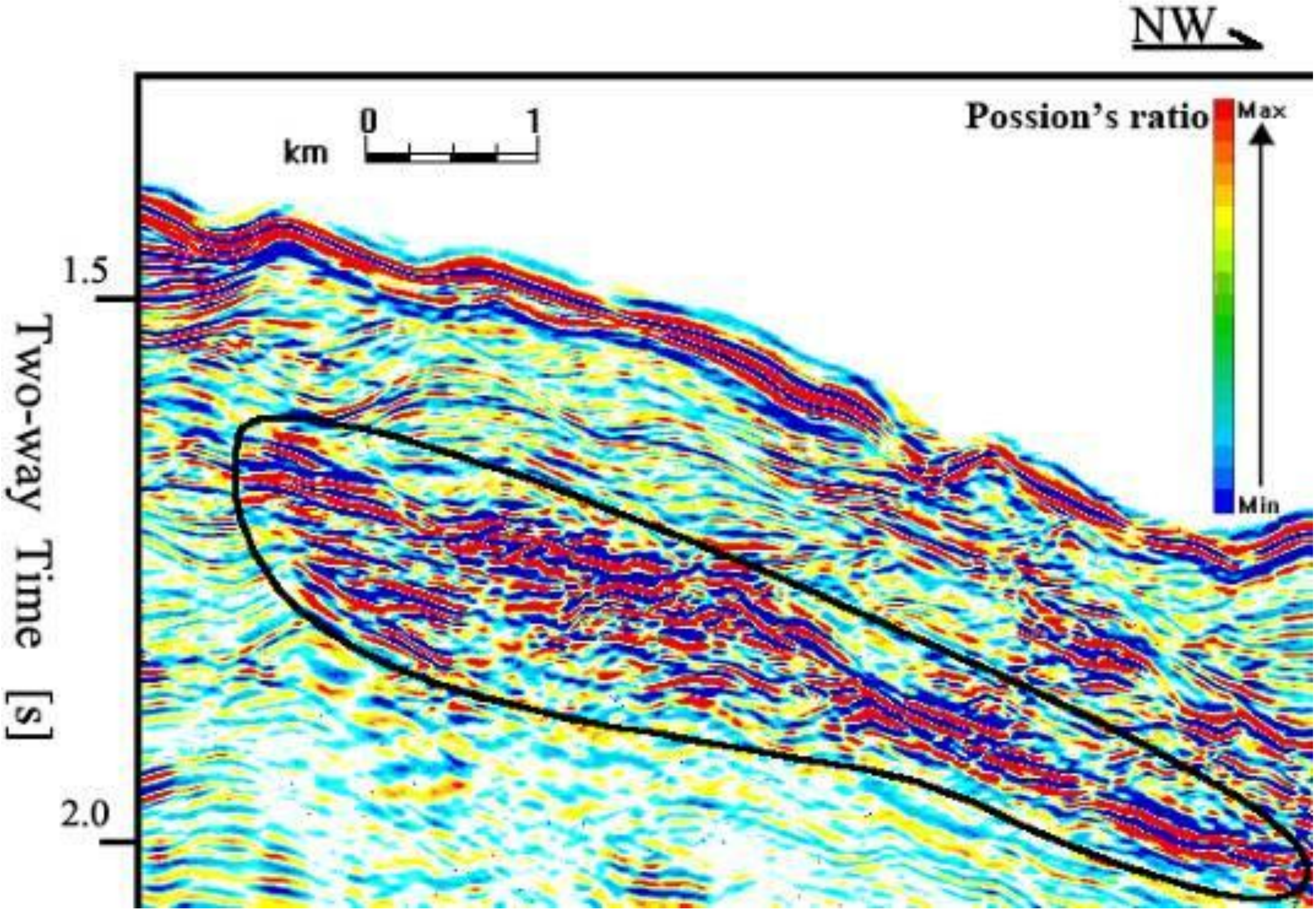

Figure 5. Poisson's ratio profile of Line A.

