Study on the Highest Rock Paleo-temperature with Thermo-acoustic Emission*

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Abstract

The thermal history plays an important role in the generation and expulsion of hydrocarbon in sedimentary basins, and therefore the paleo-temperature study is of great significance for hydrocarbon exploration. In general, the thermal history of the sedimentary basin is reconstructed mainly using paleo-thermal indicators, such as organic maturation index, fluid inclusion and so on. However, these indicators are associated with temperature by complicated dynamic functions. Thermo-acoustic emission technology is a new method to, in theory, directly measure the highest temperature the sedimentary rock experienced.

Acoustic emission is a term named for elastic waves and are brought about by sudden changes in materials which resulted from deformation, cracking, transformation, etc. (Osamu et al., 1998). Microcracking in rocks may be generated by submitting them to stress or temperature (Jones et al., 1997). Therefore, repetitive thermal loads may induce a thermal Kaiser effect similar to the case of the mechanical Kaiser effect (Choi et al., 2005), which is the basis to determine the highest temperature the rock experienced using thermo-acoustic emission technology. Rock can record the peak temperature that it has been subjected to in geological time. When the rock from an area is heated, the number of acoustic emission signals will increase dramatically at some temperature according to the signal records (Xi et al., 1996). This phenomenon is known as the thermal Kaiser effect, while the temperature at the highest paleo-temperature of the rock is known as the threshold temperature.

Samples and Experimental Program

The samples were collected from the Tarim Basin and the Sichuan Basin, including sandstone, mudstone and limestone. They were all processed into dry, solid cylinders with the
diameter and the height of 2.5 cm. Two goals were planned to achieve in the experiment. One was to verify the existence of the thermal Kaiser effect of the sedimentary rocks and the accuracy of the experimental results. The other was to measure the highest paleo-temperature of samples with different depths in the basins. The laboratory apparatus is in the work condition below 800℃.

To realize the former goal, artificial heated sandstone samples SH23-1-1~SH23-1-8 of Well S23 in the Tarim Basin, and limestone samples L1~L6 of the Sichuan Basin were used in the experiment. The sandstone was buried to 4283 m, while the limestone was buried to 5500 m. Because of the extraordinary thick sediments of the Cenozoic, the present formation temperature represents the highest temperature of the rocks. At first they were heated to 200 and 400℃ respectively, which were much higher than the present temperature of the formations (Liu et al., 2006; Lu et al., 2005). Then these samples cooled down to the ambient temperature. In the thermo-acoustic emission experiment, the sandstone samples were heated up to 240℃ at the rate of 2℃/min, and limestone samples were heated to 430℃ at the rate of 2℃/min for L1, 4℃/min for L2~L4, and 5℃/min for L5~L6.

As to the latter goal, the thermo-acoustic emission was applied to measure the highest paleo-temperature of the mudstone of the Tarim Basin. Samples YL1-1~YL1-3 are collected from Well YL1 and Samples SH14-1~SH14-3 are from Well S14. The present formation temperature of these two wells also represents the highest (Table 1). These samples were heated up to 200℃at the rate of 2℃/min in the thermo-acoustic emission.

Experiment Results

When the samples were heated, the signals of the acoustic emission were recorded in the computer. Before determining the threshold temperature at which the thermal Kaiser effect occurs, the signals without energy were filtered out, because few signals due to the rock cracking are equal to 0. And the thermal Kaiser effect is characterized by the sudden appearance of a great number of signals.

In this study, the relative energy accumulation was mainly used to indicate the change of signals (Figure 1, Figure 2, and Figure 3). The slop of the curve of relative energy accumulation versus temperature became steeper at the maximum paleo-temperature of each sample, which is shown as the dotted line in the pictures. The number of the signals varied with the increase of temperature. The measured temperatures of all the samples by the thermo-acoustic emission technique are listed in the Table 2. The temperatures of Samples SH23-1-1~SH23-1-8 are from 190 to 198℃ and the mean is 194℃by an error of 3% with 200℃. The results of Samples L1~L6 fall into the range of 369~409℃with the average value of 388℃that is off 4% compared with 400℃. Except samples YL1, the measured temperature of the other samples from Wells YL1 and S14 are close to the present formation temperature (Table 1, Table 2).

