Shallow geothermal gradient derived from a bottom simulating reflection, offshore Cameroon

Anh Ngoc Le

Hanoi University of Mining and Geology, Hanoi, Vietnam

Email: lengocanh@humg.edu.vn

A Bottom Simulating Reflection (BSR) has been identified using 3D seismic data from the Cameroon continental slope margin, covers an area of c. 350 km^2 in water depths ranging between 940 m to 1750 m, across an area characterized by high- and low-gradient slopes, gullies, scours and fans. The thickness of the GHSZ is ~100÷250 m, assuming an average velocity of 1800 m/s. The calculation based theoretical equation give the average geothermal gradient in the shallow sediments is c. 0.052 °C/m. Thermal gradient anomalies have been observed in association with gullies, in the depression areas of pockmark trains, within seafloor gullies. These positive anomalies are most likely controlled by active or recently active fluid advection and expulsion through the Cameroon slope.

Introduction

The Bottom-Simulating Reflectors (BSRs) are seismic reflectors that cross-cut sedimentary strata and are generally related to geological processes occurring after deposition of the sediments. They are controlled by processes depending on the temperature and pressure within the sediments (Berndt, Bünz et al, 2004). The depth to the base of gas hydrate stability as indicated by the Bottom Simulating Reflection (BSR) and bottom water temperature have been widely used in conjunction with gas hydrate phase boundary information to predict shallow geothermal gradient and surface heat flow in many sedimentary basins (Shipley, Houston et al, 1979; Yamano, Uyeda et al, 1982; Grevemeyer and Villinger, 2001; Hübscher and Kukowski, 2003; Martin-Henry et al, 2004; Calvès, Schwab et al, 2010).

Gas hydrate-related BSRs have been widely documented along passive and active margins where water depth exceeds 300 m (Henriet, De Batist et al, 1991; Kvenvolden, Ginsburg et al, 1993). The depth of this reflector may be used to calculate the temperature at BSR depth from the hydrate dissociation curve, and then used to calculate a thermal gradient (Martin et al, 2004).

The occurrence of the widespread BSR gives a great opportunity to estimate the geothermal gradient based on the theoretical temperature and pressure condition for the gas hydrate stability zone, providing useful information to constrain the thermal regime along the Cameroon margin.

Geological setting

The study area covers an area of 1500 km^2, between 2°20' N to 3°00' N latitude, 9°00 E to 9°50' E longitude, and is located on the continental slope of the Kribi-Campo sub-basin. Modern day sea bed gradient is c.3.4° in the upper slope and c. 0.7° on the lower slope. It lies within a water depth ranging from 600 m to 2000 m (Fig. 1).

