

# Research Progress on Shallow Gas Exploration

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**Abstract:** *Shallow gas is widely distributed across the globe, accounting for 20% of the total number of gas fields worldwide. By the end of 2005, it had accounted for 23% of the world's proven recoverable natural gas reserves. As exploitable resources in the medium-deep layers decrease and the demand for natural gas extraction continues to rise, the development value of shallow gas and the significance of engineering risk prevention and control have become increasingly prominent. This study introduces the main exploration methods for shallow gas, including Cone Penetration Test (CPT), seismic exploration, electromagnetic exploration, and microbial exploration.*

**Keywords:** Shallow gas, In-situ detection technology, Geophysical technology.

## 1. Introduction

China has proposed to “strive to peak carbon emissions before 2030 and endeavor to achieve carbon neutrality before 2060”. The “dual carbon” goals are two milestones in China’s energy revolution over the next 40 years. As a low-carbon and clean fossil energy source, natural gas plays an important transitional role in China’s energy transition [1]. China’s early natural gas exploration and development focused mainly on medium and deep reservoirs. With the decrease in exploitable resources in medium and deep layers, shallow natural gas resources, i.e., shallow gas, has attracted increasing attention in terms of exploration and utilization.

Shallow gas, a type of natural gas resource with a relatively shallow burial depth (20m-1500m) and diverse genetic origins, is widely distributed across the globe. Globally, shallow gas fields account for 20% of the total number of gas fields worldwide. By the end of 2005, shallow gas had accounted for 23% of the world’s proven recoverable natural gas reserves ( $173 \times 10^{12} \text{ m}^3$ ) [2]. As for its distribution, shallow gas is mainly concentrated in basins, deltas, and offshore sedimentary environments with specific geological conditions. Worldwide, substantial shallow gas resources have been discovered in regions such as the Gulf of Mexico coast, the Mediterranean region [3], the Northwest Shelf of Australia, and the Sea of Japan. Domestically in China, large reserves of shallow gas have also been found in areas including the coastal areas of Jiangsu and Zhejiang [4], the Qiongdongnan Basin, the eastern oil- and gas-bearing basins, the Qaidam Basin, and the Sichuan Basin [5]. Notably, shallow gas serves not only as an exploitable natural gas resource but also as an engineering geological hazard. Domestically, there have been multiple engineering accidents caused by shallow gas release, such as tunnel distortion, fracture, and foundation pit slope collapse [6,7]. Therefore, in areas where shallow gas occurs, it is essential to accurately investigate the spatial distribution of subsurface gas to ensure the safe implementation of engineering projects.

Shallow gas can be categorized into biogenic gas, thermogenic gas, and mixed-genesis gas based on its genetic origin. Biogenic gas is widely distributed in soft soil areas such as estuarine deltas and marine facies within Quaternary strata, with some also found in Neogene strata. These strata are rich in large amounts of organic matter—under suitable conditions, anaerobic microorganisms decompose this

organic matter to produce biogenic gas [8]. Meanwhile, soft soil strata not only serve as a source for gas generation but also function to confine shallow gas due to their poor permeability, preventing gas from escaping and allowing it to accumulate in the soil. Thermogenic gas is mainly distributed in the upper strata within oil- and gas-bearing basins, typically with a burial depth exceeding 1000m. It is formed when organic matter in sediments undergoes thermal cracking and thermal catalysis, generating large volumes of gas. Compared with biogenic gas, thermogenic gas has a more complex composition: in addition to methane, it may contain heavy hydrocarbon gases such as ethane and propane, and it also has a relatively heavy hydrogen isotope composition [9].