Discussion

As is shown in the Table 2, the measured temperatures of the artificial samples are usually less than the highest temperature they experienced, which may be related with the rapid increase of the temperature during the sample preparation. Due to the thermal expansion and extrusion, the crack nuclei formed in the center and boundary of grains. When the temperature is close to the threshold temperature, the energy is likely to accumulate in the area with crack nuclei, which may lead to the extension of the microcracks ahead of the temperature heating temperature.

It is known that the cracks of the rocks depend on temperature, pressure and some other factors. The conclusion that the press may bring about the Kaiser effect in advance was drawn in the experiment of repeated heating the granite samples under pressure (Xi et al., 1995). The pressure is closely related with the pores. And the pores can reduce the influence area of the press, and therefore the pores can go against the formation and propagation of the cracks (Wu et al., 2003). The pressure loads can reduce the porosity and increase the energy of the rocks, which is conductive to the development of the microcracks. However, confining pressure had small effect as long as pressure was greater than some critical value which apparently was the minimum needed to prevent thermal cracking and other non-elastic effects (Wong et al., 1979).

The measured temperatures of most of the mudstone samples are higher than the maximum temperature of the formation. The results may be affected by the experimental conditions with atmospheric pressure. The second increase of thermo-acoustic emission signals may occur in rocks because some minerals may change with new texture. Therefore, the termo-acoustic emission technique should be used combining with the reconstruction of burial history.

Conclusion

The experimental results of artificial heat samples confirm the existence of the sedimentary rock while being heated. Hence the thermo-acoustic emission technique can be applied to measure accurately the maximum temperature the rock experienced. The measured temperatures of the mudstone samples by the thermo-acoustic emission technique are close to the highest temperature they have been subjected to, providing further evidence for the feasibility of this technique to measure rock temperature.

References

Choi, N.S., T.W. Kim, and K.Y. Rhee, 2005, Kaiser effects in acoustic emission from composites during thermal cyclic-loading: NDT & E International, v. 38, p. 268-274.

Jones, C., G. Keaney, P.G. Meredith, and S.A.F. Murrell, 1997, Acoustic emission and fluid permeability measurement on thermally cracked rocks: Physics and Chemistry of the Earth, v. 22/1-2, p. 13-17.

Liu, S.W., L.S. Wang, and C. Li, et al., 2006, Lithospheric thermo-rheological structure and Cenozoic thermal regime in the Tarim Basin, Northwest China (in Chinese): Acta Geologica Sinica, v. 80/3, p. 344-350.

Osamu, M., S. Noboru, Y. Shigenori, T. Okamoto, and K. Maruyama, 1998, Acoustic emission evaluation of an arch dam during construction cooling and grouting: Construction and Building Materials, v. 12/6-7, p. 385-392.

Wong, T.F., and W.F. Brace, 1979, Thermal expansion of rocks: some measurement at high pressure: Tectonophysics, v. 57/2-4, p. 95-117.

Wu, X.D., and J.R. Liu, 2003, Factors on the thermal cracking of rocks (in Chinese): Petroleum Dring Techniques, v. 31/5, p. 24-27.

Xi, D.Y., J.Y. Cheng, and J.H. Huang, 1996, The application of acoustic emission in the study of ancient temperature of rock (in Chinese): Journal of University of Science and Technology of China, v. 26/1, p. 97-101.

Xi, D.Y., and P.G. Chen, 1995, On influence of stress and thermal fatigue on Kaiser effects of granite (in Chinese): Seismology and Geology, v. 17/2, p. 162-166.

