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冲绳海槽中段西陆坡下缘天然气水合物存在的可能性分析

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摘要 海洋中的天然气水合物主要发育在有机质供应充分、沉积速率快、热流值较高、水深大于 300 m 的大陆斜坡和活动边缘的增生楔发育区; 沉积物类型主要以泥质砂岩、砂质泥岩和浊积岩为主。似海底反射层(BSR)和极性反转是识别天然气水合物层的关键标志。冲绳海槽中段西陆坡下缘水深大于 1 000 m; 沉积物类型主要为粉砂质泥和泥质粉砂, 在部分层位见浊积层。与东海陆架相比, 西陆坡下缘的有机质含量、沉积速率的热流值都较高, 其范围分别为 0.75%~1.25%、10~40 cm/ka 和 70~437 mW/m²; 单道地震剖面具有明显的似海底反射层(BSR)和极性反转特征, 因此, 推断冲绳海槽中段西陆坡下缘可能存在天然气水合物层。

关键词 冲绳海槽 天然气水合物 似海底反射层(BSR)

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海底天然气水合物是一种主要由甲烷(含少量的 CO₂、H₂S、N₂ 和其它烃类气体)分子和水分子组成的类冰固态物质, 主要产于水深大于 300 m 的大陆斜坡地带和深海盆地。由于其储量巨大, 引起了许多国家的关注。90 年代以来, 国内的部分科研单位对国际上的天然气水合物勘查与研究进行了技术追踪和信息资料研究^[1~3]; 中国大洋矿产资源研究开发协会率先开展了海底天然气水合物信息、资料的调研, 完成了“西太平洋气体水合物找矿前景与方法”的调研报告。近年来, 我国海洋地质科技工作者根据天然气水合物的生成条件, 初步研究认为, 我国海域的东海陆坡、冲绳海槽、台湾东北和东南海域、南海北部陆坡和南沙海槽都是天然气水合物生成的有利背景区; 首次根据 BSR 特征探讨了南海北部陆缘天然气水合物分布的可能性^[4]。本文根据天然气水合物产出的地质背景, 结合冲绳海槽中段西陆坡下缘水深、沉积物类型、沉积速率、有机质含量、热流值及单道地震剖面的结构特征, 对冲绳海槽中段西陆坡下缘天然气水合物发育的可能性进行初步探讨。

1 海底天然气水合物产出的地质背景

尽管海洋中有 90% 水域的某一深度(300~3 000 m)范围内都存在适合天然气水合物稳定的温、压场,

但是天然气水合物形成与沉积物类型、沉积速率、有机质来源和流体活动密切相关。因此, 并不是所有适合于天然气水合物形成的温、压场内都有其分布^[2]。从构造环境来看主要分布在大陆边缘: 一类是分布在大陆边缘的大陆斜坡和坡角, 另一类是分布在活动边缘的增生楔发育区^[5]。对占大洋大部分面积的深海洋盆中的天然气水合物的分布情况目前还知之甚少。

从理论上讲, 在沉积盆地内形成天然气水合物必须具备如下条件: (1) 沉积物中含有丰富的有机质, 并被快速埋藏, 这是天然气水合物形成的物质条件; (2) 沉积物的孔隙度较大, 并含有足够的间隙水, 为天然气水合物的形成提供足够的胶结空间; (3) 水合物中的天然气一般有两种成因, 一种是生物成因, 另一种热解成因。对后者来说, 与热流活动密不可分。由此可见, 海洋中利于天然气水合物产出的地质背景是有机质供应充分、沉积速率较快、热流值较高、沉积物较粗的非泥质沉积、水深大于 300 m 的大陆斜坡和活动边缘的增生楔发育区。