Figure 1: Distribution Map of Shallow Biogenic Gas in China

## 2. Current Status of Shallow Gas Field Development in the World

Shallow gas has gradually transformed from either a hazard in drilling operations or an “indicator” of more deeply buried, more prospective reservoirs into an additional natural gas resource with potential, featuring favorable economic viability. Many countries abroad have achieved substantial results in the development of shallow gas fields. In the Cedar Creek Anticline in southeastern Montana, USA, there are abundant shallow gas reserves. The gas reservoirs are produced from relatively shallow Cretaceous strata: the Judith River Formation, with a burial depth of approximately 800 feet, has produced 105 BCF of natural gas; while the Eagle Formation, with a burial depth of 1,200–1,800 feet, has produced 197 BCF and is currently a key target for development [10]. In southeastern Alberta and southwestern Saskatchewan, Canada, the Upper Cretaceous biogenic gas

reservoirs cover an area of over 40,000 km<sup>2</sup>. The reservoirs consist of low-permeability sandstone-mudstone. A well-performance-based method was used to re-evaluate natural gas potential, revealing that recoverable natural gas resources range from 30.2 to 73.3 TCF [11]. The shallow zone (TSZ) of the TUNU Gas Field, located on the edge of the Mahakam Delta in Indonesia, has a burial depth of 600–2,200 m and belongs to Pliocene fluvial-deltaic deposits with a porosity of approximately 30%. Initially regarded as a drilling hazard, it later became a key target for development. By 2017, over 185 wells had been drilled in this zone, contributing 40% of the gas field's total production [12].

China is rich in shallow gas resources. By the end of 1994, the proven shallow gas reserves had exceeded 800×10<sup>8</sup> m<sup>3</sup> [13], with key distributions in the Songliao, Bohai Bay, Qaidam, and Qiongdongnan Basins. Although commercial shallow gas reservoirs have been discovered in other regions, their scales remain relatively small. China's domestic shallow gas development began in the 1960s. The Songliao Basin took the

lead in conducting systematic exploration, and commercial gas flows were successively discovered in the Sartu Oil Layer. In 1964, natural gas was accidentally blown out during the drilling of Well Beican-3 deployed in the Qaidam Basin; however, due to limited technical conditions, its development and utilization could not be advanced in a timely manner, and pilot production of the Sebei Gas Field was launched in 1995. In the 1980s, the Gudao and Gudong Oilfields of Shengli Oilfield were put into operation one after another. The proven Original Gas in Place (OGIP) and shallow natural gas production of these two oilfields accounted for 62.8% and 90.5% of those of Shengli Oilfield, respectively [14]. In 2024, CNOOC (China National Offshore Oil Corporation) announced the discovery of Lingshui 36-1—the world's first large-scale ultra-deepwater and ultra-shallow gas field—in the southern part of the Central Depression of the Qiongdongnan Basin, located in the southeastern waters of Hainan Island. The proven geological reserves of this gas field exceed 100 billion cubic meters.

**Table 1: Key Properties of Major Domestic Shallow Gas Reservoirs**

Region	Name	Genetic Origin	Period	Depth(m)	Permeability (mD)	Porosity (%)	Reservoir Pressure (MPa)	Estimated Production (m <sup>3</sup> )
Yangtze River Delta [4,15,16]	JiaZao	biogenic	Quaternary	40	-	28.0-36.1	0.36-0.41	0.15×10 <sup>8</sup>
	TouPeng	biogenic	Quaternary	52				
	LeiDian	biogenic	Quaternary	38				
Qiongdongnan Basin [17]	LingShui 36-1	mixed-genesis	Quaternary	170-300	983.7	38.9	17.25-19.24	1×10 <sup>11</sup>
Qaidam Basin	Sebei No.1 [18]	biogenic	Quaternary	410-1760	24.32	30.95	-	-
	Sebei No.2 [19]	biogenic	Quaternary	400-1400	-	-		
	TaiNan [20]	biogenic	Quaternary	800-1800	79.3	28.8		
Bohai Bay	GuDong [21]	mixed-genesis	Neogene	1000-1500	650	29.2	1700	1.2×10 <sup>9</sup>
	GuDao [22]	mixed-genesis	Neogene	470-1300	1000	33	-	4.7×10 <sup>9</sup>