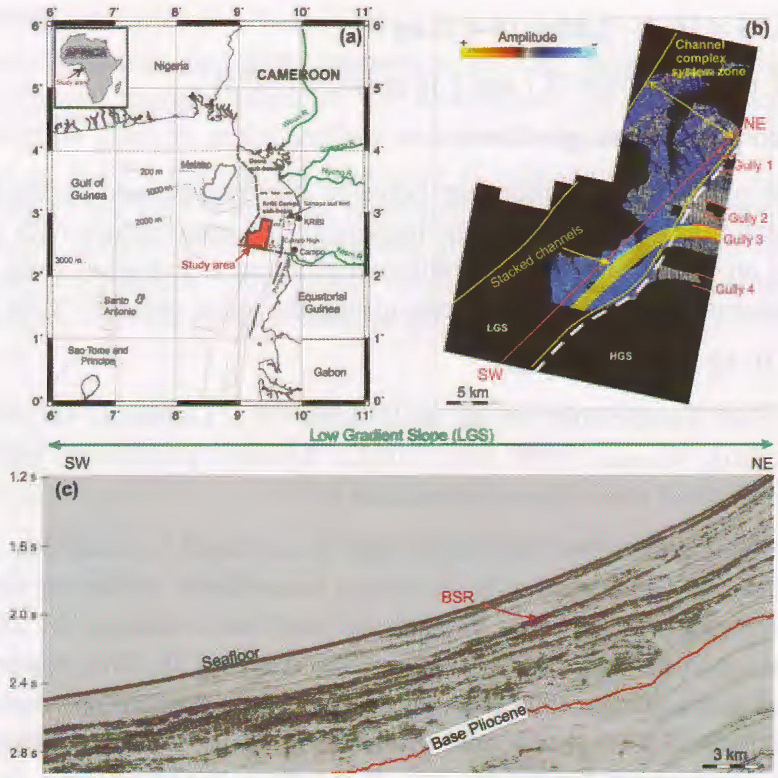

Fig. 1. a) Bathymetry map of the continental slope on the Cameroon margin shows location of the study area (Pauken 1992). The costal line map is extracted from National Geophysical Data Centre (NGDC) (http://rimmer.ngdc.noaa.gov/mgg/coast/getcoast.html). b) Amplitude extraction on the BSR surface showing the strong BSR on the LGS and weak BSR on the HGS; c) seismic cross sections illustrate for the nature of the BSR

Dataset and Methodology

Dataset

The study area covers an area of 1500 km^2, in the water depths ranging from 600 m to 1900 m, offshore Cameroon, West Africa. The 3D seismic data was acquired in a northeast-southwest orientation with a bin spacing of 25 m and a total record length of 6.6 s TWT. The interval focused on this study is down to c. 1s below the seafloor, corresponding to Pliocene to Holocene sequence.

Methodology

Geothermal gradient in deep-water setting offshore Cameroon is calculated based on the existence of BSR which is known as a surface of constant temperature at a certain depth. The method is based on the variation of temperature with depth. The pressure at the BSR can be estimated from its depth and hence if the phase boundary is known, the temperature at this depth can be estimated. If the seabed temperature is known and a linear geotherm is assumed at the site of each BSR depth measurement, the geothermal gradient may then be determined over large areas. This way is much more efficiently than by direct measurements (Yamanoet al,1982). In this study, the formula used to compute the geothermal gradient is extracted from Dickens and Quinby-Hunt (1994) applying for the "pure methane - seawater" system at the given pressure between 2.5-10 MPa or higher pressure (Dickens and Quinby Hunt 1994).

1/T = 3.75 × 10-3 – 2.83 × 10-4 (Log P)

Where: T is temperature (K) and P is pressure (MPa)

Estimated geothermal gradient

The cross-plot of the relationship between the temperature at the BSR and its depth below seafloor is relatively linear, increasing the temperature with greater depth (Fig. 3). Based on this relationship, geothermal gradient is extracted from the equation in which temperature is a function of depth, giving the value of 0.053 °C/m (Fig. 3a).

$T_{BSR} = 0.0532\ Depth_{BSR} + 6.8$

Where T_{BSR}: Temperature at the BSR depth (°C), $Depth_{BSR}$: Depth of the BSR below seafloor (m), $V_{sediment}$: 1800 m/s, 0.0532: Average geothermal gradient (°C/m), 6.8: Inferred, BSR meet sea-bottom temperature (°C)

The relationship between BSR depth and water depth is relatively a near-linear function of increasing BSR depth with increasing water depth. However, there is a set of data out of the general trend. This anomalous has been examined by dismissing the temperature values in the gully 3 and displayed in the Fig. 3b. This confirmed that the anomalous temperature in the figure 3a are caused by temperature estimated within the gully 3. The exact value of geothermal gradient for the study area, therefore, will be used by the equation generated by the dataset in which the anomalous data within the gully 3 are eliminated. The final near-linear function is displayed as below (Fig. 3b):

$T_{BSR} = 0.052\ Depth_{BSR} + 7.1$

In this case, geothermal gradient is reduced to 0.052°C/m and the BSR is expected to meet the seafloor at app. 7.1°C / m.