2 海底天然气水合物的识别标志

2.1 地球物理标志

尽管天然气水合物在许多钻孔中被发现, 但是大多数天然气水合物层都是从地震反射剖面中识别出来的。由于声波在水和物胶结沉积层中的传播速度大于

表1 冲绳海槽中段西坡岩性和沉积速率*

Table 1 Sediment types and sedimental rates of western slope Okinawa Trough

C ₁₇₀ 岩芯			C ₁₅₅ 岩芯			DG9603岩芯		
埋深/m	沉积速率/ cm·ka ⁻¹	岩性	埋深/m	沉积速率/ cm·ka ⁻¹	岩性	埋深/m	沉积速率/ cm·ka ⁻¹	岩性
0~51	20.03	粘土质粉砂	0~42	16.10	粘土质粉砂	0~64	6.61	粘土质粉砂
51~57	20.48	粘土质粉砂	42~76	7.73	粘土质粉砂	64~107	19.00	粘土质粉砂
57~75	15.90	粘土质粉砂	76~85	15.15	粘土质粉砂	107~120	13.57	粘土质粉砂
75~162	17.58	粘土质粉砂	85~150	30.81	粘土质粉砂	120~210	14.61	粘土质粉砂
162~244	65.95	粘土质粉砂	150~280	57.96	粘土质粉砂	210~294	12.50	粉砂
224~285	26.26	粘土质粉砂	280~295	15.66	粘土质粉砂	294~364	34.67	粘土质粉砂
285~294	9.39	粘土质粉砂	295~365	54.74	粘土质粉砂	364~449	8.85	粘土质粉砂
			365~483	10.17	粘土质粉砂	449~516	21.30	粉砂、细砂
			483~524	20.31	粘土质粉砂	516~564	20.89	粘土质粉砂

*引自参考文献[4]

其在下伏含水沉积层中的传播速度,因此,在两者的界面处形成了似海底反射层(BSR),该反射层与海底地形平行,而与沉积层理反射相交,且与海底反射相比具有负极性(即极性反转)^[6~8];此外,在水合物胶结的沉积层中,形成了“空白”反射带。如果BSR之下有游离气体存在,那么,在地震剖面中常有“亮点”反射异常^[5]。

2.2 地球化学标志

海底天然气水合物只能在一定的温、压场内存在。当其存在介质的物理化学条件发生改变时,会发生

天然气水合物的分解。分解的过程是个吸热的过程,因此在测井剖面中可识别出低温异常。分解的产物天然气和水形成两类地球化学异常,一是CH₄、H₂S、和CO₂等游离气体地球化学异常,另一类是孔隙水盐度和碱度异常^[11,13]。

3 研究区天然气水合物存在的可能性分析

3.1 地质背景、沉积类型和沉积速率

冲绳海槽是西太平洋典型的弧后扩张盆地,海槽的西坡是东海大陆坡的自然延伸,水深从200 m变化到2 000 m左右。有关冲绳海槽的地质构造和沉积特征前人已进行了较多的研究,其中尤以海槽中段研究的最为详尽。这里仅以海槽中段西陆坡三个岩芯(水

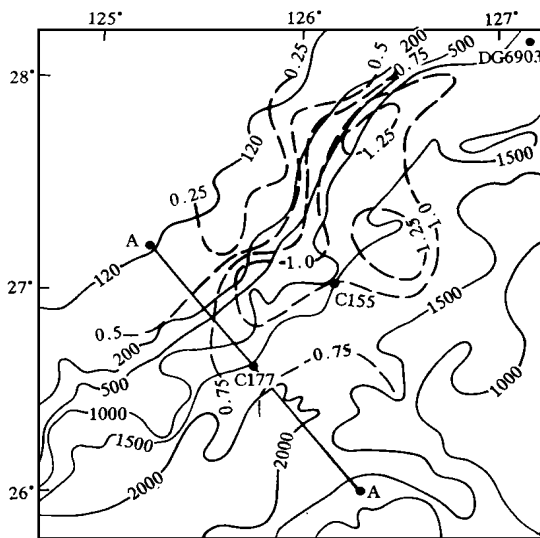


图1 冲绳海槽中段岩芯取样站位、地震剖面位置及有机质含量分布图

Fig. 1 Locations of sampling, seismic profile and distribution of organic matter in the Mid-Okinawa Trough

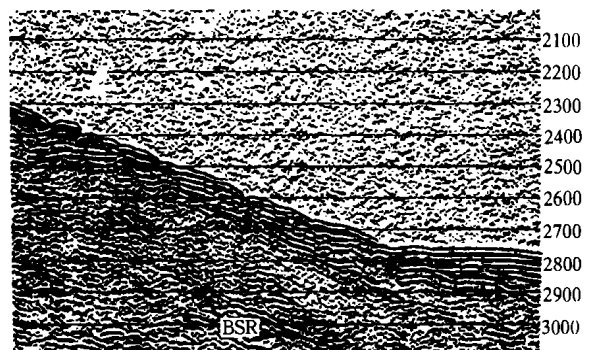


图2 冲绳海槽中段A-A'单道地震剖面(经振幅增强处理)