### 3. Main Exploration Methods of Shallow Gas

#### 3.1 Cone Penetration Test

As an in-situ exploration method, the cone penetration test (CPT) technology has been widely used in soil layer division, soil type identification, and other aspects. CPT equipment usually consists of a probe, a penetration device, and a data acquisition system. The penetration system is mainly divided into two types: “mechanical” and “hydraulic”, which are suitable for different investigation scenarios. It is equipped with a guide frame and a reaction device: the guide frame is used to ensure the probe is pressed in vertically (with a verticality error  $\leq 1^\circ$ ), while the reaction device provides penetration reaction force. The data acquisition system converts the electrical signals transmitted by the probe into directly readable engineering data, and performs real-time recording, storage, and preliminary analysis. The probe has a conical shape (with a typical cone angle of 60° and a standard base area of 10 cm<sup>2</sup>) and is equipped with various internal sensors. The key parameters measured include: Pore water pressure(kPa); Cone tip resistance (Qc, MPa), which refers to the end-bearing reaction force per unit area at the probe tip; Sidewall friction resistance (Fs, kPa), which refers to the sleeve friction force per unit area of the friction sleeve on the probe side.

The CPT method is mainly applied to ultra-shallow biogenic gas reservoirs with a burial depth of less than 150 m, and it can be divided into quantitative and qualitative analyses.

Quantitative analysis mainly relies on two approaches to achieve direct detection of shallow gas: either installing gas sensors inside the probe or collecting gas samples for subsequent laboratory analysis. Lingfa Tao [23] used a modified CPT probe, in which an air compressor was employed to blow out shallow underground gas. The gas was then collected and measured using gas metering equipment, and this method was applied in the Wave Rail Transit Project. Zhongxuan Chen [24] conducted experiments in the Zhoushan Sea Area of the East China Sea, adopting MIP-CPT technology supplemented by geophysical detection methods. This technology can identify free gas and dissolved methane within 30 m below the seabed, and the FID signals from typical boreholes are basically consistent with the results of shallow stratigraphic profiles. Based on MIP-CPT, Xiangyang Chen [25] installed porous ceramics and double-layer waterproof and gas-permeable membranes inside the probe—these components are used for the separation of mud-water and gas-water, respectively. Additionally, a methane sensor was equipped to enable in-situ detection of shallow gas.

Qualitative analysis involves using data obtained from static cone penetration tests (SCPT) to indirectly infer whether soil layers contain gas, and it is more widely applied in the field of shallow gas exploration. Aiguo Guo [26] pointed out that during the penetration of an SCPT probe, if phenomena such as an increase in cone tip resistance (Qc), a decrease in friction ratio (Fs/Qc), small fluctuations in pore water pressure (U), and the absence of negative excess pore water pressure are

observed, it can be preliminarily determined that the sand layer may contain shallow gas. RCPTU (Resistivity Cone Penetration Test with Pore Water Pressure) integrates a resistivity module into the traditional CPTU (Cone Penetration Test with Pore Water Pressure) probe. Qinhuan Wang [27] conducted laboratory experiments and found that gas-bearing dense sand exhibits the phenomenon of non-negative excess pore water pressure during shearing. They adopted this non-negative excess pore water pressure phenomenon as a criterion for identifying gas-bearing strata, jointly identified such strata using the pore water pressure data obtained during RCPTU penetration and the resulting soil layer classification, and used the acquired abnormal resistivity data for auxiliary verification. Meng Wu [28] used RCPTU and geostatistical methods to obtain the

spatial distribution of stratum resistivity at a subway station in Hangzhou, and employed reliability analysis methods to derive the probability distribution of underground shallow gas. Mingqing Liu [29] conducted RCPTU detection on underground shallow gas in the Lingkun Island Section of the North Entrance Tunnel of Wenzhou Light Rail Line S2. They analyzed the degree of resistivity changes caused by variations in shallow gas content and found that the fluctuation range of resistivity before and after soil gas release is smaller than the inherent fluctuation of the soil itself. They concluded that the resistivity data measured by the current RCPTU probe can be used as a reference, but it remains difficult to determine the location of gas-bearing layers solely based on changes in resistivity.