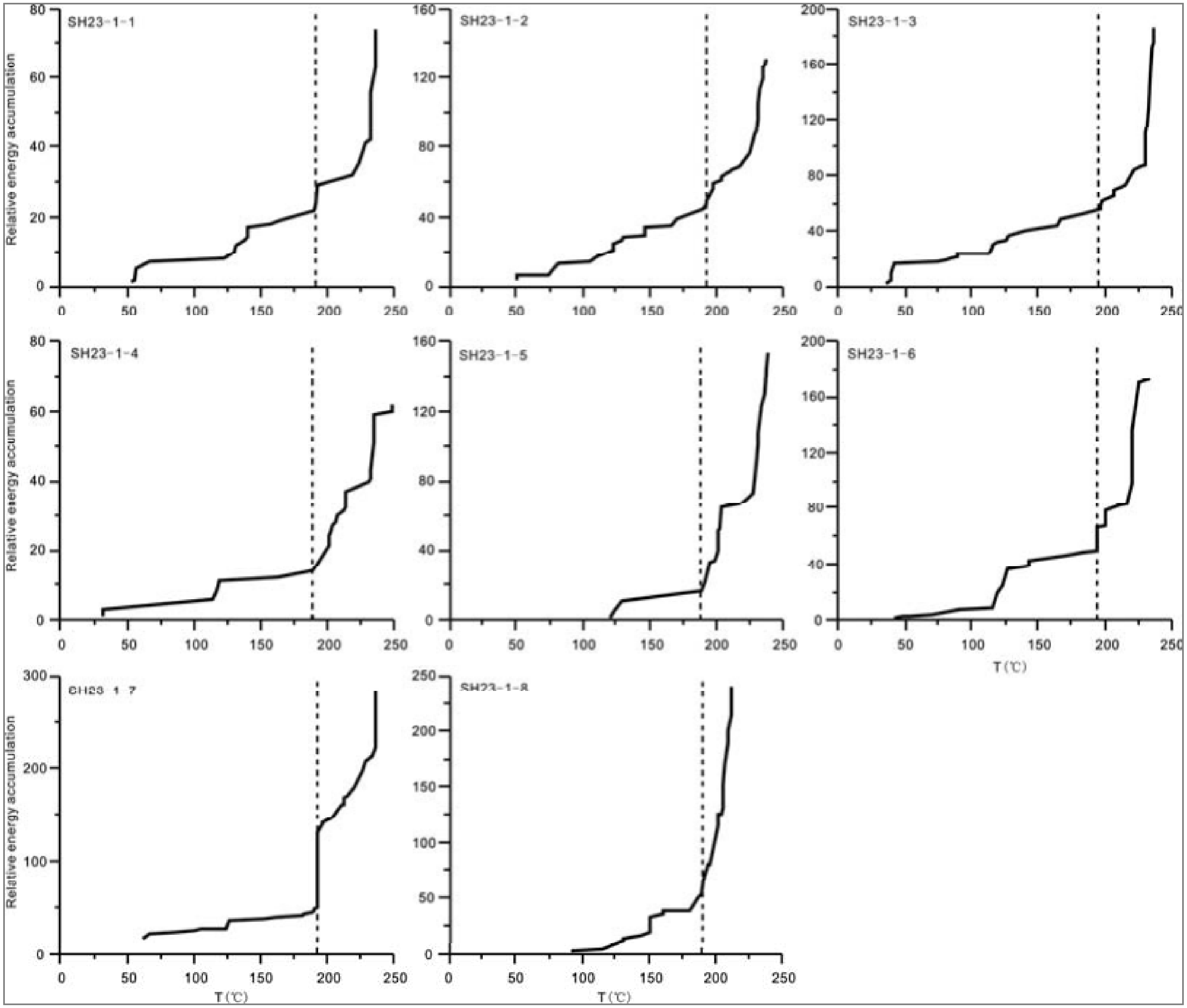

Figure 1. Thermo-acoustic emission characters of sandstone samples SH23-1 versus temperatures. Sandstone samples SH23-1 were heated up to 240°Cat the rate of 2°C/min.