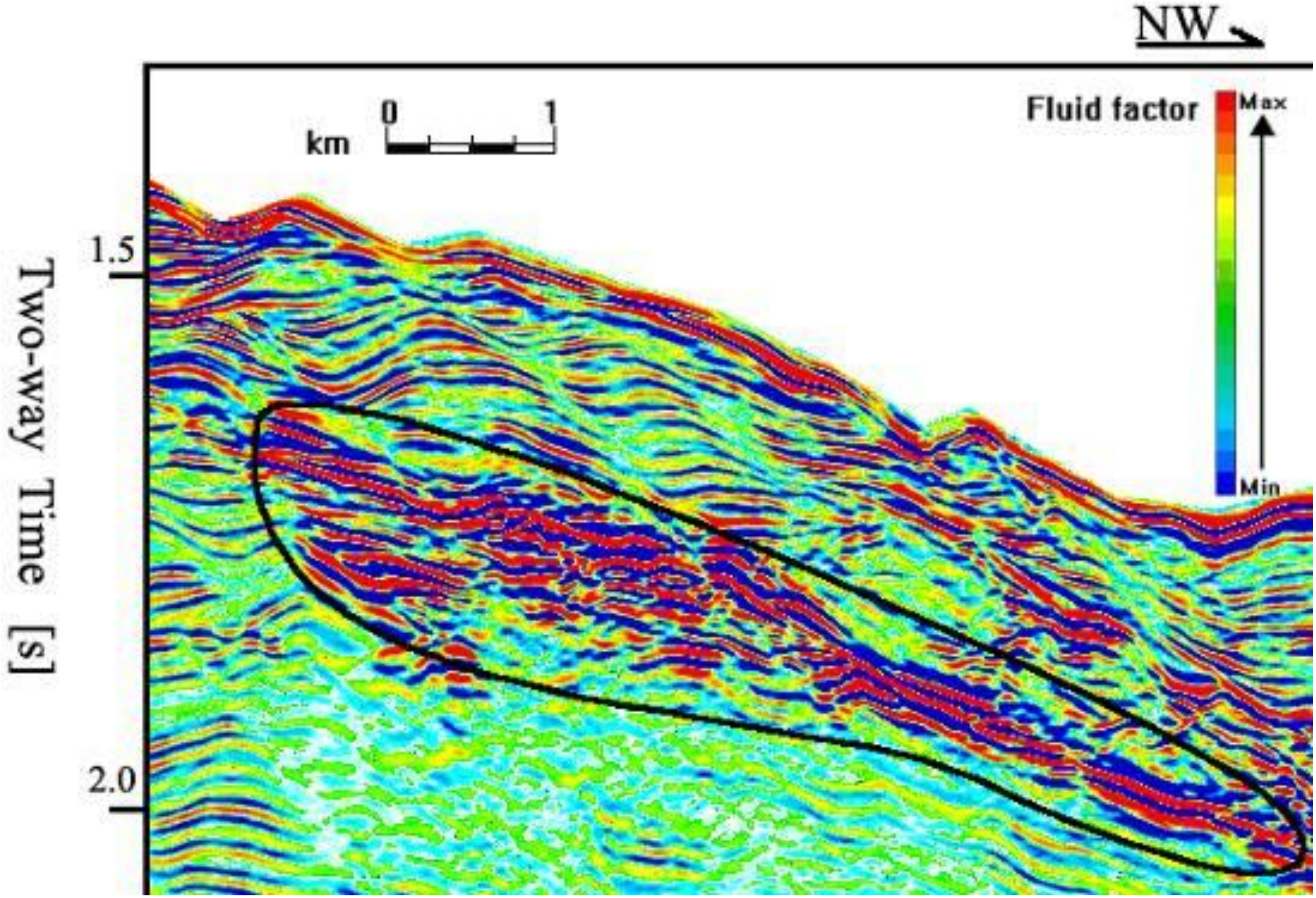

Figure 6. Fluid factors profile of Line A.