Fig. 2 Single-channel seismic reflection(A-A') in the Mid-Okinawa Trough

表 2 冲绳海槽中段西陆坡下缘个别站位沉积物热学参数表

站位	纬度(N)	经度(E)	梯度/ $\text{mk}^\circ\text{m}^{-1}$	热导率/ $\text{w}^\circ(\text{m}^\circ\text{k})^{-1}$	热流值/ $\text{mw}^\circ\text{m}^{-2}$	资料来源
1	26° 16. 2'	125° 49. 7'	223	0. 83	185	[15]
2	26° 48. 0'	126° 26. 9'	296	0. 80	238	[15]
3	27° 34. 8'	126° 28. 1'	157	0. 74	116	[15]
4	27° 37. 8'	126° 24. 0'	111	0. 77	86	[16]
5	27° 37. 0'	126° 38. 0'	120	0. 81	97	[16]
6	25° 50. 0'	125° 13. 0'	170	0. 84	142	[17]
7	26° 28. 0'	126° 9. 0'	335	1. 12	375	[18]
8	25° 38. 3'	125° 36. 9'	103	1. 25	129	[19]
9	26° 12. 5'	126° 01. 6'	426	1. 03	437	[19]
10	26° 20. 2'	125° 58. 4'	230	1. 01	211	[20]
11	27° 1. 8'	126° 33. 7'	228	0. 75	171	[21]
12	26° 57. 2'	126° 39. 0'	184	0. 75	138	[21]
13	26° 53. 0'	126° 42. 0'	137	0. 90	123	[23]
14	27° 17. 0'	126° 42. 0'	110	0. 90	100	[22]
15	26° 54. 0'	126° 45. 0'	100	0. 90	90	[22]
16	26° 30. 0'	126° 07. 0'	1	1	375	[23]
17	25° 07. 0'	126° 57. 0'	1	1	70	[23]
18	25° 22. 0'	125° 05. 0'	1	1	165	[24]
19	26° 52. 77'	126° 41. 87'	161	0. 90	144	[22]

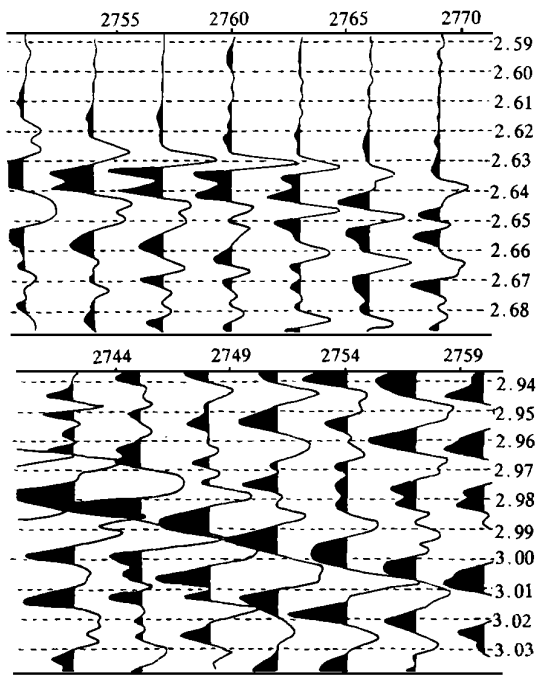


图 3 冲绳海槽中段 A—A' 剖面 BSR 的负极性特征
Fig. 3 Reversed polarity of BSR in the A—A' seismic reflection of Mid-Okinawa Trough

深为 1 500 m 左右)为对象,概括其沉积类型和沉积速率。

表 1 是冲绳海槽西坡三个岩芯(位置见图 1)的沉积物类型和沉积速率。从表 1 中看出,海槽西坡下缘沉积类型主要为粘土质粉砂,在 C155 和 DG9603 孔各含 39 cm 和 68 cm 厚的浊积层^[14];沉积速率一般在 10