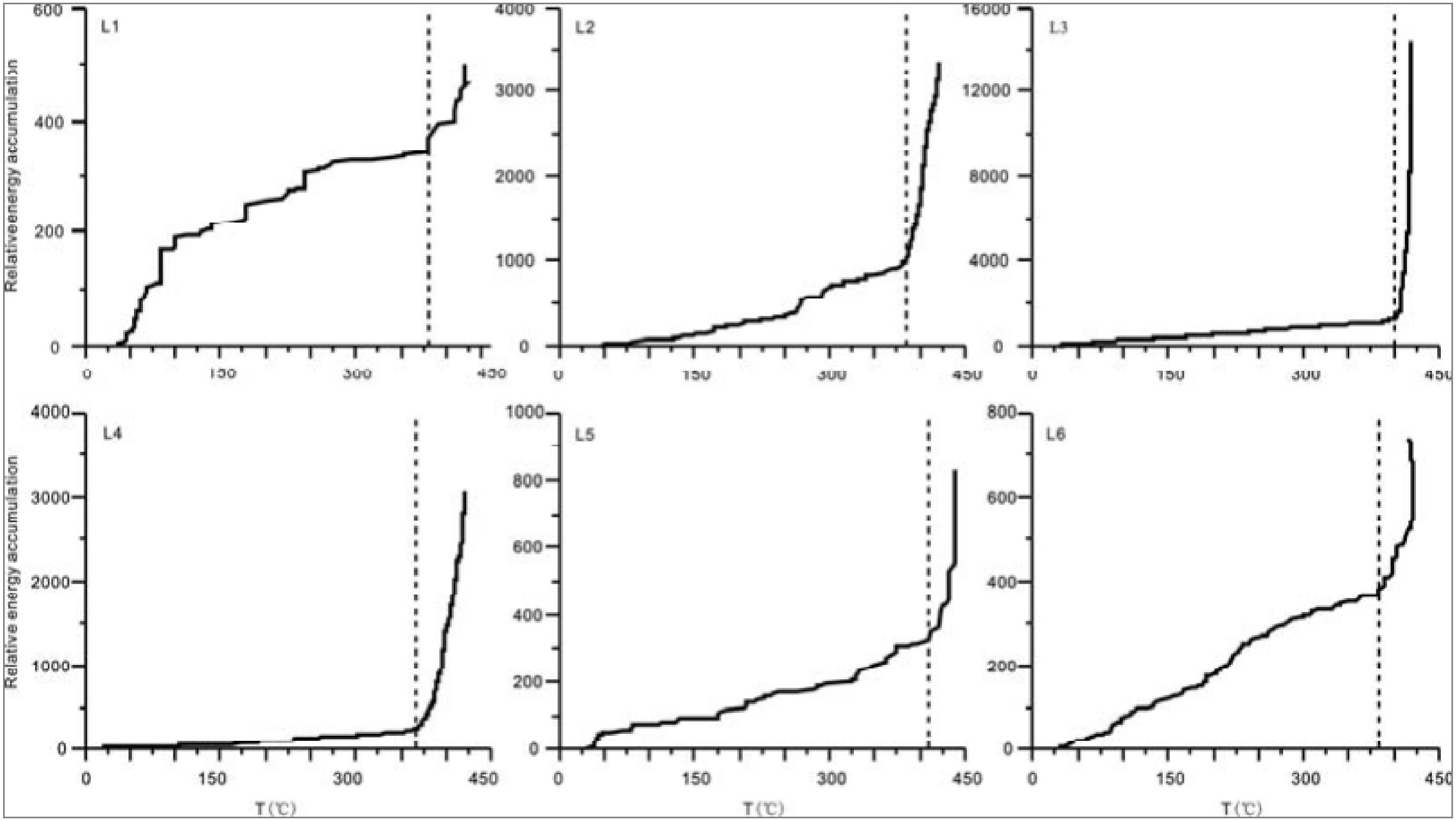

Figure 2. Thermo-acoustic emission characters of limestone samples L versus temperatures. Limestone samples were heated up to 430℃ at the rate of 2℃/min for L1, 4℃/min for L2~L4
and 5℃/min for L5~L6.