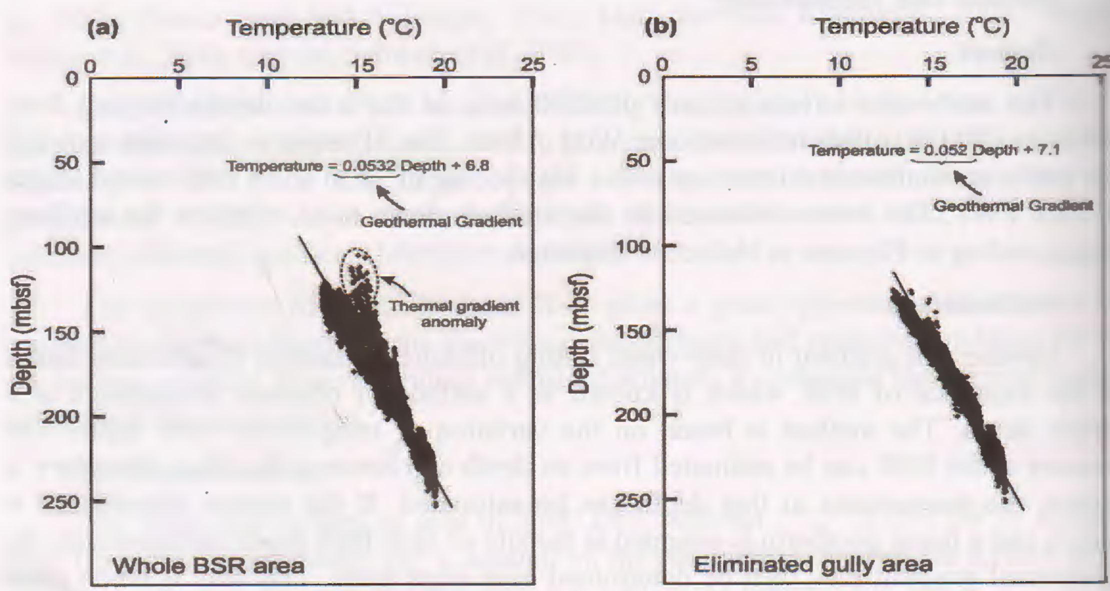

Fig. 3. Temperature profile at the BSR depths (meters below seafloor - mbsf) across the slope. The average thermal gradient ruled out for the whole data set is 0.0532 °C/m (a), and for the data eliminated gully is 0.052°C/m (b) (Vp = 1800 m/s)

Conclusions

This study presents the first estimation of the geothermal gradient in the Cameroon continental margin based on the widespread gas hydrate occurrence. The estimated geothermal gradient in the shallow sediment in the study area is c. 0.052 °C/m. The addition of c. 8-10% is possibly necessary if lithostatic pressure environment is present. Shoaling of the BSR within the identified gully (gully 3) is associated with the presence of mega pockmark trains, resulting in a local temperature anomaly. Heat advection along the gullies may cause elevated temperatures. Estimated thermal gradients are higher than the measured value from deep wells suggested for the cause of fluid migrations.

***Keywords**: Gashydrate, bottom simulating reflection (BSR), geothermal gradient, Cameroon margin.*

References

Berndt C., Bünz S., Clayton T. Mienert J. and Saunders M., 2004. Marine and Petroleum Geology, 21/6: 723-733.

Calvès G., Schwab A. M., Huuse M., Clift P. D. and Inam A., 2010. Marine and Petroleum Geology, 27/5: 1133-1147.

Dickens G. R. and Quinby Hunt M. S., 1994. Geophysical Research Letters, 21/19: 2115-2118.

Grevemeyer I. and Villinger H., 2001. Geophysical Journal International, 145/3: 647-660.

Henriet J. P., De Batist M. and Verschuren J., 1991. Special publication of the European Association of Petroleum Geoscientists 1, Oxford University Press, Oxford, 254-264.

Hübscher C. and Kukowski N., 2003. Geo-Marine Letters, 23/2: 91-101.

Kvenvolden K. A., Ginsburg G. D. and Soloviev V. A., 1993. Geo-Marine Letters, 13/1: 32-40.

Martin V., Henry P., Nouze H., Noble M., Ashi J. and Pascal G., 2004. Earth and Planetary Science Letters, 222/1: 131-144.

Pauken R. J., 1992. Mobil exploration ventures Co Texas, AAPG Memoirs, 54: 217-230.

Shipley T. H., Houston M. H., Buffler R. T., Shaub F. J., McMillen K. J., Ladd J. W. and Worzel J. L., 1979. AAPG Bulletin, 63:12/12: 2204-2213.

Yamano M., Uyeda S., Aoki Y. and Shipley T. H., 1982. Geology, 10/7: 339-343.