~40 cm/ka,某些区域或某些层位沉积速率大于 40cm/ka,远大于东海陆架和相邻槽底的沉积速率^[14]。

3.2 有机质含量和热流值

冲绳海槽中段底质沉积物中的有机碳含量分布如图 1。从图 1 来看,从水深大于 500 m 的陆坡下缘到槽底有机碳含量最高,变化范围为 1%~1.25%,远高于东海陆架沉积物。

冲绳海槽中段西坡陆下缘个别站位的沉积物热学参数列于表 2 中。

从表 2 来看,冲绳海槽西坡下缘的热流值介于 70~437 mw/m^2 之间,平均值为 179 mw/m^2 ,远远大于西太平洋边缘海的平均值(87 mw/m^2)^[25]。

3.3 BSR 与极性反转特征

利用振幅增强方法对冲绳海槽中段 A—A'地震剖面的实测资料进行了处理,结果如图 2。

从图 2 可以看出在水深 1 500~1 800 m 处的陆坡角具有明显似海底反射层,沿坡向上,反射层特征逐渐消失。该反射层与海底平行,而于地层斜交,且与海底反射相比具有明显的负极性(即极性倒转,如图 3)。

4 结论

冲绳海槽西坡下缘水深大于 1 000 m,沉积物主要粘土质粉砂,在各别地段见浊积层;沉积速率和有机质含量均高于相邻陆架和槽底;热流值也远远大于西太平洋边缘海平均值;单道地震剖面见似海底反射层(BSR),该层与地层斜交,且与海底反射相比显示出极性反转特征。因此,推断冲绳海槽中段西陆坡下缘可

能发育天然气水合物。

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Possibility of Gas Hydrate Occurring in the Western Lower Slope of Mid-Okinawa Trough

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Abstract

Although 90 percent area of the ocean with depth from 300 to 3 000 meters is suitable to occurrence of gas hydrate in view of temperature and pressure condition, gas hydrate does not occur everywhere in ocean. The occurrence of gas hydrate is tightly related to geological setting. From tectonic point of view, gas hydrate in the ocean occurs along continental margin; one kind is at active passive margin prism, the other is at the continental slope or slope foot. The formation of gas hydrate is also tightly related to sediment type, sedimentation rate and organic source, as well as heat flow, i. e. more content of organic matter quickly buried in sediments is material condition for the formation of gas hydrate; more coarse sediments, consequently more porosity and more content of porous aquifer

supply plentiful space for the cementation of gas hydrate. Gas in hydrate is subjected to biogenesis and thermal degradation of organic matter, so that more content of biomass and higher heat flow are favorable for the formation of gas hydrate.

Two kinds of marks are commonly used for distinguishing gas hydrate. In seabed sediments, one is geophysical mark, i. e. blank reflection and simulated seafloor reflector (BSR) which is caused by the different acoustic wave velocity between hydrate zone and underneath sediments and parallel to seafloor and oblique to bedding. In contrast to seafloor reflection, simulated seafloor reflector has reversed polarity. The other is geochemical mark, i. e. positive CH_4 , H_2S and CO_2 gas geochemical anomalous, as well as negative saltness or chlorinity anomalous should be present due to the decomposition of gas hydrate in the log profile. The western lower slope of Mid-Okinawa Trough possesses good geological setting and conditions for the formation of gas hydrate. First of all, the water depth is more than 1 000 meters, which is suitable to the formation of gas hydrate from the temperature-pressure point of view. Secondly, sediment is almost silty mud and muddy silt which may supply plentiful cemented space for gas hydrate. Thirdly, the content of organic matter in sediment is much higher than adjacent area, the sedimentation rate is also higher ($10 \sim 40 \text{ cm} \cdot \text{ka}^{-1}$), causing the abundant organic matter buried quickly, so that the gas source is stored for the formation of gas hydrate. The last is that the values of heat flow change from 70 to 437 mw/m^2 , much higher than the other area, supplying plentiful heat for thermal degradation of organic matter. A channel seismic reflection profile (A—A') at the lower slope margin, with depth from 1 500 to 1 800 meters, shows that a simulated seafloor reflector occurs at depth of 2 250 meters beneath sea floor and gradually disappears up slope, which is parallel to seafloor and oblique to bedding, and also has negative polarity (reversed polarity) in contrast to seafloor reflection. Therefore, we initially deduce that the gas hydrate may occur at the western lower slope of Mid-Okinawa Trough.

Key words Okinawa trough gas hydrate simulated seafloor reflector