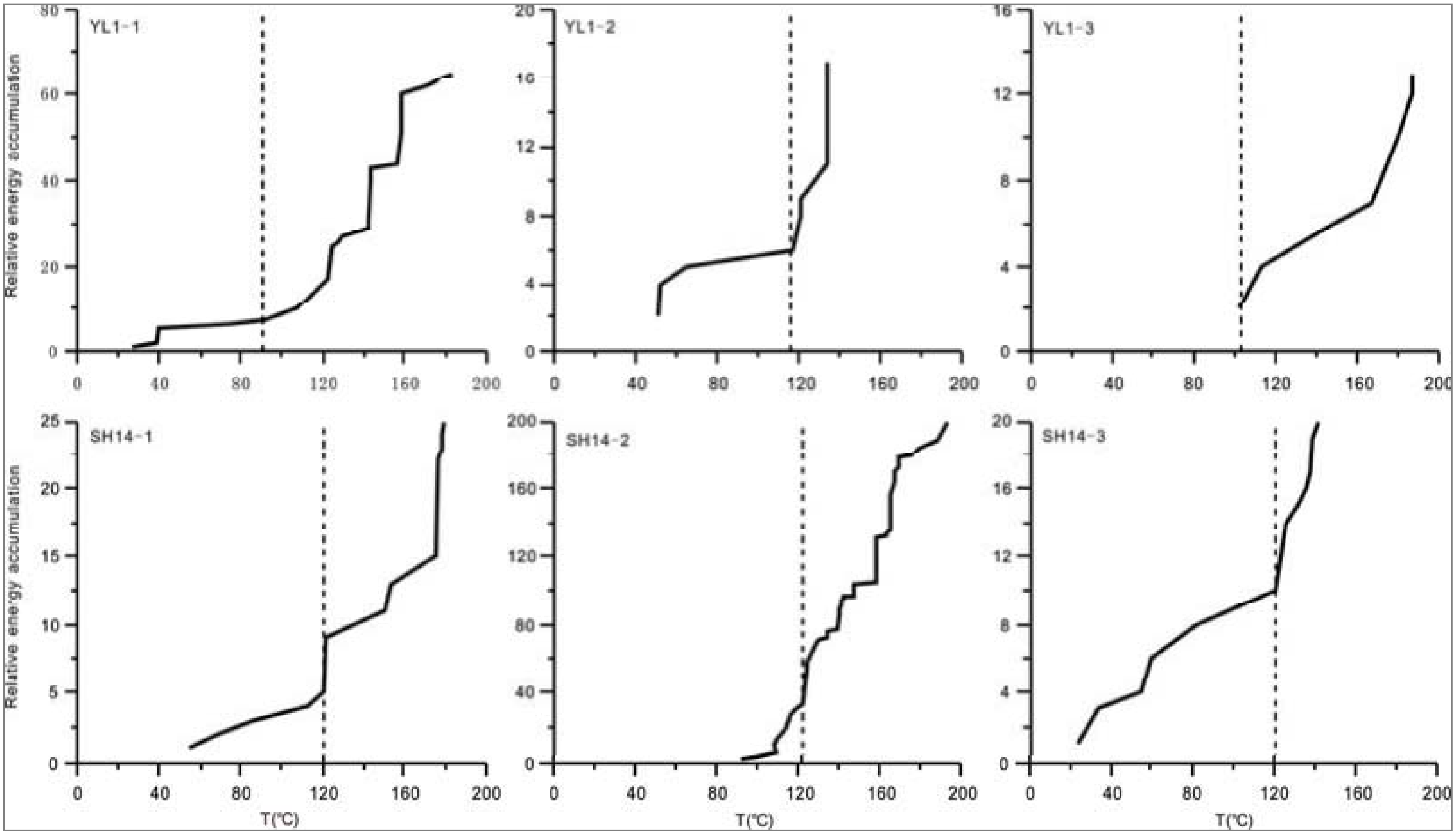

Figure 3. Thermo-acoustic emission characters of mudstone samples YL1 and SH14 versus temperatures. Mudstone samples YL1 and SH14 were heated to 200℃ at the rate of 2℃/min.

Well	Sample	Burial depth (m)	Present formation temperature (℃)
	YL1-1	2878	73
YL1	YL1-2	4335	102
	YL1-3	4335	102
	SH14-1	5185	119
SH-14	SH14-2	5185	119
	SH14-3	5261	120

Table 1. Depth and present formation temperature of mudstone samples in wells YL1 and S14.

Samples	Threshold temperature (℃)	Samples	Threshold temperature (℃)	Samples	Threshold temperature (℃)
SH23-1-1	192	L1	379	YL1-1	91
SH23-1-2	193	L2	383	YL1-2	116
SH23-1-3	198	L3	402	YL1-3	102
SH23-1-4	191	L4	369	SH14-1	121
SH23-1-5	190	L5	409	SH14-2	124
SH23-1-6	195	L6	385	SH14-3	123
SH23-1-7	196				
SH23-1-8	194				

Table 2. Threshold temperature of samples.