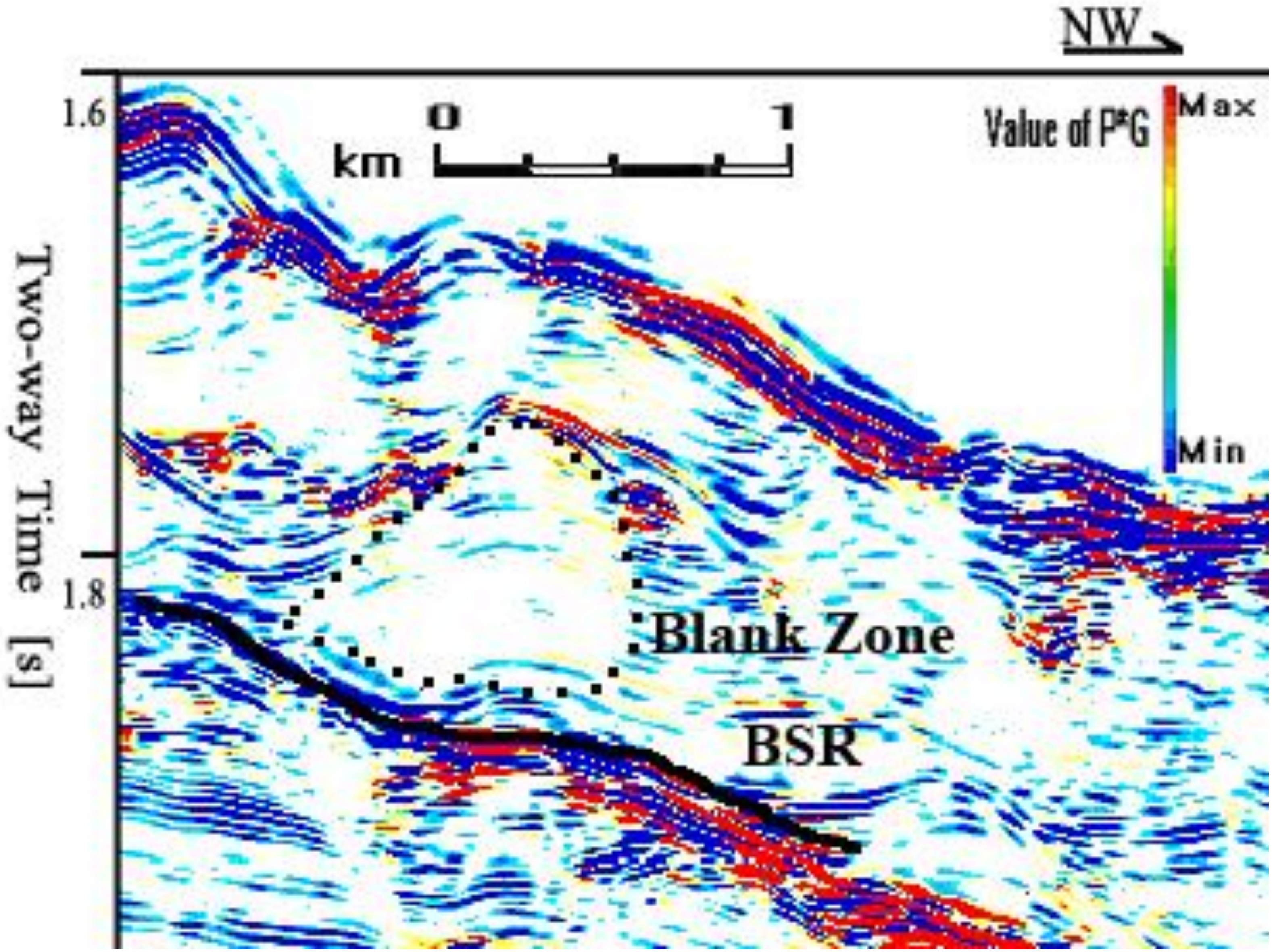

Figure 7. Free gas is on the top of blank zone.