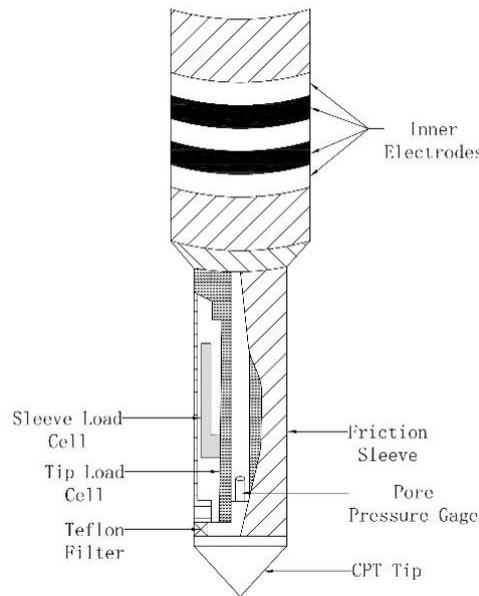


Figure 2: RCPTU Probe

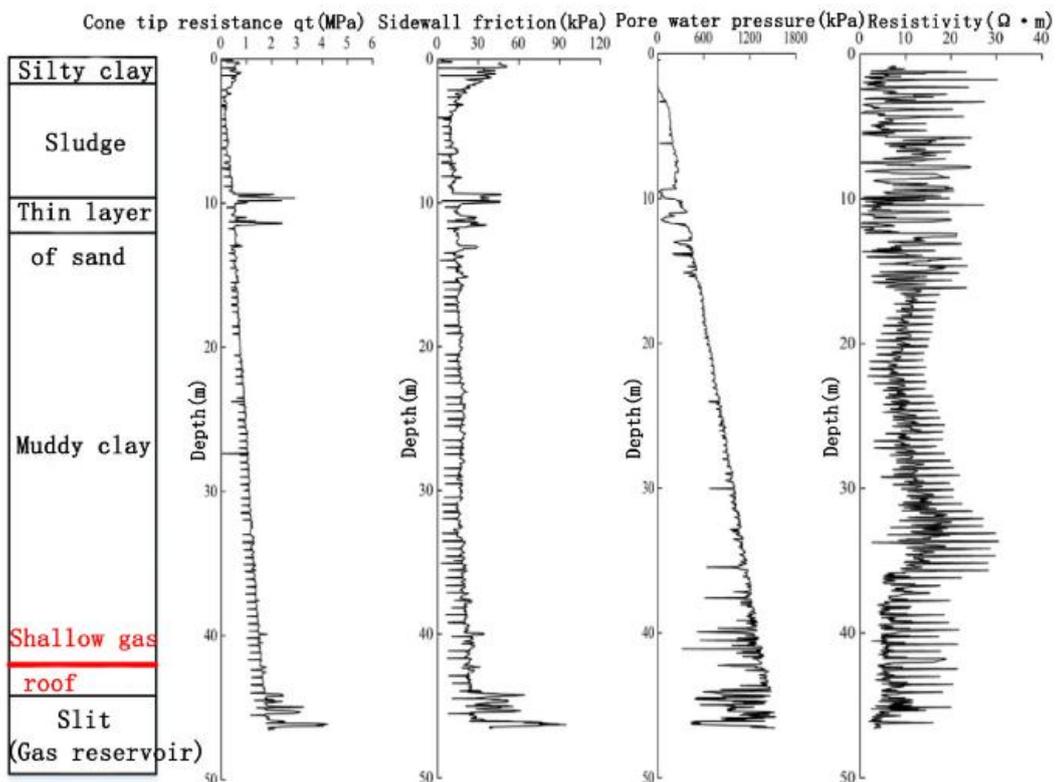


Figure 3: CPT Data Curves of Borehole 1 in the Lingkun Island Section

The CPT method features high portability and low cost, and the acquired data can be directly used for soil layer division. However, this method has the following shortcomings:

- Due to limitations from factors such as equipment type and soil layer properties, the penetration depth is restricted. For example, the investigation depth in the Hangzhou Bay area is limited to approximately 90 meters;
- Constrained by the complexity of the underground environment, the service life of MIP membranes is usually difficult to effectively guarantee;
- Parameter anomalies in gas-bearing areas require manual identification, which demands high quality of operators. Additionally, the results often have a multi-solution nature and need to be supplemented with other methods for auxiliary verification.

### 3.2 Electromagnetic Exploration

The core logic of electromagnetic exploration for shallow gas is based on the correlation mechanism of “electrical property differences of media - field response characteristics”. The implementation of this technology takes the electrical property difference between gas-bearing layers and surrounding soil layers as the fundamental prerequisite:

- In the case of free gas: Gas displaces part of the conductive pore water, leading to an increase in resistivity;
- In the case of dissolved gas (e.g., CO<sub>2</sub> dissolved in groundwater): It reduces the pH value of pore water and increases the dissolved ion concentration, resulting in a decrease in resistivity [30,31].

This change in resistivity serves as the key basis for identifying shallow gas using electrical methods. Different electrical techniques (such as the high-density electrical method and transient electromagnetic method) realize the distribution positioning, state monitoring, and migration tracking of shallow gas by collecting and inverting resistivity data. Moreover, these techniques are applicable to different scenarios, including coastal soft soil areas, Arctic permafrost areas, and coal mining areas.

Since it uses non-grounded coils to excite electromagnetic fields and is not affected by the shielding of high-resistivity strata (such as permafrost and cement layers), the shallow Transient Electromagnetic Method (sTEM) has become the preferred technology for detecting shallow and deep gas in Arctic permafrost regions. It inverts the vertical distribution of resistivity through the secondary electromagnetic field decay curve after the pulse current is turned off. A combination of 100 m × 100 m transmitting coils and 10 m × 10 m receiving coils is commonly used, with a current capacity of up to 30 A and a sampling rate ranging from 25 ns in the early stage to 25.6 μs in the late stage. The detection depth is controlled within 500 m, enabling accurate identification of the vertical occurrence characteristics of shallow gas in permafrost regions [32,33]. In the detection of

the Yamal Peninsula permafrost region, sTEM was combined with the seismic method, and three types of resistivity anomalies were obtained through inversion: Low-resistivity zones (< 0 Ω·m) correspond to gas-bearing zones in thawed regions, which overlap with seismic “chimney-shaped” coherence anomalies, confirming that faults serve as migration channels for shallow gas; Medium-resistivity zones (20–50 Ω·m) represent the main permafrost body; High-resistivity zones (> 150 Ω·m) correspond to underground ice. The shallow gas distribution model established based on this provides key support for the site selection of oil and gas exploitation infrastructure in this region [32]. In the precursor detection of gas explosion craters on the Taz Peninsula, sTEM (with a detection depth of 500 m) monitoring revealed that: beneath pingos at risk of gas explosion, vertical low-resistivity zones (< 10 Ω·m) develop. The resistivity of these zones is 40% lower than that of pingos without risk, and the low-resistivity zones extend to the permafrost base at a depth of 200 m, which is inferred to be a gas migration channel. This finding provides an important indicator for early warning of gas explosion hazards in Arctic permafrost regions [34].

Considering the particularity of shallow surface gas-rich soil layers in coastal areas, Chen Yu [35] found through high-density resistivity method tests that: the resistivity of gas-rich soil layers shows a trend of first decreasing and then increasing with the increase of gas content — when the gas content is low, gas dissolution is dominant, leading to a decrease in resistivity; when the gas content is high, the filling of pores by free gas is dominant, resulting in an increase in resistivity. This regularity is consistently observed in silty soil and mucky clay in coastal regions such as Hangzhou Bay and Wenzhou, providing a quantitative reference for the assessment of shallow gas content in coastal soft soil areas.

Electromagnetic exploration has high sensitivity and strong adaptability to scenarios. It can identify gas-bearing layers with a thickness of less than 1 m, and has applications in both Arctic permafrost regions and coastal soft soil areas. Compared with the seismic exploration method, it has lower costs and higher data acquisition efficiency. However, electromagnetic exploration is easily disturbed by stratum heterogeneity: clay lenses in soft soil areas and underground ice in permafrost regions may cause false resistivity anomalies, which requires verification by combining the seismic method or borehole detection. Additionally, the quality of electromagnetic signals is affected by electrical factors; therefore, electromagnetic exploration cannot be carried out in cities with significant electrical interference.

### 3.3 Seismic Exploration

The seismic exploration method is mainly applied to large-scale shallow gas exploration in marine areas due to its relatively high cost. The method and technology of seismic exploration mainly focus on two aspects: direct identification markers of seismic profiles and seismic attribute fusion technology.

Specific response characteristics on seismic profiles serve as the most intuitive basis for identifying shallow gas; these markers are usually related to significant changes in

stratigraphic physical properties (such as density, acoustic impedance, and acoustic velocity) caused by gas-bearing reservoirs, and seismic reflection anomalies induced by shallow gas mainly manifest as bright spots, gas chimneys, strong reflections, acoustic blanking, pockmarks, and so on. In studies of the Bohai Bay, Cukur [36] conducted a seismic exploration study on shallow gas in lacustrine sedimentary environments, taking Lake Van (Turkey) as the study area, and found that gas-bearing layers exhibit the characteristic of “weak amplitude and low-frequency anomalies,” providing scenario-specific references for the seismic identification of lacustrine shallow gas; through forward modeling and comparison with actual profiles, Yang [37] discovered that the top interface of fine-silty sand layers filled with free gas (burial depth: 14.5–25.7 m) forms strong amplitude reflections (“bright spots”) due to reduced density and velocity, with amplitude values 2–3 times higher than those of the surrounding rock, while a weak amplitude shadow zone appears below the gas reservoir due to energy absorption, and this anomalous zone completely matches the gas reservoir range (width: 40–110 m) revealed by boreholes. In the offshore area of Vietnam, thermogenic gas reservoirs formed after blowouts (burial depth: 545–630 m) in 3D seismic profiles also show continuous strong amplitudes, with RMS amplitude values exceeding 8000, and borehole verification confirmed that the natural gas concentration reaches 8%–12% [38]. Phase anomalies manifest as phase reversal and continuity interruption: for columnar shallow gas reservoirs in the Bohai Bay, the reflection coefficient at the top interface is negative (showing a reverse phase), while the phase at the bottom turns positive due to reduced acoustic impedance difference—forming a typical “top-negative, bottom-positive” pattern, the phase inside the gas reservoir is disordered, contrasting sharply with the continuous surrounding strata, and data from 22 boreholes reduced the interpretation error of this anomaly from 5 m to 3 m [37]; in gas hydrate symbiotic zones in the Dongsha Sea Area of the South China Sea, phase reversal at the top of shallow gas reservoirs extends vertically along gas chimneys (burial depth: 8–30 m), which corresponds one-to-one with cold seep locations detected by multibeam surveys—confirming it as a direct response to biogenic gas migration [39]. Frequency anomalies are reflected in high-frequency attenuation: in Chirp profiles of the Po Delta in the northwestern Adriatic Sea (Italy), gas-bearing sediments show a 40% loss of high-frequency components (>300 Hz), with instantaneous frequency dropping to 100–150 Hz—forming a “low-frequency shadow,” and the low-frequency zone is consistent with the distribution of seabed pockmarks (gas vents) [40]; in ultra-high-definition 3D profiles of Yeongil Bay (South Korea), the instantaneous frequency in gas reservoir areas is 100–150 Hz, and low-frequency gradient zones extending along paleochannels completely coincide with gas reservoir migration paths [41]. Furthermore, special geometric features such as “pull-down events” and “acoustic blanking” also have indicative significance, for example, gas chimneys in the Pearl River Mouth Basin of the South China Sea appear as vertical acoustic blank zones, where internal reflection signals disappear and only vague boundaries remain—connecting to deep gas reservoirs [42].

In seismic attribute fusion technology, interference can be eliminated by verifying the consistency of amplitude,

frequency, and phase anomalies. For shallow gas detection in the Bohai Bay, a combined process of “strong amplitude + phase reversal + low-frequency shadow” is adopted: first, strong amplitude is used to delineate suspected areas, then phase reversal areas are screened, and finally low-frequency shadows are overlaid—areas where all three overlap are identified as gas reservoirs. This reduced the misjudgment rate of single amplitude attributes (due to clay lens interference) from 30% to 8% [37]. When comparing pre- and post-blowout seismic data in the offshore area of Vietnam, Ngo [38] adopted “RMS amplitude > 8000, instantaneous frequency < 150 Hz, and instantaneous phase reversal” as joint criteria, successfully identifying 5 gas anomaly areas, among which 3 were confirmed as commercial gas reservoirs through drilling. Mathematical coupling of attributes enhances gas reservoir characteristics by constructing composite attributes. In the study of Yeongil Bay, South Korea, Won [41] quantified the characteristics of high amplitude and low frequency in gas reservoir areas based on the definition of “sweetness = instantaneous amplitude divided by the square root of instantaneous frequency”—the sweetness value in gas reservoir areas reached 100–150 (vs. < 50 in non-gas areas). Then, combined with the “frequency attenuation ratio (ratio of low-frequency energy to high-frequency energy)”, the identification accuracy was increased from 68% to 85%, and two gas reservoir zones distributed along paleochannels were delineated.

Seismic exploration can achieve high-resolution imaging from shallow to deep layers by adjusting the source frequency and data processing methods. Moreover, it can not only locate the distribution of shallow gas but also reveal its migration channels and geological controlling factors through special wavefield characteristics (such as acoustic blanking and fault-related anomalies). However, seismic wave responses are affected by multiple factors including lithology, pore fluids, and tectonic activities; single or a small number of attributes are prone to misjudgment and must be supplemented with verification using boreholes, geological backgrounds, and other means—otherwise, interpretation deviations will occur. At the same time, the costs of equipment investment, data acquisition, and processing for seismic exploration are significantly higher than those of methods such as electromagnetic exploration and static cone penetration test (SCPT). Furthermore, as the exploration range expands and resolution improves, the costs increase exponentially, which limits its application in small and medium-sized projects.

### 3.4 Microbial Exploration

Microbial exploration is an exploration method that infers the distribution of underground shallow gas by detecting anomalies in microbial communities associated with oil and gas (such as the abundance and activity of hydrocarbon-oxidizing bacteria) in soil or sediments [43]. In a study of the Yangxin Sag of the Bohai Bay, Li Yongmei [44] collected 1599 sets of soil samples, cultured hydrocarbon-oxidizing bacteria using the most probable number (MPN) method, and introduced the MU value to quantify anomalies. They found that gas anomaly areas (with MU values > 30) exhibited a “north-south zonal” pattern: the northern anomaly area was closely associated with faults, reflecting that faults control gas

reservoir distribution, while the central-southern anomaly area overlapped with nose-shaped structures — confirming that structural highs are gas-enriched zones. In the detection study of the Northern Marginal Fault Zone of the Qaidam Basin, Yuan Zhihua [45] identified gas anomaly areas through methane-oxidizing bacteria abundance detection (abundance:  $10^3$ - $10^4$  CFU/g, significantly higher than the background area's  $10^2$  CFU/g). These anomalies were distributed in discontinuous NE-trending strips, consistent with the distribution of channel sandbodies, and their intensity weakened from east to west—revealing that the gas source originated from the eastern Yibei Sag and that channel sandbodies served as migration channels. In the context of coalbed methane, a study of the Illinois Basin in the southeastern United States [46] identified key bacterial genera involved in biogenic coalbed methane generation through enrichment culture and rRNA gene sequencing. The correlation coefficient between the abundance of these genera and coalbed methane content reached 0.82, and the distribution of the genera overlapped with high-permeability zones of shallow coal seams (burial depth: 100-250 m), providing microbial evidence for coalbed methane reservoir positioning. Additionally, for shallow gas associated with heavy oil reservoirs, Zhu [47] identified shallow gas anomaly areas in regions such as the Western Slope of the Songliao Basin by detecting anaerobic microbial communities related to heavy oil degradation. A negative correlation was observed between methane carbon isotope  $\delta^{13}C_1$  values and microbial abundance, which not only enabled shallow gas positioning but also assisted in determining the genetic type of gas reservoirs (biogenic gas).

Microbial exploration for shallow gas features high cost-effectiveness; for example, the exploration cost in the Ma-10 Well Block in the Northern Margin of the Qaidam Basin is only 1/8 of that of 3D seismic exploration in the same area, making it suitable for large-area general surveys. However, it also has limitations and is susceptible to environmental interference: for instance, humic soil in the Yangxin Sag causes false anomalies, which require correction based on soil physical and chemical parameters; its resolution depends on sampling density, and low-density sampling tends to miss small-scale gas reservoirs; it is difficult to determine the gas reservoir depth independently, and the vertical position needs to be inferred based on geological data, so it cannot independently complete 3D characterization.

#### 4. Conclusion

Against the backdrop of energy transition driven by the “dual-carbon” goals, shallow gas, as a low-carbon clean resource and potential engineering geological hazard, its accurate exploration is of great significance for resource development and engineering safety. CPT, seismic, microbial, and electromagnetic exploration have all been proven to be of great significance for shallow gas exploration.

- Data obtained by CPT technology can be used for soil layer division and reservoir identification, but it has limited detection depth, mainly targeting ultra-shallow biogenic gas in terrestrial areas. Moreover, its detection range is limited to small areas around the penetration points, with poor representativeness, making it difficult

to conduct large-scale general surveys of gas-bearing areas.

- Electromagnetic exploration has high sensitivity, but factors such as moisture changes in shallow surface soil, metal components of underground pipelines, and industrial electromagnetic noise easily cause electromagnetic signal interference, resulting in deviations in the identification of anomalous areas. Meanwhile, electromagnetic exploration has weak penetration in high-resistivity strata; if shallow gas reservoirs are overlain by high-resistivity rock layers, gas-bearing information is easily missed, and it is difficult to quantitatively determine gas saturation.
- Gas-bearing anomalies can directly respond on seismic profiles with high resolution. It also identifies gas through the fusion of profile markers and attributes, improving accuracy. However, with high equipment costs, it is mainly used for exploration and research in large-area shallow gas regions on the deep-sea seabed. Moreover, it has insufficient resolution for thin reservoirs (several meters to tens of meters) and highly heterogeneous reservoirs.
- Microbial exploration has low costs but is significantly affected by the environment. Microbial communities are prone to non-reservoir anomalies, leading to false positive results. Furthermore, the migration range of microorganisms is limited, making it difficult to accurately locate gas reservoir boundaries. Detection accuracy is restricted by stratum permeability and gas diffusion rate, resulting in poor stability.

Existing exploration technologies are suitable for different scenarios but have their own limitations; in the future, technical integration is needed to balance resource development and engineering safety.

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