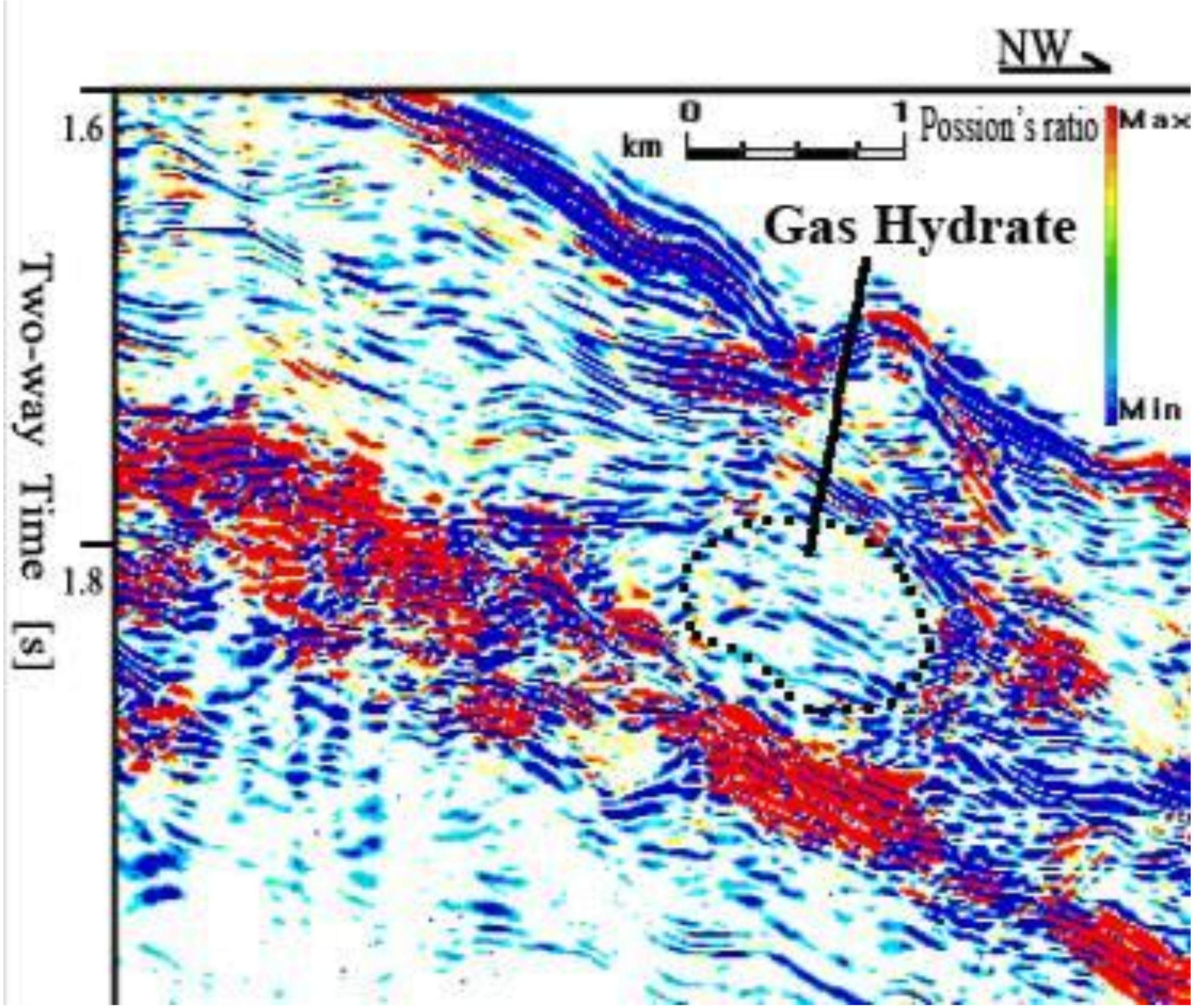

Figure 8. Gas hydrate on Poisson's ratio profile.

NO.	Name	Physical meaning
1	Intercept (P)	P-wave superposition of zero-offset profile.
2	Gradient (G)	The gradient of P-wave reflection amplitude versus offset.
3	P*G	Product. AVO distance, increase as the crest or trough.
4	P*G*C	Correlation profile of the product. Used to detect the gas reservoir.
5	Sign (P)*G	Used to detect the gas reservoir.
6	Fluid Factor	Shows the status of reservoir and fluid.

Table 1. AVO attributes and